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Sub Log-scale Heterogeneity of Fine-grained Sediments - Implications for Effective Permeability and Top Seal Risking

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SUMMARY

Effective permeability plays an important role in prediction of leakage rates, seal capacity and quality. Current best practice uses conventional log data (15 cm as maximum resolution) to assess effective flow properties in seal sections and, with a maximum resolution of 15 cm, miss out the cm-scale sedimentological variability which is quite common in some mud-rich settings. The aim of this study was to identify and classify a reasonable number of different sedimentological heterogeneities and to investigate their impact on flow properties based on high-resolution data (microresistivity and core images). Four types of fine-grained sediments were defined on a basis of lithological variability and internal structure. Methods from geostatistics, such as the variogram as a descriptor for sedimentary structures derived from microresistivity and core images, were employed to quantify differences on a cm-scale between the four fine-grained sediment types. Furthermore, 2D flow models on a meter scale based on microresistivity and core images were used to determine ranges of effective permeabilities for the different types of fine-grained sediments. Finally, these effective permeabilities were upscaled in 1D and used to compare the differences due to the sampling rate of conventional and high resolution measurements.

Introduction

Permeability controls migration and leakage rates, and thus seal capacity and quality, once the critical capillary entry pressure of the caprock is exceeded. Permeability estimates of fine-grained sediments should thus be as accurate as possible. Current best practice uses conventional log measurements for lithological interpretation (e.g. Yang et al., 2004) in combination with regional compaction curves and porosity-permeability models to produce 1D log scale permeability models along wells. However, conventional log measurements have a maximum resolution of 15 cm and assume homogeneity at smaller scales. Therefore, conventional log measurements miss important small-scale heterogeneities such as coarse-grained laminas, small sand injections, and minor slumping, all of which have a major impact on permeability contrast and anisotropy (Kh/Kv).

The aim of this study is to improve the present workflows by identifying cm-scale sedimentological variability and investigating the impact of that variability on flow properties. To do so, high resolution data, such as microresistivity and core images were examined, interpreted, and included into the common workflow. The results of the improved approach were compared with results of present practices.

Methodology

We examined approximately 900 m of both core and microresistivity data from a gas-bearing marine slope setting, including units considered to represent hemipelagites, channel levees, channels and mass transport deposits. Based on a combination of visual and microresistivity textures, a small number of fine-grained sediment types were defined, representing the full range of observed sedimentological heterogeneity and thus permeability distributions. Centimetre-scale lithological interpretations were made using measured data (grain size and pore size), log measurements and visual observation. Yang et al.'s (2004) approach was then used to estimate clay contents, porosities and permeabilities for clay-rich units, whilst permeabilities for silts and sands were taken from the literature (Nelson and Kibler 2003).

Geostatistical methods were used to describe each of the fine-grained sediment types. These methods have been rarely applied on a meter-scale but are capable of unifying both variability (variance) and structure of the respective fine-grained sediment types into one descriptor, the variogram (e.g. Lantejoule, 2002). Such a descriptor also allows for statistically reasonable reproductions on different scales, but with equal resolution. Meter-scale statistical reproductions of the rock based on the geostatistical descriptor of microresistivity and core images enables us to distribute permeability values and grain sizes on a 2D grid to create a range of realisations of each of the fine-grained sediment types. A finite element method was used to simulate fluid flow through the resulting meter-scale models, resulting also in the computation of vertical and horizontal effective permeabilities. The effective permeabilities can then be compared with those derived from a wireline log approach which assesses lithology on a 15-30 cm scale and which may thus miss the critical heterogeneities observed in core and on microresistivity images.

Observations and Results

As a starting point, we defined four different types of fine-grained sediments from our slope case study: Pure Mudstone, Silt Laminated Mudstone, Reworked Silt Laminated Mudstone, and Highly Reworked Silty/Sandy Mudstone (Fig.1).

