Book of Abstracts

Volume 1

The Québec City Convention Centre

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20th international sedimentological congress

From 13 to 17 August 2018, Quebec, Canada

A SEDIMENTARY JOURNEY THROUGH 3 BILLION YEARS IN THE NEW WORLD

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WELCOMING WORDS

The Local Organizing Committee is very happy to welcome you for the 20th International Sedimentological Congress in Québec City from August 12 to 17, 2018. The congress of the International Association of Sedimentogists (IAS) is back in Canada more than 30 years after its last stop in Hamilton (Ontario), and this time we are pleased to acknowledge the collaboration and participation, for the first time, of our sister organization, the Society for Sedimentary Geology (SEPM).

We are delighted to welcome over 1000 participants and exhibitors from 53 countries from all over the World. This conference will provide great opportunities for everyone to communicate their latest research, discuss new trends, approaches and frontiers in all aspects of sedimentology. The program includes 50 exciting scientific sessions with over 500 oral presentations and as many posters, providing the geoscience foundation of the congress. We are pleased to offer 13 field trips covering many aspects of sedimentary geology in Canada, as well as 6 short courses and workshops. We are sure that you will all enjoy the 7 outstanding plenary lectures in our program, and our social events including the conference banquet that will be held at the sumptuous Manège Militaire de Québec along the edge of the Plains of Abraham, an historical and prestigious park at the heart of Québec.

Québec City was founded in 1608, one of the first European establishements in the New World. It is a vibrant modern city with its Old Quebec District recognized as a UNESCO World Heritage Center. The city will provide every participants a unique experience of hospitality, exquisite dining possibilities and animated night life.

We are certain that the 20th International Sedimentological Congress will be remembered by all participants as one of their most outstanding scientific and social gatherings. Welcome and enjoy !!

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General Theme 1

The carbonate depositional system

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A SEDIMENTARY JOURNEY THROUGH
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ECOLOGICAL CHANGES IN CARBONATE PLATFORMS LINKED TO OCEANIC ACIDIFICATION: EXAMPLES FROM THE WEISSERT VALANGINIAN, OA1a AND OA2 EVENTS

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Three major environmental crises deeply affected the carbonate platforms during the Cretaceous, leading to their drowning and a general renewal of ecosystems, amongst, including that of carbonate organisms. These changes will heavily modify the nature of sediment deposits.

These crises are often associated with anoxic episodes: the lower Aptian OAE1a and End-Cenomanian OA2 or periods of significant perturbations of the carbonate factory such as the Valanginian Weissert episode. These events are linked with high volcanic activity, increased runoff, erosion and nutrients leading to climatic changes and increased anoxic conditions and finally a general drowning of carbonate platforms.

Current studies in marine biology on the effect of acidification on carbonate organisms show that species with aragonite shells or tests (e.g. green algae) tend to disappear in favor of non-carbonate algae and/or low Mg calcite species (e.g. some species of Corallinaceae). However, it is not a true disappearance, but a change from an ecosystem dominated by organisms producing aragonite / high Mg calcite shells and walls to dominant calcite/low Mg calcite ones.
The three crises mentioned above show the same environmental three steps evolution: (1) the disappearance of dasycladales and some bivalves such as some rudists characterized by a mixed aragonite-calcite shell (Skelton and Gilli, 2012), (2) the installation of an ecosystem dominated by echinoderms with crinoids and bryozoan characterized calcite and low Mg-calcite walls and (3) the disappearance of aragonite and high Mg calcite producing benthic foraminifera tests. To sum up, these crises led to a change from primarily photozoan to predominantly heterozoan carbonate production mode mirroring a change from oligotrophic to mesotrophic conditions. The first mode corresponds to carbonate tropical platform dominated by corals and rudists. While the second is supplying marls and limestones dominated by crinoids and bryozoans. This change in carbonate factory may be linked to decreased pH associated with the global perturbations mentioned above.

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MIDDLE PERMIAN MILLENNIAL-SCALE ALTERNATIONS OF PHOTOZOAN AND HETEROZOAN CARBONATES CAUSED BY UPWELLING OF CO_2-RICH COLD WATER ALONG NORTHERN GONDWANA (OMAN)

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In modern upwelling zones *p*CO2 waters can be as high as 1000 ppm, *i.e.* more than twice normal surface values. Upwelling brings cool- and nutrient-rich water to shallower levels, which in turn enhances productivity, leads to a drawdown of oxygen, and creates potentially lethal anoxic conditions. In turn, the associated increase in pCO_2 generates lower the pH of water that can easily fall below aragonite and saturation with potential devastating effects on aragonite-secreting biota. With the exception of the Galapagos Island, however, modern areas of coastal upwelling are clastic-dominated, thus making it difficult to assess the effect of upwelling on carbonate factories. In contrast, the rock record provides ample examples of long-lasting episodes of upwelling of cold waters that were below aragonite saturation onto low-latitude carbonate shelves or ramps. The Mississippian of western Canada is all but one example of such a phenomenon. We here document much shorter (~1000 years) recurring intervals of Middle Permian upwelling in Oman that episodically brought aggressive, nutrients-rich cool to cold waters onto the otherwise highly productive tropical shelf in that area. The result was alternating photozoan and heterozoan factories. These carbonates occur in the lower portion of the Saiq Formation in the Oman Mountains, which represents low-latitude shelf sedimentation along the northern margin of Gondwana. The photozoan carbonates are grey lime mudstone and wackestone composed of pure calcite, with only traces of organic matter (OM) and undetectable levels of P, Sr, Fe, S and Mg. Fossils include synringoporid coral, inozoan sponge, bivalve, gastropod, small foraminifer, and dasyclad and red alga. This is an aragonite-prone photozoan biota indicative of shallow, well-lit conditions comparable to modern tropical seas where annual water temperature exceeds 20 ^{o}C and alkalinity and nutrients are low. Extensive hardgrounds provide evidence of early marine cementation. This sediment accumulated in an energy- and salinity-restricted, shallow-shelf environment as shown by the dominance of lime mud, absence of storm-deposits, rarity of open marine biota (e.g. echinoderm), and the small size of most fossils. This indicates the Saiq shelf was partially isolated from the Neotethys Ocean, likely due to uplifts in the Hquf-Haushi and Saih Hatat areas. These photozoan carbonates rhythmically interfinger with thin (0.5–3 cm) heterozoan carbonates. There are more hundreds of photozoan-heterozoan couplets in the lower Saiq Formation. Heterozoan layers are red wackestone and packstone replete with whole or broken fossils of bryozoan, echinoderm, brachiopod and small foraminifer. Fossil fragments are non-abraded, ranging from fine silt to coarse sand. There is no evidence of early submarine cementation. The red colouration is due to iron oxide in the matrix. Otherwise, the heterozoan carbonates are nearly pure calcite devoid of OM, P, Sr, Mg, and S. Chrysanthemum glendonite rosettes grew within the heterozoan limestones shortly after their deposition, demonstrating the influx of cold to very cold waters. We interpret the recurring shift from aragonitic photozoan to calcitic heterozoan factories as resulting from the episodic upwelling of cool to cold, high pCO_2, iron-rich waters onto the tropical Saiq shelf due to climate forcing of unknown origin recurring every 1000 years or so.

SHORT-LIVED RETURN OF A CALCITE SEA NEAR THE CARBONIFEROUS-PERMIAN BOUNDARY IN ARCTIC CANADA CAUSED BY A CO_2 BURST IN THE ATMOSPHERE

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The Mg/Ca ratio is thought to provide the principal long term control on calcite vs aragonite seas due to the inhibiting effect of Mg on low Mg calcite precipitation. On a shorter timeframe, however, rapid and significant increases in atmospheric CO_2, even during high Mg/Ca aragonite sea intervals, were unlikely to have been buffered fast enough through silicate weathering and thus would have led to the shoaling of the aragonite saturation horizon and result in a corresponding rise in the aragonite lysocline. We here document such a short-lived interval at around the Carboniferous-Permian boundary in the Sverdrup Basin, Arctic Canada, when biotic and abiotic calcitic elements became dominant while aragonite elements were eradicated in all but the sallowest portions of the sea.

The late Paleozoic transition from a calcite sea to an aragonite sea extended well into the Early Pennsylvanian when red (ungdarellid) and green (beresellid) calcitic algae remained the dominant flora associated with calcitic radial ooids. This calcitic assemblage was global in nature as observed on both sides of Pangea. By the mid-Moscovian, however, aragonitic algae (phylloid, dasyclad, archaeolithophyllid) started appearing in large numbers and flourished for the remainder of the Pennsylvanian and well into the Early Permian. By then calcitic algae were only minor contributors to the carbonate factories. Tangential aragonitic ooids also became dominant in high energy environments during the Late Pennsylvanian indicating a complete shift to an aragonite sea. However, a short-lived return to a calcite sea near the C-P boundary is recorded in shelf carbonates of the Sverdrup Basin (Arctic Canada). For a span of ~1 Ma, calcitic flora essentially identical in composition to the Early Pennsylvanian flora reappeared in uppermost Gzhelian strata. This occurred in concert with a major decline in aragonitic algae suggesting the return of conditions favourable to the growth and preservation of low Mg calcite biota, while placing stress on aragonitic-secreting organisms. This is observed in the upper portion of glacio-eustatic cycles in which aragonitic algae were replaced for the span of three cyclothems by a rich flora dominated by *Beresella, Dvinella* and *Ungdarella*. The upper part of these cycles comprises grainstones dominated by radial calcitic ooids or bioclastic grainstones; aragonitic tangential ooids no longer occur. Aragonitic bioclasts do occur in these shallower deposits, but they are subordinate to calcitic bioclasts. These observations are explained by the rapid shoaling of the aragonite saturation horizon, and thus of the aragonite lysocline, from a relatively deep position probably well below the thermocline to a considerably shallower position near or above fair weather wave base. We explain the return of a calcite sea in the latest Carboniferous by a burst of CO_2 in the atmosphere, and corresponding CO_2 increase in the ocean, which would have pull the aragonite saturation horizon into much shallower waters, especially at the higher cooler paleolatitude of the Sverdrup Basin. Upwelling along western Pangea may have contributed to this phenomenon in bringing CO_2-charged waters into the Sverdrup Basin. Considering that Mg/Ca ratios are unlikely to fluctuate much over short geological time, nor vertically in the upper portion of the water column, a burst of CO_2 in the atmosphere, and therefore in the ocean, provides the simplest explanation for the return of a calcite sea near the C-P boundary.

Carbonate factory turnover and oceanographic cooling in the aftermath of the Devonian-Carboniferous mass extinction

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In the last half billion year of Earth history, rapid episodes of environmental change associated with major stratigraphic boundaries were often accompanied by mass extinctions. The Devonian-Carboniferous (DC) mass extinction known as the Hangenberg Event (HGE: extinction of 21% of Paleozoic marine genera and 17% of families) [1,2], was accompanied by anoxia [3], major depositional changes, and base level fluctuations that led to profound unconformities in western North America [4]. Past studies of the DC boundary focused either on the mass extinctions and the changes in taxonomic diversity through time or on the chemical changes and anoxic deposits. Yet these studies reveal little about the severity of the ecologic, environmental and paleogeographic changes that accompanied the DC mass extinction. The DC sedimentary deposits on the ancestral margin of western of North America (Laurentia) are remarkably preserved over a stretch of outcrops extending from Western Canada to the Great Basin of southern Nevada and provide an excellent record of the depositional changes across the DC boundary. Deposition of Devonian tropical warm-water carbonates was first succeeded by black mudrocks and then by Early Mississippian cool-water carbonates. A total of 6 lithofacies and 11 microfacies are recognized in the Upper Devonian to Lower Carboniferous successions of southwestern Alberta, southern Montana and southern Nevada. The spatial distribution of these microfacies shed light on the transition from warm- to cool-water carbonate factories and associated changes in carbonate ramp geometries. We propose a series of new depositional models for the carbonate platforms bounding the western Laurentian margin for the Late Devonian, the Devonian to Carboniferous transition, and the Early Carboniferous. These models enable us to properly frame important sequence boundaries, while providing a framework for interpreting the changing paleoceanography and plate tectonic configuration. This will lead to a better understanding of the nature and evolution of the late Paleozoic western margin of Laurentia which was largely overprinted by the more recent Cordilleran orogenies.

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Ocean Chemistry and Hydrodynamics as Controls of Mud Production on Great Bahama Bank

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Ocean acidification has impacted the chemistry of the global surface ocean, driving the oceans to buffer increasing atmospheric CO_2 concentrations. Carbonate saturation state, a chemical parameter of seawater impacted by acidification, plays an important role in producing whitings – sedimentological processes that contribute and/or redistribute mud-sized aragonite crystals in tropical shallow water environments like Great Bahama Bank (GBB). Triggers for whiting formation have been debated for the past 80 yrs. As a result of the contribution of whitings to the sedimentary record and by analogy to ancient carbonate platforms, we examined their occurrence in daily MODIS data to understand their seasonality, spatial distribution, and possible effects of ocean acidification. The distributions of whitings were compared with a time series of sea surface temperature (SST) and models of hydrodynamics and saturation state for GBB. We demonstrate a link between off- and on-platform circulation and the SST differential between off- and on-platform water masses. Hydrodynamics define the small portion of GBB where whitings occur; >35% of the ~3,000 whitings observed in 2012 originate in a zone covering <1% of the platform. Data suggest that more whitings are triggered in this zone during winter, when the SST differential between the shallow platform top and adjacent off-platform water body is most pronounced. Preliminary calculations of aragonite saturation state suggest that the winter SST differential acts to increase the saturation of waters in the region of mixing. In contrast, mixing of waters during summer, when a lower SST differential exists, acts to reduce the saturation state, possibly providing insight into the seasonality of whitings frequency. This observation has profound implications for the rate and locus of GBB lime mud production. Our work suggests that the high concentration of mud in the lee of Andros Island is not a result of lethargic currents, as suggested by previous studies, but is the result of the higher frequency of fine-grained sediment production by whitings, whose occurrence can be related to a delicate balance of prevailing hydrodynamics, temperature, and water chemistry. If SST differentials and hydrodynamics exert control on whitings, ocean acidification is expected to suppress their frequency during periods of acidification. This observation has particular relevance to the production of carbonate muds in early Earth history – prior to the evolution of the myriad of carbonate-secreting organisms, abiotic aragonite precipitation might have been the only means of producing carbonates. The consequence being that whitings might not have been as widespread in the geological record as previously assumed.

SPONGE-MICROBIAL BUILDUPS: A NEW LOOK AT THE ENIGMATIC BASAL TRIASSIC "CRYSTAL LAYERS" OF CENTRAL IRAN

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At the basal Triassic equatorial distal carbonate ramp of Central Iran, anomalous carbonates has been deposited, so called "crystal layers" or "carbonate crust"[1]. However, we demonstrate here that these carbonates are part of sponge-microbial buildups, similar to those of the same age recently described in South Armenia[2]. We focus on two well-known Permian-Triassic boundary localities with the same lithological succession, the Kuh e Hambast section east of Abadeh city and the more distal Shareza section near Isfahan. In both sections, the extinction horizon corresponds the top of the uppermost Permian *Paratirolites* limestone. At Kuh e Hambast, the overlying 40 cm thick boundary shale is conformably capped by 1.6 m of basal Triassic dark lime mudstone containing four successive horizons of decimeter to meter scale elongated to cup shaped mounds. Thinly laminated candelabra or chimney-like structures are protruding from a common base and/or are growing side by side; these features are interpreted here as branching columnar stromatolites. Replacement of possible keratose demosponge fibers are widely present in the lime mudstone matrix. Thus we interpret these structures as sponge-microbial buildups which can be followed laterally for several kilometers. At Shareza section (20 m), there are five sponge-microbial buildup levels overlying each other. Two of them are included within a 3 m thick shaly lime mudstone interval just above the boundary shale. The first buildup level, 10-15 cm thick and latest Permian in age, is made of micro-laminated calcite crystal bundles interpreted as digitate stromatolite, with calcite-cemented filamentous interspace in a micritic clumps interpreted as sponge fossils. The second, only 25 cm thick, is correlated with the one of Kuh e Hambast, and consists of open bowl shaped fan of digitate stromatolites surrounded by a dark lime mudstone matrix with sponge fibers (possible keratose). About 6 m above the base of the boundary shale, twelve mounds can be observed along the 300 m long outcrop. The biggest one, up to 2 m thick, is showing a core of calcite crystal fans capped by thrombolites. Others mounds, inverted cone-shaped structures of 1m high and 50cm wide, are composed of superposed thrombolitic open bowl, or consist of complex aggregates of small buildups of thrombolites, bushy dendrolites or digitate stromatolites. Sponge fibers debris in the lime mud matrix have been observed in thin sections. At 16 and 20m above the base of the boundary clay, the upper sponge-microbial layers are 20-30 cm thick mounds made of thrombolites and bushy dendrolites. The close similarities between the South Armenian sponge microbial buil-ups[2] and the Central Iran "Crystal fan" fabrics confirm the new interpretation presented here.

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Sedimentary Microfacies and Model on Carbonate around the Permian-Triassic Boundary in South Sichuan and West Guizhou

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The Xingwen borehole of Sichuan province and Zhijin section of Guizhou province, which are characterized by the carbonate platform facies and carbonate slope facies respectively, are the two typical sections in the middle-upper Yangtze area of South China. The horizontal and vertical differentiations of the carbonate facies were analyzed in the two sections. This study aims to reconstruct the sedimentary model and biological combination in the carbonate region of this area, and confirm the depositional and biological events occurred at the Permian-Triassic boundary (PTB) in terms of sedimentary petrology. Fifteen sedimentary microfacies and seven microfacies combinations were identified in the PTB within the Xingwen Zk1501 borehole. Five microfacies were identified in Zhijin section. The ecosystem evolution of the two sections were investigated preliminarily by employing the characteristic of biological combinations. Six ecosystem units including normal Permian biota, recovery-extinction Permian biota, miniaturization biota, biota dominated by cyanobacteria, remaining biota and new Triassic biota, were identified.

Based on microfacies analysis, the vertical sequence evolution of the sections were analyzed. The Xingwen borehole indicates the sedimentary evolution from restricted platform to monoclinic slope and declining process of sea level in transitional period of the PTB in Sichuan. Zhijin section suggests a continuous wide ocean slope environment, in which inner and middle slope subfacies were identified. 76 continuous limestone samples of boundary strata of Permian-Triassic, which were collected respectively from Xingwen Zk1501 borehole (42 samples) and Zhijin Section (34 samples), were used to analyze biological combination by thin-section observation. Sufficient fossils, such as Trilobites, Gastropods and Phylloid Algae were found at 6cm above the bottom of Feixianguan Formation (3cm in Yelang Formation). Then the miniaturized Ostracods (<200μm) appeared. These indicate that the major extinction horizon is located at the place, and the PTB is in the middle-lower segments of the miniaturized Ostracods layer.

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Did climate changes trigger the Late Devonian Kellwasser Crisis? Evidence from a high-resolution conodont $\delta^{18}O_{PO4}$ record from South China

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Abstract

The impact of climate change on biodiversity has been the focus of studies on Phanerozoic biotic crises. However, it is still controversial whether climate change has caused the Frasnian−Famennian (F−F) biotic crisis since there is no unequivocal view on the global climate change during this critical period. In order to reconstruct palaeotemperatures during the F–F transition in South China (eastern Palaeotethys), a high-resolution oxygen isotope ($\delta^{18}O_{PO4}$) record was obtained based on 104 measurements of conodont apatite from the Yangdi section. The oxygen isotope record based on mono-generic samples reveals an increase in $\delta^{18}O_{PO4}$ by 0.7‰ in the Lower Kellwasser horizon (LKH) and 1.4‰ in the Upper Kellwasser horizon (UKH), translating into low-latitude surface water cooling of ~ 3 °C and ~ 6 °C, respectively. These two $\delta^{18}O_{PO4}$ shifts agree well with the time-equivalent $\delta^{18}O_{PO4}$ records from the western Palaeotethys, suggesting that two climate cooling pulses in conjunction with the Kellwasser horizons are a global signal during the F−F transition. The positive shift of $\delta^{18}O_{PO4}$ coincides with positive excursion in carbon isotope of carbonates ($\delta^{13}C_{carb}$) during the UKH, indicating that enhanced burial of organic carbon resulted in a drop in atmospheric pCO$_2$ and thus global climate cooling. Cooling started immediately before the Upper Kellwasser biotic crisis, with the lowest temperature documented at the top of the Upper Kellwasser horizon. Climate cooling during the LKH is observed in conjunction with the sharp decline in metazoan reefs. The coincidence of cooling and the Kellwasser biotic crisis suggest that global cooling played a major role in the collapse of ecosystems
Keywords: Devonian; oxygen isotope; conodont; palaeotemperature; South China

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LITHISTID SPONGE-MICROBIAL REEFS, NEVADA, USA: FILLING THE LATE CAMBRIAN 'REEF GAP'

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Cambrian–Ordovician sponge-microbial reef horizons in the Great Basin of the western USA reveal changes in reef structure and composition during an early stage of the Great Ordovician Biodiversification Event (GOBE). Here we describe lithistid sponge-microbial reefs from the upper Cambrian (Furongian, Stage 10) strata of the Arrow Canyon Range, Nevada. The reefs are mound-like structures up to 1 to 2 m high and few meters wide that consist of an unidentified thin-walled bowl-shaped lithistid sponge, columnar microstromatolite fabric, and the calcified microbe *Angusticellularia*. The reef formed in low-energy, subtidal environments in which lime mud filled spongocoels and inter-reef spaces around undisturbed, in place thin-walled sponges. The reefs colonized stable substrates provided by oolitic and bioclastic grainstone shoals. The mutually attached lithistid sponges form the main framework of the reef. These thin-walled and bowl-shaped sponges most likely were adapted to low-energy environments. Spaces beneath the overhanging sponge walls were occupied by microbial carbonates. These include pendent micro-dendritic *Angusticellularia* attached to dermal sponge surfaces and upward-growing masses of microstromatolites. After death the lithistid spongocoels were mainly filled by micritic sediment that hosted soft-bodied burrowing organisms and keratose-like sponges. These Arrow Canyon lithistid sponge-microbial reefs, together with an earlier example of late Cambrian (Paibian) dendrolite-lithistid reefs in the same area, are broadly similar to Early Ordovician lithistid reefs. We conclude that Arrow Canyon reefs characterize skeletal-microbial reefs prior to the main changes to reefs of the GOBE that introduced calathiids, pulchrilaminids, bryozoans, corals, and stromatoporoids. This suggests that there was no substantial change in reef composition and structure across the Cambrian–Ordovician boundary in the Great Basin region, which differs in this respect from coeval successions in South China where mid-late Cambrian microbial-dominated reefs were succeeded in the Early Ordovician by lithistid-microbial-calathiid reefs with several additional skeletal components.

Acknowledgements

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TRANSITION FROM BRYOZOAN- TO MICROBIAL-DOMINANT REEFS IN THE ZECHSTEIN LIMESTONE (LOPINGIAN) OF WEST POLAND

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The Upper Permian records a transition from metazoan- to microbial-dominant reefs prior to the great Permian extinction. Bryozoan buildups followed by bryozoan-microbial and then microbial ones have been reported from the marginal platforms of the Zechstein Limestone in various parts of the Southern Permian Basin of Europe. In western Poland, in addition to reefs occurring at the shelf-edge, isolated reefs have been recorded in the basinal facies. Microbial carbonates are the main lithology in the upper part of the isolated reefs sections. Usually microbial deposits are typical for the transition between carbonate platforms or isolated carbonate buildups and overlying evaporites both in shallow water and in deeper water settings; they also abound in the central part of the basin. The microbial carbonates developed in the uppermost Zechstein Limestone throughout the basin are commonly regarded as a record of a shallow-water environment developed basinwide, although they are not coeval.
Microbial deposits in reefs often show the inclined (even to subvertical) position, this is probably related to the changing configuration of microbial reef complex in time, as it was spectacularly demonstrated by Paul[1] in the Westerstein reef (Harz Mts). This part of the sequence is in general much more altered diagenetically than other parts of the Zechstein Limestone.
Different nature of the carbonate-sulphate boundary in the reefs and the adjacent basin is explained by the development of chemocline at the end of the Zechstein Limestone deposition owing to the salinity rise that eventually led to the onset of the evaporite deposition in the basin facies. The sharp boundary with the overlying Lower Anhydrite in the basin facies is due to nature of evaporites which start to precipitate immediately when the brines reach saturation. The increase in sea water salinity that eventually led to evaporite precipitation, occurred during the deposition of the highest (~10 cm thick) unit of the Zechstein Limestone in basinal facies. This increase was accompanied by sea-level fall (evaporite drawdown). The coeval deposits of the reef facies have experienced some effect of this general increase in salinity but it was largely controlled by local conditions in the environment of reef flat where large fluctuations of salinity might be expected. Hence, the onset of evaporite deposition in the reef facies could predate the widespread sulphate deposition in the basin facies although the time difference could be insignificant.

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HYBRID CARBONATES: ABIOTIC-MICROBIAL-SKELETAL

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In situ Hybrid Carbonates[1] are intimate combinations of two or more of abiotic (e.g., seafloor sparry crust), microbial (e.g., stromatolite) and skeletal (e.g., reef) carbonates. They reflect elevated carbonate saturation state, at least locally, since their formation requires precipitation of abiotic or microbial carbonates. Hybrid carbonates are widespread and diverse in the marine geological record and in present-day non-marine carbonates. Their marine history reflects major changes in carbonate precipitation through time.

Widespread abiotic-microbial hybrids have confused definition, recognition and interpretation of Precambrian stromatolites. Microbial-skeletal hybrids are common in many Phanerozoic reefs, particularly during intervals of abundant microbial carbonates (e.g., Cambrian archaeocyath and Jurassic lithistid sponge reefs), and during microbial carbonate-skeletal carbonate transitions (e.g., early Ordovician, Late Devonian). Even in well-developed skeletal framework reefs (e.g., Ordovician-Devonian), cryptic microbial carbonates often created hybrid fabrics, and these continue to be locally significant in late Cenozoic coral frameworks. More complex abiotic-microbial-skeletal hybrids developed when sparry seafloor crusts also formed, as in much of the Permian (e.g., Capitan reef) and Triassic (e.g., Cipit reef blocks). In situ hybrid fabrics are also common in deeper water methane seep mounds and hot-water carbonate vent pinnacles (e.g., Lost City). Diverse abiotic-microbial spring, creek and lacustrine carbonates, as well as microbial-insect tufa, develop in non-marine environments.

Over time, intervals of Hybrid Carbonate abundance contrast with those of the ‘classic’ carbonate end members (abiotic, microbial, skeletal) that compose them. Thus, the question arises, which are more abundant, these end-member categories, or the mixtures of them that create Hybrid Carbonates? The answer depends greatly on time-period and environment. Overall, we suggest that Hybrid Carbonates are more widespread and abundant than ‘Classical Carbonates’. Studies of the nature, variety and distribution of Hybrid Carbonates will provide insights into long-term changes in marine carbonate precipitation, and into the fabrics and formation of reefs, stromatolites, travertine and tufa.

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SEDIMENTARY ENVIRONMENTS AND EPIGENESIS OF VENDIAN CARBONATES OF EASTERN SIBERIA

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Brief geological description: the studied objects are located in the Nepsko-Botuobinskaya oil and gas province of Eastern Siberia. Wells with core sampling penetrated productive carbonate Vendian-Cambrian stratas: Osinskiy, Ust-Kutskiy and Preobrazhenskiy horizons. The Precambrian conditions of carbonate sedimentation differ significantly from the Phanerozoic. Vendian carbonate rocks are predominantly microbiolites. B.S. Sokolov1 noted the following major ecostratigraphic groups of fossils: cyanophytes; mushroom-like microorganisms; microphytoplankton; macrophytoplankton; phytobenthos; Ediacar biota, which unites the Trilobozoa groups (Tribrachidium, Albumares, Anfesta genuses), Proarticulara (Vendia, Dickinsonia, Andiva, Ivovicia, Cyanorus, Yorgia genuses) and Petalonamae (Rangea, Charnia, Charniodiscus, Onegia, Ventogyrus genuses); aquatic Metazoa.

According to the core description and well logs data, the following macrolithotypes are distinguished: microcrystalline microbial dolomites (cyanobacterial mats) - from massive to horizontally laminated; granular dolomites; mixed terrigenous-carbonate and terrigenous-evaporite-carbonate rocks; intraclastic dolomites (stromatolitic breccias).

The Vendian rocks form repetitive cyclotomes, which are represented from the bottom to top: cyanobacterial mats, granular (bunched, oolitic) dolomites and dolomite-anhydrite crystalline rocks, in which sulfates have a primary sedimentary origin. In Osinskiy horizon (Cambrian), the composition of the rocks varies considerably, limestone and dolomite limestones predominate, and algae play the dominant role in the boundstones.

The sequence of layers reflects the development of cyanobacterial mats in supralithoral zone, including sabkha. Eustatic sea level fluctuations led to partial destruction and redeposition of cyanobacterial boundstones materials, oolithization fixes the location of the shoreline.

Vendian carbonate microbiolites are the hydrocarbon reservoirs. Boundstones are characterized by the maximum porosity. The peculiarity of these reservoirs is a high total porosity with the weak pore connectivity and low permeability values. The reservoir properties of carbonate rocks are controlled, on the one hand, by recrystallization and leaching, and, on the other, by compaction of rocks under the effect of geostatic pressure and sulfatization.

Thus, Vendian carbonate microbiolites formed in coastal-marine and shallow shelf environments are mainly characterized by micrite frame structures and high primary porosity, which had been partially healed in early diagenesis. Analogues of the described carbonates were studied in outcrops in Western Anabar, where field observations and analytical studies confirmed their genesis and secondary processes.

The results of sedimentological studies are taken into account in the conceptual geological and 3D models of hydrocarbon deposits

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GLOBAL MICROBIAL CARBONATE PROLIFERATION AFTER THE END-DEVONIAN MASS EXTINCTION AND A COMPARISON TO OTHER MAJOR EXTINCTIONS

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Microbial carbonates flourished following many mass extinction events. Combined with subsequent recovery of metazoans, this has been incorporated into the microbe-metazoan transitions (MMTs) concept.

The end-Devonian (Hangenberg) mass extinction event is a first-order mass extinction on the scale of the 'Big Five' extinctions with major turnover rates in many different fossil groups, including the total extinction of skeletal bioconstructors. However, to date, the extent of global microbial carbonate proliferation after the event remains unclear. The earliest known Carboniferous stromatolites on tidal flats are from intertidal environments of the lowermost Tournaisian (Qianheishan Formation) in NW China. With other earliest Tournaisian microbe-dominated bioconstructions extensively distributed on shelves, the Qianheishan stromatolites support microbial carbonate proliferation after the Hangenberg extinction. Additional support comes from quantitative analysis of the abundance of microbe-dominated bioconstructions through the Famennian and early Tournaisian, It shows that they were globally distributed (between 40° latitude on both sides of the palaeoequator) and that their abundance increased distinctly in the early Tournaisian compared to the latest Devonian (Strunian).

However, various skeletal metazoans recovered relatively quickly after the Hangenberg extinction and early Tournaisian ecosystems were already diverse. This suggests a rather short interval of overall microbial dominance, but the impact for specific environments was still severe. Reef systems provide an example. Only mud-mounds and microbial reefs and mounds are known in the Tournaisian. In the case of the earliest known microbial reefs (Gudman Formation, eastern Australia), microbialite, including stromatolites, constituted >70% of the framework. Of the diverse co-occurring skeletal organisms, large, mostly solitary corals were post-disaster taxa that did not go on to build skeletal frameworks in younger reefs. It took more than 15 million years before skeletal framework, formed mainly by lithostrotionid corals and sponges, returned to reefs in the Viséan.

Comparison of variations in the relative abundance of skeleton- versus microbe-dominated bioconstructions across the Hangenberg and 'Big Five' extinctions shows that the pattern of the Hangenberg extinction, with a shutdown of reef formation followed by an important reorganisation, is similar to those of the Kellwasser and end-Permian mass extinctions. The other three mass extinctions had less impact on reef ecosystems, ranging from regional suppressed reef development to almost no impact.

Thus changes in abundance of skeletal bioconstructors may exert a first-order control on microbial carbonate proliferation during extinction transitions, but microbial proliferation is not a necessary general feature of reefs after mass extinctions.

DISCOVERY OF MICROBIAL FOSSILS IN ORGANIC-RICH SHALE OF NIUTITANG FORMATION IN SOUTHERN SICHUAN PROVINCE, CHINA

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The organic-rich shale cores of Niutitang formation in Southern Sichuan Province were studied using environmental scanning electronic microscope (ESEM). Many microbial fossils of different size were found in mudstone and siliceous shale at depth of 3255.38 m、3348.05 m and 3383.45 m, the diameter of fossils ranges from hundreds of nanometer to approximate 2 micrometer. All the fossils are of embedded or half embedded state, and different flatten degree. Based on the external morphology the microbial fossils can be subdivided into three types as concentric circularity shape, smooth coccid shape and coccid shape with a surface crack. Although the microbial fossils are of significant difference in chemical compositions, the X-ray energy dispersive spectrometer (XEDS) data indicates that all the microbial fossils are of high N and C content (over 30%). The discovery of the microbial fossils provides fossilized evidence for the blooming of the microorganisms in palaeo-ocean in late Sinian to early Cambrian period and the microbial origin of the kerogen of Niutitang Formation. In addition, the discovery of the microbial fossils also provides new information for revealing the carbon cycle in palaeo-ocean.

Key words: microbial fossils; shale; carbon cycle; Niutitang Formation; Southern Sichuan Province

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The Paleocene/Eocene boundary event (PETM) in the Tethyan deep-water realm: evidences from the Zagros Mountains

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The Pabdeh Formation in Zagros Bain records cyclic pelagic sedimentation (shale, marl, limestone cycles) around the PETM interval, characterized by a global warming event and increased ocean-water temperatures. This paper investigates the Paleocene-Eocene sediments in a Tethyan palaeoceanographic setting at the Zagros Mountains. (Paryab section: N 33º ,15' ,14", E 46º, 37' ,3.2"). The cyclic limestone-marl successions of the Paleocene–lower Eocene consist of deep-water pelagic to hemipelagic shale, marl(stone) and limestone. A total of 394 samples has been taken from the 171m thick predominantly shaly lower part, and marly (limestone) upper part of the Pabdeh Formation. We use mineralogy including clay mineralogy, geochemical signatures of trace elements and carbon and oxygen stable isotopes to characterize the stratigraphic profiles. The PETM interval is indicated by bulk rock carbonate carbon isotope values ($\delta^{13}C$) falling from 1.5% to -0.2 % starting at 69.1 m, representing the onset of the distinct negative carbon isotope excursion (CIE) characterising the PETM interval. Higher up-section d13C values increase again at 75.6 m. However significant change from shales to shale-marl cycles can be identified in the section after the PETM interval. The mineralogical composition is generally characterized by mainly carbonates and quartz as well as mixed layer chlorite/smectite, chlorite, illite and kaolinite. Oxygen isotopes, although diagenetically altered, may also be interpreted as a warming-cooling trend. Sea-level fluctuations may be recognized in this pelagic realm by changes in grain-size (coarser during sea-level fall and lowstands) and elements concentration (e.g. calcium, manganese) in the sediments. A first longer-term sea-level trend based on Mn contents indicates a large-scale sea-level fall during the late Paleocene followed by a sea-level rise during the early Eocene.

Cross-bedded grainstones from the middle-to-outer ramp of the Urbasa-Andia plateau (Bartonian, W Pyrenees, N Spain)

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Coarse grainstones in carbonate platform successions are commonly interpreted as shallow-water deposits resulting from the dissipation of surface wave energy on the sea floor. On rimmed shelves, skeletal-oolitic sands form a rim near the shelf margin, which hinders the wave action and favors the occurrence of a back-rim lagoon. In contrast, on ramps and open shelves, grainstone facies mainly occur close to the shoreline, grading basinward into muddier carbonate successions, with two main boundary layers for ramp subdivision: the surface fair-weather and the storm wave bases. Nevertheless, most Cenozoic ramp successions lack sedimentary structures recording these hydraulic reference boundaries due to the seagrass baffling and/or intense burrowing, and ramp subdivision must be based in light penetration, as inferred from the photic dependence of the carbonate-producing organisms. This new criterion has permitted recognizing grainstone bodies occurring near the limit of light penetration, detached entirely from the shallow-water shoreline- and shoal related units.

In this case study, a 90-100-m thick Eocene example of crossbedded skeletal grainstones composed by echinoderm-, bryozoan-, red-algal fragments and orthophragminid larger benthic foraminifers is analyzed. This facies belt occurs at ca. 20-km from the paleo-coastline, downdip of *Nummulites*-*Discocyclina* facies, and grades basinward, at the outer ramp, into finely comminuted skeletal debris and marls with planktonic foraminifers. The skeletal composition of the cross-bedded belt is consistent with oligophotic carbonate production near the lower limit of the light penetration, and hydraulic turbulence to rework the coarser sediments and winnow-away the fines at the transition between middle- and outer ramp. Bedform migration reflects two main flow directions: oblique upslope traction currents (run-up) and downslope backwash return flow. These flow directions and the position within the ramp profile indicate turbulence to be detached from the surface storm waves and suggests internal waves breaking obliquely to the ramp slope. The present example documents the potential role of internal waves in redistributing sediments and shaping sand bedforms across carbonate-ramp systems, producing porous bodies close to basinal facies. These grainstone bodies may become excellent targets for hydrocarbon exploration but acquire particular relevance when a prediction of drains is needed in both exploration and production of unconventional reservoirs.

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SEDIMENTOLOGY AND STRATIGRAPHY OF CURRENT-CONTROLLED CARBONATE PLATFORM SLOPES

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Many factors control the facies and stratigraphic stacking pattern of carbonate platforms. Sea level and subsidence determine accommodation, nutrients and water temperature influence the carbonate factory, and currents, either driven by winds or tides stir and redistribute sediment particles on the platform or transport them offbank. All these controlling factors interact during the growth of the carbonate edifices but often neglected is that the outer shape the platforms is also controlled by geostrophic currents in the adjacent ocean basin.

Isolated carbonate platforms growing today or during the Neogene elucidate how the physical action of geostrophic currents is a major factor for platform development which should be taken into account especially when interpreting carbonate platform successions younger than 13 Ma that evolve in the icehouse world. This process leaves some characteristic signatures. First, this current action largely determines the where fine-grained sediment that is transported offbank is deposited. Sediment depocenters are directly linked to the exposure of the platform flank to geostrophic currents, with greater sediment thickness in current-protected zones where periplatform drifts grow and migrate, irrespective of the platform flank orientation to the dominating wind regime. Second, the winnowing effect of contour currents results in trends of basinward coarsening grain-sizes. Elevated flow velocities may also trigger toe of slope erosion, which induces incision of slope channels and canyons. Finally, slope winnowing, sediment reworking and erosion by currents may be strong enough to suppress sediment deposition at some slopes of carbonate platforms even during active platform growth during sea level highstands. In this case current activity is an important factor of carbonate platform steepening. We propose that the action of geostrophic currents on carbonate platform slope deposition and stratigraphy should be taken into account as a possible and even major controlling factor when interpreting carbonate platform outcrop and subsurface data.

HIGHSTAND SHEDDING IN THE ILES EPARSES, MOZAMBIQUE CHANNEL

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The Iles Eparses are a series of volcano-cored, atoll-like carbonate platforms in the southern Indian Ocean between the African continent and Madagascar. Sediment cores from the lower slopes and proximal basins of these platforms are composed of both shallow water-derived turbidites and aragonite-rich hemipelagic muds. The chronology of cores were derived from $\delta^{18}O$ records and nannofossils. Together, age and compositional data reveal a clear record of highstand shedding[1] of carbonate mud over the past 1 Ma. In all cores, the amount of carbonate mud in the sediment increases significantly during most interglacial intervals, and decreases significantly during most glacials. Increases in aragonite can be seen in SEM images in the form of increased abundance of micrometer-scale needle-like crystals within the mud. In general, the magnitude of Aragonite increase correlates with the magnitude of sea level rise or fall, except during MIS 11, where aragonite content is abnormally low, possibly as a result of dissolution. The highstand increases in aragonite are interpreted to be the result of a combination of factors: 1) increased productivity of the carbonate platform top due to flooding, and 2) a depositional mechanism present primarily during highstand, wherein fine-grained carbonates are winnowed off the platform top, transported in suspension, and redeposited on the basin floor. During lowstands, the platform top is likely exposed and karstified, and sediments are more difficult to mobilize due to early cementation. This study confirms that the highstand shedding model established in the Caribbean also operates as well in the Iles Eparses platforms, which are genetically different from more well-known carbonate localities like the Bahamas. Sedimentation adjacent to the types of atoll-like platforms discussed here is poorly understood; this is one of the first studies to examine the relationship between sediment transfer and sea level change in this type of environment, and is one of the longest sedimentary sea level records in the western Indian Ocean. Ongoing work examines turbidite composition, frequency, and thickness with respect to past glacial/interglacial intervals.

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The Deposition Features and Patterns of Carbonate Gravity Flow in Platform Marginal Slope in the Early Cambrian in Northern Sichuan

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On the basis of field exploration, outcrop analysis and microscopic observbation, the carbonate gravity flow located at the bottom of the Xiannudong Formation in Northern Sichuan Basin and its mechanism were analyzed. The Xiannudong Formation is typically the diamictic carbonate platform marginal slope environment in shallow water, and the results showed that the bottom of this formation is mainly composed of five rock types, including the silty mudstone, micrite grained limestone, bioclastic micritic limestone, sparry algal limestone and sparry bioclastic limestone. According to the morphologic differences in plan, two types of carbonate gravity flow deposits were classified- analogous-nodular and brecciated carbonate gravity flow depositions. Based on the grain size and lithological change of the gravity flow sediments, five development stages were divided in the outcrop zone, which showed an obvious superposition relationship in the longitudinal direction. The grain size of these sediments roughly changes from fine to coarse, which was generally consistent with the regressive environment of the Xiannudong period. In the vicinity of the platform marginal slope, slide and slump events occur due to the triggering mechanisms, like earthquake and storm. The mound and shoal mass moved down along the slope, and some of the blocks were migrated and deposited here, which formed the brecciated carbonate gravity flow deposits. With the increasing injection of water, the amount of sediment-water mixture and the decomposition of the material rised, and some of the mass were broken and flowed as the similar form of debris flow along the slope, and then the debris transformed into carbonate gravity flow deposits flow with plastic rheological characteristics. After deposition, the bottom current may rework and the seawater may also corrode them. Finally, the analogous-nodular carbonate gravity flow sediments were formed.

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SEDIMENTOLOGY OF THE DEVONIAN-CARBONIFEROUS BOUNDARY BEDS IN MUGODZHARY (WESTERN KAZAKSHTAN)

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The Mugodzhary Mountains of Western Kazakhstan (Aktobe Region) comprise one of the few regions with successions of Devonian-Carboniferous boundary beds containing conodonts and ammonoids allowing precise boundary identiofication. The successions studied are exposed within the Birshogyr (Berchogur) Syncline, the major geological structure of this area. The Upper Devonian successions include horizons of dark cherty shale overlain by polymictic conglomerates. The conglomerates contain blocks and extensive olistoliths of limestone with the uppermost Frasnian fossils. These beds are overlain by a variable series of laminated, less commonly massive limestones, sandstones, gravelites, and conglomerate showing pebble-size clasts. Various Famennian fossils are found in the conglomerates and detrital limestones. The total thickness of the Upper Devonian in this region is 350-400 m. The Lower Carboniferous series includes the Zhanganin, Byshogyr and Karabulak formations. The upper two thirds of the terrigenous and carbonate-terrigenous member contain beds of coal and carbonaceous shale. The total thickness of the Carboniferous beds is about 900 m. The Devonian-Carboniferous boundary beds in the Birshogyr (Berchogur) section represent coral-brachiopod-foraminiferal carbonate facies of a relatively shallow shelf of the south Urals marine basin, but with *Acutimitoceras* ammonoid assemblages allowing broad correlations with the Hangenberg boundary event [1]. A new study of the lithology and fossils of the Birshogyr (Berchogur) section will be useful to refine the currently ongoing Devonian-Carboniferous boundary re-examination [2], and will be an important contribution to the interpretation of the depositional environment of Western Kazakhstan at the end of the Devonian, particularly in terms of prospecting and exploration for oil and gas in this area.

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LONG-TERM OSCILLATIONS OF EARLY- TO MID- DEVONIAN CLIMATE RECORDED IN ELEMENT GEOCHEMISTRY OF PELAGIC CARBONATE DEPOSITS; PRAGUE BASIN, CZECH REPUBLIC

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A predominantly carbonate sedimentary succession of the Prague Basin is an illustrative example of continuous record across the Lower to Middle Devonian (Lochkovian to Givetian). Several bioevents of global importance, identified in these strata, were probably connected with climatically driven sea-level changes. Majority of Devonian bioevents in the Prague Basin can be characterized by significant faunal overturns associated with facies stacking-patterns changes, variations of oxygen and carbon stable isotopic composition and variations of petrophysical characteristics (gamma-ray spectrometry, magnetic susceptibility). The aim of this paper is to trace long-term trends in element geochemical record and interpret them in the frame of climate and oceanographic changes.

Multivariate statistical approach and log-ratio methodology were applied on the element geochemical composition of sediments from 14 sections in the Prague Basin, including 491 whole-rock samples analysed by energy-dispersive X-ray fluorescence spectrometry combined with ICP-MS analysis (70 samples) and field gamma-ray spectrometry (nearly 3000 assays).

Two intervals of the stratigraphic succession (lower Emsian Zlíchov Formation and Eifelian Choteč Formation) are marked by elevated values of productivity and redox proxies (Si/Al, Ni/Al, P/Al, Mo(EF), V(EF), TOC), combined with increased U/Th gamma-ray spectrometric ratios, changes in allochem composition, and increased abundance of carbonate turbidities. In contrast, the Praha (Pragian – lowermost Emsian) and Daleje-Třebotov Formation (upper Emsian) show geochemical evidence of oligotrophic, well oxygenated conditions. The major geochemical changes coincided with the Devonian bioevents close to the formation boundaries, namely the Lochkovian/Pragian Event, the basal Zlíchov Event and the basal Choteč Event. These changes indicate long-term (Myr-scale) switching between different trophic regimes in Devonian ocean. Increase of Zr/Al ratio and decrease of Rb/Al, K/Al and K/Rb ratios at the base of the Praha, Zlíchov and Choteč Formations may also indicate climatically driven changes in provenance and weathering rate at continent.

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THE EFFECT OF TEMPERATURE, SALINITY AND MG^{2+}: CA^{2+} RATIO ON MICROBIALLY-MEDIATED MG-RICH CARBONATES BY AEROBIC STRAINS ISOLATED FROM A SABKHA ENVIRONMENT

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Studies conducted in the laboratory at ambient conditions have demonstrated the role of microorganisms in facilitating the incorporation of Mg^{2+} into carbonate minerals, leading to the formation of high-Mg calcite and non-ordered dolomite that are considered as potential dolomite precursors [1]. These findings are relevant for understanding the global cycle of Mg^{2+}, and for interpreting ancient sedimentary sequences that are rich in dolomite. Most of the microbes capable of mediating Mg-rich carbonates have been isolated from evaporitic environments such as sabkhas and hypersaline lagoons, where temperature and salinity are higher than the average of those for marine environments [2]. Although temperature and salinity (and subsequent increase in saturation index) synchronize with microbial activity that influence mineral precipitation, the relative importance of these factors remains poorly constrained. Here, we report the results of laboratory experiments in which two mineral-forming *Virgibacillus* strains and one non-mineral-forming strain *Bacillus licheniformis* (used as negative control) all isolated from the Dohat Faishakh sabkha in Qatar were grown at different combinations of temperatures (20°, 30°, and 40° C), salinities (3.5, 7.5 and 10 NaCl %w/v), and Mg^{2+}: Ca^{2+} ratios (1, 6 and 12). Our results indicate the three tested factors have significant effect on the incorporation of Mg^{2+} into the carbonate minerals. The Multivariate analysis reveals that temperature has the largest impact followed by salinity and Mg^{2+}:Ca^{2+} ratio. The outcome of this study suggests that saline and warm environments are primarily favorable for microbially-mediated formation of Mg-rich carbonates and provides new insights for understanding ancient dolomite formations.

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SEDIMENTARY CHARACTERISTICS OF MICROBIAL CARBONATE AND ITS RESPONSE TO SEQUENCE STRATIGRAPHIC FRAMEWORK: IMPLICATION FOR THE LOWER CAMBRIAN XIAOERBLAK FORMATION, NW TARIM BASIN

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Sequence stratigraphy provides an integrated framework within which to examine historical patterns of sedimentary phenomena, and has become a highly successful exploration technique in determining how sedimentary basins accumulate and preserve sediments. the Aksu outcrop area is located in the northwest part of Tarim Bain, and during the sedimentary period of Xiaoerblak Formation, the area was located in the northwest margin of the Taxi Platform. Three outcrop sections, 162 thin sections and 12 SEM samples are systematically investigated in order to investigate sedimentary characteristics of microbial carbonate and establish the sequence stratigraphic framework, for the purpose of straighten out the relationship between them. The result shows that the Xiaoerbulak Formation can be subdivided into two third-order sequences. Lower part of the Xiaoerblak Formation, SQ1, corresponds to a set of microbial mats which is middle-inner ramp deposition belonging to the stage of ramp carbonate platform. Upper part, SQ2, represents a transition from ramp carbonate platform to slightly rimmed shelf carbonate platform. On slope, tempestite deposited without microbial carbonate, while on paleokarst highland, large-scale transgressive mircobial reef was built by the growth of skeletal microbes and correlatively bonding effect. HST represents stage of slightly rimmed shelf carbonate platform, where margin and inner-platform are sharply different. On platform margin, EHST is characterized with chambered *Epiphyton* bioherms, and LHST features some small-scale transgressive microbial bonding reefs. While without EHST, the inner-platform has a LHST characterized by laminites, spongiostromata stromatolites and stromatolites, whose formation is related to the sticky microbial mats.

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ISOLATION, IDENTIFICATION AND APPLICATION OF INDIGENOUS UREOLYTIC BACTERIA IN MICROBIALLY INDUCED CALCITE PRECIPITATION (MICP) FOR SOIL STABILIZATION AT HARSH CONDITIONS

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Micro-organisms are known to be involved in precipitation of minerals in different micro-environments by changing their geological and chemical properties [1]. The role of bacteria capable of hydrolysing urea and precipitating calcium carbonate is widely studied. It is important to study and enlist the indigenous species involved in biomineralization techniques such as microbially induced calcite precipitation (MICP) [2]. Biomineralization has different applications in terms of improvements in soil and ground stability. Similarly, the use of biomineralization technology to treat cracked buildings as a remediation technique is recommended due to the bio-precipitation of minerals [3]. Occurrence of bacteria in soil is affected by the environmental conditions which can serve as stressors leading to adaptation routes specific to the region. Since, Qatar has a hot and arid climate with calcareous soil, it is useful to analyse and investigate Qatari soil for the occurrence and diversity of such bacterial species that can be utilized for biomineralization. The aim of this study was to isolate, identify and differentiate local ureolytic bacteria from soil sampled around Doha city to investigate the diversity and distribution of such species in Qatari calcareous soil. The objectives of this research include (1) isolation of indigenous ureolytic bacteria from Qatari soil, identification using molecular techniques (16s rRNA) and differentiation of the ureolytic bacteria; (2) application at the laboratory and field scale of selected bacteria for stabilization of soils at harsh conditions. A total of 30 bacterial strains were isolated from the soil samples out of which 18 tested positive for ureolytic activity. Their identification concluded the occurrence of *Bacillus sp.,* mainly *B. cereus, B. subtilis* and *B. licheniformis*. The differentiation of strains by MALDI-TOF MS was based on which the grouping of the ureolytic bacteria in 5 categories. Selected bacteria were applied for biomineralization and formation of calcium carbonate in soil for the low cost application was optimised at the laboratory and then in open field at harsh weather and soils. Carbonate formation in soils exceeded 59 mg/g and the mechanical properties were highly improved in 1 cm of the upper layer on the soils, showing also high stability facing wind. The results of this research clearly show high diversity of B. cereus bacteria exhibiting urease activity but also showing many roots of adaptation to harsh conditions translated into different protein profiles.

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ATYPICAL CARBONATE-SILICA MINERALISATIONS UNDER BIOTIC AND ABIOTIC CONTROLS: THE MODERN HYDROTHERMAL EXAMPLE OF PASTOS GRANDES LAGUNA (BOLIVIA)

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Lacustrine systems are sensitive to complex chemical variations and are frequently associated with spring vents. Pastos Grandes laguna, in the Altiplano of southern Bolivia, is a present day palustrine/lacustrine system lying on a caldera resulting from an ignimbrite eruption which occurred 2.89 Ma ago. A very peculiar point is the existence of a wide (~ 40 km^2) flat platform associated with hydrothermal systems exhibiting either silica or carbonate facies in comparable proportions. Mineralogy, chemistry and facies of hydrothermal precipitations in surface continental settings are under the dependence of several factors (e.g. temperature, topography of the depositional profile, water and gas chemistry, biological communities and lithology) present along the hydrogeological pathway of thermal waters. When surrounding rocks are predominantly of volcanic origin, the resulting deposits are generally Si-rich, designated as sinters. Carbonates may also precipitate in such cases but are usually rare. As no carbonates are available in the surrounding of the caldera, part of our investigations were conducted to understand the origin of their presence. Mineralogical investigations of the surrounding volcanic rocks together with geochemical analysis of thermal fluids (gas and waters) reveal that carbonates mainly result from the conjunction between two factors promoting their precipitation: (i) volcanic rocks are relatively rich in Ca-feldspars which are locally altered and leached; (ii) hydrothermal vents with high flux of magmatic CO_2 input are scattered below the platform contributing to HCO_3 enrichment.

Our investigations also focused on one of the hydrothermal vents that flush through the platform. Along a proximal-distal depositional profile, four successive facies belts with specific physicochemical parameters and living communities have been observed: (1) the hydrothermal feeding system with diatom accumulations, associated to bacterial filaments with low calcite content; (2) the floodplain with scattered microbialites, a mixture of diatoms and micrite (calcite); (3) the bioconstructed belt formed by cauliflower-shape microbialites composed of alternation of thin silica and calcite layers; (4) the ephemeral evaporitic belt with halite dissolved by rainfalls during wet seasons. This sedimentary system illustrates the numerous interactions existing between abiotic and biotic controls associated within hybrid carbonates and siliceous precipitations.

Looking for environmental- and bio- signatures in hypersaline microbialites: a comparison of ancient and modern sedimentary systems

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In microbialites, the precipitation/dissolution, and the composition and morphology of minerals depend on three factors: (1) environmental (or extrinsic) physical and chemical conditions, e.g., water composition (e.g., pH, alkalinity, T°), temperature, light, hydrodynamics; (2) microbial activity, dominated by several interdependent autotrophic and heterotrophic microbial guilds modifying their surrounding environment; (3) physical and chemical properties of extracellular polymeric substances (EPS) and cell material, often constituting the substrate for mineral nucleation.

This study presents and compares two contrasted modern microbialite systems: one in a restricted marine lagoon (Cayo Coco, Cuba), the other in a hypersaline continental lake (Great Salt Lake, USA). In each example, we characterized water chemistry, microbial activity, EPS properties, mineral products (morphology, mineralogy, chemistry) and their succession, i.e., parageneses, in order to determine the relative influence of microbial and environmental factors on their formation. The evolution of the primary mineral products during early diagenesis, i.e. the first kyears, was also assessed. Finally, we compared the two modern case studies with various examples from the fossil record (Miocene, Cretaceous, etc.) to evaluate the preservation, but also the possibility to differentiate primary microbial and environmental signatures in ancient microbialites.

MICROBIALITES PRESERVED IN THE SEDIMENTARY RECORD: ARE THEY AN ACCURATE VIEW OF THE MICROBIAL ACTIVITY?

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Lithified microbial deposits referred to microbialites are organosedimentary structures documented since 3.7 billion years. These deposits are the oldest known bioconstructions and their occurrence is closely linked to major events in the Earth's history, such as the Great Oxidation Event (2.3 Ga), which increased the oxygen concentration in the oceans and the atmosphere. Understanding the mechanisms and environmental conditions leading to microbialites formation may provide valuable information about the origin of life on Earth and the biogeochemical evolution of our planet.
Microbial mats continue to thrive nowadays, some of them still forming microbialites. However, their abundance and diversity appear to have markedly fluctuated through time, as suggested by the fossil record. One major issue is to decipher if these variations are either representative of environmental and/or formation changes, or if they result from a bias linked to the preservation of these organo-sedimentary structures as microbialites. Consequently, understanding both mechanisms of the formation and the processes of preservation of microbial deposits through time seems crucial.
Microbialites are formed when certain conditions favor the mineralization process, either by *in situ* precipitation of minerals or by trapping and binding of sediments. However, the minerals that precipitate initially are not necessary preserved and can be dismantled and/or dissolved by both physical and chemical processes. This raises the question what the fate of the mineral products is. The investigations conducted in modern microbial-dominated sedimentary systems in Cuba and in the USA, showing contrasted preservation potentials (despite a high mineralization potential) may help to address the issue of their potential preservation and finally question how accurate the sedimentary record can be.

Microbial or not microbial? Laminated carbonate-siliciclastic domes in the Mesoproterozoic Stoer Group, Scotland, UK

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Mesoproterozoic Stoer Group rocks contain convincing evidence for Precambrian microbial life in the form of organic carbon microfossils (cf. Strother et al., 2011). Purported microbialites are more contentious. Sedimentology and stratigraphy including trough cross-bedded sandstones and unidirectional current indicators are most consistent with a terrestrial origin for the majority of Stoer Group rocks (c.f. Stewart, 2002), though Stueeken et al. (2017) have suggested that one section in the middle of the Poll a'Mhuilt Member might have been deposited in marine conditions. Layered carbonates in these otherwise dominantly red coloured siliciclastic rocks were once interpreted as 'tufted stromatolites' (Upfold, 1984) that because of their implied terrestrial setting could be interpreted as a form of Mesoproterozoic 'tufa stromatolite' (sensu Riding 1991). The interpreted biogenic origin of these 'stromatolites' was based solely on centimetre to millimeter scale morphology (Upfold, 1984). Here we use modern tools (nano- to micron-scale electron microscopy, cathodoluminescence, electron backscatter diffraction and carbonate clumped isotopes) to investigate whether there are any conclusively biogenic stromatolites in the Stoer Group that would provide robust autochthonous evidence for colonisation of an ancient terrestrial surface by carbonate-precipitating benthic microbial mats. Petrography has not revealed any preserved microbial filaments or coccoids in the stromatolites, while calcite forming the carbonate laminae seems to have been of clastic (re-worked) origin at the time of deposition. Models that might explain the domal shape of these carbonate-clastic accumulations, as well as their location in the stratigraphy and isotope geochemistry, will be presented for discussion.

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THE INFLUENCE OF MICROBIAL MATS ON TRAVERTINE PRECIPITATION IN ACTIVE HYDROTHERMAL SYSTEMS FROM CENTRAL ITALY

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The study of travertines forming in active hydrothermal systems contributes to the understanding of the interaction between physico-chemical processes (CO_2 degassing and cooling of flowing thermal water) and the role played by microbial mats in influencing carbonate mineral precipitation. Three active travertine systems were investigated in central Italy to identify the carbonate precipitated fabrics and the associated microbial mats at varying thermal water temperature, alkalinity and pH. Samples were fixed with formaldehyde and glutaraldehyde solutions, stained with organic compound dyes, impregnated in resin for petrographic analysis, and dehydrated with increasing ethanol concentrations for SEM analysis.

Samples from the Bullicame (Viterbo, Latium) travertine mound derive from a 20-40 cm-wide channel with water temperature decreasing from 55°C to 50°C along a 60 m distance, pH increasing from 6.7 to 7.4, and alkalinity decreasing from 15.6 to 14.5 meq/l due to CO_2 degassing and carbonate precipitation. The proximal channel center is colonized by carbonate encrusted fans of filamentous microbes, likely sulfide oxidizing *Aquificales*; the margins and the distal channel portions are draped by green microbial mats with filamentous cyanobacteria (*Spirulina*) associated with calcified gas bubbles and rafts. Carbonate precipitates consist of seed-shaped calcite crystals (50-100 μm long, 20-40 μm wide) or acicular aragonite crystals organized in radial spherulites, coating organic filaments or embedded within EPS (Extracellular Polymeric Substances). Bagni San Filippo (Tuscany) thermal water has a temperature of 46-49.5°C (pH 6.5; alkalinity 31.6 meq/l). The first 5 m of the dm-wide channel departing from the vent are characterized by carbonate encrusted filamentous sulfide oxidizing and rod-shaped bacteria. Carbonate occurs as calcite seed-shaped crystals 40-80 μm long organized in radial spherulites with often at the center a micrite clot 20-50 μm in diameter and acicular aragonite spherulites, up to 100 μm in diameter. These spherulites coat organic filaments or are embedded within EPS. Nearly 14 m downstream from the vent, thermal water has cooled down to 41°C (pH 7.3, alkalinity 21.5 meq/l). Carbonate precipitates within the channel consist of cm-size terraces, rafts, coated gas bubbles and mm-size clotted peloidal micrite dendrites associated with green microbial mats with filamentous cyanobacteria, including *Spirulina*. The Gorello (Saturnia, Tuscany) travertine terraced slope system consists of meter-scale horizontal pools separated by dm-high walls coated by green microbial mats. Water temperature is 33°C, alkalinity 9.1 meq/l, and pH 7.7-7.9. Within the pools, cm-size pisoids are made of 5-15 μm thick micritic laminae alternating with 30 μm thick bladed crystals coating detrital grains. Microbial mat is dominated by filamentous cyanobacteria including *Spirulina* and *Phormidium*. Carbonate precipitates are spherulites of calcite crystals 20-100 μm in diameter embedded within EPS and nanometer-scale micrite coating filamentous cyanobacteria.

This study shows that in travertines microbial communities vary as a function of water temperature; carbonate precipitation, triggered by CO_2 degassing, is influenced by microbial biofilms acting as low-energy substrates for crystal nucleation or it takes place within the biofilm EPS.

Fossil and living freshwater microbialites in Northeastern Patagonia (Argentina)

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The Maquinchao closed-basin in the Rio Negro province (Argentina) provides an ideal site to study both the present development and the paleoenvironmental implications of microbialite formation. Presently the basin encompasses two lakes joined by an ephemeral river containing different types of fossil microbialites such as stromatolites, carbonate laminated crusts, and living microbial mats. Fossil stromatolites are found along the Maquinchao River bed as well as South and South west of the largest lake. These stromatolites outcrop as extensive banks and/or distinct buildups. Additionally, carbonate crusts and living microbial mats are found in dry and active pounds of the Maquinchao riverbed.

Preferential zones of development for fossil and living microbialites have been identified and mapped using high-resolution differential GPS. Fossil outcrops are located at an elevation of 840m which is higher than the actual Maquinchao riverbed where living microbial mats have been observed. In both cases, the microbial buildups are preferentially associated to basaltic substrates. Field observations along with X-ray computer tomography and SEM imagery reveal different structural types that are dependent of the porosity and their stage of preservation/erosion. Columnar-like constructions are well preserved, whereas some other specimens have an exposed basaltic nucleus with only their outer part being in good conditions of preservation. This difference in shape and preservation stage seems to be directly linked to the porosity type of these low Mg calcite buildups. The well-preserved fossils show elongate/tubular porosity ranging between 5 and 7 micrometers in diameter. The living mats display a similar porosity type pointing towards comparable processes of formation.

Ongoing investigations include stable and clumped isotopes in the carbonate facies, detailed petrographic and geochemical characterization, as well as dating of both living microbialites and their fossil counterparts. This comparison will provide the opportunity to develop a growth /preservation model that could be applied to similar basins at various locations and back in time.

Spatial and temporal heterogeneity of microbialites and aragonite crusts in the Danakil Depression (northern Afar, Ethiopia)

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The Danakil Depression is the northern portion of the Afar triangle bordered to the west by the Nubian plateau and to the east by the Danakil horst. The Depression features the lowest elevations on Earth and is part of an active rift zone associated to the break-up of the Afro-Arabian plateau. Since the early formation of the continental drift theory, the Afar triangle developed into a true field laboratory where the onset of rifting can be studied in detail since Oligocene-Miocene times. As the Danakil Basin experienced extreme hypersaline conditions during the Pleistocene and the Holocene in direct contact with basalts and alkaline rhyolites, the basin has proven to be also an optimal field laboratory to study the nature and significance of microbial carbonates in extreme settings.

The Middle to Late Pleistocene sedimentary record in the Danakil Basin bears witness of the past connection to the Red Sea. Pleistocene aragonite crusts, spherulites and microbialites are occurring at the margins of the Danakil Depression intimately associated with open marine coralgal reefs. Aragonite crusts and spherulites are covering coralgal bioherms. Their stratigraphic position between marine and evaporitic deposits suggest that crusts and spherules are formed in restricted hypersaline semi-enclosed conditions. Fabrics of the crust are laminated to non-laminated with laminated fabrics resembling stromatolites. SEM-EDX analyses have revealed the presence of Mg-silicates intercalated with fibrous aragonite. The variety of observed fabrics studied through classical sedimentary petrography, mineralogy and high-resolution 3D micro-computed tomography combined with lipid biomarker analyses reveals a continuum of microbial mediated and abiotic mineralization mechanisms reflecting the tight and continuous interaction between abiotic and microbial processes. Microbial carbonates with distinctive fabric are occurring within the cavities of the coralgal reefs. The studied crusts, microbialites and spherulites are characterized by a variety of preservation states, which allowed reconstructing different early diagenetic steps altering the primary fabrics and shedding new light on fabric preservation through space and time.

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GROWTH MECHANISMS OF NEEDLE FIBRE CALCITE: IS MICROBIAL METABOLISM INVOLVED?

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Deposits of needle fibre calcite (NFC) have been considered as a representative example of microbial (fungal) biomineralisation in vadose terrestrial settings. Basic elements of NFC are strongly elongate, rod-shaped low-Mg calcite crystals with an average width of 1 µm and length typically reaching 10^2 to 10^3 times their width. NFC occurs in pores, mm to dm in size, forming patchy, cotton-like aggregates, typically accumulating within the rooting zone of terrestrial plants in semiarid/sub-humid climatic regions, generally characterised by seasonal moisture deficit. In caves, NFC and nanofibrous calcite forms are the main component of calcite moonmilk – a porous, soft, microcrystalline speleothem that can contain up to 95% of interstitial water, showing a distinctive pasty and plastic texture.

The basic NFC rod shapes have been explained by calcite nucleation and growth inside 'organic sleeves' (fungal hyphae), which act as moulds, inducing atypical needle crystal shape. Although the hypothesis of fungal biomineralisation (as opposed to growth of NFC by rapid evaporation) has been supported by presumptive geochemical and mineralogical/crystallo-graphical evidence, the main argument has been founded on the similarity in dimensions and morphology of calcite fibres and fungal hyphae, their co-occurrence, and the fabric of NFC deposits.

Our study is based on material from actively precipitating moonmilk deposits in caves and secondary soil carbonates precipitating within extensive root systems of plants in calcareous substrates in Mediterranean and Alpine climates (Spain and Slovenia). Distinctive crystal shapes and growth patterns of NFC occurring in different underground ecosystems and geochemical settings strongly suggest a common mechanism of crystal growth, which is not necessarily related to fungi as in the generally accepted model. Morphological evidence against the NFC formation within a tubular (fungal) organic template is based on abundant complex branching NFC structures, composed of simple rods protruding as parallel outgrowths from a common NFC rod substrate. These ordered dendritic structures apparently exhibit a crystallographic control in NFC growth, following patterns similar to a crystal lattice. Furthermore, NFC rods observed in these structures, typically terminate with a droplet (bobble) at the tip of the crystal, a characteristic feature of calcite fibres precipitated in-vitro by polymer-induced liquid precursor mechanisms (PILP). Our study suggests that NFC crystal morphologies can be explained by concepts of non-classical crystallisation systems where polymeric substances probably provide a template for $CaCO_3$ nucleation and oriented growth. In cave moonmilk and related settings in soils, microbial EPS can influence crystal morphology and growth of these distinctive non-equilibrium forms of calcite without living organisms and metabolic processes directly involved in mineralisation

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Calcimicrobes of Permian-Triassic boundary microbialites and their role in the framework construction: new evidence from the Pingguo Platform, Guangxi Province, South China

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The largest Phanerozoic extinction event occurred at the end-Permian. After the event calcimicrobialites immediately occupied at shallow settings of Tethys. Most of them straddle Permian and Triassic time so they are called as Permian-Triassic boundary microbialites (abbrev. PTBMs), as well as thus they are potential to provide evidence for the extinction event and its aftermath. However, it remains question to identify calcimicrobes in PTBMs, and it is not known well for their role in the construction of framework. PTBMs were exposed very well in the Taiping section, Guangxi Province, South China. The microbialites are *ca.* 4.5m thick and mainly comprises spotted, layered, and meshed thrombolites, with plentiful calcimicrobial fossils. It is an excellent material for the study of calcimicrobes and framework construction. Polished-surface and thin section show that the PTBMs are composed mainly of irregular clots, with 0.1-0.5 mm in diameter. Space between clots are filled with peloidal micrites, together with small infaunal metazoan fossils such as gastropods, bivalves, and ostracods. The framework are recrystallized in various degrees. Nevertheless, the well-preserved portions reveal that the framework were built by saccate microbes with 0.1 to 0.7mm in diameter, by amalgamating and connecting with each other. Saccate microbes have thicker micrite sheath that has distinct outlines and indistinct inner wall, and their hollow inner is filled with spars. Saccate microbes are different from *Renalcis* and *Tarthinia* that are characterized by lunate chambers and branching growth. Also they are similar to *Microcystis* aggregations, however, the latter are pelagic and have feature of benthic build-ups. We thus suggest to name them as "*Wangshenghaia*" following the proposal of Kershaw (2017), in order to show their uniqueness. Another kind of microbes prevailing in clots are spheroids, and ranging from 20-40μm in diameter. They have a central hollow with spar-infillings and micrite sheath, as well as are well-preserved in clots with various degrees of recrystallization. Spheroids often occur in the edges of saccate microbes and sometimes are mounted in the micrite edges of the later. A chain structure consisting of a complex lunate-shaped fabric is attached to saccate microbes in some sections. The growth direction of the chain structure is mainly perpendicular to extensible orientation of the laminae of thrombolites. So it may be bioturbation trace by endolithic coccoid bacterial activity, rather than calcified cyanobacteria *Gakhumella*. Our results provide new evidence for the composition of calcimicrobial community and the formation of PTBMs framework.

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MICROPEARLS: A WIDESPREAD BIOMINERALIZATION PROCESS?

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A novel biomineralization process was recently discovered in unicellular freshwater phytoplankton[1]. These microalgae form non-skeletal intracellular inclusions of hydrated amorphous calcium carbonates (ACC), called micropearls. The micropearls are enriched in strontium and barium compared to the surrounding freshwater and show internal nano-scale concentric oscillatory zonation, due to the variation of Sr/Ca or Ba/Ca ratios. The concentration capacity of the micropearl-forming organisms can be very high as the ratio of Ba/Ca is up to 800,000 times higher in the micropearls than in the surrounding water. Moreover, our results indicate that during periods of high productivity, these microalgae may influence the composition of the surface water through this biomineralization process regarding elements present in very low concentrations (e.g. barium in Lake Geneva, Switzerland).
The organism of Lake Geneva, that forms micropearls enriched in strontium, has been identified as *Tetraselmis cordiformis*[1]. Even though this species has been thoroughly studied by biologists, the micropearls have only been observed recently, probably because the usual sample preparation techniques dissolve or expel them from the cell. This discovery raised the possibility that other organisms might have a similar biomineralization capacity.
We tested eleven species of the genus *Tetraselmis*, which thrive in marine or brackish environments, unlike *T. cordiformis*, that lives exclusively in freshwater. Our results show that nine of these species produce micropearls. The composition of the micropearls and the capacity to concentrate strontium seems to vary among species. The biomineralization process leading to the production of micropearls is therefore widespread in this well-studied microalgal genus, demonstrating that this phenomenon is not restricted to freshwater systems, but also takes place in marine and brackish environments.

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DIVERSITY OF MICROCRYSTALLINE FABRICS IN CALCITE MOONMILK SPELEOTHEMS

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Petrographic analysis of moonmilk speleothems from caves in Slovenia has shown a wide diversity of microcrystalline textures, including several microfabrics typically found in carbonate microbialites.

Moonmilk speleothems are very porous microcrystalline aggregates that can contain up to 95% of interstitial water and show a distinctive soft and plastic consistency. They are composed of needle fibre calcite (NFC), nanofibrous calcite, mineralised and non-mineralised microbial features and microbial exopolymeric substances (EPS). Although some authors attributed its origin to purely physicochemical processes, most research suggests that microbes play an active role in the precipitation of calcite in moonmilk. Some of the studies rely on molecular and classic microbiology and geochemistry, however, the current biogenic hypotheses are largely based on SEM observations showing association of moonmilk with organic matrix and microbial communities and morphological similarities of calcite fibres to fungal hyphae and filamentous bacteria.

While most of the studies have thoroughly illustrated moonmilk microstructure under the SEM, only few have tackled the characterisation of the moonmilk microfabrics under optical microscope, possibly due to the difficulties to prepare good quality thin sections without collapse of the 3D, highly hydrated structure. As part of our project on the biogenicity of fibrous microcrystalline calcite in moonmilk we have prepared thin sections of moonmilk stalactites, multilayered moonmilk crusts and cave pearls from Snežna Jama Cave and Koševelka Cave in Slovenia, to understand the internal structure and growth patterns of different morphological moonmilk types.

Multilayered crusts are formed by alternation of laminae of dense, clotted and laminated micrite, columnar calcite and detrital layers, surrounded by a very porous layer showing alveolar septal structure with aggregates of NFC crystals filling the spaces. The studied stalactite has an internal area composed of laminae of columnar and columnar microcrystalline fabric, typical of sparitic speleothems, while the outer moonmilk layers are composed of peloidal micrite, shrubs (clotted peloidal dendritic) and microsparitic cements. Pearls can consist of a single nucleus and a cortex formed by concentric laminae of different textures or grape-like aggregates of coated grains weakly cemented by NFC surrounded by a single or multilayer cortex. Most commonly cortex textures are laminated micrite and dendritic crystalline. All studied microcrystalline textures display a bright green luminescence under UV light, indicating the presence of organic matter.

This wide variety of microcrystalline fabrics reflects the complex interplay between microbial communities, organic matrix, water chemistry, hydrology and environmental parameters. Understanding the genesis and distribution of each fabric type can help to determine the role of microbes in the depositional mechanisms of moonmilk.

BIOLOGICAL AND ABIOTIC CONTROLS ON CARBONATES FORMATION IN PASTOS GRANDES LAGUNA (BOLIVIA)

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Pastos Grandes Laguna, located in a 2.9 Ma caldera on the andean-bolivian Altiplano, presents an extraordinary diversity of carbonate-silicate facies with shrub-shaped calcites, ooids, pisolites and various stromatolites similar to the mysterious Pre-Salt carbonated oil reservoirs. In order to understand what is behind such facies and how they form, we investigated (i) the physico-chemical and biological processes that constrain the mineralization on the platform and (ii) the biological control on the construction of such complex mineralogical facies. To do so, we analyzed water and biofilm samples from hydrothermal Ca- and HCO_3-rich sources scattering the carbonated platform of Pastos Grandes.
Using PHREEQC modeling and geochemical data we identify the processes governing the global physico-chemical evolutions of the hydrothermal water and the associated mineralizations along transects. The decrease of temperature, the high rate of degassing and bio-assimilation of CO_2 and an extreme evaporation up to 89 % are the 4 main processes responsible for the increase of pH and conductivity necessary to mineralizations. Our results coupled with the isotopic mass balance of DIC also indicate that the proportion of assimilation increases rapidly from 4 to 47 % before evaporation begins. Calcite ledges dominate this area. A bloom of photosynthesis also occurs further in the evaporation zone where the shrub-shaped calcite extensively precipitates. From a thermodynamic point of view, the over-saturation of amorphous silica and the highest pH should allow the precipitation of Mg-silicate exclusively in this area while the calcite can form all along transect. Finally, the formation of pisolites is associated with the maximum of evaporation, in small basins of hypersaline water equilibrated with the atmosphere.
In the microbial mats sampled along the transect, we observed a biological control of the precipitation of Mg-silicate and amorphous silica, which are only associated with some cyanobacteria (maybe Rivularia), while the carbonate precipitation is associated with consortia of bacteria that involved at least anoxygenic phototrophic bacteria. In the pisolite basin however, cocoid cyanobacteria dominate the microbial mats and calcite nucleates from (detritic) grains in association with small-unidentified non-cyanobacterial microorganisms. Therefore, while the "shrubby" facies seems to be controlled by a bi-mineralization silicate-calcite linked to the association of filamentous cyanobacteria + adjacent bacterial consortia, the pisolite facies seems to be associated with a different community unidentified yet. This preliminary study clearly shows that particular biological assemblages are responsible for specific sedimentological facies. In the future we aim to identify the species directly involved in the bio-mineralization by coupling bulk 16S rRNA genes sequencing and specific identification of key microorganisms using laser microdissection and concomitant specific 16S RNA genes sequencing.

EFFECT OF SUBSTRATE ON THE MICROBIALITE DEVELOPMENT

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Many studies concerning microbial mats, modern and ancient microbialites are focused on the characterization of their biological or mineralogical composition and sedimentary environment, but few are interested in the effect of substrate on the development of microbial mats and the mineralization and on their resulting morphologies.

The purpose of this work is to show the influence of the substrate on the development of microbial deposits throughout five examples of continental systems: the modern Mérantaise fluviatile system (France), the Plio-Pleistocene Bonneville/Great Salt Lake, Sevier and Winnemucca lacustrine systems (Basin and Range, US) and the Oligo-Miocene Limagne lacustrine system (Massif Central, France). In all of these examples, microbial deposits set in semi-hard or indurated substrates with varied composition. Along the Mérantaise River, microbial mats are widespread but microbial carbonate deposits are only located downstream, only encrusting cobbles, pebbles and iron fragments. In the lacustrine systems, microbial deposits cover microconglomerates or conglomerates (Bonneville, Winnemucca and Limagne Basins), magmatic substrates (Sevier and Winnemucca Basins) or caddisflies pupal cases clusters and plants (Limagne Basin). Whatever the scenario, no microbialites are preserved laterally on soft and fine sediments as sands and clays.

The substrate lithology impacts the chemistry of fluvial and lacustrine waters and then the ability of microbial mats to mineralize and microbialites to be preserved. For the Bonneville and Limagne Basins, microbialites formation is partly linked with volcanic events providing Ca^{2+}, Mg^{+} and CO_2 into the lake system. In addition, the weathering of surrounding rocks provided a source of Ca^{2+} as well.

In all the cases, substrates form topography relief from the bottom providing a physical support for the development and the attachment of microbial mats and the preservation of microbialites. The shape of substrate drives the morphology of microbialites to which they fit closely. Domal or columnar microbial deposits are observed when microbial mats developed on boulders (Bonneville Basin), plants or clusters of caddisflies pupal cases (Limagne Basin). In crust-shaped or flat deposits on conglomerate lenses (Bonneville and Winnemucca Basins), basaltic lava flow (Sevier Basin) or magmatic intrusion and chimney (Winnemucca Basin).

However, this does not exclude importance of the intrinsic controlling factors related to the composition of microbial communities and their ability to indurate soft substrate, as has been observed in Great Salt Lake on oolithic sandy substrates. Hard substrate is therefore considered as main driver to favor the development, mineralization and preservation of microbial deposits.

Characteristics of microbial carbonate reservoirs in Middle Triassic Leikoupo Formation (Anisian Stage), Sichuan Basin, China

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Microbial carbonate reservoirs have become new type of hydrocarbon exploration targets all over the world. Recently, a newly found producing strata, Middle Triassic Leikoupo Formation (Anisian stage), has been discovered in western Sichuan Basin, got a gas production up to 1,150,000 m^3/d, indicating good exploration prospect in microbial carbonates both in Sichuan basin and the paleotethys tectonic region.

The microbes have been identified including *Renalcis*, *Girvanella*, *Rivularia lissaviensis*, *Entophysalis*, *Tortofimria* and *Gloeorrh*, forming stromatolite, laminite, thrombolite, spongiostromata stone, dendrolite and oncolite. The petrologic sequence is form laminate, stromatolite, thrombolite, spongiostromata stone to stromatolite, indicating subtidal to intertidal in depositional environments. There are certain rounded, spheroidal, hollow hemispherical or bead-like textures under FESEM, which are similar to the reported microbial-induced dolomites worldwide.

The microbial carbonate reservoirs lie in submember $T_2l^3{}_3$ in Zhongba area and submember $T_2l^4{}_3$ in Pengzhou area. The reservoir spaces are mostly microbial coelome pore, framework pore, fenestral pore, inter- and intra-clot dissolved pores. And the microbialite reservoirs are 0.2% to 7% in porosity and (0.003~85) $\times 10^{-3}$ μm^2 in permeability. The reservoir thickness is gradually thinner to northeast horizontally, form 40 to 70m. The extreme palaeogeolocial conditions, dolomitization and burial dissolution together decide the formation and distribution of microbialite reservoirs.

Key words: microbialite; good quality reservoirs; stromatolite; thrombolite; Leikoupo Formation; Sichuan Basin

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Characterizing the oldest archaeocyathan-microbial reef in China: a well-preserved case from Sichuan, South China

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Archaeocyaths and calcimicrobes constructed early Cambrian reef systems. However, the oldest archaeocyathan-microbialite reefs in China, which developed in the Xiannudong Formation (Stage 3, Series 2), are poorly preserved in general. We describe well-preserved archaeocyathan-microbial reefs of the Xiannudong Formation from a previously undescribed site, Tangjiahe, northeastern Sichuan. Three reef units (R1-R3, lower to upper) are interbedded with limestones. R1 is 3.5 m-thick, low-relief and undetermined size, so may be a mound or biostrome, built by *Epiphyton* with few archaeocyaths. *Epiphyton* aggregations, 1 to 10 mm across, are irregularly shaped, and connect with each other laterally to build a loose and porous framework with rare archaeocyaths, amongst which light-gray sediment is accumulated, and form geopetal structures in some cases. R2 consists of a 2.7 m thick, 6 m wide mound enclosed in oolite. The R2 framework is built by intergrown *Renalcis* and *Tarthinia* forming upward-expanding tufted, fan-shaped aggregations (0.5 to 2 cm in diameter), encrusted by lighter-coloured sediments which provide substrate for more microbe growth. Archaeocyath fossils are uncommon, and bound by microbes in the framework. R3 comprises a ca. 1 m thick small microbialite mound and an overlying thin stromatolite bed, both are enclosed in oolite. The mound framework consists of archaeocyaths (5 to 8 mm in diameter) bound by microbial micrite, with abundant cavities infilled with micrite and siliciclastic sand. Micrite binding archaeocyaths is clotted and likely attributed to microbial. The three reef units are separated from higher energy sediments, and archaeocyaths are rare and not the main framework builders, indicating their construction depended on low energy water to develop. The reefs give new insight into construction of the oldest archaeocyathan-microbial reefs in China and show that they are comparable to other similar reefs.

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MARINE X CONTINENTAL DEPOSITS – LESSONS FROM UNEXPECTED ENVIRONMENTS LIKE PRE-SALT CARBONATES IN BRAZIL

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In the last 10 years, an international race has taken place to understand the unusual carbonate reservoirs of Brazil's Pre-Salt, the largest oil province discovered in the 21st century. These carbonate deposits are located just below a thick layer of salt interpreted as the first record of marine waters in the Brazilian continental margin. For such reason the Pre Salt carbonates have been interpreted as continental, pre-opening of the South Atlantic Ocean. However, discussions point out to a different hypothesis: that these unusual carbonate rocks could represent the first marine record in the Brazilian continental margin. This possibility is based on the main carbonate facies found. Laminites and stromatolites, ([1]Terra et al, 2010) are ambiguous rocks (marine or continental) and could truly represent the first marine record since they occur at great distances from the present coastline and would represent the first break of the crust in the process of continental separation. For a long time, traditional geology and particularly paleontology have used the presence or absence of marine fossils as a definitive criterion for defining whether an environment is continental or marine. This oversimplification is even more difficult when it comes to microbial lacustrine carbonate environments near coastal areas. Often, a single marine fossil may lead to erroneously characterizing a depositional environment as marine with serious consequences for reconstitution of the geological history of a given deposit. The sedimentary mechanisms of marine or lake deposits are very different and often act in opposite ways. The microbial carbonates of the Brazilian Pre-Salt do not have outcrops. In search for an analog or minimally similar deposits for training purposes, PETROBRAS visited numerous outcrops around the world including the microbial carbonates of the Balbuena Sequence (Upper Cretaceous and Paleogene) of the Salta Basin, Argentina, where the company developed intense fieldwork and analysis ([2]Terra et al, 2012). The Salta Basin has a complex tectonic evolution and the most interesting carbonate section is located in a sag tectonic stage above a rift phase, which is very similar to the evolution of the Brazilian Pre-Salt. Because it is located in a geological context in which some marine incursions occurred in the northernmost part of the basin, again the question of marine or continental sedimentary control appears. We return to the initial questions: what controls sedimentation? Can the occurrence of some marine fossils characterize the type of sedimentation or not? Fortunately, modern geology can expand its criteria using several tools together to characterize a depositional environment. In both cases, the Brazilian Pre-Salt and the Argentine "cousin", the characterization of a microbial lacustrine carbonate environment with siliciclastic interference was made much more accurately based on the following criteria: (a) basin geometry; (b) climatic influence; (c) evolution of facies; (d) high-resolution stratigraphy; (e) isotopic analysis and (f) geochemical data.

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The lacustrine microbial carbonate records of Bonneville Basin, Utah, USA

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The Bonneville Basin is a continental lacustrine system accommodating extensive microbial carbonate deposits corresponding to two distinct phases: the deep Lake Bonneville (30,000 - 11,500 ^{14}C BP) and the shallow Great Salt Lake (since 11,500 ^{14}C BP). A detailed characterization of these microbial deposits and their associated sediments provides insights into their spatio-temporal distribution patterns. The Bonneville phase displays a preferentially vertical distribution of the microbial deposits resulting from high-amplitude lake level variations at that time. In contrast, the Great Salt Lake microbial deposits showed a preferentially large lateral distribution, linked to the modern flat bottom configuration of the Bonneville Basin. During this modern phase, the microbial deposits display a higher diversity of fabrics and sizes. Microbial deposits are discontinuous throughout the lake history showing longer hiatuses during the Bonneville phase. The main parameters controlling the rate of carbonate production are related to the interaction between physical (kinetics of the mineral precipitation, lake water temperature, runoff), chemical (Ca^{2+}, Mg^{2+} and HCO_3^- concentrations, Mg/Ca ratio, dilution, depletion) and/or biological (trophic) factors. The contrast in evolution of Lake Bonneville and Great Salt Lake microbial deposits during the lacustrine history leads to discussions on major chemical and climatic changes during this interval as well as the role of the physiography.

It provides novel insights into the composition, structure and formation of microbialite-rich carbonate deposits under freshwater and hypersaline conditions and questions the relevance of the terminology used in continental carbonates. Non-marine carbonate deposits develop under a wide range of environmental conditions, both subaerially and subaqueously. As a result, they originate from different processes (physical, chemical and biological) forming diverse sedimentary facies. A universally accepted terminology for non-marine carbonates is lacking, especially as various terms comprise both descriptive and interpretative meanings. Depending on the definition under consideration, different uses and interpretations make the distinction between certain terms (e.g. tufa and travertine) elusive. The diversity of microbial deposits observed in the Bonneville Basin the basin is relevant to clarify the use of microbial-related terminology.

Microbial Mechanisms of Mineral Precipitation: Old Wine in New Bottles

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Mineral precipitation in microbial mats and microbialites is fairly well studied and reasonably well understood. The geochemistry and mineralogy of lithifying microbial mats has been extensively investigated in a number of different environments and geographic settings. More recently, molecular biology studies have revealed species composition and gene expression patterns and even identified proteins and metabolic products in a number of lithifying microbial ecosystems as well. Yet, to date no single study combined most of the critical ingredients of what are conceived as the key factors in the organomineralization process, producing the carbonate minerals. Arguably, microbial activities changing the geochemistry of the local environment (or, alkalinity engine) and the properties of the exopolymeric matrix are key components in the precipitation process.

Here we present an example of lithifying microbial mats from Cayo Coco, Cuba, in which key metabolic rates contributing to the alkalinity engine were determined and properties of the exopolymeric substances (including calcium binding) were analyzed. This investigation revealed a pivotal role for both oxygenic and anoxygenic phototrophs as well as for sulfur cycling.

Contemporary microbial mats are often studied as analogs for fossil microbialites, yet no photosynthetic microbial mats that function completely independent of free oxygen have been described. A second example will demonstrate the potential of photosynthetic, oxygen-independent and heterotrophic cycling of sulfur and arsenic in mats of the Atacama Desert, Chile, that supports lithification, similar to what has been suggested for 2.7 billion year-old stromatolites from the Tumbiana formation, Fortescue Group, Western Australia.

Forming mechanism of Ordovician microbial carbonate reservoir in northern slope of Tazhong uplift, Tarim Basin,China

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Microbial carbonate reservoirs is one of the hot research areas. Though the observation of microbialite's core and casting thin sections of the northern slope of middle Tarim Basin, we can conclude that the microbialites of study area is given priority to fracture-pore type reservoir. Though the porosity and permeability analysis of full diameter core, we find that the microbialites are good gas reservoirs. On the analysis of the Formation mechanism and characteristics of microbialites, combined with stress sensitive experiment and imaging logging, we summarized the advantage factors of the forming reservoir space of microbialites, firstly, the generation of native dolomite can promote the dissolution of calcite. The microbialites of the study area is happendeogenetic karstification, and parts superposition late hypogenic karstification, improving the reservoir physical properties. Secondly, rich organic matter content is not only caused dissution by organic acid which is generated by microbialites in the burial diagenetic stage, but also reduce the ultimate strength of microbialites which could easy to form cracks under the tectonic movement. Therefore the reservoir space of microbialites in the northern slope of middle Tarim Basin is mainly secondary role. Though the determination of rock compressibility, it is concluded that microbialites' compaction resistance is commonly, but algae crumbs skeleton is advantageous to the protection of the algal hole. The strongest ability to resist compaction is silicified microbialites, followed by dolomitization.

Keywords: Microbial carbonate reservoir; Karst process; Fracture; Stress sensitive; Total organic carbon content; Compressibility of Rock

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Genetic mechanisms of oncoids in the Givetian (Middle Devonian) Jinbaoshi Formation of the Longmenshan area, Sichuan, China

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Abstract: Oncoids, in dark grey microbialites from the Jinbaoshi Formation (Givetian, Middle Devonian period) in Longmenshan, China, were found to actively develop Girvanella, which is the first report about Givetian oncoids enriched with Girvanella. Girvanella is common in oncoids in different epochs. There is, however, limited research on the role of Girvanella in the formation of oncoids. Field observations, thin section analyses, scanning electron microscope analyses, cathodoluminescence analyses, electron microprobe analyses, coupled with trace element and carbon-oxygen isotopic analyses of oncoids show that oncoids are divided into two groups: normal oncoids and deformed oncoids. Nucleus are generally bioclasts and concentric laminae predominantly consist of dark laminae rich in Girvanella filaments and light laminae which is the result of filaments capturing grains. Girvanella filaments exhibit four kinds of growth patterns including winding and intertwined, trans-laminar, convex and horizontal thin bedding in concentric laminae, and is effected by hydrodynamic condition and particle supply. The irregular form of deformed oncoids is controlled by the non-uniform distribution of Girvanella filaments, while the round concentric laminae of normal oncoids are related to low sea level, Girvanella growth, calcification, and Girvanella filament capturing grains in a turbulent environment. The oncoids in Longmenshan developed in the backreef lagoon environment. Bottom-up vertical changes (small to large, low abundance to high abundance, irregular ellipsoidal or tabular form to spherical form) resulted from the distribution patterns of Girvanella filaments and sea level changes. The Jinbaoshi Formation in Longmenshan was exposed at the surface in the late Givetian period, influenced by tectonic uplift and sea level decline. Evidence from mineralogy, petrology, and geochemistry indicate that meteoric water is less likely to be the dominant factor controlling the formation of oncoids in the Jinbaoshi Formation.

Keywords: Oncoid, Girvanella, trace element, C-O isotope, mechanism, meteoric water, Givetian, Longmenshan Area

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FACILITATION OF MICROBIAL METABOLISM ON THE NUCLEATION AND DIAGENETIC STABILIZATION OF EOCENE DOLOMITE FROM THE LUNPOLA BASIN, CENTRAL TIBET

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Although the microbial metabolisms are widely known to facilitate the nucleation of low-temperature dolomite in the laboratory[1], the actual mechanisms that account for the nucleation and diagenetic stabilization of ancient dolomite are poorly understood[2]. Herein, the organic-rich laminated dolomite exhibiting microbial fabric occurs in late Eocene evaporitic sequence of lacustrine Lunpola basin in central Tibet. We observed the aggregate of molecules and reticular fibres crosscut dolomite globules, both of which are reminiscent of EPS. After initial nucleation, nanobacteria-like particles (80-100nm) progressively evolve into large globules with grainy surface within EPS relics, subsequently, the growth was mediated by diagenesis, resulting in euhedral rhombs with larger size at a deeper depth. Our study reveals sequential growth phases of microbial dolomite in the geological record and suggest that the microbial metabolism plays a key role in the nucleation and subsequent biogeochemical diagenesis of the ancient dolomite. These findings demonstrate that the nucleation and mineralization process of nanoglobules within the EPS are not only limited to culture experiment but a widespread process during deep-time rock record, which could lead to insight into the "Dolomite problem".

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Primary Microbial Dolomite in the middle Cambrian sabkha Environment in the Tarim Basin, NW China

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Dolomite [$CaMg(CO_3)_2$] is abundant in sedimentary rocks throughout the geological record, but it is rarely found in modern sediments. Also, it cannot be precipitated under low-temperature conditions in the laboratory without microbial mediation and, as a result, its origin remains a long-standing enigma[1,2]. In the Tarim Basin, the formation of dolomite during the middle Cambrian is associated with evaporites, which have typically been attributed to the sabkha-style dolomite formed during the syndepositional period. According to sedimentary microfacies of the middle Cambrian dolomite formation, the middle Cambrian is an ancient analogue of the Sabkha of Abu Dhabi[3]. This study reports biologically mediated dolomite precipitation in ancient microbial mats. The ambient temperature was estimated from $\delta^{18}O$ values from early diagenetic dolomite and the presence of structure associated with extracellular polymeric substances (EPS), is composed of fibres arranged in a reticular pattern, would favor epitaxial crystallisation of dolomite on an organic substrate. Additionally, poorly crystallised dolomite formed nanocrystal aggregates that strongly resemble the morphology and size distribution observed in microbial culture experiments[4]. Magnesium that influences primary microbially mediated dolomite may be involved with the limitation of the dolomite lattice on the spatial configuration of CO_3 groups at ambient low temperature conditions, though it was not originally thought that existing cation hydration prevents Mg^{2+} and CO_3^{2-} ions from forming ordered structures[5]. These lines of evidence confirm that microbial structures can be preserved in ancient dolomite and validate their use as biosignatures. The dolomite formation of the middle Cambrian in the Tarim Basin has been considered as a classic environment of an analogue for carbonate and evaporate assemblages, the extent of microbial dolomite in sabkha environments for ancient analogue is proposed as a preferential alternative model for the dolomite formation, in which the mineral-template properties of organic substrates play a crucial role[6].

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Microbial Growth in Carbonate Buildup and Reservoir --Implications from Upper Sinian Dengying Formation of Sichuan Basin

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Microbialites are widely distributed, especially in old strata, which are deeply buried. Microbial carbonates are important targets of petroleum exploration in deep strata. However, its mechanism of forming buildups and reservoirs is still unclear. In this paper, Upper Sinian Dengying Formation of Sichuan Basin is chosen as the object to study the effects of microbe in the buildup and reservoir forming process of carbonate rocks based on previous study and well-core, outcrop and thin section observation. The results show that the role of microbial activity in carbonate rocks is different, including microbial induction, microbial influence and microbial control, as shown in SEM evidences. Tiny euhedral dolomite rhombs are observed attaching to the linear, flaky, and radial Extracellular Polymeric Substances (EPS) of the microbes.
Growing patterns of microbial carbonate rocks are identified in both 2 dimensional and 3 dimensional scopes. In the 2D growing pattern, microbial mat mainly forms stromatolite and laminate, while the 3D microbial coating growing pattern can be distinguished into the coating of carbonate grain and coating of porosity. The grains formed by microbial coating include oncolite, ooid, pesoid, etc., while “grape lace” and “spongy layer” are specific structures of the Upper Sinian formed by microbial coating around vugs. Microbial coating is essential for formation of original skeleton porosity and preservation of reservoirs spaces in deep strata.

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Are Permian-Triassic boundary microbialites anachronism? evidence from their comparison with Lower Cambrian microbialites, Southwest China

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Carbonate microbialites appeared suddenly in shallow marine carbonate platforms directly after the end-Permian mass extinction and were widespread throughout Tethys Ocean. These Permian-Triassic boundary microbialites (PTBMs), therefore, provide evidence for the extinction event and its aftermath, resulting in receiving numerous concerns. Many authors consider their widely distributed sudden appearance after the extinction to reflect earlier parts of Earth history, of Precambrian and Cambrian microbialites. Thus PTBMs are called as anachronistic facies. However, the recent work in Southwest China shows much difference between the Lower Cambrian microbialites (LCMs) and PTBMs. The Xiannudong Formation of the Lower Cambrian contains abundant microbial sediments and buildups in Sichuan, Southwest China. 5 sections exposing well have been studied and reveal three types of microbialites: dendrolites, thrombolites and stromatolites. Among them, dendrolites are most, and are built by various calcimicrobial organisms, such as *Epiphyton, Kordephyton, Girvanella, Hedstroemia, Tarthinia and Renalcis.* Notably, calcimicrobes are not the only framework builders, in some cases archaeocyaths were involved into the framework formation, although just took a small proportion. Abundant terrigenous materials with micrite deposited among the microbialite framework, indicating a relatively turbid sedimentary environment, as well as a possibility that LCMs trend to live in seawater with high nutrient level. In contrast, PTBMs are mostly thrombolites although a few stromatolites have been found recently. Nearly all their frameworks were built by a special kind of calcimicrobes that was named by Kershaw (2017) as "*Wangshenghaia*", which is a bit similar with *Tarthinia*, however, has simpler morphology. Despite of difference in calcimicrobial types, the depositing environments of PTBMs are also different. Although PTBMs developed in shallow seawater with various depth, all sedimentary environments are exclusive of terrigenous influxes. Comparison between PTBMs and LCMs herein shows it is more useful and realistic to consider microbialites after mass extinction as relating to events taking place during that time, rather than viewing them as anachronistic.

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SEDIMENTOLOGY AND DIAGENETIC MODIFICATIONS OF RATAWI LIMESTONE WITH REFERENCE TO RESERVOIRCHARACTERIZATION

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The Ratawi Formation, having a thickness of around 600 feet, deposited during Early Cretaceous period, is one of the good oil producer in Kuwait. The Ratawi Formation comprises of two members, the lower Ratawi Limestone Member, and the upper Ratawi Shale Member. The study is focused on Ratawi Limestone member, in South and West Kuwait with an objective to understand depositional and diagenetic features also their effect on reservoir characterization. Constituent grains within Ratawi Limestone are mostly skeletal fragments with few peloids and intraclasts. Matrix is dominantly micrite with minor amounts of detrital clay partly concentrated along stylolites and locally infilling karstic fissures. The clays are dominantly chlorite with minor kaolinite, illite/mica and minor mixed layer illite/smectite. Several microfacies were identified which were grouped together into depositionally significant facies associations. The Ratawi Limestone is interpreted to have been deposited on a low gradient carbonate ramp, with deposition taking place from Shallow Inner Ramp, Inner Ramp to Mid Ramp and occasionally to Outer Ramp. Two major regressive cycles are identified which are characterized by upward shallowing cycles. Diagenesis is partly controlled by depositional facies, however exposure at the tops of cycles have resulted extensive meteoric diagenesis. Short, partly open fractures formed due to differential stylolitic compaction of karstic and fissured zones close to the top of cycle, has further enhanced dissolution. The overall reservoir quality is good. The underlying control on reservoir potential appears to be diagenetic which has enhanced the reservoir quality to greater extent and reduced to some extent.

DISENTANGLING THE ORIGIN OF THE CARBONATE-CLAY-SILICA PARAGENESIS IN THE APTIAN 'PRE-SALT' ALKALINE LAKES: INSIGHTS FROM HYDROGEOCHEMICAL MODELLING

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Understanding the physical, chemical and environmental thresholds affecting skeletal producers is crucial to build refined facies models and predict the basin-scale depositional architectures. Extensive research in the last decades has focused on comprehend the way metazoan biotas interact with the environment to produce specific carbonate accumulations in the sedimentary record. However, our perception of how *non-skeletal* carbonate factories contribute to depositional profiles is seriously undermined as the mechanisms involved in carbonate precipitation and accumulation are far more diverse and complex to constrain. Indeed, in settings where non-skeletal carbonate production is elevated, carbonate precipitation is heavily dependent on physico-chemical gradients such as fluctuations in pH, alkalinity, carbonate saturation index, Mg/Ca ratios, or ionic strength, and also on the presence of microorganisms and their secreted organic substances. Further complexity is added when other mineral paragenesis such as clay and silica are also precipitated in close association with non-skeletal carbonates challenging our ability to construct reliable facies models.

Alkaline and saline lacustrine environments are among the sedimentary systems that are capable of accumulating significant amounts of non-enzymatic carbonates concomitantly to clay and silica mineral deposits. The Cretaceous 'Pre-salt' lakes of the South Atlantic margins (Brazil and Angola) are excellent examples displaying the co-occurrence of spherulitic calcite, dolomite, Mg-rich smectites and silica precipitated from exotic water chemistries in rift tectonic settings. In volcanic rift systems, climate, substrate mineralogy and geological background play a major role in the final chemical composition of the lake waters which have a tremendous impact in the mineral paragenesis and facies architecture. To provide context on the origin and distribution of these depositional chemistries, we present new conceptual models arising from data obtained in volcanic lacustrine analogue systems of the Central Rift Valley (Africa). Sedimentological, petrographical and geochemical data from the 'Pre-salt' lakes was integrated with PHREEQC hydrochemical calculations to interrogate the system about the most favourable scenarios producing the suite of authigenic and diagenetic minerals recognised. The sequential effects of water removal (evaporation) and water addition (spring, hydrothermal and seawater inputs to the lake) were evaluated towards carbonate-clay-silica precipitation revealing the existence of specific hydrogeochemical combinations inducing and/or inhibiting the formation of the 'Pre-salt' carbonates and silicates.

The combination of conceptual methods with petrographical observations can help to qualitatively understand the underlying chemical mechanisms largely operating in alkaline lakes and the mineralisation products and loci where carbonate-clay-silica minerals are likely to occur. These models have implications for hydrocarbon reservoir modelling in alkaline lacustrine basins.

BAJOCIAN HIGH-AMPLITUDE RELATIVE SEA-LEVEL FLUCTUATIONS IN MOROCCO: REGIONAL CONTROL OR GLOBAL SEA-LEVEL CHANGES?

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Mesozoic sea-level fluctuations have been a matter of debate for several decades, especially the veracity and origin of sea-level cycles that have a periodicity of about 1 Myr or less. The debate lies in the main driving mechanism for sequence development (global sea-level or sediment flux variations) as well as the reason behind water exchanges between the continents and the oceans (glacio- or aquifer-eustatism). In this study, we focus on the carbonate-dominated Bajocian (Middle Jurassic) sedimentary record of the Central High Atlas Basin of Morocco. Several aspects make this basin an appropriate location for discussing Middle Jurassic sea-level changes. Firstly, the outstanding exposures of the High Atlas Mountains, with continuous exposures for 10s of kilometres, allow to describe and track sedimentary packages and their bounding surfaces from proximal to distal settings. Moreover, a combination of ammonite biostratigraphy and carbon-isotopes chemostratigraphy allows to temporarily constrain their development, which permits to correlate and compare the Central High Atlas sedimentary record to other basins. Finally, due to high-subsidence rates, thick Bajocian sedimentary sequences have accumulated, ensuring to minimize condensation and hiatus that might prevail in other basins due to a lack of accommodation space creation. Two Bajocian long-term transgressive-regressive (T-R) packages are observed throughout the basin. They are modulated by several medium-term T-R packages, that have each an approximate duration of 1 Myr. These sequences can also be correlated on a basinwide scale. Short-term, decametric T-R sequences are the building blocks of packages. They are not correlatable over long distances. In fact, exceptional exposures clearly highlight their localised extension, showing textbook stacking patterns that can be used to better constrain medium-term sequences. Hence, combined with sedimentological and facies analyses, architectural evidence illustrates that several of the medium-term sequences are characterized by the presence of a falling stage and lowstand systems tract (FSST and LST), demonstrating that medium-term T-R stacking patterns are not solely linked to fluctuation in sediment supply, but also to episodes of relative sea-level fall. Comparison with Bajocian deposits from Scotland, where good biostratigraphic dating is also available, shows that similar sea-level fall can be observed, highlighting their potential global character. The two long-term Bajocian sequences are more difficult to correlate on a global scale, suggesting that they are rather primarily linked to fluctuation in regional sediment supply. The cause of the medium-term sea-level fall is currently unknown, but it is here interesting to note that a relatively cool globate climate has been postulated for the Middle Jurassic, leaving the glacio-eustasy hypothesis open. Further investigations, notably better constraining paleo-temperature evolutions during the Bajocian, are however needed to reach such conclusion.

STRATIGRAPHIC EVOLUTION OF THE SOUTHWESTERN GISSAR CARBONATE PLATFORM (UZBEKISTAN) DURING THE MIDDLE–LATE JURASSIC

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The Middle and Late Jurassic are characterized by the development of vast shallow water carbonate platforms along the Tethyan margins. Compared to the well-known western Tethys or the Arabian Plate, the northern Tethyan platforms are poorly documented. Sedimentological investigations have been carried out in the southwestern part of the Gissar range (Uzbekistan), which constitutes the only outcrop of the Jurassic series of the northern margin of the Amu Darya Basin. Two major sequences are differentiated, based on their contrasted platform configuration and carbon isotope signature: (i) a Callovian Sequence and (ii) an Upper Jurassic Sequence, potentially Oxfordian to Kimmeridgian. During the Callovian Sequence, the SW Gissar was a carbonate ramp with oobioclastic grainstones forming in the permanently agitated shallow water zone and patch/pinnacle reefs building up distally, close to the storm-wave base. Tide-dominated mixed coastal deposits developed to the north of the SW Gissar, close to the pre-Jurassic basement.

The transition between the Callovian Sequence and the Upper Jurassic Sequence is marked by a significant change in the carbonate sedimentary system associated with a positive shift in the bulk-carbonate carbon isotope values and local negative shifts in the oxygen isotopes. This surface is interpreted as a stratigraphic hiatus resulting from the subaerial exposure of the platform (Upper Callovian to Lower Oxfordian?) and could record a significant sea level drop linked with a climatic change during the Middle-Late Jurassic Transition.

In the SW Gissar, the Upper Jurassic Sequence is mostly composed of shallow lagoon peritidal deposits, which consist of numerous meter-thick alternations of pellets/algal pack- to grainstones, microbial oncoid float- to rudstones, ooid grainstones and mudstones. These deposits could have accumulated in a vast, mostly aggrading lagoon protected by a barrier reef south of the study area. Gypsum content increases towards the top of the platform, with the final progradation of a large-scale sabkha. This highlights a progressive regional aridification and basin restriction with a probable onset in the Late Oxfordian with optimal condition during the Tithonian, expressed by massive halite and anhydrite deposition also known in the Amu Darya Basin subsurface.

Our results are compared to other Northern Tethyan basins (Kopet Dagh, Central East Iranian Microcontinent) to test the large-scale response of carbonate platforms to the regional climatic and tectonic changes occurring throughout the Middle-Late Jurassic Transition.

THE EVOLUTION OF CARBONATE FACTORIES IN THE LATE SINEMURIAN-PLIENSBACHIAN TRANSITION – CASE STUDY FROM THE HIGH ATLAS MOUNTAINS (MOROCCO)

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The Early Jurassic is a time of repeated environmental perturbations, which had pronounced impacts on marine organisms and ecosystems. These events affected especially neritic carbonate factories, that were only slowly recovering from the late Triassic mass extinction and its catastrophic decline in reefs and reefal diversity. In the Hettangian and Sinemurian stages, reefal bodies are small and scarce. Frame-building organisms show little diversity. Towards the end of the Sinemurian and in the Pliensbachian, large Lithiotis bivalves appear as a new type of dominant frame-builder until the Toarcian Oceanic Anoxic event terminates their prevalent position on shallow water platforms.

All these developments can be observed in the Central High Atlas Basin, which serves as a case study in this project. So far, studies have focused on deep water siliceous sponge mounds as representative bioconstructions of the Sinemurian. These mounds exhibit siliceous hexactinellid sponges and demosponges in a community with microbes and annelids, and were growing in an environment well below wave base. In shallow water settings, carbonate factories were dominated by abiotic and microbial carbonate production, with abundant ooids and oncoids. Dolomitization and tepee structures are also common. In between these very distinctive environments another type of carbonate factory has been recognised but its full extent is still unknown. In slope deposits, deep water siliceous sponge mounds developed during the early late Sinemurian. Due to late Sinemurian forced regression episodes, they were occasionally placed in more agitated water masses. This lead to the colonisation of these mounds by large scaled scleractinian corals. After a short time of co-existence, the corals took over the bioconstruction and dominated, until renewed deepening led to the re-installation of a microbial-sponge rich community. Again, shortly after that, corals take over and replace the sponges as frame-building organism. This two fold development is interpreted as a response to sea-level fluctuations during the late Sinemurian oxynotum and raricostatum zones that can be tracked on a global scale. The following Sinemurian-Pliensbachian boundary event, and notably its accompanying large eustatic sea-level rise superimposed with high-subsidence pulse of the basin, was responsible for the demise of all three Sinemurian carbonate factories and a major backstepping of the carbonate production loci. This event coincides with the onset of the dominance of Lithiotis bivalves in the shallow water realm throughout the Tethys during the Pliensbachian.

Building upon previous studies, we present here a holistic picture of the evolution of late Sinemurian – Early Pliensbachian carbonate factories in the Central High Atlas Basin, emphasizing on their response to global environmental changes. The localised establishment of coral reefs upon siliceous sponge mounds is most likely the consequence of relative sea level changes within the basin, whereas the carbonate factory turnover at the Sinemurian-Pliensbachian boundary and the strong backstepping of the entire system is a result of a severe environmental perturbation that is recognised globally.

The bio-sedimentary record of the OAE-2 in the Natih Fm of Oman: global or local signature?

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Oceanic Anoxic Event 2 (OAE-2), spanning the Cenomanian–Turonian boundary, represents a major perturbation of the global carbon cycle with an extensive deposition of organic-carbon rich deposits (black shales) in ocean basins worldwide. This even strongly impacted both deep and shallow water ecosystems as well as continental ones.
Whilst the sedimentological, geochemical and paleontological aspects of deep water expressions of OAE-2 have been intensively studied in the last few decades, less attention has been given to the coeval shallow water deposits. This represents an important gap in our understanding of ecological responses to abrupt climatic change in the mid-Cretaceous, given that shallow shelves account for most of the global ocean bioproductivity and, in the meantime, are highly susceptible environments to ocean acidification.
Despite the importance of shallow water sites to understand the dynamic of OAE2,unfortunately, only a few localities in the World have been studied in detail for their ecological response across the OAE-2. Those are mainly confined in the proto Atlantic (Mexico Platform) or the North western Tethys (Apennine and Adriatic platforms). Almost nothing is known from the southern Tethys (Arabian Platform) where a large and complex system of carbonate platforms and shallow basins existed, despite their intensive study in term of sedimentology and stratigraphy linked to petroleum exploration.
In this work we present new data from the mid Cenomanian-Turonian interval of the Natih Formation in the Oman mountains which comprises quantitative facies analyses, biostratigraphy, outcrop γ-ray data and chemostratigraphy. Our approach allowed us to build a high resolution stratigraphic framework which enabled to study/observe the evolution of the platform during the time coeval to the occurrence of the OAE-2. We will, then, discuss whether the observed record could reflect a response to global perturbations associated to the OAE2 or rather local environmental conditions able to mask the global signal.

ASSESSING EARLY CRETACEOUS CLIMATE FORCING ON CARBONATE PRODUCTION: THE URGONIAN PLATFORM

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Early Cretaceous greenhouse conditions favored the development of a wide intertropical climatic belt, where widespread shallow marine ecosystems efficiently produced platform carbonates. Thanks to their sensitivity to the quality and chemistry of seawater as well as oceanographic conditions, carbonate platforms constitute a valuable record of paleoceanographic and paleoclimatic changes. We hypothesize that climate forcing triggered environmental and oceanographic changes that influenced carbonate factories of the Urgonian platform on the northern margin of the Tethys ocean. Three goals are achieved in a study area that extends from Switzerland to southeastern France, representing a latitudinal transect across the northern Tethyan margin: (1) development of a robust stratigraphic framework that permits platform-to-basin correlation, (2) identification of environmental feedback mechanisms using geochemical proxies, and (3) documentation of the impact of environmental stress in deposits of carbonate platforms.
First, the integration of available biostratigraphic, chemostratigraphic and sequence stratigraphic data constrains the duration of a prolonged period of condensation and/or non-deposition that starts in the late Hauterivian and is documented in the Helvetic Alps and the western Swiss Jura, respectively. Benthic carbonate production resumes in the end of the early Barremian, and photozoan assemblages of the Urgonian platform rise in the Late Barremian. Carbonate production is subsequently punctuated by a major period of slow down that straddles the Barremian-Aptian boundary, and ultimately ceased during the early Aptian.
Second, the studied time period exhibits changes in nutrient levels as well as several environmental crises that resulted in the preservation of organic-rich deposits in (hemi-)pelagic settings. The Faraoni level (latest Hauterivian) results from the installation of more humid conditions and enhanced weathering on land that stimulated primary productivity, promoted the installation of mesotrophic conditions and participated to the development of bottom water anoxia, whereas rather oligotrophic conditions characterize the late Barremian.
Third, mesotrophic conditions that predate the unfolding of the Faraoni event coincides with heterozoan carbonate production, especially in the Helvetic Alps. This suggests that late Hauterivian climate change induced the adaptation of benthic communities to more stressful conditions under which suspension-feeding organisms produced larger volumes of carbonate sediments compared to heterozoan ecosystems. Stronger detritism during most of the early Barremian induced a major phase of drowning of heterozoan communities. Carbonate production resumed in two steps near the early to late Barremian boundary: heterozoan ecosystems colonized epicontinental sea as detrital input decreased, whereas the photozoan, Urgonian-type carbonate platform thrived under oligotrophic conditions later in the late Barremian.

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MULTIPROXY APPROACH TO UNRAVEL THE ONSET OF OAE2 ON THE ARABIAN SHELF

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In the Late Cenomanian the Arabian Shelf was characterised by shallow marine shelf carbonates and extensive intra-platform basins. The hemipelagic carbonate successions that make up these intra-platform basins offer continuous sedimentological and detailed geochemical records from a palaeoequatorial latitude[1]. Carbon-isotope records from these shelf carbonates that span across the Cenomanian-Turonian boundary interval[1,2,3,4] are characterised by invariably low carbonate $\delta^{13}C$ values that predate the positive carbon-isotope excursion relating to OAE2.
To better understand the cause of this anomaly and the succeeding positive excursion relating to OAE2 we present a multiproxy study incorporating two coeval successions (basin center and slope) from the Shilaif Basin (UAE). The dataset includes high-resolution carbon-isotope records from bulk carbonate and organic carbon, bio- and cyclostratigraphy, characterisation of origin and composition of organic matter, and concentrations of major and trace elements. Integration of available data provided precise chronostratigraphic control between sections and allow for reconstructions on detrital sediment influx, relative sea level, differential accumulation rates, and changes in redox conditions. Orbital cyclicities obtained from core scans are in agreement with nannofossil biostratigraphy[1] and suggest a duration of both negative and positive excursions of approximately 600ka. The Late Cenomanian negative anomaly appears to be largely influenced by regional processes. The positive $\delta^{13}C$ excursion representing OAE2 is characterised by short-lived changes in sea level and redox conditions that relate to the 'Plenus' cold event.

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Extracting seasonal oceanographic changes from mid-Cretaceous bivalve shells: A multiproxy multispecies approach

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Cretaceous rudist bivalve shells have been shown to faithfully record inverse cyclic changes of oxygen isotope ratios and Mg contents, which are interpreted to represent seasonal temperature changes of the ambient sea water (Steuber, 1999). Estimating the impact of salinity changes on the rudist shell oxygen isotope composition at a given setting, however, is still problematic and calls for a calibration of oxygen-isotope based sea surface temperatures by means of additional palaeothermometers (e.g. clumped isotopes or TEX_{86}). Moreover, a metabolic control on the isotopic composition of the low-Mg calcite rudist shell cannot be completely ruled out, as no modern analogues of these extinct bivalves exist.

In order to disentangle the influence of palaeoenvironment, diagenesis and 'vital effects' on the rudist shell geochemistry, the current study compares highly resolved multi-proxy (stable isotopes, trace elements) sclerochronological records of different Late Albian bivalve taxa (requieniid and radiolitid rudists, pectinids, chondrodonts and oysters) derived from the same proto-North Atlantic palaeoenvironmental setting in Portugal (Lusitanian Basin, Horikx et al., 2014). In contrast to classical methods such as ICP-OES, the here applied micro-XRF scanning technique allows to simultaneously measure a variety of elements, which help to (i) distinguish between natural and diagenetic enrichments of indicative elements such as iron and manganese and to (ii) identify the influence of palaeoenvironmental changes (SST, nutrients, salinity etc.) on bivalve shell growth (see de Winter et al., 2017). A multivariate statistical approach is presented to identify the influence of differential diagenesis on these multi-proxy records.

In particular, the comparison of rudist and pectinid sclerochronological records is a very promising approach, as pectinids have living analogues and therefore much more is known about the metabolic control on the shell geochemistry. This in turn will help to better understand the palaeoecology of rudist bivalves and how these animals recorded palaeoceanographic signals in their shells.

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TECTONO-EUSTATIC CONTROLS ON DEVELOPMENT OF THE EARLY-MIDDLE TURONIAN BIRENO CARBONATE RESERVOIR, CENTRAL TUNISIA.

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The Early-Middle Turonian Biréno Member extending throughout central-southern Tunisia still presents a big challenge for a successful hydrocarbon exploration while up to now information on its age, stratigraphical position and reservoir properties were missing.

Our study adds new data on the sedimentology and biostratigraphy of the sequences covering central-southern Tunisia and provides new interpretations of the tectonic history of the basin. These new data have allowed us to determine the factors controlling the genetic depositional elements constituting this member, as well as their spatial distribution. The lower-middle part of the Biréno Carbonate Member reveals abrupt facies changes and discontinuities that could be related to the reactivation of an irregular inherited topography present in central-southern Tunisia. This topography is marked by the presence of horsts and grabens and/or half grabens mainly tilted northwards.

Locally, during the Turonian distensive tectonic movements, the Jebel el Kébar area (central Tunisia) was subdivided into three distinctive northward tilted blocks that have directly influenced the deposition of the Early-Middle Turonian Biréno carbonates. The block topography determined the sedimentation patterns in which: (1) shallow marine blocks favored the deposition of shallow marine carbonate deposits characterized by high porosity values mainly related to moldic, vuggy and fracture pores, (2) subsiding blocks showed a thickening of the shallow-marine carbonate deposits through time, which was not accompanied by apparent facies changes, and (3) relatively deep-marine graben structures showed more open marine and relative deep deposits. Partial drowning of the Biréno platform occurred during the Late Turonian-Coniacian and is expressed by the deposition of pelagic deposits sealing the pre-existent irregular paleotopography. These latter deposits constitute a well-developed seal. Their occurrence appears to be related to a global sea level rise and associated deepening of the depositional environment in the region. Similar characteristics have been observed, on a large scale, in many other Turonian-Coniacian series cropping out along the African Tethyan Margin.

Based on the petrographic and petrophysical analyses the Early-Middle Turonian Biréno carbonate series can be considered as a potential reservoir series in the researched Sidi Bouzid area. The carbonate sediments display a complex porous system which is enhanced by extensive fracturing. In addition, the series show pore enhancement through dissolution and dolomitization.

However, considering the regional petroleum system, the "source rock" component is the weak point of the Sidi Bouzid region. The black shales of the Late Cenomanian upper Zebbag “D” Member, which occur in the South Tunisia, reinforce the system especially in the Gafsa-Chotts area. Further research on this theme will focus on the palaeograben and half-graben areas that may host the source rocks.

ORIGIN OF LAMINATED LIMESTONES IN THE LADINIAN LONGTOU FORMATION, SOUTH CHINA: IMPLICATIONS FOR SEA-LEVEL CHANGE AND PALAEOCLIMATE

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During the Ladinian period, a narrow carbonate platform margin, consisting of Longtou Formation, extended in NE-SW direction across Guizhou area of the South China block, and separated the shallow marine carbonate platform sediments from the deep basinal terrigenous sediments. Longtou Formation comprises largely of bioclastic and/or oncolitic grainstones and packstones. In the middle and upper part of this formation, however, laminated limestones accompanied with pisoids were extensively present. Previous literature claimed that they were either pedogenic calcretes[1] or products of mixing meteoric water and marine water[2]. Here, new investigation has been carried out to examine the origin of the laminated limestones.

Multiple lines of evidence (including field work, petrographic features, stable carbon and oxygen isotopic compositions, and rare earth element distribution patterns) demonstrated in our study indicate that the laminated limestones together with the pisoids are probably precipitates in caves. The results imply that the Longtou Formation once underwent intensive subaerial exposure and meteoric dissolution. The distribution pattern of the laminated limestones is verified to be a useful tool to trace the variations of water table positions and palaeoclimate.

