HABIT EVOLUTION OF GARNETS FROM METAMORPHIC ROCKS IN THE SAKAR REGION (SE BULGARIA)

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(Submitted by Corresponding Member I. Velinov on March 13, 2007)

Abstract

An evolution change in the habit type of garnets from the metamorphic rocks in the areas of the villages Orlov Dol, Hlyabovo (along the Yavuz Dere River) and Dervishka Mogila is observed due to the change of P-T conditions during the garnet growth. This habit evolution is assumed on the basis of calculated cation $R^{2+}/R^{3+}$ and oxide $(\text{FeO}+\text{MgO})/\text{(CaO}+\text{MnO})$ ratios for the core and periphery parts of garnet crystals.

At the early stages of growth, garnet crystals form rhombododecahedral type $f$ and type $e$ (rhombododecahedral crystals with small \{211\} faces), which is transformed later to type $c$, represented by equally developed rhombododecahedral and tetragondodecahedral faces. Numerous rough growth figures, formed on the faces \{211\} in the process of crystal growth, as well as relatively smooth surface of faces \{110\} in combined habit types support this assumption.

Key words: garnet, habit type, evolution, cation ratio, Sakar

Introduction. The number, type and equal degree of development of faces in combined shapes depend on the specific physical and chemical conditions as well as on the way of crystal growth, and especially for the garnet – on the cation ratio between bivalent and trivalent cations in its structure $[1,2]$. As the $[\text{SiO}_4]$ groups remain almost invariable (the partial replacement of Si from other cations in tetrahedral coordination is insignificant), the ratio between mean radii of bivalent and trivalent cations $R^{2+}/R^{3+} = 1.60$ is accepted as habit-forming factor $[2]$. During calculation of this ratio (for garnets from the region of Sakar, Fig. 1) based on the effective ion radii after SHANNON and PREWITT $[3]$ and SHANNON $[4]$, it was established that the rhombododecahedral habit type $f$ (Fig. 2a, b, c) and habit type $e$ – combination between
Fig. 1. Geological map of the investigated area after geological map of Bulgaria M 1:100 000 (simplified with places of sampling)

Fig. 2. Habit types of garnet: a – habit type f, crystal size 13.80 mm (HY–8); b – habit type f, crystal size 5.45 mm (PL–12); c – habit type f, crystal size 9.56 mm (DM–14); d – habit type e, crystal size 19.70 mm (HY–8); e – habit type e, crystal size 4.85 mm (OD–4); f – habit type c, crystal size 11.30 mm (HY–8)
Fig. 2
Fig. 3. Habit evolution of garnets from metamorphic rocks, outcropping south-east of the village of Orlov Dol (OD–4), along the Yavuz Dere valley in the area of the village of Hlyabovo (HY–8) and in the area of peak Dervishka Mogila (DM–14)

\{110\} and \{211\} with a dominant \{110\} shape (Fig. 2d, e) are registered at values of \(R^{2+}/R^{3+}\) ratio up to 1.785. The habit type \(c\) – combination of relatively equally developed \{110\} and \{211\} faces (Fig. 2f) in garnets from the studied region is shaped at values of cation ratio under 1.740 \[^5\].

Geological notes and sampling. The studied schists are part of the rocks which formed the metamorphic frame of the Sakar pluton, SE Bulgaria. Stratigraphically they belong to the Zhalti Chal \[^6\] and Ustrem \[^7,8\] Formations. It has been suggested that they have undergone metamorphism into the amphibolite \[^8-10\] or epidote-amphibolite \[^11,12\] facies. The places of sampling are in the areas of the villages Orlov Dol, Hlyabovo, Oreshnik, Planinovo and Dervishka Mogila (Fig. 1). The garnets are of an almandine composition \[^5\].

