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THE METAMORPHIC EVOLUTION OF THE LOW PRESSURE TERRAIN IN THE CENTRAL SOUTH CARPATHIANS (GETIC NAPPE)

(Figs. 15, Tab. 1)

Abstract: The Getic Nappe crystalline of Central South Carpathians includes low pressure metamorphic rocks which are an independent entity, the Ursu Formation, in tectonic relations with the Lotru Group; two formations were recognized within the latter in the area under discussion. There are several mineralogic and structural data which show that the Ursu Formation had a continuous ascent and cooling evolution simultaneous with its domal emplacement within the Lotru Group. The metamorphic evolution was completed at ca 450° and 200 MPa, preserving relict assemblages which point to temperature decrease of ca 400 °C and pressure decrease of 500 MPa resulted from an ascent of 3 mm/year. The evolution ends with the contact metamorphism overprinted on the Lotru Group formations.

Subsequent rupture tectonics (overthrusts and faults) results in complex spatial relations of lithologic units.

Резюме: Гетское покровое кристаллиникум Центральных Южных Карпат содержит метаморфические породы низкого давления, которые представляют самостоятельную единицу — формацию Урсу, тектонически связанную с группой Лотру. В рамках последней выделяются в изучаемом регионе две формации.

Существуют минералогические и структурные данные, которые показывают, что непрерывный подъем и эволюция охлаждения формации Урсу проходили одновременно с ее куполообразным положением в рамках группы Лотру. Метаморфическсая эволюция была завершена при температуре около 450 °C и давлении 200 MPa соблюдая реликтовые ассоциации, показывающие на понижение температуры около 400 °C и давления 500 MPa вследствие подъема 3 мм/год. Эволюция заканчивается контактовым метаморфизмом наложенным на формации группы Лотру.

Результатом последующей тектоники разрывов (надвиги и сбросы) являются комплексные пространственные отношения литологических единиц.

Introduction

The metamorphic rocks of the Getic Nappe as defined by Murgoci (1905) and Streckeisen (1934) were assigned by Codarcea et al. (1961) to the Sebeș-Lotru Series, notion still largely used.

The up-to-date concept of Getic Crystalline points to the widespread occurrence of medium grade metamorphics resulted from two superposed medium pressure Precambrian events, which include limited areas of low pressure metamorphics lineamentarily distributed on some 200 km along the South Carpathians (e.g. Hârtopanu, 1982; 1986), from the Căpățîna Mts. to the Danu-

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be. The lithologic constitution of the Getic Crystalline is mainly pelitic, with amphibolites and quartz-feldspar gneisses, frequently migmatized and/or containing metamorphic pegmatites. Anatectic granitoids, eclogite cores and ultrabasites occur in places; marbles and calc-silicate rocks are subordinate.

The study of Getic medium pressure metamorphics has pointed to a Barrovian type progressive zoning, from chlorite zone up to sillimanite-muscovite zone in the western South Carpathians-Semenic and Almăj Mts. (Savu, 1970, 1975). Nevertheless, more recent studies argue for a complex structure of the investigated area, its formations being ascribed to several distinct tectonic and lithostratigraphic units (Iancu et al., 1986).

Bercia (1975) reported three succesive zones (kyanite-staurolite, kyanite, sillimanite-muscovite respectively) of the Barrovian facies series in the Godeanu Outlier.

However, the most elaborate investigation was carried out by Hârtopanu (1982) who, by means of a detailed analysis extended over the whole outcropping area of the Getic Nappe Precambrian, as well as synthesis and reinterpretation of former data (Hârtopanu, 1972; 1975; 1978), draws the following conclusions:

— the metamorphics of the Sebeș Lotru Series account for a Precambrian multiphase or polycyclic evolution, characterized by superposed textures and two isotype, commonly isograde, parageneses;

— the two metamorphic events have resulted in the mineral associations kyanite + staurolite, sillimanite + muscovite ± kyanite respectively, ubiquitous in the Getic Crystalline and typical of medium pressure type called by the cited author, according to tradition, Barrovian;

— the complex metamorphic evolution makes difficult to recognize whether the transition from a metamorphic zone to the adjacent one is due to an isograde surface, to an old tectonic contact delimited by a blastomylonite lineament or to a superposed event, while general conclusions are impossible to draw.

Structural evidences (Iancu — Hârtopanu, 1979; Iancu, 1983) account for the quality of metamorphic cycles of the events identified by Hârtopanu and imply the polycyclic character of the Getic Crystalline. In zones where a normal progressive zoning (related to the second cycle) can be traced the succesion of the kyanite + staurolite and sillimanite + muscovite ± staurolite zones respectively points to the Idaho facies series (Hietanen, 1967).

The investigation of low pressure metamorphism had started since the last century. Mrazec — Murgoci (1897) described the association sillimanite + dumortierite (?-n.n.) + cordierite + orthoclase from the Căpățîna Mts. These studies are followed by the investigations of Ghika — Budești (1934) and Pavelescu (1955). Savu (1968) defined the "lower complex of sillimanite + cordierite paragneisses". Bercia (1975) is the first to use the notion of low pressure metamorphism related to Pyrenean metamorphism in the Godeanu outlier. Hârtopanu (1975) described the low pressure metamorphics from the Bahna outlier associated with a superposed thermal dome, and Savu (1975) accounts for the same interpretation as regards the low pressure metamorphics from the Căpățîna Mts. assigned to the Abukuma or Buchan baric types.

During the eighties, Bercia — Hârtopanu (1980) reviewed the main hypotheses inferred from their investigations and mentioned the subsequent nature of the low pressure metamorphism generated by a thermal dome associated with some Hercynian supposed granitoid intrusions similar to those from the Danubian Domain. H â r t o p a n u (1982) considered that:

— the low pressure metamorphics areas with andalusite + muscovite ± sillimanite ± cordierite are superposed on medium pressure metamorphics preserving relict previous parageneses;

— in regionally polymetamorphosed areas with different baric conditions staurolite occurs as a relic of an older medium pressure paragenesis;

— the spatial distribution of low pressure parageneses corresponds to their succession in time and may be assigned to an isobar.

Regarding the lithostratigraphic assignment of the Getic Precambrian, we prefer the term of Lotru Group, designating the entity composed of the formations in which at least one medium pressure event can be recognized. It represents on the whole the entity as yet more frequently named Sebeș-Lotru Series or Group. The reasons for our choice of a term which is rather less employed than widespread will be given in the addenda, while the modifications as regards the Sebeș-Lotru Series/Group will be argued further on.

