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An Approach for Inverted Shear Acoustic Wave in Slow Formation: A comparison between LWD Quadrupole and Wireline Dipole data.

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Abstract Summary

Acoustic logs have been very important for petrophysical, geophysical and geomechanical modeling and interpretation in the oil and gas industry. Logging while drilling (LWD) acoustic technology has been developed to address the need for rig time saving and real-time applications such as wellbore stability and/or pore pressure prediction, seismic tie, seismic interpretation, as well as porosity and permeability determination.

Quadrupole acoustic measurement has been developed to obtain the shear wave slowness in the LWD slow formation environment. However, the quadrupole waves are dispersive and guided waves. Consequently, it is difficult to apply a dispersion correction in the shear wave to better represent a formation properly. For this reason, the data processing requires special attention to generate and correct the measured quadrupole-shear wave slowness.

This paper presents the results of processing the LWD shear wave slowness from quadrupole measured in slow formations and apply a novel dispersion correction. This LWD processed and corrected shear wave is compared with the shear wave obtained from dipole wireline data, defining intervals with the best and poor correlation. This approach allows to address and identify different limitations such as tool eccentricity, mud slowness and weight as well as formation vertical transverse isotropy.

Introduction

Despite the importance of the measurement of the compressional and shear wave slowness for petrophysical and geomechanical evaluation, or for geophysical applications, one of the main challenges in LWD is to measure the shear wave slowness from the monopole acoustic in slow formations.

In conventional wireline logging, in a slow formation where the shear slowness is greater than borehole fluid slowness, dipole acoustic logging tool are commonly used, which induces a flexural wave motion in the formation. At low frequency, the flexural wave travels at the formation shear slowness. This allows for direct measurement of formation shear slowness using dipole acoustic tool. Dipole acoustic wireline logging is a confident technology with worldwide commercial applications.

In the case of LWD, the shear slowness in a slow formation is commonly obtained from quadrupole, which is dispersive and need to be corrected by the dispersion effect. This dispersion correction is done by applying the slowness-frequency coherence (SFC) based on an inversion method that does not use the DTC from slowness-time coherency processing (STC).

This study shows the processed shear wave obtained from LWD quadrupole and corrected by a novel dispersion correction procedure, which improve the the reliability of the processed curve. The available data includes LWD and wireline acoustic information acquired in a sandstone formation, offshore Brazil. Wireline acquisition includes monopole and dipole information, which is usually used to obtain the shear wave slowness of the formation. The LWD shear wave slowness, obtained from quadrupole measurements is then compared with the wireline shear wave slowness obtained from dipole measurements. As dipole shear slowness is considered to be less dispersive and reliable, this comparison allows the validation of the dispersion correction applied to the processed LWD shear slowness.

Method and/or Theory

Measurement of acoustic wave propagation in the subsurface has been employed in seismic exploration for several decades. As seismic reflection data proved to be valuable in delineating subsurface structures, the need to convert seismic wave travel times in terms of depth increased. The idea of continuous velocity logging was originally conceived for this purpose but after acoustic log was found to be effective in the determination of porosity, lithology and detection of secondary porosity, it becomes one of the standard formation evaluation technologies.

In acoustic logging, longitudinal waves are referred to as compressional waves; while transverse waves are known as shear waves. The compressional wave, or p-wave, is one of the longitudinal type of elastic waves in the direction of propagation that is parallel to the direction of particle displacement. The displacement of a particle toward its neighbor in the direction away from the origin of the wave creates a compression zone in an elastic medium. The neighboring particle in turn moves toward the next one, thus, propagating the compression. After being displaced, each particle tends to return to its original position because the elasticity. In doing so, it overshoots its initial position and a zone of rarefaction is created. Thus, compressional waves consist of a compression and rarefaction traveling in a medium in the direction away from the source. Such waves can be transmitted through solids, liquids and gases, because there exists a resistance to compression in all three states of matter. A compression together with an adjacent rarefaction, preceding or following it, constitutes a complete cycle. The number of cycles propagating through a point in the medium in a unit time is the frequency.The shear wave, or s-wave, is a transverse waves. In such waves, the direction of propagation is perpendicular to the direction of particle displacement. Particles of a rigid medium undergo to-and-from motion around their mean position in a direction perpendicular to the direction on which the waves travel. Solid have the tendency to oppose shearing forces, which cause particles to slide relative to each other. Liquids and gases, on the other hand, do not possess any rigidity; therefore, shear waves cannot be transmitted through them.

The first arrival of the acoustic pulse at the receiver denotes the compressional wave, which has the highest velocity of all the different types of elastic waves. In general shear velocity is about 0.5 to 0.7 times the compressional wave velocity. Therefore, shear waves arrive at the receiver later than compressional waves. In the case of a slow formation, shear wave slowness can not be detected and the dipole and/or quadrupole should be used. Fig. 1 shows a generalized acoustic waveform signature in a slow formation.

Fig. 1. Generalized acoustic waveform in slow formation. Not shear wave detected.

