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GEOLOGY

High-Pressure Symplectitic Garnet–Clinopyroxene–Margarite–Muscovite–Clinozoisite Amphibolites of the Dakhov Block, Northern Caucasus: Genesis and Composition of Reaction Textures

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Knowledge of the petrology of metamorphic rocks composing the Dakhov Block of the crystalline basement of the Front Range in the Northern Caucasus has remained contradictory until very recent times. These rocks have been thought to have formed at low and medium temperatures and uncertain pressures [1] or at high temperatures and low pressures [2]. Our data on the symplectitic garnet amphibolites sampled in this block led us to believe that all metamorphic rocks of this massif are affiliated with a high-pressure series. As can be seen in outcrops in the lower parts of the Belaya and Syuk canyons, garnet amphibolites occur as conformable layers from a few decimeters to a few meters thick among garnet-free epidote- and clinopyroxene-bearing amphibolites, garnet schists, micaceous microgneisses (sometimes with relicts of porphyritic textures), two-feldspar biotite–hornblende gneisses, and rare muscovite–quartz schists, all of which were metamorphosed to the same grade.

The garnet amphibolites are noted for their unusual composition and contain 20–30% micro- to cryptocrystalline clinopyroxene ± hornblende–oligoclase symplectites. Along with these and with garnet, these rocks bear small porphyroblasts or round aggregates of hornblende, clinozoisite, Ca-clinopyroxene, calcic plagioclase, muscovite, margarite, and quartz.* The Cpx ± Hbl–Pl symplectites in metabasites are traditionally interpreted as resulting from the decompression-induced decomposition of early omphacite, whereas symplectite-bearing metabasites are thought to be recrystallized eclogites [3, 4]. However, no omphacite relicts have ever been found in these rocks. The Cpx–Hbl–Pl symplectites are the predominant—but not the only—type of their reaction textures, and microprobe study of them provides insight into the complicated prograde–retrograde metamorphic history of these rocks.

The relict minerals of the *presymplectite* stage make up the early equilibrium assemblage Grt + Hbl^1 + Czo^1 + Ca-Cpx^1 + Ms + Mrg + Pl^1 + Qtz ± Spl, which provides information on the conditions of the high-pressure epidote-amphibolite facies metamorphism. Judging from this assemblage, the protolith had an unusual composition—enriched in Al, Ca, and K—which suggests its sedimentary provenance. The garnet grains (both full grains and fragments), up to 8 mm across, show clearly pronounced prograde zoning with a significant increase in pyrope content from 15–18% in the cores to 33–36% in the margins with a simultaneous decrease in spessartine and grossular concentrations (table). Prismatic grains of Ca-amphibole (Hbl^1) have a composition corresponding to Mg-hornblendite [4], with moderate contents of Na, Al, and Fe (table). Clinozoisite (Czo^1) grains of similar size (Fig. 1) contain no more than 5 wt % Fe_2O_3. Round grains of primary highly calcic plagioclase (Pl^1) are zonal, with bytownite (80–87% An) cores and less calcic (20–47% An) outer zones. Rare Ca-clinopyroxene relicts (Cpx^1) contain no more than 0.5–2.5% jadeite, but none of these relicts is omphacite. The white K-mica is muscovite with minor contents of phengite (Si 3.0–3.2 f.u., (Mg + Fe) 0.08–0.40) and, occasionally, BaO (up to 2.9 wt %). Flakes of this mineral occur as round aggregates, which are either monomineralic or include tiny grains of high-Fe spinel with mildly elevated ZnO contents (table). Other round aggregates consist of margarite flakes with up to 2 wt % Na_2O (table). The quartz content varies from 0 to 15–20 wt %.

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* Mineral symbols: (Ab) albite, (An) anorthite, (Btw) bytownite, (Chl) chlorite, (Cpx) clinopyroxene, (Czo) clinozoisite, (Grt) garnet, (Hbl) hornblende, (Jd) jadeite, (Mag) magnetite, (Mrg) margarite, (Olg) oligoclase, (Pl) plagioclase, (Prp) pyrope, (Qtz) quartz, (Spl) spinel, and (Zs) zoisite.

