New data on the geochemistry of metabasic rocks from the eastern marginal part of the Madan-Davidkovo Structure, Central Rhodope

Lilan Daieva, Stefka Pristavova

Abstract. Metabasites from the eastern periphery of the Madan-Davidkovo Structure (MDS) are an interesting example of magmatic activity in the Rhodope crystalline complex. These rocks occur as several small bodies southeast of the village of Galabovo (Ahryane). They are hosted within the metamorphites of the Vishnevo Formation (Arda Group). The metabasite bodies show well preserved igneous texture and mineral composition. The high MgO, Ni and Cr abundances at intermediate SiO₂ and low Ti, Zr, and HREE are the most striking features of the rocks. Comparison of the MDS metabasites with petrographically and chemically analogous rocks from other regions shows their complicated geochemical character. According to their CaO/Al₂O₃, CaO/TiO₂ and Al₂O₃/TiO₂ ratios, Nb, Ti contents and REE patterns the studied rocks are close to boninites whereas the Ti/Zr, Ti/Y and Zr/Y ratios are typical of island arc tholeiites (IAT). The MDS metabasites show close similarity to IAT-like orthoamphibolites from the northern part of the Central Rhodope Mts. too. The geochemical features described define the rocks as transitional between boninites and IAT. Analogous composition is typical of some Precambrian high magnesian series with specific isotopic characteristics.

Key words: metagabbro, REE, trace elements, island arc tholeiite, boninite, Central Rhodope

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Да е в а, Л. С. П р и с т а в о в а 1998. Нови данни за геохимията на метабазитите от източната периферия на Мадан-Давидковската структура, Централни Родопи. - Геохим., минерал. и нефтогеол., 35, 47-54

Метабазитите от източната периферия на Мадан-Давидковската структура (МДС) се считат за една от интересните магматични прояви в Родопския кристалин. Тези скали се разкриват като няколко малки тела югоизточно от с. Гълъбово (Ахряне). Вместени са в метаморфитите от Вишневската свита (Арденска група). Метабазитовите тела притежават добре запазена магматична структура и минерален състав. Най-характерната особеност на тях са високите съдържания на MgO, Ni и Cr при средно съдържание на SiO₂ и ниски съдържания на Ti, Zr и тежки редки земи. Сравненето на метабазитите от МДС с подобни в петро графското и геохимично отношение скали от различни райони показва техния комплициран геохимичен характер. По отношение CaO/Al₂O₃, CaO/TiO₂ и Al₂O₃/TiO₂ съдържанията на Nb, Ti и разпределенията на РЗЕ изследваните скали са подобни на бонинитите. Отношенията Ti/Zr, Ti/Y и Zr/Y в тях са типични за остронощови толети (IAT). Метабазитите от МДС са близки също и до подобните на IAT ортовамфиболити от северната част на Централните Родопи. Тези геохимични особености определят изследваните скали като преходни между бонинитите и остронощовите толети. Подобен състав е типичен за някои докамбрийски високо магнезиални серии със специфични изотопни характеристики.

Ключови думи: метагаббро, REE, елементи следи, остронощови толети, бонинити, Централни Родопи

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Introduction

The presence of basic magmatic relics in the poly metamorphic Rhodopian complex is well known in the geological literature (Kozhokharyov, 1966, and others). The metasomatic rocks of the central periphery of the Madan Davidoko Structure (MDS) are considered as an interesting example of the magmatic activity in the Rhodope crystalline complex. Several authors have studied these rocks from petrological and mineralogical point of view (Toprakchieva, 1963; Pristavova, 1996). Toprakchieva (1963) described them as Paleozoic magmatites intruded in the amphibolites. Kozhokharyov and Kozhokharyov (1978) included these metasomases in the Rhodopian magmatic complex. Zagorchev (1976) considered them as an important marker and element of the metamorphic evolution of the Rhodope crystalline complex. Special attention has been paid to the corona texture formation and processes of eclogitization of the rocks by Pristavova (1996). The metasomases from MDS contain magmatic minerals (olivine, plagioclase, ortho- and clinopyroxene, amphibole, biotite, and spinel), corona textures and geochemical parameters defining them as gabbro, gabbro-norites and troctolites. These characteristics are similar to those of the druzites from the Baltic shield and some basites with typical corona textures from Norway and Canada shield. The published data on the metabasic rocks studied (Zakariadze et al., 1993; Pristavova, 1996) are insufficient to determine their specific geochemical character.

