Book of Abstracts

Volume 2

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From 13 to 17 August 2018, Quebec, Canada

A SEDIMENTARY JOURNEY THROUGH
3 BILLION YEARS IN THE NEW WORLD

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BOOK OF ABSTRACTS

Volume 2

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General theme 4

Sedimentary Processes

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A SEDIMENTARY JOURNEY THROUGH
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Contrasting Diagenesis of Tight Sandstones, Lower Permian Shanxi Formation, Ordos Basin, China

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The Lower Permian Shanxi Formation sandstones host extensive tight gas reserves in Yanchang field, Ordos Basin, China. The formation represents one major regressive succession in which subaqueous delta-front facies predominate. The lower and upper intervals have contrasting diagenetic histories. Eogenetic glauconite is found only in the lower interval indicative of seawater introduction during syndepositional /early diagenetic stage; burial saddle dolomite (mole fraction of $FeCO_3$ is 13-23%, ankerite) occludes residual porosity, replaces detrital grains and forms veins. Saddle dolomite cements have $\delta^{13}C$ values of -4.6 to -1.5‰, similar to dolomite veins with $\delta^{13}C$ values of -5.1 to -3.0‰. The relatively uniform and high $\delta^{13}C$ value suggests that inorganic carbon addition from seawater. Saddle dolomite exhibits average radiogenic $^{87}Sr/^{86}Sr$ ratios of 0.7136, marginally higher than Permian sea water (about 0.708) because of interaction with highly radiogenic detrital silicate minerals[1]. Saddle dolomite has homogenization temperature (T_h) values predominantly in the range of 107-161℃; the salinity of the palaeofluids is 10.1-20.8wt% NaCl eq., 3-6 times greater than modern seawater salinity. However, the upper interval contains early calcite cement as micritic to sparry concretion. Late sparry calcite displays a rather patchy cementaion. Early calcite has $\delta^{13}C$ values of -9.0 to -4.4‰, suggesting that mixed sources of dissolved carbon derivation from the decay of C_3 and C_4 plants and from atmospheric CO_2. The negative carbon isotopes of late calcite cements ($\delta^{13}C$=-11.3 to -7.4‰) and calcite veins ($\delta^{13}C$=-9.5 ～ -6.6‰) are related to addition of organic carbon from kerogen decarboxylation. Calcite exhibit average radiogenic $^{87}Sr/^{86}Sr$ ratios of 0.7111. T_h values of calcite varies between 95 and 145℃; the palaeofluids salinity is 2.2-14.3wt% NaCl eq, smaller than that of saddle dolomite. The fluids responsible for late diagenetic saddle dolomite and calcite precipitation have mean $\delta^{18}O$ values of 0.5‰ and -0.5‰, about 5‰ heavier than Permian meteoric waters, most likely related to fluid-rock interaction during deep burial.

The difference in diagenetic evolution patterns of the lower and upper intervals is attributed to early diagenetic pore water conditions. Early calcite concretions in the upper interval formed by the precipitation of meteoric water. Glauconite provides compelling evidence for marine fluid introduction in the lower interval. The abundant saddle dolomite also reflects effect of seawater. Thus, the pore water condition during early diagenesis exerted a major control on the later burial diagenesis.

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DOLOMITIZATION AND DIAGENESIS OF PRECAMBRIAN CARBONATES: THE CASE OF THE LOWER TRANSVAAL SUPERGROUP OF BOTSWANA

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The 2.5 Ga stromatolitic dolostones from the Lower Transvaal Supergroup in the Kanye Basin (Botswana) have been affected by multiple stage dolomitization and by circulation of metasomatic fluids (1.9-2.1 Ga). We have distinguished between altered facies, characterized by neomorphic phases, and unaltered facies, characterized by well-preserved stromatolites. Here, geochemical (ICP-MS and LA-ICP-MS) and petrographic characterization of the stromatolites is presented to shed light onto i) the effect of dolomitization and metasomatism on the geochemistry of ancient carbonates, ii) the evolution (geochemical) of the different cement phases, iii) eventually, the environmental conditions prevailing at time of deposition.

The studied samples show overall high Fe an Mn contents (ca. 2000 ppm and 3500 ppm, respectively) and very low Na contents. The overall REE patter lacks La, Ce and Gd anomalies (ca. 1, 0.9, 1.1 respectively) and shows an overall chondritic Y/Ho ratio. The Eu anomaly is slightly negative or absent in most of stromatolite samples. LA-ICP-MS revealed that trace elements and REE vary among the different cement phases identified in the stromatolitic dolostones, namely: xenotopic dolomite, hypidiotopic and rhombohedral dolomite, microcrystalline dolomite. The petrography of these dolostones suggests precipitation within the marine/meteoric mixing zone under shallow burial conditions characterized by Mn and Fe enrichment typical of Archean carbonates. A late stage of dolomitization has occurred at deep burial condition inducing recrystallization of microcrystalline and idiotopic dolomite to xenotopic dolomite. Sr and Na have been diagenetically removed from the carbonates.

Although REE+Y are normally considered robust geochemical proxies for the investigation of ancient carbonates, the patterns of dolomites under investigation have been clearly affected by the dolomitization processes. Particularly the dolomitization process has probably led to a chondritic Y/Ho ratio. It is therefore possible that Y is more prone to be mobilized during deep burial dolomitization, with respect to other REE, as previously thought. The overall lack or the presence of a negative Eu anomaly within the samples suggest that the basin where these sediments precipitated was completely restricted from open seawater, far from the hydrothermal input typical of Archean open marine waters. The late circulation of metasomatic fluids through the sediments have induced the metasomatism of dolostones localized close to the intrusion. Geochemical evidences for these hot fluids circulation is lacking in the stromatolitic dolostones.
In conclusion, although the common beliefs consider REE as stable during multiple stage diagenesis/dolomitization, the study of Neoarchean dolomites from the Kanye Basin has demonstrated that overall REE+Y pattern of ancient carbonates can indeed be altered by diagenesis, particularly by late dolomitization under burial conditions.

Acknowledgements: This work was partially supported by BIUST Initiation Grant 2016 to FF.

The ORIGIN of SILICA CEMENTS and the ROLE of TRACE ELEMENTS in SILICA DIAGENESIS REVEALED by SPATIALLY RESOLVED OXYGEN ISOTOPE MICROANALYSIS and ELECTRON-BEAM MICROSCOPY; HEIDELBERG FORMATION, GERMANY.

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Silica cements, including microcrystalline quartz, found in Late Santonian age shoreface to coastal-plain sandstones in the Heidelberg Formation in Germany occur in multiple episodes and preserve porosity by inhibiting syntaxial quartz overgrowths during diagenesis. Characterizing the silica cements and understanding the role of trace elements in cement stratigraphy can be applied to developing an understanding of the diagenetic silica cements found in siliciclastic reservoirs, which preserve porosity in deep clastic reservoirs.

High precision, *in situ* oxygen isotope analyses coupled with electron-beam microscopy of Cretaceous Heidelberg Formation detrital grains and quartz cements show four varieties of authigenic silica growing on detrital quartz grains. Detrital quartz has an average $\delta^{18}O$ composition of 9.4‰, syntaxial quartz overgrowths have an average $\delta^{18}O$ composition of 20.3‰, and microcrystalline quartz has an average $\delta^{18}O$ composition of 22.7‰. Chalcedony has $\delta^{18}O$ compositions of greater than 27.4‰. Minor quartz overgrowths grew from meteoric water at about 80°C followed by concentric bands of silica cements that covered quartz grains and overgrowths alike. A thin layer of amorphous silica was first deposited on both detrital quartz grains and quartz overgrowth cements, followed by chalcedony and then microcrystalline quartz; this cycle was then repeated. Trace element data supports this interpretation and reveals two episodes of enrichment in iron and aluminum in the chalcedony. Aluminum in the microcrystalline quartz is below the wavelength dispersive spectroscopy detection limit suggesting low temperature growth (< 70°C). If the closely-related chalcedony and microcrystalline quartz grew from the same meteoric water, then isotope data suggest that chalcedony grew at approximately 34°C while microcrystalline quartz grew at approximately 60°C from the meteoric water. Analogous to modern groundwater silcretes, the Heidelberg Formation experienced at least two episodes of chalcedony and microcrystalline quartz growth from several episodes of influx of relatively cool meteoric water with high silica, iron, and aluminum concentrations.

This provides new evidence for the mechanism of porosity preserving microcrystalline quartz growth and determination of crystal growth patterns from spatially resolved isotopic and trace element analysis of silica cements in the Cretaceous Heidelberg Formation, Germany. This is the first research to report on spatially resolved isotopic analysis of silica cements integrated into a petrographic framework and a proposed mechanism for microcrystalline quartz growth.

CARBON ISOTOPE STRATIGRAPHY IN PROTEROZOIC SEDIMENTARY BASINS OF INDIA

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The Indian subcontinent hosts a number of Proterozoic sedimentary sequences, some of which continue well into the Cambrian. The facts that most of these largely undeformed and unmetamorphosed sequences contain thick marine carbonate deposits, and that the subcontinent was part of the supercontinents of Columbia and Rodinia, it is natural to expect that rocks in these basins would have recorded physical and/or chemical evidence for the important global events of the Proterozoic. Unfortunately, however, there have been very limited attempts to unravel such signatures from these rocks. In an effort to fill gaps in the record we carried out carbon, oxygen and strontium isotope analyses of carbonate formations in the Mesoproterozoic Chhattisgarh Supergroup and the Neoproterozoic Marwar Supergroup, located in central and western India, respectively.

Least altered nature of microspar carbonate matrices in the limestones from both the supergroups, as inferred from their low Mg/Ca (< 0.1), Mn/Sr (< 3) and $\delta^{18}O$ (< -10‰), suggests that these components most likely have preserved their original $\delta^{13}C$ compositions. The $\delta^{13}C$ increases steadily with time from +2.6‰ to +3.6‰ from bottom to top in the Raipur Group in the Chhattisgarh basin. We interpret this increasing trend to be a result of enhanced primary productivity at the basin margins; a condition that was prevalent in the Mesoproterozoic global oceans at a time when only the surface ocean remained oxygenated. The $\delta^{13}C$ varies from -5.8 to +2.1‰ in the Bilara Group of the Marwar basin, which was deposited around 570 Ma ($^{87}Sr/^{86}Sr$ = 0.7081). The lowering of $\delta^{13}C$ to -5.8 from ~0 ‰ is correlatble in various sections throughout the basin and most likely represents the carbon isotope anomaly of the globally synchronous Gaskiers glaciation. We believe that this $\delta^{13}C$ excursion in the Marwar basin represents the first ever reliable chemical evidence for the latest Ediacaran glacial event in the Indian subcontinent.

DIAGENETIC CONTROLS ON THE OCCURRENCE OF ANHYDRITE CEMENT IN THE SILTSTONE DOMINATED MONTNEY FORMATION, WESTERN CANADIAN SEDIMENTARY BASIN

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The concurrence of sulfate minerals such as anhydrite with H_2S concentration in natural gas reservoirs contradicts the role of sulfate minerals dissolution, as one of key sources of dissolved sulfate required for sulfate reduction reactions and hence H_2S generation[1]. The siltstone dominated succession of the Triassic Montney Formation is mainly characterized by high amount of late diagenetic anhydrite cementation rather than its dissolution and its coincidence with H_2S gas. Therefore, the question here is why both anhydrite and H_2S have concomitantly formed. The current study presents petrographic and SEM observations and stable isotope data of different early and late diagenetic anhydrite and pyrite phases in the Montney Formation. This study evaluates the potential source(s) of dissolved sulfate, which resulted in the simultaneous generation of a late diagenetic anhydrite and H_2S, as well as pyrite in this Formation.

The early diagenetic anhydrite is predominant in northeastern British Columbia, the area of low H_2S concentration. It is less preserved due to replacement by later silica cement. Late-stage anhydrite is dominant in the high H_2S concentration area in western Alberta and occurs as replacive type, blocky and poikilotopic cements. These anhydrite phases postdate calcite, dolomite and feldspar crystals, and chemical compaction, represented by quartz, feldspar and dolomite dissolution at their grain contacts during burial. Pyrite mainly occurs as both framboids and euhedral crystals of likely multiple generations. The $\delta^{34}S$ and $\delta^{18}O$ values of anhydrite in the studied samples exhibit a wide range of variations from 5.8 to 28.8‰ V-CDT and -6.2 to 15‰ V-SMOW, respectively. The pyrite $\delta^{34}S$ values also vary widely from -32.5‰ to 36.9‰ (V-CDT).

The early anhydrite of low H_2S area exhibits minimal equilibrium sulfur and oxygen isotope fractionation from Triassic seawater, suggesting that they were directly precipitated from formation water with coeval Triassic seawater composition. The isotopic signature of late-stage anhydrite in the high H_2S area is similar to Devonian evaporites with higher $\delta^{34}S$ and $\delta^{18}O$ values than Triassic formation water. This validates the involvement of fluids from dissolution of underlying Devonian evaporites and mixing with pore water of Triassic seawater signature. This suggests that Devonian-sourced sulfate-rich brines were migrated upward to the Montney Formation through extensive deep-seated faults network occurring in the subsurface of western Alberta. The system was fed by dissolved sulfate, leading to formation of H_2S through bacterial/thermal sulfate reduction, while the excess sulfate in the system formed pervasive late diagenetic anhydrite.

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Tectonically-driven hydrothermal dolomitization of Lower Cretaceous Qamchuqa Formation, Kurdistan Region, Northern Iraq: petrographic, isotopic, fluid inclusions and geochemical evidence

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Early diagenetic non-focused strata-bound dolomitization followed by fault- and fracture-focused hydrothermal dolomitization represent the two main mechanisms of dolomite formation in the Cretaceous Qamchuqa Formation that also imposed a major control on reservoir evolution.

Integrated field observations, core descriptions, microstructural analysis, stable and radiogenic isotopes, geochemistry and fluid inclusion analysis reveals two main phases of hydrothermal fluid expulsion with multiple fluxes during and post Zagros Orogeny; an early regional non-focused hydrothermal dolomitization, and subsequently fault- and fracture- controlled hydrothermal fluid flow which led to replacement and cementation of a range of saddle dolomite and zebra textures from fine crystalline to mega size. The host rock dolostone has been affected by shortening, folding, fracturing, and thrust faulting. Saddle dolomite pipes found associated with en-échelon folding. The morphology and areal extent of zebra dolomite are controlled by pore geometry of host dolostone in relationship to fracturing and faulting. Six types of pervasive gray and black dolomites, three types of saddle dolomite and four types of calcite cements have been identified. Both replacive matrix and saddle dolomite cements reveals overlap and negative stable isotopic values -10.43 to -4.47 and -12.87 to -7.79 for ^{18}O ‰VPDB, and 0.39 to 3.57 and -0.12 to 3.11 for ^{13}C ‰VPDB, respectively, high and wide range of homogenization temperatures (Th) ranging from 71.3 to 228.3°C and 82 to 188°C, and salinity range between 14.4 to 25.4 and 15.6 to 27.97 wt.% NaCl eq. , respectively.

Major elements geochemistry indicates that both replacive matrix and dolomite cement are non-stoichiometric, and non ferroan with average 255 and 83 ppm of Fe respectively. REE profiles show moderately similar REE patterns for dolomite types, with positive anomalies of Eu in saddle dolomite and slightly less positive in replacive matrix dolomite, and negative anomalies in Dy, Ho and Yb. This support the interpretation that hydrothermal fluids that caused the formation of replacive dolomite and dolomite cement may have a similar source and comparable geochemical attributes.

Diagenetic fluids evolution revealed by SIMS and fluid inclusions in the late Ordovician Lianglitag carbonate platform (Tarim Basin, NW China)

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The Late Ordovician Lianglitag Formation has been considered as an important carbonate reservoir in the Tahe Oilfield, Tarim Basin, NW China. The diagenetic evolution and their impact on reservoir quality is poorly understood but of great importance to reservoir characterization. Based on the analysis of petrology, in-situ Secondary IonMass Spectrometry (SIMS) analysis, fluid inclusion analysis, and radiogenic isotope analysis of pore-filling calcite cements, we reconstructed the diagenetic fluids evolution. CL petrography revealed there were six stages of calcite cements: C1-C6. C1, nonluminescent, has $\delta^{13}C_{VPDB}$ values between 1.44‰ and 4.50‰ and $\delta^{18}O_{VPDB}$ values between -2.49‰ and -0.10‰. These oxygen values are slightly enriched with respect to coeval seawater, suggesting their precipitating from evaporated seawater. C2 with red zoned CL pattern, shows $\delta^{13}C_{VPDB}$ and $\delta^{18}O_{VPDB}$ values of 1.58‰ to 2.72‰ and -5.56‰ to -5.03‰, respectively. These cements probably formed during early burial with temperature from 67°C to 88°C. C3, nonluminescent, has relatively low $\delta^{18}O_{VPDB}$ values (-8.45‰ to -6.50‰), and likely has a meteoric origin as supported by low temperatures evidenced from abundant pure aqueous fluid inclusions. Meteoric water probably fluxed into aquifers during the early Paleozoic Caledonian and late Paleozoic Hercynian uplift. C4, displaying light orange zoned CL, has $\delta^{18}O_{VPDB}$ values (-5.37‰ to -2.29‰) that are typically 3‰ higher than those of C3, consistent with marine-derived fluids, and probably formed during shallow burial after uplift. C5 displays relatively negative $\delta^{18}O_{VPDB}$ values (-8.26‰ to -5.12‰), and the moderate to high fluid-inclusion temperatures of C5 imply that it precipitated in burial environments. C6 shows homogenization temperatures (up to 200℃) higher than the maximum burial (130℃) of their host strata and much lower measured salinities (＜10.61 wt% NaCl), which may suggest that the fluid was deeply recycled, with reduced meteoric water heated in deeper strata. In addition, the average $^{87}Sr/^{86}Sr$ ratios of fracture- and vug-filling calcite cements are much higher than those of the contemporary marine, indicative of incorporation of radiogenic Sr in diagenetic fluids under burial conditions. The multiple cement stages produced poor matrix porosity, whereas caves and fractures formed during epigenetic karstification, constituting the dominant reservoir spaces. A corresponding diagenesis-related reservoir evolution model was established. The paleo-karst closely related with C3 constitutes the most constructive diagenesis, non-fabric selected dissolution pores and caves formed during epigenetic karstification constitute the most important reservoir space.

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DOLOMITE/ANKERITE CEMENTS IN LACUSTRINE SANDSTONES: AN EVIDENCE FOR FAULT-CONTROLLED PORE WATER EVOLUTION

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Compared with calcite cements, dolomite/ankerite cements in lacustrine basins of fresh water and/or brackish water environments are generally rare due to the lack of Mg^{2+} and Fe^{2+}. Thus, the chemical alteration of pore fluids they precipitated were always easy to be neglected. Precipitation of dolomite/ankerite is commonly enhanced by an increase of Mg/Ca ratio, which was thought to be consequence of mixed groundwater and lake brines in lacustrine environments. Therefore, it can help to reconstruct the pore water evolution history based on the timing and elemental analysis of multi-stage dolomite/ankerite cements in lacustrine sandstones.

This work investigates the Upper Fourth Member of Shahejie Formation (Es4s) in Northern Bonan sag, Jiyang Depression, China. The lower part of Es4s contains the main sandstone reservoirs for fan-delta front and sub-lacustrine fan in fresh water and/or brackish water environments. The upper part of Es4s is mainly gypsum mudstone and dark mudstone deposited in saline lake and was thought to be the hydrocarbon source rock. An integrated approach, such as stable isotope analysis of carbon and oxygen, fluid inclusion analysis, SEM, CL and EMPA were utilized.

The gypsum mudstone and dark mudstone in upper Es4s contains abundant microcrystal dolomite (SEM images and dark red color by CL analysis). However, dolomite/ankerite cements vary widely and just occur in five of the several wells with similar micro-facies and burial temperatures. Meanwhile, statistical data shows that they are mainly distributed within 1.5 km of the faults. It suggests that the pore water of lower Es4s lacked Mg^{2+} initially, and mudstone in upper Es4s was the main source of Mg^{2+} by fault conduction. Moreover, the intensive dissolution of volcanic fragments in Lower Es4s was probably the main source of Fe^{2+}. Five types of the zoned dolomite/ankerite were distinguished, and the average FeO content of D1, D2, D3, D4 and D5 are 8.44 wt.%, 3.03 wt.%, 11.12 wt.%, 0.28 wt.% and 9.16 wt.%, respectively (inside out). Furthermore, the D2 was dissolved intensely and replaced by D3. The fluid inclusions just occur in D2 and D3 with average homogeneous temperatures of 124.2 °C (117.8 to 128.7 °C) and 139.8 °C (134.7 to 148.8°C), respectively. Formation temperatures of D4 were approximately 150°C calculated by difference values of $\delta^{18}O_{V\text{-}PDB}$ from D2 to D4 (avg. -12.4‰ to avg. -15.9‰). Combining with the burial history, the formation times of D1, D3 and D5 which contain high content of FeO have good correlation with the three times of hydrocarbon charging (24.6Ma, 5.4Ma and 2.5Ma).

The Mg^{2+} and Ca^{2+} rich fluids, acidic fluids and hydrocarbon migrated in sandstones following periodic activations of faults and caused intense dissolution of volcanic fragments and feldspars, and concentration of Fe^{2+}, Mg^{2+} and Ca^{2+}. Ankerite precipitated after consumption of the acid fluids, and dolomite precipitated following ankerite with depletion of Fe^{2+}. In the next episode, acidic fluids could result in dissolution of the former dolomite/ankerite (D2 was dissolved intensely). Therefore, the dolomite/ankerite cements could be good chemical traces for fault activations and pore water evolution.

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Carbonates U-Pb absolute geochronology by LA-ICP-MS – case of the Ries Crater lake (Miocene, South Germany)

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Carbonate minerals precipitate in a variety of sedimentary and diagenetic settings and potentially record the geochemical conditions of the parent fluids at the time of crystallization. The U-Pb absolute geochronology *via in-situ* Laser Ablation-Inductively Coupled Plasma-Mass Spectrometry (LA-ICP-MS) is a radiometric method only recently applied to carbonates. This study aims to show its potential as chronostratigraphic tool for continental carbonates, where correlations between time-equivalent lateral facies is often problematic. In particular, stratigraphic correlations in lacustrine deposits may lack biostratigraphic markers and the site-specific geochemistry of continental fluids hinders the use of proxies ($\delta^{18}O$, $\delta^{13}C$, $^{87}Sr/^{86}Sr$) conventionally applied to marine carbonates.

Here we present an application of the method to the Nördlinger Ries Crater lacustrine basin (southern Germany) that formed by a meteorite impact in the Miocene (~14,8 Ma from Ar/Ar and U-Pb dating; Ref.1,2). The post-impact deposits include: (1) a siliciclastic sequence at the crater centre (basinal units A-B-C-D; Ref.3); and (2) carbonate facies at the crater margins. Absolute ages of basinal units were constrained coupling the impact time with the magnetostratigraphy (Ref.4), though their correlations with marginal facies is still controversial (Ref.5).

We focused on 3 marginal carbonate facies: the Hainsfath-type bioherm, the Adlersberg-type bioherm and the Wallerstein cool-water spring mound. Petrography combined with O and C stable isotope analyses suggests that the investigated samples possibly preserved the original crystallization ages. The syn-sedimentary carbonates (microbialites and early cements) dated by *in situ* U-Pb chronometry display ages (2σ) which span from 14.6±1.1 to 13.1±2.0 Ma that are consistent with the meteorite impact timing. Based on the most precise ages obtained (uncertainty < 1.5% SD; MSWD < 2.5) basinal units and marginal facies were correlated for the first time: (1) the Adlersberg-type bioherm (14.2±0.2 Ma) and the Wallerstein mound (14.4±0.3 Ma) are coeval with basinal Unit C; (2) the Hainsfarth-type bioherm (13.6±0.4 Ma) is coeval with basinal Unit D. Additionally, the entire geochronometrical dataset achieved is in agreement with the previously proposed ~2 Ma lake life-time. Furthermore, two cementation events occurring during shallow burial and exhumation, at 5.7±1.0 and 9.5±2.0 Ma respectively were dated.

Being the Nördlinger Ries Crater one of the most precisely dated impact event on the Earth (Ref.1), this study represents an important validation of the U-Pb carbonate geochronometry *via* LA-ICP-MS, demonstrating its great potential for continental carbonates chronostratigraphy.

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EVIDENCE FOR THE BITTER SPRINGS $\delta^{13}C$ ANOMALY IN THE VINDHYAN SUPERGROUP, INDIA

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The Vindhyan Supergroup of India, deposited in an intracratonic basin, is one of the important Proterozoic marine successions of the world that contains some of the most controversial Precambrian fossil discoveries. Despite their importance, the chronology of the host strata and global correlation of events that occurred within the basin remain equivocal. Here, we present results of a detailed geological, geochemical and isotopic (Sr-C-O) study of the Balwan Limestone, the youngest carbonate formation of the supergroup, exposed only in the western sector of the basin, in Rajasthan. Our results suggest that the Vindhyan Basin had become a structurally controlled marginal sea towards the end of its existence and that the limestone was deposited in a subtidal environment that had strong depositional currents. We find evidence for a strong storm event or a tsunami during its deposition. The Pb-Pb age of 866±90 Ma of the formation, near-primary $^{87}Sr/^{86}Sr$ ratio of 0.70676 close to the top of the ~120 m thick formation and presence of molar tooth structures at the bottom of the formation, the youngest such structures found in India, all suggest a Late Tonian depositional age for the formation. $\delta^{13}C$ stratigraphy reveals the presence of the globally synchronous Bitter Springs anomaly (~12‰ shift) in the formation, the first such report from India. The lowering of $\delta^{13}C$ to about -5.3‰ during this event appears to have been caused by decreasing organic carbon burial in the basin.

RE-EVALUATION OF THE STRONTIUM CONCENTRATION OF ANCIENT DOLOMITES: IMPLICATIONS FOR DISTINGUISHING PRIMARY PRECIPITATION VS. REPLACEMENT DIAGENESIS

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Recent recognition of the importance of microbial mediation in the precipitation of modern dolomite implies that a re-evaluation of classic dolomite formation models is necessary to advance our understanding of the processes involved in carbonate diagenesis. The influence of microorganisms and associated extracellular polymeric substances (EPS) has now been succinctly demonstrated to control dolomite nucleation in many unique modern environments, such as in the coastal sabkhas of Abu Dhabi, the hypersaline coastal lagoons near Cabo Frio, Brazil and the Coroong lakes, South Australia. This phenomenon has been confirmed through the application of well-designed bacterial culture experiments, wherein it is possible to control the physico-chemical properties of the growth media to test the importance of various parameters on bio-induced mineral compositions. Furthermore, this geomicrobiological approach has allowed for the experimental calibration of specific geochemical proxies, such as the oxygen isotope fractionation factor for dolomite and Sr partition coefficient for dolomite. Previously, such proxy data have been used to interpret paleoenvironmental conditions of diagenetic processes associated with ancient dolomite formation. In particular, the Sr composition of ancient dolomite has been commonly used as an indicator of the origin of the diagenetic fluid. Surprisingly, our biomediated experiments used to study the Sr-partition coefficient for dolomite have revealed that microbial dolomite tends to have elevated strontium compositions (>2000 ppm) versus those frequently recorded in many ancient dolomites (<200 ppm). This discovery of elevated Sr values for experimental dolomite has inspired us to reevaluate published Sr data for ancient dolomite and compare these with our experimental dolomite and modern examples of microbial dolomite, as well as some newly analyzed ancient examples. We report our findings and propose an alternative explanation for ancient and Recent dolomite with relatively high Sr concentrations, that is, they are primary precipitates influenced and/or induced by microbes. Previously, this large Sr-anomaly has been interpreted to be the product of a secondary replacement of aragonite, an explanation which can only be applied to secondary dolomite.

Distinguishing whether a dolomite reservoir evolves from a primary precipitate or as a replacement product may have implications for interpreting the ultimate physical properties of the rock. In particular, microbial dolomite tends to precipitate as nano-scale crystals within an organic matrix (EPS). The fundamental crystalline pattern is set at the onset and subsequent diagenesis is simply a modification of the original template. Thus, the degree of micro-porosity of a reservoir rock may be the consequence of the original precipitate having a microbial influenced source. We propose that the strontium concentration has the potential to reveal the process by which specific dolomite units formed and deserves testing with future studies of selected examples.

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STRONTIUM ISOTOPE RATIOS PECULIARITIES OF ANHYDRITE FROM LOWER PERMIAN SALT FORMATION (DNIPRO-DONETS DEPRESSION, UKRAINE)

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The most popular $^{87}Sr/^{86}Sr$ application is in chemostratigraphy – development high-resolution stratigraphic schemes of marine sections, as well as estimation of the sources of material in evaporite basins (marine, continental, diagenetic, hydrothermal solutions, etc.), salinity reconstruction and evaluation of diagenetic transformations in marine and/or brackish sediments. The postrift-platform Lower Permian (Cisuralian) Evaporite Formation occupies the larger part of the Dnipro-Donets Depression (DDD). This formation is subdivided into two subformations: the rock-salt-bearing Mykytivka–Sloviansk (Asselian) Subformation and the Kramatorsk (Sakmarian) K-Mg-bearing Subformation. The rock-salt subformation, which is up to 1200 m thick, is represented by the alternated layers of rock-salt (up to 75 m thick), limestones, mudstones, marls, anhydrites and halopelites. The study of Sr isotope in anhydrite of the rock-salt subformation have been applied for the geochemical substantiation of stratigraphy, analysis of the sources of brine and to clarify the paleogeographic and paleoclimatic environment sedimentation and diagenesis features etc. $^{87}Sr/^{86}Sr$ values have been measured in 36 samples of anhydrite from core from 13 boreholes drilled in central and southeastern parts of the Mykytiv and Sloviansk members of the rock-salt subformation of the Lower Permian Evaporite Formation (Kopyly, Riabukhine, West-Spivakivka, Artemivsk, Lannivka, Kobzivka areas, ets.). The measured isotope composition ratios ($^{87}Sr/^{86}Sr$) for the rock-salt subformation vary from 0.70779 to 0.70810. Taking into account that the Upper Devonian (Frasnian) Salt Formation is considered as a source of matter inflow into the Lower Permian basin, the $^{87}Sr/^{86}Sr$ in the anhydrite from the Chutivka area was determined, which is equal to 0,70800. Thus, the obtained figures fall into the Lower Permian part of the oceanic Sr-isotope curve [1, 2]. Only one sample differs by its highly radiogenic value of 0.70924. $^{87}Sr/^{86}Sr$ values for the Mykytiv Member anhydrite are 0.70781 – 0.70792; those from Sloviansk: 0.70779 – 0.70810. The highest value measured in anhydrite from West-Spivakivka area (Sloviansk Member) could be explained by the continental influence, as justified by the presence of terrigenous layers in the section. But the anticipated decreasing trend in the measured value upward the section down to the Paleozoic minimum in the Middle-Late Permian interval has not been observed. This may indicate a restricted connection of the evaporite basin to the World Ocean or a short time interval of the accumulation of the studied anhydrite beds [1, 2]. The measured values of strontium isotope composition support the idea of the marine-type source of brines in the Mykytiv and Sloviansk evaporite DDD basin and cyclicity of sedimentation.

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DIFFERENTIAL GENETIC MECHANISM OF THE MIDDLE PERMIAN LIMESTONE-MARL ALTERNATIONS AT EAST TETHYS AREA IN THE BACKGROUND OF "ARAGONITE SEAS"

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Limestone-marl alternations (abbr. LMA) is a good carrier for the study of the high precision cyclostratigraphy by orbital-forcing. But it is believed that there exists LMA induced by diagenesis. Unfortunately, distinguishing between original and diagenetic signals in LMA is difficult and controversial. The research of LMA mainly concentrated in the calcite seas ages, especially within Jurassic and Cretaceous pelagic and hemipelagic successions. While, the large-scale LMA occurred in aragonite seas are particularly well expressed in the Middle Permian of South China, and no studies about their distribution have been published.
This paper comprehensively collected the LMA field sections and part of drilling sections of Middle Permian that located in South China. Then, the research of morphological, petrological, mineralogical and geochemical features about the LMA were carried out.The results proved that the Middle Permian LMA developed different sedimentary environments, such as onshore, carbonate platform and shelf. Macro-and microscopic characteristics, mineral composition, the content of Al, Ti, Th, Zr, Sr and rare earth element (abbr. REE), REE distribution patterns of these calcareous rhythmites had significant differences. In this paper, the identification signs of the differential genetic mechanism of the Middle Permian LMA in South China were summarized in five, including (1) the difference of biofossils content and their ecological composition, (2) the identification of sedimentary clay minerals (chlorite and illite) and diagenetic clay minerals (sepiolite and talc), (3) the identification of between terrestrial quartz and diagenetic metasomatic quartz, (4) the difference in the content of the Al、Ti、Th、Zr and ∑REE, (5) the difference of REE distribution patterns. Based on the recognition signs, we believed that the formation of LMA deposited in onshore was totally induced by climate. While, these LMA deposited in carbonate platform and shelf were involved in differential diagenesis. And for the vast majority of the calcareous couplets, diagenesis only reinforced the differences in the composition of the original sediments. However, there also existed a few LMA purely induced by diagenesis.

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The Carbon Isotopic Composition of Oceanic and Platform Components: Do They Record the Same Thing?

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The carbon isotopic record of carbonate sediments is one of the more robust stable isotope proxies to have emerged over the past 50 years. Significant growth in this field has been the result of work by Jan Veizer and his students[1]. While over the past 100 myrs the organism of choice have been foraminifera, which record the $\delta^{13}C$ value of the open ocean, dissolved inorganic carbon, for older time periods, macrofossils and bulk carbonate sediments from carbonate platforms and epeiric seas have been employed. It is essential to understand how such sediments record the oceanic signal because the $\delta^{13}C$ values of bulk sediments from settings drilled adjacent to carbonate platforms do not record the global oceanic signature of dissolved inorganic carbon at several locations over the past 10-25 myrs. This results from the mixing of sediments produced on the platforms surfaces with isotopically high values, with oceanic materials having lower values. As a result, the $\delta^{13}C$ values of the bulk sediments in these settings are more a record of sea level changes than variations in the inventory of global carbon. To explore this association further, we compared the bulk sediment and planktonic foraminiferal, *Globerigina trilobus*, $\delta^{13}C$ records from a location close to the Bahamas (ODP Site 1006)[2]. Previous work has shown that bulk sediment $\delta^{13}C$ values from this site record a mixture of oceanic and platform derived sediments[2,3], diverging significantly from the foraminiferal or oceanic record. Interestingly, it was previously documented that the $\delta^{13}C$ values of *G. trilobus* from this site differ from the global $\delta^{13}C$ values [4,5]. Clearly, either the water mass represented by the Florida Current is decoupled from the global $\delta^{13}C$ signal or the $\delta^{13}C$ signal is influenced by diagenesis. This later hypothesis is supported by the covarying trends between the $\delta^{18}O$ values of the bulk and those in *G. trilobus*. This presentation will explore this possibility as well as examine similar records from other sites drilled along the platform to basin transect during Leg 166.

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PALEOSALINITY FLUCTUATIONS IN MARINE ENVIRONMENTS AS A RESULT OF HYPERPYCNAL FLOWS

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Chemical parameters are increasingly used to determine depositional conditions of ancient deposits, and to help interpret the depositional environment. The conclusions based on such chemical parameters can, however, be incorrect if no additional field checks are carried out. An example is the way in which the continental or marine character of sediments is established on the basis of the paleosalinity preserved in the sediments: the concentration of some trace elements – and even more the ratio between some trace elements – is a proxy for the paleosalinity of the depositional environment, and consequently commonly also for the proximity to the adjacent continent. This is because fresh water, discharged into the sea by rivers, in most cases gradually mixes with the ambient sea water so that the near-coast relatively low salinity of the sea water is raised with increasing distance from the coast.
Discharge peaks of major sediment-laden rivers that induce hyperpycnal flows at their mouth, can, however, affect this simple picture fundamentally. The hyperpycnal flows run down the basin slope, occasionally over tens of kilometers or even more. The huge volume of fresh water that can thus be introduced into a marine environment tends to mix with the ambient saline seawater only slowly, diminishing the paleosalinity even far away from the coast. This may be a local and temporary effect, but it may significantly affect the bio-environment and consequently the fossil record. It may also hamper the correct interpretation of the full-marine character of the depositional environment, which may, moreover, become obscured by the introduction of riverine organisms that are brought along by the hyperpycnal flows. The temporary lowered paleosalinity may be preserved in the sedimentary record in the form of 'diverging' concentrations of trace elements and trace-element ratios, which parameters are commonly used to determine the salinity of the depositional environment. A full-marine character of the marine depositional environment may thus be obscured. This is exemplified for the Early Cretaceous Lingshandao Formation on Lingshan Island (western Yellow Sea)[1]. It is deduced that detailed facies analysis in the field is consequently required to reveal the true character of a marine environment.

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Genesis and distribution pattern of carbonate components in lacustrine sandy conglomerate reservoirs in the Es3 Members of Downthrown Block in Yidong Fault Zone, Zhanhua sag, Jiyang Depressiom, China

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Sandy conglomerate reservoirs in the rift lacustrine basin is the focus of the current exploration and development in Bohai Bay Basin, China[1, 2]. Carbonate cement is an important authigenic mineral in the clastic rock reservoirs[3,4]. The parent rock of the Es3 members of downthrown block in Yidong fault zone contains carbonate rock strata, which comes from Yihezhuang uplift. The distribution of carbonate components is a main controlling factor of sandy conglomerate reservoirs quality. There are two genetic types of carbonate components in the area, including calcite matrix formed by sedimentary, carbonate cements formed by cementation. The calcite matrix coming from the carbonate strata of Yihezhuang uplift is the main source for carbonate cementation.

During the stage of early tectonic activity, retreated nearshore subaqueous fans developed, consisted mainly of gravity flow. In the inner-fan, calcite matrix was mixed with terrestrial debris including gravel, sand and mud. Sand suspended in the matrix in the middle-fan. Outer-fan was consisted of marl. Compaction is the dominant diagenesis in nearshore subaqueous fans. Whereas in the middle-fan, mesogenetic diagenesis include weak feldspar dissolution and calcite cementation. As a result, nearshore subaqueous fans have a poor reservoir properties.

During the stage of late stable tectonic, prograded fan deltas developed, mainly consisted of tractive current. As the hydrodynamic strength weakened, the top cycle of fan delta formed a stable calcite matrix layer, gravel, sand and bioclast suspending in the matrix. The middle and bottom cycle consisted of less calcite matrix, and the bottom cycle has a better-sorted and good reservoir quality. Eogenetic diagenesis include mechanical compaction, early crystalline calcite cementation, meteoric freshwater eluviation. Mesogenetic diagenesis include dissolution of framework grain by organic acids, and subsequent precipitation of late coarse calcite cements, ferro calcite and less quartz. The middle cycle of underwater distributary channel, thick grain-support sandstones in mouth bar constitute potential hydrocarbon reservoirs.

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MIXED INTRABASINAL-EXTRABASINAL TURBIDITES IN THE GUARICO Fm (EOCENE), VENEZUELA

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The Guarico Formation in the north of Venezuela corresponds to an up to 8,000 ft thick clastic succession of turbidites and associated deep water deposits. These deposits accumulated in an extended foredeep developed as a consequence of the oblique collision of the Caribbean plate against the South American plate during the Paleogene. Marine deep water deposits comprise a complete suite of coarse to fine grained deposits related to extrabasinal and intrabasinal turbidites. Intrabasinal turbidites include cohesive debris flow (also known as wild flysch), hyperconcentrated flow, concentrated flow and turbidity current deposits. Extrabasinal turbidites compose graded to complex beds with abundant plant remains, and are mostly related to hyperpycnal fluvial discharges. In the Rio Panapo area, a 195 m thick succession of turbidites is exposed. Sandstone beds are up to 2 meters thick, and internally display normal to inverse grading. Most beds are composed of coarse to fine grained sandstones, with massive, laminated and climbing ripples as dominant sedimentary structures. Deformational and water escape structures are common, as well as mica, plant remains, clay chips and charcoal clasts. Main paleocurrents are from west and northwest. Turbidite beds compose typical finning upward cycles up to 20 metres thick. Of particular interest are several intervals of hybrid turbidity current deposits. These packages are composed of two clearly differentiated intervals. The lower interval is composed of massive coarse grained sandstones with clay clasts, showing dish and deformational (load and water escape) structures. This lower interval is sharply overlaid by massive to parallel laminates fine grained sandstones, with large (up to 15 cm) clasts of charcoal towards the top. Elongated charcoal clasts often show imbrication. The upper sandstone bed shows a very irregular basal boundary, product of overloading over a water-saturated substrate. Internally, the sandstones shows a cyclic recurrence between massive and laminated sandstones, suggesting flow fluctuations in the original discharge. It is interpreted that these packages were accumulated by an intrabasinal inertia-dominated concentrated flow followed by an extrabasinal hyperpycnal flow. Field evidences suggest that concentrated flows could have been triggered in slope areas by passing-by hyperpycnal currents. Since concentrated flows travel faster, their deposits were found in the lower part, and were rapidly covered by hyperpycnal flow deposits when the previous level was still saturated in water, resulting in a strong basal deformation.

MORPHOLOGY AND EVOLUTION OF A JURASSIC SHALLOW MARINE RIVER-DOMINATED DELTAIC SYSTEM

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The complex processes of climatic perturbations behind global sea-level fluctuations from the Triassic to Jurassic are well preserved in the North German Basin. Litho- and biofacies analyses and architectural investigations of Toarcian deltaic sediments documented in more than 400 wells in NE Germany enables the construction of time-constrained high-resolution subsurface and sand thickness maps (Zimmermann et al. 2015). In detail, the maximum progradation of two 3rd order regressions representing the evolution from a small river-dominated delta in the early Toarcian to a large river-dominated system in the late Toarcian can be shown. Both maximum progradation stages resulted in the outbuilding of delta plains stretching about 200 km from northern basin margins to the basin centre. The upper delta plain is characterized by the absence of marine influences, but towards the SW, marine phytoplankton occurs on the lower delta plain. Both delta plains were fed by networks of 2 to 3 km wide deltaic channel belts with a max. distributary depth of 15 m, bifurcation patterns are typical for avulsion processes. Furthermore, meandering channels were indicated by lateral shifting of channel belts and levee-crevasse lithofacies associations and contributive network (cf. Zimmermann et al. 2018). Subsurface lithofacies mapping and corresponding thickness distribution of net sand thickness of the upper Toarcian delta suggest moderate angles of 30 to 80° between distributary channels belts. In downstream direction, the distributive network shows an increasing bifurcation frequency, and decreasing thickness from 40 m to 10 m. On the lower delta plain, areas of interdistributary bays are formed between delta lobes, receiving detritus from surrounding distributaries. Delta front deposits are characterized by up to 50 m thick mouth bar complexes with bar-finger sand architectures formed in elongate lobes. Siltstones and very fine sandstones of the proximal prodelta can be traced about 50 to 100 km off the delta front. The transition of both deltas is characterised by an overall delta progradation of about 30 km, delta plain enlargement of more than 50 %, change of channel types (meandering to anastomosing/meandering) and increase of sand thickness up to 150 %.

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Impact of rapidly deposited layers on paleomagnetic records: examples from the Lesser Antilles accretionary wedge

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Paleomagnetic studies have mostly focused on hemipelagic sediments, avoiding all rapidly deposited layers such as turbidites to reconstruct Earth' geomagnetic field variations. Nonetheless, a few laboratory experiments and natural sediment core studies have begun to explore the impact of such rapidly deposited layers on the paleomagnetic records in order to better understand the impact of lithological changes on the paleomagnetic signal and remanence acquisition process. Here, we propose to investigate the impact of turbidites and homogenites on the paleomagnetic record of two long sediment cores collected along the Lesser Antilles accretionary wedge and characterized by hemipelagic sediments interbedded by turbidites-homogenites layers. Physical data (magnetic susceptibility, gamma density, P-wave velocity and spectral reflectance) were acquired with a GEOTEK Multi Sensor Core Logger on board the R/V Pourquoi Pas ? during the CASEIS Expedition in 2016. Paleomagnetic data were acquired with a 2G Enterprises 755-1.65UC DC SQUID Superconducting Rock Magnetometer, for u-channels and a 2G Enterprises 760-3.0 AC SQUID Superconducting Rock Magnetometer, for single cubic samples. Discrete samples and bulk sediments were also respectively measured with a KLY-3 kappa bridge and a Vibrating Sample Magnetometer. Results reveal a shallowing inclination error on homogenites coupled with a stable lower magnetic susceptibility. It will therefore be possible to discriminate homogenite deposits from hemipelagic background sediments. In contrast, turbidite deposits coupled to homogenite did not show a clear progressive shallowing inclination error between the bottom and upper layers as expected from other studies. This could be explained by multi-pulse turbidites and/or partial remobilization. Finally, ongoing statistical analysis of the different rapidly deposited layers from the Lesser Antilles area should allow us to better understand the combined influence of the amplitude of the event, sediment and magnetic grain size and changes in the concentration and mineralogy of the magnetic fraction on the paleomagnetic signal.

Acknowledgements

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Supercritical-flow deposits and their distribution in a proximal (Ainsa Basin) to a distal (Jaca Basin) environments, Middle Eocene, Spanish Pyrenees.

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Many sandy submarine fans should contain an abundance of evidence for deposition and/or erosion beneath supercritical-flow, because it has been postulated that turbidity currents are supercritical for a slope >0.6°, with the formation of an hydraulic jump at the break-of-slope, *e.g.*, the transition from submarine canyon to basin floor (Walker, 1967; Komar, 1971). Until now, researchers have focused on the recognition criteria of supercritical-flow deposits (SFDs) and on the different flow parameters to create supercritical bedforms using numerical modelling (Kostic & Parker, 2006), flume-tank experiments (Garcia & Parker, 1989; Cartigny *et al.*, 2011, 2014) or from direct observations on the seafloor on presently active deep-marine slope systems (Hughes Clarkes *et al.*, 2012).

An extensive field study was conducted in the Middle Eocene, Ainsa and Jaca basins, Spanish Pyrenees, preserving proximal canyon-channel and related deposits and distal lobe and related deposits, respectively. This study analysed the recognition criteria of SFDs and their distribution in ancient deep-water systems. Three ancient sandy sunbmarine fans, related to different depositional environments, were analysed: (i) the Gerbe-Broto fan system, from mid-slope environment (Ainsa Basin) to lobe and related deposits (Jaca Basin), (ii) the Banaston-Cotefablo fan system, from a proximal-basin floor environment (Ainsa Basin) to lobe and related deposits (Jaca Basin), and (iii) the Ainsa-Jaca fan system, from lower-slope depositional environment (Ainsa Basin) to lobe and related deposits (Jaca Basin).

SFDs are classified in two groups of facies associations: erosional supercritical bedforms (hydraulic jump and cyclic steps deposits) and depositional supercritical bedforms (antidune and upper-plane beds). The SFD distribution was analysed in two directions: (i) an axial direction, from a channel axis to the channel margin, and (ii) in a longitudinal direction, from the proximal depositional environments (Ainsa Basin) to the distal depositional environments where lobes and related deposits are observed (Jaca Basin); and shows systematic spatial changes in the proportion of the various SFDs. The results of this study will help in the understanding of the flow dynamics during deposition within an ancient deep-water system.

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HIGH-RESOLUTION CORRELATIONS OF STRATA WITHIN A SAND-RICH CLINOTHEM SEQUENCE, OFFSHORE NEW JERSEY, USA

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Clinothems are valuable archives of basin margin evolution, and the trajectories of successive clinoform rollovers are widely applied to predict spatio-temporal sand distribution. Despite the large body of work directed at understanding basin-scale relationships across multiple clinothems, the detailed internal architectures of individual clinothems remain relatively under-studied. Understanding the internal architectural complexities of complete topset-foreset-bottomset clinothem sequences (including grain-size, grain shape and sand:mud ratios) is key to understanding *how* and *when* the basinward transfer of sediment occurs, and for determination of spatio-temporal sedimentary correlations created by these processes. This study has undertaken high-resolution, core-based analyses of 267 samples from three research boreholes recovered during IODP Expedition 313, offshore New Jersey, USA. The cored intervals target quasi-coeval topset, foreset and bottomset deposits of seawardly prograding, intrashelf clinothem sequences of Miocene age. The topset deposits of one seismic sequence (Sequence m5.4) are subdivided into three (m5.4a-c) sedimentary packages based on sedimentary-facies analysis. Facies analysis of topset deposits indicates that sedimentary packages m5.4a and m5.4c record deposition under a river-dominated shelf-process-regime and that sedimentary package m5.4b records deposition under a wave-dominated shelf-process-regime. Complex stratigraphic interactions between river-, wave- and tidal-processes have a quantifiable effect on topset grain character, which can be used to correlate time-equivalent sedimentary packages in foreset and bottomset deposits. River-dominated sedimentary packages m5.4a and m5.c possess the following traits: i) coarser in mean grain-size; ii) more poorly sorted; iii) less spherical; iv) more angular and v) have higher sand:mud ratios, relative to wave-dominated package m5.4b. Additionally, the average grain-size distributions of river-dominated topset sedimentary packages m5.4a and m5.4c are bimodal, whereas that of wave-dominated topset sedimentary package m5.4b is unimodal. River-dominated sedimentary packages (m5.4a and m5.4c) have higher overall sand contents across the downdip profile, however, the grain-character of the river-dominated sedimentary packages is texturally less-mature than that of the wave-dominated sedimentary package (m5.4b).The interaction of river-, wave- and tidal-processes exerts a fundamental control on reservoir characteristics. Grain-character of seismic sequence m5.4 varies stratigraphically across the complete shallow- to deep-marine profile, according to the dominant topset- and shelf-process-regime. Grain-character can be used to correlate genetically-related sedimentary packages across the complete shallow-to-deep-marine transect, and to establish timelines at a greater resolution than is currently possible using chronostratigraphic techniques. Results challenge the commonly held ideas that sediment bypass and styles of sedimentation are consistent within a seismic sequence, and that clinoform trajectory and stacking pattern analyses are adequate to describe spatio-temporal sand-body evolution within a single clinothem sequence or across multiple clinothem sequences.

Lateral Continuity and Thinning Ratios, an Analysis of Thin Beds Within a Storm Dominated Prodelta: Cretaceous Ferron Sandstone, Utah

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Heterolithic strata are deposited in a variety of delta front to offshore marine environments. There are many physical bedding processes that cause the deposition of various sedimentary successions within these environments, including hypopycnites, hyperpycnites, ignitive turbidites, and tempestites. The purpose of this study is to analyze a three-dimensional outcrop exposure to investigate how preserved thin beds lateral continuity and thickness relate to the physical bedding processes that caused their preservation. Data for this study was obtained from five measured sections taken at the centimeter scale resolution, as well as a three dimensional photorealistic drone model of parasequence 5b of the Ferron sandstone. Parasequence 5b is an aggrading, storm dominated fluvially influenced parasequence, which transitions from the prodelta to delta front facies. The correlation and measurements of bed thickness spanned 155 meters of outcrop surface. Thickness measurements were made for five completely laterally continuous sandy beds every 0.5 meters. The completely continuous beds were used as constraints for the correlation of all other beds that lie in between. At least 10% of beds are laterally discontinuous over the 155 meters of analyzed outcrop. Thickness measurements allowed for lateral continuity estimates of hummocky cross stratified beds, which estimate lateral continuity for up to 1640 meters. Lateral discontinuity is shown to actively be caused by amalgamation of hummocky cross stratified tempestite deposits. This is pertinent to oil and gas research as a fundamental understanding of lateral continuity as it relates to physical bedding process can aid in reservoir predictions and risk assessment.

HOW VARIATIONS IN REGIONAL SETTING WILL AFFECT DIFFERENT SEDIMENTARY CHARACTERISTICS AND STRUCTURAL STYLES IN DELTAIC-DEEPWATER BASINS: CASE FROM KUTEI AND TARAKAN BASINS, KALIMANTAN, INDONESIA

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The Kutei and Tarakan basins are the Paleogene rifted-margin and Neogene deltaic-deep water sedimentary basins which developed in the east and northeastern parts of Kalimantan/ Borneo, Indonesia. These basins are separated by the Mangkalihat High, and they are terminated to the west by the Kuching High –Kalimantan Central Ranges. To the east, they open as embayment.

Kutei basin is one of the most prolific hydrocarbon provinces in the world, where its deltaic and deepwater sediments contain productive plays. Existing discoveries in these basins mainly come from Upper Miocene and Pliocene reservoirs. The sediment influxes come from the Kucing High which contains mainly melange, deepwater, and volcanic deposits. They resulted in quartzitic sandstones in the deltaic and deepwater areas of the Kutei basin through multiple erosional and reworking processes and good maturation of the sediments by long distance transportation to the east from shelf to deepwater area. The eastward progradation of the sediments have induced gravity tectonics, resulting in anticlinorium in the deltaic area and toe-thrust belts in the deepwater area. These syn-depositional structures had controlled the distribution of the sediments.

In the Tarakan Basin, mode of sedimentary transport and syn-depostional structures are slightly different from those of Kutei Basin due to variation in the regional setting. Variations of: distance from source-to-basin, volume of influx, space of accommodation have produced different characteristics of sediments in the both basins and syn-depositional structural styles. Basically, sandstones deposited in the Kutei Basin from deltaic to deepwater areas are cleaner and have more quartz preserved than those in the Tarakan Basin.

This paper will highlight how variation in the regional setting, distance of sediment transport, volume of influx, and space of accommodation will affect sedimentary characteristics and structural styles in deepwater basins.

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ARCHITECTURE OF CYCLIC-STEP STRUCTURES FROM A HOLOCENE DELTA

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It has been acknowledged that the frequency in the stratigraphic record of cyclic steps and other related supercritical bedforms has been largely underestimated. Identification at outcrop of the structures originating from the upslope migration of long-wavelength, fine-grained bedforms characterizing the deep sea remains problematic. However, our knowledge of coarser-grained and less extensive (m's to tens of m) supercritical structures recently profited from an increasing number of studies (bathymetric surveys, depositional facies, seafloor monitoring) that have essentially focused on sandy deltaic settings. Here, we present a case study from a Holocene proglacial delta succession, lying on the Québec North Shore of the St Lawrence Estuary. Large outcrops, owing to glacio-isostatic uplift and ensuing coastal erosion, have allowed the full architecture of beds and laminations deposited by the migration of cyclic steps along delta foresets to be determined.

The structures, developed in sand-sized material with subordinate muds and gravels, are observed in the upper segment of relatively low-angle (2-4°) delta foresets. Gravelly sands characterize the topsets, while fine sand and mud were exported downslope. Undulating 'beds', 5-20 cm thick, showing minimum wavelengths in the 10-20 m range and internal faint lamination, are truncated downstreamward by, and are onlapping upstreamward on, inclined composite erosional surfaces. These erosional surfaces have dips greater (10-20°) than the foresets and are regularly spaced and hence appear as pseudo-foresets. Scours, especially in the lower reaches of these pseudo-foresets, are filled in by the coarsest material. Higher up, heavy mineral concentrations are observed underlining these erosional surfaces.

Our multiscale survey (aerial photo cover, outcrop, laser particle size analysis) allow (i) the reconstruction of the parent bedforms that corresponded to three-dimensional, upstream-migrating structures; (ii) the distinction between 'laminae' vs. 'beds' in cyclic step complexes, the latter resembling individual turbiditic beds; (iii) the inventory of associated second-order sedimentary structures (load, flame, ripples and mud drapes…); (iv) the comparison with present-day active delta surfaces; (v) a better understanding of the processes tied to cyclic step migrations in deltaic settings.

Shark-fin structures: overturned flame patterns due to waves at the shear horizon of a flow-bed boundary. Examples from deposits of pyroclastic currents

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Enigmatic structures are documented in deposits of dilute pyroclastic currents and grouped under the term "shark-fins". They consist of an overturning of a few laminae on a decimeter scale, forming overbent "flames" or convolute laminae, which occur in successive, periodic patterns. More than 200 shark-fins were investigated and measured in the cross-laminated deposits from the 2006 pyroclastic currents of Tungurahua volcano (Ecuador).

These shark-fins are interpreted in terms of syndepositional soft sediment deformation pattern whereby waves form at the interface of a shear horizon at the flow-bed boundary and rework the bed. The shark-fins are not related to Kelvin-Helmholtz instabilities. Instead, a theoretical framework based on two layers separated by a shear horizon is developed. The calculated growth rate of the waves is compared to sedimentation rates in order to infer aspects of the stability and preservation of such sheared interfaces. The process-based interpretation is supported by the results from the physical model.

We identify the necessary key observations for the interpretation of shark-fin structures for different types of triggers. Such observations on flow-bed interactions contribute to the understanding of a flow rheology, shear partitioning, and the transmission of shear stress out of the flow and into the substrate. Shark-fin patterns are likely common in other types of sediments, especially in turbidites.

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ARCHITECTURE-BASED RECOGNITION OF DEEP-WATER SUPERCRITICAL BEDFORMS IN THE STRATIGRAPHIC RECORD

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Supercritical bedforms (e.g., cyclic steps, antidunes) are commonly identified in modern deep-water environments and have been increasingly acknowledged as important to the initiation and maintenance of submarine channels[1]. However, identification and interpretation of associated supercritical bedform deposits in the stratigraphic record remains challenging due to poorly established recognition criteria. This study emphasizes the architecture of stratigraphic surfaces that bound supercritical bedform deposits. The nature and geometry of sedimentary bodies resulting from upstream migrating supercritical bedforms is constructed using repeat bathymetric surveys from modern deep-water channelized settings (Squamish Delta, British Columbia and Monterey Canyon, California). These results are then applied to aid interpretation of Late Cretaceous submarine channel strata of the Nanaimo Group, British Columbia, and the Tres Pasos Formation, Chile.

Repeated along-channel and across-channel bathymetric profiles indicate significant reworking of bedform deposits between survey time intervals. The resulting stratigraphic products are highly composite, consisting of lenticular and wedge-shaped bedform remnants that are typically 5–30 m long, <30 m wide, and 0.5–2 m thick. Geometrically and dimensionally comparable, scour-surface bound stratigraphic units are identified in both the Nanaimo and Tres Pasos strata. Scour surfaces are variably defined and overlain by thin beds of laminated siltstone and fine-grained sandstone; the scour surfaces primarily bound structureless sandstones that contain localized backset stratification. Numerous, nested sedimentary units are documented over thin successions (<4 m), suggesting little to no aggradation and limited preservation of bedforms. Evidence for supercritical bedforms in the outcropping strata supports the interpretation of a high-gradient setting dominated by supercritical to subcritical flow transitions. Collectively, these linkages between modern and ancient deposits helps to establish geometric and architectural recognition criteria for supercritical bedform deposits, supporting more refined depositional models of deep-time strata.

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CHARACTERISTICS OF SUPERCRITICAL BEDFORMS ON THE SLOPE RIDGE OF THE NORTHEASTERN SOUTH CHINA SEA MARGIN

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Sea-floor scours have been imaged by numerous bathymetric data[1]; however, whether there are stacks of such features at depths is still unclear. This study describes a field of bedforms, 13 km^2 and >300 m thick, imaged in the 3-D seismic volume of the Formosa Ridge, a NW-SE oriented intercanyon area on the northeastern slope of the South China Sea. The cross-sectional profiles show series of large-scaled asymmetrical, 540-900 m long and 38-68 m high, bedforms with their relatively gently dipping (0.1° -5°) stoss sides facing upslope and the steeper (6°-15°) lee sides facing downslope. The stoss sides aggrade over time while the lees appear to be slightly erosional or non-depositional. In 3-D view, the bedforms are bowl- or crescentic-shaped depressions surrounded by elevated headwalls and sidewalls on which relatively higher sediment aggradation occurs. In the troughs, seismic reflections downlap and onlap onto the scour bases and sides. The walls of adjacent scours, together, create positive triangular relief features on the sea floor. The steep walls correspond to low seismic coherence and low seismic amplitude whereas the troughs, in particular, show consistently high coherence and relatively higher amplitudes. By comparing successive seven surface maps, on which the sea-floor slope varies from 2.6°-0.5°, we observed that the bedforms migrate upslope in the NE direction, which is an oblique angle to the modern ridge axis. The depressions become indiscernible once coalesce with a bathymetric high to the east. We interpret these bedforms as cyclic steps based on the scale, geometries, and migration pattern associated with differential sedimentation on the stoss and lee sides. This study shows that cyclic steps, often imaged as negative depressions or scours on the sea floors[1], can be long-lived while undergoing stages of being net-erosional, filled, and net-depositional. On the Formosa Ridge, cyclic steps constitute significant part of the slope stratigraphy and the deposits that might affect gas hydrate system dynamically.

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CHARACTERISTICS AND PALEOGEOGRAPHICAL SIGNIFICANCE OF THE LOWER CRETACEOUS CLASTIC DYKES IN SOUTHERN TIBET

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A clastic dyke is a seam of clastic sediments that fills open fissures in and cuts across strata. Previous studies indicate that triggers for clastic intrusions include seismic shaking, addition of fluid and build up of excess pore pressure due to depositional events. Clastic dykes could be an indicator of the deposition process and tectonic activities.

Clastic dyke swarms are widely exposed in the Lower Cretaceous shales in the Gucuo area in southern Tibet. Based on ammonite biozones and detrital zircon U-Pb ages of the underlying sandstones, the age of the clastic dykes is early Aptian. In this paper, we present data derived from field work, detrital zircon U-Pb dating and petrology analysis. The length and width of the clastic dykes are ranged from 5-50 m and 20-100 cm, respectively. The dykes are distributed along a series of NWW-SEE normal faults. The fillings of the clastic dykes consist of greyish to brown, fine to medium grained lithic quartz sandstones. The ICP-MS zircon U-Pb age analyses of one representative clastic dyke yields a youngest graphical age peak of 124.3 Ma, which is approximately equivalent to the ages of the volcaniclastic sandstones in the overlying and underlying strata. Petrology analysis shows that the lithology of the dykes is similar to that of the underlying strata, which contain abundant lithic fragments. In contrast, the overlying strata are more abundant in feldspars with only very few lithic fragments. This result reveals the dykes are more likely derived from underlying strata and injected upward along the faults.

A fault-induced clastic dyke model is proposed. The normal faults provide conduits for clastic sediments injecting from underlying unlithified sandstones by overpressure. The normal faults were probably caused by NNE-SSW extension tectonic activity, related to the opening of deep, crust cross-cutting fractures along the northern margin of Greater India when the Australia-India plate separated in the Early Cretaceous. We suggest that the Early Cretaceous clastic dykes in southern Tibet may provide insight into the deep-seated fractures, caused by regional stress-field change.

HOW DO TURBIDITY CURRENTS DISTRIBUTE ORGANIC CARBON IN FJORDS? NEW INSIGHTS FROM BUTE INLET (CANADA)

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The burial of terrestrial organic carbon in marine sediments is a key mediator of long-term atmospheric CO_2 budgets, thereby playing a critical role in climate regulation. Fjords receive high fluxes of terrestrial organic carbon and are thus considered as hotspots of organic carbon burial globally. However, little is known about how organic carbon is distributed, fractionated and buried in fjord seafloors. While a number of studies have shown how turbidity currents create highly active erosive channels in fjord seafloors, no study has examined how these channels distribute organic carbon over different sedimentary units (e.g. submarine thalweg, terraces, distal fans).

Here we use a unique dataset that combines direct monitoring of active turbidity currents, detailed seafloor mapping, and sampling of the resulting sedimentary deposits in Bute Inlet, an ~80 km long submarine fjord in British Columbia (Canada). This study allows to specifically test the potential of turbidity currents to store modern fractions of organic carbon in fjords and thus to better constrain the impact of turbidity currents and fjords on the global carbon cycle. Sediment samples were retrieved from the fjord and its catchment, this includes samples from the rivers connected to the fjord head and from the turbidity current channel which terminates to a 600 m deep terminal fan. Applying an organic geochemical approach, we measured both bulk properties (total organic carbon and $\delta^{13}C$) and organic biomarkers on the river and fjord samples. Preliminary results suggest that the turbidity current channel influences distribution of carbon which is mostly organic and of terrestrial origin. Further analyses using the Ramped Pyrolosis/Oxidation system will allow fractionation of the organic carbon age spectrum contained in each sample taken from the submarine channel. This study importantly highlights fjords as heterogeneous and dynamic systems with sedimentary processes that deliver, erode and rework carbon-bearing sediments.

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INTERACTION OF THE ARGENTINE CONTOURITE DEPOSITIONAL SYSTEM AND THE MID-SLOPE MAR DEL PLATA CANYON

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Submarine canyons are major conduits of sediment transport to the deep ocean. Many canyons have a connection to the shelf. However, in the last decades an increasing number of canyons reveal a mid slope canyon head, such as the Mar del Plata Canyon at the Argentine margin. The canyon head originates on the Ewing Terrace at about 1000 m water depth and acts as a sink for contouritic material delivered along the terrace by the Antarctic Intermediate Water (AIW) nepheloid layer (*Voigt et al*., 2013). The canyons downslope track crosses all intermediate and deep-water masses that shape the continental slope off Argentina. The canyon expires on the Necochea Terrace (3500m to 3900m water depth). Methodological approaches of our study include hydro-acoustic profiling, Xray-radiographs, XRF elemental ratios, XRD measurements, magnetic susceptibility and grain size distribution. Three coherent deep Southern Component Water (SCW) paleo-current records provide new insights on deep SCW flow strength since the Last Glacial Maximum (LGM). Coherently increased sortable silt values record an enhanced deep SCW flow strength from 14 ka to 10 ka relative to the early deglacial/LGM and the Holocene (Warratz et al. 2017). Furthermore carbonate content and preservation records indicate a shoaled Northern Component Water (NCW) until 13 ka and an upward expanded deep SCW, the later accounts for the reduced carbonate preservation at the studied deep core sites. Elevated carbonate contents in the sections younger than 13 ka indicate that NCW expanded downward causing enhanced carbonate preservation at the deep core sites. Clay mineral assemblages in the background sediments show no variation during the past 20 kyrs evidencing a persistent intermediate and deep SCW flow supplying sediments from southern source areas**.** In all cores turbidites only occur during the period from the LGM to the late deglacial. During LGM and early deglacial, turbidites are more abundant at the distal northern canyon flank whereas they are rather sparse in the exit to the abyssal plain. The suspended sediment clouds carried by the persistent deep SCW were deflected to the north and deposited on the Necochea Terrace building up a contouritic drift. During the late deglacial most turbidite beds thinned out within the distal sector or did not reach the distal canyon at all. Holocene sections at all studied locations do not reveal any turbidites. A distinct and similar grain-size distribution and mineralogical composition of the turbidites and the countouritic background sediment suggests that both originate from nepheloid flows along the Ewing Terrace. The sediment discharge of these flows into the canyon was highest under glacial conditions. In upper parts of the canyon V-shaped patterns indicate areas of instability where repetitively retrogressive failures were induced when the pore water pressure of the rapidly accumulating sediment pile was exceeded. Specific knick-points, identified along the thalweg, are assumed to act as hydraulic jumps to transform small-scale slides into turbidity currents.

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SEDIMENTARY EVOLUTION IN THE WESTERN SOUTH YELLOW SEA SINCE MIS 3: MINERALOGICAL AND ISOTOPIC EVIDENCE

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The Changjiang and Huanghe Rivers, the longest rivers in China, are considered to be the major sediment sources to the South Yellow Sea during the late Quaternary[1]. Those two rivers express distinct differences in its mineral and isotopic compositions, and their contribution to the South Yellow Sea are expected to evolve with the changes in sea level, monsoon climate, river mouth shift and ocean current, thus we can exploit these information by investigating the time series provenance evolution of the South Yellow Sea shelf[2, 3]. Our results indicate that voluminous inputs derived from paleo-Changjiang River exerted a great influence on the study core during MIS 3, likely defining the northern limit of the paleo-Changjiang delta at that time, while core sediment provenance gradually transformed from the paleo-Changjiang to the paleo-Huanghe toward the late MIS 3 along with the deltaic progradation, implying that the paleo-Huanghe River seems to empty into the SYS and build a large delta in the MIS 3 interval. Detrital materials mainly originate from the Changjiang, together with partly clay-sized materials from the Huanghe during the early MIS 1, while sea bed erosion materials are the main sediment contribution to the study area during the mid-late MIS 1. Our results also identify sea level fluctuation and monsoon climate variation as the principal factors driving such above changes. High sediment supply and limited accommodation space lead to the development of sediment-fed system in the South Yellow Sea shelf during MIS 3. On the contrary, Low sediment supply and enough accommodation space give rise to the development of sediment-starved system during the mid-late MIS 1.

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Effect of channel morphodynamics on the intertidal-dune morphodynamics and associated sediment transport in the open-coast macrotidal flats, northern Gyeonggi Bay, west coast of Korea

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The long-term morphodynamics of intertidal dunes and associated bedload sediment transport were investigated to understand their responses to channel morphodynamics in the lower intertidal zone of Yeochari tidal flat in the northern Gyeonggi Bay, west coast of Korea. Since 2014, the tributary tidal channel, running from NE to SW direction, became more sinuous and a NNE-SSW trending ebb barb formed at the meander bend. A time-series of global positioning system (RTK-GPS) profiling and unmanned aviation vehicle (UAV)-assisted photogrammetry indicate that contrasting dune morphodynamics occurred since 2016 when the ebb barb became wider and deepened. Prior to 2016, simple dunes on the channel point-bar migrate seaward as fast as 4 m/day and those on the channel bank migrate either landward or seaward at slower rates of 0.1-2 m/day. In contrast, since 2016, simple dunes on the channel point-bar remain stationary or migrate landward at rates of 0.2-2 m/day and those on the channel bank persistently migrate seaward at rates of 3–4 m/day. The spatiotemporal changes in the dune morphodynamics reflect contrasting hydrodynamic responses in the channel and channel bank to the increased channel sinuosity. Hydrodynamic observation indicate a tidal asymmetry shifted from ebb- to flood-dominance in the channel and accentuated ebb-dominance in the channel bank. Bedload transport rate (Q_b) in the channel is estimated 0.14–0.25 kg/s/m during flood tides and 0.05–0.12 kg/s/m during ebb tides in 2016, which is nearly up to four times larger than the estimates in 2014. Q_b in the channel bank is estimated at 0.03–0.07 kg/s/m, which mainly occurred during ebb tides in 2016. The difference of digital elevation models (DoD) derived from UAV-assisted photogrammetry exhibits a marked buildup and seaward expansion of compound dunes on the channel bank since 2016, implying sustained ebb-dominance due to the channel morphodynamics. The present study showcased a rapid response of the dune morphodynamics and associated sediment transport to changes in channel sinuosity that lead to a spatially variable tidal asymmetry in the open-coast macrotidal environment.

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VOLUME AND RECURRENCE OF SUBMARINE-FAN-BUILDING TURBIDITY CURRENTS

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Submarine fans are archives of Earth-surface processes and change, recording information about the turbidity currents that construct and sculpt them. The volume and recurrence of turbidity currents are of great interest for geohazard assessment, source-to-sink modeling, and hydrocarbon reservoir characterization. Yet, such dynamics are poorly constrained. This study integrates data from four Quaternary submarine fans to reconstruct the volume and recurrence of the formative turbidity currents. Calculated event volumes vary over four orders of magnitude (10^5 to 10^9 m^3), whereas recurrence intervals vary less, from 50 to 650 years.

The calculated turbidity-current-event volume magnitudes appear to be related to slope position and basin confinement. Intraslope-fan deposits have small event volumes (~ 10^6 m^3) while ponded-fan deposits have very large event volumes (10^8 to 10^9 m^3). Deposits in non-ponded, base-of-slope environments have intermediate values (10^7 to 10^8 m^3). Sediment bypass in intraslope settings and flow trapping in ponded basins likely accounts for these differences. There seems to be no clear relationship between event recurrence and basin confinement. Weak scaling exists between event volume and source-area characteristics, but sediment storage in fluvial and/or intraslope transfer zones likely complicates these relationships. The methodology and results are also applied to reconstruct the time of deposition of ancient submarine-fan deposits.

The volume and recurrence of submarine-fan-building turbidity currents form intermediate values between values measured in submarine canyons and channels ($<10^5$ m^3 and $<10^1$ yr) and on abyssal plains ($>10^8$ m^3 and $>10^3$ yr), indicating that small, frequent flows originating in submarine canyons often die out prior to reaching the fan, while rare and very large flows mostly bypass the fan and deposit sediment on the abyssal plain. This partitioning of flow volume and recurrence along the submarine sediment-routing system provides valuable insights for better constraining geohazards, hydrocarbon resources, and the completeness of the stratigraphic record.

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CONTOURITIC PROCESSESS IN ABYSSAL ENVIRONMENTS, TROPICAL PACIFIC OCEAN

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The central abyssal region of the oceans is characterized by its remote location and large depths, which entail technical challenges to perform an in-depth study about its sediment dynamic environment[1,2]. Previously, the abyssal sediment cover was attributed to only a draping (hemi)pelagic regime. Here, multibeam bathymetric data, visual AUV observations, as well as shallow boxcore samples between the Clarion-Clipperton Fracture Zone at 4000-5000 m depth have been combined with the purpose of assessing the impact of deep bottom currents in this abyssal environment. The identification of diagnostic erosive and depositional contourite morphological features on the multibeam bathymetric data has allowed to gather evidence for the existence of present-day bottom current processes, locally creating contourite drifts with a patchy distribution.

The mechanism behind the formation of these contourites is predominantly the action of secondary flows of the Lower Circumpolar Water (LCPW) and the North Pacific Deep Waters (NPDW), as well as local dynamics of the flow in the form of internal waves and bottom currents modulated by tides. In addition, their formation is also controlled by the presence of large-scale tectonic and volcanic features (ridges, seamounts, and deep elongated valleys), which affect the morphology and distribution of the basins and induce the acceleration of the typically sluggish bottom currents.Visual AUV observations in which sessile macrofauna appears consistently bent by the bottom currents have allowed to determine their direction in specific areas with complex morphology, and to create models for the local flow.

Last, the analysis of the uppermost sediments allowed to infer the near-bottom palaeocurrent intensity and to detect clear signs of a variable current regime. This could tentatively be related to broadscale oceanographic flow variations triggered by climatic shifts, such as longitudinal shifts in the boundary between the two main deep water masses (LCPW and NPDW) and vertical shifts in the depth of the main core and secondary current filaments.The combined datasets have allowed to re-assess the distribution and significance of bottom-current controlled sedimentation in a specific region of the Tropical Pacific, as well as the mechanisms for sediment transfer.

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Post-glacial Foraminifera of the incised Yangtze paleo-valley and paleoenvironmental implications

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Three gravity cores (LZK1, ZKA4 and CSJA6) from the incised Yangtze paleo-valley comprise a thick sequence of the post–glacial deposit. A total of 19 genera (26 species) of the benthic foraminifers are described from these cores, with detailed down-core foraminiferal variations to investigate their paleoenvironmental implications. Three foraminiferal assemblages are recognized for the lower, middle and upper parts of the cores respectively. The lower part is dominated by *Ammonia beccarii* var. and *Florilus decorus* with lower abundance and diversity. In the middle part, the foraminifers are abundant and diverse, dominated by both *Ammonia beccarii* var. and *Elphidium advenum*. *Cavarotalia annectens*, *Pararotalia nipponica* and the porcellaneous benthic foraminiferal forms are always present, sometimes abundant. The upper part is characterized by the *Ammonia beccarii-Elphidium magellanicum* assemblage, except for the Core ZKA4 barren of foraminifers in this interval. Both the AMS ^{14}C dates and foraminiferal assemblages confirm that the transgression–regression sequence in these cores belongs to the "*Ammonia* transgression" during the Holocene. In addition to documenting the post-glacial sea level fluctuations, the benthic foraminifers also reflect a warmer climate during the early–middle Holocene. The foraminiferal difference between the three cores can be used to interpret the influence of the sea water during the post-glacial sea level fluctuations. The area in the vicinity of Core ZKA4 was affected by marine water only during the middle Holocene, much shorter than the areas of the other cores.

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SAND PROVENANCE ALONG THE NARROW NORTHEASTERN CONTINENTAL SHELF OF THE KOREAN PENINSULA, EAST SEA

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The northeastern continental shelf of the Korean Peninsula is characterized by a narrow (< 20 km wide) and straight coastline with a supply of sandy sediments from small-scale rivers. In order to determine the provenance of sandy sediments, we collected by piston- and box-cores from the beach, shelf, and shelf edges in the Gangneung and Donghae sites (a distance of about 15 km from each other), respectively. We performed Grain size analysis, XRD analysis, and SEM observation to identify differences between the two sites. The grain size of the continental shelf sediments gradually decreases from the inner shelf to the outer shelf. The coarse-grained sandy sediments (> 1 phi) are only found in the river mouth of the Gangneung and Donghae sites. The XRD results reveal differences in compositions of sandy sediments between the two sites; the sandy sediments of the Gangneung site are composed of quartz (53%), feldspar (34%), and mica (10%), while the sandy sediments of the Donghae site are made of rare feldspar and abundant opaque minerals. The beach sediments of the two sites also reflect the compositional differences between the Gangneung and Donghae sites. The very-thick sandy sediments found in the shelf edge of the Gangneung and Donghae sites have similar grain sizes and mineral compositions to those of the river mouth sediments in the two sites. According to our results, the provenance of the sandy sediments is distinctly different between the two sites, without reflecting the mix led by the coastal currents. It indicates that during the low stand period, the small-scale rivers of Gangneung and Donghae were extended and the sandy sediments were supplied directly to the shelf edges.

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TECTONO-SEDIMENTARY EVOLUTION OF THE UPPER JURASSIC AND CRETACEOUS DEPOSITS IN THE MESCITLI AREA, GÜMÜSHANE, NE TURKEY: CLUES TO TRANSITION BETWEEN THE PLATFORM AND BASIN FACIES

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The Upper Jurassic-Cretaceous deposits are widely distributed and superbly exposed in southern zone of the Eastern Pontides (NE Turkey). This work is focused on the depositional environments and tectono-sedimentary evolution of Tithonian - Campanian succession from the Mescitli area (Gümüşhane, NE Turkey) based on microfacies characteristics, including depositional texture, grain composition, and fossil content. The studied stratigraphic sections are characterized by the following three units: (1) 450 m medium-thick to massive neritic limestone including dolostone, benthic foraminiferal packstone, allochthonous skeletal/ peloidal grainstone, sponge spicule packstone / wackestone, and allochthonous skeletal packstone facies, which are deposited in a low-middle energy shallow tidal, lagoon to deep shelf during the Tithonian- Early Santonian time. (2) The 15 m yellowish sandstone to sandy limestone derived mainly from neritic limestone that was broken up by Albian-Santonian extensional tectonic regim, deposited in the fault-slope environment during Turonien-Santonian, and (3) the 5 m red Globutruncana-bearing pelagic limestone deposited in basin environment during the Campanian. The microfacies analyses indicate that shallow marine conditions were present during the Tithonian - early Santonian in the Mescitli area. However, these conditions ended during the Albian extensional tectonic regime, when the carbonate platform was broken up, and the basin was deepened and the yellowish sandstone to sandy limestone was deposited in the fault-slope environment. Deepening of the basin continued until the deposition of red Globutruncana-bearing pelagic limestones, which are represented by the maximum flooding surface sediments. During the Campanian the entire study area had become a deep-marine depositional environment.

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ANATOMY OF CYCLIC STEPS AND ANTIDUNES IN COARSE-GRAINED DEEPWATER CHANNEL-LEVÉE COMPLEXES

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Supercritical density flows are typical for coarse-grained submarine fans on steep-gradient, active continental margins. Field examples from the Sandino Forearc Basin (southern Central America) indicate that cyclic-step and antidune deposits occur in all sub-environments of coarse-grained channel-levée complexes. The morphodynamics of the cyclic steps and antidunes strongly impacted the evolution of the channel-levée systems from the early stage of avulsion, levée construction and backfilling.

Successions related to supercritical density flows are characterized by (i) steep-walled scours filled by conglomerates and pebbly sandstones, displaying normal coarse-tail grading or back-sets, interpreted as cyclic-step deposits, and (ii) subhorizontally stratified, sinusoidally stratified or low-angle cross-stratified pebbly sandstones and sandstones, interpreted as antidune deposits. The field examples indicate that so-called crude or spaced stratification may commonly represent antidune deposits with varying stratification styles controlled by the aggradation rate.

Large-scale amalgamated, multi-storey scour fills (18 to 29 m deep, 18 to 25 m wide, 60 to >120 m long), which are incised into levée and lobe deposits, are interpreted as related to the formation of large-scale cyclic steps during an early stage of channel incision. These cyclic steps probably formed during channel avulsion, when high-density flows were routed into the evolving channel. The infill of distributary channels is characterized by deposits of small-scale cyclic steps with superimposed antidunes. Cyclic-step deposits comprise regularly spaced scours (0.2 to 2.6 m deep, 0.8 to 23 m wide) and pass upwards and downflow into antidune deposits, indicating the formation of antidunes on the stoss-side of the cyclic steps due to flow re-acceleration downflow of the hydraulic jump. The deposits of small-scale cyclic steps with superimposed antidunes form repetitive fining-upwards successions with decreasing antidune wavelengths, indicating waning flows, and are inferred to be related to successive supercritical high-density turbidity flows triggered by retrogressive slope failures. Mouth-bar deposits are characterized by laterally extensive planar and trough cross-stratified pebbly sandstones and conglomerates, representing the progradational infill of preformed scours at a channel mouth. The mouth-bar deposits are overlain by antidune deposits, which were deposited upflow of the prograding mouth bar. Within levée successions, deposits of small-scale cyclic steps and antidunes occur in the coarser-grained crevasse-splay and crevasse-channel deposits.

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EROSION AND DEPOSITION BY PURE AND STRATIFIED PLANE-WALL JETS FLOWS – INSIGHTS FROM TANK EXPERIMENTS

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Depositional settings related to expanding point-sourced flows, like submarine fans and subaqueous ice-contact fans, can be modeled as submerged plane-wall jet flows. Submerged plane-wall jet flows emerge from an orifice into a standing water body and are characterized by rapid flow expansion and deceleration. The evolution from inertia-driven jets into buoyancy-driven-plumes is primarily controlled by the initial momentum and the density difference between the flow and the ambient water. We conducted 3D experiments with submerged, horizontal wall-jets, varying several of the main controlling parameters such as the bed slope, grain-size of the sediment bed, and the flow variables (discharge, density difference and pipe diameter) that define the initial densimetric Froude number. The controlling parameters were varied systematically to test their impact on the flow dynamics and the resulting deposit. The tested experimental conditions were classified as follows: (i) non-aggrading jets on a non-erodible bed, (ii) non-aggrading jets on an erodible bed, and (iii) aggrading jets on an erodible bed.

All experimental jet-flow deposits comprised initial jet bedforms, scours and mouth bars. Initial jet bedforms, spreading concentrically around the inlet pipe, typically preceded the formation of the scour and mouth bar. The scour and the mouth bar were always coupled, with the mouth bar surrounding the margin of the scour. Flows with higher incoming densimetric Froude numbers produced scours with larger aspect ratios (length vs. width). Conversely, the scours were deeper for lower incoming densimetric Froude numbers. Scours formed by the entrainment of sediment by turbulent vortices. The entrained sediment was typically flushed out of the scour to build a mouth bar around the scour margin. Very low-relief bedforms were observed forming and evolving on the distal slope of the mouth bar, where the flow had presumably transitioned to a fully gravity-dominated density (or turbidity) flow. The dimensions and steepness of the mouth bar and bedforms were controlled by the sediment-grain size in the initial deposit, with coarser grain sizes causing the formation of higher and steeper bars and bedforms. The transition from inertia-dominated jet to gravity-dominated plume (density flow) was observed to occur toward the distal section of the scour. The turbulent plume was slowly pushed over the mouth-bar crest by the incoming jet flow, promoting the formation of a density flow down the bar front and beyond. One of the key observations was the clear absence of hydraulic jumps inside the jet scours, as the flows inside were predominantly inertial and jet-like, thus dynamically very different than interfacial gravity-dominated flows.

The experimental observations imply that (i) the role of hydraulic jumps for the morphodynamics of expanding flows may need to be re-considered, (ii) the aspect ratio and the depth of scours provide indicators for the flow conditions near the orifice, and (iii) gravity-controlled processes rapidly take-over the control on the morphodynamic evolution of the flow and are responsible for deposition on the lee side of the mouth bar and beyond.

Responses of Slope Channel-lobe Complexes to Structurally Induced Seafloor Topography, Giza Field Offshore West Nile Delta, Egypt

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Slope channels and lobes form significant hydrocarbon reservoirs, but their behaviour and resultant stratigraphic record could be markedly complicated and different from published generic models owing to their interactions with structurally-induced seafloor topography. This study deals with the Pliocene channel-lobe complexes from the Giza field, offshore west Nile Delta, focusing on their interactions with seafloor topography created by faults and folds. High resolution 3D seismic data, augmented with well logs and core data suggest that two types of channel-lobe complexes develop in locally different tectonic settings in the study area.

Type 1 involves a channel lobe complex in a fault-controlled setting. A straight channel transitions into a sandy lobe near a fault tip. The lobe then follows the fault, which is at a high angle with regional slope dip. The lobe was subsequently incised by a channel, which is filled with muddy deposits. These observations show that the fault generated accommodation space, and reduced local gradient, which triggered flow expansion and resultant channel-lobe transition. After the lobe filled the accommodation space, newly formed channels cut into the lobe and sediments mainly bypassed this area as they tried to attain a new equilibrium profile. This resulted in muddy infills that could compartmentalize the underlying sandy lobe reservoir.

Type 2 comprises mainly a sinuous channel belt associated with an anticline/syncline pair. The channel belt becomes more sinuous with time, but during the course of channel evolution, the at the syncline is more sinuous with larger bend wavelength and amplitude, while the that at the anticline is less sinuous with smaller bend wavelength and amplitude, and develops several lobes. In addition, two well penetrations show that channel fills are generally sandier at the anticline than at the syncline, but both become muddier upwards. These changes suggest spatial acceleration and deceleration of the turbidity currents in response to topography, which are superimposed on flow evolution of flow type through time, caused by extra-basinal external controls.

In summary, seafloor topography controls local gradient and/or accommodation, which exerts a significant control on channel sinuosity, bend wavelength and amplitude, channel-lobe transition location, and reservoir/non-reservoir distributions. The effects of seafloor topography can be superimposed on those caused by external allogenic controls.

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CLASSIFICATION, FORMATION, AND TRANSPORT MECHANISMS OF MUD CLASTS

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Mud clasts are common in non-marine to marine sedimentary records, however, why lack a widely accepted classification scheme? This study aims to demonstrate the formative mechanisms, transport characteristics, and classification of mud clasts. We propose that it is the relative balance of volumetric abundance, sorting, roundness, and grain size that controls the texture and fabric of mud clasts. Nine distinct types of mud clasts are identified in the study based on quantitatified properties, and fall into two groups coarse-grained and fine-grained. The generation of mud clasts can be assigned to failure, erosion, and/or bioturbation of muddy sediment. These clasts are transported within fluid flows including Newtonian fluids, Non-Newtonian fluids, and Bingham plastics (gravity flow and turbidity flow), showing various physical characteristics depended upon the density and viscosity of flows. Newtonian flows with less density and viscosity commonly form mud clasts with mature textures. In Non-Newtonian (gravity-driven) flows, mud clasts are normally transported in laminar flows with high density and viscosity, developing matrix-supported mud clasts with immature textures. The study of classification, formation, and transport mechanisms of mud clasts has implications for identifying and interpreting sedimentary environments. In traction flows in fluvial, deltaic, estuary, coastal, and shelf environments (except bank collapse), mud clasts are generally transported in turbulent, Newtonian flows with low density and viscosity, commonly forming lag deposits with mature textures. However, mud clasts can also show poor roundness due to short transport distance in some tidal channels in estuaries and meandering channels. In gravity-driven flows of the alluvial, continental slopes, and deep water systems, mud clasts are normally transported in laminar flows with high density and viscosity, developing matrix-supported mud clasts with immature textures.

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DEPOSITIONAL FACIES AND HIGH-RESOLUTION SEQUENCE STRATIGRAPHIC ANALYSIS OF A MIXED-PROCESS INFLUENCED DELTAIC SYSTEM IN A STORMY RAMP SETTING: THE CRETACEOUS GALLUP SYSTEM, NEW MEXICO, U.S.A.

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The Cretaceous Gallup Sandstone has been studied extensively owing to the petroliferous nature of the San Juan Basin, but the depositional environments and sediment processes of this progradational system are not well understood. The Gallup Sandstone was previously interpreted as wave-dominated shorefaces, strand plains, or barrier islands[1]. Our interpretation shows that the Gallup is a mixed-process influenced deltaic system with strong river and storm signature on an epicontinental ramp setting. We measured 69 sections and walked out key facies along 60 km of laterally continuous cliffs and covered slopes that are oblique to paleo-depositional dip around the Northwest New Mexico. The detailed facies analysis based on sedimentological sections and numerous photomosaic allows identifying 9 major facies associations, including marine shelf/offshore, river-dominated delta, storm-flood-dominated delta, lower shoreface, upper shoreface, distributary channels and bars, fluvial facies, nonmarine coastal facies, and tide-influenced facies. Abundant gutter casts and hummocky cross-stratification indicate a low accommodation/sediment supply ratio and strongly storm-influenced depositional environment. Such stormy environments allow deposition of the storm-flood-dominated deltas. Numerous erosional-based channelized features coupled with low bioturbation suggest river-influenced conditions. Abundant soft sediment deformation structures in various scales also indicate a mixed storm and river influenced setting. The along-strike transition from deltaic and lagoonal/bay deposits to shorefaces may be indicative of the asymmetrical delta model. Allogenically, depositional facies closely depend on systems tracts of sequence stratigraphy and shoreline trajectory that are related to relative sea level changes. Meanwhile, facies also changed due to autogenic processes. The three dimensional changes in depositional facies manifest the evolution of depositional environments in space and time. The frequent switch among various marine and nonmarine depositional environments also suggests high-frequency relative sea level fluctuations.

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SUSPENDED SEDIMENT TRANSPORT PROCESSES IN THE SOUTH CHINA SEA: IN-SITU MOORING OBSERVATION PROGRESS

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Observing the present is critical to understanding the past and predicting the future. There is a compelling need to directly observe sediment dynamic process in the modern deep-sea environment to advance our in-depth interpretation of sedimentary and paleoenvironmental records preserved in sediment sequences. The South China Sea offers an excellent case for the sediment source-to-sink transport process study, because fluvial sediments provided by various surrounding drainage systems contain characteristic mineralogical and chemical compositions. In order to trace sediment transport processes from surrounding fluvial sources to the deep sea, time-series sediment trap samples are applied in this study to demonstrate the seasonal variation of sediment provenances in the northeastern South China Sea. Suspended detrital sediments from 10 sediment traps equipped on 5 deepwater moorings, located at water depths between 2000 and 3850 m, were analyzed for particle flux, clay minerals, major elements, and Nd-Sr isotopes. The temporal variation from May 2014 to May 2015 indicates that contour currents in water depths ranging from 1500 to 2500 m transported the majority of detrital sediments southwestward with increased intensity in summer and winter. Total particle flux in the down traps (2000-3800 m) is usually 10-100 times higher than that in the upper traps (500 m). These down-trap sediments were derived mainly from the fluvial input of Taiwan. While above 500 m, the seasonal variation of sediment provenances is not remarkable although the particle flux slightly increased in summer. Both Taiwan and Luzon contributed suspended particles to the upper sea throughout the year, suggesting westward sediment transport forced mainly by surface currents. This study highlights the significant lateral transport of detrital sediments from surrounding land sources to the deep sea that is characteristic in marginal seas

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YANGTZE RIVER-DERIVED SEDIMENTS IN THE SOUTHWESTERN SOUTH YELLOW SEA: PROVENANCE DISCRIMINATION AND TRANSPORT MECHANISM ANALYSIS

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The southwestern South Yellow Sea (SYS) is influenced by the tremendous sediment loads derived from the Yellow River (Huanghe) and Yangtze River (Changjiang). However, the sediment provenance and the influence of Yangtze River-derived sediments on this area remain unresolved. In this study, we analyzed grain size, clay mineral, and elemental compositions of surface sediments in the southwestern SYS to distinguish the provenance, and illustrate the transport mechanism of Yangtze River substances with field observation data of seawater salinity and suspended sediments. Discrimination diagrams of clay mineral, Cr/Th vs. Sc/Al, and REE, indicate that the sediments in the southwestern SYS are mainly derived from the old Yellow River subaqueous delta and Yangtze River. The distribution of suspended sediment concentration and the presence of dolomite in the suspended sediments, suggest that Yellow Sea Warm Current can transport suspended matters derived from Subei coasts to the central SYS in winter. The Yangtze River substances contained in the suspended sediments, which are finally deposited off Subei coasts in summer, are carried by the northward flow of Changjiang Diluted Water and Subei Coastal Current. During the whole transport processes, the alternation of sediment source and sink of Yangtze River substances occurs off Subei coasts, with a sink in summer and a source in winter. Sediment distribution and transportation of Yangtze River substances are closely associated with the seasonal variations of circulation system in the SYS.

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LAST GLACIAL DANUBE PALEOHYDROLOGY REVEALED BY BLACK SEA LAKE HYPERPICNITES

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During the last glacial period, the Black Sea was a giant lake disconnected from the global ocean. At that time, the Danube river acted as an outlet of European Ice Sheet and the Alpine ice cap, transporting amounts of material that allowed the development of deep-sea sediment depositional systems, including the Danube Deep Sea Fan. In this study, we discuss the sediment inputs variability of the paleo-Danube river and its relationship to paleoenvironmental regional changes, including ice-sheets fluctuations and/or rainfall regime.

For this purpose, we use the GAS-CS01 core (33.4 m) which was collected on the upper slope (240 m water depth) of the NW Black Sea during the 2015 GHASS cruise (DOI: 10.17600/15000500). The chronological framework reveals that GAS-CS01 core extend back to ~31 cal kyr BP with sedimentation rates reaching up to ~6 m/kyr. Sediments of GAS-CS01 show even, parallel clastic rythmites (with a total of 3051 laminae) that have been studied through a multi-proxy approach, including scanning electron microscopy (SEM) investigations, hyperspectral spectroscopy (µm resolution), grain-size measurements, X-ray fluorescence core-scanner (mm resolution) and XRD mineralogy (cm resolution).

Our results reveal that rythmites composing core GAS-CS01 are hyperpycnal deposits likely linked to paleo-Danube flood events. Based on this result and considering both the physiographic context (shelf break) and the lowstand glacial conditions, we suggest that core GAS-CS01 was located in a prodelta environment during the last glacial period. Furthermore, counting of hyperpycnites and, by extension, reconstruction of flood frequency suggests that the paleo-Danube experienced recurrent periods of enhanced flood activity.

The origin of this variability will be thoroughly discussed in the light of paleoenvironmental changes.

THE CATANZARO AND SIDERNO PALAEO-STRAITS, CALABRIAN ARC (ITALY): TECTONO-STRATIGRAPHIC, SEDIMENTOLOGICAL, PALEO-OCEANOGRAPHIC AND ECONOMIC IMPLICATIONS

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Gateways are key areas of connection between marine basins playing an important roles in the geological history of the Earth. Gateways represent a peculiar depositional setting characterised by specific oceanographic circulation and sediment distribution. Recent geological studies and geophysical investigations have pointed out as gateways may correspond with morphologically confined basins, block-faulted compartments or narrow marine seaways, hosting unpredictable sediment routings in association with variable tectonic accommodation. In such settings, both bottom currents and associated oceanographic processes (e.g., overflows, tides, waves, eddies, etc.) and morphological constraints can result in sedimentation that departs from conventional depositional models and stratigraphic schemes. Consequently, analysis of such settings in the subsurface is often problematic, affecting for example predictions of hydrocarbon reservoir characterization. Accordingly, presence and distribution of sand-rich deposits is key risk due to the limited amount of data and direct observations. Uncertainties can be reduced by studying outcrop and subsurface analogues using facies analysis and seismic interpretation. In addition to these standard approach, the sedimentary architecture analysis of the outcrops can be performed by using virtual outcrop data (i.e. photogrammetry and LIDAR). Virtual outcrops allow filling of the gap between facies and seismic scales in a 3D environment and have the advantages of (i) analysing outcrops, totally or partially inaccessible; (ii) obtaining a larger and more representative number of measurements and data; and (iii) being an effective space of fusion with other geological data in order to make more robust estimations.

In the present study, preliminary results in terms of basin evolution, bedform geometries and facies distribution coming from the onshore-offshore analysis of the Catanzaro and Siderno paleostraits are presented.

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THE SEDIMENTARY SIGNATURE OF SHALLOW TSUNAMIGENIC EARTHQUAKES

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The 2004 Sumatra (Mw9.3) and the 2011 Tohoku-Oki (Mw9.0) megathrust earthquakes and associated tsunamis had devastating societal consequences, in part because they were much larger than thought possible at those locations. How are ‘megaquakes’ qualitatively different from the more frequent ‘great earthquakes’ (M8)? A few similar events are known (M9.4 Alaska 1964, M9.6 Chile 1960, Cascadia 1700 AD) but historic records are too short to characterize megaquakes and their impacts. An urgent challenge is recognizing where megaquakes are possible and reconstructing and characterizing megaquakes from their submarine geologic signatures at least through the Holocene to improve our understanding of where megaquakes are possible. Available results suggest that much of the sediment deposited at active margins, has been resuspended by earthquakes and that at least some of the variability in the sedimentary features and spatial distribution derives from differences in the earthquake excitations. Recent observations have demonstrated a wide range of earthquake-related sedimentary signatures: e.g., large slumps and stacked turbidites in the trench near to the 2011 maximum deformation area; homogeneous deposits extending large distances across the abyssal plain of the Mediterranean; dense plumes of suspended sediment that persist for months after the earthquake forming meters thick deposits; and surficial remobilization of sediments for 100’s of km along the strike of both the Japan Trench and the Chile 1960 megathrust ruptures. The latter seems to be independent of slope suggesting entrainment by hi-amplitude, long period relative shear between water and sea floor expected to be especially significant from large-displacement ruptures of the outer megathrust. Generally, the complexity in both structure and sedimentary deposits provides opportunities for linking sediment characteristics with surface deformation. In this study we go beyond the interpretation of classical turbidites attempting to translate specific sedimentary signatures of event deposits into what is known about the earthquake coseismic motions, shaking and deformation.

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STORM DEPOSITS IN ESTUARINE VALLEYS: A CASE STUDY BASED ON FOSSIL CONCENTRATIONS

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Storm deposits are most underrepresented in estuaries. The typical thick, amalgamated sandstone beds with hummocky cross-stratification are not well preserved, possibly due to the prevalence of current action in these settings. The taphonomy of fossil concentrations, however, can be a useful tool to recognize these deposits. In this contribution, we discuss the origin for the shell deposits of the Rio Bonito Formation preserved in Cambaí Grande (the Rio Grande do Sul State, southernmost Brazil) based on the taphonomy of shell layers. The 20-m thick sedimentary succession is composed dominantly by fine-grained sandstones and heterolithic facies and mudstones, with the local occurrence of coarser deposits (sandstones and conglomerates). Low-angle trough-cross stratification, wavy bedding, hummocky cross-stratification, double mud drapes, reactivation surfaces, and intraclasts are the main sedimentary features in the fine-grained deposits, while higher-angle trough-cross stratification and mud drapes are frequent in the coarser deposits. The shell layers occur in the hummocky cross-stratified sandstones (Shcs) and the interbedded fine-grained sandstones (Sf) and heterolithic (Het) sedimentary facies, showing different depositional signatures. The primary taphonomic attributes of these shells (e.g., valve convexity direction, breakage level of shells, sorting size, the presence of bioerosion, and shell orientation) allowed recognizing three taphofaccies named Tf 1, Tf 2, and Tf 3. Tf 1 occurs in Het and Sf facies, being characterized by shells preserved in horizontal with the convexity upward, medium shells are dominant. Almost 50% of shells are whole and articulated shells are present. Tf 1 is interpreted as formed under low-hydrodynamic energy and low-sedimentation rate conditions, signaling a quiet environment. Tf 2 occurs in Shcs facies, being characterized by horizontally and obliquely-disposed shells preserved with the convexity upward, medium shells are dominant. Almost 60% of shells occurs fragmented; nested and bioeroded shells occur. A crowed *Rosselia* ichnofabric occurs in the beds capped by Tf 2. Tf 2 is interpreted as deposits influenced by surges. Tf 3 occurs in Het and Shcs facies and is characterized by a similar proportion of shells with convexity up- and downward, horizontally, obliquely, and vertically-oriented to the bedding plane. Small size are dominant, and whole shells and fragments occur in similar proportion. Articulated shells are present, but not bioeroded ones. Tf 3 signatures point to two distinct events, one representative of high-hydrodynamic energy and high-sedimentation rates, and the other of low- hydrodynamic energy and low-sedimentation rates. The analysis of the shell concentrations allowed infers that Tf 1 was formed under fair-weather conditions and Tf 2 during storm events. Tf 3 is assumed as a hiatal concentration, representing periods of starved sedimentation and action of winnowing process into the Cambaí Grande paleovalley.

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STORM-INDUCED TURBIDITY CURRENTS TRIGGERED IN THE ABSENCE OF SHELF SEDIMENT SUPPLY

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The monitoring of turbidity currents allows a better understanding of their behaviour and timing in relation to triggering events. The triggers of turbidity currents often remain hypothetical since very few studies have directly observed them. These triggers are nearly always inferred, even when monitoring is present. In this study, the Pointe-des-Monts submarine shelf canyons were monitored using Acoustic Doppler Current Profilers (ADCPs) and repeated high-resolution swath bathymetry mapping. Repeated mapping revealed that crescent-shaped bedforms, interpreted as cyclic steps, migrated upslope during the last 10 years, despite the absence of sediment on the shelf or river inflow in the region. During the winter of 2017, an intense turbidity current, with velocities reaching 2 m s^{-1}, was recorded and appears to be responsible for the migration of cyclic steps. This turbidity current was coincident with one of the greatest storm of the year that generated 3.8 m waves along the coastline of the region. The turbidity current temperature in combination with repeated seafloor mapping suggest that it was triggered at depths of > 100 m and that it is not attributed to a canyon-wall failure. Three other turbidity currents, albeit weaker, were also triggered during storms during the winter of 2016-2017. These results demonstrate that storms can possibly trigger turbidity currents at deeper water depths than the shelf, although the exact process by which sediments are put in suspension remains enigmatic.

THE BEHAVIOR OF RETREATING GLACIERS CONTROLS SEDIMENT DENSITY FLOW ACTIVITY IN HIGH-LATITUDE FJORDS

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Ice mass loss is driving important coastal morphodynamic changes in Arctic regions, from rapid coastal erosion to substantial prograding coastlines. Sediment supply delivered by rivers due to enhanced glacial erosion/ice mass loss has dramatic consequences on nearshore sedimentary environments and associated ecosystems. However, limited data exists in Arctic coasts on the influence of ice mass loss due to climate change in modifying the nearshore hydrodynamic of fjords. Here, we show how the behaviour of retreating glaciers and ice-mass loss influences the generation of density flows in eastern Baffin Island fjords, which has important consequences for bottom water renewal and nutrient and carbon fluxes to the marine environment. Through a detailed analysis of sediment waves formed by sediment density flows on 31 delta fronts mapped from 2003 to 2014 and by extracting their correlative glacio-hydrological drainage basin characteristics, we observed that the presence of glaciers controls the occurrence of density flows. However, lakes formed during glacial retreat, small or large, significantly alter the course of sediment routing to the deltas, leading to the interruption of density flow processes in fjords. Applying these results to 700 glacio-hydrological drainage basins of eastern Baffin Island allows us to predict the location of density flows presently occurring in fjords. These findings inform local communities and stakeholders on the locations where bottom-water renewal and organic carbon and nutrient transfer is more likely to occur, which has significant impacts on ecosystems. Our results greatly improve our understanding of modern density flows and fjord hydrodynamic in high-latitude coasts in response to retreating glacier behaviour in a warming climate.

ACCOMODATION, SEDIMENT SUPPLY, DELTAIC REGIME AND THEIR CONTROLS ON SAND DELIVERY TO DEEP WATER: INSIGHTS FROM QUANTITATIVE 3D SEISMIC STRATIGRAPHY (QSS)

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Stratigraphic models predict that accumulation of shelf-edge, slope and basinal sands occur when falling sea levels promote the accumulation of fluvio-deltaic strata directly at the shelf margin (i.e. “shelf-edge deltas”). However, recent studies show that the presence of a delta at the shelf edge does not necessarily result in a significant accumulation of reservoir-grade sands along slopes and basins. Other parameters including the processes redistributing sediments at the shelf edge seem to have a significant impact on the shelf-to-basin sediment transfer mechanisms [1,2]. Here we present a new approach for the analysis of shelf margin depositional systems combining full-volume 3D seismic interpretation with a dynamic stratigraphic approach (Paumard et al;. 2018). This Quantative 3D Seismic Stratigraphy (QSS) method was applied to map several hundreds of clinothems in a variety of physiographic, tectonic and climatic (icehouse/ greenshouse) settings. For each clinothem, the data collected links together (i) key shelf edge geometries (trajectory angle, progradation/aggradation ratio, slope gradient, differential sedimentation between topsets and bottomsets); (ii) paleo-shoreline processes and; (iii) the architecture of their coeval deep-water deposits (both determined through 3D seismic geomorphology). These data are used as an input for a statistical analysis of the genetic linkages between A/S conditions on the shelf, deltaic process regime and slope and basin depositional architecture. Results show that falling to flat shelf-edge trajectory types are associated with sediment bypass to the slopes, whereas rising shelf-edge trajectory types are linked with sediment storage on the shelf. Wave-dominated shelf edges are not associated with significant off-shelf transport of sands to the adjacent slope and basin, and they generally lack of basinward turbidite system. Both the degree of architectural organization (e.g., development of canyons, feeder channels, and deep-sea lobes) and the extent of the turbiditic deposits increase as the relative importance of fluvial processes increase along the shelf edge. These variations are observed both along strike (along a single clinoform) and through times. This study sheds new light on the relationships between shelf-margin stratal stacking patterns, shoreline processes and deep-water sand delivery, and constitute predictive tools for petroleum exploration.

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AN INTEGRATED PROCESS-BASED MODEL OF FLUTES AND TOOLS IN DEEP-MARINE SYSTEMS

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Flutes and tool marks are erosional sedimentary structures that are frequently observed on the base of beds in deep marine systems. However, their utility for interpreting rocks has largely been restricted to palaeocurrent information. In contrast, aggradational bedforms have been extensively used for obtaining information concerning processes during deposition in addition to palaeocurrents. In large part, the focus on palaeocurrent information from flutes and tool marks reflects our lack of understanding of their formative conditions. Here we develop an integrated model of flutes and tool mark formation, by linking geological observations, predominantly recorded from the 1950s-1970s, to the advances in knowledge of flow dynamics since these observations were made. In particular, there have been key advances in the past 20 years in the understanding of transitional flow and debris flow dynamics. We are able to explain for the first time the observed distribution of flutes and tools within deep-marine systems. We also show that grooves cannot be formed by turbidity currents as thought for the past 60+ years, but are instead the product of debris flows that hold tools firmly within the flow, enabling regular, continuous grooves to be formed in cohesive substrates. Some discontinuous tool marks such as bounce (skim) marks are shown to be the product of transitional flows. This work demonstrates that flutes and tools can be used to provide key information about the flow dynamics during formation, and enable improved prediction of sedimentary deposits both up- and down-stream. The work also holds major implications for the Bouma sequence and for hybrid event beds.

Organic geochemistry and rare earth element of Holocene hybrid event beds and debrite on the mid shelf of East China Sea: implications for provenance and origin

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Hybrid event beds and a debrite are identified in a core on the mid-shelf of East China Sea. Four units are divided according to abrupt boundary identification, with assistance of grain size analysis. The hybrid event beds typically comprise four internal divisions from the base to the top: (1) structureless muddy sand (H1a, high density turbidite); (2) massive muddy sand with mud clasts (H1b, higher density turbidite); (3) linked debrite (H3); (4) homogeneous mud (H5, fluid mud). The radiocarbon ages of the core were in the range of 3890–8526 yr BP. Based on correlation with other surrounding cores, the depositional age of hybrid event beds and the debrite may be less than 500 yr BP. The TOC and $\delta^{13}C$ values in event beds suggest a local erosional regime. The average $\delta^{13}C$ value for turbidite (H1a and H1b) is similar to the H3 division in the hybrid event beds, implying that the organic matter in the H1a, H1b and H3 may come from the same source area. The REE data reveals the sediment source is initially from Korean rivers. Bi-plots of $(La/Lu)_{UCC}$ vs. $(La/Y)_{UCC}$, $(La/Y)_{UCC}$ vs. $(Gd/Lu)_{UCC}$, $(La/Yb)_{UCC}$ vs. $(Gd/Yb)_{UCC}$ and $(La/Yb)_{UCC}$ vs. $(Sm/Nd)_{UCC}$ of four units in the core are concentrated in the similar range, indicating these event beds have the same source area. Both regimes that partial transformation from a debris flow and erosional bulking are suggested. It is unlikely that the debris flow is triggered by a hyperpycnal flow or a tsunami, because both can carry continental and/or coastal signals which have not been recognized in the core. Typhoon can be a probable triggering mechanism.

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THE DELTA EVOLUTION OF NEOGENE IN THE PEARL RIVER MOUTH BASIN, NORTHERN SOUTH CHINA SEA

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Abstract: Pearl river mouth basin is located in the southern margin of South China continent, northern South China Sea. The facies model of Neogene Zhujiang Formation in the Pearl river mouth basin has gamed increasing research attention and been intensively investigated by many researchers. Delta systems in Pearl river mouth basin respond to changes in the relative intensity of marine and the pearl river processes. As Pearl river delta progrades farther into the Pearl river mouth basin or retrogrades landwards, changing basin morphology can systematically modify marine processes. The capacity of Pearl river transportation may also change as the tectonic, climate, or topography of the source area. Succeeding delta lobes within a delta system will reflect such changes. The delta evolution of Neogene Zhujiang Formation in the Pearl river mouth basin, northern South China Sea can be divided into four stages: active delta, delta erosion and abandonment with offshore bars emergence, delta erosion and shoreline retreat, delta reoccupation, accompanying the emergence and die of the offshore bars. These offshore bars are located in the front of the delta frontal lobe, almost parallel to the coast and have a banding distribution along the northeast-southwest direction. Their boundary is usually irregular. Highstand System Tract, Transgression System Tract, Falling Stage System Tract and Lowstand System Tract can be identified during Neogene Zhujiang Formation in the Pearl river mouth basin, northern South China Sea. Different stages of the Pearl delta evolution corresponded to these system tracts.

