# Fluid effects on bright spot and AVO analysis

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## SUMMARY

Direct hydrocarbon indicators such as bright spots and AVO anomalies can be modified substantially by natural variations in hydrocarbon properties and changes in these properties brought on by production. A simple "gas" model is often inadequate since live oils can give a similar response. Reservoir properties may change so substantially due to production that they should NOT be used to calibrate exploration procedures.

## INTRODUCTION

A primary goal of bright spot or Amplitude Versus Offset (AVO) analyses is to identify in situ pore fluids. Anomalies that indicate hydrocarbons are caused by a drop in effective fluid modulus thus lowering the compressional-wave velocity but leaving the shear-wave velocity relatively unchanged. However, a reduced fluid modulus is not simply an indicator of gas or no gas.

Hydrocarbons can have a complete spectrum of properties ranging from brine-like to gas-like. Under many circumstances, the hydrocarbon may be above the pseudo-critical point where there is no distinction between liquid and gas phases. In addition, during production, reservoir pressures are changed and often lowered substantially. The resulting changes in fluid phases, particularly gas content, can substantially alter the seismic response.

A great deal of effort has been expended developing proper processing and display tools for AVO Comparatively little effort has been used looking at the fluid types and phases, even though these are our ultimate targets.

## GENERAL RELATIONSHIPS

AVO anomalies result from a combination of lithology and fluid change effects (Smith and Gidlow, 1987). Background rock properties are usually derived from nearby wells. Global trends must often be used to supply unknown parameters such as shear velocity (Castagna, et al., 1985, Greenberg and Castagna, 1993; Kriefetal., 1990), but such trends may be too crude for a specific location. These trends are used with Gassmann's (195 1) equations to provide an estimate of fluid effects on velocity in the seismic band. Although fluid substitution techniques are well established (Castagna et al. , 1993) results can still be ambiguous.

Fluid properties are more obscure since they are often missing from nearby wells or have been modified through production. Batzle and Wang (1992) provide generalized fluid properties. Fortunately, if some simple information is available, such as oil API number, fluid properties can be estimated with sufficient acuracy.

## ANGLE DEPENDENT REFLECTIVITY

Several approximations have been developed to simplify the Zoeppritz (19 19) equations describing reflectivity versus angle. For angles of incidence $(\Theta)$ less than about 30 degrees, most approximations take the form

$$R(\Theta) = A + B\sin^2(\Theta) \qquad (1)$$

where R is reflection coefficient, A is the normal incidence reflectivity, and B is the slope factor. Shuey (1985) gives a simplified form for B

$$B = A_o A + \Delta\sigma/(1-\sigma) \qquad (2)$$

where $A_o$ is a function of average values of Poisson's ratio $(\sigma)$, compressional velocity, and density and the changes in Poisson's ratio (ACT), Compressional velocity, and density.

To illustrate the fluid dependence, we make some assumptions about rock properties (Swan, 1993): density change is proportional to the velocity change, and the background Poisson's ratio remains a constant 0.3. These assumptions are generally too simple for any true exploration situation. Equation (2) then simplifies to

$$B = -1.26\,A + 2.04\,\Delta\sigma. \qquad (3)$$

Thus, the angular dependence has simplified to a dependence on the change in Poisson's ratio across the interface. A similar dependence was shown in the approximation of Hilterman (1989)

$$R(\Theta) = A\cos^2(\Theta) + 2.25\,\Delta\sigma\sin^2(\Theta) \qquad (4)$$

This change in Poisson's ratio can be calculated by Gassmann's equation for hydrocarbon zones. For the case described below with gas saturated sand under a shale, $\Delta\sigma \sim 0.16$. Live 50 API oil in place of the gas results in a $\Delta\sigma \sim 0.1$. The general effect compared with the background brine saturated elastic trend is shown in Figure 1 for A versus B. Live oils can produce a significant response on this kind of indicator, but the effect is strongly dependent on the fluid type.

An example from a Gulf of Mexico well was used to examine this fluid effect in detail. Properties of the initial simplified blocked zone of interest are given in Table 1. This situation is complicated somewhat by a zone of partial gas saturation in the sand (layer 5) below the main reservoir level (Layer 2). In Figuer 2, an increase in amplitude due to the gas in layer 2 is obvious between 835 and 860 meters.

Light live oil (oil with gas in solution) will give a similar response. Substitution of a live API 50 oil into layer 2 results in the synthetic AVO gather shown in Figure 3. This gather is not substantially different than for the gas saturated case shown in Figure 2. With the decrease of gas content and general increase in modulus of oil as API number is lowered, the response of heavier oils will approach that of the brine saturated background.

FLUID PHASE CHANGES INDUCED BY PRODUCTION

Most oil reservoirs have a gas cap or high gas content. Even otherwise dry gas will be in contact with a gas-saturated brine (although quantity in solution is much lower than in oil). During production, pressure is lowered and gas exsolves. Gassmann equations predict drop in Vp in the oil and brine legs under some conditions. As an example, Figure 4 shows the result of discrete gas bubbles forming in the brine leg of the upper sand (Table 1, Case 2). This zone now appears to have a much thicker pay. This response is significantly different for pre-production as was shown in Figgure 2. Distinct reflections are apparent off the top and bottom of the unit.

CONCLUSIONS

Fluid properties are very important in the interpretation of Direct Hydrocarbon Indicators. Specific hydrocarbon types will result in variations in amplitude versus angle indicators. Changes in fluid phase with production can substantially alter the reservoir seismic response. However, these effects are predictable in many cases, and can be explicitly incorporated in exploration procedures.

