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A Review of 4D Seismic at Greater Plutonio and PSVM

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Summary

The deep-water developments of Greater Plutonio in Block 18 and PSVM (Plutao, Saturno, Venus and Marte) in Block 31 have each shown 4D seismic monitoring to be a very valuable surveillance tool in support of reservoir management. This paper describes the observations made from the 4D data across the two areas. Both areas have a mixture of channelised and sheet-like turbidite reservoirs: Greater Plutonio has a higher proportion of sheet-like reservoirs, with simple 4D anomalies. PSVM has a higher proportion of channelised reservoirs with more complex anomalies.

Introduction

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4D Seismic observations

Interpretation is largely based upon changes in amplitude of inverted full stack 4D seismic difference seismic, supported by 3D lithology cubes. Hardening and softening signals that occur within sands are identified, and an interpretation of the physical change in the reservoir is made. We observe 250 separate, identifiable anomalies from the Greater Plutonio Monitor 3 and PSVM Monitor 1 surveys, of which 197 are of sufficiently high confidence that we include these in the history matching of reservoir simulator models, as illustrated in Figure 3.

Figure 1 shows the proportion of different 4D seismic signals. The dominant 4D signal type is water-replacing-oil, either due to aquifer influx in response to oil production, or due to water injection. These are the most valuable 4D seismic signals for a water-flood development, as they provide direct images of water sweep through the reservoirs. Figure 2 shows an example of multiple water-replacing-oil signals in a sheet reservoir, that provided clear evidence of the need to modify injection rates into injectors B and C.

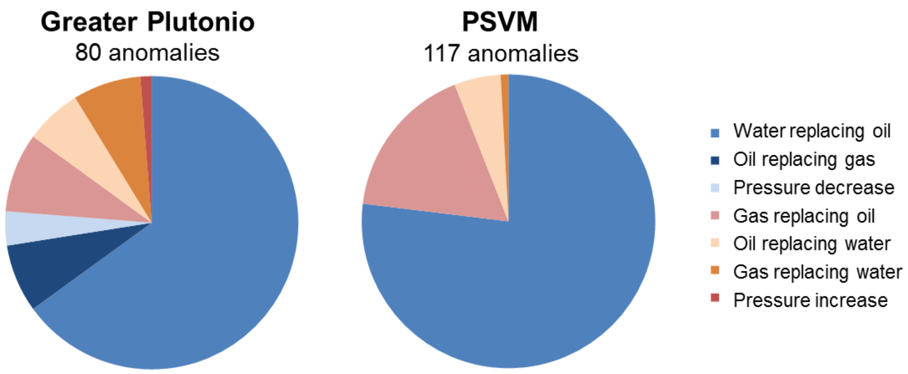

Figure 1 *The proportion of 4D anomaly type for Greater Plutonio Monitor 3 and PSVM Monitor 1.*

Gas-replacing-oil signals are the next most frequent anomaly type, due to either gas coming out of solution as reservoir pressure drops below bubble point (mostly at PSVM), or due to injected gas moving through the oil leg (mostly GtP). In addition, there are several gas-replacing-water signals where gas injection occurs below the original oil-water-contact (OWC).

There are a small number of oil-replacing-water signals, where oil has moved downward into the aquifer, often because of a water injector placed above the original OWC displacing the oil below it.

Where water is injected below the original OWC the 4D signal is a distinct softening due mostly to the injected fluid being of lower salinity (and hence lower impedance) than the in-situ aquifer water. There may be a small component from an increase in reservoir pressure above initial conditions, but rock physics models suggest this contributes less than 25% of the observed signal.

