P26

Defining Critical Capillary Entry Pressures in Heterogeneous Mudstones - A Multi-scale Stochastic Approach

K.D. Kurtev* (Newcastle University) & A.C. Aplin (Newcastle University)

SUMMARY

We demonstrate a new methodology to define and upscale the Critical Capillary Entry Pressure (CEPc) of heterogeneous mudstones on a centimeter to meter scale. Two elements are involved: (a) quantification of CEPc of mudstones as a function of lithology and (b) definition of the texture or architecture of mudstone sequences, in particular the vertical connectivity of lithologies with the lowest and highest CEPc values. Since the CEPc values of coarse-grained muds can be two orders of magnitude greater than those of fine-grained mudstones, mudstone texture plays a key role in defining meter-scale CEPc. CEPc (and thus seal capacity) on a meter (and higher) scale can be very different from measurements obtained on a sample scale.

Introduction

In water-wet systems, seal capacities or potential column heights are estimated by defining a threshold, or critical capillary entry pressure (CEP_c) for the units of interest - generally fine-grained sediments such as mudstones. When samples are available, CEP_c values are derived from capillary pressure curves measured on centimetre-scale samples using mercury injection techniques. A CEP_c value is chosen which is then assumed to be representative of the many cubic kilometers of the sealing unit. This approach is insufficient in heterogeneous mud-rich sections where CEPc values of individual lithologies (e.g. silt-rich, clay-rich) can vary by two orders of magnitude (e.g. *Dewhurst et al., 1998; Yang and Aplin, 1998*). In heterogeneous units, the connectivity of the lowest and highest CEP_c units is also vitally important. The key issues are thus to quantify the CEP_c values of mudstones as a function of e.g. lithology and porosity, and then to develop probabilistic methodologies to describe the connectivity of lithologies on a range of spatial scales.

Methodology

Here, we demonstrate a new approach to the derivation of CEP_c values in heterogeneous mudstone sequences. First, we used measured data to develop a quantitative relationship between mudstone grain size distributions (i.e. lithology) and pore size distributions (i.e. CEP_c). Secondly, we used outcrop and core to define, using stochastic methods, a range of basic mudstone texture types (e.g. thin bedded silts/clays, thick bedded silts/clays, rippled). Thirdly, we constructed a series of 3D textural models from an appropriate range of mudstone lithologies. Finally, we populated the models with CEP_c values for individual lithologies and then calculated the effective CEP_c value for the model. The stochastic nature of the process means that multiple realizations are possible, to generate a Probability Distribution Function of the CEP_c values.

Observations and results

Laboratory analysis of a large number of lithologically distinct mudstones let us define a relationship between Grain Size Distribution and Pore Size Distribution, shown in Figure 1B as a plot of non-wetting phase saturation (%) versus the mass % grains smaller than a given radius. It corresponds to construction of joint GSD-PSD cumulative distribution. Simple construction rule is MICP Saturation (%) at pore radius R (nm) corresponds to Finer volume (%) at grain size less than $Rx10^{-2}$. The obtained curves (Fig.1B) show a trend from coarser-grained (siltier) to finer-grained (clay-rich) samples . Several curves may have the same GSD which corresponds to different stages of compaction. If we know clay% or coarse silt % in a sample we can uniquely indentify few curves with a correspondent GSD. We can refine our choice to one curve on additional criteria based on eff. stress/closest depth. At 1 m^3 scale eff. stress could be considered as a constant. Using GSD-PSD graph as a nomograph we can define for each finer value a correspondent saturation value. Applying stepwise a recursive rule R_{pore} (nm) = R_{grain} (μm) $x10^{-2}$ as much as we know the correspondent values by construction we can calculate pressure (by Yang-Laplace equation) correspondent to each of the saturations for a two phase fluid system. Once we know spatial texture variability of our log scale cube model ($1m^3$) composed by samples and the P-S curve for them we can calculate their Eff. CEP_c. Thus we reduce the problem of defining of the Eff. CEP_c to finding of connected cells of similar lithology and compaction.

$1m^3$ ripple texture mudstone model (Fig 1 A) was generated using geostatistics based on a core image . Clay % vary between 12 and 80 and Coarse Silt % from 10 to 60. Model will be breached if we have continuous cell connectivity vertically. At Clay of 37.5% (Fig. 1 C) the model saturation is 9.26% (~10%) and we have no vertical continuous path.

The flow have an oblique direction (blue arrow). At clay % = 41 definning model saturation of 17.57% (> 10%) we have for a first time a fully connected vertical path. At Eff. stress of 10 MPa that point will be reached at CEP_c of 0.985 MPa (Fig. 1D). For thin and thick bedded silts/clays models we have established vertical connectivity for cells at clay 57% and 68%. Same models will be breached at 1.77 and 2.34 MPa.