Representative analyses (wt %) of some primary and secondary minerals in symplectitic Grt–Hbl–Cpx–Pl–Ms–Mrg–Qtz amphibolites and the Dakhov Block

Component	Sample 670/17				Sample 670/20			
	Grt → (Hbl^3 + Pl^3)				(Hbl^1 + Czo^1) → (Cpx^2 + Pl^2)			
	core	margin	kelyphite		large grains		symplectite	
SiO_2	38.19	39.59	40.59	51.19	50.21	39.77	53.95	62.44
TiO_2	0.12	–	–	–	0.23	0.10	–	–
Al_2O_3	21.19	22.15	17.85	30.48	8.98	29.79	0.53	23.02
FeO	24.05	20.28	14.97	0.37	7.06	4.24*	5.13	0.14
MnO	2.76	0.27	0.26	–	0.14	–	0.06	–
MgO	4.80	10.13	10.22	–	17.98	0.50	15.36	–
CaO	8.75	7.46	11.11	14.25	11.98	23.78	23.82	5.57
Na_2O	–	–	2.53	3.64	1.45	–	0.42	8.36
K_2O	–	–	0.22	–	0.15	0.04	–	0.02
ZnO								
Cr_2O_3								
Total	99.86	99.88	97.75	99.93	98.18	98.22	99.27	99.55
Fe/(Mg + Fe^{2+})	0.74	0.53	0.38		0.11		0.15	
Sps, %	6.0	0.6						
Prp	18.3	37.5						
Grs	24.1	19.8						
An, %				68.4				26.9
Jd, %							1.9	

Component	Sample 670/20						Sample 670/27	
	Czo^1 → An^2 → Olg^2			Mrg^1 → Zs^2 → Olg^2			Ms^1 + Spl^1	
	grain	double rim		grain	double rim		symplectite	
SiO_2	39.48	41.72	61.34	33.65	39.32	62.42	44.33	–
TiO_2	0.30	–	–	–	–	–	0.11	–
Al_2O_3	27.99	32.02	24.15	47.10	31.24	23.96	37.51	58.42
FeO	5.97*	0.38	0.19	0.19	1.91*	0.10	1.77	34.05
MnO	–	–	–	0.07	0.04	–	–	–
MgO	0.16	–	–	0.07	0.06	–	0.48	5.66
CaO	24.12	24.85	6.04	9.88	25.16	5.47	0.44	0.06
Na_2O	–	0.71	8.11	1.85	–	7.87	0.42	–
K_2O	0.01	0.08	0.10	0.56	–	0.06	10.23	–
ZnO								0.36
Cr_2O_3								0.41
Total	98.03	99.76	99.93	93.37	97.73	99.88	95.29	98.96
Fe/(Mg + Fe^{2+})								0.77
Sps, %								
Prp								
Grs								
An, %		94.7	29.0			27.6		
Jd, %								

Note: * All Fe is given as Fe_2O_3.

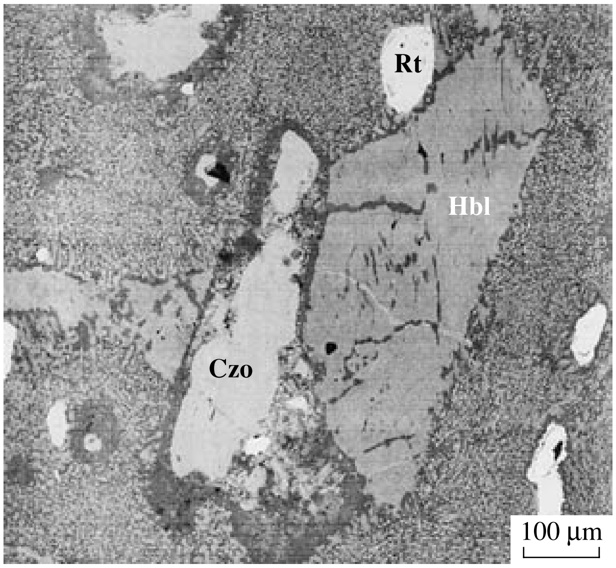

Fig. 1. BSE image of crystals of primary clinozoisite and hornblende in Cpx^2–Hbl^2–Pl^2 symplectite. The hornblende is cut by Olg veinlets that branch off the symplectite, and Czo is armored by a double Pl (An → Olg) rim.

