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Weakening and strain localization during metamorphic overprint: The example of Arnøya, Scandinavian Caledonides, Northern Norway

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Metamorphic processes such as new mineral growth, changes in mineral composition, and infiltration of water are thought to play an important role in rheological weakening and strain localization in the lower crust. However, the exact mechanisms and extent to which these processes have an effect, are not well understood. The Scandinavian Caledonides in northern Norway offer a unique field laboratory to study pervasively deformed and metamorphosed lower crustal nappes and allow for the comparison of deformation and metamorphic conditions between nappe cores, nappe boundaries, and the transition between the two. The island of Arnøya provides a 20 km-long cross section through the Vaddas, Kåfjord and Nordmannvik nappes, with metamorphic grade increasing upwards from amphibolite to granulite facies, respectively. The nappes display a pervasive foliation associated with a strong NW-SE lineation and top-to-SE shear sense consistent with Caledonian thrust deformation. Nappe boundaries occur as wide (10's of metres) ultramylonite-, mylonite- and schist-bearing shear zones, and have a different mineralogy to internal parts of the nappes. Metapelites and migmatites of the Nordmannvik nappe are kyanite-bearing (high T, high P), and the Kåfjord nappe is composed mainly of homogenous semi-pelite (medium T and P). The Vaddas nappe is more variable and contains interlayered metapsammites, amphibolites and local marbles.

A comparison of metapelitic samples from the nappes and the two nappe boundary shear zones show that grain size decreases and degree of mixing of phases increases towards shear zone cores. Also grain size becomes homogeneous towards shear zone cores. All samples show evidence of high temperature dynamic recrystallization of quartz. Quartz within aggregates in nappe rocks have a crystallographic preferred orientation (CPO), while quartz in shear zone rocks shows no CPO, indicating deformation mainly by dislocation creep in the nappes and a switch to diffusion creep in the shear zones. This switch in deformation mechanism suggests a rheological difference between the shear zone rocks and nappe rocks and begs the question: what processes control this change?

Shear zone rocks have a different mineral assemblage compared to nappe rocks, despite relatively similar bulk compositions. Thermodynamic modelling and microstructural relationships suggest that this is due to a difference in metamorphic conditions. Metamorphism and deformation evolved with time during the Caledonian orogeny, and metamorphism associated with Caledonian shearing along nappe boundaries is significantly higher pressure ($\sim$3-5 kbar higher) but a similar temperature ($\sim$600-700 °C) compared to Caledonian metamorphism in the nappes. The presence of significant amounts of white mica, which replaces biotite in shear zone rocks, and young garnets with flat compositional profiles and with different compositions from garnets in nappe rocks, suggest that mineral reactions and nucleation and growth of new minerals may play a key role in the change from dislocation creep to diffusion creep deformation mechanisms. The increase in the proportion of hydrous phases in nappe-bounding shear zones also suggests that water activity was higher in shear zones than within the nappes, so that influx of water may be an important factor in facilitating metamorphic reactions and rheological weakening.