Geophysical Research Abstracts
Vol. 14, EGU2012-11807, 2012
EGU General Assembly 2012

The direct correspondence between shear zones and fluid-rock reactions from the outcrop to the nanoscale

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Understanding the factors that control the strength of rocks is fundamental to any interpretation of crustal dynamics. Is rock strength and rheology dependent mainly on intrinsic properties of the constituent minerals (e.g. the yield strength of 'hard' and 'soft' minerals) and temperature? In other words does the classical description of rock deformation in terms of dislocation glide, subgrain formation and dynamic recrystallisation offer an adequate explanation of the origin of shear zones in high grade metamorphic rocks? Using examples from two different localities in western Norway we demonstrate that there is a direct spatial correspondence between localised fluid infiltration, mineral reaction and shear zone formation, both on an outcrop scale as well as in "micro shear zones" seen within a single optical thin section.

In the Lindås Nappe of the Bergen Arc anorthosites and anorthositic coronitic gabbros, recrystallised at granulite facies conditions at ~930My are transected by Caledonian age (~420My) eclogite and amphibolite facies shear zones. The outcrops contain relatively unaltered granulites retaining the high grade mineralogy and texture, through to highly strained and hydrated minerals within the shear zones. The spatial distribution of altered and unaltered rocks is highly heterogeneous and can be directly related to the extent of fluid infiltration. The response of the rocks to deformation varies from ductile to brittle deformation even on a thin-section scale. The textural evolution of large plagioclase (~An50) grains within the anorthosites has been studied by SEM, EBSD and TEM and related to the immediate mineralogical environment and degree of reaction in garnets and pyroxenes. The most obvious origin of the grain-size reduction associated with the feldspars within the shear zone is a phase separation within the plagioclase to form intergrowths of Ca-rich (~An65) and Na-rich (~An25) domains, accompanied by the formation of dense inclusions of zoisite and zones of kyanite-quartz symplectites. Within the shear zones the feldspars retain chemical zoning inherited from the phase separation, the zoning revealing a strong shape-preferred orientation within a crystal mosaic of grains up to 100μm in size, with abundant 120 degree triple junctions. EBSD shows that there is no crystallographically-preferred orientation in the feldspars, which we interpret in terms of fluid-induced dissolution-precipitation creep, with macroscopically very high strain in regions of low stress. The high stresses are developed in the less-reacted parts of the rock which respond by brittle failure.

The second studied area is the Kråkenes Gabbro which is a partially deformed and transformed igneous body located in the UHP/HP transition zone of the Western Gneiss Region of western Norway. The body is transected by a swarm of cm-wide hydrous eclogite-facies shear zones. The shear zones have cores of intensely deformed and fine-grained material with a high modal abundance of hydrous minerals, surrounded by a dm-wide reaction halo, where deformation is less pronounced and grain-sizes mainly still large. Fluid infiltration into the undeformed parts of the gabbro apparently occurred both along grain boundaries and through reactive minerals.As a consequence, phase separation in former magmatic plagioclase to an Ab-rich feldspar and clinozoisite resulted in a grain size reduction of >1000 times the initial size.

The major feedback mechanisms between fluid infiltration, mineral reaction and deformation will be discussed in the context of these observations.