Petrology

Petrogenetic Model of the Precambrian Regional Metamorphism of the Khrami Crystalline Massif

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(Presented by Academy Member David Shengelia)

ABSTRACT: The Khrami crystalline massif is built up mainly of the Precambrian gneiss-migmatitic complex and Late Variscan granitoids. The greatest part of gneiss-migmatitic complex is represented by biotite-cordierite plagiogneisses (paragneisses) and granite migmatisites. Plagiomigmatites and biotite-hornblende quartz-diorite gneisses (orthogneisses) are in less quantities. In the complex two stages of regional metamorphism are established – the Precambrian prograde (HT/LP) and the Late Variscan retrograde (LT/LP). The mentioned stages of regional metamorphism have been ascertained according to geological data and isotopic determinations. PT conditions of polycyclic regional metamorphism (the Precambrian prograde T=720-770°C, P<1.5 kb and the Late Variscan retrograde – T=430-510°C, P=1.3-0.6 kb) of the Khrami crystalline massif is evaluated using geothermometers, reference mineral parageneses and also standard petromineralogic schemes. In the article, a petrogenic model of regional metamorphism is presented. In the Khrami crystalline massif the Precambrian prograde HT/LP (T=720-770°C, P<1.5 kb) and the Late Variscan retrograde LT/LP (T ≥430-510°C, P ≥1.3-1.6 kb) stages of regional metamorphism are developed. By U-Pb LA-ICP-MS zircon dating the age of both stages respectively corresponds to 931±16 and 325±6 Ma. © 2013 Bull. Georg. Natl. Acad. Sci.

Key words: Khrami massif, gneiss-migmatitic complex, regional metamorphism

The Khrami crystalline massif is a salient of pre-Alpine basement of the Black Sea-Central Transcaucasian terrane. It is located in the Khrami river basin, about 100 km southwest of Tbilisi. The massif is built up mainly of the Precambrian gneiss-migmatitic complex, Late Variscan granitoids and pre-Variscan metabasalt. A small size protrusive body of serpentinites is observed in the massif.

The greatest part of the gneiss-migmatitic complex is represented by biotite-cordierite plagiogneisses (paragneisses) and granite migmatisites. Plagiomigmatites and biotite-hornblende quartz-diorite gneisses (orthogneisses) are in less quantities [1-5].

Two stages of regional metamorphism are established in the complex – the Precambrian prograde (HT/LP) and the Late Variscan retrograde (LT/LP). The mentioned stages of regional metamorphism have been ascertained according to geological data [5,6] and isotopic determinations [5,7].

In 25 zircon crystals of Late Variscan granitoids of the Khrami massif 27 point by point measurements
were performed by U-Pb LA-ICP-MS method. Results of 26 measurements show the concordant age 319-
332±6 Ma (mean 325.6±2.3 Ma). Only in one case, in the zircon crystal core the inherited age 931±16 Ma is
recorded that shows the Grenville age of regional meta-
orphism developed in thegneiss-migmatite complex of theKhrami massif[8].

The indicative mineral parageneses of thePrecambrian regional metamorphism are: Crd+Xt+Pl+Qtz±Ort, Hbl+Xt+Pl±Qtz, Bt+Pl±Cum+Qtz.

The last stage of regional metamorphism has a distinct retrograde character. It takes place in
subisobaric conditions and is a low temperature process (T=430-510°C, P=1.3-1.6 kb) compared to
the previous regional metamorphism. Within theKhrami crystalline massif this retrograde process
is of regional scale and covers all the Late Variscan formations.

Petromineralogy of the Gneiss-
migmatitic Complex

The rock-forming minerals of biotite-cordierite
plagiogneisses and migmatite restites of thePrecambrian regional metamorphism are cordierite, plagioclase, biotite,
quartz and orthoclase. In migmatites cummingtonite is
recorded. The results of microprobe measurements of
minerals are given in the Table 1.

Cordierite is one of the main rock building miner-
als of the above rock. In some samples its percentage
exceeds 50%. Its porphyroblasts in most cases are
fully pinititized and often producing an impression of
main matrix. Very seldom intact areas of cordierite are
observed. Due to cordierite alteration besides the
pine, muscovite of late generation, FeO and rarely
chlorite appear.

