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Synthetic Diagenesis - The Key to Carbonate Systems in Basin Modelling

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SUMMARY

Basin modelling tools are widely used to predict reservoir charging but, unfortunately, their application to carbonate reservoirs is far from straightforward. For carbonates, the relationships between porosity/ effective stress/depth, must be addressed before a reliable basin model can be produced. We propose using a synthetic diagenesis approach, where Pore Architecture Models (PAMs) are used to generate representative porosity values for the different diagenetic (backstripped) stages that are recognised from cores or thin sections. The synthetic diagenesis approach is then used to inform more conventional basin modelling. The viability of this method is the topic of this contribution.

Introduction and Challenges

Carbonate rocks form significant hydrocarbon reservoirs, storing around 50-60% of the world's petroleum reserves (e.g. Burchette, 2012). Basin modelling packages, which are used to predict hydrocarbon charging, need to represent the diagenetic basin evolution as well as the mechanical evolution. These packages incorporate defined relationships between porosity and effective stress (or depth) as well as defined lithology descriptions that control many other properties (e.g. total thermal conductivity). The given relationships may work well for most siliciclastic rocks but carbonates have porosity/effective stress/depth relationships that differ significantly from siliciclastic rocks. Carbonate rock porosity evolution with burial/time is very sensitive to the chemical changes that generate calcite cementation, dissolution and dolomitisation, as well as mechanical and chemical compaction. So porosity changes are not well predicted by just the thickness and density of the overburden: the diagenetic evolution must also be represented. A range of porosity-depth curves for carbonates have been proposed, using experimental data (e.g. Shinn and Robbin, 1983) and measured subsurface data (e.g. Schmoker and Halley, 1982) or using representative equations (e.g. Goldhammer, 1997). Although these datasets are very valuable, they are not applicable everywhere because they are a response to the specific geological history, and inevitably to local changes in physical and chemical conditions. Giles et al. (1998) proposed a workflow using 100 to 1000 samples from facies with similar initial properties taken over a wide depth range that have similar porosity/depth or porosity/effective stress behaviours and that are currently at their maximum effective, in an area with similar geothermal gradient and without overpressure. Although their workflow is very useful, sometimes the diagenetic history of the reservoir (i.e. cementation and dissolution phases) is too different from that of the overburden rocks and so this workflow is not always appropriate.Here we use a synthetic diagenesis approach applied to a Lower Eocene carbonate reservoir with a complex diagenetic history. This requires thin sections or core photographs as initial input and treats diagenesis as a series of textural changes (e.g. cementation and dissolution). Then we apply the method of diagenetic backstripping proposed by van der Land et al., (2013), using Pore Architecture Models (PAMs) (Wu et al., 2006) to generate representative porosity values from the solid/pore geometry and distribution. These time-sequenced values are then attached to specific depths and times using basin modelling, initially with the pre-synthetic diagenesis basin model. The synthetic diagenesis approach is used to update the basin state calculations, with an iterative cycle, leading to a solution that honours the physics and chemistry of the system. Since we can make many textural observations, they provide a useful constraint, and may allow us to choose a small set of possible basin-history cases that are compatible with the observed rock data and the underlying process understanding.

Synthetic Diagenesis and its application to basin modelling

Using photomicrographs containing the different diagenetic events, we can, using our knowledge of the relative diagenetic sequence for the target reservoir, remove the diagenetic overprints backwards in time (diagenetic backstripping *sensu* van der Land et al., 2013) creating different virtual thin sections before each event. The virtual thin sections are the input for the PAMs approach. The first PAMs step is binarisation of the pictures assigning black for pore and white for solid (Figure 1). After binarisation, each virtual picture is used as a training image to extract the three-dimensional pore architecture models (i.e. the spatial distribution of solid and pores). This network is then used to calculate porosity. Because carbonates rocks are very heterogeneous, a single thin section rarely contains the whole diagenetic history of the reservoir and so we need several training images to achieve statistical robustness for any one event. Then, the porosity values from PAMs will be compared against the values from basin modelling at the wells (bringing all the length scale issues) and the basin model inputs can be adjusted within geologically supportable bounds. But to remove the diagenetic events backwards in time, we need their timing/depth; this information will be provided by the basin modelling tool.A sensitivity analysis is also needed to produce satisfactory convergence between observation and simulation where the simulation also produces geologically believable basin evolution. We are aware that this approach requires recognition of what assumptions are built into the simulation and how they vary from the real case. The main assumption of PAMs is that when we

sequentially remove the diagenetic events using PAMs, we are left with grain positions that do not take into account any ongoing grain rearrangement because of mechanical compaction. This can be added at a later date.

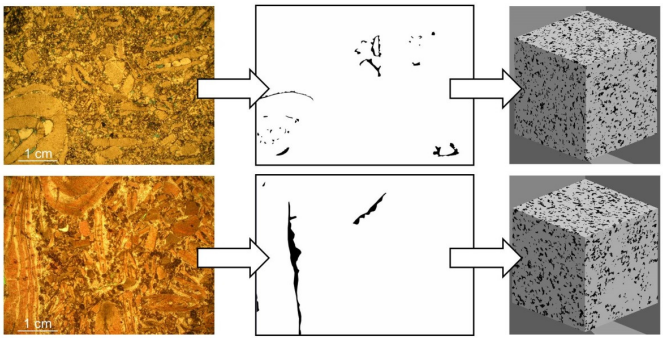

Figure 1 *PAMs workflow. The target photomicrographs (pictures on the left) are binarised (pictures in the middle) and then the pore network is obtained (pictures on the right).*

Conclusions

An application of basin modelling tools to carbonate systems is far from straightforward. Although basin modelling packages are very useful, there are many limitations that need to be overcome. We propose using the workflow suggested by van der Land et al. (2013) based on the PAMs technique (Wu et al., 2006) integrating in the basin models. In this way we can then tune the results from basin modelling simulations with the PAMs scenarios and vice versa so a better match between them can be achieved. More importantly this workflow is generic and so it is suitable to any carbonate reservoir.

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