Fluid Invasion Effects on Sonic Interpretation

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SUMMARY

Invasion of drilling or completion fluids from the borehole into the surrounding formation can alter seismic impedances significantly. Filtrates will behave differently to pressure. temperature, and gas content. Oil based filtrates can absorb substantial gas. Both sonic and density logs are modified and corrections can be significant for seismic-log ties.

INTRODUCTION

Detailed analysis and modeling of rock acoustic properties is becoming more important as seismic data is used increasingly for direct hydrocarbon indicators and reservoir monitoring. Unfortunately, both sonic velocities and densities of rocks can be altered significantly from their original values due to invasion of drilling and completion fluids. An irregular geometry results with a borehole annulus filled with mud, mud cake on the wall. a flushed zone and transition zone before reaching unaltered formation.

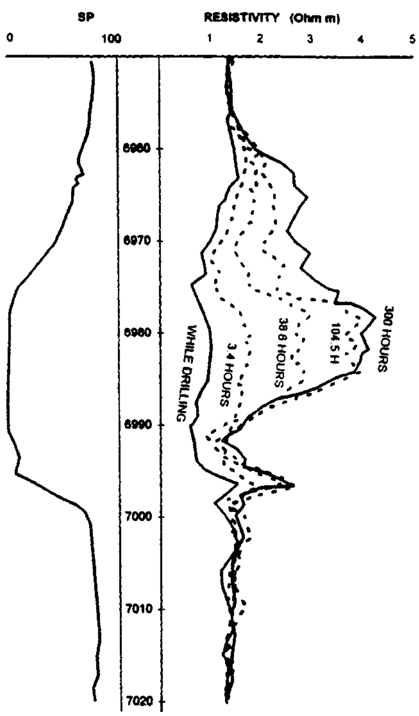

Figure 1. Shallow resistivity logs taken at various times after penetration of the formation using a measurement-while - drilling (MWD) tool (after Nuckols. et al., 1987)

Invasion can be a complicated process, and correcting affected logs is often difficult. These changes are time dependent (Figure 1), and interpretations of reservoir properties and processes will be in error. Partial saturation and gas in solution can modify both the transit time and amplitude during sonic logging. Formation evaluation based in part on the sonic log (Brie, 1995, Raiga-Clemenceau et al., 1988) then incorrectly estimate hydrocarbon saturation or porosity. Densities are altered and so impedances are also changed thus modifying predicted reflector strength and Vp/Vs ratios.

Drilling Fluids

Drilling fluids can vary significantly in composition and properties. Water-based muds can contain salts, polymers. and solids in solution, emulsion, or suspension. These additives control interaction with shales and evaporites, increase density (pressure), build viscosity, or help produce mud cake. The filtrate penetrating the formation will be basically a brine from almost fresh to saturated salt content.

Oil-based or synthetic muds are generally used for shale stabilization or to prevent sticking. Diesel fuel is a typical base component although emulsified muds can contain as much as 50 percent brine. Additives increase viscosity, density, or stabilize emulsions. Synthetic muds have similar properties but are more environmentally safe.

The temperature. pressure. and gas effects on oil-based mud filtrate (#2 diesel) are shown in Figure 2. Increasing pressure increases oil velocity but this increase is largely

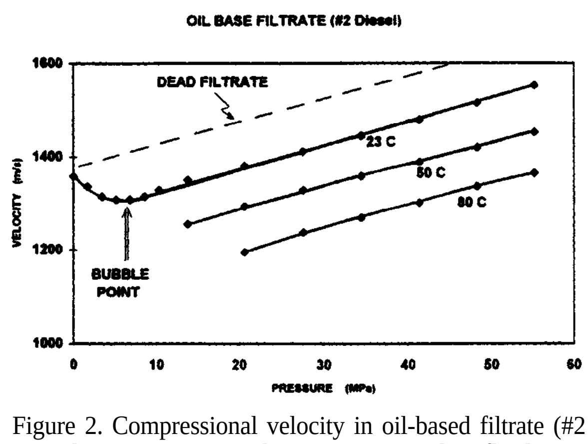

Figure 2. Compressional velocity in oil-based filtrate (#2 Diesel) at pressure and temperature. This fluid was saturated with methane at 6.9 Mpa (Bubble point).

counteracted by the drop in velocity associated with increasing temperature. On the other hand, substantial amounts of gas can go into solution into an oil based filtrate. As a result, both the liquid velocities will decrease and the semi-miscible process will be more effective in flushing gas zones. Even though the saturation pressure (bubble point) is low in Figure 2, enough gas has dissolved in the filtrate to lower the velocity significantly.

Water based filtrates can absorb far less gas, and are almost unaffected (Osif, 1988). Environmental corrections based on excessive dissolved gas in brine (Alberty, 1994) will be incorrect.

Filtrates in rocks

The effect of varying fluid types on rock velocity is shown in Figure 3. Velocities were first run room dry followed by 100% water saturation with pore pressure equal to 100 bars. Typical increases in compressional velocity are seen. After flooding with oil, velocities drop less than one percent. However, flooding with gas-charged (live) oil, drops velocity further. Thus, as a filtrate invades a gas zone, velocities could vary from original low values to the fast brine saturated case to intermediate values all depending on the filtrate type, distribution of free gas, and the amount of gas in solution. Even lower frequency acoustic logs (Homby et al., 1992) will measure some composite effect of these various saturation conditions.

