THE PROCESSES OF CATACLASIS, MYLONITIZATION AND POST-TECTONIC MINERALIZATION (BLASTESIS) RELATED TO THE OVERTHRUSTING OF THE MACERA NAPPE (THE GREATER CAUCASUS)

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Abstract. The article deals with the geological processes revealed during the overthrusting of the Macera nappe from the Pass sub-zone on the infrastructure of the Elbrus sub-zone of the Greater Caucasus structural zone. It is shown that in the contact zone of the Macera nappe and infrastructure, there is a significant difference in the degree of their regional metamorphism; the intensively developed cataclase, mylonitization and blastesis processes associated with shearing are characterized; it is shown that the energy of the thermal effect of friction is insignificant in autochthonous rocks, while it is higher in allochthonous rocks. Significant recrystallization of minerals in the autochthon is observed only in its direct contact with the allochthon.

Key words: the Greater Caucasus; Macera nappe; cataclase, mylonitization and blastesis processes.
საკვანძო სიტყვები: კავკასიონი; მაკერას ზეწარი; კატაკლაზი, მილონიტიზაცია და ბლასტეზი.

გაფართოებული რეზიუმე

მაკერის ტექტონიკური ზეწრის (კავკასიონი) შარირებასთან დაკავშირებული კატაკლაზის, მილონიტიზაციის და პოსტტექტონიკური მინერალიზაციის (ბლასტეზის) პროცესები. დ. შენგელია. კავკასიონის სტრუქტურული ზონის იალბუზის ქვეზონის ინფრასტრუქტურაზე, დროის ინტერვალში - ტურნეულსა და გვიან ვიზეურში საუღელტეხილო ქვეზონიდან შარირებულია ბუულგენის კომპლექსის ზედა ნაწილი - მაკერის ტექტონიკური ზეწარი. მაკერის ზეწრის სტრატიფიცირებული ფრანგმეტები ერთმანეთისგან განსხვავდება მეტამორფიზმის ხარისხით, რომელიც მოიცავს მწვანე ფიქლებისა და ეპიდოტ-ამფიბოლიტური ფაციესის P-T პირობებს. ამ ფრაგმენტებმა რეგიონული მეტამორფიზმი განიცადა შარირებამდე, ბუულგენის კომპლექსში, კალედონური ფაზისის გამოვლინების დროს. კავკასიონის იალბუზის ქვეზონის კრისტალონიკუმში გვიანვარისკული მეტამორფიზმის განვითარებას სხვა ფაქტორებთან ერთად, განსაზღვრავდა მაკერის მძლავრი (2500 მ) ტექტონიკური ზეწრის გადაადგილებისას, მის საგებში განვითარებული დისიპატური სითბო და მექანიკური ფაქტორები. მაკერის ზეწრის შარირების პროცესთან დაკავშირებული მინერალების გენერაცია მიმდინარეობდა მეტამორფიზმის მწვანე ფიქლების ფაციესის ფარგლებში. მაკერის ზეწრის ინფრასტრუქტურსთან კონტაქტის ზონაში აღინიშნება მათი რეგიონული მეტამორფიზმის ხარისხის მნიშვნელოვანი განსხვავება, ინტენსიურად განვითარებული კატაკლაზის, მილინიტიზაციისა და პოსტექტონიკური კრისტალიზაციის პროცესები. მაკერის ტექტონიკური ზეწრის საგებში განვითარებულია ბლასტომილონიტების მძლავრი ზონა. ხახუნის თერმული ეფექტის ენერგია ავტოქთონში უმნიშვნელოა, ხოლო ალოქთონის ქანებში კი უფრო მაღა-

ლია. მინერალების მნიშნელოვანი გადაკრისტალება ავტოქთონში შეინიშნება მხოლოდ მის უშუალო კონტაქტში. ალოქთონის კონტაქტურ ზონაში ფართოდ არის განვითარებული გვიანვარისკული გრანიტოიდები და მათთან დაკავშირებული პოსტმაგმური გარდაქმნები. ტექტოგენეზისის ვარისკული ფაზისის დროს შარირებულმა ზოგიერთმა ფრაგმენტმა გადაადგილება განიცადა ასევე ტექტოგენეზისის პოსტვარისკული ფაზისის გამოვლინების დროსაც, სადაც მექანიკური წნეხი მნიშვნელოვნად ჭარბობდა ბლასტეზს და წარმოიქმნებოდა ტექტონიკური ბრექჩიები, კატაკლაზიტები და სხლეტვის სარკეები. მათთვის დამახასითებელია მნიშვნელოვანი მეტასომატური გარდაქმნები, ასევე სიღრმული ტიპის ბლასტომილონიტებში განვითარებული ფიქლებრიობა.

INTRODUCTION

The Caucasus is located between the Eurasian and African-Arabian plates and is a part of the Mediterranean (Alpine-Himalayan) mobile belt. Within its boundaries the structural zone of the Main Range of the Greater Caucasus (it is also called the Greater Caucasus terrain. Gamkrelidze, 1997; Gamkrelidze, Shengelia, 2005) is situated; it is represented by the Elbrus and Pass subzones (Fig. 1). These two subzones differ significantly from each other in the forms of folded structures, lithological and formational composition, conditions of their formation, etc. From the Buulgen complex of the Pass subzone in the form of the Macera nappe its upper part is overthrust in the Elbrus subzone (Gamkrelidze, Shengelia, Chichinadze, 1996; Chichinadze, 2010).

