Stochastic connectivity analysis at Mallik gas hydrate field, Mackenzie Delta

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Introduction

Gas hydrates located offshore and onshore beneath thick permafrost areas constitute one of the largest untapped natural gas resource. Progress made in the last decade has shown that gas hydrates can be mapped at depth using conventional seismic data. A six-day production test at Mallik, Northwest Territories, Canada, achieved sustained gas flow demonstrating that depressurization is an efficient approach to initiate gas hydrate dissociation in high-saturation sand layer (Wright et al. 2011). The production data, although of short duration, were matched using reservoir simulation algorithm which assumed an homogeneous distribution of key reservoir parameters around the wellbore. While justifiable for a six-day production test, the assumption of gas hydrates spatial homogeneity is too simplistic to understand the long-term dissociation behaviour of gas hydrate reservoirs which are known to show high lateral variability.

In this study, we show how results from Bayesian stochastic simulations combining fine scale well-log data and large-scale seismic reflection data can be used to estimate the spatial heterogeneity and connectivity of gas hydrates within the Mallik reservoir.

Geological settings and data

The Mallik gas hydrate field is located onshore the Arctic permafrost near the coastline of the Beaufort Sea, in the Mackenzie Delta, Northwest Territories, Canada.

The upper two seconds of a 3D seismic reflection data set was available for this study. The data set was reprocessed to preserve the relative true-amplitudes. The data used in this study is a subset of the 3D cube (41x41 traces), with an inter-spacing of 30 m, leading to a total area of 1.44 km². It is centered on wells 2L-38 and 5L-38 (Figure 1) and selected by Bellefleur et al. (2006) and Riedel et al. (2009) for detailed acoustic impedance inversion.

