Petrogenesis of the south Bohemian granulites: The importance of crystal-melt relationships

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The prograde transformation of rocks from the amphibolite to the granulite facies is very often accompanied by the formation of a melt phase. Melting is fluxed by water released from fluid-absent breakdown reactions of micas and amphiboles (e.g., Clemens and Vielzeuf 1987, Clemens 1990, Johannes and Holtz 1991). Therefore, a study of granulite-facies metamorphic rocks should ideally consider the potential of crystal-melt interactions in their textural and geochemical evolution (Roberts and Finger 1997).

For the granulites in the Austrian part of the Bohemian Massif, peak PT conditions of ca. 1000 °C and 16 kbar have been estimated (O´Brien and Carswell 1993, Cooke 2000). In the course of the Variscan orogeny, the rocks were then near-isothermally uplifted experiencing partial recrystallisation at c. 800–900 °C and 8–12 kbar. Post-decompression cooling from 800–500 °C at 5–8 kbar led to the formation of retrograde, amphibolite facies parageneses in places (Cooke 2000).

Fiala et al. (1987) suggested that most of the South Bohemian granulites represent metamorphosed calc-alkaline magmatic rocks. Based on this assumption, modelling (Roberts and Finger 1997) showed that biotite-granites, chemically similar to the most common light garnet-bearing type of granulite in South Bohemia, would produce 5–20 vol. % melt when metamorphosed at 1000 °C/16 kbar under fluid absent conditions. During subsequent decompression along a steep PT path the volume of melt would increase. Inevitably, the continual presence of a melt phase would have serious consequences for the interpretation of zircon ages (Roberts and Finger 1997), because the melt has the potential to dissolve a large amount of Zr (ca. 1250 ppm at 1000 °C; see Watson and Harrison 1983). The modelling further showed that zircon precipitation would occur following decompression. Because of this, zircon ages would not necessarily record the peak PT conditions as previously interpreted (Van Breemen et al. 1982, Wendt et al. 1994, Kröner et al. 1996).

In order to gain clearer insights into the role of melting at and during decompression from peak PT conditions, the evolution of the South Bohemian granulites has been simulated in the laboratory (Konzett et al. 2001). Experiments were performed using a piston cylinder apparatus at PT conditions of 900 °C/16 kbar, 1000 °C/16 kbar (prograde branch) and 950 °C/14 kbar, 900 °C/12 kbar (retrograde branch). A Moldanubian, amphibolite facies granite gneiss from the Monotonous Series was used as starting material. In terms of chemistry, this rock corresponds almost perfectly to some of the typical light granulite varieties of South Bohemia. The results showed roughly 20–25 % partial melt at peak PT conditions (plus ternary feldspar, quartz, garnet), and confirm that the largest melt volumes occur on the retrograde path (ca. 30 % melt at 950 °C/14 kbar plus ternary feldspar, quartz, garnet).

Furthermore, it was found that the high-T garnet in the experiments has taken up large amounts of titanium (up to c. 2 wt.% TiO_2 at 1000 °C), whereas the natural garnets in the South Bohemian granulites are generally Ti poor (<0.3 wt.% TiO_2). However, exsolution of tiny rutile needles, which have been reported (Vrana 1989, Cooke 2000), suggests that these garnets could have originally crystallized with higher Ti contents.

Apart from the small rutile inclusions in the garnet, the South Bohemian granulites typically contain euhedral 0.1–1 mm long, brown rutile crystals, commonly considered to be part of the peak paragenesis. However, in the experiments at 950 and 1000 °C hardly any rutile was found, and the melt phase had rather high TiO_2 contents of ca. 0.3 wt.% at 950 °C/14 kbar, implying that, at least in some of the felsic granulites, the euhedral accessory rutiles may not have formed at peak PT conditions, but rather precipitated from the melt phase during the decompression and cooling stage, in a similar fashion to zircon.

Laser ICP-MS analyses of accessory euhedral rutiles from a felsic granulite sample from the Dunkelsteinerwald in Lower Austria, show that these contain significant amounts of Zr (up to 2000 ppm) and Nb (up to 3000 ppm), although the Zr and Nb contents in the whole rock are not high (<150 and <20 ppm, respectively). This suggests, in accordance with the experimental results, that the rutiles crystallized from a partial melt strongly enriched in these elements and thus resembling an A-type granite melt. From the strong enrichment factor it can be inferred that the partial melt volume was low.

Observations on rutile compositions, and other chemical parameters (e.g., the generally high concentration of Y in the rocks), do not support the model of Kotkova and Harley (1999), whereby the felsic granulites of South Bohemia represent high-pressure leucogranite magmas that separated during Variscan burial metamorphism from a lower crustal source. At least for the Moldanubian granulite occurrences in Austria a better model would be that most of these represent metamorphosed products of Early Palaeozoic biotite- and two-mica granitoids (see also Friedl et al., this volume). Granulite metamorphism led to the formation of an interstitial partial melt in these rocks, which was strongly enriched in incompatible elements, constituting a fertile environment for the growth of accessory minerals like zircon, monazite or rutile during the decompression and cooling stage. The Th-, U- and Cs-depleted nature of many granulites may indicate that slight melt losses occurred during the Variscan orogeny. Alternatively, these elements may have been removed by fluids.

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