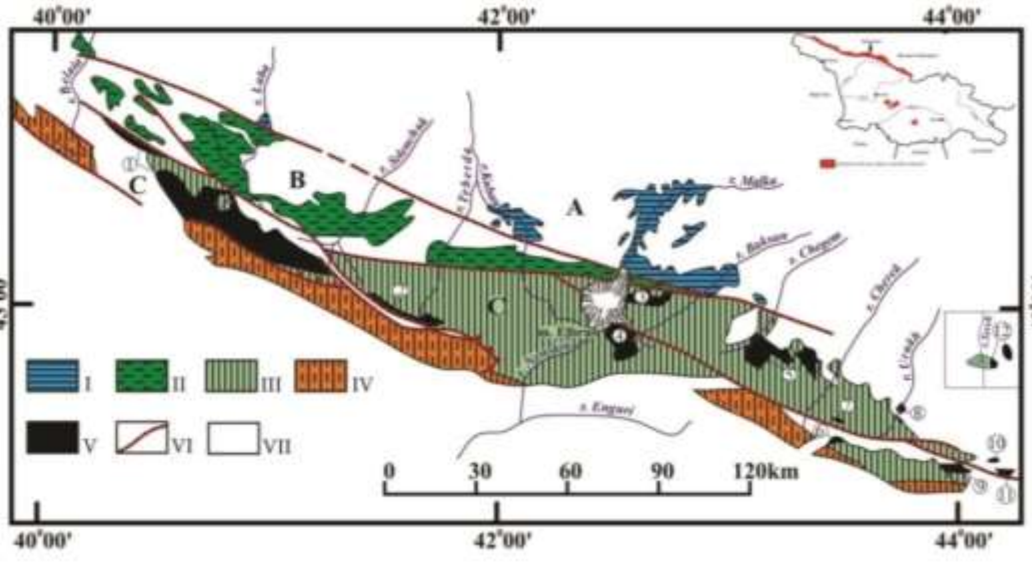

Fig. 1. Scheme of the location of the Macera nappe fragments within the Main Range zone

Exposures of the crystalline complex of the Greater Caucasus: I – Bechasyn zone, II – Fore Range zone, III – Elbrus subzone of the Main Range zone, IV – Pass subzone of the Main Range zone, V – fragments of the Macera nappe (numbers in circles): 1 – Tsakhvoa-Arkasar; 2 – Aksaut; 3 – Kyrtyk; 4 – Baksan (Donguzorun and Yusengean plates); 5 - Bezeng (Koru and Siliksu plates); 6 – Kharves; 7 - Akhsu; 8 – Matsuta; 9 - Buron; 10 - Unali; 11 - Fiagdon; 12 - Darial (Khdeissi and the Gurgala Mountain); VI – fault lines, VII – Upper Paleozoic-Mesozoic non-metamorphosed sedimentary cover (Gamkrelidze, Shengelia, 2005).

The formation of the Macera nappe took place before the Middle Carboniferous in the time interval between the Tournaisian and Late Visean and was associated with the Sudetic phase of the Variscan cycle of tectogenesis (Gamkrelidze, Shengelia, Chichinadze, 1996). It caused the unloading of the crystalline basement of the Pass subzone (removal of huge masses of the Buulgen complex) and tectonic compression and an increase in the thickness of the crystallinicum within the Elbrus subzone. Consequently, following the formation of these covers in the autochthonous substrate, a sharp change in temperature and pressure values that controlled the specific fluid regime of the environment, in turn determining the intensity of regional metamorphism is established (Gamkrelidze, Shengelia, 2005). At the same time, granitoids were generated in places: in the sialic crust of the potassium series – of the Elbrus subzone and in the ensimatic crust – the low-potassium granitoids of the Pass subzone (Gamkrelidze, Shengelia, 2005).

Nappes, with a total area of about 300 km^2, are represented by separate fragments of a previously single megaplate – the large “Macera nappe” (Fig. 1) – the Dombai, Donguzorun, Kti-Teberda, Kurgashinchat, Duppukh, Bezeg, Arkasar, Kyrtyk, Buron suites, as well as small outcrops of the Matsuta, Unala, Fiagdon, Darial metamorphic rocks (Gamkrelidze, Shengelia, Chichinadze, 1996). These exposures of metamorphites are stratigraphically and lithologically similar, only in different structural zones they differ in the degree of regional metamorphism. Only in the headwaters of the Teberda River, within the Musatchera Range, the Klich suite of the Buulgen complex that overthrust from the Pass subzone and the following Sisina suite have been mapped.

REGIONAL METAMORPHISM OF THE PASS SUBZONE

In the Pass subzone, metamorphites are represented (in the ascending section) by the Gwandra, Klich, and Sisin suites of the Paleozoic Buulgen complex. They are spread over ≈ 1600 km^2.

In the Buulgen complex, Cadomian and Variscan regional metamorphism is manifested (Gamkrelidze et al., 2020). In the Gwandra and Klich suites P-T parameters of regional metamorphism (Fig. 2) of medium-high-temperature amphibolite facies are estimated with an interval of 2-3 kbar and 530-630 °C. In the upper part of the Buulgen complex T-P parameters (high-temperature green schist and epidote-amphibolite facies) of regional metamorphism are T-350-530°C (Fig. 3, 4) (Shengelia et al. 1991). As a result of thrusting of the Macera nappe from the Pass to the Elbrus subzone, the crust was thinned to no less than 2500 m and, accordingly, the pressure decreased to no less than 1.5 kbar (see below).

