Hebron/Ben Nevis rock property analysis and modelling study

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ABSTRACT

This paper investigates the sensitivity in amplitude variation with offset (AVO) behavior to varying rock properties in an attempt to predict oil gravity (density) contrasts. Rock physics scenarios associated with Ben Nevis reservoir zone are performed using Biot-Gassmann fluid replacement modelling to vary porosity, water saturation, and oil density (API). Since there are numerous variations of these rock properties, AVO modelling volumes are utilized to analyze and interpret the results. Prior to modelling, rock property relationships are observed and used in the AVO modelling analysis. Intercept and gradient volumes are extracted from the synthetic model data and show variations associated with the rock property models. Crossplots of the intercept and gradient are used to further discriminate the input models. Relationships are observed between the variations in water saturation, porosity, and oil density. Three-parameter AVO techniques are also applied to the volumes in an attempt to predict density variations in the pore fluids.

Introduction

The Hebron asset is comprised of Hebron, West Ben Nevis, and the Ben Nevis fields. This prospect is located in the southern portion of the Jeanne d'Arc Basin, approximately 350 kilometers from St. John's, Newfoundland. Significant discovery licenses covering this asset were awarded in the mid 1980's based on four exploratory wells over an area of approximately 36 square kilometers.

Oil in place potential for the asset including un-drilled fault blocks is estimated to exceed 2 billion barrels. The CNOPB[1] states that there are about 400 million barrels of recoverable oil, based on what has been already drilled, making Hebron the second largest field in the Jeanne d'Arc Basin after Hibernia. The upper Ben Nevis horizon encountered significant volumes of crude with gravities

[1] Canada-Newfoundland Offshore Petroleum Board

in the range of 19 to 21 degree API. Oil is usually classified as heavy if it has API gravities of 20 degrees or less. Therefore, the oil encountered in the Ben Nevis is still not as dense as water. The density of this oil however presents several production challenges and may require special processing equipment. The Hibernia and Jeanne d'Arc horizons encountered marginal volumes of lighter gravity crude. The Hibernia formation encountered 29 degree gravity oil while the Jeanne d'Arc encountered highly variable gravities from 24 to 36 degree gravity oil, the higher of which are similar to those of the Hibernia oil field.

AVO methods have been used to predict hydrocarbons in clastic reservoirs offshore eastern Canada. AVO is quite useful in the fact that it has the potential to reduce the drilling risk, which is valuable for costly offshore drilling. This method can be a valuable exploration tool but traditionally it cannot distinguish between commercial and noncommercial (low hydrocarbon saturation) reservoir zones. This is because the P-wave velocity is very sensitive to the presence of a hydrocarbon in the pore space of a rock even at very low saturation of hydrocarbons. The S-wave velocity and density, however, are not as sensitive to low hydrocarbon saturations in the pore spaces. Using two-parameter AVO equations the P-wave velocity is always linked to the shear wave velocity or density and therefore there is no bias at lower hydrocarbon saturations. Lines (1999), Kelly et al. (2001), Downton (2001) and others have explored a three-parameter AVO extraction in order to get more information from P-wave seismic data in an attempt to isolate rock property contrasts. This method may prove to be an interesting approach at the Hebron / Ben Nevis prospect in an attempt to differentiate between the varying oil gravities.

Data Analysis

In this analysis wells M-04, D-94, and I-13 are used all of which encountered pay. There are four key zones of interest: the Ben Nevis formation, Hibernia formation, Jeanne D'Arc "H" sand and Jeanne D'Arc "B" sand reservoirs. The Ben Nevis reservoir is of key interest in this paper due to its low-gravity oil. The goal of this analysis is to detect density differences using a three-parameter AVO extraction in order to obtain density contrast volumes.

