Rock Physics Modeling and Analysis of Time-Lapse Seismic Response in the Pyrenees Field

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To evaluate the feasibility of monitoring reservoir drainage and performance, rock physics modelling of the time-lapse seismic response of the Pyrenees Field to production activities was carried out. To monitor the upward displacement of the oil-water contact as hydrocarbons were extracted 4D seismic was used. The likelihood of gas breakout also imposed a significant risk to the feasibility of monitoring the oil-water contact with 4D seismic. To assess this possibility, models of different reservoir pressure scenarios were analysed, and the results demonstrated that in either case observable changes in seismic properties would occur, providing technical support for 4D seismic.

The monitor seismic survey acquired in 2013 showed detectable changes in both interval velocity and reflectivity associated with the occurrence of gas coming out of solution in the reservoir, where depletion occurred below the bubble point. This confirmed pre-acquisition predictions based on rock physics modelling. Additional rock physics analysis was carried out to calibrate the observed 4D response to changes in both fluid saturation and effective stress.

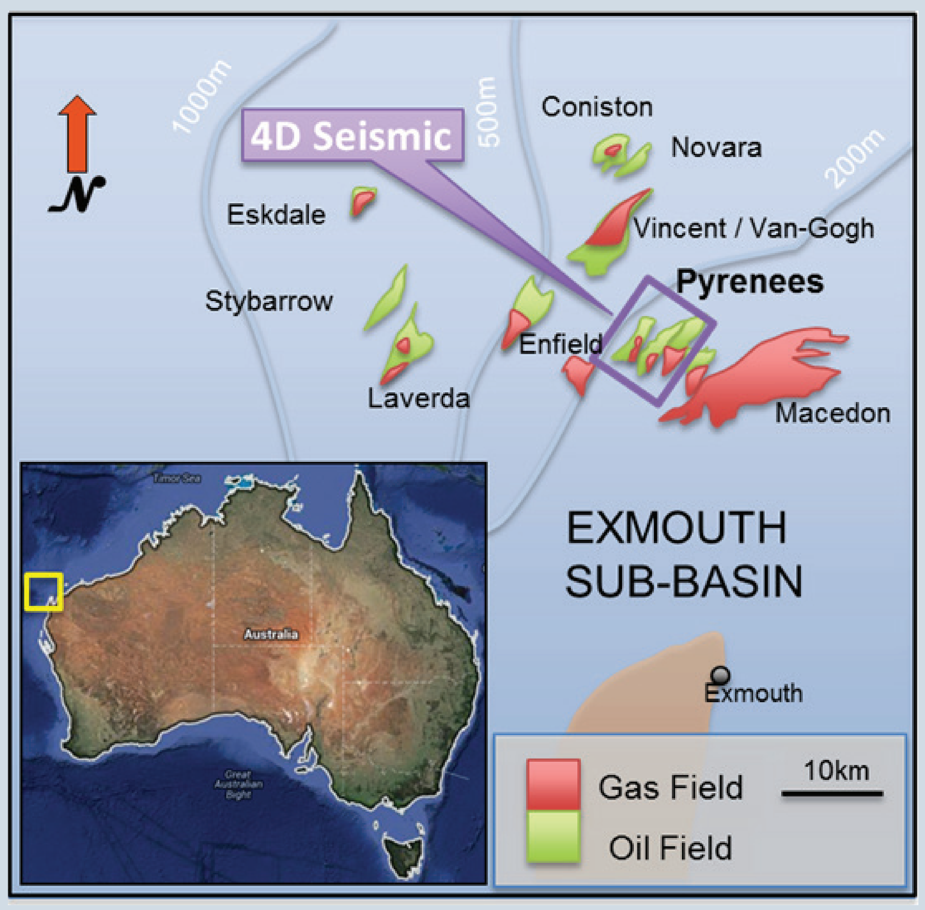

Figure 1: Location of the Pyrenees Fields

The Pyrenees reservoir is a wave dominated deltaic sand within the Barrow group (early Cretaceous). The field is approximately one kilometre below the seabed in waters between 170 and 250 metres in depth. Sand porosity varies from 28 to 34 per cent with areas of high shale content up to 40 per cent. Oil in the reservoir is 18-22 API gravity with a gas-oil ratio of 150-190 scf/stb. Gas caps are interpreted on the seismic for the three fault separated accumulations.

