CONTRIBUTIONS TO KNOWLEDGE OF GLAUCOPHANE ROCKS IN THE PARÂNG MOUNTAINS (SOUTH CARPATHIANS)

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Abstract. Two occurrences of blue amphiboles (glaucophane and crossite) are described in the paper. These have been identified in low-grade metamorphic rocks belonging to the Infragetic Complex in the Parâng Mountains, with structural position between the Getic Nappe and the Danubian Nappe Complex. The glaucophane occurs in a quartzitic mylonite with two metamorphic paragenesis: 1) actinolite-epidote-albite-hematite-ilmenite-stilpnomelane and 2) glaucophane-magnetite-stilpnomelane-zoisite-albite. The crossite occurs in an actinolite schist with stilpnomelane, albite and sphene, almost completely replacing the actinolite in a static setting. The mineral paragenesis in the studied samples point out two events of Alpine metamorphism, first in the greenschist facies and second in the transition glaucophane greenschist facies where the assemblage crossite-stilpnomelane also is stable. This biphasic metamorphism is related to the two phases of the Getic Nappe emplacemet, the first during the Mid-Cretaceous (Austrian phase) and, the second during the Upper-Cretaceous (Laramian phase).

Keywords: glaucophane-crossite, Getic Nappe, Parâng Mountains, Romania.

Rezumat. Contribuţii la cunoaşterea rocilor cu glaucofan din Munţii Parâng (Carpaţii Meridionali). În lucrare sunt descrise două ocurenţe de amfiboli albaştri (glaucofan şi crosit) identificate în roci metamorfice de grad scăzut aparţinând Complexului Infragetic din Munţii Parâng, cu poziţie structurală între Pânza Getică şi Complexul Pânzelor Danubiene. Glaucofanul apare într-un milonit cuarţitic care conţine două parageneze metamorfice: 1) actinolit-epidot-albit-hematit-ilmenit şi 2) glaucofan-magnetit-stilpnomelan-zoizit-albit. Crositul apare într-un şist cu actinolit, stilpnomelan, albit şi sfen, substituind aproape complet actinolitul, în condiţii statice. Paragenezele minerale din probele studiate pun în evidenţă două evenimente de metamorfism alpin, primul în faciesul şisturilor verzi şi al doilea în faciesul de tranziţie al şisturilor verzi cu glaucofan, în care este stabilă şi asociaţia crosit-stilpnomelan. Acest metamorfism bifazic este asociat cu cele două faze de punere în loc a Pânzei Getice, prima în timpul Cretacicului mediu (faza Austrică) şi a doua în timpul Cretacicului superior (faza Laramică).

Cuvinte cheie: glaucofan-crossit, Pânza Getică, Munţii Parâng, România.

INTRODUCTION

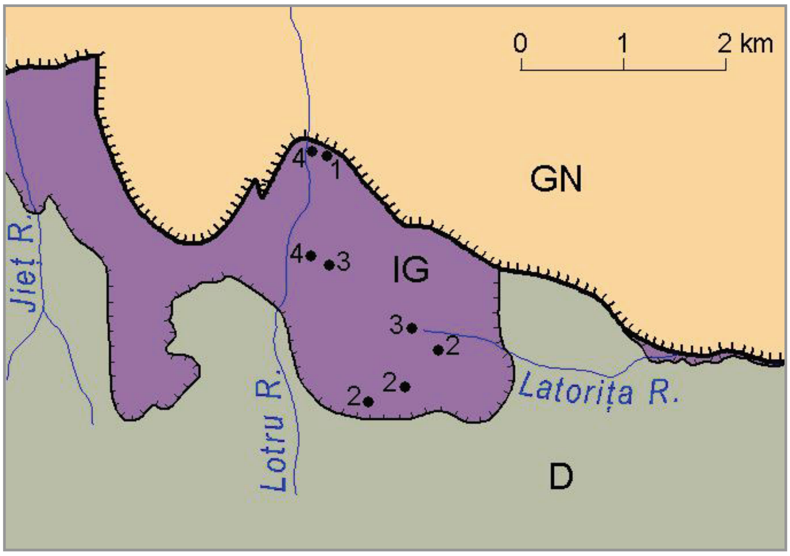

Figure 1. Simplified tectonic sketch of the Parâng Mts. in the studied area (redrawn after PAVELESCU, 1970): GN-Getic Nappe; IG-Infragetic Complex; D-Danubian Nappe Complex. Glaucophane occurrences: **1**-MURGOCI (1898); **2**-PAVELESCU & PAVELESCU (1985); **3**-STRUSIEVICZ & STRUTINSKI (1988); **4**-this study.

