Geophysical Research Abstracts
Vol. 17, EGU2015-12912, 2015
EGU General Assembly 2015

Deformation mechanisms and grain size evolution in the Bohemian granulites – a computational study

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A dominant deformation mechanism in crustal rocks (e.g., dislocation and diffusion creep, grain boundary sliding, solution-precipitation) depends on many parameters such as temperature, major minerals, differential stress, strain rate and grain size. An exemplary sequence of deformation mechanisms was identified in the largest felsic granulite massifs in the southern Moldanubian domain (Bohemian Massif, central European Variscides). These massifs were interpreted to result from collision-related forced diapiric ascent of lower crust and its subsequent lateral spreading at mid-crustal levels. Three types of microstructures were distinguished. The oldest relict microstructure (S1) with large grains (>1000 μm) of feldspar deformed probably by dislocation creep at peak HT eclogite facies conditions. Subsequently at HP granulite-facies conditions, chemically- and deformation- induced recrystallization of feldspar porphyroclasts led to development of a fine-grained microstructure (S2, $\sim$50 μm grain size) indicating deformation via diffusion creep, probably assisted by melt-enhanced grain-boundary sliding. This microstructure was associated with flow in the lower crust and/or its diapiric ascent. The latest microstructure (S3, $\sim$100 μm grain size) is related to the final lateral spreading of retrograde granulites, and shows deformation by dislocation creep at amphibolite-facies conditions. The S2–S3 switch and coarsening was interpreted to be related with a significant decrease in strain rate.

From this microstructural sequence it appears that it is the grain size that is critically linked with specific mechanical behavior of these rocks. Thus in this study, we focused on the interplay between grain size and deformation with the aim to numerically simulate and reinterpret the observed microstructural sequence. We tested several different mathematical descriptions of the grain size evolution, each of which gave qualitatively different results. We selected the two most elaborated and at the same time the most promising descriptions: thermodynamics-based models with and without Zener pinning.

For conditions compatible with the S1 and S2 microstructures ($\sim$800 °C and strain rate $\sim$10-13 s-1), the calculated stable grain sizes are $\sim$30 μm and >300 μm in the models with and without Zener pinning, respectively. This is in agreement with the contrasting grain sizes associated with S1 and S2 microstructures implying that mainly chemically induced recrystallization of S1 feldspar porphyroclasts must had played a fundamental role in the transition into the diffusion creep. The model with pinning also explains only minor changes of mean grain size associated with S2 microstructure. The S2–S3 switch from the diffusion to dislocation creep is difficult to explain when assuming reasonable temperature and strain rate (or stress). However, a simple incorporation of the effect of melt solidification into the model with pinning can mimic this observed switch.

Besides the above mentioned simple models with prescribed temperature and strain rate, we implemented the grain size evolution laws into in a 2D thermo-mechanical model setup, where stress, strain rate and temperature evolve in a more natural manner. This setup simulates a collisional evolution of an orogenic root with anomalous lower crust. The lower-crustal material is a source region for diapirs and it deforms via a combination of dislocation and grain-size-sensitive creeps. We tested the influence of selected parameters in the flow laws and in the grain-size evolution laws on the shape and other characteristics of the growing diapirs. The outputs of our simulations were then compared with the geological record from the Moldanubian granulite massifs.