In this paper we give some new data for the composition of the MDS metagabbros. By comparing their geochemical features with those of analogous rocks from other regions we make an attempt to clarify their geochemical specialization and probable geodynamic setting.

Geological position and petrographic characteristics

The metasomases studied in this work occur as several small bodies in the eastern periphery of MDS southeast of the village of Galabovo (Fig. 1). They are hosted within the amphibolites belonging to the metamorphites of the Vishnevo Formation (Arda Group) as defined by Kozhokharyov (1984). The Vishnevo Formation is build up of gneisses affected by granitization and migmatization, intercalated by beds of amphibolites of different thickness, two-mica and muscovite schists as well as sillimanite schists. The metasomases are of lens-like, boudin shapes extended conformably to the foliation of the host metamorphites. They are characterized by fine-grained massive texture and dark green colour. Xenoliths from the amphibolites can be observed in the metagabbros. Two different types of cross-cutting pegmatites in the metagabbroids and host rocks are common.

The metasomases are of well preserved igneous texture and mineral composition in their central parts. Magmatic minerals and textures gradually decrease and disappear towards their periphery. Gabbros, gabbro-norites and troctolites - gabbro-amphibolites (intermediate phase) - amphibolites can be recognized from the central to the peripheral parts. The magmatic assemblage is represented by Mg-rich olivine, plagioclase, ortho- and clinopyroxene, biotite (high-Ti phlogopite) and spinel. All these minerals with garnet (pyrope type) form typical corona textures. Magmatic temperature of about 1160-1170°C/7 kbar has been determined for the metasomases (Pristavova, 1996). Garnet (probably indicating initial eclogitization), amphibole (hastingsite), plagioclase (andesine), titanite and chlorite replaced the primary mineral assemblage during a subsequent metamorphism at 550-570°C/6 kbar determined in the host amphibolites (Pristavova, 1996). The rocks analyzed in this work are from the well preserved magmatic relics.

Geochemistry

Major and trace elements of the rocks studied are listed in Table 1. The high MgO, Ni and Cr abundances at intermediate SiO₂ and low Ti, Zr, and HREE are the most striking features of these rocks. They have various magnesian contents (Pristavova, 1996) but the value of the MgO/MgO + FeO -ratio varies from 0.60 to 0.70 and shows that they are very close to the primitive mantle derived magmas.
(Bloomer, Hawkins, 1987). This primitive character is also supported by the contents of Cr and Ni in the most magnesian metabasic rocks (G-3 and G-18, Table 1), which approach those of some ultrabasites from the Rhodope Mts. (Zheljazkova-Panajotova et al., 1978).

On the AFM-diagram the samples studied and earlier data (G-2, G-3a, G-11, G-17) after Pristavova (1996) plot close to the differentiation trend of Proterozoic dzurites from the Karelia region, Baltic sheild (Sharkov et al., 1994) which we use for comparison, and also they are near to the differentiation trend of modern boninites (Fig.2; Bloomer, Hawkins, 1987). The low concentration of TiO$_2$ and relatively high values of CaO/TiO$_2$ and Al$_2$O$_3$/TiO$_2$ ratios distinguish the rocks compared in this study from MORB. On the diagrams (Fig. 3 a, b) they plot inside or very close to the field of modern boninites and high-magnesian andesites (HMA). Two noritic parental magma compositions (B1, B2, Fig. 3 a, b) of the Bushveld complex (Hall, Hughes, 1987) are situated in the same way. Because of the low K$_2$O contents in the metabasic rocks the ratio K$_2$O/TiO$_2$ approaches that of primordial mantle - M (Fig. 3 c; Hall, Hughes, 1987). Similarly but closer to MORB are situated the IAT-like orthoamphibolites from the northern part of the Central Rhodope (Kozhoukharova, Daieva, 1990; samples 515, 724, 727b, 360b) chosen by their Ti$_2$O contents. Only one metabasic rock (sample 606, Galabovo region) falls in the MORB field because of the very high TiO$_2$ content (0.77%), near that of magnesian MORB - 0.55% (Hall, Hughes, 1987). The Ti/Zr ratio in the samples from the MDS and IAT-like orthoamphibolites from the northern part of Central Rhodope Mts. shows different values typical for boninites (30-60) as well as for MORB (60-120; Fig. 4a, Hall, Hughes, 1987). On the same diagram
<table>
<thead>
<tr>
<th>Sample</th>
<th>G-3</th>
<th>G-5</th>
<th>G-17</th>
<th>G-18</th>
<th>606</th>
<th>610</th>
<th>704</th>
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<td>Al₂O₃</td>
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<td>18.09</td>
<td>17.50</td>
<td>11.08</td>
<td>16.84</td>
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<td>7.78</td>
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<td>FeO₇</td>
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<td>9.00</td>
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<td>MnO</td>
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<td>0.15</td>
<td>0.18</td>
<td>0.13</td>
<td>0.12</td>
<td>0.15</td>
<td>0.14</td>
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<td>MgO</td>
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<td>13.36</td>
<td>24.35</td>
<td>9.06</td>
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<td>CaO</td>
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<td>10.06</td>
<td>7.21</td>
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<td>4.36</td>
<td>7.11</td>
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<tr>
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<td>1.69</td>
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<td>14</td>
<td>15</td>
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<tr>
<td>Cr</td>
<td>1382</td>
<td>212</td>
<td>293</td>
<td>1429</td>
<td>288</td>
<td>196</td>
<td>n.d.</td>
<td>n.d.</td>
<td>n.d.</td>
</tr>
<tr>
<td>Ba</td>
<td>96</td>
<td>58</td>
<td>91</td>
<td>47</td>
<td>n.d.</td>
<td>n.d.</td>
<td>160</td>
<td>233</td>
<td>288</td>
</tr>
</tbody>
</table>

