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CONTRASTING CORONA STRUCTURES IN MAFIC GRANULITE FROM THE BLANSKY LES COMPLEX, BOHEMIAN MASSIF, CZECH REPUBLIC

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Abstract

Quartz-bearing mafic granulite from Holubov, in the Blansky Les complex, Bohemian Massif, Czech Republic contains two types of corona structures: pyroxene + plagioclase rim on garnet (Type-1 corona), and garnet rim on anorthite + spinel (An + Spl) mosaics (Type-2 corona). Significantly, Type-2 structures are enclosed by an orthopyroxene-depleted halo which, in places, seems to embay the Type-1 coronal pyroxene, indicating that the Type-2 coronas are a late feature. Type-1 coronas formed during uplift by the resorption of garnet and quartz:

2 Grs + Prp + 3 Qtz = 3 Di + 3 An

and

2 Alm + Grs + 3 Qtz = 3 Fs + 3 An.

Decompression is also supported by patterns of zoning in garnet (rimward decrease in X_{Ca}, compensated by reverse zoning in andesine) and the formation of the An + Spl nucleus of Type-2 coronas at the expense of early kyanite and grossular-rich garnet:

5 Grs + (Prp,Alm) + 12 Ky = 15 An + 3 (Spl,Hc)

Coronal grains of garnet are interpreted to have formed during cooling at substantially lower pressures as the An + Spl mosaics reacted with matrix (and, locally, coronal) orthopyroxene. These contrasting corona structures record near-isothermal (~900–750°C) decompression of the granulite from ~14 kbar to ~2–3 kbar, and subsequent near-isobaric cooling. They are indicative of a clockwise P–T–t path.

Keywords: mafic granulite, corona, garnet, Blansky Les complex, Bohemian Massif, Czech Republic.

Sommaire

Les granulites mafiques à quartz de Holubov, dans le socle métamorphique de Blansky Les du Massif Bohémien, en République Tchèque, contiennent deux sortes de structures coronitiques, un liseré de pyroxène + plagioclase sur grenat (couronne de type 1) et liseré de grenat sur des agrégats en mosaïque d'anorthite et de spinelle (couronne de type 2). Les structures de type 2 sont entourées d'une auréole appauvrie en orthopyroxène qui, par endroits, semble recouper le pyroxène coronitique de type 1, ce qui semble indiquer que les couronnes de type 2 seraient tardives. Les couronnes de type 1 se seraient formées par la résorption du grenat et du quartz:

2 Grs + Prp + 3 Qtz = 3 Di + 3 An

et

2 Alm + Grs + 3 Qtz = 3 Fs + 3 An.

Un épisode de décompression semble expliquer la zonation des grains de grenat (diminution de X_{Ca} vers la bordure, que compense une zonation renversée dans l'andésine), ainsi que la formation d'un coeur An + Spl entouré d'une couronne de type 2 aux dépens de kyanite et grenat à teneur élevée en grossulaire précoces:

5 Grs + (Prp,Alm) + 12 Ky = 15 An + 3 (Spl,Hc).

Les grains de grenat dans les couronnes se seraient formés au cours du refroidissement à une pression nettement plus faible, quand les agrégats à An + Spl ont réagi avec l'orthopyroxène de la matrice et, localement, de la couronne. Ces structures contrastantes en couronnes témoignent de la décompression quasi-isotherme (~900–750°C) des granulites d'environ 14 kbar à ~2–3 kbar, et, plus tard, un refroidissement quasi-isobare. Elles sont indicatives d'un tracé P–T–t dans le sens de l'horloge.

(Traduit par la Rédaction)

Mots-clés: granulite mafique, couronne, grenat, complexe de Blansky Les, Massif Bohémien, République Tchèque.

Introduction

Corona structures typically preserve relics of both the reactant (core + matrix) and product (rim) assemblages, from which a specific corona-forming reaction can be construed. Such structures therefore can constitute a valuable source of information concerning the evolution of rocks in terms of P and T. Coronas occur in a variety of rock types, but are especially common in high-grade mafic and pelitic rocks, where they can provide evidence for isobaric cooling or isothermal decompression (Harley 1989).

In this paper, we describe a rare example of a mafic granulite that contains two distinctly different types of corona structures. One is attributed to near-isothermal decompression, the other to near-isobaric cooling. Collectively, they indicate a clockwise pressure – temperature – time (P–T–t) trajectory for the granulite.

