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Polymetamorphic Evolution of the Sebeş-Lotru Series (South Carpathians) as Result of the Aluminium Silicate-Bearing Metapelites Study

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Editorial Office:
Geological Institute of Romania
Str. Caransebeş Nr. 1
Tel. (+40) 1 665 66 25, 665 75 30
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To my parents

CONTENTS

POLYMETAMORPHIC EVOLUTION OF THE SEBEŞ–LOTRU SERIES (SOUTH CARPATHIANS) AS RESULT OF THE ALUMINIUM SILICATE-BEARING METAPELITES STUDY[1]

Ion HÂRTOPANU

Institutul Geologic al României. Str. Caransebeş 1, 78344 Bucureşti.

Key words: Metamorphic rocks. Metamorphism. Polymetamorphism. Aluminosilicates. P–T conditions. Isograds. South Carpathians.

Abstract: Two important types of metamorphism, the Barrovian metamorphism and the low pressure, intermediate one are studied in the crystalline area of the South Carpathians, Sebeş-Lotru Series. Arguments are presented for the polycyclic character of the metamorphism in the two areas between which temporal relations have been established. The intermineral relations have been mapped and the sequence of metamorphisms has been established, tracing a paleoisograde line on the map in the crystalline rock area of the Mehedinţi Mts. In the paper the conclusion is drawn that by tracing the lines of mineral isorelations the areas of physical isoconditions can be established more precisely and consequently a new image of metamorphic zonality is created. The final part of the paper represents a structural essay concerning the metamorphics in the Central South Carpathians in the light of the polycyclic character of metamorphism and as a consequence of that character. It is emphasized that deformation as an ubiquitous phenomenon in regional metamorphism can considerably change the outline of the rock bodies at mesoscopic level and the character of the boundaries of major rock bodies, due to transposition. For pointing out the blastomilonite alignments it is necessary to take into account very old disjunctive tectonics. The reasonings that have led to the conclusion of the domal structural model of the central zone of the South Carpathians represent a possible modality of approaching the study of the structure of an intensely and repeatedly metamorphosed region.

[1]Paper received on January 28, 1986, accepted for publication on October 13, 1986. This is a part of the thesis of doctor's degree held on December, 13, 1982 at the University of Bucharest.

I. INTRODUCTION

Metamorphic rocks increasingly call for the attention of petrologists, due to the complexity of the phenomenon leading to their genesis. The theoretical and practical bearings of possible reconsiderations of our knowledge of metamorphism is ever better realized. That is why, like in the case of other numerous modern sciences, the solution to specific petrology problems asks for the contribution of other basic or border sciences. Due especially to the progress of geological knowledge, the field of geology interpenetrates in fact with those of various other sciences, so that numerous phenomena are no longer possible to explain by common sense or "at hand" solutions. More and more sophisticated research tools and means are used, for which the researcher needs special qualifications.

One of the modern means of studying rocks is that of reproducing on a small scale, phenomena presupposed or deduced from observation and considered to have participated in the formation of minerals and implicitly of rocks. With this end in view are investigated the fields of stability of singular minerals, the conditions of the latter's genesis, nucleation and decay, the reactions between minerals or mineral assemblages etc.

A leading place in the investigation of metamorphic minerals has been held by the three Al_2SiO_5 polymorphous modifications – kyanite, andalusite, sillimanite – minerals of theoretical (being present in metamorphic rocks of a large spectrum of physical conditions) and practical importance (due to their particular economic importance accounted for by their high content in aluminium, by their refractory properties and generally by their possibility of being used for various other technical purposes).

In metamorphic petrology, Al_2SiO_5 minerals represent a marker of particular significance as they share, almost exclusively, the PT metamorphism field. By empirical observations and more recently by experimental checkings, it has been established that each of these three minerals has a certain specificity of its field of existence. So, andalusite is characteristic of genesis conditions dominated by high values of temperature and low values of pressure; kyanite of conditions dominated by high values of pressure and sillimanite, as generally admitted, is formed at high temperatures and pressures. Therefore, by simply identifying one of these three minerals in a certain association, it can be estimated that at least part of the minerals making up the rock were formed in conditions specific to the mineral Al_2O_3 concerned, with which they are associated. In the paper it will be evidenced that this approach to the problem is nevertheless simplistic.

In the study of metamorphism, the Al_2SiO_5 minerals are used for establishing the metamorphic zonality as index minerals of high and middle intensity zones both in regional metamorphism and in contact one. The Al_2SiO_5 minerals are specific both to low pressure (Pirinean, Abukuma, Buchan) metamorphism – the case of andalusite and sillimanite –, for middle (Barrovian) pressure – the case of kyanite and sillimanite and, finally, often for high pressure metamorphism – the case of kyanite.

A. Study Problems

This paper is concerned with metamorphism problems raised by a certain type of rock – metapelites – which frequently contains kyanite or andalusite and/or sillimanite. The intensity of the metamorphism that affected these rocks is generally high and established for the area we deal with, as belonging to the facies of amphibolites with almandine.

The petrographic and chemical specificity of the rocks containing Al_2SiO_5 minerals and their large distribution in most metamorphic areas, on the one hand, make these mineralogical associations constant enough so that mineral relations are usually quite regular and, on the other hand, being ubiquitous, make it possible for the complex metamorphic phenomenon to be studied in space – at least bidimensionally –. If we add the remark that natural outcrops – especially in mountain zones – are to be found in a large altitude range and the relations of successive mineral rise give at least an idea of the relative time formation, it can be asserted that metamorphism can be successfully studied in a quadridimensional context on rocks containing Al_2SiO_5 minerals.

We have restricted the petrographic and petrogenetic study proper of the metamorphics in the South Carpathians to the area of the metamorphic rocks of the Sebeş-Lotru Series as we consider them adequate to the study of aluminosilicate minerals and as they are ubiquitous in the series under consideration. That makes it possible to follow in space the physical conditions having governed metamorphism.

The study of metamorphism has been approached on types of metamorphism, pointing out the authors' option for dividing the metamorphic rocks of the Sebeş-Lotru Series in the two metamorphic types already established in broad lines: Barrovian metamorphism and intermediate, low pressure metamorphism.

The study of the metamorphic textures of the metapelitic rocks has evidenced the dynamic character of these rocks, that are continually, transformed, the role played by deformations in facilitating on the one hand various transformations and on the other hand the separation of metamorphic events. Textural relations are of great importance as they signify mineral reactions. The identification of these reactions, if it is correct, represents the surest step towards the establishment of the conditions of metamorphism. As any reaction can take a course or another, depending on the physical conditions favouring the formation of the final or the initial member of the reaction, it can be inferred that the study of textural relations gives the possibility of establishing not only what mineral reactions took place but also their sense.

The consequences of the specific conditions in which metamorphism took place are first of all the formation of metamorphic entities. Detailing things further, a certain zonality will be related to each type of metamorphism, finally expressing the spatial position of the gradients of physical conditions.

Finally, following the study of mineral relations in the zone of the isograde planes or at the boundary between various types of metamorphism, the modalities of mineral transformation can be identified, by which the passage is made from a zone of metamorphism to another, the prograde or retrograde sense of metamorphism and the temporal relations between various types of metamorphism. The last chapter of the paper is dedicated to the most important – in our opinioin – contribution of the paper, the establishment of the polycyclic character of metamorphism. That refers to signalling out the structural consequences of polymetamorphism, with a concrete example for the zone of the Central South Carpathians.

B. Investigation of Al_2SiO_5 Minerals. Short History

The importance of aluminium-silicate minerals being well known in practice, we must also underline their importance in petrology as markers of the conditions in which the rocks containing them are formed.

The first step in the investigation of rocks containing Al_2SiO_5 minerals is the knowledge of the minerals themselves. The empirical oservations of the relations and associations of these minerals with the other minerals in the rock permitted Miyashiro (1949) to propose the first qualitative phase diagram of the Al_2SiO_5 polymorphs. It has the shape of a reversed *Y*, dividing the *PT* metamorphism field in three domains, one for each Al_2SiO_5 mineral. The lines separating the domains being monovariant equilibrium curves, they converge in a point, called the triple point, with zero variance (Fig. 1).

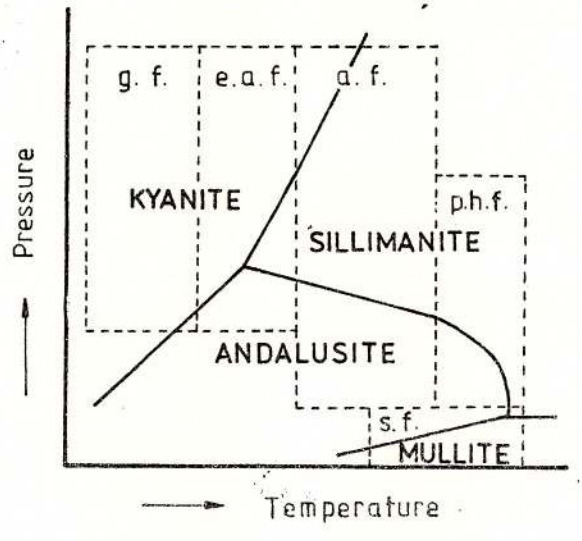

Fig. 1 – Phase diagram of the Al_2SiO_5 system (first drawn up by Prof. Akiho Miyashiro). g.f. – green schist facies; e.a.f. – epidote amphibolite facies; a.f. – amphibolite facies; p.h.f. – pyroxene – hornfels facies; s.f. – sanidinite facies.

Since 1963 this diagram has begun to be argued experimentally by ever more researchers. The first studies for establishing the field of existence of the Al_2SiO_5 minerals are contemporaneous with the first attempts of synthesizing these minerals, although that did not initially suppose such an intention on the part of the authors. So, in 1953 Coes, synthesizing the three polymorphs of the $Al_2O_3 - SiO_2$ system, made no attempt to determine their *P-T* limits of stability.

In 1954, Roy reported the synthesis of andalusite and in 1955 Kennedy, studying the transition pyrophyllite – mullite up to 2000 bars, supposes the existence of a solid solution between mullite and sillimanite.