Keywords: Northern South China Sea，Pearl River Mouth Basin，Neogene，Delta Evolution，System Tracts

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BOTTOM-CURRENT SEDIMENT WAVES AND MASS-MOVEMENT DEPOSITS ON THE SINES CONTOURITE DRIFT, SW IBERIA

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Large-scale sediment waves and mass movement deposits have been recently discovered, based on multichannel seismic reflection data, associated to the Sines Contourite Drift, on the middle continental slope along the Southwest Portuguese Margin. The sedimentary waves expand over 30 km^2 between 750 m and 1850 m water depth, having sigmoid shapes with wavelengths from 500 to 2150 m, wave heights between 40 and 63 m and wave crests subparallel to the bathymetric contours. A basal discontinuity marks the onset of sediment wave development and upslope migration towards east since the Early Quaternary (2.5 Ma ago). In addition, numerous mass-movement deposits are seen mostly concentrated in the west of the Sines Drift, associated with the steep Pereira de Sousa Scarp. The mass-movements are characterized by amphitheater shapes, head scarps and occur staggered till the slope, accumulating at the base as thick deposits.

The morphology and location of the sedimentary waves suggests a close relation to the circulation of the Mediterranean Outflow Water (MOW). This water mass exits the Strait of Gibraltar and flows northward along the continental slope, due to the Coriolis Force. Climatic-eustatic fluctuations in the Quaternary caused several enhancements and deepening of the Mediterranean Outflow Water and, subsequently, interaction with the seafloor. With this work we propose that the dynamics between the MOW and the continental slope is responsible for generating the sediment waves, but also the presence and morphology of these waves encouraged the development of mass-movement deposits, especially when the setting corresponds to an unstable and oversteepening continental slope. This research is a good example of the interaction between along- and across-slope processes and it could be useful for a better understanding of the implications of bottom currents in controlling the continental margin morphology.

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SEDIMENT TRANSPORT PROCESSES IN A MOUNTAINOUS RIVER SUBAQUEOUS DELTA AND ITS RESPONSE TO HUMAN ACTIVITIES

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Deltaic depositional system is a key object in the research plan of the Land-Ocean Interaction in the Coastal Zone, where the sedimentary record plays an important role to reflect the delta evolution and human activities in the river catchment[1,2]. However, studies for deltaic formation processes and their controlled mechanisms are still unrevealed. In small mountainous river estuarine environments, the subaqueous deltaic depositional system is very sensitive to the environmental change and human activities within the river catchment and coastal sea[3,4], so their variations and processes could be recorded in the system. Therefore, we select the subaqueous deltaic system in the Minjiang River Delta as the study area, which is a mountainous river along southeast China coast. Based upon *in situ* investigated data, such as hydrodynamic observation, samples collection (including suspended matter, settling particles, surface sediment and sediment cores) and remote sensing data at the Minjiang Estuary and adjacent shelf area, the sediment transport processes of terrestrial substances discharged from Minjiang River and their fate are discussed in this paper. When the terrestrial substances enter into the estuary, they are stored during summer and transported offshore during winter. In spring and summer, amount of suspended sediment is blocked into the area near the estuary when it discharges into the sea under the effect of southwest monsoon; during the autumn and winter, the stored sediment is resuspended and transported southward under the effect of strong hydrodynamic process induced by northeast monsoon. Generally, the suspended sediment can be transported southward to the south Pingtan Island area located at the northwest Taiwan Strait during the winter. However, under the effect of continuous strong cold air mass, the suspended sediment discharged from Minjiang River can reach middle area of Taiwan Strait southward. The sedimentation rate within Minjiang River subaqueous delta was decreased since 1986 because of the dam construction in the river catchment which reduced the sediment flux discharged by the river.

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RECOGNITION OF TURBIDITE FACIES FROM SANDY HIGH-DENSITY TURBIDITY CURRENTS IN THE LATE PERMIAN NORTH CHINA CRATON, NORTHEASTERN CHINA

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Abstract: Turbidite bedforms were recognized for the first time in the Late Permian upper Shihezi Member in North China Craton. The upper Shihezi Member was formed in a shallow marine environment affected by explosive volcanic eruptions, and sandy high-density turbidity current deposits are well developed following the eruptions. Each set of turbidite sequences is generally more than 20 m thick and consists of a slightly inversely graded at the base and structureless lower beds (similar to Cartigny Type Ⅲ layer), a well stratified and overall normally graded middle beds (Cartigny Type Ⅱ a&b layer), and a planar laminated, fine grain-sized upper beds (similar to Postma Tb2 layer). An interface is common between the lower and middle beds with a layer of floating outsized clasts on the top of lower bed deposits due to kinetic sieving. The middle beds result from high-density current deposits alternating patterns of crude stratification and spaced stratification in centimeter scale (<20 cm thick). The upper parts are generally thinner (<5 cm thick) and comprise pyroclasts, cryptocrystalline tuffs and abundant magmatic zircon, which suggests intermittent periods of volcanic eruptions and volcaniclastic sedimentation along with periods of traction carpet deposits. These three turbidite facies, showing an overall finning-upward and tuff increasing upward trend, correspond to three evolutionary stages of volcanic eruption including pre-, syn- and post-eruptive events. In the initial stage, terrestrial debris flow along the shoreline trigged by pre-eruption evolved into sediment-laden floods with high density to plunge into the shallow marine. This provide necessary conditions for the occurrence of the high-density turbidity flows during the syn-eruptive stage, where large amount of tuff deposits were engaged in transport processes as suspended materials. In the post-eruptive stage, flows were less dense and similar to low concentration flows due to weakened volcanic activities. Therefore the North China Craton was still a marine environment with turbidity developed in the Late Permian; also a volcanic eruption cycle can be described by recognizing the circular changes in turbidite facies.

Key words: turbidite facies, high-density turbidity current, traction carpet, volcanic eruptions, North China Craton, Late Permian

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Variations of deep current intensities in the northeast South China Sea since the last glacial maximum

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Grain-size analyses were performed on fine marine sediments (<63 μm) from Core MD05-2905 in the northeast South China Sea to understand changes in the velocity of deep-sea currents since the last glacial maximum. The sortable silt (SS, 10–63 μm), which reflects changes in the intensities of deep-sea currents [1], shows an obvious three-step evolution since ~29 ka. High proportions of SS (30% to 37%, in average ~34%), with a mean grain size of 21–26 μm (in average ~23 μm), are found during ~29–19 ka. The SS proportions decrease sharply during ~19–10 ka, from ~35% to ~10%, accompanied by a decrease of mean SS size from 24 μm to 15 μm. The Holocene period is characterized by both low percentage (10–15%) and fine mean grain size (21–26 μm) of SS. Using the empirical calibration equation developed by McCave et al [2], we obtain the changes of deep currents intensities since ~29 ka. In the last glacial maximum (~29–19 ka), velocity of deep-sea currents in the northeast South China Sea varies in the range of 7–12 cm/s, around 3–12 times that of the present-day values[3]. The velocity of deep-sea currents decreases sharply from ~12 cm/s to ~3 cm/s during the Heinrich 1 Event. The Holocene is featured by relative low current speed of 0–4 cm/s. The sharp decrease of deep current velocity observed herein is probably linked to the drastic decrease of North Pacific Deep Water input to the South China Sea, owing to the cease of deep water formation (>2100 m) in the northwest Pacific during the Heinrich I Event [4]. Only intermediate water (700–1750 m) is formed in the northwest Pacific after the Heinrich I Event and under the modern conditions [4]. It explains the low velocity of deep currents in the northeast South China Sea during the Holocene.

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THREE-DIMENSIONAL CHARACTERIZATION OF LONG-LIVED, LARGE-SCALE SUPERCRITICAL BEDFORMS FROM A PRESERVED SUPERCRITICAL FAN OF THE EARLY GULF OF CALIFORNIA

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Study of seafloor bathymetry, numerical and physical modeling, and direct observation of turbidity currents increasingly suggests that sediment gravity flows over moderately steep basin slopes commonly reach Froude supercritical states. However, stratigraphic qualities of supercritical deposits are incompletely understood. This work analyzes seismic-scale outcrop exposures in the Fish Creek-Vallecito Basin deposited along the steep margins of the early Gulf of California in south-central California. The result is a detailed three-dimensional (3D) characterization of an evolving supercritical fan, which is used to describe the architecture of supercritical bedforms and spatiotemporal evolution of the deposits as well as provide first order constraints on the depositing flow conditions.

The 100+ m-thick, strongly aggradational slope deposits of the Late Miocene (~6.3-5.3 Ma) Lycium Member do not fit well into classical models of deepwater depositional environments and architectures. Field data are combined with photogrammetry to characterize the deposits in 3D. Stacks of 10s of turbidite sandstone beds with intercalated fines, all accreting opposite to paleoflow indicators, build bedsets with tabular dip geometries and lensoidal to lobate strike geometries that compensationally overlap into broader tabular units. These depositional characteristics are linked to supercritical bedforms, and the bedforms are linked to flow conditions indicating successive Froude supercritical sediment gravity flow events in the lower slope of a steep, narrow, and relatively shallow deepwater margin. Lateral and vertical trends in bedform type, geometry, and facies point to systematic trends in flow confinement and energy depicting spatiotemporal evolution of a prograding supercritical fan filling antecedent topography of a young, actively subsiding rift basin.

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RICH ORGANIC MATTER ACCUMULATION OF DOMANIK SHALE OIL FROM THE POINT OF SEDIMENTARY EVOLUTION

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Domanik oil and gas deposits in Russian have been studied since they had been named in the year of 1843, for centuries in the whole Eastern European (Russian) platform different researchers has made different conclusions about its sedimentary environments, tectonic, hydrogeology and paleotemperature changes. By common conditions of sedimentation, mineral content and quantitative percentage we consider "Domanik facies" or "Domanik formation" as bituminous siliceous-clay-carbonate deposits in the Paleozoic Erathem from Upper Devonian (Russian stage - D_3fr_2) to Lower Carboniferous system (Tournaisian stage - C_1t) in the Volga-Urals and Timan-Pecher oil and gas provinces. In this paper we use geological and geophysical data such as core analysis, drilling materials, well logging curves etc., analysis the paleogeographic sedimentary evolution of Domanik facies in the southeastern Volgo-Ural basin.

Domanik formation in southeastern Volgo-Ural basin covers the period of Frasnian-Tournaisian lithologic-stratigraphic system, which was formed in uncompensated hollows and depressions from the beginning Semiluksky to early Tournaisian time. In silty basin Domanik (Semiluksky) formation is dominated by carbonate sediments of Domanik facies: dark siliceous-clayey-bituminous limestones with typical complex fauna. Higher in the cross section, Domanik facies are reduced as narrowing axial parts of the Kamsko-Kinel deflections, meanwhile it is developed weakly bituminous and unbituminous carbonate rocks closer to the inner sides.

In carbonate sedimentary environments when bioherm buildings which grew on the slope shelf developed to a certain scale, these sedimentary deposits began to subsided; at the same time the central basin sediments began to go up as the reason of basin disequilibrium compaction, then in intrabasin where low-amplitude uplifts did not reach the storm level of tidal wave could be the potential area of Domanik facies as its concentrated fracture zones, maximum thickness, high concentration of organic matter and abnormal high depressure. From this point of view small-scale uplift at the bottom of a deep-sea shelf could be the favorable areas for later exploration and development in low porosity and low permeability Domanik reservoirs.

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SEASONAL VARIATIONS OF SILICICLASITIC FLUX AND FORAMINIFERAL EPSILON ND VALUE IN THE WESTERN PHILIPPINE SEA: APPLICATIONS FOR SEDIMENT TRANSPORT AND OCEAN CIRCULATION

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Sr and Nd isotopic compositions of siliciclastic sediments and Nd isotopic compositions of planktonic foraminifera have been investigated on samples collected during 2015 with a mooring system equipped with sediment traps, Recording Current Meters, and Conductivity-Temperature-Depth sensors at 500 m and 2800 m water depths to: 1 track seasonal changes of sources and transport pattern of siliciclastic sediments to the Benham Rise; 2 constrain planktonic foraminiferal Nd isotopic compositions along the water column; 3 assess influence of lithogenic inputs on Nd isotopic compositions of water masses in the western Philippine Sea. $^{87}Sr/^{86}Sr$ ratios and ε_{Nd} values of sediment samples indicate decreasing inputs of Luzon volcanic and eolian dust to the Philippine Sea in spring, winter, as well as summer and autumn. These characteristics are mainly controlled by precipitation on eastern Luzon and the East Asian winter monsoon intensity coupled to the 2015/2016 super El Niño event. In addition, we have estimated from these results that modern eolian dust transported to the Benham Rise derives mainly from the Ordos Desert (>80%) and in lesser extent from the Taklimakan Desert (<20%). ε_{Nd} values of planktonic foraminifera collected at 500 m water depth do not change significantly during the year (-3.4 to -3.0), suggesting a negligible contribution of lithogenic Nd inputs from eolian dust (-10.6 to -11.3) and Luzon volcanic (+7.1 to +5.8). On the contrary, ε_{Nd} values of planktonic foraminifera collected at 2800 m water depth are systematically more radiogenic (-0.9 to -1.9) and display seasonal variations with the highest value during winter. Such results suggest a rapid modification of ε_{Nd} values during the settling of planktonic foraminifera in the water column by precipitation of Fe-Mn coatings. We have proposed that the seasonal variability of the ε_{Nd} values observed at 2800 m water depth could be attributed to a modification of deep-sea circulation as recorded by the mooring system with a higher contribution of colder water masses from the volcanic Luzon margin during winter time.

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DEPOSITIONAL CHARACTERISTICS AND ACCUMULATION MODEL OF GAS HYDRATES IN NORTHERN SOUTH CHINA SEA

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The South China Sea (SCS) shows favorable conditions for gas hydrate accumulation and exploration prospects. Bottom simulating reflectors (BSRs) are widely distributed in the SCS. Using seismic and sequence stratigraphy, the spatial distribution of BSRs has been determined in three sequences deposited since the Late Miocene. The features of gas hydrate accumulations in northern SCS were systematically analyzed by an integrated analysis of gas source conditions, migration pathways, heat flow values, occurrence characteristics, and depositional conditions (including depositional facies, rates of deposition, sand content, and lithological features) as well as some depositional bodies (structural slopes, slump blocks, and sediment waves). This research shows that particular geological controls are important for the presence of BSRs in the SCS, not so much the basic thermodynamic controls such as temperature, pressure and a gas source. Based on this, a typical depositional accumulation model has been established. This model summarizes the distribution of each depositional system in the continental shelf, continental slope, and continental rise, and also shows the typical elements of gas hydrate accumulations. BSRs appear to commonly occur more in slope-break zones, deep-water gravity flows, and contourites. The gas hydrate-bearing sediments in the Shenhu drilling area mostly contain silt or clay, with a silt content of about 70%. In the continental shelf, BSRs are laterally continuous, and the key to gas hydrate formation and accumulation lies in gas transportation and migration conditions. In the continental slope, a majority of the BSRs are associated with zones of steep and rough relief with long-term alternation of uplift and subsidence. Rapid sediment unloading can provide a favorable sedimentary reservoir for gas hydrates. In the continental rise, BSRs occur in the sediments of submarine fans, turbidity currents.

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TYPES OF HYPERPYCNAL FLOWS AND RELATED DEPOSITS IN LACUSTRINE AND MARINE BASINS

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A hyperpycnal flow forms when a land derived dense flow enters a marine or lacustrine water reservoir. As a consequence of its excess in density, the flow plunges in coastal areas generating a highly dynamic and often long lived dense underflow. Depending on the characteristics of the parent flow (flow duration and flow type) and basin salinity the resulting deposits (hyperpycnites) can be very variable.

According to flow duration, hyperpycnal flows can be classified into short lived (SLHF) or long lived (LLHF) hyperpycnal flows. SLHF lasts for minutes or hours, and are mostly related to small mountainous river discharges, alluvial fans, collapse of natural dams, landslides, volcanic eruptions, jökulhlaups, etc. LLHF last for days, weeks or even months, and are mostly associated to medium to large size river discharges.

Concerning the characteristics of the incoming flow, hyperpycnal flows can be initiated by non-Newtonian (cohesive debris flows), Newtonian supercritical (lahars, hyperconcentrated flows, and concentrated flows) or Newtonian subcritical flows (bedload, sandy or muddy dominated fully turbulent flows). Once plunged, non-Newtonian and Newtonian supercritical flows require steep slopes to accelerate, allow the incorporation of ambient water and develop flow transformations to evolve into a turbidity current and travel farter basinward. Their resulting deposits are difficult to differentiate from those related to intrabasinal turbidites. On the contrary, Newtonian subcritical hyperpycnal flows (NSHF) are capable of transfer huge volumes of sediment, freshwater and organic matter far from the coast with gentle or flat slopes. In marine settings, the buoyant effect of interstitial freshwater in bedload and sandy hyperpycnal flows can result in lofting due to density reversal. Since the excess of density in muddy hyperpycnal flows is provided by silt-clay sediments in turbulent suspension, lofting is not possible even in marine basins. NSHF can also erode the basin bottom during its travel basinward, allowing the incorporation and transfer of intrabasinal organic matter and sediments. Long lived NSHF deposits exhibit typical characteristics that allow a clear differentiation respect to those related to intrabasinal turbidites. Main features include (1) complex beds with gradual and recurrent changes in sediment grain size and sedimentary structures, (2) mixture of extrabasinal & intrabasinal components, (3) internal and discontinuous erosional surfaces and (4) lofting rhythmites in marine settings.

SEDIMENTOLOGICAL SIGNATURES OF PALEOGENE IN LISHUI SAG, EAST CHINA SEA SHELF BASIN

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Abstract: The East China Sea Shelf Basin (ECSSB) is a typical back-arc rift basin and is divided further by a series of sags and basement ridges. The Lishui Sag is on the southwest margin of the ECSSB. Analysis of Sedimentological signatures is based on the study of 712 feet of Paleogene cores derived from seven wells displaying a wide variety of lithofacies, sedimentary structures and ichnological data in combination with 2D and 3D seismic data of 5000km^2 area and well logging curves of 18 exploratory wells in the Lishui-Jiaojiang Field. Thirteen facies are defined and grouped into three categories (wave-influenced delta, fan delta and basin facies). Wave-dominated deltaic deposits occur mostly in the west of Lishui sag. Fluvial discharge in the delta front and prodelta was repeatedly reworked by wave and formed some isolated bars, it was similar to the Senegal river delta model. These deposits are unbioturbated to sparsely bioturbated and contain some ichnotaxa that typically do not occur in brackish water. Fan deltaic deposits are present in the southwest and northeast of Lishui sag. It is divided further into fan delta front and distal fan delta. The subaqueous fan delta front includes distributary channels and wave-influenced interdistributary bays. Further seaward, successions are characterized by terminal distributary-channel and sand sheet deposits. These deposits are the intensely bioturbated. Basin facies not only record high-energy wave ravinement and transition to deeper-water deposits with highly variable bioturbation but also record low-energy, suspension sediment fall-out deposition in the absence of waves and currents, bioturbation is typically absent. From sedimentological signatures perspective, four main depositional settings are identified: wave-dominated delta, fan delta front, distal fan delta and basin facies. Thirteen facies are defined further: foreshore, upper shoreface, wave-dominated lower to middle shoreface, weakly wave-affected middle to lower shoreface, offshore transition, upper offshore, lower offshore, wave-dominated proximal delta front, wave-dominated distal delta front, storm-influenced proximal prodelta, storm-influenced distal prodelta, transgressive deposits and shelf facies.

Keywords: Lishui Sag, Paleogene, Sedimentological Signatures, Depositional settings

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THE FATE OF FABRICS AND STABLE ISOTOPES DURING EARLY DIAGENESIS OF NON-MARINE SPRING CARBONATES

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Non-marine carbonate rocks are susceptible to a variety of early diagenetic processes that are not always easily recognized, but can profoundly affect the carbonate fabric and paleoclimatic proxies. The ability to study at increasingly smaller scales has shown that diagenesis takes place from the moment initial precipitates have formed and typically starts in nano- and micro-environments. If early diagenetic modifications are completed in a short time span compared to the (annual to millennial) time scale of interest, then recorded paleoenvironmental signals and trends could still acceptably reflect depositional conditions. The intermediate steps in early diagenetic microfabric modification and impact on bulk and high-resolution stable carbon and oxygen isotopic signatures was investigated in this project. The study shows a case of progressive diagenesis as recorded in a continuous core within the still active carbonaceous hot spring system of Mammoth Hot Springs (Yellowstone National Park, USA) and in quarry outcrops surrounding the park. They cover a range of Holocene to Pleistocene spring carbonate deposits.
Low- to high-resolution petrographic observations shows how short episodes (days, weeks) of flow or water chemistry changes can already kick off neomorphic replacement processes before precipitation retakes again. The overall result neomorphism and cementation is a tendency for erasing and homogenizing initial, fine and delicate aragonite needle textures that built elongated or radial shrubs, formed stacked laminae or that encrusted microbial filaments. Stable carbon and oxygen isotope results, both bulk analyses and spot or detailed cement transect analyses using micro-SIMS (University of Lausanne, SWISS-SIMS), indicate that the fluids responsible have been isotopically similar to the hot spring fluids today. The persistence of the overall positive carbon-oxygen isotope correlation, similar to that known from the active spring deposits, could suggest preservation of pristine signatures, but detail analysis shows that any down- to upstream trend reflecting temperature evolution and CO_2 degassing, is lost during neomorphism. More pristine signatures and trends can occasionally still be recorded when examining the neomorphosed aragonite – now calcite – core of crystals.
Early diagenesis in the Y-10 core is mostly constructive and resulted in pervasive, aggrading neomorphism and circumgranular or pore-filling cements. Neomorphism however also created isolated microporosity within $CaCO_3$ crystals where aragonite needles were micritized and became replaced by calcite. Ongoing open flume, experimental approaches under constrained conditions in the lab help to investigate and quantify this sequence of diagenetic products and rates, bridging the gap between nanoscale lab studies and the fossil field rock record.

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Bio-Precipitation of Ca^{2+} and Mg^{2+} Ions Induced by *Bacillus licheniformis* SRB2: the Biomineralization Mechanism and the Role of Biomolecules

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Carbonate biomineralization induced by microbe is a hot spot in the sedimentology field. To further understand the mechanism, a newly isolated *Bacillus licheniformis* SRB2 bacterium (GenBank: KM884945.1) identified by 16S rDNA analysis was used to induce the biomineralization of Ca^{2+} and Mg^{2+} ions at different Mg/Ca molar ratios. SRB2 had a precipitation efficiency of 98% for Ca^{2+} ions and 50% for Mg^{2+} ions, respectively. The medium conductivity decreased sharply. The kinetic model was conducted and the precipitation rates (min^{-1}) of Ca^{2+} and Mg^{2+} were much higher in the experimental groups. Calcite, vaterite, monohydrocalcite, and nesquehonite crystals were formed and some minerals had preferred orientation. The minerals were spherical, dumbbell-shaped, peanut-shaped and long-columnar. The bacterial ultrathin section showed that amorphous minerals containing Ca and Mg elements were formed inside the cell. Carbonic anhydrase increased the carbonate and bicarbonate concentration in the alkaline condition due to the ammonia produced by SRB2 bacteria. Thus, favorable conditions were provided for the biomineralization of carbonate minerals. This resulted in $\delta^{13}C$ of the minerals in experimental group (~-17‰) were more negative than control groups (~-8‰). The carboxyl and phosphate groups produced by microorganisms were incorporated into the minerals distinctly. Glutamate and aspartic acid were the two most abundant amino acids of the extracellular polymeric substance of SRB2, which had a large amount of free carboxyl groups and then were beneficial to the adsorption of Ca^{2+} and Mg^{2+} ions in the alkaline solution. More importantly, the isoelectric points of other amino acids except Lys and Arg were lower than the pH of the liquid culture medium, indicating that they all exhibited negative electricity and also greatly promoted the adsorption of Ca^{2+} and Mg^{2+} ions. Fluorescence intensity analyses proved that Ca^{2+} ions were indeed adsorbed in EPS and then entered the cell, and the fluorescence intensity of Ca^{2+} ions decreases with the increase of Mg^{2+} concentration. In our opinion, the metabolites such as the ammonia, carbonate, and bicarbonate ions and the biomolecules such as carbonic anhydrase and amino acids produced by SRB2 bacterium played an important role in the biomineralization of Ca^{2+} and Mg^{2+} ions. This study helps to understand the formation mechanism of the microbial carbonate minerals in laboratory and in nature.

Keywords biomineralization · *Bacillus lichemiformis*· carbonate minerals · carbonic anhydrase · amino acids·

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THE NON-SKELETAL CARBONATES OF THE CRETACEOUS 'PRE-SALT' LAKES: WHEN SEDIMENTOLOGY MEETS CRYSTAL ENGINEERING

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The Cretaceous 'Presalt' lakes of the South Atlantic margins (Brazil and Angola) display an unusual co-occurrence of chemical precipitates typically accumulated in extensive freshwater and hyper-alkaline volcanic environments, i.e. spherulitic calcite, dolomite, Mg-rich smectites and silica. The origin and distribution of these mineral assemblages is still hotly debated and has brought geoscientists to dig out an infinity of outcrop analogues in pursuit of basic insights. Only few locations in the lacustrine fossil record seem to have satisfied the conditions to trigger the authigenic nucleation of these mineral paragenesis and/or allowing the growth of distinctive carbonate textures (polycrystalline, fibro-radial spherules to upward bifurcating, dense radiating 'shrubs'). Although these rocks are known to host significant hydrocarbon reserves and ore deposits, understanding the mechanisms of their formation goes well beyond the 'Presalt' economic interests; they represent a scientific challenge that might require the re-examination of our phenomenological models and the conventional petrographical, geochemical and sedimentological approaches we use to construct them.

While relating process sedimentology with siliciclastic bedforms has traditionally relied on the link between water energy, grain size and accommodation space, linking environmental parameters with nucleation and growth of non-skeletal carbonate fabrics remains a fundamental challenge. This is because precipitate morphology results from the complex interaction between different physico-chemical parameters which often act simultaneously or sequentially (e.g., carbonate supersaturation, Mg/Ca ratio of the solution, presence of organic and inorganic additives, impact of metabolism, substrate mineralogy, etc). To provide context on the diversity of crystal taxonomies precipitated in aquatic environments either experimental, conceptual and numerical modelling methods are required. Building new advances from the materials science community can pave the way to better predict the specific 'driving forces' guiding the nucleation and growth of single crystal morphologies (driven by kinetics) and polycrystal architectures (driven by diffusion) commonly observed in carbonate-precipitating alkaline systems.

Experimental studies are contributing to understand the effects that solution chemistry and biomolecules have stimulating or impeding the growth of fibro-radial carbonates. Collectively, chemical engineering approaches are transforming our sedimentological view of how to address the origin of the 'Presalt' carbonate textures; also shedding light on the chemical interactions in alkaline, saline solutions: competing influences for $CaCO_3$ polymorph formation, nucleation of precursor phases, or mineral co-precipitation pathways.

The complexity to build accurate depositional models in systems dominated by non-enzymatic carbonate-clay-silica factories reflects the pressing need to address the chemistry of sediment morphogenesis from a more critical process-product perspective. This new generation of multidisciplinary techniques and methods can embody a game-changing opportunity for the environmental understanding of carbonate textures grown in a diversity of sedimentary environments on Earth and beyond.

THE APPLICABILITY OF TAPHONOMIC BIAS IN LIMESTONES AND MARLS FOR ASSESSING DIAGENETIC LOSS

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Limestone-marl alternations are often assumed to represent cyclic changes in the depositional environment and employed to reconstruct Milankovitch cycles[1]. They are also used e.g., for reconstructing paleoenvironmental conditions and as biodiversity archives[1]. Although they are of great importance in multifarious geoscientific questions, their genesis is not yet unequivocally understood[3,4,5]. So far, it is accepted that a redistribution of calcium carbonate took place, but the driving mechanisms of this redistribution are still a matter of discussion. It is also not clear if a purely diagenetic origin of the rhythm is possible or not, and which potential witnesses of changes in the depositional environment are reliable[6]. The two main models explaining the genesis of limestone-marl alternations are (1) the model of late diagenetic pressure-induced calcite dissolution and reprecipitation[7], and (2) the model of early diagenetic aragonite dissolution and reprecipitation as calcite[8]. We test hypotheses on different fossil content, composition, and orientation predicted under these two models. Our samples come from the Kungurian Chihsia Formation in South China, from the Ludfordian Varnytsya Formation in the Ukraine, and from the Telychian Lower Visby Formation from Gotland. First, the relative abundance of primarily aragonitic and calcitic components in the fossil assemblages is evaluated. Second, the orientation of components is analyzed. The results allow us to reject the first model (late diagenetic calcite dissolution and reprecipitation) in favor of early diagenetic aragonite dissolution and re-precipitation as calcite being the driving mechanism for generating a limestone-marl alternation. It is shown for both primary differences in the sedimentary input (Varnytsya Formation) and a homogenized precursor sediment (Chihsia Formation). Furthermore, taphonomic bias can be used to assess aragonite bias and to gauge primary conditions during sedimentation.

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DIAGENETIC SUSCEPTIBILITY OF BIOGENIC CARBONATE ARCHIVES

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The analysis of carbonate archives is widely used, and can provide substantial information on past depositional (and diagenetic) regimes. To better comprehend the archive in question, we must understand not only the material's susceptibility to alteration, but the drivers and mechanisms of alteration, the extent of diagenesis, and how it's evidenced in either textural or geochemical proxies. This study uses an experimental approach to hydrothermally alter various biogenic carbonates at known temperatures, durations, and water chemistries. Within autoclave chambers, samples are placed in either meteoric or brine fluids, at temperatures from 100-200°C. Results are then directly compared to unaltered aliquots from the same-specimen, allowing for reduced heterogeneity, as well as a quantitative approach to determine the controls and extent of diagenesis. Results indicate little to no directly visible alteration at the lower temperature experiments (100°C), and almost complete alteration observed at higher temperatures (175-200°C). Intermediate temperature ranges (130-160°C) allow the evaluation of partial recrystallization of the bivalve *A. islandica*, helping to indicate diagenetic controls, and well as changes to various proxy data. Results indicate that the diagenetic pathway preferentially follows inherent organic distribution, and internal structures within the organo-minerals, suggesting preferential movement of intercrystalline organics, which appear to be pushed away from the diagenetic front, causing concentration of the water insoluble organics, and a darkening surrounding fluid pathways. Geochemical analyses document the transformation process from pristine Aragonite to secondary carbonate minerals, along with depleted $\delta^{18}O$ values, lower $\Delta 47$ values (higher T), and removal of Sr^{2+} and S^{2-} in the recrystallized carbonate. A possible second phase of alteration is also seen within the altered portions, which coincides with more negative $\delta^{18}O$ values. This may indicate a greater role of intercrystalline liquids in the initial phase of alteration which are characterized but smaller isotopic shifts. These results have implications for the stabilization and diagenetic susceptibility of biogenic carbonates in the geologic record, and can be used to systematically track the alteration process using known diagenetic regimes.

INTERRACTION OF TUFA EPS, SALINITY AND TEMPERATURE ON CALCITE TRACE ELEMENT INCORPORATION

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Microbial biofilms are known to influence calcite morphology, precipitation rate and trace element ratios [1]. However, uncertainties remain about the relative roles of metabolic processes and extracellular polymeric substances (EPS). Without differentiating these roles, the "black box" of biofilm mineralization processes cannot be opened. These substances have been shown to chelate cations such as calcium and magnesium from solution in a chemoselective manner, thus influencing both the saturation state and trace element composition of the bulk water [2]. The experiments we will describe show that in the temperature range of 12 – 18 °C, the presence of EPS in the absence of living cells does influence $(Mg/Ca)_{calcite}$ values obtained from precipitates. Trace element incorporation is correlated with temperature in a manner which agrees with thermodynamic expectations, providing a stark contrast to incorporation into living biofilms, which do not show this relationship [3].

The presence of other ions, such as Na^+, may impact on the chelation dynamics of cations such as Ca^{2+} and Mg^{2+} with a consequential impact on the trace element ratios of precipitated calcite. Salinity variations in the presence of EPS but without living cells causes in $(Mg/Ca)_{calcite}$ to increase by about 3 % per ppm increase in NaCl salinity, whereas no correlation existed when EPS was absent from the solution. Experiments where EPS concentrations were varied show that $(Mg/Ca)_{calcite}$ increases linearly in freshwater solutions with increasing EPS levels, whilst precipitation rates decreased linearly with increasing EPS levels.

These results suggest that it is the metabolic processes of biofilms that cause the breakdown of the thermodynamic control on $(Mg/Ca)_{calcite}$ in freshwater carbonates and not the presence of EPS. Equally, it reveals a complex interaction between the inorganic and organic geochemistry of site water and precipitate geochemistry which will impact studies of tufa, travertine and speleothem geochemistry.

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ANALYSIS FOR GEOLOGICAL CONDITIONS OF THE TRANSFORMATION FROM ARAGONITE TO CALCITE IN THE PALEOGENE SHALE OF JIYANG DEPRESSION, CHINA

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In general, aragonite exists as a metastable carbonate mineral under near-surface conditions, and is often transformed into calcite under subsurface and during diagenesis. It is thus seldom found in sedimentary rocks. However, Aragonite is a common mineral in Palaeogene lacustrine shales of Jiyang Depression in eastern China, and belonged to chemical origin. Dissolution experiments were conducted on the Palaeogene aragonite-enriched and calcite-enriched shales under the conditions of different temperature, pressure, acetic acid concentration, and solution types. The results showed that aragonite was insoluble in the in-situ formation water, but dissolved more easily under acetic acid conditions compared to calcite. The dissolution increased with increasing temperature, pressure, and acetic acid concentrations. It is believed that the change of aragonite content in Palaeogene shales of Jiyang depression is well corresponding to the thermal evolution stages of source rocks. When the burial depth less than 2300m, aragonite is relatively stable and could not be dissolved by the connate pore water in the shales. As the burial depth reaches 2300m, the source rocks are becoming mature, resulting in the organic acid starts to be generated and the metastable aragonite began to be dissolved. When the buried depth is about 3000m, the source rocks turns into the peak of hydrocarbon-generating stage, and the rate of aragonite dissolution also reaches the maximum. Over 3500m, the aragonite in the shale is almost dissolved. As the organic matter becomes over mature and the generation of organic acid gradually ceases, the pore water is changed from acid to alkaline, then the calcite that more stable than aragonite is re-crystallized.

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Calcite Precipitation Induced by *Bacillus cereus* MRR2 Cultured at Different Ca^{2+} Concentrations: Further Insights into Biogenic and Abiogenic Calcites

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Although abundant literatures have specifically reported about calcite formations induced by the *Bacillus*, the biomineralization mechanism and the unique characteristics of bio-calcites need to be further investigated. Here, the calcites were induced by microorganism *Bacillus cereus* MRR2 (Genbank KY810857), meanwhile the control groups without inoculation of *B. cereus* MRR2 were parallelly investigated. The results indicated that carbonic anhydrase promoted the carbon dioxide hydration reaction to release HCO_3^- and CO_3^{2-} in the process of calcites precipitation, and the ammonia released by *B. cereus* MRR2 and HCO_3^- and CO_3^{2-} originated from CA reaction caused the pH to rise from 7.5 to 8.7 or more. Aspartic acid and glutamic acid of the extracellular polymeric substance were the most two abundant amino acids. In an alkaline environment their free carboxyl groups had a large number of negative charges to facilitate the adsorption of calcium ions. What's more, the minerals induced by *B. cereus* MRR2 at different Ca^{2+} concentrations were calcites with different morphologies and element compositions, and intracellular minerals without crystal structures were also found. The stable carbon isotope analysis showed that $\delta^{13}C$ of bio-calcites (-20.9 ‰) was more negative than that of control group(-15.6‰) and chemical calcite(-11.7‰), indicating that microbial activity strongly affected carbon isotope composition of biogenic calcites. More importantly, it was also found that the crystalline degree and activation energy of the calcites in the experimental groups were obviously higher than those in the control groups. That was to say, the thermal stability of bio-calcites were obviously higher. Thus, this study can provide important further insights into understanding the mechanism of microbial biomineralization and bio-calcites formation causes, in particular, the roles of environmental microbes played in the minerals nucleation and growth, as well as the unique characteristics of resultant minerals. In summary, this information could provide effective evidences for further recognizing the origins of microbial calcites in geological record.

Keywords biomineralization, *Bacillus cereus*, bio-calcite, crystalline degree, TG-DTG-DSC, amino acids

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CLUMPED ISOTOPE THERMOMETRY OF UPPER ORDOVICIAN REEF CARBONATES AND A COMPARISON WITH OTHER THERMAL INDICATORS IN THE HUDSON BAY BASIN

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The Hudson Bay Basin is the largest of the intracratonic basins in North America, but it is the only one without any known petroleum resources. Nine exploration wells (5 offshore and 4 onshore) were drilled and 46,000 km of marine seismic line data were acquired from 1964 to 1985[1]. Exploration was halted in the mid-1980s because no hydrocarbon reservoirs were discovered and the source rock was inferred to be thermally immature. However, evidence of hydrocarbons (e.g. gas shows, oil staining) has been reported in all offshore wells and recent research has discovered pockmarks and possible oil slicks in several localities across the Hudson Bay[2], suggesting that hydrocarbons are indeed present in the basin and naturally leaking out of one or more reservoirs.

A new clumped isotope facility has been developed in the Delta Lab of the Geological Survey of Canada. The purpose of this facility is to evaluate the potential of the carbonate clumped isotope thermometer in various Canadian basins. The lab is equipped with an offline gas extraction line and a Thermo Scientific MAT 253 isotope ratio mass spectrometer. This new facility is first tested with samples from the Hudson Bay Basin. This study uses clumped isotopes to better understand the thermal history of Upper Ordovician reef carbonates from the Red Head Rapids Formation, which directly overlies the potential source rock for the Hudson Bay Basin. Samples are from late calcite cement that precipitated in pore space during burial, as well as recrystallized carbonate material from the original reef framework—dominantly sponges, microbes, and synsedimentary cement. Results from clumped isotope analysis are compared with fluid inclusion temperature estimates and other thermal indicators to better understand burial temperatures and discuss the potential for hydrocarbon development in the basin.

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CARBONATE DIAGENESIS CONTRIBUTION TO THE PREDICTION OF THERMOCHEMICAL SULPHATE REDUCTION - DEVONIAN RESERVOIRS, WESTERN CANADA SEDIMENTARY BASIN

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The aim of this study is to constrain the occurrence of the Thermochemical Sulphate Reduction (TSR) reaction during the burial history of carbonate reservoirs, by means of quantitative petrography and geochemical analyses. We focused on the Devonian reefal carbonate reservoirs of the Nisku and Leduc formations from the Western Canada Sedimentary Basin, where some hydrocarbon fields have experienced TSR and contain up to 30% of H_2S.
Seven cores were chosen from areas of the basin having experienced different thermal histories and characterized by contrasting H_2S production. Detailed sedimentological description and sampling were followed by thin section petrography which identified the main diagenetic events and established their spatial and temporal occurrence in the cores (paragenesis). Quantitative petrography focused on TSR-related features such as the abundance and crystallography of sedimentary sulphates and of deep burial blocky calcite and saddle dolomite phases.
Carbon, oxygen and strontium isotope analysis on these carbonate phases provided clues on the type of parent fluids and the sources of dissolved carbon. Fluid inclusion microthermometry and Raman spectroscopy on specific calcite and saddle dolomite samples revealed the possible crystallization temperatures, the total salinity of the parent fluids involved and their gas content.
Main results indicate that saddle dolomite pre-date blocky calcite. Homogenization temperatures of fluid inclusions in dolomites vary (depending on the core of provenance) between 80 and 160 °C, with mode values always above 110 °C. Salinities of the same fluids are rather consistent and vary between 19 and 24 wt. % NaCl eq. The dolomites have positive $\delta^{13}C_{V\text{-}PDB}$, possibly inherited from Devonian host carbonates, and do not contain gaseous fluid inclusions, this overall suggesting that they crystallized before H_2S generation.
Homogenization temperatures of fluid inclusions in calcites vary (depending on the core of provenance) between 80 and 180 °C, with mode values always above 130 °C. Fluid salinity vary largely between 12 and 24 wt. % NaCl eq. The calcites have fairly negative $\delta^{13}C_{V\text{-}PDB}$ down to -23‰ and consistently contain gaseous (H_2S-rich) fluid inclusions displaying clathrate dissociation at temperatures up to 13 °C, this overall suggesting that they formed after H_2S generation. These calcites are possibly a byproduct of the TSR reaction and represent the best candidates to gather further constraints on the TSR process in this basin.
The thermal information obtained from calcite fluid inclusions was combined with the burial-thermal history modelled for Devonian rocks of each of the investigated cores. This allowed to infer possible timing for the occurrence of TSR reaction at basin scale. Further constraints were provided by U-Pb absolute thermo-chronology (by LA-ICP-MS) on some of these calcites.
This quantitative characterization data ultimately aim at calibrating and validating TSR risk analysis in basin modelling simulations.

TURNING EVAPORITES INTO TEMPERATURE ARCHIVES USING BRILLOUIN SPECTROSCOPY – APPLICATION TO THE DEAD SEA

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Determining past continental temperatures is a fundamental issue for paleoclimate reconstructions, as continents are more sensitive than oceans to climate variations. So far, surface continental temperatures have been estimated using pollen assemblages, molecular compounds in biological remains in lacustrine sediments, and the isotopic composition of minerals such as pedogenic carbonates or phosphates from teeth and/or bones of vertebrates. However, temperature estimations using these proxies rely on often-contested calibrations. For example, the strong dependence of isotopic fractionation with temperature can bias accurate estimations of the temperature of precipitation of a given mineral.
Present in virtually all rock minerals, Fluid Inclusions (FIs) are micrometric cavities containing remains of the fluid existent at the time of mineral formation. In halite, a common mineral in continental evaporitic sequences, FIs represent trapped micro-droplets of ancient lakes or lagoons. As FIs volume and composition remain unchanged after entrapment, their density is also constant providing a direct record of paleo-temperatures. Indeed, assuming that the FI's formed under atmospheric pressure their formation temperature can be constrained along an isodensity line in the pressure-temperature diagram. As such, more than a proxy, FIs in evaporitic rocks are real paleo-thermometers. We have used FIs in synthetic and natural halites to demonstrate the potential of Brillouin spectroscopy, a novel methodology in determining paleo-brines temperatures. This non-destructive approach bypasses the limitations of the so-far-used microthermometry technique reaching an unprecedented ±1°C precision. To illustrate the power of this new tool, we have sampled several tens of halite intervals from a 450-meters-long core drilled in 2010-2011 in the deepest part of the Dead Sea (DSDDP-5017-1) within the framework of an ICDP project. The application of Brillouin thermometry to this record is providing, for the first time, a unique opportunity to quantify temperature changes with high accuracy during the last interglacial. Thus, it is providing much needed data to validate climate models for the region. Furthermore, it offers an effective method that could be applied to other evaporitic sequences at different temporal and geographical scales.

GEOTHERMOMETRY OF CH_4 IN AN ORDOVICIAN AQUICLUDE: SLOW RATE OF SYNTROPHIC METHANOGENESIS?

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Recent stable isotope work on a low-permeability ($K_h \leq 10^{-13}$ m.s^{-1}) and high-salinity (>5 M Cl^-) aquiclude, situated in the Upper Ordovician on the eastern flank of the Michigan Basin, suggested a microbial origin for porewater CH_4 and CO_2. CH_4 is believed to have been produced during the early stages of burial and trapped since the Palaeozoic within the shale section of the Ordovician aquiclude.[1] Compound specific isotope analysis in this aquiclude showed: (1) a biodegradation overprint on the expected organic matter (OM) maturation isotopic effect, and (2) a stratigraphic link between biogenic CH_4 and *n*-alkane biodegradation. This suggested that *n*-alkane biodegradation partially fueled methanogenesis in this aquiclude. Questions remain regarding the metabolic pathways of the microbial communities and the relative depth and timing of this CH_4 generation. To further constrain the link between OM biodegradation and CH_4 formation, and to constrain the relative timing of isotopic equilibration of CH_4 in this system, we performed CH_4 clumped isotope measurements over the depth profile of this Ordovician aquiclude.

The clumped isotope abundance (Δ_{18}) analyses of CH_4 provides an intramolecular isotopic constraint for CH_4 formation. By using the theoretical dependence of Δ_{18} with temperature of CH_4 formation,[2] one can derive temperatures of formation or equilibration of natural gas (T_{18}). In general, Δ_{18} values in our sample set indicate CH_4 internal equilibration temperatures between 15 and 120°C, confirming both a biogenic and a thermogenic component. Moreover, re-evaluation of the bulk $\delta^{13}C$ and δ^2H of CH_4, CO_2, H_2O and *n*-alkanes revealed an apparent H-isotopic disequilibrium between CH_4 and H_2O in contrast to apparent C-isotopic equilibrium between CH_4 and CO_2 and internal isotopic equilibrium based on Δ_{18} values. However, apparent H- and C-fractionation factors between non-gaseous *n*-alkanes and CH_4 seem to have reached thermodynamic equilibrium. We explore the hypothesis that this shale gas formation analogue could have hosted slow rate of methanogenic alkane degradation that did not induce full equilibration of H-isotopes between water and methane.

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PALEOTEMPERATURE STUDIES OF COALS IN THE VOLGA-URAL OIL AND GAS PROVINCE (RUSSIAN FEDERATION)

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The study of paleotemperatures in sedimentary basins helps to solve problems of formation and oil deposits prediction. In sedimentary deposits, they are reliably determined by a vitrinite reflectance (%Ro). The vitrinite is one of the microcomponents (maceral) of the coal. On the territory of the Volga-Ural oil and gas province, there are numerous manifestations of fossil coal associated with Visean oil-bearing deposits (early Carbon). This allows the using of coal-petrographic methods to determine the nature of post-sedimentation processes by the maturity of organic matter. The Visean terrigenous strata fill erosion-karst cuts on the surface of the carbonate deposits of the Tournaisian and contain 1 to 3 coal seams. Among them the most powerful middle stratum reaches 10-30 meters. It lies at a depth of 900-1400 m. The Visean coals are humic. They were formed from the remains of higher vegetation. According to the degree of metamorphism, Visean coals belong to bituminous coals, but they retained the properties of brown ones. In Visean coals, the values of Ro vary in a fairly wide range from 0.44 to 0.73%, increasing in the direction from north to south in the direction of maximum subsidence of the seams. The values of Ro in coals correspond to the initial stage of catagenesis and correspond to paleotemperatures of 50-70°C. At the same time, according to measurements in oil wells, temperatures at a depth of about 1 km currently fluctuate in the range of 14-48°C. This suggests that the thermal regime in the ancient geological epochs (late Paleozoic-Mesozoic) was characterized by higher temperatures than in the present. The structure of the modern thermal field is closely related to the tectonic structure of the territory and the location of deep faults. The oil content of the Visean deposits is explained by the flow of oil from the deeper oil-bearing deposits of the Devonian along fault and fracture zones. The source of oil is the rocks of domanikite facies, which contain organic matter about 1-3% or more. Dominikites lie at depths of 1.6-2 km. They are also generally characterized by a low level of maturity of organic matter. Apparently, in the past geological times, the domanikite strata were locally exposed to more powerful thermal effects along the fault zones. In particular, this is confirmed by the traces of hydrothermal processes in the rocks of the crystalline basement of the territory.

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BURIAL AND THERMAL EVOLUTION OF SOURCE ROCKS IN NEOGENE TSUGARU BASIN (NORTHERN HONSHU, AOMORI PREFECTURE, JAPAN) BY MEANS OF ORGANIC GEOCHEMISTRY

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The northwestern side of Honshu island in Japan, is the area where most of the Japanese hydrocarbon fields occur and the most prospective source rock formations are distributed. These formations are of Middle to Late Miocene age, and they are composed mainly of chert, siliceous shale, diatomite, mudstone, and acidic pyroclastic rocks.
The Tsugaru basin is a Neogene back-arc basin located in northern Honshu, in Aomori prefecture. The basin is filled with pyroclastics, intrusives, mudstones, and siltstones of Miocene to Pleistocene age. The base of this succession is made of pyroclastic rocks deposited in a shallow water environment due to intense volcanic activity. Subsequently in Middle to Late Miocene, a phase of subsidence and transgression favored the deposition of argillaceous rocks of deep sea environment. This transgression was followed by a regression with concurrent volcanic activity in the late Miocene; therefore sandstones, diatomaceous siltstones and pyroclastic rocks were deposited. This succession has been widely studied by Ujiié (1995) through analysis of samples from outcropping formations. These formations are considered potential source rocks.
The 1.5 km-long cored DTH27-1 well cover the geological record in the Tsugaru basin from Middle Miocene, through Plio-Pleistocene until Quaternary. In descending order, DTH27-1 well intercepted 300 m of Quaternary volcanoclastic sediments and lava deposits (Iwaki Volcano Sequence), 210 m of Pliocene tuffaceous conglomerates (Higashimeya Fm.), 125 m of Pliocene diatomaceous siltstones (Taiaki Fm.), 441 m of Pliocene to Late Miocene diatomaceous siltstones rich in laminated well laminated levels (Akaishi Fm.), about 21 m of Middle Miocene laminated shales (Ohdoji Fm.), 370 m of Middle Miocene tuff breccias with intercalations of laminated siltstones (Tanosawa Fm.), and about 30 m of Early to Middle Miocene tuff breccias with intercalations of siltstones, laminated shales, and small horizons extremely rich in terrestrial organic matter.
In this study we evaluated the source rock potential of the Tsugaru basin succession through the analysis of some representative core samples from DTH27-1 well. These analyses allowed us to the integrate the previous studies, in our study area, with new subsurface data. Rock-Eval Pyrolysis has been performed on these samples and we collected data about source rock quality and maturity. Furthermore, with T_{max} results, we realized a burial and thermal model of the Tsugaru basin that allowed us to assess its burial and thermal evolution. We will discuss our results during the conference.

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CLUMPED ISOTOPIC TRENDS IN MODERN COLD-SEEP ARAGONITIC MATERIAL OF THE ST. LAWRENCE ESTUARY – THERMOMETRY?

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Chemosynthetic carbonate shells and micritic material from organisms thriving on sea-floor cold vents of hydrocarbons have been well characterized using regular carbonate isotopes (δ^{13}C and δ^{18}O values), and typified by very low δ^{13}C values inherited from bicarbonate produced through bacterial oxidation of hydrocarbons, with methane oxidation being frequently invoked by research groups[1,2]. The same mechanisms explain most characteristics of carbonate cements found near such cold vents including unusual appearance of aragonite cements, even during calcite sea episodes[3].

At this stage, clumped studies of such chemosynthetic carbonates are seldom. Most case studies of modern and ancient cold-seep crusts and bioaccumulations have δ^{18}O and δ^{13}C values interpreted to reflect low temperatures of sea-floor conditions and mixing of vent and marine bicarbonates, respectively. Moreover, many of these studies have suggested the authigenic carbonates to be rapidly precipitated[3] or mostly produced at disequilibrium[4]. These propositions raise the question of what would reflect clumped isotope ratios (Δ_{47}) measured in other modern chemosynthetic carbonates from sites of known temperatures? To address this question, we have studied chemosynthetic carbonates (δ^{13}C values < -25‰) collected at hydrocarbon seeps in the St. Lawrence Estuary (Canada)[5], at water depth of about 300m and sea-floor temperature of 3-5°C.

Here we will report preliminary clumped isotope results for two carbonate concretions, from otherwise unconsolidated marine clastic sediments. The studied material includes mollusk shells, cemented micrite, and pore-filling isopachous to botryoidal aragonitic cements[5]. The clumped isotopic results will be combined with the classical isotopic ratios (δ^{13}C and δ^{18}O), and discussed in terms of precipitation conditions. Do they reflect ambient temperatures during precipitation, or false temperature due to mixing and/or disequilibrium?

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DIAGENESIS OF CHALK: INSIGHTS FROM CONVENTIONAL AND CLUMPED ISOTOPES.

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Reconstruction of the diagenesis of Chalk is challenging due to the minute grain size and mono-mineral nature of the sediment (dominance of low-Mg calcite). A major problem relates to the cryptic nature of micron-sized particles (micarbs) that quantitatively dominate the sediment. During this work 30 samples from four shallow cores of uppermost Cretaceous (upper Maastrichtian) chalk in the onshore parts of the Danish-Norwegian Basin have been investigated to better understand the origin and diagenesis of the different components.

All samples have been disintegrated using a conservative variation of a technique proposed by *Minoletti et al.*[1], where the samples are saturated in neutralized distilled water, gently crushed into cm-sized pieces, frozen and reheated several times to disaggregate the sediment into the initial ooze condition. A sonic bath (30W, 20min) was used to speed up the process. A combination of wet sieving and centrifugation has been used to separate the ooze into five different granulometric classes and SEM has been used to evaluate the preservation of the components and characterize the disintegrated sediment.

Conventional stable isotopes (^{13}C, ^{18}O) have been used to investigate the origin and the evolution of the different type of particles, with a special attention to the origin of micarb and the cement formation. It has been supplemented with clumped isotope analyses to better constrain the temperature regime for early carbonate diagenesis in the chalk. The clumped isotope data represent an innovative approach using temperature as a proxy for burial and integrated with seismic data it provides a tool for recalibration of the burial maps of the Maastrichtian Chalk in the Danish Basin.

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HOW DO DEPOSITIONAL PROPERTIES DICTATE EARLY DIAGENETIC PATHWAYS? A CASE STUDY FROM A MODERN TURBIDITE SYSTEM

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The presence of clay minerals strongly influences the physical and chemical properties of a conventional sandstone reservoir. Determining their presence is therefore important for assessment of recoverable hydrocarbons. Porosity and permeability are key parameters which determine the economic value and development plans for oil and gas fields. These pore-scale attributes are initially controlled by depositional processes and subsequent diagenetic pathways that commonly act together to determine final reservoir qualities. Although there are many individual studies on pore-scale reservoir quality controls of particular fields/formations, there are only a few overarching approaches towards the predictability of reservoir quality by linking depositional processes to early diagenetic pathways.

In this study, we investigate the detrital clay distribution of an active turbidite system. The study area (Bute Inlet) is an 80km long fjord located in British Columbia, Canada. The depositional system is dominated by a 45km long and up to 660m deep submarine channel that is shaped by active and frequent turbidity currents. The fjord and the flow properties of the currents traversing the system have been measured and characterised at 6 sites along the channel axis, providing details on the flow dynamics from channel head to lobe. The resultant deposits were sampled by piston and box cores, whilst grab samples were used to characterise surface sediments. The combination of flow measurements and extensive bed sampling gives us the unique opportunity to link flow dynamics to deposits and the distribution of clays in an active turbidite system for the first time.

Detrital clay distribution (both amount and clay types) has been investigated throughout the system including the submarine channel thalweg and terraces, as well as the feeding delta. The preliminary results show that illite dominates the detrital clay fraction of channel thalweg, but is found in lower quantities in delta sediments. This possibly implies that illite can easily be transported downstream possibly due to its flaky texture and fine grain size. Vermiculite was only detected in delta sediments (minor amounts) and it has most likely derived from soil profiles. Chlorite distribution throughout the system remains inconclusive in the preliminary data set with a slight tendency to increase towards distal parts of the system. These new highly spatially resolute measurements of clay mineralogy in a well characterised active submarine channel system provide new insight to predictability of pore-scale reservoir quality at subsurface.

Novel Sand-Mud Sedimentary Structures in the Aberystwyth Grits Group and the Borth Mudstone Formation

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The interpretation of sedimentary structures formed in mixed sand–mud beds is complicated by the presence of cohesive clay, because adding even minor amounts of clay to a non-cohesive flow or bed can lead to the development of a diverse range of sedimentary structures unlike those found in pure sand. Fieldwork conducted in the distal, mud-rich part of the Aberystwyth Grits Group and the Borth Mudstone Formation (west Wales, U.K.), found many novel mud–sand bedforms. The occurrence of these bedforms in the field matched those produced by decelerated flows composed of sand, silt and mud particles in the laboratory [1]. The sedimentary structures identified both in the field and laboratory included classic current ripples, large ripples and low-amplitude bed-waves (LABWs). Large ripples have a greater height, length, and mud content than current ripples, whilst mixed sand-mud LABWs are typically a few millimeters high and up to several meters long. In the laboratory, these bedform types were stable at different flow velocities and rheologies. As the cohesive forces in the flow (and the proportion of clay) increased relative to the turbulence forces (and the flow velocity), the flows changed from turbulent via transitional to laminar, and the sedimentary structures changed from current ripples via large ripples to LABWs.

Dimensional analysis of the field data shows that these bedform types have distinct height and length ranges. In addition, the different bedform types had a preferred spatial distribution, with large ripples more common in the proximal region of the study area and LABWs more common in the distal sections. This spatial trend is interpreted to be caused by increasing mud content in the flows as they moved distally, allowing cohesive forces to progressively dominate flow behavior. Accordingly, these unique bedforms formed under mixed sand-mud flows may help to infer location within the distal parts of mud-rich deep-marine systems. A better recognition of fan-fringe facies and the sedimentary structures present, based on understanding the cohesive control on flow behavior, may also improve reservoir models.

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XRF PROFILING OF HYBRID SEDIMENT GRAVITY FLOW DEPOSITS; NEW INSIGHTS FOR BED-SCALE FLOW PROCESSESS

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Recent experimental studies have highlighted the role of detrital clays in transforming the behaviour of decelerating sand-mud suspensions through turbulence damping. A common bed motif frequently reported from lateral and distal parts of sandy fan systems shows evidence of such clay-driven flow transformation and records a complex association of clean and argillaceous sandstone lithofacies emplaced by a single flow event; these are known as hybrid event beds (HEBs[1]). A key characteristic of these beds is the presence of abundant clay matrix and/or mudclasts that introduce significant heterogeneity in the event bed make-up. However, quantifying continuous clay matrix variability and hydrodynamic fractionation of different clay types within such beds is challenging, both in terms of methodology and inferring original flow processes.

This study is based on compositional profiling of beds within behind-outcrop cores taken from the Ross Sandstone Formation, a renowned Pennsylvanian deep-water fan system exposed on the Atlantic coast in County Clare, western Ireland. The Ross Fm is a useful test case for non-destructive elemental profiling and clay-related investigations despite its significant post-depositional thermal exposure in that i) It has nine different types of clay-rich hybrid event beds (HEB1-HEB9) of diverse origin[2], and ii) the HEBs have a relatively simple bimodal mineralogy composed of predominantly quartz sand and detrital clays, such that Si, K, Fe, Ca and Zr can be used as proxies for the abundance of quartz grains, illite, chlorite, calcite cement and zircon respectively. Representative HEBs have been scanned using an XRF core scanner to obtain nearly continuous (200 µm spacing) compositional trends within different hybrid facies. The XRF results are integrated with XRD, TOC and petrographic data to further constrain the texture and mineralogy of these clay-rich sandstones. These elemental profiles give new insight into the systematic vertical compositional trends that may reflect hydraulic separation of framework grains, distribution of diagenetic cements and heavy minerals in beds. Of particular interest is the evidence of vertical segregation of illite and chlorite that may reflect longitudinal and lateral fractionation of clays within the currents. A common pattern observed in hybrid event beds is a tripartite stack of clean, muddy sandstone and sandy claystone separated by sharp textural interfaces reflecting internal shear and partitioning of the flows. Prediction of clay heterogeneity within deep-water successions is critical to our understanding of reservoir quality distribution in the subsurface.

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MEGATURBIDITES IN ALASKAN LAKES: THE RESULT OF HYBBRID FLOWS?

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Megaturbidites in lake basins are relatively thick, ponded deposits that cover a large part of the lake basin. They typically consist of a sandy base, a homogenous to graded middle part and are sometimes covered by a clay cap. While the basal part often contains sedimentary structures, the middle and top are usually homogenous, with no sign of sedimentary structures. The latter corresponds to the waning of the fluctuating seiche flow and eventually suspension fallout.

Here we study the megaturbidites that record the AD 1964 M_w9.2 Good Friday earthquake in Skilak and Kenai lakes, two varved proglacial lakes on the Kenai Peninsula, south-central Alaska. We retrieved 16 and 20 cores across Skilak and Kenai lakes, respectively, that penetrated the 1964 megaturbidite. We studied them using primarily grain-size analysis, medical and micro CT scanning, and measured Natural Remanent Magnetization to orient some of the cores and thereby some of the observed sedimentary structures. In both lakes the megaturbidite can be subdivided into three units. Unit I composes the sandy base, which is especially thick in Kenai Lake. Unit II is a non-graded, poorly-sorted muddy unit with internal banding, wavy laminations, lenses, clasts, and up to 3% clay (grains <2 µm). Unit III is a graded, well-sorted clayey mud ("clay cap") with up to 50% clays in the top. While the sands of Unit I are thickest in the vicinity of coarse-grained source areas such as deltas and alluvial fans, the interbedded Unit II shows a ponding geometry and is thus thickest in the deepest and most slope-distal areas. Furthermore, the sedimentary structures of Unit II are indicative for a debrite and we therefore interpret this unit as a linked debrite, and part of a hybrid event bed (i.e. the megaturbidite) (Haughton et al., 2009). The Unit III clay cap is draped over the complete deep basins, as can be expected from a suspension fallout that composes the tail of the hybrid flow. We hypothesize that the high clay content, typical for such varved proglacial lakes, promotes flow cohesion and is responsible for flow partitioning on the basin plain, resulting in the hybrid event bed.

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SEAFLOOR INSTABILITIES IN THE RHÔNE TURBIDITIC LEVEE COMPLEXES, WESTERN MEDITERRANEAN: MORPHOLOGY, TIMING AND EMPLACEMENT, AND POTENTIAL RELATIONSHIP WITH ACTIVE FAULTING

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The Gulf of Lion is a SW-NE oriented passive continental margin formed after the starting of the convergence between Europe and Africa in the Oligocene. The continental slope is incised by about 15 submarine canyons, feeding the distal Rhône sedimentary system. One of the distinctive features of the NNW-SSE oriented channel-levee complex is the presence of extensive areas of sediment deformation and erosion on the turbiditic levees and the presence of two large Mass Transport Deposits (MTDs) described in the literature as Eastern and Western MTD. The continental slope is dissected by several listric faults which have a dominant SW-NE strike and at times reach the seafloor. We present an integrated geophysical, geomorphological, sedimentological and geotechnical study of the deformation occurring in the Plio-Quaternary sediments of the turbiditic levees of the Petit-Rhône submarine valley. Nearly 180 km of ultra-high-resolution deep-towed multi-channel seismic data (SYSIF), collected during the PRISME2 cruise (DOI: 10.17600/13010050), allowed to obtain images of the internal structure of the deformed units with unprecedented details. These data are supplemented by multibeam bathymetric, sub-bottom profiler, and high-resolution seismic data collected aboard several French cruises. During the PRISME3 cruise (DOI: 10.17600/13030060), we obtained several transects of CPTU measurements and sediment cores in undisturbed sedimentary successions, in adjacent zones of evacuation, and in the MTDs. CPTU data provide in-situ information along two main SYSIF lines across undeformed and failed areas in both eastern and western turbiditic levees. The CPTU profiles show an 8-m thick draping unit with downwards increasing values of tip resistance, sleeve friction and undrained pore pressure. In sites penetrating MTDs, these parameters increase irregularly below 8 meters below seafloor (mbsf), underneath a peak corresponding to a coarser grained material. Coinciding sediment cores allowed to identify thin-bedded turbiditic facies (undisturbed sediment), as well as MTDs expressed either as contorted slumped or structure-less stiff units. On top of MTDs we identified coarser grained sediments likely corresponding to turbidite deposits, which is in good agreement with in-situ measurements. In this study, we attempt to 1) characterize distinct expressions of sediment deformation, their spatial and chronological distributions, 2) correlate them with undisturbed sediments to identify the source of wasted material and the nature and extent of potential weak layers at their base.

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LATE MIOCENE LARGE-SCALE MASS TRANSPORT SEDIMENTATION IN THE ARABIAN SEA

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The Nataraja Submarine Slide is a giant mass-wasting deposit that runs from the Gujurat-Saurashtra coast of western India to the Laxmi Basin, eastern Arabian Sea. It is over 330 km long and a maximum of 190 km wide, and was emplaced just prior to 10.8 Ma. This slide covers $5 \pm 0.2 \times 10^4$ km^2 and represents a volume of $19 \pm 4 \times 10^3$ km^3, exceeding in volume all but one previously described mass-transport complex on passive margins worldwide. This slide has been able to flow around massive volcanic seamounts of the Panikar Ridge, thus highlighting the capacity of the flow and its potential energy during emplacement between the slope of the western Indian passive margin and the Laxmi Ridge. The deposit is >800 m thick at its maximum, but just 300 and 190 m thick at IODP Sites U1456 and U1457. It was emplaced in two major phases. At Site U1456 the upper unit is thinner, with a sharp-based section of ~40 m of coarse calcarenite overlain by slumped interbedded mud and siltstone. Slumping, and especially high energy turbidity current flow, is the primary depositional mechanism. The muddy clastic sediment is mostly reworked Indus-derived material. The lower unit also shows a fining upwards character, but this section has a large basal sequence ~130 m thick that is dominated by limestone breccia. These limestone breccias are interpreted as heavily broken, but largely coherent slide blocks with more turbidity current-derived calcarenites overlying and below a muddy clastic top. The limestone in the breccia is a shallow-water facies derived from lower and middle Miocene sequences on the outer Indian Shelf. The margin was prone to collapse because of its steep character, as shown by thrusts and folds on the intact part of the slope to the south. This oversteepening was a product of enhanced clastic sediment delivery during the mid-Miocene. Proximity to active seismic zones within the Indian plate hint at the triggering mechanism for the final emplacement.

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RADAR STRUCTURE OF AN ANCIENT SHORELINE LANDSLIDE IN GLACIOMARINE CLAY DEPOSITS, ORKDALEN FJORD-VALLEY, MID NORWAY

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Past mass-wasting events may significantly affect the stratigraphy of fjord-valley fills. This is illustrated in the present case study at the mouth of a side-valley near the town of Orkanger in Mid Norway. The area, being part of the major Trondheimsfjorden system, was deglaciated around 14 000 cal yrs BP and glacioisostatic depression of the crust gave rise to a local marine limit of 160 m a.s.l. Glacier-marginal deposits and thick glaciomarine clays in the fjord subsequently emerged and were eroded as relative sea level lowered during the glacioisostatic rebound. A distinct terrace-like protrusion at the mouth of the side valley at around 16 m a.s.l. was previously interpreted as Holocene fluviodeltaic deposits as supported by earlier, minor gravel pits. However, reported occurrences of quick clay in the terrace and the finds of clay deposits near the land surface show that the Quaternary geology is more complex. A GPR survey reveals that the terrace-like protrusion consists of rotated landslide blocks overlain by deltaic deposits with local foreset bedding. This interpretation is supported by LiDAR data showing several landslide scars in marine clay slopes next to the terrace. The level of the protrusion and of delta foresets show that relative sea level was at around 16 m during failure. According to a local sea-level curve this corresponds to an age of c. 3300 cal yrs BP. The trigger for the mass wasting could have been river erosion, perhaps combined with shoreline abrasion. Seismic activity could also have played a role. The complex stratigraphy possibly facilitated continued quick-clay development in the landslide blocks due to leaching enhanced by interbedded permeable layers. The outlined geological history provides a general framework to better understand the local ground conditions that are considered to be challenging for engineering work.

Triggering mechanism of a Giant Megaturbidite on the Doumsan Fan Delta, Miocene Pohang Basin, SE Korea

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A giant megaturbidite (1.2 Km^3 in volume) occurs on the foreset, bottomset, and prodelta successtions of the Doumsan Fan Delta system in the Miocene Pohang Basin, SE Korea. The megaturbidite deposit comprises 1) clast-supported massive/graded conglomerate, stratified and cross-stratified conglomerate, 2) very thick, graded sandstone with giant rip-up mud clasts (max. : > 5 m in long axis) and water escape structures, and 3) thick homogeneous mudstone. The sandstones are represented by a typical Bouma sequence with massive/graded sandstone (Ta), laminated, cross-laminated and convoluted sandstone (Tb and Tc) and laminated very fine sandstone and siltstone (Td), in ascending order.

The megaturbidite deposit ranges in thickness from 40 m in the proximal part to 2 m in the distal part. Grain size variation from conglomerate to sandstone as well as sedimentary facies is evident within 8 km of the outcrop. Variation in thickness, grain size and sedimentary facies suggests north-northeastward paleocurrent direction, which differs from the general southeastward deepening paleotopography of the basin. Paleocurrent direction also differs from that of the underlying foreset, bottomset and prodelta successions of the Doumsan fan delta, showing a radial distribution pattern. The flow pattern makes several assumptions about triggering mechanisms of megaturbidite deposits. Considering the triggering point (southern part of the axis of the Doumsan Fan Delta) and paleotopography, slumping triggered by oversteepening of the slope and/or seismic shock would induce southeastward flow. Northwestward approaching tsunami, following the southeastward deepening paleotopography, may also be a triggering mechanism, because the tsunami wave can reflect against the NW-SE trending faulted basement. Combined effect of tsunami and seismic shock may be responsible for the generation of giant megaturbidite, regardless of paleoslope direction. On the other hand, uplift of the southeastern and eastern parts of the basin after the deposition of fan-delta system may form a narrow, northeastward deepening trough. Oversteepening of the slope and/or seismic shock can result in north-northeastward slump and resultant megaturbidite.

THE DISMANTLING OF THE APULIAN CARBONATE PLATFORM DURING THE LATE CAMPANIAN – EARLY MAASTRICHTIAN

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The Apulian carbonate margin is widely preserved across the Adriatic domain and has extensively been studied in the southeastern part of Italy. In Albania, the widespread exposure of Apulian platform and Ionian basin carbonates relates to the thrust tectonics during the Oligocene-Pliocene. In Albania, the part linking the platform shelf to the basin is missing preventing a direct reconstruction of the platform margin.

Syn-sedimentary deformation structures occur in the uppermost part of both the shallow-water platform and slope to basin sedimentary series. The platform series show well-bedded sediments deposited in an intertidal to shallow-subtidal environment. They are disrupted by Mass Transport Deposits (MTDs) that show significant lateral variability as well as brittle and ductile deformation. The deep-water sedimentary succession in the adjacent Ionian Basin shows an alternation of pelagites (open marine sedimentation), shallow-water derived density flow deposits and large-scale slumps made up of density flow deposits. The lateral extent of the detachment surfaces, syn-sedimentary faults and folds in the slumps point towards multiple regional destabilization events affecting the Apulian platform margin. Bio- and chrono-stratigraphic analyses suggest that these events occurred during the Late Campanian – Early Maastrichtian. Beyond the obvious interest from a stratigraphic point of view, the study of the destabilization events allows for a better understanding of the triggering mechanisms and sedimentary characteristics of MTDs at a basin scale.

The evolution of the platform-to-basin transition during the Late Cretaceous is now better constrained in the Albanian part of the Adriatic. A first mega-sequence (Cenomanian – Turonian) comprises significant aggradation of shallow-water platform carbonates while no significant sediment transfer is evidenced in the Ionian Basin. The second mega-sequence (Coniacian - Late Campanian) reveals increasing sediment transfer towards the basin because of significant highstand shedding of the rudist-factory and associated facies characterizing the shallow-water carbonate platform system. Repeated destabilization events (Late Campanian – Early Maastrichtian), most likely related to large-scale tectonic processes, initiated the dismantling of the Apulian carbonate platform margin and resulted in massive reworking and shedding of shallow-water carbonate sediments towards deep water settings.

SEAFLOOR MORPHOLOGY AND SURFACE SEDIMENT DISTRIBUTION RELATED TO SUBMARINE LANDSLIDES IN THE SOUTHWESTERN PART OF THE ULLEUNG BASIN, KOREA

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Main text: Multi-beam echosounder data and grain size of surface sediment were acquired and analyzed in order to investigate the shelf-to-slope morphology, geological character, and their geological controlling factors related to submarine landslides in the southwestern part of the Ulleung Basin. According to the morphological character, the continental shelf can be divided into two parts: (1) shallow (~100 m depth) and steep (0.5^{o}) inner shelf, (2) deep (100-300 m depth) and gentle (0.2^{o}) outer shelf. The continental slope is featured with eight distinct topographic depressions of various spatial dimension (~121 km^2 in area) and head wall gradient (~24.3^{o}). They are developed adjacent to each other and presumably formed by submarine landslides which have recurred under the strong influences of earthquakes and eustatic sea-level change. The inner continental shelf and the continental slope are dominated by fine-grained sediment, whereas the outer continental shelf is dominated by coarse-grained sediment. The surface sediment distribution seems dominantly influenced by eustatic sea-level change. The outer continental shelf is mostly covered by coarse relict sediment deposited during lowstand sea-level, while the inner shelf is covered with recent sediment during highstand sea-level. The surface of the continental slope is covered with fine-grained sediments which were supplied by hemipelagic advection process.

Progressive failure mechanism for explaining large submarine landslides

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In many cases, earthquakes and/or high excess pore pressures are invoke for initiating large submarine mass movements and their extent (more than 1 cubic kilometres). However, other mechanisms are possible to explain these large landslides, even in the absence of earthquakes or excess pore water pressure. Progressive failure has been used in this context. For example, the Storegga slide[1] was the first major landslide which was explained be a progressive failure mechanism. Similarly, the application of fracture mechanism that takes into account the strain-softening behaviour of the soil during shear can be used to explain catastrophic shear band propagation in submerged slopes[23]. On land investigations have shown that such a mechanism is quite common and is often associated to spread, often recognized by their horst and graben morphology. To be initiated, progressive failure requires that the sediment or soil has a strain softening behaviour during shear and that a stress change have to be initiated by either erosion at the toe (unloading) or accumulation at the top (loading) of the slope[4]. When unloading at the toe takes place, an upward progressive failure may be initiated, whereas if it is initiated by loading at the top, a downward progressive failure may develop. The interesting aspect of such a mechanism is that neither excess pore pressure nor an earthquake are required to explain landslide initiation and their large extent. In the marine environment, significant improvement in deep sea floor mapping using AUV, with resolution below 1 m, and our understandings of deep current dynamics make it now possible to better identify erosion processes, including knickpoints[5], along the continental slope where many of these large landslides are found. Improvements in submarine landslide characterisation and further detailed investigations of case studies will help our understanding of the implication of progressive failure in the failure mechanism of these large landslides, in a similar way as for large onshore landslides.

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PRE-FAILURE STRESS-STATE OF AN EARTHQUAKE TRIGGERED SUBMARINE LANDSLIDE: THE MARQUES THE POMBAL LANDSLIDE, OFFSHORE PORTUGAL

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The Marques de Pombal landslide deposit, with its estimated volume of 1.3 km^3, is located in the Alentejo Basin, the Northern section of the Gulf of Cadiz (SW Iberian Margin). Gravity core analyses sampled in the Marques de Pombal depositional area reveal that multiple landslide and turbidity events contributed to the deposit formation[1, 2]. Considering the moderate-to-large-magnitude seismic activity of the area, earthquakes are the main triggering candidate for the mass wasting events. The Great Lisbon catastrophic earthquake of 1755 may also have contributed to the landslide's deposit. This work reconstructs the sedimentary, stratigraphic and geotechnical conditions of the area of interest before the 1755 earthquake and aims to evaluate the development of excess pore pressure in order to balance pre-conditioning factors vs triggering mechanisms in onset of slope failure. We build a stratigraphic model of the slope failure area using seismic profiles, swath bathymetry deep-towed side-scan sonar mosaics and well and log data from the IODP 339 expedition. Gravity core samples are used to understand development of permeability, compressibility and strength with burial depth. These data are used to build a numerical finite elements model, which aims to determine the relationship between continental margin development and its hydrogeological evolution.

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3D SEISMIC EVIDENCES OF DIACHRONOUS SHALE MOBILIZATION, MUD VOLCANOES AND FLUID MIGRATION IN THE DEEP WATER OF BRAZILIAN EQUATORIAL MARGIN

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This work presents a three-dimensional seismic dataset analysis of sediment mobilization associated with mud volcano generation and fluid migration in the Foz do Amazonas Basin, offshore Brazil. Three distinct diatreme structures reaching the sea floor and connected with a gas chimney have been identified in the study area, and these structures suggest close relation with the shale deformation. Piston core samples were analyzed at the main sites with fluid escape indications and the results confirmed thermogenic signatures, corroborating the HC focused migration as a key element in the process. The mobilization has been active within the Maastrichtian sequence which is composed mainly by undercompacted shales and minor silty/sandy lenses deposited in a rapid event (around 150m/Ma). The instability, landslides and mobilization processes initiated nearby the K-T boundary as the unit was affected by progressive overburden events: (a) installation of a thick carbonate platform from Paleogene to Miocene which presents signals of landslides on its base; and (b) the progressive Amazon cone installation with a substantial sedimentation from Miocene till nowadays reaching sedimentation rates up to 1100m/My[1]. The whole Maastrichtian unit presents clear detachment surfaces from base to top and they have been active till nowadays, mostly facilitated by progressive overpressure development. Due its plasticity behavior, the deformation developed normal faults with evidences of rotational blocks and spoon shape scars. Expressive thrust faults are localized and affecting no more than the buried and confined Maastrichtian level. Initially, with slow to extreme-slow movements, the system developed at the border of the slope where carbonate sequences were deformed, rotated and detached from its original position. With the overburden progression, the seaward-dipping basal detachment enhancing gravity sliding in the system, affecting the lower levels already buried. The mud volcanoes structures are linked to this confined gravitational process and the fluid has been interpreted as the major driver in the process, enhancing the shale ductibility and feeding the formation with extra overpressure during the basin evolution[2]. Dry shale has a higher tensional and compressional strength than wet shales and the fluid recharges were essential for the process evolution. During the Amazon Cone deposition the progressive deformation and mobilization reactivated the structures creating large normal and listric faults. In some places, the structures reach the seafloor, connecting the overpressure zone with the seabed which creates the perfect conduit for the mud volcano raising and extrusion. This study aims at illustration of the shale mobilization and escape features in Foz do Amazonas Basin as an example of a direct indicative of an active petroleum system in a frontier to emerging basin.

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THE NORTH-EASTERN AUSTRALIA MARGIN: SUBMARINE LANDSLIDE CHARACTERIZATION AND TSUNAMIGENIC POTENTIAL IN A MIXED CARBONATE-SILICICLASTIC SETTING

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The socioeconomic importance of submarine landslides is related to their tsunamigenic potential with far-reaching effects and ability to damage seabed infrastructure. Submarine landslides are ubiquitous seafloor features on the slopes of continental margins worldwide, but case studies in modern mixed carbonate-siliciclastic margins are relatively scarce. The north-eastern Australia margin is the largest mixed carbonate-siliciclastic province in the world and the iconic Great Barrier Reef (GBR). We describe the main geomorphologic characteristics of four representative examples of submarine landslides along the GBR margin and evaluate their tsunamigenic potential and impact on adjacent coasts at the time of inception. Landslide-generated tsunamis were simulated using the source component TOPICS within the Geowave model, a fully nonlinear, fully dispersive, 4th-order Boussinesq numerical model.

Study examples from north to south are: (1) The Ribbon Reef Slide, the largest in the northern region. It extends over 100 km^2 from ~2000 m depth down to 2260 m, and remobilized at least 0.75 km^3 of slope material. The depositional area shows a distinctive suite of cohesive blocks up to 2 km long and 40 m in height, with a runout length of ~16 km; (2) The Gloria Knolls Slide, which is the largest landslide complex on the margin. This landslide forms a 20 km along-slope and 8 km across-slope indentation in the margin that remobilized ~32 km^3 of sediment, leaving a steep headscarp up to 830 m in height. The main depocentre comprises a cluster of km-scale knolls and over 70 smaller debris blocks; (3) The Bowl Slide is a landslide complex indented in the shelf-edge paleo-Burdekin river delta and extends down to >1000 m. It comprises three main headscarps at 100-130 m, 200-250 m and 450-600 m. Collapsed material forms a 200 km^2 cone-shaped debris field that extends over 16 km from the source area; (4) The Viper Slide is a shallow-water (90-250 m), small (~19 km^2, 0.025 km^3) and 7 km-wide shelf-edge slope failure that left a cone-shaped blocky deposit 5.5 km long and ~25 m thick.

Simulations indicate that the study landslides are potentially capable of producing 1-20 m tsunami waves at the failure source. Initial wave amplitudes are highly sensitive to several parameters, including initial submergence depth, slide volume, slide thickness, and run-out distance. Maximum run up heights at the coast are considerably reduced due to the GBR's capacity to block and attenuate wave energy, where reef-scale structural complexity counteracts deleterious focusing effects triggered by the submerged platforms.

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FORMING PROCESS OF A WATERFALL ACCOMPANYING WITH SLOPE FAILURE CAUSED BY 18TH CENTURY EARTHQUAKE, CENTRAL JAPAN

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The “Oya-Kuzure” slope failure is located in the source area of Abe River, Shizuoka Prefecture, central Japan. It is estimated that many failure events had occurred repetitively around the area[1] and that a large-scale failure occurred early 18th century caused by the Hoei Earthquake (M: 8–9), one of the Nankai Trough Earthquake[2, 3]. The landslide slope is 700 m high and 1800 m wide with an estimated 120 million m^3 in volume[1]. Deposits originated from the 18th century slope failure filled the upper reaches of Abe River[1].

The Akamizu Fall, which is located on ca. 0.3 km downstream of the confluence of Oya River originated from the “Oya-Kuzure” with Abe River mainstream, flows down on the Miocene shalestone. Investigation on distribution of shalestone and debris flow deposit around the waterfall showed that debris flow deposit detoured the waterfall. It implies a possibility that the Akamizu Fall was formed by shortcut of the incised meander valley across shalestone ridge due to filling incised valley by deposition of debris flow deposit and following differential erosion between shalestone and unconsolidated debris flow deposit. Estimated paleo-current based on average directions of imbrication of 50–80 clasts in the debris flow deposit at 4 sites show good accordance with estimated meander channel detouring the waterfall. Orientation of long axes of measurable clasts almost accord to paleo-current.

As a result of survey, we concluded that filling of a valley by debris flow deposit caused shortcut of stream of the Abe River across a ridge and generation of the Akamizu Fall. Similarly, old valley around the confluence of Oya River with Abe River mainstream was filled by debris flow deposit, and new valley was made on slope of the ridge. Debris flow deposit and the Akamizu Fall in the upper reaches of Abe River shows threat of large-scale slope failure accompanying the Nankai Trough Earthquake, which we did not experience in the 2011 Tohoku Earthquake, Japan.

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SLOPE SEDIMENTARY PROCESSES BETWEEN STORFJORDEN AND BEAR ISLAND FANS: FIRST RESULTS OF NEW CRUISE IN THE POLAR NORTH ATLANTIC

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The Barents Sea is well known for its important influence of glacial advance and retreat on seafloor morphology and on slope sedimentary processes. In this high-latitude continental shelf, submarine mass movements are common processes. Several through mouth fans (TMF) have been identified and described by many authors[1,2,3]. The northernmost located at the mouth of the Barents Sea are Storfjorden, Kveithola and Bear Island fans. The study area is located south of Spitzbergen between Storfjorden fan and Bear Island. During the MOCOSED cruise in October 2017, new sedimentary data were acquired in this area. High resolution bathymetry and subbottom profiles were collected on the continental slope between 1000 and 2000 m water depths. Three gravity cores were taken off among which one of 10 meters long which has been collected in a large landslide separating the Storfjorden trough mouth fan and the Kveithola trough mouth fan[2]. This new data analysis brings new knowledge about the sedimentary architecture and the composition of sedimentary deposits of the northern gravity systems in the Norwegian-Greenland Sea.

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DEGLACIAL AND POSTGLACIAL PALEOSEISMOLOGICAL ARCHIVES IN MASS-MOVEMENT DEPOSITS OF LAKES OF SOUTH-CENTRAL QUÉBEC

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Investigation of seismic activity in southern Québec is important for natural hazard management since two major active seismic zones with many historical records are located in the region: the Western Québec and the Charlevoix-Kamouraska seismic zones, with the latter being the most active in northeastern America. This poster describes a dataset of high-resolution bathymetry imagery, subbottom profiles and sediments cores collected in three lakes (Maskinongé, Lac-aux-Sables and Lake Saint-Joseph) located between two active seismic zones, in south-central Québec. The lacustrine geomorphology observed on high resolution swath bathymetry imagery, acoustic subbottom profiles and the sediment analysis indicate that the lakes were disturbed by seismically-induced mass-movements since deglaciation. Mass-movement deposits (MMDs) were observed on subbottom profiles at three different stratigraphic levels. The position of the MMDs in the stratigraphic sequence of the region and the use of the depositional rate from ^{210}Pb activity on sediment cores from each lake allow the identification of three distinct and major earthquake events: 1) during deglaciation between ~11.1 and 10 ka cal. BP; 2) around 810 ± 370 AD; and 3) the well documented 1663 AD M>7 historical earthquake. The second earthquake event that occurred prior the the 1663 AD event is responsible for remobilizing the largest volume of sediments in the entire stratigraphic sequences of the lakes. However, this event did not necessarily reached a higher magnitude than the historical 1663 earthquake, as its epicenter could have been located closer to the studied lakes or sediments could have been more readily available to be remobilized when it occurred.

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FORMATION OF KNICKPOINTS BY TURBIDITY CURRENTS: LABORATORY EXPERIMENTS

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Multiple knickpoints initiated by morphodynamic interactions between an erodible bed and an overriding turbidity current have been studied on the lake floor of Wabush Lake, Canada. In order to understand the different processes accountable for the initiation and migration of these knickpoints, laboratory studies have been performed to replicate the sedimentological settings and hydrodynamics of Wabush Lake. The laboratory experiments show that the knickpoints are, most of the time, initiated when there is disequilibrium between the slope angle of the delta foreset and the equilibrium slope angle dictated by the turbidity current characteristics. This disequilibrium is typically caused by a change in the flow dynamics on the topset, i.e. the transition between sheet flow and channelized flow. Some other knickpoints are initiated when a hydraulic jump is present at or near a sedimentation front on the foreset. Experimental results show that migration of the knickpoints is controlled by two factors: erosion by the turbidity current and a landsliding process in the knickpoint head scarp. Knickpoint migration has also been observed when no turbidity current is present. The migration of knickpoints in the absence of turbidity currents is explained by a mechanism known as breaching, which cause a slow retrogression of the head scarp of the knickpoints. The knickpoints may reach the shoreline, or may be buried by sediments. Finally, a comparison of Wabush Lake setting with the laboratory observations shows that most of the processes accountable for knickpoint initiation in the laboratory are also present in Wabush Lake. In particular, slope stability analysis done using knickpoint geometry seen in Wabush Lake, and taking into account the geotechnical properties of material derived from laboratory experiments, shows that knickpoint migration can also be explained in Wabush Lake by landslide mechanism, such as what was seen at laboratory scale.

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Submarine Landslides of the Mediterranean Sea: How large, how often

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An updated version of the submarine landslide database of the Mediterranean Sea[1] contains 955 MTDs and 2608 failure scars showing that submarine landslides are ubiquitous features along Mediterranean continental margins. Their distribution reveals that major deltaic wedges display the larger submarine landslides, while tectonically active margins are characterized by relatively small failures. In all regions, landslide size distributions display power law scaling for landslides > 1 km^3. We find consistent differences on the exponent of the power law depending on the tectonic setting. Active margins present steep slopes of the frequency-magnitude relationship whereas passive margins tend to display gentler slopes. This pattern likely responds to the common view that tectonically active margins have numerous but small failures, while passive margins have larger but fewer failures. Available age information suggests that failures exceeding 1000 km^3 are infrequent and may recur every ~40 kyr. Smaller failures that can still cause significant damage might be relatively frequent, with failures > 1 km^3 likely recurring every 40 years. This comprehensive database highlights that our knowledge of submarine landslide dynamics within time is limited to a few tens of thousands of years. Available data suggest that submarine landslides may preferentially occur during lowstand periods, but no firm conclusion can be made on this respect, as only 149 landslides (out of 955 included in the database) have relatively accurate age determinations. The temporal pattern and changes in frequency-magnitude distribution suggest that sedimentation patterns and pore pressure development have had a major role in triggering slope failures and control the mass wasting sediment flux to the deep basin.

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THE EARLY EVOLUTION OF THE XIGAZE FOREARC BASIN IN SOUTHERN TIBET

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The Xigaze forearc basin (XFB) in southern Tibet formed during northward subduction of the Neotethyan oceanic slab and was filled by well-preserved stratigraphic successions which document classical upward shallowing pattern of the forearc basin strata and elucidate the origin of the associated oceanic magmatic rocks. This study measured 6 marine sections of the Chongdui Formation, which represents the very base of the XFB succession, and gained the following main results. In the chert at the bottom of the formation, 26 species and 18 genera including 5 assemblages of radiolarian were identified with the age of late Barremian to late Aptian in Early Cretaceous. In QFL diagram, the detrital rocks in upper Chongdui Formation fall into undissected arc to transitional arc areas. Detrital zircons in sandstones show single age peak of 110Ma, consistent with the age of the Gangdise magmatic arc, indicating the Gangdise is probably the main source area of the Chongdui Formation. Based on these studies, combined with the stratigraphic contact between the Chongdui Formation and the ophiolite, we conclude that the Neo-Tethys Ocean started to subduct, the XFB started to develop and the detrital sediments derived from the Gangdise magmatic arc began to deposit in late Early Cretaceous.

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Contouritic processes on the slope of the South Mozambique margin: sedimentological and stratigraphic study of a recent contourite drift.

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The South Mozambique margin is characterized by the presence of huge contourite drifts, aligned along N-S trend in the distal margin. On the dip-slope profile they appear as intercalated with contouritic terraces from the upper slope down to the continental rise. This study focuses on a recent giant structure interpreted as a contourite drift between 2000 and 2500 m water depth, where the oceanographic regime is dominated by the southward Mozambique Current (MC) at superficial depth (0-2000 m) and the northward North Atlantic Deep Waters (NADW, below 2000m) in the deepest part of the margin.

New multibeam bathymetry, CHIRP sub-bottom profiles, multichannel seismic lines and five piston cores have been collected during the PAMELA-MOZ3[1] cruise in 2016. The cores underwent a full set of laboratory analysis including Multi Sensor Core Logger, XRF corescanner, colorimetry, laser grain-size analysis, radiocarbon and Sr Isotope Stratigraphy (SIS) absolute ages, and stratigraphic calibration based on oxygen isotopes.

The bathymetric analysis and the interpretation of the CHIRP profiles show that recent sediments cover the western side of the ridge. The eastern and southern sides are affected by intense erosion with old sediment outcropping at sea floor. The sedimentary facies on the western side are various, showing bioturbated hemipelagic deposits and sand beds dominated by planktic Foraminifera bioclasts. The fine (mud) component is locally low or absent, indicating a high influence of intense bottom-currents resulting in the winnowing of fine-grained sediment. The sand-size content is vertically variable and increases laterally towards the highest part of the ridge, where the sedimentation appears significantly condensed. Oxygen isotopes analyses on foraminifera and core correlation provide a good stratigraphic framework over the last 920 ka and confirm the sediment condensation with low sedimentation rate towards the top of the ridge.

Erosional processes and condensed sedimentation dominate the Quaternary evolution of the drift (reshaping stage). It contrasts with the constructional stage of the drift (occurred before the Quaternary), inducing fine-grained accumulation at the top of the drift and coarse-grained sediment into channelized structures.

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Seismic and lithological evidence of current controlled sedimentation in the region of the Ceara Rise during the middle-late quaternary

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The Ceara Rise is a bathymetric high in the Cenral Atlantic, that is covered with a thick sequence (>1000 m) of relatively undisturbed lithogenic and biogenic sediments (Curry et al., 1995). The rise represents an unique area swept by the North Atlantic Deep Water and Antarctic Bottom Water and equidistant from sources of their formation. These waters played a crucial role in sedimentation in the Atlantic and notably on the Ceara Rise (e.g. Curry et al., 1995). However, the area remains poorly studied in frame of the fast developing contourite paradigm. This work is focused on seismic and lithological evidence of contourite occurrence in the Quaternary sediment cover of the Ceara Rise. The work is based on seimoacoustic records collected during cruise 9209 of the RV *Maurice Ewing* (1992) using the *Krupp-Atlas Hydrosweep* sub-bottom echo-sounder - 3.5 kHz (>2000 nm of studied profiles), two seismic lines collected using *SES 2000 deep* parametric echo-sounder (central frequency 4 kHz) during cruises 35 and 53 of the RV *Akademik Ioffe* (2011, 2017), nine sediment cores and two grab samples retrieved along the rise in cruises 50 and 53 (2015, 2017). Split cores were subjected to magnetic susceptibility and color reflectance measurements as well as CT-scanning. Grain-size analysis was performed in 1-20 cm steps using the laser particle analyzer both on bulk sediment samples and terrigenous fractions of these samples. Sedimentary structures were also studied in thin sections. A regional map of seismic facies distribution was compiled for the study area. Seismic data revealed vast fields of small sediment waves with a height of 1-8 m. It was found out that sediment wave height depends on water depth. Maximum mean and median wave height corresponds to the boundary between NADW-old and overflow NADW. It might be explained by internal wave activity enhancing the impact of geostrophic current on sedimentation. The smallest sediment waves are related to a mixed zone between AABW and NADW. Below this zone, wave height slightly increases toward the boundary of the main AABW core at depth of 4400-4500 m. Formation of several revealed moats generally resulted from an interaction between ocean floor topography (outcrops of older deposits) and bottom currents. Recovered sediment sections demonstrate intercalation of contourites (in some cases representing turbidites reworked by bottom currents), with turbidites, mass wasting deposits, and probably hemipelagites.

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EVIDENCE FOR LATE PLEISTOCENE AND HOLOCENE BOTTOM CURRENT ACTIVITY IN BAFFIN BAY

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Baffin Bay forms an elongated ocean basin that connects the Arctic Ocean to the Labrador Sea and the North Atlantic via several Canadian Arctic Channels and Davis Strait. The modern ocean circulation in Baffin Bay is cyclonic; the West Greenland Current enters the bay in the southeast and flows northward along the east Baffin Bay margin, eventually turning westward and combining with Arctic Ocean outflow to become the south-flowing Baffin Current that exits the bay in the southwest[1]. The present-day general oceanographic pattern likely existed during the Late Miocene and Pliocene; in fact, large Pliocene contourite drifts are recognized in the eastern and western margin of the bay[2]. Throughout the Quaternary, however, it is thought that the circulation pattern was temporarily interrupted by ice sheet extension in the Canadian Arctic Archipelago that prevented Arctic Ocean inflow to Baffin Bay[3]. The purpose of this study is to examine the geological evidence for Late Quaternary bottom current activity in Baffin Bay, a time when sedimentation within the bay was largely controlled by glacigenic processes.

During the Quaternary, ice sheets carved several transverse troughs across the Baffin Bay continental shelves. Seaward of the troughs, extensive trough mouth fans form the dominant depositional feature along the Baffin Bay slope. Superimposed on the glaciomarine deposits is evidence for contour current processes. The most apparent features are along-slope furrows and moats that mark the east Baffin Bay slope, between Disko and Melville bays, in water depths to 1400 m. A sediment core from a contouritic levee shows that the sediments have a higher silt content than non-levee sediments. Furrows are also present on the southwest Baffin Bay slope off Home Bay; they occur in 1300 m water depth and coincide with elongate pockmarks, however, they are less continuous than the eastern bay examples. Farther south, linear to curvilinear bedforms are present in 500 m water depth on the southwest Baffin Bay slope and likely formed by enhancement of the south-flowing Baffin Current as it encountered Davis Strait. These results show that despite the predominance of glaciomarine processes in Baffin Bay during the Late Pleistocene, bottom currents were sufficiently active to be preserved in the geological record.

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INSIGHTS INTO SANDY CONTOURITE DEPOSITS IN THE GULF OF CADIZ: SEDIMENTOLOGICAL APPROACHES WITH IODP 339 U1389 AND U1388 SITES

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Numerous bottom current-controlled depositional, erosional and mixed features have been recognized in both modern and ancient sedimentary records along continental margins and abyssal plains throughout the world oceans. Moreover, different recent works have demonstrated the relevance of bottom current circulation in shaping the morphology of these regions and conditioning their sedimentary stacking pattern and evolution. Most of the depositional elements (drifts) are muddy but recent work highlighted the occurrence of deep-water sandy bottom current deposits. However, although these sandy deposits generated or affected by bottom currents are of great scientific and economic significance for oil companies, they are still poorly known and therefore they should be deeply explored and evaluated. Consequently, there is a current active discussion for a clear differentiation between sandy contourites, sandy reworked turbidites and pure turbidites deposits. Therefore, the main aim of this research work is to identify the criteria for characterising deep-water sandy contourites in one of the worldwide laboratory for contourite research, the Gulf of Cadiz. This project is funded by the Join Industry Project supported by TOTAL, BP, ENI, ExxonMobil and Spectrum and is done in the framework of "The Drifters Research Group".

The results have been obtained from different analyses carried out on cores from the Integrated Ocean Drilling Program (IODP) Expedition 339 along the southwestern Iberian Margin (SIM), within the Gulf of Cadiz. This project is going to be based on a correlation of detailed grain size analysis, microfacies, ichnological analysis, X-ray Florescence (XRF) scanning data, Computed Tomography (CT), and compositional data for developing a new facies model for sandy contourites. The obtained results are contributing our fundamental understanding of deep-water processes and describes new insights about modern analogues of sandy contourite systems and their principal potential reservoir characteristics.

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IMAGE TREATMENT APPLIED TO ICHNOLOGICAL ANALYSIS OF CONTOURITES: ENVIRONMENTAL CONDITIONS AND RESERVOIR PROPERTIES.

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During the last decades, the study of contourites has been considered a hot topic in Earth Sciences, because of its scientific interest in several disciplines as palaeoceanography or palaeoclimatology, but also in oil industry for hydrocarbon exploration[1]. However, they are relatively poorly known and there is not a solid model for its identification and differentiation from turbidites or mixed deposits. In this sense, ichnological content has been proposed as a potential criterion[1], but it has not been studied in detail and there are just a few ichnological studies of contourite deposits[2]. On the other hand, ichnological research has undergone rapid growth in recent decades, demonstrating their usefulness for numerous disciplines, as sedimentology, palaeoenvironment or hydrocarbon exploration, among others[3]. However, ichnological analysis is sometimes not an easy matter, especially working with cores, and it could be one reason because scarcity of ichnological studies on contourites. During the last years, image treatment has been probed as a very useful tool in ichnological study of cores, providing successful results especially for hemipelagic sediments[4]. Here we present the application of different image treatment methods to facilitate the ichnological analysis on cores from contourite sediments. It makes easier the trace fossils assemblage characterization, supports the quantification of the bioturbation and the estimation of the penetration depth; being useful features to determine palaeoenvironmental conditions associated with these deposits. Moreover, information about porosity and permeability distribution can be inferred, of special interest for fluid flow, and then for reservoir characterization. Therefore, image treatment is revealed as a powerful tool for ichnological analysis of contourites deposits from cores in both, the study of palaeoenvironmental conditions during deposition and the potential interest for hydrocarbon exploration.

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BOTTOM CURRENT INFLUENCE ON SUBMARINE SLOPE CHANNEL COMPLEXES, OFFSHORE TANZANIA

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The interaction of bottom currents with deep-marine sediment gravity flow systems is increasingly recognized globally. The basins offshore East Africa provide an excellent location to study these systems and the facies distribution within them. We present an integrated study that combines 3D seismic, well-log and core data to investigate the influence of bottom currents on Upper Cretaceous to Neogene turbidite systems, offshore Tanzania. Seismic data reveal slope channel and lobe complexes that are strongly controlled by both giant drift deposits and tectonic induced topography. These giant drift deposits and fine grained sediment waves indicate consistent but relatively low flow velocities throughout the Upper Cretaceous and Neogene. Several slope channel complexes show an interaction with associated, strongly asymmetrical, drift deposits. Core and well-log data of this channel type comprises six distinct facies associations indicative of turbidity current and debris flow deposition, with significant bottom current reworking. Interspersed with turbidite channel-fill deposits are sharp-based laminated mudstones, up to 2 m thick, and interpreted as the toes of drift deposits inter-fingering with channel-fills. Combining this information, we interpret these hybrid levee-drift deposits as fine-grained deposits of low energy bottom currents interacting with channelised turbidity currents, by flow stripping of the turbidity current and subsequent reworking of unconsolidated sediments. The toes of the drift deposits interfinger with the channel fill deposits and progressively stepped into the channel fills. This continued action pinned the slope channels to the slope throughout the Upper Cretaceous. We infer that the bottom current drift deposits developed as lee waves, with accretion predominantly on the upstream side, and consequently drift migration was in the upstream direction of the bottom currents. For this reason there is minimal levee development on the side of the channel facing the bottom currents; overbank material was stripped and deposited on the bottom-current upstream facing side of the drift deposit. The facies models differ considerably from 'standard' channel fill models and have important implications for hydrocarbon reservoirs, baffles and seals.

GRAVITY FLOWS AND DEEP CURRENTS INTERACTION IN UPPER SLOPE GULLIES: A HIGH-RESOLUTION STRATIGRAPHIC AND SEDIMENTOLOGICAL STUDY

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Gullies are ubiquitous erosive features in continental margins that are mainly related to downslope, low-density gravitational flows (turbidites), although mass transport and fluids migration may be involved in their genesis and evolution. A series of downslope-trending gullies have been identified on the relatively smooth, slightly concave-upward upper slope of the Gulf of Cadiz, close to the Strait of Gibraltar. They extend from 205-250 m (beyond the continental shelf) to 510-580 m water depth, at the Cadiz Channel northern flank along the middle slope. The occurrence of gullies in this region, characterized by active contouritic processes affected by diapiric ridges, suggests an interaction between bottom current processes and the downslope-trending gullies. This interaction is investigated in this work, based on the analysis of very high-resolution data including swath bathymetry, echo-sounder parametric profiles and sediment cores up to 310 cm long.

The gullies are generally asymmetric, with steeper and higher NE walls. Overall, they are arranged in a dendritic, convergent pattern laterally spaced 0.4-2 km. Parametric profiles show that both the gullies and inter-gully areas are covered by a thin, low reflectivity sheet-like layer, up to 10 milliseconds (two-way travel time) thick, that become thicker in the gullies SE flank. Three sediment cores collected along the axis of one single gully exhibit vertically homogeneous muddy sand and sandy mud, but with clear occasional smaller coarsening-upward sequences. In contrast, two sediment cores collected in the adjacent undisturbed upper slope contain finer sediment (mud to sandy mud) that exhibit general and smaller-scale coarsening-upward trends. These results suggest that the upper slope is affected by an increasing effect of the Mediterranean flow and the gullies are inactive features at present. This may imply that the upper slope of the Gulf of Cadiz records changes in the oceanographic control and turbiditic activity probably related to changes in the vertical distribution of water masses with glacio-eustatic cyclicity.

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EVIDENCE OF COARSE-GRAINED CONTOURITE FACIES OFFSHORE MOZAMBIQUE

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Although contour or oceanic bottom-currents were previously considered as a minor contribution to the sedimentary dynamic, and their deposits exclusively muddy, many studies during the last years highlighted their importance in shaping the continental margins and interacting with the downslope turbiditic dynamic. Contourites are now defined as sediments deposited or substantially reworked by the persistent action of bottom currents[1].

The South-Mozambique margin displays a series of terraces built by plastered and detached contouritic drifts from the upper slope down to the abyssal plain. The PAMELA-MOZ03 scientific cruise[2] has revealed occurrence of coarse-grained contourite facies deposited over one of these terraces. The questions raised by this discovery are related to the origin of the morphologic feature, its recent dynamic and evolution, the characteristics of these facies and the associated processes. Five piston cores cut at 1850-2050m water depth in superficial sediment let appear presence of sand beds dominated by planktic Foraminifera bioclasts, interpreted as contourite channel infill based on facies and mapping of alongslope channels. The core cut at the contourite crest presents a particular facies of bioturbated planktic foramifera sand that corresponds to a deposit affected by probably intense bottom-current, resulting in the winnowing of fine-grained sediment. It is therefore interpreted as a contouritic condensed carbonate sand deposited along a 12 km-long wedge imaged on 2D seismic.

Coarse-grained contourite facies (either silicoclastic or carbonate) is now proved to occur where favorable conditions are gathered: 1) Availability of sand supplied by turbidites or in-place pelagic carbonate bioclasts, 2) Persistence of hydrodynamic regime, 3) Sea floor topography resulting in acceleration of bottom currents for on-site winnowing of fine particles. A new model integrating these components can be proposed and defined by geometrical and seismic amplitude characters.

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EVOLUTIONARY MODEL OF A FAULT CONTROLLED CONTOURITIC DEPOSITIONAL SYSTEM FORMING A HABITABLE ENVIRONMENT FOR COLD WATER CORALS AT THE ANGOLA CONTINENTAL MARGIN

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Contouritic Depositional Systems (CDS) comprise sedimentary deposits and erosional features, which develop under the influence of the same bottom water mass, and record paleo-variability of current direction and intensity. Therefore, they draw major scientific interest as archives for paleoceanographic reconstructions. Especially CDSs, which are genetically related to small-scale seafloor topography, react highly sensitive to changes in the ambient current regime, since the bottom current is locally amplified by the interaction with the seafloor topography. Such settings gain additional complexity when topographic features change over time, as it is the case for both, active faults and the growth of Cold Water Coral (CWC) mounds. The impact of topography changes on the local current regime and subsequently the sedimentary record could obscure the record of paleoceanographic variability. Thus the detailed interplay of processes needs to be understood before the paleoceanographic information can be extracted.
This study explores a unique setting at the border of a salt raft in the Kwanza Basin at the shallow Angola continental margin. High resolution multichannel seismic data and multibeam bathymetry, collected during R/V Meteor Cruise M122 in 2016, are used to investigate the spatio-temporal evolution of sediment architecture, the role of faulting related to salt tectonics and the position and growth of CWCs. Integrated data analysis allows to identify indicators for an active bottom current regime, including contourite channels, separated mounded drifts and erosional surfaces, from the seafloor to 300 mbsf related to a fault bordering a salt raft. Furthermore, active and buried faults are ubiquitous in the study area. At the seafloor CWC mounds of heights up to >100 m and widths between 400 and 1000 m occur in chains in water depths between 200 and 500 m. CWCs appear to be rather recent features since only few superficially buried mounds have been found restricted to shallow water depth (<300 m). The CDS, however, is older and CWC growth starts late within the active CDS, indicating that it has developed a habitable environment for CWCs. The showcase of this study is a detailed analysis of the contourite channels as well as separated mounded drifts on both sides of the most prominent, 13-km long, N-S stretching mound chain which is underlain by a normal fault. The eastern channel and drift are fault-controlled, formed much earlier than the CWCs, and underwent several cycles of channel filling and erosion, suggesting significant changes in the local current regime over time. Contrastingly, the western channel succeeded the CWC formation, which suggests that it is formed by the interaction of bottom currents with the CWC mounds. The conceptual evolutionary model presented in this study deciphers the interaction of bottom currents with the active salt rafting process as well as eventual CWC mound formation. It is an important step towards a sound paleoceanographic reconstruction from a sedimentary record, which is strongly influenced by syn-sedimentary changes of local topography.

DEEP-WATER BOTTOM CURRENT DEPOSITS FROM CYPRUS: AN ANCIENT ANALOGUE FOR CONTOURITE TERRACES AND PLASTERED DRIFTS?

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One of the best examples described in the literature of ancient bottom current deposits come from the Eocene to the early Miocene sucession Lefkara and Pakhna formations (Cyprus). During four field campaigns (2014, 2015, 2016 and 2017) *The Drifters Research Group* has been studying these deposits in order to understand the sequence of sedimentary facies to compare this with analogue deposits in modern / recent deep-water environments. Field campaigns have been undertaken for the identification of the best outcrops at the Petra-Tou Romiou, Agios Konstantinos, Kalavassos and Korfi localities. Details sedimentary logging, and sedimentary and ichnological analyses were carried out. A revised chronostratigraphic framework was established, based on a study of planktonic and benthic foraminifera and nannofossils, improving the age-estimates of the studied sections compared with previous work. Moreover, thin section analysis, direct and indirect measurement of porosity, scanning electron microscopy for elemental analysis and X-ray diffraction for mineral analysis, have been executed. The dominant sedimentary facies consist of calcarenites, chalks, cherts, marls and calcilutites interpreted as the result of contourites, turbidites, reworked turbidites, and hemipelagic and pelagic depositional processes acting along the continental slope setting. Sandy contourite beds are identified in three main packages and, although digenetic processes have been intense, parallel lamination, cross-lamination, banding, flaser structures and dune-like geometries have been recognised. The porosity values of these deposits exceeds of 10% and bioturbation is high throughout. The ichnofacies indicate a general shallowing upward trend through the succession. These preliminary results reveal that microfacies, ichnological features and sedimentary structures could be diagnostic criteria for the determination of sandy contourites. Their characteristics in the studied outcrops are very common in modern deep-water sedimentary environments (e.g., contourite terraces and plastered drifts) and they are of great scientific and economic significance, but further research work is needed for their better understanding and distinction from other deep-sea deposits.

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INTERACTION BETWEEN GRAVITY FLOWS AND CONTOUR CURRENTS ALONG THE SOUTHERN MARGIN OF THE ORDOS BASIN (CHINA) – A STUDY OF THE ORDOVICIAN PINGLIANG FORMATION

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The Late Ordovician Pingliang Formation, accumulated along the southern margin of the Ordos Basin, contains eleven lithofacies, grouped in five facies associations. These facies associations represent deep-sea autochthonous sediments, several types of debrites, turbidites and contourites, but also sediments that consist of fine-grained turbidites that were reworked by contour currents. Though much rarer, there is some evidence that also contourites have been reworked by turbidity currents, but the evidence is not unequivocal, probably because the reworked sediments were, in turn, reworked again by the contourite current.
The various lithofacies are concentrated in different parts of the study area: micritic contourites and debrites are concentrated in the eastern part, debrites consisting of conglomerates and of sandstone and siltstone turbidites are concentrated in the middle part, and calcarenitic turbidites, contourites and reworked turbidites occur in the western part. The contour currents ran parallel to the contour lines from east to west. Whereas most of the contour current kept moving westwards in the eastern part of the study area, a minor part split off and followed a half-circular pathway through the Fuping Graben; its velocity became reduced here, so that micritic contourites were deposited. Large turbidity currents and debris flows developed in the middle part of the study area; due to their high energy, they destroyed all earlier deposited contourites, so that contourites are not present here anymore. The velocity of the contour currents was increased locally when they entered the confined environment of the Qiliangshan-Qiling Ocean Trough in the western part of the study area. The relatively high energy of the contour currents here resulted in calcarenitic contourites.

