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Seismic Characterization of Fault Facies Models

Charlotte Botter (1), Nestor Cardozo (2), Dongfang Qu (3), Jan Tveranger (3), and Dmitriy Kolyukhin (4)

(1) University of Leeds, Faculty of Earth and Environment, Applied Geoscience, United Kingdom (c.d.botter@leeds.ac.uk), (2) University of Stavanger, Department of Petroleum Engineering, Norway, (3) CIPR, UniResearch, Bergen, Norway, (4) IPGG SB RAS, Novosibirsk, Russia

Faults play a key role in reservoirs by enhancing or restricting fluid flow. A fault zone can be divided in a core, accommodating most of the displacement, and a surrounding damage zone. In high porosity sandstone, the damage zone is often constituted of deformation bands, which are millimeter to centimeter thick zones of localized compaction. Seismic data is one of the main ways of investigation of the subsurface, but fault internal structure and properties are still at the limit of seismic resolution. In order to assess the feasibility of interpreting fault-related deformation directly from seismic data, we present an integrated workflow that studies the seismic response of a vertical fault zone in a homogeneous sandstone reservoir. The km-size fault zone is modeled as an ellipsoid with a maximum throw at its center of 100 m. The fault zone is populated using four fault facies based on deformation band distributions (from undeformed to high deformation). Deformation bands reduce the porosity of the sandstone and condition its elastic properties. We use a ray-based prestack depth migration (PSDM) simulator to generate synthetic seismic cubes under realistic conditions of seismic acquisition and reservoir burial, for several wave frequencies. The definition of the fault zone on the seismic images is highly dependent on the wave frequency, and for frequencies ranging between 10 and 60 Hz, direct interpretation is not possible. Seismic attributes, such as tensor (a measure of the dominant reflector's direction) and envelope (a measure of the instantaneous magnitude of the trace), can be fine-tuned to characterize the fault volume. Based on a combination of these attributes, we can subdivide the fault zone into four seismic facies from core (high deformation) to damage zone (lower deformation), even at low (10 Hz) wave frequencies. Statistical analyses show a correlation between the seismic attributes and the fault internal structure, although seismic facies, due to their coarser resolution, cannot be matched to the input fault facies. However, the seismic facies obtained by seismic attribute analysis can be used as spatial conditioning parameters for fault facies-based reservoir modeling. Although seismic-based probability trends are approximate, they represent direct 3D observations of specific subsurface fault zone properties, which may not be provided by outcrop analogues, and can be used to condition specific stochastic fault zone models.