GEOLOGICAL FORMATION CHARACTERISATION BY ACOUSTIC WAVES

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For many years, the transmission of a sonic wave through formations has been used for drilling measurements. The tools used are of monopole or dipole type. Monopole-type tools are the most commonly used. Sources and receivers are multidirectional. In the fluid, sources generate a compression wave which creates in the formation a compression wave (P wave) and a shear wave (S wave) at the refraction limit angles. In a vertical well, such tools permit the recording of five propagation modes: the refracted compression wave, the refracted shear wave (only in fast formations), the fluid wave, two dispersive guided modes which are the pseudo Rayleigh waves (only in fast formations) and the Stoneley waves. Full waveform acoustic measurements are represented as constant-offset sections or as common source point gathers, similar to those used in seismic operations. For the different modes, the acoustic parameters which are usually measured are: picked time, amplitude and frequency. The acoustic parameters allow one to determine the propagation velocities of the various modes and some petro-physical parameters and to obtain lithologic and mechanical information if the shear velocity of the formation has been measured. Usually the picking of the refracted S wave is difficult due to the interferences of different wave trains such as leaky modes associated with the refracted P waves and the pseudo Rayleigh. To compute a continuous log of shear velocity, we propose an hybrid method based on the local measurement of the shear velocity (picking of the arrival time of the refracted S wave) and on the analysis of the dispersion curve of the Stoneley modes (Biot 1956, White 1965) . We also show the benefit of using a shape index parameter named Ic, computed from the amplitudes (A1, A2 and A3) of the first refracted P wave to detect acoustic anomalies specially in fractured formation. The Ic parameter is independent of the energy of the source. It is given by the following relationship: Ic = (A2 + A3) / A1. We present two field examples.

The results obtained with the first acoustic data set are presented in figure 1 (a, b, c, d). Figure 1 shows a constant offset section in the 330 – 390 m depth interval (a), the P velocity log with its associated standard deviation (b). The Std is used to estimate the uncertainties associated with the log. Figure also shows the amplitude log and the shape index log Ic (c), the S velocity log computed by the hybrid method and the Poisson's ratio log (d). Poisson's ratio log points out an anomalic zone at a depth of 343 - 347 m associated with a strong Ic anomaly, a decrease of the amplitude of refracted P wave. The Ic index has detected a thin shaly layer with a large change in the borehole diameter. The strong change in the signal shape is introduced by the interference between the refracted P wave and the reflected refracted P wave at the level of the shaly layer. The interference leads to an increase of the std associated with the velocity log (V_P).

The shape index is used here to detect wave interferences. The phenomena occur in presence of fractures. A second example shown in Figure 1 (e, f) illustrates that point. The acoustic data have been recorded in a well drilled in a fractured granite formation. The processing and the analysis of the data have been described in detail by Mari et al . (1996). Figure 1 (e, f) shows a constant offset section, the picked times and the amplitudes associated with the 3 first phases of the refracted P wave which are used to compute the shape index. The acoustic results are compared with those obtained by the fracturing analysis done on cores (fracture Index). The synthesis of these observations demonstrated the importance of acoustic coring for the identification of potentially circulating structures and for assessing their productivity.