La    | 3.13  | 2.74  | 3.25  | n.d.  | 3.16| 3.37 | 5.50 | 8.78 | 7.97 |
Ce    | 6.19  | 6.05  | 6.89  | n.d.  | 8.01| 6.10 | 13.95| 21.02| 17.30|
Pr    | 0.90  | 0.89  | 1.04  | n.d.  | 1.10| 0.72 | n.d. | n.d. | n.d. |
Nd    | 3.62  | 3.40  | 4.04  | n.d.  | 5.40| 3.00 | 3.84 | 8.31 | 8.18 |
Sm    | 0.87  | 0.89  | 0.95  | n.d.  | 1.62| 0.70 | 1.26 | 1.98 | 1.84 |
Eu    | 0.36  | 0.47  | 0.47  | n.d.  | 0.63| 0.48 | 0.38 | 0.55 | 0.76 |
Tb    | 0.16  | 0.15  | 0.16  | n.d.  | 0.34| 0.17 | 0.14 | 0.69 | 0.27 |
Gd    | 0.88  | 0.88  | 1.06  | n.d.  | 2.00| 0.93 | -    | -    | -    |
Dy    | 0.99  | 0.93  | 0.90  | n.d.  | 2.00| 1.10 | -    | -    | -    |
Ho    | 0.21  | 0.21  | 0.18  | n.d.  | 0.48| 0.29 | n.d. | n.d. | n.d. |
Er    | 0.52  | 0.56  | 0.49  | n.d.  | 1.30| 0.94 | -    | -    | -    |
Yb    | 0.52  | 0.55  | 0.46  | n.d.  | 1.15| 0.94 | -    | -    | -    |
Lu    | 0.01  | 0.09  | 0.09  | n.d.  | 0.21| 0.20 | 0.11 | 0.17 | 0.17 |
Hf    | 0.28  | 0.40  | 0.46  | n.d.  | -   | 0.30 | n.d. | n.d. | n.d. |
Nb    | 0.81  | 0.88  | 13.41 | n.d.  | 8   | 10   | 13   | -    | -    |

G-3 and G-18 - olivine gabbro - troctolites; G-5 and G-17 - gabbronorites from MDS; 606 - gabbro-amphibolites; 610 - olivine gabbro from MDS after Zakariadze et al. (1993); 704 - tholeiite; 705 - olivine gabbronite; 706 - hypersthene porphyryte after Shklov et al. (1994). Major and trace elements of gabbroids from MDS - XRA carried out at the Dept. of Geology, University of Glasgow, REE and Nb - ICP-MS analyses at the SURREC, East Kilbride.

Metabasites from the Karelia region lie in the field of boninites. The relative abundances of Zr and Y in the Rhodope metagabbroids correspond closely to those in boninites and island-arc tholeites (Fig. 4b). The metabasites from Karelia, Baltic shield fall outside this diagram because of their very low Y contents and high Zr/Y ratios.