The elaboration of the Geologic map of Romania, scale 1 : 50.000 (sheet Polovragi) implied investigations of the authors in the ecntral South Carpathians, which consisted, among others, in the tentative of delineation of metamorphic isogrades in the Getic Crystalline mainly those in the low pressure terrains. The metapelites were primarily studied in several hundredths of thin sections. It has resulted that the index mineral distribution is rather irregular (Fig. 2 A, B), while instead of metamorphic zoning complicated relationships occur, being characterized by the following features:

— superposed parageneses pointing to different types and grades of metamorphism;

— widespread lack of mineralogic and structural equilibrium making evidence of a continuous evolution;

— relations masked by tectonic imprints of different age and importance.

Geologic setting

In the central South Carpathians, the low pressure Getic metamorphics occur in the limbs of an eroded nappe antiform which forms a large tectonic half-window. The occurrences lie around the Petrimanu peak from the Latorita Mts., respectively on ca 85 km^2 to the north and south of the main ridge of the Căpățîna Mts. (Fig. 1).

The metamorphic rocks of the Lotru Group adjacent to the low pressure metamorphics are assigned to two formations. In the Căpățîna Mts. there is a partly migmatized formation with equally developed amphibolites and mica gneisses, quartz-feldspar gneisses, containing eclogites and ultrabasites, anatectic granites, called by us the Vaideeni Formation, mostly equivalent to the amphibolite and quartz-feldspar gneiss complex defined by S a v u — S c h u s t e r (1977).

In the Latorița Mts. lies the Steflești Formation of mainly pelitic character, consisting of mica-plagiogneisses and subordinate amphibolites, micaschists, migmatites and pegmatites, equivalent to the paragneiss complex (Savu – Schuster, 1977). In the Latorița Mountains the imprint of the second medium pressure metamorphic cycle over the Steflești Formation has resulted in the sillimanite + muscovite ± staurolite zone paragenesis, while in the Vaideeni Formation (Căpățîna Mts.) two succesive metamorphic zones (staurolite + kyanite, sillimanite + muscovite ± staurolite respectively) of the second cycle occur.

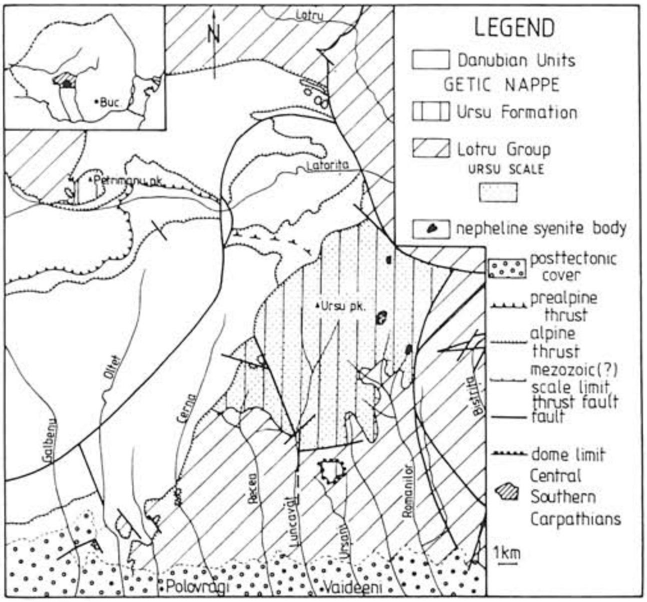

Fig. 1. Tectonic sketch with the location of low pressure metamorphics in the Central South Carpathians. Danubian structure acc. to Berza – Drăgănescu (1986, in preparation).

Most of the low pressure metamorphics (those with no relict medium pressure parageneses) represent another formation with amphibolites prevailing over mica gneisses and abundant small ultrabasite bodies, called the Ursu Formation, with uncertain appurtenance to the Lotru Group.

Generally, between the Ursu and the Vaideeni Formations there is a tectonic contact marked by a gentle dipping thrust plane outlined by a thick mylonite layer with frequent tectonically mobilized marble lenses. The tectonic plane delimits at the top the Ursu Scale built up mostly of the rocks of the Ursu Formation. The thrust is at least of Jurassic age as the plane is crossed by dolerite veins proving a K/Ar age of 155×10^6 years. To the west superposition relations turn to the opposite, perhaps due to a younger antithetic thrust fault. However, were this assumption correct, the time span between the two thrusts must be negligible as they have identical features. In some areas of both the Ursu Scale and the lower unit, the transition from one formation to another

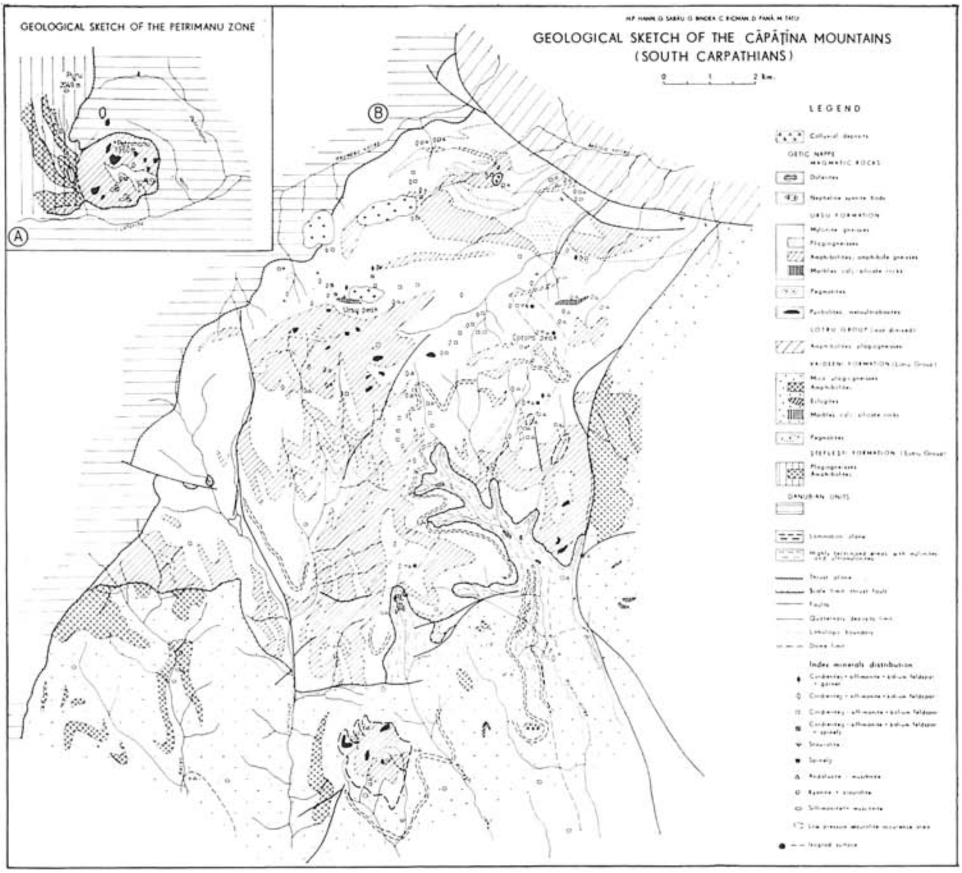

Fig. 2. Geological sketch of the investigated areas.

is not affected by thrusting, making evident the prior relationships between them.