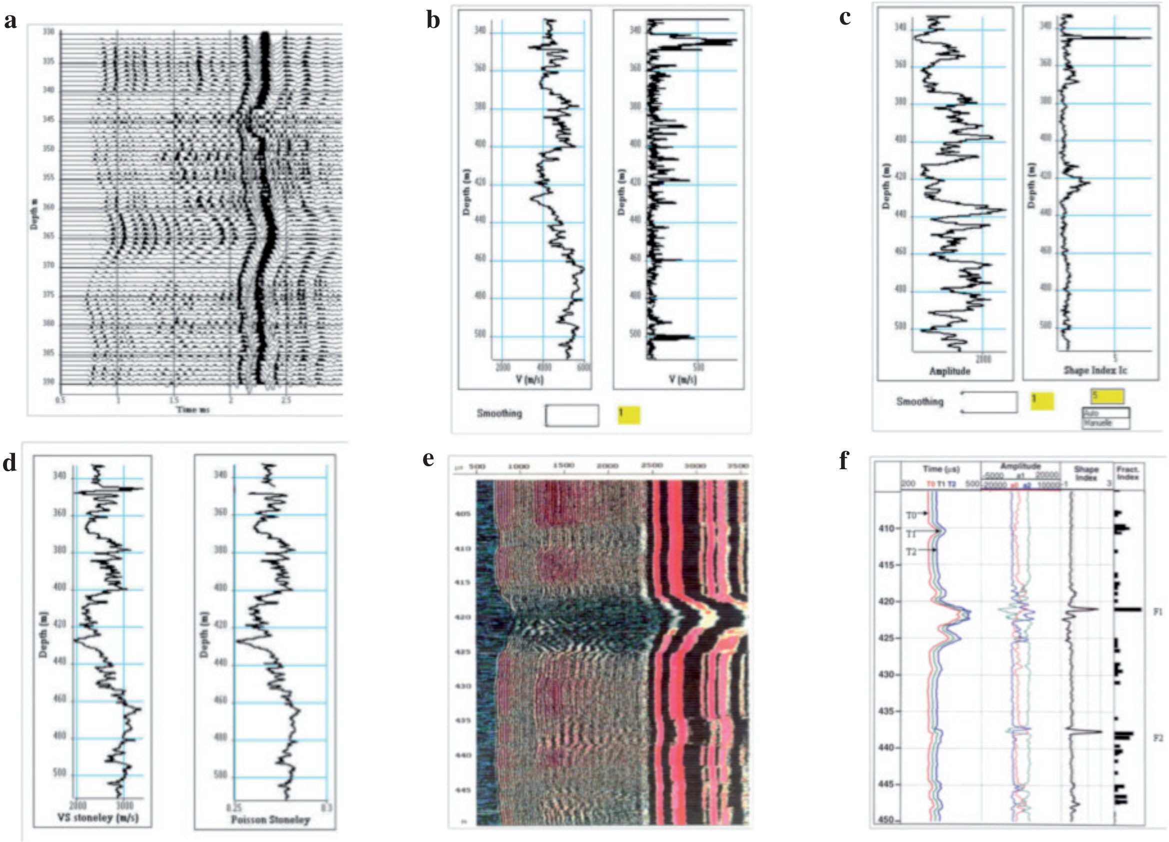

Figure 1: Acoustic logging and acoustic parameters (Courtesy of Andra)
First example : constant offset section (a), velocity log and its Std (b), amplitude log and Shape Index (c), VS and Poisson 's ratio from VS stoneley (d)
Second example : acoustic section , note the acoustic anomaly in the 420-425 m depth (e), acoustic logs (picked times, amplitude, Ic) and fracturing analysis (f).

The presented examples have shown that the full wave form acoustic logging allows a quantitative evaluation of the geological formation based on conventional logs (formation velocities, amplitudes, frequencies...) and their associated standard deviation (Std). To compute mechanical parameters such as Poisson's ratio log, the shear velocity of the formation must be estimated. For that purpose, a hybrid method (refracted wave and Stoneley waves) has been developed. Furthermore, it has also been shown that the dimensionless shape index Ic can be used as a qualitative acoustic attribute which detects the presence of interfering waves to locate fractured zones and anomalic zones.

References:

Biot, M.A., 1956. “Theory of propagation of elastic waves in a fluid-saturated porous solid”, The Journal of the Acoustical Society of America, Vol. 28, 2, pp. 168-191.

Mari, J.L., Delay, J., Gaudiani, P., Arens, G., 1996. Geological formation characterisation by Stoneley waves, European Journal of Environmental and Engineering Geophysics, 2, 1, 15-45.

White, J.E., 1965. “Seismic waves: Radiation, transmission and attenuation”, McGraw-Hill Book Compagny, New York.