4D Feasibility Study

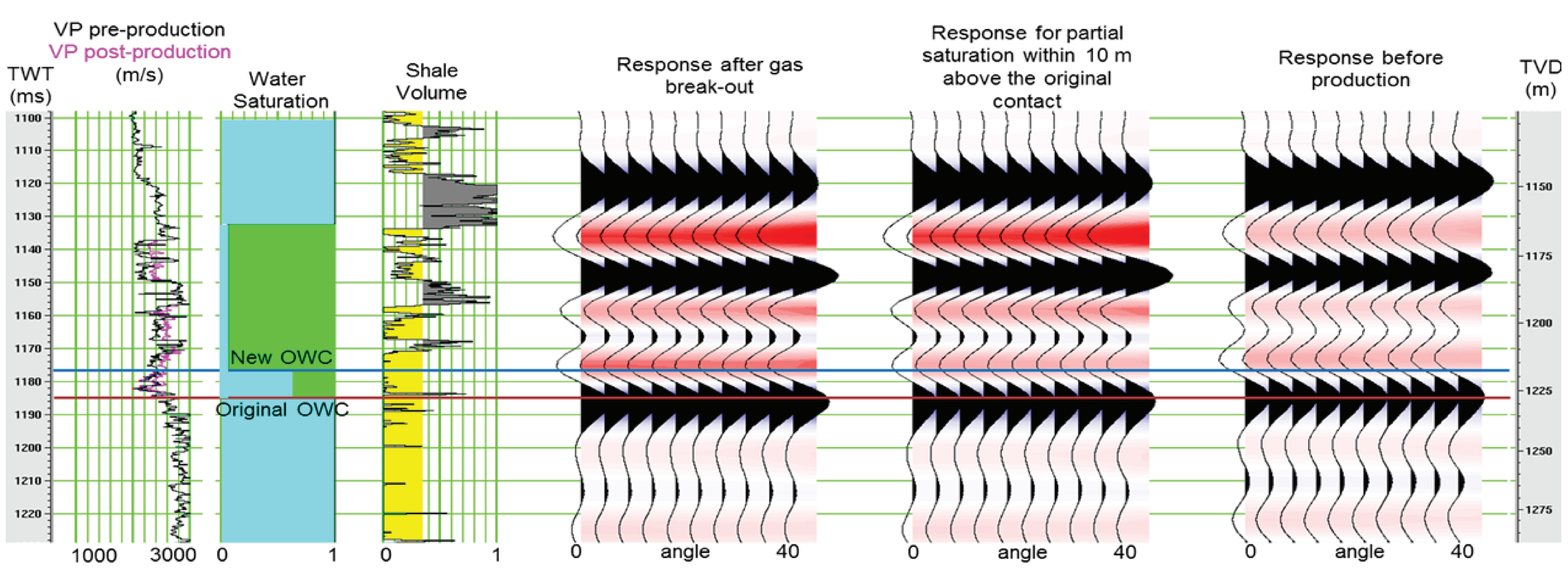

Figure 2: Synthetic seismograms from the 4D feasibility study, showing the effect of gas breakout

Oil in the Pyrenees field is close to the bubble point so a reduction of pressure by 100psi will result in gas coming out of solution (exsolved gas).

Initial production was modelled assuming gas coming out of solution evenly throughout the oil column due to pressure depletion and gas saturation reaching three per cent. After some time in production the oil-water contact moved up by 10 metres. By this stage, the water saturation was 60 per cent in the depleted oil zone below the new contact but exsolved gas of three per cent is still present.

Gas breakthrough brightens the amplitude everywhere in the oil zone, while oil depletion and contact movement has a smaller effect on the amplitude because exsolved gas remains in the oil zone.

Based on the 4D feasibility study it was determined that a time-lapse survey would provide useful information in both cases (with or without exsolved gas) and a recommendation was made to acquire the monitor survey in 2013.

If there was no exsolved gas it would be possible to track the movement of the oil-water contact. In case of the presence of exsolved gas, it would be easier to identify pressure compartments within the reservoir.

It was not clear which mixing law would be applicable to fluids in the reservoir after production: patchy saturation (Brie, et. al, 1995); or uniform mixing with a Reuss average.