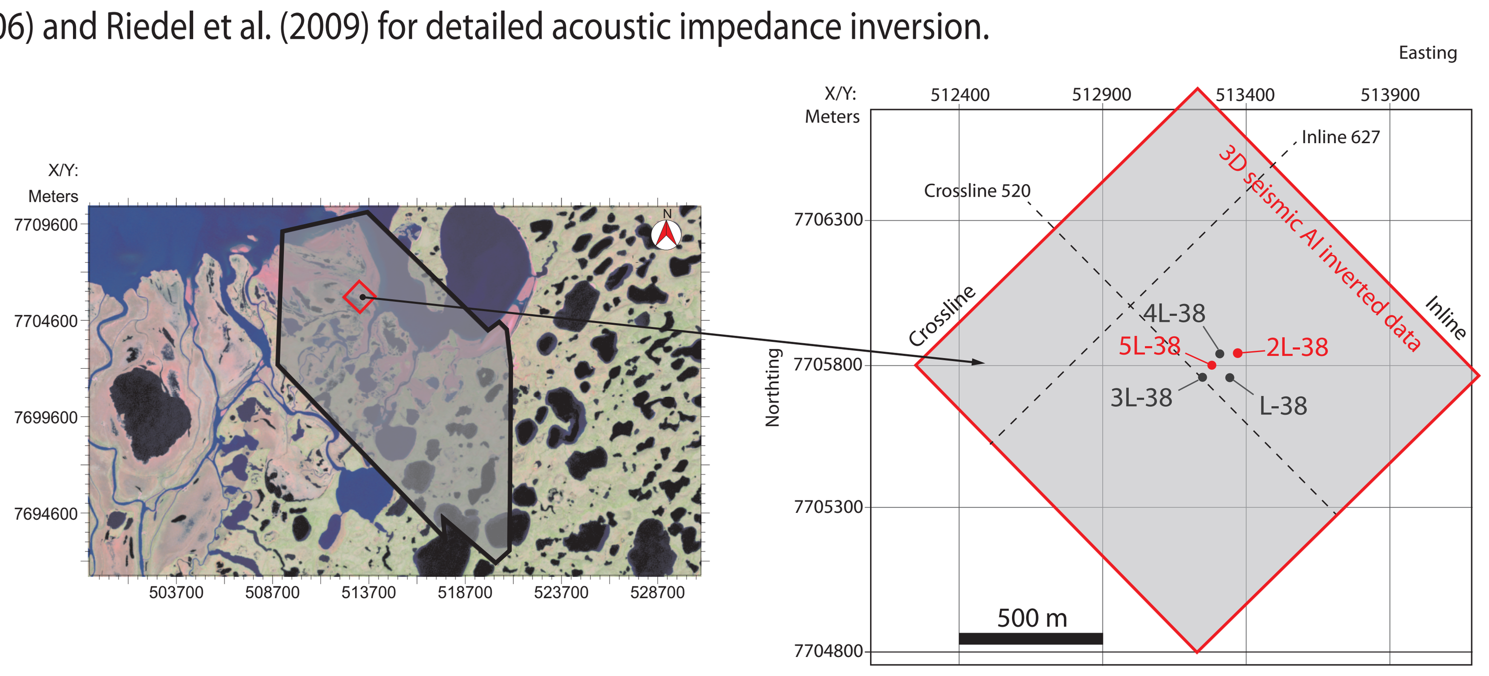

Figure 1: Disposition of the 3D seismic data and the wells 5L-38 and 2L-38 at Mallik.

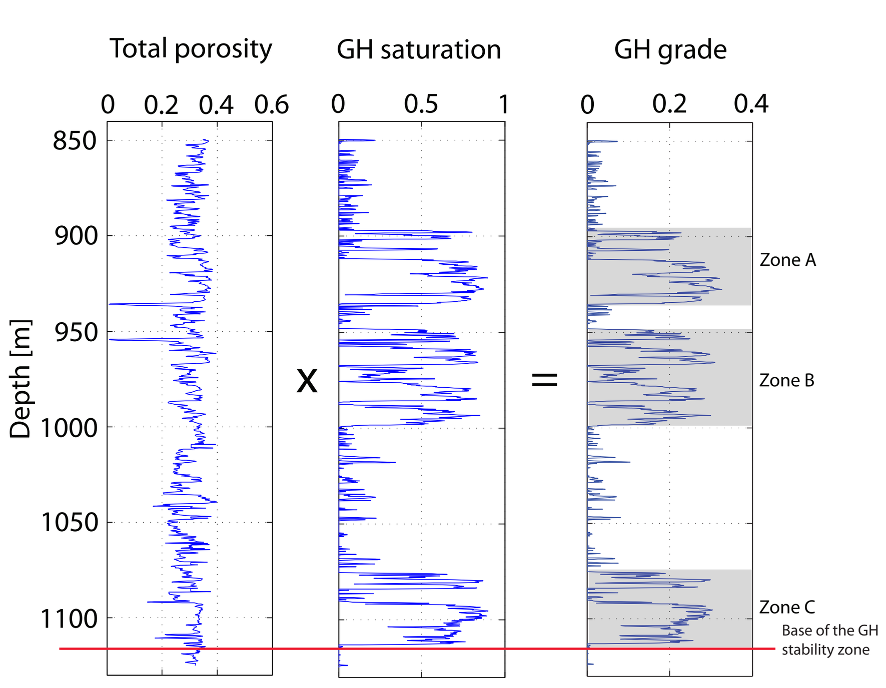

Figure 2: Total porosity, gas hydrate saturation and gas hydrate grade at well Mallik 5L-38. Gas hydrate grade data are obtained multiplying the saturation by the total porosity. The three high-grade gas hydrate layers (A, B & C) are shown.

The log data were measured at wells Mallik 2L-38 and 5L-38. Both wells cross the entire gas hydrate stability zone. Previous work on Mallik well-logs identified two high saturation gas hydrate horizons (Zones B & C), confirmed by various measurements (resistivity, P- and S-wave velocity, NMR), and a shallower one (Zone A) with less spatial continuity between wells. These horizons are located between 850 and 1100 m (Fig. 2).

In this study, the grade is used as the variable to be simulated. It is calculated multiplying the total porosity by the saturation. The grade is a variable particularly well suited for gas hydrate characterization since, in its natural form, gas hydrate is in a solid state. In addition, contrarily to saturation, the grade is an additive variable, which allows upscaling and downscaling by simple averaging.