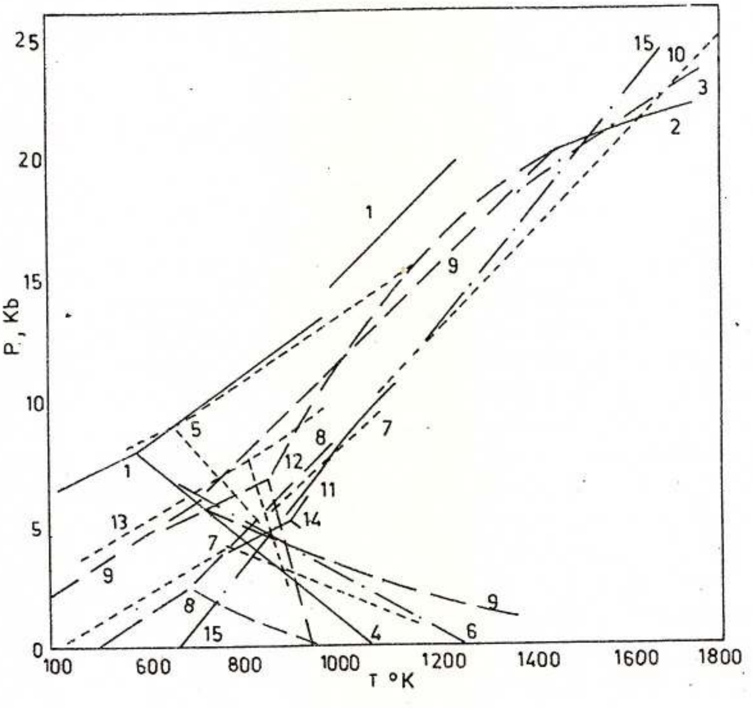

Fig. 2 – Synthesis of experimental data concerning the kyanite-andalusite-sillimanite equilibrium and the triple point location.

Griggs and Kennedy (1956) drew a curve – without any other details – on the reaction of equilibrium pyrophyllite – sillimanite + quartz + water.

In 1963, Aramaky and Roy, re-examining the system Al_2O_3–SiO_2–H_2O, found out a new Al_2SiO_5 polymorph, artificially synthetized usually in laboratory works. On the same occasion, the cited authors demonstrated the presence of the phenomenon order-disorder in mullite and probably in sillimanite. This phenomenon applied to sillimanite is much later discussed by Saxena (1974).

Richardson, Gilbert and Bell (1969) established the transitions kyanite-andalusite and andalusite-sillimanite by observing the inversions in the polymorph tranitions of the mixtures of pairs of neighbouring polymorphs. They formulated the equations expressing the limits of the monovariant equilibrium, as follows:

– for kyanite – andalusite: $P = 0.0107T - 1.173$

– for kyanite – sillimanite: $P = 0.0234T - 9.63$

These curves are convergent in the triple point, which appears in an experimental uncertainty polygon, situated round the coordinates 5.5 kbars and 622^0 C.

It can therefore be noticed that most experimentalists or theoreticians have tried to locate in a bidimensional space the position of the stability field of each of the three aluminosilicates. These efforts are partially reflected in the diagram in Figure 2, showing a few possibilities of distribution of the domains of stability of the three polymorph modifications in the PT space.

II. Al_2SiO_5 MINERALS IN THE METAMORPHIC ROCKS OF THE SOUTH CARPATHIANS

A. Distribution

The Al_2SiO_5 minerals have a large distribution in Romania and our knowledge of it has been an important step in deciphering the Carpathians chain metamorphism. The South Carpathian massifs of metamorphic rocks of high metamorphism (and adequate lithology), where a variety of baric conditions are met, have the best chances of containing aluminium-silicate minerals with a large distribution, sometimes concentrated up to economic levels.

We have investigated a large area of the South Carpathians chain, from the Olt Valley to the western part of the Semenic Massif (Bârzava Valley) in view of identifying the presence of aluminium-silicate minerals. The metamorphic rock massifs of the Getic Domain – of which we cite – Căpăţâna, Lotru, Cibin, Sebeş, Godeanu, Mehedinţi massifs and most westerly the Semenic massif – have been paid special attention in this respect, as they met most conditions of the Al_2SiO_5 minerals genesis.

1. Lotru – Cibin Mountains

These two massifs represent a geologically homogeneous zone. The intensity of metamorphism belongs to the kyanite + staurolite and sillimanite zone. The largest development of the sillimanite zone is to be found in the southern part of the Lotru Massif. Insular areas have also been identified in the northern and central part of the Cibin Massif. Sillimanite does not exceed quantitatively the level of minor accumulations devoid of economic importance. This mineral occurs as sheaves – interwoven with other minerals in the rock mass – ussually in biotitic micaschists or paragneisses and equally as lenses in the same type of rocks. More rarely, sillimanite is associated in nodules of 5–6 mm, like, for instance, the nodular rocks in the basin of the Hoteag Valley, a left tributary of the Lotru Valley.

The most important occurrences of kyanite-bearing rocks are to be found in the basins of the Sadu, Bistra and Cibin Valleys. It is characteristic of the two massifs under consideration that the main kyanite accumulations occur in zones of high altitude. There exist host rocks for kyanite everywhere on the main interstream area, the most important being those in the Strâmba, Crăciuneasa, Surdu, Bătrâna Summits and in the highest summits – Cindrel, Niculeşti, Ştefăneşti, Dobrunu, Negovanu, Clăbucet.

Kyanite is represented by granoblasts – up to centimetric sizes and is or is not associated with staurolite or/and garnet.

2. Căpăţâna Mountains

These mountains are relatively poor in aluminium-silicate concentrations that are frequent occurrences of petrographic importance. In this massif there appear all the three aluminium-silicate polymorphs. Andalusite is spread in the central-southern and western zones of the massif and is associated especially with staurolite, cordierite and sillimanite. Sillimanite occurs mainly in the northern and eastern parts of the Căpăţâna Mountains and in their central and western parts too. Kyanite occupies an area trending north-east-south-west, in the eastern half of this massif.

3. Sebeş Mountains

The presence of aluminium-silicates in this area was reported as early as 1932.

The most frequent aluminosilicate-bearing rock occurrences were identified in the basins of the Gâlceag, Valea Untu, Şipcia, Pârva, Valea Largă, Jerosu, Jigureasa Valleys – kyanite – and of the Taia, Răscoala, Sasu Valleys – sillimanite.

Like in the case of the Lotru-Cibin massifs, in the Sebeş Mountains, the kyanite-bearing rocks and sometimes the sillimanite-bearing ones are to be found in the highest zones – Şurianu, Pârva, Bătrâna, Scârna, Godeanu, Dobraia, Clăbucet. The sillimanite zone crops out on a triangular area, with the angle facing the base in the Comărnicelu – Cugir Valley region, fanning out towards the Petroşani Basin. Just like in the Lotru and Sebeş Mountains, sillimanite in nodules, as, for instance, those in the Fetiţa Valley – East Jiu Basin –, in the Jigoru Mountain at the spring of the Strâmbu Valley etc.

4. Mehedinţi Mountains

In both outliers – Bahna and Porţile de Fier – the conditions have been met for the appearance of the three aluminium-silicates. In the Bahna Outlier there is a middle zone that goes beyond the Danube in Yugoslavia, in which andalusite associated with sillimanite and/or cordierite are ubiquitous. Kyanite ± sillimanite are found both in the east and in the west of the Porţile de Fier Outlier, where only lately have our researches identified a small zone in which andalusite develops.

Comparative researches of all the metamorphic rock massifs in the South Carpathians have shown that it is in the Mehedinţi Mts that the greatest andalusite concentrations occur. We can also cite the presence of cordierite ± sillimanite – bearing zones, with contents in mineral resources comparable with those in the Căpăţâna Mts.

5. Godeanu Mountains

The occurrences of rocks containing aluminium-silicates of the Godeanu Massif can be followed according to the metamorphism zones established by Bercia (1975).

The intercalation of kyanite-bearing rocks occurring in the west of the massif, between the Idigelu and Somogotin valleys is worth mentioning. Sillimanite seems to be present everywhere on the Godeanu outlier border, in the east, associated with cordierite and andalusite. Therefore, from the point of view of the appearance of aluminium-silicates, the Godeanu Massif can be divided in a kyanite zone in the west and an andalusite one in the east.

6. Semenic Mountains

In the order of their importance, the kyanite concentrations known in the Semenic Masif follow immediately those in the Lotru-Cibin Mountains.

The Semenic Massif was investigated in search of aluminium-silicates as early as 1957 by Bercia.

As regards the constancy of the appearance of aluminium-silicates depending on the already established metamorphism zones (Savu, 1970), it should be pointed out (like in the case of the Sebeş and Cibin Massifs) that in the Semenic Mts as well we have found small "zones" with sillimanite included in a zone with staurolite + kyanite, like those on the meridian of the Gărâna locality. Another feature (also shared by the two massifs above mentioned is that no kyanite-bearing zone can be separated as an entity, the characteristic feature of the Barrovian metamorphism in the South Carpathians being the permanent association of kyanite with staurolite.

7. Ţarcu Mountains

As early as 1937, Gherasi reported the presence of sillimanite in the Metamorphic Rock Lotru Series in this massif. Equally in this zone, south-west of the Măru locality, a zone was also identified of occurrence of kyanite-bearing rocks, close to the Getic thrust line.

8. Poiana Ruscă Mountains

Generally, rocks rich in aluminium-silicates are rarely encountered and poorly developed in the Poiana Ruscă Mts. The rocks containing kyanite are frequent in the western part of the massif, in the neighbourhood of the Sacu and Lunca Cernei localities. Kyanite was identified as nests with pegmatoid development of crystals near the Băuţari locality. Sillimanite is found especially in the zone of the Băuţari-Criva and Maciova-Lunca Cernei pseudosyncline.