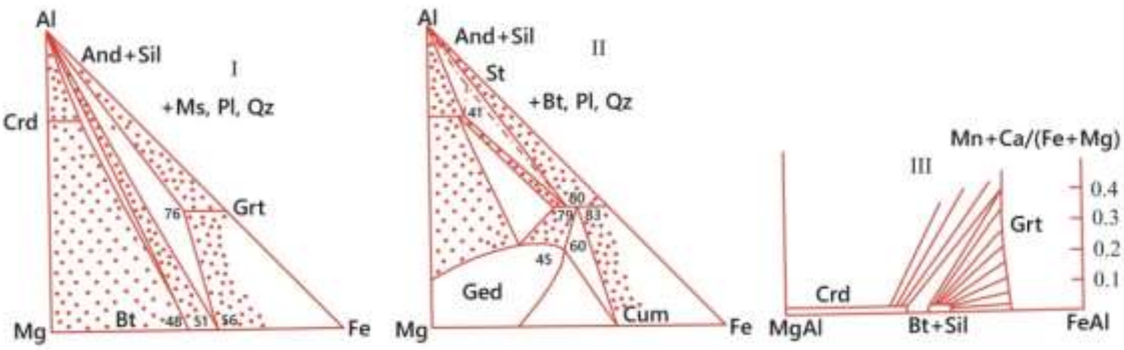

Fig. 2.Parageneses of saturated (I) and undersaturated (II) K_2O metapelites of medium-high temperature amphibolite facies of the Variscian regional metamorphism of the Gvandra and Klichsuites. Corresponding to them cordierite-garnet section with the Mn, Ca points at infinity (III).

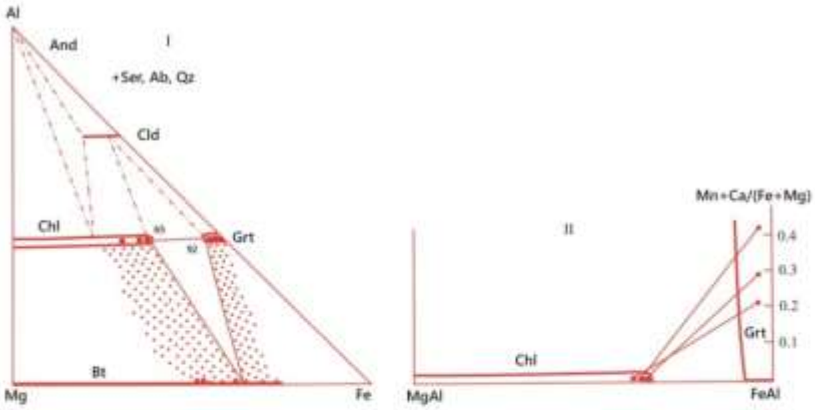

Fig. 3.Parageneses of sericite-containing metapelites of high temperature greenschistfacies of the Variscian regional metamorphism of the Sisina-Vertskhlistba suites and the corresponding chlorite-garnet section.

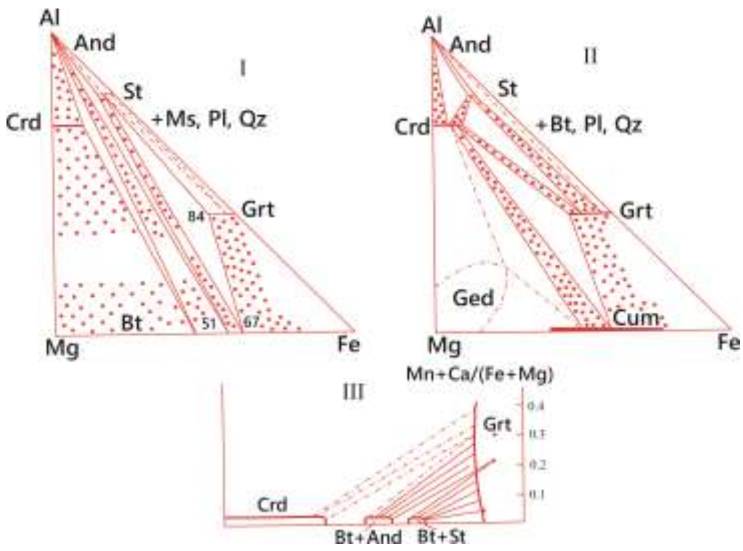

Fig. 4. Parageneses of saturated (I) and undersaturated (II) K_2O metapelites of epidote-amphibolite facies of the Variscian regional metamorphism of the Sisina-Vertskhlistbasuites. Corresponding to them cordierite-garnet section with the Mn, Ca points at infinity (III); The dots indicate the composition of minerals.

REGIONAL METAMORPHISM OF THE ELBRUS SUBZONE

In the Elbrus subzone, a non-stratified and intensively migmatized infrastructure of a high grade metamorphism is developed on a large area (more than 2000 km^2), on which the stratified and non-migmatized metamorphites of the upper part of the Buulgen complex are overthrust from the Pass subzone.

All fragments of the Macera nappe correspond to the upper mica-schist part of the Buulgen complex (Gamkrelidze, Shengelia, Chichinadze, 1996). In the metamorphites of the Macera nappe, syn- and pre-metamorphic cutting bodies of pre-Variscan granitoids are not observed in the infrastructure, along with other geological and petrological signs indicating that overthrusting of the metamorphites of the nappe occurred after the intrusion of these granitoids into the infrastructure.

In the intensively migmatized infrastructure of the Elbrus subzone, fragments of kinzigites, binary-pyroxene gneisses, and other deeply metamorphosed (granulite facies) rocks have been established; they were subsequently diaphthorized under the amphibolite and lower-temperature facies conditions (Shengelia, 1968; Shengelia, Ketskhoveli, 1969; Baranov, Kropachev, 1976).

