ATTENUATION CHANGES DURING OILFLOOD EXPERIMENTS

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ABSTRACT

Reservoir saturation changes can be detected by repeat 3-D seismic surveys. These rely on some seismic attribute such as travel time, amplitude or velocity changing with the change in saturation of either gas, oil or water. Rock physics measurements show that rocks with a high compliance or low stiffness have the greatest sensitivity of Vp to saturation changes. Stiff rocks may only exhibit small changes in Vp with saturation, which may be undetectable on repeat surveys. However other seismic attributes, such as signal amplitude may show large variations.

In the experiments described here, the velocity and signal amplitude was measured in a stiff sandstone core during the replacement of brine with oil. During the experiment Vp changed by 1%, but the signal amplitude varied by over 200%. A 1% change in velocity is unlikely to be detectable in a repeat seismic survey since it causes a reservoir base shift of only 0.3ms for a 100m thick reservoir. However a 200% increase in amplitude may be detectable.

The material used in the experiments was an aeolean sandstone known as Clashach sandstone, commonly used in rock physics as a North Sea reservoir analogue. The sandstone was from a surface deposit from a quarry in the NE of Scotland. Clashach sandstone has some variation in its properties but the samples tested had porosity of 13.5-14.5%, a permeability of 100-350mD and were strongly water wet with an Amott-Harvey index of 0.65-0.98. The material was stiff with a modulus of elasticity of 40-50GPa. The samples were initially vacuum saturated with brine, of density 1.067g/cc, then saturated under a high pore pressure of 13.8MPa (2000psi) to achieve 100% saturation. The cores were weighed prior to the experiment to confirm 100% saturation with brine.

METHOD

The experiments were performed in a Hoek cell, which applied realistic levels of *insitu* effective stress to the core. The platens of the Hoek cell were equipped with ultrasonic transducers, which were used to measure compression and shear wave velocity through the core during the experiments. The velocities were measured by the time taken for a pulse of ultrasonic waves to travel across the sample. The frequency of the waves was approximately 600kHz. Fluids can be flowed through the core under high stress and at high pore pressure to perform fluid substitutions. In these experiments a light oil with a density of ρ_{oil} =0.76g/cc and a viscosity of 1.3cp was used as a flooding fluid. The brine filled cores were flooded with oil, the average saturation S_w was calculated from the expelled fluids, which were collected in a separator vessel. The experiments were

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performed at a variety of simulated *insitu* stress states up to 55MPa (8000psi). The experiment shown was done at 21MPa (3000psi)

In each experiment oil was flowed at a known rate for two pore volumes, during this time V_P and V_S were measured at regular intervals. The initial flow rate was 0.05cc/min, which was gradually increased to 16cc/min. At the initial flow rate of 0.05cc/min, the oil swept out a certain portion of the pores and brine was expelled from the core, reducing S_w. Eventually brine production ceased as the oil was excluded from pores below a certain size due to a balance between the capillary and viscous forces. The oil flow rate was increased to increase the viscous forces and sweep the brine out of smaller pores. This process was repeated until the highest flow rate of 16cc/min was reached. S_w reduced to 0.29 at the end of the 16cc/min pumping period. These initial saturation values S_{wi} were typical of this type of dynamic desaturation (Wilson 1956). There may be a variation of S_w along the core due to capillary end effects at the outflow end. This is likely to be small especially at the high rate used at the end of the experiments.

RESULTS

During the course of the experiment the pulse waveforms for the velocity measurements were recorded. Travel times and amplitudes were picked post test.

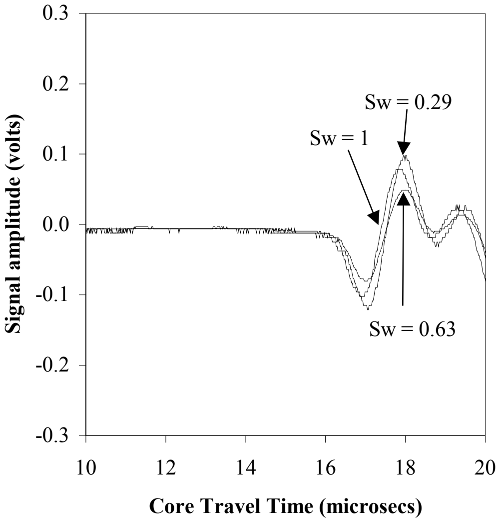

Figure 1. Transmitted waveforms recordered at 3 points during the oilflood.

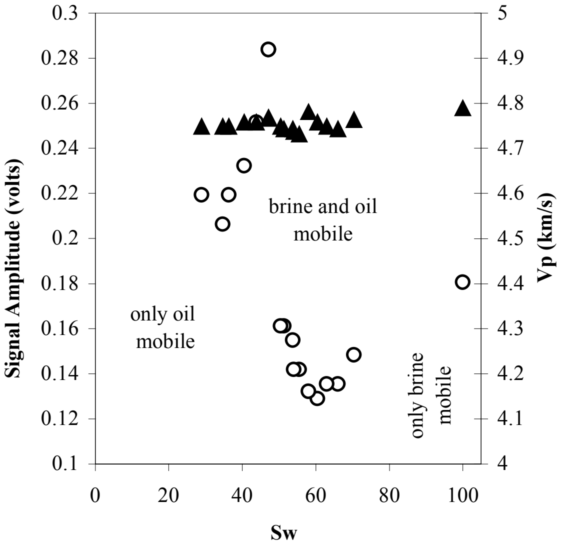

Figure 2 V_P (solid triangles) and signal amplitude (open circles)during the oil flood

Figure 1 shows three waveforms, one at the beginning of the test where the sample was fully brine saturated, the second at 0.63 brine saturation and the third at 0.29 brine saturation. There was very little change in the arrival times of each pulse with core travel times of 16.16, 16.29 and 16.29µs respectively. Figure 2 shows the changes in velocity and signal amplitude. There was a reduction in velocity of <1%, from fully brine saturated to a saturation of 0.29. The wave amplitudes however change markedly. At the onset of the oil flood when the sample was fully brine saturated the signal amplitude was 0.18 volts, the amplitude gradually reduced to 0.13 volts at a saturation of 0.63, then increased again to 0.22 volts at a saturation of 0.29.

