=========== **GEOPHYSICS** ===========

Sheathlike Metasomatic Garnet Crystals from the Maksyutovo Metamorphic Complex, the Southern Urals

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Most petrographers who have studied the Maksyutovo metamorphic complex in the southern Urals have paid attention to the sheathlike garnet crystals in schists. Such crystals have retained their outer shell (sheath) of a regular rhombic dodecahedral shape filled with an aggregate of composition similar to that of the host schist. Lennykh [1] suggested a pseudomorphic metasomatic nature of these crystals. However, their formation mechanism remained ambiguous.

The Maksyutovo Complex is located in the southern Urals as a near-meridional belt 180 km long and 12–16 km wide. Eclogites and products of their metasomatic alteration (schists) are widespread in this complex. The alteration begins from the alkaline sodic metasomatism that fostered replacement of eclogites with glaucophane schists. Sodic metasomatism gave way to potassic metasomatism. Both the relict eclogites and glaucophane schists were replaced with phengite schists. The following acid leaching led to silicification with formation of quartz–phengite schists and quartzites. The basification zone composed of garnet–diopside–epidote skarnoids and diopside skarns is conjugated with alkaline metasomatism and acid leaching zones. Thus, a classic metasomatic triad [2] is outlined in the Maksyutovo Complex.

Garnet, the major rock-forming mineral, occurs as porphyroblasts in eclogite and all varieties of metasomatic rocks. However, the garnet grains show a systematic compositional variation [1, 3]. In garnet–omphacite eclogite (protolith of metasomatic rocks), the pyrope–grossular–almandine garnet occurs as regular homogeneous crystals (Alm 49–50, Pyr 22–27, and

Gros 20–23) and occasionally contains small rutile inclusions. Garnet from pyroxene skarns and skarnoids is characterized by a prevalence of grossular (Alm 44–45, Pyr 2–4, and Gros 48–53). In glaucophane schists, garnet grains retain their euhedral shape. However, they are depleted in Mg and enriched in Fe. The Ca content remains almost constant (Alm 56–60, Pyr 10–12, and Gros 23–25). Separate glaucophane and phengite inclusions are scattered in cores of such garnet grains as incipient signs of development of sheathlike aggregates. The typical sheathlike garnet that occurs in quartz–phengite schists is sharply depleted in Ca but enriched in Fe and Mg in comparison with garnet from glaucophane schists.

The sheathlike garnet porphyroblasts (1–2 mm in size) are uniformly scattered in the lepidogranoblastic matrix with a grain size of 0.2–0.5 mm. The matrix consists of phengite flakes, equant quartz grains, and irregular grains of glaucophane (Fig. 1). The quartz–mica aggregate inside a "ring" is similar in morphology to the matrix and includes irregular, often very small garnet grains (Fig. 2). Compositions of garnet and mica were studied with a CamScanMV2300D SEM equipped with X-ray microprobe (V.V. Pavshukov, analyst). A thin (up to 0.03–0.05 mm) and homogeneous outer rim of pyrope–almandine composition (Table 1, analysis 1) is distinguished by higher pyrope content in comparison with the remaining part of garnet grain. Compositions of the inner and intermediate zones of the garnet sheath deviate from stoichiometry (Table 1, analyses 2, 3) due to an excess of SiO_2 and a deficiency in Fe. The composition of small garnet grain within the sheath (Table 1, analyses 4–6) is also nonstoichiometric but characterized by an excess of Fe and a deficiency in SiO_2. The composition of the grain measured over an area 100×100 μm (Table 1, analysis 7) at points 4–6 corresponds to the ideally stoichiometric garnet (Mg/Fe = 23.14/77.86, mol. %, Table 1, analysis 7) and differs from the garnet of the outer rim by a higher Fe content due to the replacement of Mg. It is noteworthy that phengite within the sheath is also characterized by more magnesian composition