In acoustic logging, a waveform is measured in each depth. This measurement is done for LWD and wireline. The available well log data includes gamma ray, resistivity, neutron porosity, bulk density, and acoustic from LWD readings. It is also included gamma ray and acoustic from wireline measurements. The acoustic data includes monopole and quadrupole for LWD and monopole and dipole for wireline operations. All this information was acquired in a sand-shale formation, which has a relative high slowness and is considered a slow formation.

Results

The LWD acoustic data was processed to obtain the compressional and shear slowness of the formation. Compressional and shear waves slowness were obtained from monopole and quadrupole respectivelly. The dispersion correction of this shear wave slowness was done by appying the slowness-frequency coherence (SFC) method that does not use the DTC from slowness-time coherency processing (STC).

The processed LWD shear slowness is compared with the shear wave obtained from wireline dipole data, to perform a quality control of the dispersion correction done in the LWD shear slowness. Fig. 2 shows the acoustic raw data for LWD and wireline and the results of the data processing.

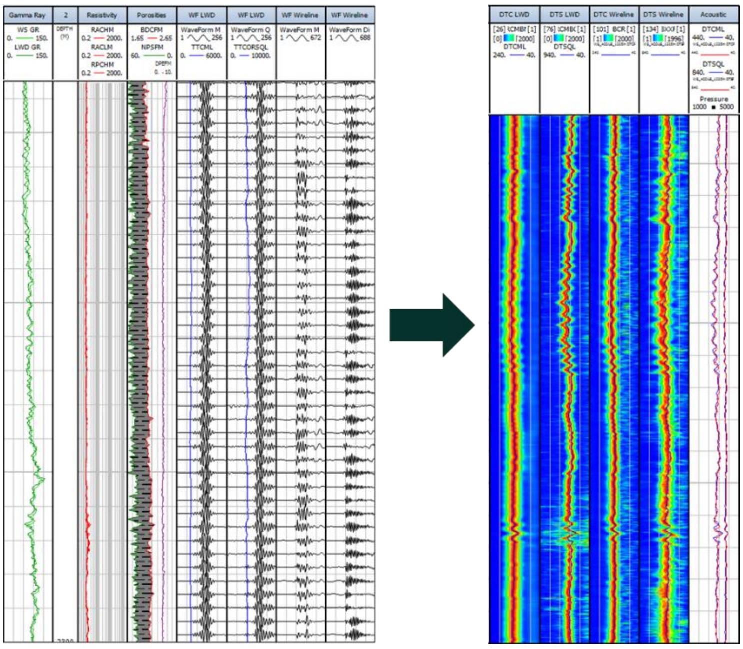

Fig. 2. a) Available well log data. First track gamma ray for LWD and wireline. LWD resistivity in second track. LWD density and neutron in the fourth track. Fifth and sixth tracks are the waveforms of LWD monopole and quadrupole. Seventh and eight track waveforms for wireline monopole and dipole. b) Acoustic processed data. First and second track are the processed LWD compresional and shear with their correlograms. Third and fourth tracks are the wireline compresional and shear slowness with their correlograms.

The comparison between LWD and wireline processed slowness is shown in Fig. 2b. It can be noticed a very good correlation between them. LWD curves are shown in blue and wireline ones in red. A crossplot between them can be done, which is shown in Fig. 3.

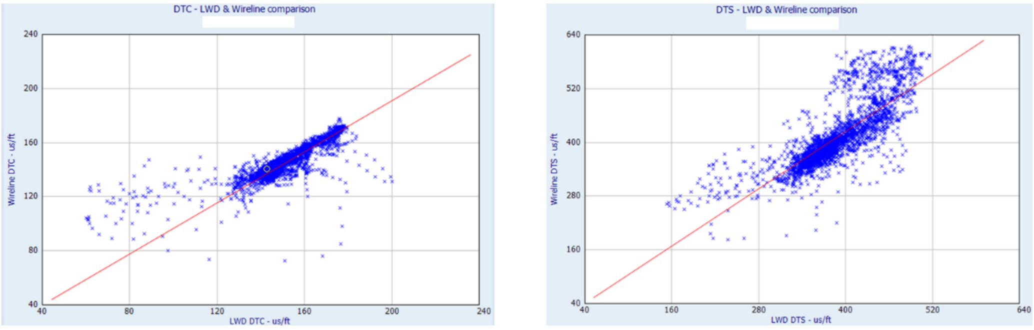

Fig. 3. Crossplot between LWD and wireline processed slowness. a) DTC. b) DTS.

The crossplot between both estimatives shows also a good correlation, indicating a good dispersion correction for the LWD shear slowness. It indicates that the correction can be applied and the dispersion effect be removed.

Conclusions

The proposed dispersion correction applying the slowness-frequency coherence (SFC) methodology is very effective to generate a LWD shear wave slowness that better represent the formation. It can be confirmed comparing the resultand LWD shear slowness with the shear slowness obtained from wireline technology.

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