The glaucophane was mentioned for the first time in Romania by MURGOCI (1898) under the Getic Thrust in Parâng Mountains, (Fig. 1) on the Ştefanu Creek, in an amphibole-bearing rock, in which the glaucophane (associated with magnetite) replaces a fibrolitic hornblende. After nearly 100 years, PAVELESCU & PAVELESCU (1985) have identified three occurrences of glaucophane in chlorite schists from the Urdele and Muntinu heights (Fig. 1). According to the authors, the glaucophane is the product of a sodic metasomatism for which they do not bring arguments. STRUSIEVICZ & STRUTINSKI (1988), have described two others occurrences of glaucophane (Fig. 1) (associated with stilpnomelane), one in quartzitic schists on the Cărbunele Creek, and one in metabasites from the springs of the Latoriţa Urdelor Valley. These authors consider that the two minerals attest a high pressure-low temperature metamorphism in the glaucophane greenschist facies.

Now we present two new occurrences of blue amphiboles from the same region (Fig. 1), giving a more detailed description of the host mineral assemblages and the metamorphic textures. The first occurrence is of glaucophane, identified in a sample (a lens-shaped boulder) of quartzitic mylonite with magnetite (Fig. 2a) from the alluvial deposits of the Lotru River. The second is of glaucophane-crossite, identified in a sample of stilpnomelane schist (Fig. 2b) from the Ştefanu Creek, the same creek where MURGOCI (1898) mentioned glaucophane in an outcrop that does not exist today. As all occurrences of glaucophane described so far in the upper basin of the Lotru Valley are located in the low grade metamorphic formations of the Infragetic Complex underlying the Getic Nappe, it is reasonable to consider that the boulder of glaucophane mylonite comes from these formations.

The paper also brings new mineralogical and textural data regarding the presence of the high pressure-low temperature metamorphism within the infragetic tectonic slices in the Parâng Mountains, squeezed between the Getic Nappe and the Danubian tectonic units during the nappe emplacement. If the glaucophane is rarely present (or rarely preserved), zoisite, epidote, chlorite, actinolite and stilpnomelane are common in the infragetic metamorphic rocks in this region. In certain associations, these minerals can also indicate a HP-LT metamorphism (e.g. WINKLER, 1966 and references therein; SPEAR, 1993).

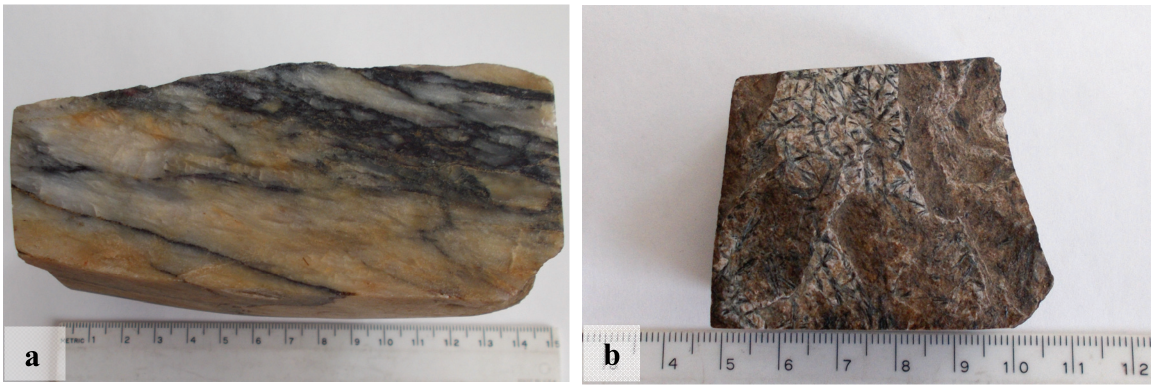

Figure 2. Pictures of the studied samples. (**a**) Polished surface on the glaucophane mylonite. (**b**) Stilpnomelane schists with acicular prisms of crosite, randomly oriented in the foliation plane.

