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Brittle-viscous deformation cycles in the dry lower continental crust

Luca Menegon (1) and Giorgio Pennacchioni (2)

(1) Plymouth University, School of Geography, Earth and Environmental Sciences, Plymouth, United Kingdom (luca.menegon@plymouth.ac.uk), (2) University of Padua, Department of Geosciences, Padua, Italy

Many rheological models of the lithosphere (based on "strength envelopes") predict a weak aseismic lower crust below the strong brittle upper crust. An alternative view, based on the distribution of crustal seismicity, is that the lower crust could also be strong and seismic. It has been suggested that a strong, seismogenic lower crust results from the dry conditions of granulite facies rocks, which inhibit crystal plastic flow. This study investigates exhumed networks of shear zones from Nusfjord (Lofoten, northern Norway) to understand initiation and localization of viscous shearing in the dry lower crust.

In the study area, different sets of ultramylonitic shear zones are hosted in the massive coarse-grained anorthosite. Metamorphic conditions of 720 °C, 0.9 GPa have been estimated for ductile deformation using amphibole-plagioclase geothermobarometry. Field evidence indicates that ductile shearing exploited pseudotachylyte veins and the associated damage zone of extensive fracturing. Undeformed pseudotachylyte veins locally overprint mylonitic pseudotachylytes suggesting that frictional melting occurred at the same metamorphic conditions of mylonitization. The deep crustal origin of the pseudotachylytes is also indicated by (1) the presence of microlites of labradoritic plagioclase and clinopyroxene, and of dendritic garnet, and (2) the recrystallization of clinopyroxene in the damage zone flanking the pseudotachylyte veins. Therefore the association of pseudotachylytes and mylonites records brittle-viscous deformation cycles under lower crustal conditions.

The ultramylonites show phase mixing, fine grain size (5-20 μm) and equant shape of all minerals. Nucleation of amphibole in triple junctions and dilatant sites is common. EBSD analysis indicates that the minerals in the matrix are internally strain free and do not show a crystallographic preferred orientation. Taken together, these observations suggest that diffusion creep and grain boundary sliding were the main deformation mechanisms in the ultramylonites. Nucleation of hornblende indicates synkinematic fluid infiltration. Ongoing measurements of intracrystalline water content along gradients from the pristine anorthosite to the ultramylonite will shed light on the effect of water infiltration on the deformation mechanisms of plagioclase and clinopyroxene.

In summary, this study indicates that brittle (coseismic) fracturing was essential to induce grain size reduction and fluid infiltration in the dry and strong lower crust. These processes promoted weakening by activating grain size sensitive creep in the fine-grained hydrated material and resulted in the ductile shear zones localized to the brittle precursors. In the absence of intense fracturing dry granulites would not undergo deformation and metamorphism, and would survive metastably in the course of Wilson cycles. This has obvious implications for long-term continental dynamics and for strain localization at plate boundaries, and will need to be included in future geodynamic models.