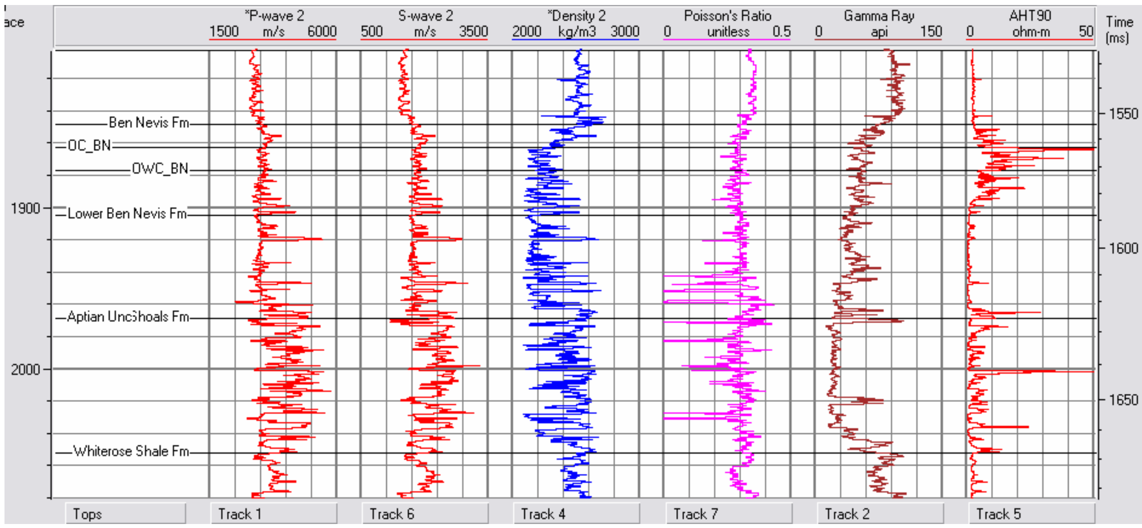

Fig.1. Original logs at M-04 well location.

In order to get an understanding of the rock properties associated with the Ben Nevis zone, Fluid Replacement Modelling (FRM) was performed on the M-04 well. This well was used because it contained full waveform sonic (*P*-wave and *S*-wave), density, gamma ray, porosity, and other pertinent logs for modelling. The input logs from the M-04 well are shown in *Fig. 1*.

Synthetic Modelling Analysis

The AVO modelling volume approach introduced by Russell et al. (2000) was used to model this data. In our case three physical parameters were varied, porosity in the in-line direction, water saturation in the cross-line direction, and oil density (API) per volume. A total of six AVO modelling volumes were created for oil densities of 16, 18, 20.5, 23, 25, and 30 API. Once these volumes were attained, regular AVO analysis could be applied to the volumes and interpreted using time slices through the volumes. A cross-line from the 20.5 API modelling volume is shown in *Fig. 2*; the water saturation is 0% and the porosity increases from left to right.

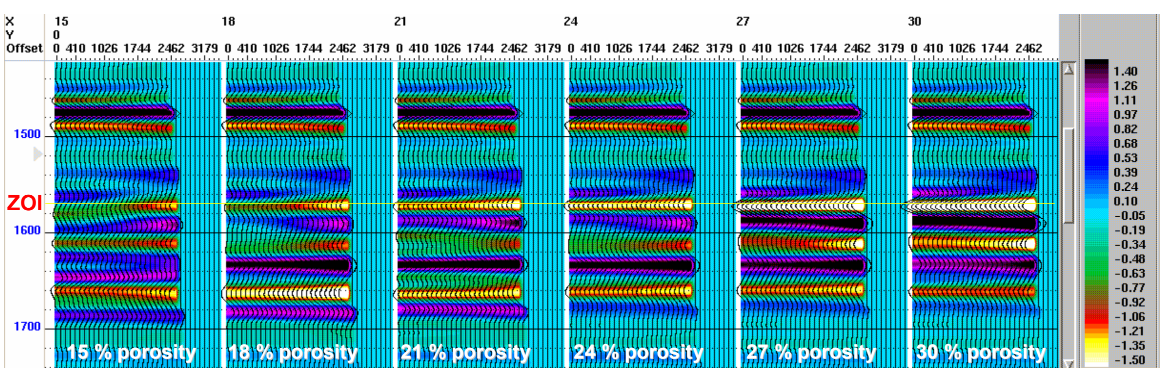

Fig.2. In-line from 20.5 API modelling volume.

The top of the zone of interest is at approximately 1570 ms and the base of the zone (OWC) is at 1590 ms. An AVO anomaly can be seen for the top and bottom of the zone of interest. Porosity seems to have a strong affect on the AVO response. An increase in the amplitude with offset is apparent to about 24% porosity. It can also be seen that a phase rotation with offset (class II AVO anomaly) is present for porosities of 15%, an increase in amplitude with offset (class III AVO anomaly) is present for porosities of 18 - 21%, and a decrease in amplitude with offset (class IV AVO anomaly) for porosities 27 and 30%.

