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Grain size reduction, fluid infiltration, and extreme weakening in the continental lower crust

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Knowledge of the rheology of the continental lower crust is essential when trying to model major geodynamic processes and to understand the mechanics and distribution of earthquakes at different depths in the lithosphere. However, whether the lower crust is mechanically strong or weak is still a debated issue, and convincing evidence for both, a weak and a strong lower crust has been shown. A key aspect in this controversy is the role of aqueous fluids, with anhydrous conditions typically invoked as the main reason for high strength of large parts of the granulite facies lower crust.

The Lofoten islands in northern Norway represent an outstanding natural laboratory to investigate the progressive microstructural and rheological evolution of localized shear zones exhumed from the continental lower crust. In the anhydrous mangerite-charnockite rocks from Lofoten, deformation is strongly localized along discrete ductile shear zones developed under upper amphibolite to granulite facies conditions (T=730° C, P=0.65 GPa).

Shear zone formation was associated with an extreme grain size reduction of the main minerals of the magmatic protolith (perthite + clinopyroxene). Grain size reduction occurred by fracturing and neocrystallization in perthites, and by fracturing and hydration reactions in pyroxene, which was replaced by amphibole + quartz + calcite. Recrystallized perthites and reaction products show fine grain size (20-30 μm), equant shape, dispersed phase distribution, and the lack of a crystallographic preferred orientation. These observations are consistent with diffusion creep as the dominant deformation mechanism in the shear zones. The occurrence of new phases (amphibole, quartz) in triple and quadruple junctions, as well as the concentration of fine quartz grains along bands with a C' orientation strongly suggest the concomitant operation of grain boundary sliding and cavitation during grain-size sensitive creep.

Bulk-rock chemical analysis indicates an increase in water content of about 1.00 wt% in the shear zone compared to the protolith, consistent with the evidence of hydration reactions in an otherwise anhydrous rock. Thermodynamic modeling predicts that a progressive increase in water content leads to a shift of the ΔG of the system towards progressively more negative values, representing a transition from metastability to equilibrium during hydration of the rock in the presence of H_2O under the estimated P, T conditions.

In conclusion, fracturing, fluid infiltration, and hydration reactions in the continental granulite lower crust promote the activation of grain size sensitive creep, resulting in mechanical weakening and in strain localization. Weakening, initiation of deformation, and strain localization in an anhydrous lower crust appear to be invariably triggered by fracturing and fluid infiltration.