The chondrite-normalized REE pattern of the metabasites (Fig. 5) is characterized by varying LREE enrichment (La/Sm ratio varies from 2.0 to 4.4) and flat or slightly U-shaped HREE pattern. The latter has been noted by several workers (Sun, Nesbit, 1978; Bloomer, Hawkins, 1987) and seems to be characteristic of boninites. In Fig. 5 it can be seen that the metabasites from Karelia region are more enriched in LREE than the rocks studied.
Compared to the fields of micropyroxenites from the Bushveld massif and boninites from the Izu-Bonin island arc (Sharkov et al., 1994) the rocks from the MDS and the IAT-like orthoamphibolites from the northern part of Central Rhodope lie in the field of boninites and partly of micropyroxenites while the rocks from Karelia region lie predominantly in the field of the Bushveld micropyroxenites.

The MORB-normalized (Taylor, McLennan, 1984) trace element patterns (Fig. 6) show clear LILE enrichment (Sr, Rb, Ba) and HFSE depletion (Zr, Ti, Y), characteristic of boninites. The patterns of MDS are in the field of boninites from the Pacific Ocean. The Baltic shield metabasites lie in the boninite field as well as in the island-arc tholeiite field (Sharkov et al., 1994).

The Zr/Sm - La/Sm diagram (Fig. 7) shows the fields of different types of Pacific Ocean boninites (Sharkov et al., 1994). Although the metabasites from MDS and Karelia regions are situated outside these fields they are closer to boninites than to tholeiites. The tholei-
Fig. 4. \(a\) - TiO\(_2\) (wt%) - Zr (ppm); \(b\) - Zr/Y (ppm) - Zr (ppm) in the metasites from MDS, Karelia region and IAT-like orthoamphibolites from the northern part of Central Rhodope. Fields and trends after Hall, Hughes (1987)

Фиг. 4 \(a\) - TiO\(_2\) (wt%) - Zr (ppm); \(b\) - Zr/Y (ppm) - Zr (ppm) в метабазитите от МДС, Карелия и IAT подобни ортоамфіболити от северната част на Централни Родопи. Полетата и трендовете са по Hall, Hughes (1987)

Fig. 5. Chondrite-normalized REE patterns in metasites from MDS and Karelia region: 1 - field of micropyroxenites from the Bushveld massif; 2 - field of boninites from the Izu-Bonin island arc. Fields after Sharkov et al. (1994)

Фиг. 5. Хондрит-нормирано разпределение на РЗЕ в метабазитите от МДС и Карелия: 1 - поле на микропіроксенитите от масива Бушвелд; 2 - поле на бонинитите от Изу-Бонинската островна дъга. Полета по Sharkov et al. (1994)
Fig. 6. MORB-normalized trace element patterns in metabasites from MDS and Karelia region: 1 - field of Mariana volcanic-arc tholeiites; 2 - field of Pacific Ocean boninites. MORB data after Taylor, McLennan (1985); fields after Sharkov et al. (1994)

Фиг. 6. MORB-нормирално разпределение на редките и разсеяни елементи в метабазитите от МДС и Карелия: 1 - поле на толепитите от Марианската вулканска дъга; 2 - поле на бонинитите от Тихия океан. Данни за MORB по Taylor, McLennan (1985); полета по Sharkov et al. (1994)

**Conclusion**

The content of major, some trace elements and REE of the rocks from MDS, their CaO/Al$_2$O$_3$, CaO/TiO$_2$ and Al$_2$O$_3$/TiO$_2$ ratios (Table 2), the negative Nb- and Ti-anomalies in the spidergrams (Fig. 5) are typical of modern boninitic lavas. Boninites are one of the few arc-volcanic rocks that have petrographic and chemical characteristics of primitive mantle-derived magmas. By their Ti/Zr, Ti/Y and Zr/Y ratios (Table 2) the metabasic rocks from MDS are closer to IAT. They are also similar to IAT-like orthoamphibolites from the northern part of Central Rhodope Mts. The geochemical characteristics of the MDS metabasites define them as transitional between modern boninite rocks and island-arc tholeiites and show their marked affinity to primitive island-arc rocks.

Hall and Hughes (1987) and Sharkov et al. (1994) have pointed out that analogous transitional compositions are typical of the Early Proterozoic high-magnesian series from a number of Precambrian terrains. The most dis-
tinctive features of the Precambrian high-magnesian series are their isotopic characteristics, displaying ancient sialic crustal contamination. Further isotopic analyses of the MDS metabasaltic rocks can determine their relation to the Precambrian magmatic activity.

Acknowledgments. We are grateful to the Royal Society for financial support through grants to S. Pristavova and particular Dr. T. Dempster for providing access to analytical work. The authors also thank to Dr. E. Kozhoushkarov for critical reviews and suggestions for improving this paper and J. Gallagher and V. Olive for analytical work.

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Accepted October 13, 1998

Приета на 13.10.1998 г.