Geological Setting

The mafic granulite was sampled in a roadcut at Holubov mill, about 1 km northeast of Holubov village, in the Blansky Les complex, the largest of the granulite bodies in the Moldanubian Zone of the Bohemian Massif in the southern Czech Republic (Fig. 1). The Blansky Les complex is fault-bounded, and consists of high-pressure felsic to mafic granulites and subordinate meta-ultramafic rocks (Fiala *et al.* 1987) that show variable degrees of retrogression to upper-amphibolite-grade assemblages (Wendt *et al.* 1994). The high-grade assemblages are related to Variscan metamorphism (*ca.* 345–350 Ma; Wendt *et al.* 1994). Analogous rocks in neighboring northern Austria yield peak conditions of metamorphism of ~1000°C at 16 kbar; overprinting assemblages yield blocking temperatures of ~725°C at ~5.6 kbar (Carswell & O'Brien 1993).

Petrography

The matrix of the mafic granulite contains orthopyroxene, clinopyroxene, garnet, andesine, quartz, perthitic microcline and biotite. Accessory minerals include rutile and ilmenite. There are two distinct types of corona structures in the rock. Both occur in quartz-free domains; quartz forms xenomorphic grains up to 0.8 mm in diameter that are restricted to the matrix at least 0.4 mm from the nearest corona structure. Type-1 coronas are composite structures that consist of an outer necklace of orthopyroxene or, less commonly, clinopyroxene, that is separated from garnet porphyroblasts by an andesine moat (Fig. 2A). Type-2 coronas consist of a partial to complete necklace of garnet that encloses spheroidal to lozenge-shaped mosaics of anorthite + spinel (An + Spl), and are themselves enclosed by a pyroxene-depleted halo enriched in andesine (Figs. 2B, C). Spinel is concentrated in the

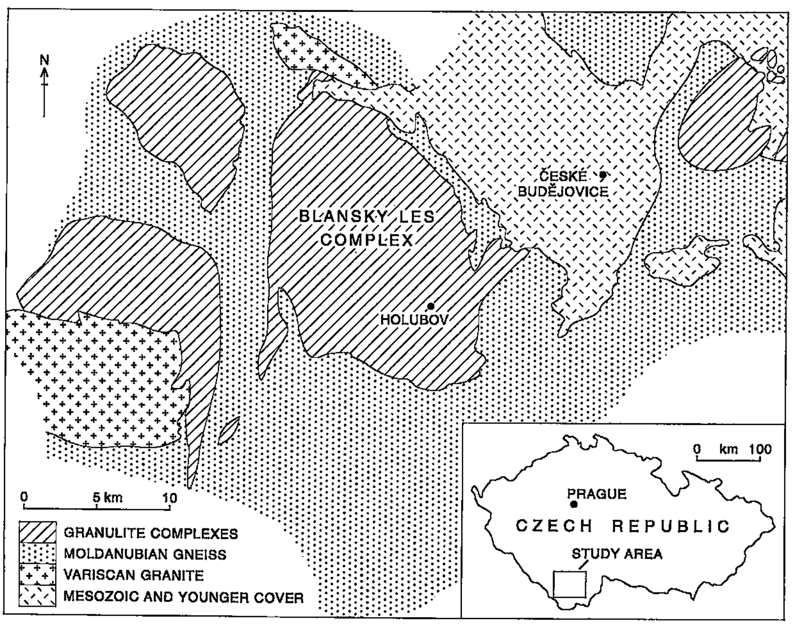

FIG. 1. Geological sketch-map of part of the Bohemian massif in the Czech Republic, showing the sample location at Holubov.