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The record of drowning of the Arabian Carbonate Platform, in the Cenomanian-Turonian Inisdere section, Adiyaman, SE Turkey: a possible cause for the OAE2 in the region

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Drowning unconformities and their related strata are important records of key tectonic and environmental events. In the Adıyaman region of SE Turkey, Cenomanian-Turonian strata record a drowning unconformity in several stratigraphic section. This study records shallow water carbonate strata overlain by pelagic units containing planktonic foraminiferal assemblages in the Inisdere outcrop section and surrounding well sections. We suggest a succession exposed along the Inisdere Valley in the northwestern Adıyaman which represent best observable outcrop for carbonate platform drowning in the region. Detailed facies analyses, biostratigraphic dating, and paleoenvironmental interpretations using benthic, planktonic foraminifera and calcareous nannofossil collected from the Inisdere succession constrain the drowning event in the beginning of early Turonian. A paleoenvironmental model has been formulated to explain the successive paleocommunity changes during the drowning of the Arabian platform. We relate the drowning of some parts of the platform to the occurrence of the Cenomanian-Turonian oceanic anoxic event. The impingement of anoxic waters over the platform could produce the drastic reduction of the carbonate production observed in the stratigraphic section and therefore a reduction in carbonate accumulation rates. Regional/local subsidence and sea level rise within the Late Cenomanian-Early Turonian interval were the cause of the drowning of the platform and this event might have withnessed the oceanic anoxic event 2 in the region.

Anatomy of Mesozoic Tethyan margins: The carbonate platforms of the Levant Basin

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The Levant Basin is located in the Eastern Mediterranean and formed during the Early Mesozoic. This basin was initially a rift type basin located at a major plate boundary initiated during Late Triassic and evolved later on through compression tectonics. The post-rift phase prevailed since the Late Jurassic and is expressed by the gradual initiation of a passive margin on which extended carbonate platform developed.

The objective of this work is to investigate the tectonostratigraphic evolution of the Mesozoic carbonate platforms that developed on the Levant Basin margins. The Egyptian margin to the South, the Lebanese margin to the East, and the Eratosthenes seamount to the Northwest. Each of these margins has shown a similar geological history recording the geodynamic evolution of the Neothetys.

Along the Egyptian margin, Jurassic carbonate platform shows a prograding profile and a distally thickening of the external platform with non-abrupt slope profiles. Since the Cretaceous, the mixed carbonate-siliciclastic platform show an alternation of steep NW-SE oblique segments and distally steepened segments. These structures of the platform edge are strongly controlled by the inherited Tethyan transform faults. Mesozoic platforms in Egypt were drowned during the Late Cretaceous sea-level rise.

The Lebanese margin is characterized by narrow carbonate platforms evolved into steep angled clinoforms towards the deep basin. The Mesozoic carbonate platforms show retrogradation and aggradation, and the Mesozoic/Cenozoic boundary is characterized by a major onlap surface which is referred to as the “Senonian” unconformity.

In the vicinity of Eratosthenes Seamount, the onset of carbonate platform is also marked by a Jurassic retrograding and aggrading seismic unit. This unit shows lateral changes in the seismic facies that are interpreted as a succession of carbonate mounds. The Jurassic carbonate platform is topped by a regional unconformity which is succeeded by a Cretaceous aggrading carbonate platform characterized by a variety of different seismic facies interpreted as fore-reef deposits, buildups and lagoonal facies.

In this contribution, we present concepts of seismic and sequence stratigraphy to achieve a better understanding of the tectonostratigraphic evolution of the Tethyan platforms. Having interpreted four significant periods of carbonate platforms development characterized by retrogradation, aggradation and progradation the dominant controlling factors for the evolution of a carbonate platform have been examined. The drowning of the Mesozoic Tethyan carbonate platforms during the late Cretaceous coincided with the global reorganization of the oceans depicting that the demise and the onset of the carbonate factory is depended on the global sea level changes in response to long-term, deep processes such as rifting, collision and not only by the eustatism.

DEPOSITIONAL ENVIRONMENT AND AGE OF THE COBÁN FORMATION AT LOS CHORROS, CENTRAL GUATEMALA

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During the Cretaceous (66-145 Ma), global greenhouse conditions favored the development of a large, warm and humid intertropical climatic belt, where diversified shallow marine ecosystems produced platform carbonates. Thanks to their sensitivity to the quality and chemistry of seawater as well as oceanographic conditions, carbonate platforms can thrive for extended periods of time and thus constitute a valuable record of paleoceanographic and paleoclimatic changes. This is well documented in series from Europe and North America[1, 4], whereas uncertainties remain on how environmental forcing influenced carbonate production in Central America.

In the folded and faulted mountains of central Guatemala, the Cobán Formation is a thick, shallow-marine succession deposited from the Aptian to Santonian[2, 3]. The lack of a robust biostratigraphic framework prevents from further constraining the age of the formation. From the Aptian to the Cenomanian, three platform drowning events punctuated the development of this platform, resulting in deposition of more basinal sediment. We hypothesize that drowning resulted from rising sea level and was associated with enhanced primary productivity and oxygen deficiency. To test this hypothesis, we (1) developed a carbon isotope chemostratigraphic framework to refine the age of the Cobán Formation, (2) monitored the stratigraphic evolution of carbonate microfacies to assess sea level changes, and (3) traced environmental forcing using geochemical proxies.

On January 4, 2009, a major rock avalanche at Los Chorros, near San Cristóbal Verapaz, Guatemala provided new, exceptionally extensive outcrops. Below a thick summit breccia of partially dissolved carbonates, the avalanche scar extensively exposed limestones and dolomites, deformed during an Eocene "laramide" event. At the base of the scarp, in December 2014, before vegetation regrowth, we sampled a continuous 100 m-thick section belonging to the Upper Limestone unit. This succession consists of dark carbonate mudstones, interbedded towards the base with gypsum and mudrock. Occurrence of the miliolid *Nummoloculina hemi* and chemostratigraphic correlation with other well-constrained sections of similar age throughout the Americas are used to restrict its age to the middle Albian-lower Cenomanian. Petrographic analysis of thin sections further suggests that sediments were deposited in a restricted platform environment, whereas the organic mudrock facies reflect drowning of the platform. Bulk rock geochemical data suggest that the mudrock facies was deposited during times of bottom water dysoxia during the early stages of a sea level rise, whereas the deposition of stratiform gypsum below the mudrock facies might have been facilitated during periods of low sea level.

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ALBIAN COMANCHE SHELF SEQUENCES: A METRONOME OF 105-96 MA TECTONISM

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Early Cretaceous plate tectonic processes resulted in large-scale plate re-organization in both Pacific and Atlantic basins from 105 to 100 Ma spanning the late Albian to Cenomanian (Matthews et al., 2012). The proto-Caribbean oceanic plateau was moving northeastward between North and South America and the "Great Arc of the Caribbean" began forming the chain of volcanic islands that encircle the Caribbean from northern South America to Cuba (Mann, 1999). However, the timing of these tectonic pulses during the mid-Cretaceous Normal Superchron is not precise enough to correlate to sea-level changes recorded on carbonate shelves. Ages were interpolated from radiometric ages of Late Cretaceous oceanic sea floor in deep-sea drill holes. Thirty-four tectonic and volcanic events span from 110 to 90 Ma, some of which were dated in a one million year time interval and other intervals ranged up to 20 to 30 myr (Matthews et al., 2012, Table A1). The majority of events were dated from 105 to 96 Ma. Such tectonic events should be recorded by sea-level changes in local basins and even globally.

An archival record of Albian-Cenomanian sea level is represented by precisely dated unconformities on the Comanche Shelf (Scott et al., 2003). Eight Albian deepening-shallowing events are documented by shale to carbonate/sandstone cycles separated by hardgrounds or transgressive contacts. The duration of these events ranged from 0.30 myr to 4.99 myr and averaged 3.09 myr. Seven similar Cenomanian flooding events ranged in duration from 0.59 myr to 1.21 myr and averaged 0.92 myr. Durations of late Albian and Cenomanian events averaged 0.72 myr compared to 3.55 myr during early-middle Albian. This suggests that sea-level changes and coincidental tectonic events became faster during late Albian and Cenomanian. Key late Albian to early Cenomanian sequence boundaries record three significant sea-level fall and rise events at 104 Ma, 100.5 Ma and 97 Ma (Scott et al., 2003; Haq, 2014).

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LATE CRETACEOUS CARBONATE PLATFORM EVOLUTION AND SHORT AND LONG-TERM SEA LEVEL CHANGES, SE TURKEY, ARABIAN PLATFORM

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In SE Turkey, the exposed and drilled carbonate successions display cyclic alternation of facies in meter-scale, and laterally may show variations along the Arabian platform.

In Coniacian-Maastrichtian interval, in SE Turkey, drowning of the platform carbonates indicates a tectonic control in behind and related to sudden subsidence and sea level rise. Phosphate deposits take place during drowning and occupied associated within pelagic facies over the exposed platform carbonates (Yilmaz et al., 2018). Within the Campanian, carbonate successions display alternation of calciturbidites and dolostone facies. Successions are covered by thick-bedded reefal carbonates including rudists, oestrea, pelecypoda and bryozoa. This large-scale shallowing upward structure indicate a tectono-sea level change.

Dolomitization takes place in two stages during burial and in late burial diagenesis. Preserved poikilotopic calcite cement partially observed but both dolomites and calcites are subjected to dissolution. Secondary porosity is observed as selective and intra and inter-crystalline porosity.

Silicification took place after secondary porosity development. So, it seems that burial and late burial diagenesis are followed by an uplift.

Tectono-sea level changes can be observed in large-scale and with relatively bigger time gap on the Arabian plate, however small-scale cycles can represent climate/oceanographic/tectono-oceanographic changes.

Small-scale cycles are generally observed as alternation of marl/clayey limestone and shale/mudstone in pelagic successions. However, large-scale cycles can be observed as drowned platform carbonate followed up by pelagic/hemipelagic mud/shale dominated successions and overlain by calciturbidites and covered by reefal carbonates.

Key words: Late Cretaceous, Carbonate Platform, SE Turkey, Arabian Plate

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TITLE: SEQUENCE SEDIMENTARY EVOLUTION AND SEA LEVEL CONTROL OF CARBONATE ROCKS IN LOWER TRIASSIC, SOUTH YELLOW SEA BASIN

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The South Yellow Sea basin is not only the seaward extension of the Yangtze Platform, but also the main part of the Lower Yangtze Platform. There are three sets of source rocks and three source-reservoir-cap assemblages in the South Yellow Sea basin. As one of the important marine carbonate reservoirs, the stratigraphic research of the lower Triassic Qinglong formation has been relatively weak. Based on the logging curve shape, seismic reflection structure, lithology section and some test data, the sequence boundary characteristics of Qinglong Formation were analysed, and the sequence stratigraphic framework was established. The strata are divided into four three-levels type II sequences. mainly consists of the transgressive system tract and the high system system tract, and the sedimentary filling characteristics and evolution rules within the sequence are further analysed. The results show that in the Early Triassic, under the background of the tilting toward the south and west. in each sequence, the curve of the logging curve shows obvious progradation-retrogradation cycle, and the seismic reflection features are obvious, indicating a complete transgression and regression process, as a whole is given priority to with sea-level drop half cycle. The study area is dominated by carbonate platform sediments, and the rise-fall of sea level controls the distribution and evolution of sedimentary systems within the carbonate platform sequence. Relative to the rise of sea level, the deposition rate slows down, and muddy sediments develop. It mainly develops the continental shelf-slope-open platform sedimentary system. During the period of relative sea level decline, the sedimentary thickness increased, the main development is restricted platform facies and evaporate platform facies, and locally developed mesa shallows.

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OOLITIC AND MICROBIAL LIMESTONES AS TIME-SPECIFIC FACIES IN THE AFTERMATH OF THE END-ORDOVICIAN MASS EXTINCTION AND GLACIATION

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During the end-Ordovician (late Hirnantian) glacial maxima, carbonate platforms in the tropics were extensively exposed and their own diverse endemic faunas, displaced to the continental margins, suffered massive extinction. Contemporaneous oolitic and microbial deposits in Laurentia (Anticosti Island) and South China (Yangtze Platform) represent late Hirnantian time-specific facies that expanded across paleotropical carbonate platforms in the aftermath of the end-Ordovician mass extinction. The Anticosti sequence, one of the most complete stratigraphic records spanning the Ordovician-Silurian (O/S) transition developed within a far-field Taconic foreland basin along the eastern margin of Laurentia. The sudden appearance of abundant oncolites and calcimicrobial-coral reefs occurs just below the O/S boundary at the same time of a major faunal turnover (conodonts, chitinozoans, acritarchs, shelly faunas); corresponding with the second phase of the end-Ordovician mass extinction. These reefal and oncolitic limestones represent a prominent regional marker unit on Anticosti Island known as the Laframboise Member of the Ellis Bay Formation. The Laframboise microbial-coral reefs form isolated metre-sized bioherms to larger decametre-sized bioherm complexes overlying a regional disconformity; thus forming a transgressive record immediately following the late Hirnantian glacial maxima. The Laframboise reefs were constructed by intergrown calcimicrobial and skeletal components (*Wetheredella*, *Rothpletzella*, *Girvanella*, bryozoans, tabulate corals, stromatoporoids) to form bindstone. Calcimicrobes are, however, volumetrically more abundant than the metazoan skeletons. In South China, extensive oolitic and microbial (peloids, oncolites, calcimicrobes) limestones together with shelly fossils (tabulate and rugose corals, conodonts, brachiopods, trilobites and stromatoporoids) accumulated along the basin margin of the Yangtze Platform. These limestones, more widespread than previously thought, represent neritic carbonate sediments accumulating as shallow water agitated shoals after the second phase of the end-Ordovician mass extinction but coeval with a major deglacial transgressive event during the latest Hirnantian. Similar coeval oolitic and microbial deposits are also known from several Mid-West Laurentian, Avalonian, Balto-scandinavian, and Siberian localities. We suggest that the extensive precipitation of ooids, calcification of microbial structures and decline of skeletal carbonate production are a distinct response to abrupt changes in oceanography, climate, and global carbon cycle during the latest Hirnantian.

MICROBIAL CARBONATES AS RECORDERS OF SEA-LEVEL, ACCOMMODATION SPACE, AND SALINITY CHANGES: UPPER ORDOVICIAN WILLISTON BASIN, NORTH DAKOTA

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Upper Ordovician Upper Katian carbonates of the Red River and Stony Mountain Formations, Williston Basin, mid-continent North America contain up to four anhydrite members that are underlain by microbial carbonates. Continuous cores from the deep subsurface in North Dakota reveal the detailed stacking pattern of carbonate-evaporite facies within the slowly subsiding and periodically isolated epicratonic basin center. Microbial carbonates include laminated dolomite (supratidal to intertidal) and thrombolite (shallow mesohaline subtidal to intertidal). Laminated dolomite (units 0.3-5 m thick) is characterized by crinkly or smooth flat laminations, whereas laminoid fenestral fabric occurs only locally. This facies lacks any skeletal grains or burrows, and is commonly interbedded with anhydrite (shallow penesaline subaqueous salina, sabkha) and barren lime mudstone (shallow mesohaline subtidal), or caps and engulfs thrombolite mounds. Desiccation cracks, rip-up clasts, nodules and laths of anhydrite are common. The thrombolitic facies (units 0.1-2 m thick) is made up of buff-colored dolomite and mm- to cm-scale, irregularly shaped dark “clots” of dolomudstone; locally, it contains cm-scale microdigitate stromatolites or exhibits microscalloped tops blanketed with thin intraclast layers. Microbial facies are characteristically stacked into m-scale cycles (parasequences) that are associated with mesohaline and penesaline settings; these include laminated dolomite-, breccia-, and anhydrite-capped cycles. They are absent or found only as thin transgressive deposits at the bases of burrowed mud- and grain-dominated cycles that formed in open-marine, normal salinity settings.

Based on the facies and their characteristic stacking pattern, the studied part of the upper Red River-Stony Mountain Fm. comprises four transgressive-regressive depositional sequences bounded by anhydrites. Basin restriction with hypersaline conditions (lowstand systems tract, LST) was terminated with transgression (TST), when normal-marine conditions were established. Microbial carbonates flourished during the highstand systems tract (HST) when they prograded downdip accompanied by relatively low-amplitude sea-level oscillations and an increase in aridity. The abundance of microbial carbonates within the late HSTs-early TSTs of the Williston Basin, suggests that they faithfully recorded short- and long-term sea level changes as well as periods of reduced accommodation space and increased salinities during the Late Ordovician Late Katian transitional climate.

BIOCHEMICAL SEDIMENTATION AND DIAGENESIS IN RESPONSE TO MID-PERMIAN PALEO-ENVIRONMENTAL DYNAMICS, PHOSPHORIA ROCK COMPLEX (PERMIAN, ROCKY MOUNTAIN REGION, USA)

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Biochemical sedimentation, near-surface diagenesis, stable isotopes, and porosity vary systematically stratigraphically and regionally in the Phosphoria Rock Complex (PRC), Rocky Mountain region, USA, in response to dynamic paleo-environmental conditions spanning the Middle Permian. Biochemical, isotopic, and environmental trends are heterogeneous across the PRC, a second-order (~9MY) cycle, and across the third-order (2-5 MY) Franson (latest Kungurian - Wordian) and Ervay (Wordian) cycles.

During transgressions, influx of cool, acidic, low-oxygen, nutrient-rich waters warmed and interacted with hot, oxygenated marine and evaporitic waters. Flourishing sapropelic algal and anaerobic microbial communities resulted in phosphorites and sulfidic-OM-rich mudrocks seaward of calcitic biota and micritic carbonates, redbeds, evaporites and microbialites. Values of $\delta^{18}O$ and $\delta^{13}C$ in carbonates and silica are depleted in distal settings due to microbial decay of OM and increase landwards due to evaporative fractionation. Values of $\delta^{18}O$ in carbonate fluorapatite are depleted in distal environments, increase landwards and towards maximum transgression, indicating warming.

During highstands warm, oxygenated, alkaline marine waters dominated in and became increasingly hot, shelf-confined, and evaporitic. Limited nutrient influx, and input of eolian-sourced silica, resulted in widespread silicified spiculites and calcitic-biota carbonates at maximum transgression and in distal highstands. Increasingly restricted and evaporitic conditions through highstands resulted in dolomitized bioturbated muds and sandstones, aragonitic molluscs, ooids, and peritidal microbialites. Values of $\delta^{18}O$ and $\delta^{13}C$ became increasingly enriched throughout highstands in marine carbonates and silica. This and abundant moganite-bearing chalcedony suggest that evaporitic reflux drove silica and dolomite diagenesis.

Environmental, biochemical, and isotopic trends in the PRC mimic diagnostic trends of the End-Permian Mass Extinction (EPME), and occurred through Kungurian-Wordian time (~274Ma to 265Ma), 13MY prior to the EPME and 5MY prior to the end-Guadalupian crisis. These indicate PRC trends are of a similar genesis to EPME, and dynamics associated with the EPME were driven by locally modified global processes spanning the Middle to Late Permian.

THE SIGNIFICANCE OF AUTOMICRITIC FABRICS PRESENT IN ORDOVICIAN CALATHID-DEMOSPONGE CARBONATE MOUNDS

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Calathid–demosponge carbonate mounds are an integral biosedimentary element of Early to Middle Ordovician shallow-marine carbonate depositional environments of tropical to subtropical palaeolatitudes. These buildups contain an important amount of autochthonous non-skeletal microcrystalline calcium-carbonate (automicrite) that is conventionally considered microbial in origin. Here, the total volume of automicrite of calathid–demosponge carbonate mounds (case study, Tarim Basin, north-west China) is broken down into five distinct fabrics: an *in situ* peloidal–spiculiferous fabric (AM-1), an *in situ* peloidal fabric (AM-2), an aphanitic–microtubular fabric (AM-3), a minipeloidal fabric (AM-4) and a laminoid–cerebroid fabric (AM-5). Type AM-1 occurs with AM-2 being succeeded by an assemblage dominated by AM-3 and AM-4. Types AM-4 and AM-5 are separated by an erosional disconformity.

By using a spreadsheet that contains six parameters and seventeen characters, AM-1 to AM-4 turn out to be non-microbial in origin. Instead, these automicrites represent relics of calcified metazoan tissues, such as siliceous sponges, non-spiculate sponges or even the basal attachment structures of stalked invertebrates. Fabric AM-5 is a microbial carbonate but is post-mound in origin forming a drape within a reefal framework established not until the formation of AM-4.

Carbon and oxygen stable isotopic composition of automicrite plot within a range of 0.28‰ to 0.84‰ PDB for $\delta^{13}C$ and -7.23‰ to -5.23‰ PDB for $\delta^{18}O$. A total of 70% of the automicritic samples plot in or near to the field defining Middle Ordovician (Darriwilian) marine calcite. In addition, a good correlation of fluorescence and cathodoluminescence of automicrites indicates that induced and supported organomineralization produced automicrite, probably *via* the permineralization of non-living organic substrates adsorbing dissolved metal–humate complexes.

The five automicritic fabrics, individually or as an assemblage, are a perennial element of Ordovician calathid–demosponge carbonate mounds in general. The reassessment of the origins of these automicritic fabrics holds consequences for understanding of the Great Ordovician Biodiversification Event what concerns community structure, biodiversity, reef ecology and reef evolution. The implied massive calcification of metazoan connective tissue at or near the seafloor (AM-1 to AM-4) represents episodes and conditions of enhanced marine calcification and might be of value to refine secular trends of pCO_2, Ca concentration and Mg/Ca ratio at the scale of individual sedimentary basins.

FORAMINIFERAL BIOSTRATIGRAPHY AND FACIES ANALYSIS OF THE PERMIAN LONGGE FORMATION IN THE RONGMA AREA, TIBET, CHINA: IMPLICATIONS FOR THE PALAEOGEOGRAPHY OF THE SOUTH QIANGTANG BLOCK

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The Permian Longge Formation in the South Qiangtang Block, Tibet, is overwhelmingly composed of carbonate rocks with various skeletal (brachiopods, foraminifers, gastropods, echinoderms, ostracods, corals, bivalves, algae, and bryozoans) and non-skeletal (intraclasts and ooids) components. Three stratigraphic sections of the Longge Formation in the Rongma area of north-central Tibet — known as South Yibug Caka, Niushan and East Yibug Caka — were selected for this study, which examined both sedimentary facies and foraminiferal assemblages. The foraminifers in these sections consist of at least 38 species belonging to 18 genera. Based on the distribution of the foraminifers throughout the composite section, two foraminiferal assemblages were established, and the age of the Longge Formation was determined to be late Kungurian to Capitanian. During lithological studies, ten microfacies were identified using depositional textures, petrographic analysis and faunal content: mudstone, bioclast wackestone, bioclast perforated foraminifera packstone, bioclast crinoid grainstone, intraclast wackestone, breccia, intraclast grainstone, ooid grainstone, fine crystalline dolostone, and residual grain dolostone[1]. These microfacies are interpreted to represent four depositional environments — restricted lagoon, open marine, shoal, and slope — which together suggest a shoal-rimmed carbonate platform. The non-fusuline foraminifers show transitional palaeobiogeographic affinities (Tethyan Cimmerian subregion), and the assemblage is considered to be influenced by the northward drift of the South Qiangtang Block, the climatic warming after the Late Paleozoic Ice Age and warm-water oceanic currents caused by the newly formed Neotethys Ocean[2]. Together, this indicates that the South Qiangtang Block was located in a relatively warm-water, low-latitude area during the middle Permian. The Permian depositional sequences in the Rongma area were also influenced by the palaeogeographic evolution of the South Qiangtang Block.

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CARBONATE SLOPES OF ISOLATED BUILD-UPS, LINEAR BARRIER REEFS OR RAMPS: CONTRASTING EXAMPLES FROM DOWNUNDER

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It has long been recognized that different types of carbonate slopes form depending on their parent platform geometries (shelf, ramp or rimmed platforms) and properties of their carbonate factories upslope. Here we explore the variability in carbonate slope processes, geomorphologies and facies based on a variety of case studies from the North West Shelf (NWS) and Southern Australia (SA). These encompass Oligocene to Holocene systems and include (1) tropical rimmed margins with extensive, linear reef barriers; (2) sub-tropical distally steepened ramps; (3) tropical, high relief isolated build ups; and (4) cool-water carbonate ramps. These carbonate slope systems are investigated using a combination of 3D seismic geomorphology, multibeam bathymetry datasets, high-resolution 2D seismic data and lithological data (from wells and shallow cores).

Our results show a broad spectrum of carbonate slope types, with sometimes some significant deviations from current facies models. Slopes and toe of slopes of high relief isolated build ups (180 individual ICBs studied) tend to be dominated by mass-transport deposits including slumps and debris slides (with up to 0.5 km-size blocks transported over > 5 km distances). These form the typical association of ICB slope deposits on the windward side of the ICBs (growth escarpment morphologies). However, the margins of the ICBs become dominantly accretionary and progradational on their leeward side, with grain and mud dominated slopes and basin deposits and a greater influence of contour current reworking.

Slope systems of continental shelves rimmed by linear barriers are mud-prone and we hypothesize that their sediments are mainly derived from the oligophotic, off-reef carbonate mud and grain factory (as opposed to the reef margin and/or platform interior). Indeed these barriers are positioned 5-20 km landward from their shelf margin, in contrast to the better studied shelf-edge barriers of the Bahamas and the GBR. Typically, those systems have evolved from distally steepened ramps to rimmed margins, which is accompanied by slope geometries evolving from slump-dominated, to gullies and then canyon-dominated. In some occasions, these canyons feed extensive base-of-slope channel belts systems, whose sinuous planform geometries and terminal lobes are comparable to their clastic counterparts.

In deep ocean basins sedimentary processes in the lower slope are dominated by rare, large-scale mass wasting. Deposits include extensive fields of slided lithified margin debris (km in size) and sediment waves, linear erosional furrows and cyclic steps from unchannelized turbidity currents. Through times retrogressive mass-wasting of the lower slope can result in the formation of very large (5-10 km wide, up to 1.5 km deep) canyons, which are not connected to the upper slope gullies and shelf margin, and essentially form a secondary (distal), mud and debris-dominated carbonate slope domain. These are observed in both T and C-factory systems. Structural inheritance has major impact on the architecture of the calciturbidite system in those settings.

CHARACTERISTICS OF CARBONATE CONTOURITE AND DRIFT DEPOSITS

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Global ocean circulation consists of wind-driven surface currents and deep ocean currents that are largely driven by water density, i.e. the temperature and salinity difference. Deep ocean currents predominantly affect siliciclastic sediments along continental margins and ocean basins but carbonates that grow into the photic zone are more exposed to surface currents. The reasons are twofold. First, the shallow-water carbonate shelves and platforms produce and export sediment into the surface currents for redistribution along the flanks of carbonate platforms in periplatform drifts (1) or as large separated and confined drifts in the seaways. Second, the carbonate edifices form obstacles for the currents, producing a variety of moats and drifts as currents are deflected around them. Frictional forces prevent ocean currents to flow on top or across the shallow tropical platforms but shallow and narrow seaways between platforms can focus the surface currents that erode and carry sediment thought the seaway and deposit a delta drift where the seaway opens into a deeper basin. Currents are able to flow across cool-subtropical carbonate platform whose platform tops are at greater water depth than those of tropical platforms. In such cases, the surface ocean currents aid with the offbank transport and cause platform progradation into the downcurrent direction (2). The high-velocity currents in narrow seaways and across platforms transport coarse sediment producing coarse-grained drifts while the separated and confined drifts in the wide seaways and basins are typically fine-grained like in siliciclastics environments.
Below the surface currents deep and opposing undercurrents and internal tides are common, in addition to the well-known perturbation of upper ocean currents that produce benthic storms in the deep. As a result, near-bottom current patterns are typically complicated as are the resulting contourite deposits. Coarse-grained sediment wave fields in moats, bidirectional sediment striations and local gravel accumulations are thus occurring in close vicinity at the seafloor.

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CHARACTERISTICS OF CONTOURITES IN THE UPPER ORDOVICIAN PINGLIANG FORMATION ALONG SOUTHWESTERN MARGIN OF THE ORDOS BASIN, NORTHWESTERN CHINA

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The southern margin of the Ordos Basin was a deep-water slope during the Late Ordovician, which include five typical lithofacies. They suggest debrites, turbidites, contourites and deep sea autochthonous sedimentation. Compared to gravity flow deposits and authochthonous sedimentation, the occurrence of contourites have been characterized in the present study on the basis of outcrop, petrology and geochemical analysis. The contourites commonly contain sponge spicule, ostracoda, brachiopoda, crinoidea fragments and show various scales of fine–coarse–fine cyclicity together with well-developed bioturbated structures. The thickness of contourites vary considerably commonly showing lenticular shape with undulating erosional surfaces. Cross-lamination and current ripple are usually developed. Current ripples are asymmetric associated with Protopaleodictyon and Squamodictyon, with wavelengths of 1 cm to 5 cm and waveheights of 0.2 cm to 0.5 cm. The grains are moderately well to well sorted, and subrounded with cumulative frequency of bipartite or tripartite divisions. Calcarenitic contourites are well developed in the west of studied area, while micritic contourites mainly occur in the eastern region. However, almost no contourites can be observed in the central region. Contour current paralleling to slope flowed from east to west. Bifurcation occurring in the eastern region was resulted from weak energy in the Fuping graben, where fine grain size contourites were developed. However, Qilianshan-Qinling Ocean Trough and "L"-shaped basin margin (depositional environment changed apparently) could enhance energy of contour current locally, resulting in the formation of calcarenitic contourites. Contour current is mainly developed during relative sea-level rising period under moist climate and dysoxicto anoxic conditions with visible varied salinity.

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CARBONATE SHELF TO BASIN SEISMIC MORPHOLOGY, SEDIMENT PATHWAY, AND RESULTING DEPOSITS: MIOCENE BROSWE BASIN NW SHELF OF AUSTRALIA

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Renewed interest in carbonate slopes in both modern and ancient depositional environments has led to revise long-standing carbonate slope models to include canyons and channels with geomorphology similar to siliciclastic analogs (Mulder et al., 2012 and Puga-Bernabéu et al.,2013). Using more than 50000 km2 of contiguous 3D seismic-reflection data, and industry and Ocean Drilling Program well data, we investigate the shelf to basin architecture of the lower Miocene carbonates in the Browse Basin of NW Australia. For more than 250 km along strike of the continental margin, the shelf to basin profile consists of a succession of six adjoining environments: (1) a wide inner shelf bordered by a thick carbonate platform, which developed at or near the shelf edge; (2) a low angle (1-3^{o}) upper slope between the carbonate platform margins and the main continental shelf break; (3) a steep (6-20^{o}) middle slope dissected by straight to low sinuosity canyons (1-3 km wide and up to 250 m deep); (4) a low angle (0.5-2^{o}) outer slope with an alternation of channel-levee and mass-transport complexes (MTC's); (5) steep (25-40^{o}) escarpment between 1500 and 3500 m high that separated the outer slope; and (6) the Argo abyssal plain at >5500 m water depth where a >100 m thick succession of unconfined calciturbidites accumulated. These datasets image carbonate channel-levee complexes on the outer slope. These channels are 60-300 m wide and up to 75 m deep. They have associated levee-overbank deposits that are up to 3 km wide and 80 m high. The channel-levee complexes have variable sinuosity controlled by MTC confinement and slope angle. Common siliciclastic deep water channel-levee complex processes such as channel avulsion, channel axis lateral and vertical migration, lateral and down dip channel bend migration are interpreted in this deep water carbonate system. Channel development is commonly interrupted by MTC's (0.2-20 km wide and 20-150 m thick). This unique dataset shows a complex shelf to basin morphology with several slope inflection points controlled by antecedent topography created by both previous tectonic events and pre-Miocene sedimentary accumulation. We document an almost complete section for more than 150 km from carbonate platform margins to unconfined carbonate fan on the abyssal plain floor that can provide a new analogue for carbonate slope to basin profiles in other continental margins in similar climatic and tectonic settings.

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DEPOSITIONAL RECORD AND SEDIMENTARY PROCESSES IN EXUMA VALLEY, THE BAHAMAS

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Exuma Valley (EV) is a giant, 130 km-long, submarine thalweg connecting the southern part of Exuma Sound (ES) to the San Salvador abyssal plain in the southeastern Bahamas. Shallow-water carbonate environments surrounding ES episodically provide sediments that are funneled in EV, which shows several sharp knickpoints, and a low sinuosity profile between 2,200 and 3,000 m deep. High-resolution multibeam imaging, very high resolution seismic (VHR) as well as sediment cores were obtained during the CARAMBAR2 cruise (2016-2017). These data allow for a detailed analysis of the depositional environments, their lateral extent as well as the nature of deposits that accumulated in the axis of EV. Five sediment cores, 3 to 6 m in length, were retrieved from the upper, middle, and lower part of the valley. The cores showed an alternation of coarse-grained deposits, interpreted as density flows, and periplatform ooze.

Two debrites (D1 and D2) occur at the base of KS26 and KS16. D1 is evidenced upstream in the upper part of EV and contains cohesive, polymict mud-clasts predominantly composed of carbonate mud as well as planktic input. An Early to Middle (?) Pleistocene age is concurred by the presence of *Globorotalia tosaensis* and *Globorotalia truncatulinoides*. D2 occurs in the middle part of the valley and contains coarse (up to 5 cm) coral debris (*cf Montastraea annularis* group and *cf Favia fragum*) attesting the shallow-water origin of the clasts within this debrite. The total thickness of D1 and D2 is unknown while the coring device did not fully penetrate the deposit, but low amplitude and contorted reflections present in the VHR seismic suggest that they likely are several meter-thick. Well-sorted, sandy turbidites occur in every core and form a significant part of the sedimentary succession in the axis of EV making up 27.0 to 62.5% of the deposits. Grain-size analyses reveal an increased proportion of clay-size particles in the turbidites in the upper and the lower part of the valley, respectively ca. 20 and 12% on average, while sand is predominant in proportions exceeding 84% in the middle part of EV.

Three specific processes govern sediment distribution along this deep-sea carbonate valley, namely: i) large-scale slope failures feeding the proximal parts of the system, i.e. in ES; ii) shedding of coarse shallow-water clasts through slope tributaries merging at high-angle with the main valley axis, and iii) sediment sorting processes documented by the enrichment in the percentage of sands in the deposits when moving from the upper to the middle valley. Although constraints of the timing of sediment shedding through EV still need to be studied in detail (work in progress), the sedimentary record of EV demonstrates its importance as a sediment transport thalweg connecting shallow-water realms to the submarine deep-water fans, it also is a sedimentary system that might have relevance in terms of reservoir potential of deep-water carbonate systems.

DEEP MARINE DUNES ON DROWNED ISOLATED CARBONATE TERRACES (MOZAMBIQUE CHANNEL, SW INDIAN OCEAN)

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Subaqueous dunes are common bedforms on continental shelves dominated by tidal currents. However, sand dunes can also be found in deep-marine settings dominated by bottom currents, although they have been poorly documented. In this study we identified dune fields on drowned terraces preserved along the flank or at the submerged top of isolated carbonate platforms in the Mozambique Channel (SW Indian Ocean). The field acquisitions include multibeam bathymetry, multi-channel high resolution seismic reflection data, photographs of the seafloor and sediment samples. These dunes are located at water depths ranging from 200 to 600 m on slope terraces of an active carbonate platform (Bassas da India Atoll) and on depressions generated by faults on drowned platforms (Sakalaves and Jaguar Seamounts). The dunes are composed of fine to medium carbonate sands. Their wavelengths range between 40 and 350 m, and their height between 0.9 and 9 m; they can be considered as large to very large dunes. Not surprisingly, the dune sizes are not related to water depth, but their maximum wavelengths seem to decrease with increasing slope basement. Dunes on Bassas da India flank and Jaguar top are close to the global maximum height-spacing (h, λ) power law correlation, while on Sakalaves top their height is much smaller. The dune migration seems to be unidirectional. Therefore, the long-term maintenance of dune migration suggests a continuous import and export of sand in the dune field, even in the drowned platforms. Oceanic currents are very intense in the Mozambique Channel and may be able to erode drowned carbonates, generating carbonate sand at great depths. A mooring located at 463 m water depth on the Hall Bank (30 km west of the Jaguar Seamount) showed vigorous bottom currents, with mean values of 14 $cm \cdot s^{-1}$ and maximum values of 57 $cm \cdot s^{-1}$, compatible with dunes formation. The intensity of the currents is highly variable and related to the presence of anticyclonic eddies near the seamounts. A better understanding of the formation of dunes in deep settings can provide valuable information about carbonate preservation after drowning, as well as about the impact of bottom currents on sediment distribution and seafloor morphology.

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GIANT CANYONS AND VALLEYS IN DEEP-SEA CARBONATE SLOPES (BAHAMAS)

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New high-resolution multibeam mapping, backscatter imaging and very-high resolution seismics expose in great details the deep-water sedimentary system in the southern part of Exuma Sound (ES) and the northern part of Little Bahama Bank (LBB, Bahamas). The data reveal the detailed and complex morphology of giant valleys like the Great and Little Abaco canyons (GAC and LAC) along the LBB slope, and the Exuma Valley/Canyon in the ES area. These valleys funnel numerous gravity flows. In GAC, finely-grained sediments originate essentially from the canyon flanks, driven by sediment slides as well as many secondary slope gullies and smaller tributaries. In LAC, gullies directly drain the upper LBB slope providing coarser particles. In the Exuma Valley/ Canyon, a part of the material comes from the slope of adjacent islands and cays through small-scale gravity processes and mass failures, which add to sediments derived from the upper slope that enter the system through tidal passes. A substantial part of the sediments also originate from alongslope sediment flow erosion. In both areas, the valleys abruptly turn into deep canyons incising the Bahama Escarpment (BE). The canyons link the LBB and ES sedimentary systems to the deep abyssal plain of the Western North Atlantic where water depth exceeds 5,000 m. The transition occurs through major knickpoints with outsized chutes exceeding several hundred of meters in height. The sudden transformation from a wide valley to a deep narrow canyon occurs as a result of flow erosion of the underlying lower Cretaceous carbonate platform stack. Huge hydraulic jumps as well as enormous and permanent plunge pools and related deposits were identified at the transition. In ES, the high kinetic flow energy constrained by narrow and deeply incised canyon formed a wide fan-shaped channel-levee complex on the abyssal plain. The latter is made up of coarse-grained carbonate turbidites and concentrated density-flow deposits that are mixed with fine-grained siliciclastics transported along the BE by the energetic Western Boundary Undercurrent (WBUC). Conversely the canyon mouth of the LBB system only reveals a small lobate structure with a thickness that does not balance the volume of sediment eroded in the canyon, probably because of the pirating of fine-grained sediment by the WBUC. Both canyon systems show different input characteristics, similar erosional morphologies cutting in the underlying carbonate platform deposits with major knickpoints, and different sedimentation patterns at their end points on the abyssal plains related to the impact of the deep-water currents.

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A FACIES MODEL FOR FINE-GRAINED CARBONATE-RICH SUBMARINE DENSITY FLOW DEPOSITS

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Fine-grained carbonate-rich submarine density flow deposits are less well understood than fine-grained siliciclastic-rich submarine density flow deposits. This is arguably due to the complexity of interplay between sedimentary basin tectonics, age, carbonate factory and sea level fluctuations associated with drowning carbonate platforms. The Lower Visean succession of the Bowland Basin, UK, provides an excellent opportunity to understand fine-grained carbonate-rich density flow deposits. Visual core description and logging combined with X-ray diffraction mineralogy, total organic carbon analysis and microscope petrography on samples from eleven boreholes along the northern margin of Bowland Basin were used to identify facies variation. From this, the controls on the stratigraphic and lateral distribution of fine-grained carbonate submarine density flow deposits were identified.

Nine lithofacies have been distinguished based on relative genetic variations in structure and composition. These lithofacies are grouped into three facies association: (1) calciturbidites, comprising ripple laminated, bioclast- and sand-/silt-rich mudstones; (2) densite mudstone which included unlaminated ungraded to planar laminated silt-/clay- mudstones; and (3) calcidebrites comprising intraclastic *en masse* debris flow deposits. Platform- and terrigenous-derived components vary within lithofacies from gravel to sand-sized calcitic skeletal fragments through silt-sized tectosilicates and silt-/clay-sized phyllosilicates. Authigenic mineral cements are generally in low concentration and included ferroan carbonates, sulfides and minor phosphates.

Facies model illustrated in this study shows submarine density flow deposits formed from combined actions of storm-generated turbidity flows, slope failures, sediment resuspension and concurrent hemipelagic fall-out in a relatively shallow water (~200 m) environment. Variations in tectonic-driven slope topography and flooded platforms produced diverse mudstone architecture. It is proposed in this study that the vertical facies stacking pattern of fine-grained carbonate-rich submarine sediment density flow deposits is dissimilar to correlative classic siliciclastic model.

DESTABILIZATION OF TROPICAL ISOLATED PLATFORMS

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Landsliding processes are relatively well-constrained on clastic sedimentary margins but remain poorly documented along carbonate slope and guyots. The southern central Mozambique Channel, between Mozambique and Madagascar, hosts several isolated carbonate platforms called the "Iles Eparses" and adjacent seamounts, which developed in shallow-water and tropical settings during the Miocene. They underwent several periods of subaerial exposure that were responsible for the formation of widespread karstic morphologies. Cessation of the shallow-water carbonate production and the drowning of these platforms occurred during Middle Miocene - Early Pliocene times.

Geophysical acquisitions carried out during recent oceanographic cruises (Pamela Projects – Ifremer/Total collaboration) on the flanks of two guyots (the Hall and Jaguar banks) and of one modern atoll (Bassas da India) display a complex geomorphology dominated by numerous lineaments (recent tectonic activity), volcanic mounts, slope scarps, residual translated blocs and gullies. The three carbonate platforms are damaged by large headwall scarps. Geomorphological analysis of their flanks reveals distinct geometries between blocks and small volcanic mounts. Seismic data investigation of the northern flank of the Jaguar bank shows that blocks correspond to triangular-shaped sedimentary bodies (up to 400 m thick and up to 800 m wide) composed of transparent seismic facies. It suggests they are remnant blocks resulting from the destabilization of the platform.

Between blocks, small perched basins are characterized by a sub-parallel seismic facies. The samples recovered by an 8 m Calypso core (Moz1-KS28) in a thick perched basin confirms a hemipelagic sedimentation and dating obtained from nannofossil assemblages allow to propose that destabilization occurred before the Pliocene. Assuming a constant sedimentation rate inside this perched basin (60 m thick), we estimate this failure event to have occurred during the end of Eocene probably before the development of the carbonate platform. The blocks may be of a volcanic origin linked to a destabilization which occurred during the early stage of the edification of the Jaguar bank, and may be interpreted an epiphenomenon of the growth of the volcanic mounts. The sedimentation rate in the perched basin remains poorly constrained. If it is greater than the one used here, the destabilization would occur during the Miocene, after the growth of the seamounts and the failure process would be very different: (1) carbonate dissolution and erosion processes during exposures or subaerial stages, (2) tectonic activity revealed by high-amplitude vertical motions and dense faulting observed along the seamount, (3) intense seismicity observed along a fault corridor observed in the southern Mozambique channel crossing the three seamounts studied here. The origin of the destabilization process of seamounts remains an active on-going debate and is a subject poorly studied as yet.

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LARGE-SCALE MASS WASTING ALONG COOL-WATER CARBONATE SLOPES: INSIGHTS FROM 3D SEISMIC GEOMORPHOLOGY OF THE BIGHT BASIN, AUSTRALIA

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Technological advances on seismic methods in the last three decades have largely contributed to petroleum exploration and geoscience research. In particular, seismic stratigraphy and geomorphology have dramatically improved the understanding of sedimentary processes and deposits in siliciclastic deep water slope environments Although it is acknowledged that carbonate slopes are influenced by the interplay between upslope carbonate production (type and rate), tectonic activity, climatic and eustatic changes, modern and subsurface analogue studies are sparse and further research is needed to fully understand the sedimentary processes and resulting stratigraphic architecture in those settings.

The Bight Basin represents one of Australia's frontier hydrocarbon regions situated along the country's southern margin. It is an example of a deep water slope-basin system initiated during a period of Middle Jurassic to Early Cretaceous upper crustal extension. This study focuses on the depositional geometries of the Cenozoic deep water, cool-water carbonates (~3000m depths) and the sedimentary processes at their origin, which have not been extensively examined previously.

Over 30,000 km^2 of high-resolution 3D seismic data was used to map the evolution of seabed geomorphology through the Cenozoic. This was achieved by mapping seismic attributes over key stratigraphic horizons. Stratigraphic constraints were provided by the integration of existing biostratigraphic data from commercial wells with basin-scale 2D and 3D seismic data. Current literature suggests that the Cenozoic was mainly characterized by thermal subsidence and flexure. Our analysis of the data however, reveals previously unknown recent to modern submarine geomorphological features and slope processes in the area. Key results include:

(a) the identification of large scale mass transport deposits including slumps and debris slides as key components of the resedimented cool-water carbonate section;
(b) existence of numerous, km-wide mega-blocks transported within those debris slides;
(c) the interaction between turbidity current processes with recent submarine volcanism; and
(d) the formation of large canyons probably resulting from repeated turbidity currents through time, enhancing retrogressive erosion at the break in slope.

The results from this study contribute to the understanding of carbonate-dominated gravity depositional systems in cool-water margins, and bring new insights to the sedimentological history and stratigraphic architecture of the Bight Basin.

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LATE CAMBRIAN RAMP TO SHELF EVOLUTION: HIGHSTAND SHEDDING AND THE LIMITS OF CYCLOSTRATIGRAPHY

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The FAD of *G. reticulatus* marks the base of the Furongian Series and Paibian Stage. This interval is noted for a major positive-negative isotopic excursion of $\delta^{13}C$, the SPICE event[1]. In western Utah and eastern Nevada, this 100–500 m thick interval records eustatic fall associated with an influx of shale (Candland and lower Dunderberg shales) and relative deepening during *Aphelaspis* through early *Dunderbergia* chrons due to rapid subsidence and suppression of the carbonate factory. Later in *Dunderbergia* chron, shallowing is recorded with deposition of the Johns Wash Limestone. A subaerial exposure surface and sequence boundary in the overlying Corset Spring Shale of early *Elvinia* chron is approximately correlative with the *I. angustilimbata* interval, a proxy for the base of the Jiangshanian Stage. A correlative carbonate interval in the Dunderberg Shale at McGill section is interpreted as a lowstand wedge. During latest *Elvinia* chron in Utah, subsequent eustatic rise is characterized by more than 300 meter-scale cycles that continue from the Sneakover Limestone through Hellnmaria Formation[2]. High-resolution analysis of $\delta^{13}C$ in lower Sneakover indicates secular variations in isotopic values within carbonate cycles[3]. The Pterocephaliid-Ptychaspid biomere boundary in the middle Sneakover Limestone, provides a time line for high-resolution correlation adjacent to this boundary. Where the Utah successions show a propensity for overall shallowing and stacking of parasequence sets, the top of the Barton Canyon Member of the Windfall Formation in eastern Nevada, immediately above the biomere boundary, is a drowning unconformity overlain by a thick succession of thin-bedded, seemingly non-cyclic carbonate turbidites that upward are interbedded with irregular grain-flow beds, which are interpreted as highstand shedding from the Hellnmaria bank.

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TURBIDITIC LIME MUDSTONES DEPOSITED IN VARIOUS OXYGENATION CONDITIONS IN A LATE PERMIAN RIFT BASIN

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Lime mudstones may deposit from low-energy coastal settings to deep basin environments[1]. For lack of physical sedimentary structures, their origins and sedimentary processes are often mystery. Here I present a thin-bedded lime mudstone sequence developed in varying oxygenation conditions by turbidity currents in a Late Permian oxygen-depleted rift basin. Detailed field sedimentological study and microfacies analysis were carried out to decipher the sedimentary processes of these lime mudstones. Meanwhile comprehensive ichnology data were analysed to reveal oxygenation conditions of their sedimentary environments. Integrated sedimentology, ichnology and microfacies studies show that: (1) these lime mudstones deposited from distal turbidity currents in a deep-water rift basin with continuous increasing oxygenation conditions from anoxic/suboxic to dysoxic; (2) turbiditic limestones formed in anoxic/suboxic conditions exhibit nearly the same sedimentary features with their siliciclastic counterparts; (3) turbiditic limestones formed in dysoxic conditions were commonly extensively bioturbated and homogenized without any primary physical sedimentary structures preserved so that they are nearly identical to pelagic lime mudstones. This study suggests that distal turbiditic origin would be popular for many lime mudstones in geological history, especially prior to Mesozoic. While due to bioburbation and homogenization by burrowers, they are easily misinterpreted as pelagic lime mudstones. So extreme caution should be exercised when we study the origin and sedimentary processes of lime mudstones formed in dysoxic or oxic sedimentary settings.

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CRYPTIC LIFE OF THE MIDDLE DEVONIAN MUD MOUND OF HAMAR LAGHDAD (ANTI-ATLAS, MOROCCO)

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Three exceptionally well-preserved fossil cryptic communities have been discovered within submarine cavities of a Middle Devonian (Givetian) mud mound in the world-renown Hamar Laghdad area (Anti-Atlas, Morocco). The studied cryptic biota encrusted the roofs of the cavities and grew predominantly in an upside-down position, forming unique “hanging gardens” (Jakubowicz et al. 2014). All studied assemblages are dominated by small solitary rugose corals, which display “calice-in-calice” growth with their calices oriented towards the cavity floor . Apart from the rugose corals, the cavities were inhabited by other sessile invertebrates: tabulate corals, cladochonids, lithistid sponges and crinoids, many of which were surrounded by microbial structures. Each investigated cavity was colonised by different sets of invertebrate inhabitants. The conodont dating of the sediment that filled the cavities show that they were open in different time intervals. The rugose corals, as well as other invertebrates identified in the studied cryptic paleoecosystems were also present in surrounding open-surface environments, within mound facies and/or well-bedded intermound deposits of the Givetian of the Hamar Laghdad area. The results support the view that, in contrast to shallow-water (euphotic and mesophotic) environments, mid-Palaeozoic deep-water (dysphotic) settings were typified by no distinct polarization between open-surface and cryptic faunas. Different taxonomic compositions of the studied cryptic ecosystems show that a regional species pool typical of the area and time was the main determinant of the taxonomic structure of these assemblages. The high density of organisms overgrowing each other indicates that intensive competition for space must have already existed in Devonian submarine crypts. All these observations show that the studied cryptic assemblages differed markedly from their both Paleozoic and modern analogues.

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Early Triassic microbial mounds and spheroids in Upper Yangtze Region, SW China：Implications for the Griesbachian biotic recovery from the Latest Permian Mass Extinction

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The Early Triassic anachronistic carbonate rocks, e.g. microbialite, are widely distributed in the shallow marine facies of Tethys Region, especially in the carbonate platform limestones deposited shortly after the Lastet Permian Mass Extinction (LPMS). Microbial mounds and carbonate spheroids are profoundly found in the upper first member of Feixianguan Formation at Baimiaozi, Beibei in Upper Yangtze Region, southwest China. Field investigations and thin-sections analyses indicate that oolitic limestone, bioclastic limestone, microbialite, marl and shale deposits are present in the first member of Feixianguan Formation. Special carbonate grains, spheroids with diameter ranged from 3 to 10 millimeters, are developed among oolitic limestones. Without laminated structure and cores, the spheroids are wrapped by clay minerals and made up of microcrystalline calcites. Leaving filamentous organisms, which indicates the effect of microbial action. The spheroids generally formed in mudstone, supposed that spheroids were rapidly solidified in relatively shallow-water environment and deposited in deep-water environment with low energy. The thickness of the microbialite, about 10m above the spheroid deposit, is approximately 4 m in thickness, and the microbial mounds growing at the upper part of this microbialite are about 0.5-1 m high, 2–3 m in diameter. Three facies are identified from the microbialitic mounds: a mound base, mound body, and mound cap. Brown-colored microbialite were found in mound base, and mound body are composed of grey microbialite. Light grey limestone is yielded from the mound cap which is covered by intact fossils of bivalves and gastropods, implying a simple ecosystem of microbes and primary consumer. Brown-colored shale and marl of the second member of Feixianguan Formation are above the microbiolite, indicating the growth of the microbial mounds was ceased by the rapid transgression. Early Griesbachian conodonts of Hindeodus parvus? were identified from the mound limestone and the overlying strata of the second member of the FXG Formation, which is suggestive of the presence of a microbialite-dominated ocean in the Upper Yangtze Region during a certain interval after the LPME.

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EARLY CARBONIFEROUS SYN-TECTONIC SEDIMENTATION AND THE ORIGIN OF WAULSORTIAN-LIKE MOUNDS IN THE OZARKS, U.S.A.

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Early Carboniferous carbonate mud mounds are commonly interpreted as autochthonous accumulations formed from the baffling and trapping action of biological organisms. New evidence from field mapping, regional stratigraphic study, and isotopic analysis suggest a plausible alternative interpretation for mounds in the western Ozarks as homogenous, allochthonous slump masses on downthrown blocks adjacent to contemporaneous faults. The Ozarks region has had a long history of tectonism. Following late Proterozoic rifting and development of a stable platform in the Ouachita embayment, a regional pre-late Devonian unconformity marked the reversal of plate motion and onset of convergence, development of a fore-deep, and flexural uplift in the Ozarks. This unconformity progressively beveled older units (middle Devonian through lower Ordovician) with angular discordance[1]. By late Devonian time, a Chattanooga Shale correlate blanketed the region. Continued epeirogenic uplift subsequently removed much of the upper Devonian succession except on the northern and southwestern margins of the Ozarks. Paleozoic paleokarst-fills and meteorite impact breccias are key for showing the timing of uplifts and denudation[2]. Uplift culminated early in the late Carboniferous during the Ouachita orogeny. Localized movements on fault systems in southwestern Missouri and northwestern Arkansas are indicated by abrupt changes in thickness and anomalous stratigraphy. In the southwestern Ozarks, faults active during the early Carboniferous included Bentonville, Brush Creek, Fairplay, Lampe, Pineville, and Ten O'Clock Run faults, and the Mt. Shira uplift. Mounds are adjacent to each of these faults, mostly in a fairway along the southern border of Missouri. Features extrinsic to mounds are consistent with structural emplacement; other features within mounds are consistent with folding downslope movement, disruption, reorientation, and de-watering. Applying abductive reasoning, faulting provided for accommodation and initiation of syn-tectonic sedimentation.

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GROWTH HISTORY OF COLD-WATER CORAL CARBONATE BUILD-UPS AT BRITTLESTAR RIDGE I, MELILLA MOUND FIELD, EASTERN ALBORAN SEA

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To get insight into the long-term development of cold-water coral (CWC) growth and associated carbonate build-ups in the Mediterranean Sea, carbonate build-ups situated on Brittlestar Ridge I (Melilla Mound Field, Alboran Sea) were re-visited during Eurofleets expedition Gateway MD194. Gravity coring provided long-term records of both modern and fossil CWC build-ups. This site offers a unique opportunity to trace CWC growth in space and time in the Mediterranean basin.

This study is based on three gravity cores retrieved on Brittlestar Ridge I, at a water depth of around 330m (i.e. MD13-3455, MD13-3459 and MD13-3462, they are 491, 752 and 928 cm long, respectively).To characterize the growth history of these build-ups, U/Th dating, CWC quantification using X-ray computer tomography, elemental chemistry (XRF), grain-size analyses, total organic matter, pore water and mineralogical analyses were performed. U/Th data reveal that MD13-3455 and MD13-3459 span the Holocene and part of the Upper Pleistocene, providing a unique high-resolution record of paleo-environmental changes during the onset of the last deglaciation and CWC growth during the Bølling-Allerød warm period. Transition into this period is marked by a striking change in facies from bryozoan-dominated to dense CWC reefs. Grain-size data of the siliciclastic fraction allow to correlate the two cores, emphasizing lateral continuity of the buildups along the ridge. The top of core MD13-3462 (0–30 cm) corresponds to similar time intervals as observed in cores MD13-3455 and MD13-3459. In contrast, CWC's in MD13-3462 reveal significantly older ages. The oldest age obtained is > 300 ka, rendering core MD13-3462 an exceptional long-term record.

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CARBON ISOTOPE SIGNATURES AND THEIR POSSIBLE LINK TO UPWELLING: MIDDLE MISSISSIPPIAN CRINOIDAL-BRYOZOAN CARBONATES, ILLINOIS BASIN

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The Illinois Basin was characterized by the development of two unique carbonate platforms dominated by crinoidal-bryozoan deposits during deposition of the Burlington-Keokuk and Ullin/Warsaw Formations (late Tournaisian–early Viséan). These carbonates were deposited on a distally steepened ramp in which crinoidal and bryozoan buildups proliferated and produced massive amounts of bioclast debris deposited as sand waves in mid-ramp settings. The outer ramp facies are characteristically siliceous and consist of very fine grained, cherty limestones in which sponge spicules are common and, in some cases, include radiolarian tests. Carbonate mud-mounds, although present, were small buildups both biodetrital and microbial in origin.

The platform carbonates lithologically resemble cool-water carbonates dominated by crinoids and bryozoans, with brachiopods and trilobites as minor components. Upwelling of nutrient- and silica-rich cool oceanic water that reached the Illinois Basin likely enhanced the proliferation of "opportunistic" echinoderms and bryozoans. These carbonates are lithologically distinct from the overlying shallow-water oolitic and peritidal carbonates. The small size and general paucity of carbonate mud-mounds at that time was likely due to rapid production of crinoid and bryozoan debris that resulted in drowning of the mud-mounds, thus limiting their lateral and areal extent.

There is no evidence for subaerial exposures in these Mississippian deposits, and the absence of green algae, peloids, and ooids indicates deposition in relatively deeper water settings. The change in lithologic pattern from cool-water-like to shallow- and warm-water deposits correlates well with carbon isotope data. For the most part, crinoidal-bryozoan deposits show a more negative carbon isotope value (~1 to 3‰) compared with the overlying shallow-water carbonates (>3 to 3.5‰). Carbon isotope data corroborate upwelling as a potential mechanism for the development of these cool-water-like carbonates. Two major carbon excursions are recognized in these carbonate successions, each of which begins with a negative excursion having a $\delta^{13}C$ value as low as 1‰ followed by a gradual increase in $\delta^{13}C$ values to >3.5‰. The negative carbon isotope shift is interpreted as having been caused by upwelling, which brought into the intracratonic basin not only nutrient-rich cool water but also $\delta^{12}C$-rich organic matter that, upon oxidation, released $\delta^{12}C$ into the water, where these carbonates were deposited. The shift to a more positive $\delta^{13}C$ may have been due to increased productivity and $\delta^{12}C$ organic carbon burial.

NEW DATA REVEALS THE COMPLEXITY OF MODERN *HALIMEDA* ALGAL BIOHERM MORPHOLOGY IN THE GREAT BARRIER REEF, AUSTRALIA

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The modern *Halimeda* algal bioherms in the northern Great Barrier Reef, Australia, form extensive (>6,000 km^2)[1] carbonate sediment deposits on the outer continental shelf, and have been described as modern analogues of the late Palaeozoic phylloid algal mounds[2,3]. The widely accepted interpretation of *Halimeda* bioherm morphology as a series of simple parallel ridges and troughs to hummocky mounds, was derived from limited seismic and singlebeam echosounder profiles, and has permeated the literature since the 1980's[4]. However, new bathymetry data reveals that *Halimeda* algal bioherm morphology is far more complex than previously thought, and suggests that previous sedimentological interpretations surrounding their formation need to be reconsidered. Using the most recently available high-resolution airborne lidar and multibeam bathymetry datasets, we digitally mapped the *Halimeda* bioherm spatial distribution and geomorphology on the northern Great Barrier Reef. Truly remarkable is their complex reticulate and annulate ring-shaped morphology, revealed in 3D for the first time, and overturning the long-standing morphological interpretation. These new findings raise questions about whether this complex morphology is unique to the modern *Halimeda* bioherms, or may also be applicable to interpreting algal bioherm morphology in the geological past.

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OASES OF BIODIVERSITY: DEVONIAN MUDMOUNDS AT HAMAR LAGHDAD, MOROCCO

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Hamar Laghdad, also called Kess Kess or Hamar El Khdad, is a world-renowned site among geoscientists for its more or less completely exhumed, mostly conical and well preserved mudmounds (1, 2). While the carbonate build-ups of the Algerian Ahnet-Basin are assumed to represent the most spectacular naturally exposed mudmounds (3), those of Hamar Laghdad in Morocco yield possibly the greatest paleobiodiversity, both horizontally in the surrounding sediments and stratigraphically through the sedimentary sequence of the Devonian. From the Ordovician to the Carboniferous, sediments of the Hamar Laghdad region and their fossil contents tend to differ slightly from those of coeval strata of other parts of the Tafilalt Platform. Here, we portray the sedimentological and paleontological record of the Hamar Laghdad region covering the late Lochkovian to Givetian interval. We use alpha-diversity data based on macrofossils from fossiliferous strata and compare the results with the abundance of bioclasts in polished sections. We show that the paleobiodiversity was comparable to that of the southern Tafilalt with a normal diversity during the Pragian, i.e., prior to mudmound initiation and growth. By contrast, the layers covering the massive mudmound carbonates show a high diversity during the latest Emsian (Red Fauna) with a trophic nucleus comprising over 40 species. This fauna is dominated by benthic suspension feeders (corals, brachiopods, and crinoids) and cephalopods. The shift in biodiversity is most likely related to the local occurrence of a favorable paleogeographic setting influenced by sea-level fluctuations, currents, and nutrient availability. The size and distribution of modern carbonate mounds in the northern Atlantic displays a pattern very similar to that observed at Hamar Laghdad, pointing to some similarities worth being explored (4, 5).

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FRASNIAN PINNACLE REEFS, WESTERN CANADIAN SEDIMENTARY BASIN; A PRODUCT OF ENVIRONMENTAL NOT EVOLUTIONARY CHANGE

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Upper Devonian, Frasnian, deep water pinnacle reefs of the Nisku Formation, are uniform at the macro-scale and heterogenous at the micro-scale. Heterogeneity is environmentally driven, imparted by the relative proportion of biota, mud, and early cementation. Examination of 14 such structures reveals excellent compositional uniformity wherein buildups are composed largely of corals, stromatoporoids, calcimicrobes, synsedimentary cement and encrusting organisms. The recurring vertical succession consists of: 1) a thick basal interval of tabulate and rugosan coral framestones and coral-pelmatozoan floatstones; 2) a thick middle unit composed of couplets of microbial-coral floatstone and low-relief microbial-spongiostromate boundstone or microbial-skeletal boundstone; and 3) a cap of reworked, biofragmental packstones-rudstones and mud. The upward change in biota is an increase in stromatoporoids and encrusting/cavity-filling tabulate corals. Current understanding of buildup growth holds that calcimicrobes are localized to shallow water and stromatoporoid-dominated intervals. Close examination of these buildups, however, reveals that: 1) the association of prostrate calcimicrobes can occur early in deepest water environments during reef accretion, 2) a diverse association of encrusting and framework calcimicrobes was present in shallow water paleoenvironments, and 3) classic synsedimentary, early marine cementation was neither restricted to the reef front nor determined by water depth but more ubiquitous as in other Phanerozoic deep water reefs and reef mounds. These observations suggest that Nisku reef growth was determined more by environmental conditions than by evolving late Devonian biotas.

SEDIMENTARY CHARACTERISTICS, FORMATION MECHANISM AND GEOLOGICAL SIGNIFICANCE OF THE SHINIULAN FORMATION REEFS (LOWER SILURIAN) IN THE UPPER YANGTZE PLATFORM

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The Shiniulan Formation in the Upper Yangtze Platform displays several coral-stromatoporoid reefs, especially in its middle-upper part. Reefs are Early Silurian in age. Reef-building organisms include bryozoans, brachiopods, cephalopods, algae, crinoids and bivalves. The scale of the reef is quite different from the corresponding reef over the world. In this paper, we propose that the Shiniulan Formation reefs were developed on the margin of the Upper Yangtze carbonate platform, and are featured by depositing biohermal limestone, bioclastic limestone, sandstone and mudstone. The Shiniulan Formation could be divided into four members according to the lithological characters and the reefs were generally outcropped in the middle-upper layer, which correspond to four growth stages the reefs: stabilization, colonization, diversification and domination. In the reefs, the argillaceous and sandy content is decreasing, the lime content is increasing upwards. Under the influence of Caledonian tectonic movement in the Early Silurian, the growth characteristics, evolution, scale and size of reefs in the Shiniulan Formation were widely influenced by three factors: agitation of external sources, fluctuation of sea level, temperature and salinity. The Upper Yangtze region was located in a shallow-marine environment with warmly, tropical and subtropical climate and high salinity during the Late Aeronian. By comparing the synchronous global reef developmental state, we uncover that reefs were globally distributed in Aeronian, chiefly centered on the margin of carbonate platform at tropical latitudes beween 20 and 30° north and south. The reefs, in corresponding period as the Shiniulan Formation, were dispersed in Laurentia, Siberia and Kazakhstan Block. However, the Shiniulan Formation presents significant differences of growth, evolution, and size compared to the corresponding reefs globally. The detailed analysis on the different characteristics between the Shiniulan Formation and the Menier Formation, aims to explain underdevelopment of large-scale reefs in the Upper Yangtze Platform during the middle and late Silurian.

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CRUSTOSE CORALLINE ALGAE AND RHODOLITHS IN SOUTHWESTERN PUERTO RICO REEFS: ANALOGUES TO ANCIENT RHODOLITH DOMINATED SYSTEMS

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The reef flats and back reef environments of Media Luna, Margarita, Laurel, San Cristobal, and Playa Buye reefs in southwestern Puerto Rico offer a unique opportunity to document rapid biological and geological changes taking place within the time span of less than half a century[1]. Until recently, modern large rhodolith beds in the northeastern Caribbean have been restricted to deep reef communities (>45m). Shallow water rhodolith dominated systems, including some which are now considered important hydrocarbon reservoirs, are not an uncommon occurrence in the geologic past. Researchers have speculated that these changes in the rock record were rapid and caused by environmental and climatic changes[2]. This ongoing research will allow us to identify the drivers for rapid change, which may lead to a complete replacement of aragonitic biota in the reef flat and shallow back reef by a high-magnesian biota within a millennia. We hypothesize that lowering of pH, warmer shallow water temperature and coral bleaching episodes are drivers of the ongoing change[3].

This study integrates petrographic, mineralogical, and geochemical techniques to document the organisms that coexist with crustose coralline algae and affect the textures, fabrics, mineralogy, and porosity of rhodoliths. Preliminary petrographic and SEM imaging reveal major textural differences within the samples, though not between locations, or among different reef zones. A diverse biota is present between red algal laminations that include serpulid worms, encrusting bryozoans, sponges, and foraminifera. Bivalves, gastropods, and benthic foraminifera are present, although not abundant. A diverse microscopic biota is present that includes cocci and bacillus shaped bacteria, fungi, and diatoms. EPS layers are common to pervasive throughout all rhodolith samples. Interskeletal porosity is as high as 60%, however substantial intraskeletal porosity is also present. Early diagenetic precipitates, especially in the conceptacles of red algae include aragonite and high-magnesium calcite with 9 to 20 mol % $MgCO_3$. Magnesian bearing carbonates including hydromagnesite, huntite, and nesquehonite are present in nearly all samples and are potential precursors to dolomite formation, increasing the possibility of dolomitization during burial.

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HOW PRECISELY DO $\delta^{13}C$ AND $\delta^{18}O$ IN FRESHWATER MOLLUSC SHELLS REFLECT THE ENVIRONMENTAL CONDITIONS?

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Carbon ($\delta^{13}C$) and oxygen ($\delta^{18}O$) stable isotope analyses are among the standard methods applied in the studies of past environment, including climate. In lacustrine sediments $\delta^{13}C$ and $\delta^{18}O$ values can be measured in fine carbonate fraction (carbonate mud), in charophyte encrustations, ostracod carapaces and mollusc shells. Application of the stable isotope record of each of the above mentioned components of the lake sediment requires knowledge about possibilities and limitations of the method. The present paper summarizes the most important results of the project concentrated on the stable isotope composition of gastropod shells, primarily, the species commonly preserved in central European Quaternary lacustrine sediments. The stable isotope studies involved also, zebra mussel (*Dreissena polymorpha*), one of the most invasive freshwater species in the world. The research involved shell isotope studies of both recent and fossil molluscs derived from the Holocene sediments.

Shell $\delta^{13}C$ values were species-specific and among the gastropods studied the same order of species from the most to the least ^{13}C-depleted was observed at all sites sampled. Shell $\delta^{18}O$ values were more uniform. Wide range of $\delta^{13}C$ and $\delta^{18}O$ values were observed in population and subpopulation, i.e., when gastropods were sampled live from restricted area within the lake littoral zone. Carbon and oxygen stable isotope values of the mono-specific shells sampled from 1 cm thick sediment samples were highly variable. Those intra-specific differences (n=20) were as large as several permill. Such significant variability in $\delta^{13}C$ and $\delta^{18}O$ values indicates that stable isotope composition of single shells is unlikely to be representative for the sediment sample.

In conclusion, samples of freshwater molluscs for stable isotope analyses should be monospecific and composed of at least several shells. The number of shells being dependant on the difference between the minimum and maximum values within the sediment layer.

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STORM DEPOSITS AND ACCOMPANYING MICROBIAL BIOHERMS IN SUGAITBLAK AND YUTIXI AREA, NW TARIM BASIN, CHINA

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Synthesis of storm deposits and accompanying microbial bioherms quantifies a geological period marked by "stormy sea with the scarcity of metazoan skeletons". Based on 4 outcrop sections, 106 thin sections and 12 SEM samples in Lower Cambrian Xiaoerbulak Formation, Sugaitblak and Yutixi Area, NW Tarim Basin, China, this representative sedimentary phenomenon was analyzed and summarized. Five types of storm deposits are recognized in Sugaitblak Area and bioherm collapsed deposits are always below layered bioherms. Synthesis of them quantifies "background sediments - storm deposits - collapsed deposits - microbial bioherms - background sediments". Background sediments on slope compose of micrite limestones, and collapsed deposits include debris of bioherms and background sediments. Donut-shaped clots are observed on the surface of bioherms, composed of chambered *Epiphyton* microscopically. Two types of storm deposits are recognized in Yutixi Area and Synthesis quantifies "background sediments - storm deposits - microbial bioherms - background sediments". The main body of bioherms is composed of thrombolites with piebald clots macroscopically, and dendritic *Epiphyton* microscopically. Sugaitblak Area is closer to the ancient storm center, because the gravels of the storm conglomerates in Sugaitblak Section arrange disorderly and spirally, and that hummocky structures and gutter casts in sedimentary succession look like the classical storm sedimentary succession. It's obvious that storm activities can prevent the growth of bioherms, or destroy them. Conversely, bioherms can block the strom back-flow to some degree, and different shapes of bioherms, formed by distinctive *Epiphyton*, may have different degree of wave resistance.

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ABIOTIC VERSUS BIOTIC CONTROL IN HYDROTHERMAL TRAVERTINE PRECIPITATION

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Hydrothermal-spring systems in continental setting have been largely regarded as potential sites for the origins of life on early Earth, and thus represent locations of exobiological interest. A novel terrestrial hypothesis for the origin of life endorses hydrothermal-springs as one of the Earth's most primitive ecosystems[1]. Defining how life diversified and adapted to hot-spring conditions from the actualistic and fossil perspective will open up the possibility to improve our understanding of the impact of life on the Earth's systems and its permanent imprint in the geological records.
In view of all the above findings, a multidisciplinary and multi-scale investigation on four modern and three fossil hydrothermal spring travertine deposits, located in Central Italy, have been conducted. The integrated approach of this research, essentially based on the stratigraphic, sedimentary, petrographic, geochemical, mineralogical, petrophysic and geomicrobiological principles, has been considered critical to gain exhaustive answers concerning the complexity of hydrothermal spring-related carbonates. The spectacular occurrence of authigenic mineral precipitation in association with microbial mats and biofilms, of diverse morphologies and pigmentations, acted as classical natural laboratories that provided an important opportunity to evaluated bio-geochemical and physicochemical factors that have direct impact in carbonate precipitation. Present-day thermal activity in the studied areas is characterized by temperature ranging from 34 to 50°C and pH values ranging from 6 of ca. 7.5. The springs expel water classifiable as Ca (Mg)-SO_4^{2-}-HCO_3^- facies. Molecular analyses indicate a high biodiversity of the microbial mats communities with a wide range of metabolic processes, varying from anaerobic to aerobic. Results suggest that the complex microbial community interfaces with the environmental abiotic factors to form peculiar sedimentary structures characterized by a wide range of architectural and facies patterns. Travertine precipitates show a dominantly calcite and aragonite in composition, with minor amount of gypsum, sulfur and pyrite. High magnification SEM analysis, according with molecular investigations and geochemistry, revealed that biological activity and degradation of organic matter play a fundamental role in the travertine formation. The individuated fabric types reflect the precipitation processes due to interplay between abiotic and biotic (i.e., biologically induced by microbial metabolic process or simply influenced by nucleation on microbial biofilm substrate) and/or a combination of both processes, which are subsequently modified by diagenesis. Defining the environmental conditions and the abiotic and microbially mediated or induced processes promoting carbonate accumulation in spring-related settings could also represent the key to provide a breakthrough for developing a comprehensive evaluation of the continental carbonate reservoir properties.

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NEW INSIGHTS INTO THE AGE AND NATURE OF LOWER PALEOZOIC CORES FROM THE LABRADOR MARGIN, OFFSHORE EASTERN CANADA

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The lower Paleozoic of the eastern Canadian Atlantic margin is poorly understood due to the scarcity of offshore samples and the occurrence of diagenetic alteration and tectonic deformation. These strata underlie the Mesozoic rift succession of the Hopedale Basin along the Labrador margin, offshore eastern Canada. Paleozoic-aged rocks were penetrated by seven industry wells (Freydis B-87, Gudrid H-55, Hopedale E-33, Indian Harbour M-52, Roberval K-92, South Hopedale L-39, and Tyrk P-100), with six corresponding conventional core samples available from four of the wells (Gudrid H-55, Indian Harbour M-52, and two cores from each Freydis B-87 and Roberval K-92). These six cores and their associated thin sections are described as part of a regional study aimed at understanding the lower Paleozoic depositional environments that existed along the western margin of the Iapetus Ocean. Five of the six cores are carbonates with one of the cores from Freydis B-87 and the core from Indian Harbour M-52 being composed of limestone, whereas the cores from Gudrid H-55 and Roberval K-92 are dolostones.

The uppermost core recovered from Freydis B-87 is siliciclastic and is dominated by mudrock with cross-bedded and laminated sandstone beds. The second core consists primarily of fossiliferous wackestone with fragments of undifferentiated shells, brachiopods, echinoids, bivalves, gastropods, trilobites, and bryozoans. Ostracods, sponge spicules, and calcimicrobes are also observed in thin section. The Indian Harbour M-52 core consists predominantly of limestone with dolomite occurring in localized patches and along stylolites. Fragments of shells, bivalves, echinoids, gastropods, trilobites, and brachiopods, along with radiolarians and sponge spicules are also present. The core from Gudrid H-55 and the two cores from Roberval K-92 are composed entirely of fabric-destructive diagenetic dolomite resulting in no identifiable fossil components. Ordovician scolecodonts, chitinozoa, and acritarchs were recovered using conventional cores and cuttings from six of the seven Paleozoic wells on the Labrador margin with varying degrees of preservation. No identifiable lower Paleozoic palynomorphs were found in Roberval K-92; however, given the lithological similarities with Gudrid H-55 and its proximity to the other Paleozoic wells, it is likely also Ordovician in age.

The diverse fossil assemblages observed in the lower core from Freydis B-87 and the core from Indian Harbour M-52 implies that these sediments were deposited under normal marine conditions, with low to moderate energy levels. The high abundance of fossils in the Freydis B-87 carbonate core and the presence of calcimicrobes suggests a somewhat shallow depositional environment, at, or near the base of the photic zone. The identification of radiolarians, and the overall lower fossil content noted in Indian Harbour M-52 reflects its deposition in a deeper-water, open marine environment. A transition from carbonate to siliciclastic sediments in Freydis B-87 signifies the termination of the carbonate factory later in the Ordovician and is likely correlative to a major, possibly eustatic, shift in depositional conditions.

A SPOT OF ENHANCED BIODIVERSITY AND CARBONATE PRODUCTION IN THE COLD TEMPERATE SHALLOW WATERS OF THE ENGLISH CHANNEL: THE NORMANDY-BRITTANY GULF

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The present-day marine sediments in the English Channel show wide ranges in grain-size and carbonate content (48 classes). However, the largest variations in carbonates occur in the Normandy-Brittany Gulf (NBG), which is located in the central area of the English Channel westward of the Cotentin Peninsula.

The carbonate fraction of the sediments is produced after disintegration of various mollusk shells, echinids and coralline algae, which thrive on the sea floor. High biotope diversity is evidenced by the large spectrum of marine habitats (17 classes). Habitat classification refers to the EUNIS/ JNCC scheme (European Nature Information System/Joint Nature Conservancy Council). The relationships between living marine habitats and production of carbonate grains resulting from crushing of shells, tests and skeletons is best illustrated by studying the succession of habitat/ sediment associations along a line-transect with a first section oriented W-NW/E-SE and a second section oriented N/S in the NBG. This line-transect crosses three different depositional domains:

(1) A large moderately deep subtidal (water depth higher than 30 m) transit area, which is characterized by a thin and patchy blanket made up of cobbles, pebbles and granules lying over the hard Proterozoic bedrock. The carbonate producers of this habitat are dominated by vagile echinids (*Ophiotrix fragilis*). Although these populations are locally highly dense, they have not yet been properly quantified in the NBG. The first part of the transect is bounded by large shallow subtidal and intertidal hard bedrock, which is largely colonized by carbonate-producer barnacles.

(2) Wide shallow subtidal (water depth lower than 30 m) areas of sediment accumulation of variable thickness and geometry (sand waves, sand sheets) preferably develop leeward of major islands (Jersey, Guernsey) or rocky platforms (Les Minquiers, îles Chausey). They consist of coarse and medium-grained bioclastic sands mainly derived from living bivalves (e.g. *Glycymeris glycymeris, Venus verrucosa, Tapes rhomboids*), gastropods (*Crepidula fornicata*) and red algae (*Lithothamnium calcareum*) hosted within or at the surface of the seabed.

(3) An extensive intertidal sedimentary wedge due to the megatidal regime in the Bay of Mont-Saint-Michel. The habitat/sediment associations are dominated by numerous bivalve colonies (e.g. *Macoma balthica, Cerastoderma edule, Spisula ovalis, Abra alba*) and local concentration of sedentary annelids characterized by sandy worms enriched in carbonate particles such as *Sabellaria alveolata* and *Lanice conchylega*.

Such a rich biodiversity contributing to a carbonate-dominated sedimentation in cold temperate shallow waters makes the NBG a unique site for unraveling the key factors, which produce this wide range of carbonate-rich sedimentary bodies.

CHARACTERIZATION AND MAPPING OF DIAGENETIC RISK IN PRE-SALT CARBONATE RESERVOIR, SANTOS BASIN, BRAZIL

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Microbial carbonates make a large part of Aptian carbonate platform in Santos Basin in the Brazilian southeastern continental margin. These rocks indicate reservoir quality strongly conditioned by the characteristics of the depositional environment and their associated diagenetic alterations. In carbonate reservoir, diagenesis is one of the most important factors in permo-porosity quality control. It is essential for the geological models to have high predictability potential regarding the processes of dissolution and cementation of the porous framework. In this context, the current work presents a methodology for petrographic description to facilitate the understanding of the main factors controlling the permo-porosity quality of the carbonates rocks. This methodology also allows the construction of a numeric model with the integration of diagenetic and depositional processes. The selected study area is characterized by two structural highs and three stratigraphic units. The methodology is performed using a combination of attributes derived from: (1) the lithology interpretation, (2) the main diagenetic processes (compaction, cementation, replacement, dissolution) and also (3) the specific textures, such as the presence of Mg-rich clays, the preservation of primary porosity and the existence of fractures. Through a systematic thin section description, the attribute that causes the main impact in reservoir quality is determined. This information is verified against petrophysical laboratory measurements, thus identifying the depositional and/or diagenetic attributes that control the petrophysical behavior of the studied section. The integration of petrographic analysis and porous system evaluation from borehole image logs allows the construction of diagenetic event logs in the available wells. From this data set, dissolution and dolomitization trend curves are obtained at the wells. Additionally, maps are constructed representing the proportion of this diagenetic process for each stratigraphic unit. The combination of maps and trend curves is used for building a 3D proportion matrix that reveals the regions with the best permo-porosity conditions. The dissolution process prevails in the lower stratigraphic unit of the study area, mainly in the structural high located in the western portion. The two upper stratigraphic units present a high proportion of dolomitization. The result shows that the petrographic description methodology is effective for the integration of different data scales used in the study. It also permits the 3D mapping of the diagenetic products in the reservoir, thus contributing to the optimization of the production development in the oil fields.

Sequence pattern and sedimentary facies of the Jiantianba reef complex: A case study of the structure and composition of organic reefs

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The late Permian Changhsingian Jiantianba reef complex is well known platform reef margin located in western Hubei Province, China. Based on field observations of the exposed entire reef complex and petrographic analysis, 12 reef facies have been distinguished by sedimentary components and growth fabrics. These are: micrite bioclastic limestone, filled skeleton sponge bafflestone, filled skeleton sponge framestone, open skeleton sponge framestone, binding skeleton sponge framestone, eroding skeleton sponge framestone, agglutinated sponge bafflestone, benthic organism bindstone, dolomite reef cap, reef bank shell limestone, reef front bioclastic debris flow and reef flank sponge rudstone. Vertically traceable stratal patterns reveal 5 phases of reef growth. Phase 1 is upper slope to open platform bioclastic limestone, constituted the substratum of the reef. Phase 2 is the first cycle of reef core facies which exhibits the features that sponge inter-skeletal spaces occluded by sediment during reef-growth. In contrast, Phase 3 is the second cycle of reef core which exhibits the features that sponge skeleton cavities remain open during the early stages of reef growth and are occupied by encrusting algae, early cements and internal sediment. Phase 4 represent the reef crest and reef cap at which water depth of this phase had become very shallow, near the tidal zone and then finally exposed. Phase 5 reveals the development of reef-bank system; reef front shell limestone and reef front filling sediment can be observed directly in situ. Jiantianba reef displays the complete development process of the entire reef. Each phase and facies revealed different tendency of sea level changes and the hydrodynamic conditions of the sediment. This study provides a better understanding of the evolutionary process of reefs and provide a more accurate description of the reef sedimentary facies.

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CHARACTERISTICS AND CONTROLLING FACTORS OF DEVELOPMENT OF PALEOZOIC REEF-BANKS IN THE SICHUAN BASIN

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Paleozoic reefs are mainly distributed in Early Cambrian, Early Silurian and Late Permian strata in the Sichuan basin. Geographically, they occur in the Daba and Micang mountains on the northern and northeastern margins of the Sichuan basin (Early Cambrian reefs), on the northern and southern margins of the Sichuan basin(Early Silurian reefs) and western Hubei, eastern Chongqing and northeastern Sichuan (Late Permian reefs). The Early Cambrian reef-bank association includes patch reefs, lime-mud mounds and oolitic shoals. Reef-building organisms are archaeocyatha and cyanobacteria and organisms attached to reefs are trilobites, brachipods, crinoids and sponges. Controlled by sea-level fluctuation, reefs have cycliciy and from west to east the horizons are raised gradually.Early Silurian reefs include patch reefs, lime-mud mounds and biostromes. Reef-building organisms are mostly corals, stromatoporoids, polyzoa and cyanobateria. Their distribution are controlled by terrigenous clastic-carbonate gentle slope affected by oldland and also related to sea-level fluctuations. Late Permian reefs are inner platform patch reefs and platform marginal reefs. Reef-building organisms are primarily sponges. Reef growth and distribution have a close relation with the paleogeomorphological framework and sea level fluctuations.

Key words：reef；development and distribution；Early Paleozoic；Sichuan basin

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Permian Carbon Cycle And Climatology In Easternmost Paleo-Tethys: Complete Carbon Isotopic Records From Xikou Section, Zhen'an, Central China

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Previous studies of Permian seawater carbon isotopic compositions have mainly focused on the Guadalupian-Lopingian Series boundary, and the Permian-Triassic System boundary. Consequently, a continuous Permian carbon isotopic record was only established as a composite, combining several different sections to overcome the lack of complete and unaltered rock records at a single locality. This study focuses on the Xikou section, Zhen'an, Shaanxi, Central China, a continuous, uninterrupted, Upper Carboniferous to Lower Triassic carbonate dominated succession, from which a total of 180 Permian limestone samples were collected for carbon and oxygen isotopic analyses to document carbon isotopic signatures and their fluctuations in the easternmost Paleo-Tethys. The preserved record includes 11 positive shifts, 11 negative shifts, and $\delta^{13}C_{carb}$ values that varied between +0.3‰ and +5.71‰, with an average value of +4.07‰. Data record major global carbon isotopic anomalies at the Guadalupian-Lopingian Series and Permian-Triassic System boundaries, as well as carbon signatures that are significant and likely global, such as the Kamura Event, the occurrence of anoxic conditions around the Guadalupian-Lopingian Series boundary, and carbon excursion around the Wuchiapingian-Changhsingian Stage boundary. The carbon isotopic variations were accompanied by climate changes, linked with glacial fluctuations during Early to Middle Permian time that correspond approximately to local sea-level changes during Late Permian time. As the most complete carbon isotope composition profile, the Xikou section has important implications for the carbon cycle and climatology in the Paleo-Tethys and surrounding areas, and can be a reference for global carbon cycle and climatic reconstruction during Permian time.

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Last interglacial reefs from the Eparses Islands (SW Indian Ocean): depositional sequences and karstification processes

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The Eparses Islands, located in the Mozambique Channel (SW Indian Ocean), are characterized by limestone outcrops exposed a few meters above modern sea level. In the frame of the REEFCORES expeditions, sedimentary descriptions, GPS measurements and rock sampling were carried out on carbonate outcrops from Juan de Nova and Lys Island (Glorieuses Archipelago). These sedimentary formations actually correspond to fossil coral reefs typified by both massive (e.g. faviids) and branching (e.g acroporids) coral colonies, which occur mostly in growth position. The buildups are locally surrounded by stratified peri-reef deposits that are characterized by large coral and bivalve fragments. *Tridacna* specimens have also been frequently reported in living position within reef deposits. U/Th dating performed on fossil corals have confirmed previous results arguing that these reefs developed during the MIS5e Highstand (Last Interglacial Period, ~125 kyr). Culminating at 6m above sea level, these fossil reefs are locally overlain by eolianites associated to dense rhizolitic networks, pedogenetic horizons and well-preserved calcified trees. This carbonate depositional sequence is marked by erosive discontinuities, grainstone interbeddings, changes in coral assemblages and topographic evolutions that might reflect high-frequency sea-level fluctuations during the MIS5e highstand (e.g. Hearty et al., 2007). Finally, these outcrops are affected by well-developed karstic features illustrating past and ongoing fracturation, dissolution and collapse processes that might provide interesting analogues for subsurface case studies.

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EARLY PALEOZOIC DOLOMITE PALEOGENESIS AND HYDROTHERMAL FLUID MIGRATION IN THE HURON DOMAIN OF SOUTHERN ONTARIO

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Strata-bound dolomite horizons occur in deep-seated Ordovician and Cambrian sediments within the Huron Domain of southern Ontario, Canada. Core samples from multiple deep boreholes within the Huron Domain were analyzed for petrographic, stable and Sr isotopic composition, and fluid inclusion microthermometry to characterize dolomitization and evaluate diagenetic fluid composition. The samples represented a range of host rocks from dolomitized limestones, dolostones, sandy dolostones and sandstones within Ordovician and underlying Cambrian formations.

Dolomite and calcite fracture infill isotopic and fluid inclusion data point to two possibly isolated diagenetic fluid systems; i) an earlier Cambrian system that is characterized by pronounced negative shifts in oxygen and carbon isotopic composition ($\delta^{18}O$ average -9.0 ‰ for dolomite and -13.9 ‰ for calcite, respectively; and $\delta^{13}C$ -3.06 ‰ for dolomite and -4.82 ‰ for calcite, respectively). More radiogenic Sr^{87}/Sr^{86} (ratios range from 0.70977 to 0.71100), warm Th - values for dolomite average 113.6 ^{o}C and for calcite; average 101.5 ^{o}C. A saline signature (salinity range from 23.2 to 27.2 wt.% NaCl eq for dolomite; average 24.3 for dolomite and 23.6 wt.% NaCl eq for calcite); and ii) a later Ordovician system that is characterized by less negative shifts in both oxygen and carbon isotopes ($\delta^{18}O$ average -8.7 ‰ for dolomite and -7.5 ‰ for calcite; and $\delta^{13}C$ average +0.37‰ for dolomite and -0.36 ‰ for calcite, respectively), hypersaline (salinity range from 22.4 to 30.1 wt.% NaCl eq.; average 27.0 for dolomite and 27.5 to 29.7 for calcite; average 29.2), comparable homogenization temperature (Th ranges from 85-132 ^{o}C for dolomite; average 109.6 ^{o}C and 66 to 153 ^{o}C for calcite; average 107.2 ^{o}C) and a less radiogenic (Sr^{87}/Sr^{86} ratios range from 0.70818 to 0. 71000) fluid system.

The results suggest that the formations across the Huron domain were subjected to higher temperatures (average 115^{o}C), than can be explained by burial history alone. The observation of highly discrete, strata-bound dolomites, only trace quantities of saddle dolomite and its associated geochemical signature suggest that diagenesis, as a result of hydrothermal fluids, was neither pervasive in volume or extent within Ordovician formations of the Huron Domain. Instead it suggests migration of hydrothermal fluids within discrete low permeability dolomite horizons, were fed by the high permeability Cambrian sandstone during Paleozoic orogenesis.

CARBONATE SEDIMENTATION ON THE AMAZON SHELF: DEPOSITIONAL EVOLUTION AND NEW AGE CONSTRAINTS ON THE BURIAL OF A TROPICAL CARBONATE PLATFORM

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The continental shelf offshore the present-day Amazon River is known to have hosted a mixed carbonate-siliciclastic platform from the Late Paleocene to the Late Miocene. However, character of this platform has not been properly described and the nature and timing of the cessation of carbonate sedimentation remains controversial. In the present work, we investigate the Neogene succession of the Offshore Amazon basin, based on the stratigraphic analysis of a grid of 2D/3D seismic reflection data, correlated to revised micropaleontological data from exploration wells. This allows us to propose a new model for the transition from carbonate platform to siliciclastic sedimentation, which is shown to have varied through time across three different sectors of the shelf. In the Central and SE shelves, carbonate gave way to terrigenous sedimentation at some point between 9.1-7.78 Ma (probably around 8 Ma), whereas on the NW shelf, carbonate production persisted until 4.0–3.7 Ma. Longer-lasting carbonate sedimentation in the latter area can be explained by a lesser influx of siliciclastic sediments, favored by the development of a ca.150-km wide embayment in the Central shelf that directed terrigenous sediments sourced from the paleo-Amazon River directly to the continental slope and deep ocean. Carbonate environments persisted across the NW shelf until 5.5 Ma, keeping up with base level oscillations by aggradation. From 5.5–3.7 Ma (Early Pliocene), increasing sediment supply from the paleo-Amazon river reached the NW shelf resulting in the progressive burial of inner-shelf carbonates beneath a prograding siliciclastic wedge up to 85 m thick. Around 3.7 Ma, the Central shelf embayment was completely infilled and lager volumes of sediments supplied by the paleo-Amazon river were transported to the NW shelf, which finally promoted the burial of carbonate-dominated environments everywhere on the basin. Thereafter, carbonate environments were restricted to reef-like features recognized on seismic data as bodies locally interbedded with muddy Plio-Quaternary succession, generally 1-3.5 km wide, but up to 55 km in extension near the present and previous paleoshelf breaks, attesting to reduced terrigenous influx to the outer shelf during interglacial marine transgressions. The end of the carbonate platform was favoured by a combination of sea-level lowering and increasing terrigenous sediment supply after ca. 8 Ma that is also linked to the rapid growth of the Amazon deep-sea fan.

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SEISMIC-REFLECTION EVIDENCE FOR EOCENE TO PLEISTOCENE EVOLUTION OF THE SOUTHEASTERN FLORIDA PLATFORM AND VERTICAL FLUID-FLOW THROUGH THE PLATFORM

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Two- and three-dimensional seismic-reflection data acquired from the southeastern Florida Platform, and linked to well data, present an opportunity to increase the understanding of the platform's Eocene to Pleistocene seismic stratigraphy, vertical cross-formational fluid-flow history, and deep karst. The seismic data, in general, show two major stages of platform growth. Stage I was an early Eocene to early Miocene episode of carbonate shelf and margin aggradation with development of a steep shelf margin and associated prograding platform slope sediments; the very latest part of the stage (circa early Oligocene to early Miocene) is a mixed carbonate-siliciclastic shelf. The early Miocene to Pleistocene Stage II was first a period of major retrogradation in sediment accumulation followed by a seaward forestepping clinoformal progradation of a mixed carbonate-siliciclastic shelf dominated by carbonate accumulation. On the top of the Miami Terrace some areas are mantled by contourite drift, presumably composed of offbank transport of sediment sourced from the topsets of the progradational clinoforms.

Vertical fluid flow within the platform is evidenced by three major types of columniform seismic chimneys. The tops of type I chimneys are capped by a pockmark, either at the seafloor or buried. Type II chimneys are capped by concordant sagging seismic reflections, everywhere buried, and the upper seismic-reflection boundary of the top of the seismic sag is overlain by reflections that onlap or downlap against the uppermost sagging reflection. The type III chimney is everywhere buried. The upper reflection boundary of the type III chimney is a horizontal reflection that is the uppermost termination of a vertical stacking of sagging seismic reflections. The sagging reflections of both type II and III chimneys are the result of the karst collapse of a cave system at the base of the columniform karst system. An onshore 3D seismic survey shows that bead-string amplitude anomalies[1] within some chimneys provide evidence for caves to be associated with at least some of the chimneys. All chimneys are rooted in the mesogenetic burial zone, a zone where porosity forming processes related to the surface are ineffective and generation of porosity has been proposed to be minor[2]. The chimneys result from vertical upward cross-formational fluid flow and associated hypogenic karstification—alternatively providing evidence for substantial porosity production focused along the chimneys within the mesogenetic zone.

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SEDIMENTOLOGY, BIOSTRATIGRAPHY AND GEOCHEMISTRY OF UPPER TRIASSIC LIMESTONES FROM WESTERN CANADA

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Upper Triassic limestones formed in the Panthalassan Ocean received little attention compared to their Tethyan counterparts. Several occurrences have been recorded along the North American Cordillera, but their origin, age and significance are still a matter of debate.
This study focuses on Triassic carbonates of Wrangellia and Stikine terranes outcropping on Vancouver Island, British Columbia, and in the Whitehorse area, Yukon.
Through a multidisciplinary approach combining sedimentology, diagenesis, biostratigraphy and geochemistry we aim at furthering our understanding of these limestones occurrences by (1) constraining the age of these carbonate successions, improving regional stratigraphy and, if necessary, proposing new insights for the evolution of North American terranes, from their formation to their accretion to cratonal North America, (2) comparing microfacies and faunal associations with other localities in Tethys and Panthalassa in order to characterize the paleogeographic distribution of benthic taxa and better constrain the origin of Panthalassan allochthonous carbonate platforms, (3) proposing models for the deposition of these limestones and characterizing the paleoclimatic and paleolatitudinal conditions under which they were deposited.
We here present the preliminary results highlighted by microfacies and cathodoluminescence analyses along with the study of foraminiferal assemblages. The Carnian to Norian Quatsino Limestone, cropping out in northern Vancouver Island, shows inner ramp saline to evaporative environments with phases of subaerial exposure to deep water Halobiid- or Radiolaria-rich wackestones and packstones. The Upper Triassic carbonate occurrences in the Whitehorse area have been grouped into the Hancock member of the Aksala Formation. Among the visited localities, perireefal facies are dominant. Foraminifera distribution is strongly facies-related: duostominds and trochamminidae are characteristic of fore-reef sands, while involutinidae, endothyridae and miliolidae occur mostly in lagoonal and less frequently in thick-bedded limestones.

PLEISTOCENE TO HOLOCENE RETROGADATIONAL ONLAP DEPOSITS AND THE MAXIMUN FLOODING SURFACE IN THE WESTERN ARABIAN GULF, SAUDI ARABIA

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Well cemented beachrock to hardgrounds extend southward and eastward along the western margin of the Arabian Gulf in central eastern Saudi Arabia. The deposits can be found from Half-Moon Bay (N 26.023148°, E 50.032806°) southward to the Salwa beach (N 24.747859, E 50.761675) near the Saudi – Qatar boder[1]. The lateral (parallel to shoreline) extensions of these cemented deposits range from hundreds of meters to tens kilometers. These deposits extend eastward from the high-water line, perpendicular to shoreline, for over 300 meters (maximum distance measured in the reconnaissance survey) and appear to continue to deeper parts of the basin. The surficial cemented layer is 4 to 6 cm thick and is underlain by unconsolidated sand consisting of carbonate bioclasts and fine quartz sand. At twenty and thirty meters from the shoreline a second cemented layer 2 to 5 cm can be found 20 to 25 cm below the surficial cemented layer and is followed by a layer of unconsolidated sand. These deposits are similar to those documented on the western shorelines of Bahrain and Qatar and in the open Arabian Gulf (between Bahrain and Qatar) [2] at depths of up to 30 m.

This transgressive cemented surface is covered by blue-green (cyanobacteria) in the 20 to 30 m proximal to the high-water line, and transitions to a rhodolith covered zone than extends for 30 meters seaward, it is followed by a surface covered by brown algae, encrusting sponges, and bryozoans. Bivalves and barnacles encrust the upper surface of most the layers in first 100 meter from shoreline. The underside of the cemented sediments has an abundant microbial cover, and serpulid worm tubes. Sediment cover at the surface is thin and does not exceed 1 cm.

Although penetration of cores was limited to less than 1 meter it is clear that the upper surface is product of a maximum transgress (current hightsand) and is onlapping onto the adjacent sabkha deposits. The striking similarity to the deeper water cemented layers[2] suggest this is the maximum flooding surface of the Pleistocene to Holocene transgressive system tract. Detailed mapping, systematic coring and fluid sampling, and hydrodynamics measurements will be conducted take place during the coming summer months.

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INSIGHTS INTO THE PALEOECOLOGY OF CARBONATE STRATA CHARACTERIZED BY EXCEPTIONALLY LARGE BENTHIC FORAMINIFERA

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Biostromes or bioherms characterized by exceptionally large specimens of larger benthic foraminifers (LBF) are commonly found in Paleogene and Miocene warm-, shallow-water carbonates, often at the base of shoaling upward sequences or at the top of drowning sequences. Such features are typically low diversity and visually dominated by very large, flat, microspheric shells of one or two LBF species. Although sedimentary features may indicate winnowing or transport, in many cases even very large specimens exhibit limited breakage. Based upon insights from oceanographic research and the biology of living LBF, an hypothesis is proposed that can account for both the sedimentological and paleontological features. Sexual reproduction by gamete broadcasting is a basic reproductive mode found in all foraminiferal lineages. Resultant zygotes develop into tiny, resistant, easily dispersed propagules. Experimental studies have demonstrated that propagules of shallow-marine species can recruit from sediments collected from deep-ocean sites. The role of algal symbiosis in the biology of LBF, resulting in dependence upon light, is well documented. Paleoceanographically, LBF proliferated during times of reduced ocean circulation, when outer shelf, upper slope or promontory sites would have provided marginally suitable habitat beneath exceptionally clear, minimally stratified, nutrient-depleted waters. Minimal input of organic matter would have limited the abundances of heterotrophic taxa. At “twilight-zone” depths, when light penetration was sufficient at least intermittently to support some photosynthesis, tiny propagules of the one or two deepest-dwelling LBF species could have recruited. Resulting microspheric individuals (“B” forms) likely grew very slowly, sparsely nourished by feeding on bacteria and photosynthate from their algal symbionts, which were adapted to very low irradiance. Slow growth and long-term survival produced the large, flat shells. Asexual reproduction by the B forms would have been limited by their slow growth rates, limiting the abundances of smaller macrospheric “A” forms in the sediment record. Resulting carbonate accumulation rates would have been sufficiently slow that even rare disturbances by currents, storms or internal waves could have induced winnowing and produced sedimentary structures. Thus, tfossil evidence of such habitats would be biostromes or low-relief bioherms of low diversity assemblages characterized by abundant, exceptionally large, flat, microspheric LBF. While not proposed as the only scenario responsible for such features, this hypothesis may augment earlier interpretations.

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CONTROLS OF BIOTURBATION ON EARLY SILICA DIAGENESIS AND DISTRIBUTION IN DANIAN CHALK, DENMARK

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This study investigates the importance of bioturbation on grain reorganisation and early silica-rich fluids in a deeper water Danian chalk succession, onshore Denmark. Silica has an extensive impact on the reservoir properties in Danian chalk in the Danish North Sea, and the onshore succession provides valuable insight of factors controlling silica distribution and diagenesis.

The Dalbyover Quarry, onshore Denmark, exposes a shallowly buried (<500m) middle Danian silica rich, pelagic chalk unit with a chaotic distribution of silica concretions, much different from the older Maastrichtian chalk and the time equivalent shallower water Danian limestone in the Danish Basin. The common notion is that silica concretions in chalk are organised to form laterally extensive bands of silica-replaced *Thalassinoides* isp. networks. This pattern is not developed in the Danian chalk at Dalbyover where, silica rather occurs in thick, concretion-rich units without any evidence of *Thalassinoides* isp. networks. Rather, the silica concretions are associated with an upper tier meniscate trace, produced by irregular echinoids (*Echinocorys* sp.). Bioturbation resulted in early grain re-organisation of the chalk, creating subtle variations in porosity and permeability, and the disorganised nature of these traces is reflected in the very uneven and thus apparent chaotic distribution of silica concretions and associated silica cement.

Silica distribution and diagenesis in chalk has been debated for decades, and this study adds to the complexity of this subject focussing on the earliest, near sea-floor controls.

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Sedimentary characteristics and lithofacies paleogeography of the Cambrian in Upper Yangtze area, Southwest China

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The Cambrian strata are the potential reservoir for hydrocarbon exploration in the Sichuan Basin. Accurate understanding of sedimentary characteristics and lithofacies palaeogeographic features of the Sichuan Basin is the basis for further exploration and is also the key to the establishment of the early tectonic-sedimentary evolution history of the basin. Based on the comprehensive analysis of Cambrian field outcrops data in the periphery of Sichuan Basin, intra-basin drilling data and seismic data in combination with published research achievements, the Cambrian tectonic setting, sedimentary characteristics, sedimentary system and palaeogeographic features of Sichuan Basin were explored in this study. The result shows that there are three types of sedimentary systems in the Cambrian of Sichuan Basin: clastic sedimentary system, clastics-carbonate mixed sedimentary system and carbonate sedimentary system. Vertically, shows the evolutionary character of clastic sediments-carbonate sediments. The three sedimentary systems correspond to three "transgression-regression" cycles of the Cambrian. The transgression in the initial period of the Early Cambrian led to the formation of clastic sedimentary system in the lower member of Lower Cambrian. The transgression in the later period of the Early Cambrian led to the formation of clastics-carbonate mixed sedimentary system in the Middle-Lower Cambrian. The transgression in the initial period of the Late Cambrian led to the formation of carbonate sedimentary system in the upper Cambrian. With the end of the Late Sinian continental rifting ended, the Sichuan Basin entered a relatively stable stage of evolution of the craton basin, while the paleo-land developed in the north and southwest. The paleogeographic pattern in the Sichuan Basin shows characteristics of high in the west and north, low in the east and south. In the Qiongzhusi-Canglangpu period, the basin from west to east developed onshore-shelf sedimentary facies; In the Longwangmiao-Xixiangchi period, the basin from west to east developed flat-platform-slope sedimentary facies.

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Nd ISOTOPE COMPOSITION OF SEEP CARBONATES: A NEW APPROACH TO IDENTIFYING FLUID SOURCES AT ANCIENT COLD SEEPS

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Owing to a relatively short residence time of Nd in seawater, Nd isotope ratios are among the most widely used tools of reconstructing circulation patterns in modern and past oceans. The temporal and spatial changes in Nd isotopic composition of the fluid reflect interactions between water and various mineral phases, which differ in their εNd values depending on their depleted mantle- or old continental crust-derived character. For the same reason, Nd isotope signals may provide a sensitive proxy of fluid origin and migration pathways in subseafloor plumbing systems of methane seeps.

To test the sensitivity of the Nd isotope signals of seep carbonates to record past interactions between the seeping fluids and mafic, mantle-derived crustal components, we performed Nd, Sr and stable isotope analyses of the Lower Cretaceous (Barremian) seep carbonates found in Baška (Czech Carpathians). These seep deposits are directly underlain by a complex of mafic igneous rocks, which the methane-charged fluids must have passed through on their way to the seafloor. The Nd isotope ratios measured in the seep carbonates are significantly more radiogenic than the signals reconstructed for contemporaneous local seawater based on analyses of fish scales. This is in good agreement with Sr isotope data: the $^{87}Sr/^{86}Sr$ values are markedly lower that the signature of coeval seawater, and shifted towards ratios typical of the underlying basalts. Clear co-variance trends are observed among various geochemical systems, attesting increasing role of the mantle-derived fluid component with increasing contribution of methane-derived carbon. The results of the present approach reveal the potential of Nd isotopes to fingerprint exotic fluid end-members present in plumbing systems of both fossil and modern methane seeps. The technique can be of particular use in studies of seeps located in tectonically or magmatically active areas associated with plate margins, where ^{143}Nd-enriched, mafic rocks are commonly encountered in the basement or in the sediment column.

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DIAGENESIS AND COMPOSITIONAL PARTITIONING OF QUATERNARY COOL-WATER CARBONATE AEOLIANITES; SOUTHEASTERN AUSTRALIA

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ABSTRACT

Middle to Late Pleistocene stranded carbonate sea beaches, adjacent aeolian dunes, and Pleistocene aeolianites together with Holocene marginal marine calcareous sediments across southeastern Australia contain the longest record of such deposition in the modern world, stretching back to at least ~ 900 ky (MIS 23). The grains are/were derived from a suite of cool-water, heterozoan carbonate sediments produced on the adjacent offshore shelf. Most modern shelf carbonate sediments in the region today are aragonite-rich but the aragonite is presently slowly being dissolved on or just below the seafloor before the deposits enter the rock record. Beach-dune sediments are derived mainly from the shallow < 30 meters deep adjacent seafloor. They are mollusk-rich but with most bryozoan particles having been destroyed in the surf zone. The mollusks are dominantly aragonite. These nearshore sediments are swept onshore before any significant seafloor diagenesis can take place and so are compositionally different from the eventual aragonite-poor open-shelf sediments. Aragonite skeletal fragments in the dunes progressively dissolve with time under a semi-arid climate and produce diagenetic low-magnesium calcite meteoric cements, a well-known process common in tropical, aragonitic Pleistocene aeolianites. The loss of metastable minerals with time is matched by a progressive and well-understood change in stable isotopes. Such alteration in this environment, however, seems to take longer than in tropical carbonates, with lithification herein not beginning until ~ 200 ka and complete cementation being achieved in ~ 450 ky Thus, neither aeolianites nor offshore marine carbonates record the composition of the original sediment; aeolianites lack the important bryozoan constituents whereas neritic deposits lack the prolific mollusks. This partitioning, revealed for the first time, answers the conundrum as to why cool-water some neritic shelf and coastal sediments in the rock record are compositionally different.

SEDIMENTARY CHARACTERISTICS AND SEDIMENTARY MODEL OF INTERBEDED CARBONATE AND CLASTIC ROCKS IN THE PALEOGENE LACUSTRINE BASIN, WESTERN QAIDAM BASIN,CHINA

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This work focuses on the origin of the strata of Ganchaigou formation (E_3^2-N_1) in Western Qaidam basin of China. Based on field outcrop survey, core sample identification, geochemistry analysis data, seismic and well logging data, the sedimentary characteristics , the distribution , the sedimentary environment and the depositional models of the frequently interbeded carbonate and clastic deposits are studied in this area.

The clastic sediments in the studied area are shale and sandstone deposited in shallow lake and delta, and the carbonate are frequently interbedded with them. The lacustrine carbonate rocks include grain limestone, algal limestone, marls and mixed sediments, and they can be further subdivided into 11 kinds. Through the analysis of their sedimentary environment, it is determined that they are deposited in the environments such as flat, beach, algae mound (reef), lake bay and semi - deep lake. By analyzing the spatial and temporal distribution character of the different carbonate rocks and their microfacies, it is believed that their development is mainly controlled by the frequent change of lake level, the intrusion of terrigenous debris, the palaeoclimate , salinity, paleogeomorphology and palaeo-water depth. Based on this, the sedimentary models of the lacustrine carbonate rocks are established.

The study suggests that the basin is a typical salinized lake basin during the deposition of E_3^2-N_1 in the west part of the Qaidam Basin, with a condition of relative stable tectonic subsidence and a frequent change in lake level. The carbonate sediments are mainly developed during the trangression, clastic sediments are mainly developed during the regression, and the high-frequency lake level change resulted in the frequent interbeds of carbonate rocks and clastic rocks. During the dry season, the clastic beach dam or delta front are developed in the slope break area of the basin. Oolitic beach and algal limestone are developed on the slope break belt of the lake during the lake transgression, and marl or gray mudstone, gypsum and salt are developed in the deep sag of the basin.

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PALAEO-ENVIRONMENT INVESTIGATION AND GROWTH PROCESS RECONSTRUCTION OF THE LOWER ORDOVICIAN CARBONATE, CENTRAL TARIM BASIN, CHINA

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Palaeo-environments of the Lower Ordovician carbonate in central Tarim Basin, including palaeo-temperature, salinity, water depth, climate and etc., were investigated using an integrated carbon and oxygen isotope and elemental analyses on both drilling cores and outcrops. Based on these palaeo-environmental constrains, the carbonate growth processes of the study area were simulated using a stratigraphic forward modeling program, SEDSIM. Major input parameters include initial topography, tectonic subsidence, high frequency sea level fluctuation, waves, temperature and salinity, which were derived from environmental reconstruction, modern analogues, and published geological literatures.
During the Early Ordovician, palaeo-temperatures of the sea surface ranged mainly from 17 to 24 degree and sea water salinities generally presented an increase trend. Four carbonate depositional facies were modelled in the study area including restrict to open platform facies, platform margin facies, slope facies and deep open-marine facies. The margin facies carbonate grew relatively fast but underwent frequent erosions due to frequent exposure. The margin facies progradated seawards over the basin facies. Carbonate gravity flow deposits were developed mainly at the toe of slope facies and deep open-marine facies, with various magnitudes ranging from tens to hundreds km^2. The carbonate gravity flow was triggered by instabilities of sediments slope, which were mainly caused by sea level fall and tectonic subsidence. Sub-seismic lithological heterogeneities within the Lower Ordovician interval were delineated by the simulations.

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Inner shelf lowstand system tract in the restricted shelf depression

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In the carbonate sequence, specific geology conditions is required for forming the inner shelf lowstand system tract (ISLST). The type-II carbonate sequence are composed by transgressive system tract (TST), highstand system tract (HST)and shelf margin system tract(SMST) in the setting of carbonate ramp and open shelf. ISLST is not developed during the period when an open shelf transformed into the rimmed shelf because the topography is relatively flat. However, ISLST is widely developed in semi-closed bay gypsum salt lake and normally in evaporite platform. The type-Ⅱ carbonate sequence consists of TST, HST and ISLST when deep depression exists in the continental shelf in dry climate. ISLST is mainly constructed by evaporite facies. The shelf marginal system tract(SMST) develops on the lateral of shelf When ISLST deposits in the continental shelf. In the spatial view, ISLST(Lens shape) is wrapped by HST with a interdigitated contact in the lateral direction. The dolomite which distributes between ISLST and the next TST begins to deposit when the seawater injects into the gypsum salt lake diluting the brine. There is a typical case in the type-Ⅱ carbonate sequence of the Ordovician Majiagou Formation in Ordos Basin. TST is mainly composed by bioclastic mudstone, wackestone and a bit of grainstone, which is deposited in normal salinity epeiric sea. HST is developed penecontemporaneous mud-powder crystal dolostone which is formed in slightly salted seawater. ISLST is developed thick evaporates which is deposited in gypsum salt lake of shelf. Besides, there is another example in Sichuang basin during early Triassic from Jialingjiang to Leikoupo period. The rimmed shelf is gradually transformed into restricted platform, evaporation platform and semi-enclosed bay gypsum-salt lake.This evolution reflects the development process of ISLST in type-Ⅱ carbonate sequence.

Keyword: type-II carbonate sequence, Inner shelf lowstand system tract, Highstand system tract, dolomite

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Sedimentary microfacies characteristics and their impact on reservoirs of the Lower Cambrian Longwangmiao Formation in Central Sichuan Basin, China

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The Anyue Gasfield in Central Sichuan Basin (CSB), China became the largest single mono-block marine carbonate gasfield in China in 2012 after the Moxi-8 well produced 1.91×10^6 m^3/d (67.4 MCF/d) of gas [1,2]. The Lower Cambrian Longwangmiao Formation (LF) in CSB has a proven gas in place (GIP) over 440×10^9 m^3 (15.5 TCF) [3]. Previous studies interpreted that LF is dominated by shoal carbonate facies deposited in an inner ramp with uniform high quality reservoirs developed throughout CSB [4]. However, production data show that there is a strong heterogeneity in reservoir distribution with well yields varying from 0 to over 2×10^6 m^3/d [5] (70.6 MCF). To understand the reservoir heterogeneities an investigation on the sedimentary facies and reservoirs anisotropy was carried out in CSB, especially around the Gaoshiti-Moxi (GM) area. Based on description of 13 cored wells, and petrographic and micro-resistivity image log analysis, seven microfacies were defined in LF: including (1) main-shoal, (2) side-shoal, (3) roof-shoal, (4) dolomictite inter-shoal, (5) mud-dolomictite inter-shoal, (6) sand-dominated tidal flat and (7) mud-dominated tidal flat microfacies. The spatial and temporal distribution of the microfacies in the GM area is depicted. Vertical lithological variations and discontinuous surfaces indicate that there exists four depositional cycles in LF, probably relating to sea level fluctuations. Each cycle starts from (mud-) dolomictite inter-shoal and terminates with the main-shoal microfacies. Seismic interpretation shows superimposition of multiple main-shoal bodies with a cumulative thickness of dolarenite (the main reservoir lithology) in the Moxi area reaching 80-120 m, a width up to 7-8 km, a length exceeding 100 km, and an area of dolarenite around CSB reaching 8,700 km^2. The large-scale sheet-like main-shoal microfacies provides a base for the formation of high quality reservoirs. It has been found that the larger the main-shoal magnitude and the larger the cumulative thickness of dolarenite, the better the reservoir would be developed.

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Differential Diagenesis of Bioclastic Limestone Controlled by Sedimentary Facies

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Abstract: The components of bioclastic limestone in the Mishrif Formation are complex in the Hafaya Oilfield. The characteristics of biological shells are various and the diagenesis is complex. Based on the core, cast thin film, scanning electron microscope and physical properties, some diagenetic model of different microfacies was established. This study shows that the Mishrif Formation develops six microfacies including the psammitic of margin platform, the bioclast of margin platform, the pelletoid of margin platform, the rudistid of margin platform, the bioclast of open platform and the tidal flat. Microfacies control the type of biokettles and the degree of transformation. Diagenesis determines the trend of reservoir reformation. The platform margin has high energy, clean particles, and primary porosity is high. The open platform has shallower water and higher energy, but the mud content is higher. The energy of tidal flat microfacies is low, and the components are dominated by mud. Each microfacies results in different in the intensity and type of diagenesis due to the characteristics of the organism shell. The psammitic of margin platform in briny environment was dominated by rim cementation, and nemorphism, selective dissolution and syntaxial cementation occured in the limno-geotic. The bioclast of margin platform occured syntaxial cementation in briny environment and selective dissolution in limno-geotic. The pelletoid of margin platform has no dominant diagenesis, and there are many diagenesis types, howerver, the degree of transformation is low. The diagenetic of the rudistid of margin platform is various, which include rim cementation in briny environment, nemorphism, selective dissolution and non-selective dissolution in limno-geotic, compaction in shallow burial environments. Diagenesis of the bioclast of open platform is vertical zonation. In hypergene karst environments occured isometric granular cementation and syntaxial cementation and strong weather erosion occurs in the upper part of the bank. Diagenesis of tidal flat was mud crystallization and bioturbation in briny environment. Under limno-geotic, selective erosion and equiaxed granular cementation dominates, and coarse-grain cementation occurs mainly in the medium-deep buried environment. The analysis of the diagenetic sequence and dominant type of different microfacies has important significance for the classification of carbonate reservoirs, the identification of interlayers and the genesis analysis of the reservoir feature.

Keywords: Mishrif formation; bioclastic limestone; microfacies, diagenesis

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Characteristics and main controlling factors of the Upper Carboniferous paleokarst reservoirs in North Truva, the east margin of Pre-Caspian Basin, Kazakhstan

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The Upper Carboniferous carbonate sediments of North Tluva oilfield, located at the east margin of Pre-Caspian Basin of Kazakhstan, have been through a long geological history for more than 300 Ma from past to present. The top of the KT-I layer of North Truva oilfield, composed of Upper Carboniferous carbonates, was characterized as the evaporitic platform and the restricted platform facies in the background of shallow-water carbonate platform. The reservoir has experienced not only complex diagenetic events but also subsequent tectonic movements, resulting in the extensive development of paleokarst with various reserving space including pores, vugs and fractures. The combination pattern and the distribution of the reserving space are extremely intricate and forming different reservoir types. In this study, we focus on the detailed analysis of features among various reservoir types and its main controlling factors on paleokarst reservoir properties.

Therefore, based on the comprehensive analysis including cores and thin sections, the reservoir types were subdivided into six types which are pore-vug-fracture type reservoir, pore-vug type reservoir, fracture-pore type reservoir, pore type reservoir, fracture type reservoir and weakly connected pore-vug type reservoir. We conducted an integrated summarise comprising multiple reservoir characteristics of lithology, faices types, petrophysical properties, pore types and pore structure parameters. Then, the orders of controlling factors on the six reservoir types are determined by gray relative analysis and optimal selection of parameters which can represent the reservoir properties, pore-throat size, pore-throat distribution and pore-throat connectivity, respectively. Finally, the main controlling factors on the complex reservoirs were unravelled from the perspectives of sedimentology, diagenesis and tectonic aspects. This study can make contributions to the paleokarst reservoir characterization and the optimazation of production strategy for different types of reservoirs.

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Diagenesis and porosity evolution of the Upper Carboniferous paleokarst reservoirs in North Truva oilfield, the east margin of Pre-Caspian Basin, Kazakhstan

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The top of the KT-I layer of North Truva oilfield, composed of Upper Carboniferous carbonates, was featured as the evaporitic platform and the restricted platform facies in the background of shallow-water carbonate platform. The reservoir has undergone complex diagenetic processes and subsequent tectonic movements, resulting in the extensive development of paleokarst with various reserving space including pores, vugs and fractures. In this study, we focus on the diagenesis and porosity evolution of the paleokarst reservoirs for the purpose of more efficient and successful E&P in North Truva area.

Based on the comprehensive analysis including cores and thin sections, SEM, cathode luminescence, electron probe and stable isotopes, the diagenesis and porosity evolution processes of the KT-I layer has been unravelled with the following conclusions: (i) Six diagenesis types were recognized, among which dissolution, dolomitization and fracturing are constructive for reservoir properties enhancement, while compaction, cementation and filling are destructive, leading to the reduction of reserving space. The paleokarst reservoirs are the interaction effects of both constructive and destructive diagenesis. (ii) The paleokarst reservoirs primarily developed in dolomites and the diagenesis and porosity evolution can be summarized as followed: a) Marine environment. The muds and bioclasts from restricted carbonate platform are modified by reflux dolomitization and meteoric waters leaching due to short-term sea level falling. The intercrystal, intraparticle, moldic and solution-enlarged pores were formed and the porosity was increased. b) Shallow burial environment. Compaction and the filling of dolomites and calcites in pores led to the reduction of porosity. c) Epidiagenetic environment. The carbonates experienced strong weathering and karstification, forming a large number of vugs in the bottom of vadose zone and the top of phreatic zone, however, some pores were partially filled with vadose sandstone. The pore types included vug, cavern, channel, intraparticle, intercrystal, moldic pores and the overall porosity was enhanced. d) Middle-to-deep burial environment. Both the primary and secondary porosity were reduced due to the compaction, cementation by calcite, and the filling of dolomite and quartz in pores.

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Spatial and temporal distribution of shallow water carbonates and their respond to tectonic evolution in the Liyue Basin, South China Sea

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Shallow water carbonates, including carbonate platform and reefs, are widely distributed in the continental margins (Pearl River Mouth Basin, Phu Khanh Basin, Central Luconia Province and Liyue Basin) of South China Sea (SCS) and were developed during the Oligocene-Miocene. The carbonate platforms are significant for their great explorational potential and tectonic-sedimentary implications for the evolution of the rifted margin. The Liyue Basin (or Reed Bank Basin) lies in the southeast margin of the SCS region, adjoining the Palawan Island in the southeast, oceanic basin of SCS in the northwest. Based on careful interpretations of 2D multi-channel seismic profiles, in combination with regional geological, drilling data, we identified the seismic characteristics of carbonate platform and analyzed the possible relationship between sedimentary developments of the carbonate platform and tectonic activities, eustatic sea level changes and terrigenous sediment input. In the Liyue basin, a set of prominent reflectors in seismic profile is associated with widespread late Oligocene to middle Miocene (28-16Ma) carbonates. The carbonate platforms are featured with high-amplitude continuous reflections at the top and low-amplitude subparallel reflections within which is similar to the proven carbonates in the offshore Palawan. Reefs distribute sporadically and are characterized by high amplitude, mounded external shape and chaotic internal bedding. Carbonates remain abundant but mainly as isolated reefs that grew on top of tilted fault blocks, basement highs after the middle Miocene, and even to present in the Reed Bank. We identified the carbonate platforms and reefs which grown upon a region seismic unconformity (T4, ～28Ma). It is a post-rift unconformity responds to the onset of seafloor spreading in the southeast part of SCS and represents the transformation from graben or half-graben basin to down-warped basin. Most of the carbonates stopped growth beneath another region unconformity (Middle Miocene unconformity or MMU, ～16 Ma), which responds to the ceasing of the SW Sub-basin spreading or Sabah Orogeny. Synthetically the tectonic evolution mainly controls the development of carbonate platforms and reefs in the Liyue Basin. The Liyue Basin was in a relatively tectonic stable condition with decrease subsidence rate during the drifting stage (28-16Ma) of SCS. An everlasting shallow marine environment and low terrigenous sediments input contributed to the formation of carbonate platforms. A flexural tectonic subsidence due to the collision and foredeep developing between the Reed Bank and Palawan Island and the rapid sea level rising resulted in the regional carbonate platforms progressively drown and die. However, local reefs which grew on the forebulge have remained active up to the present with the northwest migration of forebulge.