An overall view of the South Carpathians geology allows, at least for the Sebeş-Lotru Series, a spatial image to be formed on the zonality and metamorphism types in this area. At the same time, as evidenced by the microscopic study of these types of rocks, one can establish the evolution of metamorphism and implicitly of the physical conditions it took place in as well as of the spatial and temporal relations between various types of metamorphism.

The conclusion has also been drawn and it has been repeatedly proved, that the constant presence of Al_2SiO_5 minerals and their economically significant concentration are different things. We consider the kyanite concentrations worth mentioning are those in the Lotru Mts., the Negovanu Zone, in the Cibin Mts., in the basin of the Râul Mare Valley and in the Godeanu Mts., the basin of the Somogotin Valley.

Andalusite began to be taken into consideration only a few years ago, by the joint efforts of the geologists-prospectors, of the dressing ore researchers and our own. The most promising region in this respect is for the time being that in the Mehedinţi Mts. – Isverna and Malarişca Villages area.

Although frequently mentioned before, the area of sillimanite as an index mineral in the Central South Carpathians, has been greatly enlarged, due to our papers. But the very fine sizes of this mineral and its intimate association with other minerals in the rock – especially with biotite – which introduces an undesirable Fe percent in a possible sillimanite concentrate – make us be still uncertain as regards its possible economic use in our country. The lenses, decimetrical sometimes, which we have reported in the Central South Carpathians, in which sillimanite is concentrated up to stoechiometric Al_2O_3 proportions (on each lens) are quite irregularly distributed and so far we are not in the possession of a structural premise to facilitate the identification of a distribution law.

B. Host Rocks of Aluminium-silicate Minerals

In connection with the host rocks of Al_2SiO_5 minerals, we should point out that the most adequate expression would be "the rocks which are more likely to contain" these minerals, as there is a very large variety of association of the minerals under discussion with other minerals or with various rocks, respectively. We can cite as a particular case the association of Al_2SiO_5 minerals with amphibolites (Berza, Seghedi, 1975, Hârtopanu et al., 1977) as well as the more frequently cited association of microcline rocks with sillimanite characteristic of the upper part of the amphibolite facies.

There are nevertheless sure incompatibilities between these minerals and certain types of rocks, for instance the carbonatic and the ultramafic rocks.

Referring therefore to "the rocks that are most likely to contain Al_2SiO_5 minerals", the literature as well as our own experience lead to the idea that from the best known host rocks for these minerals – plagiogneisses and micaschists – a selection is necessary of the rocks that could possibly synthetize naturally an Al_2SiO_5 mineral.

Naggar and Atherton (1970) noticed that the rocks containing kyanite have the M/FM value higher than 0.540. That would mean that the occurrence of kyanite is restricted to a small group of rocks with a relatively high Mg content. Therefore, from the point of view of chemistry, the absence of kyanite in rocks would be due not to a low Al_2SiO_5 content in the originary rocks – as generally admitted – but to the absence of rocks with adequate M/FM values.

1. Micaschists

Are the most frequent host rocks of these minerals (with the possible exception of andalusite). They are prevailingly made up of a quartz-micaceous matrix, with grains of various sizes, with which are frequently associated- garnet, apatite, opaque minerals (pyrite, titanomagnetite, ilmenite etc.) plagioclase, staurolite. Some of these minerals are often quite largely developed, making the rock have a porphyroblastic structure, as garnet and staurolite or cordierite frequently appear in certain sillimanite and/or andalusite-bearing rocks. The Al_2SiO_5 minerals can also be porphyroblastic – kyanite and andalusite excelling in this respect – or participate together with the other mentioned minerals in the composition of the matrix, sillimanite being worth mentioning from this point of view. Almost never do the individual grains of the last mentioned mineral develop porphyroblastically in the regional metamorphism of the South Carpathians but frequently develop in large crystals in the so-called sillimanite hornfelses of "Danubian metamorphism", synkinematic in Savu's acceptation (1975).

Andalusite and kyanite crystals usually appear isolated, unlike sillimanite ones wich are associated in sheaves, nodules, lenses.

2. Plagiogneisses

We use this term for plagioclase gneisses. They represent the correspondent of what we usually call paragneisses. We prefer the first term for being consistent in the use of non-genetic terms.

In these rocks with prevailingly granoblastic structure, oligoclase plagioclase appears more frequently and is more largerly developed. Al_2SiO_5 minerals develop in smaller grains and in smaller amounts than in micaschists. Similarly, garnet and staurolite have limited development, which makes them equigranular. Both micaschists and plagiogneisses with Al_2SiO_5 minerals are more frequently biotitic, but muscovite is also always present.

III. METAMORPHISM

A. Types of Metamorphism. Areal Distribution

From the description of the mineralogical associations of aluminium-silicate-bearing rocks in the South Carpathians a paragenetic bipolarity of the types of metamorphism, results:

–mineral associations including andalusite and/or cordierite, both of them possibly associated with sillimanite;

– mineral asociations including kyanite $\pm$ staurolite or sillimanite.

The areas distribution of these associations are large enough and clear-cut so that there can be no doubts about their specificity and individuality.

The largest area is that of the rocks containing kyanite + staurolite or sillimanite, the association specific to the so called metamorphism of Barrovian type. On the territory of this type of metamorphism, another type of metamorphism, the low pressure, intermediate one was superimposed. These two types are quite well separated, the band where their elements intermingle being rather thin.

The mineralogical associations described above are highly constant in what spatial distribution is concerned, being naturally hosted in metapelitic rocks-plagiogneisses ans micaschists and only infrequently in other types of rocks, such as quartzo-feldspathic gneisses, stromatitic migmatites, amphibolites, quartzites.

A problem worth considering is that of establishing if the mineral associations specific to each type of metamorphism, including the associated minerals in the rocks containing these assemblages, are or not in equilibrium. Generally, the imbalance phase is faithfully mirrored by the mineralogical or textural imbalance identifiable in thin sections. We shall resu..ne this problem in the chapter treating of textural relations.

The distribution of the two types of metamorphism of the rocks in the Sebeş-Lotru Series has come to be known gradually, in proportion with the deciphering of the metamorphism in this area. Initially it was thought that all the rocks in this series belong to the Barrovian type of metamorphism in the facies of almandine-bearing amphibolites.

The Danubian metamorphic rocks were considered epimetamorphic for a long period of time. It is only recenly that the intensity and type of metamorphism affecting this series could be correctly determined following the identification of kyanite and staurolite in the Drăgan Series (Iancu, 1974; Berza, Seghedi, 1975). The Lainici-Păiuş Series arises even more intricate problems as the present day aspect of rocks is due to successive phenomena affecting them, such as: a wide scale migmatization, the presence of granitoid rocks – potential thermal sources additional to the regional geothermal gradient – a regional retromorphism that often effaced both the traces of previous deformations and the petrographic evidence of the intensity of metamorphism preceding the one visible now.

The aluminium-silicate minerals in the Drăgşan and Lainici-Păiuş Series have a major significance in making out the metamorphism (possibly the metamorphisms) they have been subjected to.

Other metamorphic series, more recently evidenced, will have to be discussed also in respect of the intensity of their metamorphism. But, as they do not contain aluminium-silicates or contain such minerals only accidentally, they will not be dealt with in the present paper.

The thorough but gradual investigation of metamorphism in Romania has determined the reconsideration of what, in the light of former data, appeared to be specific features of the metamorphism in the South Carapthians. The first step in this respect was the identification of minerals non-specific to the Barrovian type of metamorphism. Thus, Trifulescu et al. (1958) were the first to report andalusite in the Mehedinţi Mts; Bercia the first to describe andalusite and cordierite-bearing rocks in the Godeanu Mts (1972); Mrazec and Murgoci (1897) and Trifulescu (in Hârtopanu, 1975) have full priority in pointing out cordierite and andalusite respectively, in the Căpăţâna Mts. In Romania it is Bercia (1972) who first reported and discussed the low pressure, intermediate type of metamorphism and delimited a zonality in the area affected by it, exemplifying his assertions with the Godeanu Mts. A similar zonality as well as genetical remarks on this type of metamorphism in the Mehedinţi Mts were contributed to by Hârtopanu (1975). The same author has also formulated the hypothesis of a large area of intermediate type metamorphism, from the Godeanu up to the Căpăţâna Mts, very much fragmented at present. Bercia and Hârtopanu (1980) made certain specifications, synthetizing the existing knowledge concerning the relations between the metamorphism of Barrovian type and that of low pressure, intermediate type and formulating three genetic succession hypotheses.

Areal Distribution of Metamorphism Types

We have chosen to treat here only of the types of metamorphism to be found in the Sebeş-Lotru Series of the Getic metamorphic rocks, as they are well defined and have a relatively well known distribution.

As already shown, the apurtenance of the Danubian metamorphic rocks to a certain type of metamorphism could not be, objectively, very well established. The absence of a lithology adequate to the formation of specific index minerals, the existence of mineral associations giving equivocal or non-typical information, the dissappearance, following migmatization, of textural elements or of those of the former petrographic composition, the thermal influence due to granites regional retromorphism make it very difficult to obtain a comprehensive image of the area concerned.

The considerations on these rocks are due especially to interpolations on large areas of data concerning isolated spots, unlike in the case of the area of Getic metamorphic rocks, where the index minerals are quite frequent.

Therefore it can be said that within the metamorphic rocks area of well known distribution and Barrovian type metamorphism, low pressure, intermediate metamorphism zones can be separated, as follows (Fig. 3).