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INTERACTIONS BETWEEN ALONGSLOPE AND DOWNSLOPE PROCESSES ASSOCIATED TO THE LE DANOIS CONTOURITE DEPOSITIONAL SYSTEM (NE ATLANTIC): IMPLICATIONS FOR THE SPATIO-TEMPORAL EVOLUTION OF CONTOURITES IN CONFINED BASINS

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During the last decade, more attention has been paid on the interaction between alongslope and downslope processes, due to their significant role in testing the contouritic diagnostic criteria [1]. The Le Danois Contourite Depositional System (CDS) is located at the Cantabrian continental margin, NE Atlantic. Based on high to ultra-high seismic reflection data, a unique evolution model of a mixed contourite-mass movement system has been derived from this study area. From old to young, seven seismic units (U1 to U7) bounded by major discontinuities (H1 to H6) have been identified. Between the Le Danois Bank and the continental shelf, depositional and erosional features of contourites, slide scars and mass-transport deposits (MTD) dominated the palaeo-geomorphology of the intraslope basin (443 to 1070 m). The first observation of contourite features (a 17 km^2 plastered drift) is from U4 at the foot of the Le Danois Bank. Throughout U5 until the present day, interbedded MTD (30-40 ms TWT thick) and contourites (40-60 ms TWT thick) generated within the southern edge of Gijón Drift. The interbedded stacking patterns evidently indicate short-term disturbances of mass-wasting processes on the build-up of contourite drifts. A large area of MTD occurred at the southeast border of the Gijón Drift from U6 to the present day. The MTD gradually deflected in an alongslope direction with an increased volume from U6 (30 km^2) to the present day (90 km^2). The localized enlargement and deflection of this MTD could be related to the interaction between bottom-current and mass-wasting processes. This interaction, in turn, significantly limited the extension of the Gijón Drift. Within U6 and 7, slide scars locally thinned plastered drifts (from 30 to 20 ms TWT) at the southern flank of the Le Danois Bank, and widened the Le Danois Moat (2 km in U5 and 3.6 km in U6, 7). As such, the spatio-temporal evolution of contourites in the study area was partly limited by mass-wasting processes.

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BOTTOM-CURRENT CONTROLLED EROSION AND DEPOSITION ON A PELAGIC CARBONATE PLATFORM: MICROFACIES OF THE GIVETIAN-FRASNIAN LIMESTONES OF THE NORTHERN TAFILALT PLATFORM (MOROCCO)

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Although the facies and facies architecture of current-derived sediments in modern ocean basins have been mapped and preliminary described, little is known about facies, spatial distribution, temporal occurrence and facies architecture of fossil contourites in ancient marine basins. The ongoing project focuses on fossil calcareous contourites formed during Middle-Late Devonian time with narrowing oceanic passageways between the approaching continents, Gondwana and Laurussia. As a first step, the study aims to record, map, and describe the occurrence of current-induced unconformities and current-derived facies of the Devonian of the pelagic Tafilalt carbonate platform, in order to provide more reliable criteria for identifying contourites.

Detailed sedimentological field work, backed by lithologic logs and descriptions of microfacies, is supported by representative thin sections and measurements of paleo-current patterns. Well-established biostratigraphic conodont zones provide key information on temporal distribution of erosional episodes on the Tafilalt platform.

Preliminary results in the study area of the Tafilalt-platform, Morocco, support the interpretation of complex platform-wide erosional episodes and depositional events of calcarenites during the Upper Givetian / Lower Frasnian boundary. These calcarenite facies are showing a differential distribution pattern on multiple scales, ranging from microfacies changes to regional occurrence, and include cross-laminated grainstones of current-oriented dacryoconarids, as well as normal and inverse graded grain- and packstones locally changing into laminated, burrow-mottled pack- and wackestones. The observations are discussed in the context of the platform development, acting as a link between erosion, sediment bypass, and partial deposition within a fossil CDS (contourite depositional system). This is being expressed by large scale regional erosion, sedimentary traction structures and pulses of coarse-grained, current-aligned styliolinite sediment accumulation in an otherwise pelagic environment.

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SEDIMENTARY APPROACH TO THE EVOLUTION OF A CONTOURITE TERRACE IN THE NW IBERIAN PENINSULA

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The sandy contourite terraces of the NW Iberian Peninsula are still poorly studied from a sedimentological point of view. The main objectives of this work are to understand the mechanisms or sedimentary processes that form and affect these low-sedimentation sandy areas during the latest Quaternary and to analyze the sedimentary evolution of the Galician Margin.
The Core SEL08-02 (165 cm; 1127 water depth) mainly consisting of poorly sorted sandy mud and muddy sand sediment, was retrieved from a middle slope contourite terrace, in A Selva. This core was studied following a multidisciplinary methodology: grain size, physical properties and composition of the sediment; Computed Tomography (CT)-scan data and ichnological analysis, as an integral approach to interpret the sedimentary building up of this area. Three facies have been identified and linked to hemipelagic, turbiditic and contouritic sedimentation processes: a) low bioturbated mud; b) sand to mud and c) planktonic foraminifera sand strongly bioturbated from base to the top throughout. This data reveals two different incidences of the Mediterranean Water (MW) on the terrace of the A Selva region during the last glacial cycle. The first stage, not affected by the MW, started with hemipelagic sedimentation and was followed by turbiditic events. During the second stage, the enhanced MW reworked the previous turdite deposits, which implied a decrease in the sedimentation rates and generated a condensed facies at the top of the core. Present results are providing new insights about the recognition of condense sequences and hiatus in modern marine environments. Furthermore, this model provides a good analog for ancient sedimentary records in deep-marine environments affected by bottom currents.

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BOTTOM CURRENT-CONTROLLED QUATERNARY SEDIMENTATION AT THE BASE OF THE MALTA ESCARPMENT

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The influence of bottom-water circulation in deep-sea sedimentation is still poorly understood, but the perception of its importance is steadily increasing. New findings of contourites - sediments deposited or substantially reworked by the persistent action of bottom currents - have been discovered in many different settings in every ocean basin and even in lakes. Bottom currents, predominantly unidirectional water currents that are in contact with the sea-floor of a sidewall, are in fact pervasive and observed at all latitudes. Such currents, which are affected by tides, eddies, deep-sea storms, internal waves and tsunamis, are focused against continental slopes, escarpment and around topographic obstacles. They are capable of actively eroding, transporting and depositing sediments on the seafloor, as well as generating bedforms and reliefs. For this reason, bottom currents may pose a risk to deep-sea infrastructures, such as pipelines and telecommunication cables, or scientific observatories. The study of contourites is also crucial for hydrocarbon exploration, as well as palaeoclimatological and palaeoceanography reconstructions.
In the nineties, large-scale asymmetric, climbing bedforms were identified at the base of the Malta Escarpment only on the basis of single-channel Sparker seismic reflection profiles. These bedforms were tentatively ascribed to the action of focused bottom currents. We now describe these bedforms on the basis of recently acquired multi-channel seismic, sub-bottom echosounder and multi-beam bathymetry data, and discuss their origin by integrating these with available and hydrographic information.
These bedforms, lying at 2500 m water depth, have a height of ~30-50 m, a steeper (by about 2°) southern side, and are elongated along an ENE-WSW trend. The regular northward migration of these bedforms is roughly assumed to have begun at 650 Ka, in association with the Mid Pleistocene Transition, which may have led to a strengthening of the bottom currents.
We aim at understanding if these features are still actively migrating and if they are a potential hazard for infrastructures, and at deciphering their origin and their palaeoceanographic significance.

EVOLUTION DURING THE LATE MIOCENE TO THE PRESENT TIME ALONG THE SOUTHWESTERN IBERIAN MARGIN: SEDIMENTARY IMPLICATIONS

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The Neogene basins in the Gulf of Cadiz and west off Portugal have undergone a very complex geodynamic and sedimentary evolution since the Late Miocene to the present time. This is associated mainly with the convergence between the Eurasian and African plates that has occurred during that period. In addition, climatic, eustatic, and oceanographic processes have been prevalent, creating the diverse depositional systems that we identify in the basin today. These include down-slope (turbidite and mass transport deposits), along-slope (bottom current deposits), mixed (along- and down-slope) and hemipelagic / pelagic systems. The main objectives of this work are to evaluate the sedimentary stacking patterns and the tectono-stratigraphic evolution of the Late Miocene to present day successions in these Neogene basins (Algarve and Alentejo), decoding the influence of bottom current deposition. We identify significant changes in sedimentation style and dominant sedimentary processes, coupled with widespread discontinuities. During the Late Miocene and Pliocene, turbiditic and mixed systems were developed. Whereas, large contourite drifts have been determined along the slope during the Tortonian and Early Messinian as well as during the Late Pliocene and Quaternary due to the influence of bottom currents, which enabled the prevalence of contourite depositional system in these Neogene basins. This work demonstrates that bottom water circulation and associated processes are important in shaping the seafloor and controlling the sedimentary stacking pattern on continental margins, with important sedimentary and palaeoceanographic implications.

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EROSION AND DEPOSITION AT THE SUB-ANTARCTIC FRONT: PRE-CONDITIONING MECHANISMS FOR SUBMARINE MASS FAILURE

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The Sub-Antarctic Front (SAF), one of the three main jets of the Antarctic Circumpolar Current (ACC) is constrained by the bathymetry of the North Scotia Ridge, in particular the Burdwood Bank. The SAF flows round the eastern margin of the bank, in a cyclonic loop through the Falkland Trough and then north-eastward across the Falkland Plateau. This jet, with measured velocities locally exceeding 50 cm/s[1] (and possibly locally much higher), flows across a steeply dipping fold-and-thrust belt on the northern slope of the North Scotia Ridge. We use high-resolution 3D seismic data acquired across the slope and basin floor and an extensive 2D regional seismic dataset, to map out a number of key features that allow us to understand the impact of the associated bottom currents. In particular, we identify a deeply-incised moat that bisects the eastern slope segment, and which appears to affect the structural evolution of the fold belt; a number of small plastered drift deposits on the north side of the moat; an extensive plastered drift deposit and sediment wave field that occur on the upper slope to the south of the main jet; and a second moat which has incised and undercut the base of the same slope. This combination of along-slope sediment transport, sedimentation on the upper slope and erosion on the lower slope, has resulted in an inherently unstable continental slope to the north of the Burdwood Bank, with evidence from the adjacent basin for repeated submarine landslides. These have all come from a discrete location on the slope, where the thickest contourite deposits are accumulating. Numerical models of tsunamis resulting from these ~100 km^3 landslides indicate that a repeat occurrence would pose a significant risk to human populations in the South Atlantic. This research highlights the specific risk of catastrophic slope failure associated with contourites deposited by the SAF, but also of potential preconditioning mechanisms for other continental slope settings with strong bottom currents.

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MIXED SYSTEMS, MIXED PROCESSES AND MIXED CRITERIA: THE VIEW FROM A GLACIAL MARGIN

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Contourites commonly interbed with turbidites, mass-transport deposits, and "normal" hemipelagic deposits, but it is the distinction from turbidites that has created the most debate. The distinction depends on the scale of observation. The most universal evidence for contourite deposition comes from seismic data, whereas evidence for turbidites is more strongly rooted in bed-scale observations. Many 20th century turbidite scientists working in Phanerozoic successions argued that anything that was unbioturbated could not be a contourite.

The timescale of a mixed system influences the tools to be used and the criteria to be applied. If the system is turbidite at sea-level lowstands and contourite at highstands, that may be recognisable from seismic if the periodicity is long enough. But if the system has a turbidity current for one week a year and contourite reworking and deposition for the remaining 51 weeks, that is a quite different problem.

Turbidity current channels and fans are common on many continental margins with contourite drifts. In most settings, contour currents flow at 0.1–1 m/s, generally substantially slower than most turbidity currents (0.2–20 m/s) and are thus unlikely to significantly divert the course of turbidity currents, which flow because of the pressure differential between the turbidity current and ambient seawater. Any diversion is difficult to detect because contour currents will generally act in the same direction as Coriolis force, which has a significant effect on dilute and slow turbidity currents at high latitudes.

In unbioturbated sediment, diagnostic criteria for turbidites are (1) evidence for rapid deposition from a large sediment load; (2) compositional evidence for an exclusively downslope sediment supply; and (3) downslope paleocurrent indicators. Features such as erosional surfaces and low aggradation ripples are not unequivocal evidence of contourite reworking. If the geometry of the system is well known, oblique upslope paleoflow is diagnostic of contourites.

Glaciated continental margins play an important role in the growth of contourite drifts. Petrologic data on the eastern Canadian margin show the dominant role of marine ice-margin supply to drift growth. Distinct compositional data allows glaciomarine sediment to be tracked as turbidites, contourites and freshwater plume deposits. For example, on the Scotian Rise, red silt-mud couplets were deposited by turbidity currents derived from fallout from surface plumes carried by surface currents along the continental margin, rather than being transported by the Western Boundary Undercurrent from overbank turbidity current muds on Laurentian Fan. The paucity of overbank turbidite sands on glaciated margins means that there is little evidence for sandy contourites interbedded with turbidites.

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THE ODYSSEA DRIFT (ROSS SEA, ANTARCTICA)

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The Hillary Canyon is one of the main conduits for dense shelf water forming in the Ross Sea, over-flowing the shelf edge and transforming into the Antarctic Bottom Water (AABW). The main changes in past ocean circulation are recorded in the adjacent sediment drift. A wealth of data was acquired on the drift west of the Hillary Canyon during the 2017 OGS Explora expedition, which included the PNRA ODYSSEA and EUROFLEETS ANTSSS projects. The multi-disciplinary dataset includes: single channel seismics, sub-bottom profiling, multibeam bathymetry, gravity and box cores, XBT, water sampling, CTD (with turbidity, oxygen, and fluorescence), L-ADCP, and vm-ADCP. The sediment drift, which we named Odyssea Drift, is elongated in the NNE direction with dimensions of several tens of km. Prominent landslide scars and a giant landslide deposit, over 200 m thick and spanning 750 km^2, are visible on the drift. The sediment cores evidence well-developed cross beddings suggesting the effect of vigorous bottom currents. The oceanographic data show that the 200 m thick bottom layer was occupied by AABW (Antarctic Bottom Water with potential temperature < 0° C). The deeper layer displays also strong currents, mainly flowing along the isobaths. The energetic mixing between the along slope currents coming from the basin interior increase the turbidity of the bottom boundary layer. Our results will be merged with those obtained from the 2018 IODP drilling expedition 374 to develop a conceptual model of sediment deposition relating to marine-based ice sheet and oceanic processes along the Ross Sea continental margin occurring through the Neogene and Quaternary.

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LARGE-SCALE SEDIMENT WAVES OVER THE GULF OF ROSES SLOPE (NW MEDITERRANEAN) FORMED BY DENSE SHELF WATER CASCADING

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Sediment transport and seafloor shaping resulting from bottom currents enhanced by dense shelf water cascading (DSWC) events have been described in different margins around the world [1, 2].
In the NW Mediterranean, most of the studies addressing DSWC sedimentary processes have been mainly focussed within submarine canyons and/or in shelf areas, whereas the open slope region has received less attention. This study presents new bathymetric and high-resolution seismic data over the Gulf of Roses continental slope that allowed re-interpreting the formation processes of large-scale sediment waves. Results suggest that these waves, previously related to slump and creep-like deformation[3], are most likely formed by bottom currents generated by overflows of dense water, which cascade downslope in an oblique angle with respect the main bathymetric contours. Single-channel reflection seismic profiles show that sediment waves over the outer shelf and slope are continuously developed within Quaternary unconformity-bounded seismic units. The unit boundaries can be correlated with Pleistocene eustatic oscillations, interpreted as erosional surfaces created during 4th order sea-level falls (~100 ka).
This study offers new insights on the role of DSWC processes and associated off-shelf sediment transport reshaping the morphology of the open-slope regions and contributes to a better understanding of their sedimentary evolution.

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SEDIMENTARY MODEL OF A MIXED DEPOSITIONAL SYSTEM: THE PACIFIC MARGIN OF THE ANTARCTIC PENINSULA

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Downslope turbidity currents and alongslope bottom currents are common processes along continental margins. When the two processes act during successive times, interaction can be recorded by variations of sediment body morphology, alternations of turbidite and contourite deposits or by the presence of bottom current reworked turbidites. However, the ability to discriminate contourites from turbidites has proven to be difficult in mixed systems, where multiple processes interact with each other. One such system is identified on the offshore Pacific Margin of the Antarctic Peninsula, where contourite drifts and turbidity channel systems occur on the continental slope and rise. This work aims to better understand how bottom currents and turbidity currents controlled the development of a mixed depositional system in the Pacific Margin of the Antarctic Peninsula. Furthermore, knowledge in this margin is still scarce, concerning: i) the role and interaction between alongslope bottom currents and downslope turbidity currents; ii) the relationship with the main regional events; and iii) how to discriminate the mechanisms responsible for the formation of contourite features and the factors controlling the formation of turbidite features and how they operated through time. To approach these objectives, we employed high-resolution datasets: high-resolution seismic data, swath multibeam bathymetry, sediment samples and X-Ray Fluorescence data of the SEDANO Cores 11, 12, 13, 18 and 20. Its interpretation and integration aims to propose the construction of a sedimentary model for a modern mixed depositional system, which will clarify the role and influence of bottom currents versus turbidity currents. This modern mixed system could be a good analogue for a better understanding of similar mixed depositional systems in the ancient record.

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REVITALIZING ICHNOLOGICAL APPROACH FOR THE CHARACTERIZATION OF CONTOURITES AND MIXED DEPOSITS

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The study of contourites is held to be crucial for at least three fields: paleoclimatology and paleoceanography, slope-stability/geological hazard assessment, and hydrocarbon exploration. Thus, characterization of contourites and differentiation respect to associated facies reveals of special interest. Bioturbation is widely considered to be a diagnostic feature of prime importance for contourite characterization, although some researchers assign only minor relevance to bioturbation. However, detailed ichnological analyses of both contouritic and mixed (turbidite and contourite) deposits are relatively scarce. In the last years, *The Drifters Research Group* has been studying contouritic deposits in order to understand the sequence of sedimentary facies, from a multidisciplinary, integrative research, including a detailed trace-fossils analysis. Ichnological approach includes variations in the trace fossil assemblage (i.e., diversity, relative abundance), and ichnological attributes (size, density, tiering structure, infilling, etc.), allowing ichnofabric characterization. Moreover, ichnofacies analysis is conducted trying to find a particular ichnofacies for contourites and mixed deposits. Trace fossil analysis is being conducted on outcrops and cores, providing significant information about paleoecologic and paleoenvironmental conditions during deposition of bottom current sediments, at mid/outcrop-scale and at small-scale, in the range of the contourite facies model. Several examples from Late Oligocene and middle Miocene calcareous contourites at Petra Tou Romiou type section, southern Cyprus, and from core deposits of the Pleistocene Faro Drift, Gulf of Cadiz, southern Spain, illustrate the usefulness of the ichnological analysis in contourite research.

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SMALL-SCALE EROSIONAL AND DEPOSITIONAL FEATURES ON THE EWING TERRACE AROUND THE MAR DEL PLATA CANYON (OFF ARGENTINA)

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The continental slope off Argentina represents a highly dynamic depositional environment and is also a key location of the global thermohaline circulation due to the confluence of northward and southward flowing contour currents. Results from several cruises show that this region offers a unique depositional setting to study the fundamental interaction between bottom currents and sediment deposition. Moreover, the sediments deposited in contourites and canyons represent valuable high resolution archives to study paleoceanographic changes. Generally, the margin off Argentina is characterized by a broad shelf and a slope dominated by along-slope and down-slope sedimentation and depositional processes. Current controlled sedimentation started in Late Paleogene times and constructed along the Argentina margin major contourite depositional systems (CDS), consisting of both erosional and depositional features like several large terraces.
Two of these terraces, the Ewing Terrace and the La Plata Terraces, were the target of the RV SONNE Cruise SO 260, which recently took place in January/February 2018. During the cruise, high-resolution seismic data as well as sediment echosounder and swathsounder data were gathered. Additionally, conventional and MeBo coring were carried out. The surveying focused on areas south and north of the Mar del Plata Canyon, which is up to 1500 m incised into the Ewing Terrace in water depths between 1000 m and 4000 m. Around this canyon the seismo-acoustic data provided an image of several contouritic features as smaller scale and larger scale drift bodies, erosional surfaces, contouritic channels, and minor as well as larger elongated depressions. The size and shape of these erosional depressions vary significantly, however, most of them are characterized by a clear asymmetry in terms of their flanks: Whereas one flank reveals small-scale terraces, the opposite flank is characterized by the occurrence of small drift bodies. Additionally, some depression are refilled, and coring shows that the filling is dominated by sandy sediments indicating the impact of a highly dynamic current regime. However, the appearance of the small-scale depressions on the nearly flat terraces suggests that non-tabular bottom currents interact with the seafloor. Together with data from former cruises, the new collected data will also allow a comparison between the northern and southern Ewing terrace and the role of the canyon in the contouritic depositional system.

Geochemical proxies and hiatuses in contourites of the Gulf of Cadiz

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Regional unconformities are common and significant features of contourite depositional systems worldwide. They are caused by accelerated bottom currents that erode and winnow the seafloor or prevent deposition from occurring. Such episodes of increased bottom current activity may be linked with major tectonic and/or climatic events, as well as to changes in flow pathways and sedimentation patterns. In the Gulf of Cadiz, hiatuses are recorded at all six sites, under the influence of the Mediterranean Outflow Water, that were drilled during IODP Expedition 399. They are expressed either by a marked gap in sedimentation, or as a much condensed succession.
The two most significant hiatuses in the sedimentary record after the Miocene–Pliocene boundary unconformity, are the late Pliocene Discontinuity (LPD, 3–3.2 Ma) and the early Quaternary Discontinuity (EQD, 2–2.4 Ma).
We evaluated the nature of changes in the patterns of sedimentation, elemental distribution and microfauna across both these hiatuses. At sites U1387 and U1391, there is extensive development of fine dolomite crystals within the sediment, at the expense of both biogenic and lithogenic components. This is combined with framboidal pyrite formation and an extensive network of iron-sulphide filled *Trichichnus* trace fossil filaments.
The original composition of the contourite around the hiatuses may have been overprinted by the carbonate authigenesis. However, the distribution of grain size and stable heavy minerals remain largely unaffected. The LPD and EQD at the sites of investigation are associated with significant increase in current velocities as evident from the high Zr % and Zr/Al ratio and the increase in main grain size. Foraminiferal analyses showed marked changes in the deep-water oxygenation status from the late Pliocene towards the early Quaternary. This is particularly evident at site U1387 where the LPD and EQD hiatuses run together as one longer hiatus of around 1 My duration. Our results suggest that the dolomitisation along the unconformity surface is linked with fluid seepage from depth. These fluids encountered a partially calcite-cemented baffle to flow, which was originally due to incipient hardground formation at the seafloor, and this provided the calcite template for replacement by dolomite.

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FORMATION AND EVOLUTION OF GLAUCONITE IN THE DEMERARA CONTOURITE DEPOSITIONAL SYSTEM

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Along the French Guiana and Surinam margin, the Demerara plateau forms a bathymetric promontory and is defined as a marginal plateau[1]. This relief includes the continental shelf gently deepening between 200-3200 m of water depth and limited by the continental slope. This relief controls the bottom current speed and is likely at the origin of the recently described[2]contourite deposits. Those are generally made of grey-greenish mud and foraminifer-rich sand. The peculiar feauture is the occurrence of glauconitic grains, mainly filling the foraminifer tests. Inside those tests, neoformation of Fe-smectite and interstratified smectite/glauconite can occur during early diagenetic redox processes. The subsequent neoformation phases are also suggested by evolving pigmentation of glauconitic grains from light green to dark green.At the beginning, because of low sediment accumulation rate (caused by the winnowing effect), the iron and potassium sequestration leads to the neoformation of Fe-smectite. This process is faster for Fe than for K. If the grains stay sufficiently long-time at the sea/sediment interface, seawater K continues to be incorporated, leading formation of interstratified smectite/glauconite. Both the degree of maturity of glauconitic grains and their chemical composition are likely related to the current intensity: high current intensity, high winnowing effect and low sedimentary accumulation favor glauconitisation. In contourite sediments, the occurrence of glauconitic grains and their geochemical compositions might be an efficient tool to estimate the intensity of bottom currents that shape the oceanic deposits and record climatic fluctuations. We have used this new approach for characterizing the contouritic sediments of the Demerara plateau, in depths where sediments are under the influence of NADW. Our results indicate that during glacial periods, the glauconitic formation and maturity is higher than during interglacials, suggesting an increase of the NADW intensity during cold stages along the French Guiana margins.

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Depositional filling patterns of contourite deposits on the lower Jianfeng slope of South China Sea: implications for paleoceanographic evolution

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Abstract: An extensive distribution of contourite deposits occur on the lower Jianfeng slope of the northern South China Sea. Due to the obstacle of seamounts, the sub-sags in the lower slope are infilled by sheeted or mounded drifts and moats since the Middle Miocene. Sediment drifts have been divided into four seismic units (SU1-4) based on 2D multichannel seismic data. The lower unit (SU1) consists of sheeted drifts, and then is overlaid by the second unit (SU2) with the slightly mounded drifts and associated small-scale moats around obstacles. The SU3 unit composes by mounded drifts and related large-scale moats. Even the moats are observed in the upper and lower seamounts, more erosion and wider moat occur at the upper northern seamount. The vertical sequence indicate the increase of bottom current intensities upwards. Changes in bottom current intensities, recognized during deposition of the sediment drifts, might be related to the regional paleoceanographic and paleoclimatological events. The results suggest the depositional architectures are controlled by slope morphology and bottom currents. The strongest bottom currents during the deposition of the SU3 unit take happen from the Pliocene. Sedimentary evidence for contourite deposits are believed to derive from the South China Sea Deep Water circulations (SCSDW) flowing westwards. It is coincident with the strengthening of the Pacific Deep Water coupled with a global cooling event (approx. 5-3 Ma). Hence, the coupling relationship between the sedimentary framework evolution and the deep-sea circulation evolution is expected to further deepen the holistic and comprehensive understandings of deep-sea circulation evolution over the South China Sea continental margins.

Key words: Contourite deposits; Sediment drift; Bottom current; Jianfeng slope; South China Sea

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A giant sandy contourite drift in the ancient stratigraphic record and its multiple sedimentary process

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This study describes a regional-scale sedimentary feature in the Upper Yangtze region of China that is identified as a Telychian age(438Ma) contourite sandy drift that is 500–800 km long, 100–150 km wide, and 10–20 m thick. The palaeocurrent direction was measured in three different ways: directly from current ripples in outcrop, from the alignment of elongate particles in thin section, and by analysing the distribution of heavy minerals. The palaeocurrent direction is parallel to the ancient coastline (200°–240°), which is a characteristic feature of bottom current. Elongate mineral grains and sponge spicules are aligned in the palaeocurrent direction. Numerous traction structures in the study area also indicate a attractive current environment, including asymmetric ripple marks, erosion surface structures, horizontal and low-angle cross-bedding, and horizontal and low angle cross-laminations. The grain size distribution across the vertical sequence was used to identify three facies: normal and reverse grading together, normal grading alone, and uniform grading. The facies are divided by sharp lower contacts but gradual upper contacts. Based on provenance analysis, the Telychian contourite drift(channel reworked sandy drift) is the production of a mixed depositional systems(first turbidite deposition and then contourite deposition). The turbidite sand on the continental slope provides material source for the contourite drift, and the deposit is transported from the slope to the channel(parallel to ancient coastline). The provenance direction is identified by analyzing the distribution of heavy minerals. The unstable heavy minerals content is higher in the turbidites samples(near provenance region) than the channel reworked sandstone samples(far away from provenance region).Besides, the stable heavy minerals increases along the direction of the long axis of the channel reworked sandy drift. Biostratigraphic correlation using graptolite zones was applied to reconstruct an isochronal stratigraphic framework for the study area, and carbon isotope (δ13Corg) and trace element data (Si/Ba) were used to reconstruct the history of sea level change. This Telychian deposit is a rare example of an ancient channel reworked sandy drift.

Key words: palaeocurrent direction heavy minerals provenance traction structures mixed depositional systems turbidite

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SEDIMENTARY CHARACTERISTICS AND INTERNAL ARCHITECTURE OF FAN DELTA CONTROLLED BY AUTOGENIC PROCESS: IMPLICATIONS FROM A FLUME-TANK EXPERIMENT

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Through the flume tank experiment under the condition of constant allogeneic factors, the depositional process, evolution principles and the sedimentary architecture of a fan delta was presented. Based on analysis of the experimental fan delta, an autogenic factors forced sedimentary architecture model was constructed. The evolution of fan delta controlled only by autogenic factors are obvious periodic, and each autogenic cycle can be divided into three stages: the initial progradation stage, the middle retrogradation stage and the late aggradation-progradation stage. During the early stage of deposition, a main distributary channel developed and incised into the delta plain. A large amount of sediments was taken to the channel mouth, as a result, a long oval-shaped channel mouth bar formed. Natural levees and several crevasse splays developed on both sides of the main distributary channel. During the middle stage, the main distributary channel was blocked by the channel mouth bar growing out of the water and as a result, the upper reach of the main channel branched into two sets of distributary channels. Two crevasse lobes formed on both side of the main distributary channel near the avulsion point. With the gradual upstream migration of the crevasse point along the main distributary channel, two retrogradation crevasse lobe complexes formed on both side of the main distributary channel. The crevasse lobe complexes can cover nearly 33% area of the fan delta. The main distributary channel was filled by retrogradational channel sediments. In the late aggradation-progradation stage, the main distributary channel branches into a number of small-scale, radial channels. Each of these distributary channels can form a terminal lobe in the distal part of fan delta plain and delta front. With rapid migration of the distributary channels, a set of distributary channel-terminal lobe complexes formed and stacked together. The thick fan delta system usually consisted of a number of autogenic forced depositional bodies. Dynamic allocation of accommodation space and the following adaptive sediments filling were the two main driving factors of the autogenic evolution of fan deltas.

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Quantification of intertidal-dune morphodynamics and sediment transport based on unmanned aerial vehicle (UAV)-assisted photogrammetry

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Tidal flat is a dynamic environment whose morphology reflects the influence of various factors such as waves, precipitation and channel migration as well as tidal currents. The quantification of the morphodynamics of the tidal flat requires three dimensional temporal and spatial data. However, low accessibility and short exposure time of the tidal flat make it difficult to acquire accurate data on a larger scale. Simple and compound dunes are extensively developed in the lower intertidal zone of the Yeochari tidal flat in the northern Gyeonggi Bay, west coast of Korea. The morphological variability of the intertidal dunes was investigated using global positioning system profiling and unmanned aerial vehicle (UAV)-assisted photogrammetry to understand the spatial patterns of sediment transport. More than 200 aerial images were acquired using a drone-mounted 10-mega pixel camera for two consecutive days. To ensure the accuracy of a digital elevation model (DEM), the aerial images were taken with 80% overlap. In addition, twenty ground control points (GCPs) and six reference points were installed using a Real Time Kinematic GPS for position correction and accuracy verification of the DEM. Two DEMs of 0.26 km^2 and 0.37 km^2 each were constructed by Pix4D (version 4.1.25) through image correction and orthophoto mosaics. A channel bank area of 0.05 km^2 was selected from the two DEMs for the quantification of volume changes induced by dune migration. The changes were calculated from the differences in surface elevations from DEMs derived from the repeated surveys. Erosional and depositional sediment fluxes over two tidal cycles are estimated 1,831 m^3 and 2,131 m^3, respectively. A net deposition of 300 m^3 of sediments occurred, suggesting an ebbward residual sediment transport. The estimation is congruent with the observed dune morphodynamics: simple dunes on the seaward side of the compound dunes migrate landward at rates of 0.5 m, whereas those on the wider, landward side migrate seaward at rates of up to 1 m. The present study highlights that morphological changes and associated sediment transport on the intertidal flats can be effectively analyzed using a drone-assisted Structure from Motion (SfM) technique.

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Storm deposition layer on the Fujian coast generated by Typhoon Saola

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Typhoons have a large effect on coastal sediment budgets and the character of strata preserved in the geological record. Due to adverse weather and the difficulty in accurately predicting the path, direct observation is a formidable task. According to long-term records, an average of 4 to 5 typhoons affect the Fujian Province coast annually, which significantly affects the modern sedimentary environment and sediment transport and deposition. The Fujian coast acts as a natural laboratory for studying the modern typhoon-induced storm-event sedimentary geological record because of its thick mud sediment, which is conducive to preserving the sedimentary record. However, because of the insufficient ability to forecast typhoons and shipboard operation difficulties under severe weather conditions, there are no studies regarding typhoon-event storm layers on the Fujian coast.

We used the high-resolution Chirp sonar sub-bottom profiler and radioisotope detection techniques to examine the storm-deposited layer formed in the seawater near the path of Typhoon Saola along the coast of Fujian, China. The thickness of the typhoon-deposited layer acquired using these two methods was 10-25 cm. The thickness, sediment grain size, and $\delta^{13}C$ values of the deposited sedimentary layer indicated that it was mainly matter from the re-suspension and redistribution of seafloor sediments. The particle sizes of the sediments in the storm-deposited layer became coarser, indicating that the fine-grade compositions spread over a wider range out of the coastal zone. The results may contribute to a better understanding of the formation and identification of storm layers in coastal areas..

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Sedimentation and compaction of fine sediment

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Abstract:

Understanding the sedimentation and compaction of solid particles in water is important for many industrial applications (mineral and powder technologies, wastewater treatment, food industry as example) and for the morphodynamic prediction or paleosedimentologic studies.
During sedimentation or batch settlement from suspension, each sediment particle behaves individually (Stokes theory of settling velocity). As sediment concentration of suspension increases, hydrodynamic (long-range) interactions between particles start to dominate the dynamic of the system leading to the so-called 'hindered settling regime'. For concentration larger than a threshold value named gelling point, the system behaves no longer as suspension but as a very soft soil that undergoes slow compaction over the time[1,2,3].
The communication presents two non-intrusive techniques to measure these transition from very dilute suspension (Stokes regime) to very soft soil (compaction regime) with the intermediate stage (dense suspension under hindered settling regime). The first method is a Magnetic Resonant Imaging (MRI) vertical prototype[4,5] and the second an X-ray prototype[6]. Both are used on natural silty clay or mud which are sampled in natural estuaries. These technologies give access to the motion of supernatant/suspension interface, the time evolution of vertical profile of concentration and isoconcentration lines of the process. These results also enable space-time analysis that will serve to determine closure equations of the problem[7].

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SORTING PROCESSES AND INTERNAL ARCHITECTURE OF BIO-SILICICLASTIC COASTAL BARRIERS: PHYSICAL MODELLING

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Wave-dominated coastal barriers are dynamic systems responding to sea-level fluctuations at different time scales induced by storm surges, tides (from diurnal to pluri-annual cycles), and climate (century to millenia). They are composed of siliciclastic sand, bioclastic debris or a mixture of both. Sediment-starved epicontinental platforms of temperate areas are frequently the location of intense biologically-controlled carbonate production. As a consequence, coastal sediments of these systems are mixed, composed of siliciclastic sand (mostly quartz grains) and shell debris, essentially derived from mollusc shells. In some environments of very high biological productivity, such as the English Channel and more specifically the Normandy-Brittany Gulf, shell debris can largely dominate the overall composition of coastal sediments. With time, due to natural factors (climate changes, sea-level fluctuations) and human activities (shellfish farming, fishing, species introduction, marine aggregates extraction) the proportion between siliciclastic and bioclastic grains can vary. It is critical to understand how these modifications in sediment composition can affect sedimentary processes involved in the construction of coastal barriers and potentially their stability. This is the general objective of the present study mainly based on physical modelling. The results obtained from experiments performed in flume under unidirectional current in order to quantify shell debris transport, segregation and bedload flux show the complex hydrodynamic behaviour of bioclastic particles, mainly due to the shape, internal structure and mineralogical composition of the shell debris. Compared to quartz sand of similar sieve diameters, bioclastic particles show similar thresholds of motion when structured in a sediment bed, but have low to very low settling velocity. The shape of bioclastic particles is a factor of prime importance as it influences particle interlocking and steadiness of bedload transport. Some non-negligible differences have also been highlighted between shell debris derived from eight different bivalve species, representative of the English Channel coastal areas.

In order to study wave-induced sorting processes of sediments in the foreshore and their consequences in terms of internal architecture of coastal barriers with varying proportion of bioclastic sediment, a set of three wave-tank experiments were performed under varying mean water level and regular wave forcing, using bioclastic / siliciclastic sediment mixture in different proportions. Barrier morphology was surveyed using laser telemeter and photogrammetry, and internal architecture using side-photographs and lacquer-peels. We investigated the relationships between sediment composition and (i) sorting processes in the breaking and swash zone, (ii) response to barrier flooding by wave overwash, and (iii) barrier morphology and architecture (beach slope and length, washover geometry and structure).

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GRADED ALLUVIAL SYSTEMS ATTAINED DURING MULTIPLE SEA LEVEL CYCLES

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Conventional sequence stratigraphy of river deltas suggests that generally the alluvial systems aggrade in response to base-level rise and degrade in response to base-level fall, based on the assumption that the graded profile is developed with stationary base level and moves upward and downward with base level rise and fall, respectively. This rationale has recently been renewed with the autostratigraphic view of grade[1], which proves that the graded state of a downstream alluvial river feeding a progradational delta is physically possible only when base level falls in a particular pattern combined with a particular slope condition.

An alluvial grade model of the autostratigraphic view tells that with basin slope (φ) equal to alluvial slope (α), the downstream alluvial river will autogenically attain grade by equilibrium response to steady forcing by constant sea level fall (rate R_{sl} = const < 0) and constant sediment supply (rate Q_s). Once this autogenic grade has been attained, a deterministic delta-set thickness (h_{set}) is reached. In natural systems, the slope condition that $\alpha \sim \varphi$ might be realized after non-deltaic rapid transgression ($R_{sl} > 0$) that leaves a drowned alluvial surface which over-extended far beyond critical alluvial length that is specified with autostratigraphic length scale[1]. Theoretically, sea level cycles (i.e. alternating rise and fall) can inevitably induce graded rivers.

To examine this prediction, a series of 2D experiments on the growth of deltaic shelf alluvial systems was performed with base level cycles. The experimental results show that after an elapse of several cycles the deltaic shelf was developed with the sufficiently extended alluvial system and takes a style of development as follows: 1) during base level rising, non-deltaic transgression leaves a concave-upward sediment-starved surface, downstream of which parallels with a basinward extension of the overlying alluvial surface (thus $\varphi \sim \alpha$); and 2) during subsequent sea level fall, when the delta progrades onto the downstream part of the submerged alluvial surface of the preceding cycle (now the outer shelf where $\varphi \sim \alpha$), it approaches grade, either by degradation if the pre-existing foreset is thicker than h_{set} or by aggradation in the opposite case. In this latter stage, the state of grade is eventually attained as long as the shelf is sufficiently extended.

This contribution illustrates that in an expanding deltaic shelf setting, alluvial grade can be autogenically realized in or after multiple cycles of relative sea-level rise and fall. It thus might make sense to re-examine the generally-believed relationship between stratal stacking patterns of river delta (deltaic shelves too) and base level cycles, a fundamental theme of conventional sequence stratigraphy.

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MODELLING ORBITAL CLIMATE SIGNALS IN FLUVIAL STRATIGRAPHY

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There are certain orbital cycles influencing the relative position and location of the earth towards the sun, resulting in the cyclic insolation received on the earth, which causes climate changes and subsequent environmental response in the catchment, including precipitation, temperature, and vegetation. Furthermore, such catchment responses induce cyclic variation of source materials, including sediment supply and water discharge in the entry of a fluvial basin. Climate change related to the 21-kyr precession cycle was proposed as the driver of regularly-alternating river avulsion and overbank phases in the Eocene Willwood Formation, Bighorn Basin, Wyoming, USA [1-2]. This study aims to simulate the building-up process of fluvial stratigraphy under the action of precession.

Based on the 3D numerical forward model of Karssenberg and Bridge (2008) [3], we run several scenarios with constant/cyclic sediment supply (Q_s) and water discharge (Q_w) as well as continuously increasing base level. It is found that the absolute values of Q_s and Q_w are not the key drivers of river avulsion and bifurcation. Instead, the ratio between them is. In the scenarios with constant Q_s/Q_w including the constant Q_s and Q_w scenario and the in-phase one, there are no regular/cyclic step-like avulsion and overbank alternation, while in the other scenarios with cyclic Q_s/Q_w we can clearly see those step-like patterns with periodicity identical to precession, where the out-of-phase scenario has the largest Q_s/Q_w variation. Specifically, the increasing Q_s/Q_w triggers the avulsion, which lasts until the peak of Q_s/Q_w, corresponding to white heterolithic avulsion deposits. Then with the decreasing Q_s/Q_w from the peaks, overbank phase starts, which is favourable for soil development. Overall, such cyclic Q_s/Q_w derives from the phasing shift between Q_s and Q_w, which can be attributed to the differential response of them to the climate change and further orbital forcing. Moreover, it is found that the signal weakens in the transmission process due to the destruction of autogenic forcing, suggesting that only those orbital forcing with strong amplitude and long periodicity can be possibly transmitted. Relevant literature suggests the smaller basin size and higher Q_s/Q_w contributes to the shorter autogenic time scale, which, to a certain degree, more favours the orbital signal transmission.

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SEASONAL CHANGES IN SEDIMENT ERODABILITY ASSOCIATED WITH BIOSTABILIZATION IN A SUBARCTIC TIDAL FLAT, ST. LAWRENCE ESTUARY, CANADA.

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The erosion susceptibility of intertidal sediments by tidal currents and waves depends not only on sediment properties but also on biostabilization by microbial biofilms[1], which vary highly in time and in space. Measuring the erosion resistance of these muddy sediments is important in determining the estuarine sediment dynamics as well as the capacity of the tidal flats to adjust to sea level rise. Several studies have investigated these issues in subtropical and temperate environments[2], but little information is available for subarctic conditions[3]. Our project aims to determine the role of biofilms and their seasonal variations for sediment biostabilization in a subarctic tidal flat near Rimouski (QC, Canada), on the southern shore of the St. Lawrence Estuary. The mean sediment particle size is between 5 and 68 µm, with over 90% of all samples having a mean grain size finer than 26 µm. The poor sorting of sediments directs towards the contribution of sediments transport by ice rafting in addition to the hydrodynamic transport processes in this subarctic intertidal area. The portable Cohesive Strength Meter (CSM) was used to measure the critical erosion threshold (τ_{crit}) across the intertidal area. Small sediment cores were taken in parallel to characterize the biofilm: chlorophyll *a* and EPS (extra polymeric substances) were measured in the top three 1mm layer. In the ice free seasons (summer 2016, summer and autumn 2017) there are high differences of τ_{crit} between high and low marsh, but much less variations between low marsh, mudflat and sandflat. The winter 2018 data, which were measured under the land fast ice, revealed significantly lower τ_{crit} in comparison to other seasons. There is a positive correlation between τ_{crit} and organic matter content measured by loss on ignition. Our results also show that chlorophyll *a* and EPS are not so good indicators for τ_{crit}, except for the low marsh/high marsh difference. In general, there is no significant correlation between mean grain size and τ_{crit}. This study highlights the implications of intertidal sediment exposure to the sea ice and consequently lower τ_{crit}. The sediments were more stable in ice free seasons than in winter, when the biofilm is affected by the low temperature and the partial light blockage due to the sea ice cover.

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MONTHLY VARIATIONS IN SEDIMENT GRAIN SIZE ALONG A SHORE-NORMAL TRANSECTION ON AN OPEN-COAST MUDFLAT, CHANGJIANG ESTUARY

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Main text: The spatial and temporal changes of surface sediments on the intertidal flat have attracted extensive attentions worldwide. In this study, both the sediments and topography along a fixed transect of the Nanhui foreland, Changjiang Estuary, were monitored monthly during 12/2014-06/2016 to examine changes sedimentary characteristics in relation to physical processes. The results indicated that the sediments generally exhibited a seaward decreasing trend in grain size and a significant zonal differences, with a landward part being dominated by sand, a transitional part where sand content decreased dramatically, and a seaward part covered with silt-dominated sediments. During this period of time, the sediment zonation pattern was modified due to landward retreatment of the landward part by 62.5 m, narrowing of the transitional part by 75 m, and landward migration of the seaward part by 137.5 m. Meanwhile, the middle intertidal zone experienced significant erosion and the lower intertidal zone migrated landward significantly. Sand content of the sediments in the landward part had decreasing trend, with relatively high values occurred in 01/2015, 07/03/2015 and 02/2016; in the seaward part it had a trend of steady increase. Variations in the sedimentological zonation exhibited a distinct relationship with the hydrodynamic processes. In the landward part, changes of the sediments were associated with seasonal wave dynamics, whilst in the seaward part accretion tended to result in fining of sediments. Results of this study indicated the feedback of sedimentation/erosion to the hydrodynamics and sedimentology of the intertidal flat on the monthly scale.

INFLUENCE FACTORS ON THE DISTRIBUTION OF TIDAL BAR IN TIDE-DOMINATED ESTUARY: INSIGHT FROM DEPOSITION NUMERICAL SIMULATION

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Tide-dominated estuaries sedimentary reservoir is a hot area of sedimentology research in recent years, The oil sands of Mcmurray formation in the Athabasca region are mainly a deposits of tide-dominated estuary and an important target of oil and gas exploration of CNPC. However, the complex interaction of the fluvial and tide process aggravated the heterogeneities of the distribution of tidal bar, which poses the challenge for efficient exploration and development. Furthermore, the outcrop of tide-dominated estuary is few and the recognition in subsurface is very difficult, only the modern tide-dominated estuary can be observed to get some knowledge of the temporary status of the distribution of tidal bar. The newly develop deposition numerical simulation technology is introduced from hydrodynamics to get a thorough insight in the formation of different geological genetic units and matched the modern deposits well. So the deposition numerical simulation technology is chose to analyze the influence factors on the distribution of tidal bar in tide-dominated estuary. The typical modern Fitzroy estuary is selected for reference and the simulated parameters such as the boundary condition, hydrologic data is gathered and put into the Delft3D software. Then we observed the phenomenon of the formation of tidal bars by single factor analysis. Some preliminary result can be concluded as follows:
(1) In the process of sedimentation of estuary sand, the function of bimodal current brought by tidal action is the main reason for the formation of sand bars and also main water power of estuary sediment.
(2) Influence of sedimentation brought by fluvial process on sedimentary bodies in estuary is relatively small. When effect of fluvial process is too big, it will cause sand move towards to ocean, thus it is not suitable to save, and moreover, it will damage sedimentary bodies in estuary to a certain degree.
(3) In a certain quantity of energy body, component of sediment will have obvious influence on sedimentary thickness, and mud (viscous component) in sedimentary component is the main reason for conservation of sediment.

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SIMULATING LARGE-SCALE SAND DEPOSIT IN THE MIXED FLUVIAL SYSTEM----- A CASE STUDY OF HUAGANG FORMATION IN XIHU DEPRESSION, EAST CHINA SEA BASIN

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Abstract: Large-scale sand deposits in the Huagang Formation are known as the most important reservoirs in the Xihu depression of East China Sea Basin[1-2]. However, the complexity of the reservoirs constrains the discovery of the mid-large oil &gas field[3-4], which are manifest in the following factors: ①Depositional response of reservoir rocks to the different sources, ②the effect of sedimentary system to the reservoir types, ③the forming process of large reservoirs. By the observation of cores, logs and seismic data of Huagang Formation sand deposits from north and middle region of Xihu depression, the sedimentary condition where different reservoirs form are analyzed. On basis of that, combining paleontography and provenance characteristics, this study also presents the 3D simulation process of such reservoirs with SEDSIM software, constructing the 3D geological models and sand-filling patterns of different periods in the Huagang Formation. It is concluded that the large-scale sandstone deposits change from north to south are the low-sinuosity braided channel, high-sinuosity braided channel, anastomosed channel, shallow-water delta systems. Furthermore, Sands from H8/H7/H6 strata successively stack, forming thick and widely distributed reservoirs. The result shows that the deposition of Xihu depression mainly occurs along axial direction, supplemented by the small source from both sides.
Key words: Xihu Depression, Huagang formation, reservoir, sandbody, sediment, simulation

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DIAGENETIC ALTERATIONS AND RESERVOIR QUALITY OF THE LOWER CAMBRIAN KHALEEL MEMBER (KARIM FORMATION) SANDSTONES IN SOUTH OMAN SALT BASIN (SOSB)

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The deeply buried (>3 km) Lower Cambrian Khaleel Member sandstone reservoirs of the South Oman Salt Basin are differentiated by highly variant diagenetic alterations and reservoir quality. A combined petrographical study of optical microscopy and SEM together with XRD and stable isotope (O- and C-isotopes of carbonates) analyses helped in unravelling the impact of diagenetic alterations on reservoir quality of fine- to medium-grained and well- to moderately-sorted sandstones of alluvial to sabkha facies of the Khaleel Member (Karim Formation). The Khaleel Member sandstones are dominantly composed of mono- and polycrystalline quartz with subordinate K-feldspar and plagioclase together with lithic fragments and minor micas and heavy minerals. The sandstones have undergone various degrees of diagenetic modifications dominated by anhydrite and dolomite cements along with calcite cement and subordinate amounts of authigenic clay as well as minor feldspar, quartz, pyrite, hematite and anatase cements. Poikilotopic and micronodular anhydrite cement and pore-filing carbonate cement play a vital role in controlling the reservoir quality both in positive, e.g. preventing compaction, and in negative aspects, e.g. reducing the porosity and permeability. Minor amounts of feldspar and quartz cements developed mainly as syntaxial overgrowth on detrital feldspar and quartz grains and have no noticeable impact on the reservoir quality. Infiltrated clays occur as grain coats and tend to preserve the reservoir quality. Minor amounts of illite and chlorite, confirmed by SEM and XRD analyses, occur as pore-lining and pore-filling clay minerals and have less impact on reducing the porosity and permeability. Other diagenetic alterations such as pyrite, hematite and anatase, have no significant impact on reservoir quality of the Khaleel Member sandstones. The stable O- and C-isotope values ($\delta^{18}O_{SMOW} = -10.90‰$ to $+3.88‰$) of the carbonate cements have elucidated on the pore water composition (meteoric waters) and their subsequent diagenetic alteration. Dissolution of dolomite cements and of chemically unstable framework grains (feldspars and volcanic fragments) have resulted in a considerable enhancement of reservoir quality. Overall, porosity preservation in these sandstone reservoirs despite their great burial depth is attributed to (1) the primarily presence of grain coating clay as minute crystals and, occasionally, (2) grain coating bitumen that hindered the authigenic feldspar and quartz growths and (3) abundant cementation of rhombic dolomite prevented rapid loss of porosity by mechanical compaction.

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CHARACTERIZATION OF PALEOTSUNAMI DEPOSIT AT BINUANGEUN BAY, BANTEN, INDONESIA

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Tsunami events can be recorded by the sediments deposit in coastal area. Binuangeun Bay in Banten, Indonesia is located at the south coast of Java Island, which faces directly to the Indian Ocean. Several tsunami events occurred in Indian Ocean may leave sediment deposits in this area. This study focused on the identification and characterization of paleotsunami deposits which might be found.

Samples were taken from swampy swale behind the beach ridges by hand drilling on several spots. Identification and characterization of paleotsunami deposits was based on granulometry analisis combined with mineralogy and foraminifera fossil identification. Lost on ignition analysis was conducted to predict the organic matter and carbonate content.

Megascopic examination indicates some appearance of sandy sediment between organic matter rich silty sediment. This layers might be candidates for paleotsunami sediment. Granulometry analysis showed that the layers are silt to fine sand in size with mean value of 3.4-4.9 phi. The sortation is poor and skewness value of 0.2-0.6 (fine skewed-very fine skewed), whereas the kurtosis is between 0.7-1.2 (platykurtic-leptokurtic). Low content of organic matter and carbonate were found in this layers. Benthic foraminifera indicates depth of 30-180 m which might the source of the sediment. Mineral particles are dominated by quartz. Glauconite was found which indicated marine environment.

In this area, the candidates of paleotsunami sediment are distributed along the swale and pinched out with silty sediments. No distinct erosion features found under paleotsunami sediment. This possibly indicates the effect of morphological barrier to the sedimentation process.

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Fe AND Mn CYCLING AT REDUCTIMORPHIC ZONE IN FLUVIAL ENVIRONMENTS AND THE ORIGIN OF CONTINENTAL RED BEDS

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Conspicuous red- and black-colored layers of sand and gravelly sands were found in numerous places underneath the active floodplain of the meandering-anastomosing Morava River, Czech Republic. The layers typically occur at ~0.9 to ~1.4 m depth below surface, above water table, in point-bar sediments, channel lag deposits and floodplain fines. The layers commonly split into two sublayers, a lower, orange to red colored layer, followed by an upper, dark-grey to black one. The reddish and blackish colors are likely carried by Fe and Mn secondary phases, which are mobilized close to the redox gradient at the water table. To make an insight into origin of these phases, we studied several sections analyzing the visible-light spectral reflectance, mass-specific magnetic susceptibility and element geochemistry of bulk sediment samples across the stratigraphic record, combined with X-ray diffraction (XRD) patterns, microprobe analysis and LA ISP-MS in selected samples. The age control was provided by several AMS ^{14}C ages.
High redness index and moderately enhanced magnetic susceptibility characterize the reddish layers. The red sublayers are enriched in iron (Fe/Al; Fe(EF)) and the black ones with manganese (Mn/Al; Mn(EF)) and sometimes with other elements (Pb). The XRD analysis of bulk samples showed predominance of common silicates (quartz, plagioclase, white mica, alkali feldspar, chlorite and kaolinite), accompanied by gypsum, goethite and X-ray amorphous iron oxy-hydroxide phases. Under microscope, the Fe- and Mn oxy-hydroxides form thin coatings on sand- and gravel clasts, commonly with kidney-shaped microforms. In fine-grained facies, they form small, red-colored concretions. First derivatives of spectral reflectance data indicate goethite as the predominant coloring phase, followed by hematite. Age constraints of the red-and-black layer formation are provided by four AMS ^{14}C ages ranging from 228 ± 68 to 841±50 cal. BP, which indicates that the red- and black staining is very young and may form within two hundred years.
From the preliminary results, we can infer that the red sublayers form due to rapid growth of amorphous Fe oxy-hydroxide phases (likely ferrihydrite), goethite and partly hematite above the redox gradient provided by water table. The goethite and ferrihydrite may be transformed to a stable hematite, which can be preserved in the sedimentary record. However, with rapid vertical accretion of the fluvial siliciclastics and water table rise, the initial red layers may be submerged beneath water table, dissolve and disappear. With sufficient time to transform the oxy-hydroxides to the hematite, the reductimorphic zone may possibly contribute to the formation of the continental red beds.

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SEDIMENTOLOGY, EMPLACEMENT MECHANISMS AND DIAGENESIS OF PYROCLASTIC DENSITY CURRENTS (PCDs) IN A CONTINENTAL HYDROTHERMAL SETTING

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Despite of their volcanic origins, PDCs are sedimentary processes that allow the transportation and dispersion of hot pyroclastic particles from a volcanic center into the environment. As many other sedimentary flows, they are particularly erosive and tend to trap fragments of accidental rocks during their motion. When mix with water, flow behavior and temperature have a primary impact on the modification of their mechanisms of movement and, eventually, emplacement. This work explores the sedimentological, petrographic and minero-chemical features of three PDC deposits entombed in a continental hydrothermal setting in Central Italy. The PDC deposits are gray colored in the field, with a variable thickness up to 2.5 m. They are composed of fine to coarse ash, with accidental burnt lithics and fragments. Accretionary lapilli have been also documented, partially to totally replaced by calcite. Calcite veins also crosscut the deposits through the primary porosity among the lapilli. Under the microscope, all the deposits show an eutaxitic texture and mineralogical phases replaced by clay minerals. SEM-EDS documents the high primary porosity characterizing every single accretionary lapilli, formed by ash particles clashed together for agglutination. SEM images also show the development of diagenetic needles that pervasively decompose accretionary lapilli, glass and sanidine crystals. Burnt fragments and the presence of accretionary lapilli in the pyroclastic deposits document the hot temperatures under which all the PDCs have been emplaced, as well as the humid environmental conditions characterizing the depositional zone. Nevertheless, the development of a dark, palaeosoil horizon on top of the deposits and the absence of erosional surfaces testify that a temporal gap when the spring remains inactive occurred. Calcite veins and the replacing of different mineralogical phases and accretionary lapilli documented that diagenetic processes took place once the hot spring-related, Ca-rich waters started to flow through the deposits. A later biological contribution to the decomposition of glass and minerals has been also documented. Outcomings of this study promise to better define the importance of pyroclastic/volcaniclastic sequences as potential reservoirs, like in the giant South Atlantic hydrocarbon reservoir.

PORPHYRA CULTIVATION IMPACT ON SEDIMENTARY AND MORPHOLOGICAL EVOLUTION OF TIDAL FLAT IN RUDONG, JIANGSU PROVINCE, China

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Abstract: Tidal flats of Rudong County located in the eastern part of Jiangsu province along the South Yellow Sea, which characterized by semidiurnal tides and strong tidal flow. Owing to the active tidal processes and the abundant sediment supply, the tidal flats here are well developed and width from several kilometres to tens kilometres. With the development of economy, the tidal flats of Rudong County are mostly developed by human activities such as reclamation at the high-tidal flat and seaweed farming at the low-tidal flat. In the last decade, porphyra cultivation grows rapidly in the tidal flat of Rudong County and has became the mainstay of the local economy. It is a hot issue in the local society that whether and how the porphyra cultivation will impact the sedimentary and morphological evolution of tidal flat when the culture scale become larger more and more in the future. In this paper four sediment cores (92cm-151cm) were collected perpendicularly to the coast line in tidal flat of the eastern Yangkou Harbor, Rudong County. ^{210}Pb dating and grain size analysed have been processed aiming to get the annual sedimentary velocity of this area. Besides, the daily sedimentary velocity has been estimated through placing settlement plates. Furthermore, remote sensing imageries at January and August, in accordance with the period of porphyra culture, are processed to show morphological evolution of tidal flat of this area, respectively on the year of 2002, 2003, and 2005. Results show that the cultivation of porphyra in this area increases the rate of sedimentation and expands the siltation area slightly. However, once the cultivation of porphyra is stopped, the extra-accumulated part will be eroded in a short period. In the present work, it was proved that the cultivation of porphyra has actually very limited influence on the sedimentation of tidal flat and the morphological evolution of tidal marshes in the long run equilibrium. Meanwhile the human activities during the cultivation of porphyra accelerate the erosion rate of tidal flat in certain degree, which should be paid attention to by the local government and make further research.

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Sequence Stratigraphic Model for Passive Rift: A Case Study from Lower Cretaceous of Muglad Basin in Northern Africa

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Classic sequence stratigraphy, developed primarily from passive margin basins, has been widely applied for building isochronic stratigraphy framework within sedimentary basins during the last several decades. The sequence stratigraphic model for passive margin basins has also been used extensively in rift basins, although the tectonic settings and depositional sequences obviously differentiate from those of passive margin basins. The accommodation of passive margin basins was mainly controlled by eustatic fluctuations superimposed on long-term thermal subsidence within a stable tectonic setting, whereas that of rift basins was primarily generated by rapid mechanical subsidence due to episodic pulses of extension[1]. A typical passive rift sequence is mainly composed of a relatively thin transgressive systems tract and a much thicker highstand systems tract, while the lowstand systems tract is poorly developed or absent.

The Muglad basin, regarded as a typical passive rift, was generally attributed to the breakup of Gondwana and the opening of South Atlantic Ocean and Indian Ocean. Consequently, it differentiates from active rift by structural style of major faults, depositional sequences of syn-rift and post-rift phases, distribution and geometry of sand bodies, subsidence history, geothermal history, and hydrocarbon generation and expulsion history. The sequence boundaries and maximum flooding surfaces can be easily identified by the seismic reflection termination patterns and coarsening-upward stacking patterns due to the episodic subsidence at very fast rate followed by relatively long-term tectonic quiescence. The lower Cretaceous, deposited during syn-rift, can be divided into five third-order sequences. Generally, each sequence was dominated by shale and mudstone inter-bedded with thin and laterally well-correlated sandstone, which enable hydrocarbon has huge generation potential and high expulsion efficiency. SEQ-I, II and III, deposited successively during the initial rifting stage, were locally distributed on the Cambrian crystalline basement. SEQ-IV was dominated by thick shale and mudstone intercalated with siltstone or sandstone. SEQ-V was primarily characterized by coarsening-upward sandstone with prograding parasequence stacking patterns.

The depositional sequences of lower Cretaceous in Muglad basin largely constitute highstand systems tract, consequently, the sequence stratigraphic model for passive rift basins can effectively enhance the understanding of its depositional evolution and architecture, and remarkably improve the predictive applicability of hydrocarbon exploration and development.

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TYPES AND CHARACTERISTICS OF CARBONATE RESERVOIRS AND THEIR EFFECT ON GAS EXPLORATION IN EASTERN TARIM BASIN

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Carbonate rocks are deposited in the Ordovician, Cambrian, and Sinian of eastern Tarim Basin with a cumulative maximum thickness exceeding 2000 m. They are the main carriers of oil and gas, and a great deal of natural gas has been found there in the past five years. Based on lithofacies and reservoir differences, natural gas exploration domains of eastern Tarim Basin can be classified into five types, Ordovician platform limestone, Ordovician platform dolomite, Cambrian platform margin mound shoal, Cambrian slope gravity flow deposits, and Sinian dolomite. Carbonate reservoir characteristics of all the types were synthetically analyzed through observation on drilling core and thin sections, porosity and permeability measurement, and logging data of over 10 drilling wells. We find distribution of part of good fracture and cave reservoir in carbonate platform limestone of Ordovician. In the Ordovician, platform facies dolomite is better than limestone, and in the Cambrian, platform margin mound shoal dolomite has large stacking thickness. Good quality and significantly thick carbonate gravity deposit flow can be found in the Cambrian slope, and effective reservoir has also been found in Sinian dolomite. Commercial gas has been found in the limestone and dolomite of Ordovician in Shunnan and Gucheng areas. Exploration experiences from these two areas are instructive, enabling a deeper understanding of this scene.

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The Feature and Formation Model of septarian cold seep carbonate concretions of Cretaceous age in Gamba, southern Tibet

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Since cold seep are closely related to the gas hydrate and methane, which are viewed as the important energy and key greenhouse gas, now they are more and more highly regarded by scientists. In this thesis, we will pay attention to the petrography, mineralogy, geochemistry of the septarian cold seep carbonate concretions and discuss their composition, structure, carbon sources, and formation processes and model.

Septarian concretions, ranging from 6 cm•8 cm to 100 cm•30 cm, are parallel to the bedding. They consist of two parts: concretions matrix and septarian crack fillings. The concretion matrix is composed of micritic calcite cements (55~75%), quarz and feldspar (25~45%). The crack filling consist of early fabric calcite cements and later blocky calcite. Compared with the micritic and fabric calcite cements, the blocky calcite cements show higher FeO, and lower MgO content. Their $\delta^{13}C$ values, ranging from -26.81 to -1.86 ‰ VPDB, increase from the micritic matrix in the margin to the blocky calcite cements in the center. Besides, the homogenization temperature that we get from the primary fluid inclusion is 176.9℃. Based on the results above, the concretion matrix and fabric calcite cements are formed by anaerobic oxidation of methane, and the blocky calcite cements are formed during the burial process and are formed by heated pore water[1-3]. The concretion matrix and fabric calcite cements recrystallized partly during their burial.

Keywords: Septarian cold seep carbonate concretions, formation model, origin, Cretaceous, southern Tibet.

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TIDALLY-INFLUENCED REGRESSIVE PARASEQUENCES: EXAMPLES FROM THE WILCOX AND CLAIBORNE GROUPS, TEXAS

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Regressive tidal deposits are generally conceived as comprising a fining upwards succession, with sandy tidal flats in offshore higher energy areas transitioning into lower energy mud-prone proximal tidal flats and capped by emergent saltwater marshes (Terwindt, 1988[1]). In contrast, examples from the Sabinetown Formation (Paleocene) in Bastrop County and the Manning Formation (Eocene) in Washington County are coarsening upwards parasequences that transition from siltstone through silty tidal heterolithics into sandy tidal heterolithics, and in the Manning example, into lignite. Both locations are in up-dip, low accommodation-space settings, with tidal range amplified across a broad, shallow shelf.

The marginal marine Sabinetown has small, rare marine trace fossils and sparse dinocysts in the silt-dominated tidal heterolithics (Denison et al., 2017[2]). Sand-dominated tidal heterolithics have flaser bedding, mud rip-ups, cross-beds with plant debris drapes, and tidal doublets. In the more open marine Manning Formation, siltstones have both diverse trace fossils and marine dinocysts. Sand-dominated tidal heterolithics are extensively bioturbated, with *Schaubcylindrichnus freyi* and common *Ophiomorpha*.

Legler et al. (2003[3]) document similar coarsening upwards parasequences in a structurally-controlled embayment, but we postulate either a delta front or an open-coast geographic setting for our examples. By analogy with wave/storm modified parasequences, the vertical succession can be envisaged as lower tidal shelf, deep enough to be largely unaffected by tides, middle tidal shelf, where tides impinge on the shelf, generating muddy to sandy heterolithics, and upper tidal shelf, where tides produce sand-dominated heterolithics and dunes.

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Paleocurrent reconstruction of sandy braided river reservoirs in dense well pattern areas, Gudong Oilfield, Eastern China

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The paleocurrent reconstruction of underground reservoirs in dense well pattern areas has not been attempted and applied comprehensively due to the complexity and diversity of cutting and superposing relationships for sandy braided river. Thus, the paleocurrent of the sandy braided river in the west 7th block of the Gudong Oilfield is reconstructed by synthesizing the core data, well logging data, and production performance data in dense well pattern areas using Miall's classification method of architectural elements and hierarchical bounding surfaces.

The paleocurrent is reconstructed by dividing the compound mid-channel bar into single mid-channel bars. Multiperiod single mid-channel bars are then superimposed to form a compound bar. In the thick Sixth Member sandstone of the Guantao Formation in the west 7th block in Gudong Oilfield, according to the differences between braided channel-fills and bars, the different thicknesses of adjacent bars, variations in sedimentary rhythms, unmatched barriers in different bars, and differences of logging curve characteristics and dynamic data revealed disconnected signs, identify single bars.

A total of 1 fluvial system (7th-order), 2 compound braided rivers (6th-order), 11 braided channels (5th-order), 41 mid-channel bars (4th-order), 96 accretions (3rd-order) are developed in the study area. We divide the mid-channel bars of different periods into two depositional types, same time with different positions and same layer with different times. The developmental characteristics of the braided channels, single mid-channel bars, and single accretions are analyzed quantatively. The width and thickness of the braided channels are 300-1200m and 2.7-8.2m, respectively. The width-to-thickness ratio is 120-160. The width and thickness of the single mid-channel bars are 200-500m and 4.0-8.0m, respectively. The width-to-thickness ratio is 30-57. The thickness of the single accretion is 1.0-1.5m.

Key words: Paleocurrent reconstruction; Architecture; Sandy braided river reservoir; Dense well pattern

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Depositional Model of Saline Lake in the Background of Volcanic Development: A case study of the Early Permian Fengcheng Formation in the Mahu Sag of Junggar Basin, China

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Abstract: The Mahu sag is an asymmetric foreland basin, and Fengcheng Formation is a deposit that formed in an arid and hydrologically closed basin, with volcanic eruptions of the same period[1,2]. A transect from the northeast margin to the basin center and to the basin margin at the boundary thrust fault zone was examined in representative drillings and a seismic profile, which were supplemented with comprehensive lithofacies. Depositional environment was identified by major and trace elements and oxygen and carbon isotope geochemical analysis. Based on the data of stratigraphic sequences from the drillings, seismic profiles, descriptions of lithofacies and geochemical analysis of different cores, a depositional model of this saline asymmetric foreland basin was proposed. Multiple sources of deposits caused intricate sedimentation. The sources of the deposits comprised the weathering products of the source rocks, products of volcanic eruptions and authigenic evaporite mineral. These three sources of deposits at different percentages formed complex lithology in the Fengcheng Formation of the Mahu Sag. The weathering products of the source rocks dominated along the boundary faults, while the products of volcanic eruptions dominated to the northeast. Fine-grained material of terrigenous clastic sediments, volcanic ash, and authigenic evaporite minerals mixed in the lake center. The activity of overthrusts decided the migration of the depocenter where the authigenic evaporite minerals deposited. The lake-level fluctuations determined by the climate had a vital influence on the depositional environments in these areas. The different kinds of carbonate minerals had regular horizontal distribution as bull's-eye, which demonstrated that evaporation and concentration induced carbonate minerals deposited. The weathering and hydrolysis of the volcanic rocks offered abundant Ca^{2+}、Mg^{2+} and Na^{+} ions etc. to the formation of evaporites[2]. In summary, the particular depositional processes were jointly controlled by the basin structures, climate, and sources of deposits. Fengcheng Formation is divided into four sedimentary cycles, and the depositional process of the four cycles were reconstructed, according to the variation of the three controlling factors.

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RESERVOIR QUALITY VARIATIONS OF LOW-PERMEABILITY AND TIGHT SANDSTONE: AN CASE STUDY FROM THE OLIGOCENE SANDSTONE, EAST CHINA SEA BASIN

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The objective of this study is to determine the reservoir quality variations of the Oligocene low-permeability and tight sandstone. This interpretation is based on method and means including petrology, mineralogy, and basin modelling. These sandstones, experiencing tectonic inversion of two stages of late Oligocene Longjing movement and late middle Miocene Yuquan movement, are located in the HA and HB members of NB gas-field, East China Sea Basin, East China. Based on the overall consideration of the diagenetic imprints, lithofacies assemblage, macro distribution, tectonic setting of the HA and HB members sandstone reservoirs, this study utilized fine 3D geological model, the rock properties and burial-thermal history reconstructions to constrain the temporal and spatial evolution of porosity and permeability via diagenetic modelling.
Numerical modelling results show that: (i) In the middle Himalayan stage, the HA sandstone reservoir was affected by meteoric water leaching, acidic fluid and hydrocarbon fluid, while the HB sandstone reservoir was affected merely by acidic fluid and hydrocarbon fluid. At this stage, sandstone reservoirs in the HA and HB members underwent mechanical compaction, dissolution and cementation, and porosity and permeability decreased rapidly. But the porosity reduction of sandstone reservoir in the HB member is faster than that in the HA member. In the late Himalayan stage, sandstone reservoirs in the HA and HB members underwent chemical compaction, dissolution and cementation with the slow increase of burial depth, and porosity and permeability decreased slowly. Meanwhile, reservoir temperature, porosity loss due to compaction in the HA and HB members sandstone reservoirs have a positive correlation with the burial depth. (ii) The quality of sandstone reservoir in the southern part of the HA member is better than that in the northern part, while the quality of sandstone reservoir in the middle part of the HB member is better than that in the southern and northern part. The better reservoir quality of the HA member than HB member is attributed to the shallow-buried depth, coarse grain size and abundant chlorite coating.

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Sedimentary Characteristics and Hydrocarbon Accumulation of Oil Sands in the Qiketai Formation of Turpan Depression, Turpan-Hami Basin

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Oil sands is an important unconventional oil and gas resource. Xinjiang is China's most abundant oil sands area. The oil sands in the Turpan-Hami basin have unique geological features and great potential for resources, but systematic researches on geology and geochemistry are lacking. Based on the analysis of the distribution of oil sands in the Qiketai tectonic belt in Turpan Depression, Turpan-Hami Basin, relying on core data, logging data, oil sands and geochemical analysis data of rock samples in the study area, to evaluate the oil sands quality and formation environment, and the evolution of hydrocarbon source rocks. Through the comprehensive analysis of the oil sands in this area, the reserves of oil sands and their potential are calculated. The results show that the oil sands in the study area enriched in the sandstones of the Qiketai Formation in the Middle Jurassic. The delta front sand bodies are mainly submarine distributary channels with a sand body thickness of about 30m. The oil source comes from the Taibei Depression in the Turpan Depression, and the migration channels are faults and sand bodies. Oil sands oil content greater than 6%, with low density, low viscosity, high wax characteristics. It is a residual anticline reservoir controlled by the bottom water. The thrusting of the Qiketai thrust in the late Yanshan Period made it rise to the surface and formed high-angle tilt and denudation to form an oil sands deposit.

This paper is to explore the geological features and accumulation of oil sands in the Turpan-Hami basin, aiming to provide references for other similar oil sands exploration and development in China.

Key words Turpan-Hami Basin, Turpan Depression, Qiketai Formation, Sedimentary Characteristics

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Distribution of volcanic sedimentary strata of Shimantan formation in Pingbei area, Xihu Sag, East China Sea Basin

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As a new type of oil and gas reservoirs, volcanic reservoirs have become one of the important fields for oil and gas exploration. The volcanic gas reservoir with relatively good productivity was discovered in the Shimentan Formation above the basement in the Pingbei area of the Xihu Sag in the East China Sea Basin. However, due to the constraints of exploration data, the current understanding of the volcanic rocks is not clear, affecting the evaluation of resource potential. Based on the investigation and research of the igneous reservoir at home and abroad and the previous research results, the seismic attributes of the volcanic strata are depicted by using core, drilling and 3D seismic data, and the relationship between the geological attribute and the seismic facies response is established, The correlation of seismic profiles of volcanic strata and the correlation of vertical sequence of igneous rocks and horizontal superposition are obtained. Through comparative analysis of fracture-volcano activity-basin filling evolution, the analysis of trunk faults and volcanic activity, the controlling factors and distribution rules of volcanic strata are obtained. The results show that the volcanic strata in the study area are controlled by faults, and the volcanic eruption centers are fractured, migrating gradually from north to south and are arranged in beading. The fault controls volcanic eruptions and magmatic activities, and igneous rocks are mainly distributed along major fault zones. In the same period, the region with high activity rate of faults developed lava-type sedimentary strata, the region with low activity velocity developed clastic sedimentary strata, and the sedimentary volcanic clastic rocks were developed in relatively low-lying areas.

By studying the controlling factors and the spatial distribution of volcanic sedimentary strata, this paper aims to provide evidence for the exploration and development of the area in the next step and for finding favorable volcanic reservoirs.

Key words East China Sea Basin, Xihu Sag, Shimentan Formation, volcanic sedimentary strata

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LATE HOLOCENE SEDIMENTARY ENVIRONMENTS AND COASTAL PROGRADATION IN SOUTHWESTERN HAINAN ISLAND, SOUTH CHINA

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The reconstruction of coast environments and coastal progradation during the Holocene is an important issue for predicting future development of coastline and supplying scientific data for maritime engineering.

The study area located in the southwestern coast of Hainan Island, South China is a typical location for wave-dominated embayments. The coastline of embayment is arc-shaped with a bedrock cape at its northern and southern tips. The embayment is composed of beach and coastal dune systems intersected by small estuaries. Behind the beach and coastal dunes are exposed in landward first order (8-15m above sea level), second order (20-30m above sea level) and third order (35-50m above sea level) terraces. The first and second order terraces are features belonging to late and middle Pleistocene barrier-lagoon systems, which consist of medium to coarse sands with greenish gray and grayish white clayey medium sands which might be attributed to lagoon deposits between barriers. The third terrace is composed of early Pleistocene alluvial sandy conglomerates. A patch of beachrock about 1km wide exposes on the beach at the southern end of the embayment. The beachrock was mainly composed of coral and mollusc-bearing sands, dated as old as 6ka, probably indicating biological fragment supply during the Holocene sea level highstand. The study area has been heavily influenced by human activities such as planting tropical fruits and digging heavy minerals on the dunes and old barriers and planting rice in low land between barriers. The study aims to: 1)analyze the grain size composition of exposed sections and sediment cores and 2)document the sedimentary successions for reconstructing Holocene sedimentary environments in context of coastal progradation.

Twenty-six on-beach sections and four nearshore sections (-5m isobaths) were selected for surface sampling, supplemented by four sediment cores (8-9 m length) of Holocene age. Beach sediments are mostly composed of very coarse sands and granules ($0 \sim 2\Phi$), with moderate to good sorting, while the nearshore sediments show an obvious grain size decrease to $2 \sim 6\Phi$. The grain size trend indicates a south to north along-shore drift. The core-recorded successions reveal silty clay and clay at the bottom, overlaid by granule coarse sand (2.8-5.1 m thick), coarse to medium grain sands (0.6 -1.3 m thick) in middle and medium to fine grain sands (3.5-4.8 m thick) on the top. This sedimentary facies indicates a lagoon environment during the early to middle Holocene, according to our chronology. The lagoon was filled by sand when the beach began to prograde seaward in late Holocene and finally the beach was covered by coastal dunes. The results indicate that the old coastline was located about 850 m away from the present line at 2673±90 cal a BP., about 265m at 1949±66 cal a BP., 120 m at 1370±46 cal a BP and very close to the present coastline at 893±32 cal a B.P. The coastline prograded by about 0.8m/a in maximum between 2600 and 800 cal a BP and slowed down since the last 800 years. The result may supply a basis for coast management and planning under a fast global sea level rise and severe human impact on coast areas in south China.

Title: Coral reef development near Union Tablemount, South China Sea, China

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There are a lot of coral reefs in the area of the Nansha Islands, in the form of atolls. They have unique and characteristic geomorphological patterns. The Mckennan and Whitsum reefs of Union Tablemount are two growing atolls. Grain size analysis of surficial sediment samples collected from the two sites shows that coral fragment is the main component of sediments, and the grain-size characteristics depends on the distance from shoreline. A reef evolution model is proposed involving the parameters associated with current, wind and wave conditions. The development of the atolls is investigated using the model. The result shows that the main transporting forces involved in removing surficial sediment include wind-driven waves and currents, while catastrophic storms play an important role in short-term transport.

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SEDIMENTARY RECORDS OF EXTREME WAVE EVENTS ON THE NORTHEASTERN HAINAN ISLAND COAST, SOUTHERN CHINA

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The Rammasun typhoon was generated to the east of the Philippines on 12th July 2014, northwestern Pacific, and landed at Wengtian Town in Hainan Province on the 18th. It is the strongest disastrous typhoon that hit the southern China region since 1950, causing heavy losses to the lives and property of the Hainan, Guangdong, and Guangxi provinces. However, although the high frequency of typhoon occurrence in Hainan Island in history is well known, it is difficult to determine the frequency of occurrence of the events like the Rammasun typhoon because of lack of detailed historical records. Here we use the sedimentary record, in combination of the information on the present-day events, i.e., the Rammasun typhoon, to define the typhoon intensity and identify the super typhoons that occurred in the past. In this study, a detailed field investigation was conducted in the coastal area of Wengtian Town, northeastern Hainan. We identified storm beach-rock boulders and storm over-wash sediments interbedded within the coast dune sequence along the northeastern coast of Hainan Island. Base on laboratory and sediment dynamic analyses[1-2], we propose that the deposits was generated by super typhoon events around 3400 a B.P. We found that the intensity of the typhoon that created these deposits was stronger than the Rammasun typhoon, which is of great significance to the reconstruction of typhoon sequences on the millennial and centennial scales. Hydrodynamic analysis indicates that the wide reef flat in front of the beaches and coastal dunes plays a significant role in coast protection[3-4]. Thus, the regional coral reef degeneration that is taking place now, together with likely intensified storms due to climate change and future sea level rise, there will be an enhanced risk of coastal erosion. It is imperative to take care of the coral reefs in Hainan Island.

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SEDIMENTARY PROCESS OF CRETACEOUS GLAUCONITIC SANDSTONE IN ORIENTE BASIN, ECUADOR

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Although the Cretaceous sediments in the Oriente Basin, Ecuador have been extensively studied, the sedimentary process of glauconite-bearing sandstones in these sediments is still questionable. A reliable interpretation of sedimentary process for glauconite-bearing units requires the characterization of petrological, mineralogical, geochemical, spatial attributes of glauconite.

The glauconite-bearing sandstones that occur in the upper part of the Albian "T" Member generally has a very variable proportions of 1–50 wt% glauconite. The glauconite content commonly increase upward. In the lower part of glauconite-bearing units, quartz sandstones and glauconite-bearing sandstones are interbedded with wavy/tidal cross-bedding, implying a moderate energy environment. In the upper part, glauconite-bearing sandstones with bioturbated structure intercalated with shales, indicating a low energy environment. Glauconite appears as oval, rounded, fine to medium-grained (50–250μm), moderately- to well-sorted, green to dark green pellets. Potassium content is a reliable indicator of pellet maturity[1]. The K_2O content of glauconite shows high value (6–10 wt%) [2], which indicate evolved and highly evolved maturity. Pellet maturity apparently corresponds with the degree of winnowing and sedimentation rate[3].

Minor maturity variation, and similar morphology and geochemical composition between samples in different locations reveal characteristics of parautochthonous glauconitic minerals. Upward increasement of glauconite content suggest that the parautochthonous glauconite formed in the outer continental shelf and shifted/accumulated landward, indicating the relative sea-level rise during the marine transgressive phase. Petrological, mineralogical, geochemical composition, and spatial distribution of glauconite indicate its characteristics of intrasequential glauconitic mineral, undergone transport of tidal/wavy currents processes and mixed with terrigenous quartz in the mid- to outer shelf and inner shelf.

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STUDY ON PHYSICAL SIMULATION OF DEEP WATER CHANNEL DEPOSITION SYSTEM

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The deep-water sedimentary system has rich oil and gas resources and has become a hot field in the current oil and gas exploration. Although scholars have carried out extensive research, has achieved fruitful results, however, restricted by various conditions, formation, channel complex morphology, evolution, migration of superimposed relationship research is still in its infancy. Moreover, the deep-water channel depositional system is limited to the study of sedimentary mechanism. There is a lack of in-depth analysis of channel configuration evolution, sand body building structure and hierarchy, sand body heterogeneity distribution and sand body migration superposition relationship.

The study was conducted using a self-developed physical simulation device for the deep-water deposition system. Experimental advantages: Among them, visual cameras and cameras are added to provide a favorable data support for the research. The inaccuracy of artificial measurement is reduced by adding an underwater velocity measuring instrument. The experiment body uses transparent material to realize the visualization of the side phenomenon during the process of the experiment. The addition of movable floor has realized the transformation between different landforms. The experiment mainly analyzes water depth, source abundances, slope and flow factors. The main study from three aspects: A, the evolution of the configuration of the source and sink channel with the flow state of the fluid; B, a fine study of a single microphase and its internal size; C, the fine anatomy of the development pattern, distribution characteristics and superposition relation of the deep-water reservoir sand body is to establish the degree of quantitative or semi quantitative model. After the experiment, the experimental results were sliced. Fluent software is used to analyze the influence factors of velocity, flow pattern and sediment distribution. Finally, Petrel software is used to reconstruct the whole model and realize 3D reconstruction.

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TITLE: Facies Controls on the Distribution of Diagenetic Alterations in Fan Delta and Braided-river Delta Deposits: A Case Study from the Eocene Sandstone, Raoyang Sag, Bohai-bay Basin

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By integrating diagenesis and sedimentary facies, the distribution of diagenetic alterations and their impacts on reservoir quality were investigated within a lacustrine fan delta and braided-river delta depositional environment in the Shahejie Formation of the Raoyang Sag, Bohai-bay Basin. Core observation and analyses of petrography and geochemistry of the sandstones revealed that that the eogenetic alterations display spatial and temporal distribution patterns associated with sedimentary facies, including distributary channels of a fan delta front (DC), distributary bays (DB) and sheet sands (SS) and mouth bar (MB) (SS and MB are collectively referred to as S). Percolation of meteoric waters occurring in high permeability DC sandstones resulted in leaching of feldspar, the formation of kaolinite, as well as mechanical infiltrated clays around detrital grains. Conversely, the DB deposits containing abundant ductile lithic fragments were subjected to mechanical compaction and thus the development of a pseudomatrix. Additionally, eogenetic alterations have an important impact on the distribution of the mesogenetic alterations. Sandstones containing few eogenetic cements or thin or discontinuous infiltrated clay rims around the detrital grains were subjected to quartz cementation. However, during the hydrocarbon generation stage, the most efficient percolation of meteoric waters and organic acid dissolved feldspar minerals and carbonate cements, resulted in DC sandstones having more intragranular and intergranular porosity. Owing to high matrix contents and early calcite cement contents, the DB and S sandstones had lower permeability and were rarely dissolved. During the late mesogenetic stage, late carbonate cements occurred in all sedimentary facies and iron and magnesium ions were released from the transformation from kaolinite to illite or to chlorite. The results from this study show possible diagenetic evolutionary pathways in the reservoir sandstones within the fan delta depositional environment, which in turn provides some insights into the controls on reservoir potential.

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THE DISTRIBUTION PATTERNS OF CALCITE CEMENT IN SHAHEJIE FORMATION TURBIDITE SANDSTONES IN THE DONGYING DEPRESSION, CHINA

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Calcite cements are volumetrically among the most important diagenetic constituents in turbidite sandstones of the Paleogene Shahejie Formation, Dongying depression, Bohaiwan Basin. In the turbidites sandstone, calcite-cemented zones can occur throughout the sandstone bodies, but they are somewhat more common in the thicker sandstone bodies(＞50cm) along the contacts with the intercalated shales, remaining partially or totally porous in the middle part. Calcite cement is most common in what are interpreted to be overbank splay and lobe facies at the margins of the sandstone body, and less abundant in the channel facies in the center. This pattern suggests that the reactive aqueous fluids and components for cements are interpreted as having been transported into the sandstones from adjacent organic-rich shales (Dutton,2008). Petrographic data and stable isotopes indicate that detrital carbonate particles in intercalated siltstones were the main sources of calcite cement. Organic acids generated during thermal maturation of organic matter probably provided a source of acid for carbonate dissolution and export into the sandstones. Only if the organic-rich siltstones may have generated organic acid sufficient to keep the dissolved carbonate in solution and transport it out of the siltstones and into sandstones. When calcium carbonate was transported into the sandstones, feldspars buffered acidic pore waters near where they entered the sandstone, resulting in calcite precipitation near the sandstone-siltstone contacts. (Milliken and Land,1993). Some calcites do not correlate with proximity to siltstone beds, but have a preference for sandstones that had relatively high initial porosities and permeabilities. Distribution of other calcite-cemented zones that are not at the margins of the sandstone bodies or not near the sandstone-siltstone contacts may relate to grainsize variations that exert a control on fluid flow (McBride and Milliken,2006).

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General theme 5

Sources & Sinks

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TRACING PROVENANCE AND PATHWAYS OF HOLOCENE PO PLAIN SEDIMENTS THROUGH HIGH-RESOLUTION SEQUENCE STRATIGRAPHY AND BULK-SEDIMENT GEOCHEMISTRY

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The geochemical differentiation of sediment packages framed by surfaces of chronostratigraphic significance may represent a robust tool to quantify sediment fluxes and their link to mapped sediment volumes across downdip segments of the sediment dispersal system. In this study, a high-resolution, chemostratigraphic approach was applied to stratigraphically constrained Late Pleistocene and Holocene strata from a multi-sourced sediment-supply system (Po Basin, Italy). Through hundreds of ^{14}C dates, we focused on the quantification of geologic time within systems tracts and their component sub-units (parasequences) (10^2 to 10^4-year time scales), exploring the implications of a highly fragmented sedimentary record on reconstructing sediment fluxes and genetic relations between stratal successions. Compositional unique catchment lithologies (e.g., mafic/ultramafic rocks and dolostones) were used as end-member assemblages to trace mineralogical and geochemical signatures across alluvial and coastal depositional systems and delineate basin-wide markers of sediment provenance from distinct Alpine and Apenninic sediment sources.

Large magnitude, Late Pleistocene sea-level fluctuations had a major impact on sediment pathways, producing sharp provenance changes at key stratigraphic surfaces. Notable shifts in sediment provenance occurred across sequence boundaries and transgressive surfaces, as both surfaces imply abrupt changes in basin configuration and sediment dispersal patterns. In contrast, no abrupt shifts in sediment provenance were observed within early Holocene deposits, at the turnaround from retrogradation to progradation (maximum flooding surface).

The middle-late Holocene succession of the Po Delta forms an aggradational to progradational parasequence set, where a laterally continuous sediment body results from the complex superposition of west-to-east delta progradation and southerly-directed longshore currents. On a millennial (parasequence) scale, we document the ability of a geochemical approach to delineate within bay-head delta, delta front, prodelta and strandplain facies assemblages the different sources that effectively contributed to coastal progradation and to outline, map and quantify the geometries and volumes of individual clinothems that using conventional sedimentological methods it would be virtually impossible to restore.

This study shows that bulk-sediment geochemistry can contribute to source-to-sink analysis on a variety of temporal scales and through a wide spectrum of lithofacies assemblages. At the parasequence (millennial) scale of investigation, it provides insight into the potential complexities of sediment fluxes that can be useful for guiding interpretation in the ancient rocks.

ONSET OF NORTHERN ANDEAN DEFORMATION DEFINED BY PETROGRAPHY, LITHOFACIES AND SUBSIDENCE ANALYSIS

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Earliest phases of Andean-type deformation in the northern Andes are overprinted by strong Neogene deformation. The Eastern Cordillera of Colombia (EC), an opposite-vergent deformed belt, expose Campanian to Paleocene strata from different depocenters that record the change from marine to continental deposition. Were those depocenters joined together in a single basin adjacent to a magmatic belt to the west? Or in contrast, were they isolated from each other in hinterland basins adjacent to intraplate uplifts? Integration of detailed geologic mapping (3D outcrop analysis) with palynology, stratigraphy, sedimentology and provenance analyses (petrography, published U-Pb geochronology, paleocurrents) in the Cocuy basin, located in the central zone of the Eastern Cordillera of Colombia, supply new data to determine whether syn-orogenic accumulation took place in a large single basin or in a basin isolated by intraplate uplifts. This information is analyzed on palinspastic restorations of NW South America plate.

Shallow-marine carbonate and clayed terrigenous deposition of La Luna Formation (Coniacian-Santonian) was abruptly covered with muddy and silty terrigenous sediments of Los Pinos Formation (upper Campanian). Material was supplied from two areas located farther to the south: (1) a western uplifted magmatic arc located at > 350 km, and (2) a southeastern intraplate deformation located at > 300 kms that expose Cretaceous sedimentary cover. The overlain Maastrichtian-lowermost Paleocene Guaduas Formation include medium- to coarse-grained quartzarenite sandstones interbedded with laminated mudstones accumulated in shallow-marine to marginal environments. Sandstones show evidence of reworked glauconite and oxidized muddy matrix that indicate supply from nearby source areas with paleosol development. Paleocene Lower and Upper Socha formations record the rapid advance of fluvial environments in a basin with high rates of tectonic subsidence (1000m/7my). Sandstone composition changes up-section from quartzarenite to litharenite, suggesting the unroofing of nearby uplifts with (1) quartzose sedimentary cover and (2) metamorphic-cored basement block that supplied abundant unstable rocks fragments (up to 42%) also including volcanic rock fragments. Interpreted intraplate uplifts were located <80 km from the Cocuy depocenter, both to the west (Santander Massif with thin sedimentary cover and metamorphic rocks) and to the east (eastern intraplate uplifts exposing quartzose sedimentary cover). Short fluvial transport and rapid burial processes favored preservation of unstable fragments. U-Pb detrital geochronology in Paleocene rocks include population of Paleocene age, suggesting syn-depositional volcanism. Our results show evidence of early phases of intraplate deformation since Maastrichtian time bounding the Cocuy basin, supporting the hypothesis of generation of several syn-orogenic hinterland basins separated by intraplate uplifts and volcanism.

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THE BENGAL FAN EVOLUTION AND STRATIGRAPHY AT 8°N – INTEGRATING SEISMIC DATA AND IODP 354 DRILLING RESULTS

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The Bengal Fan is of particular scientific importance as it contains the most complete record of the tectonic and climate history of the Himalayan Mountains/Tibetan Plateau uplift as well as the evolution of the Asian monsoon since fan initiation in the early Eocene to present. Since the Late Miocene, deposition on the Bengal Fan has been dominated by channel-levee systems (CLSs), forming a complex depositional system with lateral depocenter migration over the entire fan (Curray et al., 2003, Schwenk and Spieß 2009). Here we present results from an integrated study of multichannel seismic (MCS) data and IODP Expedition 354 drilling results (400 km 7-site W-E transect, middle Bengal Fan, 8°N). We investigated the fan architecture and the succession of individual Pleistocene CLSs with respect to environmental changes in the Bengal Basin. Moreover, the seismic stratigraphy was incorporated into a core-seismic integrated age model using a Bayesian approach that respects the law of superposition and all known age constrains in order to refine the transect's chronostratigraphy. Along the MCS Profile GeoB97-020+027, crossing all IODP 354 sites, 40 individual CLSs occur above a prominent hemipelagic layer (HL1), comprising the Matuyama-Brunhes Magnetic Reversal as well as the Jaramillo and Cobb Mountain Subchrons. The CLSs are intercalated by silty/sandy inter-channel sediments deposited from unchannelized turbidity currents, which control the preservation of a nearly flat surface/seafloor. Based on thorough tracing of base reflections of all CLSs a relative stacking pattern has been developed. The large scale depositional dynamics of the transition from a hemipelagic to turbiditic-dominated regime promote the concept of individual subfans or channel-levee complexes, introduced by Curray et al., 2003, which govern only parts of the Bengal Fan while other areas receive (almost) no fan sedimentation. The variable size of identified CLSs indicates a random distribution of CLS maturity, which in turn suggests autocyclic processes such as upfan avulsions as main control on the CLS lifetimes. Based on the core-seismic integrated age model and the correlation of time markers in between drill sites we achieved a significant improvement of the chrono-stratigraphy along the transect to a ~100 ka resolution. Furthermore, we found that sediment flux reaching 8°N increased steadily between 650-250 ka, which could be driven either climatically, by a change in the input function, or autocyclic.

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BALANCING SEDIMENT BUDGETS IN DEEP TIME AND THE NATURE OF THE STRATIGRAPHIC RECORD

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The stratigraphic record comprises long-duration hiatal surfaces bounding slivers of preserved stratigraphy. Long-term 1-dimensional sedimentation rates appear to become slower, as thicker units and longer time periods are considered, begging the question of how sediment is partitioned in time and 3D space in basin fills. 3D time-stratigraphic analysis of Quaternary delta systems in the Gulf of Mexico, including the Mississippi and Lagniappe, illustrate the extremely localized nature of sedimentation and associated hiatal surfaces. Source to sink analysis allows estimates to be made of the volume of sediment delivered to a basin by a given river systems over the duration that the river existed. Integration of annual volumes of sediment discharged by the Mississippi, over its inter-avulsion period of 1500 years balance with the volumes of mapped sediment in individual deltas, as do volumes of sediment associated with smaller systems, such as the Lagniappe delta. Continental scale river systems, and associated deltaic parasequences, like the Mississippi, can prograde over the entire shelf at an autogenic frequency of a few thousand years, whereas smaller systems, such as the Lagniappe delta, may require 10 Ka-scale allogenic controls, such as eustatic forcing to transit the shelf. Both systems produce deltaic lobes with similar areal dimensions, but with rather different origin (autogenic versus allogenic) and fundamental differences in the scale of autogenic elements, such as mouth bars.

Sediment budgets can also be reconciled in deep-time river systems. Incised river systems associated with the Cretaceous Dunvegan Formation in Alberta and the Ferron Sandstone in Utah fed into the Western Interior Seaway and delivered on the order of 100 km^3 - 300 km^3 of sediment over a 20,000 year period, which roughly corresponds to the duration of a parasequence, reflecting a shelf transit cycle of sea-level. At its maximum, the Cretaceous seaway contained about 2.0 million km^3 of seawater, representing a source-to sink ratio of about 7500. A single river would take on the order of 150 million years to fill the seaway.

Regional paleogeographic mapping shows that along the western border of the seaway at peak transgression during the Turonian Greenhouse, there were perhaps as many as 7-10 major S2S river-delta systems. Assuming these rivers are of a similar scale as the Dunvegan and Ferron systems, they could collectively produce about 3000 km^3 of sediment over a 20 Ka Milankovitch period. Collectively these rivers could theoretically supply enough sediment to fill the entire seaway in about 15 million years, again assuming no new subsidence. However, most of these wedges have durations on the order of 1-2 million years, resulting in a chronically under-filled basin. The rivers are stable for 1/10th the time required to actually fill the basin. Big basins, such as the Cretaceous Seaway, fed by very localized and relatively small S2S systems result in profoundly uneven sedimentation with very high rates near the river inputs, producing localized clastic wedges, that thin and decay over a few hundred kilometres to exceedingly low sedimentation rates. In order to decipher interregional signals, correlation of the higher fidelity record within and between clastic wedges is required as well as consideration of the scales of autogenic versus allogenic controls.

SOURCE TO SINK SYSTEM OF THE LARGE CLASTIC RESERVOIR: A CASE STUDY FROM THE OLIGOCENE HUAGANG FORMATION IN THE XIHU DEPRESSION, EAST CHINA SEA BASIN

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Xihu Depression is a most important oil- and gas-bearing area in the East China Sea Basin. The Huagang Formation was the excellent clastic reservoirs, previous studies showed that the large sandbodies were up to several hundred meters. However, the characteristics of the source area and sandbodies distribution are not clear, which significantly limit the further exploration for hydrocarbon in the Xihu Depression.

Based on new drilling data of the Xihu Depression in recent years, the methods of seismic reflection analysis, paleogeomorphology reconstruction, classic zircon U-Pb dating, heavy mineral analysis and paleocurrent direction restoration were used to analyze the characteristics and distribution of source to sink system in Huagang Formation. The results of the paleogeomorphology showed that the study area was characterized by belts in E-W and blocks in S-N in the Huagang Formation. Combining with the regional stratigraphic, it was considered that the dominated source area of the Huagang Formation was Precambrian sandstone from the northern Hupijiao Uplift, and the secondary source area were Paleozoic and Mesozoic from the Western Haijiao Uplift and the Eastern Diaoyu Islands Uplift.

The characteristics of seismic reflection and fault systems showed that there were three types of transport channels in Xihu Depression, which included the axial river channel, western valley and eastern transform faults. The axial river channel was gentlely and widely, the maximum range could reach tens kilometers, and the ricer channel diverted frequently in the plane.

The paleogeomorphology and the source to sink system determined the sedimentary filling process of Huagang Formation. In the early stage of the Huagang Formation, the accommodation of the study area was small and controlled by the narrow paleogeomorphology. The sediment-routing system from Hupijiao Uplift was extended over long distances, and it was also supplied by the sediments from the adjacent distributary channels. Thus, it formed the rudiment of large clastic reservoir. During the late stage of the Huagang Formation, the range of lake was expanded rapidly, and the sediment-routing system was shanked sharply. In the upper member of Huagang Formation, this process of depositing occurred again. Therefore, the sandbodies were filled repeatedly and developed the large clastic reservoirs in the Huagang Formation.

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GROWTH OF THE LATE MIOCENE TO PLIOCENE PALEO-ORINOCO SHELF-MARGIN PRISM

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The paleo-Orinoco River delta system and associated continental slope was a mixed river, tide, wave, and sediment-gravity flow system that tracked down to deep-water submarine fans. The Orinoco River built a 10-km-thick sedimentary prism since the late Miocene, which disperses more than 200 km wide at present. The Upper Miocene-Pliocene prism, with its linkage to the southern Columbus Basin and Columbus Channel, is composed of four progradational clastic wedges, each with a thickness up to 2 km, separated by well-known, Trinidad wide marine flooding intervals of similar extent. The studied sedimentary prism spans an approximate 4 Ma period and shows an irregularly rising shelf-edge trajectory towards the Atlantic, with very thick topset aggradation (aggradation rate >200 m/Ma during the late Miocene; >550 m/Ma during the Pliocene) and rapid progradation (progradation rate =33 km/Ma during the late Miocene; =18 km/Ma during the Pliocene) of the fronting deepwater slope, despite an overall and periodic falling eustatic sea level during this global icehouse period. The tramline-like trajectory changes demonstrate at least three major stages of clinoform evolution, with each stage starting from progradational basinward shifts, followed by aggradational clinothem with decreased thickness. And for shorter (approximate less than 100 k.y.) time scale, Paleo-Orinoco shelf-margin growth was generated by repeated cross-shelf, regressive-transgressive transits (>100 km) of the Orinoco delta system, with internal variability in clinoform architecture and process-regime changes during shelf-margin construction.

The clinoform drivers of the long-term growth of the Paleo-Orinoco margin include that: (1) large sediment supply and paleoflux driven by Orinoco sediment loading from one of the Earth's biggest rivers feed the whole system persistently. The Pliocene sediment discharge is estimated to have been about 11.3×106 ton/yr based on flux calculation by using clinoform morphology and geometry parameters; (2) Forced regression at shelf margin during high-frequency icehouse sea level changes drives the topset deltas across the shelf. And a eustatic fall is considered as the driver of the shelf collapse into the Columbus Canyon; (3) as one of the most rapidly subsiding shelf-margin prisms, the Orinoco margin with high tectonic-subsidence rate up to 1000 m/Ma, provides accommodation for sediments to be stored on the shelf and delivered down to the slope and deepwater area; (4) the development of northwest-southeast oriented, down-to-the-northeast, extensional normal growth faults is the dynamic trigger for the coeval outbuilding of the paleodelta system across the region.

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TRANSMITTING EROSIONAL SIGNALS FROM THE WESTERN HIMALAYA TO THE ABYSSAL ARABIAN SEA

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Erosion of the western Himalaya and Karakoram over millennial and possibly longer scales is largely controlled by precipitation, either directly or indirectly through glaciation. Sediment produced by glaciation in the Greater Himalaya within the rain shadow during the Last Glacial Maximum was not mobilized until the summer monsoon precipitation strengthened over the early to mid-Holocene. High sediment load from mountain rivers resulted valley aggradation and transient storage, with later reworking during the latter part of the Holocene as precipitation and consequent sediment supply waned. Sediment storage results in significant buffering of at least 5–10 k.y. across the northern flood plains and potentially even longer storage in upper Indus river valleys (10^3–10^4 years). Nonetheless, millennial-scale changes in spatial distribution of erosion and erosion rates can be observed in sediment provenance at the Indus river mouth despite the ability of the flood plains to buffer sediment signals leaving the mountain front. Since the Holocene sealevel rise the shelf west of the river mouth has been supplied in part by longshore drift, while Indus River sediment has moved east to a large shelf clinoform, well as into the canyon. Bulk sediment Nd and Sr isotopes suggest a relatively close connection between river sediment supply and delivery of muddy sediments to the Indus submarine canyon. Buffering estimates between the river mouth and submarine canyon are suggested to be less than 8 k.y. In contrast, sandier material is predominantly sequestered at the river mouth and the limited sandy material that reaches the canyon differs in U-Pb zircon and AFT age provenance. Despite this variable behavior, the submarine canyon preserves evidence for rapid changes in sediment compositions, especially over the last 100 years. Although the sand supply is not direct between river and canyon it is not fully buffered and temporal variability exists into water depths of >1300 m. Over longer time scales (>10^6 years), sandier sediment supplied to the Indus submarine fan is more stable in provenance over the last ~1.9 M.y.. This indicates homogenization by reworking in the canyon or upper fan spanning at least ~100 k.y. The deep-water appears most similar to the interglacial, not glacial delta in terms of U-Pb zircon ages. This points to most sediment production to the submarine fan is most efficient when the summer monsoon increases precipitation, river discharge, and sediment supply. The Indus drainage system underlines that here submarine fan turbidites are useful for assessing tectonic-scale forcing on erosion but useless for charting continental landscape responses to millennial-scale forcing such as climatic and human impacts.

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GEOLOGICAL SIGNIFICANCE AND CONTROLLING FACTORS OF SILICICLASTIC PARASEQUENCES: A COMPARATIVE STUDY

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Parasequences are widely applied in the description of shallow-marine strata, and are commonly regarded as the fundamental building blocks in the erection of sequence-stratigraphic interpretations. Although interpreting parasequences in sedimentological datasets is heuristic and in part subjective, their diagnostic criteria are clearly defined, and were effectively established before the coining of the term to informally recognize regressive shallow-marine sandstone tongues bounded by flooding surfaces. Parasequence architecture is commonly cited to be influenced by rates of creation of accommodation space, rates of sediment supply to the shoreline, and by autogenic behaviours. However, quantitative assessment of these factors, undertaken with consideration of the genetic significance of parasequences, is to-date still lacking. This study combines data from several published case studies, with the aims of undertaking a 4D characterization of parasequences and determining the relative importance of depositional-system self-organization and allogenic controlling factors on their architecture.

Data on >30 shallow-marine successions containing >500 parasequences have been coded in a relational database, which includes outcrop and subsurface datasets (both ancient and Quaternary examples), spanning both river-dominated deltaic and wave-dominated coastal systems.

The importance of accommodation (A) and sediment supply (S) in determining parasequence architecture is assessed quantitatively, through analysis of relationships between quantities that describe these variables and of morphometric parameters of parasequences, notably of their sand-rich parts. Together with rates of aggradation and progradation, proxies for A/S ratios relevant at different scale are considered: (i) facies-tract shoreline trajectories, (ii) parasequence-set stacking patterns, (iii) parasequence progradation angle. Additionally, parasequences are classified by type of systems tract. Statistical analysis indicates the significance of proxies of A/S ratios as predictors for parasequence architecture (thickness, sandstone thickness and lateral extent, top type). Preliminary analysis of linkages of deltaic parasequences with the configuration of upstream fluvial systems is also presented in the form of scaling relationships with inferred river hydraulic geometry and size of catchment areas. However, especially where temporal control is available, results also highlight biases in the ability to resolve parasequences consistently.

Future work will focus on integration of this database compilation with estimated sediment budgets, data on internal facies architecture, and evidence for process regime.

CLASTIC BEDDING PLANES AS ARCHIVES OF TIME AND PALAEOENVIRONMENTAL INFORMATION

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Bedding planes – the first-order stratigraphic discontinuities that permeate clastic sedimentary outcrops – are often excellent archives of palaeoenvironmental information. When they represent true substrates (i.e., the morphology of the sediment-water or sediment-air interface at the time of deposition), they can host a variety of original signatures of bedforms, sedimentary structures and surficial trace fossils, emplaced at the time of deposition. Yet clearly not all bedding planes at outcrop record primary substrates and, where they do, there are often questions as to why they were preserved at all: the near-perfect preservation of delicate surface textures (e.g., raindrop impressions, arthropod trackways, adhesion ripples) can seem counter-intuitive without invoking 'special' taphonomic conditions, particularly within granular sediments.

In this talk we argue that the fidelity of bedding planes as archives of palaeoenvironmental information is dependent on the continuity of time over which an original substrate persisted: in other words, the duration of sedimentary stasis following the depositional or erosional creation of a surface. Bedding planes seen at outcrop may have been: 1) variably persistent as substrates, permitting the palimpsesting of single to multiple generations of surface textures; 2) transient as substrates due to forming under continuous aggradation of sediment (e.g., the rapid migration of dune lee slopes/foresets, or continuous sedimentation from suspension); or 3) unrelated to original substrates (e.g., forming post-depositionally due to erosional scour-fill, diagenesis, or bioturbation). While it is often impossible to quantify the duration of substrate stasis from outcrop, grouping bedding planes into these categories can permit a refined understanding of sedimentary outcrops as archives of both palaeoenvironmental and temporal information.

Demonstrating this, we present a case study of the variety of types of bedding planes from the Silurian Tumblagooda Sandstone, Western Australia; some of which are extensive original substrates yielding delicate three-dimensional primary substrate features. We show that even erosional bounding surfaces in trough cross-bedded sandstones can, in some instances, represent primary substrates because they are seen to be colonized by surficial trace fossils: attesting to an interval of stasis separating antecedent erosional bounding surfaces from overlying cosets. We use this evidence to develop a conceptual model that argues that the preservation of true substrates, with delicate surface features, should not be unexpected when it is recognized that stasis is the dominant reason behind 'missing' stratigraphic time at the scale of any individual outcrop.

A DETRITAL PROVENANCE STORY FROM GONDWANA TO NORTHWEST THAILAND

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The evolution of the Sibumasu Terrane forms a principal component in the history of the Tethys and the development of Southeast Asia. The Sibumasu Terrane is a ribbon continent that is often oversimplified in palaeogeographic reconstructions [1, 2]. During the Proterozoic to early Paleozoic, previous studies have located the Sibumasu Terrane off the northwest margin of Australia in the Gondwanan supercontinent [2]. Sibumasu rifted northwards away from the Gondwana margin in the early Permian, and subsequently collided with the other terranes that make up Thailand during the Triassic Indosinian Orogeny [1, 2]. Overall, there is little specific information known about the older palaeogeographic setting of Sibumasu and its neighbouring terranes. However, analysis of detrital age populations, geochemical signatures and statistical evidence can help us better understand the evolution of the Sibumasu Terrane. Therefore, this study uses U–Pb geochronology and Lu-Hf isotopic information from the Paleozoic and Mesozoic detrital zircon record of the Sibumasu Terrane in northwest Thailand. This study has found a significant change in source material from the older Paleozoic sedimentary sequences sourcing from the Sibumasu Terrane and other older sources, compared to the Permo-Triassic zircon sources associated with the Indosinian Orogeny in the younger sedimentary units. These temporal changes in the isotopic systems reflect the movement of the Sibumasu Terrane from the northwest Australian margin of Gondwana to its collision with the terranes of present-day Asia. In an attempt to better constrain this evolution, we have also compared our new data to those published from Sibumasu, Indochina, Sukhothai, West Burma, South China and Western Australia. These results have implications for understanding Thailand and its present-day neighbours and also their position within the Gondwanan supercontinent.

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NUMERICAL MODELING (DIONISOS) OF FALLING-STAGE DELTA TOPSET AGGRADATION AND RIVER INCISION: SOVEREIGNTY OF CHANGING SEDIMENT SUPPLY

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Numerical modeling and field studies have proved that delta topset aggradation can occur during period of relative sea-level (RSL) fall. Such a process is interpreted from a geometric point-of-view as a fluvial equilibrium profile steeper than the descending regressive shoreline trajectory which numerically corresponds to high amounts of sediment supply allied to low diffusion rates in subaerial environments, the sediment supply hence exceeding the river carrying capacities. It has, additionally been showed that variable parameters such as RSL fall and subsidence rates or basin physiography may promote a transition from topset aggradation to degradation during a period of RSL fall. The influence of changing sediment supply, presumably preponderant, has been comparatively less explored. Constraining the stratigraphic signature of delta topset aggradation to degradation forced by changing sediment supply during sea level fall is hence crucial because fluctuating sediment supply is a process arguably common among sedimentary processes.

In the present contribution, the depositional sequence of a deltaic system emplaced in postglacial times under conditions of RSL fall forced by the glacio-isostatic adjustment, inferred from the well-constrained stratigraphic architecture and timing, has been successfully modeled numerically (DIONISOS) and validated. A particular emphasis was given to the influence of sediment supply on topset aggradation and subsequent degradation. It has indeed been suggested that initial proglacial sedimentation was characterized by topset aggradation in spite of the RSL fall which rates attained several cm per years while topset degradation initiated when the ice margin retreated from the drainage basin, resulting in an abrupt drop of sediment and meltwater supplies reaching the delta.

Our findings indicate that 1) topset aggradation can occur even when RSL fall rates are outstanding and without equivalent in non-glaciated settings, provided that huge amount of sediment are supplied to the delta; 2) the transition from topset aggradation to degradation, when forced by an abrupt drop of sediment supply, can occur any time in the RSL fall history, even when falling rates are decreasing; and 3) the stratigraphic record of such a transition, largely uncoupled to any signal of RSL reversal, may be in the ancient geological record mistakenly interpreted as a turnaround from normally to forced-regressive system tracts.

