Velocity of P- and S-Waves in Arab-D and WCSB Carbonates

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Summary

Understanding the effects of porosity, pore type, saturation and pressure in the acoustic properties of reservoir rock is essential in order to adequately interpret seismic reflection amplitudes and amplitude versus offset responses. Most studies, to understand these effects, have been performed on sandstones. However, the same models are generally felt to be not applicable to carbonate rocks.

In this study we have measured the compressional and shear velocities for several carbonate samples in both dry and saturated conditions under different pressures. The samples show general increase in velocities with increasing pressure. Samples with low porosity show less velocity variation with pressure increase. The dry comprssional velocities increased with water saturation whereas the dry shear velocities decreased in the porous samples. This observation is in accordance with Gassmann's theory.

Introduction

The fact that many of the giant hydrocarbon reservoirs, such as Ghawar field in Saudi Arabia and the Grosmont in Alberta, are carbonates make carbonate rocks very important research topics. Many studies were conducted and added to our understanding of the cause of velocity variation in siliciclastic rocks compared with carbonates where few studies were made. Anselmetti and Eberli (1993) have shown that the influence of mineral compositions in carbonates is minimal, and cannot be a reason for large changes in velocities. They found that the velocity variations in carbonates is mainly controlled by porosity and pore type. Assefa et al. (2003) showed that the velocites of rocks with high aspect ratio pores are greater than those with low aspect ratio.

In this study, we are investigating the effect of pressure, porosity, permeability and saturation in carbonate rock. To date, we have measured the ultrasonic compresional and shear wave velocities for eight carbonate rocks, six of them are from Arad-D reservior in Saudi Arabia and two of the samples are from Western Canadian Sedimentary Basin (WCSB). The samples were measured both in dry and water saturated conditions under different confining pressures that varied from 2.5 MPa to 25 MPa for Arab-D samples and from 5 MPa to 70 MPa for WCB samples. In order to study the effect of microcracks closure, one Arab-D and one of WCB samples were measured at confining pressure of 40 MPa and 90 MPa respectivily. Higher confining pressures run the risk of damaging the samples.

Some preliminary results from P and S wave velocity measurements on several samples under dry and water saturation conditions are presented. These measured results and the calculated water saturated velocities from Gassmmann's equation are compared.

Sample Preparation

The samples used for the velocity measurements are cylindrically shaped plugs of 2.54 cm in diameter and 2 to 6 cm in lengths. The plugs end faces were ground to parallel (within ± 0.02 mm) in order to enhance the signal transmission. Then the samples were dried under vacuum at 70^{o}C temperature for 48 hours and afterward kept in a desiccator.

Measurement Technique

An ultrasonic pulse transmission technique (Molyneux and Schmitt 1999) was used to determine compressional and shear wave velocities. The experimental setup (Figure 1) consists of a pulse generator, pressure vessel and a digital oscilloscope (Gagescope™). Longitudinally and transversely polarized piezoelectric ceramics were used to convert an electrical pulse generated from pulse generator into compressional and shear waves respectively. The generated wave propagated through the sample and was recorded by a digital oscilloscope in 8 nanoseconds time interval. The final wave form is the stack of 256 traces to reduce random noise. The confining pressure system utilized can measure velocities under pressures of up to 200 MPa; in this study, measurements were made in a peak pressure of 90 MPa. Pore pressure system is used to simulate pressure changes in reservoirs.

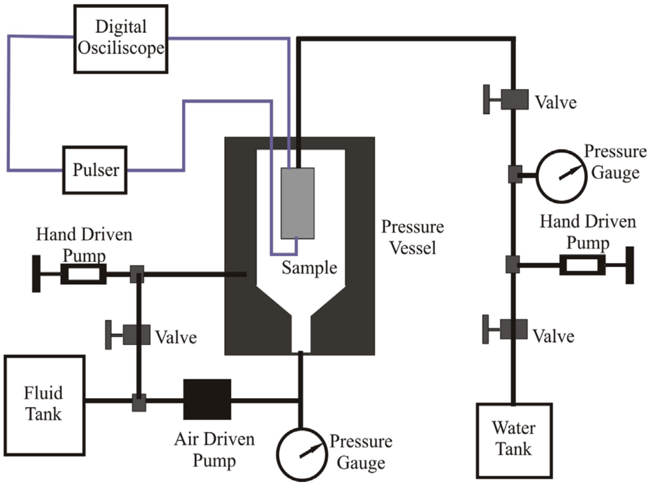

Figure1: The experimental configuration mainly consists of the confining pressure system, pore pressure system and the signal acquisition system. From He (2006)

Results and Examples

Waveforms Example: The full set of normalized P- and S- wave waveforms of sample 3-104 from Arab-D and sample B from WCSB are given in figure 2. The Samples are pressurized to the peak pressure of 40 MPa and 70 MPa respectively. Obviously, due to the lack of closing microcracks and pores in the sample B, the travel times show slight changes with the confining pressure.