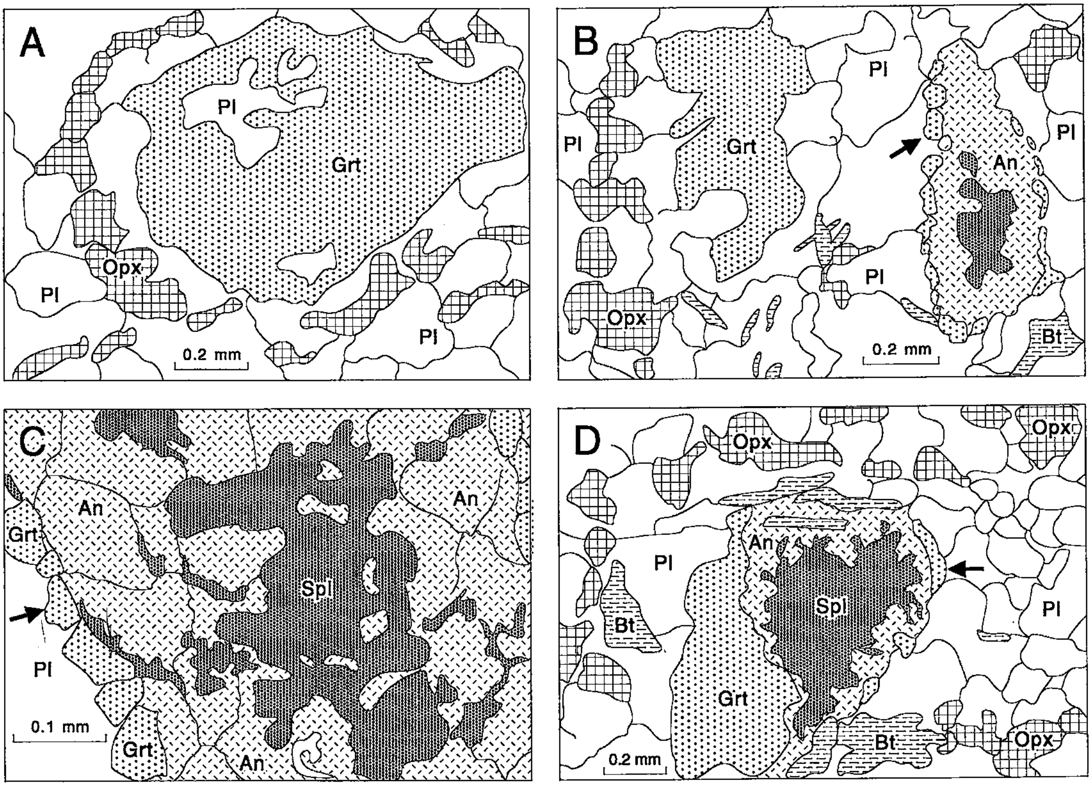

FIG. 2. Line drawings from photomicrographs of corona structures in mafic granulite from Holubov. (A) Partial orthopyroxene (+ andesine) corona (Type-1) on poikiloblastic garnet (sample G75). (B) Neighboring type-1 (left) and -2 (right) coronas. Note the depletion of coronal Opx and the occurrence of well-formed grains of coronal garnet (arrow) where the corona structures abut one another (sample G75). (C) Close-up of part of (B) showing the relatively coarse, subidiomorphic character of the grains of coronal garnet (arrow) on the Type-2 corona facing the corroded side of the Type-1 corona that is depleted in pyroxene. (D) Anorthite + spinel core of a Type-2 corona embaying a garnet porphyroblast. Note (1) the depletion of orthopyroxene in the matrix adjacent to the xenomorphic, corona-like grains of garnet (arrow; see text), and (2) the absence of corona-like garnet where biotite separates the core of the structure from matrix orthopyroxene (sample G77).

geometrical center of the Type-2 structures. The coronal garnet is absent where biotite has shielded the An + Spl mosaics from matrix pyroxenes; in these situations, orthopyroxene is not depleted in the matrix adjacent to the Type-2 structure (Fig. 2D). The coronal garnet commonly consists of tiny, subidiomorphic to idiomorphic grains (Figs. 2B, C). In these cases, it clearly does not represent the remnant of a resorbed porphyroblast of garnet (*i.e.*, the garnet enclosing the An + Spl mosaic is a *bona fide* coronal phase). In some instances, however, grains of xenomorphic garnet are seen to partly enclose a An + Spl mosaic that embays a garnet porphyroblast (Fig. 2D). Although in this case the corona-like grains of garnet resemble the relict rim of the partly resorbed porphyroblast, the depletion of orthopyroxene in the nearby matrix hints that these xenomorphic grains of garnet are a coronal phase formed by the same reaction as that responsible for the idiomorphic grains of coronal garnet preserved elsewhere in the rock. As will be seen, this interpretation is supported by criteria based on mineral compositions.

Relative timing of corona development

It is rarely the case that the timing of corona formation can be ascertained directly (see, however, Davidson & van Breemen 1988); the determination of the relative age of the different types of corona in the same rock therefore must rely in part on microstructural criteria. In the present case, grains of coronal garnet have been observed to be relatively large and well formed where the Type-2 structure abuts a Type-1 corona (Figs. 2B, C). Coronal pyroxene in the latter is depleted on the side facing the Type-2 corona, indicating resorption by the neighboring coronal garnet. Although not definitive, this relationship suggests that the garnet coronas (although not the An + Spl mosaics that they enclose) are relatively late structures. This interpretation will be seen to be supported by phase equilibria and thermobarometric arguments.