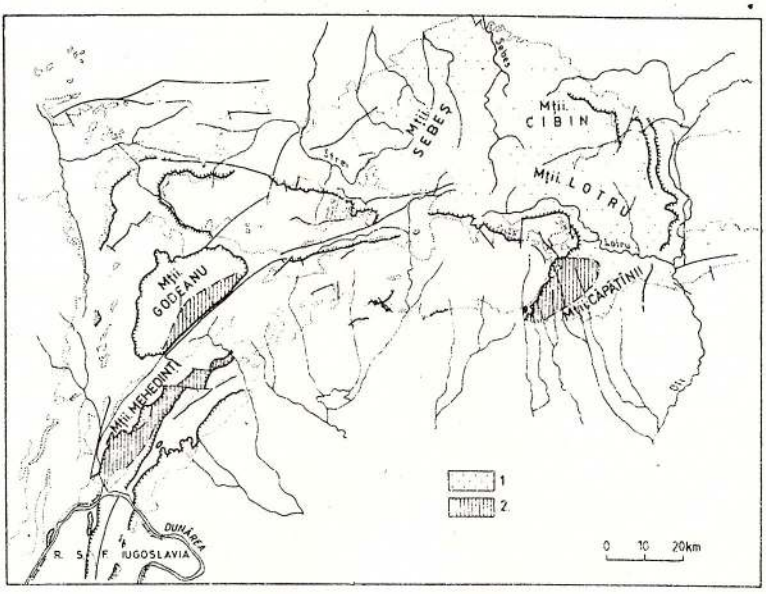

Fig. 3 - Types of Metamorphism in the Getic Crystalline Rocks. 1, Barrovian metamorphism; 2, Intermediate, low pressure metamorphism.

In the Godeanu Mts the area of Pirinean type (intermediate, low pressure) metamorphism lies east of the outlier, between the Cerna fault to the east and a slight bend to the west.

It is highly probable that the few tectonic problems mentioned by Bercia are in fact much more numerous as during our investigations in the Godeanu Mts we have found evidences of the presence of the Barrovian type in the very heart of the area of intermediate type of metamorphism, like, for instance, the kyanite-bearing rocks in the left bank of Pârâul Naiba.

In the Mehedinţi Mts, the area occupied by metamorphosed rocks of the Pirinean type represents most of the Bahna Outlier and a small part of the Porţile de Fier Outlier. In the former, the area with low pressure metamorphism lies just in the middle. This area passes beyond the Danube in Yugoslavia, as shown in the geological and metamorphism map of Europe.

We have also figured a very thin zone of intermediate type metamorphism, east of the Cireşu locality, close to the plane of abnormal contact delimiting the Bahna Outlier to the east. It probably represents the westward prolongation of another zone of low pressure metamorphism we have delimited in the Porţile de Fier Outlier, in the Nevăţ Hill-Firizu Valley zone.

In the Căpăţâna Mts, the intermediate type metamorphism has been described and defined as such more recently. The area of this type of metamorphism lies in the western part of the massif (in the Getic metamorphic rocks). Besides the three zones mentioned above, the possibility has also been considered that the Vălari Outlier of metamorphic rocks should be also part of the low pressure metamorphism area (Hârtopanu, 1975). In this outlier we have identified metapelitic rocks containing sillimanite and isometric pinnite nodules resembling those which form on porphyroblastic cordierite.

B. Evolution of Metamorphic Crystallization Deduced from Textures

The notions of structure-texture tend to be more and more frequently mistaken for each other, both because their scope interferes to various proportions in various papers and because the English literature and partially also the French one give them reversed meanings than other literatures.

Certain authors (Vernon, 1976) definitely prefer the notion of *structures* as:

–*texture* is used especially for the orientation present in synthetic materials, especially metals;

– the term of *microstructure* very well fits other two commonly used terms of structural scale, i.e. *mesostructure* and *microstructure*.

Zwart (1962) in his works of mineral chronology also uses the notion of structure or microstructure for which the notion of texture is used by Romanian researchers and by researchers in other countries.

As for us, we prefer the term *texture* as it is still frequently used – partially also out of inertia – in literature. We think it necessary to point out the specificity we give to this term for the situations we want to present. Extending the definition of texture considered to represent the shapes and sizes of the grains in a metamorphic rock or the shapes and disposition of grains in a metamorphic rocks (Spry, 1969) we have also included un the notion under discussion the mutual relations between minerals, their sizes or their degrees of deformation. We also refer to the relations of direct or mediated substitution or to the degree of idiomorphism or other features that could give indications on the relative age of certain minerals in comparison with others or with major geological events, such as metamorphism, migmatization or deformation phases.

Our intention and the purpose, declared or not, of many petrology works is that of making a chronological analysis of the formation and growth of the main minerals of the rocks.

Metamorphic rocks, as shown by their very name, represent the product of transformations of rocks pre-existing metamorphism. The much more advanced degree of knowledge of this type of rocks, the details reached in the study of their petrography have been determining a change in the understanding of the notion of metamorphism. As this notion also includes changes subsequent to the first mineral transformations it is necessary to separate in time the minerals and groups of minerals formed more or less in the same (larger) period of time.

How can this separation be made ?

First of all one should consider an important system of reference, supplying data on the relative age of a mineral assemblange, i.e. deformation. In numerous instances, deformation is only interpreted as a direct and visible effect of stress on rocks or on certain minerals. In this particular case we can consider the metamorphic rocks themselves to represent a special case of the relation between mineral deformation and blastesis. These rocks can be grouped under the general concept of tectonite, characterized by preferentially oriented textures of minerals, as an effect of stress. This effect, of changing the volume and shape of rocks, is defined by the notion of deformation, a differential movement on equivalent areas, which can take place in time at various moments in relation with crystallization. It is therefore possible for certain minerals to be formed during or after deformation movements (beside the usual situation of crystals or rocks deformed after their formation), and in this case, the minerals show certain specific features.

Syntectonic or syndeformational crystallization have been discussed by many scientists but they referred primarily to minerals growing as porphyroblasts. It is obvious that these minerals were not the only ones formed during this time interval. The minerals making up the rock matrix constituting much of its volume are equally worth taking into account. The most important of them are micaceous minerals, quartz, feldspars, if we refer to metapelitic rocks, which make the object of our study. They frequently contain garnet, staurolite, kyanite, andalusite, cordierite, porphyroblasts. Only accidentally do these porphyroblasts represent an important percent of the groundmass. It is hard to imagine that the remaining minerals building up the matrix were formed by mimetic static crystallization subsequent to deformation movements as that would suppose the existence of a source of remanent energy, one of those existent during these movements. It is more natural to consider deformation movements as an occassion and an energetic source for the massive neoformation of minerals, materializing the S planes born through the deformations invoked. Neoformation minerals are permanently *in step* with the deformation, so that when it ceases they represent their final product and the aspect of the final position of the planes in which it took place. Thus, these minerals won't be themeselves deformed but will only be the final image of movement. That could have been in fact already supposed, as the minerals for which there are evidences to have grown synkinematically porphyroblastically are not deformed. It is still difficult to absolutely differentiate between synkinematically crystallized minerals and postkinematic ones mimetically crystallized in the foliation plane. It is also equally difficult to differentiate a porphyroblastic mineral without *Si* from the others in which the *Si*/*Se* relation can be examined. (*Si* represents the inner structure of a crystal and a surface substancialized by trails of inclusions; *Se* is the surface *S* outside the crystal and can be represented by schistosity or bedding).

As already shown casually, other elements that separate in time the minerals in a rock are:

– The relations of substitution between minerals; the substituted mineral is at least synchronous but usually older than the substituting one. But as it appears at first sight, the relation of substitution can be false, as we are often tempted to judge it by the fact that the substituting mineral occupies a large area and includes the mineral considered to be substituted. In fact that could appear only as a result of the unfavourable position in which the section was cut. The certitude of the sense of substitution can only be given by the statistic character of a certain sense of substitution, to which can be added the optical and therefore also the crystallographic orientation of certain relict elements included in the substituting mineral;

– The degree of idiomorphism can also give indications of age relations, the conclusion being drawn that a "more idiomorphic" mineral is younger than a less idiomorphic one that was subject to one or more deformations. This criterion is much less frequently used than others as an idiomorphous mineral can only be formed under special conditions (in metamorphic rocks), i.e. in static, post-deformation conditions. Idiomorphism also depends on the crystallization force of a mineral, as the crystallization space in a solid environment characteristic of metamorphic rocks is by far more constraining than that in a rock of magmatic affiliation. Therefore there will be situations of static crystallization under circumstances of tectonic calmness, without the possibility of identifying idiomorphically grown minerals.

The reversed situation is also possible, i.e. an older and harder mineral than the host rock can outlive a deformation with differentiated action, the matrix behaving as a lubricant for harder porphyroblasts: the degree of deformation represents even within the same mineral species an important element of age separation. But it is unlikely that this criterion can be indistinctly used, as certain minerals are more susceptible to deformation while others react to it much less or less visibly than others.

The conclusion of enumerating the above mentioned criteria is that it is hard to determine the crystallization sequence in a metamorphic rock, that, to this end, several criteria have to be considered and the operation needs much insight and discrimination for leading to a reliable result.

For examining the sequence of crystallization of the minerals in the aluminium-silicate-bearing rocks we are going to investigate metamorphism zones according to types, as presented in the preceding chapter. That will be proved useful because in the two types of metamorphism there are different minerals. The mineral associations belonging to the two types will be discussed only when the relations between intermediate, low pressure metamorphism and Barrovian metamorphism are continued.

1. Metamorphic Area of Barovian Type

As shown, metapelitic rocks included in this area have a relativaly simple mineral association with prevailingly micaceous main minerals (biotite and muscovite), behaving like a matrix in which garnet, staurolite, kyanite, plagioclase porphyroblasts are included. In the attempt of unravelling the evolutionary character of the investigated rocks we have used intermineral relations as well as relations between minerals and deformation.

In this respect, three categories of minerals have been distinguished: relict minerals, remobilized minerals and minerals of late formation.

Relict minerals are considered those which antedate deformation movements. The species of such minerals can also be formed during or after deformation movements, but the latter have different morphologic features. They were probably formed during an older metamorphic event, whose traces were so much effaced that we can only have disparate information about it. These minerals (kyanite, staurolite, garnet, biotite) are to be found as relict only in the staurolite + kyanite metamorphism zone, being almost totally distroyed at the present level of the sillimanite metamorphism. We have faced major difficulties in deciphering and differentiating various types of generations of sillimanite, especially because of the small sizes of this mineral.

