Time lapse AVO analysis of an Alberta reef under miscible flood

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Summary
A time lapse seismic experiment has been performed over the Rainbow Keg River “B” pool to observe changes in the seismic signature due to miscible flooding. Rock physics data from core samples show that there should be some AVO effect from the solvent – oil contact. AVO analysis was done on a model of the reef simulating varying thicknesses of solvent. The model showed a differing AVO effect with thickness of solvent. Seismic data shot in 1987 and 1997 over the same location were analyzed for AVO effects of movement of the solvent bank. The apparent solvent – oil contact is visible on the 1997 seismic line and the Smith Gidlow fluid factor shows it best.

Introduction
Much of Alberta’s oil production has come from reservoirs of reefal origin. The productive zone in the Rainbow Keg River “B” Pool consists of dolomite of 5% to 15% porosity capped with about 10 m. of limestone of about 6% porosity. Above the Keg River lies the Muskeg formation consisting of roughly 30% dolomite and 70% anhydrite. This reef was discovered in the mid 60’s and was under primary production until 1968 when a waterflood program was initiated to maintain reservoir pressure. In 1984 a miscible flood program was initiated to recover additional oil from the water-swept oil zone.

Conventional primary and secondary oil production leaves a large percentage of oil behind that may be recovered with miscible flood enhanced oil recovery (EOR) (Hirsche 1990). The net present value of the additional oil recovered can total millions of dollars. A joint research project with Western Geophysical and the Alberta Research Council (ARC) was undertaken in 1987 to investigate whether seismic monitoring of injected fluid movements is possible. This would help design an optimum injection and production plan, thereby improving the cost effectiveness of the EOR method.

In 1987, a 2D test seismic line was recorded over the reef using buried geophones in an attempt to record useful data of up to 100 hz and see the seismic effects of the solvent bank. At that time, the solvent bank was 10m. thick. The 1987 study found that the seismic data matched a model of the reef with a 10m. solvent bank. In January of 1997, a 2D seismic line was recorded over the same location to see if changes in the level and thickness (now 40m.) of the solvent bank were noticeable.

Method
To effectively model a potential AVO response to miscible flooding, an understanding of the rock physics for carbonate reefs is required. During the ARC/Western testing velocity measurements were taken at Core Laboratories for dry, brine saturated, oil saturated and solvent saturated cores from Rainbow “B” pool under pressures from 1000 to 7000 psi. The results of the acoustic testing for 3000 psi. (close to the reservoir pressure of 3400 psi), shown in Figure 1, indicate a 10% difference in Vp between the oil saturated and solvent flooded cores. The laboratory data also indicates that Vs is relatively insensitive to fluid saturation. The resulting contrast in Vp/Vs and Poisson’s ratio suggests that we should be able to see an AVO effect from the solvent – oil and the gas – solvent contact.

Model offset gathers from sonic and density logs and Vp/Vs of 1.8 representing solvent bank thicknesses of 0m., 15m., 30m., and 45m. were created to study potential AVO anomalies in the seismic data. We used the Smith – Gidlow fluid factor (the difference between the P wave reflectivity and the calculated P wave reflectivity using the mudrock line) modified to use a ‘carbonate line’ to perform the AVO analysis (Figure 2). The fluid factor is near zero in water bearing rocks but is anomalous at the gas filled reservoir at 730 ms. in the synthetic.

Modeling indicates there should be a different AVO response from the seismic line shot in 1997 when compared to the 1987 line. AVO analysis of gathers from the two lines showed little indication of the solvent – oil contact on the 1987 line and the Smith - Gidlow fluid factor gave the best indication of the contact at about 1110 ms. on the 1997 seismic line (Figure 3).

Conclusions
Rock physics measurements made on cores taken from the Rinbow B pool indicate that Vp changes significantly when oil is replaced by hydrocarbon miscible solvent in the course of oil recovery. In contrast,