Fracture Detection and Imaging Using Three-Component Borehole Seismic Data

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Abstract

Loss circulation is a critical while-drilling challenge caused by uncontrolled flow of drilling fluids into formations. The risk of total circulation loss increases when drilling through highly fractured formations or across large-scale faults. Borehole seismic can be used as an efficient tool to detect and characterize such features as they have a quite distinct fingerprint on the seismic records. Zero-offset vertical-seismic-profiling (ZVSP) is often acquired post-drilling for checkshot profile reconstruction, and velocity model building and calibration. Three-component wireline geophones are installed inside the borehole and used to record the ignited wavefield at the surface. Fractures and fault tips act as point diffractors, which scatter the wavefield in all-directions. An offshore ZVSP has been acquired in a well, where multiple zones with potential fractures were drilled. Some fractures were predicted prior to drilling and drilling parameters such as mud weight and weight-on-bit were modified accordingly to prevent circulation loss. However, a total loss of circulation was unpredictable and a detailed three-component analysis of the ZVSP data demonstrated the presence of potential fractures. The tip of the fracture acted as a scattering point of the seismic energy and a secondary wavefield is ignited emanating from the diffraction point. Clear diffraction hyperbolas were noted after 3C rotations of the wavefield. Shear (SH and SV) waves emanating from the point source and propagating with the shear-wave velocity are recorded by the adjacent downhole geophones. We applied an elastic finite-difference modeling with different fracture distributions at the same formation to simulate the field gathers. Our results reveal that the field diffraction events recorded in the radial and transverse components can be potentially induced by a fracture mechanism with accurate estimates of the fracture infills, orientation, and size. We lastly applied least-squares migration to both the synthetic and field datasets to localize the fault plane in its accurate subsurface position. The migrated images demonstrated that imaging the borehole seismic wavefield is able to delineate the fracture plane that caused the total loss of circulation. We concluded that ZVSP analysis and fracture modeling of the radial and transverse components could potentially yield vital information about the loss circulation zones and the size of the fractures. It can also be an enabler to assess subsequent loss circulation curing and filling by acquiring 4D VSP datasets to analyze the diffraction patterns after treatment.