The detrital zircon U-Pb ages for the Jiefangcun Formation: implications for the final closure of the Paleo-Asian Ocean

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There is a fierce debate on the timing of the final closure of the Paleo-Asian Ocean (PAO). Four floras including Eurasian, Cathaysian, Angaran and Gondwana floras were prevailed around the world during the Permian Period. The mixture of the Cathaysian and Angaran floras signifies the evolution of the PAO and the Solonker-Xar Moron-Changchun-Yanji (SXCY) suture belt[1].

In this study, we present new zircon U-Pb ages from two samples JFC-22 and WQ-1 from the Jiefangcun (JFC) Formation in the Yanbian area in eastern Jilin Province (NE China), along the SXCY suture zone. The top of JFC Formation is characterized by the mixed flora known as JFC flora, which is dominated by the Angaran taxa, and mixed with some Cathaysian elements. Based on the paleontology study, the age of the JFC Formation is widely accepted as Permian [2].

According to our research, the youngest detrital zircon ages of the two samples JFC-22 and WQ-1 are 244-245 Ma (n = 13). Therefore, we argue that the age of the JFC flora should be assigned to Middle-Late Triassic, which is in accordance with the special taxa *Neocalamites* discovered by Yang *et al.* [2]. Our results also suggest that the mixture of the Angaran and Cathaysian floras occurred before or during the Middle Triassic in the Yanbian area, and the extinction of the mixed floras should occur during or after the Middle Triassic. Moreover, detrital zircon age groups with peaks at 1.80 Ga indicate an North China Craton (NCC) source, whereas the ages of 1000-800 Ma or 440-360 Ma most likely indicate a source in the Jiamusi-Khanka Block (JKB). An extensive late Pan-African orogenic event characterized by zircon ages of 500 Ma occurred in the JKB and not in the NCC. Thus, the detrital zircon ages of 1.8-1.7 Ga (NCC), 964-737 Ma (JKB) and 528-429 Ma (JKB) from samples JFC-22 and WQ-1 suggest that the JFC Formation is derived from bidirectional provenances in the JKB and the NCC. Thus, the final closure of the PAO most likely occurred during the Middle-Late Triassic.

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SOURCE TO SINK RELATIONS BETWEEN THE TIAN SHAN AND JUNGGAR-TURPAN BASINS, CENTRAL ASIA, IN THE JURASSIC: EVIDENCE FROM DETRITAL ZIRCON GEOCHRONOLOGY

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The Tian Shan, located in the southwest of the Central Asian Orogenic Belt (CAOB) and the middle of the Asian continent, can be divided into the West and East Tian Shan roughly along longitude 88°E. The West Tian Shan is divided into three tectonic units by two Paleozoic sutures, from south to north, the South Tian Shan, the Central Tian Shan and the North Tian Shan. While, the East Tian Shan consists of the South Tian Shan, the Central Tian Shan, the North Tian Shan and the Bogda Shan, from south to north. The Junggar Basin is located in the northern West Tian Shan and Bogda Shan, while, the Turpan-Hami Basin is an intermountain basin located between the North Tian Shan and the Bogda Shan. Both of them are important Jurassic coal- and oil-bearing basin. However, source to sink relationships between the Tian Shan and Junggar-Turpan basins are still controversial and lack of systematical analysis. In this paper, the Tian Shan-Junggar-Turpan basin system was divided into four sections, northern Western Northern Tian Shan (WNTS), northern Bogda Shan, southern Bogda Shan, and central Turpan. Then, a combined detrital zircon U-Pb chronology and depositional environment study of the Jurassic strata in each sections was presented.

Distribution characteristics of the detrital zircon ages in the Jurassic in the WNTS can be divided into two distinctive stages: 1) Lower to Middle Jurassic, showing multimodal ages. Except for the late Carboniferous peak age (301-329 Ma), there are many Precambrian and early Devonian Peak ages (416-988 Ma) from the Central Tian Shan, and the proportion of the Central Tian Shan ages peaks in the Middle Jurassic Xishanyao Formation (74%), indication gradual exhumation of the Tian Shan. 2) Upper Jurassic, characterized by abundant Late Jurassic (151-161 Ma) and Carborniferous to Permian (256-357 Ma) ages, indication uplift of the Tian Shan with relatively large scale volcanic eruption. In the northern Bogda Shan, distribution characteristics of the detrital zircon ages in the Jurassic can also be divided into two stages: 1) Lower to Middle Jurassic, all characterized by a unimodal age (300-315 Ma). The Lower Jurassic strata contain relatively rich Precambrian to Devonian ages from the Central Tian Shan. 2) Upper Jurassic, bimodal ages of 159-162 Ma and 293-331 Ma. The detrital zircon ages of the Jurassic strata in the southern Bogda Shan are dominant by Carboniferous to Permian ages, while, the detrital zircons of the Upper Jurassic in the Central Tian Shan are all characterized by a unimodal ages of 438-441 Ma.

Finally, we concluded that source to sink relations between the Tian Shan and Junggar-Turpan Basins in the Jurassic can be divided into three obvious stages: 1) During Early Jurassic, the Junggar Basin and the Turpan Basin developed into a united continental sag basin. The Tian Shan was eroded gradually with parts of drainages reaching the Central Tian Shan. 2) In the Middle Jurassic, a peneplain occurred in the Tian Shan area and the Central Tian Shan became the main provenance. At the same time, the Bogda Shan began to uplift and transport detrital materials to surrounding basins. 3) During the Late Jurassic, the West Tian Shan uplifted again with large scale of volcanic eruption along the North Tian Shan fault. The Bogda Shan continued to uplift. However, the East Tian Shan inherited the Middle Jurassic peneplanation. The rudiment of the Tian Shan-Junggar-Turpan basin system began to form until now.

Quantifying the sediment sources on the southern Yellow Sea inner continental shelf, eastern China

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Tracer methods represent an efficient way for tracing material from source to sink, which can quantify the transport patterns and processes within the system consisting of the river, the coast and the continental shelf. In the field of marine sediment dynamics, it is quite important to identify the sediment source. The radial sand ridges on the inner continental shelf of the southern Yellow Sea, with complex dynamic processes and multiple sediment provenances, was selected as the study area. The distribution characteristics of grain size, heavy minerals, and geochemical elements in the different grain size sediments and clay minerals in the different sediments from the modern Yellow River, Yangtze River and abandoned Yellow River are analyzed, to display the spatial and temporal variations in the different tracer fingerprints from the three environments. Differentiation analysis is carried out to determine the best tracer fingerprints for the three terrestrial sediments; on such a basis, the sediment sources on the inner continental shelf are quantified by using the sediment fingerprinting method and mixing model. Specifically, (1) Analytical procedures are established for selecting the best tracer fingerprints of the coarse and fine sediments, respectively. Nonparametric significance test methods, i.e., the Mann-Whitney U and Kolmogorov-Smirnov methods for two independent sets of samples, are applied, in combination with the spatial and temporal variations of the different tracer fingerprints from the abandoned Yellow River, modern Yellow River and Yangtze River, to indicate that the best tracers are garnet and zircon for the heavy minerals, Ni, P, Zn and Co for the muddy sediments, and Ba, K, Ti, P, Mn, Fe, Ni, Co for the sandy sediments. (2) Based on the identification of the best tracer fingerprints and mixing model, quantitative analysis has been carried out to trace the sediment sources on the inner continental shelf of the southern Yellow sea, which shows that the muddy sediment is mainly from the abandoned Yellow River delta, including both Yellow River and non-Yellow River materials. The sandy sediment is mainly the materials from the abandoned Yellow River and the Yangtze River. These results imply that the sediment sources are quite different for the different grain size sediments on the inner continental shelf of the southern Yellow Sea.

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SOURCE TO SINK STUDY AT CONTINENT-SCALE (AFRICA): MANTLE DYNAMICS CONTROLS AND IMPLICATIONS FOR THE SEDIMENT ROUTING SYSTEM

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A source to sink approach was performed at the scale of a continent – Africa - in the frame of the TopoAfrica project, with three main objectives (1) the characterization of the relative importance of deformation (uplift) and climate (precipitation) (2) the quantification of the deformation, its nature and causes, (3) the effect of those deformations on the past African topography and on the sediment routing system. We mainly focused on Western, Central and Austral Africa, characterized by anorogenic relief (plains and plateaus) record of long (several 100 km) to very long (several 1000 km) wavelength deformations, respectively of lithospheric and mantle origin.

The **sink** measurement was based on the seismic stratigraphic analysis of numerous regional seismic lines (from the upstream part of the margin to the abyssal plain) merge of industrial and academic data, calibrated in ages and lithologies on reevaluated wells to get the best possible ages. Volumes measured between successive time-lines, were compacted for a comparison with solid eroded volumes. Uncertainties were calculated (including ages, time-depth conversion law, porosities…) using the VolumeEstimator software (Guillocheau et al., 2013, *Basin Research*).
The **source** study was performed using dated stepped planation surfaces (etchplains and pediplains) - key morphological features of Africa - mappable at catchments-scale (Guillocheau et al., 2018, *Gondwana Research*). During Late Paleocene to Middle Eocene times, Africa experienced a very hot and very humid climate leading to the formation of an African-scale weathering surface (etchplain) known as the African Surface. This surface today deformed and preserved as large plains, domes or plateaus, can be used as (1) a marker of the very long wavelength deformations and (2) a reference level to measure eroded volumes since 40 Ma. Some other younger planation surfaces were also mapped of (1) Early Oligocene and (2) Late Miocene ages.

(1) Deformation (uplift) is the dominant control of the sediment budget. Climate (precipitation) changes only enhance or inhibit a deformation-controlled flux.
(2) The sources of clastic sediments are or closed marginal bulges or far field domes due to mantle dynamics with by-pass (transfer zones) along long-lasting polygenic surfaces located in between.
(3) Africa-scale deformations occurred during Late Cretaceous (Turonian-Coniacian) and around the Eocene-Oligocene boundary with a break contemporaneous of intense chemical erosion from 75 Ma and mainly from 65 to 40 Ma. Most of the African relief and topography are younger than 40 Ma. Late Cretaceous relief are only preserved in the Guinea Rise and the Southern African Plateau.

QUANTIFYING PRESERVATION OF FLUVIAL MEANDER-BELT DEPOSITS: IMPLICATIONS FOR THE COMPLETENESS OF THE STRATIGRAPHIC RECORD

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The completeness of the stratigraphic record has been theorized and tested using numerical and theoretical models, with relatively few case studies in real-world settings. In a seminal paper by Peter Sadler in the early 1980s, he documented that rates of net sediment accumulation in fluvial environments are inversely related to the time scale over which they are measured ("Sadler Effect"). Using net sediment accumulation rate homogenized the processes responsible for preservation (i.e. deposition, non-deposition and erosion). In order to untangle these formative processes, we consider the deposition, erosion and final preservation of meander-belt deposits through paleochannel migration reconstructions. We quantified stratigraphic completeness through deducing the total area of bar sedimentation verses what is ultimately preserved in the depositional record, using area as a surrogate metric for sediment volume. Data sets including a numerical model, the modern Mississippi River valley and the Cretaceous McMurray Formation, Canada were evaluated. In each data set, the evolutionary history of a series of meander-belt elements was discerned. Net migrated area between successive reconstructed paleochannel positions was measured, representing: total area of net bar migration (MA), the area of bar preserved (PA), and percent of bar preserved (PA/MA), at the accretion package, bar and meander-belt scale.

We find that the average preservation percent of an accretion package ranges from 27% - 68%, a bar from 35% - 85%, and a meander belt from 38% - 68%. The processes that lead to a decrease in preservation include intra-meander bend erosion (due to downstream translation or bar rotation), increasing meander-bend sinuosity and eventual cut-off (neck and chute), as well as inter-meander bend erosion due to avulsion and subsequent migration of the meandering channel.

The results of this study document a decrease in preservation over time that follows a natural logarithmic function of decay; we have termed this the "survivability" curve. The systematic, monotonic decrease in preservation over time is consistent regardless of the spatial or temporal scale and agrees with probabilities of preservation at long time scales proposed by previous workers. Therefore, we posit the results presented here support a self-similar relationship between all scales for the preservation of a sedimentary body in the rock record. Comparisons of the survivability curve between data sets allows for an estimation of the time span represented by meander-belt deposits in the deep time record.

Challenging the lithostratigraphic framework of the Nanaimo Group: evidence from detrital zircon analysis

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The Nanaimo Group is a 4 km thick sedimentary succession that was deposited in an Upper Cretaceous, forearc basin (Georgia Basin), Vancouver Island, B.C., Canada. The Nanaimo Group is presently subdivided into 11 lithostratigraphic units; the 5 formations of the lower Nanaimo Group are dominated by shallow-marine and terrestrial strata, while the 6 of the upper Nanaimo Group comprise deep-marine mudstones and turbidites (Mustard, 1994). The lithostratigraphic framework is based on position of coarse- and fine-grained strata relative to the basal nonconformity and to each other. Unfortunately, the framework accounts neither for spatial or temporal variations in lithology, nor for depositional hiatuses due to non-deposition on paleo highs of the basal nonconformity (e.g., Bickford and Kenyon, 1988; Jones et al., in press). As a result, lower Nanaimo Group strata are commonly correlated together even if deposition was separated by millions of years. Using maximum depositional ages (MDAs), kernel density estimate-plots (KDEs), and multi-dimensional scaling (MDS) of detrital zircon (DZ) analyses, we test the viability of the lithostratigraphic framework for the lower Nanaimo Group.

Seventeen DZ samples from the lower Nanaimo Group are analyzed. MDAs show greater than ten million years (and in one case, 70 Ma) difference for samples defined as belonging to the same formation, while samples with similar MDAs are derived from different formations. MDS plots show that age-distributions do not correlate by formation, but instead plot more closely by MDA. These results suggest that a more complex depositional architecture exists than previously thought, and that the present lithostratigraphic framework is overly simplistic. These results are assisting in the development of a sequence stratigraphic framework for the Nanaimo Group, which in turn, will enable a better understanding of the history of the Georgia Basin and Insular Belt.

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Source to sink sedimentation in Godavari River during Late Holocene: Inferences from Mineral Magnetic studies

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The study of sedimentation in the first sink of basin, designated as delta systems, show variations in sources over past. Being one of the largest drainage basin in Peninsular India, the characteristic sedimentation pattern in Godavari drainage basin is governed by geomorphic, geologic and climatic setup of basin [1, 2]. We carry out the high resolution mineral magnetic analysis on AMS ^{14}C dated Late Holocene sediment core from Godavari delta and Godavari River overbank sediments. The study suggested the presence of Single Domain ferrimagnetic mineralogy characteristic of Deccan source in overbank sediments which is further traced during Late Holocene deltaic sediments. The significant input of Deccan source at ~3.2 to 2.1 cal. ka BP is attributed to the deforestation vis-à-vis expansion of agricultural activities [3]. We further postulate that this agricultural expansion started during early Chalcolithic (Malwa culture) and expanded during Middle Chalcolithic (Jorwe culture) present in the vicinity of Upper Godavari River basin. This event also roughly coincides with the boundary of Subboreal to Subatlantic climatic events and therefore indicates the widespread climatic changes associated with the cultural advances.

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Sr-Nd isotopic constraints on sediment provenances in the Shikoku Basin: Variation of sediment dynamic transport with the climate change in the past 30ka

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The Shikoku Basin located at the northern of the Philippine Sea, a back-are basin that formed by rifting and spreading of the eastern part of the Philippine Sea plate. the Shikoku Basin lithosphere is subducting northwestward under the Eurasia plate at the Nankai Trough. The basin received a variety of sedimentary inputs, including terrigenous flux through Kuroshio Current, near-bottom nepheloid layer, eolian deposit. IODP Exp. 333 drilled at the Site C0011, the sediments record the climate the geological changes. We get the upper samples at Site C0011, aged from 2-30 ka, which includes two extreme climate periods. Sr and Nd isotopic composition of the detrital sediments were analyzed, to trace the provenance discrimination and comparison the sediment paths changes during the LGM (Last Glacial Maximum) and HO (Holocene Optimum) in the Shikoku Basin. The sediments with more radiogenic $^{87}Sr/^{86}Sr$ ratio and coarser grain size during LGM than HO period, slightly negative ε_{Nd} values are also observed during LGM. During the LGM, the winter monsoon and weathering was strengthened in the China Mainland, the flux of eolian dust (<5μM) with higher $^{87}Sr/^{86}Sr$ values and lower ε_{Nd} values was higher. With the decrease of sea level, the main stream of Kuroshio Current was deflected, scarcely sediments input from the East China Sea with higher $^{87}Sr/^{86}Sr$ values and lower ε_{Nd} through Kuroshio Current deposited during the LGM. The near-bottom nephloid layer taken the sediments from the southwest of Japan with coarser median diameter and lower $^{87}Sr/^{86}Sr$ values, higher ε_{Nd} values was also strengthened during LGM. During the HO, no signal of the re-entry of Kuroshio Current to the Shikoku Basin at 7.5 ka was found at Site C0011, it indicates that that there was no sediment input of East China Sea taken by Kuroshio Current in Holocene.

Keywords: Sr and Nd isotopes; sediment provenance; dynamic process, Shikoku Basin; Last Glacial Maximum; Holocene Optimum

Distinct source-sink systems responsive to the late Paleozoic orogeny along the North Tarim Continental Margin, Northwest China

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If uniform source-sink systems always exist along tectonic block margin in orogenic period or episode? Focus on the late Paleozoic sedimentary records in the South Tianshan mountain (recycled orogen) and North Tarim basin, the project studied depositional environments, clastic provenances responsive to the Carboniferous orogeny along the North Tarim Continental Margin (NTCM), Northwest China. Consequently tectonic-paleogeographic frameworks on the studied basin-range were ruled.

The research presented, Devonian through Early Visean Phase of Early Carboniferous, unstable and varied detrital assemblages, with two groups of characteristic detrital zircon ages (respectively corresponding to Late Devonian and Pan-African tectonic events) of North Tarim Uplift, occurred in the eastern section of NTCM, showing chaotic deposition and relatively short south-north source-sink systems limited in active continental margin. However, more mature sandstone components, with a lot of detrital zircons indicating basement ages of Tarim continental block, were developed in the western section of NTCM, which is of evidently depositional attributes related to passive continental margin.

Into Late Visean Phase of Early Carboniferous through Late Carboniferous, relatively higher mature sandstone components, including an amount of detrital zircons respectively indicating the middle-late Neoproterozoic basement ages of Tarim continental block and marked 390~460Ma ages with positive $\varepsilon Hf(t)$, deposited in the eastern section of NTCM, which mainly attributes to the complex orogen provenance type and middle-short source-sink systems, probably reflecting deposition in residual sea. At the same stage, even higher mature sandstones, with dominant detrital zircons indicating basement ages of Tarim continental block, accumulated in the western section of NTCM, probably showing deposition in failed ocean or residual sea, characterized by relatively long east-west source-sink systems from interior to margin of the Tarim block.

Evidently, distinct source-sink systems responsive to the late Paleozoic orogeny developed along NTCM, Northwest China. No uniform orogenic provenances are found from depositional records in the studied area till Late Carboniferous Epoch, though the South Tianshan ocean had closed after Visean Phase of Early Carboniferous.

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PROVENANCE OF SEDIMENTS FROM SUMATRA, INDONESIA. INSIGHTS FROM DETRITAL ZIRCON U-PB AGES, LIGHT AND HEAVY MINERALS SUPPORTED BY RAMAN SPECTROSCOPY

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Sumatra is the sixth largest island in the world and is situated at the southwest margin of the Indonesian archipelago. Although several onshore and offshore basins of Sumatra host abundant hydrocarbon resources, the provenance of Cenozoic siliciclastic sedimentary rocks in the basins is relatively poorly understood. Many of the underlying Mesozoic and Palaeozoic metasedimentary rocks are also poorly dated in terms of radiometric age constraints. This work is a multi-proxy provenance study utilizing U-Pb detrital zircon dating by LA-ICP-MS combined with optical and Raman spectroscopy-based heavy mineral analysis. It aims to help unravel the stratigraphy of Sumatra, contribute to palaeogeographic reconstructions of western SE Asia, and aid a wider understanding of Sumatran petroleum plays.

The results of this research are based on observations made and samples collected during two fieldwork seasons. The samples collected in the project comprise Cenozoic sedimentary strata from the main Sumatran basins (North, Central, and South Sumatra) and the Ombilin Basin in western-central Sumatra; in addition, Mesozoic-Palaeozoic meta-sedimentary basement rocks and modern day river sands were collected. 35 samples have been investigated to determine their light mineral modes from thin section analyses, heavy mineral assemblages and detrital zircon U-Pb ages. In addition, >26,000 Raman spectra of heavy minerals have been acquired to yield a better understanding of the sources of ancient and modern sediments in Sumatra.

Distinctive Precambrian zircon age populations are found in the Cenozoic sedimentary formations. The age clusters identified resemble the patterns observed in Sumatran metasedimentary basement rocks and are remarkably different from other sedimentary rocks in SE Asia (e.g. on- and offshore Borneo). In Sumatra, Neoproterozoic and Mesoproterozoic age groups are dominant, whereas Paleoproterozoic to Archaean zircons occur as minor populations. The Phanerozoic age spectra of the Cenozoic formations are characterised by distinct Triassic, and Cretaceous-Jurassic populations, alongside minor Carboniferous and other Palaeozoic zircons. Cenozoic zircons occur as dominant age clusters in sedimentary rocks from the Middle Miocene onwards. This is interpreted as a contribution from a local volcanic arc that initiated in the Miocene.

Heavy mineral signatures support the inferences from detrital zircons. The occurrence of unstable heavy minerals such as apatite are paralleled by a Late Cenozoic zircon population. Light mineral modes reflect this change in provenance with the presence of abundant volcanic quartz.

Zircon age patterns from modern river sands in Sumatra resemble those in the sedimentary strata. However, heavy mineral compositions are often dominated by different minerals, such as epidote, reflecting local sources of the present volcanic arc.

The Zircon U-Pb Chronology of LA-ICP-MS Clasolite of Mesoproterozoic Erathem in the Xiong'er Rift Trough and Its Geological Implications

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In the study, LA-ICP-MS Method is mainly used to study the zircon U-Pb isotopic chronology of clasolite on the bottom of Xiaogoubei Formation in Daimeishan Area of Xin'an County in Henan Province, the age youngest single particle $^{207}Pb/^{206}Pb$ zircon is（1720±60）Ma, it indicates that the lower limit of the formation age of Ruyang Group-Luoyu Group is at late stage of Paleo-proterozoic Era , the data show that the zircon ages of 2.80-1.80ga are all distributed, in which the zircon age of 2.80-2.50Ga is about 12.50%, it presents that the sources of Ruyang Group-Luoyu Group are originated from the rocks of Neo-Archean and Paleo-proterozoic Era. Before the study, zircon U-Pb isotopic chronology was carried out by Su Wenbo(2012) on tuff intercalation in the central layer of Luoyukou Formation, a high accuracy age no（1611±8）Ma was obtained, in his study, the lower limit of the formation age of Ruyang Group-Luoyu Group was determined as between 1750-1600Ma. It is agreeable with the result of the study. At the same time the result is in line with the study by Hu Guohui(2012) of U-Pb isotopic dating data (1732±11) Ma of detrital zircon on the bottom of Ma'anshan Formation, it can be demonstrated that the sediments in Xiaogoubei Formation and Ma'anshan Formation belong to the same sedimentary stage, stratigraphic correlation can be carried out across stratigraphic areas.

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Cyclostratigraphy of the Katian Pagoda Formation, South China

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High resolution measurements of magnetism susceptibility (MS) in the Late Ordovician Pagoda Formation were performed at the Liangcun Section in Sichuan Basin, South China. The MS variations and wavelengths of significant cycles correspond to long eccentricity, short eccentricity, obliquity and precession cycles among which long eccentricity reflects the strongest signal. This suggests that long eccentricity could be the main orbital forcing in the study area which affects isolation and sea-level fluctuations. These changes are related to the sedimentary environment of the Pagoda Formation and result in the coeval tectonic uplift which probably causes the widely known unconformity between the Pagoda Formation and the underlying strata in this area. The orbital tuning shows the deposition of the Pagoda Formation at this section lasts about 4.03Ma and the average accumulation rate is approximate 7.97m/Ma. This value of this duration is less than the one estimated based on International Community Stratigraphy (ICS) 2015. It indicates that the lower part of the Pagoda Formation is absence since the tectonic uplift stops when the Pagoda Formation began to deposit.

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FLUVIAL STRATIGRAPHY: 99.9% OF THE TIME NOTHING HAPPENS

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Studies of modern distributive fluvial systems that are undergoing avulsion by splay progradation suggest that a new channel and overbank complex develops over a timescale of tens to hundreds of years. In the case of the Taquari River in Brazil, sequential satellite images show a splay and a new channel prograding a distance of about 50 km in 25 years[1]. In the stratigraphic record this would be represented by a package of strata comprising channel-fill facies with associated sandy splay deposits and overbank mudrocks. On-going lateral channel migration and further overbank flow would modify and laterally extend the package, but the thickness of the unit would be primarily determined by the initial avulsion splay succession and associated channel.

In the Lower Miocene succession in northern Spain there are facies representing the deposits of distributive fluvial systems and associated shallow to ephemeral lake environments in an endorheic basin. A detailed paleomagnetic reversal stratigraphy has previously been established[2] in the lacustrine facies which makes it possible to determine the rate of aggradation in the basin centre. Parts of the fluvial succession appear to have an aggradational character, suggesting that the fluvial and lacustrine facies were building up at the same rate. A distributive fluvial system builds a succession by deposition of channel and overbank facies in a lobe on one part of the surface of the fan-shaped body, followed by lobe abandonment as the main channel avulses and a new lobe is built. Avulsion and fluvial lobe formation occurs repeatedly until the whole surface area has aggraded by the same amount. With the average rate of aggradation established from the coeval lacustrine facies it is possible to determine the time period between each avulsion event in a vertical succession, marked by the base of a channel-fill. This is 120 ky in medal parts of the distributive fan and 270 ky in the distal parts, where channels are more spread out in space and time.

The rates of fluvial lobe development from a modern river can hence be compared with the frequency of lobe deposition at a point on an ancient distributive fluvial system. The basic elements of a lobe form in 10s to 100s of years but the period between successive lobes in a vertical succession may be in the order of 100 ky. This suggests that at any one point the vertical aggradation occurs in 0.1% of the period, and that for 99.9% of the time there was little or no vertical aggradation. Other modern rivers may avulse at different rates and other ancient successions may have aggraded at different rates, but this comparison between modern process and ancient product provides an indication of the time scales over which stratigraphy is built.

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INVESTIGATING TURBIDITE MUDSTONE CAPS: INSIGHTS FROM THE CASTAGNOLA SYSTEM, NW ITALY

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The particulate load of turbidity currents can be divided into coarser (sand/gravel) and finer (silt/mud) components. The coarser component has been the subject of most research on deposits, because of its prominence at outcrop and its role in forming hydrocarbon reservoirs. Recently, increased attention has been given to the role of clay in affecting flow behaviour and deposit character. However, the number of studies investigating mudcap character and thus volumes and role of mud is limited. This is partly because mudcaps tend to crop out poorly, and partly because mud often bypasses down-dip where deposits from single flow events cannot be easily identified or linked to their sandier counterparts.

The Castagnola system (NW Italy) is an excellent natural laboratory to study turbidite mudcaps. First, fully ponded conditions dominated for a significant part of its infill (i.e., sand and mud were trapped together). Second, rapid basin fill and low rates of hemipelagic deposition mean that most mud is turbiditic. Finally, two sediment sources with differing petrographic signature were synchronously active, allowing a bed by bed comparison between the source of the sandstones and their mudcaps.

Thin section (sandstones) and XRD (mudcaps) analyses were conducted on over 50 beds. Results indicate a correlation between sandstone and mudcap source signature. However, while most sandstone beds show tight clustering around two petrographic types, mudcaps show signatures that are more mixed. Hence, it is thought that the turbidity currents must have had a 'single source' composition (sand and mud) at initiation, but that the mud became mixed following acquisition of mud particles en-route, likely through substrate erosion; by contrast, sand was apparently rarely eroded en-route as almost no mixed compositions were found. Further work aimed at constraining the amount of mixing will better define the proportion of mud acquired by the flows en-route and therefore help constrain the pattern of flow evolution and the resulting implications for the character and distribution of the deposits.

Determining the Absolute Age of the McMurray Formation: A Comparison of Igneous Zircons from Ash and Detrital Zircon Maximum Depositional Ages

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The Lower Cretaceous McMurray Fm of the Western Interior Seaway comprises fluvial, tidal-fluvial and inter-channel deposits that occupy topographic lows on the Sub-Cretaceous Unconformity. These depositional environments have a low preservation potential for datable material (e.g., volcanic ash beds), and the Aptian and younger age for the McMurray Fm has been established biostratigraphically (e.g., Hein and Dolby, 2018). Herein, we present the first absolute radiometric age for the early Aptian Lower McMurray Fm, and use this age to test the reliability of maximum depositional ages (MDA) derived from detrital zircon (DZ) analysis.
The Lower McMurray Fm in the northeastern extent of the McMurray Sub-Basin, Canada, is commonly capped by a thick coal and/or paleosol succession, which is interpreted as the deposits of inter-channel mires and floodplains. A 0.5–3 cm thick ash bed was found in several cored coal intervals. A ~5 cm^3 volume of ash in one interval, yielded five sharply faceted zircons (<100 µm). Chemical abrasion thermal ionization mass-spectrometry (CA-TIMS) dating of these zircons revealed a cluster of precise ages with a weighted mean of 121.38 ± 0.19 Ma. The shape of the zircons, the low-energy nature of the depositional environment, and the age-cluster is interpreted as the absolute age of aeolian volcanic deposition coeval to Lower McMurray time.
To test the reliability of MDA for predicting the depositional age of the McMurray Fm, a total of 30 DZ suites from various stratigraphic depths are compared to the absolute age determined for the ash. These data comprise new samples, and numerous DZ suites published by Benyon et al. (2016) and Blum and Pecha (2014), and are mostly taken from fluvial to estuarine channel sands. Based on comparison of MDAs with the newly acquired absolute age, only 9 of 3075 DZ (0.29 %) match the early Aptian age of the ash. Early Aptian zircons occur in 6 of the 30 DZ suites, three of which occur in the northeastern extent of the sub-basin near inter-channel environments.
These data suggest that significant variability exists in DZ populations and in zircon source. Depositional environment should be considered when sampling for DZ. Low-energy, terrestrial settings (e.g., mires) appear to be favorable sites for preserving aeolian-sourced, volcanic zircons. As well, when collecting multiple samples from the same formation, it may be possible to use the youngest cluster of grains (from all samples) to derive a MDA for the formation.

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THE ZAMBEZI OFFSHORE SYSTEM (DELTA TO DEEP-SEA FAN): SINK MEASUREMENT – A RECORD OF THE EAST AFRICAN RIFT UPLIFT AND RELATED CLIMATE CHANGES

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The Zambezi deltaic system is one of the largest in Africa after the Niger, the Congo and the Nile. This passive margin-scale delta is characterized by a topographically and tectonically segmented depositional profile studied in the frame of the project PAMELA (Passive Margin Exploration Laboratories - founded by TOTAL and IFREMER): (1) an upstream 10 km thick deltaic wedge with no gravitary tectonics, (2) the Angoche pounded deep depositional area and (3) the Zambezi deep-sea fan, bounded from the Angoche area by a major contouritic drift.
The **sink** measurement was based on the seismic stratigraphic analysis of numerous regional seismic lines (from the upstream part of the margin to the abyssal plain) merge of industrial and academic data, calibrated in ages and lithologies on reevaluated wells to get the best possible ages. Volumes measured between successive time-lines, were compacted for a comparison with solid eroded volumes. Uncertainties were calculated (including ages, time-depth conversion law, porosities…) using the VolumeEstimator software (Guillocheau et al., 2013, *Basin Research*).

Four main periods of sediments delivery were identified: (1) 94-66 Ma (Turonian-Maastrichtian) - first silicilastic imput, (2) 66-34 Ma (Paleocene-Eocene) – very low siliciclastic supply, (3) 34-5,5 Ma (Oligocene-Miocene) – second input of siliciclastic sediments and 5,5-0 Ma (Plio-Pleistocene) – sharp increase of the sediment supply.
These changes correspond to major deformation and/or climate changes. The reconstruction of the climate (precipitation) evolution was based on a palynological study along wells of the Zambezi Delta and summarized as follows: 100 to 90 Ma - semi-arid, 90 Ma (base Coniacian) - sharp increase to very humid conditions up to 40 Ma, 40-30 Ma and 15-11 Ma dryer periods, 30-20 Ma and 11-7 Ma very humid conditions again.

- The 94-66 Ma first siliciclastic sediments supply can be related to the uplift of the South African Plateau and the erosion of the Bushveld reentrant (Braun *et al.*, 2014). This can be enhanced after 90 by the sharp increase of the humidity.
- The 66-34 Ma period of low siliciclasctic supply is both a period of tectonic stability, very humid conditions and then of intense weathering with carbonate platforms.
- The 34 Ma second increase of siliciclastic sediments results from an African-scale uplift - related to mantle dynamics (Burke & Gunnell, 2008) – onset of a mechanical erosion of the Eocene weathering profiles.
- The sharp increase of sediment supply around 5,5 Ma result from more local processes. They are no major climate changes with an amplitude higher than the other Neogene variations. This even is related to a major change of the drainage pattern of the Zambezi River at time of the initiation of the Malawi Rift.

A Discussion about the Initial Uplift Time of the Bogda Mountain - Evidence From Clastic Sediments in Junggar Basin

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The tectonic evolution of southeast of Junggar Basin is unique due to orogenic processes of the northern Tianshan as well as multi-phase upliftings of Bogda Mountain. Because the original uplift time of the Bogda Mountain is still a highly debated issue, this area has become important in studying basin- mountain relationships and source-sink systems.

Our study area Fukang Sag is located in the northern margin of Bogda Mountain. The W Formation in upper Permian(P3w) and the J Formation in lower Triassic(T1j) were selected as the key strata to be analyzed. Based on the integrated analysis of cores, well logs and seismic sections, the unconformity between the P3w and the T1j Formation was identified on the Middle and Lower Permian which have intense thrust and fold deformations. The distribution of the strata is characterized as thick in the south and thin in the north, uniform from east to west. A depositional system of alluvial fan and braided river delta developed here, spreading in north-south direction. Vertically the facies transformed from the braided river delta to alluvial fan from P3w to T1j Formation, indicating an uplift of the provenance during late Permian.

The results of the heavy minerals analysis on the 48 samples from 15 wells demonstrate that: the distribution of heavy minerals is more stable in the east-west direction, while the north and south direction changes significantly; the proportion of stable heavy minerals gradually increases north of the Bogda mountain; and the content of stable heavy mineral increases from P3wt to T1j Formation vertically.

The detrital zircon analysis of 12 samples, 8 from cores in Fukang Sag and 4 from outcrop in Bodga Mountain in middle Permian, show that Late Paleozoic volcanic arc in North Tianshan Mountain is the main provenance of middle Permian sediments. Meanwhile, the P3w and T1j sandstone with early Permian peak value matches the samples from the Bogda Mountain, which shows that provenance is from Bogda Mountain.

Combined with sedimentary facies, heavy mineral analysis, and detrital zircon studies of Bogda Mountain from the Late Permian to the Early Triassic, and based on the sedimentary response to its continuous uplifting background, it confirms that continuous uplifting is credible. It illustrates that a tectonic transformation happened after large-scale orogeny of the Junggar Basin Peripheral Orogen in the late Carboniferous. This contradicts the common view that the Bogda Mountain's first large-scale uplifting was during the late Jurassic.

THE STRATIGRAPHY AGES OF THE WEAKLY METAMORPHIC ROCKS IN SOUTH ANHUI AND CONSTRAINT ON THE TECTONIC EVOLUTION OF THE JIANGNAN OROGENIC BELT, SOUTH CHINA

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The Jiangnan Orogenic Belt (JOB) situated in South China, about 1500 km long and ENE-trending, is regarded as result of collision between the Yangtze and Cathaysia cratons in Neoproterozoic. The belt is mostly composed of Precambrian weakly metamorphic siliciclastic rocks up to 10 km thick and igneous rocks. However, there has been a debate about the ages of the rocks and their tectonic setting of origin.

South Anhui located in the eastern section of JOB, widely develops a suit of weakly metamorphic siliciclastic rocks of ca. 5~6 km thick in size of about 200 km long and 100 km wide, and they are divided into Likou, Xikou and Shexian Groups, with well outcrop and successive profiles. We detailly survey ten sections of field stratigraphy, collect 26 samples for LA-ICPMS analyses, gain 2111 data of zircon ages (degree of confidence＞90%). Generally, the youngest U-Pb ages of zircon grains in populations of detrital zircons are extensively used to constrain maximum depositional ages (MDA) of stratigraphic units. According to our research, Lihou, Shexian and Xikou Groups have MDA of 710.4~822.3 Ma (YSG), 723.5~802 Ma (YSG), and 769.5~821Ma (YSG) respectively. The bottoms of the Lihou, Shexian and Xikou Groups have maximum deposition age 742.7 Ma, 734.9 Ma and 808Ma respectively, which indicates that Lihou and Shexian Groups should be late Tonian to early Cryogenian, and Xikou Group belongs to late Tonian. Therefore, the weakly metamorphic rocks have a geology time of 808~710.4 Ma, belonging to late Tonian and up to early Cryogenian.

The metamorphic rocks have wealthy Tonian ages (720~800Ma, 800~900 Ma) of detrital zircons occupying 11.4% and 58.7% of the age populations, which cover the ages (mostly 770Ma± and 830Ma±) of igneous rocks (including Jingtan Fm.) in eastern section of the JOB. This indicates the metamorphic rocks should overlay on the volcanic rocks. The Th-Co-Zr/10 and Th-Sc-Zr/10 discrimination diagrams of 78 samples from the metamorphic rocks show that their source rocks were from continental island arc, which implies they formed under a tectonic setting of arc-back basin developing during late Tonian and up to early Cryogenian.

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Authigenic $^{10}Be/^{9}Be$ dating method as a strong geochronological tool for late Cenozoic deposits: Examples from the Central Europe

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Terrestrial sediments are notoriously difficult to date due to a usual scarcity of bio-stratigraphically significant fossils and poor preservation of volcanic ashes. The authigenic $^{10}Be/^{9}Be$ dating has an unprecedented potential to overcome this problem[1]. It can be performed on generic fluvial and lacustrine clays with an age range of 0.1 to 14 Ma, provided that a suitable calibration can be made for the initial $^{10}Be/^{9}Be$ ratio in the drainage basin in question[1,2,3]. The method uses the ratio of atmospheric cosmogenic radionuclide ^{10}Be, delivered from the atmosphere to the terrestrial environment by precipitation, and stable nuclide ^{9}Be, which originates from bedrock in the drainage basin[1]. Following transport in river water, both isotopes adsorb to the surface of clay minerals during sedimentation. The isotopic ratio then decreases due to radioactive decay of ^{10}Be. The initial $^{10}Be/^{9}Be$ isotopic ratio in a drainage basin is dependent on variations in cosmic radiation, on drainage network changes impacting on the flux of ^{9}Be and on character of the depositional environment[1,4]. The initial $^{10}Be/^{9}Be$ ratio needs to be constrained in order to date sediments using the half-life of ^{10}Be. It is usually calibrated using recent alluvial or lacustrine sediments, assuming that the ratio has remained stable over geological time.

The method was applied successfully in the case of dating changes in depositional systems of Lake Pannon in the northern Pannonian Basin (Slovakia). Shifting of shelf slope, mostly induced by sediment input of the paleo-Danube, was dated to 10.5–9.0 Ma. Related regression caused dominance of alluvial environment up to 6.0 Ma, followed by inversion of the basin[3]. The method was applied to an outcrop of braided river facies, known for presence of mixed large mammal fossils of latest Pliocene and earliest Pleistocene age. Results showed age range of clay intraclasts around 1 Ma, in good accordance with expected mixing of eroded source strata of fossil material. Another application comprised dating of well-cores, which were subject also to independent burial dating using $^{26}Al/^{10}Be$ ratio. A discrepancy observed between ages modelled by separate methods implies, that more research need to be performed to understand the evolution of $^{10}Be/^{9}Be$ in time.

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MODERN VERSUS OLD ORGANIC MATTER - ON SOURCES OF ORGANIC CARBON TO ARCTIC FJORD, HORNSUND, SPITSBERGEN

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Fjords have been for long time considered as sediment and organic carbon (OC) depocenters. It has been estimated that the amount of OC buried in fjords may be as much as one tenth of the total OC stored in marine sediments. However, better understanding of sedimentary processes and sources of OC is necessary to accurately estimate OC burial in fjords and their role in the sequestration of atmospheric CO_2. In the present study we aimed to determine the origin of the OC in the sediments in Hornsund fjord, Spitsbergen. The subpolar fjords of Svalbard are of particular interest because of the rapid retreat of tidewater glaciers observed after termination of the Little Ice Age around 1900 AD and formation of new bays characterised by high sediment accumulation rates in the inner parts of the fjords.

The OC in the fjord sediments is derived from two major sources, organic matter (OM) of terrestrial origin and fresh, marine OM, from the primary producers in particular. The relative share of land-derived OM and the OM of marine origin can be determined by comparing the carbon ($\delta^{13}C$) isotope values of sedimentary organic matter (SOM) with $\delta^{13}C$ values of land and marine end-members. For Spitsbergen, average $\delta^{13}C$ values of the two end-members were determined as -27‰ and -20.6‰, respectively. However, considering that much of the terrigenous OM comes not from the modern plants but from the variable bedrock of the Hornsund fjord catchment, including limestones and dolostones, and a range of clastic sedimentary rocks: conglomerates, sandstones, siltstones, shales and bituminous and black shells, of Early Palaeozoic to Neogene age, we have hypothesized that the generally accepted and applied in the OC mixing lines, average $\delta^{13}C$ values of the land end-member are far to general.

To test our hypothesis two set of samples were collected and analysed for $^{13}C/^{12}C$ ratios: surface sediments from bays within the inner part of the Hornsund fjord, namely Burgerbukta, Samiarinvogen and Brepolen; and samples of the land end-member including diamictons, sediments from river beds, deltas and beach sand collected from the shores of the Hornsund fjord. We found close correspondence between the $\delta^{13}C$ values of the local land-end-member and $\delta^{13}C$ values of the OC in the fjord sediments. The most ^{13}C-enriched SOM and land end-member were found in Brepolen, -24.8‰ and -24.2‰, respectively, whereas the most ^{13}C-depleted OC was found in Burgerbukta, -26.6‰ and -25.8‰, respectively. The results evidence the petrogenic, land-derived organic matter as the primary source of OC to the sediments in Hornsund.

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Tectonic attributes, paleogeomorphological evolution, and provenance of the western Ordos Basin during the Middle–Late Triassic: evidence from U–Pb detrital zircon geochronology

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The tectonic attributes of the western margin of the Middle–Late Triassic Ordos Basin and structural relationships with neighboring areas have long been disputed. To help resolve these issues we provide here a comprehensive analysis of the provenance of the Yanchang Formation and corresponding strata in the western margin of Ordos Basin and adjacent Hexi Corridor basin. Twelve samples from five sections were chosen for analysis, and we examined their petrography, trace element compositions, and the U–Pb detrital zircon age spectra. The zircon grains yield a wide range of age distributions, indicating that the source areas for the Hexi Corridor and western margin of the Ordos Basin during the Triassic were large and complex. The main age populations in samples SL1 (Chang 6) and DQ2 (Chang 4 + 5) from the Hexi Corridor are 220–320, 350–450, 700–1000, 1650–2150, and 2200–2550 Ma, with age peaks at 1700 and 300 Ma (SL1), and 894 and 1858 Ma (DQ2) respectively. These data indicate that Alxa Massif and the Western NCB are the source areas for Hexi Corridor in the depositional period of Chang 6, while Qilian-Qaidam Terranes and Alxa Massif are source areas in the depositional period of Chang4+5. The age spectra for three samples from Chang 3 in the Hexi Corridor shows a strong peak at about 300 Ma and two relatively weak peaks at 1850 and 2450 Ma, which exactly match the age spectra of the Qilian–Qaidam terranes. The data for the Yanchang Formation of YS section(in the western margin of Ordos Basin) indicate the main source area for the western Ordos Basin was the western NCB, with some sediments from the Alxa Massif and the limited Neoproterozoic age populations (700–1000 Ma) indicate that the Qinling Orogenic Belt was not the direct source area for the western Ordos Basin. In combination, the Hexi Corridor was connected with the Ordos Basin at the depositional period of Chang 6, but the underwater paleouplift began to appear since the depositional period of Chang 4+5 then rise and enlarge in the depositional period of Chang 3 and entirely separated them, which also could be supported by geochemistry and petrology evidence. The great paleogeomorphologic changes are related to the collision of the southwest border of North China Block and the Yangtze Plate during Late Triassic period.

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Source-to-sink Systems and Sediment Mass Balance in the Lake Malawi (Nyasa) Rift, East Africa

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The Lake Malawi (Nyasa) Rift, a classic modern rift in the East Africa Rift System (EARS), is a long-term sedimentary archive of past climate in the southern hemisphere African tropics. Several regional drainage systems contribute sediment to the rift, producing large deltaic clinoform packages and sublacustrine fans, and other deposits. Accordingly this enclosed system is ideal for studying Pleistocene source-to-sink dynamics. Three major lowstands have been documented since 150ka, forced by orbitally-paced changes in hydroclimate. Lake level lowstands are observed at 200m, 350m and 500 m below present lake level (BPLL). Based on the integrated analysis of an SRTM 90m digital elevation model (DEM) and 2D single/multi-channel seismic datasets, we link catchment geomorphology with sediment delivery characteristics in the sink area. We employ the "BQART" model to assess sediment supply, taking into consideration the lapse rate and rain shadow effect in high-elevation hinterlands. The river discharge (Qw), a critical factor of the model, is estimated through a modified empirical relationship that associates the catchment area (A) to different climates using a global data analysis of 1255 modern catchments (Eide et al., 2017). This model indicates the overall sediment supply from these major drainages of the Lake Malawi Rift increases from 7.01 MT/yr to 8.92 MT/yr when comparing the 200m BPLL with the 350m BPLL "lowstand" stage. We also compute the volumes of the delta and sublacustrine fans associated with key catchments in order to conduct a mass balance analysis incorporating sediment supply using the Monte Carlo simulation. Our study shows that during more humid climate phases, there is significantly enhanced drainage fragmentation, increased sediment supply and higher lake levels. The drainage systems with higher offshore slopes have a lower interim storage. Larger source-to-sink systems during humid phases are more effective at long-distance mud transport into the deep lake.

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DEEP-TIME SOURCE-TO-SINK SYSTEMS OF A RIFT BASIN FORMED IN A CONVERGENT SETTING: A CASE STUDY FROM THE BOGDA REGION (NORTHWEST CHINA)

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The Source-to-sink concept has more recently been applied to deep-time stratigraphic systems [1, 2]. An unbroken record of Carboniferous–Triassic successions is well preserved in the northern Bogda region, northern Xinjiang Province, northwest China, which is thus an ideal area in which to study their deep source-to-sink systems. Systematic sandstone petrography, elemental geochemistry, heavy mineral, detrital zircon U–Pb dating, and Hf isotopic analyses were conducted to evaluate the sedimentary processes involved, as well as to understand their provenance and the source-to-sink connections of the Bogda region during the Late Paleozoic–Mesozoic. Principal component and heavy mineral analysis of elemental geochemical and mineralogical data indicate that source rocks experienced weak to moderate chemical weathering [3], and were compositionally immature, poorly sorted, and mostly intermediate-acidic, with few basic source rocks. Detrital zircon U–Pb dating yields five primary age populations: Cambrian–Devonian (541–361 Ma), Mississippian (360–320 Ma), Pennsylvanian (320–300 Ma), Permian (300–252 Ma), and Triassic (252–200 Ma), which were likely derived from volcanic rocks of the North Tianshan (NTS), Central Tianshan (CTS), and Bogda regions. Moreover, heavy mineral assemblages have similar characteristics to the NTS and CTS. Integrated provenance analysis reveals that the predominant sources were from the intermediate-acidic igneous rocks of the NTS and CTS, with minor inputs from the volcanic and recycled clastic rocks of the Bogda region. All lines of evidence suggest that the Bogda region was originally a rift basin, which formed in a convergent setting during the Carboniferous, evolving into an extensional depression basin during the Guadalupian, and undergoing rapid infilling due to the uplift and exhumation of NTS from the Lopingian to the Early Triassic. The initial uplift of this region occurred during the Late Triassic.

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Modern muddy deposit along the Zhejiang coast in the East China Sea: response to Three Gorges Dam

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Grain size and clay minerals in the surface sediment off Zhejiang Province, China, of the East China Sea were analyzed to study changes in grain size, muddy deposit boundary, and major riverine matters transport paths in the Zhejiang coastal muddy deposit since the impoundment of the Three Gorges Dam (TGD). The results show that the sediment types are mainly silt and mud in the muddy deposit, divided based on the 10% isoline of the sand-sized component. The sources of sediment in the muddy deposit are mainly the Yangtze River and simultaneously supplies from the Taiwan rivers, Qiantang Jiang, Ou Jiang, and hydrolyzed volcanic rocks around the Zhoushan Islands. The transport and dispersal of sediments in the study area are largely controlled by the Zhejiang–Fujian coastal current and the Kuroshio near-shore branch current and appear seasonally. The contributions from the Taiwan rivers, Ou Jiang, local hydrolyzed matter, and the Qiantang Jiang are enlarged owing to the decline of Yangtze suspended matter, respectively. In addition, the sediment grain size exhibits a fining trend because of the influence of the TGD. The boundary of the muddy deposit is relatively stable after the TGD impoundment north of city of Zhoushan. In contrast, south of the city of Zhoushan the boundary of the muddy deposit lies toward the east because the sediment supply from the Taiwan rivers carried by Kuroshio near-shore branch current. The changes in the grain size and contributions from smaller rivers and other derived matter as well as the boundary of the muddy deposit there will probably become more pronounced in the future.

Keywords: Source; Clay minerals; Grain size; Three Gorges Dam; Zhejiang coastal muddy deposit

INSIGHT INTO THE SEDIMENT SOURCES AND SAND TRANSPORT FROM ONSHORE TO ABYSSAL PLAIN FROM DETRITAL ZIRCON ANALYSES OF GULF OF MEXICO MIOCENE DEEPWATER FANS

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Lower Miocene deep water fans in the northern Gulf of Mexico preserve crucial sedimentary signals needed to reconstruct sediment sources and sediment dispersal pathways from onshore to deep water sinks. However, interpretation of Miocene deep-water fans in the Gulf of Mexico is challenging, as widespread salt canopies have hindered the conventional seismic imaging of sub-salt lower Miocene reservoirs. Exploration for sub-salt Miocene reservoirs is costly and usually with considerable risk and uncertainty. Previous work indicates both Paleo Red River and Paleo Mississippi River are large drainage systems that could have delivered a large amount of sediments to deep-water fans.

To illuminate the sediment source and dispersal from onshore to deep water sink, we collected four samples from Miocene Red River and Mississippi deltas as well as five samples from deep water fans for detrital zircon U-Pb analyses. All four lower Miocene deep water samples are dominated by Grenville-derived (1300–950 Ma) zircons, with secondary components of Yavapai-Mazatzal (1800-1600 Ma), Mid-Continent (1500-1300 Ma), Appalachian-Ouachita (500-260 Ma), and Western Cordillera (260-23 Ma) aged zircons. Comparing zircon U-Pb age of deep water samples to that of delta samples and published onshore samples strongly suggest sediment are sourced by the Mississippi River via the Mississippi delta.

A middle Miocene deep water sample shows slightly different U-Pb age pattern, with decreased Grenville and increased Western Cordillera components, indicating an increased sediment flux from the Western North American Cordillera and decreased sediment supply from the Appalachian Mountains to the east. This argues against conventional wisdom that the newly emerged middle Miocene Tennessee River supplied the fans in Green Canyon where the sample is collected. Meanwhile, a large-scale deep-water fan, known as McAVLU fan, was developed to the east of paleo-Tennessee fluvial axis. This supports our previous deduction that sediments derived from the paleo-Tennessee River might have been diverted by bottom currents to the east of the river input point and instead supplied the McAVLU Fan of Mississippi Canyon in the middle Miocene.

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LONG-TERM TOPOGRAPHIC AND SEDIMENTARY EVOLUTION IN WEST AFRICA: IMPLICATIONS FOR CRATONIC LONG-WAVELENGTH LITHOSPHERIC DEFORMATION

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The aim of this study is to investigate the topographic and sedimentary evolution of West Africa since Early Cretaceous rifting of the Equatorial Atlantic. The main questions are: (i) how much Mesoproterozoic-Paleozoic sediments were stored in intracratonic basins before being eroded away? (ii) How has erosion shaped the present day limits of the intracratonic basins through time and space? (iii) What was the nature of the sources of sediments delivered into the Equatorial Atlantic margin?

To do this, we constructed continental-scale cross-sections, linking onshore intracratonic basins to offshore basins of the Equatorial Atlantic which integrate surface geology, borehole and seismic data. We also integrated constraints on Cretaceous and Cenozoic denudation and deposition histories estimated from low-temperature thermochronology and geomorphology. From this, we mapped the evolution of paleo-limits of the Mesoproterozoic-Paleozoic basins.

We show that the Reguibat and the northern parts of the Leo Man basements were initially covered by Mesoproterozoic-Paleozoic sediments at least at their margins (Paleozoic paleocurrents going systematically to the North), and submitted to slow denudation during the Cretaceous. However, denudation of the Reguibat basement during the Lower Cretaceous was twice (~40m/km) the denudation of the Leo-Man basement. During the Cretaceous, the Northern Taoudeni basin and the present day Hoggar basement were subsiding, allowing for the deposition of over 2 km-thick sediments. During the Cenozoic, most of West African area was submitted to slow and steady erosion (7 m/My), except over and around the Hoggar hot spot swell and a marginal upwarp (10-40 m/My). Areas of enhanced Cenozoic rock uplift are related to long-wavelength deformation due to asthenospheric flow beneath the continent.

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ROCK PROVENANCE AND GEOMORPHIC CONTROLS ON SAND DEPOSITION IN THE LARGE COMPRESSIVE BASIN ----- A CASE STUDY OF HUAGANG FORMATION IN XIHU DEPRESSION, EAST CHINA SEA BASIN

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Abstract: Rock provenance and geomorphic controls on sand deposition mainly present on geomorphic units combination， forming various source and drainage system[1-3], which is significant to predict large-scale reservoir distributions. This study applies the methodology of the back strip of the residual strata thickness, eroded thickness, calculation, sediment compaction correction and paleo-water depth estimation to accomplish researching the paleogeomorphic characteristics of the Lower Huagang Formation, reconstructing the transition history of the geomorphic units and the basin evolvement in depression. On basis of the paleogeomorphic reconstruction, and combining such "source-to-sink" pattern, sandbody distribution model is analyzed. Meanwhile, the multiple parameters and techniques are applied in analysis of the provenance. The "source-to-sink" pattern based on the rock-dating & location-detecting technique, rock source calibration and transport channel sculpture indicates that 3 different sources, 3 different types of deposits and several channel systems contribute the deposition of the Lower Huagang Formation. Also, the result shows that the geomorphic units of Lower Huagang period in Xihu depression which are featured with belting from west to east and blocking from north to south. The Upper Huagang period inherits the characteristics of the Lower Huagang period, presenting wide and gentle terrain. The main source of sandbody comes from Hupijiao uplift from north, and partly from Haijiao uplift from west and Diaoyudao folded belt from east. Furthermore, various types of sand-transport channels develop in Xihu depression, including axial valley channels, incised valley channels from west and channels from east transition zones. Three large sandbody accumulations are identified from south to north, which are known as one of the most profitable reservoirs in the basin.

Key words: provenance, geomorphy, source-to-sink, Xihu, Huagang

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Unconformities matter: The spatial and temporal information contained in the J-3 Unconformity and the Curtis Formation, east-central Utah, USA.

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A spatio-temporal re-interpretation of a regionally significant unconformity is proposed to refine the depositional history of its basin, highlighting the fact that unconformities are dynamic sedimentary features and should not be considered as a simple "break in deposition". The Upper Jurassic (Oxfordian) Curtis Formation crops out in east-central Utah, and was strongly impacted by tide-related processes at the time of deposition. It unconformably overlies the Middle-Jurassic (Callovian) coastal eolian to marginal marine deposits of the Entrada Sandstone. The two formations are separated by Pipiringos & O'Sullivan[1] (1978) J-3 Unconformity, widely regarded as a "simple" subaerial unconformity representing a significant break in deposition between the Middle- and Upper Jurassic, followed a third order transgression within a semi-enclosed basin and the deposition of the tide-dominated Curtis Formation. This interpretation has been proven inaccurate by meticulous identification of the different types of relief characterizing this surface, by the careful inspection and by the sub-regional correlation of the various facies bounding it, both above and below the surface. The J-3 Unconformity displays an intricate poly-generational history as it was impacted by a range of erosional and depositional processes during short-lived transgressive and regressive episodes. The resultant J-3 Unconformity is thus a composite stratigraphic boundary that is not only diachronous from its distal to proximal reaches as is typical for single-generation surfaces of subaerial erosion, but also recorded episodes of erosion that are separated by larger temporal gaps. As the Sundance Sea started to transgress from the north, eolian deflation increased and slowly cannibalized the eolian deposits of the Entrada Sandstone when its sediment supply was drastically reduced. The transgression(s) was accompanied by an increased water table within continental sedimentary column over the study area. Contemporaneous fluvial erosion occurred locally as flash floods were flowing from neighboring highlands. While the Curtis Sea kept transgressing, sub-aqueous erosional and soft sediment deformational mechanisms were controlled by the distribution and magnitude of tidal forces within the basin, resulting in steeper and more localized incisions during short-lived regressive episodes, whereas transgressive phases lead to distinct and extensive, dm- to m-scale irregular relief. Sedimentary processes alone can't explain the present-day relief observed with the J-3 Unconformity. Steep faulting localizing depressions and horst-like shoulders can be linked to hydroplastic deformation by mobility of subsurface sand. Such surface expressions further shaped the J-3 Unconformity as it funneled the various erosional forces and impacted on the spatial distribution of depocentres. Typical features include; (i) m- to dm-scale graben-and-horst structures, (ii) sag basins juxtaposed with related sand-pillow uplifts, and (iii) syn-Curtis gentle folding and erosion linked to sub-regional uplift.
This study shows (i) such a poly-genetic surface is a dynamic sedimentary feature and cannot be regarded as unconformity *sensu stricto*, which will notably lead to lithostratigraphic paradoxes, and hence, such nomenclature shall be dealt with caution, but (ii) that careful mapping and understanding of such a multifaceted surface can provide valuable information regarding the dynamic of a basin and its subsequent infill.

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PAIRED PETROFACIES OF RHYOLITIC BRECCIA AND SILICIFIED ASH: CHEMICAL COMPOSITIONS AND TECTONIC PROVENANCE

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In the ideal world, barring igneous fractionation, chemical compositions of porphyritic pyroclastic flows and consanguineous ash deposits should be nearly the same. In reality, post-depositional processes (diagenesis) change their compositions differentially. In the extreme, provenance identities of the pair could be obscured. A mafic or a felsic heritage may be preserved in their trace element distributions and incompatible elemental relationships, which some attribute to collisional arc or continental block provenance. A ~1640-1630 Ma pair, constitutes rhyolitic breccia (near Kon in the east) and associated silicified ash beds (porcellanites), in the approximately flat-bedded Chopan Porcellanite Formation (aka Deonar Formation) of the Semri Group in the Vindhyan Supergroup in India. These rocks crop out along a ~300 km WSW-ENE stretch and attain a maximum thickness of about 50 m. The Formation shows some minor open folds and faults of various dimensions that have acted as conduits for mineralization, especially to the west. This pair presents an appropriate opportunity to assess the extent of preservation of provenance information despite post-depositional processes. Transmitted and reflected light optical and SEM-Color-CL observations of polished thin sections show pervasive silicification of the clayey matrix and of microphenocrysts of altered feldspars that have undergone saussuritization, illitization, and kaolinitization. Microcrystalline quartz and calcite-filled veins and secondary pores are common.

We have used published chemical compositions of 88 porcellanite samples along the 300 km stretch and 9 samples of rhyolitic breccia from the Kon area in the east. Not all samples have been analyzed for all relevant elements and the quality is uneven. Commensurate with our petrographic observation of reduction of feldspars in the porcellanites, the Eu anomaly drops by about 25% from 0.57 in the rhyolitic breccia to 0.43 in the average porcellanite. Enrichment of Co (x6.7), Cr (x2.7) Cu (x2.0), Ni (x9.4), Pb (x4.7), U (x5.6), V (3.8), and Zr (x2.3) in the porcellanite relative to the rhyolitic breccia implies that some carrier minerals (e.g., zircon) escaped silicification and new minerals (e.g., Cu-Pb sulfides; calcite) were introduced during diagenesis and mineralization. Local short-range Eh-pH conditions govern the relative mobilities of all elements during pedogenic and diagenetic processes. Whereas the chemical signal for the provenance of the rhyolitic breccia is for a continental block[1], that of the porcellanites – disregarding the diagenetically-enhanced SiO_2 and CaO, and, decreased Al_2O_3 – with relative increase of mafic indicators (Cr, Ni, Nb/Ta, Sm/Zr, Ce/Pb) supports contributions from an arc orogen[2], *for the same consanguineous depositional unit.* The results reiterate that provenance interpretation of siliciclastic petrofacies requires a comprehensive understanding of the postdepositional processes that have modified the properties of samples used in any study.

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USING ACTUALISTIC SAND(STONE) PETROFACIES TO STUDY THE COMPOSITION OF MODERN SAND AND CRETACEOUS SANDSTONE DERIVED FROM THE SIERRA NEVADA, CALIFORNIA, USA, WITH IMPLICATIONS FOR CENOZOIC AND MESOZOIC UPLIFT AND DISSECTION OF A CONTINENTAL-MARGIN MAGMATIC ARC

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The California Sierra Nevada represents the roots of a primarily Cretaceous magmatic arc that is presently being dissected extensively in the south and to a lesser degree in the north, where it is covered by Cenozoic volcanic rocks. The Cenozoic magmatic arc built on top of the Cretaceous arc has been dissected concurrently with northward migration of the Mendocino triple junction, south of which the magmatic arc is inactive. A north-to-south transect from the modern Cascade arc along the Sierra Nevada, therefore, acts as a proxy for evolution from an active undissected magmatic arc to a transitional arc to a dissected arc to intensely uplifted basement.

Discriminant analysis of Cascade and Sierra Nevada modern alluvial sand defines four compositional groups and clearly distinguishes volcaniclastic undissected-arc and plutoniclastic uplifted-basement end members. Two intermediate compositional groups are primarily volcaniplutoniclastic and metamorphiplutoniclastic. The former group represents Dickinson’s (1985) “transitional arc;” the latter represents “dissected arc.” Sand composition in the southern Sierra Nevada reflects significant uplift, resulting from a combination of latest Cretaceous-Paleogene uplift and late Cenozoic Basin and Range extension (footwall uplift of the western rift shoulder), possibly enhanced by mantle-lithosphere delamination. High concentrations of quartz and feldspar, and near absence of aphanitic lithic fragments are typical of the southern Sierra Nevada and are characteristic of Dickinson's “basement uplift.”

Cretaceous sandstone petrofacies of the Great Valley Group (GVG) of western California document dissection of the Cretaceous magmatic arc, as well as erosion of residual orogenic highlands (analogous to modern Taiwan) formed during latest Jurassic arc-continent collision (Nevadan orogeny). When Cretaceous petrofacies data are entered into the modern-sand discriminant analysis as unknowns, they are classified into the modern Cascade/Sierra Nevada groups and a group from Taiwan. The results confirm that the lowest GVG petrofacies represent erosion of the Nevadan suture belt and the undissected post-Nevadan arc. Increasing dissection of the arc occurred during the Cretaceous, but most samples represent "transitional arc," indicating that even by the latest Cretaceous (Laramide) cessation of arc activity in California, dissection of the magmatic arc was less than what we see today in the central and southern Sierra Nevada. No Cretaceous samples have compositions equivalent to the "basement uplift" of the southern Sierra Nevada.

Unlike many paleotectonic settings, magmatic-arc sand(stone) composition is not significantly affected by sampling scale, as demonstrated by diverse samples from mountain streams to submarine fans, although more homogenization is evident in the latter. The application of actualistic sand(stone) petrofacies in this study provides important constraints on models for the Cretaceous to modern history of the Sierra Nevada, as well as implications for arc evolution in general.

TITLE: ACTUALISTIC ARC PETROFACIES

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Deep-sea drilling has clarified the tectonic and volcanic evolution of Pacific margin magmatic arcs through their sedimentary records, starting with the Deep Sea Drilling Project (DSDP), then the Ocean Drilling Program (ODP), followed by the Integrated Ocean Drilling and International Ocean Discovery Programs (IODP). The database of volcaniclastic sand and sandstone compositional modes from forearc, intra-arc, and backarc basins first initiated by Ray Ingersoll and his students in the 1980's has continued to grow. The most recent additions come from IODP Expedition 351 in the Izu-Bonin-Mariana reararc. These data provide the fingerprints of intraoceanic arc evolution, from inception to maturity to demise by rifting. The latter stage can be traced across the Shikoku Basin to coeval forearc succession drilled at Site 787 during ODP Leg 126. Volcanic lithic textures, e.g., vesicularity and degree of crystallinity, are key for interpretation, as they can survive the extreme diagenetic alteration (dissolution, replacement by zeolites and clay minerals) that these successions undergo. Bathymetric data across the modern active Mariana arc and backarc region provide an actualistic source-to-sink picture of the submarine arc elements such as channels that are potential sediment pathways to the reararc, sourcing depositional lobes like those drilled during IODP Expedition 351.

NUMERICAL MODELING OF SEDIMENT GENERATION: CHARACTERIZATION OF PARENT ROCK PROPERTIES

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This research project aims to build a numerical sediment generation model (SedGen) comprising different modules dealing with specification of initial conditions (parent rock properties), chemical weathering (dissolution and precipitation), and mechanical weathering (intra- and inter-crystal breakage), respectively. The model will allow us to improve our understanding of the evolution of grain size distribution and petrographic/modal/chemical composition (as a function of size), so as to carry out provenance analysis in predictive mode. The initial conditions of a SedGen simulation are defined by the fundamental properties of parent rocks from which sediment will be derived. The comprehensive petrographic descriptor developed by Griffiths lies at the basis of the method followed in this research[1,2]. Three fundamental properties (modal composition, spatial distributions, and crystal size distributions of mineral phases) were chosen as building blocks of the SedGen model.

Data of granitoid rocks collected by Heins were used to set up the method of parent rock characterization and prepare the building blocks[3]. Modal and relative interface frequency data were readily available for data analysis. The spatial distribution of crystals has been inferred from relative mineral interface frequencies[4]. The data set was completed by obtaining 2D crystal size data from image analysis of thin sections, which were converted to 3D crystal size distributions. The parent rock module has been established, and modules handling the chemical and mechanical weathering are under development. The model will permit partial descriptions of sediments as contained in legacy data, such as grain size distributions and petrographic composition of specific size classes, to be evaluated in a broader framework.

With the innovation and potential that SedGen brings we will be able to: 1) Perform provenance analysis in predictive mode so as to close gaps in our understanding of source-to-sink models and Earth surface dynamics. Specifically, effects of environmental perturbations, possibly anthropogenic in nature, can be monitored more closely; 2) Clarify the evolution of weathering products by modeling their petrographic/modal/chemical composition and grain size distribution along the pathway from source to sink; 3) Improve reservoir quality prediction in hydrocarbon exploration and exploitation, as well as reservoir characterization for CO_2 storage and geothermal applications.

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The impact of climate change on sediment generation on the Tibetan Plateau

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Signals of past climate change are frequently inferred from changes in sediment composition of continental records. However, the sedimentary response of landscapes to climate change is mediated by sedimentary routing systems, which respond dynamically to changes in climatic boundary conditions. Such dynamical responses are attributed to interfere with climatic signal preservation, complicating a direct inference of climate change from sedimentary variations. Yet, suitable landscape response models for paleoclimatic reconstructions are missing. Here we present an inverse modelling approach to identify landscape response models from high-resolution geochemical records of lacustrine sediment sequences. The approach was tested on Holocene sequences of three lake systems situated in similar environmental conditions on the Tibetan Plateau. Despite identical process systems for the generation and transport of sediments, their Holocene sequences diverge, indicating differentiated responses to climate forcing. Using System Identification techniques on time series obtained from geochemical indices, we identified a common response model which accurately simulates the observed differences in sediment supply. Coupling the response model to a forcing function resulted in the inference of a coherent climate signal for the Tibetan Lakes. Based on our results, we argue that our approach bridges the gap between forward models of sedimentary processes and the reconstruction of paleoclimatic signals from continental sediment records.

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MARBLES IN EASTERN YARLUNG ZANGBO SUTURE ZONE: IMPLICATION TO THE FORELAND BASIN IN HIMALAYA

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The eastern Yarlung Zangbo suture zone (YZSZ) is composed of either Triassic flysch or so-called Cretaceous Langxian mélange without ophiolitic series. Within the mélange, lots of marble olistoliths were marked on geological maps in Langxian-Meiling area. Our recent investigations on these marbles turn out that the Langxian mélange isn't tectonic mélange and partly distinguish from the Triassic flysch.

Field observations indicate that marbles are various thickness, decimeters to hundreds meters, and occur harmoniously within the host strata, demonstrating the marbles are not exotic blocks but were originally formed within a basin. Petrographic analysis shows that marbles are dominated by calcite, with minor quartz and muscovite. Schists intercalated within marbles are of greenschist-facies metamorphism, indicating the metamorphism took place under 300-500℃ and has not changed the composition, including U-Th-Pb isotopic system, of zircons in the schists. In order to explore the age and provenance of the marbles, we conducted detrital zircon U–Pb geochronology and Hf isotope analyses. We took three samples of schists within marbles and one of clastic marble to obtain detrital zircons.

Detrital zircon U–Pb ages (and $\varepsilon_{Hf[t]}$ isotope ratios) cluster around 13.4-35 Ma, 55-65 Ma ($\varepsilon_{Hf[t]}$ = -16.0 - 8.6), 80-120 Ma ($\varepsilon_{Hf[t]}$ = 6.2-12.6), 500 Ma, and 950 Ma, and the peaks of the youngest populations are 13.4 ± 0.43 Ma (muscovite-bearing quartz marble), 17.2 ± 0.3 Ma (muscovite-quartz schist), 37.3 ± 0.5 Ma (sericite-quartz schist), and 64. 0 ± 2.0 Ma (muscovite-quartz schist), respectively. These youngest age clusters indicate the marbles could be originally formed in the Cenozoic, most probably in Oligocene-early Miocene (34-13 Ma), similar with the time of the Dazhuka Fm and/or Kailas Fm.

The geochronology and Hf isotope of detrital zircons suggests the original clastic compositions of schists within marbles were dominantly derived from the Gangdese magmatic arc. However, some of 13.4-35 Ma zircons with clear core-mantle structure have high U/Th ratios (>10). This feature indicates a possible provenance of upper amphibolite-facies metamorphic rocks[1], which could be from the leucogranites and metamorphic zones of the thermal domes within the Tethys Himalayan in southern Tibet.

The occurrence of marbles and the maximum depositional age together with original provenance of schists within marbles implies a Cenozoic foreland basin could exist in eastern YZSZ and seawater may not have retreated in this area if the marbles were originally precipitated in a marine environment.

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ASSESSING THE IMPACT OF BURIAL DIAGENESIS ON THE PB ISOTOPIC COMPOSITION OF DETRITAL K-FELDSPAR

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The common Pb isotopic composition of K-feldspar is increasingly employed in provenance and sediment tracking studies, particularly in large drainage systems where it offers a useful constraint on the framework mineral provenance alongside other tracers[1]. However, it is well known that K-feldspar abundances can be significantly affected by burial and diagenesis. A key question is whether the progressive removal of K-feldspar via diagenetic reactions can bias isotopically distinct grain populations. It is important to know this ahead of using the technique in sandstones that have had a deep burial history. An ideal place to test whether or not a systematic distortion of provenance information stored in K-feldspar is introduced is the Middle Jurassic Fulmar Formation in the Central North Sea. This comprises a succession of shallow-marine sands that were differentially buried to a range of depths between 3.2 and 6 km. Previous studies have shown progressive loss of K-feldspar with burial depth over a relatively small area of the Central Graben[2,3]. Here we resample the same succession and track the framework mineralogy and Pb isotopic composition of the feldspars with increasing burial. Framework mineral abundances have been quantified using a novel imaging technique, recognizing that it is easy to overlook untwinned detrital and/or diagenetic feldspar in the subsurface. BSE SEM imaging combined with element mapping confirms the framework composition changes with burial depth with K-feldspar >40% at 3.2 km depth but only ~8% at 5.8 km depth. However, element mapping reveals that the plagioclase actually increases from ~3% at 3.2 km to ~20% at 5.8 km, indicating a possible role for albitisation of at least some of the K-feldspar. The SEM imaging is used to document progressive dissolution of the remaining K-feldspar with fresh K-feldspar grains reducing from >70% to ~7% of the K-feldspar population with burial and a proportionate increase in corroded grains (~10% to ~56%) and skeletal grains (0% to ~30%). Pb isotopic analyses of both the fresh and corroded K-feldspars by LA-ICPMS identifies the same two main populations in all the samples, and whilst these vary in relative abundance with burial depth, no systematic pattern is revealed and hence these variations are thought to reflect changes in provenance rather than selective purging by dissolution and albitisation.

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TITLE: A DYNAMIC MODEL OF CHANNEL-LOBE TRANSITION ZONE ARCHITECTURE: BASED ON THE KAROO BASIN SOUTH AFRICA

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Submarine channel-lobe transition zones (CLTZs), which separate well-defined channels from well-defined lobes, are commonly located at breaks in slope in deepwater turbidite systems. Despite frequent recognition of CLTZs on the modern seafloor, they are rarely recognised in outcrop, and where documented are only partially exposed with limited up-dip, down-dip and strike correlation. Consequently, existing models for CLTZs are largely based on snapshots from the modern seafloor and lack a detailed three-dimensional understanding of their deposits, evolution and preservation over time. In this study, we address this limitation using a uniquely exposed dip transect of a CLTZ, from Unit E of the Permian Fort Brown Formation, Karoo Basin, South Africa. The excellent paleogeographic constraint of this Unit allows correlation to genetically related up-dip channel-levee systems and down-dip lobe deposits over 40 km, with strike control over 20 km.

This study demonstrates for the first time a strike change from a levee-lobe transition zone to a bypass dominated CLTZ over a width of 14 km. Key features such as: composite erosional surfaces; coalescing scours and megaflutes; remnant sediment waves and bypass lags are documented here in a single CLTZ, arranged in a zone of repeatedly juxtaposed remnant erosional and depositional features. The zone reaches 6 km in length, with the outcrop allowing recognition of at least four stages of expansion/contraction or migration. Strike variations and changes in the dimensions of the CLTZ through time are interpreted to be the result of physiographic fluctuations in flow dynamics across the base of slope. The dynamic nature of CLTZs results in a complicated and composite stratigraphy, with preservation potential generally low, but which increases distally and laterally from the mouth of the feeder channel system. This study has allowed the development of the first generic model to account for dynamic CLTZ development, which encompasses distinctive recognition criteria, morphodynamics, fluctuations within the position of the zone, and the composite transfer of these into the sedimentary record.

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STRATIGRAPHY OF MARGINAL-MARINE DEPOSITS IN A LOW ACCOMMODATION SETTING: MCMURRAY SUB-BASIN, ALBERTA, CANADA

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The regional stratigraphic architecture of the Lower Cretaceous McMurray Formation in the McMurray Sub-Basin of Alberta, Canada comprises a series of regressive stratigraphic units that consist of stacked parasequences or parasequence sets (referred to herein as depositional units (DU)), cut into by nested, deeply incised fluvio-estuarine channel belts. Five regionally extensive and relatively thin (<10 m) DUs are identified within the middle and upper McMurray, and are interpreted as being deposited in a limited accommodation setting. The 5 DUs are (from oldest to youngest): M5, M4, M3, M2 and M1. Of these, DU M5 is an under-explored stratal package that potentially hosts significantly more hydrocarbon resources than are presently proven. DU M5 is preserved throughout the southwest quadrant of the McMurray Sub-Basin, and here we present a sedimentological, ichnological, and revised stratigraphic framework for these strata.

Isopach maps of the SW quadrant of the McMurray Sub-Basin reveal that carbonate highlands restricted ocean connection and protected the area from wave action propagating from the north and northwest. Based on facies analysis of 150 cores in the study area, M5 exhibits stronger degree marine influence than previously described. In particular, M5 displays moderate to high bioturbation intensities (BI 3–4) with 8 regularly occurring ichnogenera within the trace fossil suite. Based on the sedimentological and ichnological character, M5 is interpreted as a composite succession of stacked coarsening-upward, tidally influenced paralic deposits incised by tidally influenced channels.

Reconstructing the architecture of M5 requires the mapping of multiple flooding surfaces (FS) within the unit. Throughout the SW-quadrant of the McMurray Sub-Basin, a regionally mappable surface (extending over 14 500 km^2) typically occurs 11–15 meters below Top_M5. In core this surface is identified at the base of a dark grey mudstone containing deposit-feeding structures and a moderate to high BI (3–4). On geophysical well-logs, the surface is typified by a high gamma-ray reading (>100 API) and low density-porosity (<18%) values.

Overall, M5 is a complex DU with numerous internal discontinuities dividing the succession and encompassing a regionally mappable surface. This surface highlights a major episode of transgression and marine conditions in the study area. The stratigraphic model proposed herein separates M5 into two discrete intervals. The lower interval, capped by the regionally extensive marine flooding surface, herein named Top_M6 is proposed to be M6. The upper interval capping Top_M6 retains the name M5. This refined stratigraphic architecture is presented to improve the mapping of middle-upper McMurray strata in under-explored regions of the prolific McMurray Sub-Basin.

LOOKING AT A BASIN MARGIN IN STRIKE SECTION AND ITS LATERAL VARIABILITY. TANQUA DEPOCENTRE, KAROO BASIN, SOUTH AFRICA.

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Interaction of numerous processes at ancient sedimentary transition zones has been documented along depositional dip sections, but their lateral (strike) variability and implications for sediment distribution and stratigraphic architecture are less well constrained. Continuous 70km long, NW-SE -strike to main progradation-oriented exposures in the Tanqua depocentre, have been characterized by 53 logs (9910m cumulative thickness), >2500 palaeocurrent measurements, and ground/helicopter/drone based photo panels. Main progradation direction was to the N-NE, with E-W and NE-SW bidirectional palaeoflow components.

In SE locations, upper-slope and shelf-edge parasequences (50-75 m-thick) are interpreted as river-dominated prodelta and mouth bar deposits, locally incised by amalgamated sandstone packages interpreted as distributary channels (<25 m-thick, 700 m-wide). Downdip parasequences are truncated by upper slope gullies (10s m-thick, 100 m-wide) and shelf-incised canyons (>100m-thick, 1.5km-wide). In NW sections, parasequences show better sorting, abundant symmetrical ripples and no evidence of major incision. Overlying shelf parasequences are thinner (15-50 m-thick) with symmetrical ripple tops and HCS. They are interpreted as wave-influenced deltaic or shoreface deposits. In the NW parasequences are sandier, more amalgamated and strongly influenced by wave action, with structures such as HCS, SCS and trough-cross bedding and are interpreted as shoreface, foreshore and strandplain deposits.

The SE clinothem parasequences were more river-dominated with sediment bypass and delivery across a steep and erosive margin. Wave and storm current redistribution along strike to the northern, lower gradient margin resulted in higher and better sorted sand on a wider shelf, without major incision, bypass or sand delivery to the upper slope. No evidence of major avulsions in the upstream tributary and distributary systems are interpreted because bypass and fluvial-dominated characteristics are persistent in the SE areas through time, whereas the NW margin maintained a sand-starved upper slope and a wave-dominated shelf succession.

Seismic data reflects that this differential basin margin distribution could have been allogenically controlled by a marked higher subsidence in the S part of the depocentre, which fixed the main entry point in the SE. Here, autocyclic compensation of deltaic lobes and migration of channels near the sediment entry point led to increased bypass and erosion, with the consequent development of a steeper slope and narrower shelf, compared to the more tabular and amalgamated geometries observed in the shallower and wider shelf in the NW.

This study demonstrates that although basin margin clinothem successions may appear consistently progradational in depositional dip profiles, the interaction of mixed coastal processes and differential spatial configuration results in a complex along-strike sedimentary architecture, with major implications in sediment distribution through time and space. Clinothem expression has different character and trajectory when examined laterally – with implications for local reservoir element variability and exploration-scale sand delivery over the shelf edge.

SEDIMENT DISTRIBUTION AND DEPOSITIONAL PROCESSES ALONG THE FLUVIAL TO MARINE TRANSITION ZONE OF THE MEKONG RIVER DELTA, VIETNAM

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The area of coastal rivers with a combination of fluvial, tidal and wave processes is defined as the fluvial to marine transition zone (FMTZ) and can extend up to several hundreds of kilometres upstream of the river mouth. The aim of this study is to improve the understanding of sediment distribution and depositional processes along the FMTZ using a comprehensive dataset of channel bed sediment samples collected from the Mekong River delta. Six sediment types were identified and were interpreted to reflect the combined action of fluvial and marine processes. Based on sediment-type associations, the FMTZ could be subdivided in an upstream tract and a downstream tract, whose boundary is identified 80-100 km upstream of the river mouth. The upstream tract of the Mekong FMTZ, is characterised by gravelly sand and sand sediment types and occasional heterolithic rhythmites, suggesting bed-load supply and deposition mainly controlled by fluvial processes with subordinate tidal influence. The downstream tract, is characterised by heterolithic rhythmites with subordinate sand and mud sediment types, suggesting suspended-load supply and deposition mainly controlled by tidal processes with subordinate fluvial influence. Sediment distributions in wet and dry seasons suggest significant seasonal changes in sediment dynamic and depositional processes along the FMTZ. Turbidity maxima are present along the downstream tract of the FMTZ during both wet and dry seasons and are driven by a combination of fluvial, tidal and wave processes.

New evidences on the spatial-temporal distribution of superlobes in the Yellow River Delta complex

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The Yellow River Delta complex is remarkable in the world. Delta superlobes formed at various periods could be observed along China coast zones from the northern Jiangsu to Tianjin when the large-scale channel of the Yellow River changed in the lower reaches over last 7000 years, and this distribution was unique as the river was easily plugged, breached and migrated in the lower reaches due to the huge amount of sediment loads (~ 1.2 Gt/yr at most). Since Xue and Cheng (1989) first systematically proposed the spatial-temporal distribution of ten Holocene superlobes in the Yellow River Delta, this hypothesis hasn't been evidenced and improved during last three decades. However, Xue and Cheng (1989) put forward their hypothesis mainly on the basis of the detailed historical documents and previous studies of several well developed cheniers at the coastal area of the Bohai Bay while a few of drilling cores and rare dating data had been used. Thus, except the superlobes 6, 7, 9, and 10 being widely accepted, the spatial-temporal distribution of the other superlobes remained debate. To redefine the distributional characteristics of sedimentary evolution in the Yellow River Delta complex, 12 boreholes and 60 AMS ^{14}C data with previous 23 cores and 180 AMS ^{14}C data were obtained to construct 8 age-depth curves in the coastal plain of the Bohai Bay. An important caveat to bear in mind is that the deltaic depositions generally show a similar pattern in the age-depth curves within one superlobe. Based on this method and combined with the previous studies by Xue et al. (1989, 1993, 2004, 2009), 8 superlobes are identified and proposed with the Yellow River Delta complex in this study, namely Lijin superlobe (7000~5500 cal a BP), Huanghua superlobe（5500~3800 cal a BP）, Shajingzi superlobe (3800~2600 cal a BP), Qikou superlobe (700 BC~11 AD), Kenli superlobe (11~1099 AD), Tanggu superlobe (1048~1128 AD), Subei superlobe (1128~1855 AD), modern superlobe (1855 AD~ present).

Key words: Delta superlobe, age-depth curve, Yellow River Delta, Bohai Bay, Holocene

Turbidity Currents in Channel-Lobe Transition Zones (CLTZs): Loss of Lateral Flow-Confinement Controls Patterns of Erosion and Deposition.

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On the source-to-sink flow-trajectory, turbidity currents are initially laterally confined by canyon-walls or channel-levees. At some point they lose their confinement and begin to spread laterally, which reduces their capacity to keep sediment in suspension and promotes formation of sediment lobes. However, in some turbidite systems the channels are separated from lobes by a CLTZs, characterized by large fields (10s km) of erosive features such as scours and erosional lineations. Bed morphology suggests that the structure of the unconfined flow in the CLTZ is similar to that of the channel system, rather than the unconfined flow that developed further downstream. As such, there appears to be a lag between the loss of lateral confinement and reorganisation of the current's flow structure of which the latter is hypothesised to play a significant role in creating large-scale scours in the CLTZ.

Here we present the flow structure, along with the erosional/depositional patterns, from experimental turbidity currents in a three-dimensional flume that is divided into a confined and an unconfined section. Sediment suspensions used to generate the currents were held constant, composed of sand (d50: 140µm) with a concentration of 17%(vol.). Downstream variations in the flow field is mapped with an array of ultrasonic-Doppler-profilers and erosional/depositional patterns are mapped using a laser scanner. Results show that turbidity currents exhibit a rapid flow collapse upon loss of lateral confinement, and that this flow collapse is associated with a dynamic mechanism that enhances sediment scour and suspension.

The results are the first measurements of a flow mechanism that credibly explains the erosional features often observed in CLTZs. Improved understanding of the formation of CLTZs will improve the reconstructions and interpretations of CLTZs from the rock record as well as the verification of reservoir characterisations of turbiditic deposits close to areas of lateral confinement change.

CLINOTHEM ARCHITECTURE AND SEDIMENT DISTRIBUTION IN A BYPASS- TO ACCRETION-DOMINATED BASIN MARGIN (KAROO BASIN, SOUTH AFRICA)

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A complete vertical section through a progradational basin margin clinothem succession will intersect the base-of-slope (BOSZ), shelf-edge (SERZ) and fluvial-marine (FMTZ) transition zones. A common assumption is that an observed SERZ at one stratigraphic level is similar in character to the one that supplied underlying slope and basin floor systems. However, this does not account for temporal and spatial changes in basin margin physiography, and sedimentary systems are different when delivering sand to the basin floor than when aggrading deposits in the shelf. Accurate reconstructions require sub-seismic scale analysis of transition zones from coeval clinothem topset, foreset and bottomset segments in order to adequately constrain the timing and nature of sediment dispersal across basin margins in the absence of a complete dataset.
Unit G from the Laingsburg depocentre (Karoo Basin, South Africa) is a rare outcrop example of a >60 km long, 200 m-high basin margin scale clinothem, with 10 km across-strike control, allowing an almost 3D study of a preserved shelf-slope-basin floor transition. This unit is constrained by underlying regionally-mapped basin floor-to-slope systems and overlain by shelf-to-fluvial stratigraphy. Sand-prone wave-influenced lower shoreface/distal mouth-bar facies, deposited close to the SERZ, can be physically correlated down dip for ca. 10 km as they thicken and transition into heterolithic, bypass-dominated slope/foreset deposits with incisional features interpreted as minor slope conduits/gullies. These deposits progressively fine and thin down dip into a sand-starved basin floor/bottomset. Only a few km across-strike, the equivalent foreset segment is steeper, more channelized, and records a stepped geometry with local sand-filled intra-slope topography. The channel-lobe transition zone deposits lie downslope at the true BOSZ.
Unit G is a composite sequence that records a change in large-scale stratigraphic arrangement, from condensed sandstone-rich lowstand deep-water sequences, to thicker highstand shallow-marine sequences. This change is related with the transition from an underlying bypass-dominated, sand-detached incisional slope to an overlying accretion-dominated shelf. This study demonstrates that differential subsidence and asymmetric basin geometries influenced sediment pathways and styles of deep-water sedimentation, and limited the extent, height and gradient of basin margin clinothems, resulting in an overall upward decrease in deep-water sediment delivery and an increased accumulation of sand on the shelf. This cautions against the use of analogue data from successions that do not account for the influence of inherited basement configuration and changing nature of basin margins through time, with potential implications in basin evolution models.

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Late Holocene evolution of beach-ridge progradation in the wave-dominated Changhua Delta, southern China

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Beach-ridge plain is a typical kind of prograding coastal landforms all over the world. A series of beach ridges can be regarded as an indicator of coastal evolution, which is influenced by climate and sea level changes, together with extreme, catastrophic events in history[1]. In this study, the Late Holocene history of the beach-ridge plain on asymmetrical Changhua River Delta in Hainan Island, southern China, was reconstructed by using the topographic (RTK-GPS) measurements, unmanned aerial vehicle (UAV) photograph analysis, optically stimulated luminescence (OSL) dating and sedimentological analysis of drilling data. Here the orientation of the beach-ridges is not parallel to the delta front but the coastline in the Beili Bay which is sheltered by Sigeng Spit on the downshift flank of the Changhua River delta. The chronology clearly illustrates that 4 ridges prograded seaward over the last 2900 years (relative to AD 2016). Based on the recognition and judgment of the height of each sedimentary facies, in combination with the analysis of hydrodynamic processes under normal and extreme weather conditions in the study area, the beach ridges are created by large magnitude events and the sediment supply from Sigeng Spit. As such, the landforms of the beach ridges have archived the history of intense tropical cyclones for nearly 2900 years.

Key words: beach ridges, OSL dating, wave-dominated delta, tropical cyclones, Hainan Island

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Coals in the McMurray Sub-Basin: A High Frequency Base-Level Archive

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The Lower Cretaceous McMurray Fm in the McMurray Sub-Basin comprises marginal marine, tidal-fluvial, fluvial and inter-channel deposits, the thickest of which occupy paleotopographic lows on the Sub-Cretaceous Unconformity. In the northeastern part of the basin, the top of the Lower McMurray Fm commonly comprises a coal and/or paleosol horizon. This horizon has been interpreted to have formed during initial flooding of the Boreal Sea (Hein et al., 2013). Peat-forming mires are highly sensitive archives of base-level, and in the nearshore to terrestrial realm, base-level changes are related to shifts in the water table, many of which are caused by sea level change and/or basement subsidence. Coals may exhibit a wetting-upward character through accelerating base-level rise, and a drying-upward character through declining base-level rise. Base level fall generally leads to the termination of peat-forming mires.

The thicknesses of coal beds at the top of the Lower McMurray Fm typically vary between 0.3 and 5 m, although coals may locally reach thicknesses up to 24 m. We analyzed the petrographic character of Lower McMurray coals in 5 cores (2–24 m thick) to resolve high frequency (i.e., 4th order and higher) base-level variations, and to identify allogenic controls on terrestrial deposition in the McMurray Sub-Basin. Overthickened coals (>5 m) typically comprise drying-upward cycles with high ash content (10–75%). These coal successions are commonly underlain by sedimentary successions that display soft-sediment deformation, which is interpreted to result from syn-depositional collapse (subsidence). Overthickened coals are interpreted to reflect mires keeping up with punctuated, but overall high rates of base-level rise resulting from both relative sea level rise and localized syn-depositional subsidence. Coals less than 5 m thick are not underlain by soft-sediment deformed clastic sediments, and comprise up to 4 wetting-upward cycles. Their petrographic character appears to reflect successively higher base-levels, which is interpreted to have resulted from sea level change and/or climate variations.

The petrographic character of Lower McMurray coals, northeastern McMurray Sub-Basin, suggests a complex history of base-level fluctuations. Whereas periodic syn-depositional basement subsidence led to the development of overthickened coals, the wetting-upward character of normal thickness (<5 m) Lower McMurray coals is not associated with syn-depositional subsidence. The overall wetting-upward character of normal-thickness coals is interpreted to reflect initial transgression of the Boreal Sea on a 4th order time scale. As the generation of thick coal packages within mires requires base-level rises to approximate peat accumulation rates, we suggest that base-level rise during Lower McMurray time was approximately 1-2 mm yr^{-1}. As well, multiple coal seam internal wetting-upward cycles indicate that transgression was non-linear, and fluctuated on sub-Milankovitch scales ($\geq$5th order cycles).

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TIDE-DOMINATED TRACT: A KEY SEDIMENTARY ZONE OF THE FLUVIAL TO MARINE TRANSITION ZONE IN TIDE-DOMINATED RIVER DELTAS

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Large rivers play a major role in transporting sediments from land to sea. The majority of large rivers in terms of sediment load currently occurs on tide-dominated coasts, forming tide-dominated or tide-influenced deltas. Gentle river gradients, large water discharge, and significant tidal ranges at the river mouth result in the propagation of tidal and backwater effects for long distance upstream. The distributary channels of the Mekong River delta show two distinct parts: an upstream river-dominated tract (RDT) and a downstream tide-dominated tract (TDT). The boundary between these two tracts is identified 80-100 km upstream of the river mouth based on sediment distribution and channel morphology (Gugliotta et al., 2017). The RDT is characterized by sinuous channels, relatively constant width, and highly variable depth with a seaward-deepening trend. Sand and gravelly sand are dominant, sediment size tends to fine downstream, and mud content is low. The TDT is characterized by straight channels, smooth riverbeds and seaward shallowing and widening trends. Heterolithic fine to very fine sand and mud alternations (tidal rhythmite) are dominant, sand distribution is uniform, and mud content is highly variable. The morphology of the TDT is primarily controlled by tidal processes. Here, daily tidal water-level changes are observed throughout the year, whereas water-level changes due to seasonal river floods are limited. Saltwater intrusion above 0.5 PSU is measured in the seaward ~50 km of the TDT during the dry season. However, brackish-water biofacies are observed upstream of this limit and along the entire TDT. This is likely due to the presence of diluted brackish water (<0.5 PSU) therein and/or tolerance to the freshwater environment.

The sedimentological and morphological characteristics of the TDT recognized in the Mekong River delta are also found in other large river deltas in the world. Our result show that the length of the TDT is directly proportional to the relative strength of tidal processes and inversely proportional to the coastal plain gradient. The TDT is an important feature of tide-dominated large-river deltas. Its investigation is crucial to better understand the interaction between river and marine processes in coastal areas.

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SOURCE-TO-SINK SEDIMENTATION: INSIGHTS FROM MODERN CONTINENTAL-MARGIN SYSTEM STUDIES

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The transfer of sediment from land to sea is influenced by an array of terrestrial and marine processes. Catchment size and anthropogenic modifications impact sediment signal transfer to the coast, and numerous marine processes affect signal propagation and preservation in the sea. Radioisotopes and in situ measurements help provide a temporal and spatial understanding of material transport, deposition, and accumulation. Research from several recent source-to-sink studies of modern systems, including the Waipaoa (New Zealand), Mississippi (LA, USA), and Tar (NC, USA) river margins, emphasize how marine conditions have a fundamental control on development and destruction of the stratigraphic record.

What did India collide with in the Early Eocene? Characterizing the sediment source of the Chulung La Formation, Ladakh, NW India.

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Abstract

The Tethyan Himalayan Sequence in Zanskar, NW India is a near continuous record of Indian passive margin sedimentation from the Permian to the Paleogene. However, a clear transition from shallow marine sediments to collisional sediments is recorded in the Paleocene-Eocene Dibling, Chulung La and Kong formations. Recent studies have suggested that detrital zircons, extracted from the Chulung La and Kong formations, were derived from Asian sources and therefore represent the onset of India-Asia collision. This is at odds with tectonic reconstructions that contend India collided with an intra-oceanic island arc (IOIA) at this time.

To test the validity of these models, we collected sandstone samples from the Chulung La Formation for petrographic analyses, LA-ICP-MS U-Pb dating of detrital zircons and Electron Probe Microanalysis (EPMA) of detrital chrome spinels. Petrographic analyses reveal that the dominant components are volcanic fragments, with subordinate (diagenetic) carbonate, quartz, feldspar and opaque minerals. The detrital chrome spinels are characterized by very low TiO_2 values (average of 0.14%), Cr# values ranging between 0.26 and 0.86 (average of 0.66) and Mg# values between 0.23 and 0.77 (average of 0.52). The majority of the chrome spinels are assigned a forearc peridotite signature, with a minor island arc tholeiite (IAT) or boninite component. U-Pb dating of the detrital zircons reveal that the majority of the grains are Mesozoic and Cenozoic with a small but significant component of older ages.

Our preliminary findings suggest that intra-oceanic island arc terranes supplied a significant proportion of the sediments to the Indian passive margin during deposition of the Chulung La Formation. This discovery may help to constrain the timing of an IOIA collision with India in the Eocene and may have important implications for alternative models which suggest that India collided with Asia at this time.

Linkages between margin delta systems and submarine fans in rifted basin-a example from Dampier sub-basin in offshore NW shelf of Australia

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Abstract: The shelf-edge in rift basins is often a structural complex region where high accommodation interacts with a variety of depositional processes to generate laterally continuous and thick reservoir units. The Dampier sub-basin in the offshore Northern Carnarvon basin of the north west shelf of Australia is a marine rifted basin whose fills are dominated by Jurassic-age, syn-rift sediments. The Fortuna 3D seismic survey, whole core and well logging suites are used to affect an integrated seismic geomorphologic study to examine the relationships between point-sourced, rift margin deltaic systems and submarine fans development in this basin. The results show that the rift's west-margin, Rankin terrace (footwall) is the most important sediment source area throughout all rift phases, but there is no obviously axial and hanging wall sediment supply into the downthrown Kendrew trough during the late syn-rift phase (J30.0 SB to K10.2 MFS). The development of drainage catchments along the uplifting footwalls are critical for the development of downdip transverse submarine fan systems. The J40.0 SB is the most widely weathered and incised surface and its paleogeomorphology was reconstructed to examine the drainage catchments on the Rankin terrace. Drainage area of the Rankin terrace is about 1900 km^2 in which 1/6 of the total exposed area is developed as the footwall catchments. The remaining area developed a westward draining rift back-limb, shunting flow to basins along the western flank of the Rankin uplift. As indicated by paleo-geomorphology and stratal slicing, from north to south, five sub-drainages with catchments areas of about 56km^2 (Lambert), 58km^2 (Eaglehawk), 106km^2 (Perseus), 39km^2 (Goodwyn) and 49km^2 (Dixon) were focused through breached relay ramp eastward into the Kendrew trough and generated sub-marine fan with area of 98km^2, 61km^2, 180km^2, 25km^2 and 18km^2, respectively. The amplitude extraction on J53.0 SB shows north to south morphologic features that appear to be current-generated processes reworking and sweeping sediments along the footwall. Such reworking and re-sedimentation of deposits is supported by the lack of mass-balance in some fan systems. The seismic geomorphology of the Dixon fan aprons and relatively well-preserved fan-shape of Lambert fan aprons allow us to tie these deposits to their respective source basins. The ratio of catchment area to fan area shows the Dixon fan aprons occur with smaller area, while the Lambert fan aprons appear to be outside relative to the fan volume trends. Such differences may be a product of footwall reworking of sediments in these rift settings.

Keywords: rift basin; drainage catchment; margin currents; seismic geomorphology

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Sediment provenance change and sedimentary response in the gently dipping ramp of the rifted basins, Paleogene of Raoyang sag, Bohai bay Basin, China

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Abstract: Sediment provenance and feed points are key to the quantity and quality of sand supply in rifted basins. Recent studies of ancient strata have focused on the seismic imaging of the paleomorphologic indicators of sediment transport pathways. However, not all basins are imaged to the quality necessary to use such techniques accurately. The Lixian Slope (LS) in the Raoyang sag is a Paleogene-aged gently dipping ramp in the Bohai Bay Basin. U-Pb age of 543 single zircon grains from Eocene Shahejie Formation provides a spatial and temporal constraint on the sediments that deposited along the strike of the LS. Abundant core data, as well as seismic data, are analyzed to evaluate the sedimentary responses to the allogeneic forcing of sediment supply from E*s*2 to E*s*1. The results show that the LS was fed by three paleo drainage systems and developed three shoal-water deltas and one beach-bar system correspondingly. Specifically, the paleo Daqing River carried sediments originated from Late Paleozoic igneous rocks and formed delta A around Well G32. The sediments in the paleo Tang River originated from Mesozoic igneous rocks, Meso-Neoproterozoic intrusive rocks, and Meso-Neoarchean metamorphic rocks, and formed delta B around Well G107. The sediments of the paleo Dasha River came from the Paleoproterozoic metamorphic volcanic rocks and fed the delta C around Well G29. Sediment provenance change from the E*s*2 to E*s*1 was recorded by the decrease of the Paleozoic zircon age population from 37% to 26%. It indicates a significantly diminished sediment budget of the paleo Daqing River which may have resulted from a drainage capture upstream of the paleo Daqing River. On the other hand, the sediment fluxes of the paleo Tang River and the paleo Dasha River increased in a small amount. Different responses are observed in the three deltas to the changing sediment flux. Quantitative analyses suggest that from E*s*2 to E*s*1, delta A has changed its channel dimensions and delta area while delta B and C have undergone little changes. The changes in deltas A and B are mainly due to the variation of sediment flux that is interpreted to be a result of drainage area changes, and the changes in delta C is mainly due to the lacustrine flooding process.

Keyword: sediment provenance; allogenic; zircon U-Pb dating; paleo-drainage system.

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Source-to-Sink System Analysis of the Member 2 of Dongying Formation of Paleogene in the Eastern Slope of Chengdao in Bohai Bay Basin

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Abstract: The eastern slope of Chengdao is located in Bohai Bay Basin, it is a slope where Chengbei low uplift transit to Shanan Sag and Bozhong Sag. Chengbei low uplift and surrounding areas form a complete source-to-sink system. Based on the drilling, core, logging and 3D seismic data, this paper made the base rock of provenance more explicit, recovered the palaeogeomorphology of Member 2 of Dongying Formation, analyzed the elements of the source-to-sink system quantitatively, depicted the distribution of the sedimentary sandbody carefully, and established the source-to-sink system coupling model in research area. The analysis shows that the isolated flood sublacustrine fan sediments, which mainly developed in the study area, are from the Chengbei low uplift, and the basement mainly develops the Archean clastic rock, volcaniclastic rock and Gneiss. The distribution of the sandbodies in the depositional area is mainly affected by the type of provenance, the difference of vertical height, area of the catchment unit, scale of transport channel, slope break belt, the palaeogeomorphology of depositional area and other factors. Among them, the total sediment in deposition is closely related to the difference of vertical height and the area of catchment unit. That is, the higher the difference of vertical height and catchment unit's area, the larger the size of sandbodies. In the paper, the slope break belt is divided into two types: topographic break and fold break. The angle of the slope break reveals the positive correlation between the slope angle and thickness and area of the sand body. Meanwhile, the size of transport channel also affects the distribution of sand body. Overall, the source-to-sink distribution system in the study area is relatively stable, and this paper finally constructed the coupling model which is multi-lithology (Provenance) - ancient valleys or fault trough - topographic break / fracture slope transport channel (Transported area) - isolated flood sublacustrine fan (Sedimentary area).

Keywords: Bohai Bay Basin; Chengdao Eastern Slope; Dongying Formation; Source-to-sink system

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Sediment provenance and routing pathways in the Salin sub-basin, Myanmar

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The Salin sub-basin is situated near the centre of the north-south trending Central Myanmar Basin (CMB) bounded by the Indo-Burman Ranges (IBR) to the west and the Sino-Burman Ranges (SBR) to the east. Deposition in the basin has been broadly continuous during the Cenozoic, with indications of high rates of sediment delivery to the basin throughout this time. This research focuses mainly on the Oligocene Shwezetaw, Padaung, and Okmintaung Formations to reconstruct depositional environment, the sediment routing pathways into the basin, and to identify any source switching. This was achieved through both a field campaign to collect sedimentary data from the proximal to distal environments and subsequent sedimentary provenance analysis to analyse light and heavy minerals and to acquire U-Pb dates from detrital zircons using LA-ICP-MS.

The Rupelian Shwezetaw Formation comprises a southward-trending fluvial-deltaic system grading into a tidal-dominated environment. There is a general progradation of these systems throughout the Rupelian, with the fluvial environments dominating up-section. The petrography of the sandstones suggests sources predominantly from the Tibetan Plateau. Overlying this, the upper Rupelian Padaung Formation records a rapid deepening, with rare fluvial elements constrained to the north, rapidly grading into deltaic and marine settings towards the south. A provenance switch is indicated by material derived from the locally uplifted IBR to the west. By the time of deposition of the Chattian Okmintaung Formation, we interpret a tidally-influenced deltaic environment, with very little temporal variation. This suggests relatively stable sea level at the time of deposition. Again, there is evidence of material being shed from the IBR during the Chattian, suggesting a switch in sourcing from solely Tibetan Plateau material. Interestingly, the Cenozoic formations reach almost 4000 m in thickness, suggesting that sediment supply was able to keep up with rapid subsidence. The CMB has one of the greatest Cenozoic sediment thicknesses in the region, alongside this exceptional rate of subsidence (Hall and Morley 2004).

Further work aims to understand the evolution of the Salin sub-basin, including the sediment availability, the uplift of the IBR, and the sea level variations observed in the deposits. This work will eventually incorporate palynology and ichnology to try to constrain this poorly understood basin. The Salin sub-basin has been little studied but provides an opportunity to document changes in sediment sources and tectonic changes during the early stages of India-Asia collision and uplift of the SBR and IBR to the present topography.

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SEISMIC GEOMORPHOLOGY AND ARCHITECTURE OF EARLY MIOCENE MULTI-STAGE SHALLOW-WATER TURBIDITE SYSTEM, YINGGEHAI BASIN, NORTHERN SOUTH CHINA SEA

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The multi-stage, shallow-water, turbidite system was identified in the Dongfang (DF) block of the Yinggehai basin, on the northern margin of the South China Sea in the early Miocene. Integrated analysis of 3D seismic data and well data explore the morphological architecture, depositional history, and controls on the turbidite shelf fan.

The heavy mineral assemblage shows the Blue River Delta (western Vietnam) feeds the turbidite shelf system in two DF blocks (DF-a and DF-b) during the Paleogene to Neogene. The facies architectures such as the channel, overbank deposit, and lobes of the turbidite shelf fan are identified through seismic geomorphology approaches. Four stages of turbidite shelf fan are recognized based on the stratal stacking patterns via seismic slice, which indicates the spatial and temporal difference of morphological architecture of the channel and lobe between two blocks. DF-a block generally distributes multi-stacked and isolated lobes, whereas DF-b block mainly establishes deeply incised and elongated channels. The depth of channel in the DF-b block is about twice the depth of the DF-a block.

Regional tectonic activities and topographic variations in these two blocks exert strong influences on the spatial-temporal evolution of the morphologic architectures. In terms of syn-depositional topography, the DF-a block has a relatively low gradient, in contrast to DF-b block of a steeper slope. Topographic variations in two blocks make gradient increase from the DF-a block to the DF-b block, which might force channels deeply incised. The results of high-resolution 3-D depositional system analysis illustrate that the DF-b block is the channel system, as opposed to the DF-a block which is the lobe system. The conceptual depositional model of turbidite shelf fan in these two blocks might help the interpretation of the multi-stage stacking configuration of hydrocarbon accumulation in China and similar basins around the world.

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EXPANDING THE SPECTRUM OF SHALLOW-MARINE, MIXED CARBONATE-SILICICLASTIC SYSTEMS: PROCESSES, FACIES DISTRIBUTION, AND DEPOSITIONAL CONTROLS OF A SILICICLASTIC-DOMINATED EXAMPLE

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Most of the present knowledge of shallow-marine, mixed carbonate-siliciclastic systems relies on examples from the carbonate-dominated-end of the carbonate-siliciclastic spectrum. This contribution provides a detailed reconstruction of a siliciclastic-dominated mixed system (Pilmatué Member of the Agrio Formation, Neuquén Basin, Argentina) that explores the variability of depositional models and resulting stratigraphic units within these systems. The Pilmatué Member regressive system comprises a storm-dominated, shoreface-to-basinal setting with three subparallel zones: a distal mixed zone, a middle siliciclastic zone, and a proximal mixed zone. In the latter, a significant proportion of ooids and bioclasts were mixed with terrigenous sediment, supplied mostly via along-shore currents. Storm-generated flows were the primary processes exporting fine sand and mud to the middle zone, but were ineffective to remove coarser sediment. The distal zone received low volumes of siliciclastic mud, which mixed with planktonic-derived-carbonate material. Successive events of shoreline progradation and retrogradation of the Pilmatué system generated up to 17 parasequences, which are bounded by shell beds associated with transgressive surfaces. The facies distribution and resulting genetic units of this siliciclastic-dominated mixed system are markedly different to the ones observed in present and ancient carbonate-dominated mixed systems, but they show strong similarities with the products of storm-dominated, pure siliciclastic shoreface-shelf systems. Basin-scale depositional controls, such as arid climatic conditions and shallow epeiric seas might aid in the development of mixed systems across the full spectrum (i.e., from carbonate- to siliciclastic-dominated end-members), but the interplay of processes supplying sand to the system, as well as processes transporting sediment across the marine environment are key controls in shaping the tridimensional facies distribution and the genetic units of siliciclastic-dominated mixed systems. Thus, the identification of different combinations of basin-scale factors and depositional processes are key for a better prediction of conventional and unconventional reservoirs within mixed, carbonate-siliciclastic successions worldwide.

Effects of rock type and grain size on changes in roundness of gravel and sand grains during fluvial transport process

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We have examined the characteristics of grain producing mechanisms acting on detritus, i.e., breaking and abrasion[1], during fluvial transport process. To elucidate the breaking and abrasion mechanisms according to the changes in roundness of particle to downstream direction, relationships between rock type, grain size and roundness of detritus were examined. In order to evaluate these relationships, the roundness not only of gravels but also of sands, which are produced newly from broken and/or abraded gravels, i.e., from 0.5 to 128 mm in diameter, were investigated. The rock type of gravels and sands was unified as described below.

Japanese rivers characterized by steep gradients are adequate for examining the production and transport processes of detritus. At the two tributaries of Watarase River, which flow on the Ashio mountainous region, central Japan, under similar fluvial and geological conditions, downstream changes in roundness and lithological composition both of sand and of gravel fractions were investigated with 1 phi scale intervals. Because hard chert and fragile shale grains are composed of very fine grains and rarely include recycled rounded grains, they are adequate for sand-sized grain analysis. The changes in roundness of both rock type grains to downstream direction were investigated based on Krumbein roundness chart[2].

On both rock types, as the grain size was finer, the roundness of grain was low. It would be caused by the addition of pristine and angular grains produced from coarser grains to finer grain size fraction on more downstream surveyed sites as well as by the characteristics of finer grain, i.e., high durability and/or inactive collision among coarser grains.

The tendencies of roundness between the two rock types were compared. The roundness of chert was totally lower than the one of shale according to the hardness. Focusing on the shale roundness, it did not increase beyond 0.6 roundness value (sub-rounded). Based on these data, we discuss the concept of "limiting roundness value," i.e., the roundness of no more rounding of grain during transport process[3], in other words, "roundness in saturation."