In the infrastructure of the Elbrus subzone, polymetamorphism develops in the following sequence: Cadomian - granulite facies, Caledonian - amphibolite facies and low-temperature retrograde Variscan greenschist facies. All stages of regional metamorphism took place in the ensialic crust of the island arc (Gamkrelidze et al., 2020).

The granulite facies is one of the highest-temperature facies in the Greater Caucasus. P-T conditions of the first stage of regional infrastructure metamorphism P=3.2-3.5 kbar, T=700-750 °C (Shengelia. 1968; Shengelia et al., 1991). The most characteristic mineral parageneses of the granulite facies of regional metamorphism are shown in Fig. 5.

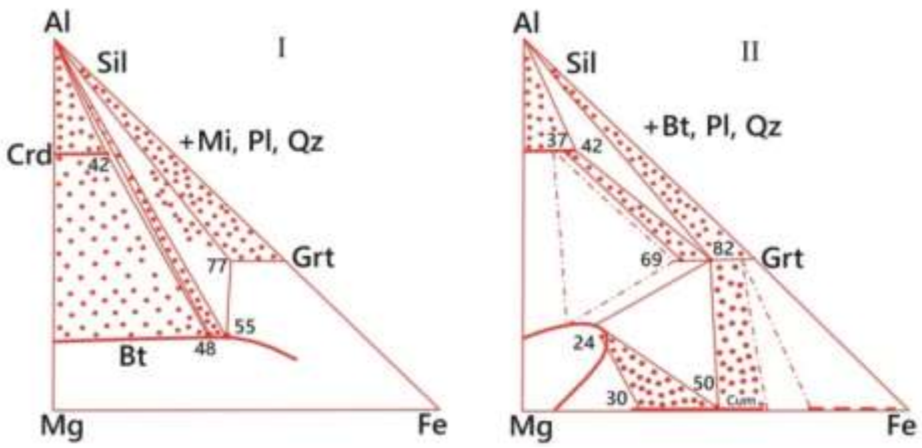

Fig. 5.Parageneses of K_2O saturated (I) and undersaturated (II) metapelites of the granulite faciesof the Cadomian regional metamorphism of the Elbrus subzone infrastructure.

Mineral parageneses of the amphibolite facies of the infrastructure (Fig. 6) were formed under T=540-620 °C, P=3-3.2 kbar conditions.

In addition to the above-described mineral parageneses of the high grade metamorphism of the Elbrus subzone infrastructure rocks, their retrograde transformation associated with the formation of Late Variscan granites is established (see below).

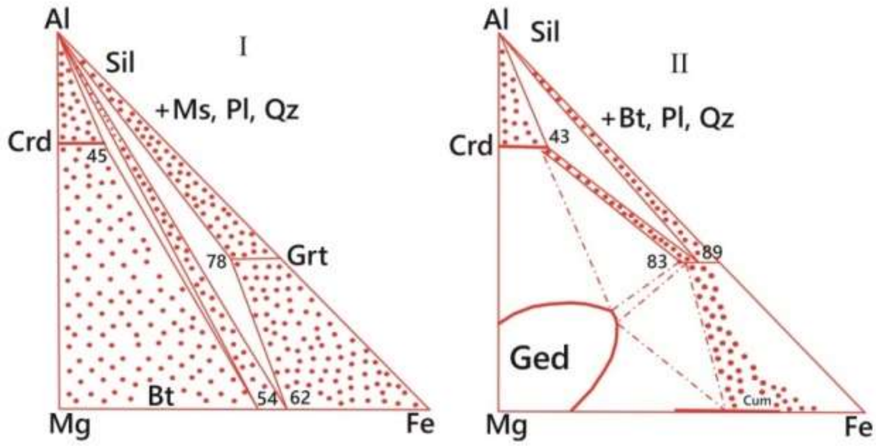

Fig. 6. Parageneses of K_2O saturated (I) and undersaturated (II) metapelites of the amphibolite faciesof the Caledonian and Variscan regional metamorphism of the Elbrus subzone infrastructure.

CATACLASE, MYLONITIZATION, GENERATED DISSIPATIVE HEAT AND POST-TECTONIC MINERALIZATION ASSOCIATED WITH OVERTHRUSTING OF THE MACERA NAPPE

The Macera nappe before the overthrusting in the Pass subzone, as mentioned above, underwent andalusite-sillimanite bar type high-temperature green schist and epidote-amphibolite facies regional metamorphism. An autonomous prograde regional metamorphic zonation is observed in a separate fragment of the Macera nappe (Korykovsky et al., 1997).

The development of Variscan metamorphism in the crystallinicum of the Greater Caucasus Main Range structural zone, in addition to other factors was also facilitated by thermal friction at the base of the large Macera nappe.

In the infrastructure and the Macera nappe far from their contact, the processes of cataclasis are weakly manifested (Fig. 7, 8, 9), mylonites are absent as a rule. The mylonitization and subsequent post-tectonic mineralization constitute only one meter in the infrastructure in contact with the Macera nappe, while in the endocontact of the suprastructure these processes constitute several tens of meters. In the contact zone of the Macera nappe and the infrastructure of the Elbrus subzone, simultaneously with cover formation, an intensive process of mylonitization (Fig. 10, 11) and subsequent re-crystallization of newly formed minerals (Fig. 12) are manifested.