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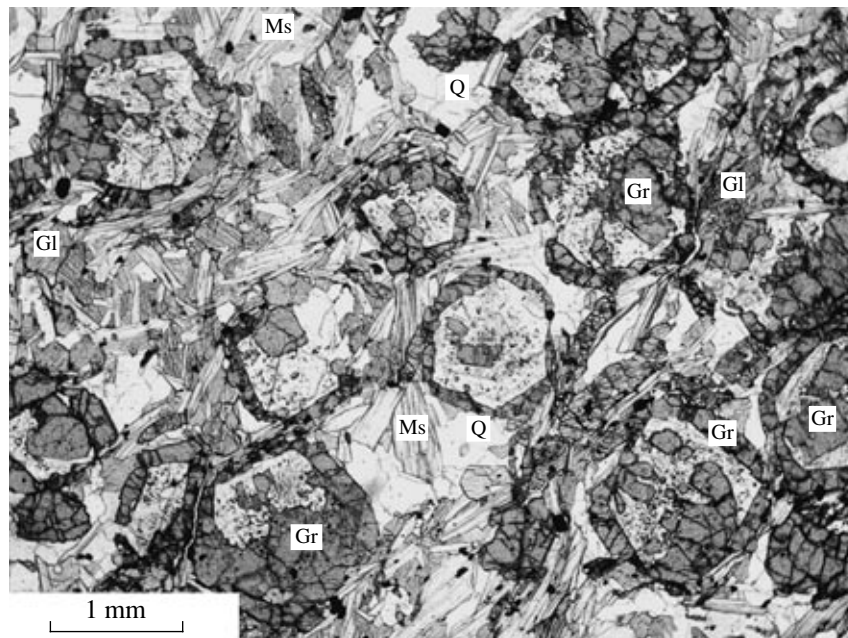
Fig. 1. Glaucophane–garnet–phengite schist with sheathlike garnet. (Gl) glaucophane, (Gr) garnet, (Ms) muscovite (phengite), (Q) quartz.
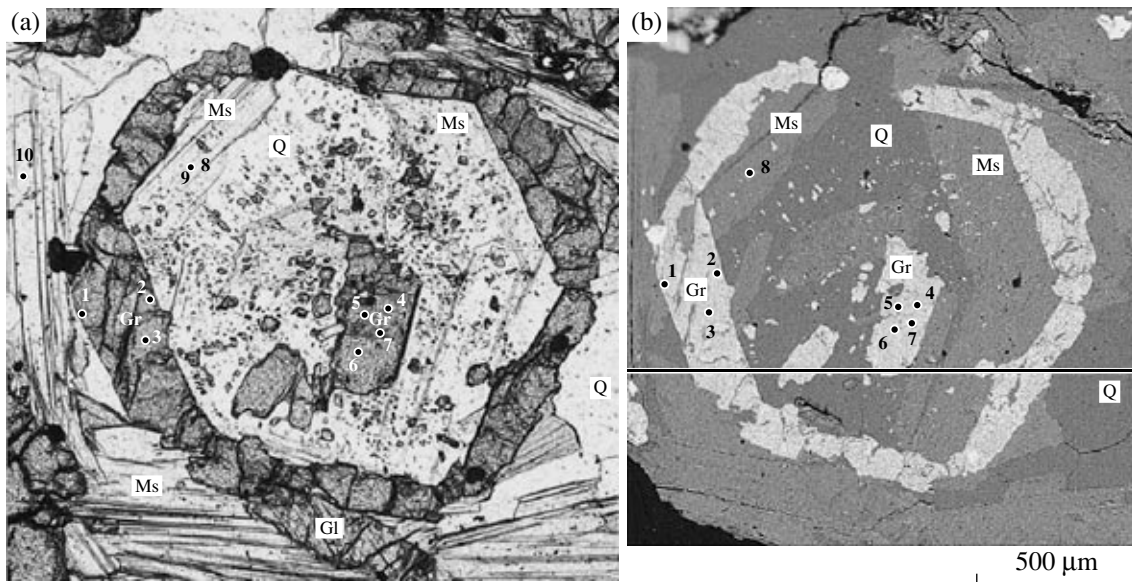

Fig. 2. Sheathlike garnet with quartz–phengite core in (a) transmitted light and (b) BSE image. Numerals are points of analyses (see Tables 1 and 2).

in comparison with phengite in the matrix (Table 2). Such a distribution of Fe and Mg in both garnet and mica is a result of acidic leaching that leads to the formation of sheathlike metasomatic garnet crystals.