MINERAL COMPOSITIONS

Mineral compositions were determined using a JEOL Superprobe 733 housed at Dalhousie University. This instrument is equipped with four wavelength-dispersion spectrometers and one energy-dispersion spectrometer, and operated with a beam current of 15 kV at 5 nA. Mineral compositions reported here were determined using the energy-dispersion system. Standards included jadeite (Al, Si, Na), hornblende (Ca, Fe, Mg, Ti), sanidine (K), apatite (P, Cl), galena (Pb) and chalcopyrite (S). The operating voltage was 15 kV; beam current was 12 nA. Count time was 30 s. Data were reduced using ZAF corrections.

Garnet compositions vary with mode of occurrence. Porphyroblasts show retrograde zoning patterns (*e.g.*, $Prp_{27\rightarrow24}Alm_{36\rightarrow56}Grs_{35\rightarrow17}Sps_{1\rightarrow4}$; Fig. 3). Grossular contents decrease near inclusions of reversely zoned plagioclase (Fig. 3) as well as near the edge of the porphyroblasts. Idiomorphic grains of coronal garnet (*e.g.*, $Prp_{27}Alm_{55}Grs_{13}Sps_5$) are homogeneous. Although compositionally similar to the rim of the zoned porphyroblasts, the coronal garnet tends to have slightly lower grossular contents. Consequently, the grossular content of garnet can be used to distinguish coronal grains from the relict rim of garnet porphyroblasts whose core has largely been resorbed by the An + Spl nucleus of Type-2 corona structures. In the example illustrated in Figure 2D, the relict porphyroblast is strongly zoned ($Prp_{22\rightarrow21}Alm_{45\rightarrow58}$ $Grs_{31\rightarrow18}Sps_{1\rightarrow3}$) even though its geometric center is not preserved. Its outer rim has a higher grossular content than the xenomorphic, corona-like grains ($Prp_{22}Alm_{60}Grs_{14}Sps_3$) that partly mantle the An + Spl assemblage that has replaced the bulk of the porphyroblast. Coupled with the depletion of orthopyroxene in the adjacent matrix, we conclude that these xenomorphic grains of garnet constitute a *bona fide* coronal phase. *Orthopyroxene* in the matrix of the granulite has a composition of about $Ca_{0.03}(Mg_{1.07}Fe_{0.84}Mn_{0.03})^{VI}Al_{0.03}(^{IV}Al_{0.01})Si_{1.99}O_6$, and is slightly more magnesian (X_{Mg} [= Mg/(Mg + Fe) = 0.56] than coronal orthopyroxene [$Ca_{0.02}(Mg_{1.00}Fe_{0.96}Mn_{0.03})(^{IV}Al_{0.02})Si_{1.97}O_6$; X_{Mg} = 0.51]. Both occurrences of orthopyroxene have low Al contents, despite the presence of garnet in the rock. The oxidation ratio, X_{Fe3+} [= $Fe^{3+}/(Fe^{3+} + Fe^{2+})$], as calculated from stoichiometry by balancing charges (Droop 1987), is low (<0.1).

Clinopyroxene compositions [$\sim Ca_{0.89}(Mg_{0.76}Fe_{0.31}Mn_{0.01})^{VI}Al_{0.5}(^{IV}Al_{0.08}Si_{1.92})O_6$] show no systematic variation according to mode of occurrence (*i.e.*, matrix *versus* coronal grains). The clinopyroxene is more magnesian (X_{Mg} = 0.70) than coexisting orthopyroxene. The oxidation ratio, from stoichiometry, is moderate (0.35–0.40).