The boundary between Ursu and Steflești formations is not clear from field data.

Description of rock types

The metapelitic rocks show some characteristic features in field and hand specimens. The abundant muscovite content of the mica gneisses of the Lotru Group and (subordinately) of the Ursu Formation results in strongly foliated aspects. However, most commonly the metapelites of the Ursu Formation (Ursu gneisses) are muscovite free. It is to note three main types:

a) Hard, dense gneisses with millimetric to centimetric lens-like and fusiform leucocrate zones included in a fine — grained schistous matrix of dark colour,

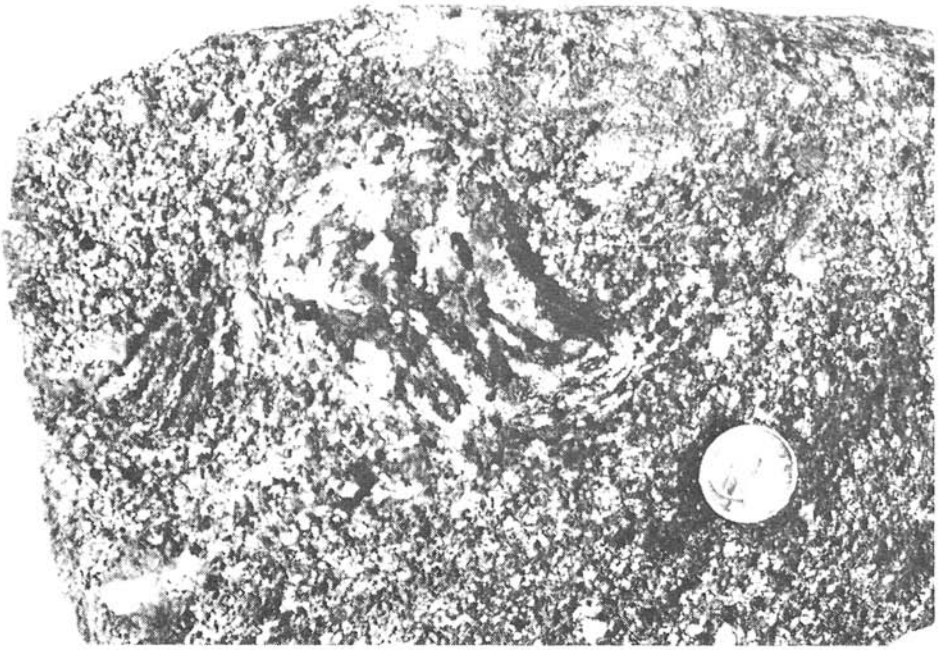

Fig. 3. Cordierite, biotite and feldspar fels with relict mylonite gneiss, Cicovanul, Căpăţina Mts.

built up of biotite and sillimanite. The schistosity is unevenly crenulated, undulated to convolute. The leucocrate zones consist of cordierite, feldspars and quartz. Both the hand specimen and the thin section show a mylonite gneiss texture.

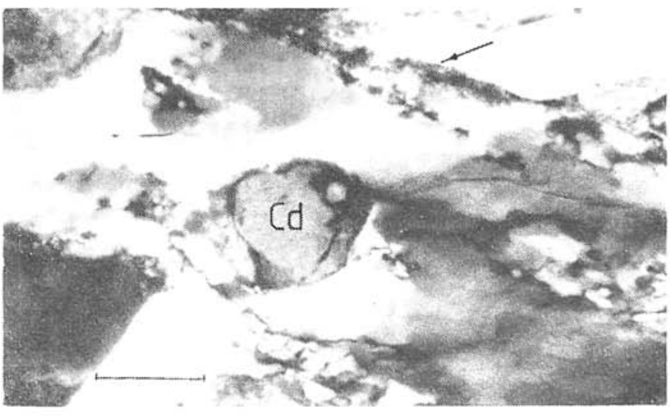

Fig. 4. Mylonite gneiss with cordierite porphyroblast (Cd) in flamboyant quartz. Arrow showing fine grained intergranular biotite fibrolite aggregates. Scale bar 100 m, thin section.

Table 1

Bulk chemical analyses of metapelites (weight %)

No.	1	2	3	4	5	6
location	N slope Ursu peak	Ursu peak	Polovrăgeni crest S Căpăţîna Mts.		Lotru Valley	
data acc. to	analyst V. Neacşu[1]		analyst C. Vlad[1]		T. Mînecan[2]	
SiO_2	59.20	58.80	60.60	64.70	61.00	55.97
TiO_2	1.12	1.12	1.08	0.98	0.50	0.65
Al_2O_3	19.86	20.84	15.60	14.85	19.00	21.28
Fe_2O_3	1.24	1.74	0.93	1.34	3.02	3.63
FeO	6.49	6.54	5.49	4.84	5.20	1.50
MnO	0.11	0.11	0.12	0.10	0.50	0.14
MgO	2.65	2.77	2.80	2.69	0.50	3.90
CaO	0.62	0.65	2.60	2.54	1.36	4.20
K_2O	3.80	2.41	2.38	2.52	2.70	3.12
Na_2O	1.54	1.24	3.37	3.33	0.60	3.23
P_2O_5	0.18	0.08	0.74	0.32	—	0.15
H_2O	3.41	3.11	3.81	2.09	3.70	1.86
S	0.11	0.07	0.25	0.18	0.08	0.27
	100.32	99.47	99.77	100.48	99.99	99.90

[1] Enterprise for Geological and Geophysical Prospecitng, Bucharest; [2] thesis for a doctor's degree, University of Bucharest, 1985.

b) Banded gneisses consisting of alternating leucocrate and melanocrate layers. The dark bands show the same composition and structure as the type mentioned above.

c) Cordierite, feldspar and biotite felses. They show centimetric mylonite gneiss "enclaves" (type a) in places and partly recrystallized areas preserved in the isotropic groundmass, accounting for their generation by recrystallization of mylonite gneisses (Fig. 3).

