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Phase distribution and flow mechanism in an amphibolite facies ultramylonite

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Rocks deforming by diffusion creep, are usually characterized by a small grain size, a weak or no crystallographic preferred orientation and an anti-correlated phase distribution of which the latter gives the most revealing insight into the active deformation mechanism. The present study focuses on the phase distribution in an amphibolite facies ultramylonite from a several meters wide shear zone within the Nordmannvik Nappe of the Norwegian Caledonides.

In the shear zone, a granulite facies protolith is transformed to a fine grained matrix of quartz (50%), biotite (20%), white mica (20%), oligoclase (7%) and ilmenite/titanite with grain sizes below 10 μm (eq. diameter). Large grains of garnet, white mica and plagioclase form porphyroclasts. At high matrix proportions white mica and plagioclase porphyroclasts are less abundant.

The matrix shows a homogeneous fabric and shows a strong anti-correlation of phases. Quartz forms single grains or clusters, which are at most a few grains thick, with a long axis inclined at 30 - 60° to the foliation, antithetic to the sense of shear. Quartz clusters have a regular spacing of $\sim$30 μm, separated by biotite-stacks and oligoclase. White mica forms parallel to the foliation and replaces longer biotite grains (during shearing of the mica). Concurrently new biotite grows at those quartz grain boundaries, which are oriented at a high angle to the foliation. Only adjacent to porphyroclasts, the matrix homogeneity is disturbed. Biotite and plagioclase are depleted in the compressional sector and grow in the extensional sector. Correspondingly, garnet porphyroclasts have newly grown Ca-rich rims in compressional sectors and signs of dissolution in extensional ones.

Thermodynamic modeling suggests that the modal composition of the matrix and the Ca-rich garnet rims form the stable assemblage. The microstructural positions of the phases can be related to the kinematics of granular flow. The alignment of quartz grains into clusters subparallel to the inferred shortening direction can be compared to the dynamic formation of force chains permitting high and low pressure sites in the matrix, similarly observed in numerical models of granular flow (e.g. Deubelbeiss et al., 2011). Biotite + oligoclase occupy sites of locally lower pressure and garnet rims + white mica those of higher pressure. It is suggested that a cyclic reaction of garnet + white mica = plagioclase + biotite, driven by dynamically changing, local gradients, causes the distribution of phases by nucleation, growth and mutual replacement during granular flow. Additionally, straining of biotite might contribute to its replacement by white mica.

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