Intercept (A) and gradient (B) volumes were created using Shuey's (1984) approximation to the Zoeppritz equations. Time slices taken through the top of the zone of interest were created for comparison of the six volumes. This comparison is shown in *Fig. 3* for the gradient volumes for the top of the Ben Nevis oil zone. It can be seen that the AVO effect is strengthening on the all API volumes from 15 – 24% porosity with the strongest response at 15% porosity. The amplitude also gets stronger with higher oil density, although this response is very subtle. The water saturation is more predominant at the lower porosities and seems to have less effect at the higher porosities.

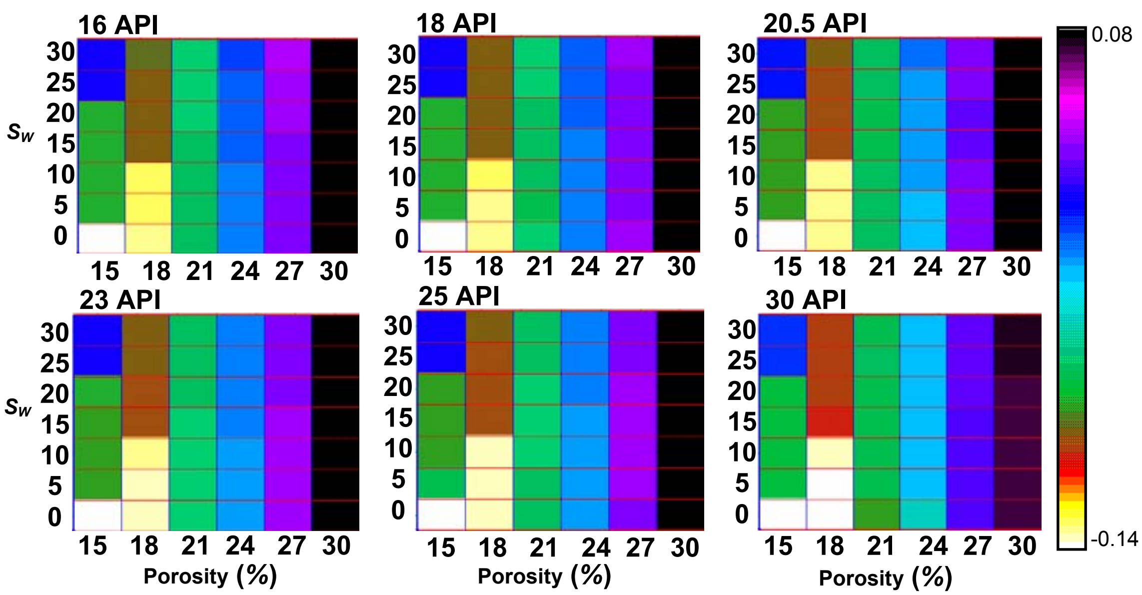

Fig.3. Time slices for gradient modelling volumes at top of Ben Nevis oil reservoir.

Crossplotting of intercept (A) and gradient (B) data provides useful insight on the nature of the pore fluid. In an intercept versus gradient crossplot, brine filled sandstones and shales should fall on a well-defined "background-trend". The gradient and intercept volumes are crossplotted to compare the effects of oil density and increasing porosity; this crossplot is shown in *Fig. 4*. Changes in porosity are represented by point color changes and oil density changes are represented by point shape. On this crossplot, it can be observed that with increasing porosity the anomalous points for the top of the oil zone move from a class II type anomaly to a class IV type anomaly, which occurs between 27 and

30% porosity. The oil density again is less sensitive than the porosity, but separates perpendicular to the background trend. The further away from the background trend the stronger the oil density separation.