The quality factor, Q can be calculated from the signal intensities at the input and output ends of the sample. Geometric spreading was assumed to be zero since the transmitting and receiving transducers are at the ends of long buffer rods, the wave front in the sample was assumed to be approximately a plane wave. This gave values of Q of approximately 30-50 for the samples used in the study. These are close to other measurements made on similar rocks (Bourbie et al 1987). The experiment was repeated several times and gave very similar results in each test

DISCUSSION

There could be a number of mechanisms causing this change in signal amplitude. One possibility is that the sample density and velocity are changing during the oil flood. This gave a change in reflection coefficient between the rock sample and the platen, but this only accounted for a few millivolts reduction in the signal during the experiment.

A model, which could be used to qualitatively account for the changes in signal amplitude, is that of Dvorkin et al (1994). They proposed a mechanism for velocity dispersion and attenuation in saturated porous rocks, which combines Biot and squirt flow mechanisms. In this theory the fundamental cause of attenuation and velocity dispersion is viscous dissipation due to pore fluids squirting through pore throats. The viscoelastic properties of the rock fluid system depend on one dimesionless parameter $\omega R^2/\kappa$. Were ω is the circular frequency of the waves, R is the characteristic squirt length and κ the hydraulic diffusivity. The hydraulic diffusivity is given by

$$\kappa = \frac{kF}{\mu\phi} \qquad \textbf{(1)}$$

Where k is the permeability, ϕ the porosity, μ the fluid viscosity and F a factor depending on fluid density, fluid acoustic velocity, and the properties of the rock under drained conditions. The theory predicts low attenuation at low permeability since the fluid has no possibility to move and acts as part of the solid. Followed by a peak in attenuation at intermediate permeability where the fluid can move and dissipate energy. Finally followed by a decrease in attenuation at higher permeability as the fluid can move more easily.

The theory of Dvorkin et al (1994) is valid for a single liquid phase. A possible way to extend the theory to two liquid phases would be to replace the viscosity in equation 1 by the effective viscosity. This would give a diffusivity and attenuation which were a function of S_w. The effective viscosity is given by

$$\mu_{effective} = \frac{1}{M_{total}} = \frac{1}{\left(\frac{k_{ro}(S_w)}{\mu_{oil}} + \frac{k_{rw}(S_w)}{\mu_{brine}} \right)} \qquad \textbf{(2)}$$

Where μ_{oil} is the oil viscosity, μ_{brine} is the brine viscosity and $k_{ro}(S_w)$ and $k_{rw}(S_w)$ are the oil and brine relative permeability. M_{total} was the total fluid mobility. The relative permeability was calculated from the oil flood data. Figure 3 shows the signal amplitude plotted against the total mobility, where two phases are present. There was a good correlation between the two parameters with the signal amplitude increasing as the total fluid mobility increased. A linear trendline was fitted to the data. While a linear relationship was a reasonable fit to the data the actual behaviour is likely to be more complicated.

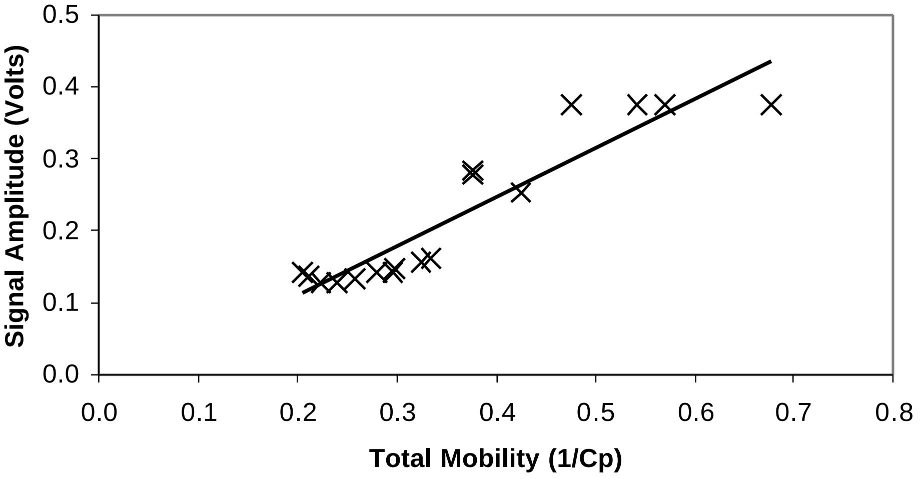

Figure 3. Signal amplitude versus total mobility

CONCLUSIONS

These results raise the possibility that repeat 3D seismic surveys could be used to detect mobile phases in different parts of the reservoir. Each combination of phases, brine mobile, oil and brine mobile, and oil mobile have different attenuation signatures. The volumes of the reservoir containing unswept oil would be prime candidates for infill drilling.

This work is a preliminary study and is being extended to other more realistic reservoir conditions such as waterflooding.

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