Chemical content of cordierite (Table 1) and a
microprobe profile (Fig.1) ascertains high Fe content

Table 1. Composition of Minerals of the Gneiss-migmatitic complex of the Khrami Massif (Mass %)

<table>
<thead>
<tr>
<th>Sample #</th>
<th>Mineral</th>
<th>SiO₂</th>
<th>TiO₂</th>
<th>Al₂O₃</th>
<th>FeO</th>
<th>MnO</th>
<th>MgO</th>
<th>CaO</th>
<th>Na₂O</th>
<th>K₂O</th>
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<tr>
<td>10-kh</td>
<td>Crd</td>
<td>48.52</td>
<td>0.07</td>
<td>33.45</td>
<td>8.87</td>
<td>0.15</td>
<td>6.02</td>
<td>0.51</td>
<td>0.35</td>
<td>0.68</td>
</tr>
<tr>
<td></td>
<td>Crdp</td>
<td>46.08</td>
<td>0.07</td>
<td>32.61</td>
<td>8.25</td>
<td>0.14</td>
<td>6.79</td>
<td>0.38</td>
<td>0.43</td>
<td>0.81</td>
</tr>
<tr>
<td></td>
<td>Bt</td>
<td>36.25</td>
<td>2.68</td>
<td>18.43</td>
<td>19.13</td>
<td>0.10</td>
<td>10.68</td>
<td>0.04</td>
<td>0.93</td>
<td>3.88</td>
</tr>
<tr>
<td></td>
<td>Pl</td>
<td>56.14</td>
<td>0</td>
<td>27.25</td>
<td>0.09</td>
<td>0</td>
<td>10.54</td>
<td>5.87</td>
<td>0.12</td>
<td>4.04</td>
</tr>
<tr>
<td></td>
<td>Ort</td>
<td>63.88</td>
<td>0</td>
<td>17.96</td>
<td>0.25</td>
<td>0.01</td>
<td>0</td>
<td>0.03</td>
<td>1.60</td>
<td>16.08</td>
</tr>
<tr>
<td></td>
<td>Ms</td>
<td>48.83</td>
<td>0</td>
<td>34.65</td>
<td>0.15</td>
<td>0</td>
<td>2.33</td>
<td>0.70</td>
<td>10.2</td>
<td>0.10</td>
</tr>
<tr>
<td></td>
<td>Chl</td>
<td>28.45</td>
<td>0.13</td>
<td>23.81</td>
<td>31.44</td>
<td>0.06</td>
<td>14.46</td>
<td>0.03</td>
<td>0.02</td>
<td>0.01</td>
</tr>
<tr>
<td>21-kh</td>
<td>Crd</td>
<td>47.65</td>
<td>0.09</td>
<td>33.54</td>
<td>9.78</td>
<td>0.28</td>
<td>7.04</td>
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<td>0.03</td>
<td>0.19</td>
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<tr>
<td></td>
<td>Crdp</td>
<td>46.15</td>
<td>0.05</td>
<td>32.38</td>
<td>8.47</td>
<td>0.16</td>
<td>6.05</td>
<td>0.40</td>
<td>0.22</td>
<td>0.78</td>
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<tr>
<td></td>
<td>Bt</td>
<td>37.13</td>
<td>3.12</td>
<td>18.70</td>
<td>21.43</td>
<td>0.05</td>
<td>9.97</td>
<td>0.03</td>
<td>0.12</td>
<td>9.41</td>
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<tr>
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<td>Pl</td>
<td>56.47</td>
<td>0.02</td>
<td>27.53</td>
<td>0.10</td>
<td>0</td>
<td>10.41</td>
<td>6.00</td>
<td>0.10</td>
<td>16.16</td>
</tr>
<tr>
<td></td>
<td>Ort</td>
<td>64.66</td>
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<td>27.00</td>
<td>0.08</td>
<td>0</td>
<td>0</td>
<td>0.02</td>
<td>0.88</td>
<td>16.16</td>
</tr>
<tr>
<td></td>
<td>Ms</td>
<td>48.26</td>
<td>0</td>
<td>35.27</td>
<td>0.17</td>
<td>0</td>
<td>2.02</td>
<td>0.65</td>
<td>16.975</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Hbl</td>
<td>44.52</td>
<td>0.76</td>
<td>10.00</td>
<td>18.14</td>
<td>0.50</td>
<td>9.53</td>
<td>11.30</td>
<td>1.30</td>
<td>0.51</td>
</tr>
<tr>
<td></td>
<td>Pl</td>
<td>56.00</td>
<td>0</td>
<td>27.50</td>
<td>0.08</td>
<td>0.01</td>
<td>11.54</td>
<td>4.87</td>
<td>0.13</td>
<td>7.90</td>
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<tr>
<td></td>
<td>Bt</td>
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<td>2.92</td>
<td>17.00</td>
<td>22.99</td>
<td>0.20</td>
<td>8.62</td>
<td>1.00</td>
<td>0.39</td>
<td>7.90</td>
</tr>
<tr>
<td></td>
<td>Chl</td>
<td>27.40</td>
<td>0.14</td>
<td>24.85</td>
<td>30.90</td>
<td>0.07</td>
<td>14.81</td>
<td>0.02</td>
<td>0.03</td>
<td>0.03</td>
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<tr>
<td>10</td>
<td>Hbl</td>
<td>45.90</td>
<td>0.50</td>
<td>10.91</td>
<td>13.66</td>
<td>0.14</td>
<td>10.24</td>
<td>11.32</td>
<td>1.54</td>
<td>0.40</td>
</tr>
<tr>
<td></td>
<td>Pl</td>
<td>55.80</td>
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<td>28.02</td>
<td>0</td>
<td>0</td>
<td>11.41</td>
<td>5.90</td>
<td>0.10</td>
<td>8.20</td>
</tr>
<tr>
<td></td>
<td>Bt</td>
<td>35.70</td>
<td>2.48</td>
<td>14.24</td>
<td>21.88</td>
<td>trace</td>
<td>9.60</td>
<td>0.45</td>
<td>0.41</td>
<td>8.20</td>
</tr>
<tr>
<td></td>
<td>Chl</td>
<td>27.90</td>
<td>0.12</td>
<td>23.60</td>
<td>31.24</td>
<td>0.02</td>
<td>15.03</td>
<td>0.02</td>
<td>0.03</td>
<td>0.02</td>
</tr>
</tbody>
</table>