Bulk chemistry of rocks

The bulk wet chemical analyses of the Ursu gneisses point to their ferro-magnesian nature as compared to the metapelites of the Lotru Group (Tab. 1).

Description and interpretation of microstructures

The microscopic study of the Ursu gneisses, type *a*, points to their texture of mylonite gneiss with lens-like monomineral porphyroclasts, or built of cordierite I, plagioclase I, orthoclase I, garnet and sillimanite aggregates (paragenesis I). The blastomylonite matrix (Fig. 4) consists of plastically deformed flamboyant quartz with irregular, blurred grain boundaries, biotite and sillimanite (± fibrolitic) of varying grain size and highly deformed. The postash feldspar is represented by orthoclase abunding in exsolution perthites of ribbon and plume types. The triclinic character determined by Nikitin method (010) Nv is 0.2, the ordering being proportional to the increasing perthitic albite content. The contact with cordiedite is marked by rational grain boundaries. The plagioclase, optically determined by migration of twin axis or of cleavage poles against the fixed vibration directions, checked by Köhler method, yields 28—30 % *An* and is twinned following albite law. The unimportant amounts of garnet are affected by brittle deformation. In case mylonitic gneisses are not affected by subsequent retromorphism, the porphyroclastic minerals are only mechanically deformed, pointing to an intense strain which generated the mylonite gneisses and which started in the conditions of the prior paragnesis stability.

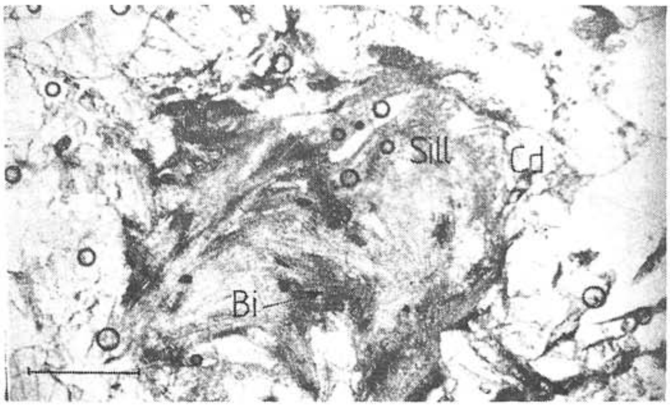

Fig. 5. Sillimanite nodule with biotite relics and cordierite cover. Scale bar 500 μm. Biotite gneiss, thin section. Plane polarized light, Tribunanul Haiducilor, Căpăţina Mts.

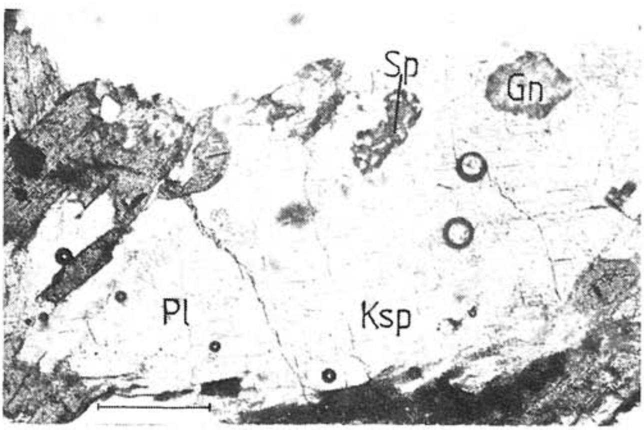

Fig. 6. Substitutions antiperthites, scale bar 250 μm. Cordierite gneiss. Thin section, plane polarized light, Şoimul brook, Latoriţa Mts.

The cordierite felses occur as lens-like cores hundredths of meters long within the mylonite gneisses, containing relics of the latter. Under the microscope, it is to note their coarse-grained hypidioblastic structure with an obvious idiomorphic character of cordierite. Their mineralogic composition includes cordierite II, orthoclase II, quartz, plagioclase II, biotite and sillimanite (paragenesis II). The cordierite crystals show frequent rounded sillimanite and biotite inclusions, not in mutual contact, preferentially arranged in the idioblastic groundmass. Cordierite is supposed to have resulted from the reaction:

$$2\ K(Mg, Fe)_3AlSi_3O_{10}(OH)_2 + 6\ Al_2SiO_5 + 9\ SiO_2 \rightarrow 3\ (Mg, Fe)_2Al_4Si_5O_{18} \cdot nH_2O + 2\ KAlSi_3O_8 + (2-3n)H_2O \quad (1)$$

The potash feldspar occurs as orthoclase-perthite (plume), with triclinicity index 0.2—0.3, $2V_\alpha = 64°—80°$ in case perthites represent 1—2 % of the grain, reaching the microcline in those blasts yielding 7—14 % perthitic albite. Later reorganisations result in microcline pseudomorphs after cordierite still within the field of cordierite stability along with potash feldspar in mutual contact. The plagioclase points to 28—30 % *An* and is twinned according to albite law. The absence of garnet is due to the reaction:

$$2\ (Mg, Fe)_3Al_2Si_3O_{12} + 4\ Al_2SiO_5 + 5\ SiO_2 + 3nH_2O \rightarrow 3\ (Fe, Mg)_2Al_4Si_5O_{18} \cdot nH_2O + 7\ SiO_2 \quad (2)$$

Partial melting may have occured in this stage, as felses sometimes have a reduced grain size towards the mylonite gneiss inclusions.

The gneisses of type *b* show, under the microscope, alternating blastomylonite bands and zones of static recrystallization, with equilibrium structure (triple points with constant interfacial angles, grain margins perpendicular to biotite piles or starting from theis ends). Neverthelles, the bulk structure is lacking balance and the mineralogic association preserves relict prior stages, while the recrystallized portions contain parageneses and associations built up in different conditions, the succession being, when noticeable, a retrogressive one. Reaction (2) may be noted in progress.

