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Digital acquisition of spatial heterogeneity and scaling of faults in sandstone

K.J.W. McCaffrey (1), G. Jiulin (1), R.R. Jones (2,3), R.E. Holdsworth (1) and D. Healy (4)

(1) Reactivation Research Group, Department of Earth Sciences, University of Durham, UK, (2) e-Science Research Institute, University of Durham, UK, (3) Geospatial Research Ltd., Department of Earth Sciences, University of Durham, UK, (4) Department of Earth & Ocean Sciences, University of Liverpool, UK (jiulin.guo@durham.ac.uk / Fax: +44 (0)191 334 2301 / Phone: +44 (0)191 334 2300)

Our study uses high-precision digital survey equipment to quantify the spatial distribution of fracture arrays seen in outcrop, and to test the relationship between sampling strategy and the granularity of heterogeneous fracture systems. We also compare the results of traditional methods of data sampling with those based on new digital survey methods.

A dense network of fault-related deformation bands were formed during Mesozoic rifting of Permian sandstones located near Appleby, Vale of Eden, Cumbria. More than 900 faults were observed in a south-facing cliff about 40 meters long and 3-4 meters high. The faults were first mapped manually using a compass/clinometer and tape measure, with measurements located on a mosaic of photographs. Subsequently, a georeferenced digital dataset was acquired using a high resolution terrestrial laser-scanner and differential GPS equipment with sub-centimetre precision.

Initial investigations suggest that the fault orientations represent a bulk bimodal point distribution that could be explained relatively simply, for example by an Andersonian conjugate fault model. However, when the dataset is subdivided into successively smaller sample lengths, the faults exhibit significant variations from the bulk spatial patterns. In particular, they show:-

1. Changes in symmetry with scale – at some scales the faults show polymodal clustering in orientation, no longer consistent with an Andersonian model;

2. Significant variations in mean fault orientation when measured at different scales (by up to 32° strike and 35° plunge);

3. Spatial variations in orientation clustering with scale, i.e. spatial heterogeneity.

From our digital dataset, we constructed a 3D model comprising a high-precision topographic surface with photo drape. In-house fracture picking software enabled us to fit a series of 3D planes to the fracture traces. We then used our field dataset to calibrate the model by comparing fitted orientations to measured orientations.

Our results clearly illustrate the inherent problems of granularity in natural systems.

In particular:-

1. Our ability to collect meaningful samples from systems that show significant variations with scale is hampered by an inability to define a representative elemental volume for such a system. This could be used to give the sampling scale to calibrate our digital data set.

2. The ability of traditional field analysis to resolve fine scale variation in data collected from natural systems is somewhat limited. Standard stereonet contouring algorithms seem particularly poor at resolving sub-clusters within point distributions.

3. The new range of high resolution digital acquisition tools allows rapid high resolution data capture in 3D. Ultimately the usefulness of this approach in producing quantitative data will be determined by our ability to define the underlying natural distributions and their spatial variation.