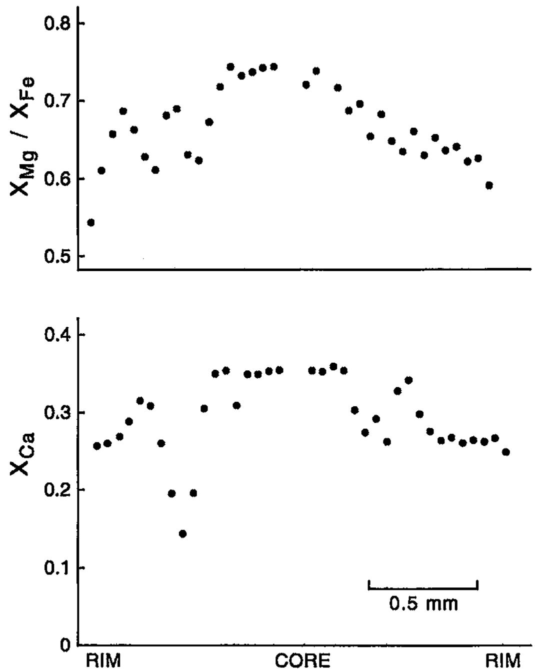

FIG. 3. Compositional profile of porphyroblastic garnet enclosed by coronal orthopyroxene and andesine (Type-1 corona) in mafic granulite (sample G75) from Holubov. Dips in X_{Ca} are related to the presence of inclusions of reversely zoned andesine in the garnet (see text).

Biotite has the approximate formula $K_{2.04}(Mg_{3.21}Fe_{2.18})(^{VI}Al_{1.93}Ti_{0.63})(^{IV}Al_{0.86}Si_{6.07}O_{20})(OH)_4$. It is slightly more magnesian (X_{Mg} = 0.59) than the coexisting orthopyroxene.

Spinel is restricted to anorthite-bearing domains in Type-2 corona structures. The spinel is pleonaste (X_{Mg} = 0.36), with a composition of $(Mg_{3.21}Fe_{5.57}Zn_{0.16})(Na_{0.29})Al_{15.28}O_{32}$. The oxidation ratio, as calculated from stoichiometry, is about 0.29.

Plagioclase compositions are highly variable. Between-grain plagioclase compositions range between An_{28} and An_{95}. Anorthite is restricted to the core of Type-2 coronas. The anorthite content of the calcic plagioclase is highest (An_{95}) in grains associated with spinel in the center of the structure; it decreases (to An_{90}) outward toward the garnet corona.

Andesine occurs in the groundmass, and as inclusions in porphyroblastic garnet. Groundmass grains in contact with orthopyroxene are more calcic

($\sim An_{50}$) than matrix grains isolated from pyroxene and porphyroblastic garnet. Relatively sodic andesine in the groundmass, however, can show strong reverse zoning (*e.g.*, $An_{30\rightarrow 40}$), consistent with the liberation of grossular from garnet rims. Plagioclase inclusions in porphyroblastic garnet show a similar compositional range (An_{28-48}) and degree of reverse zoning as granoblastic grains in the matrix. Garnet in contact with the inclusions of reversely zoned plagioclase is depleted in grossular (Fig. 3) compared with parts of the garnet distant from the plagioclase.

Ilmenite occurs in accessory concentrations in the mafic granulite. It has a composition $Fe_{2.03}Ti_{1.94}O_6$.

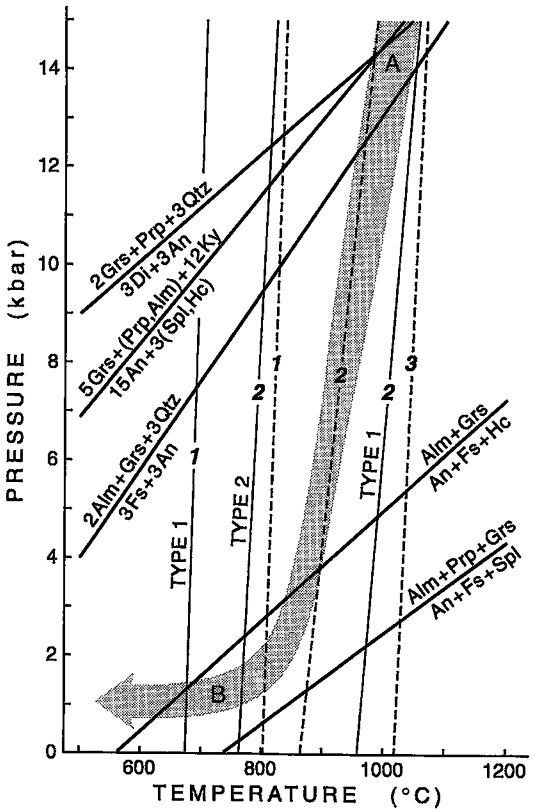

FIG. 4. P–T diagram showing corona-forming equilibria and thermobarometric constraints on mineral assemblages in mafic granulite from Holubov. Solid lines: corona-related reactions (T-sensitive equilibrium curves for type-1 and -2 coronas are labeled separately); dashed lines: reactions related to matrix assemblages. Numbered equilibria are: (1) Alm + Di = Prp + Hd; (2) Alm + En = Prp + Fs; (3) Phl + Alm = Ann + Prp. "A" and "B": approximate P–T conditions of type-1 and -2 coronas, respectively. Equilibria were positioned by TWQ software (Berman 1991) using mineral compositions reported in Table 1 (supplemented by data on core of porphyroblastic garnet). See text for discussion.