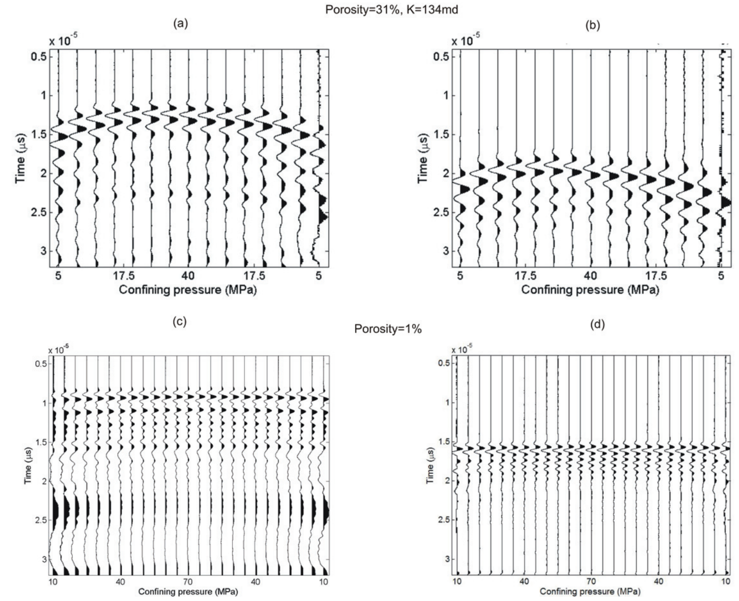

Figure 2: Normalized P- (a) and S- (b) wave waveforms for sample 256-104 from Arab-D reservoir and P-(c) and S-(d) of sample B from WCSB at different confining pressure.

Changes in P- and S-wave velocities with pressure: Figure 3 shows the effect of pressure on compressional and shear wave velocities for the same samples. Both samples show general increase in velocity with pressure increase. The tight sample shows less velocity variability with pressure than the porous sample; this is due to the lack of microcracks and pores in the tight sample. Both samples show that the velocities readings taken during pressurization cycle are slightly lower than the velocities taken during the depressurization cycle. This is due to the fact that during depressurization the closed microcracks and pores start to reopen once the pressure drops beyond the critical pressure that caused their initial closure. Sample 256-104 shows an increase in velocities with pressure but at pressure of 30 MPa the velocities start to decrease. This decrease is the result of crushing damage to the sample.

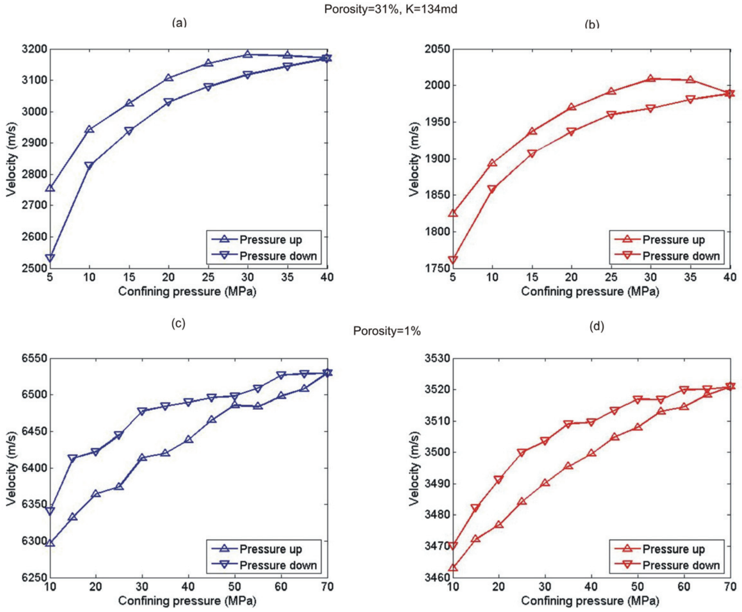

Figure 3: The P- (a) and S- (b) wave velocities of sample 3-104 from Arab-D reservoir and P- (c) and S- (d) of sample B from WCSB at different confining pressure.

Effect of saturation on velocity: The effect of water saturation on compressional and shear velocities on an Arab-D sample is shown in figure 4. The comprssional velocity increased with saturation whereas the shear velocity decreased. This observation is in accordance with Gassmann's theory.

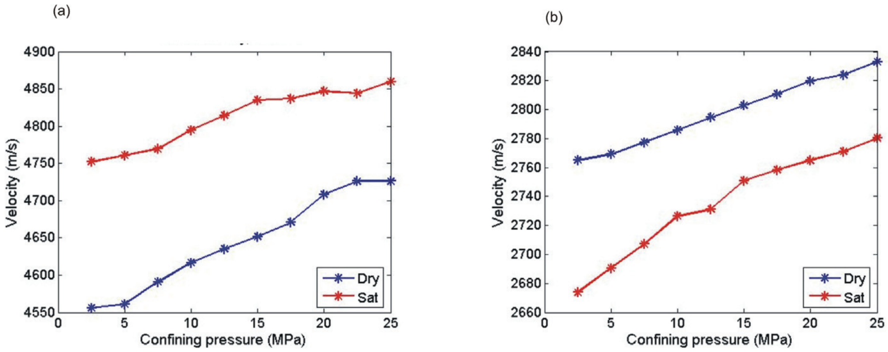

Figure 4: The P- (a) and S- (b) velocities of dry and water saturated of sample 7-16 from Arab-D carbonate as function of pressure.

Conclusions

The samples show a general increase in comprissional and shear velocityies with pressure. The tight sample shows less velocity variability with pressure than the porous sample. The observed increase in compressional velocities and decrease of shear velocities with saturation is in agrement with Gassmann's theory.

Acknowledgements

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