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CONTROLS ON CARBONATE FACIES DISTRIBUTION IN AN ARID MANGROVE SYSTEM

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The southern shore of the Persian Gulf hosts numerous natural and planted mangrove forests. Somewhat surprisingly, to date, there has been very little quantitative description of these complex settings or of the primary depositional facies hosted within them. In particular, no attempt has been made to characterise the distribution of sedimentary facies, and their component biota, within the context of the sub-environment of deposition. This paucity of data severely compromises palaeoenvironmental interpretations.

In this study we present the first quantative data set documenting sedimentary facies characteristics and distribution in the context of a range of environmental parameters at the time of deposition. This was achieved through an extensive long-term field sampling campaign conducted in order to fully characterise the sediments associated within the wide range of depositional sub-environments occurring in mangal systems. Historical satellite imagery, literature reviews and ground-based reconnaissance were employed to identify a pristine natural mangal complex within the lagoon system to the west of Yas Island. A 630 m long transect was oriented so as to sample the full range of mangal sub-environments. The transect was topographically surveyed and sampling stations were established in order to record the range of environmental conditions, both in terms of energy and in relation to the degree of tidal exposure. A range of environmental parameters were monitored, these included, temperature, salinity, current velocity and dissolved oxygen. The surface sediment at each sample station was fully characterised in terms of grain size, sediment composition and the identification of biota. Repeat sampling was employed in order to establish any changes in sediment characteristics related to seasonal influences.

This study establishes a quantifiable relationship between mangal sub-environments and sedimentary facies. This relationship can be employed to develop a predictive facies model for the interpretation of the palaeoenvironmental setting of facies within ancient sediments inferred to have been deposited within similar coastal mangal systems.

A REVIEW ON EYEBALL-SHAPED LIMESTONES OF THE MIDDLE PERMIAN IN SOUTHCHINA

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The Middle Permian in SouthChina is a special carbonate formation unit with several typical characteristics. Widely developed eyeball-shape limestones is one of the typical features. The eyeball-shaped limestone is a kind of carbonate rock with special structure because its shape resembles an eyeball. And there are some scholars who call it limestone-marl alternations, another scholars call it calcirudite. The kind of limestone developed widely in the lower part of the Qixia Formation and the middle and lower parts of the Maokou Formation of the Permian in SouthChina which consists of an eyeball and an eyelid. At present, there is not much controversy about the sedimentary characteristics of eyeball-shaped limestones. The macro- and micro-characteristics, geochemical characteristics, and trace fossils of the two parts exhibit obvious differences.However, there is a big controversy on the origin of the Middle Permian eyeball-shaped limestones in SouthChina. There are three main viewpoints about its origin. The first viewpoint is that the limestone was formed by the differential compaction, but this viewpoint can't explain the fact that there was no obvious compaction in the eyeball part. The second viewpoint is that it was formed combinatively by sedimentation and diagenesis under the influence of upwelling. This view emphasizes that the difference in productivity leaded to different types of rock, while the cause of the difference in productivity is not very clear. The third viewpoint is that the eyeball part is a calcirudite which was transported and deposited on the slope. And there are different types of calcirudite. The former two viewpoints are considered that eyeball-shape limestones was the product of shallow carbonate platform environment, while the latter viewpoint thinks that it was the products of deep water environment. The above origins have provided inspirations for understanding of the formation of the Middle Permian eyeball-shape limestones in SouthChina, but they can't completely explain the cause. In this research, it is considered that the sedimentation is crucial to the formation the eyeball and eyelid of the eyeball-shaped limestone. Because of the universality and particularity of the eyeball-shaped limstones, the study should be strengthened.
From the point of view of carbonate sedimentology, a correct understanding the formation mechanism of the Middle Permian eyeball-shaped limestones in SouthChina has important theoretical significance to understanding the palaeogeography and paleooceanography of the Permian in SouthChina, and it has a realistic significance to exploration of the formation process of marine hydrocarbon source rocks.

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GROWTH DYNAMICS OF A CARBONIFEROUS CARBONATE PLATFORM: RECORD FROM TIANLIN COUNTY, GUANGXI REGION (SOUTHERN CHINA)

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Currently, the Carboniferous is considered as a period of global recession in metazoan reef building subsequent to the Late Devonian extinction event. Shallow-water coral bioconstructions were overall small and scarce, and corals played a minor role in their construction (1). However, in Southern China, a large Pennsylvanian coral reef has been reported in Guizhou Province (2). In addition, Carboniferous coral reefs have recently been discovered in two localities in Guangxi, yet not studied in detail. To understand the occurrence of these coral reefs and constrain the factors controlling their growth, three sections located around Langping (Guangxi) have been measured and selected samples analyzed using petrography and geochemistry. One section includes three small reefs (6 to 16 m high) and another includes a large reef (50 m high), both built by branching colonial corals and dated as Visean. The third section consists of a long sequence of limestones ranging in age from Late Devonian to Early Permian. The vertical distribution of Microfacies Types allows to constrain paleoenvironments and water depths. For the reef-bearing sections, the paleobathymetry can be constrained using texture and fossil assemblages (in particular the distribution of calcareous algae) whereas for the main criteria for interpretation of the long section is the occurrence of calciturbidites. Three distinct depositional environments were identified. The small reefs were deposited in shallow water, close to the fair-weather wave base. The large coral reef was deposited in a deeper environment, between the fair-weather wave base and the storm wave base. Calciturbidites, interbedded with a low rate of shaly autochthonous sediments, are interpreted as deposited on the slope. The field data and the spatial distribution of the three sections led to interpret the depositional setting as a shallow-water platform with a low-angle slope. Similar depositional facies and platform margin morphology were described at the Béchar basin in Algeria (3, 4). However, buildups in the Béchar basin exhibit sponges and bryozoans, whereas the Tianlin examples are constructed by corals. These differences in bioconstructions indicate that the geometry of the platform margin is not the exclusive factor which can explain the exceptional coral reef occurrence in Southern China. Ongoing investigations including carbon and oxygen stable isotope geochemistry will provide additional data allowing to constrain further controlling factors such as the role of nutrient and oceanic circulation.

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CONTROLS ON CARBONATE PLATFORM GROWTH WITHIN THE LOWER CARBONIFEROUS OF THE PENNINE BASIN

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This project assesses the interplay of depositional, diagenetic, and structural processes on carbonate platform evolution within an extensional basin. Syn-rift carbonate platforms often evolve from ramp to rimmed shelves, but the interplay of fault propagation, bioconstruction, volcanism and clastic interaction remain poorly described. Two late Visean (333 to 326.4 Ma) carbonate platforms are compared: the Derbyshire Platform (DP), situated in the Pennine Basin of northern England, and the North Wales Platform (NWP), located 130 km westwards. Both platforms formed during the transition from a greenhouse to an icehouse climate, on the footwalls of normal and oblique-slip faults. The DP was remotely land-attached and experienced syn-depositional volcanism, whereas the NWP was land-attached with significant siliciclastic input and was not influenced by volcanism. This research demonstrates the multivariate control on the divergent evolution of these two contemporaneous carbonate platforms, formed within the same basin, using field-based sedimentology and petrography.

In the Asbian the windward margins of both platforms were dominated by bryozoan and coral carbonate mud-mounds with well-defined core and flank facies. Skeletal grainstone shoals infilled intra-mound topography and also formed decimetre scale sheet-like coated grain dominated sandbars. On the platform top, a mosaic of upward-shallowing crinoidal packstone-grainstones, and brachiopod and coral floatstone-rudstones are capped by exposure surfaces. These surfaces comprise thick, clay rich, and nodular cemented palaeosols on the NWP, and pot-holed limestone overlain by volcanic-ash rich clays on the DP. A numerical method has been applied to demonstrate that these episodic exposures cannot be confidently predicted on the basis of stacking patterns, implying that they are likely to have been influenced by local tectonism, in addition to previous interpretations of eustatic sea level fall.

A platform-wide emergent surface marks the top of the Asbian on the DP. Contemporaneous marine siliciclastic deposition inundated the NWP, whilst the DP was protected from this influx by an intervening basin. Progradation of turbidite and fluvio-deltaic systems from the north and south in the Brigantian increased water column turbidity. Consequently, facies became thinner and darker with abundant chert and a faunal assemblage dominated by *Gigantoproductus* brachiopods. As volcanism waned on the Derbyshire Platform, mounds became common on the platform top, rather than the platform margin, growing preferentially along faults and on the margin of intra-shelf basins. Cessation of carbonate platform growth was tied to a decrease in carbonate productivity related to siliciclastic poisoning or relative sea level rise. This research characterizes carbonate platform growth and stacking to changes in relative sea level and climate to develop predictive rules for carbonate platform facies distribution in age-equivalent settings.

SEDIMENTOLOGY AND STRATIGRAPHY OF THE PHOSPHORIA ROCK COMPLEX IN THE BIGHORN BASIN, WYOMING, USA

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The Phosphoria Rock Complex accumulated in an epicontinental sea along western Pangea during the middle Permian (Kungerian to Wordian)[1]. The group includes phosphorites, organic-rich siltstones, cherty carbonates and siliciclastics, open-marine to restricted carbonates, red beds, and evaporites[1]. These diverse deposits accumulated at a time of warming global climate following the end of the Late Paleozoic Ice Age and the aridification of western tropical Pangea[2]. This study utilizes field and core study combined with petrographic and geochemical analyses to investigate the Phosphoria Rock Complex within the Bighorn Basin of northern Wyoming. The objectives of this study are to 1) investigate the climatic and oceanographic controls on deposition and eogenesis, 2) provide an overview of the temporal evolution through the Phosphoria Rock Complex succession, and 3) relate the deposition and temporal evolution to global and regional climate. The group contains three retrogradationally stacked sequences that led to the superposition of alternating terrestrial and marine deposits, making it an ideal location to address the relation of climate and oceanography. The youngest member, the Ervay, records a transition from open-marine calcitic heterozoan carbonates to shallower-water molluscan-peloidal carbonates to peritidal carbonates with coated grains and significant microbial influence. Landward lay supratidal to terrestrial aeolian, iron-rich silt and evaporitic salinas. Older carbonate members recording earlier marine incursions are thinner but record wider expanses of peritidal deposition with limited calcitic heterozoan deposits. Facies distributions are interpreted to be the result of variable water temperature, salinity, nutrient content, and carbonate saturation state as produced by the interaction of cool, mesotrophic waters in the Phosphoria Sea with the hot and arid western Pangean desert. Eogenetic alteration records these oceanographic and climatic controls. The arid climate of western Pangea produced hypersaline nearshore waters that led to contemporaneous dolomitization and synsedimentary cementation in sabkha deposits. Offshore, cooler, mesotrophic conditions lead to widespread authigenic glauconite and phosphate precipitation in the intraskeletal porosity of calcitic carbonates. Between these two extremes, elevated salinity, decreased nutrient concentrations, and warm water lead to a dominantly aragonitic biota with marine carbonate cementation but little contemporaneous dolomitization or authigenic mineralization. Stacking patterns of the three sequences were influenced by eustatic and tectonic controls, creating a tortuous coastline and paleobathymetric highs. The Phosphoria Rock Complex within the Bighorn Basin provides a unique example of the interaction of the extreme late Paleozoic climate with regional oceanographic conditions and the influence on the resulting sedimentary deposits.

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EARLY TO LATE DIAGENETIC AND FAULT OVERPRINT OF MESOZOIC DOLOSTONES

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Dolomitic rock (dolostone), which is very common in the geological rock record, is extensively studied, but up to now it is strongly debated what kind of information can be gathered from diagenetic dolomites. This study aims at exploring the value of early diagenetic dolostones representing complex archives of depositional and diagenetic features. Combining field and laboratory techniques (petrography, isotope geochemistry), we exemplarily disentangle the complex diagenetic succession and subsequent tectonic overprint of Mesozoic carbonates along the Neogene Carboneras Fault Zone in SE Spain to better understand post-depositional alteration and anchimetamorphic pathways. A suite of rock samples collected across the transform fault mirrors increasing diagenetic and tectonic overprint stages. Transmitted light- and cathodoluminescence microscopy reveal several paragenetic phases of early to late stage dolomite. These include the i) patchy luminescent, early diagenetic dolmicrite host rock, ii) burial blocky saddle dolomites, iii) dolomitic fault gouge, and iv) late diagenetic cements likely related to Neogene transform fault activity. Blocky phreatic and pendant vadose cements formed in the latest stages of exhumation. A shift to ^{13}C-depleted carbon isotope values for both rock clasts and fault gouge is observed with increasing tectonic overprint. Patterns in oxygen isotope data disagree with hypogene hot, fault-related fluids, but instead point to a predominantly cool marine/meteoric fluid source, and hence a shallow burial position of the submerged transform fault. ^{87}Sr/^{86}Sr values indicate a Neogene seawater composition in heavily overprinted fault gouge. Preliminary results show a complex relation between textural and geochemical overprinting. Following deposition and initial lithification, the diagenetic history commences with early dolomitization of carbonates precipitated in shallow water. Evidence for early stage dolomitization comes from well preserved sedimentary textures, such as ripples and fining-upward features. During burial, the dolostones experienced a series of complex dissolution-reprecipitation steps leading to the formation of "zebra" fabrics, i.e. bedding-parallel, elongated voids filled with what are now saddle dolomites. Blocky saddle dolomite and the presence of stylolites indicate that zebra dolomite formation was caused by stress and later precipitation induced by hydrothermal fluids. In addition to textural preservation, a striking absence of a pervasive geochemical overprint is observed, supporting a conservative behavior of early diagenetic dolomites. Neogene seawater which migrated along the transform fault is a likely candidate for initiation of the observed geochemical shifts in the highly permeable fault.

FACIES CHARACTERIZATION AND DEPOSITIONAL MODEL OF MIOCENE HETEROZOAN CARBONATES (PIETRA DI FINALE FORMATION, LIGURIA, N ITALY)

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During the Miocene the Mediterranean region was characterized by a variety of carbonate successions ranging from heterozoan to photozoan association pure carbonates to mixed carbonate-siliciclastic depositional systems developed at palaeolatitudes of 30-40°N. This study focuses on the stratigraphy, sedimentology and diagenesis of a Lower-Middle Miocene mixed carbonate-siliciclastic succession (Pietra di Finale Fm.) accumulated in the area of Finale Ligure (NW Italy). The 150 m thick Pietra di Finale succession unconformably overlies glaucony-bearing sandstones, siltstones and marls containing planktonic foraminifera (Oligocene-Lower Miocene) or deformed Mesozoic and Paleozoic units affected by the Alpine orogenesis. The transgression of the Pietra di Finale is marked by basal conglomerates and sandstones overlain by bioturbated bioclastic sandstones.

The Pietra di Finale Formation consists of three superimposed lithofacies associations deposited in a marine embayment about 35 km^2 wide limited by uplifted Alpine rock substrate.

Three lithofacies can be identified. The basal Pietra di Finale 1 consists of mixed skeletal carbonate and detrital siliciclastic grains, which gradually decrease upsection and become sparse to rare in the overlying lithofacies associations. The Pietra di Finale 2 consists of skeletal packstone-wackestone with barnacles, bryozoans, echinoderms and bivalves, enriched in benthic and planktonic foraminifers indicative of transition to offshore depositional environment. The Pietra di Finale 3 is the thickest lithofacies association (120 m) and consists of skeletal packstone/grainstone to rudstone, frequently cross-bedded with skeletal fragments and common scleractinian corals and stylasterine hydrozoans associated with terrigenous clasts deriving from the deformed Mesozoic and Paleozoic units. This facies accumulated in the shoreface to offshore transition zone of a restricted marine gulf where bottom currents were accelerated, promoting the formation of seaward prograding metre- to decametre-scale sandwaves.

The detailed sedimentological and stratigraphic study, coupled with geological mapping, provided a 3D reconstruction of the geometry of the Finale Ligure gulf, controlling the facies distribution and thickness changes of the Pietra di Finale succession.

The Pietra di Finale carbonate factory was initially dominated by typical heterozoan biota (barnacles, echinoderms, bryozoans, bivalves), but during the Middle Miocene (Serravallian) it became enriched in corals and stylasterine hydrozoans. The latter are heterotrophic organisms that live in a wide range of depths, also within the aphotic zone. Thus, compared to other Miocene carbonate systems, the Pietra di Finale lacks phototrophic biota, in particular coralline red algae. It is suggested that the palaeoenvironmental conditions, such as currents, nutrient content and water turbidity in the Finale Ligure gulf, controlled the composition of the skeletal carbonate producers dominated by heterotrophic biota.

CARBON FIXED AND DEPOSITED IN LAKE SEDIMENTS BY THE SUBMERGED VASCULAR PLANTS AND CHAROPHYTES

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In aquatic environment submerged macrophytes are a key contributor to the circulation of elements, particularly of carbon, which is transformed from assimilated CO_2 into the plant biomass. Organic carbon can subsequently be deposited in the bottom sediment and it can potentially become largely unavailable in a time perspective longer than the annual cycle. The effectiveness of submerged vegetation in this regard, however, is different and depends on the group of macrophytes forming submerged communities. Significant differences in the importance for the carbon binding occur between vascular plants and charophytes (stoneworts). Charophytes are able to store carbon in two ways: by building biomass and by producing abundant (up to 80% of dry biomass) encrustations made of calcium carbonate, significantly more abundant compared to vascular plants. After the end of the growing season, both forms of carbon are deposited in sediments. In our project we aim to compare the amount of carbon fixed and then deposited in the sediments of lakes by the communities of submerged vascular plants and of charophytes. We aim to verify the hypothesis that charophytes, thanks to their specific properties, are capable of permanently bind and accumulate in sediments significant amounts of carbon, and their effectiveness in this respect is higher compared to submerged vascular plants. The study is conducted in 12 lakes located in western and eastern Poland that allows to take into account the effect of climatic differences and growing season of different length, that result from the different proportions between oceanic and continental influences in both regions. The biomass of both macrophyte groups is studied in lakes with littoral zone dominated either by charophytes or submerged vascular plants. Lake waters are analysed for pH, conductivity, alkalinity and the concentration of calcium and dissolved phosphorus and nitrogen, and chlorophyll-a to determine the effect of habitat conditions on carbon accumulation. The content of organic and carbonate carbon is analysed in plants and in vertical profiles of littoral sediments. The rate of sedimentation and deposition of both carbon forms in the sediments is determined. These data are confronted with the amount of carbon fixed annually through photosynthesis and calcite production and allow us to assess the proportion of recycled carbon to that permanently stored in sediments. Macrofossil analyses of sediment samples are used to determine, which plant communities (charophytes or vascular macrophytes) dominated the study sites in the past. The analyses of settling seston and concentration of phytoplankton are carried out to evaluate the contribution of phytoplankton to the fixation and deposition of both carbon forms.

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TRIASSIC LIMESTONES FROM THE PANTHALASSA OCEAN: NEW INSIGHTS ON HOKKAIDO ISLAND AND FAR EAST RUSSIA

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In comparison with the well-known Tethyan domain, and despite of the amount of research already carried out, Upper Triassic limestones from the Panthalassa Ocean remain poorly known. Two of the best areas to study these carbonates are Hokkaido Island (north end of Japan) and Sikhote-Alin mountain range (Primorsky and Khabarovsk Kraïs, Far East Russia) where many different Triassic limestones outcrops are exposed. These two areas are part of the South—North continuity of Jurassic to Paleogene accretionary complexes, going from the Philippines to Sakhalin Island (Far East Russia). In Hokkaido Island, two major tectonic units have been accurately explored and extensively sampled: the Jurassic Oshima Belt (west Hokkaido), and the Cretaceous Sorachi-Yezo Belt (central Hokkaido). The same fieldwork approach has been applied to the Cretaceous Taukha Terrane (Sikhote-Alin, Far East Russia). Through a complete sedimentological, diagenetic and biostratigraphic study, these limestones allow us (1) to compare the depostional settings and biotic assemblages from Tethyan and Panthalassic domains, (2) to better understand the geodynamic evolution of central part of Hokkaido Island and (3) to propose a model of evolution of these carbonates from their deposit to their accretion.

The initial microfacies analysis indicates that very similar facies characterise all the sampled blocks occuring on different tectonic units either in Hokkaido or in Sikhote-Alin. Furthermore, the lithology and the aspect of these limestones, as well as their biological composition, are closely related to the Triassic limestones observed in the southern part of Japan (i.e., Sambosan Accretionary Complex; Chablais *et al*., 2010[1]; Peybernes *et al*., 2016[2]). The microfacies are dominated by peloidal packstones-grainstones with aboundant microbial clasts and microproblematica. Oolitic grainstones and Megalodont patches are also very common.

The diagenetic analysis, made on the best preserved limestone blocks, shows major events, from early marine diagenesis to accretion-related changes. These limestones underwent a continuous evolution, with no emersion, from an early cementation to a very low compaction imprint which is consistent for mid-oceanic limestones. The carbonates also record an event related to a partial dismantling of the system, marked by the presence of early breccias after shallow burial diagenesis.

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WHAT HAPPENS WHEN A CARBONATE PLATFORM FLOODS? CENOTES, SWAMPS AND SEAGRASS ON THE YUCATÁN PLATFORM

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The dynamic relationships between marine and freshwater systems on carbonate platforms and their responses to sea level rise remain poorly understood. This is surprising given the frequency of platform exposure and flooding events seen in the stratigraphic record. The Sian Ka'an Wetlands (SKW) of the eastern Yucatán Peninsula provide a spectacular and sedimentologically unstudied example of a carbonate platform top sedimentary system. The SKW comprise a 4,000 km^2 low-relief complex of groundwater-fed freshwater marsh, lake and brackish coastal lagoons, which record a history of Quaternary sea level fall and subsequent rise now resulting in the progressive encroachment of freshwater and shallow marine environments onto the platform top.

We recognise five stages in the formation, development and ongoing southwestward migration of the SKW, closely linked with the karstic dissolution history of the platform during regression and its aquifer hydrology during later transgression. This allows us to interpret the sedimentary history of the SKW in parallel with the evolution of the MesoAmerican reef system offshore.

Quaternary subaerial exposure resulted in pervasive deep karstification of the platform, leading to the formation of sinkholes (cenotes) and regional cave systems which provide fluid transport pathways extending for tens of kilometres within the pediment. These cave systems have now been partially flooded by rising groundwater during late Quaternary and Holocene transgression.

In low-lying areas behind the reef and beach, base level rise has seen emergence of groundwater onto the platform top and the formation of extensive marsh, where biological processes and seasonal exposure define a range of palustrine environments across a vast freshwater carbonate factory which is dynamically linked to the marine carbonate factory offshore.

Rising aquifer levels have caused the marsh areas to flood and migrate landwards. At the coast, breaches of the beach barrier have led to the formation of brackish lagoons. Further sea level rise has seen progressive destruction of the barrier and partial marine flooding of palustrine sloughs and lagoons to form seagrass embayments, in which groundwater is still emergent at the seafloor.

The environments and transgressive histories of the Sian Ka'an Wetlands and the Florida Everglades are closely comparable, while the palustrine marshes on Andros Island in the Bahamas may in turn represent vestigial fragments of a once larger freshwater system.

The preservation potential of platform top carbonates is likely to be low in today's icehouse interval where eustatic change is rapid in relation to subsidence. By contrast, the accumulation of thick palustrine successions during greenhouse intervals in the Mesozoic and Cenozoic of Iberia, France and Switzerland reflected the tectonic creation of accommodation space in extensional and intramontane depocentres developed on carbonate pediments of Jurassic and Cretaceous age.

SEQUENCE STRATIGRAPHY AND SEDIMENTARY FACIES OF FEIXIANGUAN FORMATION IN THE KAIJIANG–LIANGPING AREA OF SICHUAN BASIN, CHINA

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The Feixianguan formation (Fm) in the Kaijiang–Liangping basin has been the focus of extensive research on multiple aspects. In this paper, we focus on investigating the sequence stratigraphy and sedimentary facies of the Kaijiang-Liangping area built upon the results of previous research. A combination of the drilling data of the target area, field survey, core observation, laboratory analysis and tests, and seismic data interpretation was considered to fully characterize the basin.

According to the characteristics of sequence interfaces, the Feixianguan Fm of the Kaijiang-Liangping area can be divided into three third-order sequences: SQ1, SQ2, and SQ3. SQ1 and SQ2 correspond to the member 1 and the member 2, respectively, and SQ3 corresponds to the member 3 and the member 4. In the platform, both TST and HST are developed in the SQ1, SQ2, and SQ3 sequences. However, in the basin, TST and HST are developed in the SQ1 and SQ3 sequences, and LST, TST, and HST are developed in the SQ2 sequence.

The sedimentary facies of the Feixianguan Fm in the Kaijiang–Liangping area can be divided into open platform facies and evaporate plateform facies. The open platform includes three subfacies: platform bank, interbank, and platform basin. During the first and second periods of the Feixianguan Fm, the study area was mainly platform bank, interbank, and platform basin subfacies. In the third period, the basin was filled and leveled, and the major facies were platform bank and interbank subfacies. In the fourth period, the entire area evolved into evaporate platform facies.

On the basis of the seismic reflection characteristics and the sedimentary facies, two types of development models for oolitic beaches at the west margin of the Kaijiang–Liangping basin are proposed. The aggradation model shows development mainly in the Longgang area. Oolitic beaches are developed in the SQ1 and SQ2 sequences and in TST of the SQ3 sequence of the basin margin, which are favorable exploration areas. The progradation model shows development in the Jiulongshan and Longhui areas with oolitic reservoirs occurring mainly in HST of SQ1 and TST of SQ3. With the progradation to the inner basin, the basin margin advanced gradually, the oolitic banks migrated into the basin along with the progradation.

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CHARACTERIZATION AND GENESIS OF FAULT-KARST IN TNE MIDDLE PERMIAN, SICHUAN BASIN

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Abstract: With the further exploration and development of the paleokarst in the Middle Permian , Sichuan Basin , fault-karst has attracted more and more attention. Based on the core, thin sections, logging, drilling and seismic data, we have found three fault- karst, fracture-pore, fracture and pore-fracture. We analyzed the genesis and accumulation of fault-karst. The type of fault- karst was controlled by the scale and stage of fracture and karst reservoir .Under the tensile fracture of Hercynian period and the atmospheric corrosion, there came fracture-pore karst. Fractures were formed by the combination of atmospheric corrosion, hydrothermal erosion, and organic acid dissolution in the deep faults formed in Caledonian and Hercynian phases. But pore-fracture was formed by the combination of atmospheric corrosion and organic acid dissolution in the associated faults formed in Caledonian and Hercynian phases. The fault-controlled karst provides a good reservoir space for oil and gas as a composite reservoir.

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The dolomitization of the lower Cambrian Longwangmiao Formation at the eastern of Sichuan Basin

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Dolomite is very important, as the gas reservoir of Paleozoic in Sichuan Basin. The research about the dolomitization is significant to get the origin and distribution of this kind of reservoir. Based on the detailed description and sampling of the dolomite at Bandenggou outcrop of Longwangmiao formation in eastern Sichuan Basin, by using the results of X-ray diffraction, trace elements, rare earth elements and carbon and oxygen isotope analysis, the type and origin of that dolomite has been studied systematically. The analysis results show that the dolomitization process of the study area could be divided to two types. The first is the mimetic dolomite with low order degree, which was deposited in the evaporated environment and influenced by the terrigenous clastic minerals, as the result of Sabkha dolomitization and seepage reflux dolomitization. In this kind of dolomite, MgO and CaO were positively correlated, Mg/Ca value was generally high, with low content of Sr, high content of Fe, Mn and REE+Y, also with δEu &δCe negative anomalies. The characteristics of $\delta^{13}C$ &$\delta^{18}O$ were similar to that of the limestone formed in homochronous seawater. The other one is the fine-crystal dolomite, formed by the shallow burial dolomitization, with negatively correlated MgO and CaO content, low Mg/Ca, high content of Sr, Fe and Mn, low content of REE+Y, and same characteristics of theδEu &δCe and$\delta^{13}C$ as that of the limestone formed in homochronous seawater. However, the value of$\delta^{18}O$ was a little lower than that of the homochronous seawater. According to the petrographic characteristics of this dolomite, we believe that the rock has undergone the shallow burial dolomitization, after the syndepositional dolomitization (including Sabkha effect and reflux infiltration), which lead to the division of the values of carbon and oxygen isotopes.

Key words: Dolomite, Carbon and oxygen isotopes, Sichuan Basin, Longwangmiao Formation

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DIAGENESIS OF THE PERLA LIMESTONE, GULF OF VENEZUELA BASIN: IMPLICATIONS ON THE PETROPHYSICAL PROPERTIES

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The Perla limestone is an Oligo-Miocene carbonate reservoir located in the Gulf of Venezuela Basin. This reservoir is considered the largest gas field in Latin America, with approximately 17 trillion cubic feet (TSCF) of gas in place[1]. The Perla limestone is a ramp carbonate composed of branching red algae, rhodoliths, and large benthic foraminifera (LBF) as the main constituents, with a minor contribution of corals, barnacles, green algae, bryozoans and planktonic foraminifera[2]. From a detailed petrographic, mineralogical and chemical analysis performed on well cores, several diagenetic processes that created and destroyed porosity and permeability were identified and grouped chronologically, following the evolution of the diagenetic settings and fluids. Significant porosity enhancement was produced by the early dissolution of metastable constituents (HMC and aragonitic grains), which generated micro-biomoldic and biomoldic porosity along the entire carbonate column. Additionally, mesogenetic dissolution linked to the ascent and mixing of CO_2-rich fluids, with complex circulation patterns, generated a significant increase of the reservoir quality in determined zones of the carbonate sequence. On the other hand, blocky-calcite cementation in the near surface and shallow burial environment, and chemical compaction in the burial environment were the main diagenetic events that destroyed porosity. Permeability was enhanced by grain breakages produced from mechanical compaction in the shallow burial realm: this process established connections between interparticle and intraparticle porosity previously isolated. Comparing the petrophysical properties of the Oligocene and Miocene sequences of the Perla reservoir, the Miocene units are marked in general by better petrophysical properties, mainly due to a combination of higher primary porosity and stronger burial dissolution.

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Evidences on Effective Carbonate Source Rocks of Low Organic Matter Abundance and Its Lower Limit of TOC in Tabei Areas of Tarim Basin, China

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Carbonate rocks exhibiting high thermal evolution and low organic matter abundance (TOC＜0.5%) are widely distributed in Tabei areas of Tarim basin, China. At present, TOC＞0.5% is the standard of high abundance source rock in resource evaluation, most of which are carbonate rocks. But the distribution and scale of the high abundance source rocks with TOC＞0.5% in the research area is limited, which is unreasonable for the discovered hydrocarbon scale. The test results of carbonate rocks in research area show that as the depth or thermal evolution degree increase， TOC of source rocks decreases; And hydrocarbon generation potential and residual amount increase and then decrease as the depth increase; Besides, the results of thermal simulation experiment，which indicate the source rocks of low organic matter abundance can generate and expulse a great number of hydrocarbon. All of these indicate that the low abundance of carbonate rocks can be effective source rocks. Combining study results and exploration practice, we hold the view that: 1) The carbonate source rocks with high maturity and low organic matter abundance can be effective resource rocks in Tabei areas of Tarim basin, China. So does part of which with medium maturity; 2) The lower limit of TOC in effective carbonate source rock with low maturity, medium maturity and high-over maturity stages respectively are TOC≥1.4%, TOC =0.1%～1.44% and TOC＜0.1%. The study reminds us that some carbonate source rocks with high mature degree and low organic matter abundance（TOC<0.5%）can make an effective contribution on the hydrocarbon accumulation and can be a new exploration play, which should not be ignored in the resource evaluation and the exploration of hydrocarbon.

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New Insight into the Characteristics of Tight Carbonate based on Nuclear Magnetic Resonance

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In order to further our understanding of the physical properties of tight carbonate and to explore the use of NMR to identify different rock types. In this study, we used thin-section observations, SEM (scanning electronic microscopy) data, helium porosity, helium pulse decay permeability, MICP (mercury injection capillary pressure), and NMR (nuclear magnetic resonance) data to conduct petrographic and petrophysical characteristics of tight studies on 12 carbonate samples. Our results show that nano/micropores were widely distributed between the micrite and/or dolomite crystals. The correlation between the permeability and porosity of the tight carbonates was poor, while the rapex, which was the apex of the hyperbola in Pittman (1992)[1], is well correlated with the threshold entry pressure, the maximum pore-throat radius, and the average pore-throat radius. Based on new cut-off values, we have identified three types of pores: nanopores, which mainly correspond to the intercrystalline pores; micropores, which may be related to the bio-erosion or mechanical erosion process of the aragonitic bioclasts; and mesopores, which mainly consist of well-preserved intraparticle porosity related to the diagenetic shielding effect, dissolved intragranular pores and a few intercrystalline pores. The dissolved bioclastic packstone and dolostone exhibit similar unimodal behavior with a broader wave, while each of the other four lithofacies has a unique NMR signature. The microstructures and diagenesis processes result in different NMR responses in the different rock types. The micrite envelope, neomorphism, and moderate recrystallization of the micrite matrices result in a higher T_2 spectrum value and a longer relaxation time, while the high clay content and stylolite have the opposite effect. The dissolved bioclastic packstone has a shorter relaxation time than dolostone, with a similar pore throat distribution. Geological knowledge is needed for the NMR-based core-facies classification and for evaluation of the physical properties of the tight carbonate.

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CARBONATE FACTORY TURNOVERS INFLUENCED BY THE MONSOON (XISHA ISLANDS, SOUTH CHINA SEA)

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Carbonate factory turnovers can be the integrated results of climatic, oceanographic and biological controls. As an important part of the global climate system, the monsoon has a significant potential to influence such turnovers (Betzler et al. 2009, 2016). Sedimentological, geochemical and paleontological data from core XK-1 drilled in the Xisha Islands, South China Sea, reveal that photozoan to heterozoan carbonate factory turnovers during the Early and Middle Miocene in isolated carbonate platforms were mainly caused by changes in the upwelling regime. A heterozoan open bank association thrived in tropical shallow water under conditions of nutrient excess, indicated by high Ln(Cu/Ti) and Ln(Ba/Ti), and by the increased abundances of rhodoliths and some foraminifer genera. During the Early and Middle Miocene, episodes characterized by a heterozoan carbonate production correlate with times of East Asian Summer Monsoon strengthening, especially from 21.2 to 17.3 Ma and from 15.6 to 11.6 Ma (Clift, 2006; Clift et al., 2014). This study thus provides new insights into the variability of shallow water carbonate deposition in monsoon-influenced areas and also shows that shallow carbonate factory turnovers can help to reconstruct the monsoon evolution in monsoon-affected regions elsewhere.

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Sedimentary microfacies of the dolomite in the Sinian Dengying Formation in the southeast Sichuan Basin: A case study of Well-DS1

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Abstract: Sinian Dengying Formation in Sichuan Basin is composed of fine crystalline dolomite and algae dolomite without many wells drilled, which could be divided into 4 members. In this research, the Well-DS1, which is located in the Dengying Formation of the southeastern margin, was taken as an example. According to the detailed petrological and petrographic work, the facies of dolomite in the Well-DS1 was considered as carbonate platform, which could be distinguished as three subfacies: open platform, platform edge, and restricted platform. In consideration of elements of water depth, hydrodynamic conditions, sedimentary structures, and microscopic structural features, it would be further divided into six microfacies which include open tidal flats, intra-platform mounds, oolitic tidal flats, platform marginal mounds, restricted tidal flats, and lagoon. The vertical overlap sequence of the sedimentary facies of the Dengying Formation reflects the sea level changes over the synchronous period. The sea level showed a downward trend in the depositional stage of 2nd Member of Sinian Dengdeng Formation(Z_2dn_2) in Well-DS1. And in the Z_2dn_3 stage, the sea level rose and fell more frequently. The sedimentary facies of the Z_2dn_4 showed a downward trend of sea level. Therefore, the sea level of Dengying Formation is mainly in a process of regression.

Key words: Sichuan Basin; Well-DS1; Dengying Formation; dolomite; sedimentary microfacies

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Architecture and controlling factors of the Miocene carbonate platforms in Bekang Basin, southern South China Sea

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Abstract:

The Beikang Basin is located in the southern part of South China Sea (SCS) which is one of most tectonically complex sea area which also called the Dangerous Ground. It is a deep-water sedimentary basin which mainly deposited in the Cenozoic. Due to data restriction, the researches on carbonate platform of this area were still in its infancy. Based on the analyzing of high resolution seismic data, various Miocene carbonate platforms were identified, the architecture and growth history were reconstructed, and the controlling factors were discussed. The carbonate platforms of Beikang Basin began to grow during the Late Oligocene to Early Miocene, extended during the Middle Miocene, submerged during or after the Late Miocene. The carbonate platforms developed in the Middle Miocene were the most prosperous. The development of Middle Miocene platforms could be divided into three stages, the platforms in the first stage retrograded with a wide range and thin thickness. In the second stage, the platforms aggraded with smaller range and were controlled by faults obviously. In the third stage, the platforms retrograded and were submerged gradually. The platform structure developed in the Miocene at the Beikang Basin was mainly controlled by sea level rising/falling rate and carbonate growth rate. Based on the analysis of seismic reflection characteristics and the controlling factors, the platforms could be divided into several patterns, respectively were retrogradation, submerged, aggradation, progradation, the outward with up-stepping, outward with down-stepping, and down-stepping platform. At the top of the carbonate platforms, carbonate “wings” or “mushrooms” were appeared usually, which were formed during the relative sea level decline.

Key Words: Architecture; Controlling factors; Miocene; Carbonate platforms; South China Sea.

Prediction method of abnormal high pressure in carbonate formation

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Predicting the pore pressure is the premise of achieving excellent, efficient and safe drilling operation and it is also the key part of protecting oil&gas layer. Marine carbonate basin in the middle-west of our country usually has very difficult geological structure and multivariate underground pressure system, so it is very significant to efficiently predict its pore pressure in the process of exploration and development of the basin. This thesis analyzes the mechanism of abnormal pore pressure through learning related theory knowledge,research condition and development tendency and concludes the main influencing factors of causing abnormal pore pressure in the carbonate reservoir.The thesis also analyzes the principle and defect of current prediction methods and finds the proper carbonate pore pressure prediction method by combining the forming mechanism of abnormal pressure in the carbonate.In this thesis,an experiencing model of pressure prediction is established based on the relationship of acoustic velocity and effective stress and porosity which is summarized in the experiments of the acoustic properties of carbonate rock samples of carbonate rock strata laws.Analyzing the formation factors of clay content and gas saturation which can influence the formation acoustic velocity,this thesis introduces clay content and gas saturation into the pore pressure prediction model.

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Sedimentary Process and Diagenetic Characteristics of Rudist Shoal in Cretaceous: A Case Study on Mishrif Formation, Halfaya Oilfield, Iraq

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Abstract: The rudist shoal deposited in the whole Tethys region is one of the most important oil and gas reservoirs of Cretaceous in the Middle East. Based on the combination of core observations, mineral components analysis, casting thin sections, scanning electron microscopy and petrophysical properties, the sedimentary process, diagenetic evolution and reservoir characteristics of the rudist shoal of the Cretaceous Mishrif Formation in Halfaya Oilfield were studied. The results show that: (1) The Mishrif Formation developed two sets of twelve rudist shoals with low micrite content, coarse particle size, and simple mineral composition in the descent cycle of highstand system tract, and they were distributed among the platform marginal paleotopography[1]. (2) Each high-frequency sea level oscillation forms a single rudist shoal. The complete sedimentary sequence shall be divided into low-rate construction period named Section A, middle-rate construction period named Section B, high-rate construction period named Section C and exposed period named Section D. The low-rate construction period was formed at the rapid rise of sea level. At that time, the rudist shoal was near the wave base with a medium hydrodynamic force, which grew slowly, forming packstone. The middle-rate construction period was generated when the sea level was relatively stable. During the period, the rudist shoal was beyond the wave base, the hydrodynamic force was relative-strong and the shoal gradually transformed to grainstone. The high-rate construction period was formed during the slow sea level decline with a strong hydrodynamic force, when the deposition rate was high, so the shoal deposited rapidly and formed rudstone. The exposed period was generated when the rudist shoal was beyond sea level. The hydrodynamic force was weak and plants existed in the small-scale swamp environment. Then the plants were buried and became carbonaceous mudstone. (3) The ideal rudist shoal deposition process is composed of Section A, B, C, and D from bottom to top. Due to changes in the extent and duration of sea level fluctuation, and erosion in the next period, the integrity of the rudist shoals sequence could be destroyed, forming combinations of ABC, BC and BCD. (4) The diagenesis of the rudist shoal beach is characterized by strong dissolution, weak cementation and relative-strong compaction. Thanks to the superposition advantages of high-energy sedimentary facies and constructive diagenesis, porous reservoirs with dissolution vug were formed, which turns out to be the best reservoir with the highest yield in the study area.

Keywords: rudist shoal; sedimentary process; diagenetic evolution; reservoir characteristics

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Sedimentary and Diagenetic Characteristics in platform carbonate reservoirs

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Abstract: The platform carbonate reservoirs in the Mishrif Formation of the HF Oilfield in Iraq are highly heterogeneous and can easily lead to water injection breakthrough along the high permeable thin layer to reduce the water injection sweep efficiency.Based on core observations, conventional physical property, casting thin sections, scanning electron microscopy and injection profile test, the sedimentary and diagenetic characteristics in platform carbonate reservoirs are studied. The results show that: (1) The beaches in platform can be divided into shoal and inter-shoal, the shoal is mainly composed of bioclastic packstone and grainstone, while the inter-shoal is given priority to bioclastic wackstone. The types of bioclastic are mainly benthic foraminifera and rudist, including some echinoderms and bivalves. The shoal and inter-shoal is interactively distributed, and the single beach is a reverse cycle with a thickness of about 2-6m. (2) The bioclastic shoal is formed in the high position of strong hydrodynamic, the content of micrite is low, and the atmospheric freshwater dissolution is frequent during the diagenesis stage. It includes intergranular pore, intergranular dissolved pore, mould pore and intragranular pore, throat contains reduced-neck and silm throat with medium-high permeability. The inter-shoal is a lower area with deep water between shoals, with high micrite content and less freshwater dissolution at the diagenetic stage. In addition, dissolution product from the shoals results in calcium cement which blocking throat of the inter-shoal. It includes mould pore, intragranular pore and micropore, throat contains silm and cluster throat with low-permeability. (3) On the basis of sedimentation, diagenesis further enhances the heterogeneity of the reservoir, especially the top of the shoal turns into high permeability layer, accordingly inter-shoal becomes a region with low water seepage efficiency. During the development of waterflooding, the injected water quickly breakthrough along the top of the shoal, and the water content of the production well rises rapidly, meanwhile the production-injection profile test shows the monolayer breakthrough[1].

Keywords: platform carbonate reservoirs; sedimentary process; diagenetic evolution; reservoir characteristics

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THE EARLIEST TRIASSIC METAZOAN BIOCONSTRUCTIONS FROM EAST GREENLAND: IMPLICATIONS FOR THE RECOVERY FOLLOWING THE END-PERMIAN MASS EXTINCTION

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The novel earliest Triassic bioaccumulations in the form of small bioherms and biostromes from mid-Induan (latest Griesbachian-early Dienerian transition) strata in East Greenland are reported. Unlike previously described Early Triassic metazoan bioconstructions, these developed within a Boreal mid-paleolatitude seaway, and comprised a monospecific primary framework of microconchid tubeworms. Unlike any other previously documented bioherm-building microconchids, these are characterized by their uniquely straight tubes with tiny attachment base and prostrate growth mode. Such a morphology allowed them to attach to any hard particle in otherwise soft-bottom environment, and likely facilitated their accretion into sheet-like biostromes and small, irregular bioherms. These bioconstructions were also associated with a regional paleoenvironmental shift towards well-oxygenated bottom waters, and locally punctuated sedimentation that created a favorable habitat. Although microconchids were abundant and geographically widespread following the end-Permian mass extinction, such buildups formed solely by these metazoans have not been reported from the Early Triassic outside the Boreal Realm. The present finds illuminate that such opportunistic organisms as microconchids were able to form truly metazoan bioconstructions in the immediate aftermath of the biotic crisis, well-before the more stable complex reef communities appeared. Unlike previous works that suggested a sluggish post-extinction recovery and a total absence of metazoan bioconstruction in the earliest Triassic benthic ecosystems the character of this new community points toward an early post-crisis ecological succession. The present find represents additional evidence suggesting that the recovery of benthic marine ecosystems following the end-Permian mass extinction generally began earlier in higher paleolatitudes.

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FRACTAL ANALYSIS OF PORE STRUCTURE IN TIGHT CARBONATE ROCKS: A CASE STUDY FROM THE LOWER CARBONIFEROUS IN THE MARSEL AREA, CHU-SARYSU BASIN

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Evaluation of carbonate heterogeneity, closely related to pore geometry and connectivity, is important in oil and gas field production and reservoir prediction. To profoundly understand the heterogeneity of Lower Carboniferous carbonate reservoirs in the Marsel area, including Visean (C_1v) and Serpukhovian (C_1sr), the pore structure and fractal characteristics are investigated using routine petrophysical measurements, X-ray diffraction (XRD), cast thin section analysis, scanning electron microscopy (SEM), and mercury injection capillary pressure (MICP) tests. The origin of potentially prolific reservoir, the relationships between fractal dimension and reservoir physical properties, mineral composition and pore structure are also discussed. XRD results reveal that the mineral compositions are highly heterogeneous in C_1v and C_1sr. Routine petrophysical experiments indicate that C_1v and C_1sr are generally tight. However, some high porosity-permeability zones exist in C_1sr, which is described as a potentially prolific reservoir. The cast thin section and SEM analyses identify three main pore types in the potentially prolific reservoir: interparticle dissolution pores, intercrystalline dissolution pores, and moldic pores. The MICP data reflect that the pore-throat radii in the prolific reservoir range from 0.29 to 4.6 μm, whereas those in tight section are typically < 0.14 μm. The fractal dimensions are computed based on MICP data, and the fractal characteristics of the potentially prolific reservoir in C_1sr are divided into two segments. In the tight section, relatively larger fractal dimensions are observed, indicating highly heterogeneous pore structure. The potentially prolific reservoir in C_1sr is formed mainly because of penecontemporaneous dolomitization and leaching due to meteoric freshwater ingress. Different mineral compositions have differing effects on the fractal characteristics of the pore structure. Relatively good correlations of fractal dimension with porosity, permeability, sorting coefficient, and skewness indicate that fractal dimensions are helpful in reservoir quality evaluation and quantitative characterization of pore networks.

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ORGANIC GEOCHEMICAL CHARACTERISTICS AND DEPOSITIONAL ENVIRONMENT OF CARBONATE SOURCE ROCKS IN THE MARSEL AREA, CHU-SARYSU BASIN, KAZAKHSTAN

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As an oil and gas exploration frontier in the Central Asia, the Marsel area has attracted the interest of many researchers and oil companies. To profoundly understand the hydrocarbon generation potential of Lower Carboniferous carbonate source rocks, including Visean (C_1v) and Serpukhovian (C_1sr), the organic geochemical characteristics and depositional environment are investigated on the basis of pyrolysis data, vitrinite reflectance, gas chromatography and gas chromatography-mass spectrometry. The geochemical analyses results show that C_1v and C_1sr are effective source rocks with an average total organic carbon content of 0.74% and 0.44%, respectively. The hydrogen indexes of C_1v and C_1sr are in the range of 1.69–77.78 mg/g (mean 13.95 mg/g) and 3.57–42.39 mg/g (mean 19.36 mg/g), respectively, suggesting that these two sets of source rocks are dominated by type III kerogen and mainly generate gas during maturation. The average vitrinite reflectance of C_1v and C_1sr are 1.57% and 1.23%, respectively, indicating that the source rocks are highly mature and mature, respectively. This result is further supported by biomarker ratios, such as OEP, CPI, Ts/(Tm+Ts) and $C_{29}\alpha\alpha\alpha$20S/(20S+20R) and $C_{29}\alpha\beta\beta/(\alpha\beta\beta+\alpha\alpha\alpha)$ sterane ratios. The pristane / phytane ratios of C_1v and C_1sr range from 0.50 to 1.37 and from 0.20 to 2.0, respectively, suggesting that the source rocks are mainly deposited in transitional environment. The acyclic isoprenoid ratios (i.e. pristane/n-C_{17} and phytane/n-C_{18}) further indicate that the depositional environments of C_1v and C_1sr are trending to reducing and oxidizing, respectively. In addition, the distributions patterns of n-alkanes of C_1v and C_1sr vary from unimodal to bimodal, dominated by both short-chain n-alkanes (<n-C_{20}) and long-chain n-alkanes (>n-C_{23}). These complex characteristics imply that the sources of organic matter are variable. According to the terrigenous and aquatic ratio (mean 2.20) and relative abundance of regular steranes (predominance of $C_{29}\alpha\alpha\alpha$ (20R)), the source of organic matter of C_1v and C_1sr is dominated by terrigenous plant.

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NEOGENE STORM DEPOSITS IN THE CONTINENTAL SHELF OF THE NORTHERN SOUTH CHINA SEA

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The Neogene is composed of Zhujiang Formation(23.8-16.5 Ma), Hanjiang Formation (16.5-10.5 Ma), Yuehai Formation(10.5-5.5 Ma) and Wanshan Formation (5.5-1.8Ma) shallow marine mixed carbonate-siliciclastic sediments on the continental shelf of the northern South China Sea (SCS). Based on analysis of clastic constituents, texture, structure, sequence and geometry on drilling core, photomicrography and seismic profile, the storm deposition nearby provenance is identified for the first time. The storm sediment is a 50m thick moundy body and composed of mixed calcareous bioclastic siliciclastic rocks and siliciclastic carbonate rocks such as bioclastic pebbly sandstones, arenose dolomites and sandy bioclastic limestone deposited during 21 to 16.5Ma in Zhujiang Formation in the shelf to the north of Dongsha uplift of the SCS. The clastic constituents consist of terrigeneous quartz, feldspar, detritus, foraminifers fragments mainly included benthonic foraminifera (generally more than sixty percent) such as *Miogypsina*, *Cycloclypeus* and *Nephrolepidina* and a few of echinodeums and coralgals fragments. The clastic grains are different in size and thus show poor sorting. Elongated foraminifera shells are found to distribute randomly, and were damaged more or less with part filled with fine terrigeneous quartz sand. The siliceous grains are generally sub-rounded and sub-angular to angular.There are multiple types of sedimentary structure such as truncated structure, gutter cast, graded bedding and massive bedding. Full upward sequence is composed of massive bedding bioclastic glutenite with ravinement surface(A), graded bedding sandy bioclastic limestone(B) and bioclastic pebbly sandstone(C) and shows A+B+C positive rhythm. However, the sequence is usually incomplete with only A, A+B or A+C positive rhythm. The storm sediments can be identified by a moundy geometry from seismic profile. Sedimentation mechanism is that siliciclastic sediments and biodetritus from biogenic reef and organic bank around Dongsha uplift were mixed to deposit by windstorm. The discovery of the windstorm deposits enrich the sedimentary type and is a key factor to understand the evolution of the Dongsha uplift ,deduce the sea level change and conduct the exploration of oil/gas in Zhujiangkou basin.

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Characteristics of Reservoir in a Carbonate Ramp Setting: the Mississippian Pre-salt Carbonate Rocks, Rozhkovsky Structure, Northern Pre-Caspian Basin, Kazakhstan

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The pre-salt Mississippian carbonate successions host major hydrocarbon productions in the Pre-Caspian Basin, including the Tengiz and Karachaganak fields. The pervasively Permian salts divided the sediment successions into three units: pre-salt carbonate unit, salt-bearing unit, and post-salt siliciclastic unit. Rozhkovsky structure is an anticline structure trap located in the northern margin of Pre-Caspian Basin with condensate oil and gas production from pre-salt carbonate successions at burial depth more than 4000m.

In the Rozhkovsky structure, pre-salt Mississippian succession is composed of mainly carbonate rocks with thin siliciclastic rocks layers. The carbonate sediments were deposited on a laterally continuous inner-mid ramp setting with various reservoir heterogeneity and quality. They can be grouped into 11 lithofacies based on the core, thin section and SEM examinations. Four types of pore were recognized, including interparticle/residual interparticle pore, intraparticle pore associated with foraminifera, dissolution pore (including moldic pore) and intercrystalline pore contributed by dolomitization. High quality reservoirs (average porosity 6.8% and average permeability 7.12mD) with interparticle pore are identified in high-moderate energy environment around the junction between inner and mid ramp setting, which mainly consist of the peloidal/oolitic grainstone. In contrast, the poor reservoirs (average porosity 1.088% and average permeability 0.082mD) are distributed in the low-energy environment around the inner ramp, such as tidal flat and lagoon.

Our study suggests that the depositional setting has a significant effect on the reservoir properties, in terms of the formation of interparticle pores. Analysis of porosity and permeability values, combined with thin section and SEM petrography indicate that the porosity in carbonate rocks was closely associated with lithofacies. The pore-filling cementation and compaction partially destroyed the primary interparticle pore. In this unique sub-salt setting, the burial diagenesis, represented by minor calcite cementation, dissolution and fracturing, did not significantly alter the reservoir qualities. Six third-order sequence stratigraphic cycles in the entire carbonate successions link the lithology and depositional setting to sea-level fluctuations. It shows that HST is associated with better reservoir than LST and TST.

The Influence of the Fault-cap Coupling in Subsalt Structures on the Trap Filling in Kuqa Foreland Thrust Belt

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The thick layer of gypsum-salt rock in the Kumugeliemu Group has a stable distribution in the central and western parts of the Kuqa Depression. It constitutes a regional high-quality cover for the sandstone large-scale gas field in the Bashijiqike Formation. However, the local gypsum-salt rock within the trap structure of the footwall fault is not fully covered by the plastic flow or the thickness of the gypsum-salt rock is thin at the flank of anticline. It is difficult to provide a full range of closed conditions for structural traps, affecting the scale of gas reservoirs.

Based on the numerical simulation of source-reservoir pressure evolution, this paper clarified that the source-reservoir pressure difference is the continuous driving force of hydrocarbon filling. Based on the analysis of the fault-cap combination type, it is concluded that the partitioned fault-cap combination type establishes the conditions for hydrocarbon that can be both formed in shallow and deep layers. Mathematical formulas indicates the critical capping layer thickness is not related to the height of the capped hydrocarbon column. But when the capping layer thickness is less than the critical capping layer thickness, the capping layer will lose its sealing ability under the stress mechanism dominated by structure extrusion. Combining the matching results of source rock expulsion history, cap rock seal history, reservoir diagenetic evolution history, fault activity history and pressure evolution history, the Kelasu structural belt was taken as an example to illustrate that hydrocarbon enrichment sites are closely related to fracture characteristics and cap sealing capability. The fault-cap coupling controls hydrocarbon accumulation location and distribution in the study area.

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General theme 2

The clastic depositional system

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A SEDIMENTARY JOURNEY THROUGH 3 BILLION YEARS IN THE NEW WORLD

THE ROLE OF DISCHARGE VARIABILITY IN THE FORMATION AND PRESERVATION OF ALLUVIAL SEDIMENT BODIES

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Extant, planform-based facies models for alluvial deposits are not fully fit for purpose, because they over-emphasise plan form whereas there is little in the alluvial rock record that is distinctive of any particular planform, and because the planform of individual rivers vary in both time and space. Accordingly, existing facies models have limited predictive capability. In this paper, we explore the role of inter-annual peak discharge variability as a possible control on the character of the preserved alluvial record. Data from a suite of modern rivers, for which long-term gauging records are available, and for which there are published descriptions of subsurface sedimentary architecture, are analysed. The selected rivers are categorized according to their variance in peak discharge or the coefficient of variation (CVQ_p = standard deviation of the annual peak flood discharge over the mean annual peak flood discharge). This parameter ranges over the rivers studied between 0.18 and 1.22, allowing classification of rivers as having very low (< 0.20), low (0.20-0.40), moderate (0.40-0.60), high (0.60-0.90), or very high (> 0.90) annual peak discharge variance. Deposits of rivers with very low and low peak discharge variability are dominated by cross-bedding on various scales and preserve macroform bedding structure, allowing the interpretation of bar construction processes. Rivers with moderate values preserve mostly cross-bedding, but records of macroform processes are in places muted and considerably modified by reworking. Rivers with high and very high values of annual peak discharge variability show a wide range of bedding structures commonly including critical and supercritical flow structures, abundant *in situ* trees and transported large, woody debris, and their deposits contain pedogenically modified mud partings and generally lack macroform structure. Such a facies assemblage is distinctively different from the conventional fluvial style recorded in published facies models but is widely developed both in modern and ancient alluvial deposits. This high-peak-variance style is also distinctive of rivers that are undergoing contraction in discharge over time because of the gradual annexation of the channel belt by the establishment of woody vegetation. We propose that discharge variability, both inter-annual peak variation and "flashiness" may be a more reliable basis for classifying the alluvial rock record than planform, and we provide some examples of three classes of alluvial sediment bodies (representing low, intermediate, and high/very high discharge variability) from the rock record that illustrate this point.

EXAMPLE OF UNINCISED BRAIDED FLUVIAL SHEETS DEPOSITION FROM THE MIDDLE TRIASSIC RAS HAMIA & KIRCHAOU FMS OF THE GHADAMES BASIN (TUNISIA AND LIBYA) IN RESPONSE TO LOW SUBSIDENCE AND MINOR SEA LEVEL FALL

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During the opening of the Neotethys Ocean north of the Gondwana, an extensional phase created subsidence. In the Ghadames and Jeffara basin, it resulted in the deposition of Middle Triassic strata known respectively in Lybia and Tunisia as the clastic Ras Hamia and Kirchaou formations. To document this study, 221 wells and 4 sedimentological field sections were correlated across the entire basin. An organization in two 3rd order sequences was highlighted, each including well developed Falling Stage Systems Tracts (FSST) and Lowstand Systems Tracts (LST).
Detailed correlations combined with electrofacies analysis enabled to describe singular geometries in the most proximal confines of the Lowstand Systems Tracts (LST). Instead of deep and narrow subaerial unconformities, known as incised valleys, unincised braided fluvial sheets were observed (in the range of 20 meters thick). They can be correlated over more than twenty-five kilometers, from subsurface to surface where they are nicely exposed.
In the formation of classical incised valley, a deep incision is triggered during the relative sea level fall when a nick point is developed, either in the vicinity of the former shelf break or at the depositional shoreline break. Therefore, the depth of this incision depends of two factors, the difference between the slope of the sea bottom and the fluvial equilibrium profile, but also the magnitude of the fall[1&2]. This is why over the shelf, by-pass (no incision) is a common scenario during relative sea level fall, the shelf gradient being equal or very close to the fluvial equilibrium profile (unless the steep shelf break is emerged in case of major sea level fall).
However, to explain the singular low relief subaerial unconformities we observe at the depositional shoreline breaks of the Ghadames basin, our results suggest the combined action of two factors. Low and subtle differential subsidence over the basin as demonstrated by regional correlations and mapping, leading to very gentle shoreface topographies (close to the fluvial equilibrium profile), and low magnitude sea level falls as commonly assumed during Triassic.
As a result, no narrow incised valley is evidenced. Conversely, all the fluvial systems are made of very extensive unincised and unconfined braided sheets which are linked to the LST deltaic progradations described seaward.

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INCORPORATING CONCEPTUAL GEOLOGICAL KNOWLEDGE DURING 3D GEOLOGICAL MODEL BUILDING OF A BRAIDED RIVER RESERVOIR

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Despite the boom of stochastic simulation owing to computing advances in recent years, modeling results in many cases still suffer due to lack of geological soundness. This is quite the situation for braided river reservoir. Two major challenges exist in the modeling work after analysis: without a right conceptual geological knowledge as guidance; lacking of proper way to integrate it into the model.

As one of the most important reservoir types, braided rivers attract more and more attention during the last decades. Studies were carried out from the perspective of modern analogues or ancient deposits (i.e. outcrops). However, these studies often focus either on the surface/near surface or on subsurface. So far, the geological link between these two aspects of braided rivers has not been fully explored. This study aims to address the problem by analyzing the process-product relationship between surface and subsurface, thus building a proper conceptual geological knowledge base. Another major challenge is the procedure how to transform the conceptual model into real reservoir model. To constrain the model properly, we propose a method by first constructing a training image using object modeling method. In the meanwhile, certain geological rules need to be applied considering the interaction between sand bars, such as vertical and lateral accretion, erosion, etc. Then, multiple-point statistics simulation were carried out using results from object modeling.

As a result, internal geological architectures of the training image get fully expressed by utilizing the right conceptual model. The two-step modeling strategy solves the key issue of what kind of deposition and erosion styles should be preserved within braided river reservoir. The approach also demonstrates the ability of multiple-point statistics to produce realistic subsurface reservoir.

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A CHUTE CUTOFF OF EXTREMELY SINUOUS MEANDER-BEND AND SYNCHRONOUS INFILLING OF CUTOFF CHANNEL AT THE LANDWARD LIMIT OF TIDAL BACKWATER ZONE OF SITTAUNG RIVER, MYANMAR

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The early stages of a highly sinuous meander cutoff was investigated using UAV-assisted photogrammetry, global positioning system mapping and echosounding survey to understand the morphodynamic evolution of chute and cutoff channels and associated floodplain architecture in sediment-laden rivers with distinct seasonal discharge. A chute cutoff by headcut incision, preceded by the initial chute incision in July 2015, occurred in July 2016 on the narrow neck of Nyaung Bin Bak (NBB) Bend, 150 river km upstream from the mouth of Sittaung River, Myanmar. Active point-bar growth (~80 m) with cutbank erosion (~25 m) took place along NBB Bend within the first five months during/after the cutoff event. The entrance of the cutoff channel was completely obstructed by 1.2 km-long plug bars that formed after flooding events in 2017. Point bars continued to migrate along the upstream part of NBB Bend, with no major cutbank retreat recorded. Nearly 60% of the low-flow stage channel profile was infilled with sediments in a year after the cutoff. The chute channel widened rapidly by cutbank erosion at rates of as much as 85 m in a year. Scours at the upstream confluence are locally 13 m deep at low-flow stage, which is 7 m below mean sea level and is in marked contrast to the maximum water depth of 7 m at NBB Bend before the cutoff event. Rapid growth of mid-channel bars occurred at the downstream confluence. Depositional sediment flux along the cutoff channel nearly doubles erosional sediment flux from the chute and cutoff channels combined, suggesting that the cutoff meander acts as a major sediment sink at the landward limit of tidal backwater zone of Sittaung River. Before the chute cutoff, the point bar was dominated by active dune migration during peak river floods and subsequent suspension fallout during waning river floods, resulting in seasonal inclined heterolithic stratification (IHS) consisting of cross bedded medium sands and overlying muds. After the cutoff event, the IHS grades upward into an alternation of rippled fine to very fine sands and up to 40-cm-thick muds. With active dune migration confined to the entrance of the cutoff channel, a notable downstream facies transition from cross-bedded sands to rhythmically laminated sand and muds typifies the plug bars. High discharge variability due to fluctuation between extreme wet and dry spells, enormous sediment load and erodible floodplain facilitated rapid clogging of the entrance of the cutoff channel and subsequent infilling of the cutoff channel that is synchronous with the chute incision.

FLUVIAL FACIES MODELS AND RIVER PLANFORM STYLES: QUANTITATIVE ANALYSIS OF ONE-DIMENSIONAL DATA

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It has long been claimed that attempting interpretation of the planform style of a river from one-dimensional samples of its deposits (measured outcrop sections, cores, wireline logs) is inappropriate (cf. Jackson 1977; Miall 1985; Hartley et al. 2015). Notwithstanding, facies models categorized on channel patterns (braided *vs.* meandering rivers) and river patterns (e.g. anastomosing rivers) still appear in textbooks, favouring their misuse by the non-specialist. As a result, the unjustified application of facies models abounds in the scientific literature, ultimately affecting palaeogeographic reconstructions or conceptual models of subsurface architecture.

This study presents a quantitative assessment of the value of 1D facies data as tools for interpreting the planform style of formative river systems, and, if needed, to help promote the long-advocated shift of focus. A database approach has been implemented to enable analysis of over 70 fluvial systems for which river planform style and vertical facies arrangements can be constrained with confidence, through the study of outcrops, subsurface datasets comprising of 3D seismic coupled with core and/or well-log data, and modern rivers for which sections can be examined. Channel deposits consisting of barforms and channel fills of different types are characterized quantitatively with respect to the proportions, thicknesses, and vertical transitions of lithofacies, as qualitatively represented in traditional 1D facies models. Through synthesis of these features for classes of fluvial systems, quantitative facies models are compiled. These models demonstrate that modal facies architectures of sand-rich braided and meandering systems are not distinguishable statistically, but also that certain facies characteristics might have some diagnostic value for inferring planform types. The results serve the purposes of: (i) facilitating communication of uncertainty in this type of interpretations; doing so is important in academia, in contexts of both teaching and research, as well as in subsurface studies; (ii) highlighting hitherto under-recognised features that might in fact be suggestive of a likely planform style from 1D data, based on their exclusive occurrence in river systems of a certain style.

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BAR-BRINK AND THALWEG TRAJECTORIES: A NOVEL APPROACH TO TIDAL POINT BAR GEOMETRY STUDIES

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Trajectory analysis is the study of the migration pattern of easily recognizable geomorphological features (e.g. breaks-in-slope) through time[1]. Trajectory analysis can be applied from bed-form (e.g. ripples) to shelf-edge[2] scale, and provides information about the relationship between vertical aggradation and lateral shift of depositional surfaces. The present study focuses on point bar developed by sinuous tidal channels cutting through saltmarshes of the Venice Lagoon (Italy), and analyses the meaning of trajectories defined through time by the bar brink (i.e. break between bar top and bar slope) and the channel thalweg (i.e. deepest part of the channel).
The Venice Lagoon, the largest brackish water body of the Mediterranean, is subjected to a semidiurnal microtidal regime with an average tidal range of about 1.0 m. During the last centuries, the subsidence rate in northern and southern part of the lagoon reached values of 0.5 and 1.4 cm/yr, respectively[3]. The study channels range in width and depth from 2 to 11 m and from 0.5 to 1.6 m, respectively, and define bends ranging in radius from 6 to 21 m. Eight point bars (four in the northern and four in the southern lagoon) were investigated through a high resolution facies-analysis carried out on closely-spaced sediment cores, which were recovered along the bar axis. Integration between sedimentological and architectural data allowed us to detect the position of brink and thalweg facies in different cores, whereas spatial distribution of these facies allowed us to define different trajectories generated by their lateral shift. Trajectories were classified as ascending (i.e. lateral shift + aggradation) or descending (i.e. lateral shift + incision), and can be furtherly distinguished in linear (i.e. vertical/lateral shift = constant in time) or non-linear (i.e. vertical/lateral shift = variable in time). Our analysis shows that all brink point trajectories are ascending, and that the development of their linear or non-linear shape is tightly linked with occurrence of different aggradation/subsidence rates. Geometries of thalweg trajectories are more variable and can be either ascending or descending, reflecting a complex interaction between rates of lateral shift and aggradation/degradation of the channel floor. The brink and thalweg can either shift consistently (e.g. both trajectories are ascending) or incongruously (e.g. ascending brink vs. descending thalweg trajectory), reflecting different attitudes of the channel to maintain or increase its hydraulic section.
Results from the present study show that changes in aggradation/degradation processes, along with variations in water discharge, of sinuous tidal channels can be recorded by bar-brink and thalweg trajectories. These principles were developed in intertidal channels draining saltmarshes, but could be applied also to fluvial bends developed in highly aggradational floodplains.

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SELF-ORGANIZING AVULSIONS IN AN ENDORHEIC DRYLAND RIVER SYSTEM

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Absolute age dating with Optically Stimulated Luminescence (OSL) measurements, in combination with Google Earth Pro imagery and differential GPS (dGPS) measurements was employed to unravel the processes and timing of river avulsions and the resultant sedimentary architecture of a network of Holocene Río Colorado (Altiplano Basin, Bolivia) channel belts.
A radial pattern of channel belts originated from compensational stacking of interconnected alluvial ridges. Channel-belt switching occurred by avulsions with frequencies ranging from 160 yr to 1130 yr. Rivers started with a low-sinuous (SI 1.29 to 1.64) single-channel trajectory bordered by small point bars. Over time, the rivers evolved to high-sinuous (SI 1.80 to 2.29) streams with wide point bars with a large surface area. The average lateral point-bar accretion rate is 0.5 my^{-1}.
The alluvial ridges formed by river sediment accumulation through aggradation and lateral accretion of sand in point bars, channel-floors, and levees, and by lateral amalgamation and stacking of crevasse splays. The width of the individual ridges in the study area is approximately 1.5 km. Confined inter-channel areas received crevasse splay sediment from both sides of successive channel-belt positions, and the overlapping crevasse-splay sand resulted in a higher inter-ridge elevation as compared to the unconfined side where the alluvial ridge bordered the open floodplain. Alluvial-ridge aggradation resulted in decrease of the along-river gradient and increase of cross-floodplain gradient, to the point where the channel-floor elevation became higher than the surrounding floodplain surface, whereupon avulsion occurred, and the process of alluvial-ridge growth started anew. Successive channel belts avoided the positive morphology of earlier-deposited alluvial ridges and thus formed a self-organizing, laterally-connected alluvial-ridge network over an area of 500 km^2.

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DISTRIBUTION PATTERN OF DELTAIC SAND BODIES CONTROLED BY GROWTH NORMAL FAULTS IN RIFT LACUSTRINE BASIN：A CASE STUDY OF PALEOGENE SHAHEJIE FORMATION IN THE DONGYING SAG , BOHAI BAY BASIN

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Growth normal faults in rift basins control the stratigraphic sequence architecture and the distribution of sedimentary systems[1, 2]. However, the response of deltaic sedimentary architecture to growth of normal faults in complex fault blocks still remains incompletely understood in complex fault blocks of rift basins. Small-scale growth normal faults develop with NE direction in the second member of the Paleogene Shahejie Formation (Es_2) in complex fault blocks of the Wangjiagang Oilfield in the Dongying Sag, Bohai Bay Basin. The faults were formed under combination of strike slip and extensional tectonic stress during the shrinking stage of the rift lacustrine basin. The distribution pattern of deltaic sand bodies is studied in Es2 member of W43 fault-blocks using seismic, well logging and core data. The coupling relationship between growth normal faults and internal reservoir architecture of delta is discussed to improve sedimentary model of lacustrine delta controlled by growth normal faults. Induced by the boundary faults in the basin, the scale of growth faults developed inside the delta deposition system is small with complex arrangement. During the sedimentary period of Es_2, the activity was different in different parts of the same growth normal fault. Thus, the distribution pattern of the deltaic sand bodies was controlled by topographic differences influenced by growth and spatial distribution of the normal faults. The topographic differences caused by growth of normal fault control the flow direction of distributary channels which determines the diffusion styles of deltaic sand bodies. In addition, the growth faults controlled the scale of deltaic sand body through increased accommodation spaces generated by subsidence of the hanging wall. Therefore, the spatial distribution of architecture elements of delta influenced by growth normal faults differs greatly from the previous deposition models of lacustrine delta. The study explains the relationship between growth faults and sedimentary process and provides an analog for prediction of reservoir distribution in rift basins.
Keywords: Delta; Growth normal fault; Distribution pattern; Shahejie formation; Bohai Bay basin

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EVIDENCE FOR CONCAVE-BANK DEPOSITION IN THE STRATIGRAPHIC RECORD: COUNTER-POINT BAR DEPOSITS AT DINOSAUR PROVINCIAL PARK, ALBERTA

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Concave-bank sedimentation in fluvial meander belts is a common, but often over-looked process, and its depositional products are sparsely identified in the stratigraphic record. Many studies of modern rivers have focused on concave-bank benches, which are composed of a sandy bar nucleus overlain by relatively flat-lying fine-grained interbedded deposits. However, there are numerous additional, under-studied processes of sedimentation that also occur along concave banks that yield different depositional products. In the stratigraphic record, outcrop and subsurface studies lack specific recognition criteria for the identification of concave-bank sedimentation products. It is proposed here that the term counter-point bar deposit be applied to the stratigraphic product of any concave-bank sedimentation process.

An outcrop belt in eastern Alberta at Dinosaur Provincial Park provides an ideal candidate for characterizing concave-bank deposits and defining their recognition criteria. A dissected badlands-style landscape offers 3D perspectives of a 7.5-8.0 m thick, Late-Cretaceous meander-belt deposit over 3 km^2. A combination of traditional field-based sedimentological analysis and innovative Unmanned Aerial Vehicle Structure-from-Motion outcrop mapping positively identifies a counter-point bar deposit. It is characterized by siltstone-dominated inclined heterolithic stratification, which is present immediately downstream from and adjacent to convex-shaped, sandstone-dominated point bar units. Detailed sedimentological characteristics were compiled from over 40 measured sections and abundant paleoflow indicators; intra-bar accretion and erosion surfaces were mapped in a 3 cm resolution SfM digital outcrop model, which reveals their concave morphology. The counter-point bar developed as a result of channel confinement against a resistant floodplain deposit, which promoted downstream translation of the meander bend.

Our results define micro-, meso-, and macro-scale recognition criteria for counter-point bar deposits in the stratigraphic record. Micro-scale characteristics include interlaminated and interbedded siltstone and fine-grained sandstone, abundant organic detritus, and evidence for deformation and slumping. At the meso-scale, accretion packages bounded by internal erosion surfaces are composed of dipping siltstone and minor sandstone beds that extend from the top to the base of the meander belt (i.e. IHS). At the macro-scale, positive identification relies on concave accretion surface mapping, their orientation relative to the meander-belt edge (i.e. dipping away), and consideration of meander-bend evolution. We propose that counter-point bar deposits are composed of a variety of depositional products as a result of variations in concave-bank sedimentation and meander-bend migration processes. Additional studies of concave banks that lack a concave-bank bench are needed to further characterize the suite of processes active along concave banks in meandering channels.

Facies Architecture of an Ancient Distributary Channel Complex, Cretaceous Gallup Sandstone, New Mexico

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This study documents the along-strike facies architectural elements of an ancient distributary channel in the late Cretaceous Gallup Sandstone Formation, New Mexico. Three vertical measured sections along with a high resolution photomosaic were collected to complete this analysis. Paleohydraulic parameters of flow velocity, discharge and slope were calculated using field measurements of channel elements. These measurements were tested against empirical equations to check their validity when used with sparse subsurface datasets. Two storeys of sand-dominated inclined heterolithic stratification (IHS) with marine to brackish ichnogenera as well as bidirectional mud draped cross beds characterize the early stage channel (D1). D1 was approximately 60m wide, 2.5 - 4.0m deep with a calculated discharge between 52.5 – 144m^3/s. Two upward coarsening successions of mudstone and very fine-grained sandstone line the channel scour of D1 and are interpreted as intermittent channel abandonment deposits. A late stage, cross-bar channel (D2) incises through the top of D1's IHS and is interpreted to be the cause of intermittent abandonment of D1. D2 was 51m wide, 1.7 - 2.5m deep and its calculated discharge was 30.3 – 63.8m^3/s. Due to the presence of marine/brackish ichnogenera within a channel which incises into shoreface deposits - this is interpreted to be a locally avulsive distributary channel which is subject to backwater effects, particularly during large storm surges. Distributary branching order for this channel was estimated by assuming the trunk channel discharge of the Gallup delta is within an order of magnitude of other well-documented Turonian fluvio-deltaic systems in the Western Interior Seaway. These calculations along with facies architectural analysis allow for a plan-view reconstruction of early and late stage paleochannels.
Using historical satellite imagery, modern examples of distributary channels displaying similar chute cut-off mechanisms were documented in the Kikori and Vailala rivers, Papua New Guinea. These rivers were chosen due to their ever-wet subtropical environment and their relatively short distance from source to shoreline. This was typical for siliciclastic systems on the west side of the Turonian Western Interior Seaway.

STRATIFIED MUD DEPOSITS AT THE BASE OF LARGE-SCALE POINT BARS: ORIGIN AND IMPLICATIONS TO POINT BAR FACIES MODELS

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Three end members proposed for point bar models include fluvial, micro-tidal, and meso-tidal successions (Smith, 1985). The classic fluvial point bar facies model is characterized by an upward-fining succession comprised of (i) coarse lag deposits at the channel base; (ii) dune trough cross-bedding and upper stage plane-bed lamination of the lower point bar; and (iii) ripple cross-lamination and upper stage plane-bed lamination of the upper point bar successions. Channel lag and lower point bar deposits comprised of breccia and/or cross-bedded porous and permeable sands are very similar in all three-end members. A large-scale (up to 40 m thick) point bar succession of the Lower Cretaceous McMurray Formation observed at the Type Section does not appear to fit to any of the three point bar end members described by Smith (1985). In contrast to other point bar facies models, both planar- and trough-crossbedding of lower point bar deposits occasionally contain four distinct types of fine-grained strata within lower point bar deposits occurring as: (i) bottom-dune; (ii) intra-dune; (iii) interbedded ripple-laminated sands; and (iv) scour surface mud-drape deposits. Data suggests that all four types are associated with high-suspended sediment concentration (SSC) related either to tidal influence or fluvial floods. This interpretation is in alignment with a growing amount of literature describing deposition and preservation of stratified fine-grained deposits at the base of meandering rivers characterized by high SSC in both tidally influenced zones (Fenies et al., 2016), and during fluvial flood events (Plink-Björklund). The stratified fine-grained deposits have been also documented at the base of tidal bars in open estuarine environments (Dalrymple, 2010). Large-scale point bar deposit exposed at the McMurray Formation Type Section shows evidence of high SSC caused by tides and fluvial floods. Point bars characterized by fine-grained deposits at the lower point bars are fundamentally different from the existing three end member point bar types. To accommodate the need for classifying different point bar successions than observed from previous research, a model for subsurface interpretation with a five-end member classification may be more appropriate. The classification will include the existing fluvial, micro- and meso-tidal point bars with addition of fluvial and tidally influenced high SSC point bar deposits.

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Charaterization and 3D Modeling of Reservoir Compartmentalization and Its Inner Architecture in Meandering Belt For the Rejuvenation of a Mature Oilfield：A Case study in Gangxi Area of Dagang Oilfield,China

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This paper gives the study result on characterization and 3D modeling of reservoir compartmentalization and its inner architecture in meandering belt that aimed at describing and modeling reservoir heterogeneities, forecasting remaining oil distribution, and improving the oil recovery of mature oilfield. This study focuses on the lower member of the Neogene Minghuazhen formation of Gangxi area in Bohai Bay Basin, which has been entered into high water cut stage. Surveillance data shows that the compartmentalization of reservoir and inner architecture can control the distribution of remaining oil and the movement of oil and water. Firstly modern deposits were treated as an analog for characterizing reservoir. Satellite images in Hailar river, Heilongjiang province, from different years were collected to analyze the evolution rules of abandoned channels and point bars in meandering belt. Analogy analysis between modern deposit and subsurface reservoir was made. Mud filled in the abandoned channels result in the compartmentalization of reservoir. It was concluded that the recognition and combination of abandoned channels and point bar are the key problem of the study of compartmentalization of reservoir in subsurface meandering belt. A comprehensive methodology of combining the core data, seismic data, performance data with log data from close spacing well are presented. Secondly, modern deposit researches in Mississippi river and Hailar river shows that the inner architecture of meandering river deposit is very complex. Many lateral stacking sandbodies were separated by s series of lateral stacking shale for meandering river deposit. Characterization of inner architecture includes the recognition and description of intercalation type, occurrence and distribution scale. The horizontal drilling well data show that the scale of lateral accretion sandbody is about 60~80m, and dipmeter log data show that the dip of lateral accretion intercalation layer is from 3 to 8 degree and the average is 5 degree. Thirdly, a auxiliary software was developed to characterize reservoir inner architecture in 3D model, which generate the geological modeling basic data according to the Petrel software based on the geological result that embody the reservoir compartmentalization and its inner architecture in meandering belt. Based on above-mentioned methods, some oil pools have been studied detailly, thus making the ever puzzling difficulties clear, especially the inconsistence between static geological result and dynamic performance data. And under the guidance of methodology mentioned in this paper, some important point bars were analyzed. The position and pattern of lateral accretion intercalation layer were described one by one. Combining the result to remaining oil monitoring information, the distribution pattern of remaining oil in meandering belt reservoir was presented clearly. In the end, the 3D modeling method based on Petrel software was proposed, and provided a detailed geological model for reservoir numerical simulation.The study can help us understand reservoir behavior better and this understanding can ultimately lead to improved oil and gas production.

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UPSTREAM vs. DOWNSTREAM POINT-BAR DEPOSITS: AN EXAMPLE FROM THE OMBRONE RIVER (SOUTHERN TUSCANY, ITALY)

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A progressive downstream decrease in sediment grain size is known to characterize both gravel- and sand-rich fluvial point bars. Such a grain-size variability controls distribution of heterogeneities within point-bar sedimentary bodies, and can have significant implications in terms of hydrocarbon recovery and aquifer management. Nevertheless, the majority of sedimentological studies on fluvial point bars focuses on "classical" axial sections (i.e. parallel to the bend axis), which show diagnostic, large-scale inclined beds (i.e. epsilon cross bedding), but cannot provide any information on downstream facies changes. It arises that the contrast between upstream and downstream fluvial point bar deposits is poorly known both in terms of grain size and sedimentary facies.

The present work contributes to fill this gap of knowledge investigating modern point bar deposits of the Ombrone River (southern Tuscany, Italy). The Ombrone River is 160 km long and drains from the Chianti Mts. to the Tyrrhenian Sea eroding Miocene-Pliocene unconsolidated deposits and pre-Neogene rocks. At the river mouth, the averaged discharge is $32 m^3/sec$. In the last 30 km of its route, the Ombrone River is 60-80 m wide and forms meander bends with a sinuosity ranging between 1.5 and 3. Gravels and gravelly-sand are the dominant sediments in the bends occurring in the most proximal part of this sinuous reach. In 2017, one of these bends (sinuosity: 1.6) has been artificially cutoff in order to modify the main river course and prevent local flooding. The artificial cutoff channel rips through the whole point bar, from the upstream to the downstream riffle. Dissected point-bar beds are spectacularly exposed along the hydrographic right-hand side of the cutoff channel, where a ~450 m long and ~3.5 m high cliff occurs. This exposure allows a detailed comparison between upstream and downstream point bar deposits. Upstream bar deposits consists of pebbles and cobbles forming upvalley-dipping (3°-5°), plane-parallel stratified beds, which range in thickness from 15 to 25 cm. Gravels are clast-supported, with medium-grained sandy matrix, although lenses with an open framework texture commonly occur. These gravels do not show any clear vertical grain size trend, and cover a poorly-exposed channel lag made of cobbles and large pebbles. Downstream bar deposits are made of medium to fine sand forming downvalley-dipping (5-10°) beds, which range in thickness from 5 to 20 cm. Sand is ripple-cross laminated or plane-parallel stratified. Isolated mud drapes (1-5 cm thick) occur in the upper part of the section. Downstream bar deposits show a fining-upward grains size trend, and overlay a basal channel lag made of coarse pebbles. Along the 450 m long artificial cliff, transition between gravelly and sandy facies occurs within 15 – 20 m at about 150 m from downstream termination of the cliff.

This study highlights that upstream and downstream point-bar deposits can strongly differ in terms of grains size, sedimentary structures and vertical grain size trends. It arises that different flow configurations and sedimentary processes occurring in these areas are clearly recorded in the sedimentary record. These differences, which are not commonly assessed by classical facies models, should be considered trying to interpret the origin of fluvial bar deposits in the fossil record.

IDENTIFICATION OF PALEOSOL FROM LOGGING INFORMATION AND APPLICATION IN FLUVIAL STRATA CORRELATION

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Hampson's research shows that abnormal high Th/K indicates paleosol layers in fluvial strata. According to it, a typical paleosol layer is identified at the top of the 8th Member, Lower Shihezi Formation in Sulige area, Ordos Basin, China. Besides the abnormal high Th/K, this paleosol layer is also characterized with low DEN, high CNL, low K and high Th. What's more, some atypical paleosol layers with normal high Th/K also show low DEN and high CNL, and they seem like higher resolution indexes in identifying paleosol than Th/K.

Hampson's conclusion is built on the base of high matured paleosol. After enough weathering, much feldspar is resolved. As a result, K is depleted in the strata, which forms an abnormal high Th/K. However, in much paleosol with a low or middle maturity after a short weathering, the K is not depleted seriously, so they show almost normal high Th/K. If identifying paleosol only by abnormal high Th/K, many paleosol layers with low and middle maturity will be lost. Anyway, paleosol with different maturity will become poriferous after weathering, showing higher porosity and lower density than before (of course, the density may become bigger because of calcification). It is a physical change which is not relate to mineral composition.

On the base the above analysis, correlation analysis among CNL/DEN, Th/K, DEN, CNL, K and Th are carried on. The result shows the high correlation of CNL and Th/K, CNL/DEN and Th/K, K and Th/K, which indicates high CNL and CNL/DEN are good indexes to identify paleosol.

After the CNL and CNL/DEN thresh value to identify paleosol is confirmed, they are applied in the 8th Member, Lower Shihezi Formation in Sulige area, Ordos Basin. A lot of paleosol layers are identified and a sequence stratigraphic framework is built in fluvial strata.

Key words: paleosol identification, logging information, fluvial strata correlation, sequence stratigraphic framework

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NEGLIGIBLE VEGETATION FORCING ON RIVER MEANDERING: LESSONS FROM THE GREAT BASIN, SOUTHWEST U.S.

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Much debate surrounds the study of the mechanisms responsible for the inception and progression of river meandering. While it is generally accepted that meandering requires favorable conditions of discharge, sediment supply, and bank resistance relative to slope, the controls of biotic communities, particularly vegetation, on run-off modulation and bank strengthening are subject of intense examination. Analysis of Paleozoic outcrop data demonstrates an apparent rise in meandering-fluvial deposits in concert with the evolution of macrophytes, although interpretations on the causal links between these trends are non-unique. To contribute to this debate, remote-sensing and ground evidence is presented from modern endorheic fluvial systems in the Great Basin of southwest U.S. The investigated fluvial systems are active and aggradational in landscapes that are either devoid of macroscopic life or that sustain a scattered plant biota adapted to desert conditions. Two exemplary case studies consist of the Amargosa River in southern Death Valley, California, and a set of terminal fluvial fans flanking the Great Salt Lake Desert of Utah.

The lower course of the Amargosa River displays an extensive (~200 km^2) meander plain where sinuous bends generated by channels < 35 m wide migrate laterally at rates of < 1.5 m/year. Out of 257 ground-checked meanders, 97.7% are devoid of plant life, ruling out direct controls of vegetation on bank stability. The Amargosa meanders' morphometry is in overlap with that of other sinuous vegetated channels, pointing to shared scalar properties. By comparison, smaller (< 50 km^2) meandering-fluvial fans active in the piedmont of the Great Salt Lake Desert bear a sparse shrub-dominated vegetation, with individual meanders displaying < 20% of their surface vegetated. These meanders are generated by channels < 40 m wide that migrate laterally at rates of < 0.5 m/year. Statistical analysis of meander morphometry reveals that mature meanders are invariably related to wider channels and larger catchments. At both the scale of entire fans or individual channel bens, no statistical correlation can be drawn between abundance of vegetation, channel sinuosity, or meander size. Rather, field evidence reveals that in many instances in-channel plants promote flow disturbance during floods, which generates scouring, cross-bar channel undercutting, and point-bar destruction. In summary, evidence amassed from two modern fluvial systems in the Great Basin can be employed to investigate external controls on river meandering. Shared scalar properties of sinuous channels irrespective of vegetation coverage, correlation between meander maturity and catchment physiography, and causal relationships between plant occurrence and point-bar degradation suggest that the role of macrophytes in promoting meandering is, at least in desert landscapes, negligible.

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3D ARCHITECTURE OF MIOCENE BOULDER CONGLOMERATES USING UNMANNED AIRCRAFT, PHOTOGRAMMETRY, AND GPR

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The Arikaree Group (lower Miocene) in the Wildcat Ridge in Nebraska, USA includes a thick (>20 m) channel fill of mostly clast-supported boulder conglomerates that forms the cap rock of the prominent Haystack and Little Haystack mountains (HLHM). The channels were deeply incised into the gently-sloping surface of the ancient Great Plains, fully 150 km east of the Rocky Mountain front. The boulder channel fill at HLHM exhibits prominent, continuous, large accretion surfaces 5 – 15 m in height and > 35 m in length. Boulders attain as much as 4.5 m in maximum diameter and they were derived almost entirely from calcium-carbonate cemented sandstones and siltstones within the local lower Miocene succession. Although these boulder conglomerates have been known for many decades, detailed examinations of lithofacies, sedimentary architecture, and bedding and bounding surfaces within the boulder channel fills were hitherto hindered by the inaccessibility of the exposures. Moreover, the sedimentology and paleohydrology of the streams that deposited them have yet to be addressed. We examined exposures using a combination of field mapping, 3D photogrammetry, and ground-penetrating radar (GPR) to truly elucidate the boulder channel fills for the first time. 3D point clouds and digital terrain models generated through structure-from-motion techniques provided a comprehensive and utterly new perspective on the deposits. We mapped ~2,000 linear meters of outcrop in this manner, and we obtained ~3,000 overlapping outcrop photographs from unmanned aircraft using manual flight. Vertical and overhanging cliff faces necessitated side-looking camera angles and tortuous flight patterns. We collected GPR atop some of these cliffs where access was possible. After processing field imagery, we mapped >100 bedding surfaces in detail, allowing us to reconstruct the 3D architecture of the boulder channel fill. Prominent, large accretion surfaces were rendered in 3D by the digitization of bedding planes and the mapping of exhumed ancient-bar-surface scrolls, and by correlating accretion surfaces in GPR profiles. A ~55 m-wide, compound, in-channel bar is exposed in transverse cross section. Accretion surfaces on both sides of the bar record downstream (eastward) migration and expansion of the bar to ~100 m in width. Elsewhere in the outcrop, bar accretion varies from north-northeast- to east-southeast. The presence of such very coarse, channel-filling boulder conglomerates in a continental-interior setting that is not a slope or base-of-slope alluvial fan system remains problematic. Adequate stream power for the transport of these very large clasts would seem to require absolutely large discharges and/or an increase in channel slope relative to prior conditions, and perhaps related to climate changes or uplift.

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PALEOGEOGRAPHICAL RECONSTRUCTION OF A MEGA-VALLEY USING PROVENANCE ANALYSIS AND DRONE PHOTOGRAMETRY, TURRONIAN FERRON SANDSTONE, UTAH.

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It has been hypothesized that the various delta complexes of the late Turonian Ferron Sandstone Member of the Mancos Shale Formation were fed by a single trunk river that experienced regional avulsions. It has been alternately suggested that the various delta complexes of the Ferron were fed by different tributary catchments. Provenance analysis of terraces in a compound incised valley of the youngest non-marine sequence of the Ferron Notom Delta indicates at least two tributary catchments fed a single delta complex. This lends support for multiple, versus single, catchment areas.

Analysis of terrace deposit shows distinct provenances as determined using quadrupole LA-ICP-MS of detrital zircons and trace element abundances of Samarium /Neodymium. Bulk sandstones extracted from different terraces show average Sm/Nd ages of 1.47 (± 0.02) Ga and 1.78 (± 0.02) Ga, a difference of over 300 Ma. Previously published data and new measured sections correlated with the use of drone photography, photogrammetry software and 3D outcrop models were used to identify valley terraces along strike and dip, which were then sampled in 13 individual terraces in the attempt to correlate these deposits. 3900 individual zircons were measured, of which 2983 concordant U-Pb age dates were obtained. Plotting the age spectra of these samples in a Multidimensional Scaling analysis (MDS) as an XY scatter reveals two distinct populations, suggesting two catchments.

The resulting paleogeography suggests a multi-trunk, compound incised Mega-valley that evolved to span 30 kilometres along strike and over 30 kilometres down dip. Such a system may be more analogous to the Brazos Delta, which is fed by two major tributary catchments.

CLEANING-UP TRENDS IN FLUVIAL CHANNEL FILLS: A DIAGNOSTIC PATTERN FOR SIDE BAR DEPOSITS?

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Fluvial channel fills represent significant sandstone accumulations. Identifying the nature of the fluvial system that has left the deposit is key to the understanding of the geometry and architecture of the sand bodies in subsurface.
In general, it is stated that most of the channel fills display a fining-up pattern, which is sometimes considered as diagnostic from "bell-shapes" on wireline logs. It is also generally admitted that the braided streams produce accumulations of clean sands with a thin or no fining-up cap, producing a "blocky" response. Hence, the identification of river types in subsurface is often based on the empirical interpretation of the relative response between two end members: well-expressed fining-up trends of supposed fine-grained meandering streams on one side and cylindrical responses of supposed proximal braided streams on the other side.
The study of several wells from a Permian fluvial formation has shown that amidst the typical fining-up and blocky responses, cleaning-up trends with "funnel shapes" are repeatedly observed. They are not abundant but they are quite ubiquitous and could be found in several wells; one of the wells even shows a vertical succession of three of these sequences.
Thanks to a significant amount of core, these "abnormal" cleaning-up sequences could be interpreted as the result of the downstream migration of side bars in low sinuosity systems, transitional from braided to meandering. Spits are formed at the downstream end of the side bars; the protected pools that are individualized between the spits and the channel margin allow deposition of fine-grained facies at low water stage. The lee side shore of a bar behaves as a mini-beach, where few wave-built structures may be recorded. The top of a bar shows coarser facies and chute channel incisions generated at high water stage.
The complete recording of the bar migration starts with a typical fluvial channel lag with gravels and few mud clasts and wood debris corresponding to channel base deposits; it is rapidly overlaid by thinly bedded fine sandstone to silt, which corresponds to the protected pool developed behind the spit on the downstream part of the bar. Above, a coarsening up-trend is recorded, from rather fine sandstone at the base up to coarse facies, deposited by avalanching on the shallow part the lee side of the bar during floods. This upper interval is where wave structures are seldom observed.
It is therefore proposed that coarsening- and cleaning-up patterns observed in subsurface within purely fluvial series may be diagnostic of side bar deposits laid by low sinuosity fluvial systems, which has important consequences on the prediction of the sand body extension and distribution.

TITLE: IMPLICATIONS OF RIVER TRANSITION AND ITS APPLICATION IN A SUBSURFACE AREA

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We describe characteristics of braided–meander transition characteristics and its sedimentary sequences. With the evolution of transition of river, abandoned channel could be generated. We classify abandoned channels into three types: avulsion, chute cut-off and neck cut-off based on the correlation between sinuosity and channel abandonment. Our study on the sedimentary characteristics and river's transitions from proximal to distal zones in Permian fluvial outcrops of the Beijing suburbs leads us to understand the main factor that causes the meander to braided transitions; that is the change in sediment supply, which itself is caused by changes in climate conditions. Three abandoned channels have been distinguished in this outcrop study. Furthermore, we have studied a typical fluvial Permian gas field in the Ordos Basin as an application to subsurface formation. We analyze the distribution of fluvial deposition using braided– meander transition and abandoned channel patterns. Our study has revealed that river type changes occurred from braided to braided–meander transition and then to high-sinuosity meandering channel from the northern to the southern part of the gas field. Three abandoned channels were also identified in the transitional and meandering belts in the southwest part of the gas field. Thus the concept of braided–meander transition and new ideas of abandoned channels are helpful for us to understand the fluvial-environment changes in the geological time.

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THREE-DIMENSIONAL DISTRIBUTION CHARACTERISTICS OF MIGRATION ARCHITECTURE ELEMENTS OF MEANDERING RIVERS BASED ON A SLICE SIMULATION EXPERIMENT

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The responding characteristics of section structures and planform evolution of meandering channels have arisen a wide public concern around the world. In recent years, attention has been paid to the internal structures and migrating architectures of meandering point bars. In order to deepen the anatomy of responding characteristics from the perspective of morphology and profiles of meandering rivers, this paper used a kind of point-bar "cake-like" slice model to simulate the different migrating structures, by adopting the dispersal plasticine clay-sands slice experiment.
The experiment was divided into three stages. In the first stage, five groups of various colors of dispersal plasticine clay-sands were used as the material for simulating the five periods of fluvial evolutionary course. Secondly, 5 stages of different migrating meandering rivers were simulated under the 6 migration patterns. The transverse and longitudinal profiles were cut along the simulation point bars. Finally, 6 kinds of meandering point-bar "cake-like" slice models were presented by using the transverse and longitudinal slice methods.
Studies have shown that, with the same migration structure, there are regular changes in the dip angles of the lateral layers of different sections. While in different migration structures, the dip angles of the lateral layers of the sections in the same direction are also various. Based on the corresponding relationship between dip angle changes and migration structures of different lateral layers, 6 sets of coupling models of meandering river migration and reservoir architecture of ancient paleochannels can be established. The models were successfully used to guide the reconstruction of the sedimentary process of the ancient paleochannels.

TITLE: Form, Evolution and Controls of a Jurassic Incised Valley-fill: Middle Part of the Western Sichuan Depression, China

AUTHORS (FIRST NAME, LAST NAME): Junlong Liu[1] Dongsheng Sun[1]
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ABSTRACT BODY:
The second member of the Middle Jurassic Shaximiao Formation in the rejuvenated Western Sichuan Foreland Basin contains tens of meters thick incised valley successions. Incised valleys have been widely discussed in traditional models; however, quantitative and detailed analyses of geometric variations and their interpreted controls on ancient incised valleys have rarely been attempted in the past. Using an integrated dataset of seismic profiles, well logs and cores, this study quantifies the geometric parameters of incised valleys and investigates the smaller-scale depositional patterns. (1) During this period, incised valleys (IV) were 5-17 km wide, 20-60 m deep and traceable for 120 km along their axis, placing these valleys among the longest seismically imaged incised valleys in the world. (2) Three nested incised valley successions IV-1, IV-2 and IV-3 can be identified. Except for IV-2, the incised valleys decrease in width and depth downstream. (3) In the downstream segment, the role of tectonism diminishes gradually, and periodic base level changes control the form and evolution of the incised valleys. A downstream decrease in the stream power appears to be responsible for the decreasing trend in the incised valley geometry.
Keywords: ancient incised valley; geometry; controlling factor; quantitative model; foreland basin

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PRESENTATION TYPE: Oral
CURRENT THEME: Theme 2: The clastic depositional system
CURRENT SUBCATEGORY: 2.1 Fluvial facies models: recent and future developments

Facies Model of Contemporaneous Reverse Faults Controlled Alluvial Fan-Fan Delta Glutenite —Example From P_3w Formation, B25 Block, Mahu Sag, Junggar Basin

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Questions:

In terms of alluvial fan-fan delta depositional system developed under the extrusion background, controls of contemporaneous reverse faults on glutenite sediments and the preservation degree of fine-grained sediments in distal alluvial fan, have not yet been paid enough attention. More examples of efficient oil reservoirs characterized by high lateral connectivity that developed within alluvial fan-fan delta depositional systems were well explored. These cases challenged the classical facies succession of proximal alluvial-fan, middle alluvial-fan and distal alluvial-fan for alluvial fan and that of fan-delta plain, fan-delta front and pro-fan-delta for fan delta.

Goals of this study:

1) Discuss problems concerning with alluvial fan-fan delta depositional system developed in extrusion background, as follows:

Can the fine-grained sediments in distal alluvial fan, characterized by poor reservoir property, be able to preserve effectively in strata records? And can the fine-grained sediments in distal alluvial fan be able to separate the favorable braided-channel sediments developed in middle alluvial-fan and fan-delta-plain effectively?

2) Establish facies model of contemporaneous reverse faults controlled alluvial fan-fan delta glutenite .

Conclusions:

1) Junggar basin is a typical extrusion basin in western China. The study area was in an extrusion stress setting during the deposition of the P_3w formation.Contemporaneous reverse faults were well developed and controlled the erosion of the hanging wall and controlled the distribution of glutenite sediments in P_3w formation. The forwarding evolution of the contemporaneous reverse faults results in the progradation of the glutenite sediments in P_3w group, upward-coarsening trend, upward stronger hydrology and stronger erosion capability of the overlying strata on the underlying strata.Furthermore,the relatively well developed gravity flow sediments (structureless, red muddy matrix-supported and erected floating gravels rich) which have strong erosion capability result in the stronger erosion on underlying strata, especially on the fine-grained sediments developed in distal alluvial fan. And subsequently result in the lower preserved capability of the fine-grained sediments developed in distal alluvial fan.

2) Because of the syn-deposition and periodic active characteristics of the contemporaneous reverse faults, the hanging wall of each contemporaneous reverse fault can be a secondary source area and the former sediments on it can be retransported and deformed easily. Additionally, the front of multi-superimposed prograding bodies can form steep sedimentary slope break and result in collapse-originated gravity flow sediments.

3) In summary, the forwarding evolution of contemporaneous reverse faults results in the progradation of the alluvial fan-fan delta glutenite and the fine-grained sediments in distal alluvial fan can hardly be widely preserved in strata records. The middle alluvial fan and fan-delta plain are both dominated by thick, coarse-grained braided-channel sediments and they can be defined as middle alluvial-fan&fan-delta-plain association facies.Therefore, a facies model can be summarized as follows:

Proximal alluvial fan (channel flow belt)～middle alluvial-fan&fan-delta-plain association *(braided flow belt)～ fan-delta-front (subaqueous distributary flow belt)～pro-fan-delta&shore-shallow lacustrine(fine-grained sediments belt, associated with gravity flow sediments).*

Keywords: contemporaneous reverse faults, alluvial fan-fan delta depositional system, glutenite, the fine-grained sediments in distal alluvial fan, Mahu sag in Junggar basin, P_3w Formation

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A Comparative Study of Different Modeling Techniques to Predict the Performance of Distributary Channels Dominated Deltaic Reservoirs

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Abstract: To date, the pilot test areas of old oil fields in eastern China usually have a very dense well pattern. But around them, there are still lots of areas with wide-spaced wells. How to predict the distribution of sand bodies and to increase the prediction coincident rate by using the results of dense well pattern anatomy in these areas , has not been fully investigated yet.

The study area is located in Sazhong block of Daqing Oilfield which has one of the maximum density of well pattern in China, at about 280 wells/km^2 (50-60m of well spacing) on average, and we take the distributary channel dominated deltaic reservoir as our main research object. First, by utilizing the abundant subsurface data, we finely characterize the sand body distribution in the workspace, and according to that, the geometrical parameters of the sand bodies have also been extracted. Then, we vacuate the wells pattern to 28wells/km^2, and use different stochastic modeling techniques to predict the distribution and performance of the sand bodies. Finally, these prediction results are compared with the above result of dense well pattern characterization by mean of visual inspection, facies accordance rate and the directional connectivity of static and dynamic data. In this paper, there are three modeling techniques used to compare: (1) sequential indicator simulation (SISIM), (2) object-based modeling (OBM), and (3) multiple-point statistics (MPS), and we use the geometrical parameters extracted from the dense well pattern reservoir to constrain models constructed by using each stochastic reservoir modeling technique.

The results show that the prediction performance of SISIM algorithm is much worse than that of OBM and MPS algorithms. And, although OBM and MPS algorithms both can model the branching characteristics of the delta channel sands, MPS algorithm performs a higher facies accordance rate. In consequence, we believed MPS method is more fit for distributary channel modeling. Besides, this paper also studies the relationship between prediction effect and well spacing in MPS method. By comparing and analyzing the prediction results under different well spacing, we have discovered that the prediction accuracy will decrease when well spacing added. In addition, we find the limitary prediction distance of well spacing is 300m, beyond which the sand body can no longer be effectively predicted. The above research can help us better predict the reservoir and has a certain guidance for later adjustment and arrangement of the well pattern.

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Hierarchical Modeling Method Based on Multi-level Architecture Surfaces Restriction and its Application in Point-bar Internal Architecture of Complex Meandering River

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Abstract: Until now,the modeling methods of point-bar internal architecture has still not been fully developed. Traditional methods for point-bar architecture modeling usually require a finer mesh which is more computationally expensive, and upscaling the model can possibly generates a misleading model. Consequently, a systematic approach is needed to improve the modeling process.

This paper presents a hierarchical modeling method of point-bar internal architecture based on multi-level architecture surfaces restriction. Unlike the traditional methods, this method comprehensively adopted techniques of surface restriction and heterogeneous grids to establish the internal architecture model of point-bars. First, the related bounding surfaces of point-bar architecture elements(lateral accretion beddings and lateral accretion bodies) was generated under the patterns and analysis results of reservoir architecture .Then the reservoir architecture model of a single point-bar was established by the method of multi-level architecture surfaces restriction which segmented and encapsulated the architecture elements as their spatial stack sequence. Finally, the model of complex point-bar sand body can be formed by splicing and assembling different single point bars using the hierarchical modeling method.For ease of later numerical simulation, a method of inhomogeneous grid upscaling have also been designed, which not only achieved the accuracy of the lateral accretion beddings modeling with less grids ,but also realized the simulation of the internal properties of the architecture.

This method have been validated in the north region of NmIII-2 layer of Q oilfield featured by complex meandering river environment. Compare with the original model,the new one can accuracy reflect the spatial distribution of different levels of architectural elements and have a faster convergent speed. The simulation results can also help to raise the accuracy of production history matching ,and have a certain guidance for adjustment and tapping the potential of remaining oil and water-flooding optimization in fluvial reservoir,which achieved a good development result.

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HETEROGENEITIES WITHIN A LARGE-SCALE FLUVIAL POINT BAR SYSTEM: FALSE RIVER, LOUISIANA

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The Holocene False River point bar was cut off from the Mississippi around 1722 and provides an excellent opportunity for studying the internal architecture of a large-scale point bar through geophysical logging and analysis of sediment cores. Major reorganization of the point bar occurred in the wake of flood events, resulting in large scale division of the bar complex at least ten times during its accretion over ~1000–1500 years. As expected from studies of small-scale systems there is a general fining of sediment up-section across the entire bar. Nonetheless, high-porosity sand-rich units are found within the lower part of the point bar throughout the system, albeit these being more thickly developed in the upstream parts. Deterioration of sediment sorting is noted towards the end of point bar accretion, especially in the apex area and in the downstream part of the loop. In particular, this occurs after the original simple meander reorganized into a compound point bar with smaller meanders formed within the larger system. Coring within the channel tie, which is now plugged with sediment, reveals small-scale heterogeneity with sand-rich facies adjacent to predominantly poor-quality muddy facies. Two coarsening up cycles are observed and interpreted to reflect small delta lobes building into the new oxbow lake. End-member analysis has identified four grain-size components that are linked to different current flow regimes, the coarsest being related to high energy, flood conditions in the channel thalweg.

Four near-surface (~9–30 m) 2-D SH-wave high-resolution (1.5 m) seismic reflection profiles (~750 m total) confirm the architecture of ideal point-bar models. We highlight two results (1) shear impedance inversions correlated against electric well-log data show unexpectedly high impedance in clay-rich sediment packages and lower impedance sand-rich sediment packages, that is likely the result of early-stage diagenetic processes such as compaction and dewatering. (2) By forward modeling, dip-affected reflectors at 750 locations, we see an albeit weak trend of increasing dip angles toward the paleo-thalweg where electric logs indicate also finer-grained sediments

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REVERSE-TIME MODELING OF CHANNELIZED MEANDERING SYSTEMS FROM GEOLOGICAL OBSERVATIONS

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Meandering systems shape the marine and terrestrial landscapes by their temporal and spatial evolution[a]. Witnesses of this evolution can be observed on the depositional environments crossed by these channels. Among them, lateral point bars result from the channel migration, abandoned meanders are created by stream rectifying and abandoned channels originate from avulsion.
Once buried, the channelized systems are good candidates for natural resources storage thanks to the diversity and the volume of the resulting deposits[b]. The understanding of the internal architecture of facies is thus crucial for resource exploitation.
Satellite and LIDAR (Light Detection and Ranging) images permit current system studies. Subsurface architecture can be imaged by seismic or GPR (Ground Penetrating Radar) images. These techniques give a good evaluation of the whole system last channel path. However, anterior stages, when spared by the erosion, can only be observed locally. Indeed, the reworking of the channel belt by lateral and downstream migration makes it difficult to observe the geometrical or chronological features of anterior deposits.
We propose a simulation method of channelized systems conditioning to available information. Among them, the subsurface imaging often permits to identify the last system stage and the abandoned meanders, thanks to their muddy filling after the abandonment time, that contrasts with the channel belt. Lateral point bars can also be observed, witnessing of meander paleo-migration direction. Sometimes, well data inform on the facies (e.g., muddy, sandy). The method presented here starts from the last channel path observed on the seismic image and goes back in time by reverse migration to reconstruct anterior channel paths. This stochastic migration model[c] is inspired by the analysis of historic Mississippi maps. According to a chronology simulation based on spatial and statistical criteria (e.g., distance and orientation to the current channel, abandonment probability distribution), abandoned meanders are integrated at the relevant time step inside the main channel path. Erosion of abandoned meanders is addressed by abandoned meander simulation inside the meander belt. The probability distribution of the simulation parameters can be calibrated on geometrical criteria observed on the abandoned meanders spared by the erosion, but also on statistical criteria observed on sedimentary analogs such as the Mississippi river.
An application of the complete method is proposed on 3D synthetic data and demonstrates its applicability on simple contexts.

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EFFECTS OF INHERITED RESISTANT LAYERS ON SHAPE AND LONG-TERM EVOLUTION OF THE EEMS-DOLLARD ESTUARY (THE NETHERLANDS/GERMANY)

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Erodible or erosion-resistant layers are widely acknowledged to be important for fluvial and estuary morphology and sedimentary architecture, but little is known about their effects on long-term evolution of Holocene estuarine morphology. In this contribution we show how the presence of inherited resistant layers determine the position of confluences and bars along the entire Eems-Dollard estuary. This estuary, located on the Dutch-German border, has served for decades as a prime example for autogenically developed systems worldwide. By comparing detailed historical bathymetry maps of the last two centuries to the recently mapped position of resistant Pleistocene clays and tills, we demonstrate that resistant layers at critical positions (ca. 10-15 m – MSL or two-thirds of the maximum channel depth) cause channels to widen locally where these layers are present. Channel confluences, on the other hand, preferentially form where resistant layers are absent. Estuary widening leads to mid-channel bar formation, and bend curvature subsequently causes the effect to propagate at least a meander wavelength in landward direction. The importance of resistant layers increases when sediment is exported from the system, for example during dredging. Erosion-resistant layers also occur in many other estuaries and deltas, because depth of channels is similar to thickness of Holocene wedges underlain by harder layers until dredging and channel confinement leads to deepening. Our results show how inherited geology controls the evolution of fluvial and tidal sedimentary systems and challenge the view that these are predominantly formed by hydromorphodynamics. The insights on the effects of inherited geology on channel-bar patterns will help to better manage modern estuaries in a sustainable way and to understand and predict channel belt dimensions in the fluvial rock record.

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HOW STABLE ARE MULTIPLE CHANNELS IN A DELTA? AVULSION AND BIFURCATION IN THE LATE HOLOCENE RHINE-MEUSE DELTA, THE NETHERLANDS

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Deltas have multiple bifurcating channels, that change their position over time (avulsion), to follow the path of the steepest downstream gradient. Gradients are for example affected by sedimentation, subsidence, changing backwater effects, and tidal incursion. In addition, also local meander bend radius at the avulsion point determines which branch is favoured. Given the difference in total hydraulic friction in the channels, a network with multiple channels would be less stable than a single channel. This suggests that evolution towards a single main channel in a delta is most favourable.

To test this hypothesis, we focus on late Holocene avulsions in the Rhine-Meuse delta, the Netherlands. From 2500 yr BP onwards, a large scale reorganization of the delta network took place in which a single main Rhine branch silted up in favour of five new branches that eventually evolved into three main branches, when the rivers were embanked around 800 yr BP. This suggests that the delta did not reach the most stable single channel configuration from the preceding period within this timespan. It raises the question what factors determine the most long-term stable channel configuration on a delta scale and how much time does it take to reach this stable situation.

To this end, we reconstructed the chronology of these avulsions in high detail and in a 1-D bifurcation model we explored the controls on the stability of these river branches. We show that in the early stage of the avulsion sequence, human reclamation in the lower delta peatland caused the connection between marine ingression and fluvial crevasse channel systems. This formed two new Rhine branches towards the Meuse-estuary tidal inlet around 2000-1500 BP. After these anthropogenically enhanced avulsions, discharge was rerouted into another new branch formed from 1500 BP onwards, which gradually developed towards a large channel in ca. 500 years. Before this channel could grow into the single main channel in the delta, however, other secondary branches were prevented from silting up by humans for navigational purposes and a multi-branch delta remained. These results help to understand the configuration and time control of channel belts in ancient fluvial deposits.

FLUVIAL-AEOLIAN INTERACTIONS WITHIN ARID CONTINENTAL BASINS: INSIGHTS FROM THE KAYENTA FORMATION, WESTERN USA

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The sedimentary fill of arid continental basins commonly comprise deposits of fluvial and aeolian environments. While the distribution and preservation of different facies associations within each environment are reasonably constrained from comprehensive past studies[1,2], the relationships between deposits of coeval environments, and the temporal evolution of sediment through environments, have received comparatively little attention despite their potential to affect both basin-scale fluid migration and reservoir quality.

We present results from interactions of fluvial and aeolian deposits of the Kayenta Formation across the Colorado Plateau, USA, from proximal to distal settings, along with insights into the allocyclic controls upon them. These studies are based upon extensive regional fieldwork to examine the sedimentology, utilising 3D photogrammetry techniques to examine geometries and interactions, as well as comparing and contrasting field data to a small core study on the Leman Sandstone reservoir in the Southern North Sea, UK.

Fluvial-aeolian sediments of the Kayenta Formation preserve associations of varied reservoir quality. Relationships between them are spatially predictable, governed by one system's dominance. A dominant aeolian system limits fluvial sediments to interdune corridors and controls localised sediment supply, resulting in flash-flood and debris facies of moderate reservoir quality, comprising reworked sediments of aeolian calibre and texture. Dominance of the fluvial system restricts aeolian bedforms and preserves extensive ephemeral fluvial sediments of poor reservoir quality, with fluvial textures dominated by intraformational and extraformational sediment. The temporal evolution between systems preserves unique facies, but a switch in dominant system takes place quickly, severely limiting the vertical extent of interactions and potentially isolating reservoir intervals of basin fill.

Field data coupled with 3D photogrammetric models allow reconstruction of these ancient channel forms and dune fields, providing useful information for quantifiable reservoir models. This can help better characterise basin-scale migration and reservoir quality within the basin fill. We apply our model to the Lower Permian Leman Sandstone, a principal gas reservoir in the Southern North Sea Basin, adding increased complexity to further enhance recovery.

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Sedimentary characteristics of braided river - meandering river and a discussion of the river transformation model: the Neogene Guantao Formation, Bohai Bay Basin, China

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Fluvial facies sandbodies are important reservoirs for oil and gas resources. It is of great significance to study fluvial sedimentary reservoirs, the sedimentary characteristics of fluvial sandbodies and the evolving law of fluvial facies clearly. In this study, the sedimentary characteristics and evolution patterns of braided river to meandering river were analyzed in the Neogene Guantao Formation in Gudong oilfield, Bohai Bay Basin, China. The Gudong oilfield is located on a large north-south trending drape anticline structure reservoir, which is developed on the background of the Mesozoic buried hill. Data sets used in this investigation consist of seismic, well logs and cores. The Neogene Guantao Formation in the Bohai Bay Basin was the study subject, which was penetrated by 561 wells, eight of them were coring wells. Gamma ray (GR), acoustic(DT), resistivity (RD, RS), and spontaneous potential logs (SP) from the well logging data were selected in this research. The braided river mainly develops three kinds of sedimentary microfacies, such as channel, heart beach, overbank sand and floodplain. The meandering river can be divided into the high sinuosity meandering river and the low sinuosity meandering river. There are point bars, abandoned channels, crevasse splay, natural levee and floodplain developing in high sinuosity meandering river, which is isolated in the longitudinal direction each two stages of river. The point bar is a main architecture unit in it, which is multi-stage superimposed development in plane. The curvature of the high sinuosity meandering river is between 1.7-3.5. The sedimentary facies point bar, crevasse splay, channel, natural levee and floodplain develops in a low sinuosity meandering river which curvature is between 1.2-1.5. Affected by datum change, the study section experienced sedimentary evolution from braided river to low sinuosity meandering rivers to high sinuosity meandering river. The change in sedimentary environment caused different types of fluvial sand bodies, which show different morphological response characteristics in profile, and also show different features in plane. Because of its high energy and large sediment carrying capacity, the sandbodies of braided rivers generally have large thicknesses, and overlap in the longitudinal direction. The erosion effect between two meandering rivers is smaller, and a certain thickness of mudstone develops between two meandering rivers, which makes them vertically isolated. Finally, combined with the longitudinal evolution sequence in the study area, based on the identification of depositional environment and sedimentary facies in different layers, the river type transformation mode was established.

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ROLE OF CHANNEL-ABANDONMENT MECHANISMS IN GOVERNING THE PRESERVED FORM OF POINT-BAR DEPOSITS

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Active reaches of modern rivers are widely considered as analogues for deposits of preserved fluvial successions. However, the dimensions and facies distributions measured from point-bar deposits associated with modern meanders that have been abandoned as a result of avulsion, are more likely to be representative of point-bar morphologies preserved in the rock record. Three main types of river-reach abandonment are recognized: (i) neck cut-off, where the up- and down-stream limbs of a meander bend intersect in response to bend tightening [1,2]; (ii) chute cut-off, where a cut-through channel links up- and downstream limbs of a meander [1,2]; and (iii) avulsion, where a channel reach changes orientation, thereby abandoning its previous reach [2]. The evolutionary behavior of an active fluvial channel reach markedly influences the mechanism of meander-loop abandonment; each cut-off mechanism results in the development of an abandoned channel segment with particular facies and geometric characteristics [1,2]. In this study, geometrical and morphological observations were made from 220 abandoned point-bar deposits from 11 active rivers to assess styles of meander loop abandonment. Five types of individual loop cut-off, and 8 cut-off groups (i.e. repeating patterns) are identified. The most common individual cut-off type is neck cut-off (52%), and the most common group stacking type is "nodal, unidirectional" (i.e. where the apices of overlapping point-bar deposits share a common azimuth; 18%). From an analysis of the preserved planform dimensions (width and length), of abandoned point-bar bodies, equant (1:1) and elongate (1:<1) shapes are almost equally prevalent, revealing a previously unquantified geometrical disparity between active and abandoned fluvial point-bar deposits. Elongate point-bar sandbody shapes and variability in scroll-bar morphology are currently underrepresented in 3D geological models of ancient fluvial point-bar deposits. Additionally, post chute cut-off, the shape of the resulting meander bend encourages cannibalization of the previously deposited and genetically linked point-bar deposit. Therefore, the preserved fluvial stratigraphic record is likely biased towards point-bar deposits that were abandoned via neck cut-off, rather than chute cut-off, which is an important consideration for fluvial facies models. This study has improved our understanding of the geometry of preserved fluvial point-bar deposits, which in turn, may aid in building more accurate reservoir models and refining the prediction of sandbody connectivity.

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TITLE: CHANNEL PATTERN CLASSIFICATION AND ITS INTERNAL STRUCTURE CHARACTERISTICS IN A SANDY BRAIDED FLUVIAL SYSTEM

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Sandy braided river deposits formed from different sedimentary processes have different internal structure characteristics. However, research concerning this difference is insufficient, which significantly limits their guiding value for subsurface prediction. To address this key problem, six outcrops of the Rockcave Member from the Yungang Formation in Datong Basin, north China, were investigated and detailed measurement were conducted. In the Rockcave Member, three deposit units are identified including channel, channel bar and overbank. The channel units are mainly comprised by lithofacies assemblages of trough cross bedded sandstone and ripple cross bedded sandstone, with basal concave-up erosional surfaces, whereas the channel bars are composed mainly of medium- to coarse-grained sandstones with tabular cross bedding and minor ripple or trough cross bedding. The overbank deposits consist mainly of lithofacies of laminated mudstone with thin beds of fine-grained sandstone. According to the different sedimentary characteristics, sandy braided fluvial system can be further subdivided into wandering braided river and bifurcated braided river. Both of the two braided river types develop channel bars and channels, yet the scale and shape are distinct. In the bifurcated braided river, channel unit is characterized by multidirectionally dipping trough cross bedding with low average width-to-thickness ratio, which suggests strong basal incision. Thus incision results the channel bars are separated completely by the channels and prone to behave as downstream accretion. Multiphase accretion results the multistory development of the downstream inclined interlayers in the channel bar. Lag deposits are pervasively developed at the bases of bedforms showing poorly sorted mudstone intraclasts. For the wandering braided river, the overall geometry is asymmetrical due to the lateral migration of superimposed, unidirectional bedforms. Large-scale trough cross bedding develops in wandering channel units and the average width-to-thickness ratio is higher than that of the bifurcated channels, which indicates weak basal incision. The laterally migrating bedforms form large-scale channel bars, which cannot be completely cut by wandering channels, and interlayers are rarely developed in this kind of channel bar.

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Study on Relationship among Single Sand Bodies of the Lake Delta Front

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Sand bodies reservoirs of lake delta front consist of two kinds of single sand body, underwater distributary channel and distributary mouth bar. On the basis of characteristics of the delta single body in the short-term base-level cycle, the relationship among lake delta front single sand bodies was studied by analyzing the variety of accommodation space and sediment alimentations, as well as the process of channel divagation in short-term base-level cycle. The results show that the relationship can be divided into two types, lateral splicing and vertical superposition. Specifically, lateral splicing is comprised of different contact splicing with adjacent phases and channel migration; vertical superposition includes three subtypes, namely separated type, overlap type and overlay type. When $A/S \gg 1$(the ratio of accommodation space to sediment alimentations), the separated type is formed. While $A/S \approx 1$ is overlap, when $A/S < 1$ is overlay type. During the short-term cycle, three types of superpositions, including aggradation, progradation and retrogradation, are formed by the change of hydrodynamic energy, resulting in different vertical superposition relationships, which include three major types and nine subclasses.

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Distribution Characteristics and Quantitative Study of Branch Channel of Modern Shallow Delta Plain─Taking Orinoco Delta in Venezuela as Example

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In this study, a series of quantitative relations among the characteristic parameters of branch channel, attained from southern Orinoco delta, Venezuela, were established by using Google Earth. The southern Orinoco delta can be divided into two parts: the upper delta plain and the lower delta plain, about 80-100km away from the starting point of delta. The quantitative correlations between the distance and the number of channel, channel width, number of meander, width of bend apex were studied and which are different in the upper and the lower delta plain. The width of channel increased by 0.2-0.4 times and then bifurcated into 2 sub-channels with width around 0.6~0.9 times and 0.3~0.4 times ahead bifurcation respectively. The meander length is linear positive correlation with the apex width and has nothing to do with the meander location. The bifurcation angles are mainly distributed in 50~60° and 90~100°. The change of the riverbed's gradient can affect the tortuosity obviously. These results can effectively enrich the geological database and provide theoretical basis for reservoir prediction of the shallow delta.