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THE COUPLINF RELATIONSHIP BETWEEN SHELF-MARGIN DELTA AND DEEP WATER DEPOSITE

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Shelf-margin delta is a special type of delta developed on the marginal turning belt of the continental shelf. Its development is mainly controlled by the sea level rise and down, and often develops at sea level decline or low level. The existence of the shelf-margin delta makes a large number of sandy sediments transported through the shelf to the deep-water areas such as slopes, providing favorable reservoirs for hydrocarbon accumulation. Its formation conditions, sedimentary characteristics and the relationship with the deep-water fan are the hot spots in the current sedimentary academia. Therefore, systematically studying the formation background, sedimentary characteristics and main controlling factors of the shelf-margin delta as well as the delta depositional model is of great significance for deepening the theoretical system of delta deposition and expanding oil and gas exploration area.

This study is based on the West African M.S.G.B.C basin as the research object. Combining with physical simulation, discussed the coupling relationship between forced regression under the background of shelf-margin delta and deep-water deposition. The experiment is mainly analyzed from the aspects of slope width, water depth, sediment abundance, slope change, water flow and other factors. A number of quantized devices have been set up in the experiment. The quantitative standard for the whole research process is guaranteed (Prepare Stage - Experimental Stage - Result Slice - Data Analysis - Data Integration). Through simulation experiments, the development pattern, distribution characteristics and superposition relationship of reservoir sand bodies are carefully dissected. Combined with seismic data, logging data and analysis data, can identify sedimentary types, internal configurations and reservoir development characteristics through processing and interpretation of geophysical data and carry out reservoir characterization and evaluation. Physical simulation and numerical simulation verify each other and summarize the formation process, internal configuration and evolution characteristics of delta and deep-water fans. Ultimately, the process and specifications of the fine reservoir characterization are set up to guide the oil and gas exploration.

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TWO SOURCE-TO-SINK SEDIMENT MODELS AND THEIR HYDROCARBON SIGNIFICANCE OF TERMIT BASIN, NIGER

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Keywords: Termit Basin; Source-to-sink; Marine and lacustrine facies; Sedimentary model

The Termit Basin belongs to the West-central African rift basins, with the preservation of K1, K2 (Donga, Yogou, and Madama Formation), Paleogene (Sokor1 and Sokor2 Formation) and more recent strata. This paper is first time to use source-to-sink model to study the sedimentary processes in two different geological period and environment in Termit Basin, and to discuss the hydrocarbon accumulation process. Termit is a nonmarine rift basin at early Cretaceous, and developed thick marine transgressive sequence in late Cretaceous, coincided with depression period, and became lacustrine environment again in Paleogene. Based on the seismic data, core, well drilling data, fossil, and regional paleogeographic background, the aims of this study include: (1) built the source-to-sink sedimentary model during fluctuated falling sea-level in late Cretaceous. The delta system prograded basinward, which shows coarsening-upward sequence, ended up with interbedded sandstone and mudstone layers in Yogou3 Formation; (2) constructed the fluctuated rising lake level source-to-sink sedimentary model in Paleogene. The braided river delta retrograded landward, representing fining-upward sequence, which developed from interbedded sandstone and mudstone layers in Sokor1 Formation to mud layers in Sokor2 Formation; (3) during the sea-level falling in late Cretaceous, more fluvial sediments were transported into Termit Basin, with higher content of large scale plant organic materials deposited in the mudstone layers in Yogou3 formation, which formed the main source rock of the basin, and interbedded with delta front sandstone. This kind of source rock is different from typical marine or nonmarine types, similar to some of the passive margin source rock; (4) as the lake level rising in Paleogene, less fluvial sediment was transported into lake. Sokor1 Formation was composed of braider-river delta sandstone and mudstone; Sokor2 was composed of mudstone as the regional seal, which could seal off the hydrocarbon that migrated from Yogou3 into Sokor1 reservoir through faults and formed the dominant play in Termit basin; (5) the vertical deposit pattern was controlled by the water level, the late Cretaceous seawater-covered area was much bigger than the Paleogene lake, that's why the marine source rock was distributed widely, made, that's different from most of rifted basins.

Link Between Deltaic Sedimentation and Re-transported Gravity Flows: A Case Study From the Third Member of Shahejie Formation, Dongying Sag, Bohai Bay Basin, China

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Taking the delta-gravity flow sedimentation in the third member of Shahejie Formation of the Dongying Sag as an example, the sedimentary and distribution characteristics of gravity flow deposits and the link between deltaic sedimentation and re-transported gravity flows were investigated using core, granularity, seismic and well logging and test data and stratigraphic forward modeling technique. It is indicated that deltaic sedimentation is of great importance to the formation, sedimentary characteristics and the distribution of re-transported gravity flow deposits. The mud content of delta front deposits appears to influence the gravity flow types and their sedimentary characteristics. The larger the mud content, the better developed the muddy slump and the muddy debris of debrites. Deltaic sediments with different grain sizes have different slope angles which is related to the formation, types and distribution of the gravity flow deposits. Under the same conditions, the larger the progradation slope angle is, the better developed the re-transported gravity flow deposits and the shorter the sliding distance would be, especially for the slide and slump deposits. The slide and slump deposits are mainly in the slope break and near the syn-sedimentary faults; turbidites mainly occur in the basin floor; while debris flow deposits are distributed from the slope break to the basin floor. The high accumulation rate contributes to the formation of gravity flows by decreasing the internal friction, the ratio between the accumulation rate and tectonic subsidence rate also has an impact on the vertical superimposed structures and lateral continuity of re-transported gravity flow deposits.

Key words: Deltaic sedimentation; re-transported gravity flow deposits; sedimentary characteristics; distribution pattern; Es_3^z; Dongying Sag

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General theme 6

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Lower Limit of Effective Sandstone Reservoir Based on Nuclear Magnetic Resonance (NMR) Technique

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Only those movable hydrocarbons, which can participate in the fluid flow in sandstone reservoir, have exploration and development values. Therefore, the lower limit of effective reservoir can be identified from the perspective of movable hydrocarbons. The purpose of this work is to provide further insight into the lower limit of effective sandstone reservoir for future reservoir evaluation, resource assessment and development plan.

In this paper, displacement experiment, nuclear magnetic resonance (NMR) and high-pressure mercury intrusion were performed on sandstone core samples obtained from Nanpu Sag, Bohai Bay Basin, China. The NMR technique was used to determine the T2-distribution of core samples before and after displacement. Based on the change of T2-distribution before and after displacement, the proportion of movable oil of core sample is calculated. And formulas between movable oil proportion and core porosity, movable oil proportion and core permeability, are established. The T2-distribution data are converted into pore-throat size by using the results of high pressure mercury injection and the formula between movable oil proportion and pore-throat size is established.

Experimental results illustrate that movable oil proportion is generally less than 20% for porosity and permeability smaller than 10% and 0.2mD, respectively. Besides, movable oil proportion can reach 75% when pore-throat size is larger than 100μm. In the pore-throat size ranges of 0.1~1μm and1~10μm, the movable oil is more abundant, and the movable oil proportion can reach 44% and 38%, respectively. According to the formulas between movable oil proportion, permeability and pore-throat size, when the movable oil proportion approaches 0, the permeability approaches 0.025mD and the pore-throat size approaches 0.058μm. In other words, the permeability and pore-throat size of lower limit of effective sandstone reservoir are 0.025mD and 0.058mD, respectively.

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CORE PHOTOS LITHOLOGICAL INTERPRETATION USING NEURAL NETWORKS

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With a rapid increase in digital data, oil and gas companies are constantly looking for an automatic and accurate method to extract the geological information from the core. However, methods for automatic core analysis are very limited[2]. At the moment, this is still done by an expert-geologist, which takes a lot of time and effort. Recently, Chatterje (2012) applied the multi-class support vector machine (SVM) algorithm to classify rocks[1]. Hasanov et al. 2016 used color distribution analysis on core photos[3]. Still, no comprehensive study was performed on real geological samples with complex structural and textural features.

In this study, we propose a non-destructive method for rock-type classification of core images. An algorithm for core images processing and rock-type classification is based on convolutional neural network analysis. We trained our network using 10 cm samples of core images, which uniformly sized to 128x128 px images. The training samples consisted of four lithotypes (laminated sandstone, limestone, sandstone, shale). We also added to the analysis two non-conditional core types (non-cutted and crushed core). The computer successfully distinguished 4 classes with different false rates. The best results achieved for limestones and shales (recall=83 and 91%, on 54 and 138 test images), the worst are for laminated sandstones and sandstones (recall are 53 and 73% on 15 test images each). Other two groups discern with poor scores (crushed core recall 7%, non-cutted– 32% on 30 and 57 images). In most cases these two groups got right class as a real rock type and wrong one as image predicted type (compared to true label of image). As it seen from experimental results, the rates highly depend on each class number and quality of images. The performance of low-quality images with a small number of them in class gives the poor precision.

Our results show that the convolutional neural network detects the right class of lithology with low boundary recall 85% (average, in grayscale images), even on small amount of data. Additionally, this algorithm allows studying core photos in much faster and accurate way. To improve further the accuracy of the method, more core-photos of different quality, texture characteristic and geological settings should be analyzed.

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CHARACTERIZATION OF DUVERNAY FORMATION IN THE WESTERN CANADIAN SEDIMENTARY BASIN USING HYPERSPECTRAL IMAGERY: RECOGNITION OF THE LATE DEVONIAN *PUNCTATA* EVENT

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Characterization of a shale reservoir is essential to its development but can be time-consuming and requires multiple analytical techniques. Mineralogical, elemental, and total organic carbon (TOC) data was estimated from several drill core in the Duvernay Formation, an important unconventional reservoir in western Canada, using shortwave infrared (SWIR – 1 to 2.4 µm) and longwave (TIR; 8 to12 µm) spectral imagery. Estimations were obtained from models calibrated against geochemical data. SWIR imagery (sub-mm pixels) enhances textures that aid in facies analysis, such as trace fossils and sedimentary structures. The Duvernay Formation shales and mudrocks were deposited throughout central Alberta and are divided into two different depositional domains, termed the East and West Shale Basins (ESB and WSB). Hyperspectral imagery reveals thicker sedimentary packages of similar mineralogy in the northern WSB and thinner cyclical packages in the southern WSB as well as the ESB. A middle carbonate unit, present throughout much of the WSB is highly bioturbated and coincides with intervals of low TOC, possibly as a result of burrowing organisms. The spectral data collected for the Duvernay Formation has revealed at least two distinct populations of silica; one crystalline and the other, possibly amorphous. Incidentally, intervals of amorphous silica correlate to excursions in $C^{13}_{(org)}$ data and high TOC. The C^{13} excursions are recognized in Europe and in equivalent carbonate platform strata from the Canadian Rockies as the *punctata* Event, the first in a sequence geochemical anomalies leading up to the Frasian-Famennian extinction (Śilwiński et al. 2012). This event, named after the Devonian *punctata* conodont zone, corresponds to an increase land plant diversification and pedogenic weathering, resulting in eutrophication, and increased production and burial of TOC (Pisarzowska and Racki 2012). Recognition of amorphous, potentially biogenically-sourced silica supports a hypothesis of increased primary productivity associated with eutrophication and anoxia in the photic zone during this event.

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A Novel Method for Ichnology Characterization Based on CT Scan and Mean Grain Size

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Abstract: Quantitative characterization of Ichnology is of great significance in geosciences. Several methods based on visual observation have been proposed since the 1960s. These qualitative or semi-quantitative evaluations included Bioturbation Index (BI), Ichnofabric Index, or the amount of bioturbation[1][2]. Recently, more effective methods involve the use of analytical and computational methods such as Seizes Diversity Index (SDI), Magnetic Resonance Imaging, or CT[3][4]. These methods provide results with better clarity and resolution.

This paper presents a novel method that combined core photos, CT scan, and mean grain size to characterize bioturbation quantitatively. Firstly, the BI and SDI were obtained by core photos and CT scan. The core photos were manipulated in Adobe® Photoshop® software CS6 to identify fossil types, diversity, and 2-D size. The CT scan images were handled in Avizo® to estimate the 3-D spatial scales and assemblages of trace fossils. Then, combining the lab analysis of surrounding lithofacies, a new index, "Bioturbation Comprehensive Index", was proposed by BI, SDI, and mean grain size. This method shows great superiority than previous studies which only based on core or subjective estimation.

We adopted this procedure to MacKay River, an oil sands lease in Athabasca, Alberta, Canada. The Ichnology features of McMurray Formation, Lower Cretaceous, were analyzed. Seven types trace fossils and three fossil-assemblages were identified and interpreted. Seven trace fossils include *Asterosoma, Chondrites, Ophiomorpha, Rosselia, Skolithos, Teichichnus, Thalassinoides;* three assemblages are *Ophiomorpha - Skolithos, Asterosoma - Chondrites- Rosselia* and *Teichichnus - Rosselia - Thalassinoides.* The BI varies from 0-6, while SDI changes from 0~170 mm. As for the mean grain size of surrounding lithofacies, it varies from 0.117 mm~ 0.214 mm. The final BCI can be not only an indication of sedimentary environment, but also a reference for well correlation.

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LARGE-SCALE POROSITY DISTRIBUTION IN HETEROGENEOUS SEDIMENTARY ROCKS USING MEDICAL–CT: APPLICATION TO HYDROTHERMAL DOLOMITE

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Tomodensitometry has been commonly applied to core analyses within the oil and gas sector in order to analyse permeability, fractures patterns, or assess fluid flow in porous rocks. In eastern Canada, the study of a prospective play has triggered a collaborative research partnership between the industry, university and the federal government. Hydrocarbons occurrences were found in the St. Lawrence River area (Québec) within the Silurian to early Devonian basin of the Gaspé Belt. In the Massé play, reservoir intervals correspond to highly fractured intervals, with replacive and pore-filing hydrothermal dolomites, both in the carbonate Sayabec Formation and the underlying clastic Val-Brillant Formation. The project aims at developing a new methodology using a medical CT to provide large scale and continuous porosity distribution in heterogeneous sedimentary rocks. To evaluate the validity of the methodology, porosity has been estimated on 32 reference samples selected for their relative homogeneity. Reference cores correspond to 7 different lithologies commonly used as test material in the petroleum industry, and cover a large range of porosity (1.5 to 28 %), and permeability (0.01 to 8200 mD), such as Berea sandstone or Indiana limestone. In order to investigate the application range of the methodology, tested variables include: three rock types, several sets of core diameter and length, the use of water and doping agent (NaI) and the comparison with up to three independent gas porosimeter at different labs. Silurian limestone and sandstone reservoir intervals from the Massé play were additionally made available for analysis. Both isolated samples and a continuous cored interval were saturated and scanned using a Siemens SOMATOM Definition AS+ 128 at INRS-ETE. Core-flooding experiments were conducted at room temperature using an in-house core-flooding system. No confinement pressure is required and samples were scanned in a dry state and then flooded with either water or NaI solution (15g/L). A pump is connected to a sealed PVC chamber to ensure a constant circulation of fluid in order to remove air bubbles formed during the saturation process, thus maximising fluid contact and reducing the number of connected pores that would not be saturated otherwise. The internal fittings use customized 3D printed PLA (polylactic acid) core holders to increase stability of samples, particularly when the chamber is flooded. This in-house set-up is a low cost, easy to make and to operate core-flooding setup. Several individual core samples can be scanned simultaneously, as well as continuous core sections up to 1.5 m long each. Alignment is performed within Matlab using intensity-based image registration. Comparison of images of the final and initial stages (saturated and dry) is achieved using the following equation applied on each voxel thus allowing a 3D visualization of the macro-pore networks and the calculation of porosity.

$$\%void = \frac{Ddry - Dsat}{Dgas - Dfluid}$$

Preliminary results on reference samples indicate a good agreement between the three independent gas-porosity measurements. In addition, the difference between measured porosities using CT-scan and conventional methods is less than 1.5% for all lithologies.

Diagenetic constraints on hydrocarbon reservoir quality: application of core-based analytical techniques to Cretaceous deep-marine sandstone

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Alteration of reservoir quality during burial reflects a history of complex diagenetic processes, where a number of geological factors, such as rock mineralogy, vertical effective stress, temperature are involved at various temporal and spatial scales. Rock fabric and texture as a product of depositional processes, are also equally important as constraints on burial diagenesis.

This presentation is about a case study carried out for a gas-bearing sandstone reservoir thickly accumulated as deep-marine gravity flow deposits. The sandstones are highly quartzose and are characterized by relatively monotonous mineralogy and appearance in depositional fabric; however, the porosity and permeability shows remarkable variations at different vertical scales. Since the importance of micro-textures of depositional and diagenetic origin was strongly suspected, an analytical approach comprising microscopic hyperspectral imaging of X-rays (elements), cathodoluminescence and backscattered electrons (BSE) was applied by using electron probe microanalyzer (EPMA) to core samples in order to extract quantitative petrographic information, including detrital grain size, and quantity and morphology of diagenetic minerals, which lead to the following findings;

(1) Quartz overgrowth is the most conspicuous and volumetrically important diagenetic mineralization occluding intergranular pore spaces. The cementation is typically more dominant in finer-grained sandstones. It is explained by that total surface area of quartz as nuclei for precipitation is inversely proportional to grain size of detrital quartz, and thus precipitation rate per unit rock volume is greater in finer-grained sands for a given thermal exposure.

(2) Solution seams or microstylolites provide local occurrences of highly compacted intervals, where illitic clays possibly of detrital origin are thinly intercalated in grain-to-grain contact of detrital quartz, promoting effective dissolution of contacting quartz grains. It leads to significant reduction of intergranular volume (IGV) beyond geometrical packing limit for rigid particles as referred to as chemical compaction.

(3) Pore-filling authigenic illite has strong depth or stratigraphic dependence, showing gradual morphological change from filmy or flaky to fibrous in descending order. Observed intercrystalline micropore spaces, combined with pore-throat size measured by mercury-injection (MICP) suggest that crystal morphology at least in part accounts for the permeability variations, although porosity is the primary control for the permeability. It still remains speculative; however, vertical gradient of reservoir temperature and/or type of reservoir fluid (hydrocarbon or water) may be responsible for the vertical morphological variation.

Many of the factors constraining these diagenetic processes, detrital grain size and illitic clay seams, for instance, have strong genetic linkage with the primary depositional processes and settings. This study demonstrates a set of analytical techniques based on electron microscopy as a crucial approach for better understanding the systematic interaction of diagenetic signatures with underlying depositional processes to improve the predictability of hydrocarbon reservoir quality.

Hyperspectral Analysis of the Triassic Montney Formation: Insights into biotic recovery following the end-Permian mass extinction

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Hyperspectral analysis involves pairing digital imaging with reflectance spectroscopy. While this technique has been widely utilized for the identification of geological materials, it has only recently begun to be applied to sedimentological questions[1]. For instance, while highlighting sedimentary structures within fine-grained sediment, this technique also allows for mineralogical changes to be evaluated in a sedimentological context. This study highlights the application of this tool to the question of biotic recovery following the largest mass extinction of all time, at the Permian-Triassic boundary. Within Western Canada, the earliest Triassic deposits comprise the Montney Formation (and its outcrop equivalents) of Alberta and British Columbia. Investigation of this interval via longwave infrared (LWIR, 8-12 µm) imaging spectroscopy has revealed two distinct silica populations: one is crystalline in character while the other is possibly amorphous. When paired with geochemical proxies for productivity, the presence of amorphous silica supports an interpretation of biogenic origin. If true, this suggests that during the environmental perturbations following the end-Permian mass extinction, phytoplankton blooms were preferentially preserved. A biogenic source supports paleoenvironmental interpretations, wherein 'disaster taxa' such as algae were prevalent during the initial recovery following the end-Permian biotic crisis. These findings also have practical implications regarding the reservoir characterization of the Montney Formation, one of North America's most prolific unconventional hydrocarbon deposits.

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HYPERSPECTRAL IMAGING OF THE MIDDLE MCMURRAY FORMATION: AN AID IN FACIES ANALYSIS

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The middle McMurray Formation is a stratigraphic unit of great economic interest in northeastern Alberta (Canada), and has been extensively studied by academics and industry alike. The paleoenvironments represented by the middle McMurray Formation have been actively debated within the last few decades. Two current interpretations of its paleodepositional environment constitute a predominantly estuarine environment[5, 2] versus a predominantly fluvial environment[1]. Highly detailed core studies have investigated the ichnology of the middle McMurray (Kearl Oilsands area) to refine the paleodepositional conditions of these sediments[3]. However, oil saturation makes diagnostic sedimentary and biogenic features difficult to recognize in core. Recently, shortwave infrared (SWIR) hyperspectral imaging was demonstrated to be a useful technique for enhancing the visibility of physical and biogenic features in oil sands core[4]. Comparison of such SWIR imagery with a previously studied middle McMurray Formation interval[3] revealed that the hyperspectral imagery significantly enhanced the visibility of physical and biological sedimentary structures, especially within coarse-grained, bitumen-saturated intervals. While the previous visual core analysis placed the middle McMurray sedimentation within the inner to middle estuary locale, the expanded ichnological and sedimentological dataset provided by the hyperspectral imagery strongly suggests a persistently brackish-water, tidally influenced environment that is most consistent with sedimentation in the middle estuary.

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Measurements of residual drilling cuttings at gas hydrate drilling site UBGH2-6 in the Ulleung Basin, East Sea

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In the Ulleung Basin, the Second Ulleung Basin Gas Hydrate Drilling Expedition (UBGH2) was conducted to perform the gas hydrate R&D in 2010. During the UBGH2, drilling and coring activities were successfully accomplished in 13 sites ranging from 898 m to 2,156 m water depth (Ryu et al., 2013[1]). The UBGH2-6 drilling holes were found on the seafloor with partially collapse of the margin and four short undisturbed core sediments were collected around UBGH2-6 holes during August, 2013. Ti, K, Mn, Ca, Ba, and Pb concentrations were measured using ITRAX non-destructive XRF core scanner and quantitative analytical techniques (ICP/AES and ICP/MS). 13PT-M01, the nearest site from the UBGH2-6, shows different characteristics from other sites. At the top of the 13PT-M01 core sediments, concentrations of K, Ca, and Ti are higher while concentrations of Fe, Ba, Mn, and Pb are lower than those of other cores. High Ba/Ti ratio in the core scanner and the presence of barite revealed by XRD analysis indicated that the surface sediments on the 13PT-M01 mainly composed of the drilling cutting which formed during UBGH2 activity. Based on results of Ba/Ti ratio, organic carbon content, total nitrogen content and ^{210}Pbex, the distribution of drilling cutting could be estimated that they existed in thickness as much as 2.5-6.5 cm at the top of the 13PT-M01 and horizontally within maximum 50 m from the UBGH2-6.

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PERMEABILITY CHARACTERIZATION AND RECONSTRUCTION OF RESERVOIR QUALITY EVOLUTION IN TIGHT GAS SANDSTONES USING X-RAY MICROTOMOGRAPHY

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The Upper Carboniferous sandstones in the Southern North Sea (SNS) have proven gas reserves, however they are characterised by very low permeabilities (<0.1 mD) and are therefore defined as tight gas reservoirs. The best reservoir quality in the Copernicus Discovery, SNS, is preserved within quartz and kaolinite cemented sandstones from multi-storey fluvial channels. Whilst methods such as conventional core analysis enable quantification of porosity and permeability, they do not allow us to understand the 3D pore throat dimensions, pore shapes and pore connectivity that govern fluid flow in such reservoirs.
Mapping of the pore network and quantifying different pore types is therefore an invaluable tool to understand what controls permeability and therefore reservoir quality. Samples from the Copernicus Discovery were imaged using X-Ray Microtomography (XMT) with a voxel (3D pixel) resolution of 2.5 µm. The 3D images were used to define the 3D distribution of quartz, kaolinite and porosity, and subdivide the connected and isolated porosity. The 3D models were used to simulate permeability and fluid flow in the reservoir, and compared to porosity, pore throat and permeability measurements from Mercury Injection Capillary Pressure (MICP).
Quantitative analysis of the pore network provides insight into how much extra porosity could be connected by fracking, and to investigate the connectivity of the pore network prior to the precipitation of the quartz overgrowths observed in this unit. After defining 3D maps of quartz and kaolinite distribution, the quartz overgrowths were removed stepwise by numerical erosion of the 3D volume. The gradual increase in pore volume and throat sizes changes permeability, and eventually reconnects isolated pores to the pore network. Even slight, uniformly distributed reductions of quartz cement volume results in a small porosity change but significant change in permeability as the pore throats widen and tortuosity reduces. Small variations in diagenetic style can therefore result in permeability differences of several orders of magnitude over small areas of reservoir. Here we present an assessment of how connectivity and permeability may have evolved through time resulting in the formation of a tight reservoir. We believe that reconstruction of tightening mechanisms is vital for understanding hydrocarbon accumulation history and the assessment of reservoir effectiveness.

INTEGRATED CORE ANALYSIS FOR QUANTITATIVE RESERVOIR-QUALITY ASSESSMENT

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The only way to obtain direct measurements of salient properties of reservoir rocks in the subsurface is through analysis of sediment cores. In the light of the huge investments needed to acquire cores, and the growing need of society to predict reservoir quality (RQ), it is remarkable that current protocols in core analysis have not been optimized. The current protocol for routine core analysis (RCA) results in sets of measurements acquired with different analytical techniques at different spatial resolution. The RCA protocol does not include operator-bias evaluation, or integration of continuous sedimentological core description with spot measurements on plugs and thin sections. RCA data rarely have verified uncertainty specifications, thus hampering statistically rigorous extrapolation of spot measurements to the entire reservoir volume. Our approach to integrated core analysis (ICA) directly addresses these crucial problems and aims to take RQ prediction to a new level. The starting point is an innovative mathematical-statistical framework, which enables generation of fully integrated (i.e. multivariate) near-continuous time series of rock properties with quantified uncertainties. This technique relies on embedding spot measurements of traditional core analysis in a big-data environment provided by non-destructive XRF core scanning, which permits successful prediction of standard core-analysis quantities, such as grain density, porosity, and permeability.

Petrographic analysis gives insight into the controls on RQ by identifying the diagenetic fingerprint that shapes the spatial distribution of porosity and permeability in the reservoir. Because thin-section analysis is time consuming and costly, protocols for selection of representative thin sections should aim at maximizing information obtained from small data sets, so as to minimize costs and prevent unnecessary destruction of core material. We present a flexible protocol for representative thin-section selection based on evaluation of RCA data (i.e., poro-perm and grain-density plug measurements), illustrated with a core of a Carboniferous fluvial sandstone reservoir. The results of the petrographic analysis are interpreted in terms of their relations to sedimentological and geochemical signatures. We demonstrate that application of the sample-selection protocol significantly increased the value of RCA data which to date merely served as petrophysical indicators. Through ongoing research within this project, we aim to expand the ICA workflow to include the most important rock properties needed for successful RQ prediction, i.e. petrographic composition and grain-size distribution, which control the diagenetic history of reservoir rocks.

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LATE PERMIAN CARBON ISOTOPE CHEMOSTRATIGRAPHY: PITFALLS AND OPPORTUNITIES

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In comparison to synchronous perturbations of the global carbon cycle during the Permian–Triassic Boundary (PTB) and Early Triassic, the late Permian carbon budget is comparatively poorly known and somewhat erratic. Hence, the validation of C-isotope chemostratigraphy during the Late Permian at the global scale as well as any coupling and causal relationship between perturbation in the carbon cycle and extinction phases are still widely open.

This study provides biostratigraphically calibrated C-isotope (organic and inorganic) records from early Late Permian to the basal Triassic from southern Guizhou (South China). After removing fluctuations of likely diagenetic origin, three significant Carbon Isotope Excursions (CIEs) toward lower values remain. These include a first short-lived CIE during the early Wuchiapingian, a second younger protracted CIE ending shortly after the Wuchiapingian–Changhsingian Boundary and a third CIE at the PTB. Comparison of our new C-isotope records with other time series in South China and elsewhere reveals that the only signal that qualifies as global is the CIE straddling the PTB. This suggests fundamental differences in the source of the South Chinese Late Permian CIEs, which show no lateral reproducibility compared to the globally synchronous PTB and Early Triassic CIEs. These discrepancies could be explained by differences between regionally important igneous provinces, such as the Emeishan Large Igneous Province (ELIP) for example, and the Siberian Traps as respective sources for the Late Permian and Early Triassic signals. Compared to the Siberian Traps, ELIP was much smaller, and the predominant submarine activity of the ELIP implies that the buffering effect of sea water prevented an efficient atmospheric dispersion of volatiles. Moreover, ELIP occupied an equatorial position, where the thickest and moist atmosphere offers a shield against penetration of volcanogenic volatiles into the stratosphere. Hence, Late Permian C-isotope excursions in South China could essentially be of local significance and reflect changes in bathymetry as well as variable burial of terrestrial organic matter rather than global perturbations in the carbon cycle.

This study implies that caution is to be exercised when using C-isotope records as a correlation tool during the Late Permian. Furthermore, none of the Late Permian CIEs are associated with changes in diversity or ecology of marine clades, unlike the PTB and Early Triassic CIEs.

RELATIVE SEA LEVEL USING TH/U RATIO FROM SPECTRAL GAMMA RAY LOGS, CORE AND FMI SEDIMENTOLOGICAL DATA IN LIBYAN ORDOVICIAN GLACIAL ENVIRONMENTS

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Fluctuations in sea level are a significant topic of interest for a number of reasons, and have been reconstructed using different methods and approaches. This, as is well known, has a significant impact on facies models and paleogeographies, especially if we consider the rapid lateral and vertical facies changes associated with glacially-influenced environments.

The main aim of this study is to improve the understanding of the controls on sedimentological features due to oscillating sea level in order to improve the correlation and reconstruction of depositional environments of a late Ordovician glacial succession [1] within a 30x60km2 area. The approach adopted mainly utilised Th and U abundances derived from wireline SGR data in 15 wells as a proxy for relative sea level. The resultant Th/U ratio are calibrated against sedimetological data (FMI and core) in order to extrapolate correlations and relative water depth to areas in which only the SGR log is available.

First, SGR data was quality controlled by comparing log measurements against ICP-OES and ICP-MS lab data from core and cutting samples. After validating the log data, diagenetic analysis including XRD and SEM was performed in order to understand if diagenesis was mainly local or whether some exotic fluids may have been involved thereby establishing whether initial depositional geochemistry might have been altered. Finally, core and resistivity images were analysed and interpreted following the existing facies scheme and then upscaled into facies associations and major depositional environments. Each of the facies associations was linked to a relative water depth (depositional environment) within the major depositional environments to be later compared with the Th/U ratio.

Results show a significant correlation, Th/U ratio decreases as relative water depth increases. Also, sediment source and Th-U possible sources[2,3] are discussed together with the results. This paper shows how this can be used for correlation enhancement and sediment input or provenance analysis by mapping this ratio across the study area for different formations, and how this resulted in an update of the depositional model.

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INTEGRATION OF XRF DATA AND SHADES OF GREY PROFILES TO CHARACTERIZE AND CORRELATE SHALE UNITS

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The use of XRF combined with shades of grey profiles has been tested on several core and cuttings data sets for a variety of shale and tight siltstone reservoirs, i.e. Triassic Montney siltstone from British Columbia, Devonian Duvernay shale from Alberta and Ordovician Utica shale from Quebec.

The study looked at differences in output and usefulness of shades of grey profiles between various core photography set-ups, i.e. from low resolution photos (1600 microns per pixel), high resolution from commercial laboratories or university line scanner (both at 200 microns per pixel) and very high resolution photos (35 microns per pixel) from overlapping images taken on a rolling bench with a shutterless camera. The results have delivered a series of criteria and patterns useful to recognize lighting issues that would minimize the usefulness of shades of grey profiles.

Sequence stratigraphy and correlation lines has been derived from XRF data (handheld and continuous XRF) and from shades of grey; the correlations have been made between wells despite different sampling density or photo resolution.

On extensive collections of drill cuttings, shades of grey have been extracted using a line scanner at a resolution of 200 microns per pixel. Ten successive XRF measurements for each cutting vial allowed for statistical analysis of 26 elements and gave a solid data set to evaluate the value of the shade of grey approach. These ten XRF measurements per vial were compared to single XRF values from a handheld XRF device to outline similarities and differences linked to the methods. Prediction of total organic carbon was then tested using the two sets of XRF mentioned and Leco TOC done on many of the samples.

A comparison between single XRF values and ten successive values extracted from the cuttings clearly shows that the latter can indicate how homogeneous the cuttings samples are and offers an efficient way to quality control the data before drawing some conclusions. The same exercise has been performed on shades of grey (single values versus multiple values) with similar results.

The integration between XRF data and shades of grey can be extremely useful to understand the environment of deposition and the organic matter, i.e. the origin for the darkness of the shale.

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BASIN-SCALE CHEMOSTRATIGRAHY OF MESOZOIC CARBONATE SERIES (GENEVA BASIN, SWITZERLAND)

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The fluctuations of stable isotope ratios, especially those of Strontium (Sr) and Carbon (C), represent well-established stratigraphic proxies for Phanerozoic marine carbonate series. Global $^{87}Sr/^{86}Sr$ (McArthur et al., 2012) and $\partial^{13}C$ (Saltzman and Thomas, 2012) reference curves are commonly used as chronostratigraphic markers for regional-scale studies. From the Middle Jurassic to the Early Cretaceous, various marine carbonate deposits ranging from reefal formations and coarse bioclastic limestones to marls and micritic facies accumulated in the Geneva Basin (Switzerland) (Charollais et al., 2013). The carbonate series locally contain significant terrigenous material and can be affected by extensive dolomitization. This study, which focuses on the chemostratigraphy of the complex Mesozoic carbonate succession of the Geneva Basin, aims at: (1) refining the regional chronostratigraphic framework and, (2) developing new correlation tools at the basin scale. In order to establish reliable basin-scale reference curve(s) for $^{87}Sr/^{86}Sr$ and $\partial^{13}C$, it is proposed to perform high-resolution measurements for distinct regional stratigraphic sections, ideally along a proximal-distal axis. Specific sampling and analytical techniques will be applied in order to screen for diagenetic alteration that can significantly modify the original isotopic signal (especially $^{87}Sr/^{86}Sr$). The coupled study of carbon and strontium isotopic fluctuations might also provide key results to reconstruct paleo-geographic and -oceanographic conditions during the Mesozoic times in the Geneva Basin and, potentially, to highlight a regional overprint on global isotope fluctuations trends. This work is being conducted in the frame of the GEOTHERMIE 2020 project that aims at evaluating the geothermal potential in the Geneva Canton.

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CHEMOSTRATIGRAPHY-BASED DEPOSITIONAL ENVIRONMENT ANALYSIS OF THE PERMIAN LUCAOGOU FORMATION IN THE JIMUSAER SAG, JUNGGAR BASIN, NW CHINA

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The middle Permian Lucaogou Formation (P_{2l}) in the Jimusaer Sag of the southeastern Junggar Basin, NW China hosts China's first commercial tight (shale) oil production. Two tight-oil sweet spots have been identified within the P_{2l} formation. Coupled chemostratigraphic and sedimentary facies analysis reveals that the sweet spots were deposited in deep–shallow saline lacustrine to nearshore environment under an overall relatively dry climate setting. The sweet spot intervals in the P_{2l} formation comprises several chemostratigraphically and lithologically distinct units deposited under the influence of subtle climatic and environmental changes that have previously not been recognized. A total of 11 depositional units have been identified within the two sweet spots based on an Integrated Prediction Error Filter Analysis (*INFEFA*) of the Gamma Ray logs and environmental parameters derived from the chemostratigraphic profile of Well J-315, a fully cored exploration well. The tight oil reservoir sweet spots were found to be controlled by the spatial and temporal distribution of total organic carbon (TOC) and reservoir properties (e.g., porosity and permeability) and the unique source and reservoir coupling. Two potential tight oil exploration plays are delineated, including those depositional units with porous reservoir beds interbedded with high-TOC source beds, and those units of porous reservoir beds adjacent to high-TOC source beds.

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A CHEMOSTRATIGRAPHIC ($\delta^{13}C$) FRAMEWORK FOR THE BLACKRIVERIAN-KIRKFIELDIAN (UPPER ORDOVICIAN) FORELAND SUCCESSION, OTTAWA EMBAYMENT

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The Upper Ordovician Ottawa Group of the Ottawa Embayment contains the equivalent Blackriveran-Rocklandian succession as the standard Mohawkian section established in southern Ontario and New York State. We present a regional $\delta^{13}C$ chemostratigraphic framework based on a ~ 200 km transect parallel to the axis of the Ottawa Embayment, and integrated with a newly established lithostratigraphy along with a U-Pb ID-TIMS age date for the Millbrig bentonite (Oruche et al., in revision). Three stages of lithostratigraphy are defined in the embayment: *Stage 1* consists of a Blackriveran stratigraphy (Pamelia, Lowville) and facies in common with the northern Appalachian Basin. However, the upper Lowville Formation contains an apparent regional SW-directed biofacies gradient of *Tetradium* facies (in the embayment) to microbial facies (in New York). *Stage 2* spans the Blackriveran-Rocklandian boundary. A pronounced westward transgression, net thinning, and increased stratigraphic condensation within the Watertown succession contains coeval development of local positive $\delta^{13}C$ excursions that likely reflect intrabasinal controls on organic productivity and/or burial. An embayment-wide post-Watertown sequence boundary in the Ottawa Embayment represented by accumulation of shoreface phosphatic arenite. Subsequent transgression (defined by the L'Orignal Formation) occupies the same stratigraphic position as the Selby Formation in the northern Appalachian Basin, but is lithologically distinct. The L'Orignal Formation is capped by the Millbrig bentonite, dated at 453.36 $\pm$ 0.38 Ma (Oruche et al., in revision). This event, defining the base of the Chatfieldian stage, immediately precedes platform segmentation within the embayment, producing a low-energy carbonate bank (revised Rockland Formation) and higher energy, deeper water seaway mosaic, the latter defined by shale and skeletal-rich carbonate of the lower Hull Formation (revised). Positive $\delta^{13}C$ excursions interpreted as expressions of the Guttenberg isotope carbon excursion occur at sites in the western embayment in both Rockland and the lower Hull strata, but an excursion is absent in the seaway facies in the easternmost part of the embayment. This striking anomaly immediately above the Millbrig bentonite may illustrate local influence of oceanographic stratification and circulation along the paleoperimeter of basin. Subsequent coalescence of intraplatform banks resulted in a regional distribution of facies in common with the northern Appalachian Basin by the Kirkfieldian, characterized by widespread distribution of high-energy encrinites (upper Hull Formation, or equivalent Kings Falls Limestone of New York). The record of platform segmentation during the early Rocklandian, as well as other significant facies changes across formation boundaries, all coincide with preservation of bentonites, including the Millbrig. We integrate this with periods of differential subsidence in the embayment, interpreted to reflect far-field structural control related to plate-boundary tectonism. An elevated sensitivity to this effect in the embayment when compared to the northern Appalachian Basin is related to predisposed fault reactivation along the buried axis of a Neoproterozoic fault system, now manifest as the Ottawa-Bonnechere graben.

HANDHELD X-RAY FLUORESCENCE APPLIED TO LOWER-MIDDLE PENNSYLVANIAN STRATA, FOREST CITY BASIN, SOUTHERN IOWA

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The fluvial-to-marine transition zone is the segment of a river that is affected by tidal action and partially intruded by saline waters, but is entirely landward of a coastal estuary[1,2]. This transition zone is considered one of the most complex and climatically sensitive depositional environments on earth due to the intermingling of terrestrial, marine, and biological processes. Although the fluvial-to-marine transition is known to be an important feature of coastal depositional systems, it has only been described from a few modern examples, and rarely from the ancient realm. We hypothesize that an ancient fluvial-to-marine transition zone was present in southern Iowa during the Early-Middle Pennsylvanian. During this time, eustatic sea-level was on the rise[3] and consequently, strata have been interpreted to locally contain both terrestrial and marine deposits. This study aims to reevaluate the sedimentology of these strata using a pre-existing palynostratigraphic framework[4], modern facies analysis, and the emerging analytical technique of handheld XRF analysis. Based on an existing whole-rock geochemical approach to determination of nonmarine versus marine strata[5], our preliminary data suggests that the Kilbourn, Kalo, and Floris Formations (Atokan-Lower Desmoinesian) of the lower Cherokee Group may be representative of a laterally extensive fluvial-to-marine transition zone as much as 100s of km from the coeval shoreline. This framework suggests a transition from dominantly freshwater conditions during the Early Pennsylvanian to dominantly brackish water conditions during the late Early-Middle Pennsylvanian, which is consistent with the long-term trend of eustatic sea level rise during this time. Strata in this study likely represent a relatively low-energy fluvial system confined to incised paleovalleys in a low accommodation setting. The funneling effect of the incised valleys likely permitted tidal influence to propagate far upstream and resulted in sedimentary structures and stratigraphic patterns that may be distinctive of the fluvial to marine transition zone.

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Δ^{13}C$_{ORG}$ CORRELATION OF CAMPANIAN-MAASTRICHTIAN CONTINENTAL TO MARINE DEPOSITS IN PRIMITIVE BASINS OF THE PYRENEAN OROGEN

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Late Cretaceous times correspond to the early phase of alpine convergence, for which paleogeography and type of deformation giving rise to the first orogenic reliefs in the Pyrenean-provençal domain are little known. Most of the sediments deposited between Provence (SE France) and Cataluña (NE Spain) were nearly fully continental. Therefore the lack of biostratigraphic markers makes dating difficult. The tectono-stratigraphic framework in these basins is not well constrained and therefore our work aims to improve the stratigraphical scheme in terrestrial deposits using global methods of correlation between continental realm and marine domain, where the stratigraphy is well constrained by biostratigraphy and magnetostratigraphy. We use $\delta^{13}C$ variations measured on organic matter as correlation tool, fitted with magnetostratigraphy and biostratigraphic markers when possible. This study presents the $\delta^{13}C_{org}$ records in (1) a fully continental succession in Provence (Arc Basin) and (2) a section of deltaic sediments overlain by terrestrial deposits in Spain (Tremp Basin). This new dataset combined with magnetostratigraphy in Provence (Cojan & Moreau 2006) and new biostratigraphy analysis in Tremp, will be correlated using reference marine sections (Voigt et al. 2012; Thibault et al. 2012) where the $\delta^{13}C_{carb}$ variations are well calibrated. The Late Campanian to Late Maastrichtian deltaic Tremp Basin section is one of the few $\delta^{13}C_{org}$ records in marine setting. The Campanian to Maastrichtian times record a longterm cooling trend in which several short periods of climatic variations were superimposed and marked by perturbations in the global carbon cycle (Sheldon et al. 2010). Therefore significant high-frequency $\delta^{13}C$ variations, namely the Late Campanian Event (LCE), the Campanian-Maastrichtian Boundary Event (CMBE), the Mid-Maastrichtian Event (MME), and the Cretaceous-Paleogene transition (KPgE) were defined and can be identified in the terrestrial successions and used as stratigraphic markers.

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Enhanced Characterization of Dolomitized Reservoirs: An Automated Data Mining of Biosteering Operations in Saudi Arabia

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Interpreted biostratigraphy information and thin sections of cuttings are not utilized beyond the extent of real-time biosteering operations. These operations on dolomitized reservoirs seek to keep the drill-bits of horizontal wells within biozones of best porosity and developed reservoir potential. The biozones, interpreted from cuttings under the microscope, are based on microfossils and dolomitization analysis along with other rock properties like lithology, mineralogy, and visible porosity. As opposed to seismic volumes and wireline logs, this rich biostratigraphy and dolomitization information is gathered at relatively high frequency vertically and horizontally every 10-50ft depending on the rate of penetration and has contribution that could enhance the value and reliability of regional maps and models of dolomitization and biofacies in carbonate members in Saudi Arabia. This would, consequently, lead to wiser decisions for exploration and field development. To extract and process the complex biostratigraphy datasets in a standard format, an in-house expert system has been developed to mine the data from the various operational files and register them along with their borehole trajectories as data points in the 3-dimensional coordinate system. Extraction is done by running an automatic search on operational files looking for keywords, like: “porosity”, “formation/member”, “dolomitization”, and “fossils”. After registration, different pre-defined classification schemes are offered to arrange the data into facies/groups including dolomitization degree, fossil assemblage, dominant lithology, visible porosity, stylolite presence and other important properties. Once classified, the facies/groups can be displayed in a variety of forms including, 2-dimensional maps, cross-sections and ultimately interpolated 3-dimensional models, simplifying its regional analysis and inclusion into existing geological models. Result maps of data points extracted from sample wells suggest that cuttings with mixed lithologies of grainstone/packstone and microcrystalline dolomite have better development of porosity than cuttings of pure microcrystalline dolomite. In addition, cross-sections between wells show that lithologies and porosity types (vuggy, moldic and intercrystalline) have better continuity and consistency to be interpolated than fossil assemblages. Finally, the 3-dimensional visualization shows that the spread of data points can enhance the calibration of older models and reduce their uncertainty. Further enhancement of this study is being investigated through automating the update of interpolated grids with data of new wells.

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EARLY CAMBRIAN DOLOMITE MICROBIAL BUILDUPS IN THE TARIM BASIN (NW CHINA)

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With increasing explorations into deeply-buried reservoirs, more attentions have been paid to deep-time microbial carbonates. Here we present a well-exposed progradational dolomite microbial buildup complex preserved in the upper Xiaoerblake Formation in Aksu area, western Tarim Basin. Based on the anatomy of this microbial buildup complex notably along the well-exposed cliff outcrop, five facies belts (or associations), including lagoon, backreef shoal, microbial reef, foreslope-middle slope, lower slope-basin, were identified. The platform interior lagoon facies generally comprises thin- to medium-bedded peloidal dolomudstone/wackestone. The backreef shoal facies mainly consists of thick-bedded to massive peloidal packstone/grainstone and peloidal-oncoidal packstone/grainstone proximal to the buildups, which were generally subject to intense recystallization with few primary structures/fabrics. The microbial reef is characterized by massive microbialites composed of diversified microbial elements, notably the *Epiphyton-Renalcis* assemblage. The foreslope-middle slope facies is composed of medium- to thick-bedded microbial packstone/wackestone which was subject to local syndepositional deformation (slump/slide) and silicification alongside. The lower slope-basin facies is composed of dendritic microbialite, pinnacle microbial reef and finely-laminated (pape-like) peloidal mudstone/wackestone. Four phases of progradational buildups are further revealed along the spectacular outcrop. The relative high relief created at the onset of Cambrian could have enabled the microbes to colonize there and build upwards in the general absence of frame-building metazoan fauna. On the other hand, the higher carbonate production but decreasing accommodation space particularly during the later highstand systems tract could have driven the episodic progradations of these microbial reefs in the context slow and episodic sea-level falls. Although the early or penecontemporaneous dolomitization (e.g., reflux seepage, microbial mediation) could have played an important role in dolomite formation, the dolomitization history is multiple and complex. It seems the primary porous lithofacies, i.e., the shoal deposits, were subject to more intense overdolomitization (or recrystallization), causing porosity reduction. Relatively, the microbial buildups contain more pore spaces possibly related to the high heterogeneity and poor connectivity of primary pores.

PERVASIVE SILICIFICATION OF ORDOVICIAN CARBONATES IN TARIM BASIN RELATED TO YANSHANIAN OROGENY BASED ON QUARTZ RB-SR ISOTOPE DATING

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Abstract:

The silicified carbonate reservoir was rarely reported in sedimentary basins although silicification upon carbonates occurred extensively. Here we present an unconventional porous silicified carbonate reservoir in the Middle Ordovician fractured limestone within a strike-slip fault zone in the Tarim Basin, NW China. The silicified carbonates are mainly composed of fine- to medium-crystalline fascicular quartz matrix and coarse crystalline bladed to columnar quartz cement. Fluid inclusion leachate-residue paired Rb-Sr isotopic dating of the quartz cement yields an isochron age of 167 ± 15 Ma, attesting to a causal link to the Jurassic (Yanshanian) orogeny. Pervasive replacement of matrix quartz and subsequent precipitation of cement quartz through non-isothermal effervescence probably induced by periodic influxes of the hot (150 to 190 ^{o}C) silica- and 87Sr-rich basinal brines (16 to 24 wt %) from the neighboring Manjiaer depression during a time interval of ~40 Myr. This study thus provides a useful example for using Rb-Sr isotope to constrain the age of carbonate alteration and to shed light on the determinacy genetic linkage of Yanshanian orogeny to the quartz reservoir in the Tarim basin.

Keywords:

Tarim Basin, Middle Ordovician, silicified carbonate reservoir, non-isothermal effervescence, Rb-Sr isotope dating, Yanshanian orogeny

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APPLICATION OF X-RAY DIFFRACTION METHODS TO UNDERSTANDING THE DIAGENESIS OF DOLOMITE

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For more than a century X-ray diffraction has provided a powerful tool to interpret the structure of carbonate minerals such as dolomite[1]. Here we show how standard and advanced X-ray methods are useful in understanding the diagenetic history of dolomite. The crystal structure of dolomite was determined early in the 20th century using both single crystal and powder X-ray diffraction methods[2,3]. Numerous studies since then have documented apparent changes in geochemistry, crystal texture, and porosity that are attributed to dolomitization and dolomite recrystallization[4,5]. However, no studies have been undertaken that document changes in crystal structure that presumably accompany these diagenetic events. We are using both standard and advanced X-ray methods to characterize natural and synthetic dolomites in order to quantitatively characterize dolomitization and recrystallization. Crystal structure information, such as degree of ordering of cations, atomic positons (C and O have general positions in dolomite structure), unit cell dimensions, and fractional site occupancies will be determined with high precision using Rietveld refinement of diffraction data[6]. High-resolution powder X-ray diffraction datasets acquired at synchrotron facilities will be used for these analyses. Particular care will be taken to refine the site occupancy of the Ca and the Mg sites. For this purpose, the elemental composition and quantitative crystalline phase composition will be used to determine the Ca/Mg ratio in the crystal structure model. An ideal, stoichiometric, maximally ordered dolomite has all Ca and Mg ions on their respective sites rather than randomly distributed. Recrystallized dolomites are expected to be more ordered, and more stoichiometric, and to have more contracted unit cells than un-recrystallized dolomites[7]. These data can be compared with standard X-ray powder diffraction data in order to develop a methodology that can be applied in most laboratories for determining the degree of recrystallization. Ultimately, application of advanced crystallographic methods, especially anomalous X-ray scattering[8] will be used to distinguish between Ca and Mg in the dolomite crystal structure. This will enable quantitative determination of the effect of recrystallization on cation ordering in dolomites. Secondly, total scattering and X-ray absorption spectroscopy methods[9], i.e. X-ray near edge spectroscopy and extended X-ray absorption fine structure will quantify short-range structural changes as Mg is incorporated in the calcite structure under diagenetic conditions.

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POROSITY EVOLUTION OF HIGH-QUALITY DOLOSTONE RESERVOIR IN THE LOWER CAMBRIAN XIAOERBULAK FORMATION, NORTHWESTERN TARIM BASIN, CHINA

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Abundent pores, vugs and bitumen as well as various diagenetic dolomites were found in the platform facies dolostones of Lower Cambrian Xiaoerbulak Formation[1], northwestern Tarim Basin, which indicated the potential existence of ancient dolostone reservoir under the influence of complicated diagenetic fluids. In our research, petrographical and insitu geochemical signatures of different diagenetic dolomites were studied to reveal the types and origin of the diagenetic fluids and their control on porosity evolution of high-quality dolostone reservoir.

Three types of diagenetic fluids have been identified according to the results of trace elements analysis on five kinds of diagenetic dolomites: Md1, Md2, Md3, Cd and Fd. They are as following: (1) micritic, nonplanar-a dolomites (Md1), microspar, nonplanar-a dolomites (Md2), and fine to medium crystalline, planar-s dolomites (Md3) with slightly left-leaning REE pattern (PAAS-normalized), no negative Ce anomaly, no Eu anomaly, low ∑REE, low Mn, moderate to high Fe and Sr, and high Ba contents are considered to be linked to shallow burial dolomitizing fluids at early diagenetic stage during the Middle Cambrian, which were most likely the concentrated seawater in pores; (2) fine to medium crystalline, planar-e cement dolomites (Cd) with roof-shaped REE pattern, no negative Ce anomaly, no Eu anomaly, high ∑REE, low Ba and Sr, moderate to high Fe, and high Mn contents are inferred to be slowly precipitated and sufficiently crystallized from deep-circulating crustal hydrothermal fluids during the Devonian; (3) coarse crystalline, nonplanar-a saddle cement dolomites (Fd) with slightly to significantly right-leaning REE pattern, no negative Ce anomaly, moderate to obvious positive Eu anomaly, high ∑REE, low Fe and Ba, high Mn and Sr contents are advocated to be fast precipitated and insufficiently crystallized from magmatic hydrothermal fluids during the Permian.

The shallow burial dolomitizing fluids altered primary pores to dissolution pores through dolomitization and recrystallization, but they did not generate new reservoir spaces nor increase the porosity. The deep-circulating crustal hydrothermal fluids significantly increased the porosity at early-middle stages by dissolving the matrix dolomites and generating abundant fabric non-selective dissolution pores and vugs, while they slightly decreased the porosity at late stage by precipitating the Cd dolomites. The Permian magmatic hydrothermal fluids did not show dissolution properties, they precipitated the Fd dolomites and slightly decreased the porosity. In summary, it is Devonian deep-circulating crustal hydrothermal fluids rather than Permian magmatic hydrothermal fluids that significantly increased the porosity of high-quality dolostone reservoir in the Lower Cambrian Xiaoerbulak Formation in western Tarim Basin, China.

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Geochemical characteristics and mechanisms of dolomitization: A case study from the Lower Cambrian Longwangmiao Formation dolomites in Central Sichuan Basin, China

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The reservoirs of the Anyue Gas Field, the largest marine gas field in China to date [1], are mainly the Lower Cambrian Longwangmiao Formation dolomites. The XRD, trace elements, rare earth elements (REE), carbon and oxygen isotopic compositions and strontium isotopes were analyzed to characterize the petrological and geochemical characteristics and discuss the models of dolomitization of the Longwangmiao Formation dolomites in the Anyue Gas Field, Central Sichuan Basin. The analytical results of samples demonstrate that the Longwangmiao Formation dolomite rocks have a high content of dolomite, with the range of 98.30%-100.00%, average of 99.75%; the order degree of dolomite is relatively low, ranges from 0.53-0.69, with the average value of 0.63; the Mgo content of the dolomites ranges from 19.98%-24.66%, average of 21.94%, while the Cao content is 25.55%-29.81%, average of 28.94%, the Mg/Ca values are very high, with the average value of 1.06; the dolomites are characterized by relatively high Fe, Mn, Na content and low Sr content; the dolomites have very low REE content and similar REE distribution patterns, which are generally characterized by enrichment of light REE, losses of heavy REE and obviously negative anomaly of Eu; most of the $\delta^{13}C$ values and $\delta^{18}O$ values of dolomites are relatively heavier than those of the coeval seawater[2], showing the character of evaporative water body under arid climate; and most of the $^{87}Sr/^{86}Sr$ values of dolomites are significantly higher than those of the coeval seawater. Combined with the geological settings and geochemical characteristics of the Longwangmiao dolomites, the mechanisms of dolomitization of the dolomites are probably the seepage reflux dolomitization during the early diagenesis, which could extensively preserve the pre-existing porosity, and the burial dolomitization during the burial.

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Why is it Easier to Form and Maintain High Quality Dolomite Reservoirs in Deep Layers?

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Abstract: Whether there is a high quality reservoirs in the deep-ultra deep layers is the prerequisite in an effective oil and gas exploration and development. Dolomite reservoir in deep layer is proved to play an important role during current exploration practice. High quality dolomite reservoirs was found in depth over 8400m in the two deepest exploratory wells in China, MS1 and TS1, respectively. Why is it easier to form and maintain dolomite reservoirs in deep layers? In this study, high quality dolomite reservoirs were found to form through the combined and compound mechanisms in various diagenesis stages, based on a series of case studies and high-temperature-pressure simulation experiments. In the penecontemporaneous period and early diagenesis stage, hydrocarbon generation and TSR in an open-fluid environment and deep burial conditions provided the basis for pore formation. The dissolution of dolomites overwhelms that of limestone with high temperature fluids (with specific ions such as sulfate etc.), provides the key mechanism in the formation and maintain of high quality dolomite reservoirs. Finally, the stronger ability to resist the compaction from dolomite over limestone, makes it easier to sustain the pore of the deep layer dolomite reservoirs in a long period.

Keywords: deep ultra-deep; dolomite; reservoir; water-rock interaction;

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DOLOMITISATION AND VEIN MINERALISATION OF MISSISSIPPIAN LIMESTONES ON THE FAULTED MARGINS OF A METALLIFEROUS BASIN, NORTH DUBLIN COAST, IRELAND

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Coastal outcrop in north County Dublin exposes platform to slope carbonates on the NE margin of the Dublin Basin, the centre and south of which hosts much of the world-class Irish Midlands Pb-Zn ore deposits. The studied limestones contain a variety of fault-related dolomite bodies and vein mineralisations (including calcite, quartz and Cu minerals). These have been characterised by petrography, stable isotopes and fluid inclusion microthermometry, to determine the types of fluids involved, their interaction with the limestone host strata, and relationship to the ore deposits and associated dolomites documented from the basin centre. Fault-related dolomites from each of 3 main localities are petrographically distinct, and stable isotopes from host rock, dolomite and calcite veins show large ranges in $\delta^{18}O$ (-3 to -22‰ VPDB), $\delta^{13}C$ (+4 to -4‰ VPDB) and $^{87}Sr/^{86}Sr$ (0.7080 to 0.7106). At least three fluids have interacted with each other and with the host limestones. A warm (60-135°C) high-salinity brine resembles that previously recognised from widespread dolomite occurring in Carboniferous limestones across the Irish Midlands[1]. This brine has variably mixed with hot (150-300°C) lower salinity fluids similar to those associated with the Irish and Isle of Man[2] limestone-hosted base metal sulphide deposits, and both fluids have been overprinted by a discrete hot (200-275°C) high salinity brine along certain individual faults. Isotopic trends show that latest fault-fracture hosted fluids substantially interacted with radiogenic siliciclastic basement strata along their flow paths and imposed their geochemical signatures on the host limestones rather than being equilibrated with them. The results suggest that the study area was affected by a distal part of a regional Irish Midlands saline groundwater palaeohydrology that locally encountered hydrothermal fluid cells in conduits formed by active basement-associated basin margin fault systems. Mixing of high-temperature and high-salinity fluids appears to be a key factor in fault-related dolomitization, with basement involvement promoting base metal and quartz mineralisation. Field evidence for syn-depositional reworking of fault-related zebra dolomites further suggests these processes commenced early in the basin history.

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Is SO_4^{2-} an effective inhibitor for dolomite precipitation?

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Despite research spanning more than 200 years, the origin of dolomite still remains one of the most debated topics in sedimentary geology. This challenge remains because it is difficult to synthesize dolomite abiotically at Earth surface conditions due to kinetic inhibition. SO_4^{2-} is regarded as an important inhibitor for dolomite formation[1] because it can bind Mg^{2+} to form tight ion pairs and thus prevent the incorporation of Mg^{2+} into dolomite[2]. However, the inhibiting effect of SO_4^{2-} was derived from hydrothermal experiments at ~200 ºC[1]. Is SO_4^{2-} still an effective inhibitor for dolomite formation at Earth surface conditions? To answer this question, we investigated the Mg^{2+}–SO_4^{2-} association in vapor-saturated aqueous $MgSO_4$/$MgCl_2$/NaCl solutions at temperatures ranging from 25 to 200 ºC using in situ Raman spectroscopy[3]. Results showed that the Mg^{2+}–SO_4^{2-} association increases with rising temperature and $MgSO_4$ concentration. At high temperatures (i.e., ≥200 ºC), the major sulfate species in concentrated $MgSO_4$ solutions are tight contact ion pairs (CIPs), whereas at surface temperatures, the dominant sulfate species in dilute solutions are free SO_4^{2-} and weakly associated solvent-separated and solvent-shared ion pairs.

Combined with previous research results, we propose that thermochemical sulfate reduction is an effective mechanism in removing SO_4^{2-} and free Mg^{2+} from various tight Mg^{2+}–SO_4^{2-} contact ion pairs at high temperatures, thereby favoring the formation of hydrothermal dolomite[3]. However, the inhibiting effect of SO_4^{2-} on the formation of low temperature dolomite was overstated[3]. Removing SO_4^{2-} through the metabolism of sulfate-reducing bacteria[4] is not decisive for microbial dolomite formation. This is supported by recent aerobic culture experiments suggesting that bacteria other than sulfate-reducing bacteria can also promote the precipitation of dolomite at low temperatures regardless of the presence of sulfate[5]. Other factors such as the high energy barrier in the dehydration of Mg^{2+} are likely more important kinetic inhibitors for the formation of low temperature dolomite[6].

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A Model for Development of Hydrothermal Dolomite Reservoir Facies in Precambrian Dolomite and its Geochemical Characteristics: A case study of Dengying Formation, Central Sichuan Basin, SW China

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Hydrothermal mineral assemblages and related hydrothermally enhanced fracturing are common in the Precambrian Dengying Formation of Central Sichuan Basin.Petrographic and geochemical analysis of core samples show that the hydrothermal dolomite reservoirs of Dengying Formation consist of four main types of pores in the reservoir facies. These include: 1) hydrothermal dissolution vug (or pore)，2) intercrystalline pore，3) residual inter-breccia vug (or pore), and 4) enlarged dissolved-fracture.There are 3 different dolomite fabrics in hydrothermal dolomite reservoirs, namely, saddle dolomite, fine-medium dolomite and micritic dolomite. Micritic dolomite is the original lithology of host rock. Saddle dolomite with curved or irregular crystal faces were directly crystallized from hydrothermal fluids（average temperature 192℃). Fine-medium dolomites are products of recrystallization of micritic dolomite，resulting in abnormal geochemical characteristics, such as, slight depletion of δ18O,significant enrichment of Mn-Fe and 87Sr/86Sr, and positive anomaly of Eu. A model for distribution of various hydrothermal dolomite reservoir facies is proposed here, which incorporates three fundamental geological controls: 1)extensional tectonics and tectono-hydrothermal events (i.e.,the Xingkai Taphrogenesis of Late Sinian-Early Cambrian, and Emei Taphrogenesis of Late Permian), 2) hydrothermal fluid storage in clastic rocks with large thickness (e.g., Nanhua System of Chengjiang Formation and part of Doushantuo Formation), and 3)confining bed for hydrothermal fluids (such as, the shale in Qiongzhusi Formation).Supply of the hydrothermal fluid is key. Large basement-rooted faults and associated grid-like fracture system may function as the channels for upward migration of hydrothermal fluid flow. The intersection of the above-mentioned faults (including the conversion fault), especially transtensional sags above negative flower structures on wrench faults can serve as a key target for future hydrocarbon exploration.

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Diagenetic Studies and its Implication on the Reservoir Characterization of the Anisian-Norian (Triassic) Kingriali Formation, Salt Range (Pakistan)

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Abstract

In the present studies, field observations, petrographic studies and geochemical analysis of the Anisian-Norian Kingriali Formation, Salt Range (Pakistan) suggests that replacement of limestone by dolomite is the most common process of dolomitization in the current scenario. Field observations and petrographic studies revealed eight different dolomite/calcite phases. 3-phases of dolomitization are observed, which include; matrix selective dolomitization with high porosity values, followed by closely packed mosaic of non-planar to planar low porous RD-I replacive phase which is finally modified by neomorphism process and result in the formation of RD-II replacive phase during progressive dolomitization. The process of matrix selective dolomitization, overdolomitization and dolomite cementation, presence of calcium sulphate cement, multiple phase dolomitization and and saddle dolomite formation strongly support the process of replacive dolomitization within Kingriali Formation.

Stable isotope analyses ($\delta^{13}C$ and $\delta^{18}O$) indicate that dolomitization occurred in three different conditions due to variable isotopic signatures (high temperature basinal brines and meteoric water). Decrease in ^{13}C and increase in ^{18}O for MZKD-2, MZKD-5, MZKD-6 and depletion in ^{18}O for MZKD-3 from -4.53 to -3.32, interpreted that this dolomitization is a result of slightly high temperature basinal brines and meteoric water. While the ^{13}C and ^{18}O isotope range MZKD-1, MZKD-4 and MZKD-8 shows purely marine signatures. Porosity-permeability analysis showed considerably high values of porosity and permeability which is assumed to be a result of different processes involved in the modification of shallow marine limestone to present day dolostone. Development of molds and vugs by dissolution of calcite at shallow depth, mole per mole replacement of high Mg unstable calcite and aragonite and fracturing due to active tectonism and burial compaction are the processes involved in porosity & permeability enhancement. 3-Dimensional porosity values from plugs analysis ranges from 8.62 to 16.73% while values for 2-Dimensional porosity calculations ranging from 2.16 to 30.37%, similarly values for air permeability ranges from 0.064 to 30md, while liquid permeability values range from 0.037 to 27.2md which is in the range of a good hydrocarbon reservoir.

Based on the stratigraphic position of Kingriali Formation and the support of stable isotope interpretation, it is suggested that late Permian to middle Triassic age seawater derived brines were heated up and enriched in Fe, Mg and radiogenic Sr while circulating through clastic sediments, are responsible for the replacement of precursor limestone. In addition, meteoric water conditions are responsible for the modification of dolomitization phases and dissolution.

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DOLOMITIZATION OF NEOGENE CARBONATE PLATFORMS: CONTROVERSIES ON SYNCHRONOUS EVENTS AND BIOCLAST INFLUENCE

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Within the last 60 years, our understanding of dolomite and dolomitization has progressed at an astonishing pace. However, the perennial 'dolomite problem' still remains a controversial and unresolved issue [1]. Two central parts of the problem is the source of magnesium and overcoming kinetic reaction barriers to dolomitization. The Neogene brought with it an extraordinary similarity of dolomites from many regions of the world, which has given rise to the hypothesis of simultaneous global dolomitization events [1]. For the Neogene, there are several lines of evidence that link the seemingly synchronous dolomitization events to global events to explain the phenomenon; the evidence however, is not without controversy as it has been questioned by several authors [1]. Two hypotheses have been proposed to explain the dolomite synchronicity: periods of 1) stable sea-levels and 2) global aridity[1].

The results of two different Neogene carbonate platform studies that include data from extensive fieldwork in Bonaire, Netherland Antilles and IODP Expedition 359 in Kardiva Platform, The Maldives were compared with published data from other localities. Bonaire is an isolated carbonate platform that has been uplifted and exposed with little burial history, in contrast with the Kardiva Platform which was permanently drowned during the late Miocene. Despite the two platforms having distinctly different diagenetic histories, they show very similar dolomitized facies in Mio-Pliocene intervals.

The literature currently shows there is a gross correlation between high-Mg calcite skeletons of coralline red algae with dolomitized sections[1]. However, controversies still remain about the insufficient resolution of dating to precisely define Budd[1]'s dolomitization events, which were significant in the Neogene record. We observe in our study locales that bioclastic (coralline red-algal facies) contribution may have affected the dolomitization susceptibility of those platforms by acting as dolomite seeds, which reduce the kinetic barriers to dolomitization. This ties neatly with Miocene ocean ecological conditions, which favored coralline algal deposits as Pomar and Hallock [2] suggested. In conclusion, the combination of ocean and climatic conditions with the presence of abundant coralline algal deposits at platform edges and shallow slopes may have synchronized to trigger dolomitization events during the Neogene.

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Characteristics, diagenesis and formation mechanism of organic reef-bank dolomite reservoirs of Changxing Formation in Yuanba area, Sichuan Basin

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The organic reef-bank gas-pool is found from Upper Permian Changxing Formation in Yuanba area from northeast Sichuan Basin. Based on detailed observation of cores, thin section and the analysis of porosity, permeability, combined with well logging and seismic analysis, sedimentary sequence, reservoir characteristics, diagenesis from organic reef-bank reservoir are researched. Further, the reservoir formation control factors and mechanism are summarized.

The research results show that, according to lithologic changes of different-scale sequence boundaries, Changing Formation can be divided into two third-order sequences (SQ1, SQ2) and six fourth-order high-frequency sequences, with the characteristics of electric logs abrupt change above and below the (high-frequency) sequence boundary. The platform margin organic reefs and banks were developed at the depositional period of SQ2, including inter-bank, bio-clastic bank, organic reef, back reef bank and back reef tidal-flat sub-facies. The lithofacies assemblage corresponds well to the upward shallow fourth-order sequence and the organic reef structure is well reflected with reef base (bio-clastic bank), reef core (organic reef) and reef cap (back reef bio-clastic bank or tidal flat) developed, at least including two obvious reef sedimentary cycles [1].

The main reservoir rocks, which are low porosity and moderate-low permeability, are distributed in reef cap and are dominated by residual bioclastic dolomite, middle-fine grained dolomite, algal bonded microcrystalline dolomite and a few limestones with various types dissolution pores and dissolved cavities, fractures. However, dolomite reservoirs are obviously better than limestone in their physical properties, which reflects the controlling role of rocks relative to reservoirs. Obviously, for reservoir development, the reef back is better location than reef front horizontally and reef cap is better location than reef base, reef core vertically.

Several main kinds of constructive diagenesis were developed in the Changing Formation reef reservoirs, as dolomitization and dissolution. The dolomitization genesis, which is relative to sedimentary sequence location, mainly includes evaporative pump, reflux and burial. Dissolution can be clearly divided into three stages of early atmospheric water, middle organic arid and late deep acid fluid (as TSR), which are consistent with geochemical analysis results. Further research indicates that organic reef-bank deposition controlled by high-frequency sequence is the foundation of reservoir development. For example, at the late development stage of organic reef, the sediments of bio-clastic bank and tidal flat were intensively dolomitized to form the favorable reservoirs. This also is key factor controlling atmospheric water penecontemporaneous dissolution due to sea-level decline.

Based on above all research results, thus, it was summarized that 'lithofacies-controlling reservoir, early formation and late reformation' of the organic reef-bank reservoir formation mechanism and developmental model.

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The Application of Clumped Isotope Thermometry in Reconstruction of Diagenetic Environment on Dolomite Reservoir of the Middle-Lower Cambrian in Tarim Basin

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Abstract: As a new experimental technique in recent years, the technology of clumped isotope(D47) thermometry has been applied in the study of the diagenetic environment of carbonate rock. A trick dolomite was developed in Cambrian Tarim Basin, with the breakthrough of the Well ZS1, the dolomite reservoir below salt layer in Tazhong area could be taken as succeeding intervals for furture exploration. However, the problem of the reservoir genesis is still an important factor restricting the exploration of this area. This study was based on the clumped isotope thermometry, taking the middle-lower Cambrian dolomites in Tarim Basin as an example. 11 samples were chosen to test D47 value and carbon and oxygen isotope of dolomites, and the diagenetic temperature and δ18O of paleofluids were calculated. 11 plunger samples in this study were all drilled by engine bit to ensure the oneness of sample components, analysis and tests of these samples were all completed in the Isotope laboratory of earth and space science, university of California, Los Angeles. The experimental results showed that the diagenetic temperature and δ18O of the dolomite cement in cracks and holes are higher(97.2°C~122.2°C), the diagenetic temperature of the fine crystal dolomite also represents a high value(105.7°C~129.7°C), while low diagenetic temperature(56.7°C~67.8°C)is observed in grain dolostone of Middle Cambrian and Lower Cambrian. In conclusion, the granular dolomite formed in low-temperature penecontemporaneous -shallow buried environment, and the diagenetic fluid is seawater. The fine-grained dolomite is formed in the deep-buried diagenetic environment, and the original rock is subjected to high-temperature recrystallization, and the diagenetic fluid is underground thermal brine. The dolomite cements in the pores or fractures are the products of the precipitation of Mg-rich thermal brine in a deep-buried diagenetic environment. The study proved that the clumped isotope thermometry could recover carbonate minerals diagenetic temperature better. This technology could not only make up for the difficulty of finding fluid inclusions in Package thermometer technology but also overcome the limitations of the rely on carbon and oxygen isotopic analysis of carbonate diagenesis environment. Furthermore, the reliable results add new technical means and basis for the analysis of carbonate diagenesis environment, as well as provide a new train of thought of deep dolomite diagenesis study.

MULTI-PHASE DOLOMITIZATION AND RECRYSTALLIZATION OF MIDDLE TRIASSIC PERITIDAL–SHALLOW MARINE CARBONATES OF SW HUNGARY

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The Middle Triassic Csukma Formation of the Mecsek Mts. and Villány Hills in SW Hungary is comprised of peritidal–shallow marine carbonates, which show varying degrees of dolomitization and recrystallization. Various petrographic, geochemical and crystallographic tools have been integrated to provide new insights into the dolomitization and dolomite recrystallization mechanisms that affected this formation, and to provide a better understanding of these processes with respect to porosity development and within the local and regional tectonic framework.

The lower portion of the Csukma Formation, exposed in the Mecsek Mts., was deposited in a semiarid distally steepened ramp setting[1]. The peritidal carbonates (Kán Dolomite Mb.) were dolomitized penecontemporaneously by refluxing concentrated seawater. The coeval middle ramp shoal deposits (Kozár Limestone Mb.) were out of reach of the refluxing brines and remained undolomitized at this time. In the Villány Hills, the upper part of the peritidal succession (Csukma Dolomite Mb.) shows evidence of platform development[2] under an increasingly humid climate[3]. Accordingly, dolomitization of the Csukma Dolomite occurred by normal to slightly modified seawater via tidal pumping and/or some type of convection.

In the Mecsek Mts., increasing burial resulted in temperature-driven recrystallization of the reflux dolomites in a shallow to intermediate burial setting without incursion of external fluids. In contrast, the shoal deposits later underwent fracture-related dolomitization by hot fluids that created medium to coarse crystalline nonplanar dolomites, partially or completely replacing the limestones. The dolomitizing agent was likely seawater drawn down through Early Cretaceous rift-related faults. Hot fluids of similar origin caused local recrystallization of the peritidal dolomites a second time, creating irregular bodies of coarse crystalline nonplanar dolomites within the fine crystalline succession. These processes have significantly modified porosity and permeability.

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APPLICATION OF THE RIETVELD REFINEMENT METHOD FOR THE STUDY OF DOLOMITE DIAGENESIS

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The initial crystal structure of dolomite upon formation and how it changes due to diagenetic alterations have been of long-term interest to dolomite researchers. The main parameters of interest are the degree of ordering of the Ca and Mg cations, which can be determined from fractional site occupancies of Ca and Mg, stoichiometry, and unit cell dimensions. Such crystallographic information together with other geochemical parameters can provide a better understanding of how the geological environment of dolomitization and dolomite recrystallization affects the crystal structure of dolomites.

The Rietveld refinement method[1] provides an excellent tool to extract crystal structure information from powder diffraction data of dolomites that otherwise would only be available from single crystal diffraction studies. Since most sedimentary dolomites that formed in near-surface settings are very fine crystalline, single crystals are not available for crystal structure studies. The Rietveld method is commonly used in high temperature and high pressure studies to understand phase transformations in the metamorphic realm; however, only a few studies are available where this method was applied to better understand sedimentary carbonates. In addition to crystal structure refinement, the Rietveld method can also be used to quantitatively determine the crystalline phase composition of mixed carbonates.

The Rietveld method uses a least-squares refinement procedure to minimize the difference between an atomic structure model-based pattern and the observed pattern over all data points in the entire diffraction pattern[2]. Various software packages are available for Rietveld refinement, among which the General Structure Analysis System[3] (GSAS) is available free of charge for all researchers. The dolomite structure model of Reeder and Wenk[4], which allows for mixed occupancy of Ca and Mg on both cation sites, is particularly well-suited for dolomite structure refinement. The pseudo-Voigt function, a convolution of Gaussian and Lorentzian functions, is a suitable choice of profile function for the refinement of diffraction data collected in the Bragg-Brentano geometry using a laboratory diffractometer. A wide angular range, high signal-to-noise ratio, and a sample with no preferred orientation, are other important experimental parameters. Precise crystallographic information extracted from such an experiment using the Rietveld method can be invaluable to better understand the formation and alteration of dolomite, which comprises part of the century-old "dolomite problem."

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EARLY DOLOMITIZATION AND DEDOLOMITIZATION OF THE UPPER JURASSIC LIMESTONES IN THE GENEVA BASIN (SWITZERLAND AND FRANCE)

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The Canton of Geneva (Switzerland) is currently exploring the opportunities for geothermal energy exploitation in the Geneva Basin (GB) sub-surface. In this context, a structural analysis of the basin associated with reservoir appraisal and rock typing of reservoir bodies of potential interest were conducted.

Horizons affected by dolomitization, the focus of the present study, are of particular interest because they proved to be productive in time-equivalent deposits currently exploited in Southern Germany and are suitable for geothermal energy production. The Upper Jurassic carbonate rocks of the GB represent the best potential reservoirs. However, these units exhibit strong heterogeneities in terms of reservoir quality with the occurrence of highly porous sucrosic dolomite intervals in the western part of the basin, becoming tighter to the south-east. Two study sites where the Upper Jurassic carbonates outcrop were selected at the surroundings of the GB. In addition, one core close to the prospected area was studied (Humilly-2 borehole). The detailed study in each site focused on (1) assessing texture, fabrics, types and distribution of porosity using petrographical analyses, (2) characterizing the petrophysical properties and (3) constraining the paragenesis for each stratigraphic unit using geochemical analyses (O, C, Sr) prior to discussing the cause and effects of dolomitization.

Two types of dolomite were identified: early replacive dolomites (D1) and fabric-destructive sucrosic dolomite (D2), along with two types of corresponding dedolomites. The measured isotopic compositions of D1 dolomites are consistent with a reflux type model of dolomitization induced by high-frequency sea-level changes producing pulses of dolomitizing brines. The D2 sucrosic dolomite represents an advanced level of replacement that obliterated the original fabric leading to high intercrystalline porosity during burial and to good reservoir properties. Dedolomitization is observed at different order of magnitude by either (1) an almost complete dissolution leading to the creation of secondary pore space or (2) a two-step calcitization driven by the infiltration of Ca-rich water leading to dissolution, formation of microvugs and then precipitation of calcite. Isotopic data showing depleted oxygen composition points toward the interaction with meteoric water initiating the dissolution of both early and sucrosic dolomites. This dedolomitization would have taken place during long-term emersion events or after the exhumation of the Upper Jurassic limestones.

The study presented here will help to understand the possible mode of dolomitization that occurred in the GB. The results presented here will be implemented in a stochastic model in order to predict the volume and distribution of dolomitic bodies at the basin scale. This step will ultimately help in reservoir modelling which is crucial for further potential exploitation.

DOLOMITIZATION AND MECHANISM OF DOLOMITIZING FLUIDS FLOW IN THE CAMBRIAN-LOWER ORDOVICIAN CARBONATE STRATA IN THE WEST-CENTRAL TARIM BASIN, NW CHINA

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Abstract

Extensive dolomitization has affected the Cambrian-Lower Ordovician carbonates in West-central Tarim Basin. Petrography and geochemical data revealed three types of nonplanar-a to planar-e(s) fabric-obliterated dolomites, dolomicrites, microbial dolomites, and saddle dolomite cement. These dolomites are restricted evaporative lagoon and platform reef-shoal facies formed by evaporative seawater and seawater during sabkha, reflux, and burial dolomitization. The overlap of $\delta^{18}O$, $\delta^{13}C$, and $^{87}Sr/^{86}Sr$ values of fabric-obliterated dolomites, saddle dolomite cement, and coeval seawater indicates that modified seawater was the principal dolomitizing fluids. Faults/fractures evolved from strong tensional-compressional tectonic regime in this basin effectively provided continuous conduits through which expelled Mg-enrich basinal brine fluids are thermally-driven, causing extensive dolomitization of the host carbonate rocks. Moldic-vuggy, intergranular and fracture porosities are related to burial dissolution events. This work has shown that Cambrian-Lower Ordovician dolomites with associated anhydrite seals have high potential for hosting substantial hydrocarbon resources and should be targeted for future exploration.

Acknowledgments

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CLOSED SYSTEM DOLOMITE RECRYSTALLIZATION PROCESSES HIGHLIGHTED BY CLUMPED ISOTOPE (Δ_{47}) THERMOMETRY AND LASER ABLATION U-PB CHRONOMETRY - ARAB FM. (UAE)

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Dolomites from the Upper Jurassic Arab Fm. formed by early diagenetic processes (i.e. sabkha-evaporative, seepage-reflux dolomitization), at surface temperature conditions. Despite extensive studies uncertainties still exist on how the dolomites, and related intercrystalline pores, evolved through time. Conventional diagenesis studies combined with cutting edge analytical techniques, like clumped isotope (Δ_{47}) thermometry and laser ablation U-Pb chronometry, were here applied to bring new light in understanding the origin and evolution of such dolomitic reservoirs.
A diagenetic study has been conducted on the Arab Fm. from a gas anticline field onshore Abu Dhabi (Morad et al., 2018[1]). Variable porosity-permeability values were recorded in similar dolomitized facies, suggesting that the reservoir properties are not only linked to the original depositional heterogeneities. Samples (n=15) from one well were further analyzed. Clumped isotope (Δ_{47}) data indicate that these dolomite samples record temperatures in the range 41-82 (±6) °C, therefore fairly too high to be explained by early diagenetic processes only. Laser ablation U-Pb chronology indicates ages between 135 and 92 Ma (Early to Late Cretaceous), suggesting a resetting of the original isotopic signature through time.
These data overall suggest a selective recrystallization of some portions of the dolomitic reservoir by high temperature fluids during burial, with the reset dolomites corresponding to more porous and permeable zones. They also suggest that the recrystallization affected the dolomites according to a continuous process, which occurred during the main subsidence phase of basin evolution and prior to hydrocarbon migration in the reservoir.
Recrystallization occurred in a closed system: the process was driven by the same dolomite pore-fluids evolving during fluid-rock interaction through time. The geochemical dataset (temperature-$\delta^{18}O_{fluid}$) acquired on the dolomites from this field (UAE) share analogies with other Arab Fm. fields from the Arabian platform. This suggests that dolomite recrystallization occurred in reservoirs far from each other (at basin scale), allowing to propose conceptual scenarios which could be extrapolated to similar dolomitic reservoirs.
The major implication for oil and gas industry is that the reservoir properties changed through time due to burial recrystallization of the original early sabkha-reflux dolomites.

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DOLOMITIZATION AND LATER HYDROTHERMAL ALTERATION OF THE LATE JURASSIC-EARLY CRETACEOUS PLATFORM CARBONATES, ESKI GÜMÜŞHANE AREA (EASTERN PONTIDE, NE TURKEY)

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Upper Jurassic-Lower Cretaceous platform carbonates (Berdiga Formation), which are represented by different lithofacies ranging laterally and vertically from supratidal flat to slope environments, are widely exposed in the Eastern Pontides region (NE Turkey). Petrographic and geochemical data indicate that diagenetic evolution of the Berdiga carbonates involve complex alterations occurring at early shallow burial (micritization, calcite cementation), shallow to intermediate (dolomitization associated with syn-sedimentary extensional tectonic activity during to Albian-Aptian) and intermediate to deep burial (recrystallization, dissolution, silicification and pyrite mineralization associated with the hydrothermal emplacement of the polymetallic Pb-Zb-Cu-Au-Ag mineralization during Eocene). The formation is pervasively dolomitized by fabric-destructive and fabric-preserving replacive dolomites (RD). These dolomites are Ca-rich and non-stoichiometric ($Ca_{56-58}Mg_{42-44}$) and have highly variable but low $\delta^{18}O$ (–11.38 to –4.05‰ V-PDB) and $\delta^{13}C$ (0.69 to 3.13 ‰V-PDB) values, radiogenic $^{87}Sr/^{86}Sr$ ratios (0.70753 to 0.70884), extremely high Fe (2727-21053 ppm) and Mn (1548-27726 ppm) contents. Moreover, Fe and Mn values, and fluid inclusion homogenization temperatures (160 to 230 ^{o}C) show enrichment from core to the overgrowth rim of coarse crystalline dolomite. This suggest that recrystallization of replasive dolomite under high temperature domain is most likely to have been associated with polymetallic mineralization. In addition, microcrystalline quartz cement and the scattered euhedral pyrite minerals (3-10 µm, on average 5 µm) are also observed in dissolution porosity of replasive dolomites.

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KARSTIFICATION OF THE UPPER CAMBRIAN DOLOMITE RESERVOIRS IN NORTHERN TARIM BASIN,NW CHINA

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Abstracts: The upper Cambrian dolomite is one of the main potential hydrocarbon producing horizons in northern Tarim Basin. Detailed petrographic and geochemical studies indicate that the genesis of various dolomites is different [1,2] and the development of dolomite reservoirs is still in dispute[3,4].Our research on the cores from TS2 well,YQ6 well and others indicates that karstification probably had played an important role in the development of dolomite reservoirs. A plenty of corrosion pores and fractures are distributed around unconformity, sedimentary discontinuity or strike-slip faults. There is just the significant evidence for karstification that a fracture-cavity filled with sandstones and mudstones was drilled at the depth of 6842m~6846m in TS2 well in platform. It suggest that the fracture-cavity is influenced by terrigenous clastic materials relating to meteoric fresh water on the basis of further mineralogical analysis. We proposed the other strong evidence is that there is a typical vertical percolating zone with massive karst breccias existing in YQ6 well and a plenty of immiscibility inclusions dominantly at 30℃ ~75℃ in the calcite or dolomite cements, which are the indicator of karstification. It means that a new hypothesis of ultra-deep meteoric fresh water dissolution model may provide a reasonable interpretation about the formation of the upper Cambrian dolomite reservoirs although the exposion period was relatively short. This study provides a useful analogue to understand the development of dolomite reservoirs at deep depth in Tarim basin and elsewhere.

Key words: Karstification, Dolomite reservoir, Upper Cambrian, Tarim Basin

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Petrography and geochemistry of the deeply buried Cambrian dolomite reservoirs from Tashen-1 well, Tarim Basin, China

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The karsted Ordovician limestone reservoirs at burial depths approximately 4,000-6,000 m. formed major hydrocarbon producing pools in Tahe area of the Tarim Basin. In order to evaluate the potential for hydrocarbon reservoirs in the deeper Cambrian carbonate rocks, a deep exploration well, Tashen-1, was drilled to a depth of about 8,500 m, at the carbonate platform margin, which recovered five intervals of cores from 7,200 m to 8,400 m. All these carbonate rocks were completely dolomitized. Contrary to the conventional wisdom that deeply buried carbonate rocks generally have low porosity owing to cementation associated with pressure solution, the dolomitized core samples below 8,000 meters still preserve excellent porosities, ranging from 0.6% to 9.1% and permeability from 0.03 to 34 x 10^3 m^2.

Two types of replacement dolomite and one type of cement were identified in these Cambrian core samples. The replacement dolomite includes fine crystalline matrix dolomite with well preserved precursor lithologic texture; and coarse crystalline matrix dolomite with precursor textures completely destroyed. In addition, minor white saddle dolomite also occurs as cement in vugs and fractures. Despite distinct petrographic differences among the three types of dolomite, their oxygen, carbon and Sr isotopes overlap with each other with oxygen isotopes from -6 to -14‰ PDB, carbon isotopes from -1 to 1‰ PDB, and Sr isotopes from 0.7088 to 0.7093. This, together with the homogenization temperature (110 to 160 ^{o}C) measured from two phase aqueous inclusions in the saddle dolomite cements, suggests that saddle dolomite was probably related to hydrothermal fluids in a relatively closed system that was buffered by the geochemistry of host dolostones.

The results of this study suggest that Cambrian dolomite rocks in the Tarim Basin locally occur as excellent reservoirs in spite of the deep burial. Hydrothermal processes played a critical role in formation of the dolomite reservoirs in this unusual deep burial setting. The occurrence of a regional seal for hydrocarbon traps, however, is a critical issue that needs to be addressed in assessing the possible deep dolomite play in the Tarim Basin.

GEOGRAPHIC VARIATIONS IN THE PETROGRAPHY AND GEOCHEMISTRY OF ISLAND DOLOSTONES[1]

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Cenozoic island dolostones are found on carbonate islands, platforms, and atolls throughout the world. Due to their geological youth and lack of deep burial, these dolostones provide an opportunity for resolving some of the issues inherent to the dolomite problem. Individual island dolostone bodies, which are variable in size and extent of dolomitization, show geographic and stratigraphic variations in the petrographic and geochemical properties of the dolostones. From the coastal areas towards the centres of the larger island-wide dolostone bodies (e.g., Grand Cayman, the little Bahama Bank), there are progressive increases in mole %Ca, depletion of the heavier ^{18}O and ^{13}C isotopes, and changes from fabric-retentive to fabric-destructive fabrics and a decrease in the amount of dolomite cement. These changes define geographically concentric zones that parallel the coastlines and reflect geochemical modification of the dolomitizing fluid through water-rock interactions, mixing with meteoric water and the changes in the rate and flux of seawater as it flowed from coasts to island interiors. The pattern of dolomitization embodied in each island, however, is not consistent. This suggests that the geographic and stratigraphic variations are influenced by groundwater flow pattern (e.g., geometry and size of the islands; the porosity and permeability of the precursor carbonate), the duration of the dolomitization reaction, and other factors that are specific to each island. The geographic extent of dolomitization and variation in dolomite stoichiometry of island dolostones may be comparable to the reaction stages established in high-temperature laboratory experiments.

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Detailed investigation of bedding parallel dolostone in Samana Suk Formation (Middle Jurassic), Nizampur Area, NW Himalayas, Pakistan: Possible mechanism of dolomitization and implication on reservoir Characteristics

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Abstract

The middle Jurassic Samana Suk formation of Surghar group is composed of shelfal limestone which have extensive multiphase bedding parallel dolomitization in the study area (i.e., Kahi section, Nizampur Basin, Pakistan). The investigation of multiphase bedding parallel dolomitization were carried on the basis of detailed field observation, petrographic observations, and geochemical signatures of various selected samples. Field observations show both the signatures of host oolitic, micritic limestone and multiphase dolomite bodies that are mainly associated parallel to bedding planes. Four matrix replacive dolomites were recognized on the basis of colour contrast. These include; dark grey coloured replacive dolomite (RD1), light grey dolomite (RD2), brownish dolomite (RD3) and yellowish dolomite (RD4). Beside replacive phase, voids and fracture filling cementing saddle dolomite (SD), and cementing calcites (CC) are also recognized in the field. Petrographic study shows the complex diagenetic history of Samana Suk Formation from near surface diagenesis, micritization to burial diagenesis, which leads towards saddle dolomite formation. From petrographic investigations, it is observed that RD1 is fine to very fine grained, RD2 is medium to coarse grained and anhedral crystal shape, RD3 is medium to coarse grained and subhedral crystal shape, RD4 is coarse to very coarse grained and planner Euhedral Zoned dolomite. Cementing saddle dolomite have large crystal, curved faces and shows undulose extinction in crossed polarized light, cementing calcite CC3 are twin and CC4 are ferroan in nature. Geochemistry of various dolomites and dolomite phases shows a varied range of values. The $\delta^{18}O$ isotope values of precursor limestone range from -0.73 to -5.20‰ V-PDB. Replacive dolomites RD1 have $\delta^{18}O$ isotope values ranges from -3.16 to -7.56‰ V-PDB. Cementing phase have highly depleted $\delta^{18}O$ isotope values. $\delta^{18}O$ value of saddle dolomite range from -6.83 to -10.73‰ V-PDB cementing twin calcite CC3 have $\delta^{18}O$ value -10.05 ‰V-PDB, and cementing ferroan calcite CC4 have $\delta^{18}O$ -8.51‰ V-PDB).

Based on the above-mentioned dataset and regional geological settings, it is depicted that regional thrust system (i.e., Kahi thrust), along which Samana Suk Formation (Jurassic) thrusted over the late Cretaceous Kawagarh Formation has provide pathway for Mg rich fluids from the underlying siliciclastic Formations to form fault related dolomites. In conclusion, fault related & burial compaction are the main contributors in the dolomitization of Samana Suk Formation.

Acknowledgement: Higher Education Commission, Pakistan is highly indebted for providing funding for this study. In addition, Pakistan Institute of Nuclear, Science and Technology (PINSTECH), Islamabad is acknowledged for stable isotope analysis.

MINERALOGICAL, GEOCHEMICAL AND ISOTOPIC SIGNATURES OF MULTISTAGE DOLOMITIZATION IN THE JUTANA FORMATION (CAMBRIAN), SALT RANGES, NW PAKISTAN

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ABSTRACT

In the present studies, attempt has been made to characterize geochemical/isotopic signatures of the Cambrian Jutana dolomite in the Salt Ranges, Pakistan. Based on outcrop studies and microscopic observations, three different dolomite types are identified, which include; (i) fine- to medium crystalline dolomite matrix (Dol. I), (ii) medium- to coarse crystalline dolomite cement (Dol. II), and (iii) fracture-filling, dolomite cement (Dol. III). Mineralogical studies revealed that Dol. I show non-stoichiometric low ordered dolomite nature, whereas Dol. II and Dol. III represent moderately ordered near stoichiometric dolomite nature. Geochemical signatures (major and trace elements) exhibit high concentrations of Sr and Na with comparatively low values of Mn and Fe for Dol. I, whereas Dol. II and Dol. III indicate high existence of Mn and Fe contents, while low existence of Na and Sr. Stable isotopes ($\delta^{18}O$) signatures of Dol. I indicate less depleted values, whereas Dol. II and Dol. III represent highly depleted values respectively. In addition, $\delta^{13}C$ values of all the three dolomite phases lie in the range of original marine signatures. Furthermore, Sr-isotope signatures indicate higher values as compared to original marine signatures, hence exhibits interaction of the dolomitizing fluids with radiogenic lithologies. Lastly, Mg-isotopes ($\delta^{25}Mg$ and $\delta^{26}Mg$) result elucidates altered marine (mixing zone) and hydrothermal dolomitization origin for these dolomites.

In conclusion, based on above mentioned petrographic, mineralogical and geochemical studies, it is revealed that Jutana dolomite resulted initially from near surface, mixing zone dolomitization, followed by hydrothermal dolomitization resulted from intermediate to deep burial conditions in the later stages.

Acknowledgement: Higher Education Commission, Islamabad is highly acknowledged for providing funds to carry out geochemical analysis. In addition, Prof. Adrian Immenheuser (Ruhr University, Bucham) is indebted for carrying out Mg- isotope analysis.

Cenozoic dolomitization in South China Sea: Implications from Well Xike-1 in the Xisha Islands

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ABSTRACT:

Miocene-Pliocene carbonate stratigraphy is well seen from an entire core hole, Well Xike-1, Xisha Area in South China Sea, and the dolomitization here indicates an excellent model during the Cenozoic period. Dolomite in this drilling hole, with a total thickness of approximately 380 m, is mainly distributed in the upper part of Yinggehai Formation (Pliocene) and the three Formations of upper, middle and lower Miocene. Core observation shows the dolomite sequences lies under the ironic unconformity or karst surfaces. The first appearance of dolomite layer is at the well depth of 288 m and the content of bigger dolomite crystal increases with depth. For instance, the dolomite is with powder crystal structure in the Pliocene Yinggehai Formation, while in the lower Miocene Sanya Formation, the proportion of saddle-like and middle-coarse crystalline dolomites, increases remarkably. The C and O isotopes of carbonate rocks in Well Xike-1 show the consistent trend of coordinated variation, however it doesn't indicate the correlation between the C and O isotopes, implying the meteoric water, magmatic fluid and organic acid didn't participate the dolomitization. In addition, the inorganic carbon isotopes of dolomite indicate the heritage of marine carbon from primary calcite. The C/O isotopic analyzation also illustrates the salinity of seawater during dolomitization was higher than that of normal seawater. The oxygen isotope of dolomite suggests the dolomitization environment was evaporated and concentrated seawater. The fluid inclusion measurement shows the mean temperature of primary dolomite inclusion in lower Miocene is far higher than the temperature calculated by normal geothermal gradient, by which it is deduced that the Sanya Formation had been affected by high-temperature pore liquid. The measurement of d104 face wire distance of dolomite implies the recrystallization of dolomite during diagenesis. It's concluded that most dolomite in Well Xike-1 might be produced in the isolated platform (island) environment with middle salinity seawater, interpreted by the infiltration and circumfluence model of dolomitization. The lower Miocene dolomite, however, was remoulded by the thermal liquid convection upwelling along faults.

KEYWORDS: Cenozoic dolomitization, South China Sea, carbon and oxygen isotope, fluid inclusion, dolomite recrystallization

BOTRYOIDAL-LACE STRUCTURES WITHIN DOLOMITE OF EDIACARAN DENGYING FORMATION IN SICHUAN BASIN, SOUTHWEST CHINA

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Ediacaran Dengying Formation in Sichuan Basin of Southwest China is outcropped well and is also an important gas-producing dolomite reservoir. The Dengying Foarmation is divided into four intervals. The botryoidal-lace structures are only located in the middle and lower parts of Interval Two and five meters at the bottom of the Dengying Formation.

There are five types of botryoidal-lace in the dolomite. First type is botryoidal-lace stromatoid beds which lamellas are thick to centimeter-rank and the fibrous (or prismatic) crystals grow up vertically to the lamella. The second one is fenestral-vug-lining lace in thin lamina stromatolite which the thickness of laces is millimeter-rank or less. The third one is frame-vug-lining lace between clots in thrombolite which the thickness of laces is similar to second type and millimeter-rank. The forth one is frame-vug-lining lace between micro-column thrombo-stromatolite which the thickness of laces is also similar to second type and millimeter-rank. The fifth type is vug-and-cavern-lining botroidal-lace fillings in paleokarst dolomite which the thickness of laces is thick up to centimeters, some millimeters.

The dolomite crystals in laces in later four types are vertically growed upright from the walls of vugs, caverns and fractures as lining but some botryoids with radial growth up. The residual pores or caverns filled by laces are partly filled by mega crystalline dolomite or quartz and both. They created good porosity systems for the ancient rocks as a gas dolomite reservoir rock.

PETROGRAPHIC AND GEOCHEMICAL ATTRIBUTES OF SILURIAN AND DEVONIAN DOLOMITIZED FORMATIONS IN THE HURON DOMAIN, MICHIGAN BASIN

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This study provides a preliminary examination of dolomitization and other related diagenetic processes in Silurian and Devonian carbonates of the eastern side of the Michigan Basin (Huron Domain). Nature and composition of dolomitizing fluids which modified the pre-existing limestones, timing of dolomitization, the paragenetic sequence of different types of dolomite, and the evolution of diagenetic fluids are key questions that are addressed in this research. Core samples from multiple deep boreholes within the Huron Domain were analyzed for petrographic and isotopic composition of these carbonates. The diagenetic history of the Silurian and Devonian formations include calcite and anhydrite cementation, mechanical and chemical compaction, dissolution, silicification, and dolomitization. Petrographic analysis indicates the presence of three and four types of dolomite in Devonian and Silurian formations, respectively.

Devonian formations are characterized by the presence of a pervasive replacive micro to fine-crystalline (<50µm) dolomite matrix (RD1), a pervasive replacive medium to coarse (>50-100µm) crystalline dolomite matrix (RD2), and a selective replacive medium to coarse (>50- 100µm) crystalline dolomite matrix (RD3 commonly associated with dissolution seams). All three types of dolomite are non-ferroan and show dull red to non-luminescent (RD1-RD2) and red to bright (RD3) under the CL. Same dolomite matrix types with similar characteristics were distinguished in the Silurian formations (RD1, RD2 and RD3). In addition to these types, a coarse (>500 µm) crystalline ferroan saddle dolomite cement filling fractures and vugs is observed in the Silurian rocks. Early and late stage calcite cements have been distinguished in both groups of formations including isopachous, syntaxial overgrowth, dog tooth, drusy and blocky calcite.

Preliminary isotopic data show an overlap between $\delta^{13}C$ and $\delta^{18}O$ values in Silurian and Devonian dolomites. In both Devonian and Silurian samples $\delta^{13}C$ values fit in the range of values estimated for the marine calcite of equivalent age. As a result, they are interpreted to have the same carbon content of the precursor limestones. $\delta^{18}O$ values, however show evidence of dolomite alteration upon recrystallization. The negative shift of $\delta^{18}O$ in early-formed dolomite can be due to alteration during burial. A comparison between data collected in this study and data presented in previous studies carried out in the center of Michigan Basin shows similarities in terms of $\delta^{13}C$ and $\delta^{18}O$ values.

ORIGINAL PF CRYSTAL DOLOMITE AND ITS RESERVOIR FORMATION MECHANISM IN THE XIXIANGCHI FORMATION, UPPER CAMBRIAN IN SOUTHEASTERN SICHUAN BASIN

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This paper takes the thick and widely distributed crystal dolomite of Xixiangchi Formation in Southeastern Sichuan basin as an example, the reservoir characteristics and main controlling factors of crystal dolomite have been analyzed systematically, and the genesis and reservoir formation mechanism of crystal dolomite have been discussed. It shows the main reservoir rocks of crystal dolomite are powder and finely crystalline dolomites, and the intercrystal pores and dissolved intercrystal pores are the main reservoir space, with few dissolved vugs and fractures developed. The pores structures analysis shows the throats of crystal dolomite reservoir are mainly lamellar throats, and reflecting a good configuration between pores and throats, medium- low porosity and low permeability, representing typical porous-type reservoir. Dolomitization analysis indicates the dolomitization occurred in the penecontemporaneous or early diagenetic stage. The degree of dolomitization decreased gradually from the top to the bottom of each sedimentary cycle, and distribution of dolomite in the study area shows the content of dolomites decreases from the west to the east, which reflects the degree of dolomitization weaken eastward. Combined with the geochemical characteristics of crystal dolomite, the C and O isotope show the same characteristics of sea water during the late Cambrian. It indicates that the dolomitization might be related to the seepage-reflux of sea water in the early time. Recrystallization played an important role in the genesis of the crystal dolomite, because most of crystal dolomites remain residual granular texture. The intercrystal pores formed by seepage-reflux dolomitization acted as superior seepage channels for the reservoir transformation, and the recrystallization adjusted the previous pores and make the them better, while the karstification was the key to the dissolved pores formation.

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MOTTLED DOLOMITE IN THE LOWER CAMBRIAN LONGWANGMIAO FORMATION IN THE NORTHERN SICHUAN BASIN, SOUTH CHINA

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At the end of Early Cambrian time, the Sichuan basin (South China) was located in a wide carbonate platform, with hundreds of meters of carbonate deposited. The Longwangmiao Formation carbonate in Sichuan basin is partially to completely dolomitized, displaying a mottled texture in the northern area of the exposure. The mottled dolomitic limestone developed parallel to bedding, with shape irregular boundaries with limestone that has not been dolomitized. The mottled dolomite is composed of powder crystalline and finely crystalline dolomite, while the matrix limestone is composed of micritic calcite. the isotopic composition of mottled dolomite ($\delta^{13}C$=+0.29‰PDB, $\delta^{18}O$=-1.15‰PDB) is similar to that of micrite calcite ($\delta^{13}C$=-0.49‰PDB, $\delta^{18}O$=-1.45‰PDB) indicating a fluid of like origin during dolomitization. Both isotopic values and trace element data indicate that the dolomitized fluid is originated from sea water. Some beds contain gypsum pseudomorphs and mud cracks, indicating a shallow and evaporative environment with local high salinity during deposition. Dolomitization likely took place early, in part as a result of sea water salinity concentration. Trace fossils *Thalassinoides horizontalis*, *Thalassinoides callianassa* and *Planolites* developed in the Longwangmiao Formation, and the sharp edges of mottled dolomite are similar to these trace fossils. The beds are intensely bioturbated. In the burrow network, the sediments and burrow fill were coarse and loose with little clay, and it is interpreted here as being easier to be dolomitized than the surrounding sediments. Partial dolomitization is thus interpreted to have occurred in the burrow system, and the degree of dolomitization was related to the degree of bioturbation, which is controlled by the trace-making creatures.

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NEW INSIGHTS ABOUT ULTRA-DEEP DOLOMITE RESERVOIR OF WELL TS1 (8408 m) IN TARIM BASIN, NORTHWEST CHINA

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Abstract:

Well TS1 as the deepest well onshore in Asia (2007) discovered high-quality Cambrian dolomite reservoir up to 9.1 % at depth of 8407.56 m together with a small amount of liquid hydrocarbon. Although some research works have been carried out by some scholars, the controversy about the genesis of the dolomite reservoir is endless. It has been recognized that the Cambrian strata of Well TS1 are composed of Awatage Formation (ϵ_2, evaporitic environment, platform margin facies, algae dolomite) and Lower Qiulitage Group (ϵ_3, restricted platform facies, crystalline dolomite and grain dolomite), which was previously believed that the 1,524-meter-thick stratum was Upper Cambrian. The change in strata understanding poses challenges to the previous understanding of dolomite reservoir genesis.

Based on detailed core investigation, there are three types of reservoir spaces as follows: (A) isolated, stratiform/stratified, pore-form regular-irregular millimeter-centimeter holes; (ϵ_2); (B) The centimeter-level solution-enlarged fractures associated with the high-angle fracture system which were filled with millimeter grade saddle dolomite cement or centimeter-grade calcite cement (ϵ_2 and ϵ_3); (C) a large number of micrometer-millimeter pinholes (ϵ_2 and ϵ_3). Based on the microscopic petrological analysis, cathodoluminescence analysis, carbon and oxygen isotopes, strontium isotope, rare earth analysis, and integrated published data, we propose that type A may be formed by the dissolution of quasi-stable minerals during the Penecontemporaneous period and type A&B should be related to hydrothermal fluid activity due to dissolution and recrystallization. The preservation of dolomite reservoir space may be related to multiple factors such as the role of dolomitization, limited pore fluids, and hydrocarbon charging which inhibits further cementation and filling.

Keywords:

Ultra-deep; Dolomite reservoir; Cambrian; Tarim Basin

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GENESIS OF DOLOMITE AND KEY FACTORS OF RESERVOIR IN YINGSHAN FORMATION OF GUCHENG AREA, TARIM BASIN

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Dolomite reservoir in Yingshan Formation of lower Ordovician in Tarim Basin provides a potentially important hydrocarbon exploration field. However, the ancient carbonate reservoir has experienced significant tectonic and diagenesis throughout its long geological history. These processes have greatly complicated the dolomite reservoir properties, with strong heterogeneous characteristics. This paper takes the dolomite reservoir of Yingshan Formation in Gucheng area as an example, and 500 samples were collected to reveal dolomite genesis and controlling factors of dolomite reservoir. And two new understandings have been put forward.

Firstly, reservoir space types in Yingshan Formation were systematically studied with the use of cores, thin sections, CT scanning and physical properties data. Fabric selective reservoir space includes intergranular pore, intercrystalline pore, and intragranular pore. None-fabric selective reservoir space includes structural fracture and pressure solution seam. Reservoir space is dominated by the fabric selective reservoir space and it mainly exists in fine-coarse crystalline dolomite, with average porosity, 2%-4%.

Secondly, the distribution of pores has stratification and cycle. The pores mainly developed in the top of upward shallowing sequences, and their formation was related to exposure surface, which was caused by sea-level drop. Huge oxygen, carbon, and strontium isotope elements, trace elements, and rear earth elements were analyzed, and the results reflected that dolomitization mainly took place in the shallow-medium burial phase, with the sea water as the main dolomitization fluid. Some dolomite was partially modified by hydrothermal fluid in the later buried stage, which was demonstrated by silicon isotopic and oxygen isotopic. And the size of crystals was associated with the size of protolith structure and its pore size. The bigger that the protolith structure and pore size was, the coarser the crystalline dolomite would be. This is a good explanation why most reservoir spaces in Yingshan formation mainly developed in the fine-coarse crystalline dolomite. Dolomitization did not produce pores directly. Because of its strong anti-compacting ability, dolomite mainly inherited the early pore, such as intergranular pore and intercrystalline pore. However, early dolomitization protected most early pores from being compacted. This understanding may be useful in guiding the prediction of ancient dolomite reservoir in Tarim Basin and other areas.

Characteristics of Dolomite Reservoirs of Panlongdong Outcrop in Northeastern Sichuan Basin, China

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Panlongdong outcrop lies in Xuanhan County, Sichuan Province in China. In this outcrop, both organic reefs in Upper Permian Changxing Formation, and oolitic shoals in Lower Triassic Feixianguan Formation are well exposed. According to combined lithology study and thin section identification, three depositional facies, basin margin slope, open platform, and restricted platform are identified and Permian and Triassic stratigraphic boundary is redefined in this outcrop.

The thickness of Changxing Formation is about 130m, with 2 cycles of reef complex, each cycle divided into reef-base, reef-core and reef-cap. Reef-base is mostly composed of bioclastic limestones. Mainly bafflestones and framestones formed the reef-core facies, with sponges, hydroids and algae being the main reef-building organisms, and brachiopods, bivalves, crinoids, gastropods, foraminifera, etc. and micritic or sparry cements filling the spaces between skeletons. On top of the reef-core are dolomitized bondstones and bioclastic dolostones. Grain banks and oolitic shoals deposited in Feixianguan Formation member 1, with a thickness of about 35m. Upward micrite dolostones interbedding with marlites of tidal-flat or lagoonal facies are found.

Both reef-core skeleton and bioclastic rocks in Changxing Formation and grain bank and oolitic shoal facies in Feixianguan Formation are intensively dolomitized. Favorable reservoirs are found, with a lot of dissolution pores and cavities filled or half-filled with calcite or bitumen, where dolomitization most develops, like in the 5th, 6th, and 11th layers of the outcrop. Intercrystalline and intergranular dissolution pores are the most important reservoir space, followed are vugs, moldic pores and dissolved fractures. Dolomitized sponge framestones in Changxing Formation and oolites in Feixianguan Formation member 1 form the best reservoirs, which is different from previous studies of this region, and adds Feixianguan Formation member 1 to the exploration target layers.

Dolostones in both Changxing and Feixianguan formations show similar petrographic properties of burial dolomite, and geochemical characteristics of high $^{87}Sr/^{86}Sr$ isotopes, lower Sr content, higher Fe^{2+} content, relatively higher $\delta^{13}C$, and very negative $\delta^{18}O$. The homogenization temperature and salinity of fluid inclusions are very high, indicating that the dolomitization fluid of both formations comes from the same marine-origined saline formation water in Feixianguan Formation.