Aknowledgment

We acknowledge the international partnership that undertook the Mallik 2002 Gas Hydrate Production Research Well Program: the Geological Survey of Canada (GSC), Japan National Oil Corporation (JNOC), GeoForschungsZentrum Potsdam (GFZ), U.S. Geological Survey (USGS), India Ministry of Petroleum and Natural Gas (MOPNG), BP/ChevronTexaco/Burlington joint venture parties, U.S. Department of Energy (USDOE). The first 2 s of a 3D seismic reflection survey shot in the Mallik field area in 2002 has been made available to the Mallik science program through partnership with the joint venture parties, BP Canada Energy Company, Chevron Canada Resources, and Burlington Resources Canada.

References

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Methodology

Fifty 3D grade scenarios are simulated (Dubreuil et al. 2011) using the deterministic 3D inverted acoustic impedance and the infered acoustic impedance and grades from well logs 5L-38 and 2L-38. The in situ relation is found to be strongly bi-modal and non-linear (Fig. 3). The in situ petrophysical relation between the grades and acoustic impedance is infered by a kernel density estimator, using collocated well data.

Figure 5 shows one gas hydrate realization among fifty, calculated using a bayesian simulation. The voxels of the 3D grid are 3 m high and 30 x 30 m wide. All these equiprobable scenarios show the highly-concentrated gas hydrate layers as well as the regional anticlinal structure (Fig. 5)

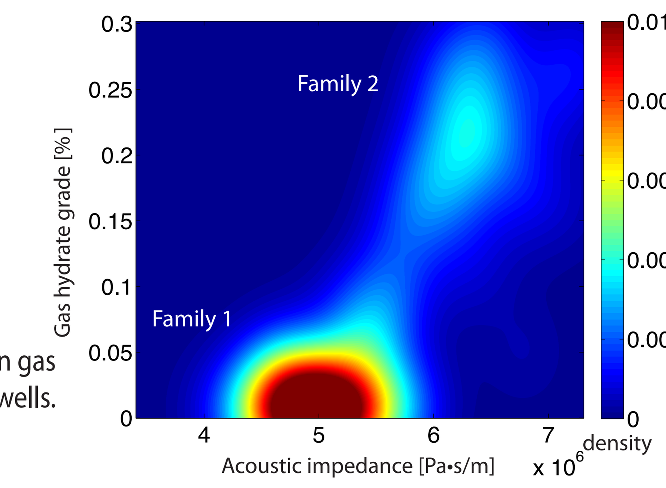

Figure 3: In situ petrophysical relationship between gas hydrate grade and acoustic impedance at the wells.

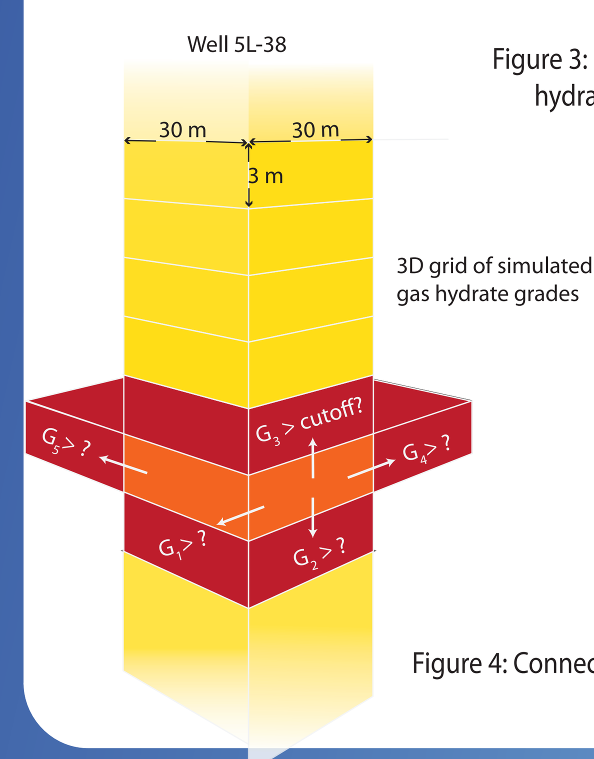

Figure 4: Connectivity analysis methodology.

The 50 scenarios are used to compute a stochastic connectivity analysis : It starts at a high gas hydrate grade voxel at a well location, in a gas hydrate layer. Then, all directly connected voxels are visited. Only the voxels with a grade value over a specific cutoff are retained. The same procedure is repeated with all the previously accepted voxels until no more connected voxels have a grade value over the cutoff (Fig. 4). Thus, the minimum connectivity corresponds to the size of a voxel. The 50 different but equiprobable connectivity patterns are then used to estimate natural gas volume ranges as well as connection paths probabilities.