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The Outcrop Heterogeneity Geology Modeling Study on Architectural Units of Original Uranium Reservoir and Carbonaceous Debris from Zhiluo Formation, East of the Ordos Basin, China

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Through detailed field investigation and fine profile realism, some different hierarchy of depositional boundaries are identified from the 11 to 25 m thick Middle Jurassic Zhiluo formation original uranium reservoir, and accordingly, this sandstone outcrop whose profile orientation perpendicular to paleocurrent is divided into three braided distributary channel elements, abbreviated as BCD-I, BCD-II, BCD-III accordingly. BCD-I at the bottom of the outcrop is characterized by single-storey, massive-bedded channel-fill bodies and a lenticular geometry. While, BCD-II and III at the middle-upper part are both characterized by stacked, multistorey channel-fill bodies and tabular, lenticular geometry accordingly. This reserch outcrop is a coarse-grained, medium grained, fine grained and very fine grained sandstone succession within which four lithofacies types (CSt、MSt、Sl、FvSl) occur in a predictable order as repeated fining-upward cycles. By the quantitative statistical analysis of the internal sedimentary boundary, architectural elements and lithofaces, it is shown that the number of high-level interface (3rd order and above) in BCD-I is less developed, and lithofacies is mainly composed of yellow medium-grained and fine-grained sandstone (MSt, Sl). Compared to other channel elements, the number and scale of high-level boundary in BCD-II is the largest, which reflects the hydrodynamic conditions during the formation of the channel is relatively strong. Lithofaces in BCD-II is mainly composed of yellow medium-grained and coarse-grained sandstone (MSt, CSt) that is characterized by the medium to large scale trough cross-bedding. There is one 4th order irregular erosional interface at the bottom of the BCD-III, which is apparently concave downward and cut into the underlying residual fine grained sediments, which reflects the scouring capability of water flow in the initial stage of the channel is very strong. The lithofaces sequence in BCD-III is relatively more completed, but mainly consist of yellow green very fine-grained stone (FvSl) and yellow fine-grained stone (Sl). In addition, there is plenty of carbonaceous debris (CD) whose main macroscopic occurrence is banded structure, and the secondary vein and nodular structure in the outcrop. In vertical direction, compared to BCD-III/I, CD is riched in BCD-II and it is often controlled by advanced sedimentary boundaries. Horizontally, the CD is concentrated in the central part of the channel elements, to both ends, the quantity is reduced, or not observed.

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THREE-DIMENSIONAL FACIES ARCHITECTURE AND HETEROGENEITY OF ASYMMETRICAL POINT BARS DEVELOPED BY MULTI-STATE ROTATIONAL SHIFTS

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Fluvial meander bends evolve through different modes of transformation: expansion, translation, rotation and combinations thereof. Commonly, as point bars expand and grow in size, they additionally undertake rotations by different degrees, with the orientation of channel migration changing repeatedly through various stages of bar development. The change in the direction of rotation of meander bends may lead to the partial erosion of bar deposits accumulated in the earlier stages of bar development, and to the juxtaposition of complicated mosaics of scroll-bar units in planform. The associated migration of the in-channel pool zone may also result in variations in the dip direction and angle of bar-accretion surfaces, and in the thickness of bar deposits in three-dimensions. However, the relationship between rotational shifts of channel migration and the resulting stratigraphic architecture and lithofacies distribution within point-bar bodies remains poorly understood due to limited outcrop or subsurface evidence of the facies architecture of such evolutionary history. To explore how the trajectories of channel migration, in particular through multi-stage rotational shifts, may influence morphology of point bars in plan-view and geometries and stratigraphic architecture in cross sections, a forward numerical stratigraphic model, the *Point-Bar Sedimentary Architecture Numerical Deduction (PB-SAND)*, has been employed to simulate a range of types of incremental fluvial point-bar rotation events using a combined geometric and stochastic approach. PB-SAND allows modeling three-dimensional architecture of point-bar elements with different evolution histories that comprise multiple stages of meander-bend rotations.

The modeling approach is constrained by quantified sedimentological data from real-world case-study examples stored in a relational database, the Fluvial Architecture Knowledge Transfer System (FAKTS). PB-SAND is able to simulate complex bar-growth histories and to incorporate facies architectures based on data from modern rivers and ancient successions that serve as geologic analogues. Informed by analogue data, the model is used to examine the three-dimensional sedimentary architecture of point bars through multi-stage rotational shifts associated with changes in autocyclic controls on channel evolution. The sensitivity of system parameters is also explored. The modeling results show that accretion geometries are significantly influenced by rotation of bar development. In particular, channels undergoing abrupt shifts in migration direction and relatively large angles of shift can determine erosion of significant volumes of older bar deposits, and result in increased bar thickness along the most recent migration direction. PB-SAND could be used to predict river response to on-going environmental changes, for instance, height peak discharge events that drive rotational adjustments, and to enhance reservoir modeling practice.

TITLE: Integrating fused spectral-decomposition seismic attributes and forward seismic modelling constrained by stacked sand body models to quantitatively predict sand bodies in meandering fluvial reservoirs

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Accurately characterising the boundaries, thicknesses, geometry, and stacked relationships of fluvial sand bodies is significant for improving production plans for remaining oil sources and enhancing oil recovery. Fused spectral-decomposition seismic attributes (SDSAs) and forward seismic modelling are usually applied to describe compound sand bodies. However, the method of reporting fused SDSAs using the Red-Green-Blue colour blending can only qualitatively describe the boundaries of sand bodies and the sand thickness, and documented forward seismic modelling is not effective for depicting the geometry of and stacked relationships between sand bodies. We propose the Support Vector Machine (SVM) algorithm as a new method that fuses high, middle, and low frequency SDSA to quantitatively depict sand thickness. The correlation coefficient of the fused SDSAs (predicted sand thickness) determined by SVM algorithm and sand thickness from wells is very high; this indicates that SVM is more accurate and reliable than the original root mean square (RMS) amplitude. The geometry, thicknesses, and stacked relationships of the sand bodies are characterised accurately by a forward seismic modelling optimization technique. The waveform response patterns of conceptual forward models and the fused SDSAs from the SVM algorithm are two crucial aspects of this optimization technique. Based on the predicted boundaries, thicknesses, geometry, and stacked relationships of the sand bodies, the sedimentary microfacies spatial distribution of the meandering fluvial reservoir is forecasted and depicted more accurately by combining core investigations and interpreting the well logs from the QHD 32-6 oil field, Bozhong Sub-basin, Bohai Bay Basin, China. This work could provide a useful technique to characterise sand bodies and sedimentary facies for other fields in a similar geological setting and for which a similar dataset is available.

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ANALYSIS OF ARCHITECTURE OF DELTA DEPOSITS OF THE YANCHANG FORMATION IN THE ORDOS BASIN

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The Triassic Yanchang Formation of Ordos basin in China has significant spatial variations of physical property and stronger heterogeneity, which results in the difficulty of the oil/gas reservoir exploration and development. Based on a large number of field outcrops, the sedimentary architectural interfaces and architectural units have been identified. Characteristic parameters of different architectural units have been extracted to accurately quantify genetic types of reservoir sandbody and its spatial distribution in the deltas.
According to the architectural units and time of interfaces, small scale interfaces such as crossbedding bedsets and crossbedding cosets, as well as large scale discontinuity surfaces and hiatus interfaces has been identified. Eight architectural units such as distributary channel (DCH), subaquous distributary channel (SDC), crevasse channel (CCH), abandoned channel (ACH), netrual levee deposits (NLD), distributary bay deposits (DBD), mouth bar deposits (MBD), sheet sand deposits (SSD) are identified. DCH consists of channel (CH), lateral accretion (LA), overbank fines deposits (OF), and NLD consists of laminated sand (LS) and OF, ACH consists of lake mudstone (LM) and CH. MBD consists of downstream accretion (DA) and slump deposites (SS) and LM.
Thus, normal delta and shallow water delta deposition are proposed to occur in the Yanchang Formation. Shallow water delta generally consist of compound channel, lateral migration channel and crevasse channel, sometimes only compound channel and lateral migration channel architectural units, lacking of mouth bar and sheet sand deposits. Although architectural elements of normal delta plain is similar to that of shallow-water delta, delta front consists of compound distributary channel, lateral migration channel, mouth bar and sheet sand deposits, sometimes only compound distributary channel, mouth bar and sheet sand deposits. Statistics show that sandbody width of distributary channel in delta plain is 24 to 276m, thickness 1.7 to 5.7m, and the width-thickness ratio is 11.9 to 52.1. In the delta front, subaquous distributary channel sand body has a width of 11 to 160 m, a thickness of 1.2 to 10.5 m, and an ratio of 9.2 to 43.1.

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The transformation of braided rivers and meandering rivers in time and space: A case study in Huanghua Depression, Bohai Bay Basin, China

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In modern rivers, river type transformation is common and there are two phenomena about the transformation. 1) For a particular river section, river type transforms in decades as a response to climate or source area change. This is transformation with time. 2) In the same river, river types change many times from the upstream to the lower reaches. Several sections are braided rivers while several are meandering rivers. This is transformation in space. There should be transitional type of rivers among the transformation. Deposition of the transitional river should be recorded both in time (recorded in vertical sedimentary sequence) and in space (recorded as sedimentary facies change on the plane). But there are few published reports about the transformation or transitional river deposition.

In this study, data from three oil fields in Huanghua Depression, Bohai Bay Basin are collected and a comparative study is made. The target layer is Guantao Formation in Neogene (Ng). Well logs, drilling cores and 3D seismic data are used in this study.

The upper and lower parts of Ng developed braided river depositions. Braided river sandstones superimposed and formed to thick layers in vertical. Sandstones deposited widely on the plane. River types change in middle Ng both on the plane and in vertical. There developed multi-channel meandering river systems in Kongdian oilfield while braided rivers in Yangerzhuang oilfield. In fact, distance of the two oil fields is only 40km. Drilling cores of a new well which is located between the two oilfields reveal that there deposited superimposed sandstones of both braided and meandering rivers. River type transformed with time in this well. At the same time, river type transformation happened laterally in the study area.

In this study, sedimentary characteristics, including lithofacies, petrology, grain size and sandstone distribution, of different types of rivers are analysed.

There are two major factors that influence the river type transformation. 1) The distance to source area; 2) neotectonic movement in middle Ng stage. Tuffaceous sandstone developed in middle Ng in the area. It is record of volcanic activity. It can indicate the active neotectonic movement in middle Ng stage. As a result of the neotectonic movement, tectonic subsidence accelerated and sedimentary basement rose rapidly. This is a reason of river type transformation in middle Ng.

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Reservoir Architecture Model of Sandy Braided River from Outcrops with Unmanned Aerial Vehicle and Ground Penetrating Radar

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Deposition of braided river is complex. Study of reservoir architecture model from outcrops can help to rebuild the process and evolution of braided rivers and to recognize the reservoir heterogeneity. A fine sedimentary model is useful in subsurface study of braided river reservoirs.
In this work, study area is in Erdos Basin, China. There developed typical sandy braided river outcrops and 12 profiles are well-exposed. The area is about 5km^2. The outcrops are formed by 2 large braided rivers of a huge alluvial fan in Jurassic and sandstone thickness of the layer is about 50m.
It is hilly landform in the area. In the study, it is found that the hills are formed by braided bar complex while the gullies are formed by fine-grained depositions among the braided bars and channels. The fine grained parts, such as flood plain deposition, are eroded and form to gullies by weathering. So, geomorphology of study area has a closed relationship with sedimentary facies and sandstone types. UAV (Unmanned Aerial Vehicle) is used in this study to scan the geomorphology and build a 3D geomorphology model of the area. Different kinds of depositional elements, especially braided bars and floodplains, can be recognized and interpreted with the geomorphology model and field investigation. The geometry parameters of braided bars are measured in the model.
Each large braided bar complex is result of river swing on the plane and superimposition in vertical. Coexistence of deposition and erosion makes reservoir architecture very complex. In this study, field investigation and GPR (Ground Penetrating Radar) are used to detect reservoir architecture of braided bar complex. Eight outcrop profiles are measured and characterized. A 3D GPR survey is gathered and interpreted.
Based on the above work, a 3D braided river reservoir architecture model from outcrops is built.

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Analysis of Microscopic Pore Structure and Distribution Characteristics of Microscopic Remnant Oil on Reservoir in Sabei Oil-water Transitional Zone

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ABSTRACT

In order to clarify the characteristics on various types of microscopic pore structure at production tail and their influences on occurrence and distribution of microscopic remnant oil, from a microcosmic view, getting a clear understanding of controlling factors on distribution of remnant oil in the later development stage and providing advice on enhancing oil recovery, with quantitative and identifiable methods. Combined with mercury injection analysis, fluorescence microscopic observation and cryopreservation thin section observation, reservoirs in Sabei oil-water transitional zone are researched systematically. The following results were obtained.

Pore throat radius are mainly distributed in 4-25μm, whose contribution is dominated by radius around 10μm. According to permeability classification and parameters of mercury injection, reservoirs of research zone are divided five types, dominated by I, Ⅱ,Ⅲ types, whose permeability classification are extra-high, high and medium, respectively.

Based on test on 18 core samples selecting from Well B2-60-FB271 in research zone and microcosmic occurrence, remnant oil can be divided into three types which are bound state, semi-bound state and free state, respectively. And the three types of remnant oil can be further subdivided according to shape and distribution. Bound state can be subdivided into three sub-types which are oil-film-shaped, adsorbed-particle-shaped and slit-shaped, respectively. Similarly, semi-bound state can be also subdivided into three sub-types: corner-shaped, throat- shaped and pore-center-precipitation-shaped. And free state is subdivided into four sub-types, including cluster, intragranular-shaped, intergranular-adsorbed-shaped and foggy-shaped. In production tail, with remnant oil of free state decreased, the rate of remnant oil of bound and semi-bound state increases naturally, contributing to remnant oil saturation reducing. Furthermore, there appear various types or sub-types of remnant oil in different types of reservoirs: remnant oil distributed in I type reservoir are dominated by intragranular-shaped and cluster, while remnant oil of adsorbed-particle-shaped is widely observed in I, Ⅱ,Ⅲ type reservoirs. It is interlayer and intralayer heterogeneity that mainly control the above differences, wAhich is also controlled by sedimentary microfacies, oil bearing grade and compaction degree.

Key words: microscopic pore structure, microscopic remnant oil, fluorescence analysis

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Reservoir Architecture and 3-D modelling of Braided River: Example from Shihezi Formation of Daniudi gas field in the Ordos Basin, China

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The reservoir modelling of braided river has been an important research object for long time due to the complex sand distribution. The Lower Permian Shihezi Formation in Daniudi gas field is the main exploration target for hydrocarbons in Northeastern Ordos Basin, China, which is considered to be a braided river deposition in previous study. This paper, which takes the Shihezi sandstones as an example, distinguishing sedimentary facies, learning sandstones architecture and building 3-D facies modelling based on drilling core analysis, well-logging interpretation, seismic data, and outcrop observation.

The results show that there are three kinds of facies in Shihezi deposition including channel, overbank, and floodplain. The channel sand bodies displayed low GR as trunks on well logging curve with more than 4m in thickness always have coarse grain deposition with trough cross bedding while the overbank composed by medium to fine sands shows finger like in logging with 1-2m in thickness. The floodplain is mainly made up of mud and other fine-grained sediments. The channel sand bodies distribute by S-N stripped shape, with wide range and large thickness. In general, the scales of a single channel are 1200-2500m in width and 4-8m in thickness. The relationship between width and thickness of channel is positively. There are three multiple superimposition patterns of channel sand bodies: vertical accretion, lateral accretion, and isolated pattern. The vertical accretion also includes vertical cutted pattern and vertical superposed pattern, while the former is primary. Reservoir modelling have been made through multiple-point statistic simulation and marked point process simulation according to architecture analysis, which show a better shape of braided rivers compared to other methods.

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Integration of High-resolution Outcrop and Subsurface Data to characterization and Modeling of Fluvial Reservoir,Su6 Block, Ordos Basin, North China

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In this paper, we use core, well log and seismic data to comprehensively characterize the reservoir architectures of braided river in the Upper Permian Formation in Su6 Block,Sulige Gas Field, Ordos Basin, north China, guided by the high- resolution channel complex patterns of outcrop in Datong, Shanxi Province, and finally build a 3D geostatistical model of the reservoir.

Firstly, reservoir units including channel and channel bar were recognized in the outcrop according to lithofacies, depositional cycle and sedimentary beddings. The channel is characterized of a fining and thinning upward sandstone conglomerate and with a convex-up geometric shape. The channel bar is definitively represented medium-fine sandstone with trough cross stratification and upslope planar cross-bedding. Bounding surfaces of channels and channel bars, acting as low-permeability baffles to fluid flow, were determined and we made a detailed description and measurement of their lithofacies, thickness, extended direction and distance, which form laterally discontinuous bounded compartments of the reservoir. A database of reservoir architecture elements of the outcrop braided river was built, including geometry lithofacies, shape, scale and configuration of every architecture unit, which would be used to calibrate the subsurface reservoir architecture characterization and modeling.

Secondly, subsurface reservoir architectures of braided river in the Upper Permian Formation in Su6 Block were studied comprehensively with core, well log, seismic and production data. (1) Different scale of architecture units of braided river was identified by core description and well log analysis, that is, channels belts, superimposed and single channels, which is analogue to that of the Datong outcrop. (2) The boundary of channel, that is, the barrier and baffle of the reservoir, was correlated with well logs guided by Datong fluvial outcrop and the scope and size of single channel and superimposed channel belts were detected from amplitude and variance slices of 3-D seismic data. (3) Flow units of the sandstone-conglomerate reservoir were divided within single fluvial channel according to physical property (porosity, permeability) calibrated with natural gas production data. Dimensions and shape of subsurface different reservoir architecture elements, and as well as reservoir connectivity, were compared to that of the Datong outcrop and adjusted accordingly.

Finally, the 3D numerical geostatistical model of the subsurface fluvial reservoir was built with object-based simulation. For this algorithm, each architecture element was populated as a discrete object with specific dimensions, geometric shapes, juxtaposition, and connectivity. The model honors all available subsurface and outcrop data, which could be used for assessment and prediction of reservoir performance.

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IS SILT THE MAIN DRIVER OF SEDIMENT GRAVITY FLOWS IN DEEP-MARINE ENVIRONMENTS?

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Deposits of turbidity currents, debris flows, and slides store the world's largest volumes of sediment on the planet. However, the physical processes by which these flows transport this sediment over distances that may exceed several thousands of kilometers and over gentle slope gradients to form submarine fans are poorly understood. Recent pilot experiments combined with theoretical models for sediment transport efficiency show that silt and very fine sand may play a pivotal role in this long-distance transport, because these sediment types are non-cohesive, have a low settling velocity, and can be present in the flows at extremely high concentrations.

The ability to interpret the shape, size, transport distance, and internal organization of submarine fans as a function of intra- and extra-basinal controls depends largely on accurate flow mobility predictions. Flow mobility is often expressed as flow efficiency, which depends on the maximum grain size (flow competence) and the maximum volume of sediment (flow capacity) a flow can carry. A combination of laboratory experiments[1] and theoretical models for flow competence and capacity[2,3] is used to show that, because of their low settling velocity, silt and very fine sand have a high mobility on gentle slope gradients, which extends to remarkably high suspended sediment concentrations (~50% by volume, thus close to the cubic packing density of water-sediment mixtures[1]). Non-cohesive silt and very fine sand are inferred to show a primary control on the long transport distance of deep-sea gravity flows, which extends to dense flows that have previously been associated with short transport distances.

In contrast to silt and very fine sand, the efficiency of flows to carry coarser sand and gravel over long distances is inhibited by their high settling velocity. In order to keep these coarse particles in suspension, this enhanced gravitational settling needs to be compensated for by enhanced upward directed components of turbulent flow. Theoretically, this can be achieved by increasing the bed slope gradient and increasing the density difference between the flow and the ambient water. However, the required slope gradients are most probably too high and too spatially constrained in the deep ocean for long-distance transport of coarse sediment, and the flow density cannot extend above the cubic packing density of sediment particles, which the silt-laden flows were already close to reaching in the laboratory experiments[1]. Moreover, the presence of finer-grained clay particles in dense flows also inhibits long-distance sediment transport, because the efficiency of such flows is inhibited by physicochemical cohesive forces between clay particles that attenuate the turbulent forces and often cause en-masse settling on gentle slopes, as shown in the laboratory experiments[1].

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LITHOLOGY VARIANCE IN DEEP MARINE SYSTEMS

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Process models, descriptive stratigraphic layering of architectural elements, and the hierarchical stacking of the same, provide a theoretical basis for predictions of depositional characteristics in deep marine clastic systems, regardless of the scale of consideration. These autocyclic controls sit within a broader spatio-temporal context, driven by first-order allocyclic processes that influence styles and combinations of autocyclic controls for any given system. Hydrocarbon exploration in deep marine systems relies upon predictive concepts to evaluate depositional character and infer resulting impact on reservoir parameters. One such parameter, Net to Gross, is broadly analogous to basic lithological variation i.e., the ratio of sandstone to siltstone/claystone, but for industry evaluations, the theory that underpins predictions of Net to Gross/lithology, is qualitative in output and difficult to translate quantitatively. From a scientific perspective, lithology and the industry parameter Net to Gross, do not lend themselves well to quantitative investigation due to the nature of research datasets which lack the quality and format of data needed and/or don't easily provide a sufficient corpus of data to robustly identify quantitative expressions of predictive concepts.

A simple classification of deep-marine architectural elements comprising Lobe, Channel-Fill, Overbank, Mass Transport Deposit (MTD), and Drape is used here in tandem with a simple hierarchy comprising Elements, Complexes and Systems, as the basis for a quantitative investigation of lithological variance in deep marine systems. A total of 98 depositional Systems have been analyzed from diverse stratigraphic and paleogeographic contexts, and contained within are 368 Complexes and 2686 Elements. This sedimentological breakdown is integrated with petrophysical interpretation to quantify lithology at all scales. Particular emphasis is placed on the key Lobe and Channel-Fill element-scale building blocks and their variants arising from several theoretical controls; spatial position within the feature, role of topographic confinement, dominant flow rheology (HEB vs HDT/LDT), and feature archetypes. Statistical tests of these theoretical hypothesis have been conducted on the dataset to identify most and least influential controls upon lithology, their magnitude of variance and dependencies between controls. This output provides the basis for robust quantitative prediction of lithology variance following construction of a sedimentological model/s via traditional sedimentological methodologies.

Sequence Stratigraphic Controls on Lower to Middle Carboniferous Siliciclastic Deposition in STACK, North-Central, Oklahoma, USA

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The STACK play in North-Central, Oklahoma is one of the most prolific hydrocarbon producing plays in North America. Recent production is concentrated within the Lower to Middle Carboniferous strata, which is a mixed siliciclastic and carbonate depositional system. The global transition from the Visean carbonate dominated world to the Serpukhovian siliciclastic dominated world can be identified within multiple cored wells in the STACK play. A sequence stratigraphic model based on these cored wells exemplifies harmonic progression of 2nd, 3rd, and 4th order sea level cycles along with their impact on carbonate vs siliciclastic deposition. The Kaskaskia 2nd order transgressive systems tract progresses through the Devonian into the Carboniferous Tournasian, which results in the widespread deposition of organic rich fine-grained siliciclastics during this maximum flooding interval. This is followed by a transition to a stable high stand systems tract in the Carboniferous Upper Tournaisian through Upper Visean, which allowed for re-establishment of a carbonate depositional system. Later, this carbonate system is choked out by the influx of siliciclastics during the low stand systems tract in the Carboniferous Serpukhovian. From here reservoir compartmentalization occurs within STACK due to superimposition of higher frequency 3rd and 4th order cycles on the Kaskaskia 2nd order cycle. Harmonic coupling occurs in the late Visean where a 3rd order low stand coincides with the 2nd order high stand. This is the last progradational push of the carbonate system and marks the onset of the siliciclastic influx. Serpukhovian deposition is dominated by the 2nd order low stand systems tract, and exhibits higher frequency 3rd and 4th order cycles that are dominated by siliciclastic deposition instead of carbonate deposition. This has significant implications because the reservoir quality within the STACK play will be driven by different variables and parameters depending on where the targeted interval is located within this sequence stratigraphic framework.

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DOWNSLOPE CHARACTERIZATION OF DEEP-WATER SLOPE CHANNEL SYSTEMS ALONG A 40 KM-LONG DEPOSITIONAL DIP-ORIENTED OUTCROP BELT, CRETACEOUS TRES PASOS FORMATION, CHILE

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Deep-water slope channels record sediment transfer processes in some of the most remote environments on Earth. Due to the relative inaccessibility of modern systems, outcrops are widely studied to elucidate the long-term record of deep-water sedimentary processes. Information on downslope changes in deep-water channel deposit character and architecture remains somewhat limited due to a paucity of outcrops that feature along-slope perspectives. We examine a 40 km-long depositional-dip-oriented segment of an ancient slope channel system from the Tres Pasos Formation, Magallanes Basin, Chile. The orientation and relatively continuous nature of the outcrop belt provides a unique opportunity to examine changes in grain size, sandstone thickness, and stratigraphic architecture for discrete channel elements (up to 30 m thick, 400 m wide) along the 40 km transect. Using these outcrops, we explore evidence for downslope changes in formative channel processes, such as sediment bypass, erosion, and deposition. We also constrain channel element stacking patterns along the transect, which inform the long-term impact of external and internal controls on the system. High-resolution GPS mapping of channelform surfaces and interpretation of photogrammetric models enabled development of a regional stratigraphic framework for the outcrop belt. Within this framework, we analyze changes in grain size and bed thickness statistics from 156 measured stratigraphic sections (cumulative thickness: 4752 m) through 409 channel element intervals.

Channel elements exhibit variations in grain size, internal architecture, and sandstone thickness along dip. Mean grain size decreases distally on average from upper coarse sand to lower medium sand, whereas maximum grain size does not appear to change systematically, ranging from very coarse sand to pebble in most areas. Amongst individual channel elements, the ratios of net sandstone thickness to gross stratigraphic thickness (NTG) and thickest amalgamated sandstone package to gross stratigraphic thickness (TSTG) both increase downdip. NTG increases downdip on average from 67% to 88% and TSTG from 33% to 61%. Analysis of sandstone thickness over stratigraphic intervals encompassing multiple channel elements (i.e., channel complexes) reveals that thick (>40 m) amalgamated sandstone packages are more common downslope, which is controlled by along-slope changes in channel element stacking patterns. Together, these data imply that bypass of coarse-grained detritus was more prevalent in updip zones (17-30 km from paleo-shelf edge), and that deposition of this sediment was elevated downdip (30-57 km from paleo-shelf edge). The results aid with interpretation of sedimentary processes and products along deep-water paleo-slopes, as well as predictions of updip stratigraphic traps in offshore petroleum systems.

Process-oriented deep-water lithofacies: Application and an example applied to the Cretaceous Point Loma Formation, California USA

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As understanding of the processes of sediment gravity-flow transport and deposition in deep-water systems has improved through direct oceanographic observations and numerical and physical modeling, it has become evident that the manner in which deep-water deposits are described and classified must evolve in order to capture the sedimentological features and trends that are necessary to deduce these processes. Deep-water lithofacies have been commonly described and classified using either the nomenclature of Bouma (1962)[1] or Lowe (1982)[2]. Although these classifications adequately capture vertical textural trends and differences in fabric, they lack some critical descriptive elements needed to interpret all important processes, conditions, and flow parameters involved in the deposition of sediment-gravity flow deposits. The recognition of the importance of 1) bedload transport, especially the formation and migration of bedforms of different scales, and 2) high sediment concentration flow processes (transitional flows, hybrid event beds, etc.) has highlighted the need for a more descriptive nomenclature to adequately capture the key recognition criteria for interpreting these features. The deep-water lithofacies classification we employ emphasizes a distinct separation of observations of composition, texture, fabric, fossil content, and stratal associations from interpretations of depositional processes. Lithofacies are first classified based on texture (grain size, sorting), then fabric (bedding, lamination, cross-bedding, cross-lamination, disruption). Particular attention is directed towards the characteristics of lamination (thickness, grain size range, sharp or gradual lamina boundaries) and cross-lamination and –bedding (preserved height/thickness, geometry of downlap/onlap/erosion surfaces, dip angle and direction). Disruption of any original sedimentary fabric is also characterized (vertical, horizontal, folding, bioturbation), as well as the boundaries of lithofacies (sharp, evidence of erosion, gradual, burrowed). These observations can then form the basis for process interpretation by first 1) determining the top and base of genetically-related strata deposits of individual and successive flow events, termed *depositional successions*, and then 2) relating the texture and fabric, and the vertical trends, to bedload and suspension-load depositional processes through modern and experimental analogs and relevant bed phase (e.g. Fedele et al, 2017[3]) and rheological regime diagrams. An example application of this method and nomenclature is presented using outcrops of the Cretaceous Point Loma Formation from near La Jolla and San Diego California USA.

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GRADIENT CONTROL ON THE INTERNAL ARCHITECTURE AND FACIES DISTRIBUTION OF SUBMARINE LOBES

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Lobate bodies deposited by distributary channels on submarine fans are more complicated than simple sand sheets typically used in geological models. They are made up of a hierarchy of nested bodies including lobe elements, lobes and lobe complexes. Their finest architecture reveals an organization of channels, mouth bars and fringes whose proportions, sizes, facies and distributions vary with depositional setting controlled mainly by slope gradient and grain size. Relying on high resolution seismic and core penetrations, a comparative study of three Quaternary Fans deposited on various gradients allowed to depict the internal architecture and facies of lobate bodies. The analysis was augmented by studies of outcrops and analogous deposits from tank experiments.
The Golo submarine fan on the eastern margin of Corsica, Mediterranean Sea is a Plio-Quaternary example of a small, sandy, steep deep water fan deposited on average gradients between 3° for the proximal part and less than 1° for the distal part. Erosive stacked sandy-leveed channels, are found in the proximal part of lobe elements. They transition rapidly to subtle aggrading channel geometries to end in relatively short unconfined sandy mouth bar deposits. Lobe elements stack in a clear retreating pattern forming 8km long, 2-3km wide lobes with 25m maximum thickness.
On the opposite end of the spectrum the Zaire Fan is a large mud-rich submarine fans deposited on average slopes between 0.5° for the proximal part and less than 0.1° for the distal part. Lobes are large bodies (20km long, 10km wide for 25m thick) but only sandy in the proximal part where distributary channels are stacked. The remaining of the accumulation appears to be composed of muddier facies attributable to slurries deposited in an array of thin and elongated channels.
Between these two end-members lies Basin IV of the Brazos-Trinity series of mini-basins, Gulf of Mexico, which possesses both high and low gradient slopes from the steep basin inlet to the flat and reverse slopes at the end of the bowl-shaped basin. The 3D imaging reveals the transition from poorly-developed channel-mouth bar pairs on the initially steeper basin slopes to increasingly elongated and sinuous channels splitting into ever smaller sandy distributary channels on the lower slopes built during fan deposition. These “feathery looking” lobes are similar in shape to other lobes from low gradient fans (i.e. Mississippi terminal fan) and are thought to be the locus of transition from sandy channels to slurry deposits as turbulent flows transition to laminar.
Fan size is generally inversely proportional to gradient, and gradient analysis augmented by studies of analogous tank experiments demonstrate an inverse relationship between channel length and slope such that longer channels are expected to develop on lower slopes. Stacking patterns and hierarchy indicate the influence of supercritical vs subcritical hydraulic regimes controlled by depositional gradients. In addition, depositional gradient also explains the dichotomy of lobe elements resulting from either retreating sandy mouth bars or dispersive slurry strings.
Accurately establishing paleo-bathymetry is therefore a critical process in the prediction of facies distributions and sand body connectivity in lower resolution datasets.

SEQUENCE STRATIGRAPHY, SEDIMENTARY PROCESS AND RESERVOIR QUALITY OF SAND BODIES OF THE THIRD MEMBER OF DONGYING FORMATION ON THE NORTHEASTERN SLOPE BELTS OF THE CHENGBEI LOW UPLIFT, BOZHONG DEPRESSION

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The Chengbei Low Uplift, located in the intersectional region of the Jiyang Depression and the Bozhong Depression, is a large buried hill structural belt. Its northeastern side is a gentle slope belt with a slope of 5°~6°. The Dongying Formation, overlaid on the Chengbei Low Uplift, has become an important exploration target in recent years, of which sand bodies of the third member of Dongying Formation are the main oil-bearing reservoirs. However, the sequence stratigraphy and sedimentary characteristics of the Dongying Formation are still poorly understood. Based on the analysis of the data sets of core, well log and seismic, three 3rd-order sequences (SQ1, SQ2, SQ3) were identified in the Dongying Formation, respectively corresponding to the first, second and third members of Dongying Formation. The third member of Dongying Formation can be further divided into three systems tracts, namely, the LST, TST and HST. The LST corresponds to the lower part of SQ3 and can be divided into two progradational parasequence sets; the TST develops in the middle part of SQ3 and can be divided into two retrogradational parasequence sets; the HST corresponds to the upper part of SQ3 and can be divided into two progradational parasequence sets. Six sedimentary facies were also identified in the third member of Dongying Formation, including proximal coarse-grained deposits and beach-bar deposits developed in shallow water, and braid channel deposits, levee deposits, lobe deposits and storm deposits developed in deep water. The proximal coarse-grained deposits are mainly composed of massive, structureless rubble-bearing coarse sandstones and breccias; the braid channel deposits primarily consists of massive or normal graded pebbly medium to coarse sandstones; the complete or incomplete Bouma sequences are the main components of levee and lobe deposits; the hummocky bedding, parallel bedding or climbing-ripple bedding siltstones and fine sandstones account for a great proportion of the storm deposits; the beach-bar deposits are mainly composed of wave bedding, wave ripple bedding argillaceous siltstones and siltstones. The gravity flow sedimentary facies are controlled by periodic flood events, whose formations involve the transformation of debris flow into high- and low-density turbidity currents. The small-scale beach-bar deposits are formed by the redistribution and redeposition of fine-grained sediment from surrounding sedimentary facies under the effect of wind wave. And the small-scale storm deposits are controlled by the episodes of storm events. In addition, based on the observation of thin sections and the analysis of porosity and permeability data, the sand bodies of braid channel and levee deposits were confirmed as the best reservoirs.

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IMPACT OF SUBTLE SEABED TOPOGRAPHY ON BASIN FLOOR FAN PINCHOUT CHARACTER

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Seabed topography, flow rheology, and flow orientation are considered important controls on the character of submarine fan pinchouts. Detailed mapping of exhumed basin-floor fans in the SW Karoo Basin has resulted in the documentation of a wide range of up-dip, lateral, and frontal sandbody pinchouts in well constrained palaeogeographic configurations. These can improve our understanding of the influence of seabed topography on flow processes and deposit geometry.

Up-dip terminations can occur between the erosional submarine slope and depositional lobes. In sand-detached systems, such as Units E and F in the Laingsburg depocentre, the facies associations preserved are thin-bedded, but intercalated with megaflutes, rip-up clast lags, and soft-sediment deformation, indicating a high-energy sediment bypass-dominated setting. Oblique up-dip pinchouts from axial to proximal lobe fringe settings, such as within Fan 3 in the Tanqua depocentre, fine and thin abruptly, but the pinchout geometry is not a sharp termination as localized thickening and reappearance of structured sandstone with localized remobilization along the pinchout margin, suggests a complicated seabed topography at the time of deposition. Furthermore, abrupt stratal pinchouts in basin-floor settings are commonly associated with widespread post-depositional clastic injections. Lateral stratal terminations are impacted by the intrabasinal slope angle and syn-sedimentary slope gradient changes. Thick aggradational lobe fringes (Unit A in the Laingsburg depocentre) require a syn-sedimentary dynamic slope to aggrade whereas the lateral pinchout of Fan 3 in the Tanqua depocentre occurred above a static slope, allowing the seabed topography to be healed and compensational stacking of lobes to occur. Frontal fan pinchouts are sand-rich but can exhibit elongated finger-like terminations with abrupt sandstone pinchout that comprises large proportions of argillaceous hybrid beds with complicated geometries that increase the heterogeneity of the pinchout.

Differences in pinchout style are predictable in terms of updip, frontal or lateral, but active vs passive topography may affect the impact of flow rheology on the resulting deposits' architecture. A better understanding of basin floor pinchouts can improve interpretations of basin dynamics and structural configurations, even where slopes are subtle and long-lived.

UPSTREAM-MIGRATING KNICKPOINTS: THE DOMINANT CONTROL ON SUBMARINE CHANNEL EVOLUTION?

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Submarine channel systems are the primary conduits for sediment transport to the deep sea. The turbidity currents that pass through them are the volumetrically most significant sediment transport mechanisms on Earth. Submarine channel deposits preserve valuable archives of Earth history, while the associated mass movements pose a hazard to critical seafloor infrastructure. Therefore, understanding how submarine channels form and develop is important. It has been hypothesized that the development of meandering, due to outer bank erosion, is a key control on submarine channel evolution. This hypothesis is based on river studies. Several recent studies show that flow in submarine channels is very different to that in fluvial settings, however. Other inferences have been made from the deposits left behind by past flows, scaled-down laboratory studies, and uncalibrated numerical models, but the key controls on the morphologic evolution of submarine channels remain elusive.

Here, we can reconcile these issues using unusually detailed time-lapse bathymetry surveys that record the morphologic evolution of a highly active submarine channel. Multiple seafloor surveys were performed in Bute Inlet, British Columbia over a ten-year period. We track the evolution of a 60 km-long submarine channel that is surveyed from its source to lobe at an unprecedented high spatial and temporal resolution. We first summarize the morphologic changes observed from these repeated surveys. Second, we classify the nature and quantify the scale of erosional and depositional patterns associated with this morphological evolution. Finally, we relate the observed morphologic changes to the processes that control channel evolution and discuss the implications of our findings for other submarine channel systems worldwide.

We find that upstream-migration of knickpoints (sharp and steep steps in the channel topography), is by far the most important process responsible for the observed erosional and depositional patterns and is the driving forces behind the channel evolution. Individual knickpoints can migrate several hundreds of meters upstream per year and can cause up to 30 meters depth of erosion over this entire migration distance. The influence of outer bend erosion is found to be negligible in comparison to knickpoint migration, with the latter capable of completely modifying both plan-view and cross-sectional morphology of the channel. High resolution bathymetry data reveals that similar knickpoints are also common in many other submarine channel systems worldwide, yet their potentially critical role in channel evolution has largely been ignored until now.

THE GEOMORPHIC AND STRATIGRAPHIC EVOLUTION OF A SUBMARINE CHANNEL: LINKING CHANNEL ELEMENTS TO THALWEGS OF SUBMARINE CHANNELS ON THE SEAFLOOR

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The deposits of submarine channels have been difficult to reconcile in the context of observations from modern sedimentary systems[1]. This stems, in part, from difficulty in directly observing formative gravity flows and the morphodynamics of channels in the deep-sea. Recent analyses of the stratigraphic record and repeated seafloor surveys have demonstrated that submarine channel settings are constantly reshaped through erosion, slumping, and deposition. Building on these observations, we reconstruct the time-space evolution of geomorphic and stratigraphic surfaces within the fill of a submarine channel ('channel element' of Mutti and Normark[1]) through analysis of the Upper Cretaceous Tres Pasos Formation in southern Chile. This is achieved through a series of mm-scale vertical measured sections spaced at 3-5 m across a channel element, from its axis to its margin across a horizontal distance over 80 m.

A critical observation of the studied channel element includes a series of internal erosion surfaces that record punctuated periods of significant erosion and sediment bypass into the basin. Outcrop measurements reveal that these surfaces were characterized by 3-7 m of erosional relief, and bound the deposits of up to ~25-75 turbidity currents. A series of these erosion surfaces coalesce and bound a composite channelform body up to 17 m thick composed primarily of amalgamated sandstone. We demonstrate the diachronous development of the stratigraphic surface that defines this sandstone body, and in doing so, highlight important sedimentologic and stratigraphic observations that support the interpretation of a poly-phase history of erosion, sediment bypass, and deposition within the channel. In particular, in-channel aggradation led to a decrease in relief and broadening of the channel through time. This results in the upward increase of bed continuity from channel element axis to margin, as well as an overall upward-bed-thickening in the margin. From this analysis we conclude that the channel element, a feature observed in stratigraphic datasets globally, records processes of both protracted erosion and deposition in only the thalweg of submarine channels – this has made comparisons to the entire relief of large-scale channels on the seafloor problematic. The analysis has implications for: (1) linking both short- and long-term sedimentary processes (i.e., bed through channel scale) with stratigraphic products; and (2) deducing more resolved predictions of reservoir properties in petroliferous basins on continental margins around the world.

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MORPHOLOGY AND PROCESSES OF THE SÃO FRANCISCO TURBIDITE SYSTEM – EASTERN BRAZILIAN MARGIN

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The São Francisco Turbidite System (SFTS) is the largest channel-levee system on the eastern Brazilian margin, a poorly known Brazilian margin sector. Despite being a major turbidite system, its structure, morphology and sedimentary processes are still largely unknown. The STSF is linked to the São Francisco River, an important Brazilian river that extends for more than 2700km. We present the geomorphologic characterization of this turbidite system based on the most recent high-resolution bathymetric data, and a preliminary interpretation of the inferred sedimentary processes responsible for the erosional and depositional morphologies. The SFTS is divided into two parts, one active and one inactive. The active part consists of a submarine canyon, a sinuous submarine channel beginning at the canyon mouth and a terminal lobe. The inactive part consists of a series of abandoned channel-levee complexes. The canyon head begins at the foot of the São Francisco delta and is deeply indented into the shelf, with a relief of almost 800 m near the shelf-break. The submarine channel has high sinuosity (1,5) and presents a fairly flat thalweg, typically <2º. The valley margins, which are formed by the crests of external levees, have similar heights until near the channel mouth, where the southern margin becomes lower than the northern margin. The channel is divided into three sections: upper, middle and lower channel. In the upper part the channel has a V-shaped profile with a flat bottom and a relief of >400 m. This upper part has the widest valley and talveg and displays a high degree of lateral migration and a short meander wavelength, mainly at the uppermost part. It is also possible to identify an earlier cut-and-fill phase in this part. The middle part shows a strong erosive character, maintaining the V-shaped profile, but with less relief than the upper part. The amplitude of the meanders is greater than in the upper part and the lateral migration of the channel increases progressively down slope. In the lower part, the channel relief decreases and the channel profile remains V-shaped until it reaches the channel mouth, where it changes to a U-shaped profile. The lobe area is very flat, typically <1º. It has an elongated shape and is diverted oriented to the northeast due to the presence of the São Francisco seamount. The lobe surface presents some small channels and on its northern part there is a larger erosive channel that suggests sediments could be bypassing the lobe. The whole system size suggests that either most of the sediment bypasses the system or it receives less sediment than expected. The cut and fill phase in the upper part suggests that channel aggradation is the main mechanism of change in the channel position and the wide and flat thalweg also in the upper part suggests that the system is inactive at present.

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EVOLUTION OF THE LOWER OLIGOCENE CERGOWA BASIN IN OUTER CARPATHIANS (POLAND AND SLOVAKIA)

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The Cergowa Beds (Flysch Carpathians in Poland and Slovakia) were deposited as a submarine lenticular lithosome by a variety of mass gravity flows during Lower Oligocene during two carbonate nannoplankton zones (Pszonka et al., 2018 in review) and document its diachronous evolution, variety of turbidity flows and basin partitioning.

(i) NP 23 – Middle Kiscellian and
(ii) NP 24 – Late Kiscellian.

Detailed measured sedimentological sections from ten localities: Iwla, Lipowica, Tylawa, Rudawka Rymanowska, Wernejówka, Darów, Komańcza, Medzilaborce, Habura and Ruska Volova brought the following new observations:

(i) during the NP23 zone the Cergowa basin was supplied from two provenance areas: the Silesian Ridge (NW) and the Fore-Magura Ridge (S, SE),
(ii) during the NP24 zone supply from the southern provenance area ceased, whereas the supply from the NW source was continuing.
(iii) changes of the paleotransport directions and sediment distribution against the age relations suggest spatial and temporal evolution of the sedimentary basin topography.

In the NP23 zone, deposition of the Cergowa Beds occurred in two narrow NW-SE elongated troughs – the northern and the southern one. The NW part of the northern trough was filled by depositional lobes (Rudawka Rymanowska, Wernejówka), whilst its SE part by classic submarine fan sediments (Komańcza). Subsequently, in the NP24 zone, the area of deposition shifted laterally, mainly to the southern trough (Medzilaborce, Habura, Ruska Volova) and in the N trough retrograded appearing only subordinately within the its NW-most part (Iwla).

Except for sediments of surge-type turbidites observed in the whole succession, deposits of sustained hyperpycnal flows were identified on the basis of depositional structures and their repeatability. The presence of such flood flows took place only in the NP23 zone, in NW and central parts of the northern trough (Iwla and Darów) as well as in NW area of the southern trough (Lipowica and Tylawa).

Cathodoluminescence analysis enabled to distinguish six microfacies of grains representing various carbonate rocks exposed to erosion in the source area located to the NW of the depository. These are: bio-microsparite, packstone and dolostone, all reflecting shallow-water carbonate system synchronous with the siliciclastic system that supplied the Cergowa deep marine basin.

Regional high diversity of facies associations reflects migration of lobes and submarine fan in time and space, and changes in intensity of clastic material supply, the sedimentary basin geometry and the diachronous nature of the upper boundary of the Cergowa lithosome.

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SEQUENCE STRATIGRAPHY AND DEPOSITIONAL MODEL OF DEEP WATER COARSE-GRAINED DEPOSITS IN THE STEEP SLOPE ZONE OF LACUSTRINE RIFT BASIN:THE EOCENE SHAHEJIE FORMATION,BOHAI BAY BASIN,CHINA

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Deep water coarse-grained deposits are common facies types in steep slopes of lacustrine rift basins and have been regarded as one of principal tight-oil reservoirs in China. Here we used a variety of methods and data, including core observations, well log, and seismic data to investigate sequence stratigraphy and the origin of the Eocene Shahejie Formation in the steep-slope zone of the Lijing Sag, Bohai Bay Basin, China. Our analyses indicate that a typical sequence in the Shahejie Formation consists of transgressive and highstand systems tracts and are represented by the stacking of retrograding and more coarse-grained prograding fan systems, respectively. The development of the two systems tracts and associated distinctive deposition patterns are interpreted as being controlled by fault actives and lake level fluctuations. During transgressive systems tracts, intense episodic movements of border-faults created more sediment accommodation and increased rates of sediment input by weakening and erosion of the rocks in source areas of the footwalls, together resulting in the deposition of retrograding fan systems which were affected by the subsequent rise of lake level. During highstand systems tracts, multiphase fan bodies occurred with a prograded fashion and accompanied by the input of abundant river-derived coarse-grained material and decreases of lake levels. Twelve lithofacies types were identified in the Shahejie Formation and were recognized as gravity flow deposits on the basis of their characteristics. We found that subaqueous debris flows and hyperpycnal flows are the dominated sedimentation in retrograding fans which are characterized by non-channelized lobate depositional bodies, whereas tractive currents generated by river-derived discharges are the dominant transportation processes in prograding fans which are characterized by channelized fan-shaped depositional bodies. In addition, the scale of retrograding fans is smaller than prograding fans. This proposed new depositional modal has important implications for guiding stratigraphic division and reservoir prediction in clastic coarse-grained sedimentary rocks in petroleum exploration and development.

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The hydrodynamic behaviour of settling carbonate grains and the implications for the composition of calciturbidites

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Calciturbidite beds deposited by particle-transporting subaqueous density flows occur in a variety of carbonate deep-water environments. Such carbonate turbidity currents can form thick sedimentary successions that host important hydrocarbon reservoirs worldwide (e.g. Adriatic Sea, Red Sea, China Sea). Capturing the hydraulic particle-sorting patterns is important to understand the porosity and permeability distribution within calciturbidite reservoirs. Whilst siliciclastic turbidite systems have been extensively studied, depositional mechanisms of calciturbidite systems remains underexplored. Carbonate turbidity currents carry heterogenic bioclastic particles that vary in their composition-dependent density, size and shape (the latter specified by form, roundness and surface texture). This study investigates the hydrodynamic behaviour of carbonate particles using settling velocities observed in experiments. Settling velocity is a fundamental parameter of physical sedimentary processes that governs the entrainment, transport and deposition of particles in a multitude of depositional environments. The hydrodynamic behaviour of 661 grains collected from four different carbonate environments on the Bahamas, Tahiti and Italy was examined using settling tube experiments and shape analysis. It was found that density and grain size are not the sole parameters controlling the falling velocity of a settling particle. Settling velocity is (co-)dependent on particle shape, which was measured in terms of elongation and flatness and classified using the Zingg-shape classes: spheres, rods, discs and blades. Equant shapes settle fastest, then rods, and then flattened shapes. Digital shape analysis reveals that form, roundness and surface textures observed for larger particles is retained also for smaller grain sizes. This is most likely due to the skeletal nature of the bioclastic particles. A revised sequential set of falling regimes was developed on the basis of particle shape and Reynolds number. Modelled settling velocities calculated with common, universal settling equations from the literature deviate at grain sizes exceeding 0.5 mm. A published compilation of settling velocity data was further expanded to better constrain settling velocities of bioclastic particles that were discriminated on the basis of biogenic composition and grain shape. Bioclast settling velocities range predominantly from 0-25 cm/s for grain sizes smaller than 10 mm. A model for the settling velocity of carbonate grains at three common grain size intervals is presented. Hydraulic sorting patterns in calciturbidites have previously been attributed primarily to grain-size dependent settling. These new results suggest that species-specific and shape-dependent hydraulic sorting should be included in the evaluation of hydrodynamic processes in carbonate turbidity currents, and calciturbidites.

HAUTERIVIAN & BARREMIAN MTC's IN PELAGICS SERIESOF VOCONTIAN BASIN (SE FRANCE) ROLE OF DIAPIRISM

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Most of the time in sedimentary basins, MTC's are deposited not far from the shelf break in the slope and in the proximal part of the basin, and are related to slope failures distributed all along the shelf to basin transition.But surprisingly in the Vocontian basin, in SE France, during Hauterivian and Barremian, the MTC's are only affecting pelagic deposits which initially consists of a regular alternation of marls and limestones climatically driven and are redeposited far away from the shelf break, They are more common in the center of the basin and are of a limited extend. In addition, their zone of occurrence is separated from the shelf break when, it is preserved, by a very extensive belt of hemipelagites where cyclical sequences of nodular limestones predominate.
Some sections are totally devoid of MTC's such as the key section proposed for Hauterivian Golden Spikes (La Charce), others include more than 20 slumps ranging from 1m up to 30m interbedded with undisturbed deposits such as the famous SerresMontclus section where slumps has been described for the first time, Goguel 1938. How to explain this distribution previously related to fault control local highs, Joseph et al. 1989, Cong 2007. Recent observations, first revealed that slumps strongly predominate in synclines axis in the center of the basin and disappear on the synclines flanks as well as in adjacent synclines both in North and South as well as to the West (i.e. proximal part) where undisturbed series occurs. Most of the slumps, because of a very detailed ammonite's base age model can be precisely replaced in consistent stratigraphic intervals. Second, when the series are exposed in the syncline flanks, small scale failures can be observed suggesting that the source of material is very local.Basin structural style is also very peculiar; it is characterized by synclines juxtaposition and a lack of anticlines and major thrust, Flandrin 1966. Here we hypothesize that these features are developed very early in conjunction with the development of salt walls creating these local highs and the salt movements appear to be one of the easiest driving mechanism to explain such MTC distribution on very gentle slope as demonstrated by Cong 207.The model we proposed have similarities with salt related mini basins as developed in the Gulf of Mexico where MTC's are fringing the diapirs.

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A 60 MYR-LASTING SLOPE AREA (OXFORDIAN-ALBIAN) IN THE SOUTHERN IBERIAN PALAEOMARGIN: SEDIMENTARY RECORD, EROSION SURFACES AND CHRONO-BIOSTRATIGRAPHY

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The Southern Iberian Palaeomargin (SIP) developed as a result of the intracontinental rifting episode affecting the southern part of the Iberian plate during the Triassic – Middle Jurassic. This process led to a spreading phase that began in the late Middle Jurassic and ended in the late Berriasian. The area largely affected by the two former phases mainly belongs to the so-called Subbetic Zone, where more open marine, locally relatively deep, sediments are recorded. Afterwards, a new rifting episode mainly affected the margin edge, to the so-called Prebetic Zone. This third phase lasted up to the middle Albian (Vera, 2004). Currently, the record of these phases can be recognized in the External Zones of the Betic Cordillera (southern Spain).

The palaeogeography of the basin over the two last phases – namely, during the interval of late Middle Jurassic to middle Albian (~60 myr) – was very diverse and changing. Deepening-upward successions that recorded platform to basin transitions are common. Meso-scale shallowing-upwards successions are also reported for some outcrops.

This contribution presents a rare example: a remaining slope area that connected shallow to deepest environments of the SIP during the whole considered interval. Olistoliths (Oxfordian), carbonate turbidites (Late Jurassic), channel-fill coarse calcarenites (late Hauterivian), and the record of a Cretaceous submarine canyon have been described in this area (Ruiz-Ortiz et al., 1996, 2006).

The olistoliths are made up by Middle Jurassic oolitic limestones, facies common in Middle Jurassic stratigraphic successions from the Prebetic and the more external part of the Subbetic Zone. Carbonate turbidites are typical of the Upper Jurassic successions characterizing platform (Prebetic) to basin (Subbetic) transitional areas (the Intermediate Units or Intermediate Domain) (Vera, 2004). Additionally, the late Hauterivian channel-fill coarse calcarenites and the middle Albian marls, which show blocks of Jurassic and Cretaceous rocks (lag deposits) in their lower part, make up the submarine canyon fill. These units show a stacking pattern dominated by two main erosional surfaces: the first one is pre-early Hauterivian and, probably, pre-late Valanginian in age; the second is post early Hauterivian to pre middle-Albian.

The chrono-biostratigraphy of the units making up the record of this long-lasting slope area of the SIP, together with new perspectives developed by integrating our new findings (García-García, 2011, Ruiz-Ortiz et al., 2014) with previous interpretations, are presented in this contribution.

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THE ROLE OF FROUDE SUPERCRITICAL SEDIMENT TRANSPORT AND DEPOSITION IN ACTIVE MARGIN BASIN FLOOR FANS, JUNCAL FORMATION, CALIFORNIA.

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Recent work in the modern Navy[1] and the Quaternary Congo fans[2] suggests that submarine fans consists of a multitude of channels and related smaller heterolithic lobes, rather than a few feeder channels and extensive sandy lobes, as proposed by current models. A linked new development is the growing body of evidence that Froude supercritical flow is significant in sediment transport and deposition in deepwater systems. Together, these new ideas raise questions about our understanding of the basin-floor fans. Thus, we hypothesize that erosional features due to channelization and supercritical flow are more common in basin-floor fans than predicted by current models. The objectives are to conduct field studies in select basin floor fans with the focus on erosion surfaces, grain-size distribution and the presence of supercritical flow deposits, followed by comparison to published outcrop data on fans, as well as to seismic datasets.

In order to test the hypothesis, we raise a null hypothesis that majority of sands in basin-floor fans are deposited in lobes, and thus lack multi-meter-scale erosion surfaces. The project aims to test whether the basin-floor fans consist of tabular sheet like beds as predicted by the models or rather consist of amalgamated lenticular bodies that indicate channels or scours. We will focus field studies on two main outcrop datasets, where we document the sedimentary facies, depositional geometries and architecture, with a focus on erosion surfaces and the link between erosion surfaces and grain-size distribution. We study the fans by drone photography and measured sections. The drone photography allows us to reconstruct 3-D photographic images to identify erosion surfaces. The initial work from Juncal Formation outcrops during summer 2017 shows an abundance of Froude supercritical flow sedimentary structures, as well as an abundance of multi-meter scale erosion surfaces in sandy facies. Field studies will be followed by comparison of the two systems, and literature data mining and comparison to systems like the Ainsa basin, Spitsbergen and Karoo etc. Outcrop data comparison will be followed by analyses of the 2D and 3D seismic dataset from the Taranaki Basin, New Zealand in order to get channel width and depth measurement from the subsurface data.

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A NEW CLASSIFICATION OF CYCLIC STEPS AND ITS APPLICATION

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Cyclic steps are a type of upper flow-regime bedform consisting of trains of bed undulations with hydraulic jumps occurring in the troughs. They form in sheet flows and ephemeral free-surface flows on land, but comprise a common, if not the dominant, bedform in subaqueous density flows in oceans, lakes and reservoirs. Cyclic steps originate from alternating Froude-subcritical (Fr<1) and Froude-supercritical (Fr>1) flow on respectively the stoss side and lee side of individual steps. The transition between these flow states is embodied by the hydraulic jump in the trough of the bedform, leading to the permanent or quasi-permanent morphology of cyclic steps. Over the past decade, numerous studies affirmed the dominant role of cyclic steps in generating bed undulations in modern and ancient glacial outwash, deltaic and turbidite environments. It was previously demonstrated that cyclic steps are net-depositional, transportational or net-erosional in different parts of such systems. These bedforms are here classified as climbing, transportational and falling cyclic steps, respectively. In analogy to the classification of ripples and dunes, the adjectives 'subcritically' and 'supercritically' indicate the climbing angle of the bedform's crest. Subcritically climbing or subcritically falling cyclic steps have crests that climb or fall under an angle smaller than the dip of the lee or stoss side, respectively. Supercritically climbing or supercritically falling cyclic steps have crests that do so under an angle that is larger than the dip of the stoss or lee side, respectively. This new classification defines distinct depositional signatures for each type of cyclic steps. The classification can be used as a predictive tool in the reconstruction of modern and ancient turbidity current environments observed in seismic reflection, outcrop and core data. As a demonstration, the classification is applied to the modern West Penghu Channel in the South China Sea (point-sourced turbidity currents) and the Pleistocene carbonate slope of Favignana Island, Italy (line-sourced turbidity currents).

SEDIMENTARY CHARACTERISTICS AND FORMATION CONDITIONS OF TURBIDITY CHANNELS IN RIFT BASIN: PALAEOGENE SHAHEJIE FORMATION, BANQIAO SAG OF BOHAI BAY BASIN, CHINA

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Deep-water gravity-flow sandstones are important hydrocarbon exploration and production targets in the Bohai Bay Basin, a Paleogene intra-continental rift basin in eastern China. Sandstones of the Palaeogene Shahejie formation in the Banqiao sag of Bohai Bay Basin, are of string-belt shaped extension, which are extremely similar to the geometry of sandstones deposited by meandering fluvial. Depositional genesis of the sandstone is one of the key basis for high resolution stratigraphic framework construction, reservoir properties distribution prediction and remaining-oil redevelopment. Combined with regional geological setting, stratigraphic succession, petrological features, sedimentary association, and sand body geometries of this member, it is considered that the sandstone of Shahejie formation, which extends along the long axis of the Banqiao Sag, was deposited by slumping-typed turbidity channels of long distance sediments source in the deep lacustrine environment with the confine of lacustrine bottom configuration. The sediment sources were from the fan-deltas, sub-lacustrine fans near the Cangxian area in the northern part. In terms of the genesis mechanism of gravity flow channel, the turbidity channel was subdivided into three types of microfacies: central channel, channel margin, and subaqueous overflow. Sedimentary succession of individual central channel equals to members association of AB, ABD and AC of Bouma sequence. Reservoir rocks in the channel center are dominated by gravelly sandstone with normal graded bedding and hybrid sandstone with massive bedding, which are medium porosity and permeability. The external controls on the slumping-typed turbidity channels in the area is of the long term base level fall caused by volcanic eruption, earthquake, episodic activity of contemporaneous faults. The internal conditioins mainly include the abundant sediments source, paleotopography, and stepped faults perpendicular to the long axis of the sag. A depositional model was proposed based on the sedimentary characteristics and formation conditions of turbidity channels.

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SEDIMENTARY CHARACTERISTICS OF LACUSTRINE HYPERPYCNAL CHANNELS: TRIASSIC OUTCROPS IN THE SOUTH ORDOS BASIN, CENTRAL CHINA

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Subaquatic channels are known as active conduits for the delivery of terrigenous sediments into related marine and lacustrine basins, as well as important targets for hydrocarbon exploration. Compared to submarine channels, lacustrine subaqueous channels created by hyperpycnal flows are understudied. Using well-exposed outcrops collected from three different locations in the southern Ordos Basin, central China, morphologies and architecture of a channelized hyperpycnal system were studied and classified. Six facies associations represent sedimentary processes from strong erosion by bedload dominated hyperpycnal flows, to transitional deposition jointly controlled by bedload and suspended-load dominated hyperpycnal flows, finally to deposition from suspended-load dominated hyperpycnal flows. On the basis of channel morphologies, infilling sediments and sedimentary processes, the documented channels can be classified into four main categories, which are erosional, bedload dominated, suspended-load dominated, and depositional channels. In very proximal and very distal locations, erosional channels and depositional channels serve as two end-members, while in middle areas, bedload-dominated channels and suspended-load dominated channels are transitional types. Erosional channels, as a response to strong erosion from bedload dominated hyperpycnal flows on upper slope, were mainly filled by mud interbedded with thin sand beds. As flow energy decreases, bedload dominated channels develop on middle slopes, which are characterized mainly by under- to balanced sediment infillings with cross-bedded sandstones and/or minor massive sandstones. Compared to bedload dominated channels, suspended-load dominated channels mainly develop in deeper water, and were filled mainly by massive or planar-laminated sandstones. Depositional channels, as a response to suspended load dominated hyperpycnal flows in deep-water areas, are characterized by thin-medium bed classical turbidites with Bouma sequences and thick- to very thick massive sandstones. Such evolution patterns of hyperpycnal channel systems are ascribed to the progressive decrease in flow capacity of hyperpycnal flows, and provide an adequate explanation for the basinward channelization behavior of hyperpycnal systems.

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Sedimentary Characteristics and Models of Underwater Alluvial Fan near Mountains in Faulted Lake Basin, China

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The Lukqin area is located in the area near the Luxi Bulge in the west and east near the Kuruguchi Bulge, Turpan-Hami Basin in Xinjiang, China. It was a faulted lake basin of during the deposition of Wutonggou Formation in Permian. Syndepositional deep-faults were developed in the tectonic movement period of the Hercynian IV to Indo-China I which led to the formation of the steep-raised terrain in the east and west and the relatively low-lying terrain in the middle. Based on core observation and comprehensive analysis of well logging and seismic data, it is concluded that the southeastern and southwestern parts in the area were mountains formed by volcanic eruptions during the early depositional period of Wutonggou Formation, which were the parent rocks areas deposited in this area. The sediments directly into the lake with a high water surface, forming a large area of underwater alluvial fan deposition near mountains with thick layers of coarse gravel rock and middle folder thin gray mudstone.

The study shows that: (1)The ZTR (zircon + tourmaline + rutile) index indicates that the sedimentary source mainly came from the southwest bulge and the southeastern bulge;(2)The Permian Wutonggou Formation is in the transition zone between lake and surface concluded by that:①Most of V (vanadium) / (V + Ni (Ni)) are found between 0.45-0.60 supported by the trace element analysis;② the plantswere mainly composed of Pteridaceae and Gymnosperm and ③ The colors of sedimentary rocks aregenerally gray or green;(3)The underwater alluvial root fans, depositing in the edge of study area, suffered the tectonic uplift and large-scale intense erosion caused by late faults activities, resulting in the development of middle and edge fans and the loss of root fans in underwater alluvial;(4)The braided channel deposition of the middle fan is the most important sedimentary type of the underwater alluvial fan in the study area. The conglomerate is the major sedimentary rock and is also an important reservoir. It consists of a series of distributary braided channels which present apparent seismic facies features of foreset filling on the seismic section;(5)Due to the continuous hydrodynamic changes in the sedimentary process, three fan-shaped braided channel microfacies with different depositional characteristics have been developed in the study area. These microfacies show different characteristics in terms of depositional structure, well logging response, rock particle size, and sedimentary rhythm. Therefore the logging facies was established respectively; (6)The depositional model of the underwater alluvial fan near mountains has been established: The Permian Wutonggou Formation in the study area was in a faulted basin during the deposition. Due to the lack of deep fault control on both east and west sides of the lake basin, the provenance could only enter the lake basin along the steep slope on both sides to form a underwater alluvial fan and the edge of underwater alluvial fan bodies, developing in eastern and western areas and crossing at the center of the lake basin.

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Architecture elements characteristics and 3D distribution simulation of Deep water turbidity channels

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The turbidite channel sandstone noted for its importance and strong heterogeneity for the deep water exploration, evaluation and development. Also the limitations of the current understanding leaded to the contradictions between the existing sedimentary pattern and practical application. Based on cores, loggings, outcrops and high-frequency seismic information, the internal facies of incised channel system (grade 3 configurations) were divided and characterized, the turbidity facies model were summarized from the perspective of lithological cycles, and the lithologic 3D distribution were simulated by means of geologic modeling. The research results showed that, four types of turbidite architecture elements could be identified from the seismic data, including the lag deposits, slump debris flow deposits, high NTG superimposed channel sand sedimentary and low NTG with natural levee channel deposits, each integrated turbidite channel sand was made of different proportion of these four architecture elements. Grade 4~5 channels within the turbidite channel system (grade 3 configurations) cut and filled repeatedly in the process of migration and swinging, which was the main reason causing the strong heterogeneity nowadays. The architecture 3D simulation result respected the sedimentary rhythmicity of turbidite channel, which also affected the development scenarios designing and well pattern optimization. This study could improve the exploration and production of deep-water oilfield from both theory and reality.

Keywords: Turbidity channel；Lithofacies；Architecture elements；Geological modelling

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Development of a submarine channel net on southern Niger Delta slope: from avulsion to confluence

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On the Niger Delta slope, a submarine channel net, named Abalama Channel System (ACS) and documented from the shallow surface, consists of seven avulsion channels and one confluence channel. This work used high-resolution 3D seismic data to investigate the chronological sequence, occurrence mechanism and distribution pattern of these avulsions and analyze the exact cause of the final confluence phenomenon. Around each avulsion or confluence site, detailed channel-architecture analysis and local-geomorphology reconstruction were implemented, from which the relative age of avulsion channels, associated flow conditions and even avulsion process were all deduced out.

It is concluded that the existence of an early large-size mass transport complex (MTC), approximately 100 km^2 in area and 50 m in thickness, acted a major role in the development of avulsion channels. On the one hand its strong but differential erosion and associated substrate entrainment left behind net degradations and narrow erosional remnant ridges on the seafloor, on the other there were often some protruding megaclasts on the MTC top surface. All of these bathymetric anomalies formed a topographically complex slope that obviously increased the instability of submarine channels and in turn resulted in the breaching of levees. That irregular topography may also explain the random temporal-spatial distribution of avulsion events instead of the radial or seaward/landward-stepping avulsion pattern. In addition, the development of mud volcanos and diapirs downstream of ACS served as an obstacle that hindered further downslope flow and hence sediment gravity flows had nothing but flow to a location with lower gravitational potential energy, i.e. the confluence site. That's why the most recent avulsion channel rejoined the older ones.

Such avulsion and confluence events are important processes in the evolution of submarine fans and they commonly record abrupt changes in the sediment dispersal patterns. Therefore, this study is of great significance for the hydrocarbon exploration.

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JIULONG SUBMARINE CANYON-FAN SYSTEM IN THE NORTHEASTERN CONTINENTAL SLOPE OF THE SOUTH CHINA SEA

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A series of submarine canyons were developed in the northeastern continental margin of the South China Sea, which include from west to east the Dongsha canyon, South Taiwan Shoal Canyon, Jiulong Canyon, West Penghu Canyon, and Penghu Canyon, etc. These submarine canyons either merge together downstream and finally confluence into the Penghu Canyon, or end in the open slope in the form of confined slope fans. Previous research has made extensive investigations to some of the larger submarine canyons, but little attention has been paid to the smaller-sized slope-confined canyon-fan systems. The latter represents one type of the most important sedimentary features in the margin. In this study, we investigated the Jiulong submarine canyon-fan system in the margin using high-resolution multichannel seismic profiles.

The Jiulong canyon-fan system extends in a NNW-SSE orientation, and is originated from the upper slope at *ca*. 400 m water depth. It consists of a series of dendritic gullies in the upper reach, which coalesced downstream into a trunk valley at water depth of about 1500 m in the middle reach. This trunk valley is downstream transitioned to distributaries in the lower-reach fan domain at water depth of over 2000 m. Further downstream, the slope fan has been intercepted by the NW-SE-trending South Taiwan Shoal Canyon. Seismic facies analysis indicates that the Jiulong canyon-fan system consists predominantly of mass transport deposits (MTDs) including slides, slumps and debrites, which could be sourced from adjacent canyon walls or canyon head region. These MTDs are separated by erosional incision surfaces that might be left by large turbidity-current flushing events. Locally distributed sandy turbidites and upslope-migrated sediment waves present additional evidence of turbidity-current activity. We concluded that the Jiulong canyon-fan system might be built jointly by mass-transport and turbidity current processes, with the mass-transport processes providing filling materials, while the turbidity currents predominantly playing a role of erosion.

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SEDIMENTOLOGY OF THE HOLOCENE ANGAMMA DELTA, BODELE DEPRESSION, PALAEOLAKE MEGA-CHAD

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An orbitally-forced late glacial to early Holocene African Humid Period (AHP) led to an enhanced hydrological cycle over the northern and central part of the continent, causing a dramatic increase in the area of lakes and wetland of which the greatest was Palaeolake Mega-Chad. This lake underwent dramatic fluctuations in area, volume and level during the late glacial and Holocene. In this paper we present stratigraphical, sedimentological, and palaeoecological evidence from sediments of the Angamma Delta for fluctuations in the level of Lake Mega-Chad at the end of the AHP. The Angamma Delta is a wave-dominated delta located at the northern end of Palaeolake Mega-Chad. The Bodélé Depression, which is the northern sub-basin of the lake, lies on the southern margin of the Sahara Desert and is now dry. The dry desert environment has preserved the delta morphology and the lack of vegetation means that is exceptionally well exposed permitting detailed reconstruction of the delta morphology and its sediments. The delta top includes a well preserved braided outwash channel pattern that is truncated by a pebbly beach ridge at an elevation of 339m, formed during the lake highstand. The profile of the delta down to the lake bed is sigmoidal with 100m relief over a distance of 3 km. Since the lake-level fell, headward erosion by ground water sapping and wind erosion have carved steep sided canyons into the deltaic sediments revealing a 25m thick section that is extremely well exposed. Two facies associations are identified; interbedded sandstones and mudstones, and bioclastic silty-sandstones. The interbedded facies contains a range of sedimentary structures including current ripple lamination, wave ripple lamination, hummocky cross-stratification, swalley cross-stratification and soft sediment deformation. These sediments are interpreted as a shallowing upwards succession deposited on the delta slope. Radiocarbon dating suggests that they were deposited over 7000 years ago during the AHP. The overlying bioclastic sediments include molluscs and ostracods. The age structure of the ostracod populations indicate that the fossils are an *in situ* assemblage and are not reworked. Some of the ostracod species are saline tolerant, but the presence of ostracods and molluscs that could not tolerate desiccation suggest that the lake was perennial. Radiocarbon dating of the bioclasts indicates an age of 4296 – 4849 cal BP. They stand at an elevation of 285 – 290 m, that is well below the palaeolake highstand (339 m) but close to the elevation of the Bah el Ghazal sill which divided the lake into two sub-basins. The age and elevation of the bioclastic rich sediments suggests that they could have been deposited during a regression as the lake waters fell at the end of the AHP. However, integration with existing dating and reconstructions of lake level suggest a more complex picture where the bioclastic rich sediments appear to represent a short lived, lake level rise after the AHP. These data attest to rapid and large, tens of meters, vertical fluctuations in lake level at this time, and provide support for other geological records and some modelling experiments that suggest 'flickering' of climate at the end of the AHP.

MODEL OF THE DELTA FRONT OF BRAIDED-RIVER OF THE LOWER YOUSHASHAN FORMATION IN SOUTHWESTERN QAIDAM BASIN

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The study stratum is the VII oil member of Lower Youshashan Formation of Miocene in Gasikule area, the southwestern Qaidam Basin. The geological background is delta front of braided river, which is based on the regional lake regression. Lacking stable contrastive maker layers, while the numerous underwater braided rivers and the common incision among them make stratigraphic contrast more complex(Li,2007). For these reasons, the research on stratigraphic correlation and reconstruction of sedimentary microfacies in this area are extremely difficult. Therefore, this paper emphasizes on the rebuilding of the sedimentary microfacies and acquiring the sedimentary model through coalescence of core rocks, well logging data and seismic data.

Given the difficulty of layer division and contrast, this paper adopts the following methods:(1) Maximum logging curve characteristics: To enlarge the contrast between sandstone and mudstone, establishing lithology sensitive index logging curve is an efficient way;(2) Single well logging analysis: It is the template of the sedimentary microfacies identification; (3) Layer division: Changes of lake level and short-term stratigraphic cycle help the layer division.

According to the sedimentary microfacies templets of core well, sedimentary microfacies of the rest of wells have been identified. Source materials came from the northwest and southwest in the primary time. In the early stage, underwater distributary channels occupied the position and multi-stage of thick sandstone overlaid one another. In the middle-to-late period, the water level became shallow and channels rarely developed. In the late stage, the water level changed deeply, thus making fewer channels and sandstone bodies. The sedimentary process experiences the change of transgression-regression-transgression cycle as a whole.

On the basis of regional tectonic, palaeogeomorphology and sedimentary characteristics, the sedimentary model has been established. Research area has the characteristics of steep slope which may result in rapid accumulation deposits of near source. The source direction controlled the characteristics of lithofacies and distribution of sandstone bodies in the depositional area.

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ARID FAN-FAN DELTA TRANSITION: LESSONS FROM HUANGYANGQUAN FAN AREA

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This paper studied the sedimentary characteristics of Huangyangquan fan through field investigation and trench excavation combined with satellite image interpretation and Quaternary geological as well as historical geography analysis. The author recognized that the Huangyangquan fan is a fluvial fan developed in the inland arid area of northwestern Junggar basin margin. The Huangyangquan fan is a gourd in plan metric shape and can be divided into three parts: upper fan, middle fan and fan margin. The fan is dominated by fluvial deposits but not debris flow deposits. Channel is most of ephemeral with minor intermittent channel. The effect of wind on the sediment of alluvial fan surface is obvious. The fan terminated in 4 types as into Eric lake, to the marshes, to the shore of small lakes and to a terrain block, these are all different to either of normal fan or fan deltas. Research shows that the ancient Lake Manas appeared six times high level in the Quaternary. Before 30 ka B. P., the fan surrounded by ancient Lake Manas as a fan delta system, after that time it changed gradually to be a fluvial fan due to the lake level down. The depositional model is built based the historical geography research results to interpret the evolution of this system, it shows the present Huangyangquan fan is in the transition period from fluvial fan delta to a fluvial fan system.

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TECTONIC CONTROLS ON THE DISTRIBUTION OF SANDY-DEBRITES IN THE STEEP-SLOPE ZONE OF TERRESTRIAL FAULTED LACUSTRINE BASIN: INSIGHTS FROM 3D STRATIGRAPHIC FORWARD MODELING

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Affected by the steep topography and tectonic movements on the steep-slope side of terrestrial faulted lacustrine basin, normally, a series of nearshore subaqueous fans and distal sandy-debrites are deposited, which are potential to form lacustrine hydrocarbon reservoirs. But quantitative characterization of such gravel-sand bodies distribution especially for distal sandy-debrites is lack of study. And it is also unclear about the impacts and controlling mechanism of the regional tectonic activities on the distal sandy-debrites deposition. Located in the steep-slope zone of Dongying depression in Bohai basin of eastern China, the Shengtuo area has deposited "apron-shaped" nearshore subaqueous fans and distal sandy-debrites on the downthrown side of the boundary fault during the sedimentary period of the upper part in the 4th member of Shahejie Formation, concomitant with the gentle uplifts caused by tectonic inversion and the slip-extensional movement of Chennan Fault and Shengbei Fault in the north, through which a relay ramp extending to the depositional area of distal sandy-debrites was formed between Shengbei Fault and Tuo94 Fault. Taking the Shengtuo area as the research area for this case study, the 3D stratigraphic forward modeling is applied in this project by adjusting the parameters of subsidence, basin flexure, lake level change, sediment transport, boundary supply on the basis of core sample observation, well logging and seismic sections analysis, together with the model calibration by comparison between key wells (strata thickness, lithology). The sedimentary evolution process of the upper part in the 4th member of Shahejie Formation is quantitatively revealed, the distribution pattern of sandy-debrites sand bodies is characterized, of which the controlling mechanism by faulting and tectonic inversion is investigated. The result is of great significance to the oil and gas exploration in terrestrial faulted lacustrine basin.

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Physical simulation and mechanism of soft-sediment slump deformation

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A lot of soft-sediment slump deformation structures were discovered in the outcrops and cores of Triassic and Ordovician in the Ordos Basin, China, significant in analyzing regional geology history and directing petroleum exploration. However, the formation mechanism is not yet clear. A set of simulation device and the complete experimental program has been designed to simulate soft-sediment slump deformation driven by gravity under the background of slope. The deformation process was observed and formation mechanism was explored.

The experimental sand included natural sand (diameter: 0.15-0.18mm) taken from the tributaries of Yangtze River and artificial quartz sand (diameter: 0.3mm). The experimental mud (diameter<0.03mm) were taken from Wuhan Zhiyin Lake. Simple layers were simulated by placing sand and mud with different grain size in a closed transparent sedimentation box. Two-group experiments were designed by the control variable method. First group included four experiments. The mud, natural sand and artificial quartz sand were placed orderly from bottom to top of the box. The thickness of natural sand layer was increased by four experiments. Results showed that the initial deformation angle of layers increased as the thickness of the natural sand layer increased, with the same thickness of the top and bottom layers. Second group included two experiments. The mud, natural sand and artificial quartz sand were placed orderly from bottom to top of the box. The thickness of mud layer was increasing by two experiments. Results showed that the scale of the final deformation structures increased as the thickness of the mud layer increased, but the initial deformation angle of layers had almost no difference.

In the first-group of experiments, the relationship between the initial deformation angle of layers and middle sand layer showed that, the component of gravity along the slope of soft sediments is the driving force of slump deformation. From two groups of experiments, sand layer always slidden down before the mud layer, because sand has lower viscosity coefficient than mud. The difference of viscosity coefficient leads to the difference of flow rate between two materials, which forms a shear effect. Therefore, the shear effect between layers with different lithologic sediments is the deformation mechanism of the slump.

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DOUBLE INTENSE EFFECT OF TECTONIC ACTIVITY AND SEDIMENTATION OF LATE PALEOCENE DONGYING FORMATION, NANPU SAG, NORTHEAST CHINA

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The "double intense effect" of the Late Paleogene Dongying Formation (32.8-24.6 Ma) in Nanpu Sag manifests by the simultaneous enhancement of intense tectonic activity of boundary faults, especially the activity of a series paralleled NE-SW orientated faults, and intense depression of the whole sag, which lead to the aggregation of great thickness up to 800m of Dongying Formation within a relatively short (4.7-8.2 Ma) period and relatively small 1932 m^2 area.
In the aspect of dynamic vertical evolution process, during the syn-depositional time of Dongying Formation, the Bohai Bay Basin switched into superimposed diversionary stage from fault-controlled to depression dominated stage generally. The phenomenon of the controlling of double intense effect shows as a pulse peak of the subsidence rate of Dongying Formation, which is about 280 m/Ma in average. This is even higher than the Early Paleogene (intense rift stage), compared to the underneath Shahejie Formation (50.5-32.8 Ma) of 100-180 m/Ma subsidence rate and younger Guantao Formation (24.6-12 Ma) with rate of 25-50 m/Ma. Similarly, the average fault activity of Dongying Formation is about 300 m/Ma, as the activity rate is <200 m/Ma during Shahejie Formation, and <50 m/Ma during the following Guantao Formation.
As the corresponding to the combination of "double intense effect", the sediment type and distribution features of Dongying Formation in Nanpu Sag represent significant difference compared to adjacent fault rifted basins during the same time in Bohai Bay Basin in northeastern China (most of them were undergoing fading tectonics in the Late Paleogene period with weak activity of major faults). Instead of partly absenting in other sags in surrounding regions, the Dongying Formation developed widely in Nanpu Sag and reached huge thickness as the whole sag was in un-compensated condition. Other than distributing along the boundary faults as in normal fault-controlled condition, both the subsidence centers (with the ancient settlement depth up to 1200m) and depocenters during the Dongying Formation migrated away from the boundary faults and towards the center of the sag, which resulted in the preservation of extra-thick strata and abundant accumulation of fairly deep lacustrine mudstones with delta front slumps in the sag center, and also caused the development of scalloped shape fan deltas and nearshore subaqueous fan systems near the downthrown side of north fault-controlled steep slope with at least 3 main source pathways around the north boundary supplying sufficient sediments into the basin.

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MULTISCALE CHARACTERIZATION EVALUATION ON PORE STRUCTURE IN A TIGHT MIXOSEDIMENTITE RESERVOIR

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Taking reservoirs on top of the Lower Ganchaigou Formation in the Yingxi District of Qaidam Basin as an example, an indepth study of pore structure characteristics in tight mixosedimentite reservoirs was conducted through the core experiment and well logging technology. The Lower Ganchaigou Formation was deposited in a saline deep to semi-deep lacustrine environment on the plateau, throats are mainly in shape of the tube bundle, with poor filtration capacity. Pores are mainly irregular intergranular pores filled with clay minerals and carbonate cement, resulting in small pore space. Dissolution pores are less developed, mainly intergranular and intragranular dissolution pores. Micro-fractures are widely developed but filled or half filled by carbonate cement, which seriously reduces filtration capacity. Macro-fractures are divided into high angle fractures, oblique fractures and low angle fractures, which can connect micro-fractures between beddings, form a reticulate filtration system and improve the reservoir physical property. Porosity in the research area is mainly 4%~12%, permeability is generally less than 1mD, and pore-throat radius is mainly 0.05~2.5μm. The pore size is mainly micron to submicron, with tight reservoir features of low porosity and permeability. Nuclear magnetic resonance curve is characterized by unimodal shape and doublet shape. And the unimodal shape leaning left is common, showing the pore-throat distribution tending to small pore and fine throat. The mobile fluid saturation is mainly 20%~40%, and the efficiency of mercury withdrawal is less than 40%. Large pore-throat ratio and fine throat restrict the flow of fluids in large pores. Based on NMR core analyzing system, a new parameter "effective saturation of mobile fluid" is proposed for the first time, to characterize the pore-throat configuration more precisely. In addition, "effective saturation of mobile fluid" takes into account the factor that fluids in large pores cannot flow freely due to the restriction of the fine throat. By the standard of "effective saturation of mobile fluid", pore structure in the research area can be divided into three types. Type I has the effective saturation of mobile fluid larger than 30%; Type II has the effective saturation of mobile fluid distributed in 20%~30%; Type III has the effective saturation of mobile fluid less than 20%. According to well logging scaled by cores, each type of pore structure has an obvious correlation with the conventional loggings of GR and DEN. Combined with the content of dolomite, clay mineral and gypsum from ECS logging, well logging identification chart of pore structure is established, which realizes continuous logging recognition and characterization of micro-pore structure in the tight mixosedimentite reservoir.

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The boundary of Qaidam Basin in Tertiary and the uplift of the Eastern Kunlun Mountains: Constraints from sedimentary facies and provenance of the southwestern Qaidam Basin

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A thick Tertiary sedimentary succession has developed in the Qaidam basin of the northeastern Tibetan Plateau. The southwestern Qaidam basin is bounded by the Qiman Tagh-Eastern Kunlun Mountains. The southwestern boundary of Qaidam basin in Tertiary remains debated. An integrated method of sedimentary facies and stable heavy mineral analysis was adopted to reconstruct the southwestern boundary of Paleo-Qaidam basin. Meanwhile, the uplift time of the Eastern Kunlun Mountains can be restricted by heavy mineral analysis and mineral chemistry.

During the late Eocene and Oligocene, the lake were in an expansion period accompanied by retrogadation process in research area. The scale of the lake expanded to the largest in the middle Oligocene. The shorelines extended southwesterly beyond the present-day Eastern Kunlun Mountains. The compositional maturity of the heavy minerals in research area are relatively high. These observations suggest the tectonic setting of the depositional areas was inactive and the source areas were far from the site of the depositional areas. However, the lake began to shrink since the early Miocene. Alluvial facies existed in the front of the present-day Qiman Tagh Range during the middle-late Miocene. Correspondingly, the shorelines moved northward, closer to the basin center. Additionally, the isolines of the stable heavy mineral index (ZTR=20) present a remarkable northward migration since late Eocene. Therefore, the boundary of the Qaidam Basin stretched southwesterly to the present-day Qiman Tagh-Eastern Kunlun Mountains in the early Cenozoic and withdrew northward since late Eocene. The specific location of the source area in the early Eocene could be inferred at the middle of the present-day Eastern Kunlun according to the isoline maps.

The stability of heavy minerals in different areas present a common variation-the amount of the unstable heavy minerals increased since the early Miocene, which indicates the source areas were in an active tectonic setting at that time. Besides, the types of source rocks performed remarkable alterations in some areas since the early Miocene, especially in Wanxi area. Therefore, the early Miocene is a relatively active period of Qiman Tagh-Eastern Kunlun Mountains.

STUDY ON SEDIMENTARY ENVIRONMENT ELEMENTS AND SEDIMENTARY MODEL OF SHALE IN E1F2 MEMBER, GAOYOU SAG, SUBEI BASIN

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lacustrine shale is rich in hydrocarbon resources, but with complex lithology, strong heterogeneity and it is also controlled obviously by sedimentary environment. By integrating cores, thin section, X-ray diffraction analysis, trace elements, organic geochemical indexes and paleontological data, the paper studies sedimentary environment elements and sedimentary model of shale in E1f2 member, Gaoyou Sag, Subei Basin. Shale in E1f2 member is totally shore continental lacustrine deposits forming under dry hot climate of tropical South-East Asia. Lake basin extended continuously, with brackish water, strong oxidation and intermediate water delimitation. Transgression resulted in water rapid rise, salinity, reducibility and water delimitation increase. With climate changing wet later, the water body decreased slightly, salinity, reducibility and water delimitation also decreased. Shale in E1f2 member is characterized by sedimentary provinces, which is divided into muddy water desalination deposit and clear water salinization deposit, including muddy water desalination deposit in flooded area, clear water salinization deposit in transition area and still water salinization deposit in clear water. Under paleogeomorphic settings of E1f2 member, combining characteristics of vertical stratification and plane division of the lake, a integrated sedimentary model of shale in flat platform has been established under climate and transgression control.

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DEPOSITIONAL ENVIRONMENT AND SEQUENCE STRATIGRAPHY OF AN EARLY PALEOZOIC POST-RIFT BASIN: EXAMPLE FROM HAIMA SUPERGROUP OUTCROPS, OMAN

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The early Paleozoic Haima Supergroup including Amin, Miqrat, Al-Bashair and Barik formations is the most productive hydrocarbon sequence in the Interior Oman Sedimentary Basin. Understanding the spatial and temporal distribution of reservoirs *vs* non-reservoirs of Haima Supergroup sequence is of prime interest in hydrocarbon industry. The outcrops of the Haima Supergroup are studied to construct a broad-based sequence stratigraphic framework showing a single long-term 2nd order depositional sequence of about 40-50 Ma duration (Early Cambrian-Early Ordovician). This depositional sequence started with the deposition of basal Amin Formation during lowstand systems tract (LST). The LST is dominantly comprised of lacustrine, braided fluvial and aeolian deposits. The LST is terminated by the appearance of the first marine signatures; the presence of wave-rippled, marine sandstones of uppermost Amin Formation. The surface that separated between the fluvial deposits below and the marine deposits above is considered as transgressive surface (TS). This TS is formed as a result of relative sea level rise during the initial stage of post-rift subsidence. The TS is overlain by the deposition of (i) wave-rippled marginal marine deposits alternating with the aeolian sand dunes deposits of the uppermost Amin Formation, (ii) tidal flat to subtidal Miqrat Formation and (iii) the basal, shallow marine (upper to lower shoreface) Al-Bashair Formation deposits. These deposits above the TS represent the transgressive system track (TST). The TST may have developed during the regional post rifting subsidence in which relative sea-level out-stepped the rate of sediment supply. The maximum flooding surfaces (mfs) is placed within the upper part of Al-Bashair Formation in which the lower shoreface is overlain by upper shoreface facies. The deposition of upper shoreface part of the Al-Bashair Formation and prograding braid deltas of Barik Formation represent the highstand system tract (HST). The HST is believed to be developed when the rate of sediment supplies out-stepped the rate of relative sea-level rise.

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THE MINERAL COMPOSITIONS AND PORE TYPES IN TIGHT MIXED DEPOSITS RESERVOIR, AND THEIR EFFECTS ON RESERVOIR QUALITY: A CASE STUDY IN THE UPPER XIAGANCHAIGOU FORMATION IN YINGXI AREA, QAIDAM BASIN, NW CHINA

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The Qaidam Basin is a typical plateau saline lacustrine basin, which is mainly covered by Mesozoic and Cenozoic terrestrial clastic and carbonate deposits. The Yingxi area lies in the northwestern of the Yingxiongling structure belts, southwestern Qaidam Basin. The Upper Xiagancaigou Formation ($E_3{}^2$) of the Yingxi area is characterized by typical sediments of salt lacustrine environments and mainly consists of carbonate, clastic particles and gray mudstone with minor gypsum and halite. Complex lithology and lithofacies cause low matrix porosity and permeability and strong heterogeneity, thus increasing the difficulty of reservoir quality evaluation. To address this issue, a multidisciplinary approach, including core observation, thin section observation, scanning electron microscopy, X-ray diffraction (XRD), conventional well logs, image logs, Litho Scanner log and dipole shear wave well log, has been undertaken. In details, the minerals were determined by the Litho Scanner dry weight logging data combined with the ELAN advanced multimineral log analysis, and the computed result was consistent with the core XRD measurements. Additionally, pore types were analyzed through thin sections and the SEM. Based the above study, the following results can be obtained. The mineral compositions are dominated by quartz, feldspar and carbonate, along with minor amounts of gypsum, clay minerals, pyrite and siderite. Four pore types, containing primary intergranular pores, intergranular dissolution pores, intragranular dissolution pores and microfractures, can be found in the study field. These pore types result in varied reservoir quality. Considering the control of pore types on reservoir quality, three reservoir types are defined, i.e. the pore dominated, microfracture dominated and the fractured pore reservoir. In addition to the pore types, the mineral composition also plays a vital role in controlling reservoir quality. Reservoirs dominated by dolomite or ankerite with dissolution pores and fractures show the highest reservoir quality, which is verified by well testing and production data. The study could provide theoretical guidance and technical support for evaluation of formations with complex mineral deposits and for prediction of favourable zones in oil-gas reservoir development.

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IS THERE A MID-PERMIAN MEGA-LAKE IN NORTH XINJIANG, NORTHWESTERN CHINA?

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Key tectonic changes had taken place from late Carboniferous to Early Permian in Northern Xinjiang, Northwestern China. Accompanied by the final closure of Paleo-Asian Ocean, the clastic rocks developed in the Permian terrestrial Lake basins. There is a widespread regional angle unconformity in Northern Xinjiang, above which it is Permian terrestrial clastic rocks, while the Pre-Permian marine basement beneath the very unconformity. In early Permian, the coarse clastic molasses formation developed in oxidizing environment. In Middle Permian, the isolated early Permian foreland lake basins gradually unified into a large depression (Carroll, et al, 2003). There is good comparability of Middle Permian stratigraphic sequence, and dark mudstones widely developed. The dark mudstones in fine-grained sediments are one of the most favorable carriers for the depositional environment analysis. In this study, mudstone samples were Systematically taken at outcrops in North Xinjiang, such as Jiangjunmiao and Shuangjingzi in Northeast Junggar, Xiaolongkou, lucaogou and Hongyanchi in Sourth Junggar, Wuerhe and Xiayan in Northwest Junggar, Daheyan and Kulai in Turpan, Qunjisayi and Bidelixi in Ili. The elements which are sensitive to the depositional environment were selected. The relationship between the content with its ratios of trace elements and sedimentary environment was analyzed. The Middle Permian sedimentary environment characteristics of the lake basins were discussed. The test results of samples indicate that the geochemistry index of the Paleo-environment of each outcrop is close. The date of *W(B)*, *m(Sr)/m(Ba)* and *m(B)/m(Ga)* reflect an extensive nonmarine with brackish - saltwater sedimentary environment in North Xinjiang in Middle Permian. The value of *m(V)/(m(V)+ m(Ni))*, *m(Th)/ m(U)*, *&U* and *m(Cu)/m(Zn)* are independently around 0.75, 3, 1 and 0.55, it shows that there was a weak hypoxic reduction environment in Middle Permian Junggar-Turpan-Santanghu-Ili-Balkhash lake basin. The value of *m(Sr)/m(Cu)* is around 12.5, it shows a weak rid and hot environment, and the water temperature is almost at 22℃ to 27℃. At the same time, the plane distribution characteristics of each geochemistry index also show that there were same Low uplifts in this Mid-Permian mega-lake, in which there was high salinity, strong reduction, and occluded environment. Combined geochemistry index with sedimentary strata, We can conclude that there was an Mid-Permian terrestrial mega-lake in North Xinjiang, Northwestern China. It Included Junggar, Turpan, Santanghu, Ili and Balkhash, covering an area at least about 400,000 Square kilometres, mayby it is bigger than the world's biggest lake-Caspian Sea nowadays.

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GEOCHEMISTRY AND DEPOSITIONAL CONDITION OF THE PERMIAN LACUSTRINE SHALE: A CASE STUDY FROM THE LUCAOGOU FORMATION OF WELL JY74 IN THE JIMUSAER SAG, JUNGGAE BASIN

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Jimusaer Sag is located in the southwest part of the East Uplift, Junggar Basin. In recent years, the Lucaogou Formation tight oil exploration has obtained an important progress. More than 17 exploratory wells obtained commercial oil flow. However, few studies exist concerning the geochemistry and depositional condition evolution of the Lucaogou Formation source rocks[1,2]. All the Lucaogou Formation cores in the Well Jy74 were obtained. Based on the testing data of organic geochemistry and biomarker for the Lucaogou Formation shale in the Well Jy74, geochemistry characteristics and depositional condition were discussed. 25 shale samples were collected from the Well Jy74. Conventional geochemical methods, such as TOC, Rock-Eval pyrolysis, extract, and hydrocarbon content were used for evaluating source rock quality, and biomarkers were used to estimate depositional condition and its evolution. The application of these methods indicates the Lucaogou Formation shale is generally good to excellent source rock, and have mainly Type II, Type II-III and some Type I and III organic matter (OM), with fair oil potential and gas/oil potential. Because of the early to middle mature stage, the shale generated mainly liquid oil. Biomarkers analysis indicates that the Lucaogou Formation shale was deposited in the dysoxic/suboxic to anoxic reducing lacustrine environment of normal salinity–higher salinity, with the contribution of both aquatic organism and terrigenous organism. The higher TOC content correlates positively to aquatic OM input quantity, OM abundance, water salinity, different source OM input, and reduction-oxidation condition of depositional environment. Depositional condition of the Lucaogou Formation were changeable from the early to late. The high quality of source rocks in the Lucaogou Formation of well Jy74 is mainly distributed in the depth intervals of 3145 m to top and 3220 m to bottom.

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DEPOSITION OF HYPERPYCNAL FLOWS FOLLOWING THE EXPLOSIVE VOLCANIC ERUPTIONS: THE CRETACEOUS BEOLGEUMRI FORMATION, SW KOREA

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The Cretaceous Beolgeumri Formation was deposited in lacustrine environments during short intervals between major volcanic eruptions. In the lower part of the Beolgeumri Formation, hyperpycnal flow deposits (< 25 cm thick) consist of an inversely graded and planar laminated lower part, a poorly-sorted and massive middle part, and a normally graded, planar laminated upper part. An internal erosional surface is common between the lower and middle parts. Boulder-sized litic clasts are also scattered in the beds of the deposits. After explosive volcanic eruptions, subaerial drainage systems would be highly disturbed by deposition by volcaniclastic sediments. The fine-grained and unconsolidated natures of the volcanic sediments gave rise to easy remobilization by surface runoff that eventually evolve into sediment-lade floods by entrainments of the sediments during flows. When the surface runoff meet the lake, its own excess density of the surface runoff resulted in plunge into the lake, providing favorable condition for the formation of the hyperpycnal flows. Compared with classic models of hyperpycnal flow deposits, predominant planar laminations in lower and upper parts suggest high fallout rates of sediments during initial and late stages of deposition, implying highly concentrated nature of the flows. Relatively thinly bedded hyperpycnal flow deposits (< 25 cm thick) in comparison with the classic models (1 to 4 m thick) can be attributed to short-lived hyperpycnal flows. Both are inferred to be as a consequence of vulnerable states of the subaerial conditions to erosion of unconsolidated volcaniclastic sediments, and heavy rainfall events (e.g. storm) are not needed to form the highly concentrated surface floods that evolved into hyperpycnal flows (Hayes et al., 2002). Thus, disturbed subaerial conditions after the eruptions offered favorable conditions for the formation of the highly concentrated and short-lived hyperpycnal flows.

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Depositional Systems and Sequence Stratigraphy of Recession-rifting Stage in the Fulongquan Depression of the Songliao Basin, China

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Abstract: This study focuses on the spatial distribution and temporal evolution of sedimentation and stratigraphy in the recession rifting stage (Denglouku Formation) of the Fulongquan Depression in the Songliao Basin, China. The succession has been divided into two sequence stratigraphic units separated by key unconformities generated by tectonic activity caused uplift and exposure of strata. Analysis of major flooding surfaces and stacking patterns of the stratal units indicates that each sequence unit can be divided into a lowstand systems tract (LST), transgressive systems tract (TST) and highstand systems tract (HST). Fulongquan Depression is segmented and consists of three main dip provinces created by differential subsidence related to activity of the major boundary faults. Major palaeosedimentary environmental reorganization, accompanied with the transition from balanced-fill to overfill, have occurred in the Fulongquan Depression due to basin-bounding fault movement decreased or even ceased. The succession generally shoals upwards, though the processes of peneplanation in different settings are complicated, from braided delta - sublacustrine fan - lake into fluvial – floodplain association. The three dimensional linked depositional systems associated with each of these systems tract will vary according to tectonic subsidence pulses, climatic variations or fluctuating lake levels and sediment supply. Together with the decrease in subsidence rate mainly controlled by master fault movement, lake level and climatic fluctuations began to have a greater influence than tectonic movements. Stratal patterns and sediment supply vary, depending directly on the climate, source rock composition and the topography.

Key words: Songliao basin; Fulongquan depression; rift degeneration stage; sedimentary systems; sequence stratigraphy; strata stacking pattern

From Alluvial Fan to Gentle-Slope Conglomerate Fan Delta of Shallow Water, A New Understanding of Sedimentary Promoted The New Discovery in Mahu Slope Area of Xinjiang Junggar Basin

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The Triassic Baikouquan formation of Mahu depression in Xinjiang Junggar basin developed conglomerate mainly, previous research shows that the sedimentary system is steep alluvial fan controlled by flood current , The slope area is lacustrine mudstone sedimentary and not suitable for oil and gas exploration. Through a large number of core observation, analysis of the characteristics of log response and seismic phase, seismic sedimentology analysis based on global optimal sequence interpretation, restoration of palaeogeomorphology based on slope correction, the Th/U analysis and saturated hydrocarbon gas chromatography Pr/Ph analysis method of mudstone etc., we reunderstand the sedimentary paleoenvironment and the characteristics of the facies belt in the slope zone. The research shows that Baikouquan formation mainly developed retrogradational large fan delta of slope environment controlled by the continuous uplift Junggar mountain, inherited ancient mountain pass, paleo sedimentary slope of 1-2 degree, shallow water body, multistage sedimentary paleo slope. Which developed many types of conglomerate facies caused by debris flow, high density flood and drag flow. Each fan deltaic conglomerate overlapped each other in space, forming a large-scale conglomerate. The fan delta front facies belt can extended to the center of lake. The research has been confirmed by the practice of oil&gas exploration and billions tons of scale reserves have been found.

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Sedimentary characteristics and morphology evolution of a coarse-grained fan-delta system: Roles of tectonic and climate

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Abstract: This study utilize core data and well-log data to investigate the facies associations, sedimentary architecture, shoreline behavior and fan morphology of the conglomeratic fan-delta system of Lower Triassic in the Mahu Sag, northwestern Junggar Basin of Northwest China. Three facies associations consist of fan-delta plain, fan-delta front and pro-delta/lacustrine are identified within the mass flow dominated fan-delta system. The fan-delta plain is dominated by braided stream conglomerates deposits, whereas the fan-delta front is dominated by channel mouth deposits. The bed thickness proportion of mass-flow originated deposits shows upward-decrease, while that of stream-flow originated deposits shows upward-increase trend. From bottom to top, the viscosity of sediment also becoming lower. The fan-delta evolution is characterized by alternating mass flow events and stream flows during intermittent period. The shoreline showed a landward migration trend with a relatively smooth morphology. The fan-delta has an overall elongate shape and the internal architecture shows that the fan-delta front slope increased-upward. The steeper slope triggers the mass-flows of the fan-delta system which are controlled also by the arid climate. The continuous subsidence and lake-level rise resulted from climate changes from arid to humid generated enough accommodation for the preservation of intermittent period fine sediments. This study suggest that the climatic changes from arid to humid play a significant role in controlling the dominant process and sediment viscosity of the fan-delta system. This study also suggests that not only fine-grained sediment but coarse-grained sediments also can contribute to building an elongate delta.

Keywords: facies associations; sedimentary architecture; sediment viscosity; morphology

THE INFLUENCE OF WIND FIELD ON DEPOSITIONAL SYSTEMS

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Wind is an important geological agent as a form of the activity of atmospheric current field. It plays an important role in controlling the distribution of depositional systems. Wind not only has the ability of erosion, transportation and deposition where aeolian systems are developed; it can also pass its energy and momentum on to water to create waves and wind-driven flows with unique underwater depositional systems developed. On the basis of direct wind impacts and indirect impacts on sediments, the siliciclastic and carbonate depositional systems influenced by wind field are classified into three categories: lee system, wind system and crosswind system.

In the siliciclastic depositional system, the source input in the leeward side is largely stronger than the wind (wave) effect on the shore, where the constructive depositional systems are developed such as the fan delta and river delta; The source input in the windward side is counterbalanced with the wind (wave) effect, where the destructive depositional systems are developed such as estuarine bay and non-barrier beach; In the crosswind side source input is oblique to the wind (wave) effect, where the deposits are destructed and modified during the sedimentary processes with resulting in the wind-wave control delta depositional system developed. In the carbonate depositional system, the leeward side commonly develop the lagoon - tidal flat system while the windward side the platform margin skeletal grainstone.

With the introduction of the wind field into the sedimentology, the sedimentary dynamics of the "wind-source-basin" system provides a new research idea and research method for carrying out sedimentology research in the sedimentary basin. It provides a new perspective for explaining the sedimentary formation (including oil and gas reservoir) and distribution as well as predicting sedimentary systems. It also helps improve the paleo-wind-field and paleoclimate reconstruction.

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THE DISCOVERY OF HYPERPYCNAL FLOW IN NONMARINE RIFTED BASIN: A CASE STUDY IN HAILAR BASIN, CHINA

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Hyperpycnal flow is a kind of persistent turbidity flow caused by river in flood period going into basin, when density of injection water greater than basin water, sublayer flow along basin bottom occurred. In recent years, as one of the hot points in sedimentology, most study focused on present and ancient deposition of marine environment but seldom continental rifted basin. Considering sedimentary theory, it is easier to develop hyperpycnal flow because of medium-small scaled rivers with abundant suspended deposits in flood period, certain topographic slope caused by tectonic movement and larger density variation in continental rifted basin. Based on the core data, thin section analysis and 2D seismic data, the channel-sublacustrine fan system of hyperpycnal flow was discovered in Dongming sag, Hailar basin, China. The sedimentary characteristic and sequence were researched. The study indicates hyperpycnal flow originates from the northern edge of basin, which is minor axis and near source sedimentary system. Abundant suspended deposits in seasonal flood and slope angle are the main conditions. The main sedimentary facies contain channel formed in the process of deposits long distance transportation and sublacustrine fan at the end. The channel-fan system dominated by fine-grained deposits shows bed-load and suspended-load transportation mechanisms, and consists of massive sandstone, sedimentary structures of fluvial flow, and abundant continental organic clasts. Gradational contacts with the top and bottom, and internal weak erosion surfaces develop. Single flood event has a lower coarsening-upward sequence and upper fining-upward sequence, both of which appear in pairs, reflecting the dynamic feature of flood strengthening and weakening cycle. Upper fining-upward sequence is always preserved because frequent flood and erosion occurred in continental rifted basin. The lower part of the fining-upward sequence with medium-fine sandstone dominated and muddy gravel interbedded has lineation muddy gravel, tearing muddy clast, frame structure and matrix support structure. The middle part contains fine sandstone dominated, massive sandstone structure with floating pebbles occasional, and random distributed continental organic clasts. The upper part with siltstone dominated contains parallel bedding formed by continental organic clast, convolute bedding and climbing bedding. The top is mudstone with horizontal bedding and continental organic clast interlaminated. The hyperpycnite could be good prospects with effective source-reservoir-seal set, and may bring new growth of oil and gas exploration in deep water of nonmarine rifted basin.

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SEDIMENTARY CHARACTERISTICS OF SHALLOW-WATER DELTAS IN CONTINENTAL RIFT BASIN: A CASE FROM LIUWUSHE SUB-SAG IN GAOYOU SAG, SUBEI BASIN, EASTERN CHINA

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Subei Basin, located in the east of China, is a Cenozoic continental rift basin formed during the end of Late Cretaceous. Gaoyou Sag is a dustpan-shaped rift basin in the south of Subei Basin and Liuwushe Sub-sag is in the east of Gaoyou Sag. Dainan Formation (Eocene) is one of the significant oil-bearing strata and it could be divided into the 1st Member (research goal in this article) and the 2rd Member from bottom to top. Wu1 fault in the east and Zhen2-1 fault in the south are two boundary faults of Liuwushe Sub-sag, which help form the tectonic framework that the slope in the north, the steep slope in the southeast and the deep sag in the middle. However the restoration of burial history shows Liuwushe Sub-sag is quite flat during period of Dainan 1st Member. Such sedimentary background indicates sediments could be transported across the deep sag. Analyses on heavy minerals, lithic fragments and compositional maturity indicate most sand bodies of Dainan 1st Member in Liuwushe Sub-sag came from the north slope, and steep slope might not be the main provenance. Abundant evidences such as the color of mudstone change between brown and celadon, cross bedding formed under strong current and plenty of biogenic sedimentary structure in cores, intermittent positive rhythms and little preservation of inverse rhythm in logging curve, as well as imbricate reflection in seismic sections all support the inference that shallow-water delta is the dominant sedimentary facies of Dainan 1st Member in Liuwushe Sub-sag. Unlike the typical depositional model in many continental rift basins(deltas in slope, fan deltas in steep slope and gravity-slide in deep sag), Dainan 1st member in Liuwushe Sub-sag mainly consists of subaquatic distributary channels extended from north to south. Previous studies have shown that activity intensity of Wu1 fault reduced significantly during period of Dainan1st Member, which might be the most important reason why shallow-water deltas deposited in rift basin. In addition, slump bedding in cores also exists in steep slope zone of Liuwushe Sub-sag but it was only found in partial strata of Dainan 1st Member, mainly appears around sequence boundary. With the increase of activity intensity of boundary faults, fan deltas can also deposit in steep slope, which might be the significant difference between shallow-water deltas deposit in rift basin and deposit in downwarped basin. Sedimentary evolution during Dainan1st Member in Liuwushe Sub-sag has also been researched in this study.

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The Past, Present and Future of Research on Deep-water Sedimentary Gravity Flow in Lake Basins of China

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Abstract: Deepwater gravity flow deposition is the hotspot of current global oil and gas exploration and research. The study of deepwater gravity flow sedimentation in continental basin in China has been in the past 50 years and can be divided into four stages, that is, the early speculation stage (1950-1960s), stages of exploration and development of turbidity flow theory (1970-1980s), stages of industrial application of turbidity flow theory (1990-2000) and stages of sandy debris flow (after 2010). In recent decade, with the development of international deepwater deposition theory and the progress of oil and gas exploration technology in our country, the research on deepwater sedimentation in the lacustrine basin has progressed rapidly and a great deal of new achievements and new understandings have emerged. There are mainly four aspects as follows: (1)There are at least four kinds of gravity flow and traction flow deposition in the deep waters of central lacustrine basin, turbidity flow, hyperpycnal flow, sandy debris flow and bottom flow. (2) There are transformations among different types of fluids in the lacustrine during the processes of transportation and deposition, forming a hybrid event bed. (3) The mud-coated intraclasts, which is the identification mark of sediment transport in lacustrine sandy debris flows, has been established. (4) The theories and techniques of seismic sedimentology have been widely used in the analysis of internal sedimentary unit of lacustrine gravity flow and in establishing sedimentary models in deepwater lacustrine basins, and achieved great success. Looking into the future, in order to meet the exploration and development needs of oil and gas industry, the research and development trends of deep water sediments in the lacustrine basin are mainly as follows: (1) the genetic type division of deepwater sandbody, the transportation-deposition process, and the establishment and improvement of it sedimentary model; (2) the genetic mechanism, type division and its significance to oil and gas of deepwater shale (fine sediments); (3) research on "source-sink" system and seismic response and evaluation and prediction; (4) experimental simulation research on the process of transportation-sedimentation of deepwater sediments; (5) establishment of newtheory systemof deepwater deposition and its application in oil and gas exploration and development.

Magmatic Hydrothermal Exhalative-related and deep-derived clastic sedimentary rocks in Permian Lucaogou Formation in Santanghu Basin, Xinjiang, NW China

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NW-SE trending Santanghu basin is located in Xinjiang, NW China, between Tianshan Mountains and Altai Mountains. Santanghu basin was in intraplate rift evolution stage, under regional extension geological background in late Carboniferous. During early-mid Permian the basin was a starved, deep lacustrine intracontinental rift basin.

Fine-grained sediments have become a focus for geologists nowadays since oil demand continue increasing. However, it is hard to conduct detailed petrology and mineralogy study constrained by their extremely fine grain size and current experimental conditions. Therefore these dark fine-grained rocks have long been considered as mixed deposits of terrigenous clasts and chemical precipitates. As a result, people think Permian Lucaogou Formation in Santanghu Basin developed lacustrine black rock series which mainly composed of mudstone, dolomicrite , micrite tuff and tuffite.In recent years, evidence of hydrothermal activities has been found in Lucaogou Formation and abundant deep-originated materials derived from volcanic and hydrothermal activities are observed. Hence this rock series turns out to be laminated fine-grained rocks which composed of deep-derived, magmatic-hydrothermal exhalative-related clastics.

This study takes the magmatic-hydrothermal exhalative sedimentary rocks in Permian Lucaogou Formation as the main object. Describe their detailed features of micro petrology and mineralogy and identify characteristics of different kinds of these rocks. By means of core and thin section observation, electronic probe and other relative data, three kinds are classified based on main mineral composition: carbonate type, silicate type and felsic type. This study challenges the conventional knowledge of lacustrine dark fine-grained rock series and may hopefully enrich modern sedimentary theories.

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Petrologic Analysis and Factors Controlling Reservoir Quality for the Steep and Gentle Slopes in the Asri Basin, Indonesia

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The Asri Basin, a petroliferous basin in Indonesia, is characterized as a half-graben with a gentle slope in the west and a steep slope in the east. However, previous studies have indicated that reservoir quality varies from the gentle slopes to steep slopes. To better understand the difference in reservoir quality between the western gentle slope and the eastern gentle slope and to identify the controlling factors, this study is mainly devoted to petrology analysis including petrologic and petrophysical characteristics of reservoir rocks from both slopes. This study involves the observation and description of thin sections as well as photomicrographs to clarify the chemical composition and pores development. In combination with data on porosity, permeability, Ro and T-max temperatures, a comparative analysis of reservoir quality in terms of intervals in time and units in space is also presented. A key result is that the compositional and textural maturities of sandstones are better in the western steep slope than those in the eastern steep slope; this difference is mainly caused by the transportation distance and provenance lithology. In addition, major diagenesis seems to affect the permeability and porosity of the reservoir but does not significantly affect the reservoir difference between the western gentle and eastern gentle slopes. Further, studies of the underlying basement show that the basement rock type somehow results in better reservoir quality in the western slope than in the eastern gentle slope. In addition, in response to depth variation, the reservoir quality improves in sedimentary rocks from the Banuwati Formation to the Upper Lower Zelda Member as a result of rock components.

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Comparison of Formation Mechanism of Fresh-water and Salt-water Lacustrine Organic-rich Shale

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Abstract

Based on the core and thin section observation, XRD, major, trace and rare earth elements test, carbon and oxygen isotopes content analysis and other geochemical methods, a detailed study was performed on formation mechanism of lacustrine organic-rich shale by taking the middle Permian salt-water shale in Dzungaria Basin and upper Triassic fresh-water shale in Ordos Basin as the research target. The results show that, the middle Permian salt-water shale was overall deposited in hot and dry climate. Long-term reductive environment and high biological abundance due to elevated temperature provides favorable conditions for formation and preservation of organic-rich shale. Within certain limits, the hotter climate, the organic-richer shale formed. These organic-rich shale was typically distributed in the area where palaeosalinity is relatively high.

On the contrary, during the upper Triassic at Ordos Basin, the shale was formed in overall warm and moist environment. Seemingly, the temperature, salinity and water depth shows negative correlation with TOC in shale deposits in fresh water. However, this picture has changed after the rock classification. There are three kinds of shale in upper Triassic, and temperature, salinity, REDOX, productivity and water depth has positive correlation with TOC in each shale respectively. In other words, vertically that the temperature, salinity and water depth seems show negative correlation with TOC, actually is due to continuous (cyclic) change of shale types.

In this sense, looking for high-TOC shale in lacustrine basin needs to follow different rules depends on the palaeoclimate and palaeoenvironment during sedimentary period. The hot climate promotes the organic-rich shale to form, by strengthening water column stratification and biological diversity. High salinity may be in favor for the organic-rich shale formation by providing reductive environment. Shale classification is significantly important and rapid variation of shale types should be paid more attention.

Keywords: formation mechanism; lacustrine shale; fresh-water; salt-water; Ordos Basin; Dzungaria Basin

Origin and Developing Model of Rock Salt: A Case Study of Kumugeliemu Formation of Paleogene in Kuqa Depression, Tarim Basin

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Abstract: The Paleogene Kumugeliemu Formation in Kuqa depression(Tarim Basin) is originated from saline lacustrine-basin sedimentation with the development of multiphase rock salt (layered halite), of which the origin and development mode is a hot issue to be solved at present. The core data reveal that the complete salt-formation single-phase cycle is an evaporation sedimentary sequence. The lithological sequence assemblage characteristics of prospecting wells show that the lacustrine basin experienced three evolutionary stages, i.e., semi-saline, salinizing and saline lake. Through the petrography analysis, homogenization temperature test and composition research of the inclusions as well as the analyses of the sulfur, carbon and oxygen isotopes of salt-bearing strata, it is explicitly put forward that the rock salt was generated through low-temperature underwater concentration and crystallization, and formed in the confined continental environment with intense evaporation; the material source was carried by terrestrial surface water. Two kinds of salt forming modes were developed in the mid-late saline stage and euryhalinous lake stage, and each mode is divided into three evolutionary stages, i.e., initial saline stage, saline stage and salt forming stage.The comparison and analysis of joint wells indicate that five rock-salt concentration development periods existed, when the saline lake experienced three evolutionary processes, i.e., the initial stage, peak stage and shrinking stage. The saline lake center had the maximum thickness with limitations in plane distribution, and multiple secondary salt depression centers were formed due to the control of paleo-terrain. The vertical development of multiphase salt rock was caused by the frequent seasonal fluctuation of lake level in terrigenous lake basin.

Key words: rock salt; origin; developing model; underwater concentration crystal formation; evaporation; Kuqa depression

ESTIMATION OF PALAEO-SLOPE AND SEDIMENT VOLUME OF A LACUSTRINE RIFT BASIN: A SEMI-QUANTITATIVE STUDY ON THE SOUTHERN STEEP SLOPE OF SHIJIUTUO UPLIFT，BOHAI OFFSHORE BASIN, CHINA

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The sequence architecture and depositional systems of the Palaeogene lacustrine rift succession in the southern steep slope of the Shijiutuo Uplift (SU) in Bohai Offshore Basin (BOB) were investigated using combined 3-D seismic, well log and core data. Four second-order/composite sequences and seven third-order sequences were identified. A detailed analysis revealed fan delta, braid delta and lacustrine depositional systems in the third-order sequences 7 (SQ7). Eleven seismic facies were chosen in the SQ7 to calculate the area and sediment budget. We also calculated the palaeo-slope parameters in the southern steep slope of SU, including the gradient of basin margin fault slope belt, the shape, average width, average height, width/height ratio and cross sectional area of palaeo-valley. The gradient of the fault slope break belt was inversely proportional to the area and volume of sediments. The higher gradient corresponded to the smaller area and volume of sediments. The width and cross sectional area of palaeo-valleys dominated the volume and facies of sediments. A larger cross sectional area of a palaeo-valley involved much more sediments supply and more favorable conditions for the origin of large-scale deltas. Because of favorable sediment transportation path and existence of large-scale braid delta, the eastern part of the SU formed better quality reservoir than that in the west.

Key words: Shijiutuo Uplift; Bohai Offshore Basin; lacustrine rift basin; palaeo-slope morphological parameters; area and volume of sediments; reservoir.

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Thin Bed Prediction from Interbedded Background: Revised Seismic Sedimentological Method

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Predicting a thin bed (<λ/4 in thickness, whereλis the length of waveform) from the interbeded background is a challenging work for seismic interpreters. According to the working order from strata division through plane view to thickness prediction a workflow is proposed in this paper by using a seismic sedimentological method. Besides the high-order sequence dividing，seismic lithology analyzing（90°degree phasing and the stratal slicing proposed by Zeng et al.(2012) in their workflow, we emphasize the importance of the following techniques in promoting the accuracy of the thin bed plan-view prediction: (1) paleogeomorphology recovering based on compaction correction with concern of different lithology, (2) interference suppressing of the neighboring beds, (3) browsing of stratal slices linked with well-logs or drilling column, (4) non-linear stratal slicing. When coming to the high-order sequence recognition, the isochronism analyzing of the seismic events and the well-seismic matching are recommended. The isochronism analyzing helps us to find the seismic reflections in accordance with the geological surfaces, and the well-seismic matching is useful for high-order sequence recognition. When concerning the thin bed thickness prediction we firstly introduce two commonly used techniques，amplitude tuning and peak frequency， then propose amplitude-frequency blending and genetic neural network as two new valuable techniques.

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THE INFLUENCE OF TERRIGENOUS SILICATE COMPONENTS ON GEOCHEMICAL TESTING RESULTS OF LACUSTRINE CARBONATES AND LIMITATIONS OF DIFFERENT ELEMENTAL TESTING METHODS

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Due to its specific sedimentary environment and close relation with terrestrial provenance, lacustrine carbonates are often mixed sediments of chemical sediments (eg. calcite, dolomite and gypsum, etc.) precipitated from water and terrigenous silicates. The mineral composition of the mixed sediments can be semi-quantitatively measured with X-ray diffraction. However, when lacustrine carbonate samples are used in geochemical research, the amount of terrigenous silicate components will definitely affect the testing results. In addition, because of the high content of terrigenous silicate components in lacustrine carbonates, many common testing methods of marine carbonates, such as acid-dissolved whole rock analysis, Electron Probe Microanalysis (EPMA) and Laser Ablation-Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS) can not simply be used to Lacustrine carbonates. However, little attention has been paid on these problems until now.

Lacustrine carbonates are widely developed in the Eocene Xiaganchaigou Formation to Miocene Xiayoushashan formation of western Qaidam Basin and provide very suitable research material. By analyzing lacustrine carbonate samples with LA-ICP-MS, the influence of terrigenous silicate components on the geochemical characteristics of lacustrine carbonates can be evaluated by the linear dependence between the amount of an element and the amount of (Al+Si+Ti). In this research, Mn, Sr, Mo, Cu, Ge, Y and REE are hardly affected by the amount of terrigenous silicate components with linearly dependent coefficient(R^2) smaller than 0.3 .While K, Fe, Ni, V, Rb and Zr are strongly affected by terrigenous silicate components with R^2 larger than 0.7.

By combining and comparing the results of acid-dissolved whole-rock ICP-OES analysis, EPMA and LA-ICP-MS, the limitations of each testing methods were summarized when they are applied to analyze lacustrine carbonates. For the acid-dissolved whole rock analysis, The alkali metal elements in carbonate minerals, such as K, will go into the solution during the dissolution process and can not be used for subsequent analysis. For the micro-area testing method including EPMA and LA, there are two limitations. First, the data between LA and EPMA should be compared with each other to determine whether these data can be used together. Second, the testing results should be treated with caution when these methods are applied to analyze micritic lacustrine carbonate samples. It is because that there are high content of terrigenous silicates in the samples, and the sampling range, especially for the LA-ICP-MS method, is much larger than the size of matrix. So the testing results will be the geochemical composition of mixed sediments, and it can reflect neither the information of lake water nor the information of provenance.

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Characteristics of fine-grained sedimentary environment in the continental freshwater lake basin--A case study of Chang 7 Member of Upper Triassic Yanchang Formation in Ordos Basin

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Abstact: It is of great significance in further understanding the characteristics of fine-grained sedimentary rocks and guiding the unconventional hydrocarbon exploration to do studies on the characteristics of sedimentary environment, such as palaeoclimate, paleosalinity, water depth etc., and the evolution rule of fine-grained sedimentary rocks. Taking the Chang7 Member of Triassic Yanchang Formation in Ordos Basin for an example, the sedimentary environment and its evolution laws are studied by geochemical element test, sporopollen assemblage, isotopes and paleontological ecology analysis on the samples selected from the outcrop section around the basin and the well cores in the basin. Combined with the characteristics of sporopollen assemblage, analysis on the constant and trace element testing results including CaO, MgO, Sr, Ba, B, V, Ni, Th, U, CaO/MgO, Sr/Ba, V/(V+Ni), Th/U and so on, which are related to the climate, suggest that the paleoclimate during the Chang 7 sedimentary period belonged to a warm humid tropical subtropical climate with an annual average temperature over 25℃, and the paleo-temperature of the early Chang 7 (Chang 7_3 sedimentary period) is higher than that of the middle and late period of Chang 7 (Chang 7_2 and Chang 7_1 sedimentary period). Comprehensive studies on the constant and trace element, isotopes and paleontological ecology reveal that the water environment during the Chang 7 sedimentary period was an open continental freshwater environment where the evaporation capacity is less than water recharge, and the salinity of the water body decreased from the Chang 7_3 sedimentary period to the Chang 7_1 sedimentary period. The lake was wide and deep during Chang7 deposition period with the water depth mainly between 30m and 100m and some area of the middle part in the lake could be more than 100m. In the rapid transgression period of Chang7_3, the lake area and depth reached the maximum, however, the constant and trace elements showed that the water was in high salinity during this period. Although there were a quantity of fresh water supply in Chang7_3, but the paleo temperature was higher and the evaporation was more than those of Chang7_2 and Chang7_1, therefore, the temperature and salinity were gradually decreasing from Chang7_3 to Chang7_1 sedimentary period.