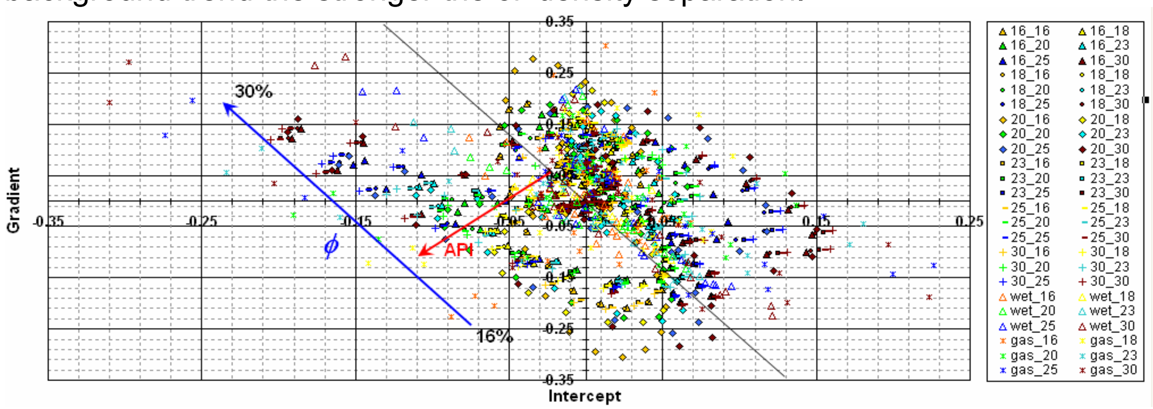

Fig.4. Intercept versus gradient crossplot for varying porosity and oil density.

A three-parameter AVO extraction was utilized in an attempt to detect density variations for the six volumes. Intercept (A), gradient (B), and curvature (C) are the outputs of this extraction. The curvature term only contributes at far offset, so good offset distribution is needed for proper application of three-parameter AVO extractions. Once A, B, and C attributes are acquired, they can be arranged to get P-wave velocity reflectivity ($\Delta V_P/V_P$), S-wave velocity reflectivity ($\Delta V_S/V_S$), and density reflectivity ($\Delta\rho/\rho$). Density reflectivity volumes were created and time slices at the top of the Ben Nevis reservoir are shown in *Fig. 5.*

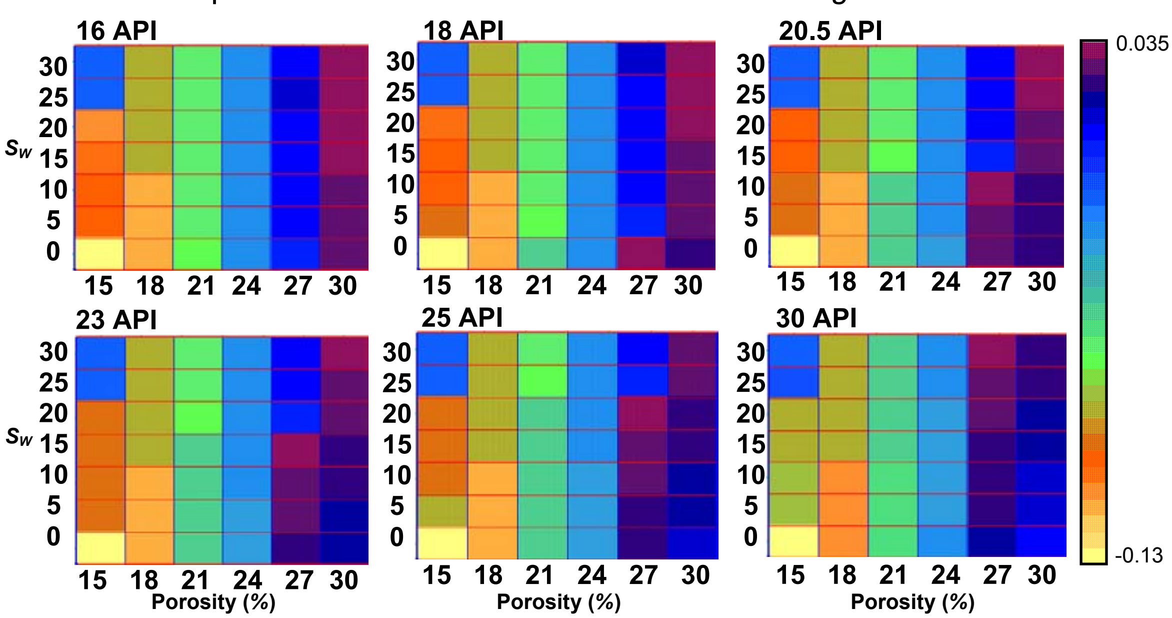

Fig.5. Density reflectivity time slices at top Ben Nevis zone.

