Paper 6

Characterising productive sands in the Shallow Clastics field: integration of Under Balanced Drilling (UBD) and core analysis results

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The Shallow Clastics field, located in the Central Luconia province off-shore Bintulu, is a large 2.5–3 Tscf field awaiting development. The Shallow Clastics reservoirs, which cover an area of ca. 210 km^2, consists of alternating sand shale sequence. It is a low-relief structure consisting of two *en-echelon* anticlines with NE-SW fold axes. Dips are extremely gentle (2 degrees or less) even out on the flanks. The gas bearing intervals occur in three main sand-shale sequences, the F-, H- and L-sands, each subdivided into higher order sequences. Of these the H1 and H2 combined contain around 80% of the total reserves and the L1/2 combined another 10%.

The depositional environment is interpreted as mid- to inner-shelf for the shales and shoreface for the sands; all based on log signature (repeated cleaning-upward successions), observations from core and sidewall samples/cuttings (sedimentary structures, fossil assemblages), as well as seismic expression (repeated progradation patterns).

The key reservoir facies are:

- Upper Shoreface: consists of relatively clean, fine to medium sandstones, typically with a cleaning-up signature and commonly a gradational base.
- Lower Shoreface: consists of relatively shaly, very fine to fine sandstones, typically with a serrated log signature and cleaning-upward.
- Transition zone: this category includes transition lithologies i.e. shaly sand or sandy shale.
- Channel – Observed as sharp based blocky sand signature on GR-logs, not observed in core.
- Shale: (non reservoir).

One core is available, taken in 1997, recovering 90 ft of H1 and 40 ft of L1/2 sands. Average net sand porosities are between 24–28%, with related permeabilities between 20–300 mD. However, capillary pressure measurements revealed that even for samples with porosities of up to 28% (and corresponding high permeability), residual water saturations (S_{rw}) were 35 to 40%. Furthermore, transition zones are up to 300 ft for above-mentioned porosities. These observations are in apparent contradiction: How do high porosities and permeabilities relate to high S_{rw} and long transition zones? Moreover, how do the observed rock properties influence the productivity of the sand intervals?

Early 2002, the first UBD well in Malaysia was drilled by Shell in to the L-sands of the Shallow Clastics field. Apart from the productivity benefits of under balanced drilling, UBD provided a "live" in-flow log while drilling. With this information in combination with well test data over the L-sand interval, productive intervals could be identified, revealing that certain sand intervals did not contribute to flow despite their predicted reservoir properties. This is not possible with conventional methods. Based on log characteristics, these intervals were identified as lower shore-face and transition zone facies with predicted permeabilities of < 20 mD. This raised the question why apparent 20 mD gas filled sands do not produce under given well test conditions?

Petrographic analysis of the available core material combined with X-Ray Diffraction (XRD) measurements and facies description showed that the reservoir rock is extremely fine grained with 50% of rock made up of fine sand and in the lower shore face and transition zone facies ~ 25% in silt/clay fraction. The fine grained nature of the rock can explain the observed long transition zones at higher porosities (capillary effect).

With XRD measurements and thin section description the amount and type of dispersed clay present in the matrix could be quantified. In the lower shore face and transition zone facies dispersed clays are an important matrix constituent which can make up to 25% of total reservoir rock. The dominant clay types are illite (30–50%), mixed layer illite/smectite (25–50%), minor chlorite and kaolinite. All of these clay minerals are hydrophilic and will bind water to their mineral structure. This will influence the capillary behaviour of the rock. The presence and quantity of these dispersed clays can therefore explain the high S_{rw} values observed.

Moreover smectite swells in the presence of (formation) water, thereby obstructing pore space and thus permeability. Laboratory core measurements are typically done on cleaned and dried core plugs. Therefore, plug permeability for the clay prone lower shore-face and transition zone facies is likely to over estimate the actual *"in-situ"* permeability.

The results of the UBD well allowed us to quantify this effect and use it in a predictive sense in the reservoir modelling part of the Field Development Planning process. Permeability is the dominant driver for well deliverability and constraining permeability uncertainty by integrating core analysis and UBD results have helped to optimise the number of development wells.