Note: Sample #10-kh – plagiogneiss (Crd+Cdp+Pl+Qtz±Ort±Ms+C±Chl), sample #21-kh – restite of
plagiomigmatite (Crd+Cdp+Pl+Qtz±Ort±Ms), sample #9 – quartz-diorite orthogneiss (Pl+Hbl+Ms),
sample #10 – leucocratic part of plagiomigmatite (Pl+Hbl+Qtz±Bt). Crd-cordierite, Bt-biotite, Pl-plagioclase,
Qtz-quartz, Ort-orthoclase, Hbl-hornblende, Cum-cummingtonite, Cdp- pinititized cordierite, Ms-Muscovite, Chl-
chlorite. Microprobe analyses were performed in the laboratory of the Local Methods of the Department of Petrology
of Lomonosov Moscow State University, using a scanning microscope Scan-4DV (operator E.Guseva).

(\(X_{Fe} = 44.46\)), it is homogenous and is not characterized by zonality.

Biotite is mainly muscovitized and chloritized. The intact biotite has a high Ti-content (\(\text{TiO}_2 \) 2.68-3.12 mas. \%, \(X_{Fe} = 50-55\), see Table 1).

Plagioclase is observed mainly as porphyroblasts. It is of oligoclase-andesine order (Table 1) and is frequently sericitized, muscovitized, albitized and replaced by latticed microcline.

K-feldspar is represented by lattice-free (disordered) porphyroblasts (Table 1) where the amount of albite molecule reaches 7-13\%, and 2\(V\) is within the limits of 59-71\(^\circ\). In the rock intact latticed (high-order) K-feldspar – microcline is more abundant. It is a secondary mineral and is induced by the Late Variscan granite-formation. Unlike the cordierite-bearing plagiogneisses and migmatites, primary K-feldspar is not observed in biotite- hornblende bearing orthogneisses.