Remobilized minerals are those possessing a high capacity of reorganization during deformation movements, making the rock form a new fabric that has the marked tendency of effacing the former. This reorganization refers especially to micaceous minerals but it can also affect some other minerals such as kyanite, garnet,staurolite that show morphologic characters and relations demonstrating their neoformation.

Synthetizing everything that has been asserted so far, we should like to point out that the elements of an older generation of minerals are reorganized in a new generation on the basis of the same mineral species.

. The group of minerals of later generation includes in the systematics presented here the minerals crystallizing statically, after deformation movements came to an end. They are oriented at random in the rock texture, which particularizes the minerals formed during deformation. But they can also crystallize mimetically, in directions of maximum growth facility in which case they cannot be too easily discernible from synkinematic ones.

Relict minerals are recognizable by the high degree of deformation which distinguishes them from the minerals in the last two categories. According to their age, we can also obtain further indications for grouping the minerlas by the more advanced degree of digesting of older minerals in comparison with younger ones, by the former being digested and included in the latter, by the degree of idiomorphism and the conformous or unconformous position in the oriented texture of the rock.

We are going to present significant mineralogical and textural features for demonstrating the coexistence in the pelitic rocks of the Getic Realm in the South Carpathians of at least two mineral generations as well as of the creation of a main foliation plane, the outcome of a deformation phase superposed on older relict planes.

As already shown, the deformation contrast can point out various periods of genesis of older and younger minerals respectively. In this respect in Plate II, Figure 1 the contrasting behaviour of garnets can be noticed, in respect of the prevailingly micaceous matrix including them. The garnets are generally broken, crushed, elongated into the foliation plane. Unlike garnets, micas, the main constituents of the matrix are not at all deformed, even when the matrix is undulated or microfolded. In this case the fold is made up of rectilinear sections of micaceous minerals, which proved they haven't been deformed after their formation, as the fold is synchronous with the genesis of micas. It is difficult to imagine the existence of a selective effort which affected only the garnets and totally spared the micas (which are not even bent). A visible deformation contrast can also obseved between the micas and the kyanite. A prevailingly muscovitic matrix, to which some biotite is added, contains bent kyanite porphyroblasts. The kyanite shows rolling extinction (PL. II, Fig. 2), coexisting with underformed micas. Even at a very marked folding (Pl. III, Fig. 1), micas can be observed in rectilinear crystals, including a kyanite crystal with deformation twins.

The kyanite can be deformed also rupturally (Pl. III, Fig. 2), the environing micaceous minerals in the wall rock remaining unaffected. The complete break of a kyanite crystal is often accompanied by the infilling of the break with younger muscovite. A relict mineral not so easily discernible by deformation contrast is biotite. Nevertheless there have been observed relict, deformed and usually chloritized biotite crystals, embedded in a muscovite matrix. From what we have observed so far, muscovite is less resistent to deformation, being able to reorganize readily in the movement-deformation plane. Rarelier, bunches of muscovite crystals are observed, cut across and persisting as relics in the newly formed matrix.

The character of older or younger mineral can be illustrated equally by the digestion of certain minerals by others, which proves the rock evolved towards new physical conditions in respect of which older minerals are not in equilibrium. So, in Plate IV, Figure 1, there is a kyanite crystal partially digested by quartz. The kyanite is bent and coexists with undeformed micas. Similar digestions can also affect garnet, which gets a skeletical look. The minerals involved in the digestion of garnet are usually quartz, muscovite, biotite and even sillimanite, that of the last one taking place under special circumstances, that will be discussed later on.

The difference in age between minerals can also be emphasized by the position of the trails of inclusions in porphyroblasts, determining the so named *Si* (that should be distinguished from the *S* of the foliation of the adjacent matrix which is named *Se*).

The *Si* in the kyanite crystals indicates an old foliation (different from that visible now) (Pl. IV, Fig. 2) that is slightly bent, that the kyanite was a little bit rotated during its crystallization. The unconformable position of *Si* in relation with *Se* points to a marked rotation of the kyanite crystals after their genesis, due to tangential movements. During these movements, the micas making up the matrix were formed and the present *S* plane was completed.

The minerals forming the pressure shadows are represented by quartz and/or micas.

Plate V, Figure 1 shows the same angular unconformity of *Si* versus *Se*. This time the old crystal is a plagioclase feldspar including a *Si* made up of rows of inclusions divergent in aspect, differing form the *S* of adjacent micas. The fan-like aspect of the rows of inclusions in the feldspar represents a consequence of the slowing down of the speed of the crystal growth in comparison with that the crystal rotates with.

The garnet was most frequently affected (due to its capacity of retaining or not inclusions, to its isometric habitus and therefore to the possibility of being easily rotated) by the deformation movements to which the rock or its constituents were subjected. That means we can extend the phenomena we intimate to have affected the garnet also to the minerals contemporaneous with it.

Plate V, Figure 2 illustrates very well the factors growth-rotation-deformation in a garnet crystal. So, the *S* shaped inclusions in the centre of the crystal attests a rapid initial synkinematic growth followed by stagnation, during which the mineral was subject to deformation efforts producing *kink* bands as well as crystal rotations. A period of very rapid static growth followed when the rows of inclusions were disposed in concentric bands. The pressure shadows, the slightly ellipsoidal shape of the garnet crystal attest the existence of subsequent movements with which we can probably correlate the formation of the present foliation, of the micas materializing it implicitly.

Another way of assigning the relative age of minerals is that of studying the reciprocal inclusions in one another. There have been found out garnet inclusions in kyanite, kyanite inclusions in garnet, kyanite inclusions in biotite and plagioclase, staurolite ones in kyanite etc. All of them indicate first of all an order of crystallization which, as results from the above-mentioned relations, can sometimes be ambiguous. But these relations can also signify that a new mineralogical association sets in place of an older one, which has become unstable, potentially replaceable.

From what has been presented so far the conclusion can be drawn that in most cases neoformation minerals are obviously represented by micas, relict minerals, such as kyanite, staurolite and garnet, being visibly resynthesized only to a lesser extent. The possibility of relict minerals to outlive a massive mineral neoformation is generally very slight. It can be considered to depend on the speed of growth of the new paragenesis and on the intensity of the deformation having destroyed the old paragenesis. An important factor in the process, especially when hydroxylated minerals are involved, is the amount of fluids existing at the moment of mineral deformation and neoformation.

In what follows we are going to present an example of advanced deformation of a kyanite-bearing rock as well as its consequences, one of which is a considerable mineral neoformation.

The coupling of these two important phenomena, strong mineral deformation – active mineral neoformation, has resulted in an altogether peculiar texture that, according to the information we possess so far is unique all over the world.

In the field, the texture we have referred to has been identified in the kyanite-bearing rocks of the Getic metamorphic rocks in the Sebeş Mts, on the right bank of the Jigureasa Valley (Strei Basin) (Fig. 6).

The kyanite-bearing rock we have identified on surface is 20–30/50–60 m in size and shows textural features that are not shared by the country, equally kyanite-bearing rocks. It is an apparently unfoliated quartz-micaceous rock, containing kyanite megablasts of important sizes (1-10 cm long/0.5–2 cm thick) oriented at random in the groundmass. Garnet, staurolite and plagioclase feldspar, (usually) chloritized biotite, (often) sericitized muscovite also participate in the rock composition.

As a whole, the rock can be regarded as consisting of a micro-medium crystalline equigranular matrix of the above composition with kyanite megablasts included in it.

What is specific to the rock is that in most cases the kyanite megablasts are bordered by staurolite microcrystals (Pl. VI, Fig. 1). The rock is surrounded by common foliated micaschists containing kyanite, staurolite and almandine.

Most staurolite crystals bordering a kyanite crystal have the same optical and crystallographical orientation. This seems to be due to the epitaxial intergrowth of staurolite on kyanite as the crystallographic relations between the two minerals are always the same: the kyanite "*c*" crystallographic axis makes a small angle (not larger than 10^0) with the staurolite "*c*" axis, as shown in the diagram in Figure 4, built up according to universal stage measurements). Therefore the two minerals joining planes are to be found in the "*c*" axis zone. The epitaxial intergrowth of the two minerals is accounted for by the identical structural configuration of the staurolite (010) face and the kyanite face. Quite frequently the kyanite and the staurolite bordering it are not in direct contact. There is usually quartz in between, that, as will be seen, replaces much of the kyanite (Pl. VI, Fig. 2).

The matrix represents the rocks groundmass. It is micro-medium crystalline and simple in composition: muscovite, quartz, biotite ± plagioclase. Unlike the other kyanite-bearing metamorphic rocks in the region, the minerals building up the matrix (just like the kyanite megablasts) are apparently disposed at random and therefore make up an isotropic texture. The statistic diagrams oriented after the micas cleavage planes indicate the spatial isotropic disposition of these minerals. That results from the relatively high dispersion of the cleavage plane poles in the three stereograms, performed on three reciprocally perpendicular sections; it is therefore obvious that there are no prefential orientations of these minerals or that there are several such orientations in superposition (Fig. 5 A,B,C).

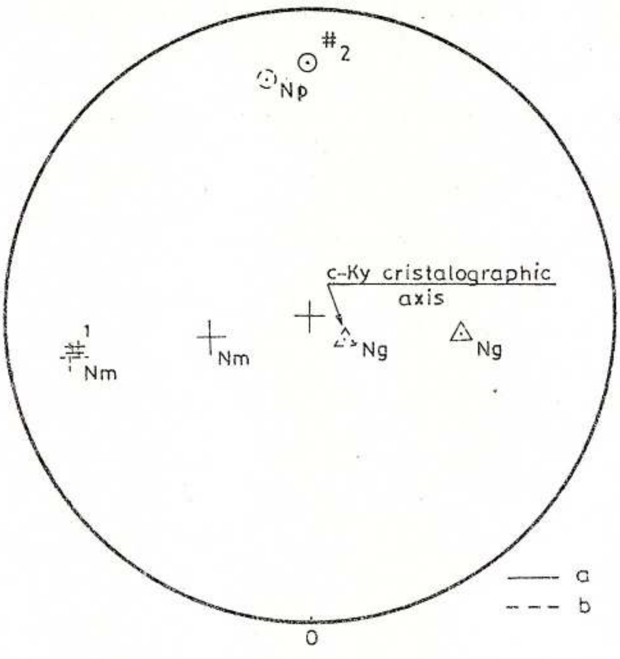

Fig. 4 – Stereographic plot of kyanite and staurolite crystallographic and optical elements: a, kyanite; b, staurolite, 1,2-kyanite cleavage planes.

