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Conceptual and mechanical models for evolution of the three-dimensional structure of fault zones

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Faults are often simplified as planar structures but are, in reality, complex zones comprised of multiple slip surfaces that contain variably deformed rock volumes, ranging from intact fault bound lenses to fault rock (breccia, gouge). Whilst there is a general recognition that fault zone structure will vary depending on the nature of the faulted sequence and the prevailing deformation conditions, supporting empirical constraints on the 2D and, in particular, 3D geometry and content of fault zones are, however, relatively sparse. For example, insufficient data are available on fault zones developed within layered sequences, with different stacking patterns and mechanical properties, and under different deformation conditions. This shortcoming will only partly be alleviated by future detailed outcrop investigations of faults.

Existing conceptual models suggest that the generation of complex internal fault zone structure can often be explained by the repeated action of one of two processes, the linkage between initially unconnected fault segments and the removal of fault surface asperities. Such conceptual models are supported by observations from laboratory analogue and rock deformation experiments. However laboratory approaches can not be simultaneously applied to the appropriate lithology, deformation conditions and scale so that they provide only a limited means of studying controls on fault zone structure. Numerical modelling provides an alternative approach and the aim of this study was to use the Discrete Element Method (DEM), and in particular PFC3D, to investigate the impact of different rock mechanical properties, different sequences and confining pressures on the 3D geometry and evolution of fault zone internal structure.

The evolution of the fault zones in our numerical models demonstrates the main processes thought to cause the complexity of structure observed in natural fault zones and the model faults replicate a range of features observed in normal faults at outcrop; these include multi-stranded fault zones, relay zones, normal drag, asperities and corrugated fault surfaces. The structural features of the model faults and quantitative measures of fault zone structure vary systematically both with the properties of the faulted sequences and the applied confining pressure. Observed correlations between structure and model parameters can be reconciled with both geometrical and mechanical models of fault zone structure.

These DEM models, to our knowledge, represent the first time that the three dimensional internal structure of faults has been reproduced in numerical models. Systematic variation in the internal structure of model faults with both changes in the lithological sequence and confining pressure suggest that this type of modelling can provide a basis for evaluating the likely complexity of fault zone structure and associated sequence juxtapositions, which may be expected in different settings and its implications for fault-related flow in the subsurface.