The ilmenite contains minor amounts (*i.e.*, ≤0.05 atoms per formula unit) of Mn, Mg and Na. The oxidation ratio, as calculated from stoichiometry, is low ($X_{Fe3+} \approx 0.07$).

SIGNIFICANCE OF TYPE-1 CORONAS

The pyroxene coronas are interpreted to have formed by the resorption of quartz and porphyroblastic garnet by the pressure-sensitive reactions (Harley 1989; Fig. 4):

$$2\ \mathrm{Grs} + \mathrm{Prp} + 3\ \mathrm{Qtz} = 3\ \mathrm{Di} + 3\ \mathrm{An} \quad [1]$$

and

$$2\ \mathrm{Alm} + \mathrm{Grs} + 3\ \mathrm{Qtz} = 3\ \mathrm{Fs} + 3\ \mathrm{An} \quad [2]$$

In the above expressions, the mineral symbols are those of Kretz (1983).

Similar coronas have been described from decompressional granulites worldwide (Harley 1989), and provide evidence for near-isothermal decompression of the Czech granulite. This interpretation is supported by patterns of garnet zoning (Fig. 3), which are characterized by a rimward decrease in X_{Ca} that complements the reverse zoning of andesine in the rock.

SIGNIFICANCE OF TYPE-2 CORONAS

The An + Spl mosaics in the core of Type-2 structures have no counterpart in the matrix of the rock. The association of these minerals has been described in metabasites worldwide, and is interpreted to be derived from a variety of mineralogical precursors. Spinel-clouded plagioclase occurs in coronitic mafic rocks (hyperite) in many high-grade terranes [*e.g.*, the Grenville Province in New York (Whitney 1972) and Ontario (Grant 1988, 1989)]. It is generally interpreted to form by the diffusion into plagioclase of Fe and Mg derived from olivine (Whitney 1972) or during magmatic crystallization at high pressure. Clear grains of plagioclase in the same rock, however, tend to be more calcic than their spinel-clouded counterparts. Furthermore, the spinel grains are exceedingly fine-grained, and occur within single crystals, rather than as a discrete phase within polymineralic mosaics. Consequently, the An + Spl assemblage described here does not correspond to spinel-clouded plagioclase found in hyperites.

Spinel can also occur with calcic plagioclase and orthopyroxene as a symplectitic intergrowth that replaces (1) sapphirine and clinopyroxene in very Mg-rich mafic to ultramafic rocks (*e.g.*, in the Ivrea Zone, Italy; Sills *et al.* 1983), and (2) garnet in a wide compositional range of metabasites (*e.g.*, Tobi *et al.* 1985). Comparatively low values of X_{Mg} in ferromagnesian minerals in the Czech granulite (0.3–0.8 *versus* 0.78–0.92 in rocks of the Ivrea Zone) preclude the likelihood that the An + Spl cores of Type-1 coronas formed at the expense of early sapphirine.

Using modal and mineral compositional data, it is evident that assemblages comprising Type-2 structures are highly aluminous (~40 wt% Al_2O_3), suggesting their derivation at the expense of garnet and kyanite which, although presently absent in the rock, plausibly existed during conditions of peak metamorphism at which this high-pressure (see below) granulite formed (J.R. Ashworth and D.A. Carswell, written comm., 1995).

A balanced reaction can be derived from the grossular-rich core of the porphyroblasts of garnet and the mineral data for the Type-2 structure reported in Table 1:

$$5\ \text{Grs} + (\text{Prp},\text{Alm}) + 12\ \text{Ky} = 15\ \text{An} + 3\ (\text{Spl},\text{Hc}) \quad [3]$$

in which An + Spl represents the lower pressure (or higher temperature) assemblage (Fig. 4).