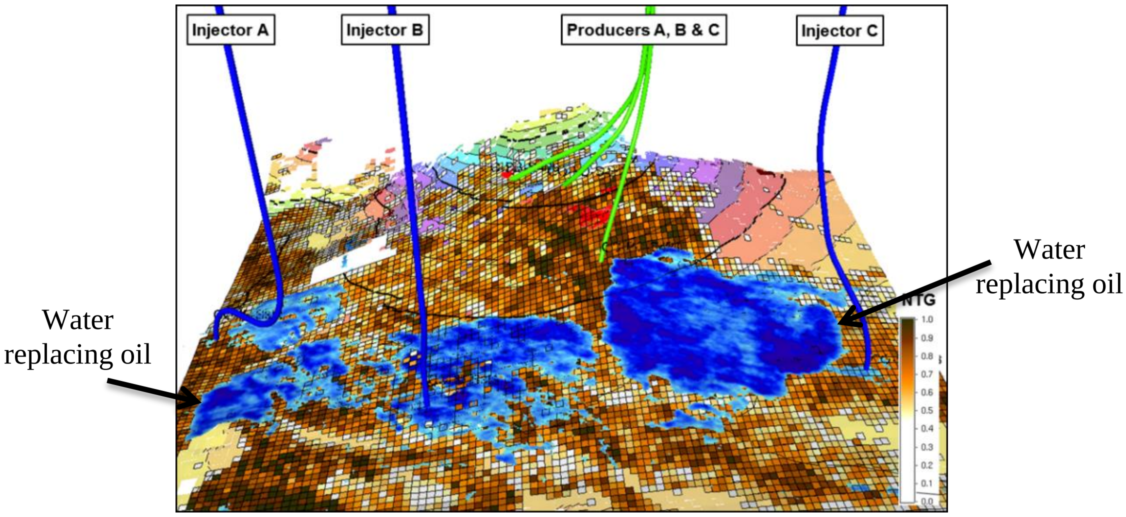

Figure 2 *A 3-dimensional image of 4D anomalies superimposed on a Net-to-Gross map of a sheet-like reservoir. The image illustrates the need to balance injection rates between injectors B and C.*

We observe very few examples of anomalies that directly image a change in pressure. In one case, down-hole pressure gauge readings show that the depletion around a producer well is approximately 1400psi below initial pressure. There is no observable 4D signal around this well - the absence of signal places an upper limit on the stress sensitivity of the reservoir. In the few cases where the 4D responds weakly to pressure it is mostly in the reservoirs with the stiffest rocks. Lastly, timeshift anomalies are observed in both areas. These are due either to velocity changes in response to a saturation change, or due to reservoir compaction. At Greater Plutonio timeshifts are generally small, and do not require a correction. In some cases, where large timeshifts occur in the shallowest reservoir a correction is necessary, and this is beneficial in determining the relative contribution from stacked reservoirs. At PSVM we observe timeshifts in the overburden, the magnitude of which correlates with reservoir pressure depletion. The 4D provided direct evidence of higher than expected reservoir compressibility, an important component of reservoir energy at PSVM.

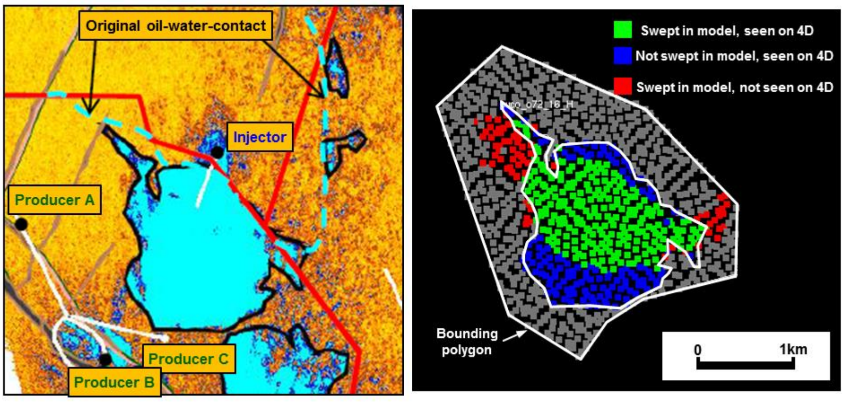

Figure 3 *A example of how the 4D (left) is used during history matching of the simulator model. The map on the right provides a simple summary of the fit between model and 4D for an early iteration.*

Conclusions

4D has been used extensively to understand well performance, calibrate simulator models and support decisions such as identifying infill targets, interventions and optimising offtake and injection rates.

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