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Origin of ferron dolomite in the Majiagou Formation of the Ordovician in Ordos Basin, NW China

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Abstract According to the crystalline form and size, dolomites from 5th member of the Ordovician Majiagou formation, Ordos basin, can be divided into two types: M-type microcrystalline dolomite and F-type fine crystalline dolomite. Both M-type and F-type dolomite have a high Fe content, however, Fe is not uniformly distributed in two types of dolomite. In the M-type dolomite, the Fe content of the matrix dolomite is 583×10^{-6}~3811×10^{-6}, the iron mainly exist in dissolved mold pore filling, the Fe content of coarse crystalline pore-filling dolomite is 29112×10^{-6}~47148×10^{-6}, and Fe evenly distributed in the dolomite crystal. The Fe content of fine crystalline pore-filling dolomite is up to 81752×10^{-6}, however, Fe enriched in the edge of the dolomite crystal. In the F-type dolomite, the Fe content of the matrix dolomite is 233×10^{-6}~2007×10^{-6}, and that of fracture and pore filling dolomite is high, up to 9178×10^{-6}. Fe is uniform distribution and enrichment in the pores. The value of δ^{13}C(V-PDB) and δ^{18}O(V-PDB) of the M-type dolomite are -3.5‰~1.4‰ and -6.5‰~-8.0‰, respectively. Those of fine crystalline pore-filling dolomite are -0.7‰~-2.7‰ and -9.8‰~-11.5‰, those of coarse crystalline pore-filling dolomite are -1.7‰~-2.9‰ and -9.9‰~-11.3‰, which could be influenced by hydrothermal fluid. The value of δ^{13}C(V-PDB) and δ^{18}O(V-PDB) of the F-type dolomite are -0.4‰~-0.8‰ and -5.3‰~-6.6‰, which are closer to that of the sea. Fe of two types dolomite may be derived from the overlying clay rocks. After experiencing a long exposure to weathering and erosion, a large number of pore in dolomite were formed, and the iron clay overlying dolomite were remained. When entering the burial again, iron-rich fluids in clay under the action of gravity, migrated to the dolomite. When reaching a certain temperature and depth, the oxidation state Fe^{3+} turned into reduced state Fe^{2+}, making it easier to enter Fe^{2+} into dolomite lattice, forming iron-rich dolomite.

Key word: ferron dolomite, pore, Majiagou Formation, Ordovician, Ordos basin

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Multidisciplinary integration research on the recognition of hydrothermal dolomitization and alteration of reservoirs in Taq Taq Oilfield, Kurdistan region, Iraq

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Abstract：Based the core petrographic description, fracture statistics, comprehensive interpretation of seismic and logging data, analogues with other confirmed examples, this paper analyzed the identification marks, development timing, genetic model and distribution of the hydrothermal dolomitization and its alteration on the reservoir quality. The lower part of Shiranish formation and most part of Kometan and Qamchuaq formations in some wells were altered by hydrothermal dolomitization (HTD), which contains mainly massive-matrix-replacement dolomites and void-or-fracture-filling saddle dolomites dotted with small amount of other hydrothermal minerals, such as pyrite, celestite. The occurrence of HTD is present by three forms: the first is that the stratabound mudstones or wackstones with planktonic foraminifera were altered as subhedral, medium-fine grade crystalline replacive matrix dolomite. The second is that thick-bedded grain (mainly rudist fragment) limestones with initial high porosity and permeability were altered into mottled coarse grain dolostone. The third is that saddle dolomites and anhydrites filled the fractures and vugs in fault belts. Celestine-saddle dolomite-anhydrite can be used as main hydrothermal mineral assemblage to identify the hydrothermal origin. The homogenization temperature of void and fracture-filling saddle dolomite exceeds the burial temperature of the host rock during the emplacement of saddle dolomite. The hydrothermal fluids preferentially flow upwards along the extensional and transtensional fault systems, where dolomitization mainly occurs on the hanging walls (graben) and extends laterally in the porous and permeable layers shortly after deposition of sediments in very shallow burial environment. The timing of fault activity can be determined by the fault growth index. In this case, the geometry of altered rocks was with stratification, the limestone strata near the fractured zone were also modified by hydrothermal dolomitization, which display great irregularity. The alteration of hydrothermal dolomitization on reservoir is complicated. The dolostone formed along the main fault has lower matrix porosity than dolomite a little far from main faults, because over-dolomitization usually happened in the position with more active hydrothermal fluid flow. Local reservoir quality is obviously improved with matrix porosity of about 6%. The dolomite is generally more fractured than the limestone, so dolomitization has greatly increased the fracture density and improve the flow capacity of the reservoir. High-resolution velocity inversion of post-stack seismic data is the foundation of prediction of lithology; this method can effectively describe the velocity change of lithologies, together with the lithological velocity differences from logging lithology, the spatial distribution of hydrothermal alteration areas can be predicted. This study is significant for reservoir modeling and production strategies.

Key words：Carbonate, hydrothermal dolomitization, genetic model, reservoir alteration

SEISMIC EXPRESSIONS OF SAND INJECTITES AND EXTRUDITES PRODUCED BY LOWER CRETACEOUS VOLCANIC ACTIVITY IN THE SOUTHERN NORTH SEA

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A recent investigation of a 3D seismic cube from the Broad Fourteens Basin, southern North Sea (Dutch sector), yielded 31 kilometer-scale vent complexes and associated sand remobilization in the form of injectites and extrudites of Mid-Hauterivian age. The vent structures were studied by using supervised neural networks on 3D seismic data tied to three wells. The structures are composites of 58 subvertical pipes and are 951 ± 364 m in height and 487 ± 426 m in diameter and emanate from directly above the V- and saucer-shaped amplitude anomalies seen in otherwise chaotic Zechstein reflections interval, interpreted as igneous intrusions. Eighteen are conical in shape, seven reverse conical – their base is wider than the tip and ten are cylindrical, while five of them are ellipsoidal in a planar view. Six structures are tilted or skewed and seven of them are relayed before Top-Triassic horizon and/or Posidonia Fm horizon (regional source rock). Two structures contain 7 and 10 linearly linked pipes while most of them (21) consists of only 1 pipe, five are composed of 2 pipes, two of 3 pipes and one structure has 4 pipes starting at the base that converge into a single pipe. The reflections surrounding the lower part of the structures in Triassic host rocks are deflected upward, while the reflections of the overlying Jurassic strata are bent downward. When imaged trough neural network the structures show lateral injectites in the form of sills that often end in a dike. The upper part vent geometry is mostly of eye shape (23), nine being partly eroded at the Base Cretaceous Unconformity, while six vents have dome-like upper structure indicating potential extrusion of sand to the Earth surface. Two vents end in extensive sills. We attribute focusing of volcanism to Late Jurassic-Early Cretaceous dextral reactivation of faults from Sole Pit Basin in the west to East Sudetic Basin in the east, including the Broad Fourteens Basin. As the hydrothermal vent complexes bypass a regional source-rock and seal, they offer new migration routes and connectivity between potential reservoirs, thus impacting future hydrocarbon exploration in the region.

Research on seismic attribute analysis in the Chepaizi uplift

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Chepaizi uplift lies in the northwest of Junggar basin, which belongs to the secondary tectonic unit of West Junggar upthrust, where is close to the Zhayer mountain in the west and takes Hongche fault Belts as east boundary, while the south boundary is Sikeshu sag and Yilinheiergen mountain and with Kexia fault-folding zone in the north.
Seismic attribute extraction has become one of the key techniques of exploring the sequence stratigraphy and sedimentology of complex depositional [1]. Seismic attributes based on measurements of time, amplitude and frequency are effective for geologic interpretation. It was found that the properties of the amplitude and complex seismograms do not have obvious response to the fan delta, and there was a certain corresponding relationship between fan-delta and properties of coherent and statistical attributes.
Coherence attribute is a type of efficient and mature tools for mapping geologic edges such as faults and/or channels in the 3D seismic interpretation. However, coherence attribute is sensitive to low signal-to-noise ratio seismic data, and the coherence results are affected by the dipping structures. Due to the large energy gap between the low and high frequency components, the low frequency components play the principal role in coherence estimation. In contrast, the spectral variance balances the difference between the low and high frequency components at a fixed depth. The coherence estimation based on amplitude spectra avoids the effect of the time delays resulting from the dipping structures. Combining the spectral variance with the amplitude spectra avoids the effect of dipping structures and enhances the anti-noise performance of high frequency components. In this study, we attempt to compute coherence by using the amplitude spectra of the spectral variance as input. Based on this algorithm, stratal slices have been used to clearly depict the boundaries of sedimentary facies especially on the lithological pinch line and the sedimentary facies types have been identified, they are shallow braided-river deltas, fan deltas, littoral and sublittoral lakes, braided rivers, and terminal fans.

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GLACIAL TO POSTGLACIAL SEDIMENTARY ENVIRONMENTS AND PROCESSES IN GRAND LAKE (LABRADOR)

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ABSTRACT

High resolution multibeam bathymetric data and acoustic subbottom profiles were collected during the summer of 2016 in Grand Lake (Labrador) in order to reconstruct the history of sedimentation since deglaciation in this 54 km-long and 3 km-wide fjord-lake that is one of the deepest in eastern North America. The newly acquired dataset reveals a complex lake-bottom geomorphology and thick sediment-fill characterized by 1) steep sidewalls incised by a dense dendritic network of gullies in glaciomarine sediments; 2) a deep (240 m) and flat bottom formed by the accumulation of a > 30 m drape of glaciomarine, paraglacial and postglacial sedimentary sequence consisting of closely-spaced high amplitudes reflections enclosing semi-transparent sediment layers corresponding to mass-movement deposits (MMDs); 3) a large-scale mass-movement scar and its associated downslope deposit in the central sector of the lake. This mass-movement was probably triggered by an earthquake that occurred during the deposition of the glaciomarine unit, i.e., during deglacial times; and 4) a large delta that progrades from the mouth of Naskaupi River showing series of crescent shaped bedforms (CSB) on its frontal slope and prodelta, indicating the occurrence of sediment density-flows in modern times. On the subbottom data, these CSB are also observed in the glaciomarine unit, indicating that such density-flows were active during deglaciation. As observed in many other fjords and fjord-lakes, a moraine forms a sill near the southern end of the lake. This ice-contact deposit indicates a phase of stabilization of the Laurentide Ice Sheet margin that occurred during its northwestward retreat slightly after 8 ka BP.

Application of high-precision Magnetic Anomaly to shale gas exploration in Lower Cambrian marine shale reservoirs: A case study of the Lower Cambrian Niutitang Formation in the Cen'gong block, southern China

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Abstract: The accumulation pattern of the marine shale gas in South China is different from that in North America. The former has generally thin reservoirs and complex preservation conditions, so it is difficult to make a fine description of the structural features of shale formations and to reflect accurately the distribution pattern of high-quality shale by using the conventional seismic exploration technology. Moreover, the complex surface conditions and and high and steep stratigraphic in the south of China limits the fuction of conventional seismic exploration methods. Most of all, The stratums exposed are mainly comprised of the Cambrian strata, being characterized by sedimentary rocks such as limestone and dolostone, which both have weak magnetic susceptibility compared with the metamorphic rock in the basement, so it's feasible to carry out high precision to meet the needs of the shale gas exploration in terms of structural interpretation, lithological interpretation and fracture prediction. In view of these, high-precision magnetic prospecting focusing on lithological survey was implemented to make an accurate description of the distribution of shale gas sweet spots so that commercial shale gas production can be obtained. Based on data processing such as data correction, reduction-to-pole of magnetic data, space transforming, derivative conversion, smoothing filter and regularization filter, 10 high accuracy aeromagnetic anomaly zones were delineated, and the top depth of buried magnetic bodies and basement buried depth of basin were calculated. It is shown that there is a tight correspondence between magnetic anomaly and the shale gas enrichment region in the Lower Cambrian Niutitang Formation in the Cen'gong block, southern China. Our research can guide shale gas exploration and development in this area and balance the high upstream exploration cost, and continue to push the efficient shale gas exploration and development process in China.
Key words: shale gas; magnetic exploration; cap rock; magnetic basement; fracture

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PALEOGEOGRAPHIC EVOLUTION DURING THE MESOZOIC DEFORMATION IN KUQA-TABEI AREA OF THE TARIM BASIN AND ITS RESPONSE TO TECTONIC SETTING

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Tectonic deformation stages of superimposed basin indicated by extensive angular unconformities, always resulted in significant mutation of paleogeographic.With the establishing of regional sequence framework by tracing tectonic unconformities, an investigation of paleogeographic evolution during deformation and its response to tectonic setting is important in unraveling dynamic evolution and petroleum accumulation of a basin. Mesozoic tectonic-stratigraphic framework is established and paleogeographic evolution during the Mesozoic deformation in Kuqa-Tabei area and its response to multiple phases of orogenesis around the basin are documented based on the integral analysis of seismic, drilling and core data in this paper. Four regional angular unconformities (TT, TJ, TK and TE) and one parallel unconformity (TK1bs) developed and divided the Mesozoic into four second-order sequences corresponding to Triassic, Jurassic, latter Cretaceous Kapushaliang Group and latter Cretaceous Bashijiqike Formation. Four key deformation stages occurred in the late Permian, in the late Triassic, in the late Jurassic and in the late Cretaceous. At the end of Permian, respective rising of Tianshan Mountain and Kulun Mountain together contributed to the extending of Wensu, Xiqiu, Xinhe and Yaha Paleo-uplift and the formation of Kuqa foreland basin. Large scale sublacustrine fan and fluvial fan developed close to the paleo-uplifts and braid delta developed along the slope area. At the end of Triassic, Kunlun Mountain orogenic zone rose abruptly, resulting in the development of unconformity TJ and the mutation of paleogeographic. The distribution range of paleo-uplifts enlarged dramatically and the development scale of braid delta also became larger. In latest Jurassic, northwards collision and suturing of Lasa Block, Qiangtang Block, Eurasia and Himalayan Terrain took place, causing the erosion of Pre-Cretaceous and the mutation of paleogeographic. At the end of Kapushaliang Group, only Wensu paleo-uplift kept explosion with a few small fluvial fans around. Delta facies mainly developed instead of braid delta in Triassic-Jurassic. The Cretaceous Bashijiqike formation period was a structural stillstand with a low sedimentation rate and a flat topography of foreland slope. Lateral migration of the channel occurred frequently, contributing to the lateral superimposition of braided delta throughout the study area. In the late Cretaceous, South Tianshan Mountain uplifted violently and finally obducted into the northern margin of the Tarim Plate. Under the tectonic compression, integral uplifting took place and paleogeographic changed again.

An integrated sequence stratigraphic analysis in three-dimensional perspective: A seismic case study of the Pearl River Mouth Basin, northern South China Sea

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ABSTRACT: Sequence stratigraphy is extensively used as a guide for stratigraphic correlation. However, unified sequence architectures based on long-distance analyses from shelves to deep basins are still scarce, leading to ununified sequence stratigraphic surfaces and regional hierarchical orders in different datasets. Lateral variations caused by supply-driven sequences along shelf margins are also poorly documented. In this study, an integrated sequence stratigraphic framework is carefully investigated by systematically correlating datasets on dip and strike orientations. The study method yields a three-dimensional (3D) perspective of seismic volumes covering approximately 12000 km^2. Moreover, several two-dimensional lines calibrated with 21 well-log data are interpreted. The investigation focused on the stratal succession between two maximum flooding surfaces within the Hanjiang Formation in the Pearl River Mouth Basin at the northern part of South China Sea that spans a sequence boundary of 13.8 Ma. The depositional sequence model is applied, and the interval of interest is divided into four, namely, highstand systems tract (HST), falling-stage systems tract (FSST), lowstand systems tract (LST), and transgressive systems tract (TST). The features of each systems tract are described by combining seismic facies, amplitude volumes of root mean square combined with 3D visualization techniques, well-log interpretations, and isopach maps. The study generated a number of results. First, the features, variability, and plan-view distribution of systems tracts in sequence along dip- and strike-oriented cross-sections suggest shelf margin evolution. Second, improvements in systems tract identification (i.e., LST, TST, and HST) indicate a uniform sequence stratigraphic framework for the region, further resulting in a renewed appreciation of physical positions and isochronous stratigraphic correlations. FSST is developed during the falling stage of base levels and it is characterized by a supply-independent feature in long and lateral distance. Third, a subtle distinction in tracking a seismic event in a limited and 2D perspective may lead to huge differences under a 3D window when establishing the sequence stratigraphic framework. A 3D perspective with sufficient and extensive data can greatly improve interpretation accuracy. Fourth, the FSST is recognized and distanced of the LST above and the HST below. Finally, key solutions for deep-water sequence stratigraphy are suggested deciphering sequence-stratigraphic frameworks in clinoforms and tracking into deep-water areas. They are monitored for spatial utility, continuity, and regional mappability. A model-independent research strategy is selected over the conventional approach of submarine fan dissection, because the latter may lead to oversimplified sequence models in a limited scope.

Keywords: Systems tracts, Depositional sequences, Pearl River Mouth Basin, Northern South China Sea

Well logs decomposition: an effective method for sequence stratigraphic analysis in conglomerate reservoir

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Sequence stratigraphy analysis is one of the most important tasks in evaluating and characterizing the reservoir system. It has been proved that we have a very good relationship between the well logs patterns and sedimentary cycles[1]. Emery and Myers (1996) defined the prototype between patterns of well logs and sedimentary cycles. They summarized five patterns: cleaning-up trend, dirtying-up trend, boxcar trend, bow trend, and irregular trend. Each pattern has a corresponding sedimentary cycle. However, the well logs patterns in the real application usually is deviated from the ideal patterns, especially for the reservoirs with strong heterogeneity, such as conglomerate reservoir.

Based on the fact that the system tracts and lithofacies usually illustrate cycle features within the basin, we propose to decompose the well logs into different intrinsic modes to characterize the sequence units at the different scale. As an example, we adopt the variational mode decomposition (VMD) [2] to decompose the selected well logs into an ensemble of different band-limited intrinsic mode functions, each with its own center wavenumber.

We validate the effectiveness of our method in the lithofacies and sequence identification for a conglomerate reservoir in the Shengli oil field, Bohai bay basin, east China. The decomposed intrinsic modes with larger center wavenumber perfectly characterize the sequence units at larger scale. While the decomposed intrinsic modes with smaller center wavenumber well reveal the lithofacies changes at small scale.

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The application of seismic isochronal strata slice and its dynamic technology in sedimentary evolution research

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Main text: The traditional research of sedimentary evolution in basins is usually based on geological outcrops and field geologic profiles due to the depth of burial. With the correlation between geophysical bodies and their geophysical responses, more and more geophysical techniques have been applied to various aspects of sedimentary basin research, especially seismic exploration techniques.

The isochronal strata slicing technique is a new research method that analyzes the distribution and shape of geological bodies from the lateral direction. Controlled by high-precision sedimentary sequence grids, the seismic isochronal strata slices which extracted from seismic data can be used to analyze the horizontal variation of the lithology of geological bodies at the moment of deposition, and to analyze the sedimentary distribution, and thus analyze the process of sedimentary evolution. Its accuracy can far exceed traditional seismic methods that rely on vertical resolution. A single isochronal strata slice can be used to study the depositional spread at that moment, and multiple consecutive strata slices can be used to analyze the sedimentary evolution of the depositional moment in the study area. This method can save the huge research cost of three-dimensional display in the past, and can be completed only with some small production software.

With the above techniques, the accuracy and efficiency of sedimentary studies in the Turpan, Junggar and Sichuan basins have been greatly improved. The research results of basin sedimentation using seismic isochronous strata slices have also been widely used, and have achieved good results in oil and gas exploration with high precision requirements.

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Geochemical characteristics of Chang-9 source rocks in Yanchang Formation of Triassic in Ordos Basin and its implications for shale oil exploration

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Ordos Basin is the most important production area of tight oil in China, mainly due to the existence of two sets of high-quality source rocks, namely the Chang-7 and Chang-9 source rocks of the Triassic Yanchang Formation. In the past, the geochemical characteristics of Chang-7 source rocks have been studied more and more deeply, but the geochemical characteristics and exploration potential of Chang-9 source rocks are weak. By using rock pyrolysis， microscopic examination of kerogen， istope， gas chromatography， GC-MS and other analysis methods， the organic geochemical characteristics of the dark mudstone of Chang-9 member in Upper Triassic of Ordos Basin and its significance of hydrocarbon exploration were studied． The results show that the main source rocks in study area are Lijiapan shale at the top of Chang-9_1, and the geochemical characteristics of the dark mudstone of Chang-9_2 show that they are not the petroleum source rocks． The source rocks on Chang-9 mainly consist of silty or siltbearing mudstone， which are not the real clay rocks． The average organic carbon content is 3.05%， and the main kerogen type is type II_1， and the average highest pyrolysis peak temperature is 450 ℃． These show that the source rocks rank is good ones and in the mutual stage． The types of parent materials are characterized by the common input of the lower aquatic organisms and higher plants， and the water environment of lake basin is the fresh water reduction condition as a whole． The comprehensive evaluation shows that Chang-9 develops the better hydrocarbon-generating condition， which tends to generate oil． The region whose thickness is over 10m is the favorable exploration target area of Chang-8 to Chang-10 petroleum accumulations．

NATURAL SEALED FRACTURES FROM THE MONTNEY-DOIG UNCONVENTIONAL RESERVOIRS TIED TO BURIAL AND TECTONIC HISTORY OF THE WESTERN CANADA FORELAND BASIN

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Characterizing the factors controlling the occurrence of natural fractures in fine-grained deposits such as mudstones, is key to better understand the evolution of porosity and permeability in these tight rocks. This understanding can provide additional constraints to calibrate basin and reservoir models for the exploration and production of unconventional resources.

A multidisciplinary approach (including sedimentology, fracture diagenesis and fluid inclusion microthermometry) has been applied for the first time to natural mineralized fractures (i.e. veins) hosted by the Lower-Middle Triassic Montney-Doig unconventional resource play of the Western Canada Sedimentary Basin. The aim was to define the factors controlling the occurrence of natural fractures in relation with the host rock properties as well as with the geological evolution of the Canadian Cordillera fold-and-thrust-belt and the associated foreland basin.

Forty-five core samples (2100-2500 m in depth) were collected from two wells from an unconventional field in British Columbia. These sediments present variable mineralogy and organic content (TOC of 1.2 to 3.7 wt% measured with the Rock-Eval 6 Shale Play protocol) and were deposited in shoreface to offshore environments.

Three generations of veins were identified. A first generation of vertical fractures is cemented by a calcite precipitated at about 110 °C from basinal brines and which carries oil and aqueous inclusions recording the migration which occurred in the Cretaceous (~100Ma). A second generation of horizontal fractures is cemented by calcite that carries mono-phase liquid CH_4±CO_2 inclusions, indicating that they formed after gas generation, probably at higher temperatures. A third generation of vertical fractures also contains monophase liquid CH_4±CO_2 inclusions and post-dated the second generation based on petrographic evidences.

The cathodoluminescence response and the oxygen and carbon isotopic signature ($\delta^{18}O$ and $\delta^{13}C$) are very similar for all the studied calcite cements, irrespective of the fracture orientation and core provenance, suggesting calcite parent fluids in equilibrium with the host rock. This suggests that the Montney-Doig formations behaved like a closed system through time, and possibly acted as the source rocks of the unconventional system, at least in this part of the basin.

Host rock facies and matrix diagenesis partially controlled the occurrence of the fractures. Indeed, vertical veins are more abundant in the coarser facies (coarse siltstone and very fine sandstone) and in hemipelagic facies (calcispheric dolosiltstones) which have undergone early cementation, whereas the horizontal veins are rather localized in very fine facies (clay and silt).

The three identified generations of fractures were integrated to the burial history of the Montney-Doig formations and discussed within the broader context of the basin geodynamic evolution.

SEDIMENTATION TYPES AND THEIR INFLUENCE ON TOC ACCUMULATION WITHIN THE LOWER SILURIAN LONGMAXI MARINE SHALE IN THE UPPER YANGTZE AREA, CHINA

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With the Fuling Jiaoshiba shale gas field (first commercial shale gas field in China) established in the southeast Sichuan Basin, more and more petroleum geologists believe that there is a great potential for shale gas in the Upper Yangtze area. However, there are different views on sedimentation types and their controls on shale gas. Based on outcrops, cores, thin section, QEMSCAN, geochemistry data, we analyzed the sedimentation characteristics and their influences on the Longmaxi marine shale in the Upper Yangtze area. The results show that normal shelf suspension, biological sedimentation, deposits of volcanic ash (bentonite), bioturbation, contourite and gravity flow deposits were developed in the Longmaxi Formation in the Upper Yangtze area. Normal shelf suspension together with biological sedimentation lead to formation of the graptolite shale which is characterized by abundant graptolites developed. Deposits of volcanic ash (bentonite) are mainly concentrated on the Wufeng Formation to the bottom of the Longmaxi Formation in the forms of thin layers interbedded with black shale. The contourite is characterized by shale interbedded with siltstone laminas with some micro low angle cross lamination, abundant graptolites with certain orientation arrangement, and some pyrites lamination showing lateral migration. Gravity flow deposit is mainly composed of massive light grey siltstone with obvious irregular scour surface, deformed beddings and some mud-gravels developed.

Varied sedimentations have different influence on TOC accumulation in the Longmaxi marine shale. The results show that volcanic ash brings abundant nutriment, leading to the blooming of algae, radiolarian and graptolite, which further result in high paleoproductivity. Combing with anoxic environment, high TOC was accumulated at the bottom of the Longmaxi Formation. However, the contourite, mainly developed in the middle part of the lower member of the Longmaxi Formation, has a dilution effect on the process of the organic matter, leading to TOC decreased in the contourite. The gravity flow, mainly developed on the upper part of the lower member of the Longmaxi Formation, brings abundant coarse terrigenous matter into the shelf, resulting in destruction of the ecological environment and leading to shale with low TOC in the gravity flow deposits.

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Thermal maturity of Devonian shales in Horn River Basin using biomarker and non-biomarker index

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We investigated the organic matter characteristics of shale samples from the Horn River Basin in Canada using Rock-Eval pyrolysis analysis, gas chromatography, and GC-mass spectrometry. To further understand and refine estimation of thermal maturity, we evaluated more thermally stable biomarker and non-biomarker, and then compare the data to thermal maturity parameters obtained from petrographic and geochemical analysis. Therefore, the most thermally stable of complex saturated hydrocarbons (e.g. pristane, phythane) and non-biomarker maturity parameters (e.g., methylphenanthrene index) should be apply for estimating thermal maturity in shale gas reservoir in Horn River Basin. TOC (total organic carbon) values range from 1.5 to 6.8 (av. 3.8) wt% and RC (residual carbon) contents represent up to 90% of TOC. The results indicate that most of PCs (pyrolysable carbons) have already been converted to hydrocarbon and organic pores have been developed. Therefore, it is difficult to estimate reliable thermal maturity from the Rock-Eval pyrolysis due to low S_2 values. On the other hands, Pristane/n-C_{17} (0.2 ~ 0.6) and Phytane/n-C_{18} (0.3 ~ 0.9) ratios show generally consistent decreases with increasing thermal maturity. Thermal maturity were examined through the use of the distributions of Phenanthrene (P) and Methylphenantrenes (MP) based on m/z 178 and 192 mass chromatograms, respectively (Radke et al., 1982). Estimated R_o from The methylphenanthrene index (MPI-1) ranged between 1.88 and 1.93 which suggests the last stage of wet gas generation. Thus, the Devonian shales in the Horn River Basin would have good potential of gas generation and storage.

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Pore System Characterization in the Cretaceous Eagle Ford Formation

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In the last two decades, the need to understand the pore systems of organic matter-rich mudstones has increased hugely as they have changed from being solely source rocks to important hydrocarbon reservoirs. Quantifying the pore systems of these fine-grained reservoirs is hugely challenging due not only to their extensive textural and mineralogical heterogeneity but also the sub-nanometer to micrometer size of pores. Definition of the reservoir storage and flow system, which underpins effective production, thus requires a very detailed, quantitative understanding of the porosity system and its relationship with rock texture. This work focuses on the Cretaceous Eagle Ford formation, an organic-rich marl that trends across Texas and which produces around 1.5 million barrels of oil and 5 bcf of gas per day. In order to understand the nature and evolution of the pore system, we have analysed a set of 46 samples from outcrops and six different wells with maturities of 0.4%, 0.8% and 1.2% Ro. XRD, transmitted and reflected light optical microscopy, EDX, and SEM techniques have been used to reconstruct the mineralogical and textural framework in which the porosities occur. Carbonate contents range from 37 to 84% and TOC values from 0.5 to 7.9%. Petrographic studies show that the organic matter is mainly marine type II and that microfacies vary from finely laminated marls to fossiliferous limestones. The paragenesis of the samples, in particular the diagenesis of carbonate and the generation and micromigration of organic phases, has been determined with BSEM and SEM-EDX. At all maturities, porosities appear more frequent in the presence of fecal pellets, which are almost entirely composed of coccolithic debris. The organic matter seems to inhibit the precipitation of calcitic cements and to preserve the porosities at all the maturities analysed. Clays, on the other hand, vary with depth as predicted and obstruct the inter and intraparticle porosities. MicroCT of mm-size cores, calibrated with high-resolution FIB-SEM, has identified the occurrence and connectivity of the main textural domains (organic matter and porosity, microfossiliferous material, fine-grained argillaceous/carbonate matrix and pyrite), and the nature of the pore system in each domain. In the low maturity samples, the main porosity types are interparticle, enclosed within the argillaceous and coccolithic matrix, whereas in most of the mature samples the pores present a more spherical shape, suggesting that they are mainly situated within the migrated and in-situ OM. Pore systems have been characterised using a combination of high-resolution SEM, mercury injection porosimetry and gas sorption. Pore sizes, calculated by analysing and combining data between SEM images and gas adsorption, appear to have a bimodal distribution with modes around 10-20 nm and 50-200 nm. Current work, using ESEM, AFM and nano-IR, is focussed on analysing wettability changes on the pore surfaces. Pure calcite crystals and freshly cleaved rock chips from different maturities were analysed at the nanoscale by means of CFM and nano-IR AFM. Variations in the samples and in the fluids at which the surfaces are exposed lead to different adhesion forces that can be converted in wettability changes. This work is aimed at understanding the controlling factors of the chemical interactions between fluids and mineral surfaces.

BEYOND BULK GEOCHEMISTRY; INTEGRATED ANALYSIS OF ORGANIC-RICH SHALES TO DETERMINE HYDROCARBON POTENTIAL: AN EXAMPLE FROM THE EARLY SILURIAN QUSAIBA.

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This study is based on organic-rich core samples taken from three wells drilled southwest of the Ghawar Field, Saudi Arabia. High resolution graptolite and palynological dating indicates that the cored organic-rich basal Qusaiba source rocks are all from the earliest Silurian *acuminatus-ascensus* graptolite biozone and underlain by the Qusaiba Transgressive Siltstone of the latest Ordovician age. Geological core descriptions and mineralogical data indicate that the 616-5 well represents a very different paleoenvironment compared to 488-31_1 and 807-3.

The Qusaiba organic-rich source rocks are often regarded as being composed of marine Type II kerogen that has matured with burial. Optical analysis of the organic matter (OM) shows that there are significant variations in the organic components making up the OM. The abundance of fluorescent structureless brown OM (BOM) and relatively higher concentration of Acritarchs and Leiospheres indicates that the geologically differentiated 616-5 well contains significantly more hydrogen-rich and oil-prone organic matter than the other two wells.

To determine the true original hydrocarbon generation potential of a sample, it is necessary to understand the composition of the organic components and their relative hydrocarbon potentials, both in terms of geochemical composition and kinetics. Initial analyses of separated fluorescent and non-fluorescent BOM using Rock-Eval, gave HI values of 415 and 160, respectively. Additionally, interpretation of initial thermal pyrolysis gas chromatograph results for separated samples of graptolites and chitinozoans indicates that they are equivalent to geochemical organic matter Type III. As a validation process, the average percentage of each organic matter component in the low maturity 616-5 and 488-31_1 wells, was multiplied by the HI value of the equivalent geochemical organic matter type. Organic component weighted HI values were determined for each of the wells that are almost identical to the average bulk rock HI values obtained from routine Rock-Eval for the same sample sets. Analysis of the biomarkers associated with each of the different organic matter components has been initiated.

Given the observed variability in organic components the use of a whole rock kinetics model (even if defined in the Qusaiba) could incorrectly predict both the hydrocarbon charge type and timing outside of the local area where it was defined. The advantage of using the organic component composition is that the appropriate ratio of the different component specific kinetics models can be used to determine the true hydrocarbon generation potential of an area.

To determine the degree of hydrocarbon generation for each organic component, a very tightly constrained maturity determination is necessary. Using organic matter grain mounts, significant reworking of organic matter was recognized that would significantly affect bulk geochemical and average reflectance based maturation estimations. While the in-situ graptolite reflectance could be converted to vitrinite reflectance equivalent (VRe), there is significant uncertainty in the grap_Ro to VRe conversion. A potentially more reliable approach to determine VRe is to use the spore coloration index (SCI) via a digital spectrum analysis on a number of key species tied directly to vitrinite reflectance.

OUTCROP SHALE CHARACTERIZATION OF BAYAH FORMATION IN GUNUNG WALAT AND SURROUNDING, SUKABUMI, WEST JAVA, INDONESIA

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Lithology of Bayah Formation is characterized by quartz sandstone to conglomeratic, shale, and coal. This formation was deposited in Bogor Basin, West Java during Middle Eocene to Early Oligocene[1]. At this period in Gunung Walat and surrounding was a transition depositional environment between marine and terrestrial, marked by deposition of Bayah Formation that evolved from deltaic in lower part to meander fluvial in middle part, and braided fluvial in upper part. Therefore Bayah Formation in this research area is deposited in fluvial-deltaic environment. Sedimentation is interpreted occur in extensional phase, probably in the form of a rift basin.

Overall, shale of Bayah Formation in Gunung Walat and surrounding areas is clay to silt dark color which indicates rich organic material. Therefore, it is necessary to evaluate its ability to generate hydrocarbon. Thus integration results of geochemical and stratigraphic analysis show that 20 shale outcrop samples have total organic carbon richness range from 0.69% to 8.44%. High value of TOC in shale Bayah Formation is due to reduction environmental condition, so that organic material can be well preserved. The depositional facies corresponds to reduction conditions are flood plain, natural levee, and delta plain. Then, pyrolisis analysis applied to 15 shale outcrop samples which have TOC value above 1%. The results indicate as kerogen type III, which is generally organic material derived from high plants where grow on the land. Based on Tmax maturity value ranges from immature to over mature (429.20 ^{0}C – 498.80 ^{0}C), but according to Ro values are immature to mature (0.422-0.904 %). Through reconstruction from geological section and stratigraphic correlation in the research area, it is known that the maturity level corresponds to stratigraphic position of shale from bottom to top. Finally, based on geochemical parameters from shale characterizations of Bayah Formation in Gunung Walat and surrounding areas are categorized as capable of producing hydrocarbon that have reached oil-gas window.

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RECONSTRUCTING LITHOFACIAL VARIATIONS AND DEPOSITIONAL PROCESSES IN CARBONIFEROUS BLACK SHALES

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The mineralogical composition and lithofacial variations of black shales within the sequence-stratigraphic context were analyzed with the objective of determine stratigraphic trends, the detrital input from the source area and the correlation between the inorganic and organic components of the shales. The Carboniferous post-rift succession of the investigated shales of the northwestern part of the Dniepr-Donets Basin (Ukraine) is characterized by cyclic deposition of siliciclastic and minor carbonate rocks in fluvial, lagoon and shallow-marine environments, whereby the orangic-rich shale intervals alternate with sand intervals. On the base of the vertical and lateral lithofacial classification of the basin[1], a well for a detailed analysis was selected, with a high sampling rate (1 metre interval) intersecting Tournaisian to Upper Viesean layers (productive horizons T-4/5 to V-16). Qualitative and quantitative X-ray diffraction analysis was carried out for the lithofacial classification by means of 99 bore core samples in the depth range of 4191 to 5733m. Leco and rock-eval parameters provided information concerning the percentages of TOC, sulphur and thermal maturity data[2].
Within the Tournaisian (T-4 to T1), Lower Visean (V-27 to V-24) and Upper Visean (V-23 to V-14) cycles, the alternating depositing conditions are reflected by variations of the following mainly occurring minerals: kaolinite-group minerals, mica-group minerals, chlorite-group minerals, expandable clay minerals, quartz, carbonates, pyrite, siderite and feldspar. The selective mineral composition depends on paleoclimatic change and varying input from the source area. The Tournaisian period is characterized by high contents of kaolinite, likely related to Hangenberg climatic event, with intercalations of quartz-rich layers, carbonate contents up to 16 %, pyrite up to 10 % and the indication of salt-tectonics. A carbonate layer constitutes the transition from Tournaisian to Lower Visean (V-25) period followed by carbonate-quartz-rich layers. In horizons V-23 (Rudov Beds) and V-22 a maximum TOC content of up to 4.2 % occurs and the main mineral groups comprise kaolinite, quartz, illite and siderite. In Upper Visean (mainly in V-22, V-19 horizons) the increasing content of expandable clay minerals indicates post depositional heat flow. The different transport properties cause the selective concentration of kaolinite and illite. The uppermost part of the Upper Visean succession distinguishes itself by the occurrence of chlorite and a higher amount of diagenetic plagioclase due to the conditions of formation in the central basin.

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The geological characterization of the Wufeng-Longmaxi shale in Sichuan Basin, Southwest China

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The Wufeng-Longmaxi marine shale in the Sichuan Basin and its adjacent area is currently the most successful shale gas exploration target strata in China (Tan et. al., 2015, Zou et. al., 2015). In order to deepen the understanding of the sedimentary environment and geological features of this organic-rich shale and to provide reference for exploration, a comprehensive research including petrology, geochemistry, petrophysics, shale gas content has been carried out.

The study shows that the Wufeng-Longmaxi shale was deposited under deep water shelf-shallow water shelf environment, which is generally a deoxidized environment with a certain layer of dehydration in the water body. The water body in early period for the shale was strongly reduced, and the water reducibility was gradually weakened in the later period. the paleo-productivity was the highest during the middle term of the Longmaxi Period. The sedimentary environment influenced the thickness and distribution of organic-rich shale, and the later tectonic movement determined the shale buried depth. The depth of the Wufeng-Longmaxi shale is mainly between 2000m and 6000m, the thickness of organic-rich shale with total organic content (TOC) over 2wt% is about 15 to 90 m. The shale has high TOC (1.0% to 6.5%), and is over matured (Ro>2%). The shale kerogen type is mainly type I. It is brittle with brittle mineral content over 70%. The reservoirs storage types of the shale could be identified as organic pores, interparticle pores, intercrystalline pores, dissolved pores, and micro-fractures. The preservation conditions of the shale are good in the basin and relatively good in the synclines around the basin.

The present study implies that Wufeng-Longmaxi shale in the south and southeast part of Sichuan Basin is superior in geological conditions and has good shale gas exploration potential. It is the most favorable shale gas exploration target in the basin. The shale geological condition in the orogen areas adjacent to Sichuan Basin is more complex but still has good exploration potential for the future.

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Determination of paleo-fluid pressure in fine sediments of Wufeng-Longmaxi Formations in the Sichuan Basin, Southwest China

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In geological history, inclusions captured in the strata recorded activity information of ancient fluid, carrying substantial weight in deciphering the secret of paleo-temperature and pressure fields, has been universally found its application in the processes of diagenesis and mineralization in petroliferous basins. In order to study paleo-fluid pressure of shale in the study area, the sandy interlayers and calcite veins in large set of mudstones were chosen as the research objects for paleo-fluid pressure analysis. It mainly includes the analysis and measurement of parameters such as homogenization temperature, salinity and freezing point temperature of inclusions, and laser Raman analysis to identify the type of fluid captured in the inclusions. In determining the paleo-fluid pressure, three methods were mainly adopted in the calculation: (1) the paleo-pressure simulation method, this method conducts pressure simulation by using *PVTsim* software and can directly obtain capture temperature and pressure of inclusions, but not all inclusions enable the determination of isochore; (2) Laser Raman analysis method. This method is suitable for analyzing the relationship between Raman shift and pressure in the methane-water system, and measuring multiple sets of data for Raman shift. An experimental formula for calculating pressure was achieved by fitting Raman shift with pressure; (3) the parameter calculation method, the formula for calculating pressure varies in different inclusion types. In the pure methane system, the trapping pressure can be determined and calculated by state equation of methane system. It is indicated in the study that different inclusion types, pure gas-phase system and liquid system were found in thin section observation. Different methods used were compared to analyze superiorities and inferiorities. Temperature and pressure have a pivotal influence on shale gas occurrence that paleo-fluid pressure in shale reservoirs is of great significance for the analysis of gas occurrence in geological history.

Keywords: Sichuan Basin, shale gas, fine sediment, paleo-fluid pressure

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The sedimentary environment and characterization of the Late Ordovician-Early Silurian dark shale in Upper Yangtze Platform, Southwest China

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The prospects of the shale gas are dark shale rich in organic matter in Upper Yangtze Platform of southwest China. So far, the sedimentary environment which affects significantly on shale accumulation and its evolution are not well understood. The current work aims to study the paleoceanic sedimentary environment of this organic-rich shale by lithofacies analysis and an integrating characterization approach including petrology, paleontology and bulk rock geochemistry (total organic carbon, $\delta^{13}C$ of bulk organic matter, vitrinite reflectance, and elemental analysis) of the shale.

According to the field investigation and sample testing results, the lithofacies of the shale could be summarized as carbonaceous siliceous shales, carbonaceous argillaceous shales, silty and calcareous shales. The plankton graptolite was prevailing in both carbonaceous siliceous shales and carbonaceous argillaceous shales, and the radiolarians could be seen in siliceous shales. Redox indices (Mo, U, Th/U, Ni/Co, V/Cr and V/(V + Ni)) and $\delta^{13}C$ values suggest that carbonaceous siliceous shales and carbonaceous argillaceous shales were deposited in a relatively anoxic and stagnant marine environment (Arthur and Sageman, 1999), whereas silty and calcareous shales were deposited in a relatively oxygenated marine environment. The ratios of Al/(Al+Fe+Mn), Si/(Si+Al+Fe) and Al-Fe-Mn ternary diagram indicate the quartz in carbonaceous siliceous shales is mainly biogenic (Tan et. al, 2015). Productivity proxies (Cu/Al, P/Ti and Ba/Al) denote that paleoproductivity (Dean et. al., 1997) was relatively high in carbonaceous shales but low in silty and calcareous shales.

The present study suggests that the Upper Yangtze Platform was a restricted deep water system influenced by its surrounding ancient uplifts, favorable for developing dark organic-rich shale with good potential for shale gas exploration.

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DEPOSITION AND DIAGENETIC PATHWAYS OF THE LONGMAXI SHALE IN THE SICHUAN BASIN, CHINA: IMPLICATIONS FOR PORE EVOLUTION IN FINE-GRAINED SEDIMENTARY ROCKS

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Depositional processes, environment condition, and subsequent diagenetic modifications are key factors in controlling the formation of organic-rich shale, pore development and preservation in shale reservoirs. In order to understand the pore evolution in fine-grained sedimentary rock, thin section examination, X-ray diffraction analysis, SEM with cathodoluminescence, geochemical analyses and pore structure characterization were combined to investigate the Longmaxi shale, which is key targets for shale gas exploration and development in Sichuan Basin, China. The results reveal that depositional process of Longmaxi shale contains the suspension, biogenic, storm, and bottom current deposition. High paleoproductivity and dysoxic/anoxic conditions controll organic matter accumulation. The Longmaxi shale with different detrital components shows an obvious difference in diagenetic pathway. Siliceous shale comprises an abundant amount of diagenetic quartz (40-60%), which inhibits compaction and preserved internal primary pores as rigid framework for oil filling during oil window. Silty shale contains a large number of detrital silt-size grains (30-50%), which is beneficial to preserve interparticle pores. Argillaceous shale with abundant extrabasinal clay minerals (>50%) undergoes mechanical and chemical compactions during burial, leading to a near-absence of primary interparticle pores. Pore-filling calcite and dolomite precipitated during early diagenesis inhibit later compaction in calcareous/dolomitic shale, but the cementation significantly reduces the interparticle pores. Besides argillaceous shale, all of the other lithofacies are dominated by OM pores, which contribute more micropores and mesopores. In addition, development degree and pore size of OM pores in different diagenetic pathway with the same OM type and maturity show an obvious difference. Therefore, we suggest that the development of OM pores should take OM occurrence into account, which is related to physical interaction between OM and inorganic minerals during burial. Migrated OM in siliceous shale with large connected networks is beneficial for forming more and larger pores during gas window. The result of the present work implies that the study of deposition and diagenesis are better understanding the pore evolution in fine-grained sedimentary rocks.

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VIRTUAL OUTCROP STRATIGRAPHY OF A DELTA FRONT COLLAPSE: CASE STUDY OF TRIASSIC GROWTH BASINS, EDGØYA, SVALBARD

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Growth basins commonly occur on delta slopes and fronts as places of thick sediment accumulation with differential rates of loading and consequent subsidence. An ancient collapsed delta is exposed on the 300-m-high cliffs of Kvalpynten in southwest Edgøya, eastern Svalbard (Norway). The 13 exposed growth-basins were studied by combining virtual outcrop, photo, and field data in order to decipher their complex stratigraphy. The growth basins are developed into the De Geerdalen Formation and were formed during the Carnian by movement of mostly listric faults (thetic and antithetic) that seem to sole out in shales of the Tschermakfjellet Formation. The basins are filled with up to three wedge-shaped parasequences deposited in a river-dominated environment with a strong tidal influence. The wedges are thickening-upward, indicating, in this shallow-marine environment, a progressive increase in available space probably associated with the main growth phase. To reconstruct the subsidence history, we use the top surface of genetic depositional units as reference datum. Thanks to this back-stripping method, 7 stratigraphic stages of deposition in the Growth – basin zone can be distinguished. Thickness differences of the deposits across basins and stratigraphic levels testify that the basins subsidence and development was temporally and spatially differentiated. The delta collapse nucleated in the northern part of the cliff and progressed by opening basin by basin until it reached its maximum at stratigraphic stage 5. The delta front stabilized again in the last two stratigraphic stages leading to thick fine-grained sediment accumulation, followed by a complex pattern of delta lobes progradation and lateral migration. We presume that the trigger for basins subsidence is a combination of regional thermal subsidence and local differential loading of the sedimentary pile. This study highlights the advantages of using the virtual outcrop environment, allowing seismic-scale inquiry of the architecture coupled with high-resolution sedimentary data obtained from field logging.

MULTIPLE SCENARIOS FROM DIVERSE THERMAL INDICATORS: CONTRASTING ORGANIC VERSUS MINERAL-BASED METHODS FOR A FRONTIER INTRACRATONIC BASIN IN THE CANADIAN ARCTIC.

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The burial and thermal histories are critical elements in the evaluation of conventional and unconventional petroleum systems. For years, thermal parameters obtained through Rock-Eval and organic petrography have been the preferred approaches to understand the thermal evolution of basins. Various mineral-based methods have also been developed and increasingly applied to comprehend the thermal history of sedimentary successions. The Paleozoic Hudson Bay Basin in the Canadian Arctic is a large intracratonic basin and after an initial exploration phase (5 wells) in the 1970-1980 period, it was abandoned as based on Rock Eval 2 data, source rocks were deemed immature. However, all wells had gas kicks and bitumen-rich intervals. A research project by the Geological Survey of Canada aims at re-evaluating the petroleum systems of this basin with a particular attention to understanding its burial-thermal history. The burial-thermal research focusses on the Upper Ordovician stratigraphic interval at the base of the 2500 m preserved succession. Organic matter-rich source rocks and porous potential reservoir units (reef and hydrothermal breccia) occur over a short stratigraphic interval. These are particularly well exposed on Southampton Island at the northern reach of the basin where satellite and airborne radar images have identified nearby potential seawater oil slicks and hydrographic surveys have mapped seafloor pockmarks. The Upper Ordovician Type I-IIs shales are rich in TOC (up to 35%), with high HI value (average 630 mg HC/g TOC). New organic-matter based thermal indicators from Rock-Eval 6 and reflectance petrography indicate that the outcropping Upper Ordovician shales are immature (T_{max} below 435°C and average R_{vit-eq} of 0.44%). Inverse modeling of apatite fission tracks data from basal Upper Ordovician sandstone suggest that the succession reach the early oil window with an acceptable temperature envelope of 65 to 85°C and best fit data of 72°C. Thermal evolution from fluid inclusions microthermometry data in early and late carbonate cements from porous Upper Ordovician reefs has identified an early hydrothermal event (T_h of 120°C) and late burial oil window conditions (T_h of 93°C); clumped isotope temperature data from these cements are currently being acquired. Therefore, assuming proper analytical techniques, various organic and mineral-based thermal analyses could yield significantly different results.

Accumulation of lacustrine shale oil in Triassic Chang 7 Member in Ordos Basin and its controlling factors

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The seventh member of Yangchang Formation (Chang 7 Member) of Triassic in the Ordos Basin contains high-quality source rocks of black shale and dark mudstone. However, it has frequently changed lithologies. In the lake-basin center, fine-grained sedimentary rocks represented by interbeds of shale, mudstone, silty mudstone and muddy siltstone are dominant, with fine siltstone sandwiches, with *TOC* of 0.27–20.7% (averaging 4.32%)[1-2]. In this study, a 178 m continuous drilling core was used. Through high-density systematic tests on geochemistry, lithofacies, reservoir property, and hydrocarbon generation and expulsion of source rock, it is found that, microcosmically, the mud shale in the Chang 7 Member contains organic lamina, clay lamina and carbonate lamina. Shale oil was generated in organic lamina, and then migrated to organic-poor formations along carbonate lamina, clay lamina, siliceous lamina and fractures. The shale oil of Chang 7 Member mainly accumulates in the mud shale interval with lower organic matter content, but less in the mud shale interval with higher organic matter content, showing the vertical difference of shale oil enrichment. Shale oil enrichment is controlled by source rock quality, thermal evolution degree and adsorption capacity of clay minerals. First, higher organic carbon abundance in source rocks corresponds to bigger hydrocarbon expulsion quantity and less detained movable oil quantity. Shale oil enriches in the source rocks with relatively lower organic matter abundance (*TOC* <1%) near high-quality source rocks. Second, clay minerals have certain adsorption capacity, which can reduce the hydrocarbon expulsion efficiency of source rocks. Source rocks have hydrocarbon expulsion efficiency >50%, and clay mineral contents < 45%. Third, for the shale with low organic matter abundance, the oil saturation index (OSI) has negative relationship with the content of minerals, especially clay minerals. For *TOC*=0.27% and clay mineral content=92%,OSI=32.85 mg/g.*TOC*;for *TOC*=0.37% and clay mineral content= 20.50%,OSI=145.55 mg/g.*TOC*.In summary,the Chang 7 Member has favorable potential for exploring shale oil. Especially, the dark massive mudstone with lower *TOC* and the mud shale with rich terrigenous debris and lower *TOC* are key targets for shale oil exploration and development.

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Study on the difference of gas and water distribution in tight gas reservoir of Guang'an gasfield, Sichuan basin

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ABSTRACT: The distribution of gas and water are complicated in Xujiahe formation of Guang'an gas field. And the production capacity is different in Xu-4 and Xu-6 formation. So comparative analysis in gas and water distribution is of great significance. According to the difficulty in interpretation of gas and water layers, a proper method was proposed to identify them. In the first place, the water saturation model was established in different subsection by core analysis. And the mobile water saturation was counted by irreducible part obtaining from NMR and relative permeability curve data. Finally, identification standard of gas and water layers was built by mobile water and production data. Then gas and water distribution characteristics were compared between Xu-4 and Xu-6 formation. The result show that a large area of gas bearing with water is found in Xu-4 formation, but considerable sweet spot areas in Xu-6 formation. What's more, the controlling factors were analyzed on the basis of gas and water layers recognition. It shows that differences in source condition make the fullness ratio in Xu-4 and Xu-6 formation different. Secondly, the reservoir constituent differences control the liquid distribution in Xu-4 and Xu-6 formation. Finally, the structure differences provide the diverse differentiation of gas and water in Xu-4 and Xu-6 formation.

Keywords: difference analysis, distribution of gas and water, Xujiahe formation, tight gas reservoir, Guang' an gas field

RECONSTRUCT PALAEOENVIRONMENT OF TERRESTRIAL SHALE WITH SALT FORMATION

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Shale oil exploitation is a hot topic in china currently, and is the next key replacement resources. An interesting and noteworthy characteristic of favorable shale oil production layer in china, is that the terrestrial shale reserivior accompany with salt enrichment, typically for Dongpu depression of Bohaiwan basin.

According to the previous studies, salt formation is associate with the palaeoenvironment tightly, such as paleosalinity, palaeoredox conditions, occlusive-open system, hydrothermal, etc. Sha-3 member of Eocene shahejie formation in Dongpu depression is a favorable shale oil production layer with abundant salt, which was chosen to make research in this study. Eighteen samples have been picked from salt region, transitional region and no-salt region separately, as the comparison. In this study, trace elements analysis methods have been carried out to analyze the palaeoenvironment.

Boron element analysis of modern sediments has been widely used to reconstruct paleosalinity of ancient lacustrine basin. We used couch calibrated the Freundlich isotherm to calculate the paleosalinity. Results show that the paleosalinity of salt region ranges is larger than the other two region when sediments deposits in ancient lacustrine. Redox-sensitive trace elements, such as Mo, Ni, V, U, Re, Mn, etc., being enriched exceptionally in various geological periods and setting of shale formation, have been used to analyze the redox environment during deposition in this study. In the study area, U/Th ratio of most samples in Sha-3 member are less than 1, indicating a normal waterborne deposits and no hydrothermal input in Dongpu depression. Overall, U/Th ratio correlate positively with the TOC in Sha-3 member, which because U/Th ratio may have a close relation with organic matter in mudstones. The U/Th ratio of salt region is larger than that of transitional region and that of no-salt region. This phenomenon indicate a fairly strong capacity for organic matter retention in the salt region. V/(Ni+V) was utilized as palaeoredox indicator, and reveal the redox conditions during deposition. Overall, the V/(Ni+V) value of samples in this study are larger than 0.5, revealing an anoxic and reduction condition when Sha-3 member formation. Whereas, the V/(Ni+V) value in salt region are larger than that in transitional region and no-salt region, indicating a more anoxic environment which is more beneficial for organic matter retention.

The researches about Salt formation mechanism of terrestrial shale are meaningful and beneficial to reveal the distribution of terrestrial shale oil.

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STUDY ON TIGHT SANDSTONE RESERVOIR OF CHINA EAST SEA BASIN: DIAGENESIS AND PORE CHARACTERISTICS

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Main text: The diagenesis of tight sandstone is mainly studied by employing cast thin section and SEM (scanning electron microscope). The diagenesis processes such as compaction, corrosion and cementation can be achieved by the observation of cast thin sections and the diagenetic intensity can be evaluated as well. By the observation of SEM, pore structures and crystal morphology of minerals can be obtained, especially for the observation of euhedral minerals which can be used for the identification of mineralogical types. Pore characteristics including physical properties of porosity and permeability, and pore structure, can be obtained by using mercury injection and NMR (Nuclear Magnetic Resonance). And the former reflects the distribution of pores smaller than10μm, with the latter reflecting a scale of less than 200μm. The data obtained from the two manners can be validated each other. Tight sandstone in East China Sea Basin mostly is in moderate compaction with a minor in strong compaction. The grains of sandstone are in line-contact, with a minor of continent and serrated contacts. It is weakly cemented, and there are the observations of carbonate cementation in several samples in only one well. Meanwhile, dissolution is ubiquitous in all samples. First, the dissolution of feldspar accounts for 60% approximately, and residual framework of feldspar can be observed due to the domination of strong dissolution. Second, the dissolution lithologic debris accounts for 40% approximately, secondary to the contributions to reservoir quality compared with that of feldspar dissolution. Under microscopic observation, the grains of sandstone are wrapped by chlorite film, a leaf-shaped structure known as only occurred in early diagenesis stage. Apparently, euhedral mineral is quartz, of which the size ranges between 10um to 100um, indicating it is in early-middle diagenetic stage. Pore radius distribution characteristics can mainly be described as "Bimodal Distribution", which means smaller pore and larger pore can be easily distinguished. Mercury injection and NMR data can be verified only under certain condition. And it is suggested that sandstone with a thinness of less than 30m and a depth of more than 4000m, mainly contains a porosity of less than 10%.

Key words: Diagenesis, Pore characteristics, Compaction, Dissolution, Euhedral quartz

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IDENTIFICATION AND PREDICTION OF KARST RESERVOIR IN MAOKOU FORMATION, SOUTHERN SICHUAN BASIN

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The karst reservoir of Lower Permian Maokou Formation has a great potential of exploration and development in Sichuan Basin, NW China. This study takes Maokou Formation in Hebaochang area, southern Sichuan Basin, as a case to analyze its development mode, evaluate and predict reservoirs by using plenty of drilling data, logging data and seismic profile interpretation. Fracture-vuggy reservoirs and fractured reservoirs are developed in research area, and the former is the main reservoir type of wells with stable and high yields according to single-well testing production and single-well cumulative production. The dissolved pores serve as the main reservoir spaces, while the fractures connect them.

Fracture-vuggy reservoirs can be identified by the logging response characteristics as followed: low gamma ray (generally between 5-20API); low density, (generally between 2.5-2.75g/cm^3); medium-low resistance (generally between 100-3000Ω•m) and obvious difference between the resistance of deep lateral logging and shallow lateral resistance logging; high interval transit time (generally between 46-55μs/ft); the values of neutron are generally above 1.5%; the calculated porosities based on three porosity log curves are generally more than 2%. The karst reservoir of Maokou Formation has explicit vertical zonality, and it can be divided into the upper reservoir (P_2m^3-P_2m^2a) and the lower reservoir (P_2m^2b), which are 0-50meters and 50-100meters from the top of Maokou Formation respectively. With poor lateral communication, the heterogeneity of reservoirs is strong. Drilling drops and leakings are common. Through forward modelling, synthetic record calibrating, wavelet picking and seismic section analyzing, the study summarizes the seismic response characteristics of fracture-vuggy reservoirs. For the upper reservoir, the amplitude of wave crest decreases at top and the amplitude of wave trough decreases below. For the lower reservoir, the bright spots are extremely clear in seismic section. On the basis of logging and seismic response characteristics, the study chooses attributes such as volumetric curvature, energy gradient calculating, and coherence to predict reservoirs.

The predictions prove a good consistence with the actual drilling wells. It is of great significance to guide the exploration and development of karst reservoir outside the high position of structures.

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Research on sedimentation control factor of deep tight sandstone reservoirs

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A major breakthrough has been made in oil and gas exploration of tight sandstones in the deep reservoir of Xihu Sag of the East China Sea Shelf Basin. Therefore, it is particularly important to strengthen the study of its deep reservoir. Deep reservoir quality is affected by many factors, this study carried out research on reservoir control factors from the perspective of sedimentation. The adoption of microscale lithofacies as the research unit, and the comparative study of lithofacies under different sedimentary microfacies, analyzed the differences in physical properties of different types of lithofacies. Studies have shown that hydrodynamic strength controls the physical properties of lithofacies. The lithofacies formed in high-energy environments exhibit better physical properties. The stronger the hydrodynamic strength is, the larger the set scale of the cross-bedding and the better the physical properties of the reservoir. The set scale of the cross-bedding is positively correlated with the hydrodynamic strength and physical properties; The more fine-grained components, the poorer the physical properties of the reservoir. It shows that the content of fine-grained components is negatively correlated with the physical properties; The lithofacies of different sedimentary structures in the same lithology, from cross-bedding, parallel-bedding, massive-bedding to ripple lamination, the physical properties of the lithofacies gradually worse. Deep favorable reservoir should be best composed of gravel lithofacies, sandstone with gravel lithofacies, and cross-bedding sandstone lithofacies formed in high-energy environments.

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Heterogeneity in oil-bearing tight sandstone:A case study on the Chang 7 oil formation in Trassic, Ordos Basin, Cental China

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Main text: The geological resources and the production of tight oil in Ordos Basin rank top in China and tight reservoir is characterized by low porosity, low permeability and low pressure. However, its oil-bearing heterogeneity and formation mechanism is rarely reported. Based on the core and thin section observation, the research on the oil-bearing heterogeneity and its origin of the Chang 7 tight sandstone is conducted by fluorenscence microscope, cathodoluminescence microscope, isotope mass spectrometer and heating/freezing stage. The observation of the thin section indicates that the main factor which cause the oil-bearing heterogeneity in the tight sandstone reservior is calcite cementation and the majority cementation happened at the same period supported by examination of cathodoluminescence microscope. The result of clumped isotope of the calcite shows that the formation tempreture is about 60 degree celsius, and the homogenization temperature of the saltwater inclusions associated with the oil and gas inclusions is 90~120 degress celsius, which means that the time of petroleum accumulation is later than the cementation in the tight sandstone reservoir. The research on the relationship between the diagenesis of Chang 7 tight sandstone and the time sequence of petroleum accumulation can provide technical methods and shed light on the study of the timing of reservoir diagenesis and hydrocarbon accumulation. This study has a great significance for the reconstruction the relationship between reservoir diagenesis and oil accumulation in Chang 7 tight sandstone.

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Sedimentary Characteristics and Genetic Mechanism of the Deep-water Gravity Flows In late Triassic Yanchang Formation, Ordos Basin, China

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Abstract: The Ordos Basin is an oil and gas-bearing sedimentary basin in the central part of China with an area of 35×10^4Km^2, In the, deep-water lake area developed at the Chang 7 group in Yanchang Formation and deposited thick sand bodies, which are with special sedimentary characteristics and unclear genetic mechanism . Based on the datum of well cores description, well loggings and particle size analysis, the deep-water sandstone encountered in Chang 7 Group of Yanchang Formation in Ordos Basin was studied. It is concluded that the deep-water sandstone is mainly composed of sand-slump, sandy debris flow and turbidity-current sedimentation; Strong sandy slump can be seen with deformation deposited on the core; Turbidity flow sedimentation developed mold structure, differential load caused by the quasi-symbiotic deformation structure, Bowma sequence; Sandy debris flow developed of large sets of massive non-layered sandstone, sandstone bedding or mudstone rupture;The occurrence of the penultimate slope break of the lake basin and the recognition of the tuff and seismites in the core. The causes of the formation of the gravity flow in the sediments in the deep water area in the Chang 7 Group of Yanchang Formation were clarified. It is verified that the distribution of gravity flow sand bodies in the deep-water sediments of the lacustrine sediments in the Chang 7 Group of Yanchang Formation is in accordance with the Shanmugam model. That is sandy silt rock is distributed in the front of the delta front to the semi-deep lacustrine-deep lake slope; Sandy debris flow concentrated in the slope foot position; Turbidite distribution more frontier deepwater. The discovery of tuffs and seismites indicates that frequent volcanic and seismic geological events occurred during the late Triassic Yanchang Formation in the Ordos Basin and triggered the formation of gravel flow and the transport and deposition of sandy debris. Triggered by geological events such as volcanoes and earthquakes, the frontal sand bodies of the delta front developed plastic slump on the slopes from shallow lakes to semi-deep lakes and form massive slump rock along the waterways. Large-scale massive plastic sandstones continue to slide, which entrap the bottom mudstone to form suspended mud gravel encased in sandstone, which accumulates at the foot of the slope to form a flower-like sandy debris flow accumulation. Later fine-grained sediments continue to form deep-water turbidite deposits at the frontward or edge of the sandy debris flow block. Large debris flow and turbidite sedimentary sand formed at the center of deep-water lakes are the major targets of tight oil and shale gas exploration in the deep water area of Ordos Basin.

Keywords: Ordos Basin; Deep-water sand body; Sandy debris flow.

Geologic Characteristics of Tight Oil Reservoir in Lacustrine Mixed Marlstone of the Shahejie Formation in Shulu Sag,Bohai Bay Basin, Eastern China

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Mixed sedimentary rocks were widely developed and played an important role to tight oil accumulation in lacustrine basins in china. However, the particular genesis and complex lithology bring about a significant constraint on the evaluation and prediction of the mixed rock reservoirs. A set of lacustrine mixed “Marlstone” was developed in the Lower of the Member 3 of Shahejie Formation(abbr. as Es^3) in Shulu Sag, Bohai Bay Basin, Eastern China, which serves as main source and reservoir to tight oil accumulation. Geologic characteristics of the mixed rocks reservoir of Es^3 are revealed by comprehensive observation of core, rock section and scanning electronic microscope, combined with physical property and organic geochemical analysis. According to the mixing pattern and rock fabric, mixed rocks of Es^3 can be divided into laminated and massive marlstiones. Laminated marlstones are mainly composed of limy-mudstone, calcareous siltite and micrite which make up mm-scaled laminaes. Massive marlstones are formed by textural mixing deposition of endogenous carbonate mud and terrigenous calcareous clasts. Dominant mineral of the mixed marlstones is calcite with average content of 58%, followed by dolomite, clay mineral and quartz. Porosity of the mixed marlstones range from 0.2% to 4.0%, and matrix permeability lower than $10\times10^{-3}\mu m^2$.The reservoir spaces are dominated by intergranular pore, dissolved pore, intercrystal pore, organic-matter pore, structural fracture and bedding fracture, most of the pores are nano-scaled pores. Laminated marlstones have double porosity medium and heterogeneous pore distribution, pores mainly be found in the limy-mudstone or calcareous siltite laminaes. Because of the bedding fractures existence and relatively higher um-scaled pore proportion, physical properties and pore structure of laminated marlstone are better than massive marlstone. High chloroform asphalt "A" content and rock pyrolysis S_1 indicate that the mixed marlstone are riched in oil. Oil content of laminated marlstone are higher than which of massive marlstone, and it also increases with the TOC increasing. The “sweet ports” for tight oil of Es^3 are controlled by sedimentary facies, rock texture, organic matter abundance and maturity, fracture densities, which horizontally distribute at the inner slope zone and deep depression area of Sulu Sag and vertically distribute at the transgressive system tract and highstand system tract of each third sequence of Es^3.

MICROSCOPIC PORE THROAT STRUCTURE ANALYSIS OF TIGHT SANDSTONE AND ITS IPPACT ON FORMATION WATER DISTRIBUTION

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The Ordos Basin with low porosity and low permeability is one of the most important natural gas producing areas in China. The difference between the gas and water layers is small. Gas wells generally produce water, and the rate of water production varies. The microscopic distribution of formation water in the tight reservoir needs to be studied. Further clarifying the microscopic distribution of natural gas water has crucial practical significance for the exploration and development of natural gas in the study area. In order to solve this problem, we used rock slice analysis, rate-controlled mercury penetration, CT scanning, field emission scanning electron microscopy, nuclear magnetic resonance, and other experimental methods to study the microscopic structure of the reservoir and the microscopic occurrence of formation water. The results show that the reservoirs of micro-nano pore throats are relatively developed, intergranular pores and intergranular dissolved pores are the major pore types. And the pore radius is distributed between 0.25-1μm. Flaky and bundled throats are the major types of throat. The throat radius ranges from 0.05μm to 0.5μm. Microporous structure plays a significant role in the control of formation water and the seepage capacity is dominated by throat radius. The reservoir with simply structure, close pore radius, good connectivity of pore throat and high proportion of large throats develops a superb seepage ability. While, the reservoir with complex structure, pores with large differences in radius, and high proportion of small throats has poor seepage ability. According to the different degrees of controlling the formation water by micro-pore throat structure, the microcosmic formation water can be divided into three types: free-flowing free water, capillary water controlled by capillary force, and adsorbed water adsorbed on the pore surface. Pore throats with a radius greater than 0.21μm are used to control the distribution of free water, pore throats with a radius of 0.07 to 0.21μm are used to control the distribution of capillary water, and pore throats with radius of less than 0.07μm were used to control the distribution of adsorbed water.

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The sedimentary model and pore-structure characteristics of saline lacustrine mixed sedimentation in Permian Lucaogou Formation, Jimsar sag

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The tight oil reservoir in Permian Lucaogou Formation, Jimsar sag is the important target of unconventional oil and gas in Chinese terrestrial facies. Based on core observation, 3D CT imaging, scanning electron microscopy, pressure-controlled mercury injection, rate-controlled mercury injection, the results showed that the Lucaogou Formation in Jimsar sag was composed of typical saline lacustrine mixed sedimentation, which contains mixed sedimentary rocks and mixed sedimentary sequence. We found that the tight oil reservoir in Lucaogou Formation is consist of complex mineral compositions and multiple rock components, which embodied a strong obvious characteristic of mixed sedimentation. The terrigenous detrital, carbonate component and pyroclastic debris (tuffaceous component) formed the mixed sedimentary rocks, while the mixed sedimentary sequence are consist of interactive deposititon of terrigenous clastic rocks, carbonate rocks and volcaniclastic rock, showing three types of sedimentary sources include volcanic source, terrestrial source and lacustrine basin source. More than 50 lithologies which observed from casting thin sections can be divided into 4 rock types and 8 kinds further. Three genetic types of mixed sedimentation were revealed in this area, including source mixing, edge facies mixing and mutational in-situ mixing. Then the "multi-sources in corresponding period" mixed sedimentary model was established for the saline lacustrine sedimentary environment. The reservoir space of mixed sedimentary rocks is mainly consisted of dissolution porosity and a few micro-fractures. The sedimentary tuff, tuffaceous siltstone and calcareous or dolomitic siltstone are the dominant lithologies which has the best physical property. Micro/nano pores take the dominant position with radius range from hundreds of micrometer to tens of nanometer.

Key words: terrestrial tight reservoir; Jimsar sag; Lucaogou Formation; mixed sedimentary type; pore-throat structure

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Distribution and Controlling Factors of Tight Oil in Deep Continental Fault Lacustrine Basin in East China- A Case Study on Nanpu Depression in Bohai Bay Basin

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Unconventional tight oil reservoirs, as a new kind of potential resources in deep continental faulted lacustrine basin, have shown very attractive potential in Eastern China. However, it is a difficult problem how to evaluate tight oil resource of the lacustrine basin, because they are very different with many founded unconventional tight oil reservoirs in marine basin. Taking Nanpu depression of the Bohai Bay Basin as a case, we studied the distribution and controlling factors of the tight oil in deep continental fault lacustrine basin in East China.

There are three advantages for tight oil resources in the deep continental faulted lacustrine basin: ①There are many sets of high-quality source rocks, such as Es_1,Es_3^4,in which abundance of organic matter are high, furthermore, in oil-producing stage. And It was best source rock in which TOC>1.0 and 0.8<Ro<1.25;②There are favorable depositional facies for tight oil in deep basin. Deep lake facies are main facies, there are made of thick mudstone, delta front sand bodies and gravity flow deposited sand bodies, thin or knoll-like sands are interstratificated with mud and near resource rock.

There are also four features for tight oil resources in deep continental fault lacustrine basin: ① distribution of tight oil in fault basin is limit and areas are also relatively small, because basins are divided into many sub basins by faults in lateral direction. ②Depth of tight oil reservoirs are larger than 4000m, shallow reservoirs are usually conventional reservoirs, so it is a question how to exploit them. ③Vertical distribution of tight oil reservoirs are controlled by two overpressure belts, which are respectively Ed_2-Es_1(pressure coefficient in-between 1.2 and 1.4) and Es_2- Es_3(pressure coefficient in-between 1.3 and 1.7).

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MICRO-PORE CHARACTERISTICS AND INFLUENCING FACTORS OF LACUSTRINE SHALE IN VARIOUS LITHOFACIES: A CASE STUDY OF NANPU SAG, BOHAI BAY BASIN, CHINA

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Main text: Recently, shale oil has gradually become a new target for unconventional hydrocarbon exploration, which has been commercially exploited in USA, China, Canada, and other countries. Although pore characterization of shales has been extensively studied, pore characteristics and influencing factors of lacustrine shales in various lithofacies received less attention. In order to address this issue, the Shahejie Formation shale from Nanpu Sag, Bohai Bay Basin, China was selected for our study. Based on the study of organic geochemistry, mineralogy, SEM observation, N2 & CO2 gas adsorption of lacustrine shale in various lithofacies, the following conclusions can be drawn.

(1) Shahejie shales can be divided into four types of lithofacies: siliceous shale, calcareous shale, clay shale, and mixed shale. Among them, calcareous shale has highest total organic content (TOC) with type I organic matter, which is deposited under deep lake environment. Mixed shale has moderate TOC values, which is deposited under the transitional zone. Clay shale and siliceous shale have the lower TOC values, which is deposited under shallow lake environment.

(2) Inorganic mineral pore has a predominance of reservoir spaces in four types of shales, but different minerals have different controls on pores. Although quartz and calcite cementations can deteriorate reservoir quality, lower content of silica (<50%) will favor for pore development. Microfissures within calcareous shale can also improve reservoir quality. Clay shale has a large amount of interlaminar and intragranular pores, but it has lower average pore size and poor connectivity.

(3) Organic pores poorly developed in four types of shales, which might be related with lower maturity of shales. However, organic pores in some samples can obviously increase reservoir space of shales, which has positive effect on pore development.

(4) In the view of lacustrine shale oil exploration, calcareous shale should be the best target because of high TOC, large pore size, and excellent fracturing nature. Siliceous shale has lower TOC, but it favors for migrated hydrocarbon accumulation, which is the effective reservoir in shale oil layer. Clay shale has strong adsorption capacity and poor percolation capacity, which is not enriched with free oil and unfavorable for shale oil exploration.

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MODELING METHOD OF DISCRETE FRACTURE NETWORK BASED ON MULTI-FACTOR CONSTRAINT AND ITS APPLICATION IN TIGHT SANDSTONE

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The development of natural fracture in tight sandstone is the result of comprehensive effects of multiple factors. It's closely related to the interaction of rock fabric anisotropy, tectonic stress, distribution of sedimentary facies and structure bodies. In consideration of the strongly irregular shape of natural fracture and the uncertainty of distribution laws, with the premise of studying on sedimentary model and tectonic evolution and the basis on reservoir geomechanics, the DFN model, which is divided into the large, small-mid and micro scales, is built through analyzing and integrating the 3D seismic data, rock triaxial mechanics data, cores, dynamic data, coupling factors that affect fracture development via regression analysis method. Taking the fracture modeling of the third member of the Paleogene Shahejie Formation tight sandstone in eastern china as a case study. Firstly, analyze of the effects of mechanical conditions of cracking and lithological association on fracture type and strength by using rock triaxial mechanics data. Then a spacial distribution of fracture development zone can be characterized based on composite three-dimensional seismic attributes. In addition, the relationship between tectonic stress field and fracture parameters is quantitatively established by finite elements numerical simulation, and the fracture development zone is determined according to rupture criterion of rocks. The fracture parameters are corrected and the rupture criterion of rocks is adjusted through the thin section observations of microscale fractures. With the guidance of geological concepts, using regression analysis method, a uniform fracture density model is calculated by coupling the rock fabric anisotropy, tectonic stress, distribution of sedimentary facies and structure bodies. The DFN model is established based on the fracture density model. By coupling the fracture model with the martrix model, fitting with dynamic data shows that the model has higher fitting consistency.

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A TYPE OF CONTINUOUS PETROLEUM ACCUMULATION SYSTEM IN THE SHULU SAG, BOHAI BAY BASIN, EASTERN CHINA

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This study analyzed crude oils from the lower part of the third member of the Eocene Shahejie Formation (Es_3^L) and three prospective source rocks from the Shulu Sag, Bohai Bay basin, eastern China using a variety of organic geochemical methods. Biomarker characteristics were used to interpret source-rock organic matter input and depositional environment, and oil-source rock correlation. The biomarker data indicate that the crude oils originated from the Es_3^L source rock, which contains a mixture of plankton and land-plant organic matters deposited in brackish-fresh water under reducing conditions. The oil in the Es_3^L is self-sourced instead of migrated from the overlying source rocks. The petroleum generation potential of the Es_3^L source rock was evaluated using organic geochemistry. Total organic carbon (TOC) values for about 100 samples are between 1.02 and 4.92 wt.%, and hydrogen indices (HI) range from 285 to 810 mg HC/g TOC. The Es_3^L source rock contains mainly Type II and III kerogen and most of the samples are thermally mature. The data show that the Es_3^L source rock has good potential for liquid hydrocarbon generation. The Es_3^L rock also acts as the oil reservoir, having very low bulk porosity and permeability. Various types of storage space in the marlstone and carbonate rudstone in the Es_3^L of the Shulu Sag, include: (1) fractures, (2) intergranular pores, (3) dissolution pores, (4) organic matter pores, (5) intragranular pores, and (6) seams around gravels. Pore size ranges from nanometers to millimeters. Because the oil was generated and stored in Es_3^L strata, which are lack of obvious trap and seal and have low permeability, the unit represents a continuous petroleum accumulation.

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Microstructure of tight-gas sandstone reservoir of the fifth member of Xujiahe Formation in west Sichuan basin

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Abstract

China is abundant in tight-gas resource. The fifth member of upper Triassic Xujiahe Formation is one of the favorable sections of tight-gas exploration in west Sichuan basin. It has wide coverage and high thickness. The east side of it is thinner than the west side. The fifth member of Xujiahe Formation mainly consists of interstratification of sandstone and mudstone. We focus on the tight-gas sandstone reservoir of the fifth member of Xujiahe Formation in west Sichuan basin. Various methods, such as core thin section, cast thin section, scanning electron microscope, were used to analyze the characteristics of diagenesis and micropore texture. PerGeos was also used to build 3D model to reveal the microstructure comprehensively.

The diagenesis research reveals that dissolution and structural fracture can improve permeability while compaction and cementation could reduce the reservoir pore space. It has been unveiled that most pore space has been filled by clay mineral. Pores are usually isolated while ones near the fractures can be related. The study of microstructure reflects that dissolved pores and microfractures constitute most of the pore space in which organogenic microfractures play an important role in porosity and permeability increase.

Key words: the fifth member of Xujiahe Formation; tight-gas reservoir; reservoir microstructure;

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Sedimentary characteristics and origin of lacustrine organic-rich shales in the salinized Eocene Dongying Depression

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Lacustrine organic-rich shales are well developed within the Eocene Dongying Depression in the Bohai Bay Basin in eastern China and across Southeast Asia. This study investigates the sedimentary characteristics and formation mechanisms of lacustrine shales based on thin sections and FESEM observations of well cores combined with X-ray diffraction and geochemical indicators. Six lithofacies were identified: (1) laminated calcareous mudstone, (2) laminated dolomitic mudstone, (3) laminated clay mudstone, (4) laminated gypsum mudstone, (5) massive mudstone, and (6) siltstone. On the basis of lithofacies associations, paleosalinity values, redox properties, and terrigenous inputs, the lower Es4s shale can be divided into six intervals from bottom to top. The thickness of each interval ranges from several meters to more than 10 m, reflecting high frequency oscillations in the environment of the lake basin.

The laminated mudstones are characterized by fine grain sizes, rich in pyrite and sapropelic organic matter. These features indicate that these lithofacies were deposited out of suspension in a quiet water body characterized by a relatively low rate of deposition. The characteristic laminae of these lithofacies indicate subtle differences in depositional processes. The laminated gypsum mudstone was likely deposited in an evaporative environment, because its formation would have consumed Ca2+ and SO42-, promoting the deposition of a laminated dolomitic mudstone. In contrast, laminated clay mudstone was deposited in a manner that increased the volume of small terrigenous materials. Laminated mudstones are dominant in the lower Es4s shale, suggesting that suspension was the main depositional process leading to formation of the lower Es4s shale. In contrast, the massive mudstones were likely rapidly deposited associated with siltstone as the result of fine grained turbidites. The lower Es4s shale was formed in a depositional environment composed of a saline, medium-depth lake under anoxic conditions, with limited terrigenous inputs. The high salinity is suggested to be related to a marine transgression, which may have been facilitated by a rise in sea level caused by global warming in the early Eocene, together with the large-scale tectonic activity of East Asia. The deposition of the Es4s shale in the Dongying Depression may help us to understand the deposition of lacustrine shale, paleoclimate reconstructions for the Eocene, and the tectonic activity of East Asia.

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THE ORIGIN AND DISTRIBUTION OF CHLORITE-COATING IN TIGHT GAS RESERVOIR: AN EXAMPLE FROM XIHU DEPRESSION, EAST CHINA SEA

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The Upper Huagang Formation is the most important sandstone reservoir for large accumulations of natural gas at a depth of 3400~4500 m, in sandstones of which chlorite-coating is abundant at a depth of 3400~4100 m, while weakly developed outside. Based on petrographic description, thin section, SEM, grain size analysis, XRD date and EMPA analysis, the occurrence and formation process of chlorite-coating are investigated.

The result shows that the present chlorite-coating are composed of two layers with distinct difference in texture and orientation. The inner layer is an aggregation of small anhedral crystals rooted tightly on the gain surface, while the outer layer comprises euhedral plate crystals oriented perpendicular to the grain surface. Athough they have difference in texture and orientation, the date obtained from EMPA analysis show slight variations in their chemical composition. The anhedral and euhedral chlorite are mainly Fe-rich and the Fe/(Fe+Mg) ratio of former is slightly lower than that of the latter. Chlorite-coating can develop widely in various grain size sandstone, from very-fine sand to conglomerate. Generally, the clay-rich finer-grained sandstone tends to exhibit the greater degree of thickness and coverage of chlorite-coating compared to clean coarser-gain sandstone in which quartz overgrowth occur more easily. Meanwhile, the distribution of chlorite-coating seems to be consistent with the early undercompaction overpressure range. The development of chlorite-coating is likely promoted within the range while the chlorite-coating is discontinuous or absent outside.

The inner chlorite-coating is likely recrystallized from clay precursors during the early diagenetic stage while the outer chlorite-coating formed from alteration of Fe-Mg rich detrital grains and volcanic rock fragments by direct precipitation from pore waters during a period of early overpressure worked. The early overpressure plays a major role in slowing the mechanical and chemical compaction and promoting development of chlorite-coating to working together to restrain quartz cement. It means that the preservation of primary porosity much depends on the effect of early overpressure rather than chlorite-coating.

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Paleogeography and shale development characteristics of the Late Permian Longtan Formation in southeastern Sichuan Basin, China

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Abstract: The Late Permian Longtan Formation is extensively developed within the southeastern Sichuan basin which lies on the western margin of the Yangtze Plate in southwestern China. The stratigraphy and sequence boundaries of the Longtan Formation were interpreted from a combined study of field data, well log data and various data analysis in order to determine the extent and thickness of shale sequences. This interpretation defined the broad sequence stratigraphic framework and separated the Longtan Formation into three 3rd-order sequences. In addition, the formation was divided into five sedimentary facies using sedimentary, paleontological, geophysical and other data. The facies identified were fluvial, low energy shore, tidal flat, melanged accumulated shelf and platform basin. Three paleogeographic maps were created based on the 3rd-order sequences: SQ1, SQ2 and SQ3. The study shows that SQ1- SQ3 sedimentary environment of the study area, which extends from the southwest to northeast, was developed followed by fluvial, shore, tide, shallow water melanged accumulation shelf, deep water melanged accumulation shelf and platform basin.

The mud shale rock types of the Longtan Formation that were identified are carbonaceous mud shale, silty mudstone and lime mudstone. According to the divided standard of mud shale effective thickness, there are three mud shale assemblages present in the sequences SQ1, SQ2, SQ3, namely, mud shale with sandstone, mud shale with limestone, and mud shale. SQ1 has the thickest mud shale identified on well logs. Mud shale with sandstone was well developed in the southwest of the study area and was interpreted to have been deposited in a shore or tidal flat sedimentary environment. This rock assemblage has a large effective thickness and extensive lateral distribution. In contrast, the assemblage of mud shale with limestone was mainly developed in the northeast of the study area and was interpreted to have formed in a melanged accumulation shelf sedimentary environment. The effective thickness of the mud shale with limestone is small and the distribution is limited. There is developed mud shale in above two type's sedimentary environment, but the distribution is also limited. The Longtan Formation's mud shale reached stage B diagenesis and is principally composed of quartz and clay minerals. The average quartz content is 43.40% and the average clay mineral content, which is mainly composed of illite, mixed illite/smectite, chlorite and kaolinite, is 39.58%. The sedimentary environment has controlled the distribution of minerals within the sequences. The clay mineral content gradually decreases as the sedimentary environment changes from shore- tidal flat in the southwest to deep water melanged accumulation shelf in the northeast. Therefore this comprehensive analysis shows that the southwest of the study area is the key area for shale gas exploration in the Longtan Formation.

Key words: Sequence stratigraphy; Paleogeography; Shale development characteristics; The Late Permian; Southeastern Sichuan Basin.

Volcanic-hydrothermal activities originated form carbonatite and their influences on tight oil formation in black rocks series

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The petrology, forming environment, hydrocarbon generation of black rocks series in sedimentary basin is a focus in geological society. Middle Permian Lucaogou Formation in Santanghu Basin, and Late Triassic Yangchang Formation Chang 7 & 4+5 members in Ordos Basin are two famous oil-bearing black rocks series and tight oil reservoirs in northwest and center of China respectively. Recently, our team observed a special type of mantle-derived magmatic-hydrothermal explosive, effusive, and exhalative rocks, which are formed by ultramafic to intermediate-acid volcanic activities[1]. One of them originated from carbonatite shows close relationship with tight oil generation.
Calcite and abundant radioactive minerals, such as rutile, uranothorite, and monazite fragmented and transported by explosion and effusion, then deposited as individual clastics, aggregate (1 mm-10 μm in size) or flocculate (<1μm in size)[2]. Coarse grains fragments formed by explosion may transport and deposit by high density debris flow or turbidity flow. Mudstone interbedded with sandstone show fake parallel bedding formed by compaction and water escaping. That may be the b section of Bouma sequence. Some vertical trace interpreted as bio-escaping structures are observed, indicating high depositional rate.
Deference micro-environment caused by differentiation between magma and hydrothermal fluid lead to deference type and distribution of thermophilic microorganism. And that features may be consistent with regional fracture and local fault. Fast and violent magmatic-hydrothermal activities caused death and translation to hydrocarbon of huge number of organisms. The forming reason of carbonatite type of tight oil is the reaction of organic and inorganic materials. The function of catalytic hydrogenation formed by mixing of carbonatite type of inorganic materials (Mg^{+2}, Fe^{+2}, and CO_2 releasing from altered Mg-Fe-rich minerals) derived from mantle and organic materials in lake or sea water. Carbonatite type oil and gas in the East African Great Rift Valley is a typical example. The distribution of reservoir is discontinuous horizontally, and lenticular vertically due to the carbonatite rock mass is small, lenticular, and banded.
Isotopic composition of Pb of black rock series show mixed features of materials from mantle and crust, whereas Sr and Nd indicate the influence on hydrocarbon generation worked by mantle materials. Interchange of material occurring during reaction between organic and inorganic activities, as well as energy transfer between endogenic and exogenic processes suggest the impaction on biogenic and microbial actions by deep carbonate magma and hydrothermal fluid. The key factor for tight oil formation is the mixture and reaction between carbonate magma, hydrothermal fluid, and organism.

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THE ORIGIN AND DISTRIBUTION OF KAOLINITE IN EOCENE TURBIDITE SANDSTONES OF NIUZHUANG SAG, DONGYING DEPRESSION: IMPLICATIONS FOR RAPID FLUID FLOW

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Mineralogical, petrological and geochemical data have been used to interpret conditions during the formation of authigenic kaolinite within Eocene turbidite sandstones in Niuzhuang Sag, Dongying Depression, China. The turbidite sandstones in Niuzhuang Sag are distributed between 2300m and 3500m at depth, mainly lithic feldspar sandstones, and kaolinite is widely common. The authigenic kaolinite occurs as aggregates with vermiform morphology acting as pore-filling cement and replacement of detrital feldspar. Kaolinite precipitation was not earlier than quartz cementation and nearly at same time with ferro-calcite and ankerite cementation.

The distribution of kaolinite cement is closely related to faults. The content of kaolinite near the fault zone is obviously higher than that far away from the fault. As increasing distance from the fault, ferro-calcite or ankerite cementation zone, great feldspar dissolution—slight kaolinite cementation zone and great kaolinite cementation—slight feldspar dissolution zone appear in turn. The order of carbonate cementation, feldspar dissolution and kaolinite cementation from the fault record the evolution of fluids as they entered the turbidite sandstone through faults. Fluid inclusion data from ferro-calcite and ankerite indicated that the injected fluid has salinity greater than 30%(wt.% $NaCl_2$ eq). The high salinity fluid is also implicated by HREE>LREE. The only reasonable source of high-salinity fluids is the source rocks in the lower part of the turbidite system. The imbalances between the feldspar dissolution and kaolinite precipitation indicates that the mass transfer scale of Al ions is greater than the scale of thin section[1]. Due to the low solubility of Al, this transport can only be achieved at a rapid fluid flow. The positive correlation between kaolinite content and porosity also implies that the precipitation of kaolinite is related to fluid flow.

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Classification, characteristic and petroleum exploration of weathering crust reservoir

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weathering crust reservoir has special characteristics. Combined with the discovered weathering crust reservoir in the world, the connotation of weathering crust reservoir is defined, three-level classification is made, and its characteristic and global distribution is present. The weathering crust reservoir can be subdivided into two types: uplift weathering crust reservoir and basement weathering crust reservoir. The weathering crust reservoir is distributed to almost all of the oil-gas province in the world and geologic eras. The lithology of the weathering crust reservoir includes clastic rock, carbonate, magmatic rocks, and metamorphic rock. The type of the reservoir space is included in pores or hole, fracture and fractured pores. The weathering crust of different lithology forms different hierarchical structure and reservoir space combination, and large scale distribution. Multi-period large and medium sized unconformities developed in superimposed basins in China. It leads to wide distribution and great exploration potential of weathering crust reservoir in China. It is main to prospect basement weathering crust in the superimposed rift basins in eastern China, and uplifting weathering crusting the superimposed craton-foreland basins in the middle and western China.

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Geological characteristics of shale rock system and shale oil exploration in lacustrine basin: A case study from the 1st sub-member of Kong 2 Member in Cangdong sag, Bohai Bay Basin, China

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The world's oil industry has entered the age of conventional and unconventional oil and gas exploration and development[1]. Compared to the marine shale of north America, continental shale of China shows great heterogeneity, tight reservoirs and deep burial[2-3]. However, breakthroughs have been made in continental shale oil exploration in China, especially in Kong 2 Member (Ek2) of Cangdong sag, Bohai Bay Basin where highest daily oil yield of single well can reach 53t. In order to resolve geologic knowledge bottle-neck restricting the efficient exploration of shale oil, and to guide shale oil zone and well selection, basic geological conditions analysis, dessert evaluation and well deployment have been done through the 140 m core observation and thousand test data systematic analysis of two wells. Studies show that shale rock system mainly developed interbedded formation of fine-grained feldspar-quartz contained sedimentary rock, fine-grained mixed sedimentary rock and dolomite; High quality hydrocarbon source rock(TOC average 3.6%) is the material base for shale oil enrichment, and the closed environment of poor oxygen ~ salt water is the key factor of organic matter enrichment in source rocks; analcite grains pore, dolomite interparticle pores and interlayer fracture makes fine-grained sedimentary rocks can become effective reservoir and the content of brittle minerals is more than 70%; high abundance laminated shale rock in the lower layers of Ek21 is the best enrichment formation of shale oil, with accumulated thickness of 70 m, burial depth between 2 800 to 4 200 m, average oil saturation of 70%, and stable favorable horizontal distribution area is 260 km^2 with hundreds of millions of predicted resources. On the bases of geologic evaluation and dessert prediction of shale oil, six wells obtained the daily oil production more than 10t. And two horizontal wells have achieved initial success with high quality reservoir drilling rate of 96% and high gas total hydrocarbon value reaching 99% many times. and these two wells are now hydraulic fracturing. Shale oil exploration shows that the shale oil has stable industrial productivity and considerable economic value, which is an important replacement area for conventional oil and gas exploration of Kongdian Formation in Cangdong Sag.

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Multi-Cycle Fault Model and Its controls on Hydrocarbon Migration and Accumulation in the Northeastern Nanpu Sag, China

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The Nanpu Sag, located in the northeast of North China Craton, is a Meso-Cenozoic petroliferous sag with highly representative structural features. The fault activity has the characteristic of cyclicity, which exerts a strong influence on hydrocarbon migration and accumulation. This paper emphasized on three-part research: (1) the analysis of the fault combination and activity, (2) establishment of the multi-cycle fault model, and (3) research on the relationship between the fault activity and the hydrocarbon expulsion and accumulation period.

The results show that the fault combination exists an obvious difference between Eocene and Oligocene on the plane. The strike of the faults in Eocene is mainly northeast -southwest, caused by the northwest subduction between the India plate and Asian plate. However, the faults in Oligocene are mainly distributed with nearly EW, controlled by the extension field in S-N direction. To the vertical, fault terrace is the major fault combination in Eocene, which reflects the characteristics of stretch deformation. And semi-flower fault and compound graben in Oligocene, which are accordance to the active tectonic episode, play an important role in hydrocarbon migration and accumulation.

Moreover, fault evolution has the feature of multi-cycle, namely, a complete fault cycle including a fault-active stage and a fault-intermittent stage. The multi-cycle fault model in the Nanpu Sag is evolved with the "weak-strong-strongest-weak-strong-weak" cycles. The first weak-active cycle was in the sedimentary period of the lower third member of Shahejie Formation (Es_3), and the stable tectonic environment provided a favorable condition for the preservation of the hydrocarbon rock. The first strong-active cycle (the sedimentary period of the middle member of Es_3) controlled the distribution of the fan-delta reservoir and the initial uplifting of Nanpu anticline. The strongest-active cycle (the sedimentary period of the upper member of Es_3) influenced the formation of the secondary fault, which has well-controlled effect on lateral migration of the hydrocarbon. The fault activity weakened during the very end of Shahejie Formation. And the last strong-active cycle (the sedimentary period of Dongying Formation) led to the tectonic reverse in the Nanpu Sag, which exerted a powerful effect on the hydrocarbon accumulation. The last weak-active cycle was during the sedimentary period of Guantao Formation, corresponding to the major hydrocarbon preservation.

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COAL FACIES AND HYDROCARBON GENERATION POTENTIALS OF THE PALEOGENE COAL-BEARING SERIES IN XIHU DEPRESSION, EAST CHINA SEA BASIN

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Xihu Depression is situated in eastern Zhedong tectonic belt of the East China Sea Basin, and has great exploration potential for oil and gas resources. The Pinghu and Huagang Formations of the Paleogene are the coal-bearing series containing major source rocks in this Depression. The lithological types of the Pinghu and Huagang Formations include sandstone, siltstone, mudstone and coal. The Pinghu Formations was deposited in the tidal-influenced delta and tidal flat environment, while the Huagang Formation was deposited in the fluvial, meandering river delta and lacustrine environment. The maceral contents of the coals were statistically counted by coal petrology, and based on the maceral compositions, the coal facies in different environments were analyzed. The results showed that although vitrinite is the dominant contributor to macerals with an average content of 90.1%, and the exinite accounts for an obviously high level compared to the other common coal samples, attaining to 8.4% on average. In contrast the average content of inertinite is only 1.4% respectively. Four coal facies were recognized, including calamite-phragmites swamp facies, limnetic facies, overlying-water forest swamp facies and deep overlying-water forest swamp facies. The limnetic facies and overlying-water forest swamp facies are well developed in Xihu Depression. The hydrocarbon generation potential of the coal deposited in different depositional environments was determined by the organic matter abundance, organic matter type, and organic matter maturity. The results showed that the TOC varied from 30% to 74.99% with an average of 44.16%, indicating a medium to high organic matter abundance. The "S1+S2" ranged from 42.76mg/g to 165.76mg/g with an average of 97.86 mg/g, demonstrating a high hydrocarbon generation potential. The organic matter types of the coals were dominated by type III and type II2 evidenced by relatively low HI and H/C value. The Ro values ranging from 0.31% to 1.41%, revealing that most of the coals were in the mature stage. The tidal flat and tide-influenced delta environments were developed in association with the favorable coal facies including the limnetic facies and overlying-water forest swamp facies and thus have the best hydrocarbon generation potential.

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Development and Application of Seismic Reservoir Geology: Applied to Tight Sand Reservoir in East Ordos Basin

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Abstract: Unconventional oil & gas exploration is becoming an important target recently. However, it is very difficult to characterize tight reservoirs using conventional seismology and reservoir geology. New theories and technologies are urgently needed for unconventional petroleum exploration. This paper explain the content and characteristics of Seismic Reservoir Geology (SRG). Combined with the fundamental research of tight sand reservoir of east Ordos Basin, the research works should focused on the following aspects:(1)reservoir geological characteristics & seismic responses, (2) seismic rock physics, (3) seismic wave propagation in complex media, (4))reservoir parameter inversion based on wave equation, (5) anisotropy AVO, (6) seismic litho-facies, (7) prediction of sweet-point via seismic data. Based on the seismic sedimentology and lab core analysis data, seismic stratal slice is made from the well- and seismic-based high-resolution sequence analysis as the reasonable diagenetic units of seismic diagenetic facies map. SRG breaks through the conventional status of seismic research. Reservoir diagenesis mechanism, distribution mode, and characterization & prediction of different reservoirs were utilized to predict the "sweet point" of east Ordos Basin. The results, which are obtained from the completed works, show that SRG should become an integrated, focused and methodic theory system, which has a structure of basic theory, information extraction and data processing.

Key words: Seismic Reservoir Geology; seismic diagenetic facies; tight sand; "sweet point"

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Evaluation of Conventional and Unconventional Oil and Gas Resource Potentials: A Case Study of Cretaceous in Songliao Basin, Eastern China

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The evaluation of oil and gas resource potential is the key to the evaluation of petroliferous basins. Songliao Basin is located in eastern China and is one of the most abundant oil and gas basins in China. The Cretaceous is Lacustrine sediments with a buried depth of 750m~3500m, and extensively develops conventional and unconventional oil and gas resources. The Songliao Basin was selected as an example for demonstrating the method to evaluate the amount of shale resources, tight unconventional oil and gas resources, and conventional oil and gas resources and their potentials. Based on the material balance method and the hydrocarbon generation potential method, the hydrocarbon expulsion threshold of the main source rocks of the Cretaceous in the Songliao Basin was 0.7%, the maximum hydrocarbon generation potential was 2000 mg, and the maximum hydrocarbon expulsion rate was 1525 mg/g. The hydrocarbon generation and expulsion amounts of Cretaceous were 1214×10^8t and 1794.2×108 t, respectively. Based on conventional and unconventional oil and gas accumulation theory, Buoyancy-dominated Hydrocarbon Accumulation Lower Boundary (BALB) in the petroliferous basin is determined, corresponding to the porosity of 10% of sandstone reservoir. Above the BALB is the conventional oil and gas resources, with a resource of 294.3×10^8t. Below the BALB is the unconventional tight oil and gas resources, with a resource of 1499.9×10^8t. The results show that the proportion of shale oil and gas resources, tight unconventional oil and gas, and conventional oil and gas resources in the Songliao Basin is 40.4%, 49.9%, and 9.8%, respectively. Unconventional oil and gas resources are abundant, and exploration potential is great.

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Petrophysics reservoir rock-type(PRT) classification based on multi-scale data intergration in low porosity-permeability reservoir

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It is an important task to correctly evaluate the reservoir capacity and improve recovery factor for the sustainable development in low permeability reservoir. Correct PRT (Petrophysical rock - type) classification to the reservoir can help reservoir engineers evaluate reservoir capacity and improve recovery factor according to the different PRT properties of reservoir. At present, the current stage of oil field is relatively matured with detailed information, but classification method on PRT of the reservoir is different. At the same time, the effect is not good based on data in a single scale. Therefore, the integration of multi-scale data including the core data, micro CT data, mercury injection data, logging data and seismic data is utilized to reservoir classification of PRT. Lithologic description and integration by the core data in combination with seismic and logging data is set in the first place for a reasonable interpretation of sedimentary facies. Then reservoir types and pore types are classified by MRGC technology and cluster analysis technology using microscale test data (micro CT data, mercury injection). According to the types of sedimentary facies, reservoir types and pore types, a comprehensive definition of PRT attribute of the reservoir is defined by which we can make a 3-d geological model according to identified PRT attribute with geostatistics theory to instruct Injection-production well pattern deployment and different development plan adjustment.

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Shuvajit Bhattacharya1 and Timothy R. Carr. Integrated Petrofacies Characterization and Interpretation of Depositional Environment of the Bakken Shale in the Williston Basin, North America [J]. Petrophysics, vol. 57, no. 2 (april 2016); page 95–110; 13 figures; 3 tables

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The identification of sedimentary microfacies with the integration of SVM(Supported vector machine) method and Geological principle in low porosity-permeability reservoir

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Sedimentary facies study is a most important work in the exploration and development of oil and gas reservoirs. The research content is mainly through the study of lithology, sedimentary structure sequence and other phase markers, simplifying the complex stratigraphic sequence as a simple form that can reflect the sedimentary law of sediments. The method of sedimentary facies study is mainly through the analysis of core data and the classification of depositional subfacies and microfacies. The coring and testing data are less, which restrict the utilization of the above methods. Well logging data is more general and informative and can be used to identify the microfacies. However, the most important problem of identification based on curve morphology and data characteristics lies in its multiplicity. SVM algorithm in machine learning, namely support vector machine. Support vector machine (SVM) method is based on statistical learning theory based on VC dimension theory and structure risk minimum principle, according to the limited sample information in the complexity of the model and learning ability to seek the best compromise in order to get the best generalization ability. It provides a good solution for small sample and nonlinear complex logging. Based on the principle of structural geology, sedimentology and sequence stratigraphy, the SVM method is ensemble to the multiresolution problem of the logging sedimentary facies. In this paper, the identification of sedimentary microfacies was carried out with the example of subfacies of Mesozoic delta plain in Gaoqing area and achieves good results.

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GENETIC MECHANISM OF EXTRA-LOW PERMEABILITY CLASTIC ROCKS IN THE MESOZOIC OF GAOQING AREA, CHINA

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The Mesozoic clastic rocks have undergone multi-episodes of subsidence and uplifting, and the diagenetic pore fluid properties have also undergone multiple changes, making the rocks' physical properties of low porosity and extra-low permeability in the Gaoqing Area of the Dongying Sag in the Jiyang Depression, Bohai Bay Basin, China. In this paper, the genetic mechanism of the Mesozoic rocks in the Gaoqing Area is systematically studied based on mercury-injection test and thin section petrographic analyses, supported by X-ray diffraction(XRD), scanning electron microscopy (SEM), cathodoluminescence (CL) and hydrocarbon fluid inclusion analyses. The results show that:

(1) The burial phases of Mesozoic reservoirs can be broadly classified into three important phases in basin evolution: early rapid deep burial; uplift and meteoric flushing; faulting and late burial. The burial process largely controls the evolution of pore fluid properties, resulting in the different diagenetic evolution and pore evolution of uplift zone and slope zone. The pore structure of the uplift zone is dominated by the mesopore throats, while the slope zone is dominated by small pore throats and microporous throats.

2) The geothermal gradient of the Mesozoic in Gaoqing Area was high with an average of about 4.7℃/100m.The maximum depth of Mesozoic reached 2700m, and the maximum temperature reached 140℃. Thermal compaction numerical simulation indicates that the primary porosity loss during the early rapid burial may up to 16%-22%, which is the main reason for the low porosity. In the relatively closed diagenetic environment due to low porosity, the reaction of leaching-solution is heterogeneous. And the dissolution products cannot be promptly discharged and precipitate in situ to form a large amount of medium-term calcite cements which clogged pores and throats in the rocks.

3) The duration of uplift and erosion determines the extent of leaching-solution reaction. Due to the formation of the Qingcheng Uplift in the late Mesozoic, the southern strata had been eroded by long-term uplift, whereas the northern strata were buried earlier, resulting in significantly higher dissolved porosity in the southern strata than in the northern strata.

4) During the late burial, the multi-episodes of faulting activities formed a large number of fractures of brittle particles in sandstone. Fractures not only improved permeability of rocks, but also increased rock heterogeneity.

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STUDY ON THE SOURCES OF QUARTZ CEMENT IN TIGHT QUARTZ SANDSTONE

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Quartz sandstone of the Shangshihezi Formation is characterized with good original lithofacies in Upper Paleozoic of Gaoqing Area, Dongying Sag, Jiyang Depression, Bohai Bay Basin, China. The amount of detrital quartz ranges from 82 to 96% with an average of 89.71%. And the majority of the samples comprise whitish medium-to coarse-grained sandstones. However, the quartz cement, occurring widely in the sandstones as quartz overgrowth and microcrystalline quartz with an average volume content of 8.56%, destroys the sandstones' properties and makes it tight. In this paper, the sources of quartz cements in tight quartz sandstone are systematically studied based on thin section petrographic analysis, supported by scanning electron microscope (SEM), cathodoluminescence (CL), X-ray diffraction (XRD) and fluid inclusion analyses on quartz cement. The results show that:

(1) The quartz cement originates from the partial dissolution and precipitation of quartz particles. The cathodoluminescence observation shows that quartz cementation shows a systematic increase in relation to depth, and the crushing of debris particles due to the fault activity is accompanied by strong quartz cementation. This is mainly due to the compressive stress generated by the formation pressure and fault activity that caused the decrease of quartz solubility, and the diffusion from pressure dissolution along grain contacts and stylolites are the sources. Furthermore, the quartz cements are to a great deal believed to have formed due to increased surface area from crushing of detrital quartz grains, creating fresh nucleation sites for the quartz.

(2) Quartz cement comes from the conversion of clay minerals, including illitization and chloritization of smectite both in quartz sandstones and nearby mudstones. Clay minerals cemented widely in the quartz sandstone of ShangShihezi Formation. With the increase of burial depth and temperature, the diagenetic stage evolved to the middle diagenetic stage B, and the large amount of smectite and kaolinite converted to illite. The acidic interstitial water and Si^{4+} removed providing the material source and favorable environment for quartz cementation.

(3) Quartz cement comes from the dissolution of feldspar. In the early stage of early diagenesis, marvelous amount of humic acid was excreted from the Shiqianfeng Formation overlying the quartz sandstone, causing the pore water acidic. Therefore carbonate cement is lack in quartz sandstone, and the dissolution of feldspar commonly formed numerous kaolinite aggregates filled in the pores and supersaturated Si^{4+}. However, this is probably volumetrically insignificant, because the dissolution of 10% feldspar grains would form only 2% quartz cements in the rock. Furthmore, it is likely that the low temperatures at shallow depth can prevent quartz precipitation supported by fluid inclusion homogenization temperatures between 140 and 165℃ in quartz cements, even though the pore water is supersaturated with respect to quartz.

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Sedimentary environmental controls on petrology and organic matter accumulation in the upper fourth member of the Shahejie Formation (Paleogene, Dongying depression, Bohai Bay Basin, China)

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The upper fourth member of the Eocene Shahejie Formation (Es4s) is a typical example of a Bohai Bay Basin lacustrine shale. These sedimentary units are characterized by markedly different mineral compositions compared to marine siliciclastic shales. Thus, understanding the characteristics and sedimentary environment of lacustrine shales enables analysis of their origin, enrichment of organic matter (OM), distribution of organic rich shales, and exploration targets for shale oil and gas.

The results show that, across the study area, the Es4s shale is mainly composed of calcite, clay minerals, and quartz, but also contains subordinate dolomite, feldspar, pyrite, and anhydrite. On the basis of mineral composition, total organic carbon (TOC) content and sedimentary structures, eight lithofacies are identified. The TOC content of samples ranges between 0.15% and 11.4%, with an average of 2.27%, while OM primarily consists of Type I kerogen. Based on paleoclimate and paleosalinity data as well as redox conditions and primary productivity, the sedimentary environment of the Es4s shale can be further divided into four intervals: Intervals I, II, III, and IV, and these four intervals have large differences, rather than persistently warm-damp climate and reducing condition.

The evolution of these intervals is also analyzed in detail in this study, and the controls on lithofacies and OM accumulation are also discussed. The results of this study suggest that the development of mineral compositions and frequent vertical lithofacies associations are strongly controlled by the cyclic evolution of the sedimentary environment. Thus, the accumulation of OM occurs as the result of a number of inter-connected factors including primary productivity, terrestrial inputs, and variation in oxidizing-reducing conditions. Across a given interval, these factors can either work together, or one can play a leading role.

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THE MIOCENE LACUSTRINE LIMESTONES AND UNCONVENTIONAL PETROLEUM GEOLOGY IN HERO RIDGE AREA, WESTERN CHINA

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The Miocene strata in Hero Ridge area is the main development segment and important production layer of the petroleum system in Qaidam Basin of western China. Based on the sedimentology and sequence stratigraphy theory and technique, a high - resolution sequence stratigraphy framework is established by analyzing the depositional trend, combining the outcrops, drilling core and logging data, and the systems tract and the parasequence set are divided. On this basis, the sequence structure characteristics, "sand body" distribution and superposition patterns of lacustrine limestone are discussed in detail, and the unconventional petroleum geological characteristics related to tight oil exploration are studied.

1)The favorable facies belt of the Miocene tight oil reservoir in the area of Hero Ridge is mainly composed of shallow lake beach bar, semi - deep lake algae limestone and marl deposits , and the favorable reservoir is mainly the thick beach bar sand body and the deep lake and semi - deep lake algal limestone and the fissured mud limestone. It is mainly developed in the transgressive systems tract and the high systems tract. When entering into the semi-deep lake area, it appears as the mixed rock distribution area of clastic rock and marl.

2)The beach bar, semi - deep lake algal limestone and the muddy limestone " sand body " are distributed in an isolated form, and the sand body of the beach bar is characterized by fine - grained lithic feldspar sandstone under the microscope, and the pore - mosaic cementation and the pores are relatively developed.

3) The Miocene high quality source rocks in Hero Ridge area are of large thickness (more than 300m), high abundance of organic matter (total organic carbon is 0.78% on average), and distributes over a wide range (about 785 km^2). It is one of the main source rocks in southwest of Qaidam basin. Mudstone and reservoir sand body has a large area of mutual layered distribution, and the formation of multiple sets of source-reservoir assemblage. The tight oil reservoir porosity concentrated in 3.0-9.0%, the average porosity is 5.9%, permeability at 0.05-1md, the average permeability of 0.43md. The study of unconventional petroleum geology indicates that the tight oil resources are abundant in Hero Ridge area, and the geological resources of the tight oil are XXX million tons comprehensively evaluated by a variety of evaluation methods.

Keywords: Hero Ridge area in western China; lacustrine carbonate rock; transgressive systems tract; Miocene; tight oil reservoir; unconventional petroleum geology

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Characterization of diagenetic heterogeneities and reservoir quality of the Upper Triassic tight sandstones in the Xujiahe Formation, western Sichuan Basin, China

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The diagenetic processes and factors controlling reservoir quality of the 2nd Member of Xujiahe Formation in the Xinchang Area, western Sichuan Basin were investigated using an integrated analytical approach comprising petrography, XRD, SEM, CL, stable carbon and oxygen isotopes, and fluid inclusion analyses. The sandstones consist mainly of litharenites, sublitharenites and feldsparthic litharenites with fine and medium grain size, good sorting and subangular roundness. The reservoir properties are quite poor, with low porosity, and matrix permeability, small pore-throat radius, and high displacement pressure. Three reservoir types (Type I, II, III) are defined based on variations in detrital compositions, textures, types and abundances of cements and reservoir quality. Type I is dominated by mechanical compaction during early diagenesis with primary porosity being significantly reduced. Mechanical compaction continued through mesodiagenesis. Type II and III are characterized by intense dissolution of feldspar and chlorite coating, forming effective reservoirs. The tight sandstone reservoirs have undergone strong diagenetic alterations including mechanical compaction, quartz cementation, carbonate cementation (mainly dolomite and ankerite), clay mineral alteration and feldspar dissolution. Mechanical compaction and authigenic quartz cementation are dominant porosity-reduction processes for Type II reservoir during early diagenesis. Dissolution of detrital grains produced some secondary pores during mesodiagenesis, making reservoir quality markedly improved. Type III is characterized by early chlorite coating on grains, which inhibited the occlusion of the primary pores, and secondary dissolution. Mechanical compaction exerted a more significant effect on reservoir property than cementation. Carbonate cementation reduced sandstone porosity, with carbonate being sourced mainly from dissolution of feldspar and rock fragment and conversion of clay minerals. Quartz cementation was another destructive diagenesis, sourced from the silica released by the pressure-solution of quartz grains. Chlorite coating preserved the storage space, and inhibited subsequent cementation. The illitization of potassium feldspar results in the formation of abundant secondary dissolution pores. These three reservoir types were formed by differential diagenetic processes and porosity evolution. Besides, fractures can effectively improve the physical properties of reservoirs and play an important role in the connection of reservoir space.