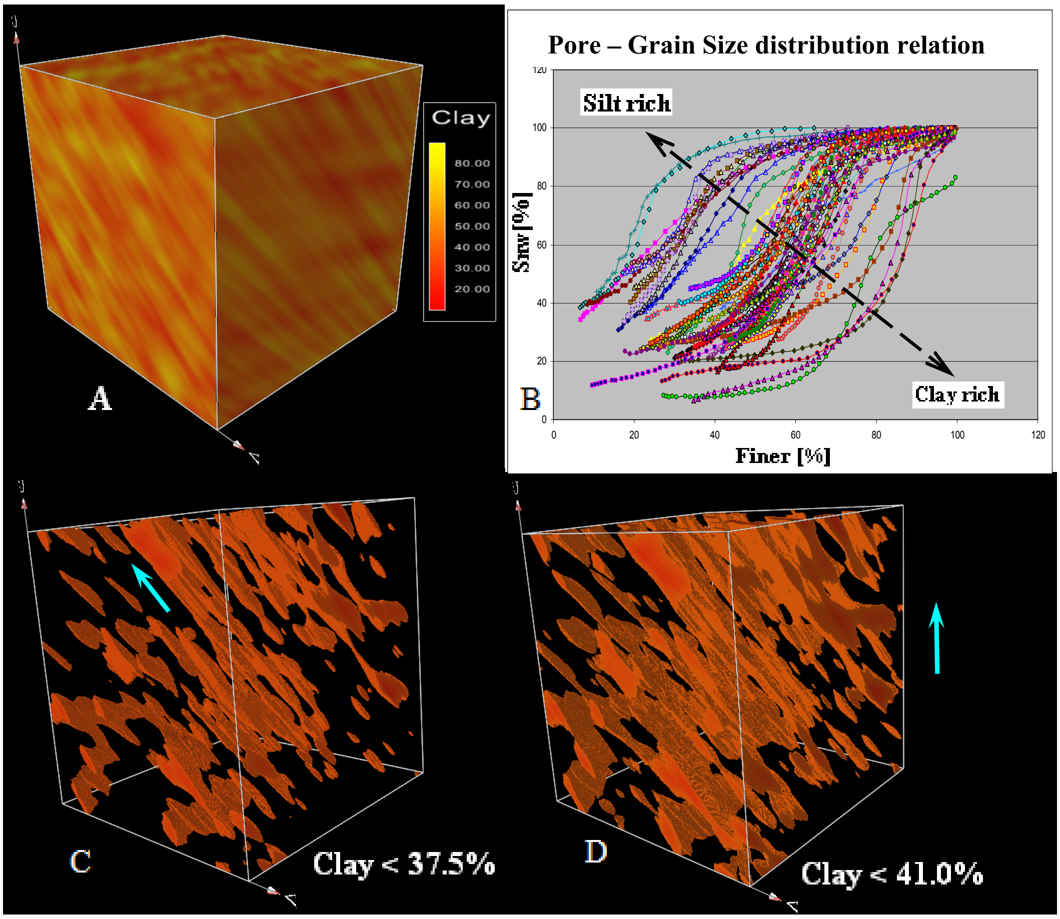

Figure 1 *Log scale mudstone model with ripple texture (A), GSD-PSD relation (B) and connectivity models at Clay% of 37.5 (C) and 41 (D). Blue arrows indicate flow direction.*

Potential gas columns calculated at these pressures are 207m and 274 m, and for rippled model (Fig. 1D) breached at 0.985 gas column is 1m.

Conclusions

From this study we can make the following conclusions:

1. Vertical eff. CEP$_c$ at log scale (~ 1m^3) depends on connectivity of low CEP$_c$ elements in vertical direction. This depends on model texture, i.e. spatial distribution of elements;
2. Connectivity of elements with different ranges of CEP$_c$ may have completely different directions. This is an important factor controlling the direction of the secondary flow;
3. The CEP$_c$ upscaling to 1m^3 scale shows that the rule of "r10%" is not applicable at log scale. Vertical continuous path could be reached at much higher saturation (here ~17%);
4. The method of defining effective CEP$_c$ based on mudstone textures can produce a set of geologically well defined models which can be used as building elements for next step of upscaling from log to seismic cube (~ 10x10x10 m);

References

Yang, Y. and Aplin, A.C., (1998), Influence of lithology and effective stress on the pore size distribution and modelled permeability of some mudstones from the Norwegian margin. *Marine and Petroleum Geology*, 15, 163-175.

Dewhurst, D.N., Aplin, A.C., Sarda, J.P. and Yang, Y., (1998) Compaction-driven evolution of poroperm in natural mudstones: an experimental study. *Journal of Geophysical Research*, 13, B1, 651-661.