Sillimanite nodules with biotite relics and covered by cordierite (Fig. 5) result from reaction (1). A new generation, cordierite III, characterized by polysynthetic and cyclic twins is noted. In those zones dominated by nucleation the neoformation cordierite shows armoured spinel I inclusions in accordance with the reaction:

$$5\ K(Mg, Fe)_3AlSi_3O_{10}(OH)_2 + 2\ Al_2SiO_5 \rightarrow 4\ (Fe, Mg)_2Al_4Si_5O_{18} + 5\ KAl_3Si_3O_{10}(OH)_2 + 7\ (Fe, Mg)Al_2O_4 \quad (3)$$

generating association III. Neoformation muscovite I (pinnite) pseudomorphoses the sillimanite contained by cordierite, without being present in the groundmass. Spinel pseudomorphoses the sillimanite or contains biotite and sillimanite relics. Potash feldspar becomes mobile and recrystallizes as clear orthoclase III, finely perthitic (string) in places, marked by triclinicity indes 0.1, $2V_\alpha = 55°$, stable along with cordierite. It may also form replacement antiperthite rods and patches within plagioclase (Fig. 6). Myrmekites abund round older orthoclase grains following the reaction:

$$\begin{Bmatrix} x\ KAlSi_3O_8 \\ y\ NaAlSi_3O_8 \\ z\ Ca\ (AlSi_3O_8)_2 \end{Bmatrix} + \begin{Bmatrix} u\ NaAlSi_3O_8 \\ t\ CaAl_2Si_2O_8 \end{Bmatrix} \rightarrow x\ KAlSi_3O_8 + 4\ z\ SiO_2 +$$

orthoclase I plagioclase I orhtoclase III

$$+ \begin{Bmatrix} (u + y)\ NaAlSi_3O_8 \\ (z + t)\ CaAl_2Si_2O_8 \end{Bmatrix} \quad \text{(after Phillips et al., 1972)}$$

plagioclase III

A new plagioclase III generation (19—24 % *An*, most often 20 %) appears, its Na amount resulting from albite exsolution from orthose. Andalusite crystallizes initially as graphic intergrowths with cordierite or occurs as pseudoinclusions with quartz border in the latter (Fig. 7).

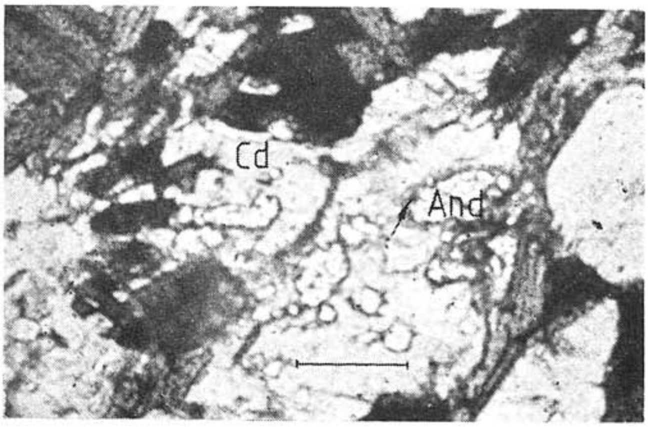

Fig. 7. Andalusite pseudoinclusions in cordierite. The arrow points to quartz rim around andalusite. Scale bar 250 μm. Biotite gneiss, microsection, plane polarized light, Muchia Durducului, N Căpăţîna Mts.

The potash feldspar represents a mobile phase, as proved by intense migmatisation. Cordierite is corroded by microcline and results in cuspate to saw-shaped contours deprived of reaction aureoles. The sillimanite inclusions in cordierite disappear gradually in the feldspar groundmass. Cordierite may react with andalusite in accordance with reaction:

$$2\ (Fe, Mg)_2Al_4Si_5O_{18}.nH_2O + 5\ Al_2SiO_5 \rightarrow 2\ H(Fe, Mg)_2Al_9Si_4O_{24} + (n-1)H_2O + 7\ SiO_2 \qquad (5)$$

experimentally studied by Richardson (1968).

Staurolite is absent from the groundmass and forms only armoured inclusions in andalusite. The reverse crossing of staurolite stability field in the absence of quartz results in spinel II (solid solution) and magnetite, the reaction altering the pH of the system:

$$2\ \mathrm{H(Fe,\ Mg)_2Al_9Si_4O_{24}} \rightarrow 8\ \mathrm{Al_2SiO_5} + \mathrm{(Fe,\ Mg)Al_2O_4} + 2\mathrm{H^+} \qquad (6)$$

Amoeboidal armoured staurolite inclusions marginally altered into spinel (Fig. 8) are formed. In the Căpăţîna Mts. the staurolite-bearnig Ursu gneisses cover an area several hundredths of meters wide which forms a crescent starting from the Cocora peak to south of Roman peak, where the above mentioned assemblage (association IV) is present.

Fig. 8. Armoured staurolite inclusion in andalusite. Spinel-andalusite simplectite develops round the staurolite grain. Andalusite rimmed by andalusite-quartz simplectites (arrow). Scale bar 500 μm. Biotite gneiss, microsection, plane polarized light, Cocora-Muchia Durducului, N. Căpăţîna Mts.

The approach to the stability field of muscovite and quartz is marked by the ubiquitous presence of andalusite-muscovite paragenesis (paragenesis V), with a different ratio between the latter and the prior assemblages. Its massive neoformation results in muscovite gneisses with constant macroscopic features, although the microscopic study points to different relict associations. It shows lepidoblastic texture with andalusite porphyroblasts, the structure undergoing equilibration or being already equilibrated.

Mylonite gneisses are statically recrystallized in places, flamboyant quartz being altered to an undeformed grain aggregate with serrated grain boundaries and similar optical orientation of individuals.

Cordierite porphyroblasts are pinnitized and andalusite pseudomorphoses them leading to "andalusite-cordierite porphyroblasts" (Hârtopanu, 1982) (Fig. 9). Andalusite also forms paramorphs after fibrolitic sillimanite (Fig. 10). A new migmatisation stage may occur and microcline replaces partly the andalusite porphyroblasts, the reaction between the two incompatible phases being absent.

In case the Lotru Group formations are in apparent nontectonic contact with the Ursu Formation, the medium pressure parageneses of the former are overlain by the andalusite + muscovite ±staurolite ± sillimanite ± cordierite paragenesis. The rock exhibits characteristic microtextural features. Biotite is inequigranular, deformed, fills the voids between the quartz grains and the undeformed plagioclases. Ductile and brittle deformed relics of the old paragenesis (biotite + sillimanite + muscovite + plagioclase ± staurolite) are preserved. Large neoformation muscovite grains appear. Staurolite occurs as rounded inclusions in andalusite. Sillimanite sheaves appear in neoformation andalusite, being gradually digested towards the crystal core (Fig. 11). A new sillimanite generation subsequent to andalusite appears as fine needles at the

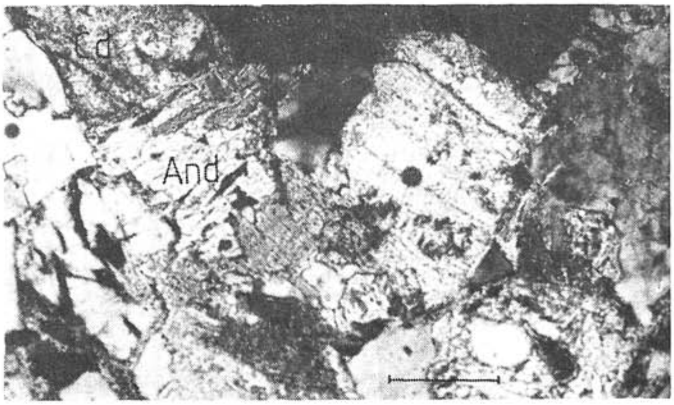

Fig. 9. Cordierite substitution by andalusite. Scale bar 250 m. Mica gneiss, thin section, crossed nicols, Piatra Roşie, Căpăţîna Mts.

