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Strain localization in ultramylonitic calcite marbles by dislocation creep-accommodated grain boundary sliding

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Strain localization in monomineralic rocks is often associated with brittle precursors, resulting in stress and strain concentration, followed by grain size reduction and activation of grain-size-sensitive deformation mechanisms such as diffusion creep, grain boundary sliding and cataclastic flow. The aforementioned mechanisms typically tend to produce a random crystallographic orientation or a decrease in intensity of a pre-existing texture. However, reports of fine grained polycrystalline materials showing a preferred crystallographic orientation indicate a need for subsequent grain re-organization by either static annealing or the activation of additional deformation mechanisms in conjunction with grain boundary sliding.

We present observations from an almost pure calcite marble layer from Syros Island (Cyclades, Greece) deformed in lower greenschist facies conditions. The presence of a crack (i.e. cross-cutting element) that rotated during shear resulted in the formation of a flanking structure. At the location of maximum displacement (120 cm) along the cross-cutting element, the marble is extremely fine grained (3 μm) leading to anticipation of deformation by grain-size-sensitive mechanisms. Detailed microstructural analysis of the highly strained (80 < gamma < 1000) calcite ultramylonite by optical microscopy, electron backscatter diffraction and scanning transmission electron microscopy show that recrystallization by bulging results in small, strain-free grains. The change in grain size appears to be concomitant with increased activity of independent grain boundary sliding as indicated by a random misorientation angle distribution. At the same time, dislocation multiplication through Frank-Read sources produces high mean dislocation density ($\sim$ 5x10^{13} m^{-2}) as well as a weak primary CPO; the latter all argue that grain boundary sliding was accommodated by dislocation activity.

Theoretical and experimental determined relationships (paleowattmeter, paleopiezometer, dislocation density) have been used to estimate the flow stress conditions. All of the applied relationships indicate differential stresses in a range between 80 and 200 MPa. Plotted in a deformation mechanism map for calcite, the data show that the ultramylonite was deformed at maximum strain rates of 10^{-9} s^{-1}. Our study shows that the switch from dominantly dislocation creep to grain boundary sliding accommodated by dislocation activity corresponds to strain softening and can be an important strain localization process in calcite rocks, even at high strain rate (10^{-9} s^{-1}) and low temperature (300 °C).