Results

The connectivity analysis is computed on all the fifty scenarios, zone C alone and A and B together (Table 1). The results show that :

- Zones A & B are composed of a large amount of voxels having grades around 0.15 but very few over 0.2.

- Zone C contains the highest grade values and is the largest gas hydrate layer.

- A higher cutoff reduces the volume of the connected area of all layers. A cutoff increase of 0.05 lowers the connected volume by 88% for zone C.

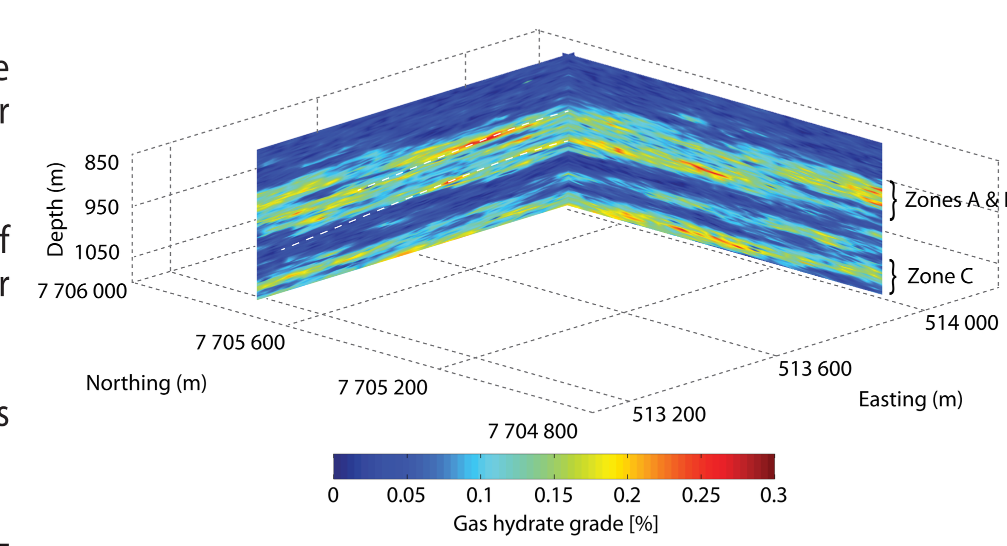

Figure 5 : A 3D grade realization obtained from the Bayesian simulation algorithm.

	GAS HYDRATE GRADE CUTOFF [x10⁶ m³]		
	0.15	0.20	0.25
Zones A & B	714 ± 114	9 ± 21	negligible
Zone C	613 ± 74	69 ± 59	2 ± 3
Zones A, B & C	1327 ± 146	78 ± 63	2 ± 3

Table 1: Volume of gas within hydrates for the two main zones at Mallik and it's associated uncertainty, at three different grade cutoffs (0.15, 0.20 and 0.25). The range with 95.4% (±2σ) confidence limits.

Figure 6 shows the plan-view of the connectivity for two different gas hydrate grade realizations, at a cutoff of 0.2 for zone C. The connectivity patterns vary significantly reflecting the variability of the connected volumes.

Figure 7 (a) shows one realization of connectivity at a cutoff of 0.18. Figure 7 (b) presents the connectivity probability of each voxels. It represents the connected volume that could be naturally solicited during a production from either 5L or 2L. Again, Zone C has a higher probability than zones A and B of having a large extend.

