ATTENUATION CHARACTERISTICS OF SAUDI ARABIAN RESERVOIR SANDSTONE AND LIMESTONE CORES

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INTRODUCTION

Lithology, porosity, permeability, pore fluids, and effective pressure are some of the important criteria for reservoir characterization. These parameters significantly affect the seismic signature of a reservoir. Thus, establishing correlations between seismic properties on one hand, and lithology, porosity, permeability, and stress on the other, will increase the reliability of reservoir property predictions from seismic measurements. Another advantage of seismic attributes is that they are much easier to measure in-situ than the above mentioned reservoir properties, and since such measurements are noninvasive, an observed correlation between them could also prove useful as an important exploration tool for oil and gas reservoirs.

In recent years, with the improvement in borehole sonic sources and receivers, full waveforms are being recorded and processed at the rig site itself. Enough expertise is gained to accurately compute the attenuation quality factors from the full waveforms recorded in the laboratory and borehole sonics. In this paper attenuation quality factors of several Saudi Arabian reservoir sandstone and limestone cores are computed and possible correlation between quality factors and reservoir properties like porosity, permeability, velocities, and wetting state are studied.

OBJECTIVE

The objective of this paper is to study the pressure dependent behavior of quality factor and to discuss the possible correlation of the seismic attributes like attenuation to the more relevant reservoir characterization properties like porosity, permeability, velocity, and saturation. It has been observed that quality factor Q does not have a good correlation with either porosity or permeability (Best et al., 1994 and Assefa et al., 1999). Hence, in this paper another term, the ratio of P-wave quality factor (Qp) to S-wave quality factor (Qs) is shown to have better correlation with porosity and permeability.

LABORATORY MEASUREMENTS

A total of twenty sandstone and limestone reservoir cores have been tested for porosity, permeability, P- and S-wave velocities and quality factors under dry and water saturated conditions. The dried cores were flushed with air, therefore in effect, dry core samples are air saturated dry rocks. Nine simultaneous P- and S-wave measurements were made in the pressure range of 0 – 82 MPa. The dry and water saturated P- and S-wave velocities and quality factors were measured on the same core sample. First the measurements on dry core were completed, the core sample was then fully saturated with water and then the P- and S-wave velocities and quality factors were measured on the water saturated core

sample under the same confining pressure conditions. Simultaneous Porosity and Permeability measurements in the same pressure range were made on a different sister sample from the same depth.

The full wave broadband ultrasonic waves used in this study had a central frequency of 700 KHz. The attenuation quality factors were calculated using spectral ratio method (Toksoz et al., 1979). Correction for diffraction loss due to the finite size of the transducer and the non-planar wavefronts (Papadakis, 1968) were applied using tabulated data of Benson and Kiyohara (1974).

To validate the calculation and diffraction correction procedure for the quality factors, Q, some experiments were performed on French Gres' des Vesges sandstone samples and the results were compared to those available in the literature (Lucet, 1989). Geological description of the Gres' des Vesges sandstone is also given in Lucet, 1989. Table 1 gives the P- and S-wave quality factor, Q, of the Gres' des Vesges sandstone samples where it is observed that the calculated and published results compare favorably.

RESULTS AND DISCUSSION
Figure 1 shows the behavior of quality factors with confining pressure. It is observed that quality factor Q increases with stress. Since quality factor is inversely proportional to attenuation, this implies that the attenuation decreases with increase in confining pressure (Tao et al., 1995 and Best, 1997). Similar affect of confining pressure is observed on P- and S-wave quality factors under both dry and saturated conditions. In Tao et al. (1995) it is suggested that the rate of increase in Q with pressure depends on the pore structure of the rock.

Several investigators (Assefa et al., 1999; Best et al., 1994 and Klimentos and McCann, 1990) have reported that, in general, attenuation increases with porosity and permeability but the correlation is very weak with a large scatter in the data. Similar weak correlations were observed between quality factor, porosity and permeability for this dataset also. Hence a new parameter, the ratio of Qp to Qs, is correlated to porosity, permeability, and Vp/Vs in this paper. It is observed in figures 2 and 3 that the ratio of P-wave to S-wave quality factor gives a better correlation with reservoir hydraulic properties like porosity and permeability. Qp/Qs is better correlated to permeability than to porosity. Considering the importance of permeability and the difficulty in predicting it in-situ from the available techniques, the authors believe that this correlation is very promising. It may be noted that in figures 2 and 3, the Qp/Qs versus porosity and permeability are plotted at in-situ conditions.