The study of the evolution in time of the phenomenon under investigation has been approached starting from the premise that it is materialized in the structural and textural details of the rock, which shows concentric zones corresponding to the processes that led to its formation. In the vecinity of the surrounding micaschists rocks show features of transition between the rock with megablasts and the neighbouring micaschists. In its central part, the most typical one, the rock is totally devoid of the textural features of micaschists. In this way, the study of the temporal evolution can be considered the equivalent of the spatial sequence of transitions between the unaffected rock and the completely transformed one.

Irrespective of the cause of the phenomena observed, the spatial succession renders the temporal one with the necessary and sufficient condition of the mineralogical uniformity of the mass of rocks subject to transformation. We consider this condition could be met with, as the volume of rocks affected by the mentioned

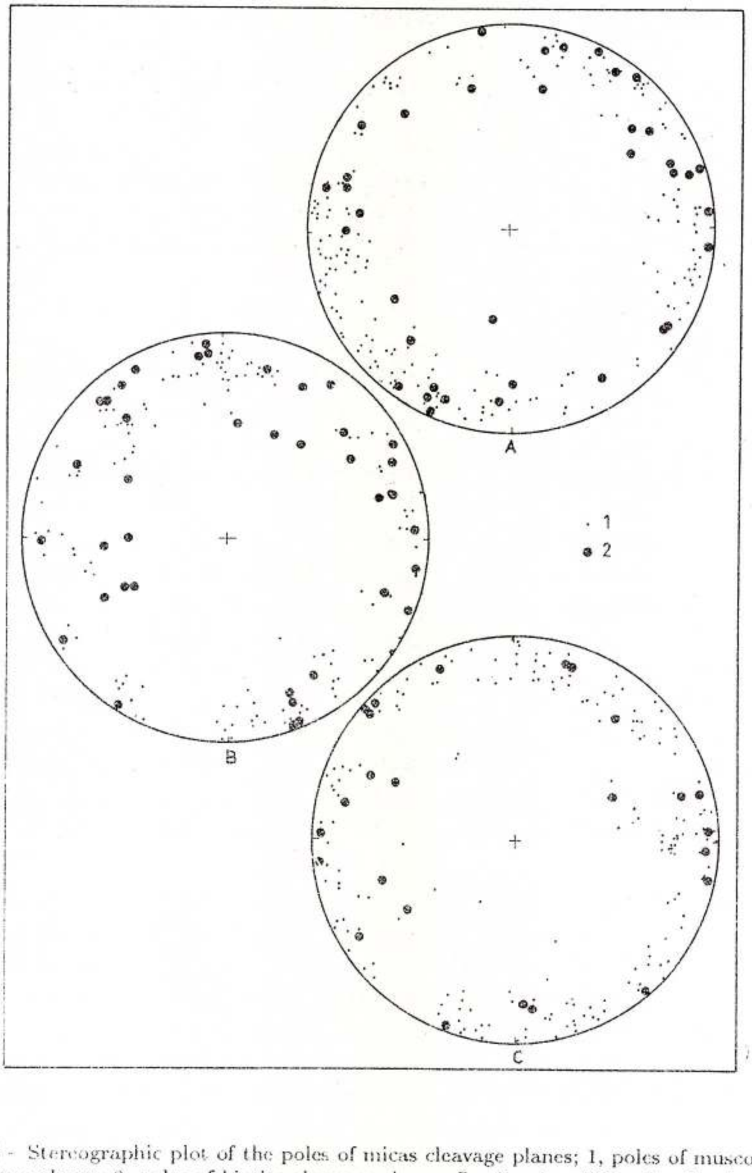

Fig. 5 - Stereographic plot of the poles of micas cleavage planes; 1, poles of muscovite cleavage planes; 2, poles of biotite cleavage planes. Section A = 221 poles; Section B = 190 poles; Section C = 224 poles.

processes was rather small. Therefore, starting from the outer part of the rock under study we shall follow the main phenomena produced.

In the zone of the first occurrence of kyanite megablasts, the almost total disappearance can be observed of the big garnet crystals that were replaced by numerous small garnet crystals with a marked idiomorphism. The latter are included either in the micaceous-quartzose matrix or in the newly born kyanite megablasts. In the matrix there are still to be found numerous deformed kyanite megablasts (Pl. VII, Fig. 2).

The newly engendered garnet can be differentiated according to its being or not included in kyanite. The garnet uncluded in kyanite further evolved in the matrix containing it, so that a lack of balance appears between its central part (probably after having ceased to grow) and the matrix hosting it; numerous grains are turned into "atolls", the garnet core being replaced by mica or quartz. Unlike it, the garnet included in kyanite has remained unaffected, showing high idiomorphism and crystal integrity (Pl. VII, Fig. 1).

No distinctions are noticed between the sizes of the garnet in the matrix and that included in the megablastic kyanite, which leads to the conclusion that the crystallization of garnet ended when that of the megablastic kyanite began.

We should also mention the existence in the kyanite megablasts of a few, often bent trails of inclusions, mainly represented by quartz and undeterminable opaque minerals, submicroscopic in size. They can be proof of a texture pre-dating the newly formed kyanite or of movement during the crystallization of kyanite. This movement may also have taken place after the growth of megablastic kyanite had ceased, as the trail inclusions have unconformable positions in the isotopic matrix as a whole, or in respect with the matrix just next to the kyanite crystal, which often has a planary arrangement, strictly in this zone (Pl VIII, Fig. 1). The possibility of subsequent movements can also be attested by the rare mechanical twinnings of the megablasic kyanite. Last but not least we should point out an element characteristic of the whole rock under discussion, i.e. the speed of neoformation kyanite and garnet growth. In our opinion the megablastic kyanite had a very high growth speed since, during its blastesis, it included not only common mineral inclusions of micronic sizes but also garnet crystals lying in the matrix.

As for the garnet crystallization growth, it can be said to have been very rapid in the first growth interval (the central zone being generally rich in inclusions) and slow in the final growth period, when the clear marginal zone was formed.

Finally, the central zone of the rock body with megablasts is characterized by the formation of the staurolite border by the end and particularly at the very end of the period of kyanite crystallization. That border is made up of separate staurolite crystals regularly disposed in respect with the orientation of the kyanite crystals with plays the role of support as shown in the general presentation.

We consider much of the quartz included in the megablasts has been emplaced after the staurolite crystallization, since there is a relation of constant position between this last mineral and the megablast-support in spite of the fact that these two minerals are never in direct contact, quartz being found in between. The disposition of the quartz inclusions in kyanite in trails looking like a paleotexture

– as is often the case – can mean that on its track favourable conditions were created for quartz to be formed (Pl. VIII, Fig. 2).

A few more elements are necessary for reaching a comprehensive description of the way in which the rock under study could have evolved. In the area where the megablastic kyanite-bearing rocks crop out lineations with two trends, SSE–NNW and E–W, coexist. On the geological map of the surrounding zone (Fig. 6) it can also be noticed that the main rock bodies trend approximately north-south, showing some east-west "appendices" or including small rock bodies trending east-west.

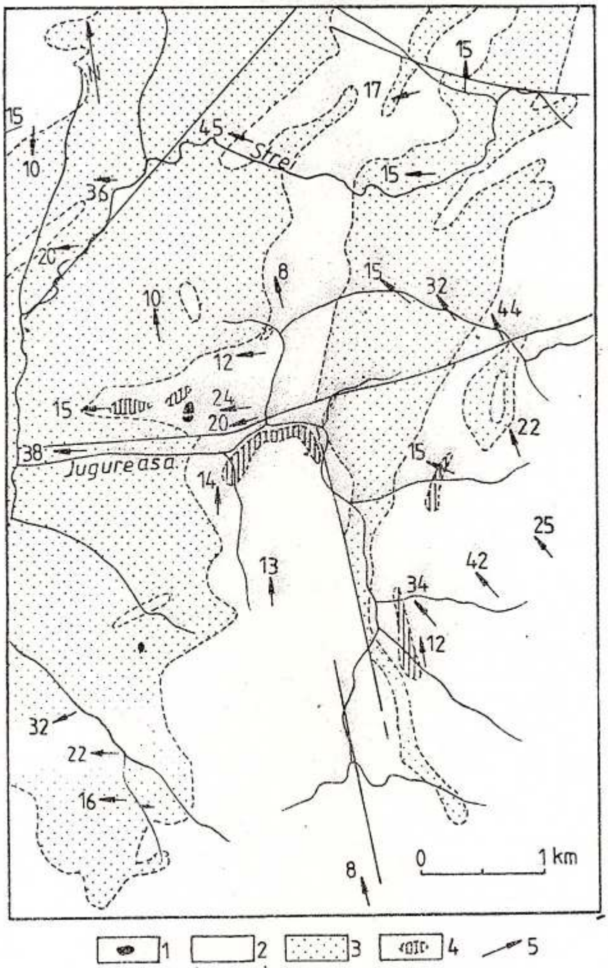

Fig. 6 Geological map of the area surrounding the kyanite megablast gneisses (acc. to Şeclăman, 1972): 1, kyanite megablast gneisses; 2, plagioclase gneisses, micaschists; 3, microcline gneisses (migmatites); 4, amphibolic gneisses, amphibolites; 5, lineations.

Secondly, we should point out that it is only in point of texture that the rock we have chosen for our investigation is peculiar among the kyanite and staurolite rocks present everywhere in the region. As far as its chemical composition is concerned, it is a "normal" type of rock containing kyanite and staurolite.