Muscovite, as a product of regional metamorphism of the Precambrian stage is not established. It is always a secondary product replacing cordierite, biotite and plagioclase. Chemical composition of muscovite (Table 1) established the presence of a small amount of phengite and paragonite.

Plagioclase, hornblende and quartz are main rock-building minerals of biotite- hornblende bearing quartz-dioritic orthogneisses. Biotite is in less quantities, rarely lattice free K-feldspar is recorded.

Plagioclase is mainly sericitized, saussuritized and albitized. It often undergoes microclinization. Plagioclase relicts correspond to oligoclase-andesine (Table 1).

In most cases, hornblende underwent biotitization and chloritization. Its relicts are represented by green or grey varieties (Table 1).

Intact flakes of biotite are rarely observed. It is muscovitized and chloritized. Here, as well as in paraplagiogneisses, high Ti biotite is recorded (\(\text{TiO}_2 \) 2.48-2.92 Mas. \%, \(X_{Fe} = 60-63\); Table 1).

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**Table 2. Temperature parameters of the Precambrian regional metamorphism of the gneiss-migmatitic complex of the Khrami crystalline massif**

<table>
<thead>
<tr>
<th>Sample #</th>
<th>Parageneses</th>
<th>T(^C), geothermometer</th>
</tr>
</thead>
<tbody>
<tr>
<td>10-kh</td>
<td>Crd(<em>{46})+Crd(</em>{54})+Pl(<em>{44})+Ort(</em>{50})+Ms+C+Chl(_{40})</td>
<td>720</td>
</tr>
<tr>
<td>21-kh</td>
<td>Crd(<em>{44})+Crd(</em>{54})+Pl(<em>{43})+Ort(</em>{55})+Ms+C</td>
<td>760</td>
</tr>
<tr>
<td>9</td>
<td>Pl(_{45})+Hbl+Ort+Qtz</td>
<td>-</td>
</tr>
<tr>
<td>10</td>
<td>Pl(_{35})+Hbl+Ort+Qtz</td>
<td>-</td>
</tr>
</tbody>
</table>
PT Conditions of the Precambrian Regional Metamorphism of the Khrami Crystalline Massif

PT conditions of the Precambrian regional metamorphism of the Khrami crystalline massif is evaluated applying geothermobarometer and standard petrogenetic schemes of reference mineral parageneses.

We could not use the conventional garnet-biotite [9-14] and garnet-cordierite [10,15] geothermometers, as in the products of the Precambrian regional metamorphism typical metamorphic mineral garnet is not recorded. At it is known, coexistence of garnet and cordierite is limited under low- and moderate-thermal conditions as well as under high temperature and low pressure (P<1.5 kb) conditions. Absence of garnet and sillimanite in the alumina-rich high-temperature rocks of the Khrami massif is explained by wide spreading of cordierite and rather low pressure conditioned by the reaction: Ms+Bt+Qtz $\rightarrow$ Crd+Ksp+H$_2$O.

To establish the temperature regime of the Precambrian prograde regional metamorphism of paraplagiogneisses and migmatites of the Khrami crystalline massif we have used the graphite thermometer [16-18]. As it is known, this thermometer is unique because even when progressively transformed rocks experienced diapthoresis or a retrograde process, it records the first maximal temperature that had ever transformed the above rock. Some other known geothermometers show temperature conditions of the last metamorphism only. Data of graphite thermometer are given in Fig. 2 and Table 2. According to the $C$ (Å) parameter of elementary cell (6.704-6.707) temperature conditions of the Precambrian regional metamorphism are within the limits of 720-760°C.

During the research A. Whitney and S. Stromer’s [20] K-feldspar-plagioclase thermometer is used as well.

The data in Table 2 show that the used K-feldspar thermometers record slightly higher temperature than the graphitic one - 730-770°C.

The cordierite-biotite thermometer [21] records the temperature within the limits of 660-750°C (Fig. 3, Table 2).

By means of hornblende-plagioclase and hornblende-biotite geothermometers, forming the temperature of leucocratic part of quartz-dioritic orthogneiss (sample #9) and of plagiomigmatite (sample #10) was specified. It covers the range 620-720°C (Fig. 4, 5; Table 2).