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Steven Roche of the Colorado School of mines provided valuable assistance in producing the AVO models

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Table 1. Model Properties:

| Layer | Rock Type | Thick. m | Vs km/s | Density gm/cc | Case 1 Pre-Production Vp km/s | Case 2 Post-Prod. VP km/s |
|---|---|---|---|---|---|---|
| 1 | Shale | --- | 0.98 | 2.28 | 2.4 | 2.4 |
| 2 | Gas Sand | 15.3 | 1.1 | 1.95 | 1.85 | 1.85 |
| 3 | Brine Sand | 27.4 | 1.06 | 2.1 | 2.38 | 1.82 |
| 4 | Shale | 24.4 | 0.9 | 2.25 | 2.29 | 2.29 |
| 5 | Gas Sand | 6.1 | 1.1 | 2.05 | 1.84 | 1.84 |
| 6 | Brine Sand | 6.1 | 1.06 | 2.05 | 2.38 | 2.38 |
| 7 | Shale | --- | 0.94 | 2.25 | 2.34 | 2.34 |

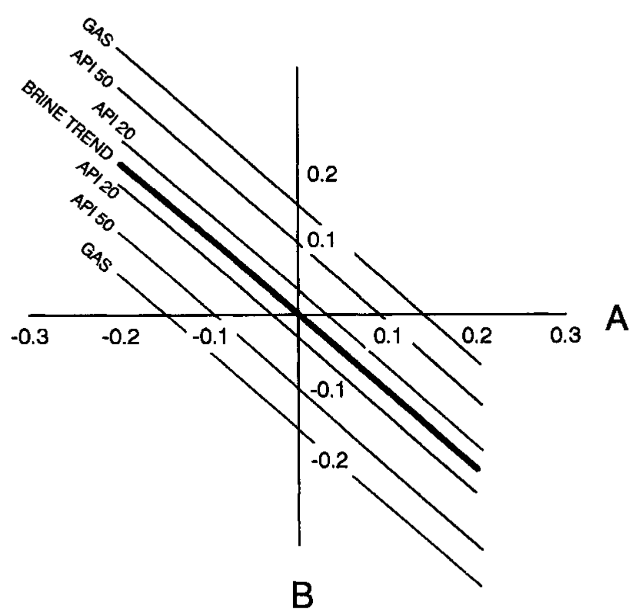


Figure 1. Theoretical A versus B plots for various pore fluids. Background Poisson’s ratio is constant at 0.3

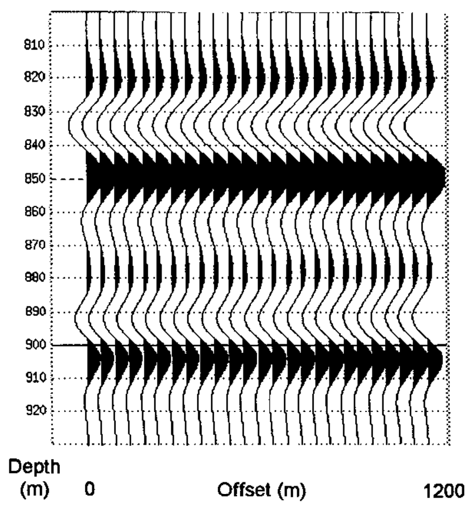


Figure 2. AVO response of a gas leg over a brine sand from a Gulf of Mexico Well. Blocked values are given in Table 1, for Casel, Pre-production. Input is a 30Hz Ricker wavelet.

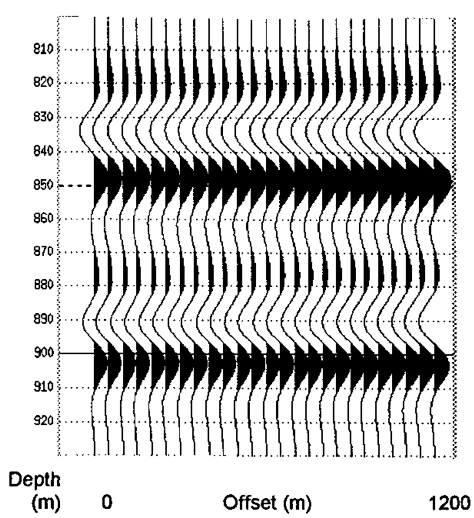


Figure 3. Effect of substituting a 'live' or gas saturated 50 API oil for the gas leg in Figure 2.

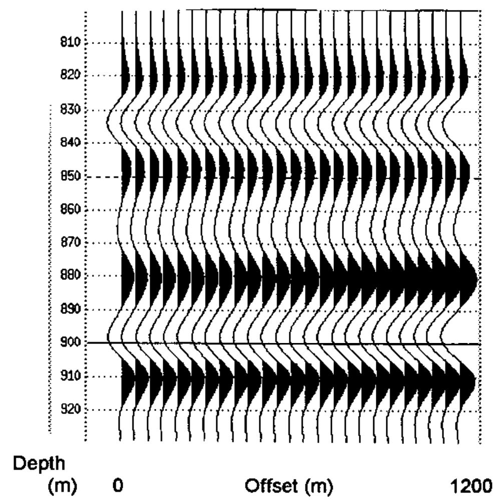


Figure 4. Expected result of gas exsolving during production. Parameters are from Table 1, Case 2, Post-Production.