In figure 4, the P-wave quality factors of dry cores are plotted against those of water saturated cores at in-situ conditions. It is observed that Qp of dry rocks is greater that that of water saturated rocks. This confirms the results presented by Klimentos (1995) and Tao et al. (1995). In figure 5, the Qp versus Qs of the sandstone and limestone reservoir core samples at different saturation conditions is plotted. It is observed that Qp is greater than Qs for all the samples except for dry sandstones. It confirms that Qp/Qs < 1 for gas saturated sandstone as reported by Klimentos (1995). For limestones and water saturated sandstone Qp/Qs ≥ 1.

Klimentos (1995) reported that a plot of Qp/Qs versus Vp/Vs distinguishes between oil and water via Vp/Vs ratio and also eliminates the possibility of the hydrocarbon being detected as gas via Qp/Qs since Qp>Qs in hydrocarbon zone. Thus combining Qp/Qs and Vp/Vs may help differentiate between gas, oil, and water. Figure 6 gives a plot of Qp/Qs versus Vp/Vs at in-situ conditions for the reservoir cores studied in this paper. It is observed that Qp/Qs ratio shows significant difference for dry and water saturated sandstones. Difference in saturations of limestones could not be distinguished on the basis of Qp/Qs ratio alone. However, this difference can be pointed out using Vp/Vs ratio.

CONCLUSIONS
- A new parameter, the ratio of P-wave to S-wave quality factors Qp/Qs gives a good correlation to porosity and permeability.
- The results presented in this paper confirm the previously published results in literature.
- In most of the studies reported in literature, outcrop rocks with emphasis on sandstone were used. Whereas in this paper sandstone and limestone reservoir cores are used. Therefore correlations developed using outcrop samples give a good estimate of reservoir rock properties.

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Tao, G., M. S. King, and M. Nabi-Bidhendi (1995). Ultrasonic wave propagation in dry and brine-saturated sandstones as a function of effective stress: laboratory measurements and modeling. *Geophysical Prospecting*, v. 43, p. 299-327.

Toksoz, M. N., D. H. Johnston, and A. Timur (1979). Attenuation of seismic waves in dry and saturated rocks. I. Laboratory measurements. *Geophysics*, v. 44, p. 681-690.

Table 1. Comparison of quality factors Q for French sandstone Gres' des Vesges.

Effective Confining Pressure (MPa)	Q_p		Q_s	
	Present Calculation	Lucet (1989)	Present Calculation	Lucet (1989)
5	18	17	-	8
10	22	23	14	11
20	29	31	15	12

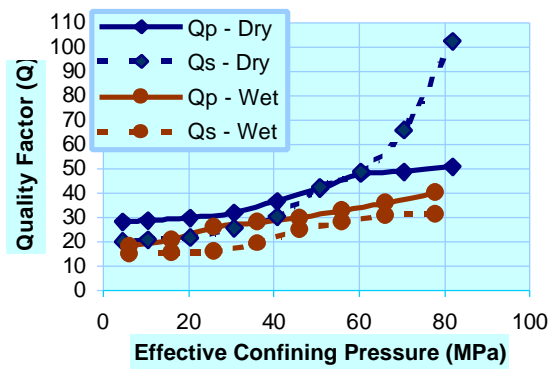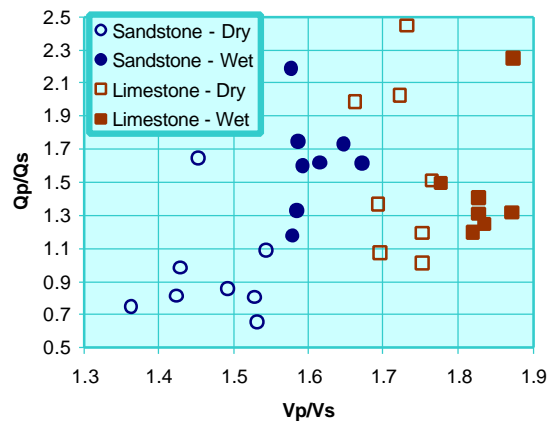**Figure 1**: Q versus confining pressure of a representative rock sample.
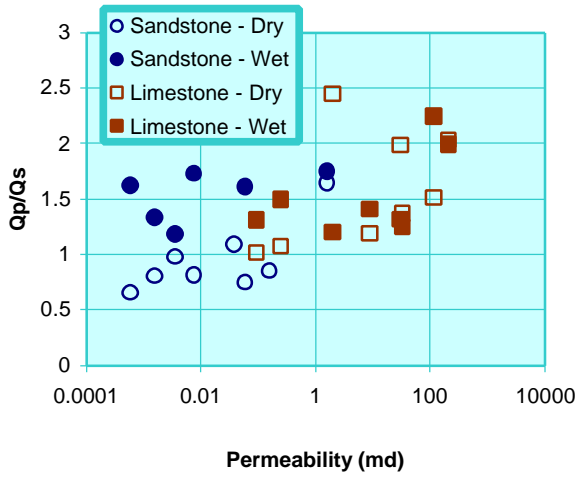