Key words: fine-grained deposition; sedimentary environment; freshwater lake basin; Chang 7 Member; Ordos Basin

THE TYPE, CHARACTERISTIC AND GENESIS OF LACUSTRINE SHALE LAMINAE — A CASE STUDY OF UPPER ES4 - LOWER ES3 SUBMEMBER IN DONGYING DEPRESSION

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A large amount of lacustrine shale laminae with various types and complex genesis mechanism of Upper Es4 - Lower Es3 Submember have developed in Dongying Depression. Based on the core and thin section observation of shale samples from the research area with the combination of SEM analysis, major element, trace element and C/O isotope test, the research on the classification of lacustrine shale laminae types and their genesis mechanism is carried out, and five types of lamina have been classified according to lamina fabric and lamina combination, including continuous/discontinuous clastic-rich lamina - organic-rich lamina - carbonate-rich lamina, continuous clastic-rich lamina - organic-rich lamina, discontinuous organic-rich lamina - carbonate-rich lamina, discontinuous clastic-rich lamina - carbonate-rich lamina and homogeneous lamina. On the basis, the genesis of various lacustrine shale laminae has been discussed according to the sedimentary environment and sedimentary mechanism of lamina components and lamina units. It has been found out that the formation of diverse types of lacastrine shale lamina is controlled by material input, hydraulic turbulence, water depth, bottom topographic, salinity, redox property and temperature of the lake.

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ARCHITECTURE AND RESERVOIR QUALITY OF LOW-PERMEABILITY EOCENE LACUSTRINE TURBIDITE SANDSTONE FROM THE DONGYING DEPRESSION, EAST CHINA.

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The deepwater, marine turbidite sandstones are known to form moderate to excellent petroleum reservoirs, but lacustrine turbidite are less known. Here, we report on the turbidites of the middle third member (Es3m) of the Eocene Shahejie Formation, where prevailing reservoir heterogeneity at multiple scale is main issue in petroleum exploration, production and remaining oil recovery. An integrated approach is adopted to characterize heterogeneity at three scales; (1) architecture element and sequence stratigraphic scale, lithofacies scale and porescale. Seismic data, wireline log, and well core is integrated to delineate the architectural, sequence stratigraphic framework. Core observations and analysis are used to interpret depositional mechanism, gravity flow types and lithofacies. A petrographic based approach is adopted to study microscopic heterogeneity using optical microscope, scanning electron microscope (SEM), routine core analyses and X-ray diffraction (XRD) analyses. Es3m is lobe dominated turbidite fan system with channelized base. This study revealed that these deposits are characterized into four–fold hierarchy arrangements from bed through to element, channel/lobe and channel/lobe complex. The Es3m member is interpreted as a sequence set that is composed of four composite sequences: CS1, CS2, CS3 and CS4. Throughout the hierarchy, the sands layers are separated by mud layers, similarly in sequence stratigraphy framework, lowstand sands are capped by transgressive or highstand silt or mud layers. Amalgamated sand beds are usually present in channels and proximal areas of lobes which indicate high flow energy. Hybrid event beds are present towards distal area of fan, because of portioning, increased concentration and entrainment of substrate mud with flow run-out downslope. The bounding units in architectural framework and transgressive or highstand caps in sequence stratigraphic framework at all hierarchical scales offer resistance to fluid flow and produce compartmentalized reservoir. The variegated lithofacies assemblage in hybrids beds produces highly composite flow units. On the other hand, amalgamation produces connected clean, massive and high-quality reservoir sands facies beds in channels and proximal lobe areas. The dominant kaolinization of feldspar and mobilization of kaolinite with fluid flow enhanced the quality of the reservoir by producing secondary enlarged pores CS1 and CS2. Production records from this area show that the recovery rates are higher in the axial areas and smaller in the marginal areas of the fan.

CLASTICS IN A RIFT LAKE: A CASE STUDY FROM THE NACHUKUI FM (PLIO-QUATERNARY, EAST AFRICAN RIFT SYSTEM, TURKANA DEPRESSION, KENYA)

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Recent oil discoveries off Brazil (pre-salt systems, Atlantic margin) and in the East African Rift System (Lake Albert) have significantly renewed interest for continental rift basins. Now, among other challenges in these complex geological systems, the identification of systematics in sedimentation is a major one. Understanding of both the type of clastics (lithology, geometry, depositional context) and their respective distribution in time and space is a fundamental issue.
Here, we investigate the Nachukui Fm (northern Turkana Depression, EARS, Kenya). It is a syn-rift sedimentary succession fringing the main border fault of the North Lake basin (Turkana Depression). Exposed on the western shore of Lake Turkana, it is composed of a ~700 m thick sediment pile formerly summarized as of fluvial-lacustrine origin, and ranging in age from ca. 4.2 to 0.7 Ma.
Building upon facies interpretation and sequence analyses, the successive depositional environments are defined. Together with the identification of remarkable stratigraphic surfaces depositional environments stacking patterns allow successive prograding and retrograding trends to be defined.
This study highlights two distinct types of (bio-)clastic lake margins that alternatively developed along the main border fault of the graben. Type-1 is characterized by large aggrading-prograding fan-deltas that entered directly the paleolake, whereas Type-2 is dominated by small fans rapidly grading laterally to prograding-retrograding wave-dominated paralic sequences. Type-1 reflects a tectonic-controlled margin that derives from a long-lasting (>500ka) supply of clastics due to a pulse of rift shoulder uplift and a resulting high topography. Type-2 expresses quiescence in rift shoulder uplift and a low to moderate topography. Lake level fluctuations forced at first order by eccentricity (~400 ka cycles) and modulated by precession (~20 ka cycles) controlled stratal pattern. Finally, we suggest that alternations through time of these two types of margin, controlled by the activity of the border fault, are creating systematic geometries and lithology distributions.

RECONSTRUCTION OF SEDIMENTATION DYNAMICS DURING THE MID TO LATE HOLOCENE IN LAKE ULAAN, SOUTHERN MONGOLIA

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This study presents a reconstruction of the mid to late Holocene sedimentation dynamics in Lake Ulaan, southern Mongolia inferred from weathering intensity, AMS radiocarbon dating and sedimentation rate. Result shows that the higher sedimentation rate of 4.6 cm/ka between 2.7 and 6.0 cal. ka BP and lower sedimentation rate of 1.6–1.8 cm/ka after 2.7–3.2 cal. ka BP are associated with the climatic shift from humid in the mid Holocene to arid in the late Holocene in the Lake Ulaan basin. This result from the Lake Ulaan basin in southern Mongolia correlates with the mid and late Holocene climatic records reconstructed from other lakes in Mongolia and Central Asia. Further investigation of lacustrine sedimentary sequences and more age data from Lake Ulaan are still needed to understand better the Holocene sedimentation history in southern Mongolia and Central Asia.

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Sublacustrine hyperpycnal channel-fan complex in the Songliao Basin, Northeast China

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Abstract: Both in marine and lacustrine environments, hyperpycnal flows and their deposits, hyperpycnites, are widely described and discussed in the literatures. In recent years gravity deposition has become one of the major targets for reserve growth in China nonmarine basins. Up to now, no large scales of hyperpycnites are found in China terrestrial basins. Based on integrated analysis of the seismic sedimentology, drilling and core data, this article reports that hyperpycnites formed by hyperpycnal flows have been found in the Songliao Basin (SLB), which is the largest(2×10^4km^2) depression lacustrine basin in northeastern China. Seismic sedimentology reveals that a large scale channel-fan complex distributed in deep water. The narrow and slightly sinuous channels derived from delta front extend to central basin, occasionally bifurcating or diverting, up to 80km from the northern lake-margin. The widest channel is about 600m with average around 200m. Fan systems developed at the terminal of channels, and maximum area of fan complexes is more than 30 km^2. Hyperpycnites are distinguished by following characteristics: (1) Individual sandstone beds ranges from centimeters to meters; (2) Besides structless aspect, key features of hyperpycnites are the common presence of parallel laminated, soft-sedimentary deformation, floating shale clasts, and internal erosional surfaces; (3) A coarsening- upward sequence and a fining-upward upper sequence always appear in pairs. A new sedimentary model has been built for hyperpycnites in the SLB. The discovery of hyperpycnite in the SLB can not only provide an example to probe hyperpycnal flow deposits in China nonmarine basins, but also has theoretical and realistic significances to study on genesis of deep water sandbodies, to reservoir forecasting and oil-gas exploration.

Key words: Hyperpycnites; hyperpycnal flows; continental basins; seismic sedimentology; Songliao Basin

SHALLOW-WATER DELTA SEDIMENTARY CHARACTERIZATION OF THE SECOND MEMBER OF SHAHEJIE FORMATION IN THE SOUTH SLOPE BELT, DONGYING SAG, BOHAI BAY BASIN, CHINA

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The research of the deposition background, sedimentary characteristics, distribution pattern and dominant factors of the delta are the current geology research hotspots. The Dongying Sag is a large asymmetry halfgraben-like rift lake basin, which located in the southeast of Jiyang Depression, Bohai Bay Basin, China. The second member of the Shahejie Formation (Es_2) is the main petroleum exploration target due to its widely distribution of the delta sand bodies.
The purpose of this research is to study the sedimentary characteristics, the spatial and temporal relationship of Es_2 shallow-water delta based on cores, well logging data, laboratory data and 3D seismic data. The palaeoclimate and paleo-water-depth are restored by paleogeomorphy characterization method. The distribution pattern of the delta sand bodies and its corresponding dominant factors were also studied using seismic sedimentology method.
The results show that the sedimentary climate of the research area was hot and dry. The water body of the lake basin was shallow, only 8-13 meters. It was favorable for developing the shallow-water delta in the sedimentary period because of the weak fault activities and small palaeotopographic gradient (0.52°-1.29°). There are three catchments (i-iii), four paleo-valleys (V_1-V_4) devoloped from west to east in the source area (Guangrao uplift). A moderate sorted, well rounding pebbly sandstone shallow-water delta system was formed in the depositional area, which river channel diverged frequently in the plane and several positive rhythm sediments overlaid each other vertically. The wedge-shaped cross bedding and erosion surface were developed in the sediments, which indicate the strong hydrodynamic environment.
The fluctuation of lake level caused by paleoclimatic change is the dominant factor controlling the scale and the distribution pattern of the shallow-water delta in the research area. The lower Es_2 sub-member shows 'small delta plain and large delta front' pattern because of the humid palaeoclimate and high lake level. The channel sand bodies are well connected, which show the cuspate shape. However, the upper Es_2 sub-member shows 'large delta plain and small delta front' pattern because of the dry palaeoclimate and low lake level. The channel sand bodies are poor connected, which show the dendritic shape.

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Syn-depositional structural slope break zone models and its control of deposition in the NE Nanpu Sag, China

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The Nanpu Sag, a Meso-Cenozoic petroliferous sag, underwent reconstruction through multi-stage tectonic rifting events. Sedimentary patterns of the Nanpu Sag is the product of interaction among the fault activity, provenance and climate. Based on the seismic interpretation, three types of conceptual models are established: (1) Antithetic fault slope break zone (VA; Vertical to the provenance direction); (2) Synthetic fault slope break zone (VS; Vertical to the provenance direction) and (3) Forked faulted slope break zone (PF; Parallel to the provenance direction).

The VA model is defined by a set of syn-depositional fault terrace, and the inclination of fault terrace is almost opposite to the sediment transport direction. In the VA model, the increment of accommodation space from the margin to the center of the sag is limited by the fault terrace. The sediment center is located near the boundary fault. The sediments are transported and accumulated into the sedimentary depression formed by the inclined strata and the generally uplifting hanging wall. The VS model is identified by a series of syn-depositional faults. Different from the VA model, the inclination of fault terrace is almost consistent to the sediment transport direction. The fault terrace leads to the increasing accommodation. A large amount of sediment accumulated in the footwalls, and the sediment center is developed towards the sag. The PF model is characterized by a series of regional faults whose strike is parallel to the provenance direction. Some secondary faults are joint to these regional faults. The forked faulted slope break zone acts as a nature space for the sediment to transport and deposit.

These models indicate that the fault slope break zone play significant effects both on the accommodation expansion and the sediment transport. The sediment at the depression of the break zone deposit preferentially. The scale of sedimentary system depends on the source supply and its tectonic relationship with the break zone.

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Gravity Flow Deposits in Large Rift Lakes: A Case Study of the Central Basin of the Lake Malawi (Nyasa) Rift

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The Central Basin of the Lake Malawi (Nyasa) Rift is a large rift segment (150 km long) that forms the most deeply subsided part of one the world's largest and deepest (700 m) lakes. The basin's sedimentary architecture is a result of the complex interplay of rift margin and intra-rift deformation, surface processes such as footwall erosion and long-term drainage evolution, and a highly variable hydroclimate. A long-lived suite of large sublacustrine fans, canyons, and channel/levees complexes has developed within this basin. An extensive suite of crustal-scale seismic reflection data was acquired in 2015, which produced superb images of the syn-rift section. These deep images are augmented by legacy single-channel high resolution reflection data that provide detailed information on facies geometries and stacking architecture of the deep-water siliciclastic systems. The ages and lithologic character of the stratal surfaces observed in the reflection seismic data are constrained by ties to the 2005 scientific drill cores acquired during the Lake Malawi Scientific Drilling Project. The South Rukuru River is an eastward flowing regional drainage (11,900 km^2) that enters Lake Malawi through an incision in the western border fault of the rift's Central Basin. The Rukuru River drainage (17,230 km^2) enters the eastern side of the lake at an accommodation zone margin between the North and Central Basins. Both are antecedent drainages that prior to rifting may have delivered sediments to the Indian Ocean continental margin. Both systems now deliver sediment to a highly confined and focused depocenter in the Central Basin. The complex interplay of extension, mainly on the border fault systems, and high-frequency and high-amplitude lake level shifts, has led to unique coarse sediment facies stacking architectures, with vertical stacking controlled by hydroclimate, and lateral positioning localized by fault behavior. Long-lived channel-levee systems observed in the seismic data demonstrate that both drainage systems have been operative for the past several million years. Central basin gravity flow deposits include mass transport deposits, high-density turbidites, as well as deposits from more dilute hyperpycnal flows.

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WIND-INDUCED HYDRODYNAMICS IN LAKES: TRANSFER AND DISTRIBUTION OF CLASTICS IN THE LITTORAL ZONE AND ON THE LAKE FLOOR

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A new category of lakes named "wind-driven lakes" (Nutz et al. 2016) comprises those lacustrine depositional systems for which the wind is the dominant driver regarding both cross-shore and alongshore transport, and the basin-scale (re)distribution of clastics through the generation of waves, drifts and shallow to deep currents.
Wind-driven lakes brings more diversity and complexity to existing depositional models for lakes and differ from previous depicted clastic sedimentation that was mainly understood as dependent from fluvial-driven processes and settling of fine sediments in more distal areas.
Here, three case studies are presented to highlight the original characteristics of wind-driven lakes. A number of other (paleo-)lakes distributed worldwide, taken from our other case studies, identified from remote sensing or selected from a bibliographic review, are also examined and contribute to strengthen the proposed depositional model (Nutz et al. 2016).
First of all, Megalake Chad is a paleolake that corresponded to the Holocene highstand of lake Chad. It is best identified from some 3,000km long clastic paleoshorelines (Schuster et al. 2005) and constitutes the archetype of a lake where the redistribution of clastics is predominantly the result of wind-induced hydrodynamics (Bouchette et al. 2010; Schuster et al. 2014). Second, the post-gacial Lake Saint-Jean (Canada, Québec) represents a comprehensive example of a lake for which wind-induced hydrodynamics are responsible for currents at both the surface and the bottom of the lake. There, bottom currents are able to generate significant erosion surfaces and sediment drifts (Nutz et al. 2015). Last, Lake Turkana (Kenya) is the largest lake of the eastern branch of the East African Rift System. It provides an interesting example of rift lake with well-developed coastal (paleo-)landforms contrasting with more traditional rift lake margins (alluvial-fans, fan-deltas).
This study shows that wind-induced hydrodynamics can act as a major control on the transfer and distribution of clastics in a great number of lakes and paleolakes. This has three main impact on limnogeology: (i) depositional models for lakes need to be updated, (ii) wind forcing needs to be considered in source-to-sink studies, and (iii) resulting clastic sedimentary bodies and landforms have to be considered as reliable paleoenvironmetal archives and for their good reservoir potential, as it is already the case for wave-dominated shallow-marine clastics.

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THE CONTROLLING EFFECT OF RAMP STRUCTURE ON THE INTERNAL RESERVOIR ARCHITECTURE IN AN ALLUVIAL FAN DEVELOPING ON THE FOOTWALL OF A CONTEMPORANEOUS REVERSE FAULT

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In view of the unclear coupling relationship between the ramp structure developing in the footwall of a contemporaneous reverse fault and the internal reservoir architecture in alluvial fan, a case study of Triassic Lower Karamay Formation at the northwestern margin of Junggar Basin is implemented based on core, outcrop, dense well and seismic data. Well-to-seismic calibration, geological comparative analysis, hierarchy bounding surface analysis and comprehensive geological analysis have been used to characterize and contrast the internal architecture of alluvial fan that developed in the hanging wall and footwall of the Karamay-Urho fault, a great contemporaneous reverse fault in the northwestern margin of Junggar Basin, China.

Research shows: (1)the ramp structure has 4 essential features: the ramp dip opposite that of fault plane, gradient spatial variability throughout the ramp, lower strata with greater gradient than upper strata in the same position and successive distribution effect; (2)the strata in the footwall is the thickest closed to the fault plane, and gradually becomes thinner with an increasing distance from the fault; (3)in contrast with sandy conglomerate bodies in the hanging wall, those in the footwall deposited closed to the fault are thicker and more continuous, with similar distance to the provenance; (4)the alluvial fan has thicker sandy conglomerate bodies, stronger channel down cut and lateral superimposition effect, closer sand body stretch and small distribution area where the ramp gradient is higher.

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SEDIMENTARY CHARACTERISTICS AND FORMATION MECHANISM OF THICK LAYER LACUSTRINE BEACH-BARS IN THE CENOZOIC BASIN OF EASTERN CHINA

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Lacustrine beach-bar reservoirs have become important exploration targets in Eastern China, especially in the Banqiao Sag within the Bohai Bay Basin, where typical thick layer beach-bar reservoirs have been discovered recently. The average single-layer thickness of the beach-bar sand bodies in the second member of the Eocene Shahejie Formation (*Es2*) within the sag is greater than 10 m and the cumulative thickness of these sands reach up to 100 m. The Es2 member in the Banqiao Sag consists of a third-order sequence of three systems tracts—a lowstand systems tract (*LST*), a transgressive systems tract (*TST*), and a highstand systems tract (*HST*). Beach-bar sand bodies were deposited widely in the LST in the Banqiao sag, but were less deposited in the other systems tracts. The sedimentary characteristics, distribution patterns, and formation mechanisms of the beach-bar sand bodies in the LST were systemically studied using cores, wireline logs and 3D seismic data. The beach-bar was divided into five sedimentary microfacies, namely, sandy bar center, sandy bar flank, interbar deposit, coastal beach, and infralittoral beach. Based on the integrated analysis of the paleostructure and sedimentary environment, it was inferred that the thick layer beach-bars in this area resulted from the combination and joint control of the sediment source system, hydrodynamic environment, lake level variations, and contemporaneous fault activity. Firstly, the sands in the braided river delta of the Beidagang structural belt served as the provenance that provided the material basis for the beach-bars. Secondly, the wave effects in the gentle-slope belt controlled the scale and distribution of the beach bars. Under the control of waves, various sedimentary microfacies were regularly distributed. In particular, the continuous activity of the contemporaneous Dazhangtuo Fault contributed to the formation of the thick layer beach-bars in the area. The contemporaneous fault controlled the allocation of the sediments, providing abundant sands in the downthrown side of the fault. In addition, there was a constant high-energy hydrodynamic environment near the fault plane, where the sand bodies experienced long-term reworking by waves and gradually formed beach-bars with large thickness. The activity of the contemporaneous fault increased the accommodation space in the LST of the Es2 member, which resulted in continuous sand deposition and provided the necessary conditions for forming the thick layer beach-bars.

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Sedimentary Characteristics of Eocene Rifting Basin Strata and Its Impacts on Reservoir Properties—A Lacustrine Delta in the Beibuwan Basin, South China Sea

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The study of rifting lacustrine basin shows that sedimentary basins are controlled by complex tectonic factors and form different types of sedimentary systems during deposition process, which makes it more difficult to find favorable reservoirs. The Beibuwan Basin is located in the northwestern part of South China Sea. The sedimentation is of great variation with sharp lateral changes and the understanding of sediment provenance and sedimentary facies is controversial.

Using core, well logging, seismic, and laboratory data, the present study attempts to: 1) analyze sediment provenance and determine the type of sedimentary facies of Liushagang Formation in the study area; 2) determine the distribution and evolution of sedimentary facies in the study area; 3) predict favorable reservoir distribution characteristics and analyze the controlling factors of sedimentation on the reservoir.

Results from this study suggest that the northern high-lying area represents the sediment provenance of Liushagang Formation, which is characterized by the delta front sedimentary sequence. The normal deltaic sediments were well developed, and the thickness of individual sand bodies is small, which manifests as multilayer interactive distribution. The Liushagang Formation is divided into four three-order sequences from bottom to top (SQ1, SQ2, SQ3, SQ4). SQ2 and SQ3 sequences formed during the short-term rapid water regression were involved into the process of longer-term water transgression. Observations from this work suggest that the buried depth and sedimentary facies play a pivotal role in the modulation of the reservoir properties. The subaqueous distributary channel and estuary dam developed near the source of the delta front are favorable reservoir distribution areas.

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From Mountain Source to Lake Sink – the Sediment Routing System Across a Rift Lacustrine Basin Margin, Daihai Lake, North China

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The sediment routing system is often described in terms of geomorphologic elements (morphology, width, length and gradient.) and sedimentological record (grain size, succession, and architecture) under control of various autogenic and allogenic conditions. Relevant studies show that a perspective is required for the understanding of how the geomorphologic elements and sedimentological records are linked and related within sediment routing system.

Daihai Lake is a hydrological closed basin which was formed during the Late Pliocene to Early Pleistocene with development of a rift system. The ephemeral streams or rivers derived from the erosion of surrounding mountains have built tens of modern alluvial-fluvial-deltaic systems deposits from the mountain source to the lake margin. To achieve the original purpose, one of the alluvial-fluvial-deltaic systems, Bantanzi system, is specifically explored in this study. Detailed geomorphological and sediementological information were collected from flied, which include morphology and geometry of channels, and corresponded trenches and river cut bank sections.

The incipient results show that significant decrease in grain size varied from boulders to very fine-grained sands within 12km distance from mountain front to lake margin. As a result of high gradient slope and high-intensity floods, deposits of this alluvial-fluvial-deltaic system are dominated by sediment gravity flow and flashflood facies which include matrix-supported cobbles, scour and fill structures, gradational planar laminations, convex-up low-angle bedforms, convolute beddings, and even cyclic steps bedforms. The recent channel geometry diminishes progressively. The hypothesis that geomorphologic elements and sedimentological records are linked needs to be further proved with semi-quantitative analysis.

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TURBIDITE FANS: NEW HYDROCARBON EXPLORATION TARGETS IN THE LACUSTRINE SONGLIAO BASIN, NORTHEAST CHINA

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The Songliao Basin in the northeast China has been intensively studied for the gigantic hydrocarbon accumulations (e.g. Daqing oilfield) in its lacustrine depositional systems. Turbidite systems in the Songliao Basin, however, are underexplored and less well-understood. This study uses cores, well logs and seismic data, and has identified the occurrence of turbidite fans at the toe of delta front deposits in the Cretaceous western slope of Songliao Basin. The turbidite deposits are recognized based on cores, well logs and seismic data. Observations of cores reveal many large mud clasts in massive sandstones, sharp contacts between sandstones and dark-grey mudstones and a great amount of liquefied deformational structure, all suggesting the nature of gravity flows. The grain size curves show dominant suspension behavior, which is also a typical sign of gravity flow. GR logs show serrated-blocky facies suggesting sharp contacts between interbedded sandstones and mudstones. Additionally, seismic profiles show that turbidite fan facies with unique lenticular reflections are developed at the toe of delta front facies. Because of the different reflection characteristics on seismic profiles, turbidite fan facies and delta front facies can be recognized and correlated independently. Interpretation and mapping of sedimentary facies based on seismic profiles and well data suggests that turbidite fans are typically prone to develop when delta progradation arrives at the slope break, reflecting the importance of basin topography. This new recognition of turbidite fans in the non-marine Songliao Basin has guided the drilling of six wells, five of which have shown commercial oil flows with two well productions exceeding 100m^3/day. Such findings in return confirm the interpretation of turbidite fan deposition, and may provide new important targets for the hydrocarbon exploration in Songliao Basin.

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Sedimentation in a Continental High-Frequency Oscillatory Lake in an Arid Climatic Background: A Case Study of the Lower Eocene in the Dongying Depression, China

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The sedimentary environment, formation conditions, sedimentary characteristics and the basin evolution model of high-frequency oscillatory lake in arid climatic background of the lower Eocene in the Dongying depression were studied through the analysis of dilling cores, sporepollen, geochemistry and geophysics data. During the sedimentary period of the Eocene Ek1-Es4x formations, because of the frequent alternation between dry and wet climates in the arid climatic background and the gentle paleogeomorphology, the lake level and salinity of the early Eocene Dongying depression frequently and rapidly increased and decreased, which is referred to as a high-frequency oscillatory lake. The sedimentation and distribution of sediments in this high-frequency oscillatory lake basin were controlled by the frequently alternating dry-wet climates. During periods with relatively wet climate, the seasonal floods and unstable rivers led to the formation of over-flooding lake deltas in the gentle slope belt, and fine-grained clastic sediments, with minor thin layers of gypsum-salt rocks in the sag belt. During the relatively arid climatic periods, sedimentation occurred mainly in the limited area of the sag belt with thick gypsum-salt rocks. Because of the impact of the salinity stratification of the lake water, these gypsum-salt rocks exhibit annular structural features. A sedimentary cycle of the oscillatory lake began with isochronous flood channels and ended with relatively thick gypsum rocks and salt rocks. The thickness of one oscillatory cycle is generally 4-20m. The superposition of multiple sedimentary cycles of the oscillatory lake constitutes the overall vertical filling sequence of the high-frequency oscillatory lake basin.

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The characteristics of reservoir genetic and oil-gas accumulation on lacustrine carbonate in Yingxi area of Qaidm basin

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Abastract Using the multiple data of core， thin section， imaging logging， geochemistry to research the reservoir genetic and oil-gas accumulation of lacustrine carbonate in Yingxi area， Qaidm basin. The space type of the dolomite reservoir mainly consisted of the intercrystalline pore, also included in dissolution pore, and fracture. Research considered the origin of the dissolution pore on dolomite reservoir was interrelated to bury dissolution. The bury dissolution accompanied with three phases petroleum expulsion, and corresponded to two dissolution intervals, respectively two temperature 80～110℃ and 120～160℃. The bury dissolution expanded the dolomite space of intercrystalline pore, improved reservoir performance and seepage capacity. Research considered the salinization deposition was in favor of accumulation organic matter and formation source rocks. The source rocks experienced three phases hydrocarbon generation and petroleum expulsion, and oil & gas injection, also, accompanied with three phases tectonic movement. The crude oil include in immature oil- low, low immature oil, and high immature oil. Lacustrine carbonate in Yingxi area had two sets hydrocarbon assemblages. The subsalt assemblage was source and reservoir. The intra-salt assemblage was the hydrocarbon pool of lower generation and upper accumulation by migration pathway of high angle structure. These hydrocarbon pools belong to unconventional tight hydrocarbon reservoir. Micron and nanometer intercrystalline pores are the main type of reservoir, and are the basement of hydrocarbon accumulation, Which ensured high and stable yield for hydrocarbon pool of Lacustrine carbonate. The dissolution pores expanded reservoir space and enhanced reservoir capacity, Which provided favourable condition for formation of high production and enrichment reservoir. The fractures were pathway for reservoir reconstruction and hydrocarbon migration, and ensured high production and enrichment reservoir with intercrystalline pores and dissolution pores togather.

Key words: Lacustrine carbonate, mixed rock, intercrystalline pore, dissolution pore, fracture, bury dissolution, Yingxi area, Qaidm basin

Evolution history of Altyn Tagh Fault system during the Cenozoic: Constraints from sedimentation in the northwestern Qaidam basin, western China

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A thick Tertiary sedimentary succession has developed in the Qaidam basin of the northeastern Tibetan Plateau, and it potentially records the tectonic evolution of the basin and surrounding orogens. The evolution process and the time of strike-slip movement of the Altyn Tagh Fault (ATF) system in the northwest of Qaidam Basin remain debatable. An integrated research of heavy minerals and mineral chemistry in the northwestern Qaidam basin was adopted to perform the provenance analysis, which reveals the types of source rocks changed during the Cenozoic.

A research of Tertiary sandstones in the NW Qaidam basin was performed, based on sandstone petrography, heavy mineral analyses, and mineral chemistry. The results of sedimentary facies analysis show that the lake shoreline in the northwestern Qaidam basin is relatively near the Altyn mountain during the late Eocene and Oligocene. Turbidity currents are observed in the Shangganchaigou Formation (ca. 35.5~22 Ma). The isoline maps of the stable heavy mineral index (ZTR=30) present that the isolines are closer to the Altyn Mountains. Although the isoline moved to the basin after Oligocene, the distances between different isolines are small, which means that the location of the provenance remained similar. It suggests that the sediments in a wide range of the NW Qaidam basin were derived from the Altyn Mountain.

The transformation interface of sedimentary facies is roughly at the bottom of the Xiayoushashan Formation (ca. 22~15.3 Ma), and the lacustrine mudstone was replaced by sandstone. The reduction of the maturity of heavy minerals indicates an increase in the amount of denudation and aggradation process from the early-middle Miocene to the Pliocene. It may be relevant to the left strike-slip of the ATF. Variations in the types of source rocks in the NW Qaidam Basin during the early Miocene may be the result of large-scale slip motion along the ATF. Therefore, the early Miocene (ca. 20 Ma) can be considered the key transforming period of the ATF system. Based on the results of this research and previous studies, the evolution of the western Qaidam basin can be divided into three major phases. (1) The accumulating of coarse-grained clastic sediments recorded the far-field response of the initial phase of India-Eurasia collision during the early-middle Eocene. (2) The tectonic setting of the Altyn Tagh was relatively inactive during the late Eocene and Oligocene. (3) The strike-slip movement of the ATF was occurred during the early Miocene. It was also a time of the uplift of the Altyn Tagh, accompanied by a decrease in the maturity of sandstones in the basin and variations in source rocks in the early Miocene.

The controls of auto-cycle and allo-cycle on sandy-conglomerate sedimentary sequences in the steep slope of rift lacustrine basins

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The theory of classical sequence stratigraphy originated from passive continental margin basins is widely used in hydrocarbon exploration. The cyclicity of strata emphasizing constrains of base level to sequence formation can be called allo-cycle. Some controversies, however, still exist in interpreting the sequence in the steep slope of rift lacustrine basins, which are always filled by many kinds of sandy-conglomerate, i.e. near-shore subaqueous fans, fan deltas, alluvial fans and so on. The sandy-conglomerate is a typical event deposition. The sequence of that is not only controlled by base level, but also by sedimentation to a greater extent. One time tectonic movement forms a sedimentary unit of near-shore subaqueous fan or fan delta, namely a parasequence. Each parasequence starts from debris flow or high-intensity flood sediment, followed by low-intensity flood sediment or lacustrine suspending mud, reflecting reducing of fluid energy. The Sedimentary process is namely auto-cycle. The mudrock do not represent change of base level. Seismic interpretation, well logging analysis and core description were performed on a suite of sandy-conglomerate formation from the lower to middle submembers of the third Member of the Palaeogene Shahejie Formation in the steep slope of the Dongying sag of the Bohai Bay basin to better understand the controls of auto-cycle and allo-cycle on sandy-conglomerate sedimentary sequences. The lower submember develops in the process of continuous rising of base level, and the middle member develops in the process of early slow rising, medium-term rapid rising and late terminal stable rising of base level. During the sedimentary period of lower submember, the base level rises rapidly in the steep slope due to tectonic subsidence and humid weather. Coarse debris from the adjacent uplift directly entered into the deep water, formed near-shore subaqueous fans. With the base level rose continuously, the fans retrograded towards uplift to form the one-division sequence, which is only constituted by a transgressive systems tract (TST). During the sedimentary period of the middle submember, the movement intensity of the basin-controlled fault became weaker than that of the lower submember, which comprised a three-division sequence, including lowstand systems tract (LST), transgressive systems tract (TST) and highstand systems tract (HST). Through overlying pattern of parasequence, types of parasequence sets can be identified. For the lower submember, the transgressive systems tract is divided into three retrogradational parasequence sets. For the middle submember, the lowstand systems tract is divided into one petrogradational parasequence set consisting of turbidite fans, the transgressive systems tract two retrogradational parasequence sets consisting of near-shore subaqueous fans and the high systems tract one petrogradational parasequence set consisting of fan deltas. In summary, the sequences are mainly controlled by allo-cycle of change of base level, but parasequence sets or parasequences are mainly controlled by auto-cycle, which is a breakthrough for understanding about sandy-conglomerate sedimentary sequences in the steep slope of rift lacustrine basins.

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Processes and deposits of lacustrine mass failure events, their economic significant and anthropogenic impact

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Abstract: Mass failure deposits in lacustrine settings are some of the most understudied facies association in the ancient or modern rock record. Modern studies focus mainly on the processes and risk of occurrence, as margin failures in modern lake systems present a significant hazard to surrounding populations and disrupt biotic processes in the lakes. Near modern (ie., the past 40,000 year) studies emphasize the impact of deglaciation of highlands and subsequent failure events occurring into or along lake margins, as well as the formation of lakes due to landslide failures and damming of streams, and the impact that these processes have had on the surrounding landscapes. However, pre-40,000 year study of mass failures in lakes is dismally thin. This is surprising given the economic importance of hydrocarbon in lacustrine basins and the bounty of information they contain on lake responses to changing climates. Recent hydrocarbon discoveries in sub-salt Brazil, rift basins of China and Southeast Asia, historical production in the numerous rift basins of the Australia northwest margin and ongoing discovery and development of the North Sea and northern Canada underscore the economic importance of these enigmatic deposits. Although research in mass failures along marine margins has increased 10-fold in the past 20 years, similar deposits in lakes remain understudied. Some of the paucity of research is likely due to the paucity of good outcropping lacustrine strata. Such is not the problem in the Green River Formation (GRF) and overlying Uintah Formation, Utah and Colorado U.S.A.. Here, Eocene-age debris flows (DF) and mass transport complexes occur in huge abundance, estimated to make up over 50% of some members of the GRF. In the GRF, organic-rich (up to 22% TOC) debrites are principally found in the underfilled sequences of the lakes, when climate drove sudden inputs into the basin of water and sediment creating an abundance of hyperpycnal gravity flows and clastic turbidite deposits, and destabilized margins causing failure of organic-rich margin sediments into the deeper distal regions of the lake. DF are classic, attached failures and are believed to have been dominantly sourced from the southern margins of the lake where deltic processes were most active. These deposits are often described as "blebby" containing an abundance of angular transported clasts. Clasts are up to several meters in thickness and would appear deceptively in core to be insitu oil shales. They were clearly lithified prior to transport, but sharp edges suggest that have not be transport too far from the source beds. Some of the debrites show a graded texture to their bedding, reminiscent of the high-density turbidites of Lowe, and may be moving through turbulent rather than laminar, plastic processes. The flows are believed to be responsible for repeatedly sweeping shelf-hosted brines into the deeper lake forming nacholite and halite. A second variety of mass failures occur in the overlying Uintah Formation and are attached clastic mass failures deposited as the lake began to fill from the north and northeast. These mass failures can be over 30 meters thick, extend for miles in outcrop and are overlain and underlain by laminated marls and oil shales. Runout distances for lacustrine mass failures could have been as long as 60-80 km during some phases of basin fill. Similar mass failure deposits are reported to be producing reservoirs in the Songliao Basin of China, and little is known of the true role that these failure deposits play in prospectivity of lacustrine basins worldwide.

CRITICALLY EVALUATING THE DEPOSITIONAL MODELS FOR THE PRE-SALT LACUSTRINE BARRA VELHA FM RESERVOIRS, OFFSHORE BRAZIL

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Cretaceous lacustrine carbonate reservoirs known as the "Microbialite" reservoirs host giant oil and gas fields in the South Atlantic, and are especially important in the Santos Basin, offshore Brazil, represented by the Barra Velha Fm (BVF). Two contrasting models exist for the depositional settings for these reservoirs: (1) deeper lakes with differentiated microbial platforms having relief of 100's metres, as well as smaller buildups; (2) very shallow, evaporitic, hyper-alkaline lakes with predominantly abiotic carbonate and Mg-silicate precipitates. The case for the former is based on the perceived presence of shelf-like platform margins interpreted from seismic data, whereas the latter is based on analysis of a large data set supported by geochemical modelling.

As seismic-scale differentiated lacustrine buildups are not known from the geological record, direct comparison with marine examples remains speculative. Discriminating isolated marine carbonate buildups from other features on seismic is now facilitated by scoring using work flows but applying this approach to published seismic data from Santos Basin shows no support for true carbonate buildups. Instead the evidence shows that the large platform-like features are largely post-BVF and structural in origin affected by varying degrees of denudation.

While available sedimentological and geochemical evidence does not support the presence of platform-like features with 100's of metres of relief, this does not preclude the presence of large carbonate mounds and ridges analogous to those seen in modern extensional systems. However, as such features can be sub-lacustrine, sub-aerial or periodically both, their presence and interpreted relief cannot be used to draw reliable conclusions about paleobathymetry.

The hydrology of the BVF lakes can be assessed by using C & O stable isotopes, by comparison with extensive studies from Quaternary lake deposits from East Africa. However, while published data sets from Santos Basin are limited, co-variant trends in these isotopes suggest the former presence of shallow, evaporitic lakes, possibly very extensive or sourced from a uniform aquifer. Thermo-dynamic modelling of the mineralogy in the BVF also supports such an origin.

Fine scale facies interpretations and especially well log correlations of shallowing-upwards units can be made across the Santos Basin in the BVF from locations which on seismic sections differ by as much as 1km of relief, prior to salt deposition. This implies that these apparent topographic differences of hundreds of metres or more were not being reflected in any lithological differences at the time of deposition. This suggests that what appear to be paleotopographic differences are due to later structuration, post-deposition of the lake sediments, and prior to salt deposition.

HETEROGENEITY EVALUATION OF LOWER TRIASSIC CONGLOMERATES IN THE JUNGGAR BASIN, NORTHWESTERN CHINA

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The successful petroleum exploration of Lower Triassic conglomerates in the Junggar Basin has attracted geologists' attention to these special and coarse reservoir rocks[1]. Compared with sandstone reservoirs, the Triassic conglomerates in the Junggar Basin are near-sourced deposits with poor physical properties and strong heterogeneity. In this study, a series of methods, including 3D laser scanning, thin section, field-emission electronic scanning microscope, CT scanning were used to investigate the heterogeneity of conglomerates from macro-scale to micro-scale, and to find the key factors on reservoir distribution. Our findings are as follows, (1) a 3D digital outcrop of Triassic conglomerates was established, revealing the spatial distribution of sedimentary facies and lithologies. There were ten types of conglomerates and the lithology assemblages were different in fan delta plain (FDP) sub-facies and fan delta front (FDF) sub-facies. The matrix content in FDP is higher than that in FDF, resulting in poorer physical properties. The porosity and permeability of conglomerates in FDP were 6%~8%, <1.0mD, respectively, while the porosity and permeability of conglomerates in FDP were 8%~10%, 1.0mD~10mD, respectively. (2) The conglomerates diagenesis of FDP was different from that of FDF. The FDP reservoirs were characterized by strong compaction, local dissolution and poor cementation. Rock clasts and feldspars are the main dissolution particles, and few zeolites were dissoluted as well. As to FDF reservoirs, the intensity of dissolution and cementation increased besides compaction, and the dissolution of rock clasts, feldspars and some zeolites were observed in the whole area. The content of tuff had affected the cementation of zeolites and calcites in the reservoirs, which led to stronger heterogeneity vertically. (3) The secondary porosity zone was developed at 3200 m and 3D porosity models were established for grain-supported medium-/fine-grained conglomerates, matrix-supported medium-/fine-grained conglomerates and coarse-grained sandstone gravels. The types and content of fillings were the key factors for porous structures, and chlorite cementation was favorable for good reservoirs. All these findings were valuable reference for sweet spotting of conglomerates exploration in the Junggar Basin.

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ARCHITECTURE AND DEPOSITIONAL PROCESS OF BIRD-FOOT SHOAL-WATER DELTA: INSIGHTS FROM MODERN DEPOSITS IN POYANG LAKE, CHINA

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As a typical constructive delta, the bird-foot delta could form fertile wetland and also become advantage reservoirs after burial. Systematic studies have been conducted on bird-foot deep-water delta, such as Mississippi delta. However, the architecture and depositional process of bird-foot shoal-water delta are not still well understood which are in great difference from that of bird-foot deep-water delta. Taking modern deposits in Poyang Lake, China as an example, the study on architecture and depositional process of bird-foot shoal-water delta is performed based on remote sensing, prospecting trench, shallow borehole data and numerical simulation result.
Results show: (1) The distributary channel within bird-foot deep-water delta front is almost straight. In contrast, the distributary channel within bird-foot shoal-water delta front is tortuous. The sinuosity of it is almost exceed 1.10 and could even reach 2. This appearance is controlled by the distribution of water depth. Distributary channel gives priority to flow into the orientation of maximal water depth. The mouth bar deposits change the distribution of water depth more greatly for bird-foot shoal-water delta. (2) The distributary channel could cut through mouth bar for bird-foot shoal-water delta. The incised location changes from central to side mouth bar as water depth increases because of increasing of blocking of front mouth bar to channel. But the volume ratio of distributary channel to mouth bar decreases from 0.5 to 0.1. (3) The frequency of avulsion within bird-foot shoal-water delta is much less than that within bird-foot deep-water delta. The avulsion occurs when flow resistance of distributary channel increases to a certain critical value. The flow resistance increases as water depth increases. And it's relative small for bird-foot shoal-water delta.

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Lake level effect on main sandbodies of delta front: A case study from outcrops of Jurassic Yan'an Formation in Shenmu, Ordos Basin

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The shallow lacustrine delta that is dominated by distributary channel sand bodies in structurally stable, flat terrain and shallow water environments[1,2]. Due to the seasonal rainfall, the level of the lake's water level rises and falls more frequently. Therefore, the delta deposition is more affected by the change of lake water level. Most scholars have focused on the role of rivers and lakes in the study of hydrodynamic conditions in the lacustrine delta[3,4], but relatively pay little attention to the dynamics of lake level changes.

The shallow lacustrine delta developed in the Shenmu area, which is located in the northeastern of the Ordos Basin, during the Yanan Formation. To study the effect of water level to the delta front sedimentary configuration, this paper takes shallow-water lacustrine deltas outcrop of Jurassic Yanan group in Ordos Basin as examples. On the basis of lithofacies and sedimentary microfacies study, statistic analysis of thickness and width of single sand body was made, and sandbodies distribution rule in underwater distributary channel, river mouth and sheet sand was studied. The results show that the sandbodies width and thickness ratio of the underwater distributary channel and sand sheet is higher at high water level, compared with that at low water level. Given certain water level, A/S value increases as the distance increases from provenance. Affected by the A/S value which is controlled by water level and distance from provenance, there are three main vertical superimposition patterns of sandbodies in subaqueous distributary channel and mouth bar, namely overlay type, joint type and isolated type. From overlay pattern to isolated pattern, the A/S value tend to become higher, and connectivity become lower.

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The significance of fine-grained gravity-flow deposits in the Late Triassic Yanchang Formation (Ordos Basin)for unconventional petroleum exploration

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Ever more sedimentological research focuses on the transport and depositional processes of fine-grained sediments, and more specifically of fine-grained gravity-flow deposits. The main reason is the ongoing exploration for shale oil and gas. Whereas the exploration for hydrocarbons was directed for a century towards sediments with a high porosity and permeability (particularly limestones and sandstones), it has become clear in the past decade that fine-grained sediments can also contain significant and economically exploitable volumes of hydrocarbons. The relatively recent focus on fine-grained gravity flows and their deposits implies that still much less is known about their characteristics than about those of, for instance, sandstones and limestones. The complexity and fluctuations of the transport and depositional conditions of fine-grained gravity flows are so large that it is commonly difficult to interpret the genesis of sediments precisely and reliably. This implies that the relatively new research field of fine-grained gravity flows and their deposits still needs new field data, experimental results and theoretical modelling.
An interesting case study[1] concerns the Triassic Yanchang Formation in the Ordos Basin, which is the most important oil producing unit in China. The formation, which consists of 1000-1300 m of fluvial, deltaic and lacustrine sediments, contains abundant fine-grained gravity-flow deposits. The most important types of gravity-induced processes that developed on the steep margins of the lacustrine basin were slumps, debris flows, and turbidity currents. Hyperpycnal flows, resulting from sediment-laden fluvial floods also contributed significantly. These different types of gravity flow could transform into one another, and also induce other gravity flows.
The Yanchang Formation houses huge shale-gas resources. Even if only 50% of the geologically probable reserves of the gas can be recovered from the shale section of the YC7 oil member, this would amount to 1.1506×10^{12} m^3. This indicates the great potential for unconventional oil and gas. More detailed studies on unconventional hydrocarbons and on fine-grained sediments will show the vital significance of more research into fine-grained gravity-flow deposits.

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New Understanding of Deep-water Banded Sand Body Sedimentogenesis in Lacustrine Basin with an Example from the Dongying Sag, Eastern China

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Deep-water lithological reservoirs with favorable source and cap rocks have been paid high attention to as the degree of oil and gas exploration improves continually. Deep-water banded sand bodies that distribute from the edge to basin center and mainly in the deep and semi-deep lacustrine facies have been documented in the exploration of deep-water hydrocarbon in lacustrine basins. The genesis of these banded sand bodies is a certain controversial topic as it accords with neither fluvial channel systems nor the traditional turbidity current theory. This study discusses the genetic mechanism of the banded sand body of the middle part of the third member of the Shahejie Formation (Es3z) in Dongying sag of Jiyang depression, based on high-resolution 3D seismic data, petrographic analysis. Banded sand body has the sedimentary characteristics: (1) the mudstones are black and dark grey, which reflects deep-water deposition, and medium and silty-fine sandstones are the primary; (2) normal grading is of great significance, and sequences with an intrasequence sharp contact or erosional surface between coarsening-up basal unit (Ha) and fining-up top unit(Hb) are also present; (3) climbing ripples and horizontal laminations are common, and there are carbonaceous fragments in the sediments; (4) typical channel characteristics—subparallel seismic reflection configuration with flat bottoms and convex tops. The distribution indicates: (1) the sand body shows banded structures in horizon and extends to the basin center along low-lying areas; (2) multi-periods channels superpose in vertical. At the early stage of the deposition of Es3z formation, the Dongying delta was small, and hyperpycnal flows, which were supported by fluid turbulence with Newtonian rheology, formed during large floods. They transported considerable volume of suspended sediments over the delta and deposited directly in the lower basin center. The hyperpycnal flow can develop a coarsening-up basal unit during the waxing discharge period and a fining-up top unit during the waning discharge period. When the high magnitude flood comes, the coarsening-up basal unit may be completely eroded during the peak flood conditions, only to leave the normally graded top unit with a basal erosional contact. With the long duration floods, sediments were carried to the basin center and formed deep-water banded sand body. The genesis research of deep-water banded sand body formed by hyperpycnal flows has significant implications for the strong deposition with a small source for the deep-water exploration in the lacustrine basin.

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SEDIMENTARY CHARACTERISTICS AND ORIGIN OF LACUSTRINE FIINE-GRAINED SEDIMENTS IN THE SALINIED PERMIAN JIMSAR DEPRESSION, JUNGGARBASIN, CHINA

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The Permian Lucaogou Formation of the Jimsar depression is a classic tight-oil play in the Junggar Basin, China. Depositional environments of a lacustrine basin exhibit a primary control on the formation of sweet spot intervals. The Lucaogou Formation comprises a variety of facies but is dominated by fine-grained sediments. Ten general lithofacies are identified based on mineralogy, sedimentary structures, textures and compositions as follows: (1) brecciated dolomitic mudstone; (2) intraclastic conglomerate; (3) mixed siliclastic and intraclastic grainstone; (4) dolomitic siltstone; (5) dolomitic mudstone; (6) pebbled sandstone; (7) intraclastic grainstones;(8) bioclastic limestone; (9) massive siliceous mudstone; (10) organic-rich laminated tuffaceous mudstone; The sequence stratigraphic framework reveals that the two sweet spot intervals of the Lucaogou Formation were deposited during a lake contraction phase, which is characterised by high-frequency cycles comprising three successive facies associations: profundal, littoral-sublittoral and palustrine, recording distinct lacustrine expansions and contractions. The development of abundant mud cracks, paleosols and vertical dissolution fractures in the sweet spot intervals indicated that these facies record deposition in an ephemeral to perennial lake of aridity. Fluvio-deltaic and eolian transport is the main mode of transport for the siliciclastic component that ultimately accumulated in subaqueous and subaerial environments. The depositional process in the profundal zone included suspension and turbidity currents. The dolomitic mudstone exhibits a distinct low 87Sr/86Sr isotopic ratio (0.7048-0.7056) that is consistent with a volcanic origin, indicating that the fall-out of volcanic glass offered calcium and magnesium ions after devitrification. The dolomite was likely originated from evaporitic concentration of lake waters, and formed during a very early diagenesis stage. Multiphase volcanic activity affected the lithofacies and prompted the accumulation of organic matter. The deposition of the Lucaogou fine-grain sedimentary rocks in the Jimsar Sag may aid in understanding the deposition of a saline lacustrine basin in the Junggar Basin.

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Study on Source Supply in Bara Area, Muglad Basin, Sudan

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The Muglad Basin is a Cretaceous rift basin located in Sudan, developing three sag-rift cycles. The Fula Sub-basin is located at the northeast of the basin, mostly extending in nearly NS[1]. And the Bara Area is located at the south part of the western steep slope of the Fula Sub-basin. However, there are various views on the sedimentary facies of Abu Gabra (AG) Formation in this area. For example, some researchers believe that it develops underwater fans, supplied by Babanusa High which is located at the west of Fula Sub-basin[2]; other researchers reveals that there is no source supply in this area, whose sedimentary environment is shallow lacustrine[3]. Therefore, further studies should be conducted on the distribution of sedimentary microfacies and the subdivision of the fourth-order sequences.

In this study, we mainly focused on AG2 Member of the Bara 3D Area, using seismic, well logging and core data to carry out the fourth-order sequence subdivision, single well facies identification, and lateral distribution features of the gross content of sandstone and sedimentary microfacies. It was considered that the AG2 Member in Bara Area could be subdivided into 4 sequences, i.e. SQ4-1, SQ4-2, SQ4-3 and SQ4-4. On the basis of the identification of typical sedimentary facies, the single well facies division was carried out, and the shoal facies and shallow lacustrine facies were identified. Lateral distribution features of the gross content of sandstone and sedimentary microfacies of each layers of AG2 Member in the Bara area were worked out, finding that the sand body in AG2 Member was mainly distributed in SQ4-2, and from SQ4-1 to SQ4-4, the thickness of sand varied from thin to thick and finally to thin. Different from the previous understanding, Babanusa High should be at the lower part in the AG Stage, so there was no near source supply.

During this study, the distributive characteristics of AG2 microfacies were described by dividing AG2 Member into 4 fourth-order sequences. It revealed that there was no supply in the Bara Area, which was mainly deposited by monsoonal flat sedimentary facies, distributed along the western boundary. In addition, there are shallow lacustrine deposits, distributed separately in the northeast and southeast.

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The Evolution Characteristics of Diagenetic Fluid in Deltaic Conglomerate Reservoir-Evidence from Mica-like Cements in Baikouquan Formation, Mahu Depression, Junggar Basin, NW China

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A first billion-ton reserve of conglomerate reservoir was discovered in the word in Mahu Depression, Junggar Basin, NW China. It is significant for well studying its reservoir characteristics. This work selects a series of mica-like minerals that develop in the pores of gravel grains, and discusses their relationship on evolution, then reflects the characteristics of diagenetic fluid, providing basic geological information for exploration and development of conglomerate reservoir.

Three features are observed as follow: ①The framework grains in the reservoir are mainly composited of middle sorted, angular, and igneous-metamorphic originated gravels. And some coarse sand sized quartz and small amount of feldspar and lithics grains are also serve as framework grains. The matrix mainly consists of clay minerals, mainly illite/smectite mixed layer, followed by illite, chlorite, and a little of kaolinite. ②Mica-like minerals are 1~2 mm in size, euhedral, occurring in pore, and no obvious transport mark. Some plastic deformation occurred due to compaction, indicating that micas were formed earlier than compaction. ③Mica-like minerals can be classified into three types according to their chemical composition: a. Hydromica stage with high content of potassium, and poor magnesium and iron; b. transition stage with poor potassium and high iron; c. chlorite stage with no potassium, and high magnesium and iron. These three types of minerals show dark-brown to yellowish-brown to light-green color under polarizing microscope, and secondary purple to the primary gray under crossing-polarizing microscope. Their extremely complete cleavages are clearly recognizable to unrecognizable. And some of them show undulatory extinction. The progressively changing suggests different stage of diagenetic alteration.

Comprehensively, the above evolutionary characteristics indicate that micas are affected by various factors such as temperature, pressure, and fluid after their precipitation in the early diagenesis: ①The early stage shows hydration; ②In the middle diagenetic stage, the Mg^{2+} and Fe^{2+} rich pore water migrated in the cleavages of original minerals, then formed a series of diagenetic products from hydromica to chlorite. Furthermore, fractures are extremely developed in this region[1], and fluid inclusions also presents two phases of hydrothermal activities. It is inferred that the conglomerate reservoir is affected by the hydrothermal fluid and seems have a certain effect on the generation and migration of oil.

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Lithologic Characteristics and Sedimentary Environment of Middle Jurassic Yangye Formation in the Southeast Depression of Tarim Basin–the Front of Altyn Mountains

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Yangye formation is an important hydrocarbon generation strata in the southeast of Tarim Basin. The autor studied the lithologic characteristics, planar distribution and longitudinal variation of sedimentary facies of Yangye formation, based on field geological profiles measured, samples collected; combining with the cores of 4 exploration wells, the material of log interpretation, paleontology and geochemistry. The palaeosedimentary environment and development conditions of high quality source rocks were analyzed by the test of the ordinary and trace elements.

The bottom of the Yangye formation is a gray thick layer of conglomerate and claret sandstone. The lower part is the purple-black mudstone, argillaceous siltstone, single layer thickness about 20-40cm, all kinds of bedding phenomenon obviously, for shore-shallow lacustrine facies. The upper part is the thick black and dark gray mudstone, with gray-yellow calcareous mudstone, single layer thickness greater than 4m, parallel bedding development, for semideep-deep lacustrine facies. There are two main types of sedimentary facies: lacustrine facies and braided river delta facies developed in the study area, and divided into 4 subfacies and 7 microfacies.

In the early stage of Yangye formation, with the balanced adjustment of the regional stress field, after the peneplanation, the pattern of the paleotopography concave and convex was eliminated, and the area of the lake began to expand. The late alluvial environment of Kangsu formation began to be transformed into braided river-braided delta sedimentary environment. In the middle and late stage of Yangye formation, several sedimentary centers with slow settlement had formed in the southeast edge of Tarim Basin; the terrain is more gradual than earlier; lake transgressive reached its climax; the sedimentary environment is mainly lacustrine facies and local fluvial facies.

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Sequence architecture type controled by differential tectonic subsidence in the Kuqa depression

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Kuqa depression is located in northern Tarim basin, China west. The type of sequence architecture and complexity of sequence filling characteristics under control of tectonic subsidence affect the decision and progress of oil and gas exploration.

The differential subsidence and accommodation space, sequence filling type and filling characteristics are studied by field outcrop, drilling data, seismic data and series of experimental data. It shows that there are 3 stages of tectonic differential subsidence, 3 types of sequence architecture and filling characteristics in early Jurassic of Kuqa depression: ① the basin is in transition from compressional to extensional tectonic environment in early Jurassic (190-180Ma). the accretion type sequence is built, and highstand systems tract (HST) is dominated by sand conglomerate and braided channel sandstone. The composite sand body with great thickness and long extended distance.② In early Jurassic (180-165ma), the basin was in a transitional stage of horizontal extension. The main sequence architecture type are HST filled with braided channel of sand conglomerate & interdistributary bay of peat-swamp and lacustrine transgressive system tract filled with shallow-deep lake black mudstone. Sand body develops in zonal distribution extended a few kilometers. ③At early stage of middle Jurassic (165-152ma), horizontal extension and subsidence of the basin continued to increase. Two types of sequence architecture are developed with progressive sequence type and regressive sequence type. The progressive sequence of HST is mainly filled with braid channel in delta front, the regressive sequence is mainly filled with mudstone and limestone in shallow lake.

Tectonic differential subsidence control base level of deposition, size of accommodation space , the sequence architecture types, sandbody thickness and distribution. The accretion type sequence architecture is mainly composed of a large and thick composite sand body, which extends far away, and is a favorable area for the oil-gas exploration of structural trap. The regressive sequence is mainly composed of lenticular sand body, which is a favorable area for oil-gas the exploration of lithologic trap.

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ORIGINAL TYPES, MICROFACIES AND MIGRATION TRAJECTORY OF SAND BEACH-BAR IN INTERIOR DEPRESSION LACUSTRINE BASINS-CASE STUDIES ON LOWER JURASSIC, CENTRAL SICHUAN BASIN AND UPPER TRIASSIC, ORDOS BASIN

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Lacustrine sand beach-bar has become a potential target and aroused serious concern[1]. The origin of sandy beach-bar is influenced by many factors, including tectonic evolution, paleo-geomorphology, hydrodynamic conditions, underwater depth and provenance[2]. Especially, paleo-geomorphology formed by tectonic evolution controls the original types and spatial distribution of beach-bars; for instance, when the lacustrine basin is in its period of depression, the shallow water and the flat terrain create the largest shore-shallow lacustrine area, which is favorable to growth of beach-bars. This paper illustrates the controlling effect of paleo-geomorphy, lake-level changes, and sediment supply on original types and migration trajectory of sand beach-bars, in order to predict favorable prospects. Detailed information has been acquired through the observation of outcrops, cores, well logs, thin sections of rocks, and analyses of particle size, paleontology, and geochemistry. The main conclusions are as follows. Firstly, two models of sedimentary sequence were established according to paleo-tectonic movements, namely, fan delta-beach bar system, and normal delta–beach bar system. Secondly, beach-bars mainly existed in the middle transgression and regression. Specifically, in fan delta-beach bar system, beach-bars were concentrated in the middle transgression, while in normal delta –beach bar system, beach-bars grew well during regression. Furthermore, high-quality reservoir was located in the middle and upper part of a parasequence with strongest hydrodynamic force. Thirdly, fan-delta front channels, sand sheets, locally distributed beach-bars, tempestite, and turbidite were discovered in fan delta-beach bar system. Subsequently, delta front channels, mouth bars, and widely distributed beach-bars, were found in normal delta-beach bar system. Fourthly, beach bar was refined into main body, margin, in-shore beach, and off-shore beach. In particular, high-quality reservoir was at the top of main body. Consequently, distribution maps showed the migration trajectory of sand beach-bars, which is of guiding significance for the next exploration.

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Detailed Architecture Analysis of Mouth Bar in Delta Front: A Case Study of Chang6^3 Layer in Changqing Oilfield

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Single mouth bar and accretive sand body within single mouth bar were identified and divided, integrating borehole data, horizontal well data with dynamic data in Chang6^3 Layer of Triassic YanChang Formation in Changqing Oilfield. A quantificational architecture pattern of mouth bar was created. Three identification marks were presented for recognizing single mouth bar, the existing difference from curves characteristics thickness of strata, the appearance of marginal bar and the difference from the number of intercalations. Using the method of model fitting combination with dynamic verifying, the angle of three-order boundary is calculated to be approximate 2°~4°, with abundant dynamic data of dense well pattern in study area. Quantitative and reliable geological model can be applied in the analysis of mouth bar, and three-dimensional reservoir architecture model is made precisely to find and produce remaining oil.

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SEQUENCE DIVISION METHOD OF RIFTING LAKE BASIN BASED ON 3D SEISMIC DATA - TAKING BAXIAN SAG OF PALEOGENE IN THE BOHAI BAY BASIN AS AN EXAMPLE

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Tectonic evolution of rifting basin is featured by cyclicity and periodcity, tectonic infilling evolutionary process in different level controls different unconformity surface, which can be considered as an isochronous interface and corresponds to sequence boundary in different level respectively. Recognizing different-level unconformities and defining corresponding relationships between those unconformities and sequences based on tectonic-sequence analysis method is an important method to establish isochronous stratigraphic framework of rift lake basin. Taking Baxian sag of Bohai Bay Basin, with application of 3D continuous seismic data, this paper predicts strata infilling process during the whole life cycle of a lake basin. Through analyzing its material records, we define basin structural characteristics during each tectonic evolution period, divide single well sequences of key sections selected by tectonic cyclicity and stages, transfer single well and single layer sequence division to whole area and whole layers stratigraphic interpretation, establish 3D seismic interpretation scheme and sequence stratigraphic framework of whole basin, and finally divide Paleogene of Baxian sag into 1 first-order sequence, 3 second-order sequences and 14 third-order sequences. The conclusions are as follows: (1) The method of sequence boundary recognition and sequence stratigraphic division in key location and individual layer of nonmarine basin is favorable for establishment of a complete third-order sequence division scheme; (2) Development characteristics of rift basin is mainly controlled by two important factors including tectonic evolution and sediments supply, and types and special distribution of depositional systems and developmental styles of sand body are controlled by coefficient of those two factors; (3) Rift basin is featured by various boundary types, asymmetery of sequence architecture, and incomplete development of single sequence. Sequence boundary recognition and analysis sedimentary infilling process of Baxian sag can provide an example for division of sequence in nonmarine rift basin and can also provide guidance and basis for further exploration of lithologic and stratigraphic reservoir in study area.

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SOURCE TO SINK SYSTEM OF WENGCHANG FORMATION IN LUFENG SAG, PEARL MOUTH BASIN, CHINA

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The research of "source to sink" has been becoming an important scientific topic in sedimentology. There developed different source to sink systems in size in Pearl Mouth Basin, South China Sea. The studying area, Lufeng Sag is located at north-eastern part of ZHU I Depression, Pearl Mouth Basin, with the filling of Wenchang Formation in Paleocene over 2000 meters in thickness, which could be divided into five third order sequences. The sedimentary center migrate with tectonic activity and accommodation change in different geological time.
There are four provenances around the Lufeng Sag. It has been found that the south-eastern Dongsha Uplift is composed of granite which constitute main provenance of early Wenchang Formation; the lower Lufeng Uplift is granite and basalt in lithology, which form main provenance of late Wenchang Formation; the Northern Uplift is made up metamorphic rock and sedimentary rock, the lower Huilu Uplift comprises mixed volcanic, granite and basalt according to the analysis of drilling lithology and seismic attribute. The providing ability of each provenance is different in Paleacene.
The fan-delta, braided delta, lake and slumped deposits are developed in Wenchang Formation in Lufeng Sag, and there are the six source to sink systems in Lufeng Sag, that are: 1) system of near provenance-steep slope-fan-delta provided by the southeastern Dongsha Uplift; 2) system of the lower Huilu uplift - faulted step(gentle slope)-braided delta; the systems of 1) and 2) form major source to sink systems in early Wenchang Formation; 3) system of the eastern lower Lufeng Uplift in southeastern- gentle slope(big valley)- braided delta; 4) system of near provenance of the central north lower Lufeng Uplift – steep slope – fan/delta; the systems of 3) and 4) constitute major source to sink systems in late Wenchang Formation; 5) system of the lower Huilu Uplift- steep slope-fan-delta; 6) system of the North Uplift-gentle valley- fan-delta; the systems of 5) and 6) have been developed obviously in late Wenchang Formation.
After all, the Lufeng is a typical faulted basin with several source to sink systems in different size and complexity. The major controlled factors of complexity of the source to sink lie in several provenances, strong tectonic activity, small catchment, and changeable climate.

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MICROBIAL MAT CONTROL ON PROTEROZOIC AEOLIAN-DOMINATED DEPOSITIONAL SYSTEMS (VENKATPUR SANDSTONE, TELANGANA STATE, SOUTH INDIA)

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Presently aeolian erosion-transport-deposition processes are strongly influenced by the vegetation covering the earth surface. Pre-Silurian earth surface was devoid of rooted-vegetation, thereby it is coherent to suppose that the wind had full dominion to mould dry, or temporally dry, terrestrial landscapes. Nevertheless, from the Archean the continental Earth was colonised by biofilms, mainly constituted of Cyanobacteria colonies. Did these organisms exercise a control on aeolian processes in the same way of the present rooted-vegetation? The Neoproterozoic Venkatpur Sandstone Formation, has been interpreted as an ancient erg deposits that displays various sedimentary structures diagnostic of microbial mats. Thus, Venkatpur Sandstone can help to define the role of Cyanobacteria colonisation on aeolian processes and perhaps elucidate the apparent irregular distribution of aeolian deposits in Precambrian stratigraphic record. In Venkatpur Sandstone four facies associations are organised into, 5-10 m thick, cyclic sedimentary sequence of strata according to the following vertical order, from bottom to the top: (i) cross-stratified, (ii) planar-laminated, (iii) irregular-laminated and (iv) wave-rippled sandstone beds. Cross-stratified beds, c. 1-m-thick, constitute c. 45% of the thickness; they were formed by small transversal dunes. Planar-laminated beds correspond to the sedimentation of climbing wind ripples and aeolian granule ripples on a dry surface. Irregular-laminated beds display microbial induced sedimentary structures corresponding to palimpsest ripples, sand dome or pustules, exfoliating sand laminae, biolaminations and petees, interlayered with adhesion structures. Wave-rippled beds record ephemeral very small lakes with waters 0.2-0.5 m deep. Each cyclic sedimentary sequence suggests a progressive upward (i) decrease of sand availability, (ii) rise of groundwater table–and (iii) growth of microbial mats. Decrease of sand availability is directly proportional to the raising of groundwater and growth of microbial mats. Water adhesion and binding by microbial films brought about the increase in the shear stress threshold for sand entrainment and movement, thereby decreasing the sand availability for the construction of dunes and/or wind ripples. The lowering of the groundwater and the renewed availability of sand reactivated the dune construction at the beginning of next sequence. In Proterozoic time, Cyanobacteria colonies could be dominant on the terrestrial surface and to inhibit the aeolian processes as the present rooted-vegetation does.

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Sedimentary Architecture of A Late Cretaceous Dry Erg System in Southeastern China: Implications for Paleowind Belts and Coastal Mountains along East Asia

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China experienced a period of arid climate during the entire Cretaceous, which leads to a wide range of aeolian deposits spread almost all over China. With the aggravation of drought degree since Late Cretaceous, extremely thick aeolian sediments concentrated in several basins (Xinjiang Basin, Jianghan Basin, Subei Basin, etc) of Southeastern Region. Especially the aeolianite in Xinjiang Basin, which belongs to typical dry erg system, over- and underlain by reddish alluvial conglomerates and sandstones. The central part of the ancient erg system is dominated by dune facies, characterized by large-scale high-angle trough and planer cross-beddings and lots of polygonal cracks. Both the portion and scale of the interdune elements increase towards to the margin, with the discovery of the wind rubstones. The erg margin districts exist a sedimentary cycle from conglomerates to pebbly sandstones to rippled sandstone, forming the fluvial-aeolian facies. A hierarchy consisted of four types of surfaces divides the erg sediments, indicating the water table variations from the center to the margin. Plus the laboratory analysis of sections and SEM, a refined erg depositional model that accounts for most of the China's ancient aeolian strata is established. The paleowind directions obtained from the analysis of over 366 sets of aeolian cross-beddings measured in Southeastern China exhibit two main trends, NEE and SE. NEE-trend is stronger and it is the record of the East Asia westerlies, indicating that the erg is mainly controlled by planetary wind system. And the relatively weak SE-trend paleowind direction may stand for the paleo-monsoonal winds between Southeastern China and the Pacific Ocean. The absence of cross-bedding records representing SW- and NW-trends paleowind directions, which should cause by southeast trades and the paleo-monsoonal winds, is significant evidence for the existence of the coastal mountains along East Asia, and can roughly limits the height during Late Cretaceous. The coastal mountains also may be an important provenance of the erg systems.

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Polydirectional cross strata architecture resulting from unidirectional wind regime

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The compound and complex dunes (according to McKee,1979) along the northeast coast of Brazil were analyzed to identify the processes causing the wide range of cross-strata dip directions in the aeolian deposits found in this area; this region is dominated by a unidirectional wind regime (Tsoar et al., 2009). Wind dynamics, coastline morphology, internal structures of aeolian deposits, bounding surface developing processes and dune migration patterns were analyzed. We take into account the understanding of Carvalho et al. (2015), who indicate that regional dune evolution is controlled by the relationship between wind direction and coastline segment orientations. The analysis of satellite imagery and low altitude photographs of large-scale morphology of the compound and complex dunes, and the associated smaller morphologies, revealed related internal structures that were also recorded in depositional sequences identified in field studies. The morphology and evolution of these compound and complex dune sinuosity crests, in association with the superposition of multiple riding dunes, such as coalescing barchans and bachanoids (chevron like) crests, justify the majority of the variety of cross strata and dip directions found in the dune trenches and GPR sections. This study also provides convincing evidence that structures observed within trenches and GPR sections (i.e., micro-scale), with strata dip azimuths that arc through 90°, are compatible with slipfaces directions of migration observed within dune field (i.e., macro-scale). However, variations due to local changing wind directions, caused by the morphology of the dunes themselves, explains much of the supposedly unexpected strata dip azimuths, which arc through 180°. The active presence of near-surface water tables that are associated with active winds favors the formation and preservation of these cross strata aeolian sequences. These findings, which are also associated with works such as Brothers et al. (2017), have potential to contribute to the challenge of developing an understanding of the complex stratigraphic record that gave rise to many analogous ancient deposits in the world.

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SEDIMENTARY PROCESSES IDENTIFIED IN PLIOCENE RED CLAY DEPOSITS FROM THE CARPATHIAN BASIN (EUROPE)

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A set of Pliocene sediment samples from the northern and southern part of the Carpathian Basin is organized according to grain size distributions and were investigated in high-resolution to gain a systematic and deeper insight into the specific depositional processes resulted in the accumulation of these red clays. The granulometry of these sediments was studied by laser diffraction (Malvern Mastersizer 3000, Hydro LV) and digital image analyses of thin sections (RADIUS)[1].
This study investigates silt/clay-rich deposits, and paleo-karst fissure sediments derived from mixtures of dust (eolian silt) and karst breccias. These materials were likely mixed during transport until they were captured in the karstified fissures, and subsequently interlocked with calcite veins and lithified. Evidence that the fluvial fissure sediments of Pliocene age in the older Triassic–Cretaceous limestones are derived from eolian red clays includes compositional and textural matches, especially grain size distribution trends observed downwards from the paleo-surface of the former landscape. These grain size trends indicate infiltration of the eolian red clay into the underlying karst system.
Various environmental factors could be recognized by the statistical evaluation of grain size distribution curves of fissure fillings sediments, such as the effects of eolian transport, type of the parent rock, weathering processes and sediment transport[2]. Distribution curves with a single maximum in the silt size class are typical for the overlying siltstone debris, for the redeposited loess and the red paleosol underlying the loess. Red clay fissure fillings display bimodal grain size distribution curves with maxima both in the clay and silt fractions.
The role of dust (eolian silt), including its inherited compositional and textural properties from a distant source area, land-atmosphere transport and depositional processes, and re-sedimentation processes on the land surface overlying the karst system, remains promising directions of future research.

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CRITERIA FOR THE RECOGNITION OF THE DEPOSITS OF LINEAR BED FORMS IN ANCIENT AEOLIAN SUCCESSIONS

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Linear bed forms comprise ~50% of dunes in the world's modern aeolian dune fields, yet only ~5% of published accounts of ancient aeolian successions interpret linear bed-form types. Given that there is no reason to suspect that linear forms were less abundant in the geological past, this suggests that current models and methods for the recognition and reconstruction of primary aeolian dune type from preserved sedimentary architectures are not sufficiently refined to reliably distinguish bed-form type. Although the majority of sediment transport via linear bed forms occurs in an orientation close to parallel to the trend of their crest lines, a minor component of transverse motion favors the preferential preservation of cross strata that dip in the direction of that transverse component of migration. Linear forms therefore tend to preserve cross strata that dip toward an azimuth that is at a high orientation to the resultant migration direction of the primary bed form. The accumulation of sets of such cross strata is difficult to distinguish from the deposits of transverse bed forms. This has significant implications for the reconstruction of paleowind direction based on analysis of foreset dip-azimuth data.

Well logs and cores penetrating the aeolian Permian Auk Formation, Central North Sea, UK, reveal sedimentological traits indicative of the accumulation of large linear bed forms. The facies architecture of preserved cross-bedded sets and cosets (each up to 35 m thick) indicates accumulation on a dry substrate via the migration and climb of large bed forms that possessed low-angle-inclined lower plinths (up to 15 m thick). Dune plinth elements are dominated by wind-ripple and reworked wind-ripple strata, and were preferentially preserved as successive bed forms migrated over one another at low angles. Packages of grainflow-dominated strata representative of accumulation on the higher part of the bed-form lee slope represent only ~10% of the succession and are preserved mostly in the upper 25% of cosets. The primary direction of sand transport was along the elongated crests of the large bed forms, as recorded by foreset azimuths within meter-thick sets representative of small dunes superimposed on the flanks of parent linear draa (mega bed forms), and by bounding surfaces arising from along-crest migration of spurs and scour pits. Linear draa enclosed dry interdune flat areas. A secondary component of transverse motion enabled the lateral creep of the linear draa, preferentially preserving lee-slope deposits that arose from a minor component of oblique migration. Few previous studies have documented linear dunes in ancient successions; the findings represent a valuable case example.

AEOLIAN REDEPOSITION OF BITUMINOUS SANDS AND SANDSTONES OF THE SHESHMIAN HORIZON IN THE EAST OF THE EUROPEAN PART OF RUSSIA.

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The object of the study is located in the Republic of Tatarstan (eastern part of the East European platform). Sand and sandstone deposits of the Permian age of the Sheshmian horizon (Cisuralian, Ufimian Stage of the General Stratigraphic Scale of Russia) are rich in accumulations of natural bitumens and super-viscous oils. In this regard, the issues of origin, deposition and formation of sand reservoirs acquire special significance. The genesis of the Sheshmian horizon has provoked debates for many decades. In many ways, this is due to the peculiarities of the composition, structure and morphology of the surface of the sandstone deposits. Sand layers are characterized by a quite complex structure. Sheshmian horizon consist of two layers - upper sandstone and lower sandy-clayey. The morphology of the surface of the sandstone horizon is characterized by a very great uniqueness. In a spatial relationship, sub-parallel linearly stretched from NW to SE sandy bodies form an extensive system of ridges, uplifts. The thickness of the uplifts, composed of sandy material, varies in the first ten meters. The specificity of the morphology of sandstones is the cause of disputes. The most popular opinions about their origin are delta and bar. Lithological and mineralogical study in combination with the paleogeomorphological analysis of their surface allowed us to reconstruct the conditions for their formation and subsequent transformation. It was taken into account that the surface could be deformed during subsequent tectonic movements. Paleotectonical reconstruction was carried out and it was found out that the morphology of the surface of sandstones retains its specificity and has a primary sedimentary nature. Therefore, the formation of the Sheshmian sands and sandstones carries features of dual origin - subaquatic accumulation and aeolian redeposition. The accumulation of extensive sand deposits occurred in coastal underwater conditions during the marine transgression, which is confirmed by mineralogical, granulometric, and paleontological findings. However, paleogeomorphological analysis showed that the surface structure of sand and sandstone resembles aeolian relief forms. The paleorelief of the surface of sands can be formed during a short-term regression, as a result of which the upper part of the sandy horizon appeared on the day surface and was subject to aeolian redeposition and deflation of the clay component. For this reason, the upper layer, almost devoid of clay particles, was formed. The lower part of the horizon, which was below the Stokes surface (below sea level) and, as a consequence, the groundwater table, retained its original composition. The surface separating the two layers reflects the level of standing of the groundwater. The principle of the horizontal nature of the water surface can be used as the basis for constructing geological 3D models used in the exploitation of bituminous deposits.

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Clastic-Evaporitic Interactions in Arid Continental Environments: Insight from The Cedar Mesa Sandstone, USA

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In arid continental settings, the interactions between competing aeolian, fluvial, lacustrine and evaporitic environments exert strong controls on the sediments deposited, their preservation, and lithofacies connectivity in the subsurface. They strongly influence basin-wide fluid migration, along with reservoir-scale character, petrophysical properties and production behaviour. While the distribution and preservation of different facies associations within any one of these environments are reasonably well constrained, the relationships between deposits of coeval environments and their temporal evolution have received comparatively little attention.

Results of the sedimentary interactions between evaporitic deposits and those of other arid environments from the Paradox Basin, USA, are presented, along with the influence of the allocyclic-controls upon them. Studies are based upon extensive regional fieldwork examining the sedimentology, geometries, and interactions, complimented with outcrop gamma ray logging from the margin of the Cedar Mesa erg of the Paradox Basin. The deposits preserved show complex interactions of clastic and evaporitic sediments and highly variable sedimentary fill. Large variations spatially and temporally are present, which grade through aeolian, sabkha and lacustrine settings with complex interactions occurring where these environments transition. Frequently the sabkha facies dominate, reworking aeolian dune sediment into poor reservoir quality evaporite rich sands and blocking fluid pathways.

This work details the facies present in a continental sabkha allowing for identification and interpretation of these complex interbedded relationships over a regional scale. The results have been developed into idealised models and recognisable log signatures which characterise and assess their impact on reservoir quality. Wetting or drying climatic cyclic trends, on various orders of magnitude, have also been identified, which govern distinct spatial facies changes. Identification of these allows for basin wide correlation and prediction of where facies will occur in space and time.

Results can applied to evolutionary models applicable to subsurface data from arid continental settings in order to better characterise basin-scale migration and reservoir quality.

IMPLICATIONS OF A PROVENANCE CHANGE ACROSS THE PENNSYLVANIAN-PERMIAN BOUNDARY WITHIN THE MIDCONTINENT (USA) INFERRED FROM DETRITAL ZIRCON GEOCHRONOLOGY

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The modern U.S. Midcontinent was part of equatorial western Pangaea (North America) sandwiched between a continental-scale orogenic zone to the east and south (Appalachian-Ouachita-Marathon orogenic belt) and a series of basement-cored, intra-plate uplifts along western Pangaea (Ancestral Rocky Mountains). Furthermore, from latest Pennsylvanian through Permian time this region records a change in climatic conditions toward increasing aridity. Here, we present a compilation of detrital zircon geochronology data from the Permo-Pennsylvanian of the Midcontinent as well as coeval strata of the east and west of Midcontinent North America to explore sediment dispersal patterns, and potential tectonic and climatic influences on these provenance signatures.
Zircon provenance data come from mostly eolian and fluvial silt- and sandstone units of Early Pennsylvanian through middle Permian age, although some data include marine sandstone units. Our new data were acquired by LA-ICPMS at the University of Arizona Laserchron, and predominant age groups include >2500 Ma (Archean), 1600-1800 Ma (Yavapai-Matzatzal), 1300-900 Ma (Grenville), 790-570 Ma (Neoproterozoic), and 480-360 (Early-Middle Paleozoic). However, the relative distributions of these populations exhibit distinctive temporal differences, especially across the Pennsylvanian-Permian boundary, but also spatially in comparison to published data from the Appalachian-Ouachita-Marathon basin, Ancestral Rocky Mountain basins, and the western Pangaean margin.
Although the Central Pangaean Mountains, and in particular the Grenville-age basement rocks, supplied a large volume of sediment to the Midcontinent, the data suggest a widespread dispersal of Neoproterozoic zircons in the early Permian. This change in provenance occurs in units within the Midcontinent and westward to the Ancestral Rocky Mountains region, but is rare along the western margin and the Appalachian basin in the early Permian. This suggests that dispersal remained segmented in the early Permian and not dominated by a simple east-west integrated paleodisperal system traversing across western Pangaea as inferred in some reconstructions. Temporal changes in paleoclimatic conditions across the boundary also impacted these provenance signatures through the Permian.

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FLUVIAL-AEOLIAN INTERACTION AT DIFFERENT SCALES IN THE MIOCENE ANDEAN FORELAND

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Fluvial and aeolian processes interact at different spatial and temporal scales in dryland environments. Different scales of interactions result in contrasting scales of sedimentary heterogeneity in the rock record and can be related either to short-term changes in available runoff, to large-scale flooding of aeolian systems, and eventually to long-term climatic changes. In this contribution, different scales of fluvial-aeolian interactions are explored in a sedimentary succession developed in the Andean Foreland during the Miocene, the period of maximum uplift and more dramatic changes of landscape and climate in the area. The studied unit constitutes a 1500 m-thick succession that records the long-term evolution of a large fluvial fan. It is greatly dominated by fluvial deposits composed of channelized sandstones and conglomerates that intercalate with thick fine-grained overbank deposits. Aeolian deposits comprise well-sorted, fine- to medium-grained sandstones that show a wide range of thickness and lateral development, suggesting contrasting processes. The arid climate and the high-accommodation setting in a foreland basin provide an ideal context to analyse a relatively complete record of the interaction of fluvial and aeolian processes at variable scales.

Small- and intermediate-scale interactions between fluvial and aeolian processes are mainly related to autogenic dynamics and to the intrinsic variability of hydrological processes in dryland systems, subject to winds capable of transporting and accumulating sand when not affected by the water table or its capillary fringe. Small-scale examples include aeolian reworking of water-lain deposits, resulting in dm-scale units that show better sorting and overall finer grain than the equivalent fluvial units. Intermediate-scale heterogeneities are in the studied case the consequence of more widespread flooding episodes of aeolian systems. These could be related to greater floods developed in the order of 10^1-10^2 years and are usually associated with low-gradient interdune areas. Irrespective of the wet or dry nature of the interdunes, large-scale flooding results in local accumulations of fluvial deposits, leading to the development of 10´s-m thick and 100-200 m wide, lens-shaped intercalations of fine-grained deposits within well-sorted, sandy aeolian dune deposits. Finally, large-scale interactions are related to allocyclic processes, mainly climate change leading to wetter and dryer periods in the evolution of this system, effective over a larger temporal framework (10^5-10^6 years). In the case at hand, the effect on the record is stronger in terms of petrophysical changes and sedimentary architecture as 10-m to 100-m thick sandy aeolian units (with subordinate fluvial-flood deposits) intercalate with conglomerates, sandstones and fine-grained intervals related to fluvial-dominated intervals (with minor aeolian reworking). Understanding this complex interactions of fluvial and aeolian processes in dryland environments and contrasting these styles with other units in the rock record may help to clarify different hierarchies of sedimentary heterogeneity in the subsurface and provide key elements in order to optimise development strategies, especially for mature fields.

THE VITAL ROLE OF MUDSTONE/SHALE STUDIES IN ADVANCING SEQUENCE STRATIGRAPHY IN GENERAL

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Studies of mudstone/shale have benefitted from using the sequence-stratigraphic approach but have also improved sequence stratigraphy as a discipline. Observations indicate that mud is a quite active component at many scales and not just passive fill among coarser grains. The influences of mud range from being essential to many sediment-transport mechanisms at the bed scale to forming distinctive types of parasequences and complex stratal geometries at depositional-sequence to sequence-set scales. It appears that various grain-size classes each have their own inherent geometry and the stratal record is the resultant of vigorous interaction among the grain sizes.

What we learned using sequence stratigraphy includes: A wide variety of sedimentary structures occur in mudstones that indicate a comparably wide range of transport mechanisms, in many of which the presence of mud alters the fluid and transport properties of the flow. At the parasequence scale, most marine shelfal mudstone strata appear to have accumulated as one of three end-members that can be differentiated quantitatively and related to depositional regimes dominated by storm waves, river floods, or tidal currents through characteristic modes of sediment transport and accumulation, as well as variations in benthic-energy and oxygen levels. At the depositional-sequence scale, most marine biogenic-rich mudstones tend to occur in one of three physiographic settings (constructional shelf margin, platform/ramp, continental slope—basin), each of which has a commonly recurring pattern of biogenic enrichment distinctive from the other settings. At the depositional-sequence-set scale, all major shale-gas plays can be grouped into four main families, based on repeated patterns of stratal stacking of depositional-sequence-scale biogenic-rich physiographic settings.

What we learned about sequence stratigraphy includes: Sequence-stratigraphic criteria (e.g., stratal terminations, geometric relations, stacking patterns) apply across the full range of grain size and composition (> 8 orders of length-scale magnitude). There are a variety of types of surfaces as well as of rocks— and surfaces are indeed much more important than the preserved strata because they record more of geological time (and are commonly easier to recognize in mudstone strata). The same types of surfaces, stratal units, and stacking patterns are seen across all grain sizes and compositions, but their expressions vary as a function of depositional environment.

Although these observations imply that most mudstones accumulate discontinuously, they still preserve detailed records of paleoenvironmental conditions and depositional history, especially in microbially mediated authigenic products. The sequence-stratigraphic approach is particularly useful for organizing all these discontinuities and varying rock properties into a hierarchy of nested scales. The resulting sequence-stratigraphic framework is essential for integrating the wide range of physical, biogenic, and chemical attributes of mudstones into a comprehensive understanding of Earth history and hydrocarbon systems.

MICROFACIES, STACKING PATTERNS AND DEPOSITIONAL PROCESSES OF AN ICEHOUSE-TO-GREENHOUSE MUDSTONE SUCCESSION, KAROO BASIN, SOUTH AFRICA

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Recent mudstone studies have focused mainly on successions deposited during greenhouse climatic periods in low palaeo-latitudes. Conversely, only a few address mudstone deposition in high palaeo-latitudes during icehouse periods, where seasonal fluctuations in sediment supply and higher magnitude eustatic sea level changes are expected to be more pronounced. Here we present data from the mudstone-dominated Ecca Group of the Tanqua depocentre (SW Karoo Basin), deposited during the Permian icehouse-to-greenhouse transition in a relatively high palaeo-latitude (~60-70°S). This study aims to characterize the range of mudstone microfacies, depositional processes and stacking patterns recorded during this important climatic turnaround in Earth history. This will help to improve our understanding of the controls on mudstone sedimentation in high palaeo-latitudes, and the effects of an icehouse-to-greenhouse transition on sedimentary processes.

A 950 m-long continuous core from a research borehole is described here for the first time. The lower half of the succession is dominated by approximately forty sharp-based 5-20 m-thick packages that show a thickening-upward to thinning-up profile. The lower half of each package is dominated by alternating 0.1-2 cm-thick beds of fine to medium mudstone. Beds are either normally graded, inversely graded or inversely-to-normally graded, and are mainly composed of clay- to silt-size allochthonous material (quartz, feldspars and plant fragments). Bed thickness decreases and bioturbation index increases upward within a package. The upper part of the package consists of churned medium mudstone with faecal pellets, carbonate concretions and 2-10 cm thick ash-rich turbidites. The succession includes two 5 to 10 m-thick deformed sections. The packages grade upward into a 200 m-thick churned fine homogenous mudstone succession, with common interbedded ash-rich turbidites and carbonate-rich concretions. This section is overlain by the 400 m-thick succession of well-known Tanqua sandy basin-floor fans.

The lower half of the succession is interpreted to represent periodic river-derived low-density turbidity currents deposited in a basinal environment with episodic gravitational collapse or development of sea-floor topography. The upward decrease in bed thicknesses, transition into churned medium mudstone and increase in bioturbation index within a package indicate a decrease in sediment accumulation rate with less frequent sediment gravity-flow events. This may be linked to a gradual deactivation and backstepping of the delivery system. The sharp base of each package marks an abrupt increase in sediment accumulation rate. The larger scale vertical transition into the less organized fine mudstone dominated upper half of the succession may indicate a major change in sediment routing system as a precursor to the overlying canyon-fed basin-floor fans. This continuous fine-grained succession represents a unique dataset to reconstruct the palaeoenvironments and mudstone depositional processes that prevailed during the Permian icehouse-to-greenhouse transition in the Karoo Basin.

Hydrocarbon retention mechanism of different types of lacustrine shale: a case from Chang7 Member of Triassic Yanchang Formation in Ordos Basin, China

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Abstract

There are abundant oil and gas resources in lacustrine basins in China, among which the Triassic in Ordos Basin is the most promising shale oil play. The Upper Triassic Yanchang Formation records the whole process that the occurrence, development and fade of the lacustrine basin. According to petrology and stratigraphy, Yanchang Formation can be divided into 10 members: Chang 1-Chang10 from top to bottom, of which Chang7 Member represents the prosperous period of lake, deposited a set of deep-water (i.e., below wave base) lacustrine facies including black shale and dark mudstone(Hanson and Ritts, 2004; Yang et al., 2009).

This paper uses core observation, thin section, and geochemistry to subdivide shales, reconstruct formation condition and reveal occurrence mechanism of hydrocarbon for each type of shale. It reduces the uncertainties caused by anisotropy and heterogeneity in lacustrine shale and provides a new approach to more accurate results in shale oil resource assessment.

Based on sedimentary structure, organic matter occurrence mode, TOC, sulfur content and geochemical parameters, shale in Upper Triassic Chang 7 Member are divided into three types: type 1-laminated shale, type 2- transformed laminated shale and type 3- bedded shale. The laminated shale has maximum abundance of organic matter. It deposited in region relatively close to lake shore. Its kerogen mainly consists of higher plants debris which is easy to form a network structure during the thermal evolution. This structure can absorb a large amount of residual organic matter and hydrocarbon, which makes the volume of total hydrocarbon retention in type 1-laminated shale-largest. However, most of hydrocarbon retention in laminated shale is aromatic, non-hydrocarbon and asphaltene, indicating poor fluidity. The TOC of bedded shale is lowest. It was formed in deep lake with main type II kerogen. Although the total hydrocarbon retention in type 3-bedded shale- is not considerable abundant, in which the volume of saturated hydrocarbon is highest among 3 types of shale. This means the potential of movable hydrocarbon of shale oil in bedded shale is greatest. The parameters of type 2- transformed laminated shale range between type 1 and type 3 shale.

The heterogeneity of shale causes stratified characteristics of hydrocarbon accumulation vertically. The results of hydrocarbon expulsion efficiency that are calculated based on chloroform asphalt "A" and its components show that, some values of expulsion efficiencies of type 2 and 3 shale are negative, indicating that part of hydrocarbons are transported from other layers. The average hydrocarbon expulsion efficiency of type 1, 2 and 3 shale is 74.6%, 26.7% and -4.5% respectively. Especially in type 3 shale, shale oil occurrence mechanism is similar to primary migration pattern, which suggests that movable hydrocarbon potential in type 3 shale is relatively high, performing a better prospect of shale oil development.

Keywords: shale oil; hydrocarbon retention; lacustrine shale; Ordos Basin

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Channels Incised into Low-Relief-Deltaic Mudrocks of Midcontinent USA

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Shales and mudrocks have long been the neglected stepchild of sedimentary rocks, despite comprising ~3/4 of the total mass. That has changed dramatically with the advent of massive hydrocarbon production from fine-grained sedimentary rocks. Shales (*sensu lato*) in the Late Pennsylvanian and Early Permian cyclothems of Midcontinent USA come in several flavors. By far the most important volumetrically are the heterolithic "outside shales" that separate each of the limestone-dominated cyclothems. The Calhoun Shale (Shawnee Group, Virgilian, Upper Pennsylvanian) of northeast Kansas provides an example of these shales. Typically 10 to 20 m thick, it conformably overlies a shallow-water regressive limestone, without clear indication of shoaling or exposure. The bulk of the Calhoun consists of heterolithic mudrock: claystone, clay shale, silty mudrock, lenticular sandstone, and thin intercalations of siltstone with ripple marks, trace fossils, and, locally, depauperate marine biota. Things get more interesting toward the top of the unit, as a drop in relative sea level led to multiple deeply incised, sandstone-filled channels. Channel fills are fluvial, although tidal influence appears possible in one exposure. Very thin coal seams drape the filled channels and adjacent interfluves. The Calhoun is capped by claystone with abundant terrestrial plant fragments and low-diversity marine fossils that grades up into the basal "transgressive limestone" of the overlying cyclothem.

These "outside shales" are generally interpreted as distal deltaic deposits on a broad, shallow shelf. The repetitive pattern of the Midcontinent cyclothems is such that observations of a single unit, such as the Calhoun, are relevant regionally throughout the upper Pennsylvanian and lower Permian strata. For example, incision of channels within the uppermost part of these mudstone units is a common feature, as are the overlying very thin coal layers and the fossiliferous transition to marine limestone. The channels, generally filled by fluvial sandstone, provide a maximum-regression marker for sequence stratigraphy. Outside shales are not potential source rocks nor "unconventional reservoirs."

CYCLOSTRATIGRAPHY AND ECCENTRICITY TUNING OF THE TELYCHIAN STAGE (EARLY SILURIAN): ORBITAL CONTROL ON CYCLICAL PRIMARY PRODUCTIVITY AND BENTHIC ANOXIA

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The identification of quasi-periodic oscillations in the Earth-Sun position on the Palaeozoic stratigraphic record represents an open research frontier in cyclostratigraphy and astrochronology[1]. In this work, we focus our attention to the Telychian Stage (Llandovery, Silurian), for which we construct a floating astronomical time scale (ATS) by means of cyclostratigraphic analysis. Digitized and image-processed photographs of a continuous core drilled through the Silurian Pasłek Formation in the Baltic Basin (Poland) served as the basis for the analysis of the studied interval[2]. The lithological rhythmicity of the analysed record, characterized by the repetitive alternation of greenish-grey mudstones and dark-grey-to-black mudstones, reflects the cyclical variation in redox conditions at the sediment-water interface[3]. Spectral density estimation by means of the multitaper method (MTM) reveals significant peaks rising above the 95% red noise confidence level that we interpret as the 405-kyr long-eccentricity, short-eccentricity, obliquity and precession components. The MTM evolutive power spectral analysis (EPSA), used to evaluate the stationarity of the cycles, shows a gradual variation in the sedimentation rate from 5.03 m/Myr in the lowermost interval to 5.48 m/Myr towards the uppermost part of the studied sequence. Accurate acritarch biostratigraphy allowed to calibrate the orbital tuning of the studied interval, that resulted in a duration of about 5.46 Myr. Furthermore, thanks to the cyclostratigraphic analysis, we can postulate that the observed cycles reflect orbitally-driven climatic variations from stable wet conditions to monsoon-like high seasonal contrasts that affected weathering intensity, runoff and nutrient supply. These cyclical variations led to rhythmic variations in organic matter fluxes and benthic anoxic conditions. In the analysed record, orbital precession influenced the repetitive deposition of the greenish-grey mudstone and dark-grey-to-black mudstone couplets, while eccentricity modulated the relative predominance of one facies over the other. Observed periodicities resemble those of Cenozoic and Mesozoic orbitally controlled records, thus suggesting that during the Silurian the orbital eccentricity forcing on the carbon flux acted in the same way as in the Cenozoic and Mesozoic.

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Refining mineral quantification methods for fine-grained hydrocarbon reservoirs: the Devonian Duvernay Formation, Alberta, Canada

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Fine-grained, unconventional hydrocarbon reservoirs often have complex mineralogy that varies on a wide range of scales. Mineralogy is an important aspect of reservoir properties such as porosity, permeability, and brittleness, and there are challenges in accurately and efficiently quantifying mudstone mineral components. Commonly utilized methods of mineralogical or elemental quantification include inductively coupled plasma - mass spectrometry (ICP-MS), x-ray diffraction (XRD), x-ray fluorescence (XRF), and QEMSCAN. Each of these methods has strengths and weaknesses and the results can vary considerably between methods. This study presents potential problems in these commonly used methodologies for mineral quantification and generates an effective workflow using complimentary datasets.

The study applies ICP-MS data from a densely sampled core interval of the Duvernay Formation of the Western Canadian Sedimentary Basin, and integrates complementary data from other analysis methods. The data set is composed of 116 XRD, 116 ICP-MS, 15 QEMSCAN, and 3 XRF measurements, allowing for direct comparison of mineralogy methods on equivalent material.

One advantage of this workflow is the ability to differentiate biogenic and detrital quartz, each of which can have significantly different influences on rock properties. Additionally, supplementing the elemental ICP-MS data with mineralogical data from XRD or QEMSCAN, the workflow is able to estimate quantities of specific aluminosilicate minerals such as feldspars and clays. Sources for contrast between datasets includes, finely-heterogeneous mineral and organic matter mixtures below QEMSCAN resolution, mineral crystal quality, and similarities in mineral composition.Subsequent work is ongoing to refine the methodology with additional wells.

A refined mineral model, as presented here, allows better accuracy when examining the relationships between mineralogy and porosity/permeability, and will allow for a more robust evaluation of rock density, particularly applicable to wireline log analysis.

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HIGH-RESOLUTION ALLOSTRATIGRAPHY REVEALS CRYPTIC, RAPIDLY-MIGRATING DEPOCENTRES IN 'MONOTONOUS' CRETACEOUS FOREDEEP MUDSTONES, ALBERTA

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The Late Cretaceous (Coniacian) Muskiki and Marshybank members of the Wapiabi Formation are dominated by marine mudstone and occupy the central foredeep of the Western Canada Foreland Basin. The Coniacian strata unconformably overlie sandstone-rich rocks of the Cardium Formation, show a broadly upward-shallowing succession, and record a major, basin-scale transgressive-regressive event[1,2]. Building on earlier studies[1,2,3], the current project uses high-resolution allostratigraphy, based on tracing flooding surfaces through a grid of 1020 wireline logs, to build a regional stratigraphic framework. Allomembers recognized in subsurface were correlated westward into 19 sections exposed in the Rocky Mountain Foothills with the use of outcrop gamma ray logs. This integrated stratigraphy provides a basis by which to assess regional stratal relationships, the stratigraphic distribution of ammonites and inoceramid bivalves, and the completeness of the carbon-isotope record[4]. The studied interval spans ~ 3.0 Myr, and contains 24 mapped allomembers, suggesting an average allomember duration of ~ 125 kyr[4].

Correlation of meter-scale allomembers reveals four subtle regional disconformities that bound five 'tectono-stratigraphic' units, each of which is inferred to span ~ 500 kyr. An isopach map of the entire sequence shows a westward-thickening wedge, readily explicable in terms of flexural subsidence. Isopach maps of each unit, however, exhibit patterns of uplift and subsidence that differed markedly through time; none of these patterns can be explained in terms of simple flexural foreland basin subsidence. The localized pattern of differential uplift and subsidence might indicate subtle syn-Cretaceous warping of the sea-floor resulting from differential movement between deep-seated, fault-bounded blocks. Unfortunately, few public-domain seismic data are available within which to seek the 'smoking gun' responsible for the observed stratigraphic patterns. This study shows that it may be naive to assume that seemingly monotonous successions of offshore mudstone in a foredeep basin actually preserve a complete stratigraphic record.

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Tectonic sedimentary response and high quality shale distribution characteristics in Ordovician-Silurian transition of Upper Yangtze Region

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The Upper Ordovician Wufeng Formation-Lower Silurian Longmaxi Formation is the key target strata of shale gas exploration and development in China, and also a rare and high resolution graphitic shale formation in the world. In this study, according to the outcrops and exploratory well data in Sichuan Basin, the control effects of tectonic-sedimentary response and sedimentary model on shale in the Ordovician-Silurian transition were analysed and the spatial distribution of "sweet spot zone" were summarized. The main conclusions were as follows:

(1) The distribution characteristics and geological significance of the thickest Aeronian bentonite were obtained. The thickest Aeronian bentonite bed, with a thickness of 5-40cm, is steadily distributed in the Middle-Upper Yangtze Region, and is the key marker layer of the segmental partition and the regional comparison of Longmaxi Formation, because its electrical characteristics are obvious and easy to identify. The occurrence of the thickest Aeronian bentonite bed indicates a significant change of tectonic-sedimentary response in Ordovician-Silurian transition, and the organic-rich and siliceous shale mainly formed before this period.

(2) In Ordovician-Silurian transition, the Yangtze Platform experiences four stages: the conversion period from platfrom to shelf, the formation of uplift and depression, the initial and the development stage of flexural process of foreland basin, whose sedimentary elements' evolution characteristics are distinct, resulting in the formation of shale sedimentary facies that are various in space and distinctive on regions.

(3) In the Yangtze sea area, black shale development models in Silurian can be divided into two types: slow deposition in weak-semi stagnant shelf and rapid deposition in upwelling zone respectively. The first model constructs organic-rich shale in most area of Yangtze, with a deposition rate lower than 15m/ma; the second mainly builds organic-rich shale in Wuxi area, with a deposition rate of 20-130m/ma generally.

(4) The evaluation method and standard of marine shale's "sweet spot layer" were proposed and the spatial distribution of the "sweet spot layer" in Wufeng-Longmaxi Formation was predicted based on the study of tectonic sedimentary response, and siliceous shale in semi-deep water are favorable facies for forming high-quality reservoirs. Wufeng Formation-Rhuddanian is the main development zone of high-quality reservoir, while Aeronian-Telychian is the secondary development zone, and the development age of high-quality reservoir gradually becomes younger from southeast to northwest.

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INVESTIGATING PALEOSALINITY FROM A GEOCHEMICAL PERSPECTIVE

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Understanding syn-depositional salinity conditions is critical for making precise paleoenvironmental interpretations, but at present there are no standardized methods for estimating paleosalinity in the rock record. Current methods for estimating syn-depositional salinity in the rock record involve ichnology and micropaleontology. These methods can be problematic due to inconsistent preservation of trace fossil and microfossil assemblages, and subjective interpretations thereof. Other previous studies have correlated trace-element concentrations in mudstone units with inferred depositional salinities. However, these studies fail to adequately reproduce the mechanisms by which salinity-dependent trace element signatures develop. In an effort to refine the relationship between environmental salinity and trace element signatures in mudstones, we use quantitative geochemical methods to make observations of trace-element enrichment in clay minerals under controlled conditions. Here, we conducted experiments with three common clay minerals that contribute to mudstones; illite, kaolinite, and montmorillonite. We tested the (i) desorption of elements from clays at various pH values to determine elemental leaching from the clays, (ii) titrations of the clays to define the type and availability of their surface sites, (iii) adsorption of trace metal cations to each clay at various ionic strengths to define the relationship between the sorption behaviour of metals to specific clays and solution ionic strength, and (iv) suspension of the clays in natural seawater and river water samples to identify sorption signatures in marine and fluvial environments, respectively. As our work progresses, we intend to establish a framework that can be applied to the rock record to enhance paleoecological and paleoclimate interpretations.

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Microbe-clay interactions as a mechanism for the preservation of organic matter and trace metal biosignatures in black shales

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Organic-rich, fine-grained sedimentary rocks, such as black shales, are important geochemical archives providing information on the evolution of seawater composition and biological activity over the past 3 billion years. While biological productivity and sedimentation rates greatly affect the organic matter content in these rocks, mechanisms linking these two processes remain poorly resolved. Here, we examine the interactions of clay minerals with the marine planktonic cyanobacterium Synechococcus sp. PCC 7002. We suggest that clays settling through the water column could influence carbon and trace metal burial in three ways: (1) the interaction of reactive clay surfaces with the bacterial cells increases organic matter deposition via mass increase in a seawater growth medium by several orders of magnitude; (2) reactive bacterial cells become completely encased within a clay shroud, enhancing the preservation potential of this organic matter; and (3) the trace metal content of the biomass buried along with metals sorbed to the clay particles contributes to the trace metal concentrations of the black shale precursor sediments. Significantly, our findings imply that the chemical composition of ancient, organic-rich, fine-grained deposits are not only archives of ancient seawater composition and redox state, but they also provide a record of the degree of biological activity in the water column through geological time.

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Geochemical fingerprinting of a condensed section and ooidal ironstone formation in the Middle Jurassic of northern Switzerland

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The Opalinus Clay (OPA) is a mudstone formation particularly known in Switzerland as being the selected host rock for deep geological disposal of radioactive waste. In the northern Swiss Jura, the Opalinus Clay is overlain by the Passwang Formation (PF). This alloformation is characterized by parasequences of sandy bioclastic marls and limestones, separated by iron-oolitic beds (1). Both formations were interpreted as being deposited in a shallow epicontinental sea covering central Europe during the Aalenian and Early Bajocian. The basal ooidal ironstone of the PF is used as a marker delimitating the OPA/PF formational boundary. This lithological transition is however diachronous, and shows a high lateral variability. Classically described as a condensed section, the formation, deposition and diagenetic processes involved in this transition have not been yet investigated.

We aim to assess, at different scales, the vertical and lateral heterogeneity within this transition. The depositional environment is investigated to decipher any diagenetic imprint with particular emphasis to the formation and origin of the iron ooids. Core and excavation material from different locations across northern Switzerland are investigated using petrographic, petrophysical and geochemical methods.

Preliminary results include the first petrographic and geochemical investigations performed in mainly two locations (Mont Terri and Riniken). µXRF, XRF core scanning and thin section data show promising indicators to distangle depositional and diagenetic processes, and provide hints on the types of iron ooids present in the transition.

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The Sedimentary Characteristics of Organic-rich Shale of Chang 7 Formation in Tongchuan Area, Ordos Basin

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Main text: Tongchuan located in south marign of Ordos Basin is the well-known oil-shale production field in China. The organic content of the Chang 7 lacutrine shale has cyclicity vertically. In order to explore whether there is a corresponding regulation in the fined-grain sediment rock in each cycle interval, the favourable outcorp of Chang 7 in Yishicun is selected to take samples in centimeter-scales and the observations of a large part of organic-rich shale are conducted in detail by X-ray diffraction, polarizing microscopy and scanning electron microscopy. The research conclude that the composition of shale is quartz, K-feldspar, plagioclase, jarosite and clay, and except the quartz devried from terrigenous debris, a large part of quartz with felsitic texture is the production of devitrified acid volcanic ash. The lenticualr lamination that mainly compose of illite is well developed in the shale, which most likely records intermittent erosion and transport of surficial muds by current[1], and it believes that the shale with this texture commonly deposits in muddy slope rather than the deep lake facies. The morphology of the lenticular lamination varies with the organic content of shale. When the abundance of organic matter is below 8%, the clay strip can be observed in the sample, the result of which is that the clay rip-ups pile with each other and the margin of lens cannot be distinguished. With total organic carbon content increasing, the typical lenticular lamination fabric is well developed. When the organic matter abundance is beyond 20%, the clay lens become flatted and pinch out laterally.

Key words: Chang 7, Ordos Basin, sedimentary environment, lenticular lamination

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APPLICATION OF SEQUENCE STRATIGRAPHY TO AN ANCIENT SHELF MUDSTONE SUCCESSION: UPPER CRETACEOUS TUNUNK SHALE MEMBER, MANCOS SHALE FORMATION, UTAH, USA

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Conducting high-resolution sequence stratigraphic analysis in fine-grained sedimentary successions remains a challenging task due to the relatively homogeneous, fine-grained nature of mudstones. In this study, we apply a multi-proxy (sedimentology, petrography, and mineralogy) analytical approach to the thick (~ 200 m) Upper Cretaceous Tununk Shale in south-central Utah, in order to test the efficacy of recognizing parasequences, system tracts, and depositional sequences based on basic sequence stratigraphic principles in mudstone-dominated successions.

The Tununk Shale is interpreted as an offshore mud blanket deposited on a storm-dominated shelf. Vertical variations in sedimentary facies characteristics indicate that the depositional environments of the Tununk Shale shifted laterally from a distal middle-shelf to outer-shelf, then from an outer-shelf to inner-shelf environment, largely controlled by the 2nd-order Greenhorn transgressive-regressive sea level cycle. The sediment supply of the Tununk Shale was derived from multiple sources, including clastic sediments eroded from the Sevier orogenic belt and volcanic highlands, primary productivity from the upper water column, wind-borne volcanic ash, and recycled sediments from intrabasinal erosion. Influenced by the storm-induced offshore-directed flows and shore-parallel geostrophic flows, sediments in the Tununk system were subject to transport and deposition across and along the ancient shelf. At least 50 coarsening-upward parasequences can be identified in the Tununk Shale. Based on stacking patterns, they can be grouped into 11 system tracts and 4 sequences, indicating that there are higher-frequency (3rd and 4th-order) relative sea-level cycles superimposed on the 2nd-order Greenhorn cycle.

Integrated sedimentological and petrographic facies analyses are highly effective in revealing depositional sequences and their component parasequences and system tracts in this study. Although variations in mineralogy of the Tununk Shale reflect the 2nd-order Greenhorn cycle, it is not always straightforward to recognize higher-order system tracts and parasequences based on these data. This is largely due to the mixing of varying amounts of sediment derived from different sources, which have probably undergone multiple cycles of resuspension and deposition across and along the shelf. The developed sequence stratigraphic framework in this study provides insights into how to apply basic sequence stratigraphic principles to ancient shelf mudstone successions, and highlights the need for integrating provenance and sediment dispersal mechanisms along both depositional dip and strike with current sequence stratigraphic concepts.

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Diagenetic variation at the lamina scale in lacustrine organicrich sha les: Implications for hydrocarbon migration and accumulation

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Abstract: Lacustrine carbonate-rich shales are well developed within the Eocene Bohai Bay Basin (BBB) of eastern China and across southeast Asia. Developing an understanding of the diagenesis of these shales is essential to research on mass balance, diagenetic fluid transport and exchange, and organic-inorganic interactions in black shales. This study investigates the origin and distribution of authigenic minerals and their diagenetic characteristics, processes, and pathways at the scale of lacustrine laminae within the Es4s-Es3x shale sequence of the BBB. The research presented in this study is based on thin sections, FESEM and SEM-CL observations of well core samples combined with the use of XRD, electron microprobe analysis, and carbon and oxygen isotope analyses performed using a laser microprobe mass spectrometer.

The dominant lithofacies are a laminated calcareous shale (LCS-1) and a laminated clay shale (LCS-2). The calcite recrystallization is the overarching diagenetic process affecting the LCS-1, related to organic acid generation from OM evolution. This evolutionary transition is the key factor driving the diagenesis of LCS-1, while the transformation of clay minerals is the main diagenetic attribute of the LCS-2. Diagenetic differences occur within different laminae and at variable locations within one lamina, controlled by variations in components and the properties of interfaces. The diagenetic fluid migration scale is limited to individual laminae, up to 100 μm in width. The dominant migration pathway for diagenetic fluid is lateral, along the abrupt interfaces between boundaries.

The recrystallization boundaries between calcite laminae act as the main migration pathways for the expulsion of hydrocarbons from these carbonate-rich lacustrine shales. However, because the interaction between diagenetic fluids and the shales themselves is limited to the scale of individual lamina, this system is normally closed. The occurrence of abnormal pressure fractures can open the diagenetic system, and cause interactions to occur throughout laminae. Multi-scale C-O systems are ubiquitous and episodic ranging from the scale of laminae to the whole basin. The small-scale systems are often superimposed onto larger ones to constitute the complex diagenetic system, combining fluid transport, material and energy exchange, and solid-liquid and organic-inorganic interactions.

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MUDDY HYPERPYCNAL FLOWS AND ORGANIC-RICH SHALES. THE UPPER JURASSIC – LOWER CRETACEOUS VACA MUERTA FORMATION, NEUQUÉN BASIN, ARGENTINA

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The accumulation of organic-rich mudstones was largely associated to low energy depositional environments with anoxic bottom waters, where mudstone deposition was mainly related to gradual and continuous mud fallout from dilute buoyant plumes. Based on this, basin inner zones were considered as unsuitable environments for source rock deposition due to the generally low concentration of OM resulting from both low inputs and production, adding an intense OM degradation during its transit time through the water column. Nevertheless, recent detailed sedimentological analyses in a variety of unconventional shales have revealed that the participation of fallout processes is probably subordinated to other still poorly known depositional processes, opening a new paradigm for source rocks origin.

In Argentina, the Upper Jurassic – Lower Cretaceous Vaca Muerta Formation is composed of organic-rich mudstones and carbonates dominated by type II kerogen representing South America's main unconventional reservoir. New cores and excellent outcrops provide a great opportunity to study the depositional history of this unit. These deposits were previously interpreted as accumulated by fallout deposition in a quiet and anoxic deep marine environment. However, recent studies revealed that the Vaca Muerta Formation is a highly heterogeneous stratigraphic unit accumulated by different and poorly know depositional processes. In fact, the formation displays distinct lithofacies alternating at centimeter to millimeter scale having variable organic matter content (up to 14% TOC), features that influence the reservoir quality and performance.

High resolution sedimentological analysis were performed on relatively uncompacted intervals preserved in early diagenetic calcareous concretions collected from the basal deposits of the Vaca Muerta Formation in basinal settings. Evidences found in concretions suggest a deposition related to fluid mud flows instead of the classic model of "normal fallout". The triggered mechanisms for the origin of the recognized fluid mud flow deposits are mainly associated to direct river discharges during flood events. Each flood event would be capable of generating quasi-steady muddy hyperpycnal flows that may be sustained for days, weeks, or even months. These long-lasting events would be able to transfer significant volumes of organic matter and fine-grained sediments for long distances towards distal basinal settings. The erosion capacity of muddy hyperpycnal flows enables the incorporation of intrabasinal components (e.g. marine microfossils, carbonate mud, type II OM) which are transported together with the primary extrabasinal sedimentary load (e.g. detrital mud, micas, plant debris). The rapid and direct basinward transfer of OM by hyperpycnal flows would have avoided its dilution and degradation in coastal marine environments. Finally, the arrival of extinguishing hyperpycnal flows to the basin inner zones would have provided a fast deposition and burial of the OM, favoring its long term preservation. Therefore, muddy hyperpycnites would have a great potential for the accumulation of type II-III source rocks. The future understanding of the complexity of fluid mud flows and their internal stacking pattern will be crucial to identify long-term exploitable intervals in unconventional oil/gas plays.

HOW FLUME STUDIES ARE CHANGING OUR PERCEPTIONS OF MUD DEPOSITIONAL PROCESSES AND OUR APPRAISAL OF SHALES IN THE ROCK RECORD

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Over the past decade, flume studies have been at the heart of a paradigm shift in the ways we interpret and view the depositional history of shales and mudstones. Although it is known that mud can be deposited in shallow water energetic environments, a mental image of "deep and quiet" has long dominated the discussion among students of the rock record. Experiments demonstrate that mud can be deposited from currents competent to move sand in bedload, that flocculated muds form migrating bedload ripples, and that the end-product of this process is a laminated mud. The compacted equivalents of these experimental muds are laminated shales, sediments once associated with deep and stagnant environments. In the brave new world of mudstone sedimentology laminated shales can be looked upon as deposited by currents rather than being the product of gravitational settling, and as such allow for interpretations of a more energetic and dynamic depositional history. Comparable advances are on the horizon for a range of other shale fabrics, pending the proper design of experimental studies.

Whereas experimental work has largely relied on rather simple clay suspensions, natural muds also contain variable amounts of non-clay silt grains and organic matter in the form of admixed skeletal debris, microbially degraded soft matter, and internal microbial coatings. All of these can significantly influence sediment rheology, erodability, and transport characteristics. Temperature matters as well, because it influences the microbial degradation of mucus and slime coatings that support sediment cohesion as well as aggregate stability. Under otherwise identical conditions of flow velocity and sediment mix, bedload transport of flocculated mud via floccules ripples appears a common mode of transport in warm water settings, whereas at the same flow velocities at low temperatures (4-5 deg C) such a flow would likely be erosive and produce rip-up aggregates of surficial muds. The latter can potentially be transported for substantial distances and redeposited elsewhere.

In the case of sand transport, an increase in flow velocity results in a hierarchy of increasingly larger bedforms. For mud transport in the form of floccules and soft aggregates, the range of "allowable" flow velocities is limited by the low shear stability of the transported particles. In experiments, however, initially small floccule ripples can over time grow to multiples of their original size, hinting at the potential for larger bedforms (such as megaripples). Examples of the latter have been observed in some ancient deep sea strata, and suggest that the stable current systems common in deep sea settings may favor larger muddy bedforms. In contrast, the short lived current systems of shelf seas may limit their muddy strata to textures that reflect small ripple migration

Ongoing flume studies of mud deposition are expanding to include multiple and variable flow histories, a wide spectrum of sediment compositions and grain size distributions, and the integration of organic matter (marine snow) into the depositional setup. Observations from these experiments will allow a close calibration of rock record textures to likely physical conditions at the time of deposition.

Fine-grained sedimentary rock lithofacies and paleoenvironmental explanations of the 1st and 2nd Member of the Upper Cretaceous of SK2e in Songliao Basin, Northeastern China

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With the development of shale oil and gas, people found that fine-grained sedimentary rocks can serve as sources, reservoirs, and seals of hydrocarbons; what's more, it contains a lot of palaeoclimatic information through geologic time, but researchers still pay less attention to it compared to those coarser sediments. Therefore, the study of fine-grained sedimentary rocks becomes increasingly urgent. Fine-grained sedimentary rocks of the 1st and 2nd Member of the Nenjiang Formation of the SK2e in the Songliao Basin give us insight to understand the hydro-climatic environment under Late Cretaceous greenhouse climate. By petrological, mineralogical, paleontological and geochemical study of these cores, 13 types of lithofacies have been identified, of which 9 kinds are fine-grained sedimentary rock lithofacies. Among these 9 different lithofacies, only 5 kinds are identified in the 2nd Member, while all of the 9 kinds are found in the 1st Member. Therefore, the 1st Member of the Nenjiang Formation was formed in more turbulent lake water, and seasonal climate change had led to the ever-changing salinity of the lake, resulting in more calcium-rich and clay-rich mudstone, but the 2nd Member of the Nenjiang Formation was basically formed in more stable lake environment, resulting in more siliceous and clay-rich mudstone. Compared with the chemical phase and lithofacies, the lower part of the 1st Member of the Nenjiang Formation is mainly controlled by the salinity of the water column, and the lithofacies of the 2nd Member of the Nenjiang Formation corresponds well with the redox phase, which suggests that the lithofacies have a very good relationship with the redox water column. The chemical element and lithofacies analysis showed that there were three transgressions during the age of the 1st and 2nd Member of the Nenjiang Formation. Two of them occurred in the lower part of the 1st Member, and the last one occurred at the bottom of the 2nd Member.

Key words: Songliao Basin, Late Cretaceous, fine-grained sedimentary rock lithofacies, palaeoclimate

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DISTINGUISHING TURBIDITIC FROM HEMIPELAGIC MUD IN CRETACEOUS DEEPWATER BLACK SHALE SUCCESSIONS: IMPLICATIONS FOR OCEANIC ANOXIA

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In Bouma's[1] turbidite facies model, all mud was classed as an "*e*" division. Kuenen[2] proposed a distinction be made between turbiditic mud (e^t or e) and hemipelagic mud (e^p or F division). The distinction between the two is not always obvious to the naked eye, however, especially when the mud contains enough organic matter to be considered a black shale (i.e., ≥0.5 wt%).
In geochemical studies of deepwater black shales, it is particularly important to distinguish turbiditic mud from hemipelagic mud. Black shales are often used as sedimentary evidence for deepwater oceanic anoxia, but it is seldom considered whether the evidence is in situ. Organic matter and proxies for anoxia in turbiditic mud represent materials that were reworked from shallower water, rather than local biogeochemical signals.
We studied partly lithified middle Cretaceous deepwater black shales from ODP Site 1276, Newfoundland Basin, Canada. Our data show that it is possible to distinguish black mud turbidites from black hemipelagites using grain size and geochemical data. From bottom to top, turbiditic mud (e^t) can be subdivided into three parts[3]: laminated mud (E1), graded mud (E2), and ungraded mud (E3). Textural grading is observed as a progressive decrease in the grain size of the coarsest grains in each successive lamina (i.e., coarse-tail grading). Compositional grading includes an upward decrease in calcium carbonate and in hydrogen index (i.e., an upward decrease in the quality of organic matter). Hemipelagic mud (e^p or F) is texturally ungraded and contains extremely degraded organic matter and no carbonate.
The middle Cretaceous deepwater black shale succession in the Newfoundland Basin results from variations in the rate of supply of organic matter. The materials were reworked from shallower water and should not be interpreted as evidence for deepwater oceanic anoxia. Detailed facies analyses of other Cretaceous deepwater black shales may reveal that more units are graded and of possible turbiditic origin than currently presumed.

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Sedimentary controls on black shale property: a case study of Wufeng–Longmaxi shales in South Sichuan Basin, China

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Based on core description, thin sections observation, geological chemistry and XRD data analysis, this study investigated the sedimentary influence on both organic carbon accumulation and mineral assemblages of Wufeng-Longmaxi marine shales of 2 wells in the southern Sichuan Basin, China. Graptolite biozones (WF1~LM4) of Wufeng-Longmaxi formation were recognized firstly. For each graptolite biozones, shale thickness, lithofacies, mineral composition, TOC and trace elements data were analyzed. The result shows:

(1) Limited terrestrial detrital flux indicated a more stagnation condition and thus favored for the preservation of organic matter. Average TOC remained constant when apparent sedimentation rate ranged from 2~15 m/Ma (WF1~LM3). Effective dilution of organic matter occurred in *Cystograptus vesiculosus* biozone (LM4) when the apparent sedimentation rate increased over 15.0 m/Ma.

(2) Anoxic condition was key factor for organic carbon preservation. Positive correlation was found between anoxic indexes (Ni/Co, V/Cr, V/(V+Ni), and U/Th) and TOC. Under similar sedimentation rate, higher organic carbon content was found in shale with higher anoxic condistion.

(3) Mineral composition of Wufeng and Longmaxi shale was significant influenced by Fe supply. Sulfate and iron reduction during the early stage will produce a diagnostic cement assemblage characterized with framboidal pyrite (FeS_2) and non-ferroan carbonate mineral (Macquaker,et al.,2014). In condition of limited terrestrial Fe supply, such as deepest and most restricted part of the basin, the consumption of iron might lead to more acidic pore water environment during early diagenesis, thus restricted early carbonate cementation and resulted in more clay-rich lithofacies.