Methods. The chemical compositions of the garnets were studied by inductively coupled plasma with atom emission spectrometry (AES ICP). The spatial variation of the chemical composition of the samples was investigated by electron microprobe analyses (ARL-SEM S30, 4 spectrometers, EDS Link, 20 KV, 20 nA).

The habit types of the crystals are defined according to the suggested habit types for garnets in Bulgaria by Kostov \[^2\]. Some of the garnet crystals were studied with the help of contact Karl Zeiss Jena goniometer at St. Ivan Rilski University of Mining and Geology, Sofia.

Results. Concerning garnets with clearly expressed chemical zonality of growth, ratios between bivalent and trivalent cations in their structure, calculated on the basis of microprobe analyses of crystals’ core differ significantly from those of the crystals’ periphery. The increasing of these values above 1.740, which represents the habit determinative factor, provides information about the evolution of crystal morphology of garnets.

Growth zonality has been registered in garnets from the studied region. As they are characteristic with layered type of growth, each newly-shaped layer is with different chemical composition compared to the previous one. Under the normal type of zonality, the content of FeO and MgO increases from the core to the periphery parts of the crystals at the expense of MnO and CaO contents. Due to the significant differences in the effective ion radii of \(Mg^{2+}\) and \(Ca^{2+}\) in octahedral coordination, i.e. \(Mg^{2+} = 0.89\ \text{Å}\) and \(Ca^{2+} = 1.12\ \text{Å}\ \[^3,4\]\, the change in the chemical composition of garnets reflects on the cation ratios, calculated for different parts of the profile line along the crystal’s diameter.

Cation ratios for the core and periphery parts of garnets from mineralizations Orlov Dol (OD–2, OD–5, OD–6); Hlyabovo (HY–7); Oreshnik (OR–9) and Planinovo (PL–11a, PL–12) (Fig. 1; Table 1) are above the limit value 1.740. No change of their habit type could be supposed. At the early stage of the garnet growth as in the final one, their habit type is of rhombododecahedral type \(f\). In this case the presence of

Fig. 4. Growth ledges shaping step-like tetragontrioctahedral faces on \{211\}
Table 1
Cation $R^{2+}/R^{3+}$ and oxide (FeO+MgO)/(CaO+MnO) ratios calculated on the basis of microprobe analyses in the cores and rims of the garnets; pre – prekinematic, syn – synkinematic

<table>
<thead>
<tr>
<th>Mineralizations</th>
<th>$R^{2+}/R^{3+}$</th>
<th>(FeO+MgO)/(CaO+MnO)</th>
<th>Core</th>
<th>Rim</th>
<th>Rim/core oxide ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>core</td>
<td>rim</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Metapelites</td>
<td>1.785</td>
<td>1.753</td>
<td>3.20</td>
<td>4.58</td>
<td>1.4</td>
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<tr>
<td>OD-2 pre</td>
<td>1.798</td>
<td>1.781</td>
<td>1.60</td>
<td>2.26</td>
<td>1.4</td>
</tr>
<tr>
<td>OD-2 syn</td>
<td>1.772</td>
<td>1.734</td>
<td>2.11</td>
<td>9.93</td>
<td>4.7</td>
</tr>
<tr>
<td>OD-5 syn</td>
<td>1.798</td>
<td>1.751</td>
<td>3.31</td>
<td>11.09</td>
<td>3.4</td>
</tr>
<tr>
<td>HY-8 syn</td>
<td>1.790</td>
<td>1.732</td>
<td>3.28</td>
<td>20.57</td>
<td>6.3</td>
</tr>
<tr>
<td>OR-9 syn</td>
<td>1.755</td>
<td>1.748</td>
<td>5.22</td>
<td>9.68</td>
<td>1.9</td>
</tr>
<tr>
<td>PL-12 pre</td>
<td>1.789</td>
<td>1.748</td>
<td>3.56</td>
<td>7.61</td>
<td>2.1</td>
</tr>
<tr>
<td>PL-12 syn</td>
<td>1.788</td>
<td>1.764</td>
<td>2.72</td>
<td>5.61</td>
<td>2.1</td>
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<tr>
<td>DM-14 syn</td>
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<td>1.720</td>
<td>4.02</td>
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<td>5.1</td>
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<tr>
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<td>2.62</td>
<td>3.44</td>
<td>1.3</td>
</tr>
<tr>
<td>HS-7</td>
<td>1.789</td>
<td>1.768</td>
<td>3.64</td>
<td>4.98</td>
<td>1.4</td>
</tr>
<tr>
<td>PL-11a</td>
<td></td>
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tetragonaltrioctahedral simple shape is possible as an extremely weakly developed thin stripe, blunting rhombododecahedral edges – type e. These results were confirmed by the garnets’ crystal shapes observed in the regions quoted above [9].