Small rutile prisms are always armored, with titanite rims.

The *reaction textures* around the minerals of the early stage are extremely diverse. Some developed at a temperature increase, whereas others were produced by exhumation-related retrograde processes. The earliest and most widespread textures are extremely fine-grained (2–20 μm) Cpx^2–Hbl^2–Pl^2 symplectites, the minerals of which can be identified only at the very greatest magnification and, otherwise, appear to consist of blackish gray optically isotropic masses under a microscope. The ternary symplectites consist of augite with 1–3% Jd (Cpx^2), green hornblende (Hbl^2) of the Mg-hornblendite series [5], and oligoclase-andesine with 25–35% An (Pl^2) (table). Individual grains of Cpx^2 and Hbl^2 in the symplectites are in equilibrium or show traces of partial $Cpx^2 \rightarrow Hbl^2$ replacement. The Cpx^2–Hbl^2–Pl^2 symplectites display no reaction relations with Grt, Cpx^1, Ms, or Mrg but, in places, corrode Czo^1 and Hbl^1 porphyroblasts (Fig. 1), with the latter cut by tiny oligoclase veinlets branching from the main symplectite body. This means that the Cpx^2–Hbl^2–Pl^2 symplectites were formed not by omphacite decomposition, but by the prograde reaction $Hbl^1 + Czo^1 + Qtz \rightarrow Cpx^2$ ($\pm$ Hbl^2) + Pl^2 (Olg) + Grt (its prograde rim) + H_2O, which has an analogous result and increases the overall Cpx and Pl contents in the rocks via the decomposition of two hydrous minerals (Hbl^1 and Czo^1). This reaction is also favorable for the development of prograde zoning in garnet and the formation of the Grt + Cpx^2 assemblage (because the garnet was, obviously, in equilibrium with the surrounding symplectitic matrix). Similar symplectite-forming reactions, proceeding at a metamorphic culmination, were described earlier in [6]. In this situation, the peak character of the metamorphism follows from the fact that larger relict grains of Cpx^1 in these rocks and the newly formed Cpx^2 in the symplectites have Jd contents (1–3%) absolutely analogous to those in clinopyroxene in the medium-grained equilibrated nemato-granoblastic Cpx–Hbl–Czo–Pl amphibolites surrounding these rocks. This testifies that the Cpx^2–Hbl^2–Pl^2 symplectites were produced under the *PT* conditions of the metamorphic culmination that affected the whole rock sequence during its prograde evolution.

Most clinozoisite porphyroblasts are surrounded by double concentric plagioclase rims, the inner portions of which consist of anorthite (table) or bytownite and the outer parts of which have an oligoclase composition, with Ab concentration gradually increasing toward the outer parts of the rim. These rims likely developed roughly simultaneously with the symplectite-forming reactions, which, in turn, also points to a general diminishing of Czo stability during the prograde stage. Morphologically analogous double concentric textures surround the margarite aggregates as well. These rims consist of inner zoisite and outer oligoclase parts (table) and also mark processes of prograde dehydration. They seem to have had a more complicated evolutionary history: first, margarite was partly replaced by zoisite, and the zoisite rims were then replaced by oligoclase, perhaps simultaneously with the growth of plagioclase rims around clinozoisite porphyroblasts.

