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Seismic imaging of deformation zones associated with normal fault-related folding

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Folds associated with normal faulting, which are mainly the result of fault propagation and linkage of normal fault segments, can exhibit complex deformation patterns, with multiple synthetic splay faults, reverse faults and small antithetic Riedel structures accommodating flexure of the beds. Their identification is critical in evaluating connectivity of potential hydrocarbon reservoirs and sealing capacity of faults. Previous research showed that seismic attributes can be successfully used to image complex structures and deformation distribution in submarine thrust folds.

We use seismic trace and coherency attributes, a combination of instantaneous phase, tensor discontinuity and semblance attributes to identify deformation structures at the limit of seismic resolution, which accommodate seismic scale folding associated with normal faulting from Inner Moray Firth Basin, offshore Scotland. We identify synthetic splay faults and reverse faults adjacent to the master normal faults, which are localized in areas with highest fold amplitudes. This zone of small scale faulting is the widest in areas with highest fault throw / fold amplitude, or where a bend is present in the main fault surface.

We also explore the possibility that changes in elastic properties of the rocks due to deformation can contribute to amplitude reductions in the fault damage zones. We analyse a pre-stack time-migrated 3D seismic data-set, where seismic reflections corresponding to a regionally-continuous and homogeneous carbonate layer display a positive correlation between strain distribution and amplitude variations adjacent to the faults. Seismic amplitude values are homogeneously distributed within the undeformed area of the footwall, with a minimum deviation from a mean amplitude value calculated for each seismic line. Meanwhile, the amplitude dimming zone is more pronounced (negative deviation increases) and widens within the relay zone, where sub-seismic scale faults, which accommodate bed rotation, affect, presumably, the acoustic properties of the rocks. We calculate the strains associated with fault displacement (using elastic dislocation models) and generate a synthetic seismic section of the model, taking into account the strain-related changes in the acoustic properties of the deformed rocks. Finally, we investigate whether variations in the magnitudes of volumetric strain correlate with the magnitudes of seismic amplitude variations near the analysed faults.