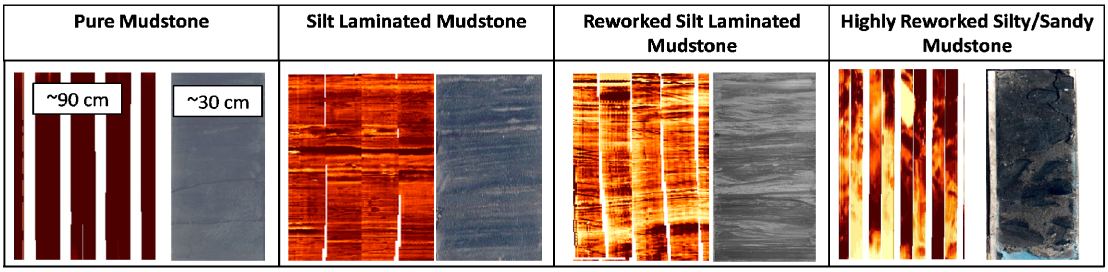

***Figure. 1** Four fine-grained sediment types.*

The four types have different geostatistical descriptors (variograms) distinguishable in shape, range, and sill (= variability).
Meter-scale reproductions of the fine-grained sediment types based on variogram models show a good visual correspondence to the original images. To populate the obtained 2D models with lithological and physical properties, relationships between lithology (clay content) and microresistivity/core image brightness have been investigated. A good approximation to calculate reasonable clay contents (and thus permeabilities) proved to be the relationship between clay content and electrical conductivity for microresistivity and between image brightness and gamma ray for core images.
Figure 2 shows the effective permeabilities of each of the four mudstone types. Vertical permeabilities vary by 5 orders of magnitude as a function of lithology (i.e. dominant grain size) and lithological heterogeneity. Directional anisotropies range from ~ 2 to 10,000, with laminated mudstones demonstrating the greatest anisotropy. Both homogeneous and highly reworked (e.g. bioturbated) mudstones show low levels of anisotropy, although the absolute permeabilities are very different.

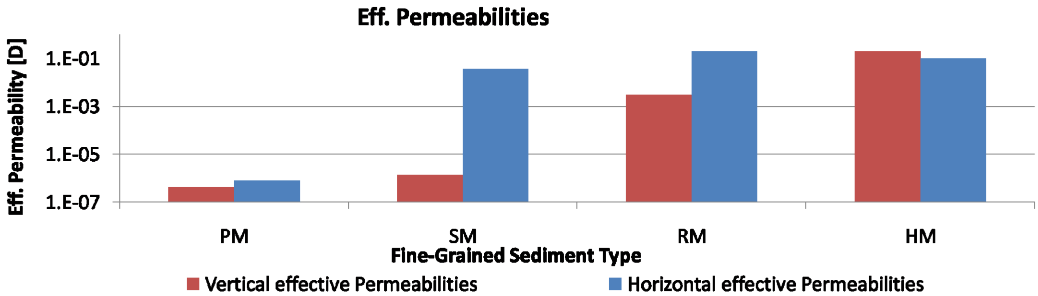

Figure 2 *Effective permeabilities for pure mudstone (PM), Silt Laminated Mudstone (SM), Reworked Silt Laminated Mudstone (RM), Highly Reworked Silty/Sandy Mudstone (HM).*

We also calculated effective permeabilities on larger scales, using both the flow simulation approach shown here and also using a standard log interpretation approach. The results show differences of less than one order of magnitude for 1D vertical flow, but major differences in anisotropies (four orders of magnitude).

Conclusions

We have developed a new workflow to estimate the meter-scale effective vertical and horizontal permeability of fine-grained sediments, based on both microresistivity and/or core gamma data. Heterogeneity which is invisible on conventional logs has an enormous effect on the accurate assessment of directional permeability; permeability anisotropies of 10^4-10^5 exist in laminated mudstones but are unrecognisable from industry-standard datasets. We recommend that the depositional setting of mudstones (e.g. hemipelagite, mud turbidite etc) is coupled to 1D log interpretations of lithology in order to enhance assessments of top seal permeability and thus the assessment of seal risk and leakage rates.

References

Lantejoul, C. [2002] *Geostatistical Simulation – Models and Algorithms.* Springer.

Nelson, P. H. and Kibler, J. E. [2003] A catalogue of porosity and permeability from core plugs in siliclastic rocks. *USGS open file reports*, 03-420.

Yang, Y., Aplin, A. C., Larter, S. R. [2004] Quantitative assessment of mudstone lithology using geophysical wireline logs and artificial neural networks. *Petroleum Geoscience*, **10**, 141–151.