Other types of reaction textures were produced after the Cpx^2–Hbl^2–Pl^2 symplectites and Pl rims around Czo and Mrg and are retrograde but not prograde. These are, first of all, hornblende (magnetite)–plagioclase kelyphites with globular textures that grew around all the garnet grains at their contacts with Cpx^2–Hbl^2–Pl^2 symplectites (Fig. 2). The kelyphites consist of intergrowths of high-Al (up to 19 wt % Al_2O_3) Ca-amphibole of the pargasite and tschermakite series [5] and calcic plagioclase with 60–87% An (table) with chains of magnetite grains in the peripheral part of the kelyphite rims. Since Hbl^3–Pl^3 $\pm$ Mag kelyphites developed only at contacts of garnet with Cpx^2–Hbl^2–Pl^2 symplectites, it is obvious that they were produced by reactions between the garnet and symplectitic pyroxene with the participation of an aqueous oxidized alkaline fluid: Grt + Cpx^2 + Na_2O + H_2O + $O_2 \rightarrow Pl^3$(60–87% An) + Hbl^3 + Mag $\pm$ Qtz. In addition to the kelyphites, this reaction was responsible for the corrosion of the outer progradely zoned parts of garnet grains and the replacement of neighboring Cpx^2 ingrowths in the symplectite by Ca-amphibole, i.e., the reversed expansion of the Ca-amphibole (Hbl^3) stability field. This reaction marked the onset of retrograde exhumation with inflow of H_2O, Na_2O, and O_2. A further temperature increase caused the fragmentation of garnet grains, a process that became more extensive with decreasing temperature, and their replacement by networks of fractures filled with Hbl^3–Pl^3–Chl–Mag aggregates with significant amounts of chlorite and equilibrium relationships between all of the four phases. The hornblende in these "veinlets" in garnet is pargasite or tschermakite, the plagioclase composition varies from andesine to bytownite (36–80% An), the chlorite has an Fe mole fraction of 40–50%, and magnetite occurs as disseminated minor inclusions. These veinlets sometimes merge to compose nearly complete pseudomorphs after garnet, the relicts of which completely preserve, nevertheless, their prograde zoning. At contacts with quartz, the outermost zones of the garnet crystals are sometimes replaced by chlorite–bytownite rims with an inner monomineralic bytownite part (82–84% An) and an outer (in contact with quartz) monomineralic chlorite rim with a minor pargasite admixture.

Indications of Na inflow are variably pronounced during all stages of the development of the reaction textures: these are the replacement of An rims around Czo by more sodic plagioclase, the replacement of Zs rims around Mrg by oligoclase, the formation of Olg veinlets crosscutting Hbl^1 porphyroblasts, the growth of Hbl–Pl and Chl–Btw kelyphites around garnet grains, and the corrosion of garnet cores by a network of Hbl–Pl–Chl–Mag veinlets. All of these reactions expand the stability of Na-bearing minerals: plagioclase and hornblende.

The lowest-temperature reaction processes are the replacement of symplectitic Cpx and Hbl by actinolite and, in places, the replacement of all clinozoisite generations by pumpellyite.

Hence, the symplectite-bearing amphibolites provide a record of both the prograde process and the retrograde exhumation. The former was responsible for the clearly pronounced prograde zoning of garnet grains in the early assemblage with Ca-Cpx, Hbl, Czo, Ms, Mrg, and Ca-Pl and, later, brought about the development of Cpx^2–Hbl^2–Pl^2 symplectites, zonal Pl rims around clinozoisite, and zoisite–plagioclase rims around margarite, which provide evidence of decreasing stability of Hbl, Czo, and Mrg and expanding stability of Cpx and Pl. During the subsequent stage of retrograde exhumation, the Grt + Cpx assemblage decomposed with the growth of Hbl^3–Pl^3 ± Mrg kelyphites and the garnet was partly replaced by Hbl–Pl–Chl–Mag and Chl–Btw aggregates.

It is difficult to reconstruct the *PT* parameters of the prograde and retrograde stages for the symplectitic amphibolites because of the massive development of reaction textures, due to which garnet is always separated from primary Cpx^1, Hbl^1, and Pl^1 porphyroblasts with kelyphite rims or symplectites. We conducted Grt–Cpx and Grt–Hbl geothermometric calculations for the selected compositions of the outer prograde zones of garnet crystals and nearby grains of Cpx^1 and Hbl^1 (which were not in contact with garnet). The temperatures were estimated approximately by a Grt–Cpx thermometer [7] at 620–660°C and by a Grt–Hbl thermometer [8] at 630–670°C. Taking into account that the primary assemblage of the amphibolites included stable Ms, Czo (Zs), and Mrg, the maximum metamorphic-culmination temperatures of 620–660°C seem to be fairly reasonable but, perhaps, slightly overestimated. The peak pressure at this temperature was evaluated by a Grt–Cpx–Pl–Qtz barometer [9] at 8–9.5 kbar, which corresponds to the high-pressure epidote-amphibolite or amphibolite facies. The stability of the highly magnesian garnet (up to 36% Prp in the margin) confirms a high-pressure type of metamorphism, but the very low Jd content (no more than 3%) of the primary clinopyroxene indicates that eclogite-facies *PT* parameters were not attained during the early evolutionary stages of the symplectite-bearing amphibolites.