All these data make us draw the conclusion that the morphological peculiarities of the rocks with kyanite megablasts are not due to a different chemistry or a chemical supply from outside. We propose therefore the following model of the genesis of the rock with kyanite megablasts.

Rocks rich in kyanite, containing much garnet and staurolite in normal quantities, were subject to two deformations acting like a couple of forces, materialized in the two lineation directions and in the (at least) two directions of the micaceous minerals (Pl. IX, fig. 1). The two deformation directions can be imagined like two intersecting planes. They act through deformation and reorganization of the minerals affected by deformation. The utmost effect of rock deformation and therefore reorganization is therefore to be found at the intersection of the two planes. As we go away from the intersection, the effect diminishes rapidly, consisting only in the reorganization of micaceous minerals. The first obvious effect is the formation of a structure of *decusate type*, – like that in the outer zone of the megablastic rock body –, probably in the first moment of the evolution of the rock under discussion. The formation of this structure was accompanied by the strong deformation and digestion of the old kyanite (D_1), of garnet and staurolite. Micas, especially muscovite, seem completely reorganized along the new deformation areas. The examination of biotite is difficult because of its chloritization that affected both the old generation and the new one in this outer zone.

A little bit later there appears neoformation garnet of small sizes in numerous idiomorphic crystals, probably in an environment oversaturated in its substance. Immediately after garnet ends its crystallization, kyanite megablasts start to crystallize (D_2), including and partially digesting the minerals in the matrix created so far. During all this time, the two directions of movement are active, micas being permanently formed, adapting their position both to the mentioned movement and to the space smaller and smaller as a result of the megablastic kyanite growth.

The considerable supply of "Al_2SiO_5" towards the forming megablasts led to a relative enrichment in iron of the rock matrix, which determined the sudden crystallization of staurolite. That took place in the environment the most enriched in iron (that is in the close proximity of the newly formed kyanite crystals) as well as in the place the most favourable to nucleation, being epitaxially fixed on the equivalent faces of the megablasts.

The *staurolite phase* was continued by a *quartz one*, maybe equally the result of a relative enrichment in quartz. It accounts probably for the existence of most of the quartz included in kyanite as well as for the apparent removal of staurolite from the kyanite support. All this time muscovite was forming, participating together with quartz in the creation of the garnet-atoll, by its core losing its equilibrium with the fully evolving matrix. Equally on that occasion many staurolite crystals lost the idiomorphism they are supposed to have had the moment they were fixed on kyanite.

The movement continued during the whole period of evolution of the rock, leading to the chaotic disposition of the kyanite crystals and of the minerals in the matrix, represented mainly by biotite and muscovite. The combination of the main movement trends, to which, at a certain moment, the rather rigid megablast bodies began to resist, finally led to the isotropic orientation of the micaceous minerals in the matrix and therefore to creating a tectonite with low symmetry.

The small size of the megablastic rock body could be explained by the rapid loss of the cumulated effect of the two planes of movement, deformation and reorganization of minerals, as the distance from the point of intersection becomes greater. The spatial position of the rock body and its shape can give information on the position and shape of the two mentioned planes. The existence of the two lineation systems in other zones as well supposes at least partially, the existence of the conditions leading to the formation of this structural type. The peculiarities of such a rock will be determined by the type of initial rock as well as by the intensity of joint deformation movements.

The foreseable consequence of the simultaneous action of two directions of movement or of two deformation planes is the higher degree of deformation of the rock and its texture becoming more intricate. The rapidity of mineral neoformation represents the premise of the (even metastable) survival of some minerals of an older paragenesis. In the chapter referring to structure we shall give another example of simultaneous deformation along two directions accompanied by a rapid mineral neoformation favouring the preservation of older minerals.

From what has been presented it results that the deformation movement we should like to point out has almost totally reorganized the micaceous minerals. Anyhow, they attest a deep zone where deformations are active, unlike the situations when micas, belonging to the same petrographic types as those examined have been subject to deformations of *kink* bands type or of bend type.

The presented elements point out certain features of the metamorphic rocks in the Sebeş-Lotru Series, the area of Barrovian metamorphism. The most important observation is, in our opinion, the classification of minerals according to their age, judging by the different degree in which they were deformed and digested. This analysis led to the conclusion that all the minerals have been subjected to a characteristic deformation. Their reaction, besides deformation proper, was of *distruction*, accompanied by permanent mineralogical neoformation. It is difficult to establish which was the way and the kind of passage from the old generation to the young one. But it is remarkable that for the rocks under study, their recomposition in the final phase has an isomineralogical and isochemical character, in most cases the minerals existing in both stages of the rock: the old one and new one.

Some minerals can combine in new species. Thus staurolite can contribute to the formation of much of the newly formed biotite; kyanite can be recomposed in sillimanite (or can) participate in the formation of muscovite; garnet can be a source for the formation of biotite, of sillimanite etc. In any case, the decomposition of old minerals as a consequence of deformation represents the premise for the formation of new ones. In this case the transformations observed have to be regarded as mineral reactions that can be materialized in equilibrium curves between the members of the reaction. But since these curves separate stable mineral assemblages in different fields proper to them, deformation proves to be a factor in metamorphic zonation.

Another characteristic element of the investigated rocks is the crystallization of much of the rock mass at the same time with the deformation episode. The minerals crystallize in the deformation plane, materializing it. The consequence of this fact is the reorganization of micaceous minerals following this plane, and implicitly, the effacement of the old plane in which these minerals were disposed.

In the case discussed here we consider the possibility of a mimetic static crystallization often invoked for justifying the micaceous mineral neoformation is admissible only for a rather small percentage of these minerals. Static kyanite, garnet, staurolite recrystallizations have also been found. But we also have to point out the frequent crystallization of sillimanite in fibrous-radial aggregates. This form is not compatible with crystallization in a field of forces like that existing in the deformation plane. That is why sillimanite crystallized as such has to be distinguished from the broken one or from that disposed in the foliation plane.

The mineral neoformation we have referred to represents a remarkable percentage in the groundmass regenerated during this deformation episode, which makes us consider that the transformations having affected the rock are quantitatively comparable with those admitted to take place in a major metamorphic event. But is has been (and still is) difficult to evidence, just because of the vastness of its spatial development, of the almost complete reorganization of the micaceous minerals (representing an important percentage of the rock mass and defining its texture) and, of course, of its age, which makes it very difficult to identify the tectonomagmatic cycle corresponding to the event discussed. The intensity of this new metamorphic event can be judged according to the index neoformation mineral. As observed, there are proofs of mineral neoformation up to the level of sillimanite, which makes us consider that the maximum level reached is comparable with that defined by the old assemblage. But it is rather unlikely that the position of the metamorphic zones be the same, areas of higher intensity possibly covering low intensity ones, and the other way round. The identification of staurolite relicts in the sillimanite-bearing zones (Pl. IX, Fig. 2) makes us suppose the first mineral is representative for a relict metamorphism zone. We have found similar examples in the Semenic, Sebeş, Cibin, Lotru Mts.

The effect of the superposition of the metamorphism zones and of the two metamorphic events is the mixing up of index minerals in the same mineral association leading to the formation of what we have called overcrowded parageneses (Hârtopanu, 1973).

Another consequence resulting in the appearance of new metamorphic zones is that the phenomena in the isograde plane became more and more intricate. It is expected that, because of the characteristic feature of the new metamorphic event, there will be fewer and less obvious elements indicating the disappearance of an assemblage or of an index mineral or the incipient appearance of another one. This new metamorphism will lead to the effacement of the old isograde plane and therefore of the sharp passage between the old metamorphic zones.

The possible consequences of the settlement of a new metamorphism also regard absolute age datings of rocks and implicitly of the most important, last metamorphic event. Many absolute age datings are based on fresh micaceous minerals. They are in fact the ages of the metamorphic event generating the fresh micas and not those of the event during which most minerals of the type of kyanite, staurolite, garnet were formed.

Finally, another consequence refers to the establishment of the geometry of the rock bodies, the final purpose of geological mapping. As it is mostly deduced on the basis of foliation measurements, it is very important that they should coincide with the lithological boundaries. The S_0 bedding foliation might have not been preserved and not coincided with the S_1 foliation of the first metamorphism and, as already shown, the S_2 foliation of the last metamorphic event, the almost complete reorganization of micas may be possibly not superposed on S_1. In this case the danger exists of tracing the boundaries of the rock bodies on the basis of geometrical elements that do not coincide with the real boundaries of the lithological complexes and on the basis of disparate lithological elements belonging to different rock bodies.

2. Metamorphic Area of Intermediate Type

In chapter IIIA we have shown that the minerals characteristic of this type of metamorphism are andalusite, cordierite and sillimanite. Numerous other foreign or Romanian authors also consider staurolite to be characteristic of this zone. Our observations on thin sections from rocks belonging to the three important zones in the South Carpathians (Godeanu, Mehedinţi and Căpăţâna Mts) in which this type of metamorphism is widely distributed have made us gradually come to the conclusion that the staurolite in the area of low pressure metamorphism is only a metastable relict. It originates in a metamorphism which preceded the low pressure one and, as we have already shown (Bercia, Hârtopanu, 1980), the relations of replacement by other minerals indicate its univocal evolution.

As we have presented in the description of the metamorphism of Barrovian type we shall approach the problem of the crystallization sequence, establishing age relations between various minerals or parageneses, in relation with the moment of deformation, expressed by S planes.

We are going to present the textural feature of the aluminium-silicate-bearing rocks in the three mountain regions mentioned above.

The regular character of the occurrence of these minerals in the investigated zones of the Getic Realm does not strictly represent identical formation conditions. It is rather due to the quite large range of physical conditions in which each of these minerals can appear, to the superposition of their fields of stability over a large area. It is therefore natural to try to identify the petrographic peculiarities of each zone, for discerning paragenetic and physical condition nuances that can differentiate them.

a. *Căpăţâna Mountains.* As outlined in a previous chapter, the area containing andalusite, corderite and sillimanite lies in the central zone of the massif, at the sources of the Repedea and Mălaia Valleys (Lotru Basin) and of the Luncavăţ, Valea Reci, Valea Mariţa, Urşani, Valea Romanilor and Bistricioara Valleys in the southern slope of the massif (Fig. 7). It is represented by granoblastic, prevailingly micaceous rocks. The most common mineralogical assemblage is: muscovite, biotite, quartz, sillimanite, garnet, andalusite, corderite, plagioclase feldspar, K feldspar, staurolite, opaque minerals, accessory minerals.

