Constraints on cummingtonite crystallization in the Gęsiniec Intrusive (Strzelin Crystalline Massif, Fore Sudetic Block, SW Poland)

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Geological Setting

The Gęsiniec Intrusive is situated in the northern part of Strzelin Crystalline Massif, Fore Sudetic Block, SW Poland. It belongs to Variscan granitoid intrusions emplaced within metamorphic rocks of Precambrian to Lower Palaeozoic age, as small, up to few kilometres, bodies (Oberc-Dziedzic 1999). The granitoids vary in composition from granite to tonalite. The Gęsiniec Intrusive consists mainly of tonalites with subordinate granodiorite, quartz diorite and two-mica granite (Puziewicz and Oberc-Dziedzic 1995). Several types of tonalites of different structure and mineral composition occur (Oberc-Dziedzic 1999, Pietranik 2002).

Petrography

The most abundant tonalite type, called in the following main tonalite, is variable and it forms four varieties: (1) dark tonalite with biotite – amphibole aggregates, (2) dark tonalite with plagioclase – amphibole aggregates, (3) light tonalite with biotite – amphibole aggregates and (4) light homogenous tonalite. Main tonalite consists of plagioclase, biotite, Ca – amphibole, quartz, ilmenite, sphene, zircon, apatite and secondary minerals (calcite, chlorite, albite, alkali feldspar, prehnite). Cummingtonite occurs within both dark tonalites. The dark tonalite is enriched in Mg, Fe and K and has higher Mg/Fe ratio than other tonalite types.

Two plagioclase types occur within main tonalite: (1) large grains with skeletal, calcic cores (60–75 % An) and more sodic mantles (40–50 % An) and (2) small grains with rounded cores (35–37 % An) surrounded by more calcic mantles (50 % An). The third type of plagioclase occurs only in dark varieties. It is characterized by diminishing of anorthite content from the core towards the rim (60 → 40 % An) that is followed by abrupt decrease in it (by 20 % up to as high as 30 %) after that anorthite content rises again up to 50 %.

Morphology and chemical composition of cummingtonite

Cummingtonite forms mantles around hornblende cores and lamellae within the cores. It occurs also in biotite (chlorite)–amphibole aggregates where coarse grains surround small, euhedral hornblende grains. The individual grains of cummingtonite are scarce. The rims of cummingtonite grains are often replaced by actinolite.

Hornblende cores have euhedral shapes with scarce embayments filled by actinolite. The mantles are either complete or they surround only minor parts of hornblende cores. The cores often contain biotite which is scarcely altered. The small sulfide grains occur at the contact between cummingtonite mantle and hornblende core. Scarce monazite grains occur within the mantles. The Si content of the cummingtonite mantles increases toward the rims from 7.78 to 7.98 a p.f.u. The X_{Fe} value (Evans – Ghiorso, 1995) is 0.40–0.41 in all types of cummingtonite grains.

Cummingtonite lamellae form sets of parallel stripes and lenses up to 2 μm thick occurring in the hornblende cores. The Si content of the lamellae varies from 7.36 to 7.99 a p.f.u. Microprobe analyses yield intermediate values between those of hornblende and cummingtonite, supposedly due to contamination.

Cummingtonite occurring as individual grains has composition similar to those forming mantles on hornblende.

Discussion

Cummingtonite is a common mineral of metamorphic rocks whereas its occurrences in igneous ones are scarce. Cummingtonite surrounding hornblende was reported from amphibolites (Mottana et al. 1994) where it was explained to form due to the reaction:

Ca- amphibole + Andesine ⇒ Cummingtonite + Labradorite, as result of temperature increase or pressure decrease.

Cummingtonite was described in rhyolitic and dacitic magmas and it is thought to be product of crystallization from water saturated magma or replacement of biotite, ortopyroxene or amphibole (Evans – Ghiorso 1995). Experiments on crystallization of dacitic magma show that cummingtonite can crystallize as late phase from sulfur saturated magma together with biotite and sulfur phases anhydrite and/or pyrrhotite (Scaillet – Evans 1999).

Morphological and chemical evidence from minerals forming Gęsiniec tonalite (two types of plagioclase crystals, plagioclase composition, increase of titanium content in biotite towards the rims, hornblende surrounding biotite) and the initial $^{87}Sr/^{86}Sr$ ratio (Oberc-Dziedzic et al. 1996) suggests a magma-mixing process in the early history of the evolution of the Gęsiniec Intrusive. The mixing produced more calcic mantles around plagioclase cores but it cannot explain crystallization of cummingtonite, which occurred late in the magma evolution.

Crystallization of anhydrite in tonalite seems to be probable explanation for later crystallization of cummingtonite instead of hornblende. Although anhydrite was not found in the Gęsiniec tonalite it could have been easily removed by post-magmatic or weathering processes (Carroll – Rutherford 1987). Moreover sudden decrease in anorthite content in third type of plagioclase grains indicates Ca depletion of the melt possibly due to anhydrite crystallization. The source of sulfur necessary for crystallization of anhydrite was supposedly mafic magma or late mafic melts intruding only into the dark tonalite.

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Development and exhumation of an inverted metamorphic sequence: Example of the Champtoceaux Complex (Massif Armoricain, France)

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A common feature of orogenic belts caused by continental collision is the presence of crustal-scale thrusts that superpose high-grade metamorphic units over lower-grade ones. The result is an inverted metamorphic zoning. Structural elements associated to these thrusts are often overprinted by later tectonic events (late-orogenic extension, etc.), and the inverted metamorphism is often the only trace of continental collision in old orogens. Despite numerous studies, the development of inverted metamorphic zoning, its preservation and exhumation remain still poorly understood, although it is a key-point in understanding of orogenic processes.

Such a zoning is preserved in the Champtoceaux Complex (Massif Armoricain, France). From the bottom to the top of the metamorphic rock pile, the following sequence is observed: chlorite + biotite-bearing metagreywackes (para-autochthonous), micaschists with chloritoid + chlorite + garnet, staurolite + biotite + garnet (with chloritoid inclusions), kyanite + staurolite + biotite + garnet, and finally migmatites. Numerous layers of leptynitic gneiss are interlayered with the metasediments and prevent the continuous paragenetic evolution to be studied. Therefore, we concentrated our efforts on constraining the PT evolution of several pelitic samples suitable for a detailed petrological analysis. Average PT calculations performed with the software thermocalc yielded 520–570 °C and 10–14 kbar for the Cld-Chl-Grt-bearing micaschists, and 590–630 °C, 9–10 kbar for the St-Bt-Grt±Ky-bearing o1nes, whereas the overlying migmatites recorded temperatures in excess of 700 °C. The field metamorphic gradient is therefore inverted in temperatures, but not in pressures. We compare the PT paths inferred from these units, based among others on the thermodynamic analysis and modeling of the chemical zoning of garnets in the model systems NCKFMASH and MnNCKFMASH.

The presence of a major thrust at the top of the para-autochthonous is suggested by the presence of eclogite lenses in all units with the exception of this basal one. Lenses of serpentinised peridotites mark the boundary between the micaschists and the overlying migmatites, suggesting the presence of another major thrust. It's under this latter contact that the inverted metamorphic zoning develops. On the basis of these observations and the petrological data we discuss the various models of development of inverted metamorphic zoning. The proposed model suggests a dynamic view where the temperature inversion is due to the overriding nappe and the crustal units record thermal reequilibration during the propagation of the Variscan thrusts.