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Normal fault growth above pre-existing structures: insights from discrete element modelling

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In extensional systems, pre-existing structures such as shear zones may affect the growth, geometry and location of normal faults. Recent seismic reflection-based observations from the North Sea suggest that shear zones not only localise deformation in the host rock, but also in the overlying sedimentary succession. While pre-existing weaknesses are known to localise deformation in the host rock, their effect on deformation in the overlying succession is less well understood. Here, we use 3-D discrete element modelling to determine if and how kilometre-scale shear zones affect normal fault growth in the overlying succession.

Discrete element models use a large number of interacting particles to describe the dynamic evolution of complex systems. The technique has therefore been applied to describe fault and fracture growth in a variety of geological settings. We model normal faulting by extending a $60\times60\times30$ km crustal rift-basin model including brittle and ductile interactions and gravitation and isostatic forces by 30%. An inclined plane of weakness which represents a pre-existing shear zone is introduced in the lower section of the upper brittle layer at the start of the experiment. The length, width, orientation and dip of the weak zone are systematically varied between experiments to test how these parameters control the geometric and kinematic development of overlying normal fault systems.

Consistent with our seismic reflection-based observations, our results show that strain is indeed localised in and above these weak zones. In the lower brittle layer, normal faults nucleate, as expected, within the zone of weakness and control the initiation and propagation of neighbouring faults. Above this, normal faults nucleate throughout the overlying strata where their orientations are strongly influenced by the underlying zone of weakness. These results challenge the notion that overburden normal faults simply form due to reactivation and upwards propagation of pre-existing shear zones rooted in crystalline basement. Instead, the pre-existing shear zone appears to focus the stresses throughout the overlying succession, even leading to near surface fault nucleation. In summary, these results demonstrate that, as observations from natural rifts suggest, pre-existing shear zones can indeed focus normal faulting in the overlying succession.