The garnet coronas are interpreted to have formed by a reaction independent of that responsible for their An + Spl cores. The omnipresent orthopyroxene-depleted haloes enclosing these structures suggest that the coronal garnet formed by a reaction of the type:

$$\text{An} + \text{Spl} + \text{Opx} = \text{Grt} \quad [4]$$

The coronal garnet represents the lower-temperature (or higher-pressure) assemblage (Fig. 4). From this inference, we conclude that the Type-2 structures formed by a two-stage process encompassing the early formation (during near-isothermal decompression) of the An + Spl mosaics and subsequent crystallization (during near-isobaric cooling) of coronal garnet. In addition to microstructural criteria, progress of reaction [4] is supported by the grossular content of the coronal garnet (X_{Ca} in the range 0.13–0.14), which approximately corresponds to that in garnet [X_{Ca} = 0.167; see Thost *et al.* (1991, Fig. 12)] formed by the isochemical breakdown of Opx + Pl + Spl in the CMAS and CFMAS systems. The rimward decrease in grossular content that characterizes the garnet porphyroblasts indicates that these matrix grains re-equilibrated (along with andesine) during decompression to essentially the same P–T regime responsible for the growth of the grains of coronal garnet. These P–T conditions can be estimated by mineral thermobarometry.

Mineral Thermobarometry

Patterns of mineral zoning and corona structures provide a qualitative record of evolving P–T conditions of the granulite. A more quantitative assessment of metamorphic conditions can be made using the composition of P- and T-sensitive mineral assemblages. Evidence for disequilibrium (*e.g.*, mineral zoning, corona structures) in the granulite, however, hampers the reliable application of mineral thermobarometers.

Garnet forms a paragenesis with biotite and plagioclase, but not pyroxene. This places limitations on the use of reactions [1] and [2] to estimate P and T. These

TABLE 1. RESULTS OF ELECTRON-MICROPROBE ANALYSES OF SELECTED MINERALS FROM MAFIC GRANULITE FROM THE BOHEMIAN MASSIF, CZECH REPUBLIC

	Type-1 Corona						Type-2 Corona							
	Orthopyroxene Corona			Clinopyroxene Corona			Garnetiferous Corona			Matrix Assemblage				
	Opx*	Pl*	Grt (r)	Cpx*	Pl*	Grt (r)	Grt*	Pl	Spl‡	Opx	Cpx	Bt	Pl (c)	Pl (r)
SiO_2 wt%	50.40	57.93	38.37	52.07	57.15	38.20	38.75	44.39		52.57	52.38	37.09	62.29	60.39
TiO_2	0.13		0.20	0.14							0.78	5.12		
Al_2O_3	0.37	26.33	21.51	1.54	26.40	21.71	21.43	34.86	57.88	0.89	2.48	14.44	24.05	26.00
FeO_t	29.33	0.25	21.08	10.00	0.17	21.97	26.01		29.74	26.49	10.05	15.90		
MnO	0.80		0.84	0.39		1.00	2.33			0.87				
MgO	17.16	8.46	5.66	13.74		6.49	7.13		9.62	19.07	13.58	13.15		
CaO	0.59	6.67	12.38	22.40	8.85	10.18	5.09	20.53		0.71	22.93		5.90	8.13
Na_2O	0.31	0.40		0.55	6.49			0.55	0.66		0.75		7.30	6.71
K_2O					0.31							9.78	0.67	0.36
Total	99.09	100.04	100.04	100.83	99.37	99.55	100.74	100.33	97.90	100.60	102.95	95.48	100.21	101.59
X_{An}^{Pl}		0.403			0.422			0.954					0.296	0.393
$X_{Mg}^{Px,Bt,Spl}$	0.510			0.710					0.366	0.562	0.707	0.596		
X_{Mg}^{Grt}			0.211			0.243	0.267							
X_{Fe}^{Grt}			0.440			0.462	0.546							
X_{Ca}^{Grt}			0.331			0.274	0.137							
X_{Mn}^{Grt}			0.018			0.021	0.050							

* Denotes coronal phase. ‡ The spinel contains 1% ZnO. The symbols follow Kretz (1983); c indicates core, and r indicates rim.

assemblages, however, represent the only thermobarometric constraints on metamorphic P, an estimate of which is required for Grt–Bt and two-pyroxene thermometry, both of which have only slight P-dependence. Traditionally, core and rim compositions of minerals have been used to determine different points on the P–T path of granulites, but this approach can yield results that are inconsistent with P–T trajectories constrained by reaction textures (*e.g.*, coronas) (Selverstone & Chamberlain 1990). Furthermore, even if local (mm-scale) equilibrium is assumed, the compositions of coronal phases involved in reactions [1] and [2] can give spuriously low estimates of P because of significant down-T diffusion (approaching Mg–Fe diffusional blocking values) between garnet and pyroxene. This, however, does not appear to be the case in the present example.