GEOLOGICAL CONTEXT

POPESCU-VOITEŞTI (1923) was the one who deduced the existence of a new nappe between the Getic Nappe (MURGOCI, 1910) and the "Danubian Autochthonous" in the Parâng Mountains, consisting of basic rocks, greenschists and sedimentary sequences, which he called it Urdele Nappe. At regional scale, this nappe is correlated with the Severin Nappe ("Severin Para-autochtonous") in the Mehedinţi Plateau (CODARCEA, 1940). The lithological assemblage of the Urdele Nappe was later attributed to the Infragetic Complex (synonymous with the Jieţ Series), of Mesozoic age (PALIUC, 1937).

Following mapping works for the 1:50,000 geological map of Romania, the Infragetic Complex was included in the epimetamorphic series of Tulişa (PAVELESCU, 1970), Latoriţa and Vidruţa (SAVU & SCHUSTER, 1975), considered of Paleozoic age and Hercynian metamorphism in the greenschist facies. The identification of some Alpine thrusts within these series (e.g. STĂNOIU, 1984; BERZA et al., 1986) led to their subdivision in several Alpine tectonic units whose outline and lithostratigraphic content are different from one author to another.

Here we adopt the structure established by BERZA et al. (1986), in the form revised by STRUSIEVICZ & STRUTINSKI (1988) in the Parâng Mountains region. The two authors attribute the lower Urdele Unit and the upper Petrimanu-Ştefanu Unit to the Latoriţa Series, redefined as ophiolitic mélange formation. This consists of prograde epimetamorphic greenschists (metabasites), wrongly considered retrograded by BERZA et al (1988), with olistoliths of basic and ultrabasic rocks. The median Vidruţa Unit is composed of Liassic ankimetamorphic rocks (Schela Formation) and their Upper Jurassic-Lower Cretaceous carbonatic cover. The three tectonic units represent the former Infragetic Complex, with structural position between the Getic Nappe and the Danubian nappes complex.

At the South Carpathians scale, the ophiolitic Urdele and Petrimanu-Ştefanu units in the Parâng Mountains correlate with the Obârşia Ophiolitic Complex in the Severin Nappe (STĂNOIU, in BERCIA et al., 1977), of Upper Jurassic-Lower Cretaceous (Neocomian) age. The Jurassic ophiolites of the Obârşia Complex show a low-grade metamorphism in the prehnite-pumpellyite and greenschist facies, considered by MĂRUNŢIU (1987) as ocean-floor metamorphism.

According to STRUSIEVICZ & STRUTINSKI (1988), the rocks of the upper Petrimanu-Ştefanu Unit have been metamorphosed in the chlorite greenschist facies while that of the lower Urdele Unit underwent a higher pressure metamorphism, in the glaucophane greenschist facies. Without a detailed mapping of the region we cannot confirm this difference of metamorphic facies. Spatial distribution of the glaucophane occurrences identified to date, as well as the chaotic mélange structure of the two units, suggests that the HP-LT metamorphism has affected the entire pile of pre-metamorphic rocks in the Infragetic Complex, but in a non-penetrative way.

MICROSCOPIC STUDY

The study is based on the mineralogical and textural analysis of 120 thin sections on various petrographic types from the infragetic metamorphic formations outcropping at the springs of the Lotru River and its tributary Latoriţa River, between the Urdele Pass (to the south) and the Ştefanu Creek (to the north). It was a quite difficult approach due to the fine grain size of the minerals. In order to observe the relationships between minerals we needed several sets of thin sections on the same sample. Not less than 30 thin sections were made on the glaucophane quartzitic mylonite in which macroscopically only quartz and magnetite can be recognized. The minerals identification was based on their optical properties, also taking into account the associated minerals and the geological context.

