Geophysical Research Abstracts
Vol. 19, EGU2017-7502, 2017
EGU General Assembly 2017

Protracted weakening during lower crustal shearing along an extensional shear zone

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This study investigates grain-scale deformation mechanisms in the mafic lower continental crust, with particular focus on the role of syn-kinematic metamorphic reactions and their product – symplectites – in promoting grain size reduction, phase mixing and thus strain localization. The investigated extensional shear zone is hosted in the Finero mafic-ultramafic complex in the Italian Southern Alps.

Field and microstructural observations indicate that strain partitioned in gabbroic layers where the primary mineralogical assemblage contained amphibole, forming ultramylonites. These ultramylonites are characterized by isolated porphyroclasts of amphibole, garnet, clinopyroxene and orthopyroxene, embedded in a matrix of plagioclase (ca. 39 vol%) + amphibole (25 vol%) + clinopyroxene (18 vol%) + orthopyroxene (11 vol%) + Fe-Ti oxides (6 vol%) $\pm$ apatite ($<$1 vol%). Matrix grain-size is consistently below 30 μm for all phases.

EBSD results are consistent with deformation by grain-size sensitive creep. Amphibole shows a CPO with [001] axes preferentially aligned parallel to the stretching lineation, which we interpret as oriented grain growth during heterogeneous nucleation of amphibole. Pyroxenes and plagioclase lack a CPO and evidence for dislocation creep and dynamic recrystallization. Protracted shearing was initiated by syn-kinematic metamorphic reactions: garnet porphyroclasts formed orthopyroxene + plagioclase symplectites and amphibole porphyroclasts formed pyroxene + plagioclase symplectites. The latter reaction indicates that strain localization initiated with dehydration reactions leading to primary amphibole breakdown into pyroxene and plagioclase, now preserved in the ultramylonite. Geothermobarometry using plagioclase-amphibole pairs in the ultramylonites indicate temperature conditions of ca. 800˚C and pressures from 8 to 6kbar. This suggests that protracted shearing in the ultramylonites occurred at decreasing pressure and nearly constant T. We suggest that the fluids released during the dehydration reaction were channelized in the ultramylonites and subsequently assisted amphibole nucleation in dilatant sites during creep cavitation, as shearing protracted at P, T conditions at which amphibole was stable again. The addition of fluid to the system, combined with chemically-driven grain-size reduction, promoted deformation by diffusion-accommodated grain boundary sliding.

This study highlights the importance of dehydration reactions for grain size reduction and strain localization in the lower crust, as well as the possibility that fluids can be channelized in discrete shear zones during protracted tectono-metamorphic events.