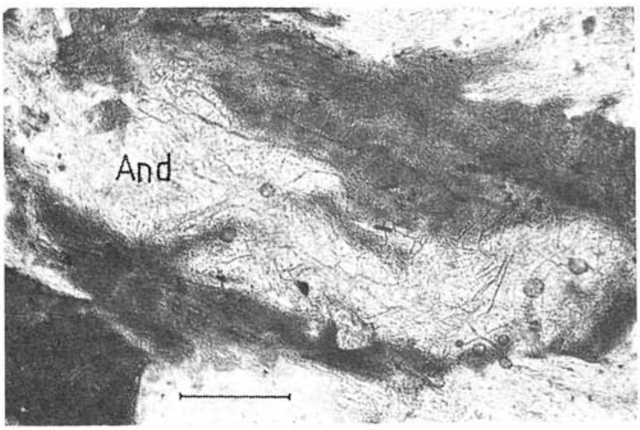

Fig. 10. Andalusite paramorphosis after fibrolitic sillimanite. Scale bar 250 μm. Mica gneiss, thin section, plane polarized light, Podul Cărpănoasei, Căpăţîna Mts.

boundary of quartz grains pointing to the proximity to andalusite sillimanite phase boundary or to the metastable growth of the latter.

The structural relations show the staurolite neoformation in places, subsequent to the deformation and unstabilisation of the medium pressure paragenesis.

The old paragenesis may also occur as kyanite and staurolite relics (as it is the case) in decussate muscovite aggregates generated during andalusite neoformation (Fig. 12), rarely accompanied by cordierite.

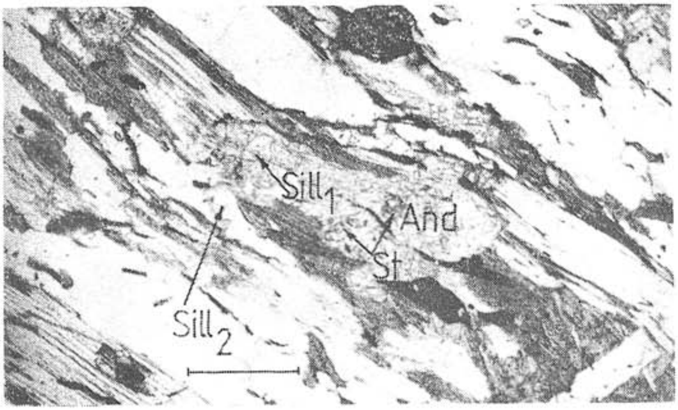

Fig. 11. Two sillimanite generations separated by an andalusite porphyroblast which includes staurolite. Scale bar 250 μm. Mica gneiss, Luncavăț-Urșani interfluve, Căpățina Mts.

Laterally to the superposed andalusite zone, the Lotru Group metapelites exhibit the neoformation of olive-dark brown coloured biotite and fine-grained Mn-rich garnet which point to a lower grade of the same metamorphic event. Prior biotite and corroded garnet relicts with atoll textures are often present. In the upper course of Urșani brook (South Căpățina Mts.) one may distinguish between S_2 folded foliation corresponding to the last medium pressure event and S_3 axial plane foliation with mica neoformation related to F_3 folding (Fig. 13).

The presence of the chlorite zone of superposed low pressure metamorphism may not be accurately stated, as far as all over the Căpățina massif a younger (Hercynian?) low grade retromorphism affected differently and unevenly the older metamorphics, while the abundant mylonitized lineaments are altered to chlorite.

Fig. 12. Staurolite and kyanite relics contained by muscovite; neoformation andalusite developed far from unstable aluminium silicate minerals. Mica gneiss, sketch acc. to thin section, Cocora brook, Căpățina Mts.

Metamorphic evolution and thermobaric estimations

The conditions of metamorphic evolution were not accurately defined because of lack of data on the composition of mineral solid solutions. However, the study of mineral reactions inferred from microstructures as compared to experimentally determined stability curves may supply adequate information. Figs. 14, 15 show the succession of transformations.

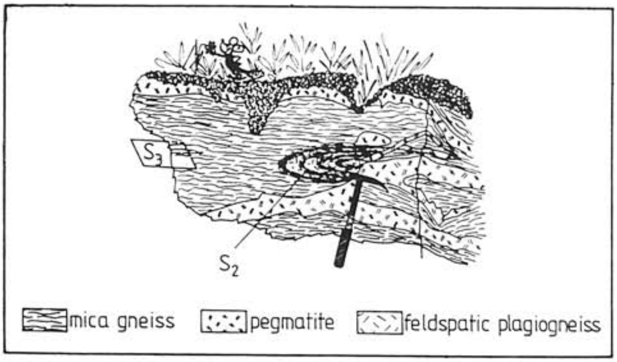

Fig. 13. Relationships between S_2 and S_3 superposed foliations. Outcrop sketch, Urșani brook, Căpățîna Mts.

Paragenesis I, formed in the field of garnet and cordierite coexistence. The presence of intense deformation affecting it is probed by blastomylonitic textures with porphyroclastic relicts belonging to paragenesis I. Garnet and cordierite-bearing pegmatites are generated.