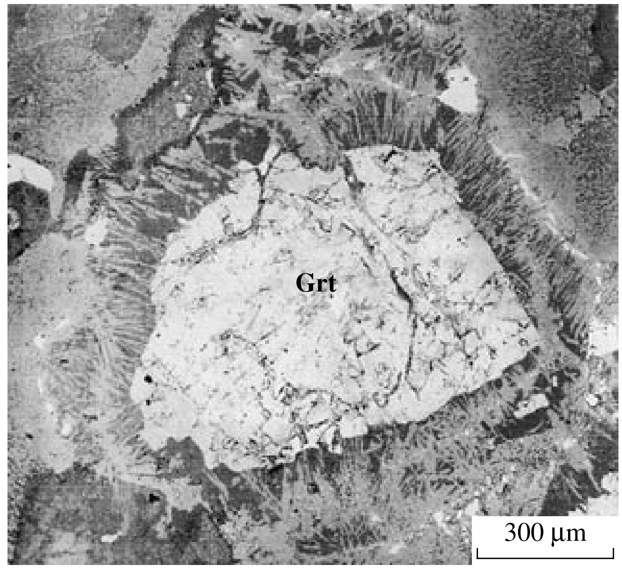

Fig. 2. BSE image of crystals of a hornblende–plagioclase kelyphite rim around a progradely zoned garnet grain in contact with Cpx^2–Hbl^2–Pl^2 symplectite. Magnetite dust (white) is concentrated in the peripheral portion of the kelyphite.

The high-pressure character of the metamorphic rocks from the Dakhov Block makes them similar to the Blyb eclogite-bearing complex in the southern part of the Front Range [2, 10], but the maximum pressures in the block were lower than in the Blyb Complex, at least in the part containing kyanite eclogites and showing evidence of pressures as high as 16 kbar [10]. Other stratigraphic units of this complex also offer apparent evidence of high metamorphic pressures [1], but no exact evaluations have been made for them as yet. The Dakhov and Blyb metamorphic rocks mark, along with the spatially related ultrabasites, a broad ancient (Late Paleozoic) subduction zone, the development of which may have induced many events during the pre-Alpine evolutionary stage of the Greater Caucasus.

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REFERENCES

1. D. M. Shengelia, *Petrology of Paleozoic Granitoids of the Northern Caucasus* (Mecnieroba, Tbilisi, 1972) [in Russian].
2. D. M. Shengelia, S. P. Korikovsky, G. L. Chichinadze, *et al.*, *Petrology of Metamorphic Complexes of the Greater Caucasus* (Nauka, Moscow, 1991) [in Russian].
3. V. Joanny, H. van Roemund, and J. M. Lardeaux, Geol. Rundsch. **80**, 303 (1991).
4. P. O'Brien, J. Metamorph. Geol. **11**, 241 (1993).
5. B. E. Leake, A. R Wooley, C. E. S. Arps, *et al.*, Eur. J. Mineral. **9**, 623 (1997).
6. S. P. Korikovsky and D. Hovorka, Petrology **9**, 119 (2001).
7. E. Krogh Ravna, J. Metamorph. Geol. **18**, 211 (2000).
8. L. L. Perchuk, Geochem. Int. **12**, 1 (1989).
9. J. O. Eckert, R. C. Newton, and O. J. Kleppa, Am. Mineral. **76**, 148 (1991).
10. A. L. Perchuk and P. Philipot, J. Metamorph. Geol. **15**, 299 (1997).