Glaucophane quartzitic mylonite

It is a non-foliated fine grained rock consisting of a leucocratic matrix of quartzo-feldspathic nature with melanocratic segregations of 1-10 mm thick following the trace of some relict microfolds (Fig. 2a). The thick bands are mainly composed of magnetite, clinopyroxene, actinolite, epidote and glaucophane. The thin bands are in fact discontinuous alignments mainly consisting of hematite and ilmenite microblastic grains. Clusters of minute hematite and ilmenite are also present inside the thick bands (Fig. 3d).

The mylonitic matrix. It consist of quartz, albite and minor K-feldspar as intergranular phase. The matrix between melanocratic bands has inhomogeneous texture, with domains affected by intracrystalline plastic deformation, syn-tectonically recrystallized, and domains chiefly affected by intergranular cataclastic deformation, post-tectonically recrystallized, which preserve angular porphyroclasts of quartz and relict microfolds (Fig. 3a). The albite porphyroclasts are much rarer.

The matrix on both sides of the melanocratic bands has homogeneous texture, with syn-tectonically recrystallized grains, fusiform porphyroclasts of quartz and S-C microstructures (Fig. 3b). The S-planes are materialized by the deformation lamellae in the quartz porphyroclasts, disposed at small angle (18-42 degrees) to the C-shear planes materialized by the preferred orientation direction of the grains in the matrix. Along the shear planes, the microfolds are disrupted by transposition on the preferred orientation direction of the matrix.

The microfolds, on the one hand, and the S-C microstructure, on the other hand, reflect two different stages of deformation, first by folding and second by shearing that point out two metamorphic events (M1 and M2). The metamorphic segregation is synchronous with the M2 event.

The melanocratic bands. The general mineralogical assemblage of the melanocratic bands consists of clinopyroxene, actinolite, tremolite, Fe-Ti oxides (hematite and ilmenite), epidote, zoisite-clinozoisite, magnetite, glaucophane, stilpnomelane, sphene, albite and quartz.

Clinopyroxene (aegirine-augite?) is the oldest mineral in the rock, largely replaced by actinolite, epidote and glaucophane. It usually appears as partially decomposed microgranular aggregates, with residual opaque powders (Fig. 3c), rarely as small relicts with crystalline structure. During the first event of metamorphism (M1), the clinopyroxene was syn-tectonically replaced by actinolite (sometimes associated with tremolite) and epidote (Fig. 3c,). Most of the opaque remains have post-tectonically recrystallized as microblasts of hematite and ilmenite (Fig. 3d), sometimes accompanied by tiny plates of stilpnomelane (Fig. 3e).

In the second metamorphic event (M2), the relict clinopyroxene and the actinolite formed on its expense were syn-tectonically replaced by glaucophane, grown in fasciculated crystals oriented on the bands direction (Fig. 3d). The post-tectonic glaucophane crystallizes in euhedral crystals grown across the bands (Fig. 3d), sometimes grouped in radial fascicles (Fig. 3e), or in anhedral crystals grown directly on the pyroxene (Fig. 3f). The glaucophane contains remains of pyroxene and actinolite as well as inclusions of Fe-Ti oxides and epidote (Figs. 3d, f).

On the expense of epidote and of pyroxene remains post-tectonically crystallizes magnetite in euhedral crystals of large sizes compared to the other minerals (Figs. 3e, f). Adjacent to magnetite porphyroblasts often occur pressure fringes consisting of fibrous quartz and albite (Fig. 3c) sometimes associated with stilpnomelane. Rare aggregates of post-tectonic stilpnomelane associated with microblastic magnetite and sphene also appear in the matrix, along the relict microfolds. We mention that all the stilpnomelane in this rock has yellow to green pleochroism, specific for ferroan stilpnomelane (Fe^{2+} dominates over Fe^{3+}).