Deformation is accompanied by decrease of temperature and pressure. This results in crossing the biotite-garnet univariant line which leads to resorption of garnet according to reaction (2). Locally, paragenesis II felses crystallize, reaction (1) playing an important role. The reactions mentioned above assign paragenesis I to relatively high pressures as they imply a variation slope of thermobaric conditions more abrupt than the slope of type 1 univariant reactions for successive iron-richer isopleths corresponding to solid solutions. The continuous neoformation of cordierite makes evidence of uninterrupted decrease of pressure. Neoformation cordierite occurs in undeformed laminae and pressure shadows, while previous, more magnesian generations become unstable. Potash feldspar became mobile, released Na accounting for temperature decrease and generated the myrmekites. Later, the conditions change resulting in spinel I according to reaction (3). Pinnites are also obtained, the absence of muscovite from the groundmass showing that association III formed between the two thermal instability curves of muscovite, in the sillimanite field. The evolution continues as temperature decreases crossing the sillimanite andalusite boundary. Then, the staurolite stability field is intersected, rapidly crossed and association IV results from reactions (5) and (6). Cordierite is pseudomorphosed by andalusite, the former being frequently unstable. The decrease of temperature results in

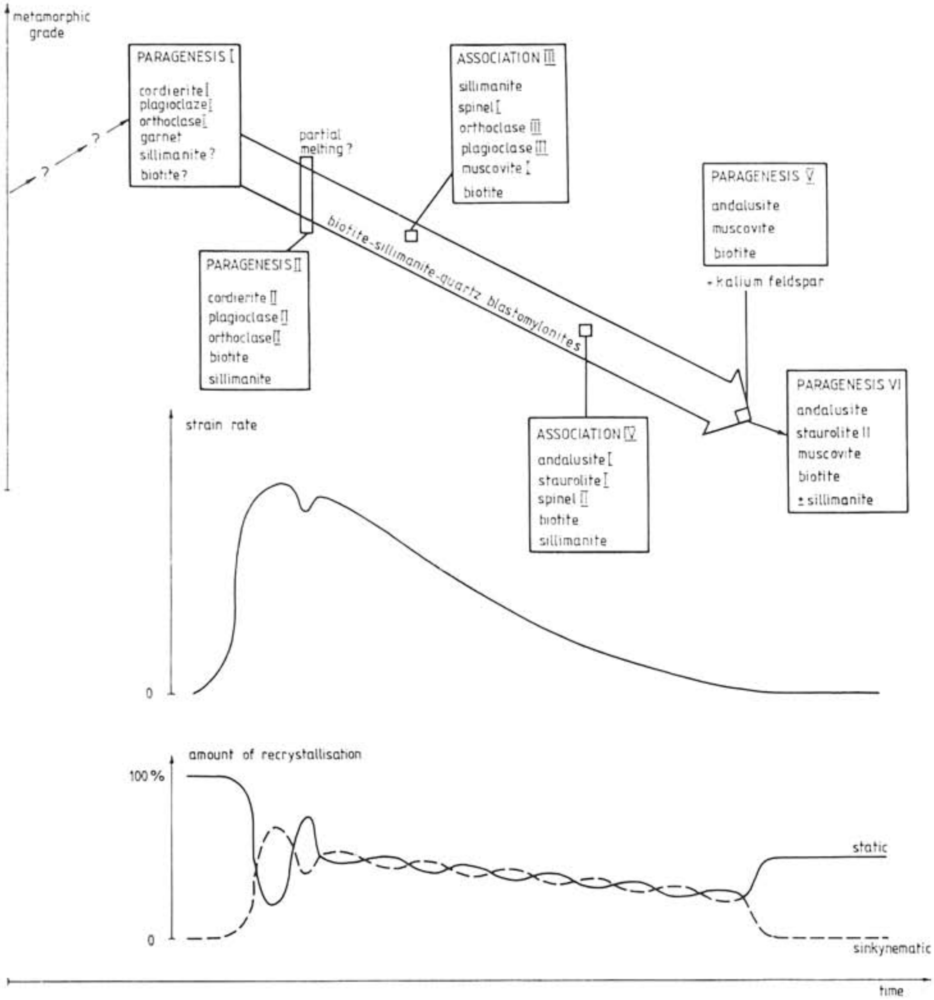

Fig. 14. Schematic diagram of the metamorphic evolution.

entering the muscovite stability field in quartz-rich assemblages. During this stage andalusite pagmatites are formed. Blastomylonitic laminae alternate with recrystallized portions containing one or more of the above mentioned assemblages, making evidence of a steady state strain. Further deformations aren't noticed, and the andalusite grows postkinematically in the groundmass. Flamboyant quartz of mylonite gneisses recrystallizes in places. No decrease of pressure is recorded, while the cooling is of isobaric nature. The potash feldspar evolution, characterized by an increasing ordering degree at the same time with the exsolution of sodic component, and gradual decrease of plagioclase *An* content as well as preservation of basic relics point to relatively slow and continuous decrease of temperature. The contact areas with the Lotru Group are marked by advanced recrystallization and generation of two-mica gneisses with S_3 penetrative foliation. The andalusite + muscovite ± cordierite paragenesis and S_3 foliation are superposed on the Lotru Group near the contact area. The andalusite zone may also include staurolite (paragenesis VI) and passes laterally to biotite zone. The curve which links the successive associations I—VI is shown in Fig. 15.

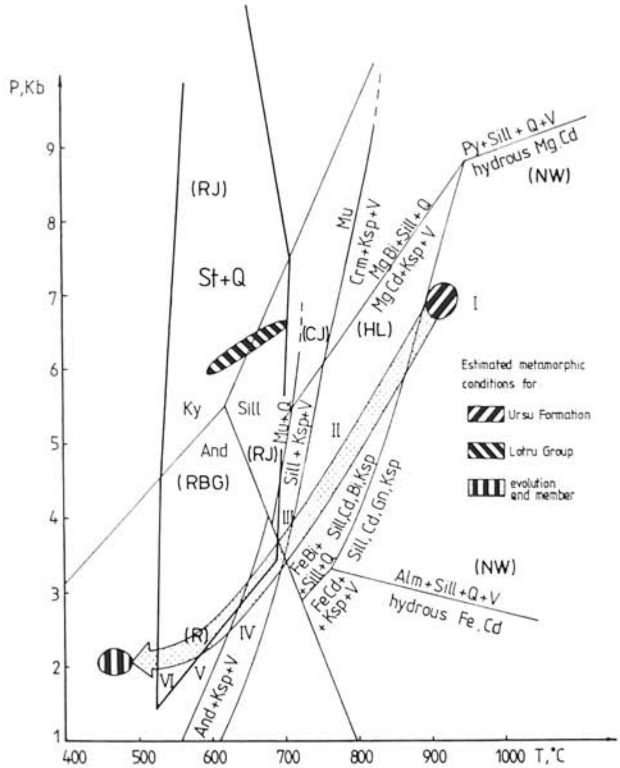

Fig. 15. The succession of observed mineral associations on the PT diagram stability curves after Chatterjee—Johannes (1974) (CJ); Holdaway—Lee (1977) (HL); Newton—Wood (1979) (NW); Rao—Johannes (1979) (RJ); Richardson (1968) (R); Richardson et al. (1969) (RBG); modified if the case to obtain consistency.