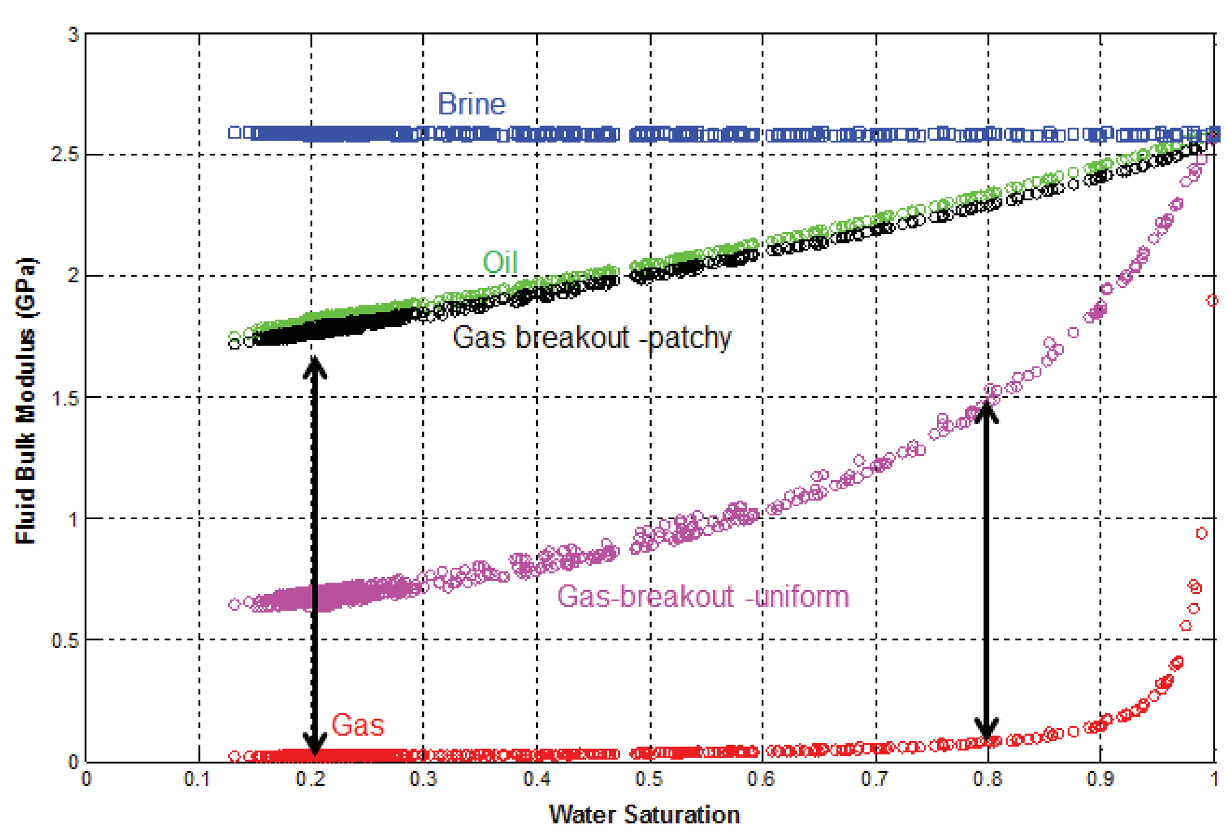

Figure 3: Fluid bulk modulus for different mixing laws after gas breakout used in the feasibility study