The zoisite post-tectonically crystallizes as byproduct of the epidote replacement by magnetite. It is associated with magnetite and stilpnomelane in microgranular or scaly aggregates with remains of epidote and pyroxene along the microfolds limbs. Polycrystalline aggregates of zoisite associated with magnetite and glaucophane sometimes occur in the hinge zones.

The clinopyroxene is the only relict mineral in relation to the M1 metamorphic event, suggesting that the protolith of the actinolite-epidote schists was a basic rock with pyroxene and amphiboles, probably. In their turn, the actinolite-epidote schists are the protolith of the glaucophane mylonite formed during the high pressure-low temperature M2 metamorphic event.

Crossite-stilpnomelane schist. It is a schist of brown color with differentiated layering due to the alternation of some melanocratic bands of 1-2 mm thick with quartzo-feldspathic bands of submillimetric thick. Randomly oriented acicular prisms of crossite (*garbenschiefer* texture) are visible with the naked eye in the foliation plane (Fig. 2b). The brown color is given by stilpnomelane.

The quartzo-feldspathic bands are made up of medium-grained quartz and albite, syn-tectonically recrystallized. The albite also appears as intergranular phase and sometimes on fissures. Rarely occur clasts of hematite and apatite and fine-grained aggregates of calcite. The bands have homogeneous texture and S-C microstructures (Fig. 3g) similar to those in the glaucophane mylonite (the angle between the two planes varies between 18 and 35 degrees).