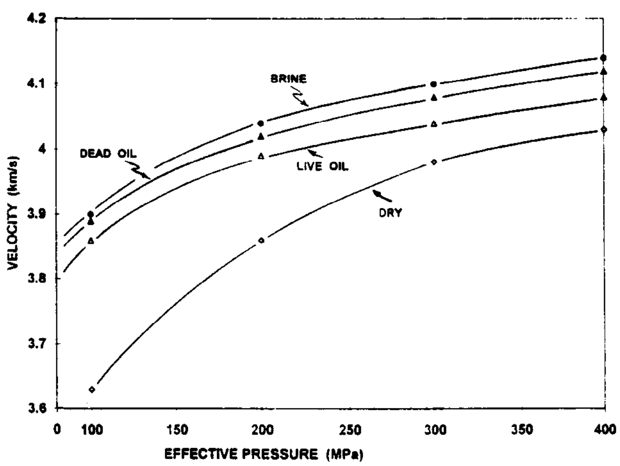

Figure 3. Compressional velocity in sandstone as a function of saturation by various fluids (filtrates).

Density

Changes in density can be more important than those in velocity. The greatest variations involve replacing a light gas with heavier liquid filtrate. At a given location, density is a simple arithmatic sum of the component densities. In a 30 percent porosity rock, for example, brine replacing gas can increase bulk density by more than ten percent. This change, coupled with an increase in velocity, produce a substantial change in the seismic impedance.

Amplitudes

It has been shown recently that compressional velocities at high frequencies are often insensitive to partial saturation. (Gist, 1995, Cadoret et al., 1995, Enders and Knight, 1997). This would cause errors in comparing sonic logs to seismic data. However, wave amplitudes show pronounced effects due to partial saturation even at ultrasonic frequencies (Figure 4).

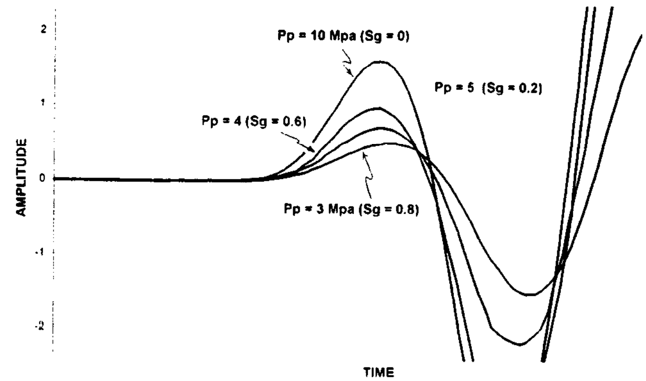

Figure 4. Waveforms recorded at ultrasonic frequencies as gas replaces liquid in the pore space. Velocities are insensitive but amplitudes change by as much as 60 percent.

Full-waveform sonic amplitudes could be used as a saturation indicator. Inhomogeneities in the gas saturation permit fast travel paths and maintain high acoustic velocities. Amplitudes will be a summation of different paths and will record variations in overall gas saturation. Amplitudes shown in Figure 4 systematically decrease as gas content increases. For threshold picking techniques, gas zones are characterized by cycle skipping due to reduced amplitudes.

Application to logs

As an example of the calculated changes required in modeling a hydrocarbon zone, for an invaded sands we substituted gas for brine. Figure 5 shows a set of logs in a Gulf of Mexico well drilled with low salinity water-based mud. Sandy zones (low SH) have the typical decrease in deep induction versus shallow resistivity tool. Movable pore fluid volume must be calculated from the induction and shale curves before fluid substitution. The results of

Figure 3 were used to guide velocity changes and densities were calculated assuming a 20 percent irreducible brine saturation. Resulting changes in impedance (IMPG) are large and driven primarily by the density change.

CONCLUSIONS

The invasion process is complicated and mud filtrate can have a large effect on log derived seismic or reservoir properties. Realistic filtrate properties need to be understood and applied. Standard sonic logs may not record flushed zone properties. Sonic amplitudes can be a more sensitive tool to asses degree of invasion.

ACKNOWLEDGMENTS

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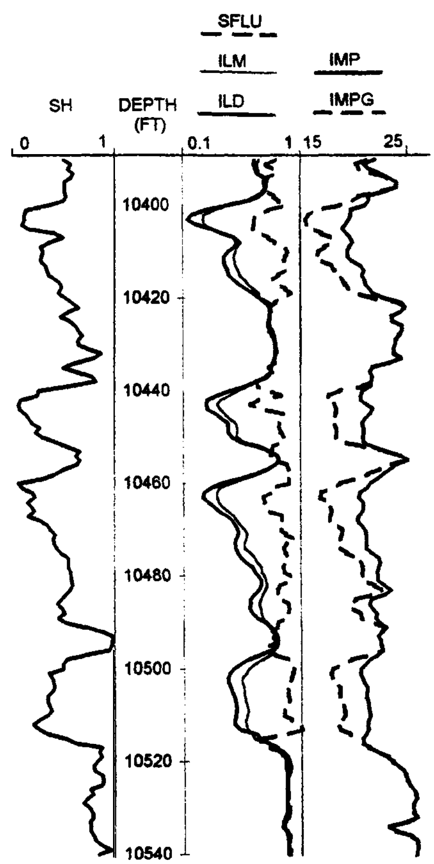

Figure 5. Logs from a Gulf of Mexico well used for hydrocarbon substitution. SH is shaliness derived from gamma ray, SFLU, ILM, and ILD are the shallow, intermediate and deep electric logs respectively, IMP is the seismic impedance from measured logs (velocity * density), and IMPG is the calculated gas zone impedance.