4D Rock Physics Analysis of Time-lapse Data

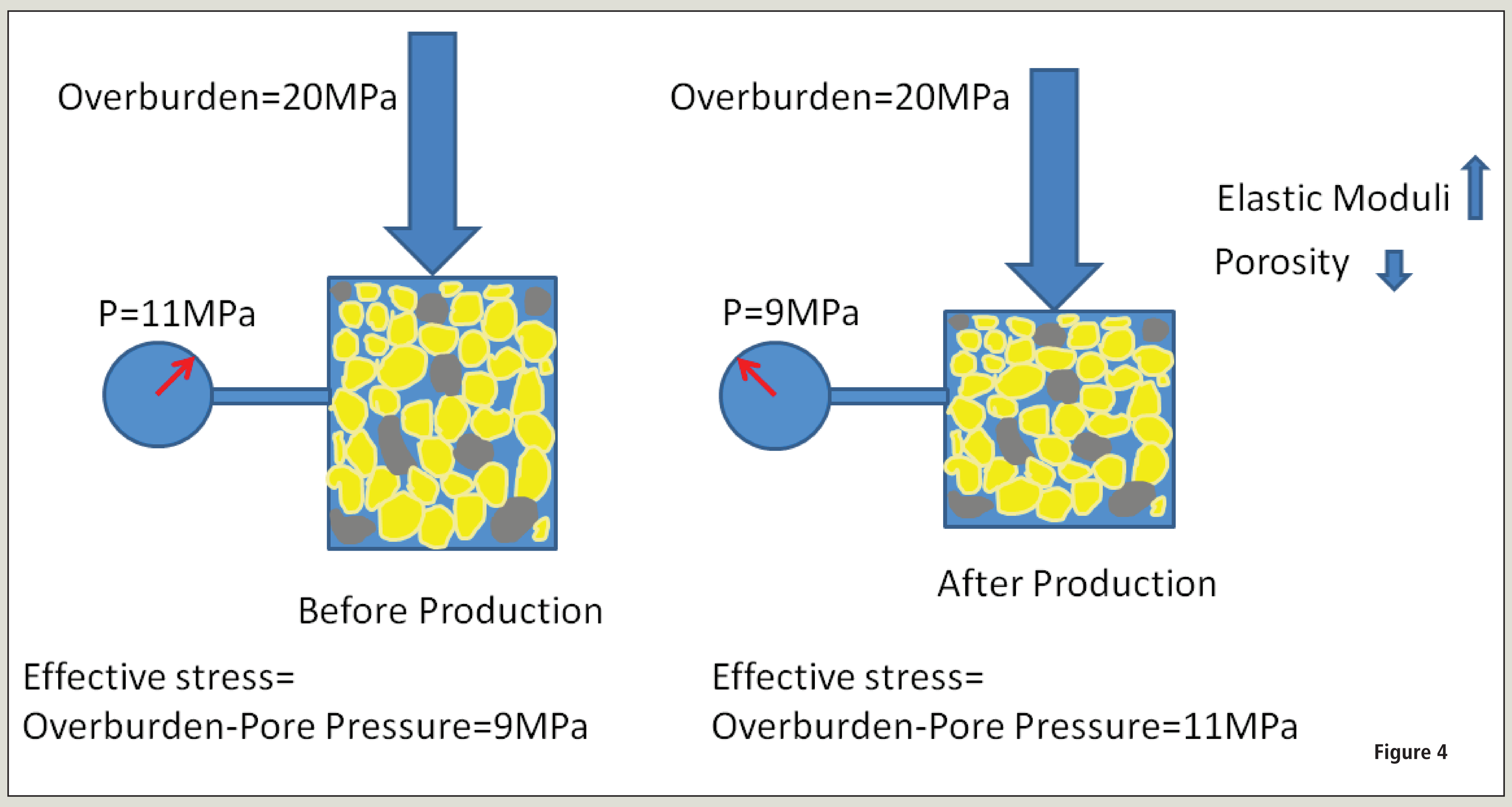

Figure 4

1. Gassmann fluid substitution from fluid in-situ to dry frame;
2. Alter the dry frame elastic moduli and porosity according to the effective stress change (derived from core compressibility laboratory data, as shown in Figure 5);
3. Substitute the new fluid in the reservoir after production. Try different saturation profiles for oil, gas and brine, and evaluate different mixing laws;
4. Compute band-limited impedance from the fluid substituted logs and compare it to the coloured inversion from the monitor survey.

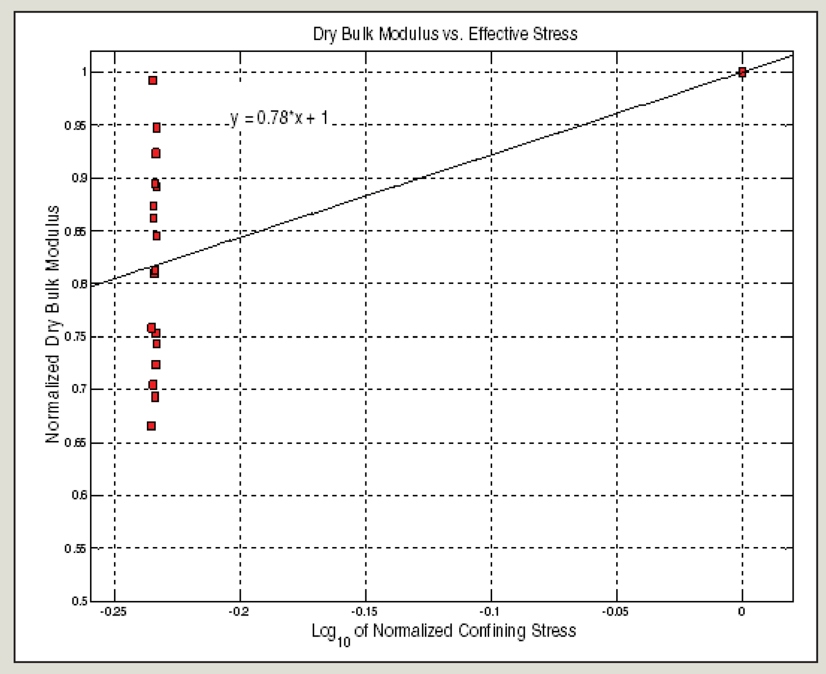

Figure 5: Estimate of reservoir dry frame elastic properties on effective stress.

