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Extensional strain in the upper crust - sampling deformation over 7 orders of magnitude

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Extension in the upper crust is largely accommodated by slip and opening on fractures, producing faults, joints and veins. This brittle deformation occurs over a wide range of scales from grain-scale processes up to major fault zones with kilometre displacements.

It is commonly assumed that populations of fractures follow fractal scaling relationships. Innumerable studies dealing with scaling laws support this assumption, but are mostly based on data covering only about two orders of magnitude of displacement, or combine data from different sources (different study areas, tectonic settings, lithologies, strains, etc). In many cases the mechanics of fracturing involves factors with differing length scales (e.g. unit thickness) that lead to normal or lognormal distributions. Numerical and analogue models also show that fracture populations may evolve from power-law to negative-exponential scaling as strain increases.

In this study we directly measure extension over 7 orders of magnitude instead of predicting size-distributions from restricted data-sets and then inferring strain. To do this we chose two localities in southwest England with long continuous cliff sections. High resolution stratigraphy allows us to determine fault-displacements accurately. Analysis of size-frequency distributions at each scale range reveals strong links between deformation mode and scaling properties. Mode I fractures (joints and veins) at the lower end of the scale range take up a rather constant strain, largely independent of their aperture. Faults at the other end of the scale range show a strong link between size and accommodated strain with the largest structures taking up most of the strain. The transition between Mode I and shear (Mode II/III) deformation is represented by small pull-apart structures (mixed Mode I/II/III), often developed as zones of damage

around larger faults. These mixed-mode structures show a slight dependence between accommodated strain and size of the structure. Faults account for about 90% of the total strain, the other 10% are about equally distributed over the vein and mixed mode scale ranges.

Comparison of the two study areas, with similar lithology but different strain, allows some initial interpretation of fracture population changes in relation to increasing extension. The low strain region around Kimmeridge Bay, Dorset, shows strain scaling close to power law with a slight kink at the transition from vein to fault-strain. The moderate to high strain region around Kilve, Bristol Channel reveals a more pronounced concentration of strain on larger faults. In both study areas small-scale deformation is mainly localised in the wall-rocks adjacent to faults. Faults are more continuously distributed over the entire region, although some localization of strain occurs, even at low extensions.

We will briefly discuss the implications of our study in the context of assessing strain deficits often encountered in estimations of basin extension and in the moment deficit from studies of earthquakes.