Figure 2: Qp/Qs versus porosity.

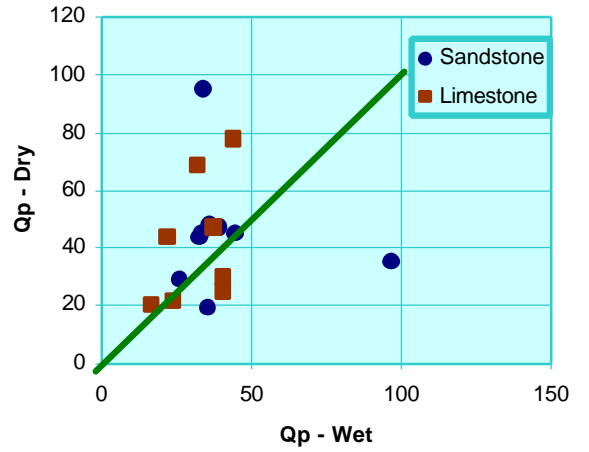**Figure 3:** Qp/Qs versus permeability.

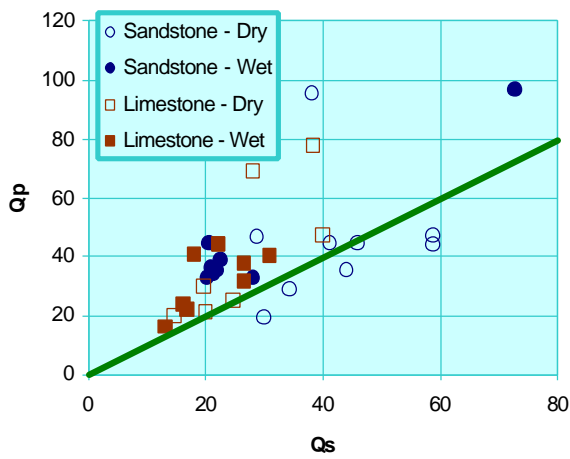**Figure 4:** P-wave quality factor for dry and water saturated rock samples.

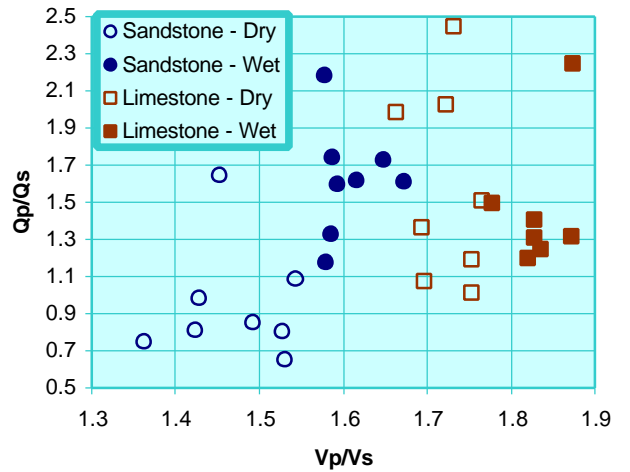**Figure 5:** P-wave versus S-wave quality factors.

Figure 6: Qp/Qs versus Vp/Vs ratio for the Saudi Arabian reservoir rock cores.