Porosity has a strong effect on the density reflectivity values; the oil density also shows variation. The oil density values show stronger negative variations at lower porosities. The water saturation does not have as much effect on the density reflectivity as the porosity. A trend can be seen between the oil saturation and the water saturation. At higher oil densities the water saturation has less effect on the density reflectivity, and at lower oil densities the water saturation has more effect on the density reflectivity. The variations of density reflectivity with oil density and porosity at 0% water saturation are shown in figure 6 and the variations in density reflectivity with oil density and water saturation at 24% porosity are shown in *Fig. 7*.

Porosity change is most evident; oil density variations are stronger at lower porosities from about 15 – 23%. The water saturation has more effect at lower values. There seems to be a drop-off point associated with increasing water saturation and oil density. This may be due to increased water saturation in association with the denser oil (lower API) giving a lower density contrast. Therefore there may be a saturation point at which a certain combination of water saturation and oil density does not show much density reflectivity variation.

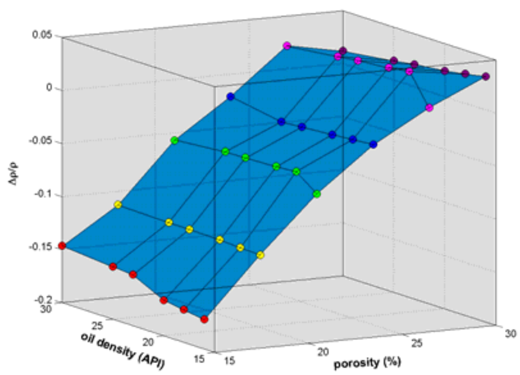

Fig.6. Δρ/ρ vs. oil density vs. porosity.

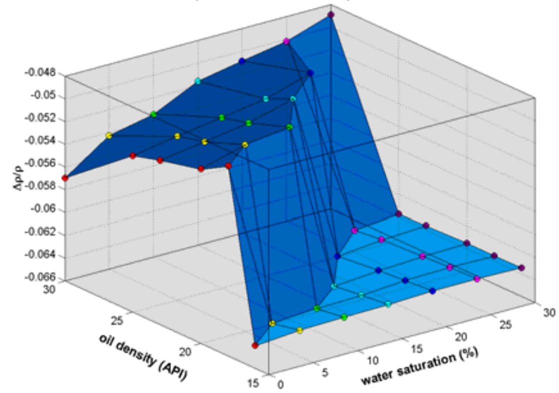

Fig.7. Δρ/ρ vs. oil density vs. water saturation.

Conclusions

On the AVO synthetics, the porosity variations affected the AVO response dramatically more than the oil density variations. The AVO signature changes from a class II type to class IV type anomaly. The *A-B* crossplots show the strong effect of porosity, with the points for the top of the oil sand moving from quadrant 4 (class II) to quadrant 2 (class IV). The oil density separation with increasing API is stronger further away from the background trend. The density reflectivity volumes show variations for water saturation, porosity, and oil density variations. The strongest deviations are seen with varying porosity. The oil density shows variations especially at lower porosities. The water saturation shows variation but is not as influential as porosity. Therefore a good knowledge of the porosity should be known to possibly extract variation on fluid density. A more definitive answer may be attained when the I-13 and D-94 wells are analyzed with different oil gravities in the Ben Nevis reservoir zone.

Acknowledgements

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References

Downton, J. E., and Lines, L., 2001, Constrained three parameter AVO inversion and uncertainty analysis, CSEG 2001 expanded abstracts.

Kelly, M., Skidmore, C., and Ford, D., 2001, AVO inversion, part 1: Isolating rock properties: The Leading Edge, *20*, no. 3, 320-323.

Kelly, M., Skidmore, C., and Ford, D., 2001, AVO inversion, part 2: Isolating rock properties: The Leading Edge, *2***0**, no. 4, 425-428.

Lines, L., 1999, AVO and Density: Canadian Journal of Exploration Geophysics, *35*, no. 1/2, 32-35.

Russell, B. H., Lines, L. R., Hirsche, K. W., and Peron, J., 2000, The AVO modelling volume: CREWES Research Report, 12.

Shuey, R.T., 1985, A simplification of the Zoeppritz equations: Geophysics, *50*, 609-614.