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DISTRIBUTION AND CHARACTERISTICS OF LACUSTRINE TIGHT OIL RESERVOIRS IN CHINA

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Abstract

Lacustrine tight oil resources in China are important exploration targets, just as marine tight oil resources in North America, while there are obvious differences on the forming environment, and reservoir properties of these two systems. In this paper, the geological characters of lacustrine tight rocks are discussed, including the distribution, petrology, storage space and movable fluid saturation. The tight rocks consist of tight sandstone, tight carbonate rock, tight peperite and tight sedimentary tuff, in which inter-granular pores and dissolved pores in the dimensions of 30 nm to 900 nm dominated the storage space. The oil saturation commonly exceeds 50% and the oil mobility is controlled primarily by pore-throats with diameter less than 1 μm. These four types of reservoirs showed different potentials for tight oil, and tight sandstone plays in the Ordos Basin and the Songliao Basin are considered as the preferred targets for exploration and development. Although the distribution area, physical properties and mobility of lacustrine tight oil in China are not as good as that of tight oil in North America, the lacustrine reservoirs are often stacked in multiple layers, resulting in great thickness, and have relatively high oil saturation, which make them producible and commercially viable. Fluid properties are critical to tight oil recovery effectiveness, and more comprehensive geological evaluation and study of fluid mobility are required.

Keywords

Lacustrine tight oil; oil saturation; flow mobility; nano-pore system

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TITLE: DIAGENESIS OF TIGHT-OIL SANDSTONES IN THE UPPER TRIASSIC YANCHANG FORMATION, ORDOS BASIN, NORTH-CENTRAL CHINA: IMPLICATIONS FOR RESERVOIR QUALITY

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Main text:
The Chang 4+5—Chang 7 Members sandstones of the Upper Triassic Yanchang Formation in the central western part of the Yishan slope in the Ordos Basin, North-Central China form the newly discovered tight-oil reservoirs. The Yanchang sandstones are mostly fine-grained, moderately to poorly sorted, lithic arkoses (average $Q_{53}F_{30}R_{17}$) deposited mainly in a river-dominated lacustrine-deltaic environment. Diagenesis in these rocks comprises compaction and cementation by calcite, dolomite, ferroan calcite, ankerite, quartz, chlorite, kaolinite, and illite as well as partial dissolution of feldspars and minor rock fragments. The porosity ranges from nil to 6.7% of the rock volume and was destroyed by cementation more than by compaction. The fractures (tectonic macrofractures and diagenetic microfractures) with relatively high density provide very important oil migration pathways and trapping mechanism for the reservoir rocks with low porosity and permeability. The majority of the reservoir porosity is intergranular porosity, and variation of macropore network is indicative of a function of the type and distribution pattern of diagenetic cements. Diagenetic features and porosity characteristics of core samples from the Yanchang sandstones has led to the recognition of six reservoir petrofacies, and their characterization has allowed reservoir quality prediction. The best reservoir-quality segments are encountered in the sandstone petrofacies containing abundant pore-lining chlorite with lesser amounts of kaolinite and minor carbonate cements as well as sandstone petrofacies displaying abundant kaolinite pore-fill cement abundance but low volumes of chlorite and carbonate cements.

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Diagenetic sequence and evolution of tight oil reservoirs of Fuyu Oil Layer, Central Sag, southern Songliao Basin

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Diagenetic sequence and evolution are challenging subjects as regards reservior studies, which are critical for successful exploration and production of hydrocarbons. In this study, we first ascertain the diagenesis sequence of Fuyu tight Oil reserviors of central sag in southern Songliao basin, based on authigenic mineral precipitation and association index, metasomatism and incision relations. We then establish the diagenetic evolution of Fuyu tight oil reservoirs, via an integrated analysis of fluid inclusion homogenization temperature, carbon and oxygen isotope, and the time window of main diagenesis inferred from oxygen isotope formation temperature. The results of this study suggest that the diagenetic sequence is as follows: from early compaction, through dissolution offeldapars, volcanic detritus and calcites, quartz overgrowth, and finally to hydrocarbon charging, and cementation of iron calcites, iron dolomites. In all that, the fluid inclusion homogenization temperature of siliceous cementation ranges from 70℃ to ca. 95℃, whereas that of saline fluid inclusion contemporaneous with hydrocarbons is between 80℃ and ca. 105℃. In contrast, the temperature for the carbonate cementation is 80℃~130℃, respectively. The division of diagenetic evolution phases based on illite-smectite minerals, coupled with the characteristic diagenetic sequence recognized above, allows for reconstruction of the diagenetic evolution process of Fuyu tight Oil reserviors.

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Hydrocarbon generation and expulsion features of the Upper Triassic Xujiahe Formation source rocks and their controlling effects on hydrocarbon accumulation, Sichuan Basin, Central China

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The quantitative study of hydrocarbon generation and expulsion of the Upper Triassic Xujiahe Formation (T_3x) in Sichuan Basin is relatively weak. As yet, exploration for favorable exploration zones in T_3x in Sichuan Basin has been less than satisfying to petroleum prospectors. According to the principle of mass balance, the hydrocarbon generation and expulsion of source rocks of the Xujiahe Formation are characterized with a novel method, hydrocarbon generation potential index, using the pyrolysis data. The hydrocarbon expulsion threshold is determined to be Ro = 0.9% and the peak of hydrocarbon expulsion is determined to be Ro = 1.15%. The hydrocarbon generation and expulsion amounts of the Xujiahe Formation are 4525.5×10^8 t and 2420.5×10^8 t, respectively. Besides, there are three hydrocarbon expulsion centers identified of Xujiahe Formation in Sichuan Basin. According to the hydrocarbon generation and expulsion features of source rocks and distribution of oil and gas discovered, the hydrocarbon accumulation probability quantitative characterization model under the control of the Xujiahe Formation source rock is established using single factor regression analysis. Prediction results show that the oil and gas favorable exploration areas in the Xujiahe Formation are distributed in the Qionglai, Chengdu, Deyang, as well as in west of Yilong regions. The results show that 78% of discovered oil and gas are located in the predicted oil and gas favorable and relatively favorable exploration areas.

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CONTROLS ON RESERVOIR HETEROGENEITY OF TIGHT SAND OIL RESERVOIRS IN UPPER TRIASSIC YANCHANG FORMATION IN LONGDONG AREA, SOUTHWEST ORDOS BASIN, CHINA

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Compared to conventional reservoirs, pore structure and diagenetic alterations of unconventional tight sand oil reservoirs are highly heterogeneous. The Upper Triassic Yanchang Formation is a major tight-oil-bearing formation in the Ordos Basin, Central China. Based on the data of outcrop and core, using the data from analyses of thin-section, scanning electron microscope, rate-controlled porosimetry experiments, X-ray diffractions, 3D X-ray micro-CT imaging analysis, and so on, the factors that control reservoir qualities and the heterogeneity of oil accumulation in tight oil sandstones were summarized.
The reservoir quality of the Chang 8 tight oil sandstones is extremely heterogeneous due to large heterogeneities in the depositional facies, pore structures and diagenetic alterations. Small throat size is believed to be responsible for the ultra-low permeability in tight oil reservoirs. Most reservoirs with good reservoir quality, larger pore-throat size, lower pore-throat radius ratio and well pore connectivity were deposited in high-energy environments, such as distributary channels and mouth bars. For a given depositional facies, reservoir quality varies with the bedding structures. Massive- or parallel-bedded sandstones are more favorable for the development of porosity and permeability sweet zones for oil charging and accumulation than cross-bedded sandstones.
Authigenic chlorite rim cementation and dissolution of unstable detrital grains are two major diagenetic processes that preserve porosity and permeability sweet zones in oil-bearing intervals. Nevertheless, chlorite rims cannot effectively preserve porosity-permeability when the chlorite content is greater than a threshold value of 7%. Stratigraphically, sandstones within 1 m from adjacent sandstone-mudstone contacts are usually tightly cemented with low porosity and permeability. The carbonate cement most likely originates from external sources, probably derived from the surrounding mudstone. Most late carbonate cements filled the previously dissolved intra-feldspar pores and the residual intergranular pores, and finally formed the tight reservoirs.
The petrophysical properties significantly control the fluid flow capability and the oil charging/accumulation capability of the Chang 8 tight sandstones. A pore-throat radius of less than 0.4 μm is not effective for producible oil to flow, and the cut off of porosity and permeability for the net pay are 7% and 0.1 mD, respectively.

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Controls on reservoir heterogeneity of tight sand oil reservoirs in Upper Triassic Yanchang Formation in Longdong Area, southwest Ordos Basin, China: Implications for reservoir quality prediction and oil accumulation. Yong Zhou, Youliang Ji, Liming Xu, et al, *Marine and Petroleum Geology*, 2016, 78: 110-135.

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A truncated cone structure offshore Joetsu as a potential submarine mud volcano in the Sea of Japan

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A truncated cone structure offshore Joetsu was studied because it has potential to be first report of submarine mud volcano (MV) in the Sea of Japan. The area of Joetsu is part of region with high contraction which consists with an initiation of incipient subduction zone along the eastern margin of the Sea of Japan [1, 2, 3]. Terrestrial MVs are also distributed in this region [4, 5]. Although distribution of faults and folds offshore Joetsu indicates continuation of similar geological condition in the sea, no submarine MV has been found.
Approximately 500 m wide flat crest of the structure is located at water depth of ~540 m. Part of the crest is characterized by high backscatter anomaly. At the crest, massive gas hydrate was recovered with carbonate nodule-bearing sediments. The carbon isotopic compositions of these carbonate concretions are around -50 ‰VPDB, suggesting methane-derived authigenic carbonates. These findings indicate high methane flux at the crest.
Lower part of sediment core recovered at the northern margin of crest contains diatom tests of *P. curvirostris*, which became extinct at 0.3 Ma. Around this study area, sediments with such diatom assemblage boundary distribute some tens meter bellow seafloor [6]. Inclusion of such diatom tests in sediments at ~4 m below seafloor suggests contamination of old sediments in the past. Although mud clasts which are popular in submarine MVs were not found in sediment cores, weak mud volcanism might have transported deep sediments older than 0.3 Ma at certain area of the crest.

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A COMPARATIVE STUDY OF THE CHEMICAL AND MINERALOGICAL COMPOSITION OF MUD FROM A HYDRATE-BEARING AND A HYDRATE-FREE CORE FROM THE EASTERN MARGIN OF THE SEA OF JAPAN

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Shallow gas hydrate, consisting mostly of methane and water, is widely distributed across a 40 m topographic rise located in the eastern margin of the Sea of Japan. Two cores consisting of mud with and without methane hydrate were recovered at this location. The hydrate-bearing (MH) core was recovered in an area identified by acoustic blanking in sub-bottom profiler (SBP) images. The second (REF) core was recovered from a well-stratified part of the SBP imaging and consists of hydrate-free sediment with interbedded laminated and bioturbated mud. To understand various geological phenomena caused by migration of methane gas and coupled with the formation and dissociation of methane hydrate, we compared chemical and mineralogical compositions of mud from the MH core and the REF core using XRF and XRD.
Based on TiO_2 concentrations, the mud can be described as primarily silici-clastic material which is comparatively unaffected during burial diagenesis. The ratios of TiO_2/Al_2O_3 from the two cores resemble to each other irrespective of the presence or absence of methane hydrate. This suggests that the migration of methane gas associated with gas hydrate formation at the topographic high is not accompanied by the emplacement of exotic mud from a deep sediment sources such as commonly occurs during mud volcanism.
Both Na_2O and CaO concentrations reveal striking differences between the two cores. A horizon that is characterized by high concentration of Na_2O is observed in the MH core. This horizon is likely to have formed under the influence of saline water that is released during the formation of methane hydrate. Within the REF core, a slightly Na_2O-rich horizon is detected at a stratigraphic level which is almost contemporaneous with the MH horizon, but not at the same depth below the seafloor. The methane hydrate-derived saline water likely migrated to the methane hydrate-free area when methane hydrate was formed.
Calcium is much more concentrated in mud of the MH core. We consider the high flux of methane gas in the MH core to have formed methane-derived authigenic carbonate (MDAC) within sulfate-methane transition (SMT) and that this occurred at a very shallow depth below the seafloor. Formation of MDAC resulted in the uptake of abundant seawater-derived Ca and Mg in the sediments. In contrast, the comparatively low flux of methane gas in the REF core resulted in limited formation of MDACs. In the REF core, the SMT is as deep as 9 mbsf and the mud is much more compacted at that depth, further limiting the uptake of Ca and Mg from seawater.

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FRESHWATER LAKE TO SALT-WATER SEA CAUSING WIDESPREAD HYDRATE DISSOCIATION IN THE BLACK SEA

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The Black Sea deserves attention for decades partly due to the fact that the Danube deep-sea fan is one of the largest sediment depositional systems in the world, and also because it is considered the world's most isolated sea, the largest anoxic water body on the planet and a prolific petroleum basin. Due to the high sediment accumulation rate with high input of organic materials from the Danube River, the Black sea sediment offshore the Danube delta is rich in microbial gas. Seismic data in the area show widespread occurrence of Bottom Seismic Reflector, indicative of extensive development of hydrate accumulations.
The geomorphological analysis of the continental slope north-east of the Danube canyon reveals complex sedimentary processes such as seafloor erosion and instability, mass wasting, gas hydrate accumulations and fluid migration features. The imprint of geomorphology seems to dictate the location of gas seeps (GHASS cruise, DOI: 10.17600/15000500). More than 1400 gas seeps within the water column have been detected between 200 m and 800 m water depth using acoustic records. Only 2% of gas flares were detected within the Gas Hydrate Stability Zone (GHSZ). At the landward termination of the GHSZ, numerous gas seeps within the water column are detected. These results suggest a geomorphological control of the degassing processes at the seafloor constrained by the occurrence of gas hydrates (Riboulot et al., 2017).
In addition, the study of the gas hydrate dynamics in the Black Sea showed hydrate dissociation due to salt diffusion is the dominant process occurring between 660 m and 720 m of water depth (Riboulot et al., 2018). Indeed, the Black Sea was a freshwater lake before 9000 year B.P. After the reconnection with the Mediterranean Sea via the Bosphorus strait, the salinity content at the sea bottom increased up to the current concentration. Geotechnical simulation results, based on the analysis of a consistent multidisciplinary dataset, predict that recent and forthcoming salt diffusion within the sediment may destabilize gas hydrates by shrinking the extension and thickness of their thermodynamic stability zone. The communication will present scenarios of simulation on how the existing gas hydrate stability zone will evolve over time, and will subsequently trigger destabilization of gas hydrates covering at least 2800 square kilometres of the Black Sea margin. This process is predicted to occur in a region prone to kilometre-scale slope failures which may trigger the release of 4.2×10^{10} to 2.1×10^{11} m^3 of methane into the sea. We argue that the present work will provide a starting point for subsequent analysis in areas where local seas and basins have been totally or partially disconnected from the open oceans during recent geological history (e.g. Marmara and Caspian seas).

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SATURATION LEVEL, PRESENT AND PAST GAS HYDRATE SYSTEM AND RECORDS OF AOM IN SEDIMENTS OFFSHORE SOUTHWESTERN TAIWAN

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Understanding duration and time of gas hydrate formation in the hydrate bearing sediment layer could lead to a better understand on mechanism of gas hydrate formation. Traditional method in dating sediments could not fit for the hydrate formation since most hydrate were formed after deposition of sediment. In addition, gas leak during core retrieval is a major difficulty encountered for an accurate determination of gas hydrate content in the muddy sediments. However, two methods have been used to calculate gas contents when leaking gas was possible: salinity and stable oxygen isotopic values of the pore water. Water molecule in gas hydrate could release into sediments in diluting pore water salinity and oxygen isotopic signature. In this study, variations of pore water chloride concentrations and stable oxygen isotopic values were used to model formation of gas hydrate, saturation level, duration of formation and the effect of calcium carbonate precipitation on the pore water variations. Two piston cores were taken on board the *r/v Marion DuFresne* with lengths reaching approximately 12 and 35 m taken from sites offshore southwestern Taiwan.

Rapid sulfate reduction, higher concentrations of pyrite, increasing alkalinity and decreasing of calcium were found in pore water of these two sites. We have used a transport-reaction model to calculate time of gas hydrate formation, fluid advection, gas hydrate dissociation and carbonate formation.

Our model calculation indicated that for the accretionary wedge system sediments, duration of gas hydrate formation required about 5000 years to reach equilibrium. The system would also require a fluid/gas advection to supply sufficient methane to the hydrate formation layer. In addition, the system also require authigenic carbonate formation to better fit the calculation results into existing pore water signatures.

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GEOTHERMAL INVESTIGATION OF THE THICKNESS OF GAS HYDRATE STABILITY ZONE IN THE NOTHERN CONTINENTAL MARGIN OF THE SOUTH CHINA SEA

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The search of unconventional energy resources has emerged as the focus of energy issue worldwide, given the increasing shortage of the fossil fuels. As a potential energy resource, gas hydrate exists only in the condition of high pressure and low temperature, mainly distributing in the sediments of the seafloor in the continental margins and the permafrost zones in land. The accurate determination of this thickness of gas hydrate stability zone is essential yet challenging in the assessment of the exploration potential. The majority of previous studies obtain this thickness by detecting the bottom simulating reflectors (BSRs) layer on the seismic profiles. The phase equilibrium between hydrate stable state with its temperature and pressure provides an opportunity to acquire the thickness with geothermal method (Grevemeyer and Villinger, 2001). Based on the latest geothermal dataset available, we determined the thickness of the gas hydrate stability zone in the northern continental margin of the South China Sea. Our results demonstrate that the thicknesses of gas hydrate stability zone vary greatly in different areas of the northern margin of the South China Sea. The thickness mainly concentrates on 200~300 meters and distributes in the southwestern and eastern areas with belt-like shape. In addition, the thickness of hydrate stability zone is found to be large where the heat flow is relatively lower. The thickness increases with the increase of the water depth, but it tends to stay steady when the water depth larger than 3000 meters. These results are of significance for assessing the resource potential of gas hydrate in the South China Sea.

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GROWTH OF A HYDRATE MOUND IN THE SEA OF JAPAN AS REVEALED BY U-Th AGES OF METHANE DERIVED AUTHIGENIC CARBONATES (MDACs)

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The geological and geophysical exploration of shallow gas hydrate in the Sea of Japan for the last decade has revealed dense accumulation of massive hydrates within gas chimney structures. Gas chimneys often give rise to "hydrate mounds", *pingo-like* topographic features on the seafloor (1). Logging-while-drilling (LWD) has demonstrated anomalous profiles including both very low natural gamma ray (<10 API) and high acoustic velocities (2.5 to 3.5 km/s). These anomalies extend down to 100 to 120 mbsf, the base of gas hydrate stability (BGHS), indicating that the average volume fraction of hydrates is 35 to 86 volume % of the sedimentary sequences within gas chimneys (1). Shallow gas hydrates are often characterized by high H_2S concentration, corresponding to AOM-induced production of HS^- in shallow subsurface. However, the amount of H_2S in deep hydrates is very little or nearly zero. This seems to indicate that the initial high H_2S hydrates may have lost H_2S during re-equilibration with surrounding H_2S-poor interstitial waters during burial. Regardless of depth, massive hydrates in gas chimneys are closely associated with MDACs, which are composed of variable mixture of 13-C depleted aragonite, high Mg calcite and dolomite. MDACs are considered to have been formed at a few meters below seafloor as a response to increased alkalinity caused by AOM. δ^8O of carbonates, ranging between 2.0 and 5.5 ‰VPDB, is not likely to correspond to the temperature of shallow subsurface of approximately 0.5℃. This apparent discrepancy may reflect oxygen isotopic fractionation between the interstitial waters and gas hydrates as well as the secular variation of the temperature and δ^8O of the bottom seawaters. As such, the MDACs are assumed to represent approximate paleo-seafloor at times of enhanced methane flux and intensive accumulation of shallow gas hydrates.

MDACs zones have been identified at 6 stratigraphic levels from seafloor to 75 mbsf within a single gas chimney, suggesting that the enhanced AOM and dense accumulation of gas hydrates took place at these 6 stratigraphic levels, ranging in age from 20 ka to 350 ka as revealed by U-Th age of MDACs. Biostratigraphy and tephra chronology of the sediments surrounding the gas chimney have revealed that the 350 ka datum occur at around 100 mbsf, indicating that the hydrate mound stood as a "hydrate-pingo" of 25m high relative to the surrounding seafloor at 350ka, and has successively grown to form the present mound-shaped topography. U-Th age of MDACs corresponds to the glacial low stand period, at which BGHS should shoal up by 10 to 20 meters at the gas chimney sites, causing (1) regional dissociation of deep seated gas hydrates right above the BGHS, (2) enhanced migration of methane through gas chimneys, and (3) formation of MDACs and intensive accumulation of gas hydrates in shallow subsurface.

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TIME-SERIES ANALYSYS OF INTERSTITIAL WATERS COLLECTED BY OSMOSAMPLER IN SHALLOW GAS HYDRATE FIELD, EASTERN MARGIN OF THE JAPAN SEA

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Recent marine surveys using Remotely Operated Vehicle found the location and intensity of gas venting on the seafloor have changed within a few days in the shallow gas hydrate fields in the eastern margin of the Japan Sea[1]. It suggests geochemical environment of shallow gas hydrate system including gas venting and gas hydrate accumulation may change rapidly relative to other processes which happen on a geological time scale. To describe and clarify the change of geochemical environment near the seafloor and its time scale, we applied long term osmotically pumped fluid sampler named "OsmoSampler". We collected interstitial water at 30 cm below seafloor at intensive venting site (Torigakubi Spur), weak venting site (Umitaka Spur), and venting free site (Torimi-Guri) for one year. We measured concentrations of dissolved ions (SO_4^{2-}, Cl^-, Ca^{2+}, Mg^{2+}, K^+, Na^+) and hydrocarbons (methane, ethane) with a resolution of 1 day.
All the major ion concentrations show synchronous increase and decrease (10 to 30% variation of average concentration) repeatedly over periods of 3~5 days at all sites. Input of saline and fresh water due to the formation and dissolution of gas hydrate effectively controls major ion concentrations at all sites. We also found large fluctuations (200 to 350% variation of average concentration) occasionally at Umitaka Spur and Torimi-Guri where methane concentration is constant at low level of ~10 mM. On the other hand, at intensive venting site, Torigakubi Spur, ion concentrations were stable at 50% lower than seawater with methane concentration exceeding 10,000 mM; indicating the presence of gaseous methane in samples. This probably results from enhanced gas hydrate formation at Torigakubi Spur in relatively deeper section compared with other sites due to high gas (methane) flux, gas hydrate predominantly dissolutes in shallow section close to the sampling depth. The geochemical environment of interstitial water in shallow gas hydrate field is constrained mainly by the intensity of gas venting and formation/dissolution of gas hydrate.

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CHRONOSTRATIGRAPHY AND EVIDENCE OF GAS SEEPS IN THE OLD HARRY AREA, GULF OF ST. LAWRENCE, EASTERN CANADA

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The Old Harry offshore oil and gas prospect is subject to numerous estimates of its volume, extractable quantities, and environmental hazards associated with its possible exploitation. Located along the main axis of the Laurentian Channel in the Gulf of St. Lawrence at the border between the Quebec and Newfoundland and Labrador provinces, this geological structure remains scarcely documented. The aim of this project is to provide a sedimentological characterization of this study area using an integrated analysis of sedimentary processes and stratigraphy derived from the interpretation of geophysical data and sediment cores covering the Holocene. This multiproxy approach includes geophysical, geochemical, geochronological (^{14}C dating) and paleomagnetic analyses (inclination, declination and relative paleointensity) on 9 box and piston cores retrieved in 2015 on board of the R/V Coriolis II. Multi Sensor Core Logger, grain size measurements and ^{14}C ages are integrated with seismic data to establish the chronostratigraphic and lithological framework of the study area since the Last Glacial Maximum. Moreover, 230 km^2 of multibeam coverage highlights the presence of more than 3000 pockmarks. Their morphological features (size, relative depth, diameter, shape and orientation) were determined, and will be related to other parameters (nature and composition of the seabed, water depth, bedrock geology and currents). The multibeam data reveal a northwest-southeast preferential orientation of most pockmarks. The spatial distribution of pockmarks is most likely controlled by local bedrock structural conditions associated with the stratigraphy of glacial/postglacial episodes. Finally, a carbonate concretion retrieved in a pockmark was characterized using a scanning electron microscope coupled with an X-ray spectrometer. Stable isotope analysis (^{13}C and ^{18}O) will be performed on the concretion in order to determine the origin of the methane released from those pockmarks (thermogenic *vs.* biogenic).

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Stable isotopic composition of microdolomitic aggregates associated with saline inclusions within Japan Sea massive gas hydrate

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Shallow gas hydrate recovered in the Sea of Japan has proven itself unique in that it contains relatively pure microcrystalline dolomite aggregates which have developed within saline inclusions. We present results of stable isotopic analyses of carbon and oxygen within the hydrate gas, hydrate water, and interstitial water in surrounding sediments, as well as the dolomite aggregates themselves. Overall, the aggregates have a stable carbon isotopic composition which is both extremely enriched in carbon-13 and in equilibrium with surrounding dissolved inorganic carbon. In this case, the carbon in the dolomites appears to be derived primarily from deep methanogenisis, whereby disproportionation yields methane depleted in carbon-13 and dissolved inorganic carbon enriched in carbon-13. Other indicators of the system suggest that the dissolved inorganic carbon pool is from a somewhat depleted carbon source where the isotopically lighter, more labile carbon has already been removed from the system. Rather than being indicative of the source, oxygen isotopes in the dolomites are compared to those of the hydrate water to provide valuable information regarding the proportion of water that has been taken up by hydrate during its growth. In some cases, the dolomites which tend to be have a positive oxygen isotopic composition trend towards more negative values, indicating equilibrium with water in the hydrate inclusions what has been depleted in oxygen-18 during active hydrate growth.

In addition, we present gas and helium isotopic composition of inclusions found within a small subset of dolomite aggregates. These inclusions have near-atmospheric helium isotopic values and are devoid of measurable methane. Instead, the inclusions appear to be primarily comprised of carbon dioxide which, coupled with the presence of organic matter in the voids suggests that ongoing methane oxidation occurred even after the internal contents was isolated from the methane-saturated fluids outside of the dolomites. The hydrate-associated microdolomites also show a number of trends with depth which are either due to compositional changes that occur in the dolomites as they are buried over time along with the massive gas hydrate or, alternatively, differences in the rate at which hydrate-associated saline inclusions developed within the hydrate itself.

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MINERALOGY OF STRATIFIED TAILS OF ENRICHMENT FACTORIES AS TECHNOGENIC MINERAL RESOURCE

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The scientific novelty of the paper is a comprehensive study of the conditions for the formation of the tailings storage, the regularities in the distribution of useful tail components in the volume of the storage, stratification of the material under the influence of internal and external factors that allow us to assess the prospects for using them as reliable sources of mineral raw materials. So far, the matter composition of the tail material and its properties have not been properly studied. Fragmentary studies were limited to declaring the possibility of practical use of tailings concentrating factories without sufficient justification. Because, until now, the tailings storage system has not been systematically studied. Answers to all emerging issues related to the practical use of the accumulated vast number of tailings can be obtained only after drilling the mapping wells to the full depth of the depository, conducting geological and testing work and micromineralogical studies [1].
At present, Kazakhstan has accumulated more than 20 billion tons of solid waste from the mining and metallurgical complex [2]. A sizable proportion of this waste is accounted for the tailings of ore dressing, including copper-containing ones.
In the conditions of a progressive raw material deficit, the accumulated tailings of enrichment factories can be an important source of its replenishment. Today, various companies in the countries of North and South America, Canada, Africa, Australia, etc. use bacteriological and chemical technologies for the extraction of copper, cobalt, nickel, gold, zinc, uranium. In China and Mexico, experimental installations for the bacterial leaching of copper ores are being built. The valuation of such enterprises shows that with capital expenditures for the construction of the installation of the order of $ 900 million, the cost of one ton of the product is less than $ 50 and the payback time of the plant is reduced to 18 months. That means that in a year or two after the development of the installation net profit is $ 375 million [3]. This problem exists not only in Kazakhstan, it is manifested in the entire global copper industry.

stratified tails,

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SOME EXAMPLES OF ORE GEOLOGY IN SEDIMENTARY REALM FROM MOROCCO

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During the phanerozoic geological times in Morocco, ore geology in sedimentary realm will concern some types of deposits:

Phosphorites:

The element phosphorus is essential to all terms of life on earth. The element plays a fundamental role in many metabolic processes and as a major constituent of skeletal material.
Phosphorus occurs in over 200 mineral species. The most common forms are minerals of the apatite family, a calcium phosphate with various substitutions.
The general occurrence of phosphate rocks is commonly bound to lithofacies associations which are rich in organic matter. But in smaller scale, the phosphate mineral contents in the rock are usually associated with a decrease in the organic matter compound. The term phosphogenesis summarizes all processes of apatite precipitation/Mineralization explained by the oceanographic "upwelling models".
During Late Cretaceous-Paleogene time in Morocco, the phosphorite depositional paleoenvironment, is predominantly developed in epicontinental sea along a ramp setting.
Sea-level induced environmental shifts to more agitated water conditions in a tectonically stable basin, this ramp setting attributes sediment remobilization to sea-level stages, respectively to transgressive and highstand system tracts.

Manganese:

The economically important high-grade manganese ores of the Imini district are exceptional because of their unusually high Mn/Fe ratios and exceptional enrichment in Ba and Pb. There is example evidence that the three strata-bound manganese ore bodies of the Imini district formed in a laterally extensive karst cave system, associated with internal sediment, and developed in a shallow marine dolostone succession of Cretaceous age. The manganese ores occur in dolostone breccias and ferruginous clays that represent the earliest phase of internal sediment in the cave system. Later phases of cave infilling are ferruginous without manganese enrichment. Ore formation, karstification, and meteoric dolomitization are all related to an extended period of exposure and terrestrial weathering, prior to the deposition of terrestrial red beds and evaporites of Upper Cretaceous age that overlie the ore-bearing dolostone succession above an erosional unconformity. The manganese ores formed when warm, acidic Mn^{2+}-bearing meteoric water migrated from the elevated regions of the Anti-Atlas region into the exposed carbonate succession. Alkali feldspar-rich igneous basement rocks were the source for Mn, Pb, and Ba. Metals were deposited in a zone of mixing between metal-bearing, reducing meteoric water and oxygenated ground water resident in the cave system.

During our presentation other ore geology sedimentary in sedimentary realm will be discussed (cool, copper, ...).

SEQUENCE STRATIGRAPHY AND GEOCHEMICAL SIGNATURE OF SYSTEM TRACTS: APPLICATION TO PHOSPHATE DEPOSITS OF MOROCCO.

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Maastrichtian-Paleocene phosphorite deposits across the Atlasic system of Morocco have been subjected to sequence stratigraphic and geochemical investigations to discuss the geochemical behavior of phosphatic facies within different system tracts. The studied sections show a transgressive-regressive mega-sequence, bounded by conspicuous discontinuities; a karstic surface underlying the transgressive system tract and a condensed section at the bottom of the high-stand system tract. This system tract shows a phosphorite at the condensed section, passing upwards to interbedded phosphorites /carbonates.

19 samples were analyzed for major and trace elements, including the REE. PAAS-normalized REE exhibit a sea water pattern with a flat HREE segment, depleted LREE, and negative Ce anomaly.

The samples show a wide range of total REE contents, marked by progressive enrichment towards the top of the highstand system tract, while the P_2O_5 content of the phosphorite beds remains in a low variation range. This REE enrichment is probably due to evolution of sea water composition during highstand induced shallowing.

VARYING PROCESSES OF PHOSPHATE ACCUMULATION IN THE ATLASIC SYSTEM OF MOROCCO.

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Maastrichtian-Paleocene phosphate-bearing sediments of the Moroccan Atlas range, belong to the upper Maastrichtian-Eocene phosphogenic province, extending from northwest Africa to the Middle East. Tens of sections have been measured and selectively sampled along the Atlas margins. Most previous studies have focused on phosphogenesis. In the present study, we focus on sedimentary and biological processes, allowing to uncover the forcing parameters of phosphate accumulation and preservation in the sedimentary record.

The studied sections show a transgressive-regressive mega-sequence and different accumulation modes related to different sedimentologic contexts. Field surveys and petrographic investigations have revealed the existence of two main phosphatic facies:

-*In-situ pristine phosphate* consists of parallel, thinly laminated marl, containing abundant homogeneous phosphatic pelletal grains. Phosphatic particles are cemented by calcite, chalcedony and dolomite. The pristine facies is commonly found at the base of the highstand system-tract above the condensed surface.

-*Reworked phosphate*facies occur in three distinct modes: i) Granular phosphate, overlying a karstic surface and infilling the karstic cavities down to a depth of three meters. ii) A thickly laminated phosphatic sandstone trapped in the back-shoal depressions, during transgressive periods. iii) Very coarse-grained phosphatic beds, with a mixture of various phosphatic particles, (coprolites, bone and vertebrate fragments, fish teeth, composite grains) and detrital particles (quartz and lithoclasts up to centimeter-scale). This occurrence is exclusively encountered at the distal part of the studied transect (In the south-west).

The associated detrital inputs and sub-aqueous gravity flow deposits suggest a deposition system of mixte platform to the west. Our results suggest a complex paleogeography, including areas where phosphogenesis is dominant and areas where reworking and winnowing are prevalent.

A Holistic Basin Analysis Approach for Sediment-Hosted Base Metals Exploration: Example from the Proterozoic McArthur Basin, Australia

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The Paleo- to Mesoproterozoic greater McArthur Basin in the Northern Territory of Australia is a 5–15 km thick mixed siliciclastic-carbonate succession with minor bimodal volcanics at the base. Together with the laterally equivalent Isa Superbasin in Queensland, it represents one of the most important base metals provinces in the world. The 1640 Ma Barney Creek Formation of the middle McArthur Group is the most important exploration target as it hosts the world-class McArthur River Zn-Pb-Ag deposit and the Teena Zn-Pb prospect.

The Barney Creek Formation was deposited in a basin with complex architecture characterized by paleohighs and sub-basins. This resulted in significant lateral facies changes and hinders basin-wide stratigraphic correlation. Furthermore, the most prospective organic-rich siltstone and shale facies, which commonly hosts syngenetic or early diagenetic Zn-Pb mineralization, is confined to sub-basins. This highlights the need for a detailed understanding of sub-basin development and architecture.

We present a multidisciplinary study of the middle McArthur Group in the Glyde sub-basin of the southern McArthur Basin including facies analysis, carbon isotope chemostratigraphy, and sequence stratigraphy. Our work is based on detailed logs of 11 drill cores (ca. 5500 m), which have been used to construct fence diagrams across the sub-basin.

Depositional environments in the middle McArthur Group range from deep subtidal and slope environments to supratidal sabkhas. However, the prospective Barney Creek Formation is mostly composed of dark grey to black dolomitic siltstone deposited at or below storm wave base. Transition from paleohighs into adjacent sub-basins coincides with transition from carbonate rocks to siliciclastic sediments, and significant thickening of the formation. Carbonate carbon isotope data (n=850) show significant and systematic variation in the middle McArthur Group, with a distinct subordinate $\delta^{13}C_{carb}$ trend in the Barney Creek Formation. These isotopic trends demonstrate the applicability of carbon isotope chemostratigraphy in the McArthur Basin and future work will likely significantly improve our understanding of basin-wide stratigraphic correlation. The Barney Creek Formation comprises two transgressive-regressive (T-R) sequences. Whereas the lower T-R sequence is only truncated by the sub-Cambrian unconformity in the southern Glyde sub-basin, the upper T-R sequence is significantly truncated in the northern part and completely removed by the unconformity in the south. This is insofar significant as the two maximum flooding surfaces of these sequences are the most important Zn-Pb host intervals, indicated by paleoredox data that suggest deposition under euxinic conditions and known mineralization.

The results of this study will be integrated with paleoredox chemistry, geophysics, and numerical deformation-fluid flow modelling. Furthermore, this study highlights the value of multidisciplinary basin analysis for mineral exploration by reconstructing basin architecture, establishing basin-wide correlations, and identifying exploration targets.

HYPOGENIC KARSTIFICATION OF AMERICAN AND JORDANIAN SANDSTONES: ROLES OF CO_2, CH_4, SIDERITE, AND IRON OXIDE

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The eolian Glen Canyon Group (Lower Jurassic of central Utah, USA) and fluvial Umm Ishrin Formation (lower Paleozoic, southern Jordan) are locally cemented by calcite, and contain abundant iron-oxide crusts. In the basal Glen Canyon, red sandstones overlie bleached sandstones with similar sedimentary structures; the Umm Ishrin underlies the bleached (but otherwise similar) Disi Formation. Previous published work has shown that the iron-oxide crusts and stains in these rocks had late-diagenetic siderite precursors[1,2]. Migrating hydrocarbons bleached the rock, and hydrolysis of feldspars to kaolinite (linked to CO_2-charged pore waters) and degassing led to precipitation of siderite and ferroan calcite. Uplift, denudation, and the influx and lateral flow of meteoric water led to oxidation of the siderite. Cliff-face exposures of these sandstones display meter-scale dissolution voids and cm-scale tafoni. Many of the large, vertically elongated voids in the Umm Ishrin were half-tube channels along vertical joints prior to their exposure. In the Glen Canyon, many voids developed parallel to cross-strata. Voids are best-developed in red (non-bleached) rocks in both USA and Jordan, suggesting that the agressive waters carried little methane. Vertical, full-tube voids exposed within fallen blocks show that dissolution was not restricted to joints or to surfaces exposed to weathering along cliff faces. The voids are Quaternary features produced by the most recent of a two-stage process in which an older, deep-subsurface phase of dissolution was eventually followed by physical flushing of weakly cemented sand from zones adjacent to cliff faces[3]. CO_2 reservoirs are numerous on the Colorado Plateau, and have been linked to Oligocene-Miocene volcanism. Lateral thinning and downdip pinchout of bleached rock at the base of the Glen Canyon indicate that dense, CO_2-rich (and methane-poor) water moved down dip. Dissolution of cement formed masses of poorly lithified “ghost rock” or “alterite”. As Neogene exhumation of the Colorado Plateau progressed, siderite and ferroan calcite concretions formed within the sandstones. In a still-later diagenetic episode, oxidizing meteoric water became acidified as iron oxides were precipitated during siderite oxidation, leading to further carbonate dissolution. The Umm Ishrin records a similar sequence of events, but the vertical orientation of voids suggests dissolution was by buoyant, warm (?), upward-migrating fluids.

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SEDIMENTARY CONTROLS ON CARLIN-TYPE GOLD MINERALIZATION IN NORTH CENTRAL YUKON: FROM BASIN TO BED SCALE

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Sedimentological controls at various scales are considered important in the development of many of the giant Carlin-type gold deposits of Nevada. To what extent are those sedimentary controls essential or critical in the genesis of such type of gold deposits is a largely unresolved question due to a lack of analogues elsewhere. However, the recent discovery of a series of unequivocal Carlin-type prospects in north-central Yukon now allows to further address this question.

In Yukon, Carlin-type prospects are located in a deformed belt that marks the northern boundary of the Selwyn Basin. The present-day location of the major faults that delineate this belt roughly coincides with the location of facies boundaries during the Neoproterozoic and Paleozoic, suggesting that depositional patterns were controlled by a major, presumably deep-seated, structure. This is supported by evidences for syn-sedimentary tectonism in mid-Proterozoic to mid-Paleozoic sedimentary units. Gold mineralization is hosted in three main units of massive to silty limestone, thinly laminated limestone and limy siltstone that range from Neoproterozoic to mid-Paleozoic in age.

At the 1-10 m scale, gold-rich intervals show a wide spectrum of mineralization styles. Mineralized zones are commonly hosted in concordant sedimentary breccia intervals interpreted as debris flow units resulting from downslope transport of instable platform margin deposits. Mineralized zones also include intervals characterized by a pervasive network of pre-mineralization brittle fractures or veins mainly filled by barren calcite (and/or quartz or dolomite) that were later variably replaced by ore-associated minerals. In this case, facies and diagenesis affect fracturing of limestone beds (mechanical stratigraphy) resulting in a variable ‘ground preparation’ within the sedimentary succession and in an indirect control on mineralization.

The regional to local sedimentary controls documented in Yukon are to a large extent similar to those described in the type localities of Nevada. This indicates that the role played by sedimentary facies in developing Carlin-type gold mineralized zones is indeed critical and therefore an essential aspect to take into consideration in designing geologic and exploration models for such ore deposits.

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METASOMATISM OF THE NEOARCHEAN-PALEOPROTEROZOIC LOWER TRANSVAAL SUPERGROUP CARBONATE PLATFORM (KANYE BASIN, BOTSWANA)

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The Taupone Dolomite Group (Lower Transvaal Supergroup) is a carbonate platform sequence that rimmed the north western Kaapvaal Craton during the Neoarchean-Paleoproterozoic. The Taupone Dolomite Group dolostones in Botswana are known as Ramonnedi Formation. These carbonate sediments have been intruded by the granitoids and dolerites of the Moshaneng Igneous Complex (ca. 2.1 Ga) and Moshaneng Dolerites (ca. 1.9 Ga), which have induced alteration of the dolostones with consequent calc-silicate metasomatism. The zone in contact with the intrusion presents peculiar laminated facies with formation of chrysotile+talc deposit, accompanied by the formation of acicular and equant crystals of tremolite/actinolite. Metasomatism of the dolomite host rocks induced mobilization of Mg with formation of Mg-bearing silicates and formation of replacive calcite that substitutes dolomite as dominant carbonate phase.

Petrographic characterization of the altered dolostone reveals mineralization of secondary replacive minerals, which include calcite, serpentine and calcic-amphibole. Calcite considered first to crystallize whereas the calcic-amphibole formed at latter stages. The electron probe micro-analyzer (EPMA) maps generally indicate Fe-poor amphiboles (tremolite) and minor amounts of Mn-rich fibrous amphiboles.

The altered dolostones show uneven distribution of trace elements such as Mn, Fe, Ni, Sr and Pb. Mn and Ca are generally enriched in the altered facies (average 4,700ppm and 36,300ppm respectively) while Mg and Na are generally depleted. The overall PAAS-normalized rare earth elements (REE) patterns vary consistently across the studied samples with some samples showing light REE (LREE) and medium REE (MREE) enrichment. The samples revealed variable Ce anomaly and near chrondritic Y/Ho ratio. Most of the samples show slightly positive Ce anomaly (average 0.95).

These preliminary data suggest that the common alteration styles described in Taupone Dolomite Group metasomatism can be divided in 3 distinct zones or patterns: 1) amphibole-epidote-rich zones, 2) talc-chrysotile zones and 3) (chrysotile)-calcite zones which reflect temporal evolution in hydrothermal fluid compositions as well as in fluid/rock ratio These metasomatic processes have important implications for the study of the Taupone Dolomite Group platform: 1) they form economical deposits of chrysotile, skarn deposits and Mn mineralization; and 2) affects the overall composition of the carbonates providing new evidences for understanding the diagenesis of ancient carbonates.

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OUTCROP ANALOG STUDY OF A CARBONATE-DOMINATED RAMP: THE CENOMANIAN ZEBBAG FORMATION (SOUTH TUNISIA)

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An unexpected decline in production in the Cenomanian Zebbag reservoir (SE Tunisia) triggered the need for a reassessment of subsurface data in combination with new insights gained from an outcrop analog. The misinterpretation of geological parameters such as shale volume, porosity and water saturation, amongst others, relies on the presence of clay, specifically kaolinite that does not have a radiogenic signature. This oversight is responsible for the overestimation of hydrocarbons in place by 25% and the total estimated recoverable volume by about 30%. Here, an outcrop analog is explored in order to improve our understanding of heterogeneities that might account for the remaining discrepancy between the original estimate and the actual recoverable volume.

The locality Dkhillet Toujane is situated 100 km west of the Zebbag oil field. In this region, the Zebbag Formation crops out with a total thickness of about 300 m. A detailed field-based sedimentological analysis was performed in combination with rock sampling (50 samples) for microfacies analysis. Within the Zebbag reservoir, three facies units display good reservoir properties: ooid-peloid grainstone, algal-laminated wackstone/packstone and bioclastic packstone. In the outcrop analog (loc. Dkh Toujane) ooid-peloid grainstone by volume is the most abundant facies unit. Beds vary in thickness from 30 cm to 2 m and their lateral extent is in the order of several hundred meters. Porosity is mainly intergranular but might had been enhanced by fracture-controlled dissolution. Algal-laminated wackstone/packstone forms lenticular bodies, 10 to 50 cm thick and tens of meters wide. Here, fenestral and vuggy porosity are common. Bioclastic packstone forms lenticular intervals, 15 to 70 cm thick and tens to hundred meters wide. Beds are thickening in eastward direction. Porosity encompasses moldic, intergranular, and intraparticle pores. Frequently, fracture-controlled dissolution enhanced matrix porosity.

In the Zebbag reservoir, two facies units are identified as fluid bafflers: argillaceous mudrock and tight brecciated intervals that formed in combination of karstification (caliche) and evaporate dissolution-collapse. In outcrop analog, argillaceous mudrock is 0.2 to 1 m thick and its lateral extent varies greatly (200 to 1000 m). Breccia occur in intervals 0.5 to 2 m thick and appear laterally continuous in the hundreds of meters scale.

This study provides new insights for production issues and alternative exploration strategies. The good lateral and vertical extension of the porous ooid-peloid grainstone favours future efforts by applying enhanced oil recovery scenarios. By contrast, the lenticular geometry of bioclastic packstone and algal-laminated wackestone/packstone likely resulted in stratigraphic intervals of low net-to-gross ratio thereby affecting the overall net-to-gross ratio of the entire reservoir.

POROSITY AND PERMEABILITY-REDUCTION BY CLAY MINERAL AUTHIGENESIS IN AN UNDERGROUND GAS STORAGE FIELD, NORTH ALPINE FORELAND BASIN, AUSTRIA

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Secondary processes within reservoir sandstones during and after hydrocarbon production are poorly understood. This study looks at the effect of secondary water fill on a sandstone reservoir within a time span of eight years. The reservoir rocks consist of medium grained litharenites with large clasts of shales and carbonates. They originate from a depleted gas reservoir which has been converted into an underground storage field for natural gas. Gas production resulted in a rise of the gas-water-contact of about 30 m. Based on their initial and final gas and water saturations, four zones can be identified.

Observed diagenetic changes in all four zones include carbonate cementation, K-feldspar overgrowths, authigenic quartz overgrowths, pyrite formation, and poorly crystallized authigenic clay minerals. However, the authigenic clay mineral fraction differs significantly within the zones. Total clay mineral content and crystallinities of smectite, chlorite, kaolinite and illite increase from the gas-bearing to the initial water zone. Additionally, expandable clay minerals and kaolinite were not identified in the gas-bearing zone. This is different in the secondary watered zones, where smectites and kaolinites are developing. The study shows that within a maximum of eight years from the start of water influx into the gas zone new clay minerals are forming.

The porosity and permeability reduction caused by this artificially induced process might continue and could also be of relevance within other producing reservoirs, where water saturation increases during production.

3D DIGITAL OUTCROP CHARACTERIZATION TECHNOLOGY BASED ON UNMANNED AERIAL VEHICLE OBLIQUE PHOTOGRAPHY

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With the fine and complicate target of geological study, the scale of the geological body characterization is smaller and more difficult. Reservoir distribution patterns and existing prediction methods need to be improved. This paper reviews the traditional limitations of field geological investigation, and introduced technical features of unmanned aerial vehicle (UAV) and oblique photography, which proposed the 3D digital outcrop characterization technique with UAV oblique photography. Subsequently, reservoir architecture patterns are analyzed by UAV collection model for instance. Research shows that seven aspects of the limitations of traditional geological investigation. However, UAV oblique photography has obvious technology advantages and innovative. The collection and processing 3D digital model have anywhere location coordinate and image information, which fully meet the field outcrop architecture analysis. Example analysis found that collection and processing model architecture analysis of high resolution about 3~5 centimeter, architecture of sand body was researched more quantitative and fine understanding. UAV oblique photography technology not only make digital outcrop to become a reality, but also to improve efficiency of geologists field outcrop investigation.

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CHARACTERISTICS AND MAIN CONTROLLING FACTORS OF PALEKARST RESERVOIRS IN MAOKOU FORMATION, SOUTHERN SICHUAN BASIN

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Based on the analysis of core data, cutting data, thin section data and logging data, this study preliminarily analyzes characteristics of paleokarst reservoirs at the top of Maokou formation in Hebaochang area, southern Sichuan basin, and discusses the main controlling factors affecting reservoir development, in order to find the distribution law of paleokarst reservoirs. In accordance with production test data analysis, the poorly- connected and strongly-heterogeneous palekarst reservoirs at the top of Maokou formation, can be be divided into the upper reservoir (P_2m^3- P_2m^2a) and the lower reservoir (P_2m^2b), which are 0-50meters and 50-100meters from the top of Maokou Formation respectively . The phenomenons of drilling drops and leakings are common. It is deemed that the development of reservoirs is controlled by erosion palaeogeomorphology and sedimentary facies. Through the analysis of conodont zones and the positive excursion of the carbon isotopes[1], the study finds that it is the sea level falling during the global Ice Age from the Carboniferous Period to the Permian Period that results in the local erosion palaeogeomorphology on the top of Maokou formation. The palaeogeomorphology is reconstructed by using the residual thickness method and the karst slope unit is the main favorable reservoir growing area. Bioclastic limestone and marl , the symbols of higher-energy environment and low-energy environment respectively, are recognized under microscope. Then the correlation between lithology and gamma-ray logging data is established to identify the grain beach facies quantitatively. It is clear that the reservoirs are controlled by grain beach facies, whose main characters are as followed: the values of gamma-ray are among 0-40API and the curves are box-shape or zigzag.

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GEOTHERMAL POTENTIAL OF ANTICOSTI SEDIMENTARY BASIN, EASTERN CANADA

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The assessment of the geothermal energy potential of the Québec sedimentary basins is crucial with the view to provide scientific-based information for energy providers and decision makers to take informed and strategic decisions for the future of the province energy plan.
In this context, the geothermal potential of the Anticosti sedimentary basin, covering the northern part of the Gulf of St. Lawrence, is being evaluated by building a 3D geothermal model. The work conducted is inspired by that of Bédard et al. (2017) on the St. Lawrence Lowlands (SLL) sedimentary basin in southern Québec. Both basins are part of the St. Lawrence platform geological province, the Anticosti basin representing its eastern part. The sedimentary sequence of Anticosti Island, whose thickness reaches almost 4 km southwesterly, consists of gently SW-dipping Ordovician-Silurian mostly carbonate sedimentary rocks that uncomfortably overly the Precambrian basement. Unlike the SSL basin, the Anticosti basin lacks the porous basal sandstone unit that is the main geothermal target for a hot sedimentary aquifer system in the SLL basin. The input data for the construction of the 3D geothermal model consist of geological maps, onshore seismic profiles and oil and gas exploration wells. The 3D model is composed of 8 distinct thermal units, corresponding to the whole sedimentary sequence, that are constrained by the basin geometry. Compared to the SLL basin 3D model, the Anticosti basin 3D model includes fewer normal faults (1 vs 13) that shift the sequence.
Complementary to the geothermal 3D model, 25 non-equilibrium bottom-hole temperature (BHT) data and 13 non-equilibrium temperature profiles were recorded for the whole basin in oil and gas wells. The temperature data were adjusted for drilling disturbance with the Harrison correction and for paleoclimate variations with a paleoclimate correction. The resulting temperature data are assumed to be close to equilibrium and give an average temperature gradient of 21.8 °C/km for the Anticosti basin. This is somewhat lower than what is observed in the SLL basin, where the average gradient is 23.1 °C/km. Thermal conductivity and heat generation rate are being estimated for each thermal unit of the Anticosti basin using analysis of field samples, deep well cores, geophysical well logs and literature data. These thermal properties will be interpolated in the 3D geothermal model in order to evaluate their spatial distribution within the basin and to calculate the subsurface temperature in the whole 3D model.

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Heavy mineral analysis – automatization. Avoiding pitfalls by detection of polymorphous alumosilicates by Correlative Raman Imaging and Scanning Electron Microscopy (Raman-SEM)

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Heavy mineral analysis of stream sediment samples is performed in our lab for analysis of quaternary sediments in Lower Saxony, Germany: Classical optical microscopy. In order to analyze also “opaque” minerals and to speed up the routine analysis so-called automatic mineralogy methods were applied. The advantages of this fast method were eliminated by disadvantages such as the problem, that grey scale values of polymorphous phases do not allow distinguishing between polymorphs[1]. To overcome this problem a new approach was developed which is based on the combination of SEM-based mappings with an additional spectroscopic method such as Rama spectroscopy.
The aim of the study is to present first results of this method validation: how to distinguish the polymorphs like Al_2SiO_5 and TiO_2 with automated mineralogy methods. After enrichment of the heavy mineral fractions polished specimen were prepared and mapped using SEM. In the resulting maps identified minerals are shown using different colours. The polymorphs: kyanite, andalusite, and sillimanite, however all have the same colour (greyscale) although they have a different crystal structure and accordingly a different meaning for the reconstruction of the sediment generation. Therefore these minerals could not be recognised with EDX-based Mineral Liberation Analysis (MLA) method[2]. With light optical method these polymorphs are recognizable, however, this technique is time-consuming and cannot be applied on the same sample specimen after polishing for SEM analysis.
A suitable analytical approach to overcome these problems and to allow fast analyses of large data sets could be the correlative Raman imaging and scanning electron microscopy (RISE)[3]. Al-coordination differs in the mineral structures of the polymorphs which allows for differentiation by the Raman-Effect to clearly distinguish the species. The workflow is presented as follows: First the heavy mineral polished block will be measured with MLA and a “mineral map” will be obtained. Secondly the polymorph grains will be localized by software and measured with integrated Raman System. Here all these grains are analyzed and the spectra are compared with a suitable Raman library. Ideally as final product we will get a MLA-Mosaic with distinguished Al_2SiO_5 polymorphs.

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Diagenesis modeling experiments under the influence of feldspar supergene leaching

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Secondary porosity is the most important type of pores in sandstone, and its formation is closely related to the dissolution of soluble matrix particles in the process of burial diagenesis. With feldspar being an important component of detrital particles, the dissolution of feldspar is very common in secondary pores of sandstone, and its dissolution mechanism and control factors have attracted wide attention from researchers. In particular, many understandings have been raised about the process of dissolution of feldspar and other minerals into pores and their accompanying material migration and precipitation of new minerals. The feldspar particles, in addition to being dissoluted by acid generated by organic mattter during its thermal evolution, may also be related to surface leaching.

Using the self-developed diagenetic physical simulation system, we selected the medium grain single feldspar as the research object, and simulated the process of the microscopic characteristics of the feldspars dissolution, soluble components, the change of diagenetic fluid ions and dissolution products of feldspars which are in the mechanism of supergene-leaching. We found that: under the condition of acidic fluid, different types of feldspar have different degrees of dissolution, the plagioclase shows a great degree of dissolution, and the surface of the particles presents a harbor-shaped deep groove or dissolution along the direction of the twin crystals, and potassium feldspar mostly dissolved in the edges or in the interior of the particles. In the diagenetic fluid, the amount of K, Na, Ca, Mg, Si and some other ions reflect the rate of feldpar dissolution, and the amount of K^+, Na^+, Ca^{2+} indicate the dissolution of K-feldspar, albite and anorthite respectively. Since concentration of K^+ required for sedimentation of illite is hard to reach due to the low content of K^+ and its being taken away quickly, most of the authigenic clay minerals produced by feldspar dissolution are kaolinite, the change of Mg^{2+} may represent late dissolution of carbonate minerals and clay minerals. The main factors that influence the corrosion of feldspar are the velocity of fluid, temperature, surface area of feldspar grains, corrosion time and pH value of the fluid.

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Carbon, Nitrogen geochemical characteristics and their inplications on environmental change in the lagoon sediments of the Dongdao Island of Xisha Islands in South China Sea

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Abstract: ^{210}Pb geochronology of core DD-01 and sediment core profiles of grain size, biological remains, multiple biogeochemical indicators including total organic carbon(TOC), total nitrogen (TN), organic carbon isotope (δ^{13}C) values were used to trace the organic matter sources change and reconstruct the local sedimentary history and the influence of human activities on the ecological environment of Dongdao Island located in Xisha Islands, South China Sea. The results show that 4 depositional units of the core can be divided with the depth.

The sediment unit below 34cm is more influenced by guana than the others. The TOC and TN contents are 1.78% - 2.8% and 0.15%-0.27% respectively, δ^{13}C ranges from -24.86‰ to -23.84‰, and there is a large amount of guano sediment, caryopses, and fresh Ostracodes residues. At a depth of 28-34cm (about 132 a BP), the guano sediment, caryopses, and fresh Ostracodes residues disappear, and the number of Foraminifers and sea urchin spines increases sharply. The TOC contents in this unit are between 1.25% and 2.28%, and TN contents range from 0.11% to 0.29%. δ^{13}C values vary in the range of -25.95‰ to -25.45‰, which is much lower than those in the upper depth of 28 cm and below the depth of 34cm. The sediment is much coarser in this unit with the grain size of 1.3Φ, and TIC values are higher in the range of 10.95% and 11.26%. All of this data shows that this sediment unit may have been influenced by marine dynamic events, which changed the environment of the lagoon over a long period. At a depth of 19-28cm, TOC and TN show an increasing trend, and the caryopses reappear. The δ^{13}C values remains at a low level. Above 19cm (about 90 a BP), the TOC and TN values increase rapidly with fluctuations, which indicate an increasing source of organic matter. The heavier δ^{13}C is related to the input of guano, which may show the recovery of the sea bird population.

Key words: biogeochemical indicators, organic source change, marine dynamic events, Dongdao Island of Xisha Islands

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FACIAL MODEL AS A KEY FOR SUCCESSFUL EXPLOITATION: CASE STUDY, PANNONINAN BASIN, LATE MIOCENE

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Key words: Submarine fan, turbidity channel, Stow and Bouma sequences, spectral decomposition.

Principal mistakes and inaccurate solutions in reservoir development are frequently associated with conceptual misunderstanding of fields' geology. In this study, we would like to present the critical multidisciplinary approach to evolve a conception, show paramount reservoir features, and how they affected on the field exploration and development plan. Area of interest is located in the southeast part of Pannonian basin, Serbia. Diverse depositional environments characterize this region, and tectonic activity sufficiently influenced rock formation process. Target formation is comprised of terrestrial laterally heterogeneous sediments of Late Miocene. The reason for geology reevaluation is discrepancy between actual and forecasted well production behavior. According to the first geological comprehension, there should be no water in production due to isolating shale bed. However, in fact, watercut increased in 3-5 months after production started. To resolve this contradiction we recalled hard data and carried out a detailed sedimentological analysis. Turbidity sediments were found in a number of wells. Turbidity accumulations are associated with gravitational redistribution of sediments on a relatively deep-water slope. This redistribution lead to sandy-claystone submarine fanes forming and accompanying facies. Core samples are represented by massive and thin-bedded, fine-grained sandstones of turbidity channel, often with intraclasts shaly composition. Horizontally and obliquely layered sandstones with water escape structures were formed by low-density flows. Thin-layered siltstones with sandstone interlayers, variation of Stow and Bouma sequences and complex landslide structures are typical for levees. As well as thin-layered shaly siltstones and mudstones with comparatively deep-water (hemipelagic) background sedimentation are present. Due to the fact that Pannonian basin was isolated local system with the depth of about 1 km during the Late Miocene, investigated deposits were determined by the mechanism of formation as turbidities. The differences between classic turbidities and studied turbidities are hypsometric position and sedimentation rate, which determines their features and scales. To verify the turbidity genesis of sediments, 3D seismic data was used. Resulting maps of spectral decomposition show us the presence of sand bodies – the turbidity flow channel, levee and crevasse splay, and terminal turbidity lobe. The main objects on the oilfield are crevasse splays – sandstone bodies with the sizes up to1-2 km in associations with distributional channels and levees. As far as sedimentological analysis results were confirmed by seismic data the conceptual model of turbidity current were realized in 3D geological model and facial division became the basis for geological risks assessment. Updated geological model which represent turbidity mechanism help us to understand and find solutions for correct exploration rate and find the reasons for oilfield watercut.

MICROSTRUCTURAL CONTROLS ON THE LOWER CARBONIFEROUS TIGHT CARBONATE RESERVOIR IN SOZAK GAS FIELD, CHU-SARYSU BASIN, SOUTHERN KAZAKHSTAN

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Kazakhstan traditionally exports oil but nature gas output is confined. In the last five years, Sozak oil and gas company has invested enormous amount in drilling, seismic exploration and made a significant breakthrough in Chu-Sarysu Basin. The Lower Carboniferous marine carbonate section is widespread, establishing widely distributed tight reservoir over the entire basin. In this paper, controls of microstructure for the Lower Carboniferous Visean and Serpukhovian formation selected from Sozak gas field have been investigated. Photomicrography of thin section, Helium porosity, helium pulse decay permeability, Mercury Injection Capillary pressure (MICP), Field Emission Scanning Electronic Microscopy (FESEM), and X-Ray diffraction (XRD) have been used to investigate the effect of microstructure on the variation of porosity, permeability and reservoir quality. Based on these data, three major lithological units are identified in reservoir. These include (1) ooid grainstone, ooid-intraclast grainstone, ooid-bioclast grainstone-packstone, porosity ranges 0.082 to 0.208, permeability ranges 1.5 to 18.8mD, the grainstones present a good reservoir quality, (2) dolomite- dolomitic limestone, porosity ranges 0.022 to 0.1038, permeability ranges 0.019 to 2.15mD, and (3) intercalation of shale and marl, porosity ranges 0.015 to 0.046, permeability is less than 0.1mD. Meanwhile these data have allowed us to classify the Visean and Serpukhovian Formation into three microstructure pore types. Types A is a dissolved meso-pore (moldic, intergranular pores, intragranular pores and vuggy pores), pore diameter is more than 10 μm. Types B is a matrix composed of micro-intercrystalline pore with a corresponding micron-scale pore-throat distribution ($1<d_p < 10$ μm). Types C is a matrix composed of nano-intercrystalline pore(d_p<1 μm and a nanoporous pore-throat size), representing a common pore system type across the basin. Aeidization and sand fracturing technology is an effective way of stimulating this tight reservoir, with gas production increasing from 0.2 MMscfd / well (drill-stem testing) to 3.52 MMscfd / well (fracturing) in vertical well.

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FROM CORES TO AN ENTIRE FIELD: IMPROVING RESERVOIR SEDIMENTOLOGICAL MODELS USING MACHINE LEARNING

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The use of accurate sedimentological models in hydrocarbon reservoirs is fundamental to reduce exploration and production risks. The most accurate sedimentological models are those derived from detailed description and interpretation (facies analysis) performed on cores. Unfortunately, many mature fields are characterized by a large number of producing wells with a limited core database. Consequently, precise and accurate sedimentological studies performed on cores are often difficult to apply to the entire field model due to scale problems between well logs and seismic analysis. One possible solution is the definition and calibration of electrofacies from core studies. However, the interpretation of electrofacies maps are often complex and poorly accurate.
Machine learning constitutes a useful tool that allows to apply detailed sedimentological studies to a large well log database inside a desired stratigraphic intervals. Algorithms are trained to recognize facies using as input a set of lithologic well logs in the available core intervals. The result consist on a new set of logs (.las files) that contains the inferred facies distribution for the rest of the analyzed reservoir wells. The new predictions allow a fast and accurate mapping of facies, facies associations, and depositional elements in the study area. If facies and depositional elements are populated with results of conventional analysis, it is also possible to generate detailed maps showing changes in porosity and permeability along the entire field. This information contributes to a substantial risk reduction in predicting reservoir quality in undrilled areas. The procedure was successfully applied to different oil fields in Argentina, Mexico and Russia.

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Early Holocene regression and its impacts on Neolithic settlement in the Northern Yangtze Delta Plain

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Human activites during Neolithic period have been dramatically impacted by the sea level changes in the coastal areas around the world. The east China region is one of these areas. In the past 50 years, the sea level changes have been discussed by many scholars, and a consensus was reached that the Northern Yangtze Delta Plain had been uplifted before 6000 cal. yr BP. But why this had happened when the surrounding areas were still underwater? Previous studies did not clearly uncover the process. In this study, based on the detailed analyses of marine microfossils, pollen, grain size and geochemistry from Taozhuang site and Qingdun site in the Northern Yangtze Delta Plain, the transgressive or regressive process recorded in the sediment of Taozhuang site and Qingdun site have been reconstructed. The results show: 1) Lots of marine microfossils and pollen of Chenopodiaceae were found in the profiles of Taozhuang site and Qingdun site, and combined with geochemistry and grain size analysis, the sedimentary environment of Taozhuang site was subtidal or intertidal environment, subtidal or estuarine beach environment and continental lake environment. While, Qingdun site had experienced the process of open intertidal, semi-closed supratidal and coastal environment. 2) According to the AMS 14C dating in the marine layer in Taozhuang site and Qingdun site, the period of studied marine sediment in Taozhuang site and Qingdun site are 10000-8200 cal. yr BP and 8100-7700 cal. yr BP, respectively. As a result, the ages of Taozhuang site and Qingdun site becoming land are 8200 a BP and 7700 a BP, respectively. 3) Combined with the foundation in Taozhuang and Qingdun and the characteristics of regional Holocene paleogegrphic environment changes, when the early Holocene transgression was occurred, the reasons of regression in study area the terrain highland, the gradual development of tidal sand embankment and offshore tidal sand ridges in the east of study area, the development of mouth bar and shell sand embankment in the southeast. 4) the people had communicated with each other between the west Lixiahe plain and Northern Yangtze Delta Plain, and the persons had transformed to the southeast from west Lixiahe Plain, while west Lixiahe plain was influenced in 6300 cal. yr BP by the transgression.

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HIGH FREQUENCY OBSERVATION OF TURBIDITY NEAR THE SEAFLOOR IN BRITTANY (NW FRANCE)

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The ROEC project (high frequency observation system in costal environment) is a regional project around the Brittany (North-West of France) who aims to follow the environmental state of the coastal waters. Different physical, hydrological and biogeochimical parameters have to been measured for a long time period in order to evaluate natural or anthropic changes and variability. This project rests on technological innovation or existing systems strengthening the development of benthic bottom-mounted measurement system in order to observe turbidity near the sea floor. The objective was to acquire continuous turbidity measurements with time step of 20 minutes. Seven measurements sites were defined considering their ecological interest (environmental protection of benthic habitats) or known for local anthropic activities (e.g. fishing, aggregate extraction, port activity). After one year of mooring immersion, the first results emphasize that: (1) high frequency observation over a long period of time is possible, pertinent for research but includes some constraints as nautical means, sensors battery life, biofouling; (2) the seven turbidity time-series underline a high variability of the turbidity near the bottom with important outburst of turbidity at different periods; (3) the interpretation of the time-series reveals a good agreement between some environmental factors (wave, river flows, currents velocity) and the turbidity increases but several turbidity peaks stay unexplained if we only take into account the natural hydrodynamics forcings.

The influence of human activities seems to be the origin of the increase of the near-bottom turbidity but it needs to be more explored. Yet, the lack of high resolution data (higher frequency and higher spatiotemporal scale) of the anthropic forcing doesn't allow to clearly link them to the turbidity increase.

The long time-series obtained constitute good opportunity to understand the bottom sedimentary dynamics through the observation of the suspended load. The demonstration of the anthropic impact is a real challenge and these results will also be necessary for the hydro-sedimentary models calibrations.

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Geothermal gradient and heat flow estimation in New Québec Orogen (Labrador Trough), Northern Québec, Canada

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Temperature-depth (T-z) profiles are scarce in Northern Québec[1], leading to a lack of heat flow density data in this region and a difficulty to evaluate geothermal resource potential. Therefore, the present work is a contribution for the existing database. One well located in the sedimentary sequence known as Labrador Trough was studied for this purpose. The well was drilled in the middle member of the Baby Formation. The T-z profile has a TVD of 120 m and was acquired with an RBR duet probe, that has an accuracy of ± 0.002 ºC and ± 0.25 cm. Daily and seasonal temperature perturbations were removed using a harmonic function[2] and paleoclimatic effect for the last four glaciations and global warming periods were corrected using a step function[3]. Thermal conductivity of six core samples was analyzed using the optical scanning technique[4]. The corrected geothermal gradient is 15 ºC km^{-1}. Thermal conductivity measured perpendicular and parallel to the foliation of the samples are respectively 3.4 and 4.3 W m^{-1} K^{-1}, highlighting the high quartz veins (oriented 320-350/70-75 ºN) content in the samples. Applying a paleoclimate correction to the temperature gradient, the heat flow increases from 28 – 36 mW m^{-2} to 52 – 68 mW m^{-2}. The value obtained is higher than expected, pointing out toward potential geothermal direct use while suggesting that geothermal power production is difficultly feasible in the region.

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LANDSCAPE EVOLUTION OF THE STRAND-PLAIN OF NAYARIT (WEST-CENTRAL MEXICO) DURING THE RECENT HOLOCENE

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Strand-plains are composed by beach-dune ridges that constitute coastal sedimentological records of continental erosion and associated climatic and geological controls on their formation. The strand-plain of Nayarit is one the most prominent strand-plain of the world (Tamura, 2012) as it is composed by > 250 well-preserved beach-dune ridges that distributes along > 200 km between the states of Nayarit and Sinaloa (west-central Mexico) and occupies ~13 km inland. Although the strand-plain of Nayarit is of broad interest for understanding the evolution of Quaternary landscapes, it has remained poorly documented. Curray and Moore (1964) studied the strand-plain of Nayarit as part of a tangential research of the oceanic platform of the California. They studied the Holocene strand-plain using air-photographs and constrained its geochronology in ~4 ka by using a few radiometric dating analyses. More recently, Abe (2011) investigated the source of the sediments composing the beach-dune ridges of the strand-plain of Nayarit using geochemical analysis. To contribute to a better understanding of the landscape evolution of the strand-plain of Nayarit we present here a complete geochronology using OSL dating across three different transects that go from beach-dune ridges located towards the coast to those found most inland. In the three transects we consistently obtained that the oldest ridges initiated ~2 ka, indicating that the strand-plain is younger than previously thought. Additionally, we identified the different formative periods in the strand-plain and calculated that depositional rates range between 0.6 and 12.3 m/yr what indicates high denudation rates in the continent. We finally debate accuracy of OSL dating analysis.

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First characterization of the stratigraphy and sedimentary processes in the waterway of the Port of Montreal in a perspective of optimizing no destructive data acquisition

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A good understanding of the stratigraphy and the sedimentary processes are required to ensure the security of maritime transport and dredging operations around an international port. A project was thus established to characterize the sediments, their composition and stratigraphy, and the sedimentary processes acting in the Port of Montreal and its waterway. The first step of the project was to develop a geodatabase from the geotechnical archives of the Port of Montreal and its partners. Several data processing and correction steps were necessary to integrate borehole descriptions from relatively old (up to 1830) and recent studies. An expedition was then realised on board the scientific vessels L.-E. Hamelin and F.J Saucier and resulted in the acquisition of 148 km of acoustic subbottom profiles (3.5 kHz) and 27 short sediment cores.

Multiannual bathymetric multibeam echosounding data provided by the Canadian Hydrographic Service, combined to the seismic data are used to establish the stratigraphy and identify sensitive areas affected by either sediment accumulation or erosion. The preliminary results reveal that the water/sediment interface in the waterway close to the Island of Montreal is characterized by a strong reflector that allows little penetration, where sand and gravel are assumed dominant. On the other hand, up to 3 reflectors reaching 60-70 m of penetration are located in the central portion of the study, where sampled sediments are mainly composed of finer silt and clay. The analysis of the physical properties of the sediments concord with the visual description of the short cores and reveals that most cores are composed of fine sediments with traces of pebbles at the core surface. In addition, 10 sediment cores are characterized by parallel laminations that have been observed both by visual description and X-ray imagery. These cores, sampled between Verchères and Sorel under a strong current, suggest to be marine laminated clays and silts that originated from the Champlain Sea, but this hypothesis needs to be verified by further analysis. The other 17 cores were mostly collected upstream of Verchères and are more uniform with a fine-grained matrix and the presence of organic matter. Finally, the surface of each core will be analysed in the laboratory, then compared to echosounding backscatter imagery in a perspective of developing this new technology to characterize the sediment surface in parallel of doing annual bathymetric monitoring and geophysical surveys.

Late Holocene sea level changes inferred from the traditional salt (Jayeom) production of the Gomso Bay, Korea

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Salt is indispensable for human beings. The beginning of agricultural life made salt absolutely necessary. The history of salt extraction has been with human civilization. Various countries have developed diverse salt production methods. Salt is used as a seasoning for many kinds of foods, preventing the corruption of fish and meat. Salt is also contained in fermented foods such as salted seafoods, soybean pastes, and kimchi (fermented vegetables). This study is about the sea level changes in the historical period through the Korean history of salt production from sea water.
The traditional salt of Korea is the boiled salt (Jayeom) obtained by boiling the sea water. The Gomso Bay tidal flats in Buan and Gochang areas are traditionally famous for their salt production. In the Gomso bay, people made a salt field (brine pit) on tidal flat sediments to obtain dense salt water (brine water). At this time, the location of the brine pit would be on the most upper part of the tidal flat where the sea water comes in only at the time of spring tides. The location of the brine pit must have been very sensitive to the location of the spring tides in order to save labor and working time.
Based on the records of ancient documents, the locations of the brine pit in the area of Gumdang village of the Gomso bay have been changed. According to the first Korean encyclopedia, 'Jibong yuseol (Su-Gwang Lee, 1614)', the brine pit were on the tidal flats just in front of the village in about AD 500. The Korean geography book, 'Shinjeung Dongguk Yeoji Seungram (Hang Lee, 1530)', reported the locations of the brine pit were moved about 800 m toward the sea. However, the records from 'Taekliji (Jung-Hwan Lee, 1751)' suggest that the brine pits were moved back on the recent positions. The brine pit positions of the 500s, 1500s, and the 1750s differ and imply that the sea level positions and/or the tidal ranges have been changed. Such sea level changes inferred from the historical records closely coincides with regional and global sea level variations.

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ACCRETION RATES OF COLD CLIMATE SALT-MARSHES, ST. LAWRENCE ESTUARY, CANADA

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Salt-marshes are valuable ecosystems that are threatened at many places around the world by drowning, lateral erosion by storm waves, and land reclamation. The drowning risk is becoming more serious with the expected acceleration of eustatic sea level rise. Future evolution and persistence of marshes will depend on the marsh capacity to accumulate enough sediments to compensate the local relative sea rise.
Several marshes on the south shore of the St. Lawrence estuary have been studied with accretion plates, accretion poles, and sediment cores in order to determine their evolution and their capacity to follow the sea-level rise. Quarterly accretion measurements are characterized by important temporal and lateral variations, with generally values of 2-10 mm erosion or accretion. This patchy evolution is due to the local topography and vegetation distribution. In winter, sea ice also tears up, transports and redistributes sediments, with a net sediment export from the marshes. This ice-rafting contribute to the patchy sedimentation. During the ice-free season, the accretion is slow, as the vegetation trapping efficiency is limited by low suspended sediment concentration. The general trend is an erosion of the lower marshes (-10 to +2 mm/year) and slow accretion of the upper marshes (-2 to +5 mm/year). In addition, a marsh scarp, which marks generally the low-high marsh limit, retreats due to erosion by 0.3 to 1.5 m/year. The low marshes offshore of this scarp are in survival mode, with no sign of compensating the volume loss due to the scarp erosion.
The local relative sea-level rise is influenced by the postglacial isostatic rebound (uplift of 0-2 mm/year). Presently, the high marshes are at equilibrium with the local sea level rise, but not with the faster sea-level rise expected during the 20th century. Accretion of these minerogenic marshes is constrained by available suspended sediments in the coastal waters and sediment discharge of rivers, which decreased due to change in land use and construction of hydroelectric dams.

COMPARISON ON LITHOFACIES MODELLING USING LOCAL VARYING AZIMUTH-CONTROLLED STOCHASTIC AND OBJECT MODELLING METHOD: DELTAIC RESERVOIR CASE STUDY

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During the static reservoir modelling, many reservoir geologists will face a challenge on understanding the lithofacies lateral distribution. Lateral facies distribution is highly influenced by the physical, biological, and chemical condition that are represented by the interaction between sediment supply and the accommodation space or basin architectures during the time of deposition. Thus, this lithofacies distribution will have substantial contribution on gross rock volume (GRV) that will directly impact the hydrocarbon in place calculation.
In this study, lithofacies models for a progradation interval of deltaic reservoir were generated by sequential indicator simulation (SIS) and then compared with deterministic method called object modelling. Novel method was introduced during this lithofacies modelling to control the commonly scattered and unrealistic distribution of SIS. Local varying azimuth map was built based on the isopach map and general palaeocurrent direction. While during the object modelling, modern analogue from satellite image was used to understand the lateral geometry distribution. All variables and settings from structural modelling to petrophysical modelling were maintained using the same value, while only the facies modelling steps that were adjusted.
From these compared methods, volume calculation using object modeling resulting 27% higher than classical SIS. From this study, different method of lithofacies modelling was proven to be highly impacting the hydrocarbon volume calculation. Both of the methods have the pros and the cons. SIS method produced more geologically realistic model where in this prograding interval, there are only one thick sandstone deposited on fluvial environment across 89 wells represented by one meandering channel flowing from northwest to southeast. In contrast, using the object modelling method, it would produce more optimistic hydrocarbon in place where more channels were stacked in the same interval to keep the same facies proportion in the data. This method might be statistically correct where all the models would have the exact same value between the well and the model, but geologically, this method is more questionable. In conclusion, SIS method that was controlled by local varying azimuth map would help to produce more reliable and geologically realistic static model, even though it might be less optimistic, in comparison to object modelling method.

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AN IMPROVED METHOD FOR BRAIDED RIVER DELTA FACIES MODELING BASED ON PRINCIPLE COMPONENT ANALYSIS AND PR MODEL

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Facies are important in reservoir modeling because the petrophysical properties of interest are highly correlated with facies type. Due to limited hard data, the integration of multiple secondary data can reduce the uncertainty in facies prediction and provide accurate facies models. PR (Permanence of Ratio) model is a probability combination scheme under assuming that ratios of probability increments from different sources are constant[1]. However, when many secondary data are considered and they are highly redundant, the resulting probability has a large deviation.
An improved method based on principle component analysis (PCA) and PR model is proposed in this paper to integrate multiple secondary data for facies modeling. Firstly, select several secondary data highly related to facies types through correlation analyses, including GR, SP, AC logs (other or more logs) and RMS seismic amplitude data. Secondly, construct the spatial distribution of GR, SP and AC values and calculate their values for each cell by krigging method (SK or OK) and extract RMS seismic amplitude value at each node. Then, PCA of these selected secondary data leads to fewer and independent principal components, which easily satisfies the assumption. Thirdly, make the training image of interest based on the areal facies model. Next, PR model is used to approximate the facies probability for each cell through linking the individual probability that is computed using each principal component or training image. Finally, facies type and its probability are determined at each cell, with more secondary data involved. Through PCA, the independence of principal components leads to a reasonable probability based on PR model. This improved method considers more hard data (well log data) for calculation. Seismic data and geologic pattern are also used as interwell constraints to improve the accuracy of facies modeling.
This improved facies modeling technique is applied in a block of Honghe oilfield in Ordos Basin in the northwest of China, which is dominated by braided river delta front sediments including subaqueous river channel sandstone and mud between channels. The results are more continuous and realistic compared with indicator krigging or indicator cokrigging.
Keywords: Facies modeling; PR model; Principle component analysis; Braided river delta; Ordos basin

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RELATIONSHIP BETWEEN HOLOCENE ESTUARY FILL SEDIMENTS AND TSUNAMI DEPOSITS IN MINAMISOMA CITY, FUKUSHIMA PREFECTURE, NORTHEAST JAPAN

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Study area is one of the alluvial lowland (referred as the Idagawa Lowland) which locates along the coast on the Pacific Ocean in Fukushima Prefecture, Northeast Japan. The area has used as rice-growing area until Tohokuo-oki tsunami inundated in 2011. According to a comparison of the digital elevation model of the Geospatial Information Authority[1] of Japan before and after the 2011 Earthquake, the elevation of the ground surface subsided by approximately 0.5 m in the study area. As the result of basin subsidence, 2011 tsunami deposits were preserved.

Even before the 2011 Earthquake, it has been pointed out that the study area has tended to subside during Holocene epoch. We drilled at the central part of the study area and took 26.5 m-long core samples of the Holocene estuary-fill sediments. The sediments were characterized by mud with intercalated gravel and sand layers. On the basis of detailed analyses of sedimentary facies, diatom assemblages, TS and TOC contents and carbon isotopic ratios, we reconstructed environmental changes of the lowland as follows, (1)10,000~8,000 yrBP: the area changed backshore to sandy tidal flat and muddy tidal flat caused by the sea-level rise following the LGM. (2)8,000~5,500 yrBP: the area changed to central basin of estuary by the sea-level rise. (3)5,500~100 yrBP: the area changed to salt marsh due to filling by sediments and reduce the lagoon area of estuary by sea-level fall. Some evet sand layers are preserved in the core in this term. Most of sand layers yield marine diatom fossils and shows the similar characters to those of the tsunami deposits in 2011. It suggests that they are possible tsunami deposits. Some of sand layers yield fresh diatom fossils and represent inverse grading, and they might be flood deposits. The upper part of Holocene estuary-fill sediments were composed of mud and mainly sandy tsunami deposits which preserved due to the compaction of sediments and basin subsidence caused by big earthquakes.

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Diagenesis and reservoir quality of Mesozoic unconformity zone in Changdi area， Jiyang Depression, Bohaiwan basin, East China

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The Changdi area has undergone multistage tectonic movements, during which several unconformities were developed. Multi-phase fluids and diagenetic transformation have led to reservoir heterogeneity. Through comprehensive utilization of cores, thin slices, analysis and test data of cathode luminescence, fluid inclusions, and geochemistry, the reservoir characteristics in the Mesozoic unconformity zone in the studied area have been systematically studied; and by combining the differences of diagenesis between different lithofacies types, the controlling factors of the reservoir in the research area are discussed, and the reservoir types are divided. The employed methods included cores observation, core wafer observation, cathodoluminescence, fluid inclusion determination, and geochemistry analysis. The results indicated that the reservoir developed grain supported conglomerate facies, pebbly sandstone facies, sandstone facies and siltstone facies. The space of the sandstone reservoir is mainly composed of secondary pores, including intergranular pores formed by cementation dissolution, intragranular dissolved pores formed by feldspar dissolution, and moldic pores with high permeability and middle-high porosity. The main diagenesis types of the reservoirs in the studied area are mechanical compression, cementation, metasomatism and dissolution. Based on analysis of the diagenesis types and intension, four kinds of diagenetic facies have identified and eight kinds of lithofacies-diagenetic facies combination have been summarized. According to our comprehensive analysis of lithofacies - diagenetic, facies combination and physical properties, the reservoirs are into three categories: Type 1 is controlled by sandstone facies and moderate-strong dissolution diagenetic facies and displays high permeability and porosity. Type 2 is controlled by siltstone facies and weak cementation and dissolution diagenetic facies, and can be characterized as medium permeability and porosity. Type 3 is controlled by grain supported conglomerate facies, pebbly sandstone facies and strong cementation and weak dissolution diagenetic facies, and has extremely low permeability and porosity.

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FRACTURE PATTERNS OF DIFFERENT TECTONIC STYLES: AN EXAMPLE FROM KUQA FORELAND THRUST BELT OF THE TARIM BASIN

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Naturally fractured reservoirs in the Kuqa foreland thrust belt of the Tarim Basin contain a substantial percentage of oil and gas resources. Because of the complexity and heterogeneity of fracture networks, the characterization of fractures remains a longstanding challenge in geological engineering. Toward this objective, we explored the effects of the tectonic stress and fold kinematic on the natural fractures by integrating outcrop, cores, FMI and thin slice data. Two representative structural styles, that is, the thrust-nappe monoclinic and high-angle thrusting anticline are presented for remodeling fractures distribution. The results show that the fractures were mainly formed in the Himalaya Orogeny, during which time the reservoirs had experienced several periods of southward tectonic extrusion.

Paleogene-Miocene(65～23.3Ma), the tectonic environment of the Kuqa foreland thrust belt transformed from extend to extrude. The maximum principal stress(σ_1) changed from vertical to horizontal, and the study area is in the horizontal compression environment of near the N-S direction, formed the NNW/NNE trending vertical conjugate shear fracture and nearly NS tension fractures. Faults of the high-angle thrusting anticline reactivated earlier, formed fractures which perpendicular to the strike of the fault. Miocene-Pliocene(23.3Ma~5.3Ma), the strata had folding deformation under the regional tectonic extrude of N-S direction. The maximum principal stress(σ_1) was nearly N-S direction horizontal stress and the minimum principal stress(σ_3) was vertical stress, formed the EW trending low-angle fractures. Since Pliocene(5.3Ma～), tectonic extrusion has reached the strongest and anticlines formed. The maximum principal stress(σ_1) was horizontal stress and the intermediate principal stress(σ_2) was vertical stress, which formed high-angle fractures. Affected by the deformation of the northern boundary, the local maximum principal stress(σ_1) of the high-angle thrusting anticline was N-W direction, formed NEE/SWW trending conjugate shear fractures and N-W trending tension fractures. The local maximum principal stress(σ_1) of the thrust-nappe monoclinic is still N-S direction, formed EW trending conjugate shear fractures and tension fractures parallel to the maximum principal stress. In conclusion, differences of tectonic stress and fold kinematic in the high-angle thrusting anticline and the thrust-nappe monoclinic are the main causes of different fracture patterns.

The paper construct new models of the the thrust-nappe monoclinic and high-angle thrusting anticline: tectonic stress and fold kinematic control on the fracture pattern, providing the favorable reservoirs targeting the compression basin for prospecting.

DIFFERENT PORE STRUCTURE MODALITIES IN SANDY CONGLOMERATE RESERVOIRS AND THEIR FORMING MECHANISMS

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In view of the lack of understanding on the causes of complicated pore structure modalities in sandy conglomerate reservoirs, based on laboratory core analysis, lithofacies classification, features of different pore structure modalities, quantitative characterization of pore structure modalities, and differences in oil displacement efficiency caused by different pore structure modalities have been investigated by using data of mercury injection, constant rate mercury penetration, cast thin section, scanning electron microscope and X ray scan. The research results show that: (1) sandy conglomerate reservoirs are complex and diverse in lithofacies, according to oilfield development with practical, it can be divided into 3 major types, 7 sub-type, 13 tiny types; (2) Different pore structure modals have different features, the rock with single pore structure modality, mostly make up of coarse sand grains， has high pore development degree, 3D pore structure in network shape, and good connectivity between pores; the rock with bimodal pore structure, mostly gravel and middle-coarse sandstone, is made up of particles of 2 grades, and rich in pores, with 3D pore structure in sparse network shape and average connectivity between pores; the rock with multimodal pore structure, is composed of grains of 3 grades, gravel, coarse sand, silt sand or clay， and has pores in average development degree, star point scattering distribution and poor connectivity; (3) same lithofacies but different pore structure modalities, and different lithofacies and same pore structure modality are common in sandy conglomerate reservoirs, the former is caused by different grain arrangement modes and differential reformations of various diagenetic process to pore structure, while the latter is the result of particle sorting, roundness, and arrangement mode, etc sedimentary and diagenetic factors; (4) different pore structure modalities would lead to quite large differences in oil displacement efficiency, in single modal pore structure, the displacement is dominated by network connected pattern and high in efficiency; in bimodal pore structure, the displacement of oil is dominated by star connected pattern and average in efficiency; while in multimodal pore structure, the oil displacement is of sporadic scattered pattern and poor in efficiency on the whole, although with high permeability zone in local part.

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Sequence stratigraphic controls on the diagenetic heterogeneity of continental deposit sandstone reservoirs: evidence from the Bashijiqike formation, Kuqa depression, Northwest China.

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Bashijiqike formation is the main production layer of Kuqa depression, whose maximum burial depth is about 8000m. Buried deeply make the reservoir suffered diagenetic transformation intensively, which results to strong heterogeneity. The dominate view of controlling factors of reservoir space is the Neutral Surface theory. However, the spatial and temporal distribution of diagenetic alterations can be predicted well by an integrated approach between sequence stratigraphy and diagenesis.

The target formation is exactly a third-order sequence ever suffered uplift and erosion from 100Ma to 70Ma. Most of the reservoir space distributed in HST and the upper part of TST, meanwhile, the bottom reservoir has lowest porosity. The analytical conclusions are as follow: (1) The deposits of highstand systems tract (HST) are mostly braided channel with high porosity, then cemented by carbonate and anhydrite in shallow buried stage. These cements dissolved by atmospheric water when uplifted, then a large number of pores can be saved. (2) Transgressive systems tract (TST) deposits prodelta and delta-front facies, whose lithology is sand and mudstone interbeding. This kind of lithology combination results to the mudstone water squeezed out to sandstone, and generate numerous cements when gradually buried. Only upper cements can be dissolved by atmospheric water and present significant porosity. (3) The reservoir of LST characterized by super-low porosity and strong compaction. This phenomenon to a great extent due to the poor sorting features of incised-valley, which lead to compacted easily when buried deeply.

A NEW RECOGNITION OF FLUVIAL SEDIMENTARY MODEL IN SULIGE GAS FIELD OF ORDOS BASIN， CHINA

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Abstract: Ordos basin is the second largest sedimentary basin of China. Sulige gas field is located in Shanbei slope belt of Ordos basin and is the largest unconventional and extremely low permeability gas field in China. The correct geological recognition can guide the exploration and development of oil and gas effectively. Analysis is based on the outcrops and cores displaying a wide variety of lithofacies and sedimentary structures in combination with 2D and 3D seismic data and well logging curves. Sulige area developed a special anastomosing fluvial model. This complex sedimentary system of Permian existed typical braided fluvial sedimentary characteristics: the runoff was not stable and changed with the seasons, the channel was wide and shallow with small bending and migrated frequently on the transverse, sediments were given priority with gravel and sand, sedimentary sand body distributed widely on the plane, it often showed no regular sequence on vertical. During the same sedimentary period it also existed meandering fluvial sedimentary characteristics: the channel was single with strong bending and low wide-depth ratio, sand body was isolated and lateral connectivity was very poor, fine grained flooding deposition in vertical accounted for a large proportion, the channel sand body distributed as an isolation belt on the flood plain, binary structure was obvious. This sedimentary system was not a single developmental stage, but a variety of sedimentary characteristics coexisted together, the channel developed like net and the distribution of sediment was regional and controlled by complex fluvial sedimentary system, it was a kind of untypical continental fluvial sediment model. Basing on the new recognition of the fluvial sedimentation model, the distribution of reservoir can be identified more clearly and effectively, and then allocated the resources of exploration and development reasonably to realize the gas field developed effectively.

Keywords: Ordos Basin, Sulige Gas Field, Lithofacies, Fluvial Sedimentary Model

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Depositional architecture of the deltaic systems of the Late Oligocene to Quaternary and their response to the tectonic and sea level change, Pear River Mouth Basin, northern South China Sea

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Based on integral analysis of abundant well logging, seismic and drilling core data, the depositional architecture of the deltaic depositional systems of the Late Oligocene to Quaternary in The Pear River Mouth Basin and their relation to the tectonic and sea level change are documented in the study. The deltaic systems, fed by the long-term active fluvial systems (Paleo-Zhujiang) from the western basin margin, display various depositional geomorphologies and frequently shifted basinwards or landwards since the late Oligocene along the northern continent margin of the South China Sea. Various scale of progradational clinoforms of deltaic-shoreline clastic deposits are recognized based on integral analysis of seismic and well data, in term of which the palaeowater depths of the deltaic deposits are estimated. The delta systems with palaeowater depths around 30 to 80m are regarded as inner shelf delta deposited along the basin margin during relative highstand of the sea level and those with palaeowater depths of 300-1000m are attributed to shelf-edge delta which prograded into the outer shelf to shelf edge when sea level fell.

Seven regional transgressive-regressive cycles (composite sequence, 4-10Ma) and twenty subordinate sequences are identified in the Late Oligocene to Quaternary in the study area. In term of this a sequence stratigraphic framework is established, with dating based on biostratigraphy of Calcareous Nannofossil and Foraminifera and palaeomagnetic ages of the IODP in the study area, which reflects the regional change of sea level in the basin. Compared with the sea level curve of the Haq., the sea level change in the study area seems to be generally controlled by global sea level change. But it is also apparently that the sea level variation has been significantly affected by tectonic movements in the study area. The study shows that the composite sequence boundaries and the maximum marine transgressions were obviously enhanced or accelerated by tectonic upliftings or rapid basin subsidences. It is found that the shelf edge delta systems are typically associated with sandy turbidite fan deposits along the prodelta slopes, which may shift basinwards as the progradation of the delta systems. The shelf-edge delta sandy deposits and the associated prodelta turbidite fan systems have proven to be the most important oil/gas bearing reservoirs in the continental slope area.

Key words: Depositional architecture, deltaic systems, sea level change, Late Oligocene to Quaternary, Pearl River mouth Basin

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IMPORTANCE OF THE QUANTITY OF INFORMATION AND SEDIMENTOLOGICAL STUDIES IN THE PROPERTY POPULATION OF A CRETACEOUS OIL FIELD IN THE EASTERN ECUADORIAN BASIN

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This study (Zuniga Mayra, 2015) is based on the generation of different geocelular models in order to represent the geological subsoil features. These models were generated from three, nine and fourteen existent wells in a Cretaceous field in the Eastern Ecuadorian Basin, in addition to the seismic data. This work is mainly focused on the comparison between the different models after varying the amount of information used in their generation. The main goal of this study is to show the impact of the information on the quality and reliability of a geological model and how it could be misinterpreted if there is not a proper sedimentological and geostatiscal analysis.

This project was developed for the Rumi – Pindoyacu field, which is a fictitious name assigned to a real field due to the confidentiality policy of Shlumberger of Ecuador, which is the company that provided all the information and data required for the development of this work. This field is located in the east region of the Ecuadorian Oriente Basin. The analyzed interval is the M1 sequence of the Napo Formation.

A sedimentological and geostatistical interpretation was done in order to construct the models. Also, seismic attributes were applied in the 3D amplitude volume, in order to observe existent anomalies, reaching this way the visualization of deltaic lobes throughout the field, for which a stratigraphic evolution is brought forward. The final conclusion of this work was that geocelular models constructed without a proper geological interpretation are going to represent an unreal field. Moreover, the quantity of information is going to be an important factor in order to understand the subsoil of the field. Not less important, the value of developing a proper geocelular model is going to be substantial in order to have a proper hydrocarbon extraction.

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INCREASED HEAVY METAL INPUT INTO THE FIRTH OF THAMES (NORTH ISLAND, NEW ZEALAND) DURING THE LAST MILLENIUM

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Human activities in coastal areas can pose profound changes to the natural environmental setting, increasingly so since the Industrial Revolution. Of particular interest are contaminants, such as heavy minerals, as they can have adverse effects on marine ecosystems. Nearshore depocenters offer the potential to reconstruct heavy metal inputs to the marine environment as far back as into the pre-anthropogenic era, allowing to establish not only a chronology of contamination, but also to distinguish between natural background concentration and additional, possibly anthropogenic, sources.

This study analyses past heavy metal inputs to the Firth of Thames, a shallow marine embayment on New Zealand's North Island. Eight sediment cores were analysed by X-ray fluorescence (XRF) for their heavy metal concentrations, Some of these cores were further analysed by X-ray diffraction (XRD) and for their grainsize distribution, with the resulting data put into a radiocarbon-based age models. A sharp increase in lead and zinc contents occurred between the arrival of the Maori (700 yrs. BP) and the arrival of European settlers 250 years ago. The concentrations of zinc increase from a relatively stable value around 50-60 ppm in the lower core section to a maximum of 350 ppm near the core top. A similar pattern is observed for lead concentrations, ranging from ~10 ppm in the deeper core segment up to 150 ppm in the upper unit. The heavy metal concentrations in the lower core sections are interpreted to reflect the natural background and, consequently, the following increase to be of primarily of anthropogenic origin. Further improved age control will help to constrain the driving forces behind the observed changes. Moreover, it might offer implications to assess input pathway into the embayment, its circulation patterns and potential ecological consequences.

Our findings underline the importance of near-costal sediment depocenters for the reconstruction of historic anthropogenic impacts on the environment as an important tool to (i) determine the natural background concentrations of these heavy metals,(ii) reconstruct the temporal development of anthropogenic impacts on the marine environment and (iii) put current and future heavy metal contaminations in relation to the natural background.

A QUANTITATIVE ASSESSMENT OF SEDIMENT TRANSPORT IN AN URBAN RIVER USING UAS-SFM PHOTOGRAMMETRY

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The recent emergence of small unmanned aerial systems (UAS, commonly referred as drones) allows rapid, automated and inexpensive field imagery. Images acquired from different viewpoints can then be combined using Structure-from-Motion (SfM) photogrammetry to generate 3D terrain models in scaled elevation. Applications combining UAS with SfM photogrammetry remain, however, scarce due to a lack of quantitative testing and comparisons with other well-established topographic surveying techniques[1]. Here we present an application of this combined method in fluvial sedimentology. A quantitative assessment of sediment transport was performed using high-resolution images (2 x 2 cm) and associated digital elevation models (DEM) from the Saint-Charles River, in downtown Quebec City (QC, Canada). The aim was to evaluate the impact of dam management operations at the outlet (i.e., floodgate opening) vs. seasonal variation in river discharge on sediment transport within an urban reservoir where important pollutions have been reported[2]. To reach this objective, four datasets were collected during low flows between November 2016 and 2017 along a 4-km transect upstream the dam. Accuracy of topographic reconstructions was ensured by the settlement of artificial ground control points whose location and elevation have been measured using Real Time Kinematic GPS. The assessment of sediment transport was then performed by comparing high-resolution images and DEMs once corrected for light refraction in submerged areas[1]. This method is effective to quantify topography in both emerged and submerged areas up to 0.7 m water depth. Noticeable exceptions are river sections displaying very turbid waters and/or shaded areas. Along the Saint-Charles River, this method allows the identification of several hot-spots for erosion and siltation. So far, the comparison of high-resolution images and DEMs between fall 2016 and summer 2017 (closed and open floodgate) shows active sediment transport through sandbar migration and shore erosion likely related to spring high-flows ensuing ice breakup. Comparison of dataset collected in summer 2017 and fall 2017 (open floodgate) suggests storm events result were able to transport sediment downstream. Strong similarities between high-resolution images from November 2016 and 2017 finally suggest the natural hydrological cycle shapes river topography rather than dam management operations. The ongoing quantification of sediment transport at the reservoir scale based on DEM comparison is however essential to assess the efficiency of dam management operations and to prevent both siltation and remobilization of severely contaminated sediments.

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THE ROLE OF HUMANS IN HOLOCENE FIRE OCCURENCE IN THE CENTRAL EUROPEAN LOWLANDS

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The questions since when and to what extent humans have affected regional landscapes significantly beyond natural variability, especially concerning land cover and sedimentological dynamics, are strongly debated. Fire is both a natural component of many biomes around the globe, but also closely related to human land cover change. Humans clearly affected natural fire regimes and landscapes in the most recent centuries, while little is known since when Paleolithic to Neolithic fire use affected natural landscapes beyond the local scale.
Here, we discuss natural and human-driven fire occurrence from the central European lowlands (CEL), a landscape of low natural flammability and long human history. We present composites of microscopic sedimentary charcoal records from lake and peat deposits that were aggregated on subregional to subcontinental scales. We compare them with climate model output, land cover reconstructions from pollen, records of soil erosion and archeological findings. We find that fire was naturally important only during the early Holocene, when pine forest was widespread and climate was drier than today. First indications of fire use by Mesolithic hunter-gatherers are detectable already 8,500 years ago on the subregional scale. Regionally, divergent fire occurrence between western and eastern CEL reflect the Neolithisation at ~6,500 years and ~4,000 years ago. During the last millennium, farming intensification drove fire up to early Holocene levels across all CEL. Fire activity reduced only in the highly fragmented landscape of northern Germany during the last centuries. We propose charcoal composites as human impact proxies for periods when natural conditions (climate and vegetation) limited wildfires. Compilations of soil erosion records mirror Holocene fire trends, suggesting that past human land cover change could have affected sub-regional landscapes more and earlier than previously thought.

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THE POTENTIAL FOR RECONSTRUCTING THE HYDROCLIMATIC VARIABILITY IN THE BOREAL FOREST OF QUÉBEC-LABRADOR FROM GRAND LAKE VARVED SEDIMENTS

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Analysis of short sediment cores collected at Grand Lake (Labrador) coupled with high resolution swath bathymetry data and subbottom acoustic profiles indicate that this lake is an excellent candidate for the preservation of annually laminated (varved) sediments. Indeed, the great depth (245 m) of this stratified fjord-lake, its important river inflow and the availability of fine sediments in the watershed have favored the formation and preservation of a high-resolution sedimentary archive. Clastic varves of fluvial origin have been retrieved near the two main tributaries (Naskaupi River and Beaver River) at depth greater than 90 m. These varves are composed of a coarse layer made of fine sands and silts that is overlain by a fine silty layer rich in clay and organic matter. The coarse layer is interpreted to be generated by the spring peak discharge during snowmelt, and the fine layer as resulting from the settling and flocculation of fine particles from the late summer through the onset of lake ice. The fine particle layers are sometimes interrupted by coarse sediment layers associated with high-discharge events induced by rainfalls. Ice-rafted debris comprising gravels and pebbles often lie on the clay cap termination. Cores were analyzed using sediment density analysis from CT-scan images and a geochemical analysis by X-ray microfluorescence. The chronology built from the lamina counts is consistent with the ^{137}Cs dating technique and stratigraphic marker linked with the modification of the watershed for hydropower generation, which supports the varve hypothesis.

Preliminary varve-thickness measurements are compared with daily river discharge records and reconstructions of historical lake inflows, based on geopotential height field reanalysis over the 1851-2014 period. We obtain a statistically significant positive correlation (R^2= 0.34, $p<0.01$) between varve-thickness and maximum annual discharge of the Naskaupi River over the 1977-2012 period. The relationship between the properties of these clastic varves and the local and regional river discharges gives an exceptional opportunity to develop hydroclimatic reconstructions in the boreal forest of Québec-Labrador beyond the instrumental period.

WHEN DID HUMANS START TO INFLUENCE RIVERS?

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Modern rivers worldwide have been enormously affected by hydrodams, irrigated agriculture, and pollution, among other factors. However, interpreting Quaternary fluvial archives requires researchers to consider the onset and intensity of earlier anthropogenic activities, which would have been focused along rivers. Qualitative evidence from sedimentology and archeology suggests many potential influences on trunk and tributary rivers, riparian zones, floodplains, and adjacent uplands.

The use of fire, perhaps by 1.6 Ma in Africa, may have been the first anthropogenic influence on river landscapes. Indigenous use of fire in hunting may have affected Australian vegetation by ~45 ka, although this is controversial.

Grain collection and processing by hunter-gatherers may have influenced floodplains and uplands locally before 30 ka. However, the rise of agriculture and associated deforestation greatly enhanced sediment runoff, creating recognisable "legacy sediments" that date back to nearly 8 ka in New Guinea. Preceded by cultivation of wild cereal species, domestication of wheat, barley and other founder crops after ~10.7 ka in the Near East ushered in a more intensive use of river lands. Rice was domesticated by 9 ka in China, with widespread ricefield irrigation after 7 ka. Maize and squash were cultivated in Mexico by ~9 ka, and bananas at 7 ka in New Guinea. Cultivation of grapes and other fruits led to wine production by 8-9 ka in China and Georgia.

Cattle, sheep, goats and pigs were domesticated by 10 ka, yaks by 7 ka, donkeys and horses after 7 ka, and water buffalo by 5 ka. Animal husbandry would have led to vegetation change and loss through grazing and fodder supply, transport routes along rivers, and enhanced ploughing of floodplains. Manuring of fields was active by 8 ka across Europe.

Direct evidence of anthropogenic effects on rivers includes irrigation systems, which were in place in Jericho after ~10 ka. Sedentary communities, many along rivers, go back to about 14 ka in the Near East, but the rise of riverside cities after ~6 ka in Mesopotamia, Egypt and the Indus Valley was associated with large urban supply systems, irrigation canals, and salination of floodplain soils in Mesopotamia. By 3 ka, principles of groundwater extraction were well understood, bringing subsurface water to fields. Following early brushwood and earth dams, the Pharaohs built the first stone-faced dam in 4.5 ka, and the Romans constructed 45 large dams in the Middle East.

Floodplain clays were excavated for pottery (after ~20 ka), ochre (large workings by 15 ka), and bricks for city construction (~9.5 ka). Riparian trees, river reeds and papyrus had a range of uses, and the rise of navigation may have modified channels and banks.

In summary, a range of anthropogenic effects that likely influenced rivers is evident as early as the latest Pleistocene at many sites worldwide, intensifying early in the Holocene. Their effects on many river catchments may have been underestimated.

Acknowledgements

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MICROSTRATIGRAPHY AND GEOCHEMISTRY OF LAMINATED SHALLOW LAKE DEPOSITS IN DRY MOUNTAIN ENVIRONMENTS OF THE CENTRAL ANDES, ARGENTINA

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Laminated lacustrine sediments have classically been associated to processes of watershed erosion, chemical precipitation, bio-induced, or to a combination of them. Ideal conditions for the formation and preservation of rhythmical lamination have been related to relatively deep lakes with small surface areas, without bioturbation in wind protected basins. Contrasting conditions are currently developed in the Laguna Salada Grande (LSG) closed system, in the Eastern Cordillera from Northwestern Argentina. The LSG (23°S/65°W) is a small (5.8 ha), shallow (~ 1 m depth) lake. In this area, strongly seasonal (December-March) precipitation is below 400 mm yr^{-1}, mostly controlled by the South American Monsoon system. Freshly retrieved sedimentary cores show a succession from laminated to massive units. The presence of lamination in such atypical setting led us to investigate the processes involved in their formation and their relationship with the dominant paleohydrological conditions. The laminated sections of the cores have been analyzed in detail through magnetic susceptibility, XRF scanning, micro-XRF, microscopy of smear slides and SEM observations. The high resolution core images and micro-elemental analyses allowed us to have a closer look into the microstratigraphy and the lamina composition. Mixed laminas are formed by different alternations of silty sands with carbonates, white carbonate muds, siliciclastic clays and ochre Fe rich layers. The elemental mapping of Ca/Fe ratios indicates changes in detrital input to the lake pointing towards runoff, slope wash and rainfall processes controlling the development of lamination. Biogenic sediments also indicate seasonal changes in productivity. Ochre and dark-grey laminas (composed of Fe, Mn and organic matter) indicate variable redox conditions and subsequent diagenetic processes. The combination of geochemistry and image analysis at different scale resolution allows establishing a high frequency event stratigraphy for this high-altitude lake system. It also helps identifying major events that occurred in the basin and their correlation with regional climatic shifts.

A GLOBAL SYNTHESIS OF LAKE SEDIMENTATION FLUXES SUGGEST ENHANCED SOIL EROSION RATES WITH LAND COVER CHANGES BEGINNING CIRCA 3000 YEARS AGO

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Anthropogenic activities have caused rapid change in erosion, transfer and storage of sediment along the hydrological pathways, altering the lateral exports of nutrients, carbon or contaminants, influencing terrestrial and aquatic ecosystems and carbon cycle. However, the lack of long-term instrumental data often impedes analyses aimed at quantifying the responses of soil erosion to long-term climate and land cover changes. As such, there is a lack of understanding on the timing, the amplitude and the extent of soil erosion globally. Here, we reconstruct sedimentation rates (SARs) based on varve chronologies and ^{14}C for 651 lakes to assess the relative changes in lake-watersheds erosion over the period 12000 B.C. to A.D. 2000. The autochtonous contribution to SARs - related to lake productivity - is also assessed between sites. The sedimentation rates are then complemented with reconstruction of modeled precipitations and temperatures land cover and from pollen records. We find that erosion changed substantially beginning around 3000 years ago in many sites around the world. In particular, increasing sedimentation fluxes are recorded in 44% watersheds, and many of these sites show a decrease in arboreal pollen that is congruent with the sedimentation rate changes. Further analysis reveals that land cover change is indeed the main driver of erosion in 70% of our studied watersheds, but the responses have large spatial heterogeneity. For example, the proportions of watersheds with increasing rates are similar in Europe and N-America, but the timing of shifts in sedimentation fluxes are as much as thousands years apart. Overall, our synthesis show that land cover change has been the primary driver of accelerated sediment transfers for the past 3 millennia.

CHARACTERIZATION OF RECENT SEDIMENTS FROM THE NOTWANE DAM (BOTSWANA): PRELIMINARY RESULTS FROM THE PULA PROJECT

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In a semi-arid environment like Botswana, even the long-waited rain after prolonged dry season can become a threat, especially if it comes as an 'exceptionally' intense rainfall event. The effects of exceptional heavy rains on Botswana are the subject of study of PULA project which aims at better understanding the impact of extreme rainfall and floods on water resources quality and availability through extensive monitoring of ground and surface water following the extreme, destructive flood event that took place during 2017 rain season in Botswana. While the event resulted in the reservoirs reaching full capacity for the first time in 10 years, it also resulted in important damages of infrastructures and possible mobilisation of contaminants from landfill and urban areas. A multidisciplinary investigation plan has been deployed involving high spatiotemporal resolution monitoring of ground and surface water level and quality, geophysical surveys and characterization of flood sediments within dams and reservoirs. Here we report the preliminary results of the characterization of the sediments coming from 10 cores from the Notwane and Mogobane dams in the Gaborone dam catchment, combining grain size analyses, organic matter contents and distribution of trace metals in the dam sediments.

Sediment cores of ca. 1 meter have been sampled using gravity corer from shore or from a boat. Recovered cores have been analyzed for their particle size distribution using a Malvern Mastersizer Range. Samples from selected intervals have been analyzed through Atomic Absorption Spectroscopy (AAS) for trace metal (and pollutants) distribution. AAS have been coupled with in situ non-destructive X-Ray Fluorescence analyses using a portable XRF and measured directly on the core every 2 cm. Characterization and quantification of the organic matter have been performed on bulk sediments using pyrolysis techniques.