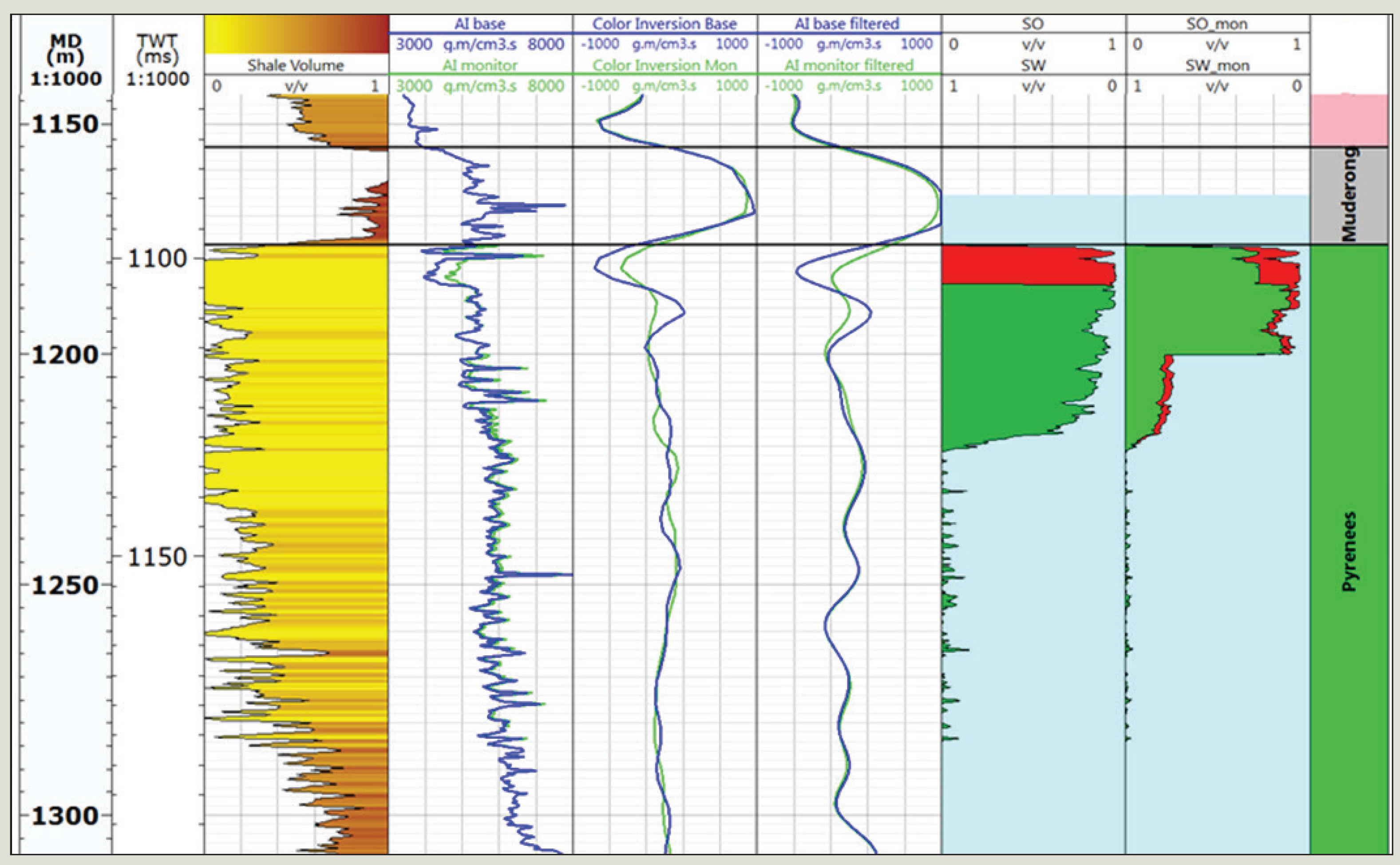

Figure 6 : Comparison of results from forward modelling of postproduction profiles and band limited impedance from coloured inversion.

The amplitude change inferred using a uniform mixing law did not agree with the amplitude change observed in the monitor survey. Therefore it was assumed that the mixing law was closer to patchy saturation so Brie's law was used to calculate the bulk modulus of the gas-oil-water mixture. A patchy saturation model allowed us to match the observed change in amplitude response.

Conclusions

Our results indicate that pressure effects are small and comparable to the effects of replacing oil with brine. In contrast, the observed reduction in acoustic impedance can only be explained as the result of gas coming out of solution. The observed change in amplitude strength can be matched best using a patchy saturation model.

Rock physics modeling of time-lapse seismic response in the Pyrenees Field has been useful for both assessing the expected added value of this technology and calibrating the observed seismic response. The results obtained are being used to constrain dynamic reservoir simulation.