Therefore, the favorable shale gas reservoirs usually distributed in an environment that not only preserves sufficient organic matter, but also produces sufficient brittle minerals such as carbonate and quartz.

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MAY SUBAERIAL HYPERCONCENTRATED FLOWS GENERATE BEDFORMS? OUTCROP CANDIDATES FROM THE ALLUVIAL RECORD

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Subaerial hyperconcentrated flows (HCF) are increasingly recognized as common vectors for supplying sediment to alluvial systems, normally associated to an interplay of high sediment discharge and a flashy mode of flood generation. In processual terms subaerial HCF's are transient phenomena related to significant variations of sediment concentration in channelized as well as unconfined flows. This variability, occurring both in space and time, expresses, beyond end-member flow classifications, the wide gradation existing between mass (i.e debris flows) and selective (i.e stream flows) transport mechanisms, in turn resulting in a wide variety of deposits. In this perspective the subaerial HCF's are a rheologically intermediate category of sedimentary process sharing many features with the re-sedimentation processes of the subaqueous realm. Bedforms in confined/unconfined turbulent flows are related to a selective mode of bedload transport involving a grain-by-grain sediment motion, a transport dynamic virtually prevented when subaerial flows are congested with sediment, as occurring in HCF's, determining *en-masse* modes of bedload transport. Nevertheless, the growing recognition of different bedform types, in large part ascribed to supercritical flow regimes in turbiditic settings, supports the hypothesis of bedform generation even in density-stratified flows. Similarly, the alluvial record provides examples of dune- to bar-scale bedforms escaping the classic structure and architecture of those formed through grain-by-grain accretion, that will be presented and discussed from different stratigraphic settings. In the interpretation of possible candidates of HCF-related bedforms the role of flow transformation and the balance between critical to supercritical flow conditions and high deposition rate will be discussed.

CLIMATIC CONTROLS ON CLASTIC DEPOSITION - EARLY EOCENE HYPERTHERMALS FORCE DELTAIC REGRESSION IN THE SOUTH-PYRENEAN FORELAND BASIN, RODA DE ISABENA, SPAIN

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This study highlights the dominant role of climate on landscape evolution and stratigraphic records even in an active foreland basin. The Early Eocene Roda Sandstone Formation is a shallow marine deltaic depositional system composed of mixed siliciclastic and carbonate sediments deposited in the NE margin of the Tremp-Graus Basin, Southern Pyrenees, Spain. The sequence stratigraphic architecture of this formation shows several episodes of deltaic progradation followed by carbonate accumulation that have been classically ascribed to sea-level changes or hinterland tectonic pulses. However, the Early Eocene was punctuated by important climatic variations and carbon cycle perturbations (hyperthermals). We here document the link between these prominent early Eocene climatic signals and the stratigraphic evolution of the Roda formation in order to explore landscape response to hyperthermals. We generated carbon and oxygen stable isotope profiles as well as major and trace elements. Thanks to existing magnetostratigraphic constraints, the obtained isotopic profiles can be correlated with target curves from ODP site 1258, which allows identifying the presence of five hyperthermals correlatable to the I1, I2, J, ETM 3 and L events. Deltaic progradation is systematically correlated with these hyperthermals, while carbonate deposition systematically occurs at the end of hyperthermals or in between. Based on analogy with similar observations in New Zealand (Slotnick et al., 2012) these results suggest that deltaic progradation of the Roda formation could be related to increased sediment transport and continental weathering due to enhanced hydrology during hyperthermals. Conversely, carbonate deposition could result from sediment "starvation" after hyperthermal “clearing events”. If this is correct, unlike classical sequence stratigraphic models, our results imply that deltaic progradation is primarily driven by climate-controlled sediment supply in a background of rising and high sea-level, while carbonate deposition represents maximum flooding because of a lack of available clastic material in generally lower sea-level stands.

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THE STEPHANIAN GRAISSESSAC BASSIN: PRELIMINARY RESULTS FOR RECORDING THE COLLAPSE OF THE VARISCAN OROGEN IN SOUTHERN FRANCE

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The Graissessac Basin is one of the so-called "stephano-permian" coal-bearing intramontane basins in the outer zones of the French Massif Central. These basins formed during the late stages of the Variscan Orogeny in an extensional/strike-slip context as response to the late orogenic collapse in the latest Carboniferous. They also record the gradual transition from the hot humid Carboniferous climate to the arid to semi-arid climate of the Permian, which characterize this part of the Pangea.

The Graissessac Basin is situated north of the central granitic-migmatitic dome of the Montagne Noire at the south-eastern tip of the French Massif Central. This small basin, triangular in shape and W-E elongated, opens to the east into the large Permian Lodeve Basin. A fault system is located in the southern border, separating the Graissessac Basin from the Cambrian sedimentary rocks and the metamorphosed aureole of the dome (so-called Shistes X). North of the basin Cambrian sedimentary rocks with rare granitic intrusions crop out. Based on structural and stratigraphic evidences the basin was subdivided into an older western unit and a younger eastern unit. However, our preliminary results show that the boundary between these two units is less sharp than previously considered.

The basin filling starts in a depocenter in the western unit. Alluvial fans systems, recorded as mass-flow and debris-flow deposits, dominate the lower part of the succession. Sedimentary succession evolves gradually to more fine-grained deposits, which dominate the upper half of the basin fill of the western unit. These mudstones and siltstones with interbedded small channels filled with coarse-grained sandstones and conglomerates and rare coal seams are interpreted to represent a fluvial and backswamps/peatland environment. Locally, alluvial fans formed along the basin margins. Petrographic analyses show that clasts are all derived from local source, mostly Cambrian rocks, most likely transported from northern directions into the basin. It is important that no clasts related to the granitic-migmatitic dome in south have been found.

After the filling of the western depocenter, deposition is concentrated in the eastern unit with a single large depocenter. The succession is thicker and exclusively composed of fluvial and backswamps/peatland deposits; alluvial fans are absent. Several thick coal seams are intercalated into the middle and upper part of the succession. Overall, channels are much deeper and wider as in the succession in the west and also arkosic sandstones are much more abundant. This implies a change to a system with deeper and larger rivers connected to a larger scale drainage system. This basin plain was larger than the today Graissessac basin as shown with the absence of differentiated deposits at the southern and northern basin margins. Possible sources of the feldspar are situated north of the basin, and may indicate a possible position of the drainage area.

These preliminary results do not confirm the previously postulated basin fill within a half-graben with a southern boarder fault, but they indicate that the transition into the large-scaled deposition of the Permian basins already started in the latest Carboniferous.

ROBUST GRAIN-SIZE DISTRIBUTION UNMIXING WITH THE R PACKAGE EMMAGEO

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The analysis of grain-size distributions has a long tradition in sedimentology and related disciplines studying Earth surface processes. The decomposition of multimodal grain-size distributions into inherent subpopulations using end-member modelling analysis (EMMA) allows to infer the underlying sediment sources, transport and depositional processes. Most of the existing deterministic EMMA approaches are only able to deliver one out of many possible solutions. We introduce user-friendly protocols for the EMMAgeo package of the free and open software R. They support deterministic EMMA and robust EMMA accounting for incomplete knowledge about input parameters. In robust EMMA, setting the grain-size class limits for determination of robust end-members is the most sensitive step.

Going beyond previous validation tests, we compare the performance of all available EMMA algorithms using four real-world process end-members (alluvial fan, dune, loess, floodplain sediment) that were randomly mixed to a synthetic data set. All models provide reliable estimates of the input data. The original data set was modelled with average R values between 0.868 and 0.995. Average R values of modelling the original grain-size distributions ranged between 0.910 and 0.969. The contributions of end-members to the data set (mixing ratios) were modelled with average R values between 0.645 and 0.867. Each of the models exhibits individual strengths and weaknesses throughout the validation criteria, with only robust EMMA providing an objective way to estimate uncertainties of the end-members. End-member interpretation should carefully consider the geological and sedimentological meaningfulness in terms of sediment sources, transport and deposition as well as post-depositional alteration of grain-sizes. EMMA might be powerful also in other geoscientific contexts, where unmixing of sources and processes plays a role.

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TRANSGRESSIVE STRATIGRAPHY AND SYN-RIFT SEQUENCE DEVELOPMENT IN A TIDE-DOMINATED EMBAYMENT (EARLY PERMIAN IRWIN RIVER COAL MEASURES, NORTHERN PERTH BASIN, WESTERN AUSTRALIA)

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Stratigraphic patterns and sequence development in tectonically active extensional basins remain poorly documented in comparison with passive-margin settings. In rift basins, the interplay between footwall uplift and hanging wall subsidence typically allows for the rapid creation of accommodation later filled by enhanced sediment supply from the rejuvenated rift margin[1]. This phase, where newly-formed rift depocentres are backfilled during subsequent tectonic quiescence, is to be stratigraphically compared with the transgressive filling of incised valleys formed along passive margins.

The Early Permian Irwin River Coal Measures in the Northern Perth Basin (Western Australia) record a complex stratigraphic arrangement and have been attributed to delta plain environments that developed in a cool–temperate climatic setting during syn-rift activity[2]. Sedimentary analysis of outcrop and core data from the fault-bounded Irwin Terrace is used to distinguish nine facies associations reflecting deposition in braided rivers, fixed-anastomosing channel belts, tide-influenced coastal environments, and storm-affected distal bays. The broader depositional system is interpreted as a morphologically asymmetric tide-dominated embayment with a fluvial and wave influence. The dominantly retrogradational stacking pattern suggests progressive flooding of marginal-marine areas that were subsequently overlain by more distal marine elements.

In the active rift basin, it is proposed that the preservation of a shallow-marine syn-rift succession was made possible by continuous tectonic subsidence and confinement of the embayed system hampering transgressive ravinement. High-frequency stratigraphic cycles of autogenic origin were recorded by channel incision, infill, and abandonment, and may contain ‘transgressive’ or ‘regressive’ coals. Their superposition suggests major phases of delta lobe expansion or abandonment. Tidal and wave ravinement surfaces are recognized at the base of backstepping subtidal bars and storm-generated beds, respectively.

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SEDIMENTARY FACIES AND DEPOSITIONAL EVOLUTION OF THE JEJU STRAIT, SOUTHWEST KOREA

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The deposits of the Jeju Strait shelf can be divided into nine sedimentary facies that are grouped into four depositional units, which formed in response to late Pleistocene to Holocene sea level changes. The lowermost Unit IV consists of late Pleistocene shallow marine deposits (Facies A) and overlying tidal deposits (Facies C). OSL dates of the base of Unit IV is 124.4 ± 10.0 ka. Extreme pedoturbation characterizing the middle part of Unit IV suggests that pedogenesis occurred after initial transgression. Abundant oyster fragments in the marine deposits indicate that rapidly sedimentation prevailed during the last interglacial. Intermediate Unit III is tidal-influenced deposits (Facies D) and overlying unconformity boundary, suggesting erosional process. OSL dates of this unit range from 76.7 ± 4.7 to 74.2 ± 4.7. Facies D composed of thin silt-mud couplets that vary systematically in thickness, suggesting tidal influences. Upper part of Unit III is strongly oxidized. Unit II consists of fluvial deposits (Facies E, F, and I) and overlying weathered deposits (Facies G). The OSL dated age of Unit II ranges from 50.6 ± 2.9 to 39.6 ± 2.2 ka, the deposits belonging to the Weichselian glacial period. Facies E and I are interpreted to have formed in a meandering channel and associated floodplain environment, respectively. Facies G is variably indurated and pedoturbated, suggesting prolonged subaerial exposure. The uppermost Unit I consists of early Holocene transgressive deposits (Facies J) and overlying middle to late Holocene shelf deposits (Facies K and L). OSL and ^{14}C-AMS ages of Unit 4 range from 0.32 ± 0.02 to 11.2 ± 0.1 ka. Up to 4 m thick shell beds in early Holocene deposits indicate reworking transgressive sand sheets. Age dates and stratigraphic position thus indicate the occurrence of marine incursions through the Jeju Strait during last interglacial.

Deep-derived clastics-fed shale in Permian Santanghu Basin, NW China

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Lacustrine fine-grained sedimentary rocks are important hydrocarbon-bearing rocks with complex mineral composition. Their features of organic geochemistry and reservoir have been well researched; however, the petrology, mineralogy and forming mechanism are relatively ignored, due to the extremely fine grain size. For a long time, these rocks have been simply regarded as mixed deposits of distal-terrigenous clasts and inner-chemical precipitates commonly. We provide a particular type of shales, composed of abundant deep-originated materials derived by volcanic and hydrothermal activities from the bottom of lake in Permian Lucaogou Formation in Santanghu rift basin, NW China.

The shales are well laminated and intercalated with/within laminated dolomicrite, and with little intervals of volcanic-hydrothermal exhalative rocks. Most of individual laminae of shales show matrix; however, some of them show normal grading with an erosional base. Grains in shales are bedding-parallel, poorly rounded and sorted, and shard-like, indicating an igneous origin. Differing from typical shale, the black shale is lack of clay minerals, which suggests weak weathering processes. Above features may indicate a subaqueous volcanic activities[1].

Three types of volcanic-hydrothermal exhalative rocks[2] are mainly composed simply magmatic and/or hydrothermal crystals. Two of them are the combination of orthopyroxene-alkanline felspar, and dolomite-smectite that are interpreted as derived from ultrabasic-basic carbonatite and pyroxenite; whereas the third one is analcime-ankerite that was precipitated from syndepositional or penecontemporary hydrothermal fluids. The former two rocks are thin bedded without inner stratified structure either erosional base, indicating fast and mixed deposition processes from a density debris flow. The latter one is laminated and normal graded with erosional base, indicating low density turbidity flow.

A special type of composite quartz (Qc) grains in the shales reflects algae bloom related to hydrothermal and volcanic activities[3]. The uniform shape and size of Qc grains and preferential occurrence in some laminae and the radial internal pattern of individual quartz crystals suggest a biogenic origin. Individual grain is composed of a core of anhedral microcrystalline quartz and an outer part of subhedral mega quartz grains, whose edges are composed of small euhedral quartz crystals, indicating multiple episodes of recrystallization, indicating alteration by hydrothermal fluids.

This work provides a new insight for studying provenance of deep-water sedimentation patterns.

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Depositional environment and tectonic controls on chert sources: Silurian Longmaxi Formation, Yangtze Craton, South China

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Contributions from disparate chert sources — siliceous microfossils (biological), detrital grains (detrital), and hydrothermal sediments(hydrothermal)— can be assessed geochemically(Adachi et al., 1966) and then used to interpret characteristics of the paleoenvironment (e.g., proximity to land and hydrothermal activity, tectonic evolution of a basin). Herein, geochemical proxies are used to quantify chert sources in a vertical succession (Baizitian outcrop that is situated west of Oldland Upland) of the Silurian (Rhuddanian Stage) Longmaxi Formation. These results are then compared to similar data derived from seven outcrops and wells (situated to the east) across the Yangtze Craton, South China.

Twenty-eight chert samples from Baizitian outcrop (32.5 m of chert with limestone lenses) are characterized geochemically. Samples are plotted on an Al-Fe-Mn ternary plot to discriminate between hydrothermal, non-hydrothermal (biogenic or detrital sources), and mixed sources. Of the 28 samples from Baizitian outcrop, 3 are dominated by hydrothermally-sourced cherts, 3 show a mixed source, and 22 show a non-hydrothermal source. The seven outcrops and wells (12 to 132 m thick), from the literature (Zhao et al., 2016), comprise dominantly dark-grey black shale and silty mudstone with uncommon interbedded chert. The amount of interbedded chert present in each outcrop or well decreases to the east (away from Oldland Upland), and in younger strata. A total of 43 chert samples were analyzed from these sections, and silica in all samples are dominantly derived from biogenic sources (80% average): radiolarians and sponge spicules. This biogenic source manifests geochemically as high Si/(Si+Al+Fe+Ca) ratios, and is attributed to high biogenic productivity in the paleo-seaway.

Chert derived from hydrothermal sources is relatively uncommon in Longmaxi Fm,but occurs in greater concentrations than in strata east of Oldland Upland. Hydrothermal activity and associated chert formation is interpreted to form due to extensional tectonics in the southwest Yangtze Craton. Specifically, hydrothermal chert is considered to derive from venting of hydrothermal fluids through Anninghe Fault, which is about 40 km away from Baizitian outcrop. In contrast, the seven outcrops and wells east of Oldland Upland are situated near either Huayingshan or Qiyaoshan and Dabashan faults, and yet show no evidence of hydrothermal silica contributions. Instead, these cherts are dominated by biogenic chert, and show limited terrigenous supply. The significant variations in chert character in the seaways east and west of Oldland Upland during the Rhuddandian are interpreted to reflect active tectonism west of Oldland relative to the east.

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TITLE: THE DEVELOPMENT CHARACTERISTICS OF GENETIC SAND BODIES OF SHALLOW-WATER DELTA UNDER CONTROL OF HIGH-FREQUENCY BASE LEVEL CYCLES: A CASE STUDY OF CRETACEOUS QUANTOU FORMATION IN XINMIN OILFIELD, SONGLIAO BASIN

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Guided by high-resolution sequence stratigraphic theory and sedimentology[1-2], and based on core data and logging data, the high-resolution sequence stratigraphic framework of the Q4 Member of Cretaceous Quantou Formation in M36 block of Xinmin Oilfield in Songliao Basin has been established. The Q4 Member has been divided into 1 long-term base level cycle (LSC), 4 medium-term base level cycles (MSC1-MSC4) and 14 short-term base level cycles (SSC1-SSC14) in the light of hierarchical base level cycle interfaces. It shows that the development characteristics of genetic sand bodies of shallow-water delta, such as distributary channel, subaquatic distributary channel, natural levee, crevasse splay, sheet sand and so on, are under control of high-frequency base-level cycles. Take MSC1 and MSC3 for examples. MSC1 deposited when the long-term base level began to rise slowly, composed of bottom-up SSC1-SSC3 which were mainly up-deepening non-symmetry short-term base level cycles of low accommodation. During the period of MSC1, the paleoclimate was drought, the sediment supply (S) was enough and the accommodation (A) was low. Under the condition of A/S<<1, high-energetic fluvial-dominated shallow-water delta plain developed and distributary channel sand bodies which vertically stacked and incised each other were the main genetic sand bodies. MSC3 deposited when the long-term base level rose rapidly, composed of bottom-up SSC8-SSC10 which were mainly up-deepening non-symmetry short-term base level cycles of medium accommodation. During the period of MSC3, the paleoclimate was relatively drought, the sediment supply was relatively enough and the accommodation was medium. Under the condition of the transition from A/S≤1 to A/S≥1, low-energetic fluvial-dominated shallow-water delta plain developed and distributary channel sand bodies, natural levees and crevasse splays were the primary genetic sand bodies. Vertically stacked channel and natural levee sand bodies or vertically stacked channel and crevasse splay sand bodies constituted two common combination styles of sand bodies.

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Deltaic Depositional Architecture response to Stratigraphy Evolution in Different Tectonic Stages: Paleogene, Baxian Sag, Bohai Bay Basin, East China

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Facies associations, the evolution of stratigraphy architecture and ancient deltaic successions and their response to the integrated evaluation of a tectonic and depositional process regime are discussed in this study based on a seismic interpretation and sedimentary facies analysis[1]. The case is from a comprehensive analysis of stratigraphy and the depositional process of a deltaic to continental succession in the early to late Paleogene in the Baxian Sag, Bohai Bay Basin, East China. The evolution of three genetic successions with a total thickness of 1000-7000 m comprising three facies associations including a fan delta, braided to shallow water delta and lacustrine deposit, record the initial rift stage, continuous rift stage and post-rift stage. ① The initial rift stage is made up of several fining upward successions mainly stacked in retrogradation style that pass from the fan delta plain-, through the fan delta front to mudstones in a deep lacustrine environment. This stage is characterized by high intensity rifting and sufficient deposit supplement. ② The continuous rift stage is made up of several successions stacked in both progradation and retrogradation styles, and the braided delta is well developed in spatial and vertical directions, including channels, subaqueous channels, a swamp, natural levee, and fluvial dominated mouth bar. This stage is characterized by a decrease in the intensity of rifting and finer-grained deposits. ③ The post-rift stage is made up of several successions stacked mainly in an aggradation style. A shallow water delta developed in the early phase, and lacustrine deposits developed in the late phase. The aims of the study are as follows: to demonstrate that the trigger of the evolution is mainly attributed to the decrease in intensity of tectonic activity and is influenced by paleogeomorphology, provenance and lacustrine level; to better understand the stratigraphic architecture and its corresponding depositional process in different tectonic backgrounds, and to provide new insights into the relationship between tectonic properties, stratigraphic architecture and the depositional process in continental lacustrine rift basins.

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Changes in inner- to outer-shelf delta architecture, Oligocene to Pleistocene Pearl River shelf-margin prism, northern South China Sea

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Inner shelf to shelf-margin delta and slope-fan deposits in the Cenozoic Pearl River Mouth Basin in the northern continental margin of the South China Sea comprise the most important petroleum reservoirs in the basin and their evolution reflects a changing interplay of tectonics, sea level change and sediment supply. Integrated analysis of 3D seismic, well logs and core data allows interpretation of depositional architecture and evolution of the delta systems as they responded to the major controls. Inner shelf-delta systems, sited on the landward reaches of the continental margin, are characterized by thickly stacked distributary channel, thin (20-40m) but relatively coarse delta-front and thin, fine-grained, distal delta to prodelta deposits. In contrast, outer shelf to shelf-margin deltaic systems formed 200m (merging outwards to 1000m) high clinoforms with steep slopes imaged on 3D seismic profiles as S-shape or tangential progradational reflections. Slumps and debris flow as well as sandy turbidite slope-fan deposits are common on the slopes of the clinoforms. Basinward and landward, cross-shelf transits of the delta systems are evident, as they formed some 18-20 stacked, high-frequency transgressive-regressive deltaic cycles and five megacycles. Development of the deltaic cycles is interpreted as the result of high-amplitude sea level falls and rises related to glacio-eustasy as well as to changing sediment supply. The large-scale transgressive-regressive evolution of the deltaic clastic wedge is likely to have been controlled mainly by long-term changes in tectonic subsidence rate and sediment supply. The shelf-edge deltaic regressions are likely to have developed during sea level fall, but also during periods of high sediment input enhanced by uplifted tectonic relief and catchment enlargement or at times by monsoonal intensification events. The time-space distribution of the deltaic and associated slope-fan deposits provides a base for prediction of the key reservoirs in the basin.

Evolution Model of a Modern Delta Supplied by Seasonal River in Daihai Lake, North China: Determined from Ground-Penetrating Radar and Trenches

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Deltas fed by seasonal rivers are considerably widespread in modern sedimentary environments, but their recognition and analysis remain limited in comparison with those fed by perennial rivers. In recent years, as persistent studies of seasonal river conducted, more and more attention has been gained on deltas fed by seasonal rivers. In this study, a small delta discharged by a seasonal stream in Daihai Lake, northern China, was taken as a classic example for investigating the evolution and genesis of deltas controlled by lake-level changes and distinguished sediment supply from ephemeral and high-energy flood events. Ground Penetrating Radar (GPR) data were used together with sedimentologic observations from trenches to define the radar surface, radar facies, and sedimentary architecture of the delta. Four types of radar surface were identified in the radar profile, and they were classified into two groups. Six different types of radar facies were identified and classified into three groups: inclined, plane, and irregular. The characteristics of the delta from the proximal to distal zones were defined and interpreted as five depositional units. Two basic architectural elements, channel and clinoform, were identified in the radar profile through trench correlation. The criteria for identifying records of seasonal discharge were expanded, which include significant decrease in grain size within a short distance, abundant supercritical flow sedimentary structures, poorly developed barforms, and small scale cut and fill structures. Based on the known lake-level variation and sediment supply in the past ~60 years, a chronological framework of the consequent depositional units was reconstructed. The model demonstrates that deltas fed by seasonal rivers tend to accumulate large amounts of sediments carried by violent floods within short periods.

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Formation of middle Miocene red beds in the South China Sea: Element geochemical and mineralogical analysis

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The formation of oceanic red beds that usually present oxic and oligotrophic conditions with low sedimentation rate has been used to trace depositional paleoenvironment and paleoclimate change. Red beds overlying oceanic basalts were drilled at Site U1434 of IODP Expedition 349 in the South China Sea. The biostratigraphic and paleomagneic data confirm its formation during middle Miocene (16.7-10.5 Ma). The occurrence of middle Miocene red beds may indicate oxic and quiet marine environment in the deep South China Sea. To understand their formation of red-color, local depositional condition, and potential paleoceanographic significance, major elements (XRF), trace and rare earth elements (ICP-MS), Fe chemical speciation (modified sequential iron extraction procedure), and Fe oxic (CBD and DRS) minerals were analyzed.
Our geochemical and mineralogical data indicate that: (1) after treatment using the CBD procedure, the red samples presented a change in color to greenish, showing iron oxides of hematite and goethite being responsible for the sediment color; (2) enriched Mn, depleted U and S, negative Ce anomaly, and decreased Fe3+, and increased V/Cr ratio show that the water mass was pre-oxidized before transported to the study location; (3) low primary productivity was inferred from the lower P, Ba enrichment factors in red beds compared to non-red beds. We conclude that the red beds at Site U1434 developed in oxidized water mass and low primary productivity condition. In the Miocene, the South China Sea was open to the western Pacific, and our study suggests an oxidized deepwater environment in the Pacific during the Miocene.

Tectonic subsidence and along strike stratigraphic differences of the Carboniferous Myall Trough, east Australia

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The late Carboniferous Myall Trough of South Eastern Australia is a 2.5 km thick sedimentary sequence that records an initial deepening of the basin followed by shallowing trend[1]. This sedimentary basin, situated in the most south-eastern part of the New England Fold Belt exhibits synchronous accretionary and non-accretionary transgressive deposits along strike. Within the framework of sequence stratigraphy and shoreline trajectory we use detailed measured sections and facies analysis from outcrop to discuss these observations.

Location A (Booti Booti Beach), is characterized by basal fluvial deposits that deepen to off-shore mudstones within 10m of stratigraphy. Whereas location B (Boomerang Beach) exhibits fluvial deposits overlain by estuary facies that deepen up-sequence to over 90m of lower and upper shoreface deposits. To account for the differences, we suggest a variance in sediment supply along strike caused different styles of transgressive deposits during tectonic subsidence. In Location A, overlying lowstand fluvial deposits, a transgressive lag marks the ravinement surface suggesting non-accretionary transgression. In this setting, shoreface deposits are minor in thickness and, contacts between different depositional environments sharp, indicating rapid base level rise. Sharp contacts are also observed at location B between the fluvial and estuary, and the estuary and shoreface deposits. However, shoreface deposits are thicker and show both coarsening and fining upward cycles and transitional contacts. In location B, accretionary transgression occurs, sedimentary cycles are primarily controlled by sediment supply which produces aggradation and progradation.

This study supports recent modelling that shows differences in sediment supply along strike can significantly alter stratal geometry and sequence boundary development[2]. During relative sea level rise, sediment supply dictates the type and thickness of depositional facies independent of the rate. Where sediment supply matches or outpaces base level rise, accretionary deposits transpire, allowing for deposition of sediments in the upper shoreface environment[3,4]. Where base level rise proceeds without significant sediment supply, erosion in the upper shoreface prevails and results in ravinement and relatively thin lower shoreface deposits[4]. We show that even in actively subsiding tectonic basins sediment supply can be a dominate control producing progradation stratal geometry.

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CHARACTERIZATION OF A SHALLOW-MARINE TRANSGRESSIVE SUCCESSION (LATE MIOCENE, NE GUADIX BASIN, SPAIN)

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Shallow-marine transgressive successions deposited in dominantly high-accommodation settings are considered to develop relatively thin and well-sorted deposits, but are rarely preserved in the stratigraphic record. Although a few examples have been described in subsurface and outcrop studies, existing models of transgressive sand development are still based in classic seismic and sequence stratigraphic principles, and their understanding, particularly in active tectonic settings, is still poorly constrained. In this study, an outcrop example from the late Miocene of northern Guadix Basin (Spain) is presented, with the aim to a) refine the depositional model of a dominantly clastic transgressive succession in a tectonically-active setting; and b) to constrain controls on stratigraphic architecture and facies development, and their response to variable basin morphology. To do this, a >600 m-thick succession has been studied along a >10 km continuous exposure, with detailed mapping, sedimentary logging and physical correlation of stratigraphic units, integrated with biostratigraphic, ichnological and petrological data. The succession shows a marked retrogradational fining-upward character, with several minor order regressive units. The integration of facies and ichnological analysis records the vertical transition from coarse-grained, transitional and deltaic inner shelf deposits, dominated by sand waves, mouth bars and erosive conglomeratic packages, into shallow-marine mid to outer shelf sandstones, dominated by structureless and organic-rich sandstone lobes, deformed hummocky-cross stratified sandstones and bioclastic bars. These deposits are capped by a thick mudstone-dominated succession where benthic foraminifera indicate a neritic-epibathyal paleobathymetric range. The studied unit displays a marked onlap termination against the Mesozoic basement to the E-SE, and expands to the N, as deposits progressively fine and transgressive muddy wedges thicken. Fine-grained petrography indicates a prolonged influence of metamorphic domains of the inner orogen, whereas coarse-grained facies indicate eventual phases of tectonic uplift and erosion of the intra-basinal sedimentary domains.
The documented vertical and lateral facies and thickness changes, together with the provenance anaysis suggest a marked syn-tectonic character of the upper Tortonian in the north of the Guadix Basin. Here, dominantly high accommodation conditions were locally punctuated by several tectonic pulses, which increased sediment supply towards the basin margins, but promoted local subsidence in deeper and more axial basinal positions, thus giving a complex and laterally variable stacking pattern within an overall transgressive period.

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PROTOTYPE BASIN AND RESPONSE OF PALEOGEOGRAPHY TO TECTONISM DURING THE MIDDLE-LATE TRIASSIC PERIOD, ORDOS BASIN, NORTHWEST CHINA

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The Ordos Basin deposited a large set of high quality sandstone reservoir during the Middle-Late Triassic. However, the boundary location of the Palaeo-Ordos Basin and the relationship between paleolake transformation and surrounding tectonic evolution are still vague. Here, by conducting detailed stratigraphic and sequence analyses of 165 boreholes and 57 outcrops in the Ordos Basin and surrounding basins, the boundaries of the paleo-basin were determined while its paleogeographic evolution were reconstructed. The basin is restricted by Dalateqi to Datong on the north, Ningwu - Taiyuan - Yushe - Anyang - Henan - Kaifeng - Dengfeng on the east, Chenhe - Luonan - Nanzhao on the south, Malianggou on the west and western margin fault zone of Helan Mountain on the northwest. The migration of the depocenter and the paleogeographic differentiation in the basin was controlled by the different tectonic evolution history of the Qinling–Dabie Orogenic Belt (QDOB) in the south and the Xingganling–Mongolia Orogenic Belt in the north. Moreover, the study shows that the southwestern margin of the basin is characterized by a similar foreland basin separated from the main cratonic basin by low amounts of uplift and the subsidence of a minor north–south uplift in the western margin during the Late Triassic, which are derived from the western collision of the QDOB. These results are of practical significance for oil and gas exploration and geologic theory about basin–mountain coupling.

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Continuous sedimentation across the end-Permian mass extinction event and the recovery of benthic biota, revealed by two shallow cores from Central Spitsbergen, Svalbard

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The Siberian Traps voluminous igneous activity is considered a likely trigger for the end-Permian global extinction event. However, documented evidence of the Siberian Traps environmental effects decreases away from the center of volcanic activity in north-central Russia. Previous research on the Permian-Triassic boundary (PTB) mostly relies on field observations, and resolution has thus depended on outcrop quality. This study reports on two *ca.* 90 m cored sedimentary successions (DD-1 and DD-2) intersecting the PTB in Central Spitsbergen, Svalbard, providing high-quality material to a comprehensive documentation of this stratigraphic interval. The cored sections are calibrated with outcrop data from near the drill site. The base of both cores records the uppermost 15 m of the Permian Kapp Starostin Formation, which is dominated by completely bioturbated green glauconitic sandstones with chert nodules. The Kapp Starostin Formation is in turn sharply yet gradually overlain by 1 m of thoroughly bioturbated mudstones and 0.5 m of green sandstone, representing the base of the Vikinghøgda Formation. These bioturbated units are conformably overlain by 9 m of ash-bearing laminated black mudstone. A negative shift in the bulk organic carbon isotope curve begins at the formation boundary (*ca.* 88 m DD-1 core depth), and is an important chemostratigraphic tool for the late Permian. The extinction event is here characterized by the disappearance of extensive bioturbation, directly following the isotope excursion. Identified conodonts indicate that the PTB occurs a few meters higher, within the black mudstone interval. Descriptive sedimentology, organic geochemistry and sequence stratigraphic concepts reveal the onset of relative sea level rise at the base of the Vikinghøgda Formation. The disappearance of bioturbation and the abundance of pyrite in the overlying laminated black mudstone of the Vikinghøgda Formation suggest anoxic conditions. Sedimentary content and a positive peak in amorphous organic matter suggest that a maximum flooding surface is recorded 6 m above the base of the Vikinghøgda Formation, within the laminated black mudstone, and indicates that the lower ash layers are tied to igneous activity during relative sea level rise in the earliest Triassic period. The remaining succession above the laminated black mudstone records an overall progradational interval of interbedded clay- and siltstones of the Vikinghøgda Formation, notably characterized by the return of bioturbation.

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ORDOVICIAN IRONSTONE OF THE WESTERN ASTURIAN-LEONESE ZONE, SPAIN: COASTAL UPWELLING, OCEAN ANOXIA AND PALEOZOIC BIODIVERSITY

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Middle to Upper Ordovician ironstone and associated sedimentary rocks of the Western Asturian-Leonese Zone (WALZ), Spain, provide new information regarding the paleoceanography of the Rheic Ocean and the Paleozoic Fe cycle. The Rheic Ocean formed when the peri-Gondwanan terrane Avalonia drifted northward from Gondwana during the Late Cambrian and Early Ordovician. Examination of drill cores and outcrops indicates the southeastern margin of this narrow seaway was a dynamic continental shelf where upwelling of ferruginous seawater and storm currents controlled lithofacies character. Parasequence composition and stacking relationships suggests the accumulation of ironstone occurred between fairweather and storm wave base as accommodation increased from lowstand conditions. Proximal parasequences consist of interbedded hummocky cross-stratified sandstone and organic-rich siltstone that shallows upwards into swaley cross-stratified sandstone and granular Fe-silicate-rich ironstone capped by a flooding surface. Distal parasequences are composed of variably bioturbated organic-rich siltstone with thin Fe-chlorite and phosphorite layers. These lithofacies associations support an emerging model for ironstone deposition where coastal upwelling delivered and stimulated the precipitation of Fe in shelf sediment. This notion provides further evidence for the development of persistent anoxic water masses in an Ordovician ocean that was near the threshold of becoming fully ventilated. New data suggests that minor extinction events punctuating the Great Ordovician Biodiversification Event may be traced to these anoxic waters, which in addition to Fe were also enriched in biologically toxic trace elements. Precipitation of upwelling-related ironstone may have helped sequester these redox sensitive trace elements, providing a negative feedback response to aid post-extinction recovery.

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Sedimentary evolution of Donghetang sandstone in Tarim Basin

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Abstract: The Donghetang Formation in the Tarim Basin is an important exploration stratum. How to understand the basin distribution of the Donghetang sandstone has been in dispute. It has directly constrained the understanding of the Donghetang Formation reservoir and sealing conditions. Through the stratigraphic division single-well and contrast of well-to-well of the Donghetang Formation-the Lower Mudstone Segment of Bachu Formation in the Tarim Basin, and evidence from paleontological conodonts,they are the deposition products of the same period of transgression but in the different phase zones. Clearly based on the above, combined with the results of previous studies, we have fully utilized field data, drilling data, seismic data, and experimental data to study the deposition characteristics durning diachrpnic sedimentary of the Donghetang sandstone in the Tarim Basin. The Donghetang Formation is a set of marine quartz sandstone with relatively high lithology, high compositional maturity and high structural maturity. It has a large thickness and a wide distribution range. Using the principle of sequence stratigraphy, the Donghetang Formation is divided into six sequences, each of which has the continental shelf to onshore sedimentary facies development features from west to east. Shoreline sandstone are vertically superposed and progressively overlap eastward in the SQ1-SQ3 sequence. The continental shelf sedimentation area is located in the west of the BT7 Well; the shoreline sandstone in the SQ4-SQ6 sequence are mainly developed in the east of the He4 Well. In the western part area of the Well He4 is mainly deposited on the continental shelf. The distribution of a single bank sand body is relatively limited, and the six-perimeter shoreline sandstone transgression from west to east and shoreline sandstone are widely distributed in the plane. It is shown that the genetic model of the Donghetang sandstone is characterized by "multi-periods development, vertical overlap, lateral migration, and large-area distribution."

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The provenance characteristics and depositional system of the Carboniferous Benxi Formation in the Ordos Basin, China

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Several favourable exploration areas have been found in Carboniferous Benxi Formation in Ordos Basin，China. However, the provenance orientation and sedimentary system of Benxi Formation have been controversial, which have been researched in detail based on the data of outcrops, drilling, logging, thin sections, heavy mineral analysis and cathodoluminescence analysis. It is found that there’s a bi-directional provenance of north and south in the basin, which is different from the predecessors' view that only the northern provenance exists. There are stable gravel and conglomerate layers in outcrops and drilling sections of the northern and southern margin of the basin, showing that the hydrodynamic force is strong. The stability coefficient of heavy minerals increases from the northern and southern margin to the central of the basin. The cathodoluminescence analysis show the quartz in southern basin is dark brown and mainly metamorphic, while the northern basin is blue, mostly magmatic. Compared with the paleo-continental basement rock on both sides of the basin, the southern provenance is mainly from the Precambrian metamorphic rocks of the northern Qinling Mountains. And the northern provenance is mainly from the uplifted Yinshan archicontinent. 4 types of sedimentary facies that rivers, deltas, shores and tidal flats are identified, and the paleogeographic pattern is determined that river - delta depositional system in northern basin and shore - tidal flat depositional system in southern basin. In the northern basin, the grain size is coarser, and the plate cross bedding, the gravels are more abundant. The auto-cycle in sand bodies, each of which has a scour contact with the lower layer indicates that the fluids are mainly traction current and the stream action is strong. In the southern basin, the grain size is fine, and the bi-directional interlaced bedding are developed. Many dam-shaped and lenticular sand bodies were found, which indicates that the action of wave and tide is stronger. Sub-sea distributary channels, tidal channels and shore bars are main oil and gas reservoirs. The area of river and delta facies are distributed in the northeast of the basin, extending south-west. The tidal flats are mainly located near the edge of the central uplift. Shore bars mainly developed in Hancheng, Puxian etc., and the extension direction is parallel to the coast. The results are of great reference value to search for potential exploration areas and can also be used for reference in the study of other formations or basins with inherited tectonic setting.

Ratio of Strontium and Barium of Selective Extraction and Distinguishing Between Marine and Continental Sedimentary Environments

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Discrimination between marine and continental sedimentary environment is one of the main task of the sedimentology. Currently, it is common and reliable to only use fossils to distinguish. Some scientists use geochemical method to study, but as this method is ineffective, it can not be used independently up till now. Differences of supergene geochemical behavior that Sr and Ba show in the marine and continental sedimentary environment make that the terrigenous clastic sediments is relatively rich in Ba and poor in Sr in continental sedimentary environment and is relatively rich in Sr and poor in Ba in marine sedimentary environment, which generates that the ratio of Sr/Ba of terrigenous clastic sediments increases gradually from continental facies to marine facies. Thus, we can make use ratio of Sr/Ba to evaluate the marine or continental sedimentary environment of terrigenous clastic sediments. However, analysis of continuous extraction, derived from surface sediments of the modern Yangtze delta, has shown that more than 50% of strontium and more than 80% of barium exist in residue state in terrigenous clastic silicate minerals, which has nothing to do with the sedimentary geochemical environment. Strontium, which generated from deposition related to the sedimentary environment, accounts for about 40% of the total strontium while barium that generated from deposition accounts for only less than 10% of the total barium. Meanwhile, only Sr/Ba ratio existing in exchange and carbonate state can reflect the changes of sedimentary environment of marine and continental sedimentary environment; Ratio of sedimentogenic Sr/Ba of sediments from continental sedimentary environment in the surface of modern Yangtze by selective extraction, is less than 1, and that of marine and continental transitional sediments is between 1 ~ 8, while that of marine sediments is bigger than 8; Thus, ratio of sedimentogenic Sr/Ba of selective extraction can distinguish the marine or continental sedimentary environment more accurately and indenpendently.

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Comparison of incised valley estuary and tectonically-controlled estuary in the Brent Delta of the northern North Sea

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Some potentially attractive reservoirs, containing anomalously thick (10s to a few 100 meters), cross-stratified sandstone, have been locally encountered within both the classic regressive (lower Brent) and the transgressive (upper Brent) segments of the Brent Delta. Three documented cases of these sandstone bodies are re-examined. They are internally dominated by simple and/or compound dunes, and typified by two types of deepening-upward successions, recording retrogradational or transgressive shoreline history. Herein, incised valley estuary, occurred in the regressive limbs of Brent Delta, is expressed as a single estuary succession changing from erosive, coarse-grained channelized deposits into outer estuary tidal bars, which are underlain and overlain by deltaic deposits. By contrast, tectonically-controlled estuary, occurred in the transgressive limbs of Brent Delta, is easy to understand and typified by lacking of significant erosively-based rivers and composed by stacked mixed-energy and tide-dominated estuaries, with deltaic base and open marine top, and intermediately separated by deltaic interval. Considering the Middle Jurassic eustatic change and the structural evolution in the northern North Sea basin, we suggest (as did some earlier researchers) that these sandstone bodies were local or broad transgressive estuaries, formed any time during large-scale Brent Delta growth and decay. The estuary generation was likely triggered by fluvial incision coupled with/or active faulting, further producing variable accommodation embayments, where tidal currents became focused and deposition became transgressive at both the regressive and transgressive limbs, presenting in different forms.

Key words: Brent Delta; Estuary; Rift basin

The Cretaceous Sedimentary palaeogeography of the southern East China Sea Shelf Basin

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The southern East China Sea Shelf Basin is a Mesozoic-Cenozoic superimposed petroliferous basin located on the southeastern continental margin of the Eurasian Plate, overlying the Proterozoic and Paleozoic cratonic basement. Major oil discovery has been made in the Cenozoic strata, while there has not been any breakthrough in oil exploration in the Createaceous. One of the most important reasons is that the Cretaceous sedimentary paleogrography has not been systematically studied. In this study, the sedimentary characteristics, provenance, tectonic setting and volcanic activities of Cretaceous strata were studied in detail based on lithology and seismic character, well logging, core and geochemistry. There were medium-coarse-grained sandstones, grayish white siltstones with locally thin black mudstones layers intercalated. The presence of well-developed sedimentary structures, such as wave rippled bedding, foreset laminae, burrows, bidirectional muddy laminae and asymmetric plumose cross-bedding. *Tintinnids* and glauconites are found in the cores of Cretaceous deposits in the study area which were also typical marine indication. Combined the Dickinson diagram, Tucker diagram with the trace elements data, the tectonic setting of Cretaceous in the study area was island arc transition belt. From west to east, the southern Cretaceous East China Sea Shelf Basin and its adjacent area can be divided into eight sedimentary systems: Zhemin continental volcano belt, AAA volcano clastic-alluvial belt, Yandang paleo-uplift belt, WWW volcano clastic-littoral belt, Taipei underwater volcanic belt, slope fan belt, bathyal-turbidite belt and the Diaoyu Islands uplift-fold belt.
Keywords: Southern East China Sea Shelf Basin, Cretaceous, *Tintinnids*, Glauconites, Sedimentary system

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MULTI-POINT STATISTICS INVERSION: THE TEST AND EVALUATION OF A NEW SEISMIC INVERSION APPROACH

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Multipoint statistics, along with seismic data, has long been used as a tool in addressing subsurfaces uncertainties. Multi-point statistics inversion, in particular, is an area of focus in recent years. Despite this, multi-point statistics inversion is still in its early stage, and significant work yet needs to be done to push the technique forward. The current study introduces, test and evaluates a new approach for multi-point statistics inversion. The approach can be divided into 5 steps, including: 1) establish training images, and derive probabilistic distribution functions (PDFs) of seismic attributes for different facies using near-well seismic trace analysis or forward modeling; 2) facies modeling with multipoint statistics (MPS); 3) based on facies modeling results for a particularly cell, randomly select seismic attributes/impedance using the PDFs derived in step 1; 4) generate seismic traces through convolution, best-match to real seismic traces and compare with previously generated traces; 5) repeat steps 2-4 until all the cells are modeled to get the final inversion results. The approach is tested and evaluated using a 2-D synthetic profile, and results shows that inverted facies models and seismic matches the synthetics very well. The approach, thus, potentially could be utilized in real subsurface data to address reservoir geological uncertainties for well positioning and production optimization purposes.

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STRATIGRAPHY AND SEDIMENTARY ENVIRONMENTS BETWEEN THE SOUTH YELLOW SEA COAST, INNER SHELF AND ADJACENT YANGTZE DELTA REGIONS, EASTERN CHINA DURING THE QUATERNARY

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The South Yellow Sea is a semi-enclosed epi-continental sea between China to the west and the Korean Peninsula to the east. Since the late Quaternary, the South Yellow Sea has experienced several eustatic sea-level changes and sediment delivery from the paleo-Yellow River to the north and paleo-Yangtze River to the south. This study aims to: 1) describe radiocarbon and OSL dated sedimentary facies of several cores obtained from the study areas; 2) propose a detailed stratigraphy and depositional history in relation to late Quaternary sea-level changes and source material input.

The cores can be divided into five depositional units designated to U1, U2, U3, U4 and U5 in descending order based on the assemblage of sedimentary facies, major erosional surfaces and core correlation. Unit 5 (not penetrated completely) is mainly composed of fining-upward successions of fine to medium-grained, granule bearing and trough cross-bedded sands, intercalated with clay and silty clay beds. The absence of marine faunal remains and fining-upward sandy successions characterized by trough cross-beddings suggest as part of a fluvial system, probably from a point bar to partly over-bank deposits of a meandering river system. The unit has been constrained as depositional sequences of MIS6 age according to regional core correlation and OSL datings. Unit 4 is composed of olive compacted clay in the lower part and greenish gray silt to fine sand in the upper part. A shallow sea foraminifera species and a coarsing-upward succession indicate a prodelta development and upward to a delta front environment. The unit 4 was dated as old as MIS5 according to OSL datings. Unit 3 is mainly composed of rhythmic-stratified silt and mud in the lower part, followed by laminated sequences and lenticular-bedding mud. Massive mud layers >1cm thickness in the upper part has been recognized as fluid mud deposited in a fluvial-marine transition zone. The unit has been interpreted as a depositional environment from a distal delta front to a proximal delta front. AMS ^{14}Cand OSL ages suggest a deposition during MIS3. The unit 2 is mainly composed of granule-bearing fine to medium sands of a paleo-Yangtze River valley and mud with reddish color mottles and plant root remains. The granule-bearing sand facies has been interpreted as a point bar of a meandering river system. The mud facies is most likely analogous to the speckled facies of paleo-soils, probably deposited during MIS2 under a prolonged subaerial exposure of land surface. The unit 1 is composed of a variable lithofacies mainly composed of rhythmic sand and mud, commonly found in estuary, delta and open coast tidal flat systems, as well as massive and flaser-mud sand in sand ridge formation.

The results show that the South Yellow Sea coast/shelf and Yangtze Delta regions were dominated by delta deposits during the late Pleistocene attributed to abundant material input from rivers. Sea-level changes and sand delivery by rivers play an important role for the development of stratigraphic patterns.

LATE QUATERNARY TRANSGRESSIVE SYSTEMS TRACT ON THE KOREA STRAIT SHELF, SE KOREA

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Analysis of high-resolution seismic profiles and sediment data from the Korea Strait shelf reveals that the late Quaternary deposits in this area consist of five sedimentary units deposited during transgression phases of sea level changes between about 15 and 6 ka BP: ancient beach/shoreface complex (unit P1), estuarine deposits (unit P2), mid-shelf sand sheet (unit M1), sand ridge system (unit M2), and inner-shelf sand sheet (unit M3). They are paralic and marine separated by a ravinement surface. The lower paralic component below the ravinement surface consists of two sedimentary units (P1 and P2) preserved from shoreface erosion. The top surface of the paralic unit is truncated by a sharp erosional surface. This surface is overlain by three sedimentary units (M1, M2, and M3), which were produced by shoreface erosion that shifted landward during transgression.

The transgressive deposits in this area, considering geometries and distribution patterns, can be divided into three types (I, II, and III). Type I overlying the lowstand systems tract is confined to the shelf margin, and consists of a thick paralic unit P1 and a relatively thin marine unit M1. Type II on the mid shelf has no paralic component and the marine units M1 or M2 directly overlies the sequence boundary. Type III, found in the inner shelf, includes a thick paralic (unit P2) and a thin marine (unit M3) component. It is completely covered by the highstand systems tract.

Selective Crystallization and Precipitation of Authigenic Pyrite during Diagenesis in Uranium Reservoir Sandbody in Ordos Basin

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Abstract:

The occurrence characteristics of authigenic pyrite during diagenesis in uranium reservoir sandbody of Zhiluo Formation in Ordos Basin was investigated. Based on outcrop area investigations and drilled cores observations, the pyrite is most closely related to carbonaceous debris. Microscopically, the host components for pyrite consist of organic and inorganic compositions through analyses including optical microscope and scanning electron microscope equipped with energy dispersive spectroscope. The organic compositions are mainly presented as carbonaceous debris, and inorgainc compositions comprise clay minerals, biotite, the earlier pyrite, and ilmenite. Three kinds of distribution pattern of pyrite could be classified as: (i) periphery; (ii) infilling; (iii) the combined form of the above two. In the pyrite formation process, it is necessarily that both dissolved iron monosulfide and the hydrogen sulfide take part in, and with the organic matter participation during reaction process as well. Significant differences in the effect of host components to authigenic pyrite formation were discussed. The hydrogen sulfide could be supplied by carbonaceous debris in the forming process, and the biotite could provide the source of iron for pyrite precipitation. The ferrous ion could be adsorbed on the surface of the clay minerals. While the authigenic pyrite distributed in or around the earlier pyrite and ilmenite by the indirect way of adsorption to ferrous ion, and the ilmenite may also provide the source of iron.

Key words: authigenic pyrite, diagenesis, uranium reservoir, Zhiluo Formation, Ordos Basin.

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RECONSTRUCTION OF AEOLIAN BARCHANOID RIDGE DUNE COMPLEXES FROM MESOPROTEROZOIC GALHO DO MIGUEL FORMATION, DIAMANTINA, SE BRAZIL

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Recognition of aeolian deposits from Precambrian sedimentary successions is important for understanding the earth surface processes before the advent of land vegetation. Such recognition is important to test the prevalent theories on the abundance or absence of aeolian deposits reported from the pre-Silurian stratigraphic record. However, the antiquity of these sedimentary successions, and the metamorphism and tectonic deformation of these units, makes this task difficult. The Mesoproterozoic Galho de Miguel Formation is a metaquartzite that crops out extensively in south-eastern Brazil. Although grain-scale recrystallization is quite intense destroying the primary textural attributes, the mesoscopic features including delicate adhesion structures, thin pinstripe layers, salt-related deformational features and alternation of huge cross strata with flat bedded units, allow recognition of the aeolian origin of the deposits. The major facies associations include (a) up to 15 m thick cosets of trough and planar cross-beds representing dune complexes alternating with (b) 0.3 -1.7 m thick flat-bedded strata with pin-stripe laminae, adhesion structures, wave-rippled pavements, irregular layers inferred to be salt-related deformational features identified as interdunes, and (c) > 9 m thick isolated units of flat-bedded strata with abundant features of salt-crust layers forming in sabkhas. No evidence of sub-aerial channel flow or a wave-dominated shallow marine regime could be recognized. In the sections sub-parallel to wind flow, dune cross-beds reveal a complex organization with scalloped bases truncating the underlying sets and laterally developing into compound sets. In flow-transverse sections cross-strata display stacked large trough-shaped sets. The largest of the cross-beds are solitary planar sets often with trough cross-strata eroding into its top. Compound cross-sets and reactivation surface are common, revealing the superimposition of smaller sets over larger dune bedforms. The complex architecture of the trough and planar dune cross-beds are inferred to represent large asymmetric barchanoid ridge dunes. These barchanoid ridges had laterally linked curve-crested segments as well as straight crested segments. The dominant sand transport direction was tightly clustered between NE to E.

Development of large aeolian bedforms indicates adequate sand supply. The repeated alternation of thinner interdune flat-bedded strata with thicker compound cross-strata indicates smaller length of interdunes within larger dune complexes in an erg where water table was rising slowly. Presence of a 9 m thick succession of flat-bedded strata with abundant salt-related deformation, indicate a period of long-term cessation of dune building activity in the erg. The bedforms and architecture of the dune-interdune deposits do not suggest any significant departure in the Mesoproterozic erg building processes as compared to that of the present-day dune fields.

Acknowledgements

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SEDIMENTOLOGY AND STRATIGRAPHY OF THE MURRAY FORMATION, GALE CRATER, MARS: LAKE-BASIN DEPOSITION ON A VEGETATION-FREE LANDSCAPE

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Gale crater is located astride the dichotomy boundary on Mars. Sedimentary rocks filling the crater were deposited, buried, lithified, exhumed, and eroded before 3.3-3.1 Ga and form a 5 km high mountain (Aeolis Mons). Sedimentary rocks record depositional environments on a vegetation-free landscape, similar in many ways to deposition on early Earth. The lower slopes of Aeolis Mons comprise a diverse rock package dominated by mudstones, termed the Murray formation, which is > 300 m thick, and is interpreted to interfinger with the fluvio-deltaic strata of the Bradbury group. The Murray formation (> 300 m thick) is presently divided into seven members (representing three major facies associations) in ascending order: Pahrump Hills, Hartmann's Valley, Karasburg, Sutton Island, Blunts Point, Pettegrove Point, and Jura. Contact relationships between members are difficult to ascertain, but mostly considered to be conformable. As previously documented, contacts with the Bradbury group are considered transitional. Facies 1 is typified by thinly laminated mudstones (Pahrump Hills, Karasburg, Blunts Point, Pettegrove Point members). Persistent fine lamination, coupled with an absence of desiccation, suggests deposition from suspension in a lake with a generally stable level. Facies 2 forms an ~25 m thick interval exhibiting dm- to m-scale cross-bedding, consistent with curved-crested dune bedforms resulting from bedload transport. While the fine grain size points to an aeolian setting, such structures are also produced in fluvial settings. This facies is best observed in the Hartmann's Valley and possibly Pettegrove Point members. Facies 3 comprises a package of heterolithic mudstone and sandstone. Identifiable in Mastcam and MAHLI images are maroon-colored, finely laminated mudstone, cm-scale ripple cross-laminated sandstone, and dm-scale cross-stratified sandstone. Concretions occur commonly and obscure primary lamination where abundant. Facies 3 also shows distinctive, small-scale polygonal fractures that resemble desiccation cracks. Their presence, with locally developed possibly contemporaneous gypsum precipitates, suggests deposition in lake and lake-margin environments dominated by suspension fallout with less common traction deposition. This facies is best exemplified by the Sutton Island member. The broad facies arrangement of the Murray formation and Bradbury group is consistent with progradation of fluvial deposits from the crater margin to a lake setting that occupied part of the crater interior. Overall, the facies types and architecture are consistent with a lake basin that has abundant fluvial input and relatively stable lake levels, where water and sediment load generally exceeded overall evaporation, similar to overfilled lake basins recognized on Earth.

The characteristics and distribution of the gravel from modern fan and fluvial of Yanqi Basin in Xinjiang, China

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The Yanqi Basin, located in the south of Tianshan mountain in Xinjiang province of China, is 170 km long, and the width is 80 km, with a area of 13,000 square kilometers. Various types of sedimentary bodies including the rivers, alluvial fans, fan deltas, lake, and lake beach aeolian sand dunes developed in Yanqi Basin. The sediment provenance is from the Tianshan mountain.

Huangshuigou alluvial fan and Malan-Golden Beach fan delta developed in the northern of Boston lake in Yanqi Basin. The lithology of gravel in Huangshuigou alluvial fan is migmatite gravel . Other gravel components include fine sandstone, vein quartz, granite and tuff gravel. The average diameter of boulder is 20.63 cm in fan-root, then reduce to 6.35cm in fan-middle, and the average diameter of gravel reduce to 4.84cm in fan-middle and fan-terminal. From fan-root to fan-terminal, gravels transported more than 20 km. And the gradient is 0.01016 to 0.01036. The distance from Malan-Golden Beach fan-root to the Boston lake coast is *ca* 30 km. The lithology of gravel of fan delta plain are migmatite and marble. Other gravel components are vein quartz, granite, sandstone, and tuff gravel. The average diameter of gravels in the middle of fan delta plain is about 9.89cm. In the Boston lake coast, there is dominated by sandy sediments and gravel is not developed . The gradient is 0.04311 to 0.00084.

The Kaidu river is the most important river in the Yanqi basin. From Chahanwusu hydropower station to the mouth of Boston lake, 4 river types occurred in whole Kaidu river, the mountain river, braided river, meandering river and straight river. Modern boulder and gravel are mainly observed in mountain river, and the gravel mainly developed in braided river and meandering river. The lithology of main gravel is siltstone gravel in the Kaidu river. Tuff, granite, migmatitic granite and migmatite gravel are the other gravel components. The average diameter of boulder is 60.62 cm in the mountain river, then reduce to 8.02 cm in braided river, and reduce to 1.02 cm in meandering river. From Chahanwusu hydropower station, after transferring more than 100km, the gravel converted into sandy gravel and began to deposit extensively. The gradient from the mountain river to the meandering river is 0.00686 to 0.00034.

The analysis shows that a lot of gravels are distributed in the northern of Yanqi basin. In alluvial fan and fan delta gravels transported *ca* 30 km. And the average diameter of gravels reduced *ca* 70%. In Kaidu river, gravels transported more than 100km and the average diameter of gravels declined more than 90%. The decline of gravel diameter is controlled by deposition gradient and water velocity.

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ARCHEAN FLUVIAL DEPOSITS

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The recognition of Archean fluvial deposits is complicated in many cases by post depositional deformation and metamorphism. Most surviving deposits can be categorized as deposits of alluvial fans, with and without debris flows, and sand and gravel bed braided river deposits. Examples of possible intermediate to high sinuosity meandering systems have been tentatively identified in Australia and India: both lack clear evidence of lateral migration and can be reinterpreted in terms of shallow tide-influenced marine and deep-water mass flow deposits respectively. Mudstone intervals in Archean fluvial strata are exceptionally rare, and where present are mostly of silt grade. These may represent ponds developed with channel thalwegs or where more extensive may be of lacustrine, rather than floodplain origin. Prior to 3.2 Ga preserved fluvial deposits appear to be confined to the flanks of volcanic cones or plateau, perhaps reflecting globally high sea-levels combined with the small scale of cratonic nuclei. The onset of modern style plate tectonics in the early Mesoarchean allowed for more extensive generation and preservation of fluvial strata. Most of these are first cycle deposits that were preserved in rift and foreland basins, with rare examples accumulating in syn-tectonic piggy-back basins.

THE SEDIMENTARY CHARACTER OF PRE-VEGETATION ALLUVIUM

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Pre-vegetation alluvium – the rock deposited by rivers during the first 90% of Earth history – has fundamentally distinct sedimentary signatures to younger, syn-vegetation alluvium. This has been explained because plants affect multiple aspects of modern river functioning.

Here we re-iterate and define, supported with new field and database evidence, that there are three first-order distinctions of pre-vegetation alluvium: 1) there is a global paucity of mudrock in pre-vegetation alluvium; 2) there is a dominance of 'sheet-braided' architectures (stratal components with aspect ratios exceeding 20:1) in pre-vegetation alluvium; and 3) there are almost no examples of 'classic meandering river facies' in pre-vegetation alluvium.

Whilst some traditional assumptions regarding pre-vegetation rivers have recently been challenged, any discussion of the effects of the evolution of the earliest land plants on Earth's ancient landscapes (i.e., *rivers*) must not overlook the fact that pre-vegetation alluvial strata (i.e., *rocks*) are effectively unique. As these deposits are representations of physical laws of fluvial fluid-sediment interaction that have not changed since the formation of Earth, it appears most likely that it is the theatre in which these physical processes operated which changed: apparently irrevocably, and coevally with the greening of the continents. The rock product of extinct pre-vegetation rivers can be used to inform interpretations of the 'abiotic skeleton' that underpins river behaviour, and help to understand the rock record of other, presumably unvegetated, rocky planets such as Mars.

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FLUVIAL ARCHITECTURE OF THE CAMBRIAN MIDDLE MEMBER WOOD CANYON FORMATION BRAIDPLAIN, MARBLE MOUNTAINS, CA, USA

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Detailed mapping of an outcrop of Cambrian middle member Wood Canyon Formation (mmWCF) in the Marble Mountains, CA, reveals the architecture of a shallow, perennial, sandy, braidplain upon the non-vegetated Laurentian craton. Stratigraphic panels at different scales and ~1000 orientation measurements on bounding surfaces detail the internal and external geometry of braidplain sediments. Three facies occur in the mmWCF. Facies 1 (F1) contains trough and minor tabular cross-stratified coarse sandstone separated by thin gravel lags, tan siltstone, and numerous horizons of single-clast-thick desiccation chips. Meter-scale stratigraphic panels indicate that abundant sandy bedforms (SB) accreted to build the barforms that are preserved to ~50 cm thickness in the mmWCF. Barforms accreted near-vertically in a majority of examples, with downstream accretion (DA) and possible upstream accretion (UA) elements bounded by steeply dipping (15-20°) 3rd order surfaces near bar margins. F1, with the coarsest grain size and stacked barforms, is proximal to the main channel belt. Facies 2 (F2) is less abundant, trough cross-stratified medium sandstone that is orange-to-rust-coloured. Thinly bedded sets of cross-stratification and crumbly texture form low relief in outcrop. F2 may represent lowest-energy overflow settings in the fluvial system. Facies 3 (F3) occurs in ~3-meter thick beds within the stratigraphy, preserving scoured large-scale troughs with high-angle cut-offs composed of subangular, medium sandstone that lacks extensive desiccation chip surfaces. F3 is interpreted as a lower energy setting characterized by extensive sand sheet (SH) elements. Contacts between each facies are sharp, especially at the base of F1, suggesting avulsion of the main channel belt. Three units (M1, M2, M3), determined by the abundance and spacing of facies, divide the mmWCF. Paleocurrent measurements on 0th order surfaces in each unit show northwest paleoflow. M1 and M3 are composed entirely of Facies 1, whereas M2 preserves facies variation that begins with the occurrence of F3. Within M2, cyclicity occurs between F1 and F2-3. Laterally, F2 and F3 are observed to interfinger, providing evidence that they represent closely related subenvironments. Multiple facies provide the differentiating material to observe channel (CH) bases. These 5th order bounding surfaces below F1 are near depositionally flat, but local scours present as steeply dipping surfaces. CH margins are not directly visible, and are assumed have width-to-depth ratios exceeding 500:1. Much of the mmWCF was deposited by broad channels filled with submerged sandy barforms that incised the braidplain and carried the coarsest sediments (F1). DA elements developed via incremental bar growth, indicative of systems experiencing perennial flow. Abundant desiccation chip layers and mud intraclasts suggest frequent channel avulsions and reactivations. Flanking the main channels were extensive sheets of SB made up of finer-grained sediments that experienced weaker or even ephemeral flow (F2-3). The progression from F1 dominated stratigraphy in M1, to multiple overbank facies preserved in M2, and the absence of overbank facies in M3 is likely accommodation controlled. Higher accommodation space during the deposition of M2 allowed for the preservation of finer overbank subenvironments.

Evidence of alluvial fan, axial fluvial and lacustrine interplay from late Cambrian-Early Ordovician rift system of western and northern Tasmania, Australia

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The coarse-grained conglomerates and sandstones of the late Cambrian Owen Group dominate western and northern Tasmania, where they are divided into four informal formations that have been correlated on a lithological basis. These formations vary from the high-energy fluvial conglomerates of the Lower Owen Conglomerate, to the proximal sandy turbidite facies (Newton Creek Sandstone) of the Middle Owen Sandstone and to the reworked shallow marine sandstones of the Upper Owen Sandstone. Despite this nomenclature being adopted by the regional map series and previous studies, recent fieldwork has indicated distinct variations in stratigraphy around the state, suggesting that the Owen Group is strongly heterogeneous vertically and restricted in lateral extent. Modern rifts systems such as the East African Rift and Baikal Rift Zone highlight the various changes in depositional environment and the resultant stratigraphy that can occur along the length of an entire rift system. Fieldwork in the Mt Osmund-D'Aguilar Range area in southwest Tasmania has indicated that large successions of lacustrine sediments, totaling 150 m, were deposited during the initial stages of rifting. Large mudstone successions (>20 m thick) are rare in late Cambrian sedimentary record of Tasmania, hinting at a unique depositional environment in the southwest. Fieldwork has led to the delineation of seven depositional cycles within the Owen Group, with a prominent and complex interplay between alluvial fan and lake development during the early stages of rifting. Changes in base level and the development of alluvial fans and piedmonts have led to intense lateral variations in stratigraphy. Subsequent stacking of alluvial fan and lacustrine facies also greatly increased the vertical heterogeneity of the stratigraphy. Decreased accommodation eventually led to the development of a widespread, high-energy, braided river system running along the axis of the rift. A second period of alluvial fan development forced the braided river system westwards, with the progradation of fans leading to a coarsening-upwards trend in grainsize from fine sandstone to pebble and cobble conglomerate. Continued subsidence in the final stages of rifting led to the ingress of seawater and the development of tidal flats and widespread shallow marine environments. The general stratigraphic succession in this area has always been considered to be predominantly marine in origin, as with similar aged sediments across Tasmania. However, the fluvio-lacustrine origins of these sediments indicate that the unifying stratigraphy used across Tasmania for late Cambrian-Early Ordovician sediments is incomplete or incorrect.

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LATE PALEOPROTEROZOIC TERRESTRIAL SANDSTONE DEPOSITS ON THE CANADIAN SHIELD: PRODUCT OF NUNA SUPERCONTINENT ASSEMBLY

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Fraser et al. (1970) proposed that several large and now geographically separated sedimentary basins preserve remnants of a formerly contiguous blanket of sand that was deposited unconformably across the Canadian Shield ca. 1.8-1.6 Ga. Subsequent provenance and coupled sedimentological studies suggest that the blanket was deposited by a vast river system that drained northwestward from the Trans-Hudson orogen, which formed during the assembly of the supercontinent Nuna ca. 1.9-1.8 Ga (Rainbird and Davis, 2007). Subsequent uplift and erosion isolated the deposits, currently preserved within the Athabasca, Thelon, Hornby Bay and Elu basins, which are interpreted to represent intracontinental sags that formed in response to the thermal insulating effects of the supercontinent. Similarities of these basins include their great size, thickness and dish-like geometry. Each is composed of a lower succession of relatively immature alluvial fan and gravel-bed-dominated braided stream deposits that are confined to rifts. Above are more widely distributed and mature, cross-bedded sandstones that define west- to northwesterly flowing, mainly braided river deposits. The fluvial strata are intercalated with large-scale cross-bedded, medium-grained quartz arenite interpreted as eolian deposits. In all basins, the terrestrial sandstones pass upward through marginal marine, mixed siliciclastic and carbonate strata into stromatololitic platformal carbonate rocks indicating marine transgression across Laurentia ca. 1.6 Ga. The presence of correlative silicified regolith at unconformities beneath the basins and on basement rocks between basins is further evidence of their former continuity. Provenance studies employing detrital zircon analysis reveal a source region composed of a broad variety of protolith ages but with a dominant component of 1.9-1.8 Ga crust. This age is characteristic of the Trans-Hudson orogen, which strikes northeasterly from the US Midcontinent to central Greenland and is interpreted to represent the remnants of a collisional mountain chain from which the late Paleoproterozoic river deposits were sourced. Remnants of the distal reaches of the river system have been recognized in correlative deposits exposed in the Canadian Cordillera (e.g. Muskwa assemblage; Ross et al., 2001). The late Paleoproterozoic sandstone blanket is analogous to similar deposits interpreted to have formed in response to uplift and erosion of the Grenville orogen following amalgamation of supercontinent Rodinia in the late Mesoproterozoic (Rainbird et al., 2012).

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SHEETFLOOD FORMATIONS IN THE MIDDLE PROTEROZOIC BELT SUPERGROUP, NORTHWESTERN MONTANA, USA

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Sheetfloods in the Revett and Bonner formations of the Belt Supergroup were deposited on vast sand plains in the Belt basin from ~1,460 Ma to ~ 1,400 Ma. The block fault Belt basin formed within the Nuna Supercontinent and was internally drained, with sediment sources from the west, south, and east, and with a shore zone on the north (present coordinates). Episodic floods crossing the plains filled playa lakes that established base level. As sediments filled the lakes, base level rose, and with it, base level of the surrounding plains. The floods are inferred to have flowed at grade, and therefore incapable of incising below base level. Consequently, they spread as sheetflows. Lack of incision promoted the preservation of event layers and they are categorized into sediment types, based on layer thicknesses, grain size, and vertical succession of sedimentary structures, that together generally reflect decelerating flow velocities.

Tabular, fine-grained sand beds up to a meter thick characterize the Revett Formation. Bed bases rest on tops of beds below them or slightly cut them. Main bodies of the beds are flat-laminated sand recording upper regime flow. Where flow was deep enough, trough crossbeds locally cut the flat laminated recording shifts to dunes in the upper part of the lower flow regime. As floods shallowed, flow returned to the upper regime and the dune crests were planed flat. Climbing ripples high in the tabular beds record shifts to the lower part of the lower flow regime as flow decelerated. Above these are layers of mud drape that are cut by desiccation cracks as the floods waned and sediments dried. Proximal flat-laminated sand and trough crossbeds thin distally to thin flat-laminated very fine sand beds and tabular silt beds. Antidunes also occur in the middle Revett and range from meter to centimeter scale and from well-sorted sand to muddy sand.

The lower Revett forms a lithosome that interfingers eastward into the Grinnell Formation, characterized by centimeter scale, graded silt-to-mud layers of distal mud flats and mudcracked silt-to-clay couplets of playa lakes. The lithosome has eight lithostromes, with cycles 5-15 m thick. Lithostromes 1, 3, 5, and 7 have playa lake couplets at their bases. Above these are antidunes that are overlain by flat-laminated sand beds at the tops of the cycles. The cycles record abrupt transgressions of playa lakes across sand plains, followed by eastward regression. Lithostromes 4 and 8 are composed of flat-laminated sand beds.

The Bonner Formation is coarse-grained sand and has tabular trough crossbeds capped by mud.

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General theme 3

Paleo-environments and Paleo-climates

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PALEOGEOGRAPHIC RECONSTRUCTION OF LIBYAN LATE ORDOVICIAN GLACIAL ENVIRONMENTS USING SEISMIC SPECTRAL DECOMPOSITION, SEISMIC GEOMORPHOLOGY AND SEDIMENTOLOGICAL CORE DATA ON 3D SEISMIC DATA

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The study of ancient glacial sediments[1,2] is of significant importance for several reasons, as hydrocarbon plays in several parts of the world (most notably North Africa, Latin America, the Middle East, etc.), aquifers and as analogues for depositional models to improve the understanding of the processes underneath present-day ice sheets. Exploration and production activities have provided a good data set for research aimed at improving our understanding of these depositional environments.

This paper focuses on methodologies for improving definition of intra-glacial reservoir depositional architectures using 3D seismic data from the study area (30 x 60km^2 aprox.) within the Murzuq Basin in North Africa together with well logs, resistivity images and detail core descriptions from several wells.

The workflow starts with the analysis of the 3D seismic dataset in order to understand the frequency content and extract the optimum frequency bands after applying the Spectral Decomposition[3] in order recombine these frequencies in an R (red) G (green) B (blue) [4]volume. This volume will then be treated as an image in which geological features can be distinguished and compared to modern glacial analogues (from Google Earth). Mapping at different depths (time slices) of this features will then be tied to specific depositional environments following the facies scheme created and used in the sedimentological interpretation of core and resistivity image data where wells are available. To finish, this depositional environments were then extrapolated into areas with less or no data using the Spectral Decomp as framework, always taking into account the significant difference in vertical resolution between the seismic data set and core-scale descriptions.

The end product of this study is a set calibrated to well data maps, at different depths, showing a paleo geographical reconstruction of the Hirnantian glacial depositional environments in this area and the evolution through time (at different depths/time slices 2D+1) of these glacial settings.

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LATE QUATERNARY SEDIMENT DYNAMICS IN THE GULF OF SAN JORGE (PATAGONIA): A MULTI-PROXY APPROACH

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The Patagonian coast of the Argentine Continental Shelf (ACS) extends along a relatively stable continental margin at the intersection of the present Antarctic ice sheet and the relic of the former Patagonian ice sheet. Since the Last Glacial Maximum (LGM), the sedimentation on the Atlantic shore of Patagonia has changed significantly due to the marine transgression at first, but also because of the decrease of glacial meltwater flows to the Atlantic derived from the Northern Patagonian Ice Field (NPIF) [1]. The Patagonian shore of the ACS thus provides a preferential area to study the impact of post-LGM sea-level fluctuations and ice extent variations on sedimentary processes. In this context, we investigate Late Quaternary marine sediments from the Gulf of San Jorge (GSJ) to characterize the sedimentation in the central part of the Argentine Patagonian margin since the LGM. The GSJ is a semicircular basin forming an encroachment of the South Atlantic Ocean between latitudes 45°and 47° S, in which the sedimentation is presently controlled by oceanic and aeolian inputs, and inner Gulf erosion/runoffs [2]. The post-glacial evolution of the sedimentary environments as well as the climatic and oceanographic variations were reconstructed using paleomagnetic parameters, major and trace elements, bulk and clay mineralogy, multi-sensor core logging and radiocarbon dating, coupled with the interpretation of seismic lines. The ~2000 km of geophysical data (subbottom profiler and sparker) and the 15 sediment cores (gravity and piston cores) used in this study were collected on board the R/V Coriolis II during the MARGES (Marine Geology of the Gulf of San Jorge) expedition in the GSJ and continental shelf in 2014. The base of the lithostratigraphy identified in the Gulf is characterized by a decametric-thick highly-indurated sediment layer corresponding to a high amplitude and laterally continuous seismic reflection extending through the entire GSJ. This facies most likely reflects both the sea-level lowstand and absence of seawater in this part of the GSJ during the LGM. Furthermore, our results illustrate two main sedimentary sequences: a Late glacial sequence with relatively high sedimentation rates (>65 cm/kyr) and an Early Holocene to present sequence with lower sedimentation rates (<25 cm/kyr). The former is associated with the marine transgression (e.g., tidal flat environment) coupled with the influence of the NPIF drainage system prior to 13 700 cal yr BP. The latter corresponds to the end of the marine transgression with a progressive decrease of energy to reach contemporary conditions between 10 250 and 7400 cal yr BP.

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CHRONOSTRATIGRAPHY AND EVOLUTION OF SEDIMENTARY PROCESSES ON THE DEGLACIATED MARGINS OF EASTERN CANADA DURING THE HOLOCENE

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Ice sheet retreat following the Last Glacial Maximum triggered important sediment transport and delivery on the formerly glaciated continental margins of NE North America. This involved several sedimentary processes that are crucial to understand in order to better reconstruct past ice-sheet dynamics and identify the associated climatic and environmental forcings. However, the influence of some of these processes on the shelf sedimentation is poorly constrained, such as paraglacial processes that deliver sediment on the continental shelf while the ice-margin is located on land. By combining acoustic sub-bottom profiles and sediment core data, this project aims to study Holocene chronostratigraphy and sedimentology of the Eastern Canadian margins in order to better understand the evolution of sedimentary processes during the retreat and complete ablation of the Québec-Labrador Sector of the Laurentide Ice Sheet.
During the R/V Maria S. Merian research cruise MSM46 in the summer of 2015, several gravitycores were collected in Hudson Strait, Lake Melville, Honguedo Strait and the Lower St-Lawrence Estuary where basins and troughs contain several meters of glaciomarine, paraglacial and postglacial sediments. Sub-bottom profiles (Parasound) were also obtained in these areas. Magnetic susceptibility profiles combined with preliminary radiocarbon age-models allow identifying the establishment of postglacial conditions. Postglacial sediments are finer and more homogeneous compared to the underlying units of glaciomarine and paraglacial sediments that also contain high quantities of ice-rafted debris. Additional AMS ^{14}C measurements combined with paleomagnetic data and sub-bottom profiles will provide chronostratigraphies of the different areas in order to identify different sedimentary units and study the evolution of sedimentation rates. Sediment physical, chemical, mineralogical and magnetic properties will be analyzed in order to understand the evolution of sedimentation processes and differentiate glaciomarine and paraglacial influences. This project will also complement upcoming micropaleontological studies to reconstruct Late Holocene environmental variations in the areas.

CENOZOIC PALAEOENVIRONMENTAL HISTORY OF THE ANTARCTIC CONTINENTAL MARGIN REVEALED BY THE STRATIGRAPHY OF THE VICTORIA LAND BASIN

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The Victoria Land Basin (VLB) forms part of the failed West Antarctic Rift, and preserves a Cenozoic succession up to 4 km thick that records the onset of Cenozoic glaciation, and the history of Antarctic glaciation over the past 34 m.y. This succession is relevant both to investigations of modern climate change, and to studies of long-term (palaeo)environmental change in general. This presentation provides a sedimentological and stratigraphic review of the VLB succession, based on analysis of several continuous drillcores acquired over the past 40+ years, and supported by seismic stratigraphic analysis of a large array of seismic reflection data. An array of fifteen lithofacies is recognized within the VLB Cenozoic succession, ranging from fossiliferous and diversely bioturbated mudrocks and diatomites, texturally mature sandstones and conglomerates, through mixed mud- and sandstones with dispersed gravel with restricted bioturbation, to diamictites and associated lithologies. These facies record a variety of marine, glaciomarine, proglacial and at times (sub)glacial environments. Locally, volcanic and volcaniclastic deposits are interbedded in the succession. Lithofacies are arranged in repetitive vertical stacking patterns (depositional sequences) that record glacial advance-retreat cycles with attendant relative sea-level changes. Seven varieties of depositional sequences (stratigraphic motifs) are recognized within the succession as a whole, and interpreted to record a spectrum from cold, polar glaciated environments such as that of today (Motifs 1-2), through varying degrees of glacial influence with abundant meltwater contributions (Motifs 3-6), to settings unaffected by glacial ice (Motif 7). Overall, there is a gradual trend upward through the succession from Motif 7 at the base towards Motif 1 at the top, but the trend is not monotonic. A significant conclusion of this work is that a record of dynamic climate and glacial conditions is preserved through the entire 34 m.y. period of the Cenozoic icehouse, at least in the VLB.

Intervals characterized by consistent stratigraphic style (motifs) are recognised throughout the VLB succession. These intervals are of 1-6 m.y. duration, each containing numerous depositional sequences. They are 1-2 orders of magnitude longer than glacial-interglacial cycles, and record periods of relatively consistent climatic and paleoenvironmental variations They are considered to reflect convolutions of orbital parameters that remained stable for periods of 10^6 a, and then switched to alternative configurations. Such intervals are directly analogous to 1-8 m.y. intervals characterized by glaciogenic strata that are preserved within the Late Palaeozoic of eastern Australia among other areas, and may be a recurring stratigraphic response to icehouse climate regimes through geological time.

Late Visean-Serpukhovian cyclic sequences in Southern China, recording the onset of the Late Paleozoic Ice Age

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The late Paleozoic Ice Age (LPIA), spanning from late Mississippian (late Visean) to middle Permian, is one of the most prominent glacial events identified as a series of shorter, discrete glacial events separated by warmer periods (1, 2). The beginning of the LPIA was characterized by localized events with small ice depocenters in South America and a series of cyclic shallow-water limestones in the late Visean to Serpukhovian (2). In late Mississippian, the South China Block was located in tropic, which was free of glacial deposits. The upper Du'an Formation, deposited during this time interval, features the oncolithic packstone, algal boundstone and peloidal grainstone. Four cycles of shallow subtidal and peritidal beds have been recognized in upper Du'an Formation in Long'an County, Guangxi Province. A distinct regression event in the latest Visean has been identified, as demonstrated by the occurrence of siliciclastic and coal-bearing strata, limestone solution breccia and reflux dolostone and peritidal deposits in the uppermost Visean in South China (3).

A series of shallow-water limestones showing a pronounced cyclicity characterized by the alternation of mainly subtidal carbonates and subaerial exposure surfaces also developed in British Islands in Late Visean (4). Four to six short shallowing-upward T-R cycles are reported in Dnieper Donets Basin (Russia) during the Late Visean-Serpukhovian (5). This widespread cyclicity occurring in several settings in Western Europe and North America, is most likely the results of (glacio-)eustatic sea-level fluctuations, possibly with local influences of tectonics movements. This pattern is interpreted to represent the expression of the onset of LPIA in low-latitudinal successions.

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Lithofacies of shallow-water deposits in upper Visean-Serpukhovian, Southern China

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A complete section exposing Carboniferous shallow-water deposits in Long'an County, Guangxi Province in South China, provides an ideal site to study the Upper Visean and Serpukhovian. The shallow-water succession consists of cyclic alternation of subtidal and peritidal facies, which belongs to upper Visean-Serpukhovian based on foraminifera biostratigraphy (1). Fifteen lithofacies types have been distinguished and grouped into lithofacies associations A (LF-A), B (LF-B) and C (LF-C).

Mid-ramp or foreslope facies (LF-A) comprises the lowest part of the section, consisting of bio-lithoclastic packstone and bioclastic packstone, which suggest a subtidal depositional environment with a relatively deeper part at the earliest depositional stage. As the water shallows, lithofacies association B formed. LF-B is composed of oncolithic packstone, aggregate-grain grainstone and coated bioclastic grainstone. This facies association is common in platform interior environments (e.g. sand shoals, restricted environment) with shallow water conditions (2). The peritidal facies (LF-C) mainly consists of supratidal, intertidal and shallow-subtidal deposits, forming a distinct level in this succession. Ten lithofacies types are recognized in association C: thrombolite-like limestone, fenestral packstone, peloid packstone and grainstone, ooid-intraclast grainstone, peloid-intraclast grainstone, laminated peloid packstone, pisoid dolopackstone, pisoid-peloid dolopackstone, densely laminated bindstone and peloid-ooid grainstone.

Four cycles consisting of LF-B and LF-C have been recognized. Cycles are interpreted to result from high-frequency sea-level fluctuations, most likely eustatic in origin. This succession therefore is thought to record Late Visean-Serpukhovian glacio-eustatic sea-level changes characteristic of the late Paleozoic ice age.

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Facies analysis of the Cryogenian Fulu Formation, South China: implication for the waning stage of the Sturtian glaciation

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There are two Neoproterozoic global glaciations, the Sturtian and Marinoan in chronological order. In the South China Block (SCB), the younger Marinoan glaciation is represented by the Nantuo Formation that is distributed throughout the whole SCB. In contrast, the Sturtian glacial deposits are restricted in deep basinal environment and are represented by the Changan and Fulu formations. The Changan Formation is dominated by massive diamictite, whereas the Fulu Formation is mainly composed of sandstones. Although it is proposed that the Fulu Formation may be the deposits of the waning stage of the Sturtian glaciation, little is known about the sedimentary history of the Fulu sandstones. In order to address this issue, we carried out detailed facies analysis of the Fulu Formation in the SCB.

The Fulu Formation can be divided into five lithological members (Member I to Member V). Member I is characterized by ferruginous silty mudstone with regional occurrences of banded iron formation. Member II is predominantly gravelly sandstone. Member III consists of stratified sandstone and laminated siltstone. Member IV is dominated by massive diamictite and pebbly sandstone. Member V is a suit of laminated siltstone with rare occurrences of carbonate interbeds in the lower parts. According to systematic sedimentological analysis of the Fulu Formation, 3 facies associations were recognized: the proximal glaciomarine, distal glaciomarine, and non-glacial marine facies associations. The Fulu Formation displays pronounced variations in facies association vertically. From the ferruginous silty mudstone unit at the base of the Fulu Formation to the diamictite unit in the Member IV, a sequence of deglaciation–distal glaciomarine–non-glaciomarine–proximal glaciomarine sedimentation can be recognized. And the siltstone unit in the top of Fulu Formation represents the interglacial deposits.

Our study suggests that the deposition of Fulu Formation is strongly influenced by ice sheets. We also speculate that ice sheets during the waning stage of the Sturtian glaciation may be dynamic.

NEW INSIGHTS INTO ANCIENT ICE SHEETS: THE LUOQUAN GLACIATION (EDIACARAN-CAMBRIAN) OF NORTH CHINA

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The Luoquan Formation represents the record of Ediacaran-Cambrian glaciation in the North China Craton. The sedimentary record is well expressed in the Henan Province along the central China orogen, and includes a rich archive of striated pavements, diamictites, and dropstone-bearing laminites. Reappraising the sedimentological evolution of the Luoquan Formation we note the following. First, striated pavements with crosscutting striations do not necessarily record multiple phases of glacial (re)advance, but more likely originate through the development of sticky spots in a palaeo-ice stream setting. The development of obstacles, basal adfreezing, or porosity variations in the subglacial substrate resulted in curvilinear and bifurcating striae, which can superficially be mistaken for crosscutting striae in isolated sections. Second, "massive" diamictites as previously described are in fact commonly weakly stratified, and there is a continuum from dropstone-bearing rhythmically bedded shales and siltstones, through stratified diamictites to massive diamictites. This continuum is interpreted to indicate that those diamictites with less pronounced stratification were also deposited by rain out from debris rich ice, in contrast to a mass flow hypothesis that has been suggested previously. Thirdly, we reveal the presence of large-scale, recumbent folds with associated thrusts at the type section. The suite of large-scale deformation structures- measuring >30 m in amplitude- is sealed by undeformed diamictites. The deformation structures are interpreted to reflect soft-sediment deformation structures produced through ice bulldozing. Integrating these observations, we propose deposition of the Luoquan Formation in a large paraglacial lake setting, with a range of ice contact to ice distal environments recognised.

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ARE THE LATE ORDOVICIAN HICE EVENT CONTEMPORANEOUS AROUND THE WORLD?

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The HICE event, which was first identified based on inorganic carbon isotope data, is the largest isotope carbon excursion event during the Ordovician. It has been widely reported from those Upper Ordovician carbonate or mix-facies sequences in the world. However, in those area where deposited only mudstones or shales, it is quite difficult to obtain reliable inorganic carbon isotope data, and the organic carbon isotope data are mostly used for the recognition of the HICE event.
Due to the Influence of the Kwangsian Orogeny, the Yangtze Sea became a semi-closed, limited and stagnant environment since the Late Ordovician, deposited with the Katian (Late Ordovician) to Telychian (Lower Silurian) organic-rich black shales. In the upper Yangtze region, the Ordovician-Silurian transition interval is mostly composed by the Wufeng Formation (black shales), Kuanyinchiao Bed (argillaceous limestone) and Lungmachi Formation (black shales) in ascending order, among which, the Kuanyinchiao Bed represents the shallow-water environmental sediments during the Hirnantian glaciation and glacioeustatic sea-level drop.
A total of 147 samples around the HICE event were continuously collected and analyzed for $\delta^{13}C_{org}$ from two drill cores on the Yangtze Platform, i.e., Yihuang-1 and Yijie-1. Through graptolite biozonation, the two drill cores can be precisely correlated with other contemporaneous drill cores or outcrop sections, including the offshore Wangjiawan "GSSP" section[1]. The two drill cores both show the HICE event in the interval from the upper Wufeng Formation to the Kuanyinchiao Bed, which starts from the upper *Paraorthograptus pacificus* Biozone with peak values of −27.2‰~−28.4‰ and shifts of 2.0‰~3.0‰. However, in the deeper-water drill core (Yijie-1), the peak value occurs in the Kuanyinchiao Bed and the HICE excursion ends in the upper Kuanyinchiao Bed, while in the relatively shallow-water drill core (Yihuang-1), the peak value lies in the uppermost Wufeng Formation and the HICE excursion ends beneath the Kuanyinchiao Bed. It is notable that the $\delta^{13}C_{org}$ HICE records from the deeper-water localities on the Yangtze Platform resemble the $\delta^{13}C_{carb}$ HICE records from those open-sea localities such as Anticosti Island[2] and central Nevada[3], which may indicate that the deeper-water $\delta^{13}C_{org}$ records are less influenced by local sedimentary environments.

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THE SEDIMENTARY RECORD OF THE EARLY PHASE OF DEGLACIATION IN A DAMMED VALLEY SYSTEM OF THE APPALACHIAN HIGHLANDS, EASTERN QUEBEC: GLACIAL LAKE MADAWASKA

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The thick and extensive rhythmites deposits of the former Glacial Lake Madawaska (GLM) provide sedimentary archives for understanding its evolution in relationship with topography and the configuration of the retreated margin of the Appalachian Ice[1] (AI). Previous studies reported that this glacial lake occupied the Témiscouta-Madawaska Valley[2] for a duration of at least 1,200 years during late glacial times, as attested by the counting of rhythmites[3]. However, the total duration and configuration of each phases of GLM in relationship with the retreating ice margin still remain unknown. Sedimentary archives of glaciolacustrine deposits can provide stratigraphic evidence for reconstructing the multiple phases of the evolution of a glacial lake[4]. Such archives are used in this project to reconstruct the evolution of the former GLM, from its early inception to its final phase, by the analysis of: 1) sedimentary facies of exposed rhythmite deposits, both from conventional cross-section stratigraphic descriptions and CT-Scan data from u-channels sampled in outcrops; 2) radiocarbon dates on organic matter collected in cross-sections; and 3) acoustic subbottom profiles collected in modern lakes. These results indicate that GLM persisted in the Témiscouata-Madawaska valley for >5,000 years, as evidenced by radiocarbon dating spanning from 12,729 (ULA-6310) to 7,535 (ULA-6308) cal. BP. During the early phase of the lake, where it reached a maximum elevation of 240 m asl, glaciolacustrine sedimentation was highly influenced by iceberg calving, as indicated by iceberg dump structures and ice-rafted debris into the glaciolacustrine sediments. Silto-sandy rhythmites ranging from 8 mm to nearly 5 cm in thickness were deposited during this initial phase of the lake as attested by cross-section description and acoustic subbottom profiles. From the early phase of GLM to its maximum extent, where it reached >500 km^2, the dynamics of the AI margin and the Appalachian Highlands topography both conditioned the processes of lacustrine sediment infilling[4]. The relation of the glacial lake to the ice margin directly influenced the pattern of AI retreat. At its maximum extent, the direct glacial influence on varves deposition of GLM fades out. The silto-clay varves have a constant thickness of 4 mm; they have been identified on the acoustic subbottom profiles in a unit of closely-space high amplitude reflections. Sedimentary facies of GLM indicate that the early lacustrine phase was marked by iceberg calving and high sedimentation rates. The ice-contact and the calving processes contributed to the rapid deglaciation of the valley. Varves of regular thickness correspond to the maximum extent phase GLM, which today fill the valleys and modern lake basins.

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Mineralogical and geochemical characteristics of K-bentonites from the Late Ordovician-Early Silurianin South China and their geological significance

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There are numerous K-bentonites, interlayered with black shales from the Late Ordovician-Early Silurian, widely distributed in South China. In this paper we carried out mineralogical and geochemical investigations on K-bentonite samples collected from six sections in South China. The petrological features of thin sections, XRD (X-ray diffraction) data and major element results show that in addition to clay minerals, which are dominated by illite/smectite mixed layer and illite, the K-bentonites also contain quartz, microcline, albite, pyrite and zircon. Zircon U-Pb dating for two K-bentonite beds(WXP-BT2 and LBP-BT1) by the LA-ICP-MS method yielded two weighted mean^{206}Pb/^{238}U ages of 443.5±1.9 Ma and 440.4±5.6 Ma, respectively. The concentrations of rare earth elements ranges from 141.28ppm to 854.44ppm, chondrite-normalised Rare Earth Elements patterns display a negative Eu anomaly and an enhanced enrichment in LREE. Samples plot in the fields of trachyte, trachyandesite, rhyodacite(dacite) and andesite in a plot of Nb/Y against Zr/TiO_2, suggesting that the K-bentonites are most probably derived from felsic magmas with sub-alkaline to alkaline affinities. The discrimination diagrams(Y-Nb, Y+Ta-Rb, Y+Nb-Rb) show that the tectonic setting of the source volcanoes ranges from a volcanic arc to within-plate setting. The widely distributed bentonites suggest intensified volcanic ash eruptions in early Late Ordovician, which released huge amounts of volcanic ash. The SO_2 emission and the weathering of the volcanic ashes probably resulted in global climate cooling and indirectly caused the Hirnantian glaciation and the mass extinction at the end of the Ordovician Period.

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MISS INTEGRATED ANALYSIS: PALAEOENVIRONMENT INSIGHTS

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Thin-bedded, fine-grained tabular rhythmites are the most pervasive deposits at the topmost of the Itararé Group (Paraná Basin, southern Brazil). They crop out as patches along the eastern and south basin borders and were deposited during the deglaciation cycles that characterize the demise of the Gondwana glaciation in the Paraná Basin. Two different paleoenvironmental interpretations have been proposed for these deposits: (i) they represent varvites; (ii) they characterize distal turbidites accumulated in perennial glaciolacustrine/glaciomarine settings. In this contribution, we analyze some geochemical signatures and the cyclicity of the rhythmites exposed in the Trombudo Central region (Santa Catarina State) to improve this debate. The geochemical data comes from the clay layers that compose the rhythmite couplets and includes Total Organic Carbon (TOC) and Sulfur (TS) content, as well as metal trace-elements that are redox-sensitive elements. The cyclic analysis considered the thickness of each couplet and was based on Milankovitch cycles. The rhythmites are characterized by the prevalence of siltstone-claystone couplets, the dominance of granule-sized dropstones, and the pervasive occurrence of microbially-induced sedimentary structures (MISS), including microbial earths, and trace fossil assemblages preserved only in the bedding planes and dominated by non-marine arthropod trackways, trails, furrows, and resting structures. Acritarchs and prasinophytes may occur in some beds. The average thickness of couplets is 4 cm, being thicker to the top, reaching up to 15 cm. The thicker couplets are sandier in composition, but the claystone layer is still present. The claystone layer thickness varies from 1 to 4 mm, being 1 mm the prevalent thickness throughout the succession. The contact between the siltstone beds and the claystone layers in each couplet is abrupt. Average TOC value is 1.8%, and the TS is 0.21%. The analysis of the redox-sensitive elements (e.g., U, Mo, V, Ni, Zn, Co, Cu, Pb) revealed that the claystone layers were available in oxic-suboxic bottoms, rarely reflecting anoxic conditions. The oxic-suboxic conditions are corroborated by the occurrence of cyanobacteria filaments in the claystone layers. Framboidal pyrite formed by anaerobic bacteria occur locally, into circular, slightly domic structures interpreted as ancient gas domes. Thin $CaCO_3$ rich-layers occurs at the top of some rhythmite sets and were interpreted as formed during climatic amelioration periods in which evaporation rates should be high. Cyclostratigraphy analysis allowed to identify eccentricity and precession Milankovitch cycles with sedimentation rates of 113 years/mm. These low sedimentation rates refute the varvite interpretation. The oxic-suboxic conditions, the occurrence of cyanobacteria filaments and microbial earths structures, and the presence of the $CaCO_3$ rich-layers indicate a shallow condition for the water bodies and periodical exposure of the bottoms, at least those from the shallower portions. The presence of marine palynomorphs indicates proximity with marine settings, but trace fossil assemblage denotes the prevalence of freshwater conditions. The obtained data allow suggesting that these rhythmites represent deposition in shallow ponds formed in the seaward-side of outwash plains, probably in supratidal settings.

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DYNAMICS OF SEDIMENTS ON A SEDIMENT STARVED, CURRENT-SWEPT CONTINENTAL MARGIN ADJACENT TO A FORMER CONTINENTAL ICE-SHEET: THE SE GRAND BANKS SLOPE OFF NEWFOUNDLAND

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The periodic expansion and contraction of the Laurentide ice-sheet (LIS) during the last glacial cycle facilitated the transfer of enormous amounts of terrestrial sediments into the Labrador Sea and Scotian margin. Numerous eastern sector ice-streams of the LIS played pivotal a role in transferring those sediments and supplying accompanying meltwaters that were then transported to the south and west by the Labrador Current. In contrast to three large and numerous smaller ice-streams entering the Labrador Sea and Scotian margin, no known ice-stream is recognized on the Grand Banks despite a large ice-sheet centered on Newfoundland. Thus, the SE Grand Banks margin might represent an end member sediment starved contourite margin compared to Orphan Basin and the Scotian Slope. Here we used multi-beam bathymetry, high-resolution seismic profiles, and new geotechnical and sediment data from seven reference cores from the SE Grand Banks Slope during the last glacial cycle. By so doing we (i) documented the extent to which the meltwater, sediment-plume, and iceberg-derived sediments influenced the downslope and along-slope sedimentation on the SE Grand Banks Slope; (ii) assessed the extent to which these fine-grained sediments facilitated landsliding and sediment failures; and (iii) compared the sediment dynamics and sedimentation pattern to other ice-streams of the SE sector of the LIS. Detrital carbonate-rich Heinrich layers are present throughout the succession, but red mud layers of glacial meltwater origin from ice-streams in the SE sector of the LIS are identified only during MIS2 and late MIS3. Sediment thickness variations suggest concurrent downslope and along-slope transport during MIS2 whereas only along-slope transport processes were prevalent during MIS3. Such changes in the sediment dynamics and sedimentation patterns have influenced the nature of slope failures. Three regional mass-transport deposits (MTDs) were identified spanning the upper and lower slopes. Sediments on the upper slope above H1 are condensed and the section above H0 is < 50 cm thick, indicating that the powerful Labrador Current winnowed the section above H2. In contrast to the upper slope, approximately 3 to 5 m sediments were recorded in the mid-slope above H2 suggesting that the Labrador Current was weak. Regional stratigraphic variations compared to Flemish Pass and Orphan Basin to the north suggest that NE Newfoundland sources played an important role which may have been previously underestimated. Overall, this study demonstrates the local complexity of contourite deposition on a distal glacially supplied slope.

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Pleistocene drumlins of the Canadian Shield and their implications for recently proposed theories of drumlin formation

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Subglacial beds across glaciated landscapes are rarely flat. Rather, they typically exhibit complex landform patterns, such as fields of drumlins and ribbed moraines [1]. Recent theories have centered on instability mechanisms to explain the genesis of these landform patterns, their highly variable internal sediment characteristics, and the evidence for both erosion and depositional processes [2, 3]. Due to access issues, and in some cases permafrost, few field-based studies have focused on the remote drumlin fields of the Canadian Shield and, consequently, little is known about these drumlins. Here, we summarize observations from five remote drumlin fields in different settings of the Canadian Shield and explore potential implications for theories of drumlin formation. Our methods include various combinations of stratigraphy, sedimentology, geochemistry and petrography (till provenance analysis), geophysics, as well as remote sensing and supervised classification techniques.

It has been suggested that Pleistocene drumlins were formed through erosion [4]. While we find in this study supporting evidence for dominantly erosional drumlins, such as drumlins with a core of either bedrock or pre-existing sediment (based on provenance analysis) capped by till veneer [5], we also find in many drumlins evidence for substantial till deposition associated with drumlinization [6]. To our surprise, in one setting, we document several similarities with Icelandic ice marginal surge-related drumlins; i.e. multiple layers of subglacial traction tills with interbeds of sorted sediments and conformable and unconformable bounding surfaces [3]. Here we propose that cycles in basal conditions (e.g., effective stress, basal velocities) other than those related to surging behavior may explain the similarities. Overall, we suggest that drumlins of the Canadian Shield which formed at great distances from the ice margins developed through erosional and depositional interplay, some involving cyclical variations of subglacial conditions and basal velocities.

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Deep-sea carbonate preservation in the western Pacific over the past 1.7 Ma

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We present a continuous record of calcium carbonate ($CaCO_3$) content that covers the last 1.7 Ma from core MD06-3050 (15°57.0943'N, 124°46.7747'E; water depth, 2967 m), which was collected in the western Philippine Sea. The age model of the core MD06-3050 was based on the oxygen isotope of benthic foraminifera correlated to LR04 stack (Lisiecki et al., 2005). The $CaCO_3$ content record shows a long trend of decreasing since the last 1.7 Ma, from the high value 50% around the 1.7 Ma to the low value 10% around 0.1 Ma. Proxies of dissolution and productivity ($CaCO_3$MAR), the $CaCO_3$ content and the coarse fraction (>63μm) record from this core are compared throughout the 1.7 Ma study interval to improve our understanding of the mechanisms that affected bulk $CaCO_3$ content at this site. The abundance of coarse fraction was higher during the period before 1.0 Ma than after, with the average value 9.5% in the first stage (1.7 Ma-1.0 Ma) and average value 5% in the second stage (1.0Ma- 0.1 Ma). The planktonic foraminifera shell fragmentation ratio (%shell fragment) is used as a dissolution proxy in this study. The %shell fragment data from MD06-3050 provide evidence of good preservation during the period of 1.7-1.0 Ma than the period of 1.0-0.1 Ma. However, there is nearly no long-term trend of $CaCO_3$ MAR, which indicate that productivity was not the main factor to influence the $CaCO_3$ content. Compared with the other record published in this region, it was inferred that the high $CaCO_3$ content before 1.0 Ma may be induced by the low terrigenous materials and good preservation condition of calcite microfossil.

During the past 1 Ma, the $CaCO_3$ content in this study core is characterized by maxima during deglaciations and minima during the onsets of glacial periods and generally shows Pacific-style patterns, with relatively high and low values during glacial and interglacial periods, respectively. The %shell fragment data from MD06-3050 provide evidence of preservation maxima during most of the deglaciations, whereas intense dissolution is recorded at the onsets of glacial periods within the past 1 Ma. The variations in %shell fragments are similar to those seen in the $CaCO_3$ content, which demonstrates that the bulk $CaCO_3$ content patterns were controlled by dissolution in deep seawater during the past 1 Ma. The primary productivity from the coccolith record shows limited similarity with the $CaCO_3$ content on glacial-interglacial time scales since 1 Ma, which suggests that PP played a negligible role in the glacial interglacial $CaCO_3$ cycle. However, a bloom of the coccolithophores *Geophyrocapsa caribbeanica* that extended from MIS 9 to MIS 12 likely contributed to the increased $CaCO_3$ content observed during the Mid-Brunhes interval over the glacial-interglacial fluctuations.

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DEVELOPMENT OF A PALAEOVALLEY COMPLEX ON A LATE ORDOVICIAN GLACIATED MARGIN IN NW SAUDI ARABIA

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Late Ordovician glacial deposits are of great importance in North Africa and the Middle East as a result of their significance as reservoirs for hydrocarbons and groundwater. The sedimentary record of this glaciation in NW Saudi Arabia (the Sarah Formation) is generally preserved in meridionally oriented palaeovalleys cut beneath northward-flowing ice sheets. In the Tabuk region of NW Saudi Arabia, an apparently intersecting complex of north–south- and east–west-oriented palaeovalleys occurs in the Alwizam area. Field relationships show two generations of palaeovalley incision, suggesting that the north–south-oriented palaeovalley was cut subglacially, filled, subsequently deformed and then cross-cut by the east–west-oriented palaeovalley. Abundant facetted and striated quartzite clasts occur at the base of each palaeovalley, testifying to a subglacial origin. Detailed examination of the north–south-oriented palaeovalley shows it to be well-defined with symmetrical sides. Its fill is composed of nine lithofacies grouped into four facies associations. About 80% of the fill consists of three sandstone facies: a parallel-bedded massive sandstone, a stacked scoured sandstone and a massive sandstone. Centimetre-scale extensional faults developed in soft sediments are commonly found throughout the stratigraphy, along with a glacially striated surface seen mid-way through the succession. These features provide evidence for direct ice contact, synglacial fill, and consequent reworking, cannibalization and deformation by the fluctuating ice margin.

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Geomorphic windows into Neoproterozoic ice ages: a complex subglacial topography from the Yuermeinak Formation of NW China

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The erosive behaviour of ice masses may produce a suite of characteristic erosional bedforms, providing insights into the thermal regime of overlying ice. Whereas such bedforms are well presented in Quaternary deposits, they are rarely preserved in Neoproterozoic strata. We describe an outcrop of the Cryogenian to Ediacaran aged Yuermeinak Formation of the Tarim Craton, NW China, which exhibits various glacial features, including such erosional bedforms. The basal surface of the formation has an undulating relief of several metres and locally hosts glacial striae and a likely roche moutonée, both indicating ice-flow direction. Locally abundant bullet-shaped clasts, with striae parallel to their long-axes, are indicative of subglacial sculpting. Their concentration within diamictites immediately overlying the basal surface allows an interpretation of subglacial tillite. The remainder of the section is characterised by laminated mudstones, punctuated by cm-scale medium to granular sandstones and metre-scale diamictite beds. The sandstones are normally graded to massive, possibly representing gravity flows. Stratified diamictites are consistent with rain out of debris from an overlying ice shelf. The presence of ice rafted debris within the section is further supported by pebbles and cobbles that vertically penetrate the laminated mudstones and well-bedded sandstones. Taken together, these lines of evidence suggest a wet-based, possibly streaming ice mass, that terminated in a standing body of water.

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PERMO-CARBONIFEROUS GLACIAL VALLEYS, ALONG ETHIOPIA SOMALIA BORDER A MAJOR ICE STREAM? , THE MISSING LINK

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Permo-Carboniferous glacial deposits are widespread over the Gondwana. In East Africa, they are reported: in North Ethiopia, in Tigray region as well as in Eritrea with the Upper Enticho Sst & the Edaga Arbi Glacial deposits, Bussert & Schrank 2007, Bussert 2014; in SE Ethiopia (Calub Sst), Hunegnaw et al. 1998, in Kenya (TaruFm), in Tanzania with the Idussi Fm. and in Masdagascar with the Sokoa Fm. They are also known on the other side of the Red Sea and Indian Ocean respectively in Yemen (Akbra Shales), Kruck &Thiele 1983, in Saudi Arabia (JuwaylFm), Mc Klure 1980; and finally in Oman (Al Khlata Fm.)Braakman et al. 1982.
Surprisingly in Somalia which is right in the middle, to date they are no mention of glacial deposits of this age, most likely because over the country, Jurassic is directly transgressive on basement. In the framework of a regionals synthesis, it appears that in Ogaden, along the border with Somalia, Precambrian basement is deeply incised (up to 500m) prior to Mesozoic, by very elongated features which are revealed by seismic profiles. They point toward N30°-40°, this orientation is similar to North Ethiopia glacial lineation's reported by Bussert 2010. By restoring Africa & Arabian plate, closing Red Sea and Indian Ocean, it appears that these erosional features are on trend to Oman glacial deposits. It is suggested here that these features along the Ethiopia / Somalia border, could be part of a major ice stream linking East Africa to Oman. In this respect, thick Al Khlata omani deposits could be at the ice stream mouth. Our interpretation fits with the palaeogeography proposed by Kidane et al. 2013 based on paleomagnetism in Ethiopia and invalidates the Leuwin & al.2017 map which suggests more patchy ice caps. To date no wells allow to document the full nature of sediment infilling the valley; however in some interfluve settings, the basal sandstones also known locally as Calub Sst could be glacial in origin. It is also of interest to re-date the pre-Adigrat Formations such as Gumburo and Bokh, both in Ogaden and Somalia which are almost impossible to correlate because of their very dissimilar log patterns as commonly observed in other Palaeozoic glacial deposits in Africa.

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OFFSHORE TO ONSHORE GEOPHYSICAL AND ALLOSTRATIGRAPHICAL CHARACTERIZATION OF A SUBMARINE GROUNDWATER DISCHARGE SITE IN THE FIRST SALPAUSSELKÄ ICE-MARGINAL FORMATION, SOUTH FINLAND

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Submarine groundwater discharge (SGD) has been implicated as a significant source of nutrients and other potentially harmful substances to the coastal sea. However, stratigraphy and aquifer geometry at SGD sites are rarely studied in detail cross the shoreline. This study describes a high-latitude SGD site, which is connected to the First Salpausselkä ice-marginal formation on the Hanko Peninsula in Finland, northern Europe. The study combines offshore seismic sub-bottom profiles, multibeam and sidescan sonar images of the seafloor, and onshore ground-penetrating radar profiles. An allostratigraphic division is presented for the SGD site on the basis of major unconformities recognized in the offshore and onshore profiles.

The aquifer comprises the distal sand-dominated part of an ice-contact subaqueous fan and foreset, where gravelly interbeds and lenses provide conduits for the groundwater flow. The submarine groundwater discharge takes place through pockmarks on the edge and slope of the shore platform, as shown by sidescan sonar images of the seafloor. Salinity and temperature profiles of the water column demonstrate that some of the pockmarks were active at the time of the fieldwork.

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Distribution, provenance, and onset of the Xiashu Loess in Southeast China with paleoclimatic implications

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Abstract Loess deposits are important archives of past climate change in subtropical China, where long-term terrestrial records are scarce. However, only a few long-term records with reliable dating were reported in Jiangsu Province, where loess deposits in southeastern China were first discovered and designated as the Xiashu Loess. Moreover, the provenance of the Xiashu Loess is still controversial. This study presents the magnetostratigraphy and detrital zircon U–Pb age results of loess deposits at Zhoujiashan in Nanjing, Jiangsu Province. To date, this section (with basal age of approximately 0.88 Ma) may be the oldest loess deposits discovered in southeastern China. Based on the detrital zircon U–Pb ages of the Zhoujiashan section, together with published results of geochemistry, geomorphology, sedimentology, and meteorology, we propose that the Xiashu Loess has two mixed sources. Local materials derived from the Yangtze River Basin (including exposed river/lake beds, floodplains, and mountains) served as a major contributor. The distal eolian dust that originated from the arid areas of North China (including deserts, piedmont alluvial fans, and drylands) played a minor role in the formation process of the Xiashu Loess. The nearly synchronous onset age (approximately 0.88 Ma to 0.85 Ma) of the Xiashu Loess was attributed to a regional environmental event during the middle Pleistocene transition.

Keywords: Southeast China; Xiashu Loess; Provenance; Magnetostratigraphy; Loess chronology

FORCED REGRESSIVE ICE-MARGINAL DELTAS IN GLACIAL LAKE BASINS

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This study presents a synthesis of the geomorphology, facies variability and depositional architecture of forced-regressive ice-marginal deltas. These deltas have been deposited in front of the Middle Pleistocene Scandinavian ice sheet and are considered as representative of delta styles in glacial lake basins, affected by rapid base-level change. The integration of digital elevation models, outcrop, ground-penetrating radar and high-resolution shear-wave seismic data allows for a comprehensive analysis of delta systems and provide information about the distinct types of deltaic facies and geometries generated under different lake-level trends. The exposed delta sediments record mainly the phase of maximum lake level and subsequent lake drainage. The stair-stepped profiles of the delta systems reflect the progressive basinward lobe deposition during forced regression when the lakes successively drained. Depending on the rate and magnitude of lake-level fall, fan-shaped, lobate or more digitate tongue-like delta morphologies developed. Deposits of the stair-stepped transgressive delta bodies are buried, downlapped and onlapped by the younger forced regressive deposits.

The delta styles comprise both Gilbert-type deltas and shoal-water deltas. The sedimentary facies of the steep Gilbert-type delta foresets include a wide range of gravity-flow deposits. Delta deposits of the forced-regressive phase are commonly dominated by coarse-grained debris-flow deposits, indicating strong upslope erosion and cannibalization of older delta deposits. Deposits of supercritical turbidity currents are particular common in sand-rich Gilbert-type deltas that formed during the lake-level slow rise and highstand. Foreset beds consist typically of laterally and vertically stacked deposits of antidunes and cyclic steps. The trigger mechanisms for these supercritical turbidity currents were both hyperpycnal meltwater flows and slope failure events. Shoal-water deltas formed at low water depths during both low rates of lake-level rise and forced regression. Deposition occurred from tractional flows. Transgressive mouthbars form laterally extensive sand-rich delta bodies with a digitate, multi-tongue morphology. In contrast, forced regressive gravelly shoal-water deltas show a high dispersion of flow directions and form laterally overlapping delta lobes. Deformation structures in the forced-regressive ice-marginal deltas are mainly extensional features, including normal faults, small graben or half-graben structures and shear-deformation bands, which are related to gravitational delta tectonics, post-glacial faulting during glacio-isostatic adjustment and crestal collapse above salt domes.

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DEFINING THE MAXIMUM EXTENT OF THE LAURENTIDE ICE SHEET IN CENTRAL-EASTERN BAFFIN BAY WITH GLACIOGENIC DEBRIS FLOWS AND TURBIDITES

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Baffin Bay is an oceanic basin located between the Canadian Arctic Archipelago and Greenland. It is located at the northeast margin of the Laurentide Ice Sheet (LIS), which covered a vast area of North America during the last glaciation. Baffin Bay has a narrow margin along Baffin Island, as well as a number of channels and fans (i.e., deep-sea fans and trough mouth fans -TMF) spread out on their slopes. In this study, we present the physical, magnetic and sedimentological properties of three cores collected in Baffin Bay in order to determine the stratigraphy and sedimentary processes in Baffin Bay with a special emphasis on the Home Bay TMFs. The sedimentary records in these TMFs, located approximately 80 km offshore of Baffin Island are of great interest to reconstruct advances and retreats of the LIS and if the later has reached the shelf edge during the last glaciation. Four lithofacies were identified in the Home Bay cores AMD16-LGM-09 and AMD0217-01, based on the different sediment properties and CT-scan images. The lowermost lithofacies is composed of a massive, matrix-supported diamict facies originating most likely from glacigenic debris flows and turbidity currents, reflecting a glacial environment. The three other overlying facies are composed of bioturbated mud (hemipelagic sedimentation) with occasional scattered clasts, a laminated pebbly mud (hemipelagic sedimentation with IRDs) and a laminated mud (hemipelagic sedimentation with no IRDs), which represent deglacial and postglacial environments. These facies are also imaged on subbottom profiles (3.5 kHz) on which they are characterized by acoustically stratified units representing an alternation of mud and debris flows/turbidites topped by acoustically transparent postglacial mud. Preliminary paleomagnetic results from u-channel samples and hysteresis data reveal that the sediments from Home Bay are composed of a strong, well-defined (maximum angular deviation <5°), single component magnetization characterized by median destructive fields varying between 20-30 mT, pseudo-single domain grains and hysteresis loops typical of magnetite, indicating that the magnetization is carried by low coercivity minerals such as magnetite. In addition, except in intervals associated with debris flows, turbidites and detrital carbonate layers, the inclination records calculated from principal component analysis are oscillating around the expected value (geocentric axial dipole) for the latitude of the sites and indicate that paleomagnetic secular variations (inclination, declination) and relative paleointensity can be reconstructed for the different cores. These paleomagnetic changes and preliminary radiocarbon dating indicate that core HU2013-029-077 may span the last 41 ka cal BP, providing the initial chronostratigraphic framework for the analysis of the Home Bay TMF cores (AMD16-LGM-09 and AMD0217-01) who will be needed to build a dating model to validate the presence of glaciogenic debris flows during the Ice Age. These results indicate that a series of debris flows and turbidites were generated during the last glaciation, suggesting that the LIS margin reached the shelf edge, while postglacial sedimentation led to the deposition of mostly hemipelagic bioturbated and/or laminated pebbly mud.

Study on glaciochemical and microparticle characteristics of three snow pits in East Antarctica

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Abstract: In the Antarctic summer of 1998/1999, the third Chinese Trans-Antarctic inland glaciological scientific expedition successfully entered Dome A area and extended its research to the site of 79°16'S, 77°00'E, 3,931 m.a.s.l, 1,128km away from Zhongshan station. We present the glaciochemical and microparticle characteristics of three snow pits which were drilled at the 1128km(DAP1), 1000km(DAP2) and 800km(DAP3) site along the investigation route.

From the dating results of the three snow pits, we come to a conclusion that the DAP1 snow pit, which was 3.3m deep, represented the whole sediments from 1987 to 1998; while DAP2 snow pit which was 2.1m deep represented a 7-year long sediment from 1992 to 1998 and DAP3 snow pit of 2.4m deep represented a 8-year long sediment from 1991 to 1998. Comparing the different radius part of the microparticles in the snow pits, we find that they are well linear related which implicates that the main source of the microparticles is the remote continents and the local factors have weak influence on them. The concentration of microparticles also coincides with the accumulation rate, that is, high microparticle concentrations agree with high accumulation.

From the glaciochemical analysis results, we find that the concentration of calcium in the snow pits changes smoothly, which implicates that it is from the deposit of the remote continents and the local influence is not evident. But for DAP3 snow pit, the calcium concentration slightly fluctuates for the unknown local causes. The sulfate in the snow pit exhibits a noticeable wave crest for the eruption of Pinatudo volcano in 1991, which verifies the preciseness of the snow pit dating. What's more, the precipitation calculated by the snow pits well agree with the trend of global warming. The snow pit contains instructive information on the sedimentary characteristics and the climate change.

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EXPLORING NEW FRONTIERS IN ICHNOLOGY APPLIED TO FACIES ANALYSIS AND SEQUENCE STRATIGRAPHY

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The recognition that trace-fossil distribution is strongly controlled by environmental factors has led to the success of ichnology as a valuable tool in facies analysis. In addition, refinements in our understanding of the genetic implications of substrate-controlled trace fossil suites paved the way for the application of ichnology in sequence stratigraphy. Intense research during the last decades has resulted in more sophisticated trace-fossil models for wave-dominated shorelines (with detailed zonations from backshore to shelf), incised estuarine valleys (both tide- and wave-dominated), deltas and, to a lesser extent, tidal flats. However, not all depositional environments have been explored to the same extent. In recent years, increased attention has been given to subtidal sandbodies, resulting in the ichnologic delineation of sand sheets, tidal sand ridges, compound dune fields and isolated dune patches. End-members with respect to wave and tidal dominance are better understood than mixed systems, although progress has been made in the characterization of tidally modulated shorefaces and wave-dominated tidal flats. Muddy coasts are still poorly known from an ichnologic standpoint, remaining essentially unrecognized in the geologic record. The vast majority of ichnologic studies dealing with marginal-marine environments focuses on either estuaries or deltas, and there is an unfortunate lack of models for other transitional settings (e.g. bays). In turn, wave- and river-dominated deltas are much better understood than tide-dominated deltas. Mixed deltaic systems remain to be explored in more detail. In addition, ichnologic studies of deltas are mostly restricted to shelf deltas, with very few analyses performed in shelf-edge deltas. Deep-marine trace fossils have been the focus of detailed systematic work, but further study is needed to finely tune sedimentologic and ichnologic datasets. Recent research, however, is yielding insights into the significance of trace fossils to characterize deposits formed due to a variety of processes, such as hyperpycnal currents, episodic turbidity currents and bottom currents. The ichnology of carbonate systems remains much less explored that that of siliciclastic systems, with work focused on Bahamian-type carbonates and, to a lesser extent, reefs, rocky shorelines, and chalk. Continental ichnology evolved from an unexplored field to an explosion of research, with detailed studies dealing with lakes, rivers, paleosols and deserts. On a negative note, invertebrate and vertebrate ichnology has evolved independently, and there is still a pressing need for integrating these two disparate datasets. The bulk of sequence-stratigraphic applications has been on marine clastic successions. Nevertheless, recent progress has been made on the use of ichnology in lacustrine and carbonate sequence stratigraphy. Promising lines of research on this front include the use of paleosol ichnofacies in the recognition of sequence boundaries, increasing our database on trace fossils and discontinuity surfaces in carbonates, distinction between autogenic and allogenic examples of the *Glossifungites* ichnofacies, and elucidation of stratal stacking patterns in mixed tide- and wave-influenced settings. The role of climatic and latitudinal controls on ichnofaunas is gradually starting to be recognized through studies in tropical and glacially influenced settings. Similarly, the role of macroevolution is helping to calibrate secular changes in ichnofaunal composition for various depositional settings. Appreciation of the role of tectonic context is becoming of paramount importance. Progress has been made regarding the contrasting ichnologic characteristics of passive-margin fine grained and active-margin coarse-grained turbidite systems, but further research is needed.

THE DUAL ICHNOLOGICAL NATURE OF SHELF-MARGIN DELTAS

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Ichnologic analysis of the Plio-Pleistocene Orinoco Megadelta deposits reveals the wide variety of depositional subenvironments as a result of interaction between the Paleo-Orinoco and Paleo-Atlantic processes at the shelf-edge (Dasgupta *et al.*, 2016). The depositional variability itself is characterized by the diverse ichnological expressions in the different subenvironments in combination with their sedimentological characteristics. The paleo-megadeltaic regime covered a vast submarine physiographic terrain which is expressed in the oblique stacking of the outcropping Mayaro Formation megasequence in south-eastern Trinidad. The amalgamated sandstone and layered sandstone-heterolithic intervals in the southern exposures bear the signatures of direct interaction between oceanic processes, processes involving the river-mouth opening adjacent to the upper slope, metastable slope condition, enormous accommodation, and befitting sediment supply, all of which essentially suppressed bioturbation. In the younger part of the succession exposed towards the north of Mayaro Bay, roughly the very same subenvironments reoccur, however, with the ichnological characteristics that are more typical of a delta developed on the shelf. The paleo-shelf was perhaps a sliver of the medial to outer shelf. This ichnological and sedimentological duality between bioturbation suppression and archetypal deltaic trace-fossil assemblages may be inherent to the prograding shelf-margin deltas because their lobes can develop on the gentle shelf as well as at the much steeper shelf-edge in immediate vicinity of the deep ocean. Furthermore, the out-of-trend occurrence of unbioturbated upper-slope deposits (e.g., canyon-fill and mass-transport deposits) within the megasequence not only illustrates this ichno-sedimentologic duality, rather also adds a unique interchangeable depositional milieu between the marginal-marine setting and the upper slope, as a response to the low-order transgressive-regressive cycle(s) within an overall deltaic progradational megasequence.

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Ichnological variations in shallow-marine strata of active-margin basins *versus* passive margins and intracratonic foreland basins

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Prevailing logic and assumptions suggest that a complex interplay of factors ensures substantial variability in trace fossil character of shallow-marine strata (< 100 m water depth) across all basin types, and that there are no diagnostic features for differentiating between active-margin basins (AMB), passive margins (PM), and intracratonic foreland basins (IFL). However, there appear to be general differences in preserved trace-fossil suites based on basin style, and these vary as a function of water circulation and salinity, grain size and sedimentation rate, and subsidence rates and magnitudes. Herein, a comparison is presented of the ichnological characteristics of Cretaceous-aged strata in three Canadian sedimentary basins: an AMB (Trent River Formation, Georgia Basin (forearc), British Columbia), an IFL (Viking and Cardium Fms, Western Canada Sedimentary Basin, Alberta), and a PM (Ben Nevis Fm, Jeanne d'Arc Basin, offshore Newfoundland and Labrador). This comparison is intended as an initial attempt at resolving differences in ichnological signatures as a function of basin type.