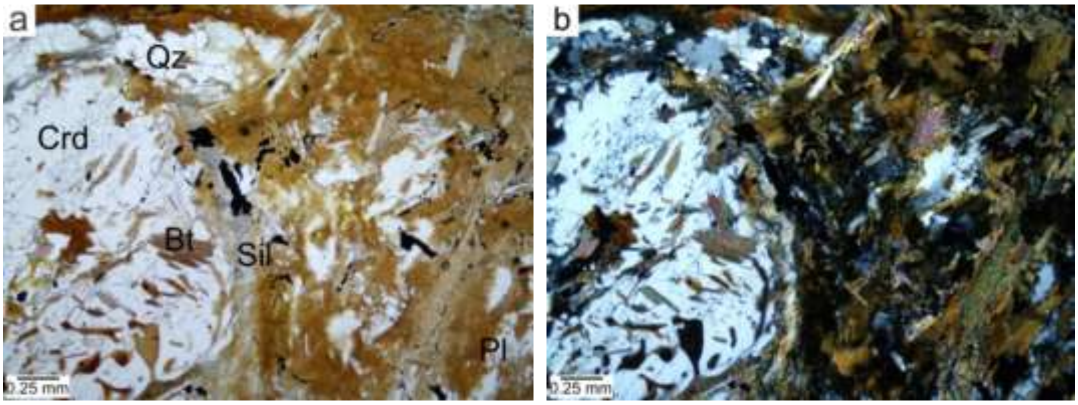

Fig. 7. Weakly broken up migmatites of the Elibrus subzone far from the contact of the Macera nappe – cordierite-biotite-sillimanite-plagioclase-quartz migmatite. a) PPL; b) XPL.

The structure of milonitized rocks is variable. There are fine mylonite, coarse mylonite, coarse blastomylonite, breccia and other structures. In the contact zone of infra- and supra-structures, a thin mylonite structure with a secondary gneiss-like texture is more common. The original feldspars and quartz, as well as garnet and cordierite are crashed and ground.

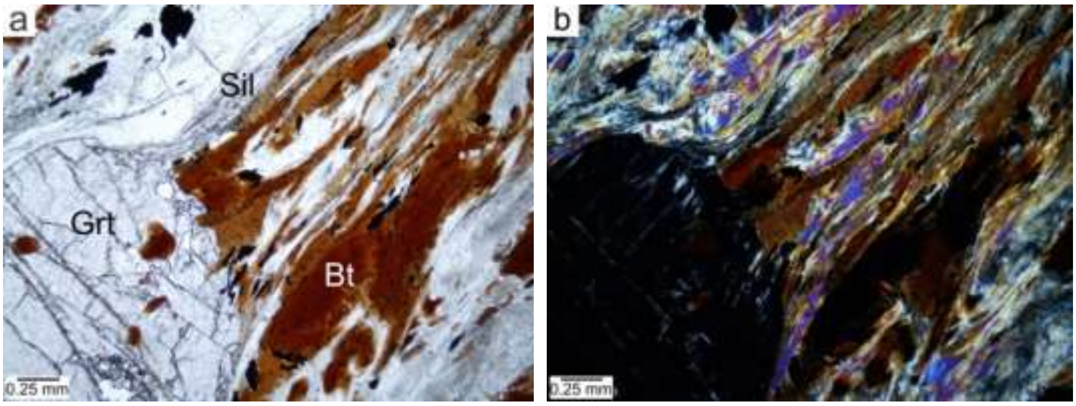

Fig. 8. Weakly cataclised garnet-biotite-sillimanite (fibrolite)-plagioclase migmatites of the Elbrus subzone far from the contact of the Macera nappe. a) PPL; b) XPL.

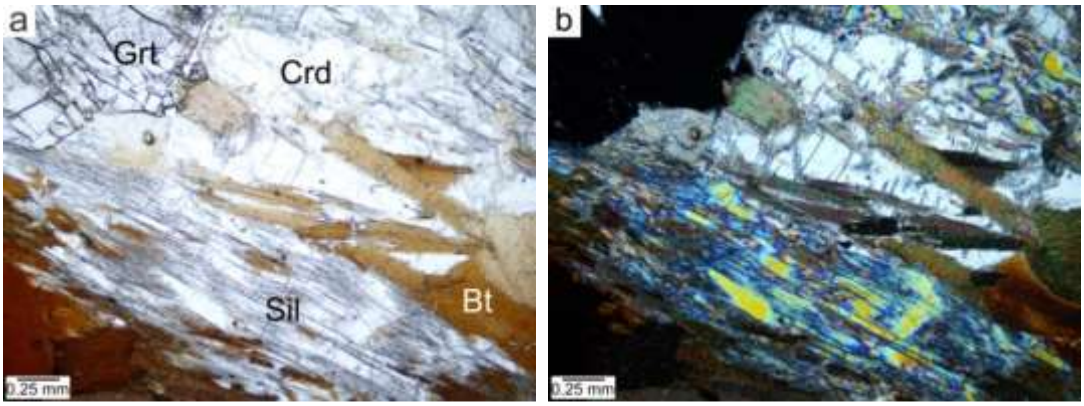

Fig. 9. Weakly cataclised cordierite-garnet-sillimanite-biotite migmatites of the Elibrus subzone. Far from the contact. a) PPL; b) XPL.