This approach has provided the first data for the reconstruction of the long-term trends in sediments input into the reservoirs and the correlations between floods and pollutant distribution. Grain size distribution clearly highlight the occurrences of major floods (coarse sediments) in contrast to a fine-grained dominated deposition during regular wet and dry seasons. The timing and magnitude of alternating droughts and floods has been identified characterizing horizons for their organic material and clastic material content. Sedimentation during droughts is generally characterized by higher organic matter content while flood sediments are dominated by siliciclastic material. This has been coupled with geochemical data from AAS and XRF showing the effects of such cycles in the mobilization of pollutants and trace metals.

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MICROBIAL FOOTPRINT IN LAKE SEDIMENTS FROM CENTRAL EUROPE

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Lake sediment studies have become increasingly popular in the last 20 years. Lacustrine sediments especially laminated deposits offer the possibility of paleoclimatological and paleoenvironmental studies. High-resolution analysis helps to understand the sedimentary processes and the in situ transformations. Moreover, microbial activity can provide an accurate source of information on the sedimentation process and lake parameters (Eh etc.). The research area (lake Bolatau-Feredeu) is located in the Eastern Carpathians, Romania, Central Europe and is part of the Triangle of Bukovinian Millennial Lakes. The max. water depth is 5.1 m with small water-surface (~ 0.3 ha.) and the lake has a catchment area of 31 ha. The sediment is laminated based on drill core samples[1]. The total sediment section represents the last ~ 6000 years based on C-14 AMS dating which was supplemented by Pb-210 isotope analyses. Recently analyzed sediment core was retrieved in November, 2013. [2,3] The time period examined in this pilot study covers approximately 500 years.

Analyses were carried out on 4 representative thin sections using high-resolution petrographic microscope and FTIR-ATR spectroscopy. Observations show microlaminations of samples which are mostly parallel, but in some cases irregular laminae and rarely microfossils also occur. High magnification showed widespread filamentous pearl necklace-like mineralized, microbially-produced biosignatures, which basically contribute to the sample material. FTIR-ATR study determined feldspar as the main constituent and also quartz. Rarely ferrihydrite (FeOOH), apatite, montmorillonite and chlorite were detected. Highly variable embedded organic matter occurs in all 4 samples (C=N/CH-amid, graphite, O=C, dCH2, C-O).

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LOOKING FOR A NEEDLE IN A HAYSTACK. NEW DISTAL CRYPTOTEPHRA FINDINGS IN ANNUALLY LAMINATED SEDIMENTS IN POLAND

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Tephra from explosive volcanic eruptions can be transported and deposited over long distances from the source and, if well-dated, is ideal for synchronising sedimentary records and detailed palaeoenvironmental reconstructions. Numerous tephra studies have shown that northern and central Europe was regularly impacted by large-scale eruptions from Iceland and the Eifel Volcanic Field in Germany since the Late Glacial. So far, tephra studies in Poland are limited to only a few sites due to the distal to ultra-distal position to European volcanoes that minimises a deposition of macroscopic visible ash layers. However, observations of the recent eruptions of Eyjafjallajökull (AD 2010) and Grimsvötn (AD 2011) in Iceland have demonstrated that Poland may also be prone to volcanic ash fall.

Hence, we systematically analysed annually laminated sediments from selected lakes along a W-E transect in northern Poland in order to extend the knowledge about the occurrence and dispersal of cryptotephras (macroscopic non-visible tephra layers) erupted from Iceland during the last two centuries. We investigated short gravity cores and focused on the detection of tephra from the large-scale Askja AD 1875 and the low- to medium-scale Eyjafjallajökull AD 2010 and Grímsvötn AD 2011 eruptions. The results allow for the first time to create volcanic hazard maps for Poland and to update existing tephra dispersal maps in Central Europe. Furthermore, the combination of high-resolution proxy studies (microfacies analyses, XRF elemental scanning) with independent dating methods (varve chronology, tephrochronology) will enable detailed spatiotemporal reconstructions and comparisons of palaeoenvironmental changes over a large area.

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Long-term high resolution records of productivity and meromixis from lake sediments using hyperspectral imaging spectroscopy: methods and applications

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The Anthropocene has seen unprecedented environmental change and fundamental ecosystem services are increasingly at stake. Anthropogenically altered biogeochemical cycles, combined with climate change have resulted in adverse ecosystem impacts, increased productivity and anoxia in freshwater ecosystems [3,4]. However, little is known about lake eutrophication and episodes of hypoxia and meromixis in the past, because this is difficult to measure analytically. Here, we review recent developments in novel hyperspectral imaging HSI techniques and discuss applications from lakes across Europe (Switzerland, Greece and Poland) showing how and when meromixis/hypoxia has developed over Holocene time scales and how meromixis has been modulated by anthropogenic impacts (deforestation, erosion, nutrient cycling). A sound scientific assessment of such changes must rely on a long-term perspective and high-resolution data. Hyperspectral imaging (HSI) is a novel nondestructive method to detect diagnostic sedimentary pigments at very high spectral (3 nm) and spatial (40 µm pixel size) resolution. We use hyperspectral indices to infer quantitatively Chl *a* and chlorins as an indicator for aquatic productivity and Bacteriopheophytin a (Bphe *a*) as an indicator for meromixis [2]. Indices are calibrated with absolute pigment concentrations of selected samples as measured by HPLC, using linear regression (e.g correlation coefficient of R=0.94, $p < 0.001$ with a coefficient of determination of $R^2 = 0.89$) [1]. Long-term Holocene/Late Glacial HSI data provide evidence for naturally occurring meromixis for short periods long before any human intervention. In the Mid-Holocene, meromixis appears/disappears repeatedly for longer periods of ca. 300 years, after substantial human disturbance in the catchment (Neolithic and Early Bronze Age land use, deforestation and reforestation). In the twentieth century, human impact is related to increased nutrient inputs and intense eutrophication, when meromixis can become established permanently.

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HOLOCENE CHRONOLOGY AND MULTI-PROXY ANALYSES OF THE ANNUALLY-LAMINATED RECORD FROM LAKE DISS MERE (EAST ANGLIA, UK).

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Diss Mere (Norfolk) is one of the few known lakes in the UK that provides an annually-laminated (varved) sediment record of the Holocene. Here we show the first continuous, high-resolution and independent dated Holocene record for the British Isles. The Diss sedimentary record is 17 metres long. The sediments consist of calcite mud and silt with a high organic matter content. The first 9 m are faintly laminated and a total of 8,535 varves are well preserved from 9 to 14 m of sediment depth. The lower three metres display a transition from calcite mud to grey sand. The chronology is based on varve counting, radiocarbon analyses and it is validated by tephrochronology. 35 radiocarbon dates along the sediment sequence shows the Diss Mere record covers the entire Holocene. According to the 14C-based age-depth model, the varves date between 2000 and 10,600 cal. a BP, which is in close agreement with the floating varve count. In addition, 8 cryptotephra layers corresponding to 4 early-Holocene, 1 mid-Holocene and 3 late-Holocene volcanic eruptions have been identified along the varved sequence and used to validate the Diss Mere chronology. The discovery of these tephra combined with the precise varve chronology provides opportunity to revise the age estimates of less securely dated tephra and is a major contribution to the ongoing development of a Holocene tephrostratigraphic framework in Europe. Multi-proxy analyses based on microfacies observations combined with micro X-ray fluorescence core scanning data, and analyses of pollen, chironomids and ostracods allow reconstructing the environmental evolution of Diss Mere during the Holocene and show the sediments responded to major climate changes affecting the North Atlantic region. The combination of tephrochronology and the highly-resolved sediment record makes it possible to synchronise the Diss Mere record with that of the equally high-resolution Meerfelder Maar record in Germany and to compare and contrast the climatic signals in both sites, which is an essential requisite in understanding the regionality of abrupt climate change during the Holocene.

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A HIGH-RESOLUTION APPROACH TO EVALUATE THE OCCURRENCE OF VARVED SEDIMENTS IN LAKE WALKER, QUÉBEC NORTH SHORE (EASTERN CANADA) USING μ-XRF, CT-SCAN AND THIN SECTION IMAGE ANALYSIS

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Abstract

On the Québec North Shore, in the southeastern Canadian Shield, three lakes (lakes Pentecôte, Walker and Pasteur) were studied for the possible occurrence of laminated sediments. Facies analysis using CT-scan images and thin-sections of short sediment cores sampled along transects reveals that lakes Pentecôte, Walker and Pasteur contain bioturbated, partially laminated and well laminated sediments. It has been demonstrated that of the three studied lakes, Lake Walker is characterized by morphological factors (such as higher relative depth, mean depth, maximum depth, critical boundary and topographic exposure) that favour the preservation of sediment laminae [1]. However, the existence of an annual rhythmicity has not been confirmed yet. Hence, the objectives of this study are to: (1) establish a depth-age model based on ^{14}C dating of a ~8-m long composite section from Lake Walker, and (2) conduct a microfacies analysis of the laminated sediments from that lake in order to confirm whether they are indeed varved. The methodology includes multi-parameter approach of manual counting using high-resolution X-ray-microfluroescence (XRF) and X-radiography data with the *PeakCounter* software [2], supported by image analysis of thin sections [3]. Measured XRF elemental variation of Si, Ti, Fe, Zr, Ca and the inc/coh ratio were compared to alternating laminae structure, in order to test the cyclicity of the varve thicknesses. A semi qualitative index, the "Lamination visibility index (LVI)" was introduced to describe the visibility of laminations, as observed from the digital images. Similarly, a varve quality Index (VQI) was also used to describe the occurrence of rhythmic laminae and varve interpolation in the composite sequence. This research confirms the hypothesis that Lake Walker contains varved and non-varved intervals, with a basal age of 7060 ± 25 ^{14}C BP (7900 ± 30 cal BP), which marks the transition between the underlying glacial sediments and the overlying postglacial (annually) lacustrine laminated sequence [1, 4].

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RECENT VARVE SEDIMENTATION IN A LAKE UNDER STRONG ANTROPOGENIC PREASURE. A CASE STUDY OF LAKE KIERSKIE, WESTERN POLAND

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In urban Lake Kierskie (Western Poland) distinct, however discontinuous, varve deposits were observed in the lower and uppermost Holocene sediment sequence. Varves occurring in the uppermost 50 cm of the sediment sequence are linked with man induced eutrophication of the lake. To recognize the conditions of these varves deposition sediment traps were installed at 16 and 30 m of the water depth, at the deepest part of the lake (35 m). Monitoring study of the water characteristics and trophy was carried out in roughly monthly intervals between November 2015 and October 2016 and included standard physico-chemical water properties related to thermal conditions and oxygenation dynamics, water clarity, hardness, alkalinity and nutrients and solute content. In addition to abiotic parameters, trophy indices included chlorophyll-a concentration and the structure and quantities of the phytoplankton assemblage. Along with water sampling sediment samples were collected and analysed for elemental composition (CNS) and stable isotope ($\delta^{13}C$ and $\delta^{18}O$) composition of carbonates. The latter analyses were supplemented with stable isotope composition of dissolved inorganic carbon (DIC) and water.
Depending on the season and the shift in phytoplankton composition, the geochemical composition of the trap sediments varied. In the early spring the sediments were enriched in biogenic silica while in the late spring and summer calcium carbonate was the major constituent of the deposits. During late autumn and winter the sediment resuspension and redeposition was evidenced in the trap material, this particularly was the case for the deeper traps. The total mass of the sediment deposited at the peak of primary productivity in the lake differed between the trap depths, being greater at 16th meter. This resulted from enhanced organic matter decomposition and $CaCO_3$ dissolution between 16th and 30th meter. Carbonates were precipitated out of oxygen equilibrium with water throughout the vegetative season. The extent of the ^{18}O-depletion was greater in the summer compared to the spring, 2.8-4.0 ‰ and 1.3-2.5 ‰, respectively, probably as a result of elevated primary production and strong supersaturation of waters with respect to calcium carbonates. This is in contrast with other eutrophic lakes, e.g. Lake Baldeggersee (Teranes et al. 1999) in which disequilibrium carbonate precipitation was limited to the spring. The difference observed may result from the high eutrophy and even hypertrophy of Lake Kierskie. Our study, as one of the first in central-eastern Europe, monitor the process of biogenic varve formation in highly eutrophic, hardwater lake. The results point to the potential and less commonly described limitations of those sediments in palaeolimnological studies.

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INFLUENCE OF LAND USE CHANGES ON LAKE MIXING REGIME AND REDOX CONDITIONS AS RECORDED IN VARVES OF LAKE ŻABIŃSKIE, NORTHEASTERN POLAND

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Recent spread of hypoxia has become important threat to the lakes. Long-term records of changing oxygen conditions are necessary to understand the mechanisms responsible for these processes. Here, we present 2000-years-long record of geochemical proxies from varved Lake Żabińskie (northeastern Poland) to determine the influence of land use changes in the catchment on mixing regimes and redox conditions in the lake. Precise varve counting and microfacies analysis provide chronological frame for the reconstruction. Annually resolved sedimentological and geochemical proxies as well as pollen data are used to explain character, timing and reasons of changing conditions. During periods of increased human activity and landscape opening, geochemical proxies (Fe/Mn, TS, Mn/Ti, TOC/TS) indicated more intensive lake mixing and at least seasonal oxygenation of hypolimnetic waters. In contrast, decreasing human impact and forest restoration in the catchment led to weaker mixing and meromictic conditions. Transitions between these periods were characterized by highly variable conditions and short-term changes. Despite changes in erosion intensity and varying inputs of minerogenic material to the lake, the Fe/Mn ratio shows reasonable course that may be used to reconstruct water column mixing and hypolimnetic oxygen conditions.

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General theme 7

Other topics

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A SEDIMENTARY JOURNEY THROUGH
3 BILLION YEARS IN THE NEW WORLD

POST-OROGENIC SEDIMENTARY EVOLUTION OF THE PYRENEAN RETROFORELAND (AQUITAINE AND BAY OF BISCAY BASINS RECORD)

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The Mesozoic Aquitaine Basin (alternations through time of rifts and intracratonic to passive margin basins) is inverted during Cenozoic times to become the retro-foreland of the Pyrenees Mountain Belt. A lot of studies were carried out on the paroxystic phase of the retro-foreland activity, few paid attention on the latest –post orogenic – stage, the so-called “Molassic” periods. This can be explained by the monotonous facies distribution along poor outcrops with few dating available.
For a better understanding of the last stage evolution of both the Pyrenees and Massif central relief – and their consequences on the sediment routing system – we performed a stratigraphic study of the “Molassic” deposits and their marine equivalent, from the upstream part (Lannemezan area) to the distal part (Landes Plateau and Biscaye Bay abyssal plain). This study was mainly based on subsurface data, seismic lines and wells (industrial and BSS) provided by the BRGM and TOTAL. Wells correlation was based on the principles of stacking pattern calibrated in age and facies on cuttings and clabs. The seismic lines were interpreted using the principles of the shoreline trajectory and calibrated in age and facies on wells. We performed the first seismic transect interpretation between Toulouse (onshore) and the Cantabria Dome (offshore, abyssal plain).

The main results are as follows.
(1) A **sharp transition** from **continental** to **marine Bartonian environments** characterized by mixed **carbonate**-siliciclastic (clays and silts) platforms. The Bartonian to Priabonian shelves are reefal platforms, the Priabonian wedge is a major lowstand (LNR) which continue during Early Rupelian. . The Late Rupelian and the lowermost Chattian are progradational agradational. A major unconformity occurred during the Chattian (establishment of a large lowstand). This one is also located in the offshore part, in the Chattian wedge in front of the current basin of Arcachon.
(2) **Continental** environments (Priabonian to Chattian) are made up of palustrine to **carbonate lacustrine** sediments passing to **mixed to suspended-load rivers**, local base level of conglomeratic alluvial fans located in the extreme inner part of the basin at the feet of the Pyrenees.
(3) A **major erosion** occurred in the Late **Chattian** with present-day preservation of the Chattian in the inner part of the basin along the Pyrenees (500 to 1500 m-thick wedge). Chattian sediments were partly removed by erosion in the western part of the Lannemezan Plateau area and are mostly missing along the Aquitaine Basin.
(4) **Lower to Middle Miocene** sediments (with the same facies than above) are quite thin (50 to 200 m – **low preservation**). They record a major fall in the subsidence pattern. The offshore time-equivalent deposits correspond to establishment of important progradation wedges.
(5) A **two phases major uplift** of the Lannemezan and Ger Plateaus occurred during **Serravallian** and base **Tortonian** times sealed by weatherings and fluvio-lacustrine sediments (Orignac lignites)
(6) From **Late Miocene (Tortonian) to today**, the Aquitaine Basin is a sediment transit zone with deposition on the Landais Plateau as thick siliciclastic prograding wedges. All the post-Tortonian wedges seem to be corresponding to a 3rd order lowstand normal regression (LNR).
This work is founded and carried out in the framework of the BRGM-TOTAL project Source-to-Sink.

THE INITIAL STAGES OF EVOLUTION OF A RIFT BASIN (OLIETE SUB-BASIN, BARREMIAN, SPAIN): FROM CONTINENTAL SEDIMENTATION TO EARLY MARINE INFLUENCE

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During the Late Jurassic–Early Cretaceous the central and eastern Iberian plate was submitted to a rifting phase associated to the double influence of the spreading of the central Atlantic and the westward propagation of the Tethys. The Maestrazgo basin (eastern Spain) forms part of this rift system. Sedimentation in this basin occurred in separated subsiding domains or sub-basins bounded by areas with concentration of major extensional faults, including the Oliete sub-basin located in its northwestern marginal area. A review of the initial stages of the synrift sedimentation of the Oliete sub-basin is presented here based on data acquired after extensive sedimentological and structural analysis of its sedimentary fill (the Blesa Fm). The studied synrift succession has been divided into three genetic stratigraphic sequences bounded by sub-basin-wide unconformities. The lower Blesa sequence (LBS) is characterized by distal alluvial to palustrine marls/clays grading upwards to palustrine–lacustrine limestones. Its lower boundary is a prominent erosive unconformity overlying Jurassic units. The upper boundary is a planar to irregular transgressive surface, locally encrusted by oysters. Above this discontinuity, the middle Blesa sequence (MBS) consists of oyster-rich limestones deposited in a shallow restricted bay, which grade to distal alluvial and palustrine–lacustrine marls and limestones towards the marginal areas of the basin. The boundary between the middle and upper Blesa sequence (UBS) is a regressive surface with the local presence of conglomerate beds. The UBS starts with distal alluvial red clays, which grade upwards to palustrine and lacustrine carbonates. Locally, heterolithic alternations are also present, indicating deposition in coastal environments. The upper boundary of the Blesa Fm is marked by a widespread transgression, giving rise to shallow marine bioclastic limestones. Successive stages of tectosedimentary evolution are distinguished, including the initial uplift, breakup and erosion of the earlier Jurassic carbonate platform (Tithonian–Hauterivian); the onset of synrift sedimentation, which was highly controlled by extensional faulting and differential block subsidence (early Barremian); the homogenization of the basin subsidence and coeval incursion of marine waters from southeastern areas, during the middle part of the Barremian; and the significant fall in base level, also involving siliciclastic input in the northern areas of the Oliete sub-basin around the middle part of the late Barremian.

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FROM INCIPIENT ISLAND ARC TO DOUBLY-VERGENT OROGEN: EVOLUTION OF ARC-RELATED SEDIMENTARY BASINS IN SOUTHERN CENTRAL AMERICA

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This study presents a synthesis of the sedimentary and structural evolution of arc-related sedimentary basins in southern Central America. Linking onshore and offshore geology allows for a comprehensive understanding of the basin development that can serve as a general model for the long-term (> 100 Ma) evolution of island arcs.

The evolution of the southern Central American island arc can be subdivided into three phases: 1) A pre-extensional phase in the Late Cretaceous that is characterized by terrane accretion along the continental crust of the Chortís Block and the CLIP plateau. These accreted terranes and CLIP basalts form the basement of the island arc. 2) An extensional phase during the Maastrichtian to Oligocene, which was accompanied by rapidly subsiding sedimentary basins, and deposition of thick arc-derived volcaniclastic material. 3) A compressional phase during the Neogene, characterized by the transformation of the island arc into a compressional arc with a doubly-vergent geometry, dominated by fold-and-thrust belts in the forearc and backarc area.

The first order controlling factor for the subsidence of the arc-related sedimentary basins was slab rollback and related trench retreat, indicated by increased subsidence in the forearc and backarc basins, extension in the intraarc area and shift of the volcanic arc. In addition, the basin subsidence has been controlled by subduction erosion, caused by the subduction of aseismic ridges and slab segments with rough crust. These factors shaped the forearc and controlled the lifespan/longevity of sedimentary basins. Smaller-scale, short-lived forearc and trench-slope basins with complex subsidence and uplift patterns formed, when subduction erosion was high. In contrast, in the absence of major subduction erosion, larger, long-lived forearc basins with thick sedimentary fills developed. The structural and sedimentary evolution of the arc-related basins has therefore been strongly controlled by regional subduction parameters, especially the angle and morphology of the incoming plate.

During the Neogene the sediment supply of the arc-related basins was closely related to the evolution of drainage systems in response to compression and evolving topography leading to a much higher sediment supply to the backarc basins than to the forearc basins.

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Late Paleozoic Sedimentary Evolution Characteristics of the Bohai Bay Basin

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The Late Paleozoic sediments in the Bohai Bay Basin were formed under the background of terrestrial sea environment evolving to continental environment. Late Paleozoic is a special historical stage in basin sedimentary evolution and plays an important role in connecting late and early stage as well as marine and continental facies. The Late Paleozoic sedimentary evolution model of the Bohai Bay Basin is as follows:

①During Late Ordovician-Early Carboniferous, the Bohai Bay Basin subsided and began to accept sediments in Late Carboniferous Benxi Period as a result of the weathering, dissolution and planation that last for up to 140 Ma. At the same time, seawater entered into the basin from northeast direction. With the gradual expansion of transgression range, epicontinental sea sediments were formed, with carbonate platform and tidal flat sediments alternately occurred.

②During the transitional period from Late Carboniferous to Early Permian Taiyuan Formation, the provenance area in the north further uplifted. At this time, the supply of terrigenous clastic materials was sufficient. With the development of carbonate platform facies and tidal flat facies, the dark mudstone of lagoon facies and the sandbodies of barrier islands and tidal channel were well developed.

③During the depositional period of Early Permian Shanxi Formation, since the basement of northern North China Plate gradually uplifted, regression began to occur. As a result, shallow water delta-dominated sea-continental transitional facies occured in the basin. Delta plain and delta front subfacies were alternatively developed, but prodelta subfacies was not. The sandbodies of distributary channel and the underwater distributary channel were well developed.

④ During the depositional period of Middle Permian Xiashihezi Formation, the tectonic movement in the north was intensified and the seawater continued to retreat southwards. The shallow water delta-dominated sea-continental transitional facies transited to the meandering river-dominated continental facies. The sediments were dominated by yellow-gray glutenite, with obvious "binary" structure.

⑤During the depositional period of Middle Permian Shangshihezi Formation, the tectonic movement of the basin was active once again. As a result, braided river-dominated fluvial facies occurred. The sediments were dominated by mauve glutenite, with mudstone content increasing upwards.

⑥During the depositional period of Late Permian Shiqianfeng Formation, fluvial-lacustrine sedimentary system was formed in the basin. The floodplain sediments formed at early stage were replaced by lacustrine sediments.

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Lithology Characteristics and Sedimentary Association of the Shanxi Formation in the Bohai Bay Basin

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Shanxi Formation in the Bohai Bay Basin was deposited in transitional facies in the continental sea of North China Craton. The lithology, deposition pattern and sedimentary facies distribution were identified in this study through field observation, core description and log and seismic data analysis, which is of great important to understand Early Permian sedimentary evolution and explore oil and gas in the deep Bohai Bay Basin. The result suggests that, source was primarily derived from the north of the Yanshan orogenic belt during the Shanxi period with stable tectonic, favorable climate, smooth terrain and shallow water as well. The Shanxi Formation is mainly shallow delta facies deposits, which can be characterized by following points.

① It is dominated by gray middle-fine sandstone, siltstone and mudstone. Coal bed is widely developed and varies significantly in lateral, which commonly overlaid by sandstone.

② Thick complex sand-body generally comprises multiple thin sand-bodies, forming vertical normal cycle. The primary sedimentary structures is cross bedding, e.g., trough cross bedding, wedge cross bedding and planar cross bedding, etc., with intense bioturbation.

③ Delta plain and delta front subfacies occurred alternately without prodelta subfacies. Distributary channel and sub-water channel can be widely developed without mouth bar

Shallow delta facies in the Shanxi Formation is characterized by obvious period, varying with the periodic variation of sea level. Therefore, the Shanxi Formation can be divided into 3 subsequences, corresponding to 3 main periods (origin, developing and conversion) of shallow delta system.

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DETERMINATION OF TRACE METAL IN SURFACE SEDIMENTS OF THE VAZA-BARRIS RIVER IN THE STATE OF SERGIPE, NORTHEAST, BRAZIL

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Potentially toxic elements in sediments and their bioavailability were investigated by to evaluate the impact caused by anthropogenic actions. The basin of the Vaza-Barris River is located between Bahia and Sergipe states, Northeastern, Brazil, and covers about 50% of the population of Sergipe[1]. This study aims to determine the concentration levels of Al, Co, Cr, Cu, Li, Mn, Ni, Pb and Zn in the fine fraction (<63 µm) of the Vaza-Barris river surface sediments and to relate potential sources of pollution. The samples were collected in nine points, distributed among Aracaju, Itaporanga D'Ajuda, and São Cristóvão cities, Sergipe, Brazil. The metals were partially extracted according to a method described by US EPA (200.8), using a diluted HNO_3 (7.2 mol L^{-1}) and HCl (2.4 mol L^{-1}). To obtain the total fraction, concentrated HNO3 (14.4 mol L^{-1}) and HCl (12.0 mol L^{-1}) were used[2]. In order to evaluate the accuracy, the methods were applied for certified reference material of lake sediment (LKSD-1 CCNRP / Canada) and the recovery ranged from 87% (Ni) to 113% (Mn) and 93% (Zn) to 104% (Cr), partial methods for the extraction and total respectively, for the partial and total extraction methods, respectively, demonstrating good accuracy and efficiency of the opening of samples for the procedures used. The analyzes were performed by flame atomic absorption spectrometry (FAAS) and the Al (1.99 – 5.16%), Co (1.02 – 14.4 µg g^{-1}), Cr (5.74 – 27.62 µg g^{-1}), Cu (0.49 – 7.98 µg g^{-1}), Fe (0.84 – 1.86%), Li (0.72 – 8.38), Mn (169.55 – 11108.25 µg g^{-1}), Ni (0.61 – 8.57 µg g^{-1}), Pb (0.88 – 7.10 µg g^{-1}) e Zn (0.38 – 123.12 µg g^{-1}) concentrations were determined. The highest concentrations observed for Al and Fe indicate that the mineralogical composition of the studied sediments is mainly of aluminosilicates. It was observed strong correlations (> 0.70) between the concentrations of the studied elements ranged from 0.75 (Al-Cr) to 0.97 (Pb-Mn), suggesting that the studied elements are associated with the surfaces of the aluminosilicates. In one of the points, the contribution of the elements Mn, Zn, Cu, Cr, Co, and Pb showed above the normalization prediction line, indicating anthropogenic contribution due to the domestic sewage contribution. In other points, anthropogenic contribution to Cr, Li, and Ni, from different sources is highlighted. Cr (0.75), Cu (0.91), Fe (0.89), Li (0.76), Mn (0.79), Ni (0.83), Pb (0.80) and Zn (0.77) showed strong correlations with aluminum, suggesting that aluminum was one of the main factors controlling the levels of metals in the sediments. The results indicated that the region studied has received lithic material, especially domestic discharges.

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CHEMICAL EVALUATION OF TEMPORAL RECOVERY OF A FLUVIAL ENVIRONMENT IMPACTED BY DISCHARGES OF PRODUCED WATER IN A RIVER IN BRAZILIAN NORTHEAST

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The extraction and production of oil generate many effluents and, among them, produced water is discharged. Japaratuba River was used as receiving body of these effluents in the oil production fields in Carmópolis, Sergipe, Brazil. This study aims to assess the environmental conditions of Japaratuba River in regions receiving the discharges of oil fields after five years of withdrawal of these evictions[1]. Samples of surface sediments were collected, in nine points sampled, in the course of the river and the partial and total concentrations of Al > Fe > Ba > Mn > Zn > Cr > Pb ~ Cu > Ni > Co > V > Cd, in increasing order of abundance, were determined region studied. The partial extraction was performed using dilute acids, HNO_3 (1:1 v v^{-1}) and HCl (1:5 v v^{-1}), in a closed system with heating (95 °C) and total digestion was performed with HNO_3 (65%), HCl (37%) and HF (48%). After evaporation, the residue was dissolved in HCl solution (0.5 mol L^{-1}). To evaluate the extraction methodologies, certified reference material lake sediment LKSD-1 (CCNRP/Canada) was used, which recoveries were obtained by ranging from 81 to 103% in the partial extraction, and 89 to 112% for the total extraction. The concentrations range were found: Al (3.17 – 3.93%), Fe (1.22 – 1.56%), Ba (823 – 1918 µg g^{-1}), Mn (484 – 988 µg g^{-1}), Zn (28.9 – 95.7 µg g^{-1}), Cr (4.56 – 78.6 µg g^{-1}), Pb (2.37 – 29.9 µg g^{-1}), Cu (0.58 – 29.4 µg g^{-1}), Ni (1.42 – 30.4 µg g^{-1}), Co (0.61 – 19.3 µg g^{-1}), V (0.09 – 8.19 µg g^{-1}) and Cd (0.06 – 6.36 µg g^{-1}) for partial extraction. The total concentration ranged as follow: Al (3.02 – 4.04 %), Fe (1.22 – 6.15 %), Ba (571 – 2110 µg g^{-1}), Mn (379 – 1030 µg g^{-1}), Zn (30.2 – 102 µg g^{-1}), Cr (2.80 – 82.4 µg g^{-1}), Pb (4.48 – 33.4 µg g^{-1}), Cu (0.18 – 39.7 µg g^{-1}), Ni (0.94 – 32.5 µg g^{-1}), Co (0.46 – 24.9 µg g^{-1}), V (0.04 – 9.62 µg g^{-1}) and Cd (0.04 – 7.49 µg g^{-1}). The organic carbon content present in the superficial sediments of the Japaratuba river varied between 0.64 and 4.23%. The concentration of nitrogen varied between 0.0 and 0.23%. The organic carbon/nitrogen ratio ranged from 17.29 to 444, indicating that the sediments studied have predominantly terrigenous organic matter[2], with great contribution of discharge of the produced water.

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Controlling factors on the tectonostratigraphic evolution of Cenozoic basins of the Northern Tethys: The Northern margin of the Levant Basin, onshore Southern Cyprus

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The Eastern Mediterranean represents the northern margin of Neotethys Ocean, and corresponds to a tectonically complex region which is linked with the convergence between Africa and Eurasia.

Present-day geometries are poorly constrained due to the absence of exploration wells. This makes the understanding of the tectonostratigraphic evolution of the northern Levant margin difficult. Cyprus is a key area to assess the link between the deformation and the sedimentation in the Northern Levant margin, as the whole structuration and sedimentation recorded the geodynamic history, especially during the Miocene.

The objective of this contribution is to investigate, through field data analysis, the timing and the mechanisms of basin deformation as well as the sedimentary filling of the Polis and the Limassol basins located onshore Cyprus since the Cretaceous, and to show how this is linked with the geodynamics of the region. The southern part of Cyprus presents several Paleogene and Neogene basins that recorded the main tectonic events related to the convergence of the Africa and Eurasia after the Troodos Ophiolite emplacement.

The Limassol and the Polis basins are bounded to the North by the Troodos ophiolite complex, and to the South by the external Cyprus arc thrust belt. The sedimentary infill of these basins is affected by a complex tectonic deformation associated with a paleoenvironmental evolution. Their deformation is linked with the N-S Cyprus arc compression, as well as the strike slip movement related to the Levant fault and the Anatolian fault activity, that accommodate the compression of the African plate and the Eurasian plate. The sedimentary infill gradually records an overall shallowing depositional conditions from a deep marine environments (Eocene-Lefkara Formation) to shallow marine environments (Miocene-Pakhna Formation), and the Quaternary exposure of the Cyprus island including erosion and fluvial deposits.

Based on fieldwork (facies analysis and distribution, concepts of sequence stratigraphy, structural analysis), the tectono-stratigraphic evolution of the Polis Basin and the Limassol basin were reconstructed from the Late Cretaceous onward in order to propose a model of evolution of the Northern Levant margin, in accordance with the main geodynamic timelines.

STRUCTURAL CONTROL ON SEDIMENTATION SINCE THE LATE MIOCENE IN NORTHERN GULF OF CADIZ AND WEST OFF PORTUGAL

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Tectonism has influenced the formation and evolution of the Neogene sedimentary basins in the Southwestern Iberian margin. The SW Iberia is located nearby the Eurasia–Africa plate boundary and has undergone convergence throughout the Late Cretaceous to present time. The inversion and further reactivation of Mesozoic rift faults in the Miocene has led to the formation of structural highs in this margin. There is also growth of diapiric structures in relation to the emplacement of the Gulf of Cadiz accretionary wedge during this time. Synchronous to the evolution of these tectonic features since the Late Miocene, different depositional systems (e.g. down-slope turbidite and mass transport deposits, along-slope bottom current deposits, mixed and pelagic/hemipelagic systems) were developed in these Neogene basins. The aim of this work is to evaluate how tectonism affected sedimentation since the Late Miocene in these Neogene basins (Algarve and Alentejo), emphasizing on the development of Contourite Depositional System along the middle slope. High quality multichannel seismic reflection lines covering the northern Gulf of Cadiz were used to establish a detailed tectono-stratigraphic evolution for the SW Iberia Margin. We have identified development of contourites drifts alongside basin topographic reliefs such as the structural highs and the diapiric ridges. These features control the intensity and pathway of bottom currents, and the accommodation spaces for sedimentary deposition in these basins. Various phases of deformation affecting the SW Iberian Margin were identified, with older seismic units (until the Late Miocene) showing a higher intensity of deformation, related to the regional tectonism. In comparison, the Late Miocene and Pliocene-Quaternary deposits have been deformed by small-scale folds and faults in the proximity of diapiric structures, caused by the upward movement of salt and mud bodies. This work demonstrates that the sedimentation is influenced by the existence of seafloor palaeo-reliefs and newer phases of diapirism that control the pathways of the bottom currents.

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THE INCEPTION, EPISODIC GROWTH, AND DEPOCENTER MIGRATION OF A FORE-ARC BASIN IN AN ACTIVE ACCRETIONARY WEDGE, NORTH ISLAND, NEW ZEALAND

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Forearc basins are sensitive to changes in tectonism along the plate margin, and therefore potentially record uplift and subsidence events, basin inversions and associated deformation, rates of sedimentation, sea level variation and cyclicity, and the broader tectonic regime. To understand the formation and architecture of a forearc basin alongside an actively deforming plate boundary, it is important to consider the deformational history of the sediments within the basin, the evolution of the structures bounding it, and the relationship between the subducting and over-riding plate. The focus of this research is to provide a better understanding of the geometry and style of sedimentation related to forearc basins situated adjacent to an active accretionary wedge, how this relates to progressive regional tectonics, and the evolution of the Australia-Pacific plate boundary.

The forearc basin, situated on the southeast of the North Island of New Zealand, provides a good case study as the basin succession, including the bounding structure, are entirely emergent. It has been possible to study the region by field mapping and compare the results with interpretation of off-shore seismic data.

During fieldwork in the northern Wairarapa region, a detailed geologic map of the Early to Middle Miocene basin succession, as well as the intensely deformed Coastal Ranges, has been compiled. The construction of an associated cross-section and stratigraphic analysis has made it possible to refine and characterize both the end of subduction during the middle Cretaceous, and its re-initiation at the beginning of the Miocene. New discoveries in the Pakowhai and Mataikona rivers has given unique and exciting insight into the Cretaceous cover-basement relationship as well as to the magnitude of Neogene deformation. Detailed structural and stratigraphic mapping within the adjacent Early Miocene basin, has provided evidence for a close connection between the actively uplifting wedge and the sediments filling it.

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CHARACTERISTICS OF UNCONFORMITIES AT THE END OF EARLY OLIGOCENE IN PEARL RIVER MOUTH BASIN, SOUTH CHINA SEA

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Abstact: Breakup unconformity of Pearl River Mouth basin is one of the most important boundary in northern South China Sea. This tectonic event, reflected by breakup unconformity, led to significant changes in the source, sedimentary environment and climate. Its mechanism is closely related to basin dynamics evolution, sea level fluctuation and hydrocarbon accumulation. Based on seismic data and logs, this study documents the distribution and characteristics of breakup unconformity, describes the changes in sedimentary environment and paleogeography, and finally discusses the mechanism of breakup unconformity with basin evolution. Pearl River Mouth basin was in the continental sedimentary environment before formation of the unconformity (32Ma), while it changed to shallow marine environment later. The distribution of breakup unconformity can be divided into three zones: Angular unconformity zone (like Enping, Xijiang, Lufeng Depression); Local unconformity and onlap zone (including Baiyun, Shunde Depression); Disconformity zone (such as Liwan and Shuangfeng Depression). Angular unconformity zone can be subdivided into local uplift belt and fault terrace area. These three zones show different characteristics on seismic: Angular unconformity zone is characterized by shoulder truncation due to fault block rotation; Zhu II Depression including Baiyun and Shunde Depression mainly shows onlap and obvious decreasing area of truncation; Disconformity Zone is located on the south of southern uplift in PRMB featuring onlap in depression margin and disconformity contact in depression center. The distribution pattern of breakup unconformity in this study suggests these variations are controlled by the tectonic and geomorphology in different zones of a basin. It also reflects such a post-rift progress: the lithosphere became thinner under tension while rift basin and graben formed, then the breakup unconformity formed at shoulder uplift and the passive continental marginal zone under combinational influence of shoulder uplift and thermal effect. Such results provides evidence for poor magma passive rifting mechanism in South China Sea.
Keywords: Breakup unconformity, Pearl River Mouth basin, South China Sea

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DETRITAL ZIRCONS REVEAL MAJOR CRETACEOUS VOLCANISM ALONG NORTHEASTERN GONDWANA

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The breakup of eastern Gondwana during the Late Cretaceous was preceded by extensive volcanism, as evidenced by volcanic records along eastern Australia and surrounding regions; these include the Whitsunday Volcanic Province[1,2], the volcaniclastic sediments of the Great Artesian Basin[1,3], Otway and Gippsland Basins[1] and New Caledonia[4], and dredge and core samples from the Lord Howe Rise[5]. We present new evidence that Cretaceous volcanism extended as far north as Papua New Guinea. Our samples were sourced from Port Moresby, Papua New Guinea and from DSDP, Leg 21, hole 209, on the northeast Queensland Plateau, offshore northeastern Australia. Detrital zircons were analysed for U-Pb geochronology and Lu-Hf isotopes using (multi-collector) laser ablation ICP-MS. Our results from both Port Moresby and the northeast Queensland Plateau show continuous volcanism between 120 Ma and 90 Ma (n>300); however, the detrital zircon record continues to ca. 70 Ma on the northeast Queensland Plateau. Further isotopic analysis of Cretaceous detrital zircons from Port Moresby have εHf values between +5 to +13. These values are comparable to the εHf record from detrital zircons from the same age in the Great Artesian Basin[3] and New Caledonia[4]. Similar εHf values along the eastern margin of Gondwana during the Cretaceous indicates that Port Moresby, the Queensland Plateau, New Caledonia and Great Artesian Basin were subject to similar crust-forming processes.

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Pre-Turonian strata in the Georgia Basin (Nanaimo Group) and implications for Mesozoic Insular Belt evolution

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The basal unconformity of the Upper Cretaceous Nanaimo Group (Georgia Basin), Vancouver Island, B.C., Canada is predicted to be Turonian to Santonian in stage; an age determined through molluscan biostratigraphy (Haggart et al., 2005). However, the basal strata are often unfossiliferous, and hence depositional age in many areas is interpreted based on the position of strata relative to the basal nonconformity. Maximum depositional ages (MDAs) and kernel density estimate-plots (KDEs) of detrital zircon (DZ) samples present an alternate method for constraining depositional ages, and enables correlation of strata with unknown affinity.

Eleven DZ samples taken from strata in close proximity to the basal nonconformity show highly variable MDAs, three of which are significantly older than the Turonian. Two samples yield Albian (106 and 109 Ma) MDAs, and possess age signatures suggesting predominantly allochthonous sediment input from continental North America. The third sample yields an Oxfordian (160 Ma, Jurassic) MDA, and possesses age signatures implying predominantly autochthonous sources from the underlying Wrangellia Terrane, and minor sediment contribution from Alexander Terrane.

The data indicate that some strata attributed to the Nanaimo Group belong to older sedimentary deposits, and are cut by unknown unconformities. This entails that the Georgia Basin's tectonic evolution is more complex than a single late Cretaceous subsidence event, and also suggests an additional history of pre-Turonian subsidence, deposition, uplift, and erosion. Overall, the results enable a better understanding of Insular Belt history, especially with respect to transitions between tectonic environments in the area.

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A New Model for the Formation and Evolution of Middle-shallow Faults in Daqing Placantieline, Songliao Basin, NE China

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Main text: The middle-shallow faults which are full of concentrated oil and gas are well developed in Songliao Basin. Previous studies find that differences exist in the faults' developing degree between different reflection interfaces and that was considered to be results of multi-stage tectonic activities. However, the results of predecessors lacks regularity and the faults-developing pattern remains obscure, thus making the exploration orientation of oil and gas in this area indeterminate. To identify the developing law and the causing mechanism of the middle-shallow faults in Songliao basin, the authors applied the model of faults' effect under conditions of pre-existing tectonics and utilized 3D seismic profiles to structurally re-analyze the middle-shallow faulting system. The result shows that: ①the middle-shallow faulting system of Daqing Placanticline in Songliao Basin can be divided into eight types, according to faulted successions, displacements, extents and strikes; ②the average strike of faults in T2、T1、T06 reflection interfaces is 322°, 320° and 316°, respectively; and there is an anti-clockwise rotating change trend lies in the average strike which can be observed from older successions to newer ones;③tectonic stress mechanisms had been transformed from extension during sedimentation of Quantou Formation -Mingshui Formation into strike-slip at the end period of the Mingshui Formation since formation of middle-shallow successions in Daqing Placanticline. However, the principal stress direction of the tectonic stress field did not changed; ④the complicated faulting system in the study area came into being under the condition of maintaining a relatively steady principal direction of tectonic stress field and in the process of a progressive deformation. These results demonstrates this new model is much more suitable to explain the formation and evolution of the faults , and will has a guiding significance for the further exploration and development of the study area.

Key words: Daqing Placantieline; fault system; pre-existing faults; progressive deformation.

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CHRONOSTRATIGRAPHIC AND TECTONOSTRATIGRAPHIC ANALYSIS OF THE MIOCENE FORELAND BASIN DEPOSITS OF THE SUBALPINE MASSIFS AND SOUTH JURA (WESTERN ALPS, FRANCE). AN UPDATE.

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If sub-basins located in the western Alps foreland basin have been extensively documented (e.g., Swiss and SE-France molasse basins), the molasse-bearing synclines along the subalpine massifs, the southern Jura massif and the eastern border of the "Bas-dauphiné" basin still remain poorly described and the deposits in these synclines are barely dated or undated. This lack directly impacts our understanding of the timing of the successive syn-sedimentary deformation phases during the Miocene, which results from complex interactions between tectonic, stratigraphic and lithospheric dynamics. The aim of this multi-disciplinary study is to build an updated and integrate picture of the sedimentology, chronostratigraphy and deformation history of molasse deposits throughout the Miocene between the subalpine massifs, the southern Jura massif and the eastern border of the "Bas-Dauphiné" basin within the foreland basin.
Our preliminary results show:

- Numerous sedimentary sequences equivalent in age to the SE-France and "Bas-Dauphiné" molasse basin sequences have been reappraised and constrained in time between the Lower Burdigalien (S1) and the Langhien (S3) by using nannofossils and strontium (e.g., chemostratigraphy) data. East-West sequence correlation highlights a westward migration of the depocenter.
- Evidence of paleo-topographies have been commonly recognized in the field. Genrally, the origin of these paleo-highs was attributed to normal faults created by the extensive Oligocene period. However, the subcrop mapping of the basal Miocene unconformity and sedimentological description of the basal Miocene deposits show E-W incised-valleys in the westward migrating Alpine forebulge. This suggests that the paleotopographies resulted from erosion.
- Three evidences of syn-tectonic deposits have been evidenced. The onset of deformation in the foreland basin is nowadays attributed to the Late Miocene (e.g., Tortonien); however, our new field data suggest that the deformation initiated much earlier, during deposition of Sequence S2 in the Late Burdigalien.

Ultimately, we aim at updating current infill models in foreland basins, both in time and space (e.g., 4D).

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Allostratigraphic Framework and Paleodepositional Environments of the lower Nanaimo Group: Comox sub-basin, Vancouver Island, B.C.

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The Upper Cretaceous Nanaimo Group is a 4 km thick sedimentary succession that infilled the forearc, Georgia Basin. Nanaimo Group strata are currently subdivided into 11 lithostratigraphic units, which are identified based on grain size (i.e., dominantly coarse- or fine-grained), and position relative to both the basal nonconformity and to each other (Mustard, 1994). Unfortunately, significant topography on the basal nonconformity ensures that lithostratigraphic units are not time correlative, and hence, cannot be used to accurately reconstruct basin evolution. Herein, we propose an allostratigraphic framework for lower Nanaimo Group strata in the Comox Sub-Basin (northern Georgia Basin), Vancouver Island, British Columbia, Canada. Thick and continuous outcrops of the lower Nanaimo Group are logged and are compared to a 400 m long core through similar strata. Outcrops and core are divided into facies and facies associations, and these are used to identify bounding surfaces. Maximum depositional ages (MDAs) provide age constraints for strata and are used to refine regional correlations. Correlating strata via bounding surfaces, facies associations, and MDAs reveal substantial topography on the basal nonconformity.

The overall stratigraphy of the lower Nanaimo Group reflects drowning of the basal nonconformity with the main source of sediment to the north and west. Depositional environments show a marked pattern: overall transgression with brief periods of progradation. Basal terrestrial fluvial belts and swampy floodplains shift to paralic strata and shelf deposits up-section. Maximum depositional ages also show that the lowermost Nanaimo Group strata contain major unconformities, and deepening upwards successions, as defined by Jones et al. (in press), are prevalent throughout the shallow-marine stratigraphy of the lower Nanaimo Group. The results of this work demonstrate a complex depositional history for the lower Nanaimo Group that was non-continuous and was significantly impacted by topography on the basal nonconformity. These observations are expected for drowning of a forearc basin and assist with reconstructing the evolution of the Georgia Basin through the Cretaceous.

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Initial growth of the Northern Lhasaplano in the early Late Cretaceous (93-87 Ma)

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Constraining the stepwise growth of the Tibetan Plateau in time and space is critical to test geodynamic models of subduction and continental collision, as well as environmental and climatic changes at the regional and global scale. The Lhasa block is a key region to unravel the early stages of Tibetan Plateau growth before the India-Asia collision. Stratigraphic, sedimentlogical, geochronological, and provenance analysis of the Jingzhushan Formation in the northern Lhasa terrane and of the Daxiong Formation in the central Lhasa terrane provide new information to reconstruct the paleogeographic evolution of the central part of the Tibetan Plateau during the Cretaceous. Sharply distinct from the underlying shallow-marine limestones, the over 1000-m-thick Jingzhushan and Daxiong formations mainly consist of conglomerates and coarse-grained sandstones deposited in alluvial-fan and braided-river systems. Both units were deposited during the early Late Cretaceous between ca. 93 and 87 Ma, as determined by geochronology of interstratified tuff layers, youngest ages of detrital zircons, and micropaleontological data from limestone pebbles. Clast composition, U–Pb ages and Hf isotopic signatures of detrital zircons, and paleocurrent data indicate that the Jingzhushan and Daxiong formations were derived from the same elevated source area located in the central-northern Lhasa block. These two parallel belts of coeval conglomerates record a major change in topography of the source region from a shallow seaway to a continental highland, implying initial topographic growth of an area over 80,000 km^2 wide named here the Northern Lhasaplano. Early Late Cretaceous topographic growth of the Northern Lhasaplano was associated with demise of seaways, development of thrust belts, and thickening of the lower crust. The same paleogeographic and paleotectonic changes were recorded earlier in the Northern Lhasaplano than in the Southern Lhasaplano, indicating progressive topographic growth from north to south across the Bangong-Nujiang suture zone and Lhasa tectonic domain during the Cretaceous.

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High-resolution sequence architecture and depositional evolution of the Quaternary northeastern shelf margin of the South China Sea

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The northern continental slope of the South China Sea (SCS) is characterized by the development of large scale complexes since Quaternary. Based on integral analysis of the seismic, well logging and paleontological data, Successions since ~3.0 Ma can be defined as one composite sequence, consist of a set of regional transgressive to regressive sequences. They can be further divided into six 3rd order sequences (SQ0 - SQ5) based on the Exxon sequence stratigraphic model.. Since ~1.6 Ma, five sets of deltaic systems characterized by development of wedge-shaped foresets complexes or clinoforms had been identified. High-resolution seismic data and the thick foresets allowed further divided of sub-depositional sequences of regression to transgression, which is basically consistent with published stacked benthic foram O-isotope records.

Depositional systems identified in the study area include deltaic deposits (inner-shelf deltas and shelf-edge deltas), incised valleys, and slope fan deposits. Since SQ5, clinoforms prograded from the southern Panyu Lower Uplift toward the northern Baiyun Depression, shelf slope break migrated seaward, whereas the shelf edge of SQ0 migrated landward. While the Holocene highstand delta was limited within the continental shelf during the postglacial period. The development of incised valleys in the continental shelf increased upward, especially intensive on the SB3 and SB2. The fan deposits migrated basinward in general.

The evolution of depositional systems of continental slope mainly controlled by the combined influence of sea level changes, tectonic movements, sediment supply and climate changes. Since ~3.0 Ma, relative sea level of the northern SCS, had been experienced transgression (~3.0 Ma. BP) to regression (~1.6 Ma. BP). The regional regression and maximum transgressions of the composite sequences were apparently enhanced by uplift or subsidence related to tectono-thermal events. In addition, climatic variations including monsoon intensification and the mid-Pleistocene transition may have enhanced sediment supply by increasing erosion rate and have an indispensable influence on the development of the incised valleys and 5 sets of deltaic systems since ~1.6 Ma.

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DETERMINATION OF METALS CONCENTRATION IN SEDIMENT CORES COLLECTED AT CONTINENTAL SHELF OF SERGIPE STATE, NORTHEAST, BRAZIL

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The Northeastern continental shelf is narrow and consists almost entirely of biogenic carbonate sediments such as sand (particles between 0.053 mm and 2.0 mm) and gravel (particles larger than 2.0 mm), or by the abundance of calcareous algae. This work aims to characterize the geochemical distribution in the sedimentary profile, in the samples collected in the region of the mouth of Sergipe (10.0 m), Vaza-Barris (15.0 m) and Piauí Real (20.0 m) rivers of Sergipe State[1]. The samples were collected during campaigns of the "Physico-chemical characterization of marine waters, geological, geochemical and biological slope of sediment Sergipe and south of Alagoas", financed by Petrobras SA, along the continental shelf of Sergipe, Brazil. The cores were cut into 2.0 cm septa. The extractions were performed using dilute acids, HNO_3 (1:1 v v^{-1}) and HCl (1:5 v v^{-1}), in a closed system with heating (90 °C). The determination of inorganic compounds was performed by inductively coupled plasma optical emission spectrometry (ICP OES)[2]. The concentrations elements varied as following Al (2.24 – 2.83 %), As (2.34 – 2.51 mg Kg^{-1}), B (29.1 – 43.1 mg Kg^{-1}), Ba (1289 – 1343 mg Kg^{-1}), Cd (0.31 – 0.69 mg Kg^{-1}), Co (2.85 – 3.16 mg Kg^{-1}), Cr (23.9 – 24.6 mg Kg^{-1}), Cu (3.68 – 3.84 mg Kg^{-1}), Fe (1.89 – 1.97 %), Hg (0.0 – 0.05 mg Kg^{-1}), Li (11.1 – 11.6 mg Kg^{-1}), Mn (255 – 262 mg Kg^{-1}), Ni (10.7 – 11.1 mg Kg^{-1}), Pb (19.9 – 20.4 mg Kg^{-1}), V (25.9 – 26.3 mg Kg^{-1}) and Zn (23.6 – 24.4 mg Kg^{-1}) for core Sergipe River. For the Core of Vaza-Barris River varied from Al (1.30 – 1.47 %), As (3.75 – 3.96 mg Kg^{-1}), B (36.6 – 37.3 mg Kg^{-1}), Ba (359 – 362 mg Kg^{-1}), Cd (0.63 – 0.79 mg Kg^{-1}), Co (2.22 – 2.51 mg Kg^{-1}), Cr (17.4 – 18.0 mg Kg^{-1}), Cu (8.74 – 9.34 mg Kg^{-1}), Fe (1.63 – 1.75 %), Hg (0.02 – 0.06 mg Kg^{-1}), Li (9.82 – 10.0 mg Kg^{-1}), Mn (280 – 288 mg Kg^{-1}), Ni (7.24 – 7.49 mg Kg^{-1}), Pb (29.0 – 29.7 mg Kg^{-1}), V (50.1 – 50.5 mg Kg^{-1}) and Zn (25.6 – 26.0 mg Kg^{-1}). The concentrations for core Piauí Real River varied from Al (1.67 – 1.80 %), As (3.16 – 3.31 mg Kg^{-1}), B (26.8 – 27.0 mg Kg^{-1}), Ba (177 – 178 mg Kg^{-1}), Cd (0.49 – 0.62 mg Kg^{-1}), Co (0.78 – 0.83 mg Kg^{-1}), Cr (13.5 – 13.8 mg Kg^{-1}), Cu (1.86 – 2.03 mg Kg^{-1}), Fe (1.61 – 1.65 %), Hg (0.04 – 0.08 mg Kg^{-1}), Li (7.03 – 7.30 mg Kg^{-1}), Mn (78.4 – 80.1 mg Kg^{-1}), Ni (2.72 – 2.80 mg Kg^{-1}), Pb (10.9 – 11.2 mg Kg^{-1}), V (16.7 – 17.1 mg Kg^{-1}) and Zn (9.4 – 9.6 mg Kg^{-1}). All concentrations decreased with increasing depth for the sediments of the Sergipe continental shelf. Except for Cd and Hg which showed mixed trend throughout the profile and which rises up to the first 10 cm.

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EVALUATION OF THE CONCENTRATION OF DEEP CORES FOR ESTABLISHMENT OF THE GEOCHEMICAL BACKGROUND OF THE CONTINENTAL SHELF, SERGIPE, NORTHEAST, BRAZIL

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Commercial exploitation of mineral resources is part of the range of human activities that have most contributed to the increased concentration of trace elements in the hydrosphere. The establishment of background concentration allows evaluating potential contamination risks, identifying the natural concentrations of trace elements for a given area and the influence of anthropic activities[1]. This work presents the geochemical background concentration for the Sergipe continental shelf region, based on the analysis of the deepest profiles of the samples collected in the region of the Sergipe, Vaza-Barris and Piauí river mouths, Sergipe, Brazil[2,3]. The samples were collected during campaigns of the "Physico-chemical characterization of marine water, geological, geochemical and biological slope of sediment Sergipe and south of Alagoas", financed by Petrobras SA, along with the continental shelf of Sergipe, Brazil. The mean values for the geochemical background were calculated in sediments at depths of 16 to 20 cm, these are at concentrations below the surface concentrations, more homogeneous and constant. It is observed that at 16 cm, all concentrations are invariably reduced, showing geochemical background values for the Sergipe River continental shelf [Al (2.23 %). As (2.33 mg Kg^{-1}). B (29.52 mg Kg^{-1}). Ba (1287. 97 mg Kg^{-1}). Cd (0.48 mg Kg^{-1}). Co (2.87 mg Kg^{-1}). Cr (23.69 mg Kg^{-1}). Cu (3.65 mg Kg^{-1}). Fe (1.89 %). Hg (0.01 mg L^{-1}). Li (11.29 mg Kg^{-1}). Mn (253. 34 mg Kg^{-1}). Ni (10.65 mg Kg^{-1}). Pb (19.79 mg Kg^{-1}). V (25.57 mg Kg^{-1}) e Zn (23.64 mg Kg^{-1})], of the Vaza-Barris River continental shelf [Al (1.30 %). As (3.71 mg Kg^{-1}). B (36.47 mg Kg^{-1}). Ba (357.36 mg Kg^{-1}). Cd (0.51 mg Kg^{-1}). Co (2.20 mg Kg^{-1}). Cr (17.41 mg Kg^{-1}). Cu (8.70 mg Kg^{-1}). Fe (1.62 %). Hg (0.04 mg L^{-1}). Li (9.81 mg Kg^{-1}). Mn (279.95 mg Kg^{-1}). Ni (7.18 mg Kg^{-1}). Pb (28.82 mg Kg^{-1}). V (50.17 mg Kg^{-1}) e Zn (25.46 mg Kg^{-1})] and of the Piauí Real River continental shelf [Al (1.67 %). As (3.12 mg Kg^{-1}). B (26.39 mg Kg^{-1}). Ba (176.36 mg Kg^{-1}). Cd (0.52 mg Kg^{-1}). Co (0.66 mg Kg^{-1}). Cr (13.39 mg Kg^{-1}). Cu (1.85 mg Kg^{-1}). Fe (1.48 mg Kg^{-1}). Hg (0.04 mg L^{-1}). Li (7.01 mg Kg^{-1}). Mn (78.27 mg Kg^{-1}). Ni (2.71 mg Kg^{-1}). Pb (10.52 mg Kg^{-1}). V (16.64 mg Kg^{-1}) e Zn (9.27 mg Kg^{-1})]. The trace elements presented low concentrations, being able to be considered as background or natural levels, being related to the anthropogenic impacts in the region.

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Towards understanding tectonic sedimentary successions in asymmetric extensional basins

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Recent studies have shown that the evolution of extensional basins is often conditioned by inherited rheological weakness zones, such as nappe stacks and suture zones inherited from a previous orogenic evolution or faulting itself may lead to strain weakening and partitioning on major structures. The inherited presence or the creation of such weakness zones leads frequently to the formation and evolution of asymmetric extensional basins, where the major controlling structures and associated deposition migrate in space and with time. Such an evolution creates sets of sedimentary successions that reflect a tectonic-induced depositional cyclicity and are diagnostic for quantifying structures and evolution of sedimentary facies. In particular interesting is the analysis of extensional sedimentary basins associated with the orogenic evolution, where the thick and the rapidly deposited sedimentary successions allow an increased resolution of sedimentary facies both in outcrop and depth studies. Our analysis of a number of basins located in the fore- or back- arc areas of the rapidly evolving Mediterranean orogens has demonstrated a close interplay between changes in structural asymmetry and sedimentation. As long as the shallow subsidence is driven by the migrating large offset and low-angle normal faults, the sedimentation dynamics reflect an overfilled basin where diachronous successions may be regionally linked often in continental and shallow-water environments. When regional thermal effects start to become important in the overall subsidence, the basin rapidly deepens and moments of fault activation can be detected directly in the variation of the facies associations, while sourcing of the basin is directly affected by the migration of faults in the creation of barriers and gateways. Such basins are often shallow and are eventually filled by rapid deltaic progradations, where the cyclicity of sedimentary successions reflects the balance between the slow creation of accommodation space and the inherited presence of gateways, while gradually other external climatic and eustatic forcing factors become more dominant in sedimentation. We illustrate this mechanics by the means of observations in a number of orogenic asymmetric extensional basins, where the link between sedimentation and tectonics is validated by numerical modelling studies.

Laurentian crust in NE Australia: A critical tie-point during the assembly of the supercontinent Nuna

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A key tie-point for Rodinia between Australia and North America was initially based on similarities noted in sedimentary successions 1. This tie-point between east Australia and west Laurentia has also been proposed for the Proterozoic supercontinent Nuna 2, mostly in a Proto-SWEAT (Southwest U.S. - East Antarctica) configuration 3. In this configuration, the Proterozoic Georgetown Inlier of NE Australia is juxtaposed to the Yukon region of NW Canada 4,5. Detrital zircon age spectra from sedimentary strata within the Georgetown Inlier show three distinct signals in sedimentary provenance : (1) The lowermost units (Dep age ~1700-1650 Ma) have detrital zircon age spectra that strongly resemble Laurentian magmatic ages; (2) Sediments deposited from ~1650 to 1610 Ma show a unique proximal signature, and (3) sediments deposited post-1550 Ma have zircon age spectra that resembles the Mt. Isa Inlier of NE Australia. Along with new paleocurrent measurements, the detrital zircon age data challenge current models that suggest the Inlier was part of the North Australian Craton before ~1700 Ma 6. Rather, we suggest it was a continental ribbon rifted from west Laurentia during slab-rollback and development of an east-dipping subduction zone at approximately 1690 Ma. By 1650 Ma the Georgetown Inlier had completely rifted from Laurentia and by 1600 Ma was colliding with Australia. We show that the Georgetown Inlier is an important tie point between west Laurentia and the North Australian Craton during Nuna assembly between 1700 and 1550 Ma. The geological evolution of the inlier indicates Nuna assembly was unlikely completed prior to 1700 Ma as numerous previous studies suggested 3; instead, the assembly likely completed ca. 1600–1550 Ma through the accretion of the Laurentia-originated Georgetown Inlier terrane with the NAC, and the closure of an internal subduction system between the inlier and Laurentia.

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CONTROLS ON SEDIMENTATION WITH TRANSGRESSION ACROSS A COMPLEX SLOPE DURING THE SYN- TO POST-RIFT TRANSITION

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The evolution of sedimentation in tectonically-active rift basins is widely overlooked during the transition from syn- to post-rift conditions. In particular, controls on the development of shallow- and deep-marine clastic systems across complex inherited rift basin physiography have been poorly demonstrated. For the first time, we examine sediment dispersal processes and resultant stratigraphic architecture recorded by an exhumed Early Jurassic shallow- to deep-marine succession during the syn- to post-rift transition, in the Neuquén Basin, Argentina. The succession was deposited across a complex slope, within partially connected volcanic rift sub-basins, which stratigraphic variability is constrained by a 27 km long, proximal-to-distal, slope-parallel transect, using 10 (250-450 m), high-resolution measured sections. In distal sub-basins, the early post-rift stage is marked by deposition of areally extensive, organic-rich mudstone (40-70 m thick), which records long-lived sand starvation. Through time, sandy flows reached the distal sub-basins, depositing thick (70-230 m), sandstone-rich packages texturally "dirty" and immature at base and cleaning upward, and comprising lobes and minor channel-fills. These deposits are time-equivalent to thinner (maximum 160 m thick), clean, more mature, sandstone-rich successions including channels and minor lobes in proximal sub-basins. These relationships suggest trapping of cleaner sands in proximal shallow-marine sub-basins, bypass and accumulation of relatively 'dirty', sand-rich material in distal sub-basins. Changes in sediment storage and the textural characteristics of sandstone deposits are associated with variations in the contributions from extrabasinal and intrabasinal sources, sediment supply rates, and the evolution of rift basin physiography. Interactions between sand-rich flows and inherited rift topography had a major impact on the location and reservoir quality of sand-rich accumulations, with significant implications for subsurface exploration of analogous slope systems in rift basins.

FINAL CONTINENTAL BREAK-UP AND EVOLUTION OF DEEPWATER BASINS IN THE NORTHERN MARGIN OF SOUTH CHINA SEA

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Based on seismic profiles interpretation, integrated with gravity and magnetic data, an analysis has been undertaken to identify the structural units of the northern continental margin of the South China Sea (SCS). It reveals that from land to ocean, the northern margin can be divided into the proximal belt, necking belt, distal belt (DB), Oceanic Continental Transition (OCT) and oceanic crust domain. Comparing to the representative Iberia margin, the OCT in the NSCS is narrower with more complicated lithologic compositions. Except for the serpentinized mantle, strong magmatic intrusions and outer highs with basement complexes can be observed in the seismic profiles. One explanation of the typical OCT mantle hardly being observed is that the exhumed mantle had been infiltrated by tholeiitic basaltic magmas at the critical point before the lithospheric breakup.

We have built the structural frameworks of the basins in the proximal belt, distal belt, and OCT, respectively, which shows the basin pattern of the deepwater and ultra-deepwater basins in the Northern South China Sea (NSCS) is a supra-detachment basin controlled by large-scale detachment faults rather than high angle normal faults solely as was previously assumed. By the calculation of stretching factors of the crust in different structural units, Combining the quantification analysis of the fault activity and basin subsidence history, we propose that the margin has been experienced 3 episodes of rifting. The first episode featured by uniform lithospheric stretching with pure shear deformation, forming scattered rift basins; The second episode featured by strong lithospheric thinning and strain concentration with simple shear deformation, forming supra-detachment basins in necking belt and distal belt; And the third episode occurred close to the future oceanic domain, leading to the mantle exhumation. The polyphase faulting created a large accommodation space vertically and horizontally and formed a deep and wide shape of the deepwater Rift.

Moreover, we implement a state-of-the-art computer modeling on the deepwater region to understand the mechanism of the development of the deep water margin, build non-instantaneous extension break-up model of co-evolution between oceanic domain and extremely thinning continental margin, and reconstruct processes of lithospheric stretching, thinning, breakup and seafloor spreading. As a region between stretching continent and normal oceanic crust, DB-OCT records important information of the final break-up of the continent and birth of oceanic crust. Therefore, the study will improve our understanding on the transitional processes from continent to ocean in the South China block, and birth of the oceanic crust in the South China Sea under the convergent plate tectonic systems.

Key words: South China Sea; Detachment fault; Deepwater basins; Ocean-continental transition

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DANAKIL BASIN (AFAR, ETHIOPIA): FROM FIELD, SEISMIC AND BOREHOLE DATA TO BASIN DYNAMICS IN A RIFT SETTING.

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The Danakil basin is located in the northern apex of the Afar depression, where the Red Sea rift, the Gulf of Aden rift and the main Ethiopian rift interact, forming a triple junction. The Danakil basin is characterized by intense thinning of the crust[1] and represents the southernmost part of the Red Sea rift. It is bounded to the west by the Ethiopian plateau and to the east by the Danakil block,which is rotating counterclockwise and drifting eastwards together with the Arabian plate. In the center of the basin, the Erta Ale volcanic range, a NNW elongated ridge, produced significant volumes of basalts during the Quaternary, being still active today. Most of the basin is situated at altitudes below sea level and several flooding events from the Red Sea are recorded by the deposition of reef carbonates on the margin of the basin and by evaporites, filling the >2 km deep tectonic depression. This setting is thought to represent the transition between continental rifting and onset of oceanic spreading[1].

The stratigraphy, the structure and the recent dynamics of the Danakil Basin is poorly known but further investigations will contribute to the better understanding of this critical stage of continental breakup. Mining companies drilled boreholes and conducted geophysical investigation surveys, including reflection seismic in the western part of the basin. Access to these data along with recent[2] and future field data offers new opportunities for academic research. Based on these data, a new basin model will be produced, which will lead to the better understanding of its history and give insights into the marine flooding and dessication events, the tectonic movements and possibly the kinematics of the lithospheric stretching.

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NEW INSIGHT INTO THE EARLY AND MIDDLE MIOCENE DEPOSITIONAL SYSTEMS OF THE NORTHERN CENTRAL PARATETHYS SEA

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The remnants of the northern Central Paratethys are today dispersed in the territory of Slovakia, Hungary and Austria. This area has a long history of research, but many questions still linger on. The aim of this study is to fill in the missing pieces by assigning depositional environment and stratigraphy to the selected outcrops and correlate them with seismic and well data. To acquire this aim, we applied: facies analysis, biostratigraphy and numerical dating. The first site is located on the NE margin of Vienna Basin. The outcropping sediments are more than 30 m thick, and arranged in multiple cycles of fining-upwards conglomerates and sandstones with erosional contacts. Clasts are covered in trace fossils. This site can be interpreted as a fan delta that evolved on an actively degrading fault scarp. The Eggenburgian age (~21.4-18.2 Ma) is inferred based on molluscs[1].The second site is found in the North Novohrad-Nógrád basin. It is composed of an 8 m thick massive or plastically deformed mudstones, with rich marine fauna and flora. Deep water conditions are expected here and nanofossils indicate the NN4 Zone which ranks these sediments to the Karpatian stage (~17.2-16 Ma). The third site is located on the W margin of the Malé Karpaty Mts. and it is composed of laminated sandstones with rhizoliths. These are overlain by a rhyolite tuff which was used for Ar^{40}/Ar^{39} and AFTA analysis. Both methods indicate an age of ~15 Ma (lower Badenian). The section is interpreted as a shallow lacustrine environment. The fourth site is located on the border of Danube and Vienna Basin. Here the sandy cross-beds and paraconglomerates yield abundant marine fossils. Tide and wave activity points to marginal marine conditions. Based on statistical analysis of foraminifers, the Badenia/Sarmatian boundary is indicated here (Bul-Bol Zone/ large Elphydia zone; ~13.1-12.6 Ma). This dataset correlates well with seismic and well data from the region and it can be concluded that the Vienna Basin and NW Danube Basin are the oldest depocenters yielding Eggenburgian to Sarmatian sediments, while the Central Danube Basin is much younger and yields only late Badenian to Sarmatian strata.

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FAULTED & FRACTURED ZONES IN THE GERMAN NORTH SEA: FLUID MIGRATION PATHWAYS THROUGH BARRIER FORMATIONS?

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Any subsurface use (e.g. geological storage of fluids) requires inter alia a detailed knowledge about possible fluid migration pathways. Sedimentary and structural elements in the Mesozoic to Cenozoic deposits may have high impact on the barrier integrity of sediments in which they are hosted. Aside from a possible formation of a fluid migration network by superimposition, also a hypothetical genetic dependency of such superimposed structural elements is discussed in literature. Within the present study we investigate the superposition of e.g. glaciogenic erosional structures, (step) faults and crestal fault systems of diapirs, as well as polygonal fault systems (PFS), seismic pipes and sediment bodies of a Neogene delta system in the German North Sea sector and the possible (genetically) mutual interaction. Hereby a joint view and systematic mapping of these features with respect to fluid migration and the possible existence of a "seal bypass system"[1] is accomplished for the first time. To achieve this, the occurrence of all afore mentioned structural elements is mapped. In absence of 3D-seismic data, mapping is based on a comprehensive 2D-seismic data set. Subsequently surface modeling is accomplished and the superimposition is analyzed by attribute maps. The attribute maps illustrate regions, where combinations of structural elements are superimposed (i.e. vertically aligned) or in contact to each other (vertically aligned and overlapping) and where these are penetrating barrier horizons, such as the Rupel Formation (Base Oligocene).
Our results indicate that locally the overburden of the German North Sea sector is characterized by superimposition of different sedimentary and structural elements, possibly also creating a fluid migration network. Polygonal fault pattern are an almost extensive feature within the German North Sea, with tiers affecting the fine-grained clayey Oligocene/lower Miocene and partially the Eocene. Locally also the Rupel barrier formation is affected. We assume that the occurrence and pattern (size/throw) strongly varies with subsidence (rate), the lithology of host sediment and overlying mass transport deposits of the southwest prograding delta system. As consequence, several classes of PFSs are differentiated, based on regional framework conditions. In dependence to the activity of salt movements during Cenozoic, the host sediments of PFSs are either lacking in the top of diapirs or are connected with mainly complex crestal fault systems, which frequently extents up to the surface/seafloor. Together, the systematic classification of crestal fault activity and presence of PFSs also reveals regions with a possible decreased barrier integrity. Locally tunnel valleys are in contact to crestal faults along with PFSs and step faults (especially in the southwest study area). However, at the present status of work a systematic linkage between tunnel valleys and crestal faults is not apparent. The characteristics of isolated seismic pipes observed in the study area strongly differ. Often they affect the entire Mesozoic to Cenozoic, either terminating at the Rupel barrier formation or reach to the surface, then also penetrating the PFSs. Based on these observations we will present a qualitative estimation of regions affected with a possible loss of barrier integrity. However, no statements concerning the hydraulic conductivity can be made here.

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TITLE: THE JURASSIC SEDIMENTARY RECYCLING IN THE DONG CO AREA, CENTRAL TIBET: IMPLICATIONS FOR THE SUBDUCTION OF BANGONG-NUJIANG OCEANIC LITHOSPHERE

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The Middle Jurassic deposits in the Bangong-Nujiang suture zone in the central Tibet, can provide effective information for reconstructing the subduction processes of the Bangong-Nujiang oceanic crust. In this study, the newly finding of the Gamulong conglomerate are well exposed in the Dong Co area, central Tibet. The sedimentological analysis shows that this conglomerate has been deposited in a submarine fan environment. The youngest detrital zircon ages imply the Gamulong conglomerate was formed in Middle Jurassic time (at least to 166 ± 2 Ma). The gravels in the conglomerate are dominated by the limstones and sandstones, which is consistent with the sandsaone petrology, showing the limestone and sandstone fragments as the main framework components. Detrital zircon U-Pb ages from the interbedded sandstones yield the age populations of 164-178 Ma, 200-500 Ma, 700-1000 Ma, 1700-2100 Ma and ~2500 Ma. The corresponding zircon εHf(t) values are distributed between -23.5 and +11.1 with TCDM model ages of 2.8−0.6 Ga. These zircon features are similar to the previous published Mugagangri Group and Sewa Formation, indicating the Qiangtang-affinity zircons. Accordingly, the provenance results point out that the Gamulong conglomerate has recycled from the provious strata in the Bangong-Nujiang suture and southern Qiangtang subterrane. Together with the previous studies, the findings of Gamulong conglomerate of this study, enlighten the northward subducted system and the tectonic evolution of the Bangong-Nujiang suture zone.

MESOZOIC TECTONIC EVOLUTION OF EASTERN AUSTRALIA: INSIGHTS FROM THE SEDIMENTARY RECORD OF CENTRAL NORTH QUEENSLAND

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The tectonic and geologic history of eastern Australia was characterized by a long-lived convergent margin during the Paleozoic to at least the early Mesozoic, which was followed by rifting and development of the Coral Sea Basin during the Cenozoic. However, the mid-late Mesozoic history of eastern Australian remains elusive because the former continental margin lies buried beneath the Coral and Tasman seas. Porcupine Gorge in central North Queensland, Australia exposes an exceptional stratigraphic record of late Permian to Early Cretaceous sedimentary rocks of the Galilee and Eromanga basins and represents an opportunity to incorporate detailed sedimentary analysis and provenance techniques to provide new insights into the tectonic evolution of eastern Australia for this poorly understood period. Through the implementation of facies analysis, palaeocurrent analysis, sandstone petrography and detrital zircon geochronology on five sedimentary rock units in Porcupine Gorge it was possible to infer several key tectonic insights. Firstly, the dominant sediment source for fluvial systems of the northeastern Galilee and Eromanga basins is to the north and northeast of the study area. This source is interpreted to be the Carboniferous to Permian Kennedy Igneous Association in the Charters Towers Province. Second, detrital zircons from the Triassic succession detail a Late Triassic uplift event that may be linked to the Hunter-Bowen Orogenic event, which is part of the Tasmanide sequence of eastern Australia. Thirdly, the distribution of detrital zircon age spectra suggests continuous volcanism occurred throughout the Late Triassic to Early Cretaceous. A relative paucity of Jurassic grain ages suggests the volcanic arc was located distal to the interior basins and sediment was deposited into a presently buried offshore depocentre. Alternatively, the emplacement of a continental divide like the Great Dividing Range of eastern Australia may have provided a barrier to sediments draining westward off the arc. Finally, a provenance shift occurred in the Early Cretaceous, evidenced by palaeocurrent directions changing to northwesterly flowing, a lack of the Kennedy Igneous Association grain populations, and a change in sedimentary lithofacies from a fluvial to backshore to shallow marine environment. This facies change marks the onset of the Early Cretaceous marine transgression event.

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The Cenozoic stratigraphy architecture and structure styles of southeastern margin of South China Sea: Implications for tectonic evolution

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Abstract The southeastern margin of South China Sea (SCS) is located at the tectonic junction region of continental blocks collision and subduction leading edge zones. By using recently collected 2D seismic profiles, drilling wells and outcrop data, we established a stratigraphy correlation framework consisting of the structural units which relate to the different tectonic settings and distribution characteristics of representative stratigraphy formations. On this basis, we identify 6 major structural unconformities and analyze their geological nature by a comprehensive interpretation of the regional 2D seismic profiles and relevant drilling wells. Result shows T7 representing the termination of early episode rifting in the continental margin, and corresponding to the initiation N-S trending spreading in central oceanic basin of the SCS. T4 is the breakup unconformity, which marks the significant transition from early-stage rifting to sagging in southeastern continental margin and favors the development of the Nido platform carbonates. T3 is the most significant regional structural unconformity which is corresponding to the cessation of seafloor spreading in southwest sub-basin and collision of Nansha (Dangerous Grounds)-Liyue (Reed Bank) continental blocks with Cagayan arc choking the subduction zone of proto-SCS. This tectonic event resulted in the Sabah Orogeny, which indicates the inception of peripheral foreland basin developed from northwest Palawan trough to Reed Bank. The key tectonic events happened in the study area include south-dipping subduction and consumption of the proto-SCS, the opening and closure of SCS, and arc-continent collisional orogeny, all of which were placed in the regional context of general convergence of the Eurasian plate, India-Australia plate and Philippine Sea plate since Late Cretaceous. It also leads to the Nansha-Liyue-North Palawan blocks successively rifting from South China continental margin subsequently drifting southward and ultimately colliding with the Cagayan volcanic arc. Consequently, we conclude that the southeastern margin of SCS has undergone a complicated tectonic evolution from rifting basin through post-rifting depression to collisional foreland basin in the Cenozoic.
Keywords Stratigraphy correlation framework; Structural unconformity; Tectonic event; Tectonic transition ; South China Sea

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Along strike transfer of present deformation across Dinarides: connecting the Alps with the Hellenides

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Abstract

The mechanics of contractional deformation and associated subduction and plate motions have been well studied in the Mediterranean area. The process of indentation and related collision commonly induced a specific crustal and lithospheric deformation pattern across orogens situated between subduction systems. One of the places where the mechanics of indentation and associated sedimentation can be optimally studied is the External Dinarides orogen of Central Europe. Here, the indentation of Adria induced a lateral transfer zone of contractional deformation, which connects two subduction systems, one in the Alps and one in SE-Montenegro and its continuation into the Hellenides. In this study we have performed a kinematic analysis with the focus on the latest phase of extension and contraction associated with basin formation during the indentation of Adria in the External Dinarides. The results demonstrate that a system of Miocene intra-montane basins opened in response to a generalized moment of extension observed in the entire External Dinarides, which recorded lacustrine endemic fauna and endorheic sedimentation. This was followed by a latest Miocene-Pleistocene contractional deformation, which is being transferred from the Internal Dinarides in the NW to the present-day active continental subduction recorded in the SE-External Dinarides of Montenegro, effecting all inherited nappe-stacking and extensional structures. The along-strike transfer of contractional deformation is being focused along rheological weak zones such as the Miocene basins and areas of deep-water deposits. The Miocene sedimentation proved to be a critical recorder of both the genetically associated extension and the subsequent inversion, which facilitated the definition of these novel processes for the overall evolution of the Dinarides.

The gravitational collapse coupling with diapirism in Zengmu Basin, southern South China Sea: under the control of West Luconia Deltas

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Abstract Gravitational collapses were found at passive continental margins with thick shale or salt layers. This paper is the first comprehensive study for the Zengmu Basin's gravitational collapse which developed from Early Pliocene to present on temporal and was divided into three domains on spatial, the extensional domain, synthetic domain and contractional domain from shelf to deep basin. Comparing to the typical mud-shear model, the syn-collapse folds in the contractional domain in this study are accommodated mainly by diapirs instead of thrust faults. Mud diapirs are differentiated into three zones on lateral, a mud-volcano zone, a blur zone and a mud-diapir zone. Two sections on vertical are divided for the mud diapirs in the contractional domain, a titled lower section and an upright upper section. The main mechanisms for the collapse in the study area were supposed to be gravity spreading due to the basinward progradation of the West Luconia Deltas, a shelf-margin delta. The evolution process of gravitational collapse is divided into 5 stages, pre-delta, beginning of the West Luconia Deltas' progradation, seal for the detachment layer, initiation of collapse, processing and cease of collapse, all under the control of the basinward progradation of West Luconia Deltas.
Keywords West Luconia Deltas; Gravity-driven system; Zengmu Basin; South China Sea; mud diapir

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The Basin-Mountain Coupling about the South Tarim Basin During the Early Paleozoic Regional Tectonic Event

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Tarim Basin is an important multi-stage composite superposition basin, located in Northwest China. And it is also an important oil basin. There are many mountains and big fractures along this basin. Next to the South Tarim Basin, there are Altun Mountain and West Kunlun Mountain. During Cambrian to Ordovician, there are many orogenic events between the South Tarim Basin and the Altun Mountain, with the West Kunlun Mountain. In basin, the big event has obvious geology record at Madong and Tangnan Tectonic Belts. These areas recorded the whole orogenic very well, from deep structure and the surface landscape. This paper will tell the evolution process with the evidence of tectonic deformation, sedimentary facies change, the lithology and original sedimentary thickness change. This paper also give some balanced evolution profiles to illustrate the process better. During Early Cambrian to late Ordovician, the South Tarim Basin had a conversion from extended environment to the extrusion environment, because of the collision between the South Tarim Basin and the Altun and West Kunlun Mountains. And during Early to Middle Ordovician, the thrust deformation was transmitted to the Tangnan. In Late Ordovician, it arrived Madong thrust deformation belts. Until to Silurian, the event ended with formation up to the thrust belts. Compare the South Tarim Basin with the South China, there are so many same places during Early Paleozoic, from the sedimentary, deformation and geochemistry ways. So we think they maybe be in a same tectonic domain during Early Paleozoic, next to the Gondwana.

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CONTROLS ON STRATIGRAPHIC ARCHITECTURE AND INTER-BAR CONNECTIVITY OF MEANDERING RIVER SUCCESSIONS IN EVOLVING RIFT BASINS

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The spatial organization of meandering river deposits varies greatly within rift-basin fills, depending on how differential rates of subsidence and sediment supply interplay to drive changes in channel-belt position and rate of migration, avulsion frequency, and mechanisms of meander-bend cut off. This process fundamentally influences stacking patterns of the accumulated successions. Quantitative predictions of the spatio-temporal evolution and internal architecture of meandering fluvial deposits in such active settings remain limited. A numerical forward stratigraphic model – the *Point-Bar Sedimentary Architecture Numerical Deduction (PB-SAND)* – is used to explore the relationships between differential rates of subsidence and resultant fluvial channel-belt migration, reach avulsion and stacking in active, fault-bounded half grabens.

PB-SAND is used to reconstruct and predict the products of the complex morphodynamics of fluvial meanders, i.e., their generated bar forms, and the associated lithofacies distributions that accumulate as heterogeneous fluvial successions in rift settings. Point-bar connectivity and stacking patterns are predicted in response to temporal variations in fault kinematics. Fault-slip periods are described by Weibull distributions, in accordance with field observations and laboratory experiments that the probability of earthquakes increases with the accumulation of strain over time. PB-SAND is able to simulate the behavior of normal faults according to growth models proposed in the literature, for example by honoring the following situations: (i) constant ratio of maximum displacement to length, (ii) increased ratio of maximum displacement to length, and (iii) constant length as displacement accumulates. PB-SAND allows simulation of the progressive drift of rivers toward an active fault at rates of lateral migration that are controlled by local gradient within the basin. PB-SAND can also model the abandonment of meanders and the avulsion of river reaches. Results show how the connectivity of point-bar sandbodies changes along and away from the locus of fault displacement. Model outputs are analyzed quantitatively in terms of horizontal and vertical changes in static-connectivity metrics at multiple scales, to document the modeled connectivity of channel belts, point bars within them, and intra-bar sand-prone packages.

Focused fluid flow systems discovery and their implications for hydrocarbon accumulations, the southern margin of South China Sea

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Abstract:

Various focused fluid flow systems were discovered at the southern margin of South China Sea (SCS) through high-resolution seismic data. And the researches on their seismic response and implications for hydrocarbon accumulations was conducted for realizing the characteristics and searching “sweet spot”. Diverse focused fluid flow systems were identified, such as mud-diapir/mud-volcano, gas chimney, pipes and the focused fluid flow related fault. Different seismic reflection features were showed on these focused fluid flow systems, gas-bearing high-amplitude anomalous field, low-amplitude chaotic reflection, and “drop-down”/ “arch up” reflections which considered as recognition marks of focused fluid flow systems appeared frequently. Focused fluid flow systems were affected as tectonic movement and sedimentation factors, and were related to the deep high temperature and high pressure plastic fluid. Focused fluid flow systems were preferentially developed in the weak part of the stratum. Focused fluid flow systems and associated faults and/or fractures were often used as transport routs for hydrocarbon to accumulation zones. Moreover, the strong dissolved fluid and deep hydrothermal fluid transported by the focused fluid flow systems were beneficial to the formation of reservoirs, especially for the carbonate rocks. Focused fluid flow systems were not only served as migration passage of hydrocarbons, but also could improve porosity and permeability of reservoirs. Therefore, they are great significance to diagenetic process and the prospecting of hydrocarbon accumulations.

Key Words: Focused fluid flow systems; Mud diapir/mud volcano; Gas chimney; Diagenetic; Hydrocarbon accumulations; South China Sea.

Estimation of geometric parameters for non-parallel conjugate normal faults: Insight into the Lufeng Sag of Pearl River Mouth Basin in China

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Two sets of normal faults dipping in opposite directions are referred to as conjugate normal faults which develop at different scales in extensional basins. Equations of geometric parameters of non-parallel conjugate normal faults can be deduced from their trigonometric relations. Physical models can also be used to verify the theoretical calculations and compared with natural examples. In this study, we have used a theoretical approach to outline some key geometric parameters of non-parallel conjugate normal faults (intersection angles, plunge of intersection line, and vertical and horizontal distances of the intersection point, etc.) and compared them to equivalent geometric values in scaled analogue models. The comparison shows that theoretical plots used for geometric estimation of conjugate normal faults constrain reasonably the geometric parameters in natural cases. Interpretation of seismic data from the Lufeng Sag of Pearl River Mouth Basin in the northern part of South China Sea, where non-parallel conjugate basement faults propagate and intersect in cover units are compatible with the theoretical geometric estimation. A series of analogue models are used to investigate the intersection patterns and deformation in the sedimentary cover sequences above a basement horst bounded by two non-parallel faults. Modelling results show that during their upward propagation, the basement faults may intersect within the cover sequences and form a graben above the basement horst. Length and width of the graben increase with cover thickness. The strike and dip intersection points are controlled directly by the thickness of the cover sequences, dip and strike of the basement faults, and width of the basement horst. The intersection point migrates along the axis of the graben toward the wide end of the basement horst, when the cover sequence thickens. The intersection point moves upward with increasing width of the basement horst crest. Model profiles also indicate that in the presence of a ductile layer between the cover and basement such intersection patterns do not form. Interpretation of seismic data and model results show that the intersection pattern developed in the Lufeng Sag is a result of propagation of basement faults into cover units during different extension stages of the basin. Results of this study can be applied to many other sedimentary basins where such fault intersection patterns are likely to form when non-parallel conjugate basement faults are active during sedimentation.

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The relation of sedimentary basement type of depression and plaeo-tectonic compressive stress to the reservoir properties: a case study of Cretaceous in Southwest edge of Tarim Basin, China

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The Southwest Depression of Tarim Basin is located in the front of Kunlun Mountain, where more than 200 m thick sandstone reservoir develops in the Upper Cretaceous and constitutes the important hydrocarbon exploration target. Outcrops Tongyouluke (Section I), Tamuhe (Section II), and Qimeigan (Section III) with the spacing of approximately 20 km expose the feldspar lithic sandstones deposited in front subaqueous distributary channels of braided river delta, which came from the same provenance and experienced the similar buried depth and burial history, and geothermal gradient, and however have the distinctive reservoir properties. According to the analysis on the outcrop, experimental, and paleostress data, it was concluded that, Section I located in the outer edge zone of thrust belt has the plastic basement and relatively weak compression stress, which is favor of the development of high-quality reservoir. Section II located in the edge zone of foremountain thrust belt has the rigid basement and is beneficial to the development of medium-quality reservoir. Whereas, Section III located in the front edge zone of foremountain thrust belt has the rigid basement and consequently the low-quality reservoir develops. The types of basements in the foremountain depression basin and the tectonic compressive stress strength in the different part of thrust belt play considerable influences on the evolution of diagenesis and the reservoirs properties, and thus, should be taken into account during the reservoir evaluation within the foremountain trust belt.

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"Double Intense Effect" of Nanpu Sag in the Bohai Bay Basin, Eastern China: Response to the Cenozoic Stagnant Pacific Slab

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The Nanpu Sag, located in the NW part of the Bohai Bay Basin, eastern China, has significant oil discoveries in recent years. Sedimentary process in Dongying Formation (28.5-23.8Ma) of late Oligocene was controlled by intense boundary fault activities and intense depression, which are called "Double Intense Effect". Based on structural-stratigraphic framework sections, such effect was detailed recorded: both strata close to the boundary faults and located in the sag center were thick, comparing to the other periods in Cenozoic and same time interval in surrounding regions. As a result, the basement subsidence of late Oligocene period was intense, the subsidence rate was even higher than that during the rifting stage of Eocene.
Widespread occurrence of mafic volcanic rocks of Eocene to Miocene in Nanpu Sag have been revealed by extensive drilling and geophysical research. On the basis of petrological and geochemical studies from core samples, the magma experienced slight crustal contamination and the fractional crystallization was not very significant, through samples have an average Mg# value of 0.48 which suggests they are not primary magmas. Besides, the Nanpu Sag basalts have remarkable positive Pb, Sr and Ti anomaly, low Rb/Ba and Rb/Sr values, thus these features were inherited from source region. Mafic rocks of Dongying Formation have distinctive characteristics as sub-alkaline basalts with rare earth elements (REE) patterns which are parallel to E-MORB. Sm/Yb vs La/Sm plots are applied to evaluate the source mineralogy and degree of partial melting, indicating that the mafic magmas of Dongying Formation were created from a mixture origin of garnet-lherzolite with relative high degree of partial melting (30%-50), and garnet+spinel-lherzolite transition zone with lower partial melting degree (3%-10%). In contrast, most of basalts during corresponding stage in surrounding areas and other periods of Cenozoic in Bohai Bay Basin, are alkaline with light REE enrichment and OIB-like-pattern, their magmas originated from garnet+spinel-lherzolite transition zone with small partial melting degree lower than 5%. Combined with previous research about the mantle wedge above stagnant Pacific slab in the mantle transition zone of East Asia, which formed around 30Ma, our results infer that deep dehydration reactions of subducting slab cause upwelling of hot and wet asthenospheric materials like garnet-lherzolite, leading to the formation of the rift basin and volcanic events, Nanpu Sag in Dongying Formation was one of the most significant area of such period.

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The precipitation sequence of hydrothermal minerals and their controlling factors during the sedimentation——a case study of the Lower Cretaceous Tenggeer Formation in the Baiyinchagan Sag

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Hydrothermal sedimentary rock is a kind of sedimentary rock which deposited from the mixture fluid of hydrothermal water and the lake/ocean water from sedimentary basins, and which belongs to a transitional type between magmatic rocks and sedimentary rocks. They not only have some similarities, but also some differences in mineral composition, rock texture and structure as to magmatic rocks and sedimentary rocks. Hydrothermal sedimentary rocks contain much alminosilicate formed from the magma hydrothermal fluid, such as zeolite and feldspar, and also much carbonate minerals formed at normal lake/ocean water temperature, such as dolomite, magnesite, siderite, etc. A set of more than 300m thick hydrothermal sedimentary rocks has been found in the Tengger formation of the lower Cretaceous Baiyinchagan Sag Erlian Basin. Base on the microscopy, electronic probe and Qemscan, some sequences of mineral precipitation are established. In lamellar rock,there is a sequence of precipitation from aluminosilicate to carbonate. In the association of aluminosilicate minerals, the analcime deposited first, then followed by natrolite, and the last by albite. In the association of carbonate minerals, magnesite first appears, the followed by siderite, and the last by ankerite, and sometimes the reverse of the above sequence appears. Calcite can appear after dolomite precipitation. In flocculent nodule, pyrite appears at the center, and analcime, natrolite, magnesite, siderite, ankerite appear outward gradually. In the fractures, the filling sequence is from aluminosilicate such as zeolite, chlorite to carbonate such as ankerite, from the edge of the fracture to the center. The most complete and ideal sequence of precipitation in the study area is from pyrite to analcime, natrolite - albite - orthoclase - magnesite – siderite – dolomite – calcite.

The investigation of microbial communities from lake sediments and their relevance in paleoclimatic studies

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Lacustrine systems are very sensitive to climatic variations. Their sediments constitute targets of choice for paleoclimatic and paleoenvironmental studies. Given the specific characteristics of each system, a good understanding of the sedimentation and post-depositional processes is necessary to carry out this kind of reconstructions. However, deciphering primary signals from diagenetic overprinting remains complicated in many environments.
The main actors of early diagenesis in lake sediments are microbial communities. They play a critical role in the precipitation-dissolution of minerals, remineralization of organic matter and isotopic fractionation of the corresponding elements. While they have always been acknowledged, only recently have they been the target of dedicated research, integrated within multidisciplinary efforts to resolve past climatic changes.
In this contribution, we provide an overview of the recent advances made in the field of lake sediments applied geomicrobiology. By combining the analysis of past and present microbial activities in sediments retrieved from scientific drilling, we show how limnogeological studies can benefit from a better understanding of microbial turnover and biogeochemical cycling. The revolution guided by omics techniques allows to trace the taxonomy, functions and activities of subsurface microbial populations with the prospect to shed light on the much-discussed deep biosphere composition. Approaches including environmental DNA, lipid biomarkers, isotopic fingerprints and organic/inorganic mineralization traces have been implemented in several lake studies, encompassing a wide variety of lake systems and limnological regimes. Beyond the insights that can provide these analyses to joined reconstructions, these studies have also shown that the deep biosphere of lake sediments is active and diversified, and that it responds to past environmental conditions, possibly involving differential overprint in relation with climatic shifts. These results call for a generalized effort to integrate microbial ecology to paleoenvironmental reconstructions in order to resolve interdependent biological and geological processes.

STRATA FORMATION IN SHELF AND SLOPE CONTROLLED BY LONG AND SHORT TERMS SEA LEVEL FLUCTUATIONS, RESULTS FROM IODP EXPEDITION 317

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Strata formation in land ocean linkage areas is considered to be controlled by relative sea level changes, which consist of eustatic sea level fluctuations and sedimentary basin subsidence (Posamentier et al, 1988). Rates of glacial sea level change are more than 5 m/1000 yr., while rates of subsidence of the basins are commonly several cm/1000 yr. Therefore, subsidence has almost no influence on glacial sea level changes. Strata packages have formed in shelf and slope areas with the duration of 0.5 m.y. or several m.y. They include systems tracts which responded to sea level positions, such as lowstand, transgressive and highstand. Marine isotope stages (LR04 stacks: Lisiecki and Raymo, 2005) show glacial and interglacial cycles with the Milankovitch scale periodicity, and also show long term sea level trends with million-year scale durations. Rates of long term sea level trend have similar rate of sedimentary basin subsidence. Depositional sequences are considered to form with these long-term cycles.

In the Canterbury Basin of offshore New Zealand, high dense grid of 2D seismic survey was carried out and IODP Expedition 317 drilled four sites on the shelf and the upper slope. We recognized seven sequence boundaries in Pleistocene strata based on reflector terminations and facies analyses of the cores from IODP sites. We named them SB1 to SB7 in descending order. Biostratigraphy indicated strata between 2.7 and 1.8 Ma are missing at SB7 in shelf and slope, and strata between 1.2 and 0.8 Ma are missing at SB5 in shelf. While, other sequence boundaries have no hiatuses. We also measured oxygen isotope ratio of benthic foraminifera in the cores from the upper slope site and correlated them with LR04 stacks. And we proposed the precise age model for the Pleistocene cores. Sequence boundaries, SB1,2,3,4 and 6, formed at the lowest sea level of glacial stages. While strata packages between SB7 and SB5, and SB5 and present-day sea floor, consist of lowstand systems tracts, transgressive systems tracts and highstand systems tracts. These sytems tract responded to long term sea level trend in LR04 stacks. Shelf edge progradaion occurred at long term highstand stage, such as 1.4 to 1.3 Ma and 0.3 to present-day. Depositional sequences on shelf and slope are controlled by long term sea level cycles with durations of million-year scale. Sequence boundaries are formed at falling stage of sea level and high frequency sequence boundaries or para-sequence boundaries are formed at lowest sea level position of glacial stages with ~90,000 years periodicity.

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SUBSIDENCE ANALYSIS OF THE WESTERN MENTELLE BASIN, OFFSHORE SW AUSTRALIA (IODP EXPEDITION 369, U1513)

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The Mentelle Basin (MB) is part of an extensional rift system on the western margin of Australia and formed during the Paleozoic to Mesozoic breakup of eastern Gondwana. The MB has a complex evolution history of rifting, volcanism and sedimentation related to tectonic events, paleoclimate and paleoenvironmental changes. IODP Expedition 369 generated important data to investigate the tectonic and rifting history of the region and the Cretaceous climate system of the high-latitude Southern Hemisphere. Site U1513 is located on the western MB and the eastern margin of the Naturaliste Plateau, and 1.1 km ENE of Site 258 (DSDP Leg 26). It cored a thin layer of Pleistocene - Miocene sediments and a succession of Cretaceous units including Early Cretaceous volcaniclastic sequence and basalts related to Gondwana breakup and rifting activity. To improve our understanding of the basin evolution on the different stages, this study analyzes total and tectonic subsidence curves of Site U1513. Detailed stratigraphic and paleobathymetric data acquired from Site U1513 allow construction of high-resolution subsidence curves during Cretaceous and Neogene. Decompaction and backstripping techniques were applied based on parameters that are arranged mainly from the shipboard physical properties and paleontological data. The resulting decompacted sediment thicknesses are also used to revise sedimentation rate of each stage. After rapid subsidence during Early Cretaceous, the curves are variable including several uplift events. The resulting variation is considerably influenced by paleobathymetric record and global sea-level change. Overall, however, the subsidence pattern shows exponentially decreasing trend, especially for the Cretaceous part. To evaluate post-rift subsidence, the tectonic subsidence curve is compared to various sets of exponential thermal subsidence curves.

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NEW INSIGHTS INTO THE LATE QUATERNARY SEQUENCE STRATIGRAPHIC MODEL OF THE NORTHERN GULF OF CADIZ THROUGH INTEGRATION OF IODP EXP. 339 SITES U1386 AND U1387

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Cyclic variations in the Earth's orbital geometry (Milankovitch cycles) control solar radiation and global ice-sheet volumes, and thus pace climatic and sea-level variations. Several deep-sea sediment core proxies reveal that the 100 kyr eccentricity cycle has been dominant during the middle to late Pleistocene. The resulting sea-level fluctuations in turn exert a primary control on the architecture of continental margins worldwide. As a result, Milankovitch cyclicity can also be identified in high-resolution seismic stratigraphic studies of late Quaternary sequences on modern continental margins. A basic tenet in these studies is that the 100 kyr glacio-eustatic cycle generates well-marked shelf-wide erosional unconformities, separating sequences that consist of mainly progradational units. However, some examples for which borehole information was available have shown that the inferred one-to-one correlation between depositional sequences and 100 kyr glacio-eustatic cycles might be too simplistic, indicating the need for more robust age control in high-resolution sequence stratigraphic studies.
Accordingly, this study focuses on the northern Gulf of Cadiz continental shelf and slope. Here, the recent availability of IODP expedition 339 sites U1386 and U1387 on the middle slope, along with a dedicated seismic dataset connecting these sites to the shelf, allow to integrate the borehole's age information with the shelf's late Quaternary sequence stratigraphic schemes. Notably, the results show that the seismic surfaces related to the last and penultimate major sea-level falls and lowstands (i.e. marine isotope stages (MIS) 2 and 6 respectively) have different expressions in the stratigraphic record. Whereas the MIS 2 surface appears as a high-amplitude, shelf-wide erosional unconformity, the MIS 6 surface exhibits a lower amplitude and a less pronounced erosive character; in addition, it is confined to the outer shelf where it is truncated by the MIS 2 surface. It is hypothesized that this dissimilarity is caused by a tectonic imprint on the formation of the MIS 2 unconformity. These two surfaces enclose a shelf-margin wedge with alongslope elongated depocenters on the upper slope, which hint at an additional oceanographic control. Evidently, these findings provide surprising new insights into the sequence stratigraphic model of the northern Gulf of Cadiz, and suggest that, instead of a purely glacio-eustatic/Milankovitch control, additional controls (tectonic, oceanographic) have to be considered as well. From a more conceptual perspective, this study confirms that, if direct age control is unavailable, a one-to-one correlation between depositional sequences and 100 kyr glacio-eustatic cycles should not be straightforwardly adopted as a premise in high-resolution, Late Quaternary sequence stratigraphic interpretations.

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VARIATIONS IN CLASTIC INPUT INTO LAKE CHALA, EAST AFRICA: UNDERSTANDING THE 'SOURCE-TO-SINK' PROCESSES AND CHANGES

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The clastic fraction found in lacustrine sediments has proven to provide valuable information about sediment dynamics within lakes, and can be used to define distinct terrestrial source areas and transport mechanisms from source to sink. Along-core variations in the clastic fraction yield indications for changes in clastic sediment dynamics over time. However, to be able to apply mineralogenic proxies for palaeo-environmental interpretations, we first have to understand and quantify the modern conditions at the study site.

In this study we test if grain-size distributions and mineralogical data of clastic sediments extracted from lacustrine sediments of Lake Challa, can be used to infer source to sink processes into the lake. Lake Challa is a small freshwater lake of volcanic origin, located on the eastern slope of Mt. Kilimanjaro. The finely laminated lake sediments of Lake Challa are characterized by a fine-grained texture and are mainly composed of organic matter, biogenic silica and authigenic carbonate, but also detrital mineral components. The lake is situated close to the equator and provides one of the few locations worldwide, where inter-hemispheric dynamics can be studied. In order to identify the modern dynamics of terrigenous sediment input (i.e. aeolian vs. run-off) into Lake Challa, and to map out differences in sedimentological properties, core and surface sediment samples as well as on-shore samples from several locations around the lake and in the catchment were investigated.

Variations in grain-size distributions and mineralogy can be linked to distinct terrestrial source areas, whereas the downcore trends gives information about past changes in transport dynamics in the area during the last 25,000 years. In the future, the results from this study will be applied on the 215 m long ICDP DeepCHALLA record to describe changes in terrigenous sediment input into the lake further back in time.

EARLY CRETACEOUS VOLCANICLASTICS OF THE MENTELLE BASIN: PRELIMINARY RESULTS FROM IODP EXPEDITION 369

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The Mentelle Basin (MB) and Naturaliste Plateau (NP) at the southwestern margin of Australia hold important information for understanding the tectonic events, volcanism and paleo-environmental changes at different stages of the Gondwana breakup between Australia, Antarctic and India. The SW Australia region is characterized by the distribution of onshore and offshore volcanic rocks, such as the Bunbury basalt, and volcaniclastic sequence recovered by DSDP Site 264 located near the southern edge of the NP. However, the structure, stratigraphy, depositional and tectonic history of the MB and NP are yet poorly understood. Recent IODP Expedition 369 aims to reveal the unique Cretaceous tectonic and paleo-oceanographic settings of the region and drilled four sites, U1513 - U1516, in different parts of the MB and adjacent NP. At the deepest site, U1513 (774 m) located in the western margin of the MB, volcaniclastic sequence and basalts from the base of the sedimentary sequence have been successfully recovered. Based on shipboard magnetostratigraphic data, the volcaniclastics were deposited during Aptian to Valanginian, while the underlying basalts are inferred to have been emplaced during Valanginian. The 234 m thick volcaniclastics sequence consists of volcanic-rich sandstones with volcanic lithic clasts, siltstones and claystones, which are highly influenced by hydrothermal alteration and mineralization. The volcaniclastic sequence and volcanic rocks can provide Early Cretaceous stratigraphic control on the age and nature of the pre-, syn- and post-Gondwana breakup succession. We will report our preliminary study on the possible origin and depositional mechanism for the volcaniclastic sequence based mainly on shipboard descriptions, physical properties, paleomagnetic, paleontology, geochemical results and additional post-cruise data.

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BACTERIA RECYCLE ARCHAEAL BIOMASS TO SURVIVE IN THE DEEP DEAD SEA SEDIMENTS

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The Dead Sea is currently experiencing a massive retreat with lake level drop at a rate of ca. 1 m per year. Hypersaline conditions dominate in the whole basin and its waters have reached a total salinity of 38.5 %, more than ten times that of seawater. As a result, primary production is almost inexistent in the lake and halophilic *Archaea* – the organisms that are the best adapted to such salinity- are the only stable life forms in this setting.
Within the Dead Sea Deep Drilling Project -an ICDP-sponsored project that aimed at reconstructing paleoclimatic conditions of the Dead Sea Basin during the Quaternary- a geomicrobiological investigation has been carried out to unravel the current and past history of the Dead Sea deep biosphere. Microbial communities that were associated to sediments formed during the most arid conditions (halite and gypsum) showed very similar compositions to those observed today in the surficial sediments and in the water of the lake[1,2]. Halophilic *Archaea* of the *Halobacteria* class largely dominated these assemblages and almost no 16S rRNA gene sequence from *Bacteria* could be identified. However, it seems that some *Bacteria* have been able to develop in these environments at one point. This has been recently evidenced by the composition of molecular fossils found in these very same facies[3]. The discovery of bacterial wax esters in halite and gypsum sediments precipitated during the lowest stands of the lake show that *Bacteria* have been able to develop in those environments. Most of these wax esters exhibit an isoprenoid structure typical of archaeal membrane lipids, suggesting that they were formed from fragments of dead archaeal cells. The presence of intermediate products, deriving from the stepwise degradation or archaeols and extended archaeols -the characteristic lipids of halophilic *Archaea* of the *Halobacteria* class- support a recycling of the archaeal biomass by *Bacteria* within this sediment. We hypothesize that this strategy constitutes a way to build carbon stocks and to produce free molecular water in the deep hypersaline sediment of the Dead Sea, hence favoring the survival of less adapted bacterial communities. These biomarkers constitute the first evidence of deep survival of *Bacteria* in the Dead Sea sediment, and uniquely show the transfer of material from one life domain (*Archaea*) to another (*Bacteria*).

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A HIGH-RESOLUTION LATE QUATERNARY PALEOMAGNETIC SECULAR VARIATION RECORD FROM IODP EXPEDITION 341 DRILL SITE U1419 IN THE GULF OF ALASKA

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The International Ocean Drilling Program (IODP) Expedition 341 drilled the upper continental slope at Site U1419 in the Gulf of Alaska. This Site contains an exceptionally expanded sedimentary record containing information on late Pleistocene and Holocene dynamics of the Earth's magnetic field. The entire 112 m long splice record was sampled with u-channels and scanned with high-resolution CT for density estimation and visualization of sedimentary structures. The stepwise alternating field (AF) demagnetization procedure was used to study the natural and laboratory induced magnetic remanences. Information on the magnetic properties of the sediments, including magnetic concentration, grain size, and mineralogy, was obtained from u-channel magnetic susceptibility measurements, as well as hysteresis loops and isothermal remanent magnetization (IRM) acquisition curves from selected discrete samples. A high-resolution radiocarbon age model for Site U1419 was derived from 72 dated levels of foraminifera, as well as correlation to the independently radiocarbon-dated site survey core EW0408-85JC in the Holocene[1,2]. The age model dates the base of the splice record to ~56 000 cal yr BP and suggests that much of the pre-Holocene record was deposited at rates exceeding 300 cm/kyr[1]. AF demagnetization data demonstrate that these sediments preserve a complex, although generally interpretable, directional secular variations record. The complexity results from a combination of an energetic and variable depositional environment including non-steady state diagenesis resulting in variations in magnetic mineralogy and grain-size. In consequence, the record is not optimal for paleointensity studies. Inclination varies around that expected for a geocentric axial dipole (GAD; 73.6°) value for the site latitude, and both inclination and declination features are consistent with, when independent chronologies allow, shipboard derived directional records from Exp. 341 Surveyor Fan Sites U1417 and U1418. Building upon Holocene through late glacial reconstructions[3], Exp. 341 drill Sites are beginning to define millennial-scale geomagnetic field variability of the eastern North Pacific region from the Late Pleistocene into the Holocene.

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CONTINENTAL SCIENTIFIC DRILLING PROJECT OF CRETACEOUS SONGLIAO BASIN (SK-1 AND SK-2): HIGH-RESOLUTION TERRESTRIAL ARCHIVES AND GREENHOUSE CLIMATE CHANGE

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The Continental Scientific Drilling Project at the Cretaceous Songliao Basin is a drilling initiative under the framework of the International Continental Scientific Drilling Program (ICDP), to recover a nearly complete Cretaceous terrestrial sedimentary record in the Songliao Basin, northeastern China. The recovered cores will provide unique opportunities for the geosciences community to advance the understanding of climate change in the Cretaceous greenhouse world, and provide a documentation of geological events relevant to the carbon cycle during this time period. This drilling project will address significant geological questions, such as the identification of important stratigraphic boundaries and the marine-terrestrial correlations of stratigraphy, the reasons for the biotic response to the terrestrial environmental changes, the terrestrial response to the Cretaceous oceanic anoxic events, the formation of terrestrial petroleumsource rocks, and the mechanisms for the Cretaceous magnetic Normal Superchron.

In the first stage of this drilling project, the SK-1 drilling, Late Cretaceous rock cores of 2485.89 m in total length were recovered in 2007 and the recovery ratio reached 96.46%. The second stage of the drilling project, the SK-2 drilling targeting Early Cretaceous strata, is completed on March 17, 2018 with a drilling depth of 7022m. The core of SK-2 from Lower Cretaceous to pre-Cretaceous strata is over 4300m long in total. Several milestones of drilling technology, including the deepest hole in history of ICDP and of scientific drilling in Asia, have been achieved during the drilling process of SK-2.

During the past decade, a multidisciplinary study of the SK-1 and SK-2 cores has been conducted to establish ten continuous, high-resolution, geologic profiles of terrestrial Cretaceous, including lithostratigraphy, biostratigraphy, paleomagnetics, chronostratigraphy, inorganic geocheminstry, organic geochemistry, geomicrobiology, logging results, cyclostratigraphy and stable isotopes. An integrated chronostratigraphic framework has been established to prove the duration of SK-1 core from ~92.1Ma to ~64.7Ma. Terrestrial paleoclimatic and paleoenvironmental changes in multiple time-scales have been reconstructed in the Songliao Basin in Late Cretaceous. Furthermore, paleontological and organic geochemical evidences suggest that seawater incursion events may cause salinity stratification of water column and bottom water anoxia in the paleo Songliao lake, which may induce the formation of the source rocks.

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