In terms of crystal genesis [4], the sheathlike garnets and their filling are pseudomorphs, which, together with host matrix, are products of metasomatic replacement of the garnet–glaucophane rock. Garnet shells and adjoining quartz–phengite zones compose the mono- and polycrystalline portions of pseudomorphs. The

shapeless large garnet grains in pseudomorph cores and small garnet particles in quartz–phengite zones (Fig. 2) are relics of the initial garnet. Such an interpretation is supported by specific outer and inner morphological features and the chemical composition of garnet.

Preservation of outer garnet zones was promoted by the excessive-volumetric replacement at the early stage. Consequently, the outer zones attained equilibrium with the solution and the metasomatic process did not develop in inner zones of the grain. This is indicated by

Table 1. Composition of different zones in a sheathlike garnet grain (Fig. 2)

Compo-nent	Ring						Irregular grain in ring center						Integral composition over an area of 100×100 μm	
	outer margin		middle zone		inner margin									
	1		2		3		4		5		6		7	
	wt %	f.u.	wt %	f.u.	wt %	f.u.	wt %	f.u.	wt %	f.u.	wt %	f.u.	wt %	f.u.
SiO_2	38.37	3.00	40.05	3.09	39.03	3.04	36.15	2.91	36.08	2.92	37.02	2.96	38.21	3.00
TiO_2	0.15	0.01	0.10	0.01	0.19	0.01	0.10	0.01	0.15	0.01	0.10	0.01	0.01	0.01
Al_2O_3	21.56	1.99	21.99	2.00	21.83	2.00	19.45	1.89	19.34	1.84	20.65	1.94	1.96	1.96
FeO	29.37	1.92	27.90	1.80	29.30	1.91	33.20	2.24	33.93	2.30	32.42	2.17	30.24	2.00
MnO	0.73	0.05	0.64	0.04	0.56	0.04	0.06	0.06	0.81	0.06	0.81	0.05	0.85	0.06
MgO	6.20	0.75	5.70	0.66	5.91	0.69	5.58	0.67	5.45	0.66	4.88	0.58	5.17	0.61
CaO	3.69	0.31	3.65	0.30	3.20	0.27	0.36	0.36	0.38	0.38	0.35	0.35	4.16	0.35
Total	100.09	8.00	100.03	7.90	100.0	7.96	99.9	8.13	100.0	8.17	100	8.06	100	8.0

the following facts: the presence of autoepitaxic overgrowths (Fig. 3, arrow) typical of the excessive-volumetric mechanism of isomorphic monocrystalline replacement; the homogeneous darkening of the thin outer part of the replacement zone (Fig. 3); and the enrichment of the outer part in Mg relative to the intermediate and inner parts and central relict grains (Mg/Fe = 28.09/71.91, 26.83/73.17, 26.54/73.46, and 23.14/77.86, mol %, respectively). Judging from darkening beneath the overgrowth, the mass exchange was most intense in its vicinity. This conclusion is consistent with experimental data [4, p. 100]. As a result, the process of replacement was realized further in the inner (nonequilibrium) zone of the crystal adjoining the sheath, and the mass exchange was developed along thin cracks that cut the garnet sheath. "Fans" composed of ultramicroscopic Mg–Ca–Fe aggregates are observed at outlets of these

Table 2. Composition of phengite (Fig. 2)

Com-ponent	In ring center				Beyond the ring	
	analysis 8		analysis 9 $(60 \times 60$ μm)		analysis 10	
	wt %	f.u.	wt %	f.u.	wt %	f.u.
SiO_2	50.62	3.41	51.73	3.39	50.70	3.34
TiO_2	0.53	0.03	0.46	0.02	0.94	0.05
Al_2O_3	27.29	2.16	28.30	2.18	27.54	2.14
FeO	1.69	0.09	1.89	0.10	4.46	0.24
MgO	3.01	0.30	3.16	0.17	3.12	0.31
CaO	0.15	0.01	0.09	0.01	0.01	0.00
Na_2O	1.07	0.14	1.32	0.17	1.59	0.20
K_2O	9.55	0.82	9.45	0.79	8.13	0.68
Total	93.91	11.00	96.46	11.00	96.56	11.00

Note: Analyses 8 and 9 (integral) were carried out at a single point.

cracks from garnet grain (Fig. 3), indicating intense removal of bivalent bases from the central part of the pseudomorph. This process is typical of acidic leaching. Cracks (conduits) are also surrounded by thin (uniformly darkened) zones (Fig.3). They are similar to the outer zones and testify to the excessive-volumetric replacement. The spotty character of optic transmission (Fig. 3) demonstrates nonuniform distribution of isomorphic components as a result of the excessive-volumetric replacement [4, p. 97].