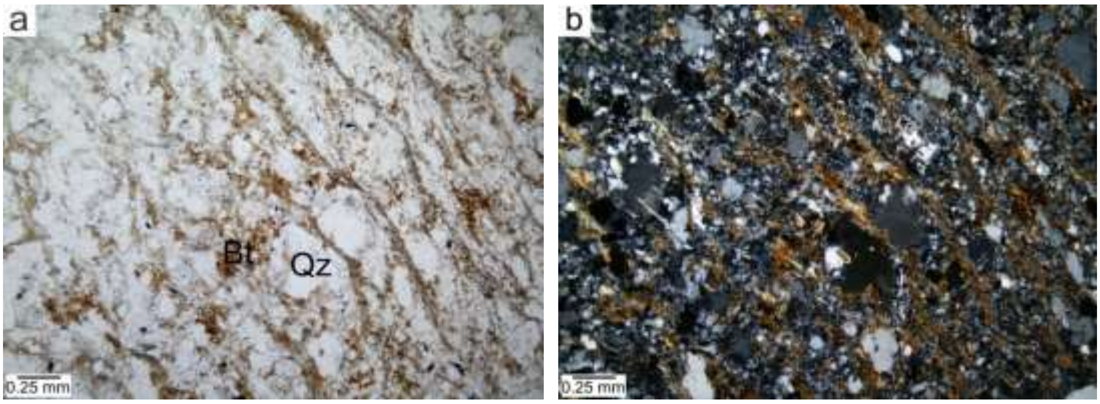

Fig. 10. Migmatites in the Elbrus subzone infrastructure in the contact with the Macera nappe.
a) PPL; b) XPL.

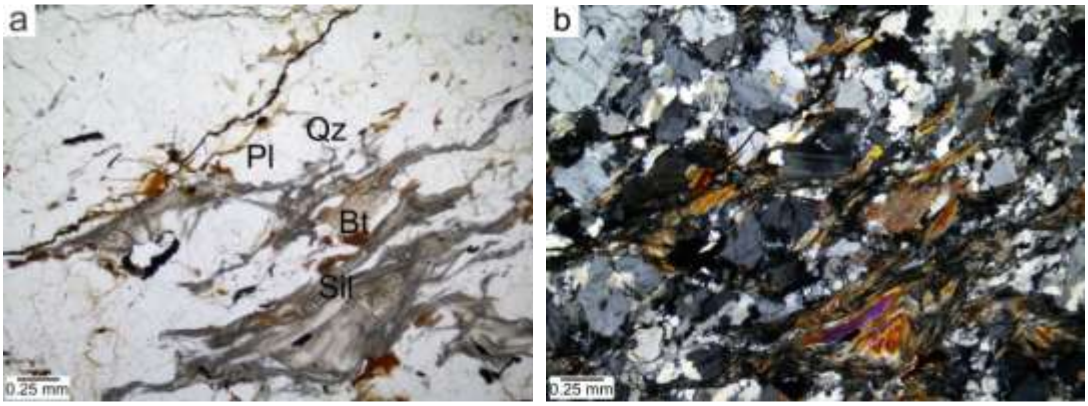

Fig. 11. Migmatites in the Elbrus subzone infrastructure in the contact with the Macera nappe.
a) PPL; b) XPL.

In the foot of the Makara nappe, a thick blastomyllonite zone is observed, where metamorphic blastesis was almost simultaneous with crushing. The thermal effect of friction energy in the autochthon was secondary, and in the rocks of the allochthon it was higher. Significant recrystallization of minerals in the autochthon is observed only in direct contact with the allochthon (see Fig. 12).

An additional source of heat that determined the higher grade of regional metamorphism of the rocks of the lower parts of the Macera nappe compared to the upper "mica" part of the Buulgen metamorphic complex was frictional heat arising in the process of thrusting of the thick Macera nappe, which contributed to the increase of geothermal gradient not only at a depth but also in the body of the tectonic nappe itself.

Since the thermal effect of friction in the upper mantle of the Earth, along with the speed, temperature, elasticity and viscosity of sliding bodies, depends on the thickness of allochthonous masses, the amount of thermal energy released in these zones due to the more impressive thickness of the lithosphere plate in the subduction zone is inferior to the energy of subduction friction.

The friction that arises between the infrastructure and the Macera nappe is a dissipative process, which is characterized by the transition of mechanical energy into thermal energy.

The friction force depends on the thickness and speed of the sliding bodies of the Macera nappe.

The thermal effect of crushing is not sufficient for the formation of pseudotachylytes: veins of pseudotachylytes have not been detected in the zone of mylonite spreading.

During the Variscan orogeny, some overthrust fragments were displaced also during the manifestation of the post-Variscan phase of tectogenesis.

A characteristic feature of the post-Variscan tectonites of the Macera nappe is the predominance of mechanical pressure over blastesis with the formation of tectonic breccias, cataclasites and gliding surfaces. They are not characterized by noticeable metasomatic changes, as well as schistosity that occurs in blastomylonites of the deep-seated type.