Basin-scale differences impacting preserved ichnological characteristics can be grouped in the context of their temporal recurrence. At inter-annual to decadal time scales (lifetimes of infauna), oxygenation of the water column and salinity are two major factors that impact ichnological character. Diversity, density, and burrow size generally decrease with decreasing water-column oxygenation and lowered salinity. Relatively unrestricted, fully marine basins (e.g., AMB and PM), typically support a higher diversity of trace makers and populations in equilibrium with their environments, and therefore, contain robust trace fossils. By contrast, restricted basins and those prone to greater physico-chemical stress (e.g., IFL), tend to have populations characterized by opportunistic organisms prone to higher mortality, resulting in the occurrence of more diminutive trace fossils. At annual to millennial time-scales, sedimentation rate and grain size exert the greatest controls on preserved trace fossil character, manifest by decreases in density and diversity of traces with increasing sedimentation rate and grain size. Active margin basins have high to very high sedimentation rates, short source-to-sink lengths, and rapid uplift, and hence contain abundant coarse clastic successions. By contrast, IFL and PM are dominated by very fine- to medium-grained sandstones and relatively low sedimentation rates. These differences are expressed ichnologically by lower trace diversity and density in AMB relative to PM and IFL. At the longest time scales reside periods of uplift and erosion, leading to stratal complexity and enabling recolonization and overprinting of trace fossil suites. Subsidence rates, depositional slopes, and tectonic loading all operate at long time scales. Active margin basins typically display high subsidence rates and limited lateral extents of erosion surfaces, owing to rapid uplift and steep slope gradients. Conversely, both PM and IFL experience overall slower subsidence rates and show widespread erosion along stratigraphic surfaces. Sedimentary strata contained therein are more likely to show complex tiering relationships and omission suites overprinting earlier biogenic fabrics.

The predicted ichnological character of shallow-marine strata in AMBs is that of generally more robust trace fossils with high diversity but lower density. Similar deposits in IFL are expected to show moderate-to-high diversity and high density of trace fossils that range from small to large structures. Those in PMs likewise show high diversity and density, and should comprise overall larger trace fossils. Omission suites are expected to be more common and widespread in stratal architectures of PM and IFL successions.

TERRITORIAL BEHAVIOR IN PALEOCENE *OPHIOMORPHA*

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The boundary between the Calvert Bluff and the Sabinetown, the uppermost formations of the Wilcox Group (Paleocene), is exposed in a construction excavation at the Jackson Street/SH71 intersection in Bastrop City (30° 6'12.61"N, 97°18'23.77"W), Bastrop County, Texas. In the upper part of the Calvert Bluff tidal deposition was widespread along the outcrop belt (Galloway, 2002[1]; Klein, 2000[2]; Sturdy, 2006[3]), and the Sabinetown in the Bastrop vicinity has tidal sedimentary structures and marine dinocysts (Denison et al., 2017[4]).
A transgressive surface at the base of the Sabinetown truncates common, closely spaced *Ophiomorpha nodosa* shafts in the uppermost 0.2 m of Calvert Bluff. Nearby, about 0.5 m below the top of the Calvert Bluff, an irregular ovoidal shaped area of bedding plane, approximately 50 m^2, provides a rare view of the horizontal distribution of *O. nodosa*. The surface is very fine grained sandstone, lacks evidence of bedding, and has an irregular surface texture that suggests churning by extensive bioturbation. Robust *O. nodosa* (2 to 3 cm diameter) are indurated and resistant to erosion. Curvilinear sub-horizontal tunnels are widely spaced, up to 1 m long, before inclining or declining, with rare vertical shafts.
Tunnels diverge from 5 irregular lumpy masses, spaced from 1 to 3 m apart, which largely lack the pellets of the tunnel walls. Three small masses may be satellites of 2 large masses. There appears to be no direct connection between the large masses, possible evidence of territorial behavior of clans or family groups. The larger masses may be the central hub of activities, with smaller hubs at a distance. Rare shafts suggest little connection to the sediment surface. The tunnels may be mainly communication pathways, possibly quite deep and used continuously for a considerable period. Shafts giving access to the surface are either located elsewhere, or may be common at shallower depths in the now-removed overlying sediment.

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DIFFERENTIATION OF TRACE FOSSILS ASSEMBLAGES IN THE PROSPECTIVE FOR SHALE GAS LATE ORDOVICIAN AND SILURIAN FORMATIONS FROM NORTHERN AND EASTERN POLAND (EXAMPLES FROM SELECTED BOREHOLES).

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Thick sequences of fine-grained Upper Ordovician and Silurian deposits in Poland occur in N, NE and E part of country, on the area of East European Platform. From few years they are of interest because of their unconventional hydrocarbons potential. These studies aim to identify prospective zones and to determine the prospects of occurrence unconventional gas resources in them. One of the using methods is sedimentological analysis which included trace fossils identification and determination of bioturbation index.

A comprehensive investigation was carried out on the distribution of trace fossils observed in Ordovician: Sandbian-Hirnantian (= Caradoc-Ashgill) and Silurian (Llandovery-Wenlock, lower Ludlow) fine grained deposits occurring in the area of the north-eastern part (Baltic Basin) and south-eastern one (Podlasie-Lublin Basin) of East European Platform. From both basins were analyzed formations prospective for shale gas: Sasino Fm., Pasłęk Fm. (with Jantar Mb.), Pelplin Fm., and Udala Fm. Cores from 10 deep wells were examined in detail. The purpose of the work was to identify genera of trace fossils and their associations and to determine their distribution in particular formations and resulting changes in oxygenation.

Distributions of trace fossils in these formations are diverse. In Sasino Fm. and Jantar Mb. of Pasłęk Fm. massive grey claystones / clayey mudstones without bioturbations dominate and only few-several dozen centimeters weakly bioturbated levels with *Chondrites* and *Planolites* are observed. They are point to short term oxygenation events in normally anaerobic to dysaerobic conditions. In Pasłęk Fm. (without Jantar Mb.) grey massive or laminated claystones / clayey mudstones without bioturbations intercalated in equal proportions with green-grey weakly (1-2) or moderately/strong (4-6) bioturbated ones with *Helminthopsis* or *Chondrites* and *Planolites* ichnogenera. From west to east bioturbated lithofacies dominate more and more. This suggests improvement of oxygenation conditions of sedimentary environment in this direction. In Pelplin Fm. laminated claystones and/or clayey mudstones without bioturbations dominate but in lower part of formation very thin weakly bioturbated levels appear (western area) or intervals strongly bioturbated by very small *Chondrites* (almost homogenized) can be observed (eastern area). The most bioturbated is Udala Fm. In lower part it is dominated by grey massive claystones / clayey mudstones with intercalations of weakly bioturbated by *Chondrites* ones. In middle and upper part, where partly dominate green color of sediment, index of bioturbation increases gradually from 1-2 to 3-4 and in the upper part to 5-6; in lower part *Chondrites* is observed, higher *Chondrites* and *Helminthopsis* are abundant and next small and big *Planolites* also appear. Such a trace fossils succession indicates gradual increase of oxygenation of bottom water sedimentary environment.

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Ichnology and Sequence Stratigraphy of the Upper Cretaceous Dinosaur Park – Bearpaw Formation Transition in southwestern Saskatchewan, Canada: Transgression on a mixed wave-tide influenced muddy coastline

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The Upper Campanian Dinosaur Park Formation (DPF) is a south and eastward thinning fluvial to marginal marine clastic wedge in the Canadian Western Interior Sedimentary Basin. The DPF is overlain by the Bearpaw Formation, a fully marine clastic succession representing the final major transgression of this epicontinental sea across Western North America. In the Cypress Hills region of southwestern Saskatchewan, the DPF is comprised of coal, carbonaceous shale, and heterolithic siltstone and sandstone grading vertically into marine sands and shales of the Bearpaw Formation. Historically these deposits have been interpreted as fluvial delta systems along a paleocoastline (McLean, 1971). This study revisits this interpretation via the integration of modern ichnologic, sedimentologic, and sequence stratigraphic concepts.

Detailed facies analysis indicates the upper DPF is not a delta system, but instead was deposited in a low relief coastal plain influenced by microtides. Marginal marine facies, interpreted as lagoons, tidal flats, and estuaries are bioturbated by typical brackish water ichnogenera, such as *Asterosoma* isp., *Chondrites* isp., *Cylindrichnus* isp., *Teichichnus* isp., and *Skolithos* isp. Fine-grained sands, interpreted as estuary mouth bars and barrier island bars, protected the coast from wave reworking. As the seaway transgressed across the coast, fully marine wave-dominated parasequences replace those of the coastal plain. Typical trace fossils include *Asterosoma* isp., *Chondrites* isp., *Diplocraterion* isp., *Nereites* isp., *Phycosiphon* isp., *Planolites* isp., *Rhizocorallium* isp., and *Zoophycos* isp., and are typical of nearshore, wave-dominated coastlines. This study establishes an ichnologic and sequence stratigraphic framework to characterize and reinterpret a mixed silicilastic coastline undergoing regional transgression.

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IMPACT OF BIOTURBATION ON RESERVOIR QUALITY AND PERFORMANCE – AN EXAMPLE FROM THE CHALK

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Trace fossils, the fossilized structures produced in the substrate by the activity of organisms, are invaluable in the reconstruction of paleoenvironmental conditions (Knaust and Bromley, 2012). Furthermore, bioturbation often has an impact on sediment properties and thus on the quality and performance of reservoirs (Knaust, 2013). Investigation of the ichnological data together with sedimentological, diagenetic and structural features of a reservoir is therefore an efficient and precise method for reservoir characterization.

To enhance existing models, the approach in this study not only regards the presence of particular trace fossils in an interval but provides detailed logs including bioturbation intensity, ichnofabric distribution and burrow appearance, i.e. qualitative and quantitative data. In contrast to conventional reservoir units, in which ichnological investigations are common practice, chalky and mixed carbonate intervals are only sporadically analyzed.

The Shetland Group (Maastrichtian, Upper Cretaceous) of the Gullfaks Field (Norwegian North Sea) mainly consists of argillaceous chalks to silty calcareous mudstones that alternate with or pass gradually into cleaner, both cemented and porous, chalk beds and concretions. Potential production of hydrocarbon is supported by open fractures; however, heterogeneities, mainly consisting of burrows (trace fossils), into the rock matrix contribute to the connectivity in the reservoir too. Depending on the kind of trace fossil (including ichnological features such as shape, size, orientation, etc.) and the timing of origin of such burrows, various scenarios can be recognized, in which the impact on reservoir quality and performance can vary from open conduits to completely tight rocks. The main purpose of this study is to work towards a better understanding of the impact of bioturbation and resulting burrows on the reservoir quality in the Shetland Group of the Gullfaks Field.

This approach is new within that area, and the applied methods have not been used previously. While comparable studies elsewhere have used a rather empirical approach for investigating the ichnological information given by a chalky interval, this study utilizes a systematic collection of qualitative and quantitative data over the entire interval of interest and a large area.

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THE CONTINENTAL ICHNOLOGICAL RECORD IN GLACIAL ENVIRONMENTS

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Trace fossils from the Late Carboniferous-Early Permian Gondwana and Northern Hemisphere Pleistocene glacial deposits represent until now the bulk of the known glacial trace-fossil record. They occur in fine-grained deposits formed during interglacial periods by massive meltwater discharges. Although the assemblages preserved in marine deposits share the same characteristic and composition observed in brackish-water ichnofaunas[1], the assemblages preserved in laminated rhythmites formed in glaciolacustrine settings show a particular composition and share the same characteristics, despite occurring in disparate time periods. In this contribution, we present the characteristics of these continental trace-fossil assemblages and compare their structure with the living communities of similar settings. Horizontal biogenic structures including arthropod trackways, trails, furrows, and resting traces; fish swimming trails; and regularly sinuous to randomly meandering tiny shallow burrows produced by worm-like animals dominate the ichnoassemblage. They occur almost exclusively within and on bedding planes, showing a relatively low ichnodiversity, high abundance, and patchy distribution. Aquatic and terrestrial ichnocoenoses may occur on the same bedding plane in palimpsest-type preservation, the latter superimposing the former, suggesting a diminished water table and community succession. Vertebrate tracks and trackways are unknown in the glaciogenic record. Three distinct suites characterize the aquatic ichnocoenosis. The first is composed exclusively of arthropod trackways (e.g., *Glaciichnum* ispp., *Kouphichnium* ispp., *Maculichna varia*, *Protichnites* ispp., *Umfolozia sinuosa*) and resting traces (e.g., *Gluckstadtella* ispp., *Rusophycus carbonarius*) and characterizes the most common trace fossil assemblage in the glacial fossil record. These structures are attributed to the activity of merostomes, isopod crustaceans, and apterygote insects. The second is composed of non-specialized trails and shallow horizontal burrows (e.g., *Cochlichnus anguineus, Cruziana problematica, Gordia* ispp., *Helmithoidichnites tenuis, Hormosiroidea* ispp., *Protovirgularia* ispp., *Treptichnus pollardi*) made by invertebrate bilaterians, including arthropods. The third is formed by fish swimming trails (*Undichnia* ispp.). The terrestrial ichnocoenosis is composed exclusively by myriapod trackways and trails, represented respectively by *Diplichnites gouldi* and *Diplopodichnus biformis*, and records periods of exposure of the lacustrine margins. The pattern of biogenic structures observed on the bedding planes of ancient ice-proximal glaciolacustrine deposits, the frequent presence of fish swimming trails, and the patchy distribution of trace fossils are consistent with the opportunistic colonization pattern observed in modern shallow glaciolacustrine settings. The extant pioneer invertebrate communities had the same small-scale spatial heterogeneity as the fossil sites, a fact that might explain the similarity of these trace-fossil assemblages across different ages and basins.

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ALLUVIAL DRYLAND EVENT STRATIGRAPHY: USE OF TRACE FOSSILS IN FACIES ANALYSIS OF SILURIAN OLD RED SANDSTONE VALLEY FILLS, ANGLO-WELSH BASIN, UK

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Late Silurian (Ludlow-Pridoli) sediments in the Anglo-Welsh Basin reveal the infill, abandonment and inversion of the former marine Welsh Basin. Widespread terrestrial conditions subsequently prevailed across southern Wales, dominated by dryland alluvial sedimentation in subtropical latitudes. The current study documents development of basin-wide incision during the Pridoli into earlier ORS alluvium, followed by valley fill and eventual re-establishment of terrestrial dryland fluvial environments.

The facies associations present are streamflow conglomerates, alluvial fans, ephemeral sheetflood deposits, ephemeral channels, inclined and non-inclined heterolithic alluvial deposits, pedogenically modified mudstone, coastal plain, tide-influenced inclined heterolithic stratification, estuarine bayhead delta, tidal flat heterolithic strata, estuarine bayhead delta mouth bar and estuarine central basin deposits. These facies associations are described and interpreted using both sedimentological and ichnological analysis.

CROWDED *ROSSELIA* ICHNOFABRIC: THE PERSISTENT SURVIVORS OF EARLY TRANSGRESSION IN POSTGLACIAL GONDWANA

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Trace fossils allows refining the sedimentological and stratigraphic interpretations. Ichnology has widely been used in paleo-ecological, paleo-environmental, and evolutionary analysis. A crowded *Rosselia socialis* ichnofabric (CRI, *i.e.*, dense abundance of *R. socialis*) provides in this study a valuable guide to recognize the depositional units of a transgressive system tract (TST). *Rosselia* is a dwelling burrow of the infaunal detritus-feeding worms (terebellid polychaetes) and is common in the Phanerozoic shallow-marine deposits. This study aims (1) to interpret the occurrence of *Rosselia* and others associated trace fossils in the Sakmarian-Asselian postglacial deposits of the Rio Bonito Formation (RBF) of Paraná Basin in southern Brazil and (2) to evaluate potential of the CRI as a powerful tool for the refinement of stratigraphic framework, explicitly, in this unit. The deposits of the RBF are coeval to the climatic amelioration associated with the postglacial Gondwana drifting away from the southern paleo-pole. In the study area, a glacially incised paleovalley is exposed (the Capané paleovalley, near Caçapava do Sul, RS) which was initially filled with sediments deposited in a tide-dominated estuarine setting and later in a wave-influenced shoreface environment. The succession indicates a confined retrogradational stacking pattern during the estuarine phase of sedimentation followed by an open-marine shoreface deposition after the filling and then complete burial of the paleovalley. In the outcrop, the CRI occurs in the sandy heterolithic facies of the estuarine setting indicating a relatively high-energy sedimentation likely associated with the storm events influencing the paleovalley. The CRI units are preserved primarily in the oldest parasequence(s) of TST. The *Rosselia* specimens are either vertical or inclined with respect to the bedding surface and have 5-7 cm diameter with a 5-10 mm wide central burrow. The partial decapitation by erosion of the spindle-shaped bulbous top of the burrows resulted in their funnel-like shape in the cross-sectional exposure. In the bedding-surface view, the decapitated bulbous top of *R. socialis* appears like concentric circles. The CRI reflects the tolerance of these organisms to the stress caused by high-hydrodynamic energy and high-frequency depositional events during storms within the TST. This scenario inhibits the presence of other trace-fossil producers that are, otherwise, common in the surrounding subenvironments of the paleovalley, therefore, resulting in the monospecific occurrences of *R. socialis* explicitly in the storm deposits. The partial decapitation and the recurring stacked occurrence of *R. socialis* further point toward the successive events of erosion followed by the resumption burrowing activity by the trace maker after each event. The further diligent analysis of this record will lead to refining the current stratigraphic interpretations of the RBF and to evaluation of the potential of CRI deposits for the correlation purpose in the regions that constitute the Sakmarian-Asselian basinal depocenter of Paraná Basin.

APPLIED ICHNOLOGY TO INTERPRETATION OF DEPOSITIONAL PALEOENVIRONMENTS AND SEQUENCE STRATIGRAPHY OF NONMARINE DEPOSITS OF THE BAURU BASIN, BRAZIL

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This research shows that continental trace fossils are also highly informative for paleoenvironmental interpretation and analysis of sequence stratigraphic frameworks of nonmarine deposits. The purpose of this case study is to investigate the initial evolution of the Bauru Basin, comprising the Caiuá and Pirapozinho formations. This basin developed from Cenomanian to Paleocene in the backbulge province of a retroarc foreland system. Pterosaurs and lizards cannot date the age of the studied sequence more precisely than Cenomanian-Turonian. Despite some earlier efforts that indicated eolian, fluvial and lacustrine sedimentation, an integrated ichnological and sedimentological model has not yet been proposed for these deposits. Subsurface investigations of trace fossils, facies relationships and stratigraphic correlations, core and well-log-based, afford an interpretation of paleodepositional subenvironments, and allow the characterization of staking patterns and system tracts. The studied depositional sequence starts with a LST characterized by amalgamated channel deposits associated with eolian dunes and interdunes deposits, followed by a relatively greater proportion floodplain fines deposits. This succession has no to moderate bioturbation, with low diversity of trace fossils, mainly *Skolithos*, *Arenicolites* and *Planolites*, and secondarily *Palaeophycus*, *Taenidium* and *Scoyenia*, associated with root traces. These deposits pass upward into a TST represented by isolated channel bodies encased within floodplain fines and hydrologically open lacustrine deposits, which are followed by the progradation of meandering distributary channels over delta front deposits, characterizing the HST. These successions are moderately bioturbated, with more diverse suites of trace fossils, comprising (i) *Skolithos*, *Arenicolites*, *Planolites*, *Taenidium* and root traces on fluvial channels bars, crevasse splays and littoral lacustrine environments, (ii) *Scoyenia*, *Spongeliomorpha*, *Camborygma*, *Taenidium*, *Beaconites* and *Planolites* on floodplains and marginal lacustrine deposits, and also *Edaphichnium* and root traces on pedogeneized floodplains deposits. The HST is followed by a stage of lake-level fall and subaerial erosion.

The ichnological analysis of this depositional sequence was particularly useful to: (1) recognize marginal lacustrine deposits, (2) distinguish different degrees of pedogenesis, (3) estimate the water table position, (4) recognize submerged or subaerially exposed fluvial top bars and their colonization windows, and (5) decipher paleodepositional trends. In a final analysis, this case study demonstrates the applicability of ichnology to the characterization of nonmarine paleodepositional environments, including interpretations about water table positions, saturation of the substrates and sedimentation rate, being particularly relevant sequence stratigraphy.

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TECTONIC CONTROL ON ICHNOFABRICS: EXAMPLES FROM THE EARLY TO MIDDLE MIOCENE FOREARC BASIN FILLS OF SW JAPAN

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During the early to middle Miocene, the SW Japan Arc rapidly rotated clockwise in accordance with spreading of its backarc. To the south of the arc, another backarc almost concomitantly spread and started forced subduction underneath the arc. These tectonic events were also associated with, or followed by diverse volcanisms that formed various igneous rock bodies scattered in the forearc region. Although most of the sediments recording those "catastrophic events" have been removed due to uplifting of the entire arc from the late Miocene, early to middle Miocene sedimentary bodies are sporadically preserved in the arc. These sediments allow testing the influences of tectonics on ichnofabrics.

The shallow marine to nonmarine successions of the Misaki Group is a 3,000 meters thick forearc basin fill, and is characterized by extremely low ichnodiversity and basin-wide paucity of ichnofabrics[1]. Such ichnological characteristics were ascribed to environmental stresses caused by highly frequent and rapid sedimentation, which was induced by sediment mass-production in the hinterland, as recorded in coeval, coarse-grained terrestrial deposits of the Kuma Group, located approximately 80 kilometers north[1]. Uplifting of the terrestrial forearc region due to the forced subduction was interpreted to be a main causal factor of the sediment mass-production[1]. If this interpretation is correct, other forearc basins should also show the similar characteristics of ichnofabrics. Another forearc basin fill of the Tanabe Group situated approximately 200 kilometers ENE of the Misaki Group is also characterized by its slightly less bioturbate sediments comparing to "normal" ones in more stable settings. However, unbioturbated or considerably less bioturbated sediments like those in the Misaki Group are not so common.

The Tanabe Group consists of up to 1,500 meters thick, shallow marine to nonmarine sedimentary successions. Judging from its thickness and reconstructed palaeogeography of its hinterland, it is most likely that the Tanabe Basin was experienced less subsidence and the hinterland was much smaller and less uplifted comparing to those of the Misaki Group.

In the Misaki Basin, subsidence was probably much greater as shown in its thickness. Its sediment source (Kuma Group) was cut and/or overlain by igneous or pyroclastic rocks bodies of the Ishizuchi Group, whose volcanism was chronologically overlapped with top of the Kuma Group. Moreover, the Kuma Group clearly shows several dome structures of which centers are roughly correspond to the large-scale Ishizuchi intrusive rocks. These suggest that sediment mass-production in the Misaki source areas was probably enhanced by considerable uplifting caused not only by the forced subduction but also by the Ishizuchi volcanisms.

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WATER TOXICITY AS A STRESS FACTOR IN ESTUARINE SETTINGS: A HYPOTHESIS BASED ON TRACE FOSSILS

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This contribution discusses a unique suite of a monotypic 'crowded *Palaeophycus* ichnofabric' (CPI) in a paleo-estuarine succession and its relationship with potential water toxicity caused by storm surges in the peat-rich estuarine valleys. The basal succession of the Rio Bonito Formation (early Permian of the Paraná Basin, southern Brazil) exposed in Cambaí Grande region is represented by the incised-valley-fill sediments deposited during the rising relative sea level after the demise of glaciation in the western Gondwana. The facies associations of 7 depositional settings characterize this succession: deposits of glacially-influenced outwash plain, fluvially-influenced delta, tide-influenced estuary, lagoon, fairweather-wave-influenced estuary, storm-influenced estuary, and beach bar. Although the coal beds are ubiquitous in the Rio Bonito Formation reaching up to 6 m-thick seams, they are either absent or present as thin-bedded lenses in the Cambaí Grande region. Two trace fossil suites occur besides the CPI: a brackish-water and a fully-marine suite. The brackish-water suite predominates in the whole sedimentary succession. The fully-marine suite occurs locally in the fair-weather wave-dominated and beach-bar deposits. However, the CPI occurs solely in the heterolithic sediments of the facies association deposited in the fairweather-wave-influenced estuary overlying the storm-wave-influenced beds. The CPI is represented by a tight bunch of non-branching burrows, *Palaeophycus tubularis*, with smooth walls, an average diameter of 0.5 cm, and passive infill. The wrinkle structures occur at the top of storm beds, indicating microbial mat growth and substrate biostabilization and, thus, defining a short diastem. Monotypic trace-fossil assemblages are common in the estuarine settings due to stresses caused by frequent salinity fluctuations and disoxia. For our case, however, the fairweather-wave action must have promoted enough substrate oxygenation; and, also the marine incursions should have sufficiently mitigated the effects of abrupt salinity changes. Moreover, despite these two stress factors, the moderate- to low-energy hydrodynamic conditions as interpreted for the deposition of heterolithic strata should have somewhat favored more ichnodiversity and its consequent composite ichnofabric. Instead, the occurrence of only the CPI point toward some additional stress factor that must have inhibited any benthic colonizer other than the producers of *P. tubularis* during the fair weather conditions. The good preservation of biostabilization structure immediately after every storm surge suggests a suitable short-lasting environmental condition only for microbial communities within the Cambaí Grande estuary. The missing coal seams in this paleo-valley, which are ubiquitous in other estuarine valleys in the basin, indicate the likely erosion and remobilization of the original peats by the storm scouring that resulted in the massive release of toxic heavy metals and methane, and, thereby, exterminated all lifeforms in the valley except the microbes. With decreasing toxicity, it opened up a colonization window to the polychaete producers of *P. tubularis* that apparently were more tolerant to toxins, especially to the heavy metals due to the complex symbiotic ethology of worms.

BOTTOM CURRENTS IN THE JURASSIC-CRETACEOUS VACA MUERTA FORMATION BLACK SHALES (ARGENTINA): AN EXAMPLE OF BENTHOS RESPONSE TO OXYGEN DELIVERY IN OXYGEN-DEFICIENT ENVIRONMENTS

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The Vaca Muerta Formation represents marine bottomset and foreset facies of a mixed carbonate-siliciclastic ramp developed during Late Jurassic-Early Cretaceous in the Neuquén Basin, Argentina. Mudstone, marl and limestone deposited in low-energy, oxygen-deficient settings constitute the main lithologies of this formation. The present contribution describes mudstone and minor very fine-grained sandstone lithofacies showing variable intensities of bioturbation in cores from two wells (239 m thick in total) from the central Neuquén Basin area. Nine cycles of oxygenation events occur within outer to mid ramp settings and are subdivided in low- and high-energy. Low-energy cycles (30-50 cm thick) are characterized by very thin-bedded, parallel- to ripple cross-laminated, coarse to medium mudstone couplets. Intervals grade from highly bioturbated to sparsely bioturbated, showing *Teichichnus* and biodeformational structures. High-energy cycles (1-10 m thick) show typical coarsening-upward trends in the lower part to fining-upward patterns in the upper part. Their bases consist of a mottled mudstone and minor sandstone, grading towards sharp-based, thin-bedded, current-ripple cross-laminated mudstone. The cycles end with a mottled interval capped by cryptobioturbated mudstone. Bioturbation index displays a distinctive decrease to increase pattern, showing particularly small occurrences of *Asterosoma*, *Bergaueria*, *Conichnus*, *Cylindrichnus*, *Palaeophycus*, *Planolites*, *Phycosiphon*, *Skolithos* and escape trace fossils. Equilibrium behavior is inferred for *Bergaueria* and *Conichnus*. The cycles record bottom current activity at the upper slope, with hydrodynamic energy and oxygenation being limiting factors for the benthos and, therefore, controlling bioturbation. The cycles display increasing to decreasing energy conditions that show an inverse correlation with bioturbation index driven by shorter colonization windows in the higher energy settings (middle parts of the cycles). Bottom currents delivered oxygen to bottom waters, supporting a moderately diverse ichnofauna. Waning of bottom currents towards the end of the cycles generated progressive deoxygenation of the seafloor. Cryptobioturbation on top indicates that smaller organisms were able to thrive in lower oxygen conditions, documenting the last stage of the oxygenation event.

CHRONOSTRATIGRAPHY AND ENVIRONMENT OF FURNAS FORMATION BY TRACE FOSSIL ANALYSIS: CALIBRATING THE LOWER PALEOZOIC GONDWANA REALM IN THE PARANÁ BASIN (BRAZIL)

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Ichnology is an important tool for facies and sequence stratigraphic analysis, typically yielding greater resolution than that provided by body fossils. Less commonly, ichnofossils also can be applied to ichnostratigraphy, a variant of biostratigraphy that aids in determining stratigraphic age of sedimentary sequences. Previous publications on the Furnas Formation (Paraná Group, early Paleozoic of the Paraná Basin), have yielded different interpretations of age, depositional environment, and sequence stratigraphic framework. Deposition in fluvial environments has been proposed in many papers, although a tide-influenced marine context has been inferred since the presence of *Cruziana* and *Rusophycus* was reported during the 1990s. Sequence stratigraphic interpretations also differ, mainly regarding the presence or absence of a sequence boundary between the middle and upper units of the Furnas Formation. The absence of body fossils in all but the topmost part of the upper unit, which contains Lochkovian (Lower Devonian) palynomorphs and primitive plants, has precluded age determination for the Furnas Formation in general. Here, we demonstrate the utility of both ichnofacies and ichnostratigraphic analysis to elucidate such questions. The studied sections are located in the cities of Tibagi, Palmeira and Ponta Grossa (Guartelá, Sítio Canei and São Jorge sections, respectively). Seventeen ichnotaxa are recognized, doubling the number of previously known ichnotaxa: *Cruziana acacensis elongata* and *Rusophycus acacensis* n. ichnosp. (in the lower and middle units); *Arthrophycus alleghaniensis*, *A. brongniartii, Rhizocorallium commune, Didymaulyponomos rowei* and *Heimdallia chatwini* (middle unit only); *Arenicolites, Cylindrichnus* and *Diplocraterion* (lower and upper units); *Lockeia siliquaria* and *Psammichnites implexus* (middle and upper units); *Rosselia socialis* (upper unit); and *Palaeophycus tubularis, Didymaulichnus lyelli, Skolithos,* and *Thalassinoides* (all units). Assemblages of these ichnofossils are assigned to Skolithos and proximal Cruziana ichnofacies. Ichnologic data, combined with associated physical sedimentary facies associations, indicate predominantly tide-influenced marine depositional environments. The presence of ichnotaxa of stratigraphic value (*Arthrophycus alleghaniensis*, *A. brongniartii* and *Cruziana acacensis elongata*) in lower and middle units indicates an Early Silurian age. This, in turn, indicates that a significant unconformity exists between the middle and upper units of Furnas Formation. Although the precise magnitude of this stratigraphic gap is difficult to establish, this break likely is linked to the Late Silurian global regression.

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SEDIMENTARY CONTROLS ON THE TRACE FOSSIL RECORD OF TERRESTRIALIZATION: COMBINING NEW EVIDENCE FROM AUSTRALIA, EUROPE AND NORTH AMERICA

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Our ichnological understanding of major evolutionary events can sometimes be biased to particular geographic regions. For example, the known record of terrestrialization – the Silurian-Devonian colonization of the land by animals – is heavily biased to ichnological and sedimentological data from Europe and North America. This does not only reflect a historical bias in study locations, but also the exposure of rocks of this age: the extensive heterolithic redbed successions of the 'Catskill Delta' and 'Old Red Sandstone'. These strata archive a huge amount of ichnological information but they may not be globally representative because they were almost unanimously deposited in basins bordering the Caledonide/Acadian mountain belts, under warm climates, near the palaeo-equator; and dominated by fine grained continental deposits, representing muddy coastal plains and alluvial floodplains.

Less well studied, a suite of similar aged strata occurs across the modern continent of Australia, within a variety of palaeoenvironmental sedimentary facies. Among these, the heterolithic Grampians Group, Victoria, is arguably most akin to 'Old Red Sandstone'-type facies, recording a range of offshore to continental depositional settings. However, other locations are dominated by coarser (sandstone-dominated) strata that are rare in Euramerican settings, including estuarine facies of the Tumblagooda Sandstone, Western Australia, and aeolian facies of the Mereenie Sandstone, Northern Territory. This talk presents new field data comparing the sedimentology and ichnology of these Australian sections with other original data from successions in Europe and North America. We show how physical sedimentological factors, such as grain-size, have influenced ichnological characteristics including trace fossil size, diversity and the most common ichnotaxa. Additionally, those strata deposited under higher energy conditions (e.g., in-channel fluvial deposits) have inherently lower ichnodiversity. We suggest that the properties of sedimentological media, with which the first non-marine animals interacted, exerted a first order control on the ichnological record of those interactions.

Combining the Australian data with the Euramerican data provides a similar record in terms of the broad Silurian-Devonian timing and ichnodiversity of the colonization event. The greatest ichnodiversity occurs in marine-influenced terrestrial strata, whereas arid continental strata record lower diversity ichnoassemblages. Further, we emphasize the importance of documenting different types of sediment in which ichnotaxa are hosted, when trying to understand the colonization of the land. This is because organisms may have needed to overcome different obstacles before occupying them, e.g. the different biomechanical constraints of burrowing in sand versus mud.

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OCEANIC RED BEDS – ONLY TRACE FOSSILS RECORD PREVIOUS TROPHIC LEVELS (A CASE STUDY OF EOCENE DEEP-SEA SEDIMENTS IN THE CARPATHIANS)

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Oceanic red beds formed in an oxic setting below the calcite compensation depth (CCD) are effectively barren of organic matter in the present state. Trace fossils and ichnofabrics are very suitable for deciphering the environmental setting as macrofossil and microfossil remains are sparse to absent. Trace fossils indicate that benthic food was sufficient to support a weakly tiered burrowing fauna that penetrated to depths of up to 10 cm, comparable to those in modern sediments.

Organic matter deposition on the sea floor fluctuated seasonally as evidenced by the trace fossils *Scolicia*, *Nereites,* and *Avetoichnus*. *Scolicia* produced by sea urchins may cover the lower surface of distal low-erosive turbidites that preserve the nearly complete bioturbated zone underneath. *Scolicia* is large (>4 cm diameter) and may cover a whole surface while showing guided meanders. These traces are indicative of the presence of considerable amounts of nutritious organic matter. The sea urchins exploited the buried sea floor shortly after turbidite deposition. *Nereites* producers supposedly lived like today above the redox potential discontinuity where pore water oxygen content is somewhat lowered. They respond rapidly to seasonal deposition of organic matter on the sea floor and utilized it as additional food source and hence, move upward and downward. *Avetoichnus* producers store organic matter in a spiral surrounding a central tube.

Seasonally deposited organic matter probably provided by upwelling appears to have supported bulldozing organisms on the sea floor that, in cooperation with *Nereites* producers counteracted the formation of graphoglyptids. In modern deep-sea settings graphoglyptids have so far only been reported from areas affected by weak seasonality.

Sedimentary organic matter experienced later oxidation even if high amounts arrived seasonally while sedimentation rate was very low and thus, oxygen exposure time of the organic matter was considerably long (>500–700 yr). Oxygen exposure times provide a minimum estimate for the recurrence time of turbidites. Low sedimentation rates in combination with bioturbation facilitated oxidation of organic matter buried by turbidites because the burrowing organisms enhanced flux of oxygen into sediment while pumping oxygenated respiration water into considerable sediment depth. In this way, the deposition of organic matter facilitated its latter degradation and final absence. Thus, in red mudstone, trace fossils exhibit special adaptations to the food-restricted deep-sea environment, such as small size (e.g., *Planolites* and *Thalassinoides*-like burrows). Also, the vertical extent of the bioturbated zone is small, c. 10 to 12 cm (after decompaction). These observations match findings in modern, slowly accumulating, food-limited deep-sea settings.

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EDIACARAN AUTHIGENIC CARBONATES FROM THE EAST EUROPEAN CRATON PRODUCED BY EARLY-DIAGENETIC DEGRADATION OF ORGANIC MATTER ON LAND?

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The Ediacaran sedimentary rocks of the East European Craton are mostly clastic deposits (sandstones, siltstones and mudstones). What is particularly striking, they are usually not lithified, exhibit low diagenetic overprint and have not experienced deep burial. Quantitative mineral composition was studied by XRD in core samples from several tens of wells. Carbonate minerals are common, but their contents rarely exceed 30%. We investigated petrography and geochemistry of these carbonate-bearing rocks with optical and electron microscopy, CL and stable C and O isotopes to understand their formation and the sedimentary environment.

None of the samples examined microscopically contain sedimentary marine carbonate. Calcite usually occurs as intergranular poikilotopic cement with very low $\delta^{13}C$ and $\delta^{18}O$ values indicating recrystallization of microbial cements at increased temperature. Marine calcite cements were found, but they are Upper Cretaceous in age, as indicated by U-Pb dating. Carbonate cements in basalts are products of Ediacaran continental weathering, as confirmed by their U-Pb ages. Dolomite and siderite usually occur as early-diagenetic cements in clastic rocks. Siderites are often developed as spherosiderites that are regarded as meteoric water-derived precipitates associated with pedogenesis. Their $\delta^{13}C$ values are negative (~ -10‰) or strongly positive (up to +14‰), which indicates that the source of inorganic carbon was microbial oxidation of organic matter (OM) and methanogenesis, respectively. Idiomorphic microcrystalline dolomite and siderite with low $\delta^{13}C$ and moderate $\delta^{18}O$ values formed in a phreatic environment (marine or brackish) due to microbial degradation of OM. The dolomites from Arkhangelsk area are strongly enriched in ^{18}O, which indicates formation in a saline lake with high evaporation. Our work indicates that OM content in the Ediacaran settings of the East European Craton, both marine and continental, was high enough to support intensive microbial processes, such as fermentation. Such redox conditions during diagenesis normally favor preservation of carbonate, which suggests that significant production of $CaCO_3$ did not occur in the basin.

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A BIOLOGICAL BASIS FOR CYCLIC ENRICHMENTS IN ORGANIC CARBON OF MESOPROTEROZOIC BLACKS SHALES

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It is widely appreciated that high levels of primary productivity and organic matter export can influence basin redox, in particular, Johnston et al (1) demonstrated the relationship between high levels of organic carbon export and euxinia, while Anbar and Knoll (2) highlighted how basin redox, in particular euxinia, could influence nutrient concentrations, in particular nitrogen. Such processes could naturally influence primary productivity and organic carbon burial.

Building upon these initial hypotheses, we present coupled $\delta^{15}N$, $\delta^{13}C$, TOC, Mo and V data that suggests cycling of high TOC sediments in a Mesoproterozoic black shale succession of the McArthur Basin is controlled by oscillations between nitrogen replete and nitrogen limited conditions. These are a consequence of oscillations in euxinic conditions and its impact on molybdenum concentrations, an essential trace nutrient that regulates N_2 fixation. Due to the Mo dependence of N_2-fixation, the cyclic organofacies observed in the Velkerri Formation are a consequence of the interaction between biological metabolisms and redox processes.

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Cavity-filling dolomite speleothems and submarine cements in the Ediacaran Dengying microbialites, South China: Responses to high-frequency sea-level fluctuations in the "aragonite-dolomite sea"

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Speleothems mostly composed of calcium carbonates, are widely present in modern karstic caves but have rarely been identified in paleokarst systems. This study presents unique dolomite speleothems followed by submarine cements, recorded in the Upper Ediacaran Dengying Formation in South China. These cavity infills occur in karstic cavities that cut the dolomicrobialite host. The speleothems consisting of micritic, micro-crystalline and acicular dolomites, formed the innermost cavity infills as micro-stalactites/stalagmites exclusively within the bedding-parallel sheet-crack cavities. All these suggest a meteoric environment under which the host dolomites were subject to intense dissolution followed by speleothem precipitation in the cavities. Their co-occurrence with other exposure features (e.g. tepee structure) agrees with this meteoric dissolution-precipitation process. Furthermore, protodolomite, acicular Mg-calcite and micro-crystalline calcite precursors were identified in these speleothems, seemingly having been precipitated from supersaturated cave water with variable Mg/Ca ratio, probably attributed to the dissolution of dolomite host rock supplemented by prior calcite precipitation. Meanwhile, the C-O isotope compositions of these speleothems show similarity to the coeval marine dolomites, further suggesting dolomitization of these precursors in seawater. The isopachous morphology and crystal fabric (e.g. smooth growth bands) of more extensive radiaxial dolomites and their similar C-O isotope compositions to the host dolomites attest to their primary precipitation as radiaxial calcites and then mimetic dolomitization in seawater. Thus, these cavity-filling speleothems were initially formed in meteoric environments immediately after meteoric dissolution of the peritidal dolomicrobialites and followed by more extensive submarine precipitation and mimetic dolomitization by seawater flooding. Periodic subaerial exposures and marine floodings of the broad mild tidal flat in the upper Yangtze area driven by the high-frequency sea-level fluctuations could have provided an exclusive condition favourable for the rapid switches of meteoric-marine environments. Futhermore, the Neoproterozoic specified seawater chemistry of "aragonite-dolomite sea" was an advantage for syndepositional dolomite precipitation.

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THE BYLOT SUPERGROUP OF NORTHERN BAFFIN ISLAND: A RICH ARCHIVE OF MESOPROTEROZOIC GLOBAL CHANGE

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The Bylot basins are a series of late Mesoproterozoic intracratonic basins that occur in the Arctic Islands of northeastern Canada and in northwestern Greenland. The Bylot Supergroup, which fills the Borden basin in northwestern Baffin and Bylot islands, is the best studied of these basins and has proven to be an unusually rich source of data informing the geodynamics of Laurentia and the evolution of the global environment in the late Mesoproterozoic. Like the successions in the other Bylot basins, the Bylot Supergroup includes a lower interval of basalt flows (Nauyat Formation), which is considered cogenetic with the 1270 Ma Mackenzie dykes. Whereas a thick succession of carbonates in the middle Bylot Supergroup (Iqqittuq, Angmaat, Victor Bay, and Athole Point) were believed to be ca. 1200 Ma, based in part on a simple rift-drift model of Borden Basin evolution, new geochronological results indicate these rocks are much younger. Re-Os ages from black shales in the middle Arctic Bay Formation (1048 ± 12 Ma) and the lower Victor Bay Formation (1046 ± 16 Ma) imply the Angmaat Formation is ca. 1045 Ma. These results provide a critical new age for the first appearance of the oldest taxonomically resolvable fossil of photosynthetic alga (*Bangiomorpha pubescens*) and support an age of ca. 1.25 Ga for the origination of photosynthesis within eukaryotes. These dates also refine the timing of the onset of increased variability in the carbon isotope ($\delta^{13}C$) composition of seawater and apparent growth of the marine sulfate reservoir. Finally, they add a new wrinkle to the late Mesoproterozoic Logan Loop apparent polar wander path: the Strathcona Sound Fm. is < ca. 1045 Ma and cannot lie, as previously proposed, on the ascending part of the loop between 1270 and 1100 Ma. Radiogenic isotope (Sr, Os, Nd) data imply that the Borden basin was variably marine and restricted or lacustrine throughout its history. Strontium isotope data from marine carbonates and evaporites also provide important constraints on the influence of the Grenville orogeny on global silicate weathering and ocean chemistry. The tectonic origin of the Borden basin (and by extension, the other Bylot basins) remains controversial, but the new Re-Os ages and varied depositional history suggest that its evolution was complex and long-lived, similar to many other Proterozoic intracratonic basins.

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DEVELOPMENT OF SOFT-SEDIMENT DEFORMATION STRUCTURES IN THE PALEOPROTEROZOIC GORDON LAKE FORMATION, HURONIAN SUPERGROUP, CANADA

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A variety of soft-sediment deformation structures (SSDS) have been identified in the Gordon Lake Formation of the Paleoproterozoic Huronian Supergroup in four regions of Ontario, Canada. Structures preserved in strata near Flack Lake and Baie Fine include load casts, convolute bedding, ball-and-pillow structures, pseudonodules and flame structures that range from 1-45 cm in diameter. In the Bruce Mines area, the types of SSDS are similar, but are significantly larger with diameters reaching 1.2 m. Additional SSDS in this region include a dewatering pipe. Near Gowganda, Ontario, only small-scale synsedimentary faults and folds were identified. The most spectacular representation of SSDS in the Gordon Lake Formation was found in a 230 m long outcrop exposure of siltstone and fine-grained sandstone near Bruce Mines. The rock types coupled with the presence of wave ripples, low angle cross-bedding, and desiccation cracks towards the top of the stratigraphy support deposition in a shallow shelf setting in this region. Determining the trigger mechanisms and order of events for SSDS in shallow marine environments is challenging as there are several possible trigger mechanisms to consider. Using a context-based approach, the main trigger mechanism is interpreted to be storm or tsunami activity, based in part on the presence of mud rip-up clasts, graded beds, sandy event deposits, truncated flame structures, and large size and lateral variability of several SSDS intervals. Earthquakes, unstable density contrasts, or a combination of these processes may have influenced the formation of SSDS to a lesser degree. There is also evidence of biofilms in the outcrop exposure, including flat to wavy carbonaceous laminae, local botryoidal texture and concentrations of heavy minerals. Several intervals of SSDS appear to have formed below stabilized surfaces. In the absence of vegetation, biofilms would have played an important role in sediment stabilization. In general, the sandy event beds, which sourced the pseudonodules in the Bruce Mines area, appear to have been stabilized prior to the formation of SSDS. The pseudonodules are approximately 1-15 cm wide, appear circular and well-rounded, and are present in both detached and partially-detached forms. Texturally, these structures consist of siltstone to medium-grained sandstone, with mud-stone rip-up clasts and heavy minerals. The relatively coarser-grained event beds may have provided a favourable surface for microbial mats to colonize and locally appear to have prevented more pseudonodules from forming. Microbial mats may have played a minor role in the formation of SSDS, but do not appear to have been a prominent driving mechanism. The smaller size of the SSDS identified in the Gowganda, Flack Lake and Baie Fine regions suggests that the deposits near Bruce Mines were either affected by local events or different sedimentary processes related to basin configuration.

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CHARACTERISTICS OF EDIACARAN CAP CARBONATES IN SHENNONGJIA AREA, NORTHERN YANGTZE CRATON，SOUTH CHINA AND THEIR PALAEOGEOGRAPHIC IMPLICATIONS

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An integrated Cryogenian - Ediacaran sequence developed very well in Shennongjia Area, the northern margin of Yangtze Craton, South China. Based on 6 Ediacaran profiles bearing cap carbonates, this paper systematically studies their stratigraphy, sedimentology and C-O isotope geochemistry, sedimentary environment and their geological implications, and reconstructed the Ediacaran basin framework and the paleogeographic setting according to a series of sedimentary facies markers developed in cap carbonate rocks. Cap carbonates from Shennongjia are composed of fine powder crystal dolomites with horizontal beddings or block stratifications. There are few other special sedimentary structures or lithological and mineral components but some cumularspharolithe and leaf branch-like algae. The $\delta^{13}C$ values of the cap dolomites show that they have a negative drift from the extremely lower (-6 ‰～-9 ‰) to middle lower (-4 ‰～-5 ‰) in ascending order, and the $\delta^{13}C$ values still keep a middle to lower negative drift on the overlying sediments. Which proves that the cap carbonate rocks in Shennongjia can be correlated with the Yangtze craton and the other place of the world[1]. The cap dolomites mainly developed in the shallow water shelf tidal in the central-west part of Shennongjia Area. The cap dolomites and overlying strata formed the rapidly transgressive sequence. The sedimentary facies index indicate that it formed synchronously and diachronically with sea level rapidly rising and mainly deposited in a shallow water shelf Intertidal – supratidal flat. The Yangtze craton was a widely shallow water shelf environment during the early Ediacaran period that the cap carbonates deposited. The watershed of the Kongling-Huangling Anticline spans through the southern Yangtze Sea and the northern Qinling Sea. And the paleogeographic patterns of the basin - slope break-continental shelf-tidal flat deposited respectively on both sides of Huangling Anticline (in the North and the south) during Cryogenian – Ediacaran period.

Key Words: the northern margin of Yangtze Craton, Shennongjia, cap carbonates, sedimentary Characteristics, Paleogrography

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A TALE OF TWO PROTEROZOIC ORGANIC-RICH UNITS FROM THE CANADIAN ARCTIC: ORIGIN, PETROLEUM POTENTIAL, AND THE FATE OF GENERATED OIL WITH IMPLICATIONS TO PALEOENVIRONMENTS†

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Previous multidisciplinary studies of organic-rich units of the Mesoproterozoic Arctic Bay Formation (superbly exposed at the Shale Valley, Borden Basin, northern Baffin Island; Turner and Kamber, 2012), and the Neoproterozoic Wynniatt Formation (retrieved from a subsurface core GNME 07-04, Amundsen Basin, Victoria Island; Thomson et al, 2015) were focused on reconstructing the paleo-depositional environments, origin of early life, and the genesis of mineral enrichments. The shales are characterized by a mean residual total organic carbon (TOC) content of ~4.9 wt. % and ~6.1 wt. %, respectively. However, the nature of their organic matter, petroleum potential, and the fate of the generated petroleum is poorly understood.

In this study, Rock-Eval 6 analysis, organic petrology, geochemistry, palynology, depositional environment interpretation (based on lithological descriptions), and/or the reconstructed tectono-stratigraphic post-depositional history are integrated to reconstruct the burial history and evaluate the initial petroleum generation potential of those units.

Results suggest that both units are excellent source rocks. The 220 m thick shale of the Arctic Bay Formation, interpreted as lacustrine Type I source rock with calculated initial TOC of 11 wt. %, had the ultimate hydrocarbon potential of 256,400 barrels per square kilometer (five times higher than well-known source rocks in Gulf of Mexico and West Africa). The 40 m thick shale of the Wynniatt Formation, interpreted as marine Type II source rock with calculated initial TOC of 8.5 wt. % had the ultimate hydrocarbon potential of 26,000 barrels per square kilometer. While small fractions of generated petroleum might be entrapped within Proterozoic units, such as the estimated 28 billion barrels of recoverable oil in Walker Bay Anticline (Pelechaty 1991) and/or the overlying stratigraphic units, the vast majority of oil has leaked out to paleo-environments. Literature review forms the basis for understanding the petroleum migration and losses as well as commonly overseen impact of natural petroleum seepages on paleo-environments.

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PRECAMBRIAN PALEOSOLS OF THE EAST EUROPEAN CRATON: CLAY MINERAL FORMATION AND PALEOCLIMATE

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Paleosols are formed at the Earth's surface in direct contact with climatic and environmental conditions that prevailed at the time of their formation and therefore they offer a unique opportunity for studying past climates. In this contribution we investigate Meso- and Neoproterozoic paleosols collected from different areas of the East European Craton (EEC): Estonia, Lithuania, Belarus, Ukraine, and Poland. These paleosols offer a chance to examine continental weathering sequences from early to advanced stages of weathering on a variety of different parent materials (gneisses, granites, gabbros, amphibolites and basalts[1]). Paleosol profiles are on average 10 meters thick, reddish colored, and many of them are characterized by a well-developed and well-defined alteration sequence with a lateritic uppermost horizon indicated by Chemical Index of Alteration – CIA[2] values reaching 90–95. The paleosol profiles are affected by low-temperature (<100°C) Paleozoic diagenesis evidenced by K-Ar dating of clay fractions containing illite-smectite and aluminoceladonite. The maximum dioctahedral smectite illitization is ca. 30% S, however some profiles offer a unique record of paleoweathering with minimum diagenetic overprint of 90–60% S. A well-developed weathering profile is characterized by a gradual decrease of primary rock-forming minerals and simultaneous increase of secondary minerals towards the top. The EEC paleosol profiles developed on mafic parent materials show a weathering trend where dioctahedral smectite is the first weathering product at the bottom, it dominates in the middle-upper horizons and it later becomes unstable and alters into kaolinite. The EEC paleosols developed on acidic parent materials show a different weathering trend: kaolinite forms already at the first stages of weathering as a result of plagioclase dissolution and pure smectitic zone is absent. Kaolinite content in the uppermost horizons typically remains around 20 wt%, however in profiles developed on basalts it can reach 60 wt%. Fe-minerals show a clear increasing trend towards the top, reaching up to 30 wt% in profiles developed on basalts. The studied EEC paleosols indicate that the dominant type of weathering leads towards kaolinite and Fe-mineral assemblage through smectitic intermediate stage, more pronounced in paleosols developed on basic rocks. It is likely that uppermost kaolinite dominated horizons which are lacking in some profiles have been eroded. Such paleosol composition indicates oxidative weathering and is usually interpreted to represent warm and humid climate, which seems to have prevailed at the EEC over entire Mezo- and Neoproterozoic.

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Enigmatic giant ooids in the Doushantuo Formation, Ediacaran, Yangtze Platform, South China: Origin and paleoenvironmental significance

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Giant ooids, as an anachronistic facies, were identified in the Doushantuo Formation and exhibit unusual features that may provide a window into oceanic chemistry of interglacial Ediacaran period. Based on the in-situ laser ablation-inductively coupled plasma-mass spectroscopy (LA-ICP-MS), isotope chemical and petrographic techniques, signals indicative of paleoseawater rare earth element (REE) composition were identified in the cortices of the giant oolite. The occurrence of the giant ooid is in the second positive C-isotope excursion interval of Ediacaran (EP2) by chemostratigraphic correlation. Petrographic observations revealed dark-colored cortices with dark-red cathodeluminescence and structures that resemble microbial filaments and extracellular polymeric substances. The shale-normalized REE and yttrium (Y) data of these layers show 1) light REE depletion (Lasn/Ybsn=0.54±0.13), 2) positive La anomalies (mean (La/La*) sn=2.01±1.13, and 3) high ratios of Y/Ho (mean 54.36±13), which are similar to modern seawater compositions, Bahamas ooids and Triassic giant ooids. The Sr isotope value ranges from 0.708917-0.709018 proving to the seawater composition. These findings imply that giant ooids in the study samples faithfully record the paleoseawater REE+Y distribution information in the Ediacaran. Most oolite dark laminae are characterized by negative Ce anomalies indicative of an oxygenated environment, but minimal negative or positive anomalies in some laminae may be influenced by anaerobic microbial activities and/or porewater. Giant ooid precipitation may have been promoted in shallow water setting during these events by increased watermass agitation, supersaturation with respect to CaCO3, as well as microbial activities. This present study provides a biosphere-environment co-evolutionary perspective of giant oolite origin. The ooid as a proxy of paleoseawater chemistry indicate that the shallow water is an oxygenated open marine environment in the Doushantuo Formation.

Keywords: Giant ooids; Biosphere-environment co-evolutionary; Oxygenated setting; REE+Y; Doushantuo Formation; South China

FACIES ANALYSIS OF FOSSILIFEROUS EDIACARAN DEPOSITS IN SOUTHERN NAMIBIA

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The latest Neoproterozoic (Ediacaran: 635–541 Ma) is a crucial period of Earth history because of the emergence the first known, large complex, multicellular organisms commonly referred to as the Ediacara Biota[1,2]. These organisms are diverse and have a worldwide distribution with the some of the youngest of the Ediacara Biota found in southern Namibia, close to the Ediacaran- Cambrian boundary[2]. Ediacaran fossils in the Nama Group were deposited in a foreland basin associated with the Damara Orogen during the assembly of Gondwana (580 to 680 Ma)[3]. The Kuibis Subgroup in the southern subbasin is significant because it hosts an abundance of *Ernietta*, a classic Ediacaran fossil that has received a considerable amount of study in recent years[4]. Detailed sedimentary analyses utilizing facies-based approaches can provide valuable insight into the paleoecology of the Ediacara Biota. The distribution of facies at a known Ediacaran fossil site, the Kuibis Subgroup exposed Farm Hansburg was investigated by conducting a facies analysis based on 16 measured sections. Lithologic samples were collected at 4 sites and used to provide evidence of the differences in macrosedimentologic structures between the fossil rich layers and other sandstone beds. The 8 identified facies and 3 facies associations were then used to interpret the paleoenvironment as a tide-influenced fluvial to marine transgression with an abundance of microbial mats and identify limiting factors that could have impacted the Ediacara Biota. There are still many questions related to *Ernietta*, in terms of its feeding strategy, reproduction, and resilience to changing environments; as such, facies analyses can be used to set realistic boundaries on the likely natural history of this group based on its response to limiting factors. *Ernietta* were found in the storm influenced muddy tidal flat paleoenvironment indicating these organisms thrived in environments with periodic clastic sediment supply, fluctuating salinity, and medium to high flow velocity. This study emphasizes the importance of paleoenvironmental studies grounded in facies analyses to constrain the physical and chemical characteristics that would have influenced ecosystem development at the base of the metazoan tree.

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ON LITHOLOGICAL NATURE OF PROBLEMATIC FOSSILS

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The Ediacaran (Vendian) sequence of Volyno-Podillia is one of the most complete in the world and being well exposed, full, simple bedding, grate diversity of fossils are considered as characteristic for this stage of geological history. Each stratigraphical Vendian unit possesses facial, lithological and some of them ichnological features, which are persistent laterally. The Bronnytsia beds, which are the part of this section, are represented by solid pelitomorphic rocks: tuffaceous siliceous mudstones, pelitic chocolate-brown tuffites and fine-fractured micaceous mudstones. They contain several thin bentonites. The images of three new forms from the Bronnytsia beds of the Mohyliv-Podilsk Series of the Middle Dniester area were presented in 1972 by Boris S. Sokolov together with numerous other Vendian (Ediacaran) fossils. *Charniodiscus planus* Sokolov sp. nov., *Planomedusites grandis* Sokolov nov. gen et sp., *Medusinites patellaris* Sokolov sp. nov. were discovered in the Borschov Yar exposure of the Mohyliv-Podilskyi town, Vinnytsia area, Ukraine [1]. The images were accompanied by short descriptions. Since then, these fossils, together or individually, have repeatedly appeared in the paleontological characteristics of the stratigraphic subdivisions of the Vendian East European Platform and some other regions. Recently, during the preparation of the Atlas of the Late Vendian macrofossils of Eastern Europe (Middle Dniester area and Volhynia) [2] this point of view of Borys S. Sokolov later has been critically revised. Comprehensive studies of entities similar to those described by Boris S. Sokolov (including SEM EDS-WDS technology) have shown that they are not imprints of nonskeleton organisms (jellyfishes or "medusoids"), but are structures in the sediment (Leisegaung Rings or Layers) formed in the process of diagenesis and visually manifested predominantly as a result of weathering the surface of fragments of lithified rocks. Thus, *Planomedusites grandis, Charniodiscus planus* and *Medusinites patellaris* should be excluded from the paleontological characteristics of the stratigraphic units concerned, and objects described or referred to these names by other authors need to be revised.

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CYCLICITY OF EDIACARAN (VENDIAN) DEPOSITES OF VOLYNO-PODILLIA (UKRAINE)

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The section of the Ediacaran (Vendian) deposits of Volyno-Podillia is one of the most complete in the world and considered as characteristic for this stage of geological history. The base of the Vendian is represented by glacial deposits (tillites) of the Brody Suite that approximately correspondes to the Vilcha Series, which is traced throughout the East European Platform [1]. The upper boundary occurs at the bottom of the *Phycodes pedum* bioglyphs Zone and corresponds to the boundary of Precambrian - Cambrian. The Vendian succession in the Volyno-Podillia is well exposed in rivers valleys [1, 2]. The Vendian deposits are consist of terrigenous siliciclastic strata (up to 600 m thick) of conglomerates, gravelstones, sandstones, silt- and mudstones. The transition from “icehouse” to “greenhouse” conditions was recorded in these strata. At least 9 cycles of sedimentation are distinguished in the Vendian sequence. The first one is represented by the Lower Vendian Volyn Formation, in which Bakhtyn (red-colored coarse-clastic) and Vinkivtsi (grey-colored fine-clastic) members are described. In the Upper Vendian (Mohyliv, Yaryshiv, Nagoriany, Kanyliv formations) 8 sedimentary cycles were preserved. Two cycles identified in Mohyliv Formation, are represented by the Olchedaiv (grey-colored conglomerates, gravelstones, deltaic sandstones) – Lomoziv (gravelstones, sandstones, dark-grey mudstones) and the Yampil (light-grey colored cross-bedded sandstones with numerous imprints of *Nemiana simplex* Palij) – Liadova (greenish-grey, brown mudstones) members. The third cycle corresponded to Yaryshiv Formation is represented by the Bernashivka (light grey sand-, siltstones), Bronnytsia (chocolate-brown tuffites, tuffaceous siliceous mudstones) and Zinkiv (greenish-bluish-grey mudstones, siltstones with the richest in the sequence association of microphytofossils) members. The fourth cycle, the Nagoriany Formation, includes the Dzhurdzhivka Member (gravelstones, sandstones, siltstones) and Kalius Member (dark-grey mudstones). The Kanyliv Formation consists of four sedimentation cycles, each of them correspond to one member. These are in ascending order: the Danylivka, Zharnivka, Krushanivka, Studenytsia members. Lower part in each cycle is more coarse-clastic with dominance of sand-, siltstones. More clayey upper part with essential content of mudstones is recognized. New data on nanotextures, nanostructures and geochemical peculiarities of rocks have been obtained based on study of ichnology, petrography and by SEM, EDS-WDS [3]. In particular, it is revealed paleoenvironmental peculiarities of phosphorites and pelites cyclic accumulation in the Lomoziv, Liadova, Zinkiv, Kalius members, corresponding to transgression, mostly caused by eustatic sea level rise.

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TONIAN EVAPORITES AND THEIR ROLE IN CARBON ISOTOPE CHEMOSTRATIGRAPHY (AMADEUS BASIN, AUSTRALIA)

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The Tonian Bitter Springs Group (~830-750 Ma), within the Amadeus Basin in central Australia consists of thick halite and sulphate evaporite accumulations. The Bitter Springs Group chemostratigraphy has been correlated globally and the negative excursion in the Loves Creek Formation was named previously after this succession (Bitter Springs Stage anomaly). Although recognised globally, the cause of the highly positive $\delta^{13}C$ and the negative excursion is less understood.

In the Amadeus Basin, the deposition of halite occurred in shallow marine, lagoon (salina) environment (Gillen Formation), and developed into sulphate-dominated supratidal sabkha during sea level regression (Johnnys Creek Formation). The overall regression was interrupted by a transgressive phase lasting at least 20 Ma and leading to deposition of basin-wide stromatolitic dolostone (Loves Creek Formation). The global transgression during deposition of the Loves Creek Formation coincides with a period of volcanic activity between ~830 and ~780 Ma in Australia and the onset of the breakup of Rodinia.

The positive $\delta^{13}C$ in carbonates (+4 to +6 ‰ VPDB) of the evaporitic Johnnys Creek and Gillen formations is interpreted to be a result of evaporation-driven fractionation and not related to changes in the DIC-derived carbon reservoir. Conversely, the shallow marine incursion of the Loves Creek Formation (-2 ‰ $\delta^{13}C$) show typical marine carbonate isotopic values. The influence of evaporite-driven might also be recorded in $\delta^{18}O$, with unusual isotopic values of ~+2 ‰ VPDB in carbonates of an anhydrite-dominated interval.

The strong global correlation throughout the pre-glacial Neoproterozoic succession advocates similar climatic conditions and isotopic fractionation mechanisms in other evaporite-bearing sedimentary basins worldwide.

STRATIGRAPHY AND AGE-CALIBRATED CARBONATE $\delta^{13}C$ RECORD FROM THE BYLOT SUPERGROUP, BAFFIN ISLAND: EVOLUTION OF SURFACE-OCEAN CHEMISTRY IN LATE MESOPROTEROZOIC

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Keywords: Meso-Neoproterozoic transition, Bylot Supergroup, carbon isotopes, carbonate platform.

The late Mesoproterozoic to early Neoproterozoic (1.2–0.8 Ma) was a period of gradual oxygen expansion in shallow marine environments. Northern Baffin Island (Arctic Canada) is home to well-preserved strata of the ~6km-thick Bylot Supergroup. Carbonates dominate the middle Bylot Supergroup stratigraphy. The Iqqittuq Formation records the transition from a siliciclastic margin to a NW-deepening carbonate ramp. This ramp evolved into a rimmed platform with the overlying Angmaat Formation representing the rim and restricted inner platform separated from the basinal area in which the Nanisivik Formation was deposited. The contact with the overlying Victor Bay Formation records reactivation of the basin. The Victor Bay Formation represents a carbonate ramp dominated by shales, rhythmites and floatstone in the outer-ramp, limestones rich in molar-tooth structures in the mid-ramp, and microbiolaminated limestones in the inner-ramp. Generation of accommodation space during this time allowed the build-up of large deep-water stromatolitic reefs transitioning from the outer-ramp to the mid-ramp. The Athole Point Formation is a unit of fine grainstones alternating with rhythmite facies at the base and becoming increasingly siliciclastic approaching the upper contact with the Strathcona Sound Formation. The age of the Angmaat Formation has been constrained by new Re-Os ages from organic black shales ca. 1048±0.012 Ma below and at ca. 1046±0.016 Ma above (Gibson et al., 2018). Building upon previous chemostratigraphic studies, we present a high-resolution and new age-calibrated $\delta^{13}C_{carb}$ record from a platform transect spanning the calcareous middle Bylot Supergroup. These new data reveal reproducible fluctuations in $\delta^{13}C_{carb}$ between -2‰ and +4‰, similar to patterns seen in late Mesoproterozoic successions globally. The Iqqittuq Formation displays a positive excursion from -3‰ to +3‰ followed by the beginning of a plateau at +4‰, which continues into the Angmaat Formation. The onset of Victor Bay Formation is marked by a negative shift to -2‰ and after which values gradually increase up to +2% continuing into the entire Athole Point Formation. A high-resolution carbon stable isotope profile associated with well-detailed stratigraphy of the Bylot Supergroup carbonates is the first step to reconstruct oxygen evolution in shallow marine environment at the end of the Mesoproterozoic.

Sedimentary Characteristics of the Forth Member of Sinian Dengying Formation in Gaoshiti-Moxi Area, Sichuan Basin, SW China

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Based on detailed description of cores from the forth member of Sinian Dengying formation in Gaoshiti-Moxi area, 8 types of rock assemblages, namely micro-facies types, are identified, including algal clot dolomite, stromatolite dolomite, algal-laminated dolomite, doloarenite, algal adhesion doloarenite, dolomicrite, crypto-crystal dolomite and argillaceous dolomite. These rock assemblages or micro-facies can be genetically classified into 4 micro-facies assemblages, including algal lime mud dome, inter-dome or inter-shoal, sand shoal and tidal flat. Algal lime mud dome is made up of algal clot dolomite and stromatolite dolomite. Inter-dome or inter-shoal are mainly crypto-crystal dolomite. Sand shoal is made up of doloarenite and algal adhesion doloarenite. Tidal flat consists of dolomicrite, algal-laminated dolomite and argillaceous dolomite. According to the research, Gaoshiti-Moxi area is a restricted platform during the forth member of Sinian Dengying formation. The development degree of dome and sand shoal increases from bottom to top. Domes and shoals change from isolating distributed into continuous distributed horizontally, with isolating distributed turn into lateral contacted and superimposed vertically. Regional tectonism and eustacy are main factors controlling the changing of micro-facies assemblages during the forth member of Sinian Dengying formation in Gaoshiti-Moxi area.

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Petrology and Sedimentary Environments of Bituminous Sandstone in Xiamaling Formation, Jibei Depression，Chian

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Abstract：The authors studied Xiamaling Formation outcrops profile, and the study measurement involved thin section analysis and SEM observation. The system analysis including the distribution of bitumen, composition of the rock such as ratio of the clastic particle and interstitial material, structure such as sorting rounding and particle size, diagenesis character such as compaction, cementation replacement, dissolution and bitumen filling. The analysis help to improve the grading analysis of the bituminous sandstone, and the grading analysis parameter could reflect the sedimentary environments of bituminous sandston in Xiamaling formation. As a result, the bituminous sandston was composed by mainly high maturity quartz sandstone and 5-15% bitumen within the interparticle pores. The sandstone mainly fine grain sandstone and the sorting of it was good or extremely good. The comprehensive analysis shows that the sedimentary environment of the bituminous sandston in Xiamaling formation was shoreside facies with no barriers. The sedimentology position was in the high energy foreshore to shoreface. The probably sedimentology position of the bituminous sandston was from the lower foreshore to middle- upper shoreface. Besides, the sediment was also composed by several tideway deposition. The samples indicate different sedimentary environments in different profile. The samples of Lingyuan and Pingquan profile mainly indicate middle-up shoreface high energy sedimentary environments, while the samples of Kuangcheng profile mainly indicate up shoreface and lower foreshore sedimentary environments. The tideway deposition was slightly discovered in Lingyuan and Kuangcheng profile.

Key words： Bituminous sandstone, Sedimentary environment, Meso-neoproterozoic, Xiamaling Formation; petrologic characteristics, Jibei depression

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A LOESS DEPOSIT IN THE LATE TRIASSIC OF SOUTHERN GONDWANA, AND ITS SIGNIFICANCE TO GLOBAL PALEOCLIMATE

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Characterization of the depositional systems in the Santa Maria Supersequence (Middle to Late Triassic of the Paraná Basin, southern Gondwana), integrating field, chemical and paleontological data, allowed the discussion of its paleoclimatic significance. Facies analysis led to the identification of three dominant facies associations (dry mudflat, distal sheetflood and sheet delta), in addition to a fourth facies association (ephemeral braided fluvial system) that occurs at the base of each third-order sequence. The dry mudflat facies association was dominant in the Pinheiros-Chiniquá and Santa Cruz Sequences. Distal sheetflood and sheet delta facies associations occurred only in the Candelária Sequence. Dry mudflat deposits, recognized in the lowermost sequences, were interpreted as wind-blown dust (loess) reworked by distal alluvial processes. Evidence for loess deposits included the absence of floodplain feeding channels, the presence of thick, structureless siltstone bodies, the dominance of grain-size mode in 0.0031 mm (silt) and the age dispersion of dated zircons. The age range found in the siltstones is larger than that found in sandstone bodies in which paleoflow directions indicate a provenance from the Sul-Riograndense Shield. Throughout the Santa Maria Supersequence, the chemical index of alteration (CIA) indicates semi-arid climate, in agreement with global-scale paleoclimatic conditions. However, during the Carnian the abundance of calcrete in the studied succession decreased, concomitant with an increase in the occurrence of aquatic and semi-aquatic fauna, implying increased humidity during this interval, even though this trend was not visible in the CIA. This was accompanied by a dominance of distal sheetflood and sheet delta over dry mudflat facies associations, indicating that the water supply was enough to maintain water bodies. Other fossiliferous units in Gondwana, such as the Chinle Group and the Ischigualasto Formation, recorded the same short-lived, humid event. Although the humid peak may be associated with an abnormally wet season, some authors (e.g. Ogg, 2015) relate the Carnian "Wet Intermezzo" to the development of the Wrangellian large igneous province (LIP).

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A METHOD TO DEFINE THE PALEOWIND STRENGTH FROM LACUSTRINE BEACH RIDGE THICKNESS

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Quantifying paleowind strength is challenging because the ability of wind to transport sediment is limited. Fortunately, wind blowing over water surface generates waves, whose magnitude depends on wind power. Gravelly beach ridges, which are formed purely by swashing processes, can accurately reflect the wave conditions that formed them. The thickness (or height) of a gravelly beach ridge approximately equals the height of wave inundation, which can be converted into wind intensity based on wind–wave relationships. The relationships between beach-ridge thickness and wind conditions can be encapsulated into equation (1)[1].

$$t = \frac{KU^2F}{2gd}\cos\beta + \left(3.63\times10^{\;4}\right)bU^{1.23}\sqrt{F\cos\beta} \qquad (1)$$

where t is the thickness (m) of a particular gravelly beach ridge; K is the coefficient of frictional resistance with a classical value of 3.6×10^{-6} here; U is the wind speed (m/s) at a height of 10 m above the water surface; F is the fetch (m); g is the acceleration due to gravity (9.81 m/s^2); d is the average water depth (m); β is the incidence angle (degrees) of the wind relative to the beach-ridge axis; b is a proportionality coefficient related to the particle size.

Equation (1) tells that once the paleofetch (F), paleowater depth (d), the paleowind direction relative to the normal to the shoreline (β), as well as general grain size of the sediments constituting the objective beach ridge (for reasonable selection of b), are ascertained, paleowind speed (U) can be calculated with beach-ridge thickness (t). Uncertainty analysis reveals that if a water body is sufficiently large (F > 40 km), deep (d > 10 m) and waves (or winds) are determined to approach to the shoreline with high angles (β < 35°), then the calculational errors will be small to negligible.

Equation (1) is proven to work well by verifying it with a modern lake, i.e., Qinghai Lake in northwestern China. This technique was then applied to an ancient example in the Eocene Dongying Depression, located in eastern China, indicating that the average paleo-north wind speed ranged between 2.27 m/s and 8.36 m/s from 45.0-42.0 Ma, and displayed a generally decreasing trend including at least two peaks.

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Study on the Storm Sedimentary System of the Third Member of Paleogene Funing Formation in the Subei Basin

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Based on the theory of storm sedimentology, the storm sedimentary model of the third member of Paleogene Funing Formation is re-established by using the regional geology, core, logging and testing data. The distribution characteristics and controlling factors of the storm sedimentary systems are discussed in the paper.

Storm sedimentation is formed under the action of storms. It formed muddy water on the windward side of the lake, resulting in the lake surface lifted. On the leeward side of the lake, the lake surface dropped. When the effect of storms is weakened, the lake water moves in the opposite direction and keeps oscillating until the lake surface becomes calm. Lake water will erode and re-suspend the riparian zone sediments. The sediment oscillates with the lake water and is carried into the deep water area to form storm deposits. The storm sediments are thin sand bodies that develop on a dark gray, gray-black mudstone background. It is obviously no longer in the shallow water environment, but should belong to the semi-deep lake water environment.

There are six sags in Subei Basin. They are Jinhu, Funing, Lianbei, Yancheng, Gaoyou and Haian sag. Subei Basin prevails in the south wind. The south of the Jinhu uplift, Funing sag and Lianbei sag are located in the windward gentle slope belt, and are dominated by the wave-dominated delta which includes beach bar system and nearshore reformed beach bar system, where the waves are strong and the shallow lake is widely distributed. Jinhu western sag and Yancheng sag are located in the leeward side, and are dominated by the river-dominated delta system, where the waves are week. Gaoyou southern sag and Haian southern sag are located in the steep slope belt, and are dominated by nearshore underwater fan system, with paleogeographic features of height difference, near source, deep water. In the vast semi-deep lake environment, the thin layer of storms deposition system is developed.

The storm deposits mainly develope in the deep-water areas of the Jinhu sag, the southern sag of Gaoyou and the Haian sag, and the wells of Jin 1, Jia 4 and Tai 6 encounter storm deposits. The lithology is mainly mudstone siltstone and muddy siltstone. The color of mudstone is dark gray or grayish black, reflecting the deep-water deposition environment.

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The discovery of large-scale lacustrine storm-seiche deposits as hydrocarbon reservoir in the Triassic Yanchang Formation of Ordos Basin, China

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The Yanchang Formation of Triassic Ordos Basin is one of main areas for tight oil exploration in China. Traditional views thought the hydrocarbon reservoir are dominated by delta and sandy debris flow deposits in lake center. However, we recognized large-scale storm-seiche deposits based on new data from seismic, well log, core and thin-section analyses. Detailed sedimentological analyses on lithofacies were conducted to address flow types dominant during their origins. The beds are normal graded and contain Bouma-like sequences. The typical and complete sedimentary sequence consists of fining-upwards successions from an erosive base, followed by gravity flow-induced massive or faint laminated bed or soft sediment deformation structures and unidirectional-combined-oscillatory flow induced beddings, which are attributed to storm wave and seiche processes. A single bed of storm-seiche deposits is 3-5m thick, and the superimposed beds reaches 15-20 m thick. The storm-seiche deposits are widely distributed with an area of ca. 2000 km^2. The organic-rich mudrock interbedded with storm-seiche deposits provided the oil source. Profitable oil streams have been collected from more than 40 wells in 2017.

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Microfacies and petrographic analyses of the Kuwait Group at Jal Al Zoor Escarpment- Kuwait

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Kuwait Group is the only exposed part of the total Tertiary stratigraphic sequence of the Arabian Peninsula cropping out in Kuwait. The top most 145 meters of the Group crops out in the north at Jal Al-Zoor Escarpment which runs parallel to the northern side of Kuwait Bay. The total thickness of the Kuwait Group is 400-350 m and span in time from Miocene to Recent. The different facies indicate that the area was affected by different sedimentological environments, especially fluvial and marine environments. Several exposure surfaces were identified by paleosoil leaching zones, weathered pebbly surfaces, nodular rich horizons, plant root horizons, and burrowing rich horizons. The sedimentological study indicated that Kuwait group is composed of 11 different sedimentological sequences of clastic rocks that lays on a marker bed of fossiliferous-sandy limestone unit (Miocene age). The petrographic study reveal the following rock types: conglomerates, pebbly sand stones, arenites, lithic sandstones, fossiliferous sandstones, calcretes, and sandy limestones which are grainstones, packstones and mudstones. The main cementing mineral within the sandstones is calcite which is isopachous, drusy mosaics, and poikilotopic. The matrix of most of the sandstones is composed of microcrystalline calcite and/or clay. The bioclastic fragments consist of mollusks (bivalves and gastropods), brachiopods, bryozoans, coral and coralline algae, and foraminifera. The bioclastic constituents indicate a close proximity to a back reef environment, oyster banks, and high wave action beach environment. The clastic facies indicated fluvial environments, which are parts of meandering stream system including: floodplains sandstones, point-bar sandstones, and channel lag conglomerates. Where as the non-clastic facies indicated mixed marine environments that include berms to shallow marine environments. Geochemical and petrographic correlation of the rock formations indicates a change in sea level and environment of deposition from west to east throughout the Jal Al-Zoor escarpment. The Kuwait Group could be the record of the final sedimentary stage related to the Zagros Orogeny.

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FLUVIAL CARBONATES IN HIGH ENERGY RIVERS: AN EXAMPLE OF COOL WATER CONTINENTAL CARBONATES

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Some of the high energy mountain rivers draining carbonate catchments in the Pyrenees show carbonate coatings on the bedload and also as framestone patches, which can be included within the term tufa. However, the size of coated clasts (several dm) and the high energy of the waters make them different to the commonly described tufa or fluvial carbonates. The studied carbonates come from Orós and Oliván streams, all tributaries from the East of the Gállego River, and draining carbonate catchments within the Spanish Pyrenees. In many areas of the rivers water velocities are higher than 1 m/s. Temperatures vary along the year from 4 to 20ºC and pH is around 8. At present the coarse clastic dominated deposits of the streams are formed by pebble to boulders sourced from the Eocene Flysch. The carbonate precipitates within these streams occur as: 1) Irregularly laminated carbonate coatings (oncoids), 1-15m thick, around pebbles to boulders and phytoclasts; 2) Framestone patches formed by “in situ” coated plants occur in relatively protected areas and also in cascades; 3) Rudstones of coated phytoclasts joined together by carbonate.
All the carbonate is LMC. Diatoms and vegetal debris are common in all the deposits. The laminated coatings of oncoids, framestones and phytoclastic rudstones are composed by coarse calcite and/or micrite-microspar laminae. Coarse calcite laminae/crystals are relatively thick (1 mm) and composed either of: a) bladed to fibrous crystals about 1 mm long and from 0.5 to 0.1 mm wide, b) irregular bands formed by fans of crystals containing micritic filaments. Micrite laminae constitute the first coating of any nuclei, they are dark and relatively homogenous with low porosity. Micrite to microspar laminae are very porous, the crystals are arranged following irregular lines and leaving high porosity. Micritic filaments are common.
Carbonate precipitation in these mountains cold-high energy rivers is not uncommon, but rarely studied because the dominant coarse detrital sedimentation and the reduced amount of carbonate precipitates in comparisons with tufas. Carbonate sedimentation in these environments is favoured by the suitable pH and the high concentration of calcium and carbonates sourced from the hinterland. Although CO_2 mechanical degassing due to turbulence is the main driving force for precipitation microbial biofilms also contributed either actively (photosynthesis) or acting as templates. The alternation of different type of laminae reflects changes in environmental conditions either seasonally or on a longer term. The location in a mountain area and wide range of water temperature along the year, very low in winter very low, suggests that these carbonates could be considered as cool water continental carbonates.
Our study widens the scope of carbonate fluvial deposition and provides clues to better understand some features of the sedimentary record, such as some carbonate coatings and matrix found in fluvial coarse deposits, allowing so more precise palaeoenvironmental interpretations.

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DISTINCTION BETWEEN CLIMATE AND STREAM PIRACY FROM A PALEOHYDROLOGIC RECONSTRUCTION

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Meandering rivers can be found in many places around the world and their sandy fossil deposits can host valuable resources such as water, oil, gas, geothermal energy or ore deposits. Reconstruction of the hydrologic and physiographic variable associated to these ancient river deposits brings valuable information regarding channel geometry, paleodischarge, meander wavelength dimension, sediment load and physiography of the ancient catchment area when only sparse data are available.

Original climatically controlled hydraulic relationships have been developed from modern streams flowing under well defined conditions: sand-bed meandering streams, a subtropical climate (MAP- mean annual precipitation 1200-1650mm; MAT- mean annual temperature 15-18°C), unconfined coastal plains, and limited man influence. These relationships relate all parameters (channel width, discharge, stream length and drainage area) to the channel mean bankfull depth in order to propose direct relationships with the most easily observed parameter in field studies: the height of the lateral accretion sets. Comparison of the channel geometry obtained from the new climatically constrained equations with previously published equations underlines the high influence of fluvial style and climate on the channel parameters. Equations built from larger data set tend to overestimate the channel width as the channel depth increases, as they incorporate data with a larger variability.

Paleohydrologic reconstruction of the Oligo-Miocene fluvial succession of the Digne area (South-East France) enables testing the robustness of these equations in a basin where the sediment source is known. The influence of climate fluctuation versus stream piracy on the sedimentary record is discussed based on a comparison with climatic relationships built from modern streams.

PEDOGENIC CALCRETES OF THE MARÍLIA FORMATION (UPPER CRETACEOUS, BRAZIL): MORPHOLOGIES, FORMATIVE PROCESSES AND ENVIRONMENTAL SIGNIFICANCE

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Deposits and interbedded paleosols of the Marília Formation cropping out in southeast and central parts of Brazil provide important climatic and environmental records on the Late Cretaceous scenario of Brazilian intracratonic areas. Pedogenic calcretes constitute conspicuous secondary accumulation of calcium carbonate in paleosols of the Marília Formation. The accumulations are concentrated in pedogenic horizons of cumulative and polygenetic Aridisol and Vertisol profiles. The aim of this study is to describe, interpret and relate the pedogenic calcrete morphologies to their formative processes and contextualize the different calcrete morphologies in terms of soil profiles, environments and climates of the Late Cretaceous of Brazil. The Aridisols form profiles with calcic Bk, Bkk and Bkkm horizons in which calcium carbonate concentrations exhibit different morphologies and stages of concentration from faint discontinuous carbonate wisps coating ped surfaces through nodular facies manifested by great variety of forms and replacement stages to very hard and continuous cemented layers associated with brecciated and pisolithic textures. The Vertisols show carbonate concentrations mainly in Bssk horizons and the laminar structure is the predominant morphology. The depositional environment of the Marília Formation is attributed to distributive fluvial systems and eolian sand sheets developed on interchannel areas. The Aridisols developed over eolian deposits whilst Vertisols developed on overbank sediments linked with fluvial deposition. The carbonate concentration in calcic Aridisol horizons has its genesis related to windblown eolian dust and rainwater, which supplied calcium ions, and the morphological differentiation is attributed to landscape stability, degree of horizons bioturbation and the time for pedogenic development. The laminar structures developed in Vertisol profiles are biologically-influenced and the calcite precipitation was mediated by roots and microorganisms in a more humid environment. The climate and the organisms are the main controlling factors which favored carbonate accumulation. During more arid phases, the eolian deposition was prevalent and the depositional surface was covered by eolian sand sheet deposits. Pedogenesis occurred in more humid climatic conditions, in which pedogenic carbonate accumulated in Aridisol profiles in stable interfluve positions and in Vertisols closely to fluvial channels enabling the calcium content to be supplied both via rainwater and via lateral seepage from fluvial trunks. This study has implications for paleoenvironmental and paleoclimatic interpretations of the Late Cretaceous continental areas of Brazil and to the understanding of the mechanisms of pedogenic calcrete formation in different soil orders.

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SHALLOW WATER DELTA DEPOSITS IN IN THE LATE CRETACEOUS RED BED SUCCESSION (SONGLIAO BASIN, NE CHINA): IMPLICATIONS FOR THE ROLE OF FLOOD EVENTS IN THE SEDIMENTARY PROCESS OF DISTRIBUTARY CHANNELS SEMI-ARID CLIMATE

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The variability of sediment supply in semi-arid climate influences clastic depositional processes in lacustrine basin. However, limited understanding of the high variability of sediment discharge in semi-arid climate challenges the precision of conventional sedimentary facies models in lacustrine basin[1]. Shallow water delta deposits developed in the Late Cretaceous Yaojia Formation in the Songliao Basin, northeast China. The distributary channels system records the influence of frequent change of sediment discharge on sedimentary process in late Cretaceous greenhouse world. According to sedimentary description and interpretation from the distributary channel deposits, the sedimentary model of distributary channels is controlled by flood events in the late Cretaceous semi-arid climate. The flood events reflects the high variability of sedimentary discharge in semi-arid climate, which leads to flood period and dry period in shallow water delta system. The records of seasonal flood promote our understanding of the terrestrial environment during the late cretaceous global warm climate and future terrestrial climate of the world. Furthermore, the sedimentary model of distributary channels gives important implications for prediction of reservoirs in lacustrine basins.
Key words: Semi-arid climate; Distributary channels; Cretaceous; Songliao Basin.

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TITLE: REGIONAL UPLIFT AND GLOBAL COOLING CAUSED DIACHRONOUS ARIDIFICATION IN THE WESTERN USA DURING THE LATE EOCENE-EARLY OLIGOCENE

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Transition to eolian deposition in continental interior is commonly linked to aridification and changes in tropospheric circulation. The mid-Cenozoic aridification of central Asia is a well-documented example, with potential causes attributed to a single or combined factors including global cooling at the Eocene-Oligocene transition (EOT), land-sea redistribution, or Asian tectonism. Beyond central Asia, mid-Cenozoic eolian deposits were rarely documented, posing a major challenge to studying continental-scale hydroclimate transition at the EOT. Here, we document a similar transition in the central Rocky Mountains (Rockies) and adjacent central Great Plains during the middle Cenozoic. The transition is defined by relatively abrupt changes from poorly-sorted, stratified fluvial lithofacies to massive, well-sorted, fine-grained sandstone of eolian origin in four localities in Wyoming and western Nebraska. Quartz surface textures also show changes of characteristics from water transport to wind transport. The grain size distribution of the fluvial lithofacies varies between unimodal and multimodal, and that of the eolian sandstone is bimodal, with a major peak at 30-130 mm and a minor peak at 2-10 mm. To varying degrees, rock magnetic parameters, including bulk magnetic susceptibility, anhysteretic remanent magnetization intensity, and saturation isothermal remanent magnetization intensity, all show appreciable enhancement within the eolian sequence. Compiled geochronologic age data show that the eolian deposition began during the latest Eocene-earliest Oligocene and expanded eastward through time. This transition postdates most, if not all, crustal shortening of the central Rockies, and persisted across the global cooling event that occurred at the EOT. Complex climate model simulations based on late Eocene boundary conditions and climate forcings suggest that uplift of the Cordilleran hinterland and central Rockies during the early Cenozoic resulted in drying in the Cordilleran hinterland and immediate foreland but moistening farther to the east. Global cooling at the Eocene-Oligocene transition eventually drove the observed eastward-migration of continental aridification. The co-occurrence of aridification at both Asia and North America continental interior potentially suggests a major perturbation in the global dust cycle at the EOT and large-scale reorganization of global hydroclimate.

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THE PERMIAN-TRIASSIC TRANSITION IN THE SOUTHERN HIGH LATITUDES OF GONDWANA

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The Permian-Triassic transition was marked by an end-member ecological catastrophe involving rapid and severe environmental change that led to the largest mass extinction of the geological record. Most work on the continental record of this interval has focused on low-palaeolatitude settings. As such, the extents to which terrestrial systems at high palaeolatitudes were impacted remains relatively poorly constrained. The Upper Permian to Lower Triassic succession in the Sydney Basin, Australia, deposited along an ancient continental margin that stretched from polar to temperate palaeolatitudes, comprises one of the best geochronologically calibrated terrestrial records for the time period. This work integrates sedimentology, geochemistry, palaeobotany, and climate modeling to investigate the nature and timing of environmental stresses that led up to and followed the end-Permian extinction eve End Permian Mass Extinction (EPME) as recorded in eastern Australia. Specifically, we document a reference section for patterns of sedimentological, geochemical, floral, and environmental change through the Lopingian and Lower Triassic succession based on a fully cored borehole (Pacific Power Hawkesbury Bunnerong DDH1) drilled in the depocentre of the Sydney Basin. Age-calibration is provided by CA-ID-TIMS dating of tuffs and palynostratigraphic and chemostratigraphic correlation to nearby dated successions. Floral data indicate that multi-storey vegetation persisted throughout the Lopingian and Early Triassic. However, this ecosystem was marked by a complex record of extinction and replacement interpreted as system response to a series of environmental thresholds related to temperature or the availability of moisture atop a long-term trend of intensifying seasonality. Weathering indices (CIA) show a perturbation across the EPME towards higher values, indicating a shift towards climate conditions that favored increased chemical weathering before returning to background values. Sedimentological facies analyses indicate little change in fundamental fluvial style and no evidence of abrupt aridification seen in other localities around the globe. The simulated climate record for this region is consistent with the constant trends in the sedimentary record of the Sydney Basin. Results highlight complexity and regional variability in the terrestrial response to environmental changes associated with the Permian-Triassic transition.

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LATE CRETACEOUS PALEOSOLS IN THE FLUVIAL-LACUSTRINE SIFANGTAI-MINGSHUI FORMATIONS, SONGLIAO BASIN AND IMPLICATIONS FOR PALEOCLIMATE

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Extensive concern on modern global climate change has raised the significance of studying deep-time greenhouse climate, such as the late Mesozoic to early Cenozoic greenhouse. The Late Cretaceous (late Campanian to Maastrichtian) was characterized by a variable greenhouse climate, with evidence for fluctuations of pCO_2, temperature and precipitation on continent. Located at the largest land-mass in Late Cretaceous, the Songliao Basin in northeastern China preserved nearly continuous fluvial-lacustrine Sifangtai-Mingshui Formations of that time period. We report sedimentological and geochemical characteristics of paleosols developed in the Sifangtai-Mingshui Formations recovered from the SK-1 scientific core under the framework of ICDP. Five types of paleosols, namely Entisol, Inceptisol, Aridisol, Vertisol and Alfisol, were classified in terms of the modern soil taxonomic system. Paleotemperatures are derived from new stable oxygen and hydrogen isotopic compositions of pedogenic clay minerals and recently published clumped isotopic records of pedogenic carbonates[1]. Paleoprecipitations were qualitatively and quantitatively determined by paleosol types and depths to calcareous horizons. Collectively, we infer a semi-arid to semi-humid, temperate paleoclimate during the deposition of the Sifangtai-Mingshui Formations. Furthermore, according to the established chronostratigraphic framework for SK-1 core, the average duration between two paleosol layers is close to the cycle of short eccentricity. We therefore infer that orbital cycles probably controlled the high-frequency development of paleosols in the Songliao Basin in Late Cretaceous.

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CLIMOFUNCTIONS DEDICATED TO CALCISOLS, INPUT TO THE RECONSTRUCTION OF THE PALEOCLIMATE IN SOUTH WEST EUROPE DURING THE LOWER TO MIDDLE MIOCENE

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Many classic climofunctions based on the quantification of the leaching processes in the soils have been developed and are very useful to reconstruct the paleoclimate parameters such as the mean annual precipitation (MAP), mean annual temperature (MAT) and mean annual range of precipitation (MARP). In calcisols, due to the interactions between the leaching and accumulation processes of chemical elements in the soil, the classic climofunctions cannot be applied. For modern soils, climatic reconstructions from the morphologic characteristics (depth and thickness of the Bk horizon) provide estimations of the MAP and seasonality. Nevertheless, these cannot be applied to truncated soil profiles that are very frequent in fossil continental successions.

Climofunctions dedicated to calcisol have been developed based on a geochemical analysis of modern calcisols from northern Spain. Major element concentrations in the soil profiles where measured in the field, using a field XRF analyser (Gillot, 2014). A comparison conducted with data obtained from ICP-AES shows little differences between the two methods in the element content except for some elements (K, Mn). The climofunctions relate the present climate parameters (MAP) and (MAT) to indexes built from the major element content. The major element method can be applied to truncated soils, as long as part of the Bt horizon is preserved. A comparison between the paleoclimatic reconstructions from the paleosol morphologic characteristics and the major element climofunctions shows a good agreement.

The paleoclimatic reconstruction based on the analysis of more than 70 paleosols (morphologic characteristics and major elements) from the lower to Middle Miocene continental successions from SE France and Central Spain indicates a low latitudinal gradient between these two regions (MAT between 13 to 19°C and MAP ranging from 250-700 mm/yr). The estimated MAT are within the range of those estimated from northwest Europe, Portugal and northern Spain. Conversely, the estimated precipitation in our study are two times lower than in the other regions. Such results raise the question of a proto-Mediterranean climatic belt as early as lower Miocene in south eastern France and Central Spain.

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PALYNOSTRATIGRAPHY OF ORGANIC-RICH CHICHALI FORMATION, TRANS-INDUS RANGES, PAKISTAN: IMPLICATION FOR CRETACEOUS PALEOCLIMATIC RECONSTRUCTIONS AND SOURCE ROCK POTENTIAL

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Abstract: Palynomorphs, the organic microfossils, most commonly comprises of spores, pollen and dinoflagellates were widespread during the Mesozoic time. Worldwide, these palynomorphs are used to construct palynostratigraphy and provide relevant information for paleoclimatic reconstructions. The palynofacies analyses involved the quantitative and the qualitative particulate organic particle component and sub groups. The studied Chichali Formation of the upper Indus Basin, Pakistan, is composed of shelfal clastic sandstone, shale and some carbonaceous intervals. A controversy regarding paleoclimate during this time i.e. whether the climate conditions were cold or warm, prevails. Secondly no schematic biostraghtigraphic was available. Previous worker assigned various ages based on ammonoids (Spath, 1930, Badshah et al., 2000, etc.). Current research involves the organic petrographic studies along with TOC and Rock-Eval analysis. Three Oppel biozones are established in the Chichali Formation, two on the basis of dinoflagellates and one on the basis of pollen and spore assemblages. On the bases of these assemblages, the lower part of the studied formation is believed to be of Kimmeridgian age, while middle member is Valanginian in age. The recorded specific families of plants, ferns and the gymnosperms, show warm humid climatic conditions prevailed on the Indian sub-continent during early Cretaceous. The studied organic shales also hold a potential for hydrocarbon source but various controversies prevailed regarding the maturity. The TOC (mean value 2.02) and Rock-Eval analysis for the studied shale show high source rock potential. The modified van-Krevelen diagram shows that the overall organic matters within the shale are of kerogen type III, supporting the terrestrial source and a gas generation potential. The geochemical parameters suggest that the selected samples are mature to post mature (also supported by spore color index data), with 'good' hydrocarbon potential. The lower values of HI and type of kerogen also support gas prone tendency for the suggested samples. Overall, the current studied provides the evidence that the Chichali Formation show a fair to good source rock potential.

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CARBON ISOTOPE COMPOSITION OF TERRESTRIAL PLANT MATTERS IN ALBIAN SHALES

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Carbon isotopic values ($\delta^{13}C$) in C3 plants have been known to be good proxies of paleoclimate (Wilson et al., 2002). When organic matter in lacustrine shales consists mainly of C3 terrestrial plant material, the $\delta^{13}C$ values of terrestrial plant matters ($\delta^{13}C_{TPM}$) in lacustrine shales have been used to understand paleoclimate in the surrounding watershed. Because there is no conclusive presence of C4 plant for the Early Cretaceous (Jacobs et al., 1999), the terrestrial plant matters of the Albian lacustrine shales might have been mainly composed of C3 terrestrial plant matter. This study presents carbon isotopic records of terrestrial plant matters from the Albian lacustrine shales in the Gyeongsang Basin which is the largest Cretaceous non-marine basin located in Southeast Korea. The organic matters of the Albian lacustrine shales in the Gyeongsang Basin are mainly composed of detrital wood particles with insignificant degree of thermal maturation. The $\delta^{13}C_{TPM}$ variation mostly exceeds isotopic variation of the contemporaneous atmospheric CO_2. This indicates that the variation was primarily affected by climate change rather than atmospheric source. The $\delta^{13}C_{TPM}$ values corrected to modern atmospheric CO_2 fluctuate between -27.8 and -23.3‰, reflecting that periodic variation of water availability in hinterland of the lake. The mean annual rainfall calculated from the corrected $\delta^{13}C_{TPM}$ values indicates that Albian climatic condition in the Gyeongsang Basin might have been fluctuated between sub-humid (500-1,000 mm) and humid (1,000-1,500 mm) conditions.

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INTERPRETATION OF MASSIVE SANDSTONES IN EPHEMERAL FLUVIAL SETTINGS: A CASE STUDY FROM THE UPPER CANDELÁRIA SEQUENCE (UPPER TRIASSIC, PARANÁ BASIN, BRAZIL)

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The characterization of an ephemeral alluvial system, developed under a strongly seasonal climate in the Upper Triassic of the Paraná Basin, southern Gondwana, aimed at contributing to better understand the wide range of upper- and lower-flow regime structures in ephemeral rivers. The development of flow structures in these settings, especially the formation of thick, massive sandstones, is yet uncertain. Interpretation of the depositional processes in the studied succession was based on the comparison with similar deposits from literature, and flow characteristics and depositional signatures compared with flume experiments. The alluvial system was divided into four facies associations: (1) waning channel fill, characterized by low width/thickness (w/t) ratio, tabular bodies, scour-and-fill structures with upper- to lower-flow regime bedforms; (2) massive channel fill, characterized by low w/t ratio, sheet-like bodies, scour-and-fill structures with massive sandstones; (3) proximal sheetflood, characterized by moderate w/t ratio, sheet-like bodies with upper- and lower-flow regime bedforms and (4) distal sheetflood, characterized by high w/t ratio, sheet-like bodies with lower-flow regime bedforms. Evidence for the seasonal reactivation of the riverine system includes the scarcity of well-developed macroforms and presence of in-channel mudstones, thick intraformational conglomerates, and the occurrence of well- and poorly-preserved vertebrate bones in the same beds. The predominantly massive sandstones were interpreted as a result of deposition from a hyperconcentrated flow during abrupt changes in flow speed, caused by de-confinement or channel avulsion, whereas turbulent portions of the flow formed the upper- and lower-flow regime bedforms following deposition of the massive layers. The upper portion of the Candelária Sequence records a good example of strongly ephemeral alluvial systems in which massive sandstones are conspicuous.

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THE RESEARCH ON PALAEOGEOGRAPHY AND PALAEOCLIMATE RECONSTRUCTION BASED ON GIS--A CASE STUDY ON CRETACEOUS IN CHINA

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Compared with the marine environment, the continental environment is more sensitivity to climate changes since it is affected by more factors. Therefore research based on terrestrial geological records could reflect the changing process of paleoclimate and analyze the controlling factor better. Research and geological survey on Cretaceous in China has been continued for tens of years, and quantities of Cretaceous profile data have been accumulated. It is necessary to manage these data using the technology of computer, database and geographic information system (GIS). Therefore, we collected the Cretaceous profile data from reports and publications, designed and established a Cretaceous sedimentary profile information system with the function of data storage, management, sharing and visualized analysis, which laid a firm data foundation for subsequent research in the field of Cretaceous. Meanwhile, some special terrestrial sediments include abundant climate information, the research for climate sensitivity sediments could provide a clue to analyses climate. On the basis of previous stratigraphy study and paleogeography reconstruction, we established a "climate sensitivity sediments-climate zones" corresponding system, and retrieved climate sensitivity sediments from the Cretaceous profile information system. A research on the spatial and temporal distribution of climate sensitivity sediment such as coal bed, gypsum, calcareous nodule, and desert sedimentary and dinosaur et al. was carried on using GIS spatial analysis technology.

JURASSIC PALAEOCLIMATE HISTORY RECONSTRUCTION OF QAIDAM BASIN, NORTHERN TIBET PLATEAU

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China's complete Jurassic continental sedimentary and variety paleontological records are advantaged condition for related land-based climatic history research[1]. Qaidam Basin located at the northern margin of Tibetan Plateau, its Jurassic strata provides important information about palaeoenvironment change. Several significant geologic events such as the collision of Bangong-Nujiang Suture and the interior aridification appearance at NW China are likely recorded in the succession[2], which makes it an ideal window of palaeoclimate investigation. This study focus on Dameigou section in northern Qaidam, based on sedimentology, geochemistry and micro-palaeontology analysis, Jurassic palaeoclimate was represented.

According to the vertical variation of climate sensitive sediments, geochemical indicators and palynological assemblages, Jurassic palaeoclimate evolution of Qaidam Basin can be divide into 4 stages were: ① Early to middle episode of Early Jurassic. In this unit, deposits were characterized by dark mudstone, coal and siderite, while pteridophyte flourished; CIA in a high value matching the $\delta^{13}C_{org}$ negative excursion; all these observations strongly suggest a warm and humid condition. ② Late episode of Early Jurassic. This episode marked by *Classopollis* high-content zone in the red beds. CIA, K/Na and Rb/Sr ratios are characterized by a significantly decrease, which is consistent with the change of temperature and humidity profile. These dramatic transition indicates a regional hot-arid event. ③ Early to middle episode of Middle Jurassic. Extremely thick coal seam, massive growth of HMI plants and strong chemical weathering, which displays a warm and humid condition. ④Late Middle Jurassic to Late Jurassic. The appearance of lacustrine carbonate and *Classopollis* high-content zone pointing a significant climate change. The long-term chemical parameters suggest the hot-arid degree of palaeoclimate is constantly reinforced, the northern Qaidam Basin under arid/semi-arid environment.

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EVIDENCE FOR HYPERCANE IN THE AFTERMATH OF PERMIAN-TRIASSIC MASS EXTINCTION IN TERRESTRIAL ENVIRONMENTS OF NORTH CHINA

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The elongated delay of Triassic biotic recovery following the end-Permian mass extinction has been ascribed to the long-term instability of environmental conditions during the great Paleozoic-Mesozoic transition. Most evidences on these events are from the studies in marine facies, whereas rarely on land. The terrestrial Permian-Triassic (P-Tr) successions well developed on the North China Block, located in middle latitude regions, with well biostratigraphically constraned the P-T boundary at the upper part of the Sunjiagou Formation. Dozens of horizons of tempestites are observed throughout the Liujiagou Formation, overlying the Sunjiagou Formation, in some localities of the Henan, Shanxi and Shaanxi provinces. The sedimentological and paleogeographic study indicates that these tempestites formed in the shore-shallow lacustrine and/or fluvial facies. The storm-generated sedimentary structures include radial-arranged pebbles, wave-generated cross-beddings, gutter casts, erosion surfaces and etc. The reconstructed tempestite sequences were resulted from the variable hydrodynamic energy and storm energy. The occurrence of microbially induced sedimentary structures (MISSs) over the tempestite sequences might be corresponding to the subsidence of these stormy events. Based on the climatic dynamics of modern storm events, global warming might play significant role in driving the hypercanes during P-Tr transition, contributing to the biotic crisis.

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ROSEBUD FORMATION IN NIOBRARA VALLEY, NEBRASKA, USA: SILT-DOMINATED ALLUVIAL TO EOLIAN DEPOSITION ON THE LATE OLIGOCENE GREAT PLAINS

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The Rosebud Formation (RF), which records continental-interior deposition during a time of environmental and geographic changes, remains poorly understood after 110+ years of research. We drilled fully-penetrating cores through the RF and compared outcrops, thereby developing an emerging view of the RF (now considered to attain at least 90 m in maximum thickness) that is the most complete yet; prior authors measured only incomplete outcrop sections in Nebraska and a ~120 m complete section in South Dakota. The upper, extensively exposed part of the RF in the study area is dominated by crudely bedded, massive and subangular-blocky-weathering siltstone that is mostly very pale brown to brown when dry, but reddish brown to dark reddish brown when wet. These upper siltstones are distinguished by their wet colors and common, wavy, horizontal to slightly inclined, bands of white to pale yellow clay, ≤ 5 cm in thickness and vertically spaced by centimeters to a few decimeters. Mild rubefaction, horizontation, and widespread prismatic and blocky structure, as well as other features, comprise a pervasive ancient pedogenic overprint. Subordinate lithologies within the upper, widely exposed, siltstone-dominated part of the RF are, in roughly decreasing order of abundance: faintly laminated to massive very pale brown, light yellowish brown, and brown siltstones lacking blocky structure; massive, insect-bioturbated siltstones; lenticular to sheetlike friable sandstones of varying thicknesses; and intraformational, granule to cobble breccias or conglomerates, consisting of strongly cemented siltstone clasts and appearing in thin lenses or within complex fills of small channels (possible gullies or ephemeral-stream channels). Fully-penetrating cores also reveal a lower succession of silty, very fine, thick-bedded and locally cross-stratified sandstones (with common, thin beds of laminated claystone) below the upper, siltstone-dominated interval. We once interpreted this lower succession as the Brule Formation (BF), but it is coarser than the BF in western Nebraska and there is no consistent demarcation in cores between it and the overlying siltstone-dominated strata of the RF. Therefore, we now consider it to be a fluvial unit within the RF. We tentatively interpret the RF overall as an alluvial to eolian succession that: (1) received very little extrabasinal clastic sediment coarser than fine sand, (2) bears some similarities to Quaternary loess-bearing continental successions in the interior USA, (3) may have resulted from mechanisms of sedimentation similar those of the latter, and (4) likely represents ancient subhumid or drier climates.

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ISOTOPIC COMPOSITION OF LAND AND FRESHWATER SNAIL SHELLS FROM SUBTROPICAL MESOAMERICA – INDICATOR OF SEASONAL(ITY) CHANGES?

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Since the seminal work of Goodfriend[1], several studies confirmed a relation between the isotopic composition ($\delta^{18}O$, $\delta^{13}C$) of land snail shell carbonate, and environmental parameters like precipitation amount, moisture source, temperature and vegetation. The advantages of using snail shells as environmental archive are a double-edge sword. Due to their relatively limited mobility snails have an intrinsic aptitude of recording local and site-specific conditions. Alas, the risk lies in extrapolating these site-specific signals to regional scales.

To test the fidelity of land and freshwater snail shells as environmental archives, we perform sequential isotopic analyses on well dated shell samples from a Pleistocene/Holocene archaeological site in subtropical Mesoamerica (Belize). Assuming relatively stable temperatures over the last 15 ka, we interpret our results mostly in terms of seasonal precipitation variability. The taxonomic range of the utilized species from different habitats (ponds, litter, tree canopies, limestone bedrock) facilitates singling out site-specific effects.

We construct a matrix of punctual high-resolution time-series discretely distributed over the last 15 ka. At each time step, sequential analyses from individual shells reflect the amplitude of seasonal environmental variability over the life span of an individual. Comparison of our results with continuous time series from the wider region (e.g. speleothems, marine sediments) suggest that the isotopic composition of land and freshwater snail shells is a valid indicator of the seasonal precipitation changes over short time scales (10^1 years) as well as of the variation in amplitude of the seasonality over longer time scales (10^2 – 10^4 years).

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HIGH-FREQUENCY PEDOGENESIS AND CYCLIC PCO_2 CHANGE RECORDED FROM THE MID-CRETACEOUS TERRESTRIAL SEDIMENTS IN SOUTH CHINA

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Pedogenesis is a common sedimentation in the late Mesozoic sequence in China, but how often it took place remains unclear, and so is the pCO_2 change reconstructed from the carbon isotope of pedogenic calcretes. The investigations of paleosols and pCO_2 estimate from South China could give us an answer.

The thick Cretaceous-Paleogene terrestrial succession is well exposed in Hengyang Basin, Hunan province, South China, and they are totally over 10,000 m thick, indicating a relatively continuous sedimentation. Within the basin, the Dongjing Formation well outcrops as the lower part in the Hengyang Basin, providing a good opportunity for the researching of pedogenesis and pCO_2 in deep time.

The observe cross-section is 3,000 long near Baishui Middle School, Hengyang county. The Dongjing Formation is mainly composed of reddish brown fine (para-) conglomerates and mudrocks, intercalated/interbedded with sandstones/graywackes and siltstones. Youngest age populations of detrital zircon from sandstone samples and former spore-pollen biostratigraphy as well as magnetostratigraphic correlation indicate the formation is of the early Aptian (~125-120 Ma, lower C34n).

About 130 calcisols are recognized in about 1,700 m thick stratal succession, showing a high-frequency pedogenesis. The punctuated pedogenic horizons often display in silty mudrocks or muddy siltstones with more or less calcites, which are probably related to subordinate environments such as levee, overbank, split fan, flooding plain, inter-channels. Calcretes are abundant in most calcisols, changing 1-3 %, up to 15%. They mostly shape in globe, ginger-like, ellipse. They alter in size, from 5 mm to 200 mm. Those small calcretes (5-30 mm) are often developed within few calcic mudrocks, and big ones (50-150 mm) within calcic and harden (silty) mudrocks. ~130 calcisols divided by ~5 Myr result in an interval ~0.038 Myr per calcisol formation in the Hengyang Basin.

Carbon isotope of ~130 calcrete horizons shows that $\delta^{13}C$ are -3‰ to -8‰, mainly -5‰ to -7‰, compatible with those from published pedogenic carbonate data. pCO_2 concentrations from the calcrete $\delta^{13}C$ are estimated as 500-2,500 (mainly 1,000-2,000) ppmV. Two stages can be distinguished in change of both $\delta^{13}C$ and pCO_2. Fourteen and half distinct of increasing-decreasing pCO_2 concentration are distinguished. ~15 pCO_2 cycles have an average 0.33 Myr interval per cycle when it is divided by 5 Myr, indicating a 1000 ppmV rising or falling could be completed in about 0.3 Myr.

LATE EOCENE-OLIGOCENE PALEOELEVATION OF HOH XIL BASIN: EVIDENCE FROM LEAF-WAX HYDROGEN ISOTOPE OF THE YAXICUO GROUP

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The surface uplift history of the Tibetan Plateau is critical for testing various tectonic models related to the geodynamic evolution of the Tibetan Plateau. The plant fossils and stable isotopes of sedimentary carbonates indicate lower Hoh Xil during the Paleocene-Eocene and relatively higher elevation after the Middle Miocene[1]. But the specific uplift history between Eocene and Miocene remain elusive. We choose fluvial-lacustrine sediments of Yaxicuo Group crop out in Tongtianhe area (TTH section) for quantitative paleoelevation study. Detrital zircons from the bottom of TTH section exhibit youngest Yc1σ (13) age of 37.1±0.8 Ma. Combining with previous geological mapping and magnetostratigraphy studies, we suggest a Late Eocene to Oligocene age for TTH Yaxicuo Group. Due to the intense evaporation indicated by large amount of gypsum layers in TTH section, the extensively utilized carbonate stable isotopic values may be commonly strongly enriched. The leaf-wax *n*-alkane hydrogen isotope is relatively resistant to water evaporation, thus it should be a suitable and promising paleoaltimetry in this region. Here, we present new *n*-alkanes δD values of fluvial mudstone, lacustrine mudstone, marl, and limestone from the Late Eocene to Oligocene Yaxicuo Group in TTH section. The *n*-C_{31} δD values instead of *n*-C_{29} δD values are chosen for paleoelevation estimates in order to decrease the influence of aquatic sourced *n*-C_{29}. Considering all the possible moisture sources and isotope-elevation gradients, we finally get the average paleoelevation of ~1800 m for Late Eocene to Oligocene Hoh Xil basin.

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MESOZOIC BASIN AND ASSOCIATED PALAEOGEOGRAPHIC EVOLUTION IN NORTH CHINA

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The united continental of China was formed due to convergence between the North China Plate and the Yangtze Plate in the terminal T_3. Late Triassic mafic or alkaline rocks and intrusions of T_3 occurred on the northern and southern margins of North China Craton (NCC) and XMOB, implying that intensified extension occured all over the North China from T_3 to J_{1-2}. Additionally, a series of small to medium-sized basins with coal-bearing strata and some volcanic rocks in other areas of North China, which was supposed to be the result of subduction of the Palaeo-Pacific Plate during J_{1-2}. However, in the end of J_{1-2}, because of the Yanshanian orogeny characterized by complicated thrust and fold, the previous unified Ordos-North China Basin was separated by the northeast-oriented Great Xing'an Range and Taihang Mountain uplifted linearment. The differential evolution of basins and sedimentary palaeogeography between eastern and western North China was initiated.A variety of faulted basins occurred in the Yanshan and Yinshan areas in the northeastern North China in the Late Jurassic. In Yanshan area, basins were filled with thickened intermediate volcanic rocks and purple-red coarse-grained clastic rocks. In contrast, only thick layered sedimentary rocks with rare volcanic rocks developed in the Yinshan faulted basins, the Ordos Basin and basins in sourthern North China. During J_3-K_1^1, the northern and northeastern North China experienced extension after the subduction of the Palaeo-Pacific Plate, the closure of the Mongolia-Okhotsk Ocean and the subsequent Yanshanian orogeny. A NE-oriented, giant rift basin system (NE Asia Rift) extended from the Yanshan to the western Great Xing'an Range, where rift basins were filled with the regional, thick coarse-grained clastic rocks and volcanic rocks.In K_1^2-K_1^3, rift basins developed and accumulated alluvial sediments and interbedded alkaline volcanic rocks in the western and northern North China. Basic volcanic rocks and fluvial-lacustrine sediments were deposited in small- or medium-sized rift basins in the northeastern China. The Songliao Basin was a typical giant basin that was mainly filled with K_1^3 lacustrine sediments. A group of rift basins occurred in the Sanjiang area, central Heilongjiang Province, northeastern China.From K_1^2-K_1^3 to K_2, depositional and subsiding center of the basins constantly shifted southeastwards in Heilongjiang Province. Besides, during the Late Mesozoic, a huge terrestrial biota, mainly dinosaur fauna, dominated in North China. The Yanliao biota of J_{2-3} and the Jehol biota of K_1 are characterized by feathered dinosaurs, primitive birds, mammals, pterosaur, insects and plants (angiosperms).

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Aeolian silt deposition sequences unravel formation and evolution of Asian Gobi-desert during late Cenozoic era

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Abstract The Gobi-desert in East and central Asia produces a great amount of silt material that is entrained to Chinese Loess Plateau and North Pacific Ocean, which probably impact global climate by participating in geobiochemical cycle. There are inconsistent hypotheses regarding formation and evolution of Asian Gobi-desert, e.g. from middle Eocene to late Pleistocene, driven by either tectonic uplift or climatic forcing. In this study, we use thick and continuous aeolian deposit sequence in northern China as a direct proxy record to reconstruct formation and evolution process of Asian Gobi-desert during Cenozoic. Our results show that the Gobi-desert was stepwise formed under global climatic cooling and landform deformation in Asia. The Gobi-desert probably appeared at late Eocene and early Miocene, but its modern form, namely the yellow Gobi-desert was not established until late Pliocene, associated with the high-latitude ice volume expansion and global cooling. Unambiguous expansion and contraction of the Gobi-desert area was controlled by glacial-interglacial climatic alternations manifest forcing of global temperature on modulating the Gobi-desert variations during late Cenozoic. Both geological evidence and numerical modelling support our "cooling drives drying" hypothesis of the Gobi-desert formation.

Key words: Asian Gobi-desert, aolian silt deposit, global cooling, late Pliocene

SAME AS IT EVER WAS: PERSISTENT CASE FOR VERY LOW $\delta^{18}O$ VALUES FOR POLAR PALEOPRECIPITATION IN CRETACEOUS GREENHOUSE WORLDS AND NEW EXAMPLE FROM THE SVERDRUP BASIN OF NORTHERN CANADA

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Mesozoic & Cenozoic warm periods in Earth History were characterized by extreme polar warmth, to the extent that the existence of contemporaneous polar ice caps has been subject to debate. Researchers working on terrestrial stratigraphic records in polar regions from these warm periods have studied polar paleoprecipitation using stable isotope proxies including pedogenic minerals to investigate the possible role of the hydrologic cycle in sustaining ancient polar warmth[1]. One important question concerns applicability of a modern empirical relationship first described by Dansgaard[2] that associates higher precipitation $\delta^{18}O$ values with higher surface air temperatures, and vice versa. Studies of Cretaceous sites (≥ 70 °N paleolatitude) in the Colville Basin of Alaska have yielded estimates of water $\delta^{18}O$ values ≤ -20‰ VPDB, much lower than predicted by the Dansgaard relationship[3]. Earth System model simulations also predict much higher $\delta^{18}O$ values for Cretaceous paleoprecipitation in Alaska, suggesting that orographic influences from proximity to ancestral Brooks Range may have biased proxy data from the Colville Basin[4]. We report new meteoric siderite data from the Cenomanian upper Bastion Ridge Fm of Axel Heiberg Island in the Sverdrup Basin of Canada. These siderites have mean $\delta^{13}C$ values of +4.0±0.3‰ VPDB and mean $\delta^{18}O$ values of -18.95±0.3‰ VPDB. Based on Cretaceous zonal MAT (~ 13 °C) at approximately 70° N paleolatitude, we estimate a water $\delta^{18}O$ value of -23.1‰ from the Bastion Ridge Fm. These results are similar to those from the Colville Basin in Alaska, but come from locale far from likely orographic influences on the composition of mid-Cretaceous paleoprecipitation. The paradox of this model-data misfit, of possible relevance to historic Arctic Amplification, continues as a challenge for deep-time paleoclimatology.

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THE STRUCTURAL DEFORMATION FEATURES OF TWO PHASES TRANSFER ZONES AND THEIR INFLUENCE ON SEDIMENTS IN BAXIAN SAG, BOHAI BAY BASIN, NORTHERN CHINA

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Baxian sag is one of many Cenozoic intracontinental extensional basins that developed in the North China plate. New structural evidence and latest research results about Bohai Bay basin indicated that the Baxian sag underwent two phases extension with different direction during Paleogene[1]. That is, structural deformation of Eocene is caused by NW-SE direction extension with Mesozoic pre-existing weakness, while structural deformation during Oligocene is caused by NS direction extension[2]. Based on the two phases extension model, the two phases transfer zones are recognized as follows: (1) NW-SE-trending Eocene transfer zone, and (2) NS-trending Oligocene transfer zone. The former developed between the joint terminations high of the two bounding faults, while the later developed along the axis of central S-type bounding faults. The bounding fault (Niudong fault) can be divided into three segments (north segments, central segment and south segment) with different strike. And transfer faults are discussed in different periods, the north segments and south segment acted as transfer faults in Eocene, while the central segment showed as a transfer fault in Oligocene. The movement polarity of different segments of Niudong fault alternates transfer faults and normal faults. The two phases transfer zones and transfer faults invariably exerted fundamental control on the deposition of syn-tectonic sediments, flow direction of drainage systems and locations of sediment entry points, as well as the reservoir properties[3]. The Eocene transfer zone has a great effect on the southwest sediments entry point and syn-rift sandstone reservoir property, while the Oligocene transfer zone mainly affects the syn-rift sandstone reservoir property. The transfer faults often act as the important sediment entry points, and further cause the difference between the deep and shallow sedimentary systems.
Keywords: Transfer zone; Transfer fault; Two phases extension; Paleogene; Rift basin

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THE ORIGIN OF MICROBIAL LACUSTRINE CARBONATE AND ITS PALEOCLIMATE SIGNIFICANCE IN THE QAIDAM BASIN, THE NORTH OF THE TIBETAN PLATEAU

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Stable isotopes of bulk lacustrine carbonate in the Qaidam Basin has shown an obviously $\delta^{13}C$ positive excursion and progressively $\delta^{18}O$ negative excursion during the Oligocene and Miocene. Previous researches regard it as strong evaporation and low ^{18}O inflow respectively [1]. However, our recent research reveals that the positive excursion of $\delta^{13}C$ in lacustrine carbonate might be related to microbial activities, and $\delta^{18}O$ negative excursion is likely the result of the uplift of the Tibetan Plateau. Systematic petrography, Scanning Electron Microscope and Energy Dispersion Spectroscopy (SEM-EDS) mapping, micro-drill sampling and carbon and oxygen isotopes were conducted to discover the origin of microbial lacustrine carbonate, including aragonite varve and oolite, in the Qaidam Basin, as well as to understand the paleoclimate and environment evolution with the uplift of the Tibetan Plateau during the Cenozoic era. The strong $\delta^{13}C$ positive excursion at about 4‰ between pure aragonite layers and mix layers shows the origin of aragonite layers might be related to algal blooming during warm seasons, as evaporation just could not reach the excursion and organic matters were well saved in the varve. Micro-drill sampling from successive aragonite layers and their isotopic shows gradual stable deviation of $\delta^{13}C$ from the Eocene to Miocene, which could be interpreted as the result of the monsoonal climate establishment progressively due to the uplift of the Tibetan Plateau. Besides, the isotopic results also show negative excursion of $\delta^{18}O$ from -6.1‰ to -6.9‰ in the Eocene while strong positive excursion in the Oligocene and Miocene, from -5.2‰ to -3.7‰ and -7.1‰ to -5.2‰ respectively, which is regarded as the gradual aridification in the center Asia from the Oligocene. In addition, the $\delta^{18}O$ shows negative excursion from the Oligocene to Miocene. It could possibly be related to the uplift of the elevation. Furthermore, the $\delta^{13}C$ of oolite also shows positive excursion at about 3‰ than marlite in the Qaidam Basin. From the SEM-EDS mapping we can see the abnormally high Mg content of the outer cortex of the ooid and high C content among these circles, which could be interpreted as the photosynthetic related organic matters. In this progress, the ^{13}C was elevated in the lake and the algal oolite formed due to the microbial activities. The strong $\delta^{18}O$ positive excursion of oolite in the Miocene also indicates the strong uplift of the plateau and the probably atmospheric precipitation into the lake at high elevation.

