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Evidence for a strong felsic lower crust during melt-assisted deformation

Luca Menegon (1), Pritam Nasipuri (1), Holger Stünitz (1), Erling Ravna (1), and Harald Behrens (2)
(1) Institutt for Geologi, Universitetet i Tromsø, Norway (luca.menegon@uit.no), (2) Institut für Mineralogie, Universität Hannover, Germany

The Seiland Igneous Province (Northern Norway) is a rift-related magmatic suite emplaced in the span from 570 to 520 Ma. The magmatic province comprises dominantly alkaline mafic and ultramafic intrusives. The high-grade paragneisses from the Øksfjord peninsula represent the country rock of a large portion of the Seiland Igneous Province.

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. The pre-intrusion mineral assemblage, consisting of Bt + Sill + Qtz ± Fsp, was transformed into Grt + Kfs + Qtz + H2O. The inclusions within the garnet and the peak metamorphic mineral assemblage suggest the reaction Bt + Sill + Qtz -> Grt + Kfs + melt. Subsequent cooling of the intrusives was accompanied by strong shear deformation, which formed a gneissic foliation, both in the mafic rocks and in the hosting paragneisses. Mylonitic high-strain-horizons along the gneissic foliation were the product of intense strain localization. Deformation occurred under granulite facies conditions and was probably related to the opening of the Iapetus Ocean.

According to P-T-X pseudo-section modelling using synkinematic mineral assemblages, shear deformation occurred during cooling from T>800° C to 760-780° C at P>0.6 GPa, and in the presence of small amounts of Kfs + Sill – rich residual melt. Little to no biotite is observed along the granulite facies foliation, most likely indicating H2O-deficient conditions during metamorphism and shearing. The granulite facies assemblage is well preserved in both the gneissic and mylonitic foliation, and no evidence for late stage retrogression has been observed.

SEM observations indicate that in the mylonitic paragneiss the melt fraction occurs as (1) sillimanite grains completely rimmed by thin (≤10 µm thick) Kfs films, (2) thin, elongated Kfs films along the foliation, and (3) small pockets of Kfs, preferentially on quartz triple junctions. Quartz grains (300-400 µm average grain size) in the paragneiss show undulatory extinction, bands of misorientation, formation of subgrains, and bulging of grain boundaries. In the mylonitic high-strain zones, quartz recrystallizes to a fine-grained aggregate (20 µm average grain size) showing a weak shape preferred orientation synthetically inclined with respect to the sense of shear. The c-axis pole figure exhibits a strong peripheral maximum consistent with dislocation glide dominantly on the basal <a> slip system. According to the grain size piezometer for quartz calibrated by Stipp & Tullis (2003), an average grain size of 20 µm yields differential stress in excess of 60 MPa.

In summary, despite the very high temperature conditions of deformation, quartz shows deformation microstructures, c-axis CPO, and grain size commonly attributed to low temperature crystal plasticity. The quartz in the Øksfjord mylonites should have deformed at strain rates which are just 1 or 2 orders slower than laboratory rates, 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. FTIR measurements on quartz single grains yield very low H2O contents, consistent with the petrography and thermodynamic modelling. Thus, strong dry quartz forms up to 70% of the Øksfjord paragneiss and most likely governed the rheology of this felsic rock. Therefore, our study presents evidence for substantial parts of strong, dry lower crust. In addition, it is indicated that small amounts of melt may not be sufficient to induce a dramatic weakening effect during deformation under water-deficient conditions.