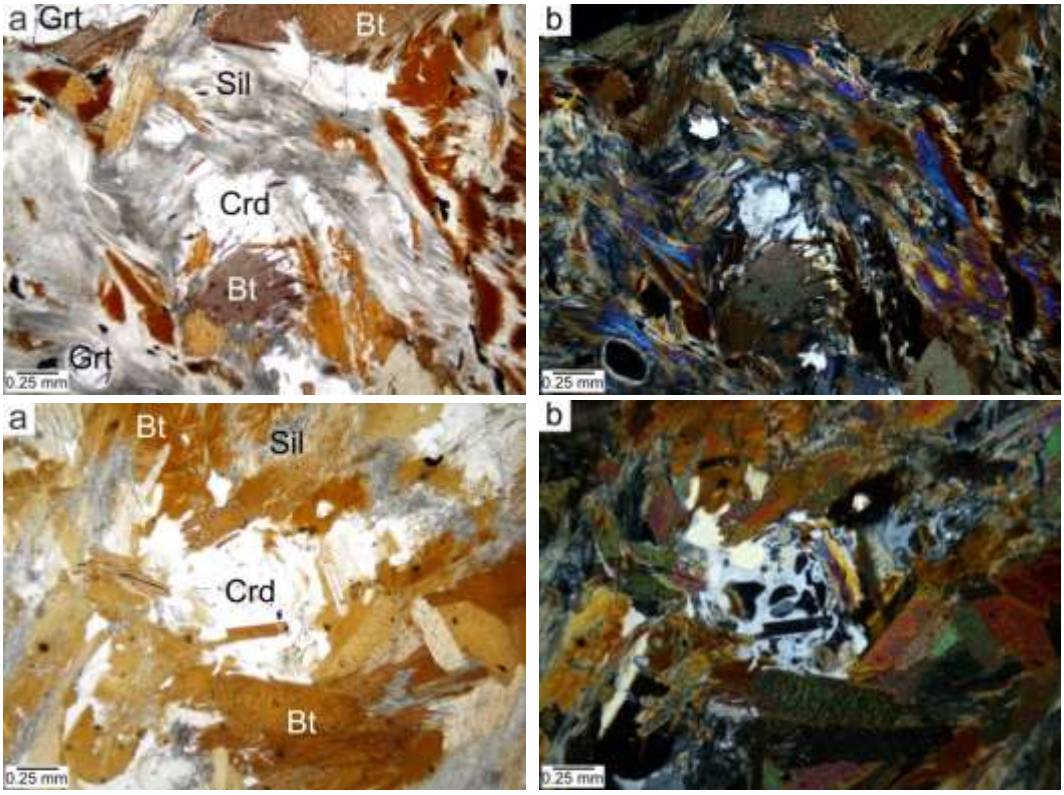

Fig. 12. Blastesis of minerals in the Elbrus subzone infrastructure in contact with the Macera nappe. a) PPL; b) XPL.

Geologically and petromineralogically, the post-Variscian tectonic transformations of the extreme eastern fragments of the Macera nappe, Mt. Gurgala, and the left bank of the Khde river valley, and related blastesis events were studied comprehencively (Chikhradze, 1979; Shengelia, Mgaloblishvili. 1984; Tsutsunava, 1988; Gamkrelidze, Shengelia. 2005).

On the left bank of the Khdestskali, metamorphites are represented exclusively by K_2O saturated metapellites. The most widespread are chloritoid-chlorite-quartz-sericite schists, followed by sericite (muscovite) - quartz and chlorite-quartz-sericite varieties. The composition of white potassium micas reveals a subordinate role of phengite and paragonite molecules, which is typical for low-temperature high-alumina associations with the participation of chloritoid (Korikovsky, 1973). Chloritoid exhibits a fairly constant composition with Fe content of 90-96%. The characteristic mineral parageneses – Cld90-96+Chl83+Ser5-36±Ab+Qz and Ep+Ser+Qz±Ab+C indicate that most of the metamorphites on the left bank of the Khdestskali belong to the medium-temperature greenschist facies subfacies of prograde regional metamorphism (Fig. 13). Only rocks with a clearly expressed clastic nature with newly formed minerals serecit-chlorite-quartz-chloritoid-albite are metamorphosed under the conditions of the lowest grade of the greenschist facies (Fig. 14).

The metamorphic rocks of the tectonic wedge of the Gurgala Mountain area are represented by K_2O-saturated metapellites. The most common are graphite-sericite(muscovite)-chlorite-quartz, graphite-quartz-sericite and graphite-chlorite-chloritoid quartz-sericite schists. Less common are graphite-biotite-chlorite-quartz-sericite schists. Mineral parageneses of K_2O-saturated metapellites correspond to the medium-temperature part of the greenschist facies conditions similar to those of the left bank of the river Khdestskali metamorphites (see Fig. 13).

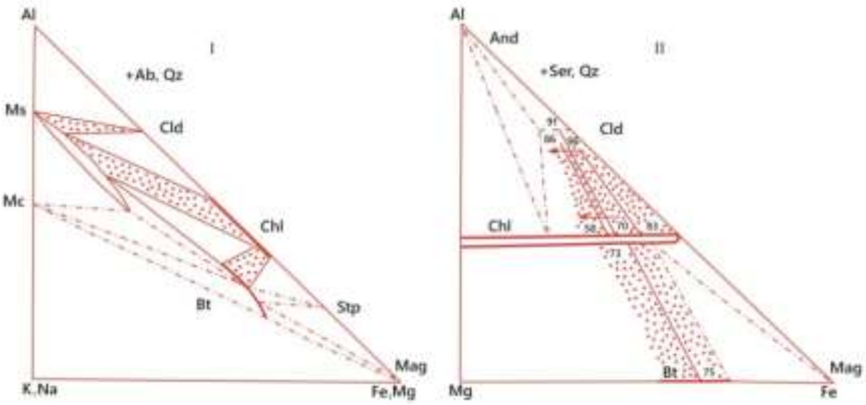

Fig. 13. Parageneses of sericite-bearing metapelites of the biotite subfacies from the left bank of the river Khdestskali plotted on the Al – (K-Na) + (Fe+Mg) (I) and AKFM (II) diagrams. Dots indicate mineral composition; arrows show the direction of displacement of mineral compositions with increasing temperature (according to Tsutsunava, 1988).

