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Strength evolution of the lower crust - examples from Northern Norway

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Large portions of the lower continental crust are exposed at the surface in the Seiland Igneous Province (SIP) and the Lofoten islands in Northern Norway. The largely undeformed magmatic rock suites are well suited for the study of deformation processes because deformation is mostly localized in shear zones.

The formation of strong lower crust is well documented in the SIP. During the intrusion of the mafic plutons the hosting paragneisses were contact metamorphosed at peak T of 930-960° C and P of 0.55-0.7 GPa. Contact metamorphism was associated with dehydration melting of biotite. Subsequent cooling of the intrusives was accompanied by shear deformation, responsible for the formation of mylonitic high-strain-horizons.

According to P-T-X pseudo-section modelling using synkinematic mineral assemblages and bulk rock chemistry, shear deformation in the studied samples occurred at T=760-820°C, P=0.85 GPa and in the presence of about 5 vol% of Kfs-rich residual melt. Consistently, Titanium-in-quartz geothermometry indicates 820° C as peak T (at 0.85 GPa) during shearing.

FTIR measurements on single quartz grains in mylonites indicate that they are essentially dry (average H2O content of 22 ppm). Quartz recrystallizes to a fine-grained aggregate (15 μm average grain size). The c-axis pole figures exhibit a strong peripheral maximum consistent with dislocation glide dominantly on the basal <a> slip system. According to the grain size piezometry for quartz, an average grain size of 15 μm yields differential stress of 80 MPa. The quartz should have deformed at strain rates of 10-6 to 10-10 s-1, if flow laws for wet dislocation creep are used. That appears unlikely, and, instead, we believe that the strength of quartz was very high due to dry conditions during deformation. Thus, there is evidence for the formation of substantial parts of dry lower crust by dehydration partial melting and removal of aqueous fluid in the form of melt. The resulting restitic crust is dry enough to be mechanically strong.

The Lofoten islands and the SIP show examples of localized shear zones in dry lower crustal magmatic rocks. Invariably, the deformation commenced by fracturing and/or formation of pseudotachylites. Pseudotachylites have subsequently been deformed as fine-grained aggregates with an ultramylonite fabric. Deformation temperatures have been determined to range between 650 to 800°C at pressures of 500 to 1200 MPa. The fracturing at high temperatures is evidence for the high strength of the dry lower crustal rocks.

The ultramylonites commonly show hydrated assemblages containing amphiboles. The fluid access is restricted to the shear zones and is interpreted to be facilitated by fracturing. The deformation mechanism is in all cases diffusion creep in very fine grained reaction products, which have nucleated in phase mixtures.

Microporosity measurements show a low porosity in amphibole-bearing cracks, indicating effective crack sealing by reactions with a positive ΔV. Porosity is higher in mixed-phase domains, consistent with dilatancy during grain boundary sliding. Pervasive reaction and deformation depends on further fluid infiltration, which will be facilitated by repeated fracturing and/or grain boundary sliding. Brittle deformation facilitating fluid access appears to be a necessary prerequisite for the weakening and viscous deformation of otherwise dry and strong lower crustal rocks.