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TITLE: PRE-QUATERNARY DECOUPLING BETWEEN ASIAN ARIDIFICATION AND HIGH DUST ACCUMULATION RATES

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Main text: Theories of late Cenozoic climate cooling assume that central Asian aridification and high dust accumulation rates in the Chinese Loess Plateau and the North Pacific Ocean are genetically related. Based on detailed sediment provenance analysis, we show that high dust accumulation rates in the Chinese Loess Plateau and the North Pacific Ocean during the late Miocene-Pliocene were mainly caused by increased erosion in the Qilian Mountains and low elevation eastern Asia areas, driven by the effects of East Asian summer monsoon intensification. We conclude that precipitation-driven erosion increased dust input to the North Pacific Ocean and may have played a pivotal role in late Cenozoic climate cooling.

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EVOLUTION OF LATE MESOZOIC DRAINAGE PATTERNS IN CENTRAL AFRICA: NEW INSIGHT AND IMPLICATIONS FROM U-PB DETRITAL ZIRCON ANALYSIS.

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The tectonics, paleogeography and sedimentary provenance of central Africa during the Jurassic-Cretaceous is poorly understood and still debated[1, 2]. This is problematic because central Africa is well endowed with natural resources and a good appreciation of the timing and controls on late Mesozoic sedimentary basin development, drainage patterns and palaeoenvironments in this region is fundamental to a better assessment of hydrocarbon and alluvial diamond exploration targeting. Refining the depositional age of late Mesozoic units and understanding of drainage patterns and palaeogeography are also essential to testing recent ecological and evolutionary hypotheses about the origins and dispersal pathways for Mesozoic, Cenozoic and modern faunas in central Africa[1].
Over 3500 detrital zircon grains from 50 samples collected from outcrop and drill core across central Africa were analyzed for their U-Pb ages and Lu-Hf isotope ratios. The samples were collected from (i) the Congo Basin in Democratic Republic of Congo (DRC) and Angola, (ii) the Dinosaur Beds of Malawi, (iii) the Zambezi Rift in northern Zimbabwe, (iv) the Turkana Basin in Kenya, (v) Tendagaru Formation of Tanzania and (vi) the Wadi El-Milk and Shendi formations from the central Sudan rifts. U-Pb detrital zircon results demonstrate that Neoproterozoic Pan-African Mobile Belts (e.g., Mozambique, Zambezi, Lufilian) provide the dominant sediment sources for late Mesozoic basins (>75%) and were the most conspicuous topographic features at the time. Petrographic and palaeocurrent data were used to support provenance interpretations. The initial results suggest a pattern of large ephemeral lakes in the Middle Jurassic to Early Cretaceous in the Congo and Zambezi basins, followed by the development of a large, dominantly northward directed fluvial system across the continent in the Middle Cretaceous. The north-eastern margin of central Africa particularly, in the Sudan and Turkana rifts, show complex drainage patterns, with generally south- to southwest directed flow. The results support the hypothesis of a major drainage divide between southern and central Africa during the late Mesozoic and the concept of a major NW trending fluvial drainage pattern into the Central African Rift System, although the ultimate depocentre still remains uncertain.

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PROVENANCE AND PALAEOGEOGRAPHY OF THE EARLY CRETACEOUS JIAOLAI BASIN, EASTERN NOTRH CHINA

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Jiaolai Basin, as a Cretaceous basin, located in the eastern North China Craton, is a key area to record the major geological events of the late Mesozoic in North China, which comprise the Early Cretaceous Laiyang and Qingshan Groups (K_{1l}: 135–125 Ma and K_{1q}: 120–105 Ma) and the Late Cretaceous Wangshi Group (K_{2w}: 88–65 Ma) in ascend order. The Laiyang Group consists of a 2000-5000 m thick sequence of fluvial-lacustrine yellow-green sandstones, shales and conglomerates. Above the Laiyang Group is the later Early Cretaceous Qingshan Group characterized by a series of intercalated volcanic and clastic rocks that largely crop out along the eastern and southern margins of the Jiaolai Basin. The Late Cretaceous Wangshi Group is mainly composed of purple sandy conglomerates, coarse sandstones, yellow mudstones and siltstones. The paleocurrents, gravels composition and detrital zircons chronology are analyzed for the provenance of Early Cretaceous Laiyang Group.The paleocurrents show a stable northward direction in Wulian-Zhucheng, but gradually change from E-SE at the early stage to W-NW at the late stage in Laiyang-Rushan. Gravels in Wulian- Zhucheng- Jiaozhou comprise mainly granite gneiss, granite, marble and quartzite; in Laiyang- Rushan, however, granites are dominant at the early stage and multiple gravels are present at the late stage. The detrital zircons showing main LA-ICPMS U-Pb age clusters at ca. 2600-2400, 2000-1900, 950-600, 250-200,180-150 and 145-110 Ma, together with the analysis of paleocurrents and gravels composition, indicate three main sources for Early Cretaceous Jiaolai Basin including of (1) HP-UHP metamorphic rocks and low-grade metamorphic Neoproterozoic metaigneous rocks or metasediments of Sulu terrane; (2) Precambrian basement in Jiaobei terrane and (3) late Mesozoic igneous rocks (Yanshanian granites ,$J_{2\text{-}3}$-K_1) in the northern part of the Jiaobei terrane and Sulu Belt. The evolution of sedimentary characteristics and detrital provenance indicate that the southern Sulu Belt experienced largescale uplift and was stable, whereas the northern Sulu Belt was subjected to small- scale uplift and then experienced massive collapsed. It is also concluded from the provenance that the ancient landform of Jiaolai basin in the southwest was higher than in the east during the sedimentation of Laiyang Group. And the east part of the Jiaolai basin did not uplifted until the upper Laiyang Group deposisted.

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PRELIMINARY RESULTS OF SEDIMENTOLOGICAL AND CYCLOSTRATIGRAPHIC ANALYSIS OF THE ÇAKRAZBOZ FORMATION, NW TURKEY

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3 Stratigraphic sections in the Triassic Çakrazboz Formation have been measured in Bartın (Amasra) and Kastamonu (Cide) regions in NW Turkey. In the study area, the thickness of the measured section in the vicinity of the village of Çakraz is 40 meters, in the vicinity of the village of İncigez is 60 meters and in the vicinity of the village of Başköy is 135 meters.
Detailed lithofacies analysis were carried out in this study. Accordingly, mudstonesandstone and carbonate rich facies are defined in Çakrazboz formation. Some of the mudstones are classified as sandy mudstone, silty mudstone, shale and carbonate mudstones. Mudstones containing relatively high amount of organic matter are defined as oil shale. In addition, evaporites and soily textures have also been observed in some of the mudstones. As a result of the observations, mudstones are interpreted as deposited in the saline lake environment under humid climatic conditions in the Triassic period and have possible source-rock potential. According to petrographic studies, sandstones are classified as Quartzarenite and Quartzwacke. For sandstones facies, sedimentological analyzes such as grain size and sphericity have been carried out and possible depositional environments have been discussed. Grain size distributions of studied samples indicate dominancy of fine to medium sand size fraction. The sorting of the samples varies between medium good and very good. It was interpreted that the main transporting agent is wind and/or wave according to grain size and sorting values. The possible depositional environments of sandstones can be stated as marginal lake and/or coastal environment.
Cyclostratigraphic studies based on color and lithofacies in the 3 measured stratigraphic sections were performed. The stratigraphic sections were divided into large-scale-cycles including smaller-scale cycles. The small-scale cycles are composed of alternation for sandy mudstone, clayey mudstone, carbonate mudstone/marl, limestone with wackestone and packstone facies for the Çakraz section. Alternation of reddish-brown sandy mudstone and greenish-gray silty mudstone lithofacies form the small-scale cycles in the İncigez section. Alternation of quartzarenite, quartzwacke, reddish-brown sandy mudstone, greenish-grey silty mudstone and black clayey mudstone form the small scale cyclicity in the Başköy section. Milankovitch cycles have been determined along the measured stratigraphic sections. In general 3 types of small scale cycles are defined as cycle A, B and C. Cycle A is characterized by carbonate mudstone, wackestone and packstone alternation, cycle B is characterized by greenish-gray silty mudstone and reddish-brown sandy mudstone. Due to the mud crack structures in reddish-brown sandy mudstone, it can be placed in the cycle tops. Cycle C is characterized by fining upward and deepening upward cyclic alternation as starting with quartzarenite and ending with clayey mudstone. In this study, the studied interval was predominantly composed of precession (19-21 ka) and eccentricity (100 ka) cycles, and was generally thought to be represented by a 5:1 bundle.

Keywords: Cakrazboz Formation, Milankovitch cycles, Paleoclimate, Lacustrine environment, Triassic

RECENT ADVANCES IN DEVELOPING A U-PB ZIRCON CHRONOSTRATIGRAPHY OF CENOZOIC STRATA IN THE HIGH PLAINS OF WESTERN U.S.A.

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A new approach targeting paleosols as a source of geochronologically useful detrital zircons is significantly revising our understanding of the chronostratigraphy of Cenozoic deposits in the High Plains of North America. As condensed terrestrial sections, mature paleosols may preserve a record of air-fall tephra deposits that are largely missing from continental sedimentary deposits. Volcanogenic zircons are introduced into the paleosol matrix via pedoturbation, including piping through root channels, desiccation cracks, and animal burrowing activity. Thus, mature paleosols may function as likely hosts for volcanogenic zircons from ashfalls that temporally overlap with periods of soil formation.

Scientific drilling was conducted in Cenozoic strata constituting the High Plains Aquifer (HPA) to improve understanding of its chronostratigraphy and hydrostratigraphic architecture. To date, 26 long continuous cores totaling over 860 meters have been collected from 10 study areas. High-precision U-Pb zircon dates of volcanogenic and detrital zircons via laser ablation inductively coupled mass spectrometry (LA-ICP-MS) from the cores and outcrops were generated to improve correlation of heterolithic sedimentary units and to delineate significant hydrostratigraphic subunits.

Maximum depositional ages (MDAs) derived ashbeds and paleosols of the Ogallala Fm in northwestern Kansas range from ~12.2–6 Ma. These MDAs correlate well with Neogene-aged super-volcanic eruptions associated with the Snake River Plain-Yellowstone hotspot (16.1–0.6 Ma). Cores from southwestern Kansas, however, show superposed, progressively older MDAs at depth ranging from ~27.9 Ma at 16 and 24 m; ~35.4 Ma at 34 and 52 m; and ~36.2 Ma to 87 m. Lithologically, the cores show decameter scale intercalations between suspended load fluvial deposits composed of fine-sands with pedogenically modified overbank deposits, and very coarse-grained sands and gravels suggesting a high energy, bed load dominated fluvial systems.

Zircon populations in southwestern Kansas likely originated from explosive volcanism associated with the Mid-Tertiary ignimbrite flare-up (36–18 Ma) which blanketed much of western North America in vast ash-flow tuffs. The absence of Middle-Late Miocene zircons from cores in this region is striking given that such Neogene grains are readily identified in the Ogallala Fm in northern and central Kansas and Nebraska. MDAs in southwestern Kansas suggest Eocene to Oligocene age deposits equivalent to the White River Group in Nebraska—ages previously unknown from Cenozoic strata in Kansas. Paleogene deposits in this region are consistent with continental-scale reconstructions of Eocene-Oligocene paleodrainage showing strongly southeast-trending fluvial systems that flowed through southwestern Kansas before turning southward toward the Gulf of Mexico.

CLIMATIC AND GEOMORPHOLOGIC CYCLES IN A SEMI-ARID DISTRIBUTIVE FLUVIAL SYSTEM (BAURU BASIN - BRAZIL)

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Distributive fluvial systems (DFS) are ubiquitous features over a large spectrum of modern sedimentary basins. They occur globally and across a wide range of climatic settings. These systems are expected to represent a substantial part of the geologic record and play a major role as petroleum, gas and water reservoirs. Therefore, understanding the dynamics of DFS and testing their resultant facies model is imperative to better identify and reconstruct the geologic record of fluvial deposits. State-of-the-art studies on distributive fluvial systems rely primarily on the large-scale longitudinal distribution of architectural elements, controlled by channels radiating outward from the basin margin. This approach focuses on the downstream dynamics of the channels network, providing minor attention to their temporal variations, relative controlling factors and resulting stratigraphic organization. In order to understand how spatio-temporal variations of channels produce vertical organization in deposits of ancient distributive fluvial systems, this work analyzes the proximal part of an Upper Cretaceous, semi-arid, distributive fluvial system, localized at the northeastern margin of the Bauru Basin (Southeast Brazil). To unravel refined internal architecture of channel deposits, their relationship with floodplain deposits and the factors influencing its sequential organization, five detailed stratigraphic sections were measured and analyzed, each one c.10 m thick. An interval of three fining- and thinning-upward fluvial sequences was identified. Two paleosol profiles separate the interval at the top and the bottom. Each sequence demonstrate channel and floodplain architectural elements. Two types of channels were identified. The first was associated to fluvial activity during more humid climate periods, when river flows assumed more perennial behavior. A second channel type was related to drier climate periods when rivers assumed more ephemeral hydraulic behavior and were characterized by highly erosive and supersaturated flows operating near supercritical conditions. The vertical alternation of these channels suggests a fluvial belt organization brought out by high-frequency climate-induced cycles. The two paleosol profiles that mark top and bottom of the fluvial interval indicate temporary interruptions on the fluvial sedimentation, related to autogenic avulsion of the fluvial belt. Thereby the studied succession reveals high-frequency climate-induced allogenic sedimentary cycles encompassed by a longer-period autogenic geomorphologic-induced sedimentary cycle. Finally, this work suggests how climate and geomorphology act jointly as remarkable mechanisms controlling the vertical organization in deposits of distributive fluvial systems under seasonal climate settings.

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PALEOGEOGRAPHIC RECONSTRUCTION AND DEPOSITIONAL MODEL OF THE UPPER TRIASSIC SEDIMENT IN WRANGEL ISLAND, CHUKOTKA (N-E RUSSIA)

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Triassic deposits are widespread in Chukotka and Wrangel Island. On Wrangel Island they are observed in the south of the island, where they are represented by alternating mudstones and sandstones. The stratigraphic age of the Triassic deposits on Wrangel Island includes the Carnian and Norian ages, as evidenced by the presence of rare fauna.
In the Novosibirsk-Wrangel fold system, to which Wrangel Island belongs, the Triassic deposits are the upper part of the section of deformed Paleozoic-Triassic sedimentary cover. The lower part of the Triassic section is represented by the predominance of argillites and fine-grained sandstones, in the upper part sandstones predominate. In all the analyzed sections, a two-membered structure can be traced. The most powerful interlayers of sandstones from the upper part of the section are observed in the west of the island, in the area of the m. Ptichii Bazar, Chertov (Devil's) Ravine, and also in the east, near the Hawaii Mountains. The thickness of sandy beds are 10-30 cm, sometimes it can reach 50 cm or more.
At the base of the sandy beds of the “sandstone” unit, traces of sediment flow, as well as almost unrounded large (10-12 cm), flattened mudstone’s intraclasts are observed. Besides, there is a large number of small plant remains, chaotic located in the sandstone beds.
Earlier in publications, the Upper Triassic deposits of Wrangel Island were considered as deposits of proximal turbidites (Kos’ko et al., 2003). Our research shows that Upper “sandstone” unit are a continuation of small deltas in the shelf zone of the sea basin. Comparing the results derived from this work, it can be inferred that the Triassic “sandstone” unit was formed during a period of stagnation and sea-level fall.

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LATE CRETACEOUS LACUSTRINE ENVIRONMENT AND CLIMATE IN NE CHINA

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The Songliao Basin is the largest Cretaceous oil and gas-producing lacustrine basin in China. For the environment and paleoclimate study, we present micropaleontology, biomarkers, stable isotops from ostracods collected from the basin. Our data offer a unique opportunity to perceive Cretaceous environment and climate of terrestrial settings. The sediments contain variegated clastic and volcanic rocks, diverse terrestrial fossils, and important coal and oil resources. Four Cretaceous biotas of Jehol, Fuxin, Songhuajiang and Jiayin occurred in biostratigraphic seccesion[1]. The specific biological markers (24-n-propyl and 24-isopropyl cholestanes) trace two SWIEs which caused high total organic carbon (TOC) and negative d^{13}Corg values during high levels of aqueous CO_2, due to the mixing of alkaline seawater and acidic lake water[2]. Ostracods carapaces record robust isotopic trends with numerous carbon and oxygen isotope shifts that are not only rapid but also long-term. We tentatively interpret this record to reflect the changes in both global climate and regional basin evolution. In the Turonian and Coniacian Qingshankou Formation we observe several carbon isotope shifts that appear to be correlative to marine isotopic records based upon timing and magnitude of the isotopic changes. Thus we suggest that the carbon isotope record in the Songliao basin reflect the decrease in carbon isotope ratios following the strong positive excursion at the Cenomanian/Turonian boundary, a positive isotope excursion in the late Turonian, and the negative isotope shift that occurs at the Turonian/Coniacian boundary. Upward in the section, however, the marine and Songliao isotopic records diverge as sediment sources shift from the southwest, east and north to more northerly. Strontium isotopes record the change in source region as they increase markedly between the Coniacian/Santonian Yaojia and Santonian/Campanian Nenjiang Formations. The rich isotopic records are compared to global climate changes and basin evolution as well. Lake water salinity changed in a freshwater–brackish water –freshwater cycle, along with a Coniacian-Santonian marine incursion. Lake-level fluctuations resulted in the development of periodic anoxic environments in the deepest parts of the basin. One of these times of deposition of organic-rich mud correlates with the mangnetochron boundary of C34N/C33R and Coniacian-Santonian planktic foraminifera. This marine flooding correlates with OAE 3 and it is possible that the global oceanic anoxic event may have influenced organic carbon burial in the Songliao Basin for this brief period[3]. The signal from Songliao Basin shows that the terrestrial climate change is somehow similar to marine recode as under one single Earth system.

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MG ISOTOPE SIGNATURES ON EOCENE TO OLIGOCENE SALINE LACUSTRINE PRIMARY DOLOMITE: EVIDENCE FROM NORTHERN MARGIN OF TIANSHAN, CHINA

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During the Eocene to Oligocene, the lacustrine dolostone was first found in Anjihaihe Formation of northern margin of Tianshan, southern Junggar Basin. Dolomite formation is conditional and restricted in specific environmental and geochemical conditions, which contain much information on palaeoenvironment and paleoclimate signatures. To further reconstruct the Eocene to Oligocene evolution of paleoclimates in the northern margin of Tianshan, especially reveal the origin of lacustrine dolomite, systematic micro-drill sampling, petrography, SEM scanning, Mg isotopic compositions as well as conventional stable isotope systems (C/O) of dolostone samples collected from the Anjihaihe Formation. Dolostone is white to grey white, consisting of 5-10 μm in size, homogeneous and nearly stoichiometric dolomite (Mg/Ca molar ratios average in 0.98). The high Sr content (ranging from 1021 to 3408 ppm and average in 1723 ppm), relatively heavy $\delta^{18}O$ values (ranging from -0.2 to -3.9‰ and average in -1.8‰) as well as the occurring of the halite and gypsum reflect evaporating and saline conditions in shallow lacustrine environment. The $\delta^{13}C$ values of dolomite are relatively negative, ranging from -4.1 to -5.9‰ and average in -5.1‰. These traits of $\delta^{13}C$ may influenced by low rate of biological production under an oxidation environment, organic matter decomposed or bacterial oxidation/sulphate reduction. Especially, we chose 5 spots evenly (2 cm interval) of four single intact dolostone layers (10cm thick) from the bottom to top to $\delta^{26}Mg$ analysis in detail. The $\delta^{26}Mg$ values of dolomite range from -0.806 to -2.44‰ with a mean of -1.78‰. What's more, there is an obvious positive correlation between the $\delta^{26}Mg$ values and depth (R^2=0.96, 0.90, 0.90 and 0.99, respectively), as well as the strong relationship between $\delta^{26}Mg$ and $\delta^{18}O$ (r=0.85, n=25). Which probably indicate the process of $\delta^{26}Mg$ fractionation with the evaporation: in the formation of dolomite, preferentially taken up the light Mg isotope and the Mg isotope become heavier constantly with the evaporation strengthen continuously. Moreover, the microbes can be found and covered on the surface of dolomite and associated with a few framboids of pyrite. Sulfate reduction largely through the rise in pH and alkalinity, which favor the dolomite formation. The results show that understanding of lacustrine dolomite in the southern Junggar Basin is significant and essential to reconstruct the high-resolution paleoenvironment and to decipher the Eocene to Oligocene evolution of paleoclimates in the northern Tianshan. Meanwhile, the Mg isotope broadens a train of thought to reveal the formation process and mechanism of dolomite, and provide a possible model to explain the primary dolomite formation in a saline evaporative lacustrine environment.

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LATE TRIASSIC PALAEOCLIMATE VARIATIONS INFERRED BY GEOCHEMICAL COMPOSITION OF NON-MARINE RECORD IN THE NORTHEASTERN SICHUAN BASIN, CHINA

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Identifying and understanding the influence of climate and depositional processes becomes a frontier topic in Mesozoic lacustrine sedimentary system. In Sichuan Basin, the Late Triassic sediments strata represented by the Xujiahe Formation mainly consist of coal-bearing clastic rocks deposited in inland lacustrine-fluvial-coal swamp environment. Previous palynological and megafossil plant studies showed the palaeoclimate was generally characterized by humid and warm tropical-subtropical conditions with any fluctuates in Sichuan Basin during the Late Triassic (Norian-Rhaetian). However, due to the hiatus and low resolution of this non-marine record, the result of climate change has been controversial. Here, a set of major and trace element data of mudstones were measured by inductively coupled plasma mass spectrometry (ICP-MS) from depth of lacustrine clastic successions in Xujiahe formation at Qilixia section in Sichuan Basin. The analytical results reveal that an unstable and variable climate prevailed during the Late Triassic. Specifically, the palaeoclimate index such as: CIA value, Ca/Mg, Sr/Cu, Sr/Ba, ∑(Fe+Mn+Cr+Ni+V+Co) / ∑(Ca+Mg+Sr+Ba+K+Na) ratio consistently showed several hot and dry period interrupt the overall humid and warm climate condition in Late Triassic. Moreover, the sedimentary cycles in Xujiahe Formation may interpreted to be related to variations of the wet/day runoff cycles, which indicate that orbital forcing may played an important role in climate change in Late Triassic.

Keywords: Geochemical composition; Palaeoclimate; Xujiahe Formation; Sichuan Basin

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LATE CRETACEOUS SEAWATER INCURSION EVENTS IN SONGLIAO BASIN, NE CHINA: EVIDENCE FROM CLUMPED ISOTOPE THERMOMETRY OF DOLOMITE CONCRETIONS

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The Daqing oilfield, located in the Songliao Basin, is the biggest oilfield of China. Since the 1950s, hypotheses have been proposed that seawater incursion events occurred frequently in the paleo-Songliao Lake during the Late Cretaceous and that such events were closely related to the development of the oil-source rocks found in Qingshankou and Nenjiang formations. The evidence includes the marine and brackish-water fossils, biological markers, and stable sulfur isotopes and elements[1,2]. However, it is difficult to use geochemical parameters to distinguish non-marine and marine environments directly, which weaken the reliability of the evidences of seawater incursion events. In this study, by applying clumped isotope (Δ_{47}) paleothermometry to dolomite concretions in the Qingshankou and Nenjiang formations both from the outcrops and cores, we suggest that these dolomite concretions were formed syndepositionally at ~20-40 ºC. After evaluating the isotopic evolution of water-calcite systems during open and closed system diagenesis and mass-balance model of the effects of seawater incursion on paleo-Songliao Lake $\delta^{18}O_{water}$, we conclude that the paleo-water, from which the dolomite concretions formed, was a mixture of lake water and seawater. We, therefore, infer that the source-rocks deposited during these formations were probably caused by the frequent seawater incursion events.

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Isotope geochemistry characteristics of Chang 7 two kinds of causes carbonate concretions in Middle Triassic Yanchang Formation of Ordos Basin

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Abstract

Carbonate concretions developed in sedimentary rocks are authigenic mineral aggregate, and are common in sandstone and shale, especially in organic-rich shales. Plentiful carbonate concretions distributed in Tongchuan north Ordos basin in Chang 7 middle and upper Triassic Yanchang fromation, mainly within pure oil shale of lower Chang7_3 or fine sandstone , siltstone, pelitic siltstone or silty mudstone of middle and upper Chang7_2. The diameter of concretions changes from several mm to cm. Asphalt can be found in the hole or cracks of the inside of concretions commonly. Turtle cracks are also found on the surface of carbonate concretions.

Limestone or dolomite is the main composition of concretions, that limestone concretions are composed by calcite of radial structure, and dolomite concretions are granular dolomite. Clay mineral analysis shows that mineral composition include quartz, potash feldspar, plagioclase, calcite, dolomite, iron, dolomite and clay mineral, partly siderite and pyrite, rock salt, aragonite, analcime, gypsum and tuff stone.

The $\delta^{13}C$‰(VPDB) value of concretions appeared in Beiyingou profile varies in the range from -5.019‰ to -12.013‰, and the $\delta^{18}O$‰(VPDB) value of that varies in the range from -17.6‰ to -19.281‰, the ^{87}Sr / ^{86}Sr value varies in the range from 0.710072 to 0.710392 with an average of 0.710204, clumped isotopes shows that the temperature 60.4 ℃ is conducive to the formation of concretions.

The $\delta^{13}C$‰(VPDB) value of concretions appeared in Bawangzhuang profile varies in the range from -3.274‰ to 14.189‰ with large different, and the $\delta^{18}O$‰(VPDB) value of that varies in the range from 18.297‰ to -10.073‰, the ^{87}Sr / ^{86}Sr value varies in the range from 0.711222 to 0.711594 with an average of 0.711382, clumped isotopes shows that the temperature 42.8℃ is conducive to the formation of concretions.

Extremely positive $\delta^{13}C$ indicates that concretions within organic-rich shale controlled by bacterial sulfate reduction and methanogenesis. Organic carbon isotope fractionation caused by methanogenic bacteria. Calcite or dolomite spheres of carbonate concretions may be the products of calcilization or dolomitization of Cyanobacteria, occurred in early diagenesis. Negative $\delta^{13}C$ value of concretions within silty mudstone and argillaceous siltstone indicates that dehydroxylation occurred in the early-middle diagenesis.

Acknowledgements

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EPICONTINENTAL SEA IN SOUTH HEMISPHERE: BEHAVIOR OF PERMIAN TIDES IN THE PARANÁ BASIN

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The Paraná Basin is an intracratonic Gondwana basin covering an area of approximately 1,600,000 km^2 in Brazil, Paraguay, Argentina, and Uruguay. During the Permian, sediment deposition took place in a large epicontinental sea located at latitudes around 50°S[1] with a South connection to the Panthalassa ocean. Transgressive environments of the Lower Permian succession were likely influenced by circulation patterns within this epicontinental sea. Little is known about the Permian ocean circulation; however, the Rio Bonito Formation wave- and tidally-influenced deposits are likely important records for this understanding. The epicontinental sea is estimated to have 1,000,000 km in area and shallow depths (a similar dimension to the Hudson Bay). Thus, the dimensions added to the latitude and hemisphere would fit in a micro-tidal regime. This condition is evidenced throughout the paleocoastline in the eastern border of the Paraná Basin, with straight and elongated sandy barriers recording wave influence in sediment deposition[2,3]. However, interiors outcrops of the paleovalleys reveal several medium and large size tidal sandy bars[4]. Recent studies in one of these bars had shown a mixed semidiurnal tidal with a 15-days neap-spring cycles, and tidal bundles with thicknesses ranging between 1.5 and 7.5 cm[5]. Therefore, even though wave processes have controlled sediment deposition along the paleocoastline, tidal processes also played a roll. Coast morphology must have controlled the occurrence of wave- and tide-dominated coast in different parts along the eastern paleocoastline of the Paraná Basin.

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HOLOCENE ENVIRONMENTAL CHANGES IN NORTHEASTERN BAFFIN BAY: A MULTI-PROXY APPROACH

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Reconstructing the evolution of past sediment dynamics and sea-surface conditions is key to understand the paleoclimatic and paleoceanographic history. The high-sedimentation rates occurring in the cross-shelf troughs of the northeastern Baffin Bay offer excellent locations to study those variations during the Holocene. Hence, three sediment cores were collected on the northwestern Greenland margin (AMD14-204; AMD14-210) and Kane Basin (AMD14-Kane2B) in order to (1) track changes in sediment inputs and transport pathways and (2) estimate the evolution of sea-surface conditions (temperature, salinity, sea-ice cover and productivity). The chronology of the cores was constrained by combining paleomagnetic analyses with AMS ^{14}C ages and confirms that the three sequences cover the Holocene. The physical, sedimentological, mineralogical, geochemical and magnetic proxies indicate fluctuations in the sedimentation during the Holocene, reflecting changes in the Greenland Ice Sheet dynamics. Overall, sediment from core AMD14-Kane2B is mainly derived from Paleozoic carbonate-bearing rocks, while sediments from the two cores on the west Greenland margin are mainly derived from granite and gneiss from the Precambrian Shield. Similarly, the palynological results from cores AMD14-204 and AMD14-Kane2B reveal three dinocyst assemblage zones corresponding to different sea-surface conditions. The base of each core is composed of glaciomarine sediments (~9.5 to 7.5 ka cal BP) likely corresponding to the end of the deglaciation. The sediment input was ice-proximal and mainly from very local detrital sources near the coring sites, reflecting major ice rafting and meltwater input events. This period is also characterized by cold sea surface conditions and extended sea-ice cover, as shown by the dominance of heterotrophic dinocyst species (e.g., *Brigantedinium sp.*, *Islandinium minutum*) and a low productivity. A change occurred around 7.5 ka cal BP with the establishment of a more ice-distal hemipelagic sedimentation and the dominance of autotrophic dinocyst species (e.g., *Operculodinium centrocarpum*, *Spiniferites elongatus*) associated with a seasonal sea-ice cover, high species richness and productivity. This period reflects improved sea surface conditions and warmer temperatures, and coincides with the well-observed Holocene Thermal Maximum in the Arctic. Lastly, no major lithological changes occurred at the top of the cores (after ~3.5 ka cal BP), but we observe the occurrence of an autotrophic dinocyst species (*Pentapharsodinium dalei*) and a decreasing productivity. This period thus reflects the establishment of modern sea surface conditions in Baffin Bay, with a general cooling trend that started following the Holocene Thermal Maximum, driven by a reduction in boreal summer insolation. These specific variations of almost all proxies measured in this study are synchronous with other regional records, supporting the hypothesis that the Greenland Ice Sheet fluctuations are mainly driven by changes in the intensity of the West Greenland Current, themselves related to Holocene climate variability.

Abundant microspherules from the Upper Ordovician of northern Tarim Basin, Northwest China: Origin and palaeoenvironmental implications

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Abstract: A continuous record of abundant microspherules, pyrite framboids, and bacterial fossils is obtained from the Upper Ordovician in the Dawangou section of northern Tarim Basin, Northwest China. Chemical and physical characteristics of these microspherules were determined using a scanning electron microscope and an energy dispersive spectrometer. Microspherules were formed as a single spherule, spherule aggregates, and drop - like particles. Physical morphology of the spherules has no relation to its formational process. Energy dispersive spectrometry results indicate that microspherules are mainly composed of Ca, C, O, Si, Al, S, Fe, and Ti. Thus, these microspherules are further categorized into 5 major types: iron, titaniferous - iron, siliceous, calcareous, and organic microspherules. The first 3 types of microspherules are likely of volcanic origin rather than extraterrestrial origins (i.e., impact event or cosmic dusts) or modern industrial pollutions due to their orphologies and chemical compositions. Both calcimicrospherules and organic microspherules are biogenic, and they are distributed in the lower part of the studied section (Beds 4–6), in which cephalopods, brachiopods, and bacterial fossils are also commonly present and pyrite framboids are absent. These features generally point to an oxic condition. In contrast, other microspherules are abundant in the upper part of the section (Beds 9–13), in which tiny pyrite framboids (mean diameters 4.6–7.3 μm) are rather abundant and typical of euxinic to dysoxic conditions. Both microspherule and pyrite framboid evidences indicate that the northern Tarim region became oxygen - poor conditions, which were coupled with intensive volcanic eruptions during the Late Ordovician.

Keywords: Katian, Late Ordovician, microspherules, pyrite framboid, volcanism, Xinjiang Province

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The expression of early Aptian to latest Cenomanian oceanic anoxic episodes in the sedimentary record of the Briançonnais domain

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The Briançonnais domain is an important paleogeographic unit in the Alps, which represents a structural high within the former Alpine Tethys Ocean. Expressions of the most important Cretaceous oceanic anoxic episodes (OAE1 a-d and OAE 2) are exceptionally well preserved in the Subbriançonnais unit at Roter Sattel (Fribourg Prealps, Switzerland). The main target of this study is to reconstruct oxygen contents and trophic levels in the water column for each OAE. For this an integrated multi-proxy approach ($\delta^{13}C_{org}$; total organic carbon, TOC; phosphorus; redox and productivity sensitive trace elements, RSTE, PSTE) was used.

At Roter Sattel, RSTE distributions show three intervals of significant maxima in concentrations associated with the highest TOC values (up to 5.45, 4.8, and 5 wt%) and with the lowest Mn contents, in sediments equivalent to the Selli (OAE1a), Paquier (OAE1b), and Bonarelli Levels (OAE2). Our data indicate the presence of intermittent anoxic to euxinic conditions during these episodes. Mo and U enrichment factors (EFs) in the lower Aptian and lower Albian intervals suggest the characteristics of an unrestricted marine environment. In the Cenomanian-Turonian boundary interval, they point to the participation of a particulate Fe-Mn-oxyhydroxide shuttle within the water column. In the OAE1a interval the elevated total phosphorus (P) content associated with higher C_{org}:P_{tot} ratios and maxima in TOC values suggests that a part of the remobilized P remained trapped in the sediments. In contrast, the lower P values associated with RSTE and C_{org}:P_{tot} enrichments in the OAE1b and OAE2 intervals indicate that a significant part of P was remobilized and escaped to the bottom water. Our results highlight the combined roles of regional and global parameters in the development of anoxia and increase in organic-matter preservation during the OAEs. The differentiated topography of the Briançonnais domain associated with global climate and sea-level change and its influence on weathering in general and more specifically on the mobilization of sediments on the adjacent ridge modulated nutrient availability in different proportions during the different "mid"-Cretaceous OAEs.

Calcareous nannofossil of the Jurassic black shales from the Qiangtang Basin, northern Tibet

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ABSTRACT: The marine Jurassic sedimentary strata of the Qiangtang Basin, northern Tibet are well known for their organic carbon-rich shales, abundant fossils and the most complete and extensive sections, especially as regards Middle to Upper Jurassic strata. The lack of well-preserved ammonites makes recognition of key Jurassic stages particularly difficult. However, the recent discovery of coccoliths in the section described herein has proven particularly useful as a biostratigraphic aid.

We chose two sections of Jurassic black shales from Qiangtang Basin, northern Tibet for calcareous nannofossils and a number of samples yielded age-significant coccoliths. Preservation is generally poor, although intact coccospheres were observed. Biostratigraphic interpretations follow the zonal schemes of Bown and Cooper (1998) and Mattioli and Erba (1999). Thirty-five taxa were identified, including various morphotypes of *Watznaueria britannica* and differently sized *W. manivitiae*. In general, nannofossils are very poorly to quite moderately preserved in the two studied sections, although assemblages from the Biluo Co section are overall slightly better preserved. Etching is common but overgrown was also observed. The assemblages are dominated by species of the Watznaueriaceae, as it is the case for most of the known sections of Middle Jurassic. In spite of the generally poor preservation of coccoliths, entire coccosphaeres were observed both in optical microscope and SEM. Some enigmatic specimens of *Rucinolithus* and *Pseudoconus enigma* were recorded. Interestingly, these taxa are reported by Tiraboschi and Erba (2010) from the Bathonian of SE France.

Biostratigraphic interpretations are according the zonal schemes proposed by Bown and Cooper (1998) and Mattioli and Erba (1999). In the Amdo section, the presence since the base of the section of *Watznaueria barnesiae* suggests a Bathonian age. From sample 22-1, *W. barnesiae* becomes abundant and the presence in sample 29-1 of *Cyclagelosphaera wiedmannii* suggests a Callovian age.

Nannofossils from the Biluo Co section are more abundant. Similarly to Amdo, the abundance of *W. barnesiae* and the presence of *C. wiedmannii* from sample 26-1 mark at least the latest Bathonian or earliest Callovian. This age is also confirmed by the occurrence of *B. dorsetensis*, *A. helvetica*, *O. decussatus*, *S. hexum* (all appearing in the Late Bathonian) in sample 29-4. Therefore, the attribution of the samples to the Bajocian, Bathonian and possibly Callovian stages of the Middle Jurassic for the middle–upper part of the two sections is secure.

Keywords: Nannofossil, Jurassic black shales, northern Tibet

CHEMICAL WEATHERING AND ATMOSPHERIC CO_2 EVOLUTION DURING OCEANIC ANOXIC EVENT 2

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Paleoclimate during the Cenomanian-Turonian OAE 2 was characterized by elevated atmospheric CO_2 concentrations and peak global temperatures. Massive sequestration of carbon into marine sediments is thought to be the major factor that terminated the event. Possible mechanisms for CO_2 drawdown and burial of organic carbon are enhanced silicate weathering and elevated productivity, respectively. In this study, pCO_2 fluctuations and changes in weathering intensity during OAE 2 were studied in an expanded section from southern Tibet using well-established proxies (i.e., $\Delta^{13}C$ and chemical index of alternation, or CIA). The offset between $\delta^{13}C$ of carbonate and organic carbon ($\Delta^{13}C$) can be used as a qualitative pCO_2 proxy in Cretaceous marine sediments. The $\Delta^{13}C$ and CIA plots in the studied section show covariant trends, except for the lower part of the OAE 2 interval. $\Delta^{13}C$ values indicate significant fluctuation in pCO_2 throughout OAE 2. Evidence from prior studies suggests that volcanic pulses were responsible for pCO_2 rise at the onset of, and later during the main phase of OAE 2. Elevated chemical weathering intensity on the Indian continent, as indicated by CIA values at the beginning of OAE 2, may have played an important role in decreasing pCO_2, leading to the Plenus Cold Event in the early part of the interval. Correlation of the $\Delta^{13}C$ curve from this study with the sea surface temperature (SST) plot from the western equatorial Atlantic indicates covariant trends in pCO_2 and SST. We thus infer that fluctuations in pCO_2 are a key factor controlling global paleotemperature changes through Cenomanian-Turonian transition. We also suggest that enhanced weathering intensity may be one of major causes for the decrease of pCO_2 in the Early Turonian, and ultimately the termination of OAE 2.

Sequence stratigraphy of the Yellow Sea and East China Sea shelf since the Late Pleistocene

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Based on analyses of shallow seismic profile and borehole data from the areas to the east of the Yangtze River estuary, the evolutionary patterns of the sedimentary environment since late Marine Isotope Stage 6 (MIS 6) are presented. According to geomorphology, sedimentology, seismic sequence stratigraphy as well as radiocarbon dating data, a good correlation was discovered between 5 seismic units and borehole sequences. Here, the environmental change since late MIS 6 was mainly related to sea-level fluctuations and huge sediment discharge of the Yangtze River. The Pacific tide system dominated the East China Sea continental shelf for a long period. During the regressive-transgressive cycles, three river deltas were developed, together with tidal sand ridge sequences in the transgressions. During late MIS6, sea-level rose rapidly, inundating the East China Sea shelf. A delta was formed during the sea regression in the inner shelf in the MIS5 period. Sea level fell rapidly for a short period during MIS 4, with the deposits of this stage being too thin to be detected at the seismic record resolution. Relatively high sea level lasted for a long time with small fluctuation during MIS 3, when the river deltaic system prograted steadily towards the sea, mainly located at the present-day middle-outer shelf. At the MIS2 stage, once again, sea level fell rapidly, reaching the lowest sea level up to -130~-140 m at 18 ka BP. When the time came to MIS1, due to rapid sea level rise, the continental shelf sediments were reworked to form a series of tidal sand ridges. Sea level started to be relatively stable at about 6 ka BP, and the modern Yangtze River delta began to develop. Such an evolution pattern indicate that the formation of the sedimentary systems on a wide continental shelf area can be deduced from the sea level curve, with a large quantity of sediment being supplied by the Changjiang catchment.

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Pliocene-Quaternary Sedimentation in the Central Arctic Elevations, Deep-Water Arctic Basin: Paleomagnetic study

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Nowadays, there are no any doubts, that understanding of processes taking place in the Arctic Ocean throughout its evolution is a high-priority geological objective. Nevertheless, accurate age determination for marine sediments in the deep-water Arctic Basin still remains a subject of great debates.

According to the undertaken paleomagnetic study on nine sediment cores, retrieved from the Mendeleev Ridge area, the Brunhes-Matuyama boundary (0.78 Ma) has been observed at the first two meters below the seafloor. Supplemented by the identified Gauss chron (2.58-3.58 Ma), that implies low mean sedimentation rates of 0.1-0.15 cm/kyr in the area during the Quaternary and Late Pliocene. Moreover, the study has been complemented with one core from the Lomonosov Ridge, PS87-023/1 (Stein, 2015), providing insights into the dramatic difference in sedimentation rates between the ridges.

The bulk of most cores is relatively homogeneous aleuropelites (silty clay) with sporadic calcareous constituents, which are inversely related to magnetic susceptibility. Moreover, measurements of magnetic properties performed at fine intervals have identified five horizons with peak values, which occur to consist of tuffite interlayers. Increased concentrations of ore minerals and pyroxene together with a significant decrease in concentration of obviously clastic minerals as garnet and titanite have been also observed in the sediments. Apparently, for a short period of time there was five times increase of sedimentation rate comparing to its average value. That, amongst other related findings, is considered to indicate active, at times even catastrophic, Pleistocene volcanic activity in the Arctic Basin.

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PALEOCLIMATE SIMULATIONS CHALLENGE PERCEIVED WISDOM OF A PERSISTENT CRETACEOUS GREENHOUSE CLIMATE

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The Cretaceous Period is often regarded as a persistent greenhouse interval, characterized by uniformly warm climates, and lacking significant land-grounded ice at the poles. Nonetheless, research during the last twenty years has suggested the possibility of several "cold snaps" within the Early Cretaceous, characterized by cooler climates and the possible development of polar ice sheets. These cold snaps are commonly considered to be exceptions in the Cretaceous overall greenhouse paradigm.

However, the climate-sensitive proxy evidence for Cretaceous ice sheets is growing, including dropstones, glendonites, and dramatic shifts in sea water temperature, as expressed in stable isotopes and orbital-forcing signatures in the rock record. Moreover, such views can now be supported by global atmosphere-hydrosphere paleoclimate simulations, which have been linked to large-scale, high amplitude, fast paced eustatic cycles, of presumed but debated glacioeustatic origin. In turn, the possibility of glacioeustatic events plays a key role in the formation of specific, predictable, global sedimentation patterns, some of which have petroleum system significance. Based upon a global synthesis of geological data, combined with the results of paleoclimate simulations, three Early Cretaceous glacioeustatic events will be discussed.

The first two examples are associated with worldwide, large-scale, prograding successions culminating in deep incised valley development in the late Early Valanginian and latest Aptian. These are associated with high-amplitude falls in global sea level, increased siliciclastic sediment fluxes along basin margins, karstification, and incision of existing carbonates. The third example is associated with the Early Aptian high-amplitude transgression, which resulted in the deposition of worldwide source rocks (OAE 1a), including within shallow, carbonate-dominated, intra-shelf basins.

For each of these examples, climate-sensitive proxies (as previously described) have been captured and support the notion of Early Cretaceous cold snaps. Furthermore, these events are associated with rapid, high-amplitude eustatic changes. This pattern of sea level change is common throughout the Cretaceous; consequently, it may suggest multiple cooling and warming events, with the records for the Early Cretaceous climate events to the waxing and waning of significant polar ice caps. Although not precluding greenhouse intervals, these results suggest that the Cretaceous climate oscillated between cool (possibly glacial) and warm (possibly hot) episodes, challenging the perceived belief of a continuous state of greenhouse conditions for the Cretaceous.

Late Ordovician Paleoceanographic Changing Process: Sedimentary and Geochemcial Evidences from the Upper Ordovician of the Tarim Basin and Middle Yangtze regions, China

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Abstract: Sanbian-Katian is a key period while the Middle Ordovician Radiation convert to the end Ordovician extinction, it has provided important clues for the effect of extreme changes on biological events. Here, we selected Dawangou section (Tarim) and Puxihe section (Yangtze) as studying object, size distribution of pyrite framboids, redox sensitive elements, carbon and strontium isotope are used for the marine environmental reconstruction and evolution during this period.

We performed a high-accuracy carbon isotope analysis of the two section. The result shows that global Guttenberg isotope carbon excursion (GICE) were recognized in both Tarim and middle Yangtze region. The most important is the GICE in our section is not only one peak distributed in Sanbian-Katian boundary but three stages: GⅠ, GⅡand GⅢ. The result of size statistics of pyrite framboids and redox sensitive elements indicate that the redox history experienced four periods during Late Ordovician，which is from short-term euxinic-anoxic events to stable euxinic event. During this interval. This imply that the euxinic condition might be one of the main genetic mechanism for the transformation. This result suggests that euxinic events might be the key genetic mechanisms of the extinction.

In summary, the euxinic event happened in middle of Late Ordovician. Long-term environmental degradation maybe the main reason for the extinction, weathering increasing and paleoproductivity variation may be connected with mass extinction.

Keywords: Guttenberg isotope carbon excursion, glacial, pyrite framboids, size statistics of pyrite framboids, euxinic event, Dawangou section, Puxihe section

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UPPER ORDOVICIAN OUTLIERS ALONG THE NORTHERN OTTAWA-BONNECHERE GRABEN, CENTRAL ONTARIO, CANADA: SIGNIFICANCE FOR DEPOSITIONAL SYSTERMS IN THE LAURENTIAN INTERIOR

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Several small (< 7 km^2) outliers of sedimentary rocks occur within the northern Ottawa–Bonnechere graben in the southeastern Canadian Shield. They occur north of the erosional limits of the Michigan and Appalachian basins to the south, and the Ottawa Embayment to the southeast. These small areas of Paleozoic strata are erosional remnants of a once expansive Upper Ordovician sedimentary cover across the Laurentian interior. Previous paleontological data indicated that the youngest preserved strata were of Turinian-Chatfieldian age. This prompted our study to evaluate if widespread paleoceanographic change across southern Laurentian in this time period can be traced into the Laurentian interior? The age of these outliers is confirmed from integration of old and new biostratigraphic (conodont, chitinozoan, and macrofossil) and new chemostratigraphic ($\delta^{13}C$ profiles) data sets showing that the Deux Rivières, Brent Crater, and Manitou Islands outliers preserve upper Turinian strata, whereas a small outlier (Owen Quarry) south of Lake Nipissing contains dolomitized limestone of early Chatfieldian age, overlapping with the end of the Guttenberg $\delta^{13}C$ excursion (GICE). Lithostratigraphic correlation identifies a regional Upper Ordovician connectivity with stratigraphy of outliers and adjacent sedimentary basins, although local variations in siliciclastic and carbonate facies patterns exist. In particular, rocky shoreline siliciclastic-dolostone facies of Manitou Islands outlier reveal transgression across a once significant paleotopography in the Lake Nipissing region in association to sites of Neoproterozoic alkaline intrusions within the graben. Unlike the lower Chatfieldian cool-water carbonates interpreted across southern Laurentian, time-equivalent Laurentian interior carbonates possess warm-water indicators such as altered ooids and tabulate coral colonies. Preservation of outliers is related to three factors: 1) location within a regional topographically low graben system; 2) differential subsidence that preserves ~ 250 m of sediments within the Brent impact crater; and, 3) local down-faulting related to post-Ordovician wrench-fault tectonism along the graben.

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SEDIMENTOLOGICAL, PHYSICAL AND MAGNETIC PROPERTIES FROM THE CANADIAN ARCTIC ARCHIPELAGO: A MULTI-PROXY ANALYSIS TO RECONSTRUCT SEDIMENTARY PROCESSES SINCE THE LITTLE ICE AGE

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Several box cores (50) distributed over a large area covering the Makenzie Shelf/Slope, the Amundsen Gulf, the M'Clure Strait, the shelf of Banks Island, the Queen Maud Gulf and the Barrow and Victoria Straits were recovered in 2016 and 2017 on board the GCCS Amundsen as part of the ArcticNet program in order to compare the sedimentological, magnetic, geochemical and physical properties of sediments during the Little Ice Age (~1550 et 1850 AD) and the recent period. This will allow the reconstruction and comparison of sediment dynamics during these climatic periods.

Preliminary results of the geochemical (XRF core scanning), magnetic (volumetric and frequency dependent magnetic susceptibility, hysteresis measurements, natural, anhysteretic and isothermal remanent magnetizations), physical (Multi Sensor Core Logger) and sedimentological (grain size) properties of the surface sediment samples reveal a West-East trend described by all the parameters. Principal component and clustering analysis of log-ratio transformed XRF data have allowed us to divide the study area in three main provinces with distinct sedimentary compositions: (1) **the West** (Mackenzie Shelf/Slope, west of Banks Island, Amundsen Gulf) is characterized by a high input of detrital (Al-K-Ti-Rb-Y) and Fe oxide materials near the mouth of the Mackenzie River, and detrital carbonates in the west of Banks Island; (2) **the intermediate zone** (central Amundsen, Coronation and the Queen Maud Gulfs) with a predominance of reddish sediments ($a^*>6$) and redox sensitive elements (Mn-Fe-Zn); (3) **the East** (Victoria Strait and Barrow/Lancaster Sounds), described by a predominance of detrital elements (Ti-Fe-Si-Al-Zr-Sr-K) and carbonates gradually diminishing in proportion toward the Barrow Strait. Moreover, the shape of hysteresis loops, the pseudo S-ratio (>0.94) and the median destructive field suggest an assemblage dominated by pseudo-single domain low coercivity minerals such as magnetite. Magnetic susceptibility increases from 10 in the West to 50 ($\times 10^{-5}$ SI) east of Barrow Strait and seems to be correlated with the magnetic grain size. Indeed, the variation from West to East of magnetic grain size ratios (increase of Hcr/Hc, SIRM/k_{ARM} and reduction of Mrs/Ms and k_{ARM}/k) depict a similar West-East trend as detrital grain size with finer unsorted grains in the West and coarser poorly sorted grains in the East. Combined with XRF core scanner data, these results on recent sedimentation suggest that the West province is dominated by detrital sediment supplied by numerous rivers (e.g., Mackenzie plume, Coppermine, Ellice, Back and Hayes Rivers) and by coastal erosion of dolomite cliffs and glacial tills cropping out on the shelf of Banks Island. On the other hand, the East province seems influenced by sediment-laden sea ice and icebergs with important carbonate inputs likely originating from the coastal erosion of Ordovician- Silurian carbonate-bearing rocks cropping out in the Victoria and the Prince of Wales Islands. In addition, preliminary results from the base of the box cores indicate changes in the sedimentation dynamics. Indeed, in the West province the redox sensitive elements seem to disappear whereas in the East province the carbonates still increase. The detritic grain size becomes generally finer from the base to the top (7.3 to 8.2 Φ in the West and 7.5 to 8.0 Φ in the East) just as the magnetic grain size. Finally, recent ^{210}Pb measurements indicate that sedimentation rates are varying between 100 and 300 cm/kyr. These rates will be used to establish the chronology of key cores to reconstruct variations in the sedimentary processes since the Little Ice Age.

REGIONAL DEPOSITIONAL CHANGES AND THEIR IMPACTS ON CARBON AND SULFUR CYCLING ACROSS THE ORDOVICIAN-SILURIAN BOUNDARY, NORTHERN GUIZHOU, SOUTH CHINA

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Regional depositional controls on stable isotope records spanning the Ordovician-Silurian boundary on the Yangtze Platform receive scant attention. The objective of this study includes reconstruction of regional depositional settings and assessment of how sedimentary processes may have influenced carbon- and sulfur-isotopic characteristics. Seven shale facies have been recognized in the Wufeng Formation to Longmaxi Formation interval. Completely bioturbated claystone of the basal Wufeng Formation accumulated on an oxic muddy shelf, arguing against the establishment of anoxic conditions at the beginning of the Boda transgressive event. High levels of authigenic silica derived from dissolution of radiolaria within overlying organic-rich faintly banded black siliceous shale suggest deep starved conditions. However, the presence of fecal pellets of benthic organisms indicate that the late Katian ocean was periodically dysoxic, rather than persistently anoxic as previously assumed. Organic-lean muddy fossiliferous facies of the overlying Guanyinqiao Formation reflects a glacial sea-level lowstand setting, and the observed proximal to distal heterogeneity of facies matrix supports shallowing in the proximal area. Overlying organic-rich faintly banded black shale facies of the Longmaxi Formation tell of rapid transgression, although it contains an evaluated abundance of detrital material relative to the Wufeng Formation. The carbonaceous deposits are overlain by banded gray and dark gray muddy siltstones reflecting increasing bedload transport by bottom currents and suggest a shoaling upward trend. The shallow-water facies display relatively heavier $\delta^{13}C_{org}$ values, whereas deep-water facies are characterized by lower $\delta^{13}C_{org}$ values. Differences between Hirnantian positive $\delta^{13}C_{org}$ excursions in proximal and distal areas probably reflects spatial gradient in seawater $\delta^{13}C_{DIC}$ induced by glacioeustasy. Deposits that accumulated under oxic and physically dynamic conditions display strong positive $\delta^{34}S_{sulfide}$ excursions, perhaps a consequence of diagenetic sulfate reduction that occurred at some depth below the sediment-water interface and removed from the sulfate pool of overlying water column. The generally negative relationship between $\delta^{34}S_{sulfide}$ and TOC displayed by the studied sections indicates that redox conditions and physical reworking of sediment at the sediment-water interface controlled the rate of microbial sulfate reduction and sulfur isotope fractionation. Discrepancies between isotopic excursions in proximal and distal areas suggest the depositional environment can significantly influence biogeochemical processes.

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The temporal-spatial distribution of carbonate red beds in the Lower-Middle Ordovician of South China

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A set of red-color argillaceous limestone, including the Zitai Formation and its contemporaneous units, developed on the Yangtze Platform, South China paleoplate during the Early-Middle Ordovician when the Great Ordovician Biodiversification Event (GOBE) occurred (see the latest revision by Servais and Harper 2018). Understanding this marine red beds is crucial for illuminating the environmental background of the GOBE in South China. The temporal and spatial distribution of this reddish limestone has been discussed on the basis of the published data and field observations. It is proposed that such marine red beds were developed along the margin of the Yangtze Platform under a ramp setting (*sensu* Read 1985), with four stages observed, i.e. (0) early Fl1 to middle Dp1, (1) late Dp1 to early Dp3, (2) middle Dp3 to middle Dw1 and (3) late Dw1 to early Dw2 (time slices after Bergström et al. 2009), which may be related to the sea-level changing and terrestrial supply. According to the carbon chemostratigraphy, a worldwide positive shift of $\delta^{13}C$ can be recognized in the interval immediately below the red beds. Both the ramp setting and the positive excursion of carbon isotope may be induced by a global sea-level rising. The oceanic oxidation is normally necessary for marine red beds (Hu et al. 2012), but oxic oceanic condition in South China was found just prior to this marine red beds as the first diversity acme of GOBE, suggesting that the source of iron and other factors might control the occurrences and distribution of the red beds. Further investigation is needed to reveal the dynamics of these red beds and the trigger of the GOBE.

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Oceanic Anoxic events from Upper Jurassic sequences in the southern Caribbean margin using C-and Sr-isotopes.

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The Mesozoic oceans experienced several periods of marine anoxia, seawater acidification and marine biological crises. These periods known as Oceanic Anoxic Events – OEAs, have been linked to punctuated intervals of massive injection volcanic derived carbon into the atmosphere, increasing atmospheric $p\mathrm{CO_2}$, global warming, elevated continental discharge, enhanced nutrient input to the global ocean and increased marine primary productivity. The combination of all these processes and the differential action of their natural feedbacks resulted in major perturbations of the global marine biogeochemical cycles that are distinctively reflected by the geochemistry of the OAEs marine records. The Toarcian (Early Jurassic) OAE is the unique reported event in the Jurassic. Recently, several lines of geologic and geochemical evidence obtained from diverse global late Jurassic marine sedimentary records suggest the occurrence of several periods of expanded global anoxia in the Jurassic. Similar to the other Mesozoic OAEs, these Late Jurassic anoxic intervals are related to major perturbations on the marine carbon cycle, as reflected by major global C-isotope anomalies in the organic rich marine sedimentary records. Here we report C isotope compositions of Upper Jurassic (Oxfordian-Tithonian) organic-rich marine sedimentary rocks from the Alta Guajira basin (northernmost Colombia), which are currently evaluated for their hydrocarbon potential. Our results allow identifying two positive C-isotope anomalies. $^{87}\mathrm{Sr}/^{86}\mathrm{Sr}$ isotopes data suggest that these anomalies occurred during the Middle Oxfordian and Upper Oxfordian-Lower Kimmerigdian transition. The presence of Hg anomalies, high TOC and elevated concentrations of redox dependent trace metals coinciding with the Oxfordian C-isotope anomaly allow suggesting that these potential unconventional hydrocarbon sources were deposited during a period of global anoxia and enhanced global volcanism. This is further supported by iron speciation data, which suggest changing bottom waters redox conditions (from euxinic to anoxic to oxic).

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SEDIMENTARY EVOLUTION OF THE AGADIR TISSINT FEIJA (ANTI-ATLAS, MOROCCO) BETWEEN CA. 75 AND 10 KYR: IMPLICATIONS FOR PALAEOENVIRONMENTS IN NORTHWEST AFRICA

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Mountainous depocentres are complex sedimentary systems that constitute the single available archives in some intracontinental regions. As such, the investigation of their sedimentary dynamics is the only way to reconstruct the palaeoenvironmental evolution in such regions.
In this contribution, sedimentary dynamics that characterized the Agadir Tissint “Feija” (Anti-Atlas, Morocco) are described and interpreted. The Agadir-Tissint “Feija” is a striking example of a depocentre in a regional intracontinental region filled by a *ca*. 40 m thick fluvial and lacustrine succession. Spanning a period of *ca*. 65 ka, it is among the few long-term onshore late Quaternary pre-Holocene sedimentary archives in northwest Africa. Building upon facies and sequence analyses, clay mineralogy and precise datings (OSL and U/Th), the basin-scale sedimentary evolution of the “Agadir Tissint Feija” is reconstructed for the interval between *ca*. 75 ka and *ca*. 10 ka. Three depositional sequences (S1-S3) are identified. Both S1 and S2 represent the evolution of a paleolake characterized by low-energy vegetated shores and a low-energy basinal portion, separated by periods of marsh to fluvial environments, with deposition of carbonate-rich deposits. These sequences are indicative, for the first time, of prolonged existence of a late Quaternary lake in the region. Superimposed on these three relatively long-term depositional sequences, sub-millennial scale (750-900 yr) short-term lake level fluctuations are identified in S1 and S2. The low-energy lacustrine system is capped by sequence S3, which shows evidence for the development of a clastic fluvial system and disappearance of lacustrine conditions.
All three sequences are genetically associated with three pulses of carbonate tufa buildups at the outlet of the depocentre, which controlled accommodation space, to be filled subsequently with sediments. Origins of tufa buildups and short-term lake fluctuations are discussed and previous paleoclimate reconstructions are questioned. This depocentre constitutes a valuable new archive for Late Quaternary paleoclimate in Northwest Africa. Moreover, we highlight the potential of field sedimentological investigations on Quaternary sediments for the identification of unexpected new long-term palaeoenvironmental archives.

Depositional conditions during the Lower Alum Black Shale Event (middle Tournaisian) in Polish part of Laurussia: an integrative approach

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Here we present a detailed reconstruction of the paleoenvironmental conditions prevailing during sedimentation of the Lower Carboniferous black shales and lydites representing the Lower Alum Shale Event (LASE) on Polish part of the Laurussian continent. The best and most complete Tournaisian succession in Poland at the well-known Kowala quarry in the Holy Cross Mountains has been investigated in detail, using integrated high-resolution palynological, petrographic, gamma-ray spectrometry and organic and inorganic geochemical methods. The lower part of the investigated succession (~15 m thick) consists of yellow and green siltstones with four thin intercalations of black shale and several horizons of limestone intercalations and carbonate nodules (Radlin beds). The upper part (~7 m thick) consists of black, organic-rich siliceous shales and lydites with phosphoritic nodules and ash layer intercalations (Zaręby beds). Based on the presence of index and characteristic miospores, the Zaręby beds are assigned to the one stratigraphic assemblage and dated as the HD Miospore Zone. This zone is considered as the lower part of the middle Tournaisian and tentatively correlated with the lower part of the *crenulata* conodont Zone, which corresponds to the Lower Alum Shale Event. Based on inorganic proxies, the older part of the succession was formed under generally oxic conditions as confirmed by e.g., high values of Th/U ratio (> 3) and lower values of Mo (often below detection limit 0.1 ppm). In contrast, the upper part represented by black siltstones and lydites, an equivalent of the Lower Alum Shale, was deposited in anoxic/euxinic conditions in photic zone of water column and bottom waters, which is reflected in almost all samples by low values of Th/U (generally < 2), high Mo contents (generally above 4-5 ppm), high TOC (usually > 2%) values, small size of pyrite framboids and high concentration of biomarkers typical for anoxic conditions (e.g., Me,i-Bu maleimides and isorenieratane). These rocks were generally formed in a very high-productivity regime, with volcanic influence which can be confirmed by several ash and zircon-enriched cryptotephra (non-visible volcanic ash horizon) layers.

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Redox conditions, productivity and volcanic input during deposition of uppermost Jurassic and Lower Cretaceous organic-rich siltstones at Isfjorden, Spitsbergen

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The uppermost Jurassic and Lower Cretaceous siltstones of the Rurikfjellet Formation from Spitsbergen were studied using palynological, petrographic, and geochemical (organic and inorganic geochemistry as well as Rock-Eval pyrolysis) methods in order to decipher the depositional conditions prevailing during their sedimentation, the type of organic matter from which they were formed, and their potential for generating hydrocarbons. The age of these sediments encompasses an interval from the upper Tithonian–Berriasian to the Hauterivian, as based on dinocyst biostratigraphy. The ammonoids found loose at the base of the section, such as *Laugeites groenlandicus*, are indicative of the upper part of the middle Tithonian. Based on palynology, biomarkers, and Rock-Eval data, the kerogen in the investigated deposits is of the mixed II/III type; the organic matter has mixed marine and terrestrial character, and represents the early to peak 'oil window' maturation stage (T_{max} around 440ºC). These siltstones were deposited under a high-productivity regime with oxic/dysoxic bottom water conditions, as evidenced from the distribution of pyrite framboid sizes, in which pyrites with diameters > 5 μm predominate. Values of Th/U and C_{org}/P ratios generally above 3 and 30, respectively, along with pristane/phytane ratios > 2 and sterane/hopane ratios < 0.3, also indicate oxic to suboxic sedimentary conditions in the water column. Anoxia, if present, must have been brief and formed oxygen minimum zone in the water column. Elevated productivity in the photic zone may have resulted from an increase in volcanic activity, as confirmed by higher Hg contents and/or terrigenous nutrient supply.

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HIGH RESOLUTION MODEL FOR BEACH RIDGE EVOLUTION, AN EXAMPLE DURING THE HOLOCENE CLIMATIC OPTIMUM FROM ARGENTINA.

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Beach ridges constitute landforms that provide worthy information about the littoral environment where they formed. At Bahía Samborombón area (Argentina), one of the most spectacular marine Argentinean Holocene deposits associated with the last climate optimum are preserved. Geomorphologic analyses based on satellite images allows recognizing a series of beach ridges parallel to the current coast up to around 30 km inland. Twenty detail sedimentary logs (perpendicular to main axis) were measured and sampled in order to generate an environmental sedimentary and chronostratigraphic model. In order to constrain the time of the beach ridge evolution, paleontological and taphonomical strict sampling methods combined with ^{14}C ages were carried out.

At the study area it is possible to recognize a unique beach ridge geoform, which presents internal surfaces, recognized from a 3D photogrammetric outcrop model, which can be divided into eight bodies. The first two bodies correspond to the development of a sand ridge as a response to the erosion and reworking of previous aeolian Pleistocene sediments. Subsequently, a bioclastic ridge was amalgamated with the sand ridge (bodies 3 to 8). Simultaneously to these eight bodies, in a landward position, a lagoon and washover deposits were developed. Finally, after the deposition of the ridge the continuous sea level fall generated the modern coastal plain deposits. Six 14C ages were analyzed in the main bodies, ranging between 5,240±110 BP and 3,910±90 BP. These results imply that in ca.1,330 years the beach prograded ca. 290 meters. Results from stable isotope analyses suggest that the sea surface temperature during the evolution of the chenier has two maximum values at bodies 1 and 6 (ca. 22.5 ºC), with a minimum at body 7 (18.5ºC). The salinity values range between 32.53 and 33.16‰, showing little variability.

We document a novel precise age-controlled model for the Holocene beach ridge evolution in the southwestern Atlantic coast. The sudden change in the composition of the ridge, from sandy (bodies 1-2) to carbonate (bioclastic in bodies 3-8) sediments, can be interpreted as a combined result of an increase of carbonate productivity along with a decrease of siliciclastic supply at the coast. This stage would have been developed approximately 5ka B.P., in coincidence with the Holocene Climatic Optimum or Mid-Holocene Thermal Maximum when the very special climatic oceanic-atmospheric conditions may have led to the proliferation of large communities of benthic organisms. In particular, bivalve mollusks, which are absent or not so abundant today in the Argentine coast. In this way, the increased extension and intensification strong activity of the Brazil current during the Mid-Holocene Thermal Maximum generated excellent conditions for the development of a carbonate warm beach similar to that occurring at tropical areas northwards nowadays. In turn, this study provides an example of the strong changes occurred in coastal environments as a result of climate change, particularly in the context of global warming episodes which characterized interglacial periods of the Quaternary in South America.

HYDROLOGY OF THE LAST TWO GLACIAL CYCLES IN TROPICAL SOUTH AMERICA: A HIGH-RESOLUTION MULTI-PROXY STUDY ON SEDIMENTS OF THE COLÔNIA BASIN (SE BRAZIL)

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Hydro-climate patterns in South-America are still unresolved on glacial-interglacial timescales, particularly east of the Andes. Primary moisture sources to Southeast (SE) Brazil are the South American Summer Monsoon (SASM) and Southern Air Masses. New high-resolution multi-proxy data for the Colônia paleo-lake and peatland show hydrological variability during two glacial cycles. The lake to peat/wetland evolution from this depositional environment is evidenced by the degree of crystallinity (DCr) of the sediments, the mineralogy obtained by XRD (major assemblage composed of quartz, muscovite, kaolinite, and pyrite), the amount and quality of the organic matter (TOC, TOC/N and $\delta^{13}C$), and supported by statistical compositional data analysis of the elemental compositions obtained with an XRF core scanner (Al, Si, S, K, Ca, Ti, Fe, Rb, Zr and the inc/coh ratio). The first principal component (PC1) gives a rainfall index that is well-correlated to other South American paleoclimate records. The Colônia peatland is dominantly ombrotrophic during interglacials, with moisture supply maintained by southern sources. During the last glacial, minerotrophic peatland prevailed due to an enhanced SASM explained by a southern positioning of the Intertropical Convergence Zone (ITCZ). The onset of the peatland accumulation seems to be concurrent to the beginning of the last interglacial, in an analogous scenario to the expansion of modern boreal peatlands. The rainfall index (PC1) shows similar patterns of hydrological variability preceding glacial terminations TI and TII, followed by a long-term trend of reduce in moisture supply. These patterns retain the wettest event during the glacial periods and are timely concurrent with prominent cooling events of the adjacent southern Atlantic, followed by long-term warming trends.

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ARCHAEAL AND BACTERIAL COMMUNITIES AS BIOMARKERS OF PALEOSEDIMENTARY EVENTS ENABLE TO UNDERSTAND THE BIOGEOCHEMICAL HISTORY OF LAKE PAVIN

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Lake Pavin, a meromictic maar lake located in the French Massif Central, represents a modern analog of the Archaean ocean chemistry making it an exceptional study site for Earth and Biology Sciences. In June 2012, a 7000-yr sedimentary record (PAV12) collected from the center of the lake gave us the opportunity to investigate its complete biogeochemical history. Sedimentological analyses using different proxies revealed some parts of this story, notably major geochemical shifts recorded after 3900 and 650 cal BP that were attributed to dramatic detrital and slump events, respectively[1]. But was the biogeochemistry of Lake Pavin water column impacted following these events? To address this question, we extracted bulk DNA and lipid biomarkers of bacterial and archaeal communities from sediment samples covering the whole sedimentary archive. Taken together, sedimentological and biological proxies allowed us to propose a biogeochemical evolution scenario for Lake Pavin. Following the rapid development of the lacustrine aquatic ecosystem from 6900 cal BP onward and *ca*. 5 centuries of intense microbial and phytoplanktonic productivity, euxinic conditions developed in the water column and reached the photic zone, as revealed by lipid biomarkers characteristic of anoxygenic phototrophic bacteria. The rise of sulfides in the water column associated with a high-discharge event from the catchment, was likely responsible for the collapse of the whole lake ecosystem observed around 3900 cal BP. This extinction event was followed by a second period of intense aquatic (both microbial and phytoplanktonic) productivity. Simultaneously, changes in the isotopic signature of some microbial biomarkers as well as the phylogenetic structure of archaeal communities suggest an enhancement of methanogenesis/methanotrophy. This euxinic period ended with another major environmental perturbation (*e.g.*, 650 cal BP) that apparently initiated the (still actual) meromictic and ferruginous characteristics of the lake, and allowed the reappearance of phytoplankton species adapted to well-oxygenated surface waters. Our results highlight an unusual biogeochemical history for Lake Pavin and document a rare case of aquatic ecosystem shifting from sulfidic to ferruginous conditions. We further show that changes in archaeal structural patterns closely followed the dramatic environmental shifts that drove the biogeochemical evolution of Lake Pavin. Overall, our multidisciplinary approach supports the use of microbial biomarkers as paleolimnological proxies.

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HETTANGIAN TO PLIENSBACHIAN CLIMATIC AND ENVIRONMENTAL CHANGE

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The late Triassic – Early Jurassic interval is well known for the end Triassic mass extinction event (eTME) and for the Toarcian oceanic anoxic event (T-OAE). However, more and more studies highlight the fact that the intervening period (Hettangian-Pliensbachian) witnessed also important paleoceanographic, climatic and environmental changes influenced by major paleogeographic changes and possible CO_2 releases. Indeed, this time is characterized by the opening of the Central Atlantic Ocean starting in the Hettangian, the opening of the Hispanic Corridor during the latest Sinemurian-Earliest Pliensbachian interval and the opening of the Viking Corridor in the Late Pliensbachian. Furthermore, several carbon isotopic shifts suggesting carbon cycle perturbations have been recorded. At least four of them seem to record global events. They correspond to the main CIE (earliest Jurassic), the Sinemurian-Pliensbachian boudary event, the Spinatum negative event (end Pliensbachian) and the Pliensbachian-Toarcian boundary event. Nevertheless, the causes of these perturbations, their environmental and climatic impacts and their link to the paleogeographic changes are quite unknown. Furthermore, most of the studies focused on small time intervals and therefore does not allow to observe large-scale changes.

In order to better describe the climatic and environmental changes during the Hettangian-Pliensbachian interval we will show and compare a wide array of geochemical data from three European sections in the Wessex Basin (Dorset), the Swiss Jura mountains (between the Paris Basin and the Southern German Basin) and the Lombardian Basin (Breggia). The stable carbon isotopes recorded in organic matter and carbonate allow to trace the major perturbations of the carbon cycle in great detail. The associated climatic variations, paleoceanographic changes, water oxygenation conditions and productivity will be discussed using carbon and oxygen isotopes, bulk-rock and clay mineralogy, the alteration index (CIA), organic matter content (TOC), hydrogen index (HI), phosphorus content and the composition of major and trace elements.

PALEOKARST IN THE CANTABRIAN ZONE: WITNESS TO PENNSYLVANIAN PALEOCLIMATE EVOLUTION AT EQUATORIAL LATITUDES

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The Cantabrian Zone is the external domain of the Variscan Orogen in the NW of the Iberian Peninsula and is characterized by thin-skinned tectonics. During the Carboniferous, it represented a marine foreland basin where thick carbonate and siliciclastic successions accumulated. These successions include some of the most remarkable and well-known outcrops of Carboniferous microbial carbonate platform systems in the world. This basin was located in the western embayment of the Paleotethys Ocean at paleoequatorial latitudes. It neighboured the growing Variscan Orogen that formed during the collision between Gondwana and Laurentia, coinciding with the assemblage of Pangea.

Glacio-eustatic-driven cyclothems are frequently documented in Late Paleozoic deposits and have been reported globally. Subaerial exposure surfaces developing at the top of cyclothems linked to sea-level lowstands are typical features in these deposits. The study of subaerial exposures can provide important information about paleoclimates at the time of emergence.

Recently, paleoclimate interpretations of the Bashkirian Valdorria carbonate platform have been made by investigating outcrop morphology and mineralogy of paleokarstic and calcretic systems of major subaerial exposure surfaces. Based on these local-scale results, a regional study was triggered to investigate the paleoclimate evolution throughout the Pennsylvanian units of the Cantabrian Zone. Thirteen subaerial exposure surfaces have subsequently been discovered in the Picos de Europa carbonate platform, which represents the most distal realms of the foreland basin. The exposure surfaces typically exhibit paleokarstic systems associated with collapsed karst-infill and paleosols. They range from Middle Moscovian to Late Kasimovian, therefore an attempt at reconstructing the paleoclimatic evolution of the Cantabrian Zone through this interval has been done by studying outcrop morphology, mineralogy, and geochemistry from karstic units of the Picos de Europa Formation. Unconformable Permian paleosols of the terrestrial Sotres Formation have also been investigated for comparison purposes. Analyses have been acquired by petrography, X-ray diffraction, and ICP-MS whole-rock geochemistry.

The combination of a petrographic and mineralogical framework, while using geochemistry as a tool to understand the sedimentology, has proved to be a powerful approach for paleoclimate reconstruction worldwide. This study is an attempt to show that a similar approach is possible with the terrestrial units of the Cantabrian Zone.

High-Resolution Reconstruction of Terrestrial Environmental Stresses across the Permo-Triassic boundary in the northern Sydney Basin, southeast Australia

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The Late Permian-Early Triassic is a period characterized by global anoxia, euxinia, hypercapnia, and ocean acidification in the marine realm and global warming, reduced atmospheric oxygen content, wild fires, and aridity on land. The end-Permian Mass Extinction (EPME) is thought to have occurred slightly before the Permo-Triassic boundary (PTB: 251.9 Ma: Burgess et al., 2014). Precise timing relationships are under investigation across the world. In this study, we examine the stratigraphic record of the PTB interval in the high southern palaeolatitude, palaeocontinental margin of the Sydney Basin, eastern Australia. The dominantly fluvial stratigraphic architecture of the northern Sydney Basin has been examined across the PTB from Catherine Hill Bay to Birdie Beach, central New South Wales. The dataset comprises measured sections, correlations of sediment bodies continuously exposed in coastal cliffs, and analyses of samples for petrography and geochemistry. The succession is rich in detrital and in situ organic matter, which, provides an opportunity to evaluate changes in atmospheric CO_2. As $\delta^{13}C_{org}$ has a propensity to sometimes mask $\delta^{13}C$ excursions, it is ground truthed by the aforementioned sedimentological and stratigraphic interpretations. Elemental geochemistry is used to derive a series of indices for chemical weathering, so as to assess weathering intensity. The succession comprises a series of erosionally-based conglomerate and sandstone bodies, interpreted as the deposits of deep, laterally mobile rivers that drained a rising orogenic hinterland to the east. Upright, *in situ* tree fossils indicate that the palaeoclimate was strongly seasonal. Interbedded with these bodies are mudrock and coal-rich intervals that are the product of sediment accumulation in floodbasins and mires. Local evidence of incipient pedogenesis is preserved in the form of plant roots. The fluvial style is unchanged across the level of the EPME, as is the sediment dispersal direction. Over the succeeding 20-30 meters of section, mudrocks become progressively more strongly colored, but nonetheless remain indicative of gleyed conditions. The PTB lies within this interval. The dataset reveals a subdued response to environmental triggers in this high southern palaeolatitude setting, which is markedly different from the conventional view of an abrupt, severe degradation of the continental landscape at the EPME.

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Cambrian–Ordovician tide- to wave-dominated shallow-marine clastic environments from Sierra de Cajas, northwest Argentina

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Well-exposed Cambrian–Ordovician clastic sedimentary rocks from northwest Argentina have been the subject of intense paleontologic work aiming to unravel the evolutionary dynamics of the Great Ordovician Biodiversification Event (GOBE). However, detailed sedimentological studies in order to reconstruct paleoenvironmental conditions are less common. This study represents one of the first attempts to evaluate the depositional framework of the Cambrian–Ordovician transition in Sierra de Cajas, Jujuy Province with the aim of evaluating the potential impact of environmental factors on biodiversity at the onset of the GOBE. The studied interval ranges from Stage 10 (Furongian; late Cambrian) to early Tremadocian (Early Ordovician), which corresponds to the *Parabolina (N.) frequens argentina, J. keideli* and *Kainella andina* trilobite biozones. This section is *ca.* 350 m thick and is mainly composed by siltstone and sandstone. From base to top, this sedimentary succession has been subdivided into the Padrioc Formation and the Guayoc Chico Group (GCG; Lower, Middle, and Upper members). The Padrioc Formation mostly consists of cross-bedded sandstone with associated mudstone drapes on foresets alternating with rhythmic intercalations of sandstone and siltstone. This heterolithic interval comprises hummocky cross-stratified (HCS) and wave-ripple cross-laminated sandstone displaying ladderback ripples. The Lower Member of the GCG consists of massive siltstone intervals interbedded with cm-thick micro HCS sandstone (cm to dm-scale wavelength). The Middle Member of the GCG is characterized by a higher proportion of thicker (more than 1 m) HCS sandstone, either amalgamated or forming discrete layers, as well as wave-ripple cross-lamination and low-angle cross-bedding associated with keystone vugs. The Upper Member of the GCG is composed by a siltstone interval with thin sandstone layers displaying cm- to dm-scale micro HCS. The Padrioc Formation seems to reflect subtidal to intertidal environments in a tide-dominated to mixed tide- and wave-influenced embayment, whereas the GCG records deposition within a wave-dominated shallow-marine environnment, with the Lower Member corresponding dominantly to offshore settings, the Middle Member representing offshore transition to foreshore environments. The Upper Member represents a return to offshore transition - offshore conditions. The stratigraphic succession clearly highlights relative sea-level changes and coastal physiography controlling parasequence and parasequence set architecture and reflecting an overall passage from tide-dominated to wave-dominated conditions. The Lower Member of the GCG records the highest trilobite diversity in the basin for this period, most likely as a result of the interplay between normal marine salinity and low energy conditions.

Formation mechanism of the Middle Jurassic sublacustrine fan conglomerates and relationships with paleoenvironment in the Kashi sag, Southwestern Tarim Basin, China

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Kashi sag, where the Middle Jurassic sediments are widely distributed, is one part of the most favourable petroleum exploration areas[1]. Well YD-1 occupied a key strategic position, where firstly drilled into the Middle Jurassic strata in the Kashi sag. Recently, the conglomerate reservoirs have gained increasing attention and interests by geologists[2]. Interestingly, conglomerates with a thickness of 64 m were also formed into the upper Member of the Yangye Formation in the YD-1 well, which are of significant importance that bitumen and liquid oil were discovered. The conglomerates are tightly contact with semi-lacustrine dark mudstone facies rather than sandstone facies, and show distinct GR, SP, LLS and RLLD values with mudstones, revealing they were likely deposited in the sublacustrine fan facies caused by a sudden event[3]. Then, what is the formation mechanism? We initially infer that they were deposited in likely triggered by the strike-slip activity of Talas-Ferghana fault which was collectively considered quiescent during the Middle Jurassic[4], as well as paleoenvironment. The interpretations are as followings: (1) geochemical parameters Paleoclimate Index "C" (~0.16) and Sr/Cu (~8.27) values of mudstone show a strictly hot and arid climate, as indicated by high Ba (~820,ppm) and CaO (~14.1,%). (2) relatively low B (~74.1, ppm) and gammacerane index (~0.12) and relatively high Mn/Fe ($\sim 17.1\times 10^{-3}$) suggest the relatively lake level rose rather than declined in such arid paleoclimate, due to sufficient supply of fresh water by rivers. (3) stronger hydrodynamic force continuously entrenched Paleozoic carbonate strata, and thus forming main grooves, where numerous eroded carbonate materials could be transported into the lake by rivers when high-angle strike-slip activity of Talas-Ferghana fault was reactive during the Middle Jurassic. This accounts well for the widespread presence of subangular to moderate roundness, poor to medium sorting and upright carbonate gravels over the whole conglomerates.

Keywords: Middle Jurassic; Conglomerates; Talas-Ferghana; paleoenvironment

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LATE-PERMIAN PEATLAND NET PRIMARY PRODUCTIVITY AND THE RELATED ATMOSPHERIC O_2 AND CO_2 LEVELS IN SW CHINA

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Peatland, as a significant terrestrial carbon accumulation pool, has great significances for global carbon (C) cycle and climatic variations. In this study, three coal seams in the Middle Member of the Xuanwei Formation (Lopingian) in Songhe mine of western Guizhou province were selected for Late Permian palaeo-peatlands ecosystems production research as well as exploring the palaeo-climatic information in coal. Milankovitch cycles of 0.20, 0.63 and 1.09 m^{-1} corresponding to periodicities of 123 ka (eccentricity), 35.6 ka (obliquity), 21.2 ka (precession) are identified from the geophysical well-logs of three coal seams (No.17 coal (5.6m), No.18 coal (6.4m) and No.17+18 coal (5.4m)). Using the astronomic time frame as a time measurement, deposit period of No.17, No.18 and No.17+18 coals are constrained within 119.8-140.8 ka, 136.2-160 ka and 119.8-140.8 ka respectively. Then these deposit periods are divided into several short time-span parts based on different orbital cycles by Continuous Wavelet Transform (CWT). The short time-span part corresponding to the same orbital cycle with different thickness indicating the variable sedimentary accumulation rates in coal. Additionally, C accumulation rate in peatland is estimated of 60.6-72.3 g C m^{-2} a^{-1}, which is consistent with existed research achievements. Based on the correlation between net primary productivity (NPP) and C accumulation rates in Holocene tropic peatlands, Late Permian tropic peatlands NPP is estimated in a low level of 606-1446 g C m^{-2} a^{-1}. Integrated analysis shows that these independent estimates are consistent with expected variations derived from modeled atmospheric O_2 and CO_2 levels in the Lopingian suggesting that atmospheric CO_2 and O_2 contents, especially CO_2 contents, have a significant impact on palaeo-peatlands ecosystems production level. Thus, rely on the non-marine coal measures of the Late Permian, it is possible to obtain more detailed environmental information before the End-Permian terrestrial ecosystem collapse.

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Evolution of sedimentary process inferred from sediment grain size and shape in fluvial terraces and its influence on hominid settlement in the Hanzhong Basin, Central China

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Abstract: Recently, many important Paleolithic archaeological sites with abundant stone artifacts in Qingling mountains area (QLM) in Central China, which is the climate boundary between cold, (semi-) arid in the north and warm, humid in the south, have been reported. Artifacts here situated on fluvial terraces were buried in layers of inter-bedded clay and silt, overlying coarse fluvial deposits generally. To understand detailed information of sedimentary evolution could provide practical clues of relationship between hominid settlement and environments. Two Paleolithic archaeological sections located on terraces in south piedmont of QLM has been logged in detail. The sediment sequences with stone artifacts are comprised three sediment units. Unit 1 at the base, is constitutes by sand and silt with bimodal size distribution. Unit 2 also contains analogous two grain components, in which the percentage of sand fraction decreases from ~25% to 5% upwards gradually and silt is up over 20% correspondingly. Unit 3 is composed by fine grains with modal size at 20-35 μm and 8-10 μm, while coarse fraction, sand, occasionally presents. The features of grain size distribution, end-member-modeling components, and grain shape of these three units are compared to deposits from certain sedimentary environments. It shows that the unit 1 deposited in fluvial channel, and the unit 2 is floodplain, displaying a transition from high energy water current sediments to settling deposit of reworked loess during low energy of flood, and the unit 3 is aeolian loess which is disturbed rarely by episodic surface runoff. This gradual evolution of sedimentary process indicates there is no visible age gap between these two sedimentary environments (fluvial and aeolian). It show that not only an aeolian environment, but also a floodplain environment during relatively warm period would be occupied by hominid, since the convenience for water and row materials of artifacts.

Keywords: sedimentary process, floodplain environment, grain size, end-member modeling, grain shape, hominid settlement

BIOSTRATIGRAPHY, CARBON ISOTOPES AND CYCLOSTRATIGRAPHY OF THE ALBIAN-CENOMANIAN TRANSITION AND OCEANIC ANOXIC EVENT 1D IN SOUTHERN TIBET

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During the Albian-Cenomanian transition, the Earth underwent profound climatic and oceanographic changes that were recorded in sedimentary successions on a global scale. Carbon isotope curve spanning this time interval shows a broad positive excursion, which is further divided into four minor peaks. This carbon isotope excursion implies a significant carbon cycle perturbation event during Albian-Cenomanian transition with Oceanic Anoxic Event 1d (OAE 1d) at its base. This event has been reported in the western Tethys, eastern Pacific and North Atlantic Oceans, but not yet in the eastern Tethys Ocean. In the last two years, we investigated the marine sediments of Albian-Cenomanian boundary interval (ACBI) in the Tethyan Himalaya of southern Tibet, which is located in the north margin of Indian continent at the south margin of eastern Tethys Ocean during the Cretaceous. Two sections, named Youxia and Qiangdong sections, were studied. Based on biostratigraphy and the bulk rock $\delta^{13}C$ curves of both sections, the ACBI was identified and can be well correlated to the ones in western Tethys and Atlantic Ocean areas. $\delta^{13}C$ values range from approximately 0 ‰ to +1.31 ‰ in the Youxia section and -1 ‰ to +1.9 ‰ in the Qiangdong section. Four minor peaks were distinguished in the ACBI carbon isotope curve via correlation with other representative sections. The amplitudes of these four peaks in the Qiangdong section are larger than the amplitudes in the Youxia section. We infer that the methane-derived authigenic carbonates in the Qiangdong section may result in larger amplitudes of carbon isotope excursions. Based on a spectral analysis of the carbonate content of the Youxia section, we recognized Milankovitch short eccentricity (~100 kyr) and precession (22.2 kyr) cycles, suggesting that orbital variations modulated depositional processes. The duration of the ACBI was estimated at ~311 kyr, while OAE 1d lasted for ~233 kyr in the eastern Tethys Ocean, consistent with the duration calculated from Atlantic Ocean records.

Sedimentary Records and Paleoclimate Interpretation of Holocene Transgression for Hole ZK2 in Liaohe River Delta

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Among the four major deltas in China, the Liaohe River Delta is recognized as the one most sensitive to climate change. A 41.4m-long coring hole of ZK2 was drilled at the Liaohe River Delta in 2013 for the purpose of sedimentary records and carry out paleoclimate research. Based on the lithology, grain size, foraminifera abundance and molecular markers of the cores, we firstly established the stratigraphic framework of the region and reconstructed the environmental changing history of the Liaohe River Delta since late Pleistocene 33kyrBP. Results show that the deposits formed during the Holocene transgression (segment U3, 2.65-15.75m) are thick enough and continuous. Several kinds of climate indexes were adopted, such as macro and trace elements, organic carbon/nitrogen, pollen and biomarker GDGTs, for climatic interpretation. Vertical variation in the climatic proxies from the segment U3 suggest that two indexes, Chemical Index Alteration (CIA), a geochemical index and Mean Annual Air Temperature (MAAT), a biomarker index, are most sensitive to climate change, and could be chosen to reconstruct the paleoclimatic change since 9100yrBP. The results also suggest that the region had experienced four climatic stages: the rapid warming stage in early Holocene, the warm and humid stage within early mid-Holocene, the cold and dry stage in late mid-Holocene, and the warm and dry stage in late Holocene. There are at least six distinct dry cooling events discovered in the depth of 14.2m, 12.25m, 10.65m, 9.35m, 8.15m and 5.65m respectively. The results are in good agreement with some findings in previous publications, except for the timing of climate fluctuations as well as the intensity of cooling events. It is also revealed that the CIA and MAAT are more sensitive climatic indexes than others in this region, and thus could be used as proxies to reconstruct paleoclimate. And the index MAAT is a better proxy than CIA before the mid-Holocene paleoclimate response.

Keywords: paleoclimate indexes, Holocene transgression, Liaohe River Delta, sedimentary records, GDGTs, coring hole

REPEATED COLD WATER INGRESSIONS IN THE LATE JURASSIC GULF OF MEXICO

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Towards the Jurassic–Cretaceous boundary increasing temperatures have been reported in the Tethyan Ocean, although interrupted by significant climatic oscillations and sea-level fluctuations[1]. During this time the Gulf of Mexico played an important role on the distribution of global oceanic currents between the Pacific and the Tethyan Ocean. Recent records of Kimmeridgian–early Berriasian cold-water indicative mollusk faunas in tropical latitudes[2] appear to be causally related to changes in the marine current system.

Here we present a correlation of biogeographical data with microfacies analysis and geochemical proxies such as major and trace element concentrations and the characterization of organic matter. Bed-by-bed investigation of a shelf to upper bathyal sediment sequence at Puerto Piñones (NE Mexico) indicates that cold-water indicative high latitude mollusk occurrences correlate with relatively lower sea level, increased phosphorous contents, and organic matter of predominantly terrestrial origin. Both endemic and Tethyan tropical faunal elements appear to vanish during five Late Jurassic cold-water episodes. Despite the palaeoequatorial setting of the Gulf of Mexico, tropical faunal associations are repeatedly replaced by assemblages that are indicative of boreal and possibly antarctic origin. The findings add significant evidence to the existence of oscillations and turnovers in the oceanic current system of the Gulf of Mexico and support the interpretation that these repeated Kimmeridgian to earliest Berriasian environmental changes are expressed by profound faunal turnovers.

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POTENTIAL TSUNAMI DEPOSITS IN TWO COASTAL LAKES IN SOUTH-CENTRAL CHILE

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Overlying the subducting Nazca Plate, Chile's west coast is notoriously prone to megathrust earthquakes and associated tsunamis, as illustrated by e.g. the 2010 Maule (Mw 8.8) and 1960 Valdivia (Mw 9.5) events. In order to significantly assess the imposed hazard, there is a need for long records of seismic events, rupture extent, tsunami generation, and areas affected by extreme waves. Here, we explore the tsunami-recording potential of two coastal lakes in south-central Chile -Laguna Vichuquén, 200 km SW of Santiago, and Lagunas Gemelas West, 45 km SW of Valdivia- by studying side-scan sonar imagery, reflection-seismic profiles and short sediment cores (< 1.5 m). Vichuquén is connected to the Pacific via a 6.5-km long inlet, whereas only 400 m of beach separate the ocean from Gemelas, whose basin is shielded by up to 30-m high sand dunes. In Vichuquén, laminated, dark silt is interrupted by 14 chaotic to homogeneous units (I), which correspond to strong reflectors on seismic imagery when sand admixture is important (II). In Gemelas, we observe organic mud, seemingly devoid of structure. CT scans and high-resolution grain-size measurements, however, allow us to identify a sequence of 8 sand-enriched intervals with sharp lower boundaries that fade upwards (III), and with weakly defined lower and upper boundaries (IV). All of these interrupting layers are likely associated with high-energy events, which can include floods and earthquakes (I), tsunamis (II, III), and periods of strong aeolian activity (IV). Besides depositional structure and texture, deviating sediment colour, increased magnetic susceptibility, strong X-ray attenuation, and peaks in XRF element ratios (e.g. Sr/Fe) are used to distinguish event deposits from their background. Preliminary dating, using ^{14}C and $^{210}Pb/^{137}Cs$, suggest the presence of multiple historical tsunami deposits dating back to ~1500 AD, including 2010 AD and 1960 AD. These promising results already encourage the future recovery of long cores and potentially long records of prehistorical tsunamis from both coastal lakes.

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A 7-8 KYR LONG RECORD OF EXTREME WAVE EVENTS IN COASTAL LAKE HAMANA, JAPAN

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Tidal Lake Hamana is located near the convergent tectonic boundary of the Nankai-Suruga Trough, which gives rise to repeated tsunamigenic megathrust earthquakes (Mw $\geq$ 8). Lake Hamana represents a good sedimentary archive of past tsunamis and tropical storms (typhoons), also referred to as "extreme wave" events, as it features improved accommodation space and preservation potential compared to the nearby coastal lowlands. By applying a broad range of surveying methods, sedimentological analyses and dating techniques, we attempt to trace extreme wave event deposits in a multiproxy approach. Seismic imagery shows a vertical stacking of strong reflectors, interpreted to represent coarser-grained sheets of beach and dune sand, deposited by highly energetic waves. Systematic sampling of lake bottom sediments along a transect from ocean-proximal to -distal sites enables us to evaluate vertical and lateral changes in stratigraphy. Ocean-proximal, up to a depth of 8 m into the lake bottom, we observe a sequence of 15 sandy layers, separated by silty background sediments. These sandy layers have a thickness that varies between 1 and 25 cm, and typically display an erosive base, a fining-upward grain-size trend, internal semi-parallel to chaotic layering, an increased magnetic susceptibility and density, and stronger X-ray attenuation. They are interpreted to be extreme wave event deposits. Overall, event layers quickly thin and/or become finer-grained land-inward. Seismic-to-core correlations show a good fit between the occurrence of strong reflectors and sandy deposits, hence confirming presumptions based on acoustic imagery alone. Seven additional event layers appear further down the central lake basin, where the depositional record is less fragmentary and not as prone to sediment reworking and bypassing, during e.g. the Yayoi sea-level lowstand, adding up to a total of 23 extreme wave event deposits. Radiocarbon dating and tephrostratigraphy (3090 BP Osawa Fuji scoria and 3150 BP Kawago-daira pumice) yield extreme wave event age ranges with recurrence interval modes of 70, 150, 450 and 650 years. The youngest event, dated as 2013-2015 AD, most likely corresponds to the 2014 AD Phanfone Typhoon. This long record of Lake Hamana provides important new evidence of paleo-extreme wave events beyond 4 ka BP, with age ranges of 4140-4420, 4320-4540, 4760-4890, 5600-5780, 5700-5860, 5960-6080 and 7270-7450 cal yr BP.

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RECONSTRUCTING PALEO-ENVIRONMENT OF EARLY-MIDDLE JURASSIC, CENTRAL SICHUAN BASIN: EVIDENCE FROM STORM CURRENT AND GRAVITY FLOW EVENT DEPOSITS

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Large area of lacustrine carbonate shoals were distributed in Da'anzhai Member, Ziliujing Formation, lower Jurassic, Central Sichuan Basin (Toarcian Stage). However, delta-lacustrine clastic sediments dominated the underlying and overlying strata[1]. Why did bivalves the basis of carbonate shoals flourish and decline in such a certain period? Was there any interrelationship with causative events? Five three-dimensionally preserved pterosaur eggs associated with pterosaur fossils were first reported from the Early Cretaceous in Hami, Xinjiang, China. The fossils were discovered in lacustrine gravel tempestites. It was indicated huge storm caused the group death of pterosaurs and rapid embedding[2]. Based on the enlightenment of the discovery, this paper discriminated a large number of tempestites and turbidites, and reconstructed paleo-environment evolution in the study area, according to the analyses of paleo-tectonic and paleo-climate. Detailed information has been acquired through the observation of outcrops, cores, thin sections of rocks, and analyses of particle size, paleontology, and geochemistry. The main conclusions are as follows. Firstly, three types of tempestites were identified in Da'anzhai Member, namely proximal, distal and transitional. Subseqently, two depositional models of gravity flows in origin have been defined, which were slump-induced terbidite fan and flood-induced terbidite fan. Secondly, climate generally kept warm and humid during Early Jurassic. Nevertheless it changed into drought and heat, with evidence of palynological assemblages Classopollis. Thirdly, Da'anzhai Member was deposited in an open freshwater lake indicated by ^{13}C and ^{18}O isotopes. Furthermore, its outlet met the Ganxiangqian Gulf eastward. In addition, Huanying Mountain, the eastern border, had not formed, so strong storm influenced the interior lake. Fourthly, the decline of bivalves paced the Toarcian (Early Jurassic) Oceanic Anoxic Event. The Oceanic Anoxic Event led to climate changing, sea level rising[3], storms erupting, and flood with terrigenous clasts draining into the lake. Consequently, the severe environment with the turbid and shrinking water caused the bivalves gradually disappearing.

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AN UP-TO-DATE HOLOCENE CATALOG OF SEDIMENTARY EVENTS RECORDED IN VOLCANIC LAKES FROM THE FRENCH MASSIF CENTRAL

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A decade of scientific investigation, combining subsurface geophysical mapping techniques and coring operations, highlighted several sedimentary events in volcanic lakes of the French Massif Central[1,2,3]. Here, we present a synthesis of recent studies dedicated to lakes located around the Puy-de-Sancy stratovolcano (i.e., Pavin, Chauvet, Aydat, Montcineyre, Guéry, and Crégut) with new data collected in Lake Lacassou, nearby Lake Chambon, and in the northernmost maar lake Gour de Tazenat. A multi-proxy characterization allowed the identification of mass-movement deposits and coarse-bed turbidites related to subaqueous slope failures. The radiocarbon-based chronological framework allows the creation of a catalog of sedimentary events over the late Holocene that give insights about past geohazards in a low-medium seismogenic area. The dating of coeval deposits between sites was attributed to historical earthquakes documented during the VIth, XIIIth and XIXth centuries. Among them, an undocumented earthquake has been identified as the regional trigger for synchronous deposits in AD 1275 in four lakes around the Puy-de-Sancy stratovolcano[1]. New chronological constrains from Lake Lacassou suggest this event could have also triggered the `Dent du Marais` collapse and the subsequent formation of Lake Chambon. Regular occurrences of single sedimentary events suggest either a growing human pressure and/or unsettled climatic conditions have also been involved in the generation of extreme events such as for the 5500 cal BP slope failure in Lake Cregut, the AD 180 delta collapse in Lake Aydat, and the AD 600 outlet break in Lake Pavin. The absence of deposit related to the major earthquake dated AD 1490 (Mw > 6) also suggest studied lakes are too distant and/or sediment loadings were too low since the last slope failures two centuries prior. Finally, we reported unusual deposits across the subaqueous plateau (oxic waters) in Lake Pavin during late XVIIIth and early XXth centuries. Their iron-rich signature suggests a formation under an iron-rich mixolimnion consecutive of a lake rollover carrying dissolved iron species from anoxic deep waters to oxic waters[2]. Consequently, these layers constitute first evidences of recent roll-over phenomena in Lake Pavin and may support further work about similar hazards in volcanic settings.

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PALEOHYDROLOGICAL CHANGES RECORDED FROM A SMALL MOROCCAN MIDDLE ATLAS POND DURING THE LAST 6000 CAL YRS BP.

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Precipitation over the Middle Atlas Mountains, considered as one of the main Moroccan “natural water towers”, is known to be sensitive to climatic changes. It is then crucial to better understand the past precipitation changes under different environmental conditions in order to elaborate scenarios and programs that will protect these areas from future changes. Lacustrine archives could provide continuous, scalable and datable records of climatic and hydrologic changes in such area.
The present research is based on a 3 m sequence cored at Flower Lake (32° 59’ 04’’N, 5° 27’ 13’’ W, 1554 m asl) which is, nowadays, a small pond lying on the Liasique calcareous dolomites of the tabular Middle Atlas. A high-resolution geochemistry (X-ray (XRF) with 500 μm spatial resolution) and sedimentological studies (facies distribution and grain size) of this sequence are supported by five coherent and calibrated radiocarbon dates.
The preliminary results give a reconstruction of the environmental changes that occurred in the Middle Atlas region during the last ~6 cal kyrs BP.
Sedimentological facies distribution is well correlated with XRF elemental variability: i) clastic sediments intervals are rich in Si, K, Ti and Fe; ii) calcareous facies show the highest intensity of Ca and Sr/Ti. These two facies and geochemical data most probably reflect phases of low lake levels alternating with period of positive water balance. The complex Mn contents behavior could be due to the changes of redox conditions at the water-sediment interface in the lake.
Before 2500 yrs BP, low Ca contents coincided with an important detrital input characterized by high Si, K, Ti and Fe values. This could be related to more humid conditions with higher erosion of the surrounding landscape.
The relative high Ca and Sr contents during the last 2500 yrs BP could be connected to drier conditions. Precipitation of Ca carbonates occurs in shallow waters due to high evaporation and photosynthetic activity of charophytes algae and other aquatic plants.
These preliminary interpretations will be completed with additional proxies especially isotopic analyzes from ostracod and diatoms and compared with available datasets of lakes sediments and other regional palaeoclimatic archives, especially speleothem from Middle Atlas caves.

Keywords: Middle Atlas, palaeohydrology, lacustrine sediment core, XRF scanning.

EARTHQUAKE-TRIGGERED MASS MOVEMENT DEPOSITS DURING THE OXYGEN ISOTOPIC STAGE 3 IN SOUTHERN PATAGONIA (ICDP-PASADO PROJECT): POTENTIAL LINKAGES WITH VOLCANIC ACTIVITY

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The multi-proxy "International Continental Scientific Drilling Program - Potrok Aike Maar Lake Sediment Archive Drilling Project » (ICDP-PASADO) provided a paleoclimate archive since the Oxygen Isotope Stage 3 (OIS3; 52 ka cal BP)[1]. Past changes in the strength and position of the Southern Hemisphere Westerly Winds (SWW) belt strongly impacted the hydrology in Southern Patagonia, as highlighted by pluri-decametric aerial paleo-shorelines surrounding Lake Potrok Aike (52°S). The 107-meters long sedimentary sequence remains partly understood because 50% of the sedimentary sequence is composed of mass movement deposits (MMDs)[2] of unclear origin. Mainly deposited during the last Glacial period, these MMDs were attributed to persistent permafrost that reduced the infiltration of water and increased surficial runoff, creating rapid lake fluctuations and remobilizating sediments. This hypothesis is only supported by the discovery of relict sand wedges 1 km North of the lake, and dated at about 35 ka cal BP[3]. In order to better constrain the genesis of these MMDs, this study investigates a 5 m-long MMD from OIS3. Based on macro- and micro-scale sedimentology, rock-magnetic and XRF analyses, this MMD is now interpreted as a sequence of debris-flow/turbidite/homogenite/turbidite, depicts sedimentary structures typical of a seiche effect and contains tsunami-like altered quartz grains. We interpret this sequence as induced by an earthquake, the so-called "sismites". The earthquake origin of MMDs could be derived from the shaking induced by volcanic eruptions since Lake Potrok Aike is situated in an active volcanic region: the Pali Aike Volcanic Field. This hypothesis is supported by small, but significant, determination coefficient (R^2=0.4 (n=40), $p<0.05$) obtained by comparing the number of homogenites (previously hemipelagites) with the number of unreworked tephras with regards to depth. Moreover, significant determination coefficient (R^2=0.94 (n=4), $p<0.05$) obtained from the comparison of homogenites and tephras frequencies during climate periods OIS3, OIS2, Lateglacial and Holocene (normalized by each period duration), suggest potential linkages between climate and volcanic activity at the millennial time scale. Finally, since most of the ^{14}C samples were taken in homogeneous sediments during the OIS3, the re-interpretation of hemipelagites as homogenites can potentially explain why it was challenging to provide a robust chronology for the Glacial period.

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RECENT HYDROLOGICAL VARIABILITY OF THE MOROCCAN MIDDLE-ATLAS MOUNTAINS INFERRED FROM MICRO-SCALE SEDIMENTOLOGICAL AND GEOCHEMICAL ANALYSES OF LAKE SEDIMENTS

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The frequency and/or intensity of extreme precipitation events and droughts is expected to increase in the Mediterranean basin in the XXI century. Future adaptation to water availability in Mediterranean regions will require a precise knowledge of recent and past hydrological variability. The Moroccan Middle-Atlas Mountains are considered as the "Moroccan water tower" and contains several natural lake systems of tectono-karstic origin functioning as "pluviometer". This region suffers from scarcity of observational hydrological data required for a coherent management of water resources. In this context, the precise study of the lacustrine sedimentary infill can provide some key information about past hydrological changes. However, the hydro-sedimentary dynamics need to be fully understood before extracting relevant hydrological reconstructions. In this work, we focused on the micro-scale analysis of well-dated sedimentary deposits of Lake Azigza (32°58'N, 5°26'W, 1,470 meters a.s.l.) in the Moroccan Middle-Atlas. A combined approach based on elemental/mineralogical and geochemical measurements coupled to microfacies characterization of the sediments was conducted on the lacustrine sequences. The main axis (PC1=57% of the total variance) of the principal component analysis of X-ray fluorescence data has been related to runoff-derived clay particles, streaming in small canyons present in the proximal lake catchment. Several types of microstructures, i.e. very thin laminations composed of different biological and detrital materials coming from the shoreline, were linked to increased superficial runoff during high/low lake level periods. We were therefore able to provide proxies of runoff activity and lake level changes calibrated to hydro-climate observations available for the last 50 years. Extending these interpretations to the end of the sequence, changes in hydro-sedimentary dynamics offer the possibility to reconstruct past hydrological changes since 1879 at inter-annual to decadal time-scales. Our results also highlights drastic lake level drops marked by different hydro-sedimentary dynamics since the last two decades. Recent drier conditions are unique regarding the past 134 years.

Towards refined recurrence rates and distribution patterns of rock-slope failures by studying lake sediments (Lake Oeschinen, CH, and Lake Eibsee, D)

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Rock-slope failures account for about two thirds of the most catastrophic landslide events. A key question is how often catastrophic rock-slope failures happen and how the deposits are distributed, but single rock-slope failure deposits can hardly be distinguished because failed rock material may fall onto and partially cover older deposits. Hence, the frequency of rock-slope failures is often highly underestimated when analyzing subaerial deposits only. Revealed in lake sediments, the single events can be deciphered in time and space more comprehensively.

Here we want to present and discuss the key results of two studies at Lake Oeschinen (CH) and Lake Eibsee (D) in the European Alps, where we investigated the rock-slope failure history and event-related mobility processes.

The study at Lake Oeschinen in Switzerland discloses eleven rock-slope failures that impacted onto and/or dammed the lake over the last ~2.5 thousand years[1]. The lake in its present state is much younger than expected, and the dam is rather built by at least six rock-slope failure deposits than by one or two, as previously thought[2,3]. We also calculated the seismic trigger potential of well-known earthquakes in the region and found four earthquakes which might have prepared or triggered rock-slope failures around Lake Oeschinen.

At the Eibsee rock avalanche at Mount Zugspitze in Germany we applied geophysics and sedimentology both in Lake Eibsee and to terrestrial sediments in the runout zone. The data provide information on the presence and dimension of a paleolake, the fluidization of the rock avalanche resulting in a long-runout event, and the multistage character of the rock-slope failure.

Here we show that studies of lake sediment archives may help to improve recurrence rates of rock-slope failures and give new insights into their interactions with lakes situated in the runout path.

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Earthquake-induced homogenites in the Eocene half-graben lake basin (Shulu Sag): Two different depositional mechanisms and a new facies model

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Homogenites are structureless, fine-grained rocks. They have been studied extensively in marine settings and are typically interpreted as being related to catastrophic events such as earthquakes[1]. However, limited work has been done on the lacustrine homogenite-like rocks. The Shulu Sag is a confined basin located in the southwestern corner of the Jizhong Depression in the Bohai Bay Basin[2]. New core data from the Shulu Sag reveal that thick massive calcilutites exist in the lower Shahejie 3 Formation, which formed during the active phase of basin evolution. Based on petrographic, geochemical, and mineralogical data, these massive calcilutites are interpreted as homogenites and grouped into two types. Type A homogenite is composed of local materials characterised by high calcite and total organic carbon (TOC) content and high $\delta^{13}C$ value. Type A homogenite has two facies successions, the first of which is characterised by homogeneous appearance capped by an erosional interface and the second is characterised by repeated sedimentary successions. Type B homogenite contains abundant allochthonous materials displaying relatively high dolomite content and low calcite, TOC, and $\delta^{13}C$ content. Type B homogenite is the uppermost unit of the megaturbidte, which is composed of four main sedimentary units: the slump facies, the debrite facies, the turbidite facies and homogenite facies. Earthquakes are the most reasonable triggers of homogenite formation in the Shulu Sag because homogenites have a close relation with seismites and isolated conglomerate masses. Type A homogenites might be the reworked deposits *in situ* or from nearby localities within the basin. Type B homogenites might be the deposits of distal turbidity currents and turbid clouds transformed from other gravity flows. Strong shock, seiche effect, basin landform control, and mass material sources control the sedimentary characteristics of homogenites in the Shulu Sag. The result of this study provide a better understanding of the formation of homogenites in a confined lacustrine basin in response to earthquakes.

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Turbidites as proxy for past events (Lake Geneva, France/Switzerland)

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Turbidites recorded in lake sediments are often used to establish catalogues of past floods and seismological events and to calculate frequencies and return periods over entire regions. However the identification of the origin and causes of the recorded turbidites, need to be clear for such a reconstruction.

In this study, we test if turbidites can be used as paleohydrological archive based on the sedimentary record of Lake Geneva resulting from inputs by the Rhone and Dranse clastic river systems. Our approach is based on several methods combining high-resolution seismic reflection data with geophysical (magnetic susceptibility, grain size) and high-resolution XRF/XRD data measured on ca. 10-m-long sediment cores (dated by geomagnetism, radiocarbon ages and 137Cs activity).

This dataset allows distinguishing between the different sources (rivers or hemipelagic sediment) of the turbidites deposited in the deep basin of Lake Geneva. However, no clear distinction between the various trigger processes (mass failures or floods) could be made, thus flood deposits could not be clearly identified.

From our results and detailed historical record from Wallis, we also conclude that the lack of turbidite deposits in the deep basin between the 15th and 18th century seem to be linked to a change in turbidite depocentre due to the Rhone River mouth shifting possibly triggered by human activity and not by any direct climate effect.

This study demonstrates that a least three conditions are needed to perform an adequate paleohydrological interpretation based on turbidite records: (1) the holistic understanding of the basin sedimentary system and (2) the distinction of flood-induced turbidites from other types of turbidites (mass failures etc.) and (3) accurate dating.

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SEARCHING ONSHORE TSUNAMI DEPOSITS IN SWITZERLAND

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It is well known that tsunamis happen not only in marine realm but in lakes too. In the past decade, data from Swiss lakes, based on historical reports, multibeam bathymetry, seismic-reflection surveys and numerical wave modelling, revealed that devastating tsunamis occurred in perialpine lakes in Switzerland. These events were due to earthquakes, rockfalls or large spontaneous subaquatic mass movements. For example, a tsunami with run-up heights exceeding 13 m occurred in Lake Geneva in AD 563 after a major rockfall. This event resulted in local inundation over a distance of maximum 3.4 km inland and caused an unknown number of causalities. At Lake Lucerne, a tsunami with run-up heights exceeding 4 m is reported after an earthquake (Mw 5.9) in AD 1601.
This study focuses on the search and identification of onshore and near-shore tsunami deposits around large Swiss lakes based on coring and drilling in historical coastal marshes. It will provide clues to confirm the extent of historic tsunami events on land. Deeper tsunami deposits will define a tsunami event catalogue to the prehistoric time period. This tsunami chronology will be correlated with major mass-transport deposits observed in various deep lake basins. Information gained from historic tsunami deposits will serve to ground truth results yielded by numerical modelling.

Acknowledgements

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LANDSLIDE AND MEGATURBIDITE RECORDS REVEAL A 2.5 KYR HISTORY OF SEISMIC SHAKING IN SKILAK LAKE, ALASKA

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On 27 March 1964, a M_w 9.2 megathrust earthquake ruptured an 800-km-long segment of the Alaska-Aleutian Subduction Zone (in south-central Alaska). In order to better understand the recurrence pattern of such large earthquakes in that region, we studied the sediments of Skilak Lake, a proglacial lake located in the area affected by the 1964 earthquake, using a combination of high-resolution seismic stratigraphy (3.5 kHz), multibeam bathymetry (50 kHz) and sediment cores (~13-16 m).

Seismic profiles and bathymetric maps reveal 23 lacustrine landslide deposits caused by the 1964 megathrust earthquake. We also identified a series of six older landslide events in the subsurface, which we infer to result from multiple, coeval slope failures, and can thus be attributed to past seismic shaking.

Sediment cores in two sites show varved "background" sedimentation that is occasionally interrupted by megaturbidites and slump deposits. From this megaturbidite record we can infer five large mass-wasting events, which can also be observed in the upper part of the landslide record. In order to precisely date our paleoseismic records, we organized a student crowdsourcing project, in which continuously varved core sections were counted by multiple observers. Varve counts, combined with 10 ^{14}C ages, provide a high-resolution age framework for our 2.5 kyr-long paleoseismic record.

As Skilak Lake lies in a position between a more fully locked part of the megathrust beneath Prince William Sound, and a more creeping part of the megathrust offshore the Kenai Peninsula, the results of this study may elucidate the extent of past ruptures, rupture pattern variability and interplate coupling.

LANDSLIDE AND TURBIDITE RECORDS REVEAL A 2 KYR HISTORY OF FREQUENT SEISMIC SHAKING IN EKLUTNA LAKE, ALASKA

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On 27 March 1964, a M_w 9.2 megathrust earthquake ruptured an 800-km-long segment of the Alaska-Aleutian Subduction Zone (in south-central Alaska), representing the largest measured earthquake in North America. In order to better understand the recurrence pattern of such large earthquakes in that region, we studied the sediments of Eklutna Lake, a proglacial lake located in the area affected by the 1964 earthquake. We used a combination of high-resolution seismic stratigraphy (3.5 kHz), multibeam bathymetry (50 kHz) and sediment cores (~8-17 m).

Seismic profiles and bathymetric maps reveal 15 lacustrine landslide deposits caused by the 1964 megathrust earthquake. We also identified a series of older landslide deposits in the subsurface, which we infer to result from multiple, coeval slope failures, and can thus be attributed to past seismic shaking.

Sediment cores in five sites show a varved “background” sedimentation that is frequently interrupted with earthquake- and flood-triggered turbidites. We constructed an event stratigraphy (earthquake or megaflood) by performing a statistical outlier study of varve thickness data. As distinguishing between flood- and earthquake-triggered turbidites in proglacial clastic lakes is a challenge, we measured a selection of variables including grain size parameters, spatial distribution and reflectance data for each turbidite at every coring site. We performed a principal component analysis on historical and prehistorical turbidites to ascertain the seismic origin of the turbidites. This statistical method also allows us to explain which variables account for most of the variability, providing a powerful tool for distinguishing between earthquake- and flood-triggered turbidites in future studies.

A continuous 2250-year varve chronology together with seven ^{14}C ages provide a robust age framework for our paleoseismic records of landslides and turbidites. The resulting time series shows that the paleoseismic records not only reveal information on large megathrust earthquakes, but also on earthquakes generated by surrounding fault systems. Unraveling the different seismic sources and their characteristic recurrence intervals will be crucial for understanding the seismic hazard of southern Alaska and, in particular, the densely populated city of Anchorage.

Quantifying past hydrological extreme events by inverse modelling of flood layer records

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Flood deposits in annually laminated lake sediments provide highly resolved records of hydrological extreme events on millennial time scale. The occurrence of flood layers in lacustrine records is closely linked to the exceedance of hydrological and climatic thresholds within catchment areas, providing the opportunity to quantify past hydrological extremes on the basis of sedimentary records. However, numerous sedimentary processes during the erosion, transport and deposition of flood-derived sediments can influence the formation of individual flood layers within the lake basin. As a consequence, establishing a link between sedimentary characteristics of individual flood layers and the magnitude of an event is not straight forward. Here, we re-evaluate µ-XRF scans and detailed microfacies analysis of flood deposits recorded in Lake Ammersee[1] in central Europe. The deposition of flood layers is followed by characteristic changes in sediment composition of subsequent varves, indicating time-dependent adjustment of catchment processes to major runoff events. To quantify associated response times, we identified a dynamical landscape-response model using multivariate statistics and System Identification routines on high resolution geochemical time series. Comparing our results to instrumental time series of hydrological data implies a link between inferred response times and flood magnitude in the record of Lake Ammersee. We discuss implications for landscape responses to extreme climate events and the applicability of long-term flood records for quantitative paleoclimatic reconstructions.

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A REVISED CONCEPTUAL MODEL FOR THE DEPOSITIONAL PROCESS OF A MEGATURBIDITE: EVIDENCE FOR A COMBINATION OF TURBIDITE AMALGAMATION AND SEICHE INFLUENCE IN LAKE LUCERNE, SWITZERLAND

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Megaturbidites in lakes have regularly been attributed to seiche events triggered by seismic shaking. Flow-strength fluctuations due to seiching are not only held responsible for the strong ponding geometry of these deposits, but also for grain size and sorting fluctuations at the base of the megaturbidite. However, other studies have ascribed such fluctuations to the amalgamation of synchronously-triggered turbidity currents along different slopes.

Here we study the earthquake-triggered AD 1601 megaturbidite in Lake Lucerne in order to distinguish turbidite amalgamation from a seiche imprint. We retrieved 28 gravity cores along several transects through the megaturbidite across the lake basin and studied them using primarily medical and micro CT scanning, grain-size analysis and Natural Remanent Magnetization (NRM). The analyses allowed to divide the megaturbidite into four units that are, from the bottom: Unit I: the coarse sandy base, which is thickest in the east; Unit II: a strongly ponded silt-to-fine-sand unit with a laminated nature in some of the cores; Unit III: a ponded homogenous mud; and Unit IV: a ponded to draped homogenous clayey mud. While the coarse sandy Unit I usually constitutes the base of the megaturbidite, both core and reflection-seismic data show that it also occurs below some of the landslide deposits that are sourced from the northern slopes. Micro CT analysis of grain orientations on an oriented core shows that most of these coarse sands are sourced from the northeast, but at least one pulse has a different source area. In Unit II, variable orientations of grains and organic matter, strong ponding and poor quality of the magnetic signal (high Mean Angular Deviation; MAD), provide evidence for a very strong seiche influence in this unit. Throughout the ponded Unit III, high MAD and unstable NRM show the persisting influence of the seiche movement. The draping geometry, higher clay content, low MAD and stable NRM in uppermost Unit IV are evidence of deposition under calm conditions, after all currents have ceased. We conclude that the sedimentary imprints of turbidite amalgamation and seiching can be disentangled in the 1601 AD Lake Lucerne megaturbidite. The applied methods will also be applicable to megaturbidites in other lake basins.

PALEOSEISMOLOGICAL RECORDS DERIVED FROM MASS-TRANSPORT DEPOSITS ALLOW PROBABILISTIC EVALUATION OF EARTHQUAKE SOURCES: AYSÉN FJORD CASE STUDY

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Lake and fjord settings around the world have been the subject of paleoseismological research. The presence of mass transport deposits (MTDs) in these basins has played a major role in identifying past earthquakes. In some cases, the observed MTDs could even be attributed to major prehistorical earthquakes that are linked to activated faults. However, one can usually not directly identify the rupturing fault based on the observed MTDs and assessment of the earthquake source is therefore challenging. Efforts have been made to estimate epicenter locations and magnitudes based on the appearance of simultaneously deposited landslides in different lakes [1]. The presence of MTDs triggered by historical earthquakes can be compared to the observed seismic intensity to determine the minimum levels of seismic shaking required to trigger these MTDs. Combining these findings with intensity prediction equations (IPE) allows to estimate the most likely earthquake source. This method, however, considers minimum intensities as actual intensity values and does not take into account possible deviating threshold values.

We developed a new method to estimate earthquake parameters based on an MTD record that meet the shortcomings of currently existing methods. Firstly, it is important to take into account the possibility that the triggering intensity was larger than the assumed threshold values. Secondly, one needs to consider IPE uncertainties. Assuming the actual fault network instead of using uniformly gridded hypocentral positions allowed further improvement of our method.

To test our methodology, we applied it to Aysén Fjord (southern Chile), which has been affected by both megathrust and crustal earthquakes. The latter originate from the Liquiñe-Ofqui Fault Zone (LOFZ); a dextral strike-slip zone of which several fault branches intersect Aysén Fjord. Seismic reflection data showed that its sedimentary infill records a minimum of five Holocene and possibly four older MTDs related to activity of the LOFZ, in addition to at least one megathrust earthquake. Application of our methodology to this earthquake record showed the possibility to distinguish different potential fault ruptures and identify the most likely one(s) for most of the identified earthquakes, as well as the most likely magnitude. Therefore, this methodology has great potential in identifying prehistorical fault activation in both lacustrine and fjord settings around the world.

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WPWP AND ENSO PACES AND TYPHOON VARIABILITIES IN SOUTH CHINA SEA DURING THE MID-LATE HOLOCENE: SEDIMENLOLOGICAL EVIDENCE FROM SOUTHEASTERN HAINAN ISLAND, CHINA

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Main text:

There has been a lack of an understanding of large timescale controlling factors for the South China Sea (SCS) cyclone activity. SCS tropical cyclone (TC) variabilities are thought to be controlled by a combination of the thermal state over the western Pacific warm pool (WPWP), Pacific Decadal Oscillation (PDO), ITCZ; on inter-annual timescales, significant variabilities are associated with the El Niño-Southern Oscillation (ENSO). However, multi-millennial paleo-storm records with a high resolution are rare, which makes the exploration of the potential climate drivers of tropical cyclone variability over centuries to millennia timescales difficult, reducing our ability to fully assess the risks associated with future tropical cyclone activities. Here, we found a suitable sedimentary record to reveal mid-late Holocene storm variabilities, from a coastal lagoon in Hainan Island, China. An examination of the timing of recent high-energy deposits shows that they match well with the observed tropical cyclone strikes, indicating that coarse deposition layers in the sequence are storm derived. Longer records show that tropical cyclones were highly active for the periods of 5000 to 3800 and 1500 to 1000 yrs BP, compared with the relative quiescence period 3500–2500 yrs BP. The inverse correlation between tropical cyclone reconstructions from the South China Sea and the Kamikoshiki area of Japan reveals an oscillating pattern across the western North Pacific (WNP) region on centennial to millennial timescales. A comparison of the sedimentary record with palaeo-climate records indicates that ENSO was not the only mechanism responsible for typhoon variability at the time of 6000 yrs BP, and that the thermal state over the WPWP profoundly influenced the SCS tropical cyclone variability, even in the Western North Pacific region.

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INRS Université de recherche / A research university

Université Laval

COX Analytical Systems

CSPG Canada's Energy Geoscientists

ECORD European Consortium for Ocean Research Drilling

IODP International Ocean Discovery Program

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