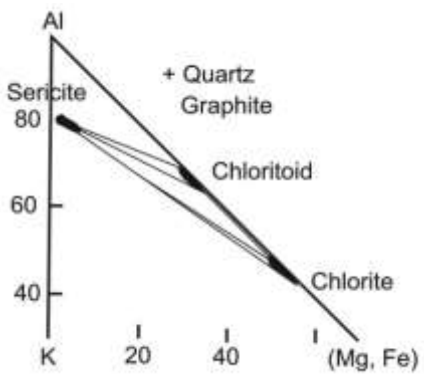

Fig. 14. Paregenesis of the lowest stage of the greenschist facies of chloritoid-bearing rocks of the river Khdestskali gorge.

In the metamorphites of the left bank of the Khdestskali River and the area of Mount Gurgala, an intensive process of mylonitization and subsequent re-crystallization of minerals is evident (Fig. 15, 16, 17). Chloritoid porphyroblasts do not bear traces of deformations, are not oriented along the schistosity (see Fig. 16) and were formed as a result of post-tectonic crystallization of cataclased rocks (Chikhradze. 1979).

Fig. 15. Cataclastic metasandstone with a sericitic matrixs and fine crystals of newly occurring chloritoid. a) PPL; b) XPL.

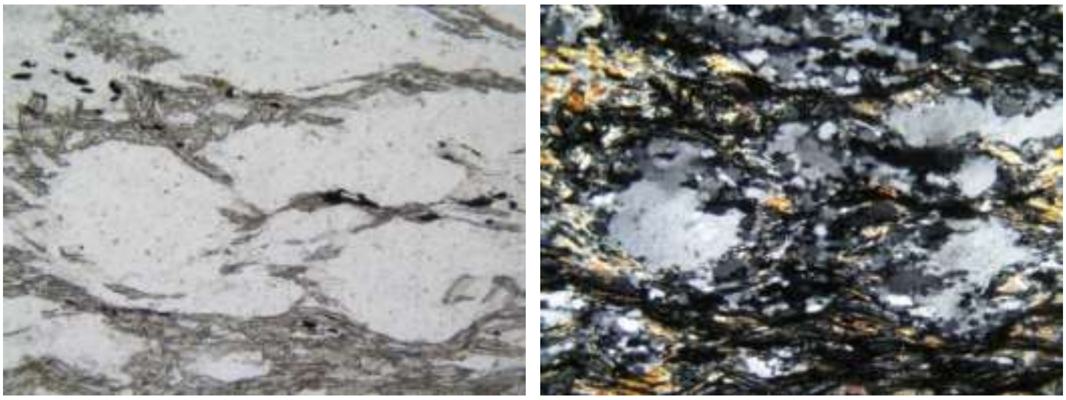

Fig. 16. Mylonitized quartz during further crystallization causes adjacent chloritoid crystals to adjust to their shape. a) PPL; b) XPL.

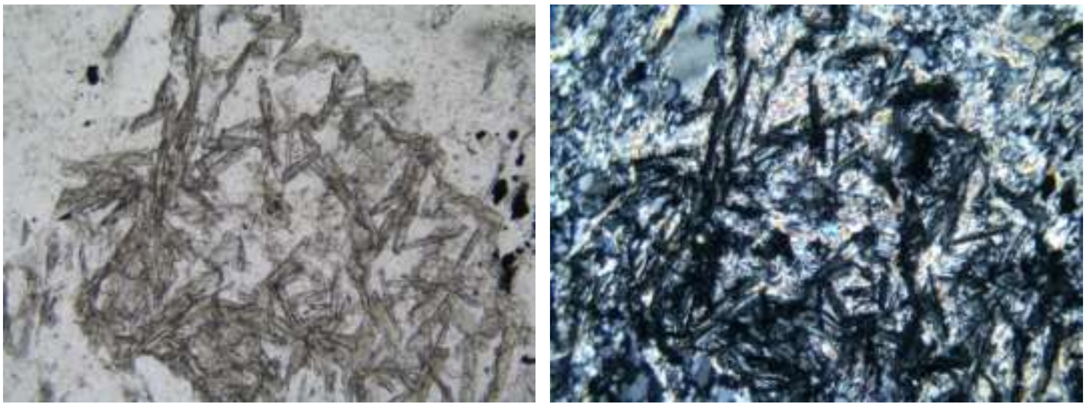

Fig. 17. Chloritoid developed in sericitic mass do not bear traces of deformation and are not oriented according to the schistosity. a) PPL; b) XPL.

CONCLUSIONS

On the infrastructure of the Elbrus subzone of the Greater Caucasus structural zone, the upper part of the Buulgen complex - the Macera nappe - is overthrust from the Pass subzone in the Tournaisian and Late Visean time intervals. The stratified facies of the Mackera nappe differ from each other in the degree of metamorphism, which includes the high-temperature green schist and epidote-amphibolite facies P-T conditions. They underwent regional metamorphism before overthrusting in the Bouulgen complex during the manifestation of the Caledonian phase. The development of Late Variscan metamorphism in the Greater Caucasus Elbrus subzone, along with other factors, was determined by the heat dissipation and mechanical factors developed in its base during the movement of the thick (2500m) Macera nappe. The generation of minerals related to the Macera nappe overthrusting process took place within the green schist facies of metamorphism. In the contact zone of the Macera nappe and infrastructure, there is a significant difference in the degree of their regional metamorphism, intensively developed cataclase, mylinitization and post-tectonic crystallization processes, and extensive development of Late Variscan granitoids and the related post-magmatic transformations. During the Variscan tectogenesis, some of the overthrusting fragments underwent movement also during the manifestation of the post-Variscan tectogenesis, when mechanical pressure significantly exceeded blastesis and tectonic breccias, cataclasites and slikenslided surfaces were formed. They are characterized by significant metasomatic transformations, as well as schistosity developed in deep-seated type blastomylonites.

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