The calculated cation ratios for the cores in crystals from Orlov dol (OD-4), Hlyabovo (HY-8) and Dervishka Mogila (DM-14) are above the established limit value 1.740, whereas in their periphery parts values are respectively 1.734; 1.732 and 1.720 (Table 1). During the early stages of their growth, the crystals have been probably of habit type f up to type e, which later has been altered to combined type c, represented by equally developed rhombododecahedral and tetragonaltrioctahedral faces (Fig. 3). The cation ratio under 1.740 established for the garnet periphery from the mineralizations OD-4, HY-8 and DM-14 coincides with the fact that garnet crystals with equally developed simple shapes {110} and {211} have been observed only in these outcrops [9].

The gradual substitution of rhombododecahedral with tetragonaltrioctahedral simple form is confirmed by the observations on the outer surface of the minerals. In the combined habit types, the {110} faces are characteristic with relatively smooth surface, whereas numerous growth ledges shaping step-like tetragonaltrioctahedral faces are observed on {211} (Fig. 4a, b). In the combined habit type numerous rough figures of growth on the faces of one simple form and relatively smooth surface of another simple form as a rule are observed during the change of a crystal habit type, resulting from the change of the outer growth conditions. Rough figures correspond to the faces with a higher rate of growth [13].

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The increase of the oxide ratio \((\text{FeO}+\text{MgO})/(\text{CaO}+\text{MnO})\) in garnets indicates an increase of the temperature of the metamorphic process. It is connected to the pressure as well [14]. After the calculation of the oxide ratio by the data from microprobe analyses of the cores and rims of the garnets from the studied outcrops, it was established that in the periphery of crystals from OD–4, HY–8 and DM–14 the ratio is five to six times higher compared to the calculated value for their cores, i.e. the P–T conditions in these mineralizations have changed drastically during the garnet growth (Table 1). This has reflected on the significant change of the cation ratio \(R^{2+}/R^{3+}\) in the periphery parts of the crystals compared to their cores. In the cores the \(R^{2+}/R^{3+}\) ratio determines formation of habit type \(f\) up to type \(e\), and in the periphery parts – habit type \(c\), i.e. the habit type of the garnets has evolved during their growth from rhombohedral type (without or with tetragonalhexagonal faces developed in insignificant degree) up to combined type with relatively equally developed \{110\} and \{211\} faces as a result from the change in the mineral forming conditions.

**Conclusion.** As a result of the established dependence of external morphology of garnets on cation ratio \(R^{2+}/R^{3+}\) an evolution in their habit type is supposed. For the synkinematic garnets [15] from outcrops in the region of the villages of Orlov Dol (OD–4), Hlyabovo (HY–8) and Dervishka Mogila (DM–14) the gradual substitution of rhombohedral with tetragonalhexagonal simple shape is assumed as following: \{110\} \(\rightarrow\) \{110\} with subordinate \{211\} \(\rightarrow\) \{110\} + \{211\}. The last habit type is evidence for a quick crystal growth in non-equilibrium conditions, i.e. a change in temperature and/or pressure, increased fluid circulation and other factors.

**REFERENCES**


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