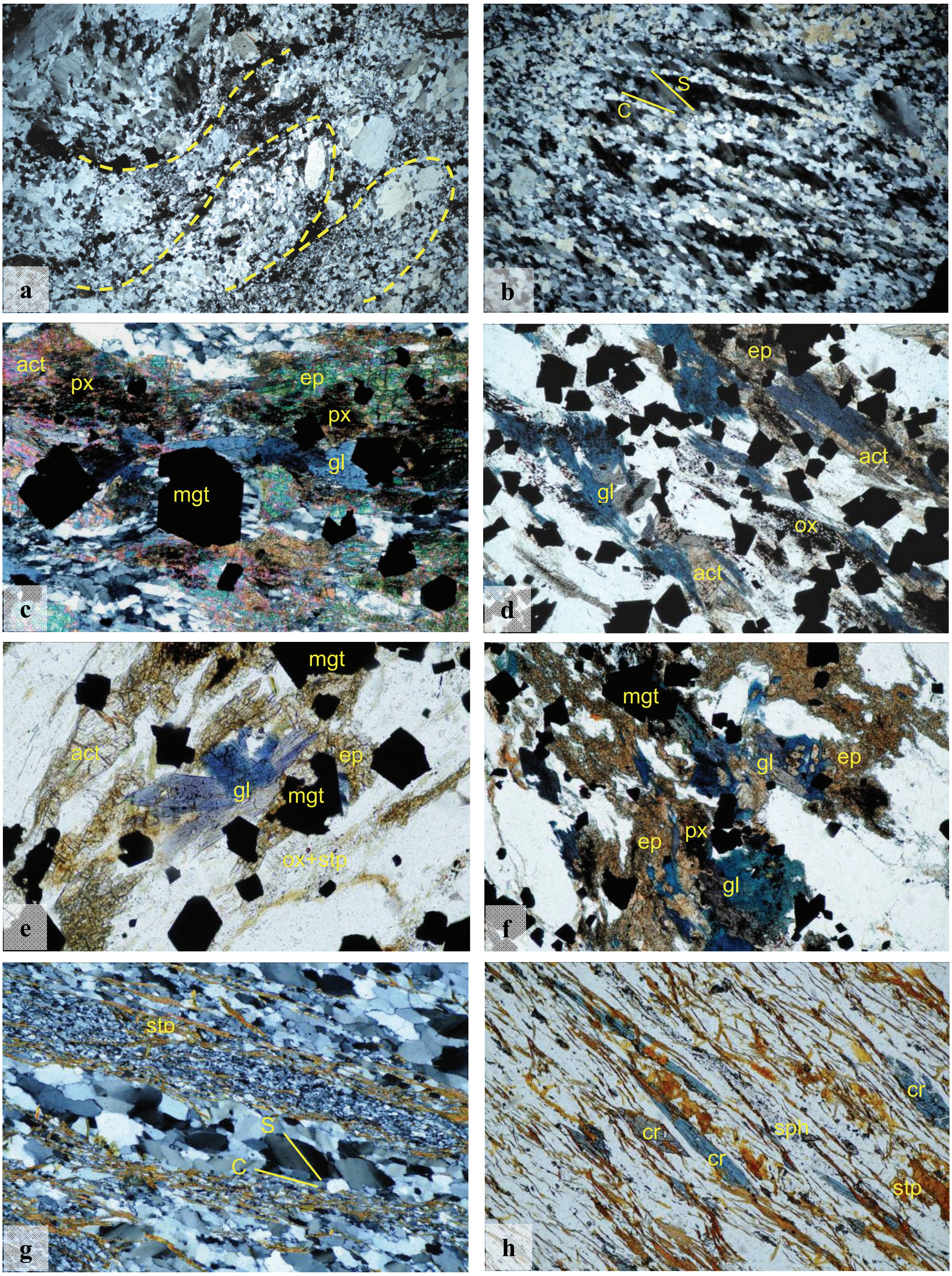

Figure 3. Photomicrographs of the glaucophane mylonite (a-f) and the crossite schist (g-h). (**a**) Inhomogeneous quartzo-feldspathic matrix with relict microfolds (yellow dashed lines) and angular porphyroclasts of quartz (N+, lenght (L) 5.89 mm). (**b**) Homogeneous matrix, syn-tectonically recrystallized, with S-C microstructures (N+, L 5.89 mm). (**c**) Melanocratic band with remains of clinopyroxene (px), actinolite (act), epidote (ep), glaucophane (gl) and magnetite (mgt) grown on the expense of epidote. The magnetite porphyroblast in center shows pressure fringes (N+, L 2.35 mm). (**d**) Syn-tectonically crystallized glaucophane (gl) with remains of actinolite and inclusions of Fe-Ti oxides (ox) (NII, L 2,35 mm). (**e**) Detail with radial fascicle of glaucophane, magnetite grown on the expense of epidote, and clusters of Fe-Ti oxides and ferroan stilpnomelane (NII, L 1.17 mm). (**f**) Post-tectonic anhedral glaucophane grown on the expense of pyroxene, with inclusions of epidote (center-right) (NII, L 2.35 mm). (**g**) Differentiated layering with medium-grained quartzo-feldspathic bands alternating with fine-grained bands rich in stilpnomelane. S-C microstructures are seen in the medium-grained bands (N+, L 2.35 mm). (**h**) Melanocratic band with crossite (cr), ferric stilpnomelane and alignments of microblastic sphene (sph) (NII, L 2.35 mm). Details in text.

The melanocratic bands are poorly differentiated and consist in a fine-grained matrix of quartz and albite, with consistent alignments of closely associated stilpnomelane and crossite alternating with discontinuous alignments of microblastic sphene (Fig. 3h). Calcite rarely occurs on fissures. The stilpnomelane is syn- and post-tectonically crystallized in thin plates arranged in subparallel or plumose aggregates. The pleochroism of this stilpnomelane is golden yellow to orange and reddish brown, specific for ferric stilpnomelane (Fe^{3+} dominates over Fe^{2+}).

The actinolite has synchronously crystallized with the stilpnomelane. It was almost entirely replaced by crossite in static conditions. Rare remains of actinolite usually appear in the crossite that replaces the syn-tectonically crystallized actinolite. The pseudomorphs of crossite after syn-tectonic actinolite often show irregular interference colors, with slightly different extinction angles.

The differentiated layering and the actinolite-stilpnomelane association represent the first metamorphic event (M1). The actinolite replacement by crossite in the absence of deformation suggests that the second metamorphic event (M2) in the history of this rock seems to have been a burial metamorphism.

The protolith of the actinolite-stilpnomelane schist was probably a basic rock with amphiboles, with or without pyroxenes, with relatively high content of titanium, secondary concentrated in the sphene microblasts. As argument, we mention the actinolite-stilpnomelane-epidote schists with relicts of green hornblende which outcrop in the neighboring area on the right bank of the Lotru River. The post-tectonic actinolite in the foliation plane of these schists has the same *garbenschiefer* texture as the crossite in the sample we studied.

DISCUSSIONS AND CONCLUSIONS

The metamorphic textures and the mineral substitutions in the glaucophane mylonite highlights two paragenetic associations of minerals corresponding to two metamorphic events, M1 and M2. The mineral association M1 pointing a low-grade metamorphism in the greenschist facies consists of:

- actinolite + epidote + albite, as syn-tectonic minerals, and
- hematite + ilmenite + stilpnomelane (I), as post-tectonic minerals.

The mineral association M2 is specific to a high pressure-low temperature metamorphism and consists of:

- glaucophane (I), as single syn-tectonic mineral, and
- glaucophane (II) + magnetite + stilpnomelane (II) + zoisite + albite, as post-tectonic minerals.

Like STRUSIEVICZ & STRUTINSKI (1988), we consider that the glaucophane and the stilpnomelane in the M2 mineral paragenesis correspond to the high pressure type of the greenschist facies, defined by WINKLER (1966, p. 98, 123) as glaucophane greenschist facies in the intermediate P/T metamorphic facies series, specific to regional metamorphism. In this facies other high-pressure minerals may be also present, such as crossite, alkali pyroxene, stilpnomelane, albite, chloritoid, chlorite and calcite.

The thermobaric field of the glaucophane greenschists, characterized by pressures greater than 8 kb and temperatures of 400-500 degrees (WINKLER, 1966, p. 142), intersects the blueschists PT field in the high P/T facies series, specific to subduction zones. The thermobaric field of blueschist facies is characterized by pressures of 6-14 kb and temperatures of 200-500 degrees (SPEAR, 1993). The greenschist to blueschist facies transition is commonly found in metabasites, being marked by the appearance of some mineral associations with glaucophane, zoisite (or epidote), albite, chlorite and actinolite, in which the glaucophane and the zoisite are omnipresent (SPEAR, 1993, p. 428-429).

The mineral paragenesis M1 in the crossite schist, specific to the greenschist facies, consists of actinolite + stilpnomelane + albite + sphene. Except the actinolite, almost completely substituted by crossite, this association also remains stable in the thermobaric conditions of high pressure and low temperature following the actinolite schists formation.

The basic rocks and the associated sedimentary sequences of the Infragetic Complex have been metamorphosed in the convergent tectonic context of the Getic Nappe emplacement and of subduction that preceded it. The nappe emplacement was performed in two phases, during Mid-Cretaceous and Upper-Cretaceous (CODARCEA, 1940; SĂNDULESCU, 1984, 1994). The subduction of the Jurassic-Lower Cretaceous Severin paleorift on the European continental margin under the Getic paleogeographic domain took place in the first phase (Austrian phase). In the second phase (Laramian phase), the emerging Getic Nappe was overthrusted on the Danubian-Moesian paleogeographic domain together with the volcano-sedimentary sequences decoupled from the subducting ophiolitic crust which form the Severin Nappe. The M1 and M2 metamorphic events identified in the studied glaucophane rocks are related to the two tectonic phases of the Getic Nappe emplacement.

If the overthrusting was the mechanism of the Getic Nappe emplacement, this means that the Getic domain was the active crustal block during the convergence. In this case it is quite curious that the Alpine deformations inside the moving nappe are insignificant. The deformations related to the thrusting have strongly affected the Danubian basement and the obducted volcano-sedimentary formations (internal thrusts, tectonic mélanges and HP/LT metamorphism). At the same time, the upper Getic block was only slightly affected by cataclastic deformations, without metamorphism, and only on small thickness, of 100-200 meters above the thrust plane. These observations suggest that the Danubian domain was the crustal block moving under the relatively stationary Getic block. Therefore, the tectonic mechanism which generated the Getic Nappe seems to have been an underthrusting.

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