Detection of fractures from image logs

In general, the term ‘fractures’ refers to all breaks or ruptures in rocks, whether they are accompanied by a displacement or not. They correspond to a surface along which there is loss of cohesion (Serra, 1986). Fractures may be closed (with crystalline material) or open. Clearly, it is the open fractures which are of interest from a production standpoint because they create permeability and enable a flow path for fluids. The open fractures are caused by tension or torsion, while the closed fractures are generally associated with compression. Often, the fracture openings are less than 0.1 mm, so that the fracture porosity is generally negligible (< 2%). Boyeldieu and Winchester (1982) estimated that if the fracture system is broken down into cubes with 10 cm edges, a gap of 1 mm would be necessary to create a porosity of 3%.

Fractures appear predominantly in brittle rocks, hence in consolidated formations. Very often they disappear on entering formations which are more plastic (clays) or friable (sands). In formations of low porosity and permeability, the production potential relies on an extensive system of open fractures. The productivity varies greatly according to the number, extent and opening of the fractures as well as the porosity and permeability of the matrix. The porosity of fractures is insignificant in all but some exceptional cases (highly compacted rocks) and makes no significant contribution to the reserves. However, the presence of fractures may significantly enhance drainage surface, and thereby the contribution of the matrix porosity to the production. Open fractures considerably increase the permeability but may cut the potential output of reservoir if they are not considered during the secondary recovery phase.

Two logging tools are capable of detecting fractures. These are the Sonic Scanner (acoustic tool which deals with the propagation and detection of compressional and shear waves) and Formation Micro Imager (FMI) tool (micro resistivity tool which deals with the detection of resistivity in azimuthal direction). In the Sonic Scanner tool two parameters can be used for fracture detection, the amplitude of received signal and its transit time. The amplitude of the signal is reduced due to the dispersion of energy at the edges of the fractures, while the transit time increases.

Fracture detection from acoustic logs

The travel time of a compressional wave is unaffected by fractures which do not cross the shortest time path. This is the case with subvertical (almost vertical) fractures which are parallel to the tool axis, and these are not detected by the sonic tool. The shear wave velocity on the other hand is more affected by fractures than the compressional velocity. Shear velocity seems to decrease while the compressional velocity remains constant. Thus, by comparing shear transit time ($\Delta t_s$) with the compressional transit time ($\Delta t_c$), possible fractured zones can be identified when $\Delta t_s$ increases, while $\Delta t_c$ remains constant. These measurements are made by the ‘Array Sonic’ tools.

The amplitude of an acoustic wave is decreased when it crosses fractures which happens because of transfer of energy. The fractures can also be detected with azimuthal acoustic anisotropy. The coefficient of transmission is a function of the apparent dip of the fracture relative to the direction of propagation. The inclination of the fracture is very crucial for the conversion of shear wave or compressional wave to fluid wave to cross the fracture. The anisotropy generated due to travel difference between transit time of fast shear and slow shear may be attributed to the presence of drilling induced fractures or natural fractures.
Figure 1 shows a field example of logs exhibiting anisotropy (Che et al., 2015). It can be observed that from depth 1295 m to 1307 m (green section), the slowness of the fast shear wave and slow shear wave have big differences (track 2); the phenomenon of splitting between the fast shear wave and slow shear wave is clearly observed in track 3; the computed anisotropy in track 4 also shows a high value, and the azimuth of anisotropy keeps stable and its value is about 120°. All the above indicate that this section is anisotropic.

