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Tectonic inheritance, reactivation and long term fault weakening processes

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This talk gives a geological review of weakening processes in faults and their long-term effect on reactivation and tectonic inheritance during crustal deformation. Examples will be drawn from the Atlantic margins, N America, Japan and the Alps.

Tectonic inheritance and reactivation are fundamentally controlled by the processes of stress concentration and shear localisation manifested at all scales in the continental lithosphere. Lithosphere-scale controls include crustal thickness, thermal age and the boundary conditions imposed by the causative plate tectonic processes during extension. At the other end of the scale range, grain-scale controls include local environmental controls (depth, stress, strain rate), rock composition, grainsize, fabric intensity and the presence of fluids or melt. Intermediate-scale geometric controls are largely related to the size, orientation and interconnectivity of pre-existing anisotropies. If reactivation of pre-existing structures occurs, it likely requires a combination of processes across all three scale ranges to be favourable. This can make the unequivocal recognition of inheritance and reactivation difficult.

Large (e.g. crustal-scale) pre-existing structures are especially important due to their ability to efficiently concentrate stress and localise strain. For big faults (San Andreas, Great Glen, Median Tectonic Line), detailed studies of the associated exposed fault rocks indicate that reactivation is linked to the development of strongly anisotropic phyllosilicate-rich fault rocks that are weak (e.g. friction coefficients as low as 0.2 or less) under a broad range of deformation conditions. In the case of pre-existing regional dyke swarms (S Atlantic, NW Scotland) – which may themselves track deep mantle fabrics at depth - multiple reactivation of dyke margins is widespread and may preclude reactivation of favourably oriented local basement fabrics.

In a majority of cases, pre-existing structures in the crust are significantly oblique ($<70°$) to far field stress orientations. As a result, even quite modest amounts of reactivation will inevitably lead to transtensional/transpressional strains involving variable components of strike-slip and extension or shortening. The occurrence of bulk non-coaxial, non-plane strain leads to strain partitioning and/or (non-Andersonian) multimodal fracturing where the deformation cannot be described or reconstructed in single 2D cross-sectional or map view. Further complications can arise due to repeated seismogenic rupturing of larger offset faults leading to local stress transfer and reactivation of widely distributed smaller pre-existing structures in the wall rocks (e.g. Adamello Massif, Alps).

The Atlantic margins demonstrate that pre-existing structures can influence deformation patterns across a range of scales, but such reactivation should never be assumed to be the norm. In many cases, the scales of faulting and displacement magnitudes associated with these reactivation events are modest compared to the regional-scale deformation of the margin. However, reactivation most certainly does influence the kilometre and smaller-scale complexity of faults, fractures and folds. It will therefore impact significantly on the development of geological architectures and their economic importance, e.g. location and nature of fluid channelways, trap geometries, reservoir performance, etc.