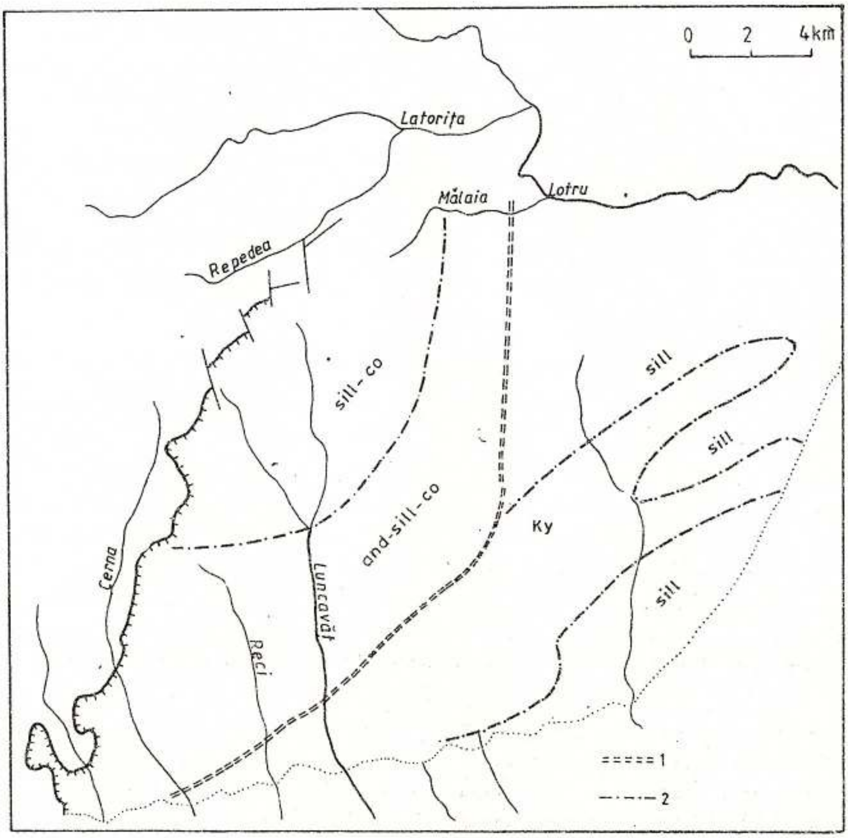

Fig. 7 - Metamorphic zonality in the Căpăţâna Mts: 1, Boundary between various types of metamorphism; 2, Metamorphic isogrades.

Of all these minerals, cordierite is the most altered, pinnitization being ubiquitous. In the order of susceptibility to alteration there follow the garnet chloritized on fissures or rarelier marginally, biotite, equally chloritized, plagioclase feldspar with irregular scaly muscovite (sericite) patches and pinnitized staurolite. Of the minerals studied by us it is only cordierite that has been mentioned as such on the geological map of Romania, scale 1:50 000, Voineasa sheet: ocular and stromatic migmatites with cordierite.

Andalusite is less frequently found in the area under investigation. It was first identified by Trifulescu (in Hârtopanu, 1975) in Valea Reci gallery and then by us in the upper basin of the Mălaia Valley, on the valleys in the southern slope of the massif as well as in the main crest, in the Cocora Summit zone.

Sillimanite occurs either in largely developed crystals or as fibrolite, throughout the area under discussion.

The minerals of the metapelitic rocks containing aluminium-silicates and/or cordierite are, in numerous cases, in reciprocal relations, observable under the microscope. They can be related to deformation movements, the most important of which determined the foliated texture of rocks, marking therefore a major event in the history of their formation.

One of the most interesting observable relations is that of cordierite with andalusite (Fig. 8). No direct relations have been observed between these two minerals. Cordierite makes up porphyroblasts of the order of 1 cm in which it is only rarely associated with andalusite. In Figure 8 the cordierite seems to have been pre-existent to the present schistosity and the andalusite has a static post-kinematic growth.

Figure 9 shows the relation of cordierite with sillimanite. The presence of sillimanite as acicles incorporated in cordierite can mean its simple inclusion. This phenomenon is also proved by the sillimanite needles getting out of the cordierite boundary, therefore their inclusion was not total. There are no elements leading to the idea of the selective corrosion of cordierite by the surrounding quartz and micas. In Figure 10 an aggregate is presented made up prevailingly of andalusite and staurolite. In the andalusite crystal mass, staurolite and sillimanite crystals are included. A staurolite megablast is in direct contact with andalusite. The staurolite crystals included in andalusite show the same optical orientation as the big crystal, attesting the advancemet of andalusite towards the staurolite, accompanied by the latter's digestion by the former. In this case we interpret the inclusion of sillimanite in andalusite as simple incorporation, judging after its orientation along the rock foliation.

In Figure 11 the staurolite digestion is disputed between andalusite and biotite. Both the grains included in biotite and the one included in andalusite have an optical orientation common with the big "parental" grains. In its turn, biotite is replaced by other minerals such as quartz, muscovite and chlorite. The muscovite crystal disposed across the schistosity and which seems to cross the biotite crystals, discontinuing them, is in our opinion younger than the muscovites along the schistosity. And so is, we think, the biotite formed on the garnet fissure. Therefore the staurolite seems to be one of the older minerals of the rock, as it appears at present.

Fig. 8 – Cordierite-andalusite relation: a, andalusite; b, biotite; c, cordierite; o, opaque mineral. Andalusite paragneiss, Valea Reci, Căpăţâna Mts.

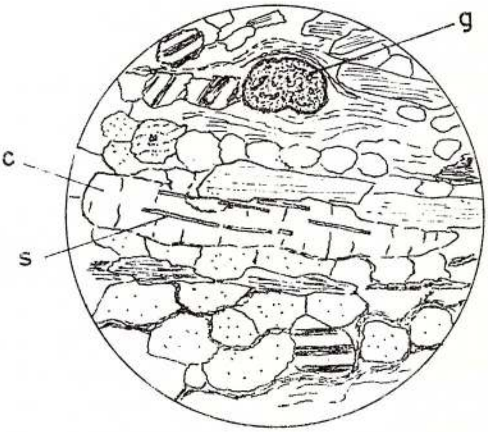

Fig. 9 – Cordierite-sillimanite relation: c, cordierite; s, sillimanite; g, garnet. Cordierite gneiss, Valea lui Gurgui-Căpăţâna Mts.

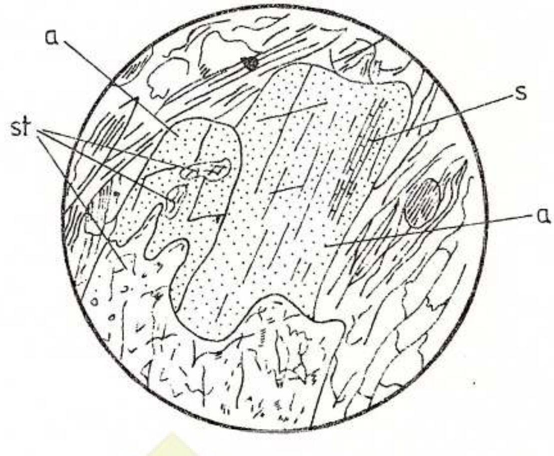

Fig. 10 – Substitution of staurolite by andalusite: st, staurolite; a, andalusite; s, sillimanite. Andalusite paragneiss, Valea Reci, Căpăţâna Mts.

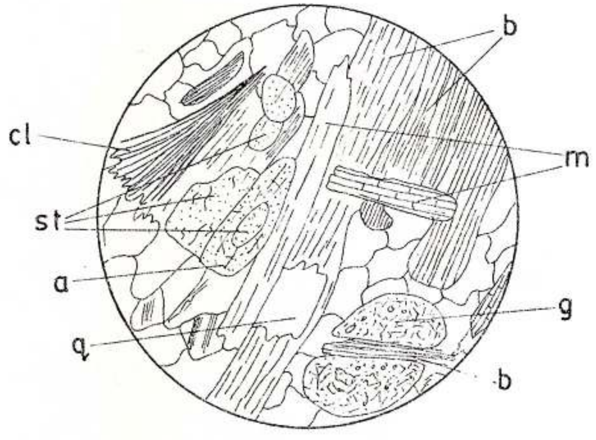

Fig. 11 – Successive substitutions; cl, chlorite; st, staurolite; a, andalusite; q, quartz; b, biotite; m, muscovite; g, garnet. Andalusite micaschist, Valea Reci, Căpăţâna Mts.

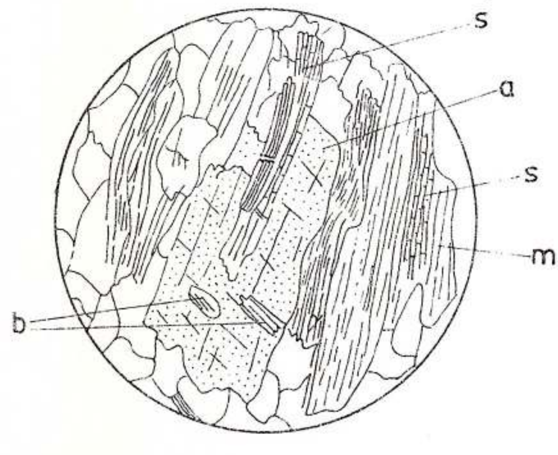

Fig. 12 – Substitution of biotite: b, biotite; s, sillimanite; a, andalusite; m, muscovite. Andalusite micaschist, Valea Reci, Căpăţâna Mts.