![Figure 1: A field example of logs exhibiting anisotropy (After Che et al., 2015)](image)

Stoneley wave is a surface wave which travels along the interface of two media whether it is solid-solid or solid-liquid. The low frequency component of the Stoneley wave is known as tube wave, which is borehole fluid mode that propagates as a pressure wave along the borehole. The acoustic energy of the Stoneley wave is not lost through inefficient mode conversions, but more as a result of moving the fluid in fracture system, resulting in the pressure drop in the borehole. As a result, the direct Stoneley wave is attenuated and a reflected Stoneley wave is generated. Fast formation is formation where the velocity of compressional wave \((V_{P,\text{mud}})\) travelling through mud is less than the velocity of the shear wave \((V_{S,\text{formation}})\) travelling through the surrounding formation. Fast formations are brittle in nature and susceptible to generate fractures. In fast formations, where we generally look for fractures, Stoneley wave amplitude is much higher than the compressional and shear wave arrivals. The Stoneley wave travels through the interface and travel distance between transmitter and receiver is less than the compressional and shear wave. Hence less energy is attenuated on travelling the path (Figure 2).

The Stoneley wave, being mainly influenced by borehole fluids, does not react much to changes in lithology. Thus, detection of a strong Stoneley velocity reflection on the recorded waveform most likely indicates an open fracture.

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Figure 3 shows the identification of open natural fractures using Stoneley wave and shear wave. This template consists of 9 tracks. Track 1 shows gamma ray, caliper log and Stoneley fractures curves, track 2, shows quality index of anisotropy detection: min and max cross-energy of the signal recorded in directions orthogonal to inline emitted signal, and the space between the two curves shaded green. A small min-energy associated with a high max-energy is a reasonable indicator of the presence of S-wave anisotropy.

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Track 3 shows Variable Density Log (VDL) of fast shear wave, track 4 shows slowness projection of transit time of fast shear wave, and track 5 shows slowness frequency analysis of fast shear wave. Track 6 shows variable density log of slow shear wave, track 7 shows slowness projection of transit time of slow shear wave, and track 8 shows slowness frequency analysis of slow shear wave. Track 9 shows the resistivity image log with resistive to conductive scale from left to right with azimuth from 0 - 360°.

The fractures (conductive dark colour) shown in the resistivity log in track 9 are near vertical and they were originally interpreted to be drilling induced fractures. Stoneley wave measurements represented in track 1 (violet colour) made it clear that the fractures were open natural fractures and not drilling induced. Natural fractures exist with inclination relative to borehole axis and Stoneley waves reflect from inclined fractures, they do not reflect from fractures which are parallel to the borehole and drilling induced fractures are vertical fractures parallel to the borehole wall in 180° opposite pads.

Fracture detection with micro resistivity image log

Formation Micro Imager (FMI*) tool is a pad mounted micro device which measures the resistivity near the borehole wall. Pad-mounted micro devices only respond to fractures in front of the pad and show drop in resistivity. If the hole is ovalized because of fractures, the usual orientation of the tool will be with two of the four arms across the major axis, the other two being perpendicular. Thus, in compact, fractured formations, the two opposite pads which “see” the fractures, will show a drop in resistivity while the other pair will show a high resistivity with little or no curve activity. The presentation of the image is from resistive (light colour) to conductive (dark colour) shades in azimuth directions from 0-360 degree from left to right.

Figure 4 shows the resistivity image with dark colours being less resistive and light colours more resistive. The image A (Figure 4) shows a bed boundary green line from a horizontal well showing a dark conductive plane. The thick dark image above the green line shows conductive bed while light image below green line shows resistive bed. Image B shows two conductive fractures (thin dark colour lines) that are symmetrical and cross all the borehole circumferences. The two dark lines are in between the resistive bed which implies two open fractures filled with conductive borehole fluid. Image C shows partially conductive fracture which does not cross the entire wellbore image. Image D shows a mineralized fracture (light colour) trace that is brighter than the surrounding rock. This is a closed fracture filled with secondary mineral having high resistivity. Image E shows a microfault that is similar to the natural fracture (joint) in shape, but it has small displacement (< 2°). Image F shows a conductive drilling induced fractures (appear on opposite pads with almost parallel to borehole axis) cutting through many lithofacies. Image G shows breakouts (appearing on opposite pads with almost parallel to borehole axis) appearing as dark enlargements along the borehole pads.

References


* trademark of SLB

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Figure 4: Examples of fracture detection from micro resistivity image logs. (After Milad et al., 2018)

References (cont'd)


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