Thus, we consider it more authentic that temperature conditions of the Precambrian stage of regional metamorphism of the Khrami crystalline massif falls within 720-770°C and corresponds to the high-temp-
Petrogenetic Model of the Precambrian Regional Metamorphism of the Gneiss-migmatitic Complex of the Khrami Crystalline Massif

As mentioned above, in the pre-Alpine formations of the Khrami crystalline massif polycyclic character of regional metamorphism was established [5, 6, 23, 24], the Precambrian (Grenville) and the Late Variscan stages of regional metamorphism are distinguished. The age of each stage of regional metamorphism was dated by geological-geochronological data.

Prograde regional metamorphism of the ancient rocks of the Khrami crystalline massif was dated at 931±16 Ma by U-Pb LA-ICP-MS zircon age method [8, 25, 27]. The thermobarometric data show that regional metamorphism of the Precambrian stage was of isobaric character. Limits of pressure variation are insignificant (P<1.5 kb) and temperature range is wider (720-770°C) (Fig. 6). Conditions of regional metamorphism correspond to the biotite-sillimanite-K-feldspar and garnet-cordierite-orthoclase facies conditions. The products of metamorphism – cordierite-bearing plagiogneisses, plagiogranites, plagio- and granitic migmatites and also less quantities of hornblende-bearing plagiogranites and orthoquartz-diorites form a subcontinental crust, where prevail K nonsaturated metapelites and less amounts of K-saturated metapelites are present. Amount of CaO rich rocks is insignificant. The latter points to the unimportant role of overheated ascending fluid currents induced by the center of basite formation in the development of regional metamorphism. To our assumption, along with the subduction heat radioactive heat is the main heat source of regional metamorphism.
Conclusions

In the Khrami crystalline massif the Precambrian prograde HT/LP (T=720-770°C, P<1.5 kb) and the Late Variscan retrograde LT/LP (T=430-510°C, PH=1.3-1.6 kb) stages of regional metamorphism are developed. By U-Pb LA-ICP-MS zircon dating the age of both stages respectively corresponds to 931±16 and 325±6 Ma.

სივრცე

ბალახის ტრანსგაზიურ მასივის კამარდელურის მდგომარეობა რეგიონალური მინერალურობის სტადიებში შეღაბუთები

J. თუღელიძიძე

ა. გუდსახანის სასწავლების სწავლებრივი უნივერსიტეტის ა. გუდსახანის ჯგუფი/უმრავლესი, თბილისი

(კარგებით აქტიური ავტორი წერს დ. მელიკიძის მხრივ)

ბალახის ტრანსგაზიურ მასივი აღმართულია ძვირადმინიან კამარდელურის ბენიოგრაფიური კოინცენტრაციით და ვაგინგებრიულ ბამბაქით. ბენიოგრაფიურ კოინცენტრაცია გამოიყო ლაშქრობის ხარჯში და არაგონიტ-ვაგინგებრიულ კოინცენტრაციების გარდაქმნით. დედამიწის ბალახგაზიური კომპონენტის გაზეთში ხარჯზე მდგომარეობს ლაშქრობის კოინცენტრაცია და არაგონიტ-ვაგინგებრიულ საკვადრატულ ათენზე. საპირისპირო პალეოგენური ვაგინგებრიული კოინცენტრაციებში გამოიყო ბალახის ტრანსგაზიური მასივის პოლიგონური ულტრაბურალური გადაწყვეტილების პორტ-პროტოს: კამარდელური ბოლო პერიოდი — Т=720-770°C, P<1,5 კარატმა და ვაგინგებრიულ ულტრაბურალური — Т=430-5100°C, P=1.3-1.6 კარატმა. ლაშქრობის ვაგინგებრიულ სასწავლების შეღაბუთები, ბალახის ტრანსგაზიურ მასივი გალოკორობულ რეგიონალურ გადაწყვეტილებაში გამოიყო კამარდელური ბოლო პერიოდი — HT/LP (T=720-770°C, P<1.5 კარატმა) და ვაგინგებრიულ ულტრაბურალური LT/LP (T ≈ 430-510°C, P ≈ 1.3-0.6 კარატ) დედამიწის ვაგინგებრის LA-ICP MS U-Pb მეთოდის მიხედვით, შესაბამისად, ტეხნოლოგია 93±16 და 325±6 Ma.
REFERENCES:


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