Metamorphic conditions were determined using updated GEØ–CALC (Brown *et al.* 1988, Berman & Brown 1988) software (TWQ; Berman 1991) and the rim compositions of phases comprising P- and T-sensitive assemblages. TWQ performs multi-equilibrium calculations using an internally consistent thermodynamic database (Berman 1988) and recent activity–composition models [*e.g.*, garnet: Berman (1990), Berman & Koziol (1991); biotite: McMullin *et al.* (1991); plagioclase: Fuhrman & Lindsley (1988)] to calculate phase diagrams for specified mineral assemblages. In the present case, these include the Cpx – Grt – Pl – Qtz and Opx – Grt – Pl – Qtz assemblages from Type-1 coronas, and Grt–Bt and Opx–Cpx from the matrix. To avoid re-equilibration effects, the core compositions of matrix grains were used to estimate P and T.

Two-pyroxene thermometry indicates extreme metamorphic conditions (~900°C at 14 kbar) at the onset of decompression, leading to the formation of the Type-1 coronas. Note that the equilibrium curve pertinent to the formation of the An + Spl mosaics passes through the conditions inferred for the Type-1 coronas. This finding suggests the contemporaneity of these structures, but not of the garnet coronas themselves, which apparently resorb matrix (and locally Type-1 coronal) pyroxene (Figs. 2B, C, D), and are therefore interpreted as being relatively late structures. The elevated P–T estimates for the Type-1 structures are consistent with P–T conditions reported for granulites from the Bohemian massif in Austria (Carswell & O'Brien 1993). Garnet–biotite temperatures, however, approach 1100°C (at 14 kbar) and are considered to be overestimates because of indeterminate Fe^{3+} in biotite, which is likely to be considerable because of the presence of ilmenite in the rock (*cf.* Guidotti & Dyar 1991). Garnet–orthopyroxene and Grt–Cpx thermometry yields disparate temperatures (~1000° and 800°C, respectively), considered to be unreliable owing to probable disequilibrium between garnet porphyroblasts and matrix pyroxene. In both instances, these temperatures are 100–150°C higher than those determined for Type-1 corona structures comprising the same assemblages (Fig. 4).

We contend that cooling after near-isothermal decompression to pressures perhaps as low as 2–3 kbar (Fig. 4) led to the formation of coronal garnet at the expense of An + Spl mosaics and orthopyroxene. Assuming that domainal-scale equilibrium was achieved, the composition of coronal garnet and of nearby orthopyroxene suggests that the grains of coronal garnet formed at a temperature on the order of 750°C; this is a relatively high temperature, given the low pressure surmised for the Type-2 corona structures. Other investigators, however, also have concluded that elevated temperatures were maintained during decompression in parts of the Moldanubian Zone of the Bohemian Massif (O'Brien & Vrána 1995). Note that equilibrium curves representing the corona-forming reactions do not converge up-temperature (Fig. 4), such that the composition of the Type-2 structures is not simply an artifact of re-equilibration processes. This further supports the hypothesis that the grains of coronal garnet formed independently of, and at significantly lower pressures, than the An + Spl mosaics that they enclose.

The data reported here indicate that rocks presently exposed in the Blansky Les granulite complex followed a clockwise P–T–t path during tectonic uplift from the deep (~40 km) crust, whereupon cooling proceeded at shallow structural levels (~5–10 km) with comparatively little decompression.

Conclusions

High-P mafic granulite from the Blansky Les complex contains contrasting coronal structures that record near-isothermal decompression and subsequent near-isobaric cooling. The near-isothermal decompression leg of the P–T path for the granulite is recorded by pyroxene + andesine coronas on porphyroblastic garnet, the formation of An + Spl mosaics at the expense of early kyanite (now completely resorbed) and grossular-rich garnet, and the complementary patterns of zoning in porphyroblastic garnet (rimward decrease in grossular) and plagioclase (rimward increase in anorthite content). Near-isobaric cooling at a substantially lower pressure is recorded by the formation of low-grossular coronal garnet enclosing the An + Spl mosaics. The lower-T (or higher-P) character of the coronal garnet (*versus* the lower-P or higher-T nature of the coronal pyroxene) strongly suggests that the Type-2 structures are not contemporaneous with the Type-1 coronas, even if their An + Spl nucleus may be.

Mineral thermobarometry on coronal and matrix minerals indicates that the granulite was decompressed from pressures of ~14 kbar to ~2–3 kbar, and cooled from peak temperatures of ~900°C to ~750°C, whereupon the granulite followed a near-isobaric cooling trajectory. These data are indicative of a clockwise P–T–t path.

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