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Determination of small-scale structures around faults using 3D kinematic retro-deformation - Examples from Permian strata in the NW German Basin

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When horizons are displaced by faults, the faults also actively deform the area surrounding it. Much of this small-scale deformation is below the resolution of reflection seismics (i.e. sub-seismic). The magnitude and spatial distribution of this small-scale deformation is mainly dependent on the variation in the morphology of the fault plane (in the direction of fault movement) and on the rate of change in fault-plane parallel displacement, rather than total displacement along the fault. By kinematically restoring faulted horizons in 3D to their pre-faulted state, the relative displacement of a horizon's nodes can be used to calculate the strain tensor for each node in the model, and hence the spatial distribution and magnitude of fault-displacement induced small-scale deformation.

We show examples of Permian Rotliegend faults, picked from a $10 \times 15\,\mathrm{km}^2$ 3D reflection seismic block situated within the North German Basin. The faulted Rotliegend aeolian and fluviatile sandstones form an onshore gas play, which lies at a depth greater than 4500 m.

We propose the eigenvalues of the modelled strain tensor, and thus the magnitude of the strain, are equivalent during retro- or forward deformation. From the strain eigenvector information we are able to predict the orientation of possible fracturing around the faults.

In one example of thrust faulting, where the along-strike fault displacement varies from $0 - 50\,\mathrm{m}$, 3D retro-deformation using the algorithm fault-parallel flow, shows that maximum strain in the hanging-wall is 15%, but the distribution is strongly heterogeneous. Consequently, the zone of strain ($> 2\%$) varies from 20–1000 m from the fault plane. The largest strain maxima occur where the along-strike displacement varies most. Furthermore, assuming extensional fractures are oriented perpendicular to the maximum (e_1) strain direction, we predict only 50% of fracture strike to be sub-parallel to the fault, otherwise fracture strike can locally diverge by up to 50^o from the fault plane. Two groups of fractures are predicted (steep N–S striking, and flatly south-dipping, E–W striking).