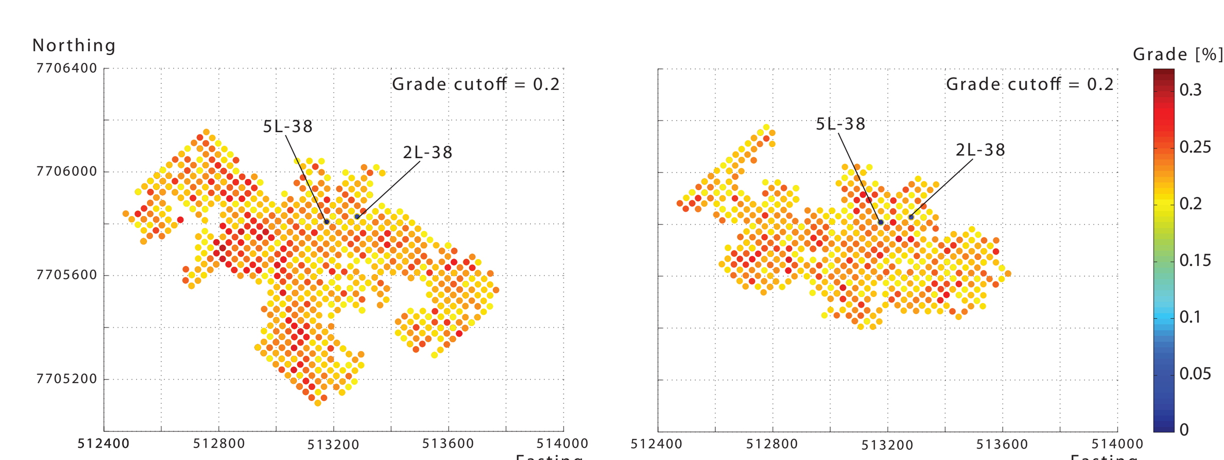

Figure 6 : Plan view of the grade connectivity at a cutoff of 0.2 for two 3D grade realizations at zone C

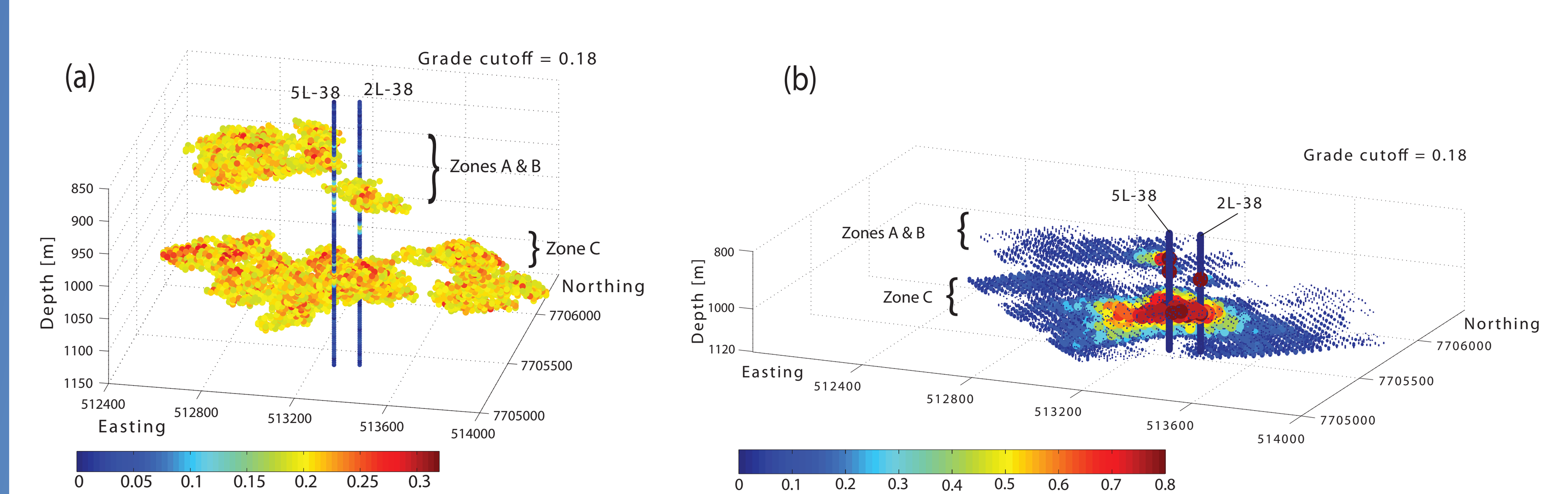

Figure 7 : 3D view of (a) a grade realization (b) the connectivity probability, for zones A, B and C at a cutoff of 0.18

Conclusion

The strong link between acoustic impedance and gas hydrate grades allows using 3D seismic data and well data to model gas hydrate reservoirs. The connectivity analysis confirms that zone C, marking the base of the stability zone, is the most favorable gas hydrate layer for futur reservoir developments. Our approach provides a probabilistic estimation of the reservoir connectivity which is of major importance for reservoir management, well planning and reservoir engineering.