The identity of outer and inner contours of garnet sheaths is the most remarkable feature (Figs. 1, 2). The outer contours are undoubtedly related to growth, whereas the inner contours should be regarded as a replacement front, the morphology of which is controlled by dissolution as a limiting factor of replacement. It is known that crystal cavities are faceted by dissolution. Moreover, they are faceted by slowly dissolving surfaces that govern the outer shape of crystal growth. On the contrary, if the cavity is filled, it is faceted by rapidly growing surfaces [5 and others] and therefore cannot reproduce an outer shape of crystal growth. The opposite replacement front developed around relicts of the primary garnet (central zones and small inclusions in pseudomorphs) has a shapeless surface typical of corrosion. At the same time, zones around the pseudomorphs are characterized by the replacement of glaucophane with phengite. Glaucophane relicts are also retained (Fig. 1).

Most likely, the pseudomorphous replacement proceeded rather slowly under conditions close to the equilibrium. This is confirmed by three circumstances: (1) the coarse-crystalline structure of the quartz–mica aggregate owing to a low concentration of crystallization centers (even monocrystalline mica cores are observed in some pseudomorphs); (2) the abundance of small garnet relicts in the zones replaced by muscovite (they should have been readily replaced in the course of
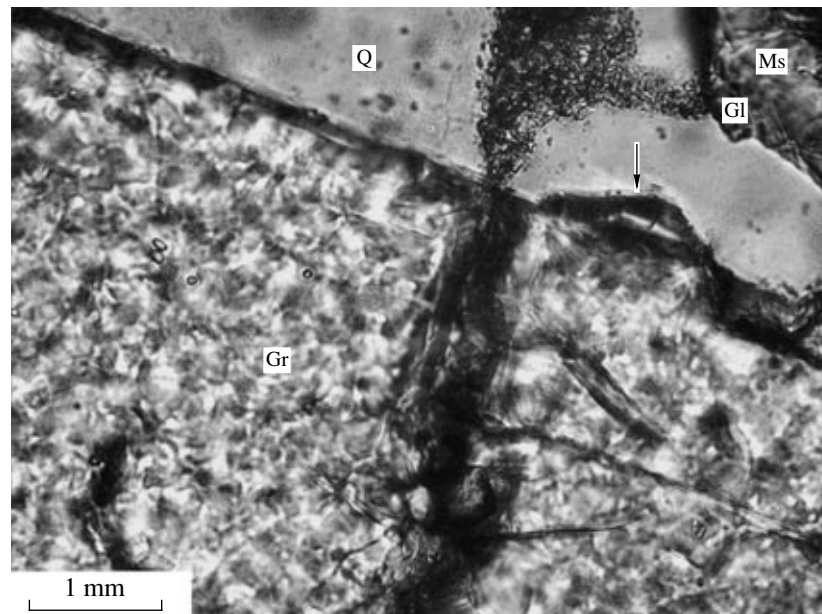
Fig. 3. A fan of removal of bivalent bases from garnet, autoepitaxic overgrowths (arrow), replaced marginal and near-crack areas (dark zones), and inhomogeneity of garnet grain. Plane light.

intense nonequilibrium dissolution); and (3) rather similar compositions of the replaced and equilibrium zones in garnet crystals. However, it is remarkable that even minor variations in proportions of isomorphic components in crystal may exert crucial impact on the course and results of replacement.

Thus, we are dealing here with an unusual case of garnet crystal replacement from the inside, while the outer zone is retained as a monocrystalline (isomorphically replaced) sheath that envelopes the secondary quartz–phengite aggregate with relicts of primary garnet. The process requires a change of physicochemical conditions that provides the fast replacement of the peripheral zone of the primary crystal up to its equilibrium with a solution at the initial stage, whereas the subsequent stage is characterized by intense replacement of a nonequilibrium relict. A similar process with a change of conditions produces sheathlike polycrystalline pseudomorphs [4, p. 47]. Data points corresponding to changes in the character of replacement should be referred to as singular points in phase diagrams [6, p. 51].

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