Summary and geological interpretation

The synthesis of our available data points to the following main features:

The Ursu Formation and the Lotru Group formations respectively differ as regards their lithology, the bulk chemistry of similar lithons and the type and grade of metamorphism.

The metamorphic grade is constant on large areas in each formation.

The Ursu gneisses exhibit blastomylonitic texture, ordering of potash feldspar, gradual evolution of plagioclases to acidic components, disequilibrium mineral associations pointing to continuous decrease of temperature and pressure owing to simultaneous uplift and cooling.

The Lotru Group does not show evolution of this type.

In the absence of younger tectonic relations there is an apparently graded lateral transition from the Ursu Formation to the Lotru Group, concealing the old tectonic relationship between the two different lithostratigraphic entities with different metamorphic history.

The evolution of the Ursu Formation ends with the partial retrograde equilibration to andalusite + muscovite paragenesis, also present in the Vaideeni Formation as a narrow stripe next to the contact area.

All these data account for the domal ascent and the emplacement of the Ursu Formation within the Lotru Group when in the hot stage, resulting in a contact aureole characterized by the same paragenesis which represents the final stage of metamorphic evolution of the former marked by mineral assemblages and textures at 450 °—500 °C and 200 MPa. The comparison between the evolution curve and Albarrède's (1976) calculus shows an ascent rate of ca 3 mm year. Considering a pressure decrease of 500 MPa. the ascent is of ca 18 km obtained in $6 . 10^6$ years. It is possible that the ascent had two components, an "active" one marked by dome location and a "passive" one due to synchronous erosion of geometrically upper formations.

The andalusite-muscovite paragenesis may be assigned to an independent superposed metamorphic event as regards the Lotru Group, while in the Ursu Formation it represents the end-member of a continuous evolution process.

With respect to the origin of the Ursu Formation, it might be regarded as representing a deeper and higher metamorphosed level of the Lotru Group; nevertheless the absence of transition metamorphic zones between the two formation, which could account at least for their common prograde evolution, makes this interpretation uncertain.

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ADDENDA

Lithostratigraphic assignements regarding the Getic Crystalline – a comment

The study of the Getic Crystalline lithostratigraphy went over increasingly detailed stages, from large-scale separation of entities on to local refinements and regional correlations.

As a first step, its lithologic and tectonic unity were recognized as it was included in the Group I Crystalline (Mrazec, 1898) and later in the Getic Nappe (Murgoci, 1905) subsequently being named Lotru Crystalline (Streckeisen, 1934).

During the thirties, the contributions due to Paliuc (1937), Manolescu (1937), Gherasi (1937) offer supplementary petrofacial arguments regarding the regional constancy and the unitar character of the Getic Crystalline, for which they consacrate the term of Lotru Series.

Later, a rather poorly argued division was made, as Pavelescu (1959) distinguished within the above mentioned entity the Lotruu and Sebeş Series respectively, with very ressembling features. In the latter, the cited author makes the first lithostratigraphic horizontation, separating three complexes.

This twofold classification of the Getic Crystalline persist during the V-th Congress of the Carpatho-Balcan Association in 1961, despite the absence of obvious discriminating criteria for the two series, while the Excursions Guide is at the odds with the annexed map as regards the appurtenance of some lithons (the Stefanu-Sălanele and Negovanu-Vîrfu lui Pătru Zones). It is from the mentioned Congress (Codarcea et al., 1961) on that, by combining the two erronously separated entities, one begins to use the name Sebeş-Lotru Series, rather inadequate a term as it denominates a lithology widespread all over the South Carpathians west of the Olt by the names of two adjacent massifs.

During the following decade, this term is used as an alternative, together with the older name of Lotru Series —.eg. Giuşcă et al., 1969), preferrable in our opinion due its simplicity and according the principle of priority. Less widespread, but still present, is the name of Lotru-Sebeş Series (Pavelescu, 1969).

The first regional separations and correlations of the "complexes" (formations) assigned to the "Lotru or Sebeş-Lotru Series" in the Lotru, Sebeş, Cibin and Semenic Mountains belong to Savu (1968), followed by Bercia (1975) in the Godeanu Mountains, Savu – Schuster (1977), etc.

From about the early seventies on, as a result of an extensive collective fieldwork caried out in the purpose of elaboration of the geologic maps scale 1 : 50 000, an advanced lithostratigraphic correlation of the Getic Crystalline formations (initially separated as complexes) was accomplished. As during the map elaboration the term Sebeş-Lotru Series (Group in the contemporaneous published papers) was exclusively used, it became more widespread than the concurrent one.

During the last years, there have been a few attempts in defining, as regards the crystalline terrains in Romania, more comprehensive lithostratigraphic units, some of them containing the Lotru Group.

Kräutner (1980) separates three "supergroups" starting from lithologic similarities among the groups and metamorphic correlations, but his classification fails to be consistent with the Hedberg Code as the cited authors'supergroups link similar groups with different locations and unclear mutual relationships, not a vertical (and temporal) succesion of groups.

Iancu (1983) included in "supergroups" (A, B) spatially not contiguous groups and formations, on the ground of metamorphic and deformational characters (which in our opinion can make evidence but of a partly common, if not merely similar metamorphic history), so that these entities don't equally fit in the definition as given by the Hedberg Code.

Balintoni et al. (1986) distinguish two "multigroups" made up of Precambrian metamorphic in the South Carpathians and use the notion of "Sebeş Lotru Multigroup" for several metamorphic terrains ("all the formations and groups with similar metamorphic evolution and assigned to the same metalithofacies"), while a subdivision of it, equivalent with the formerly named "Sebeş-Lotru Group", is called the Căpăţîna Group. The utilization of the new term "multigroup" is, in our opinion, successful in its lithostratigraphic aim, as it merely represents a petrographic facies: however, the statement that there are two types of medium grade crystalline in the South Carpathians remains valid (and not only for the South Carpathians).

As regards the Căpăţîna Group, although designating an actual entity (which required no new entitling), it has an inadequate name, for the assignement of some metamorphics from the Căpăţîna Mountains (viz. the Ursu Formation) to the group defined by these authors is doubtful, while uncharacteristic features steming of retromorphism, mylonitization and cataclasis are frequent in the remainder.

As a conclusion, in our opinion the most adequate lithostratigraphic assignement for the Getic Crystalline (pro parte) is the Lotru Group, while any attempt to include it in more comprehensive entities is hindered to the unsurmountable due to the effects of polymetamorphism, such as polydeformation, superimposed differentiations and transpositions a.s.o., as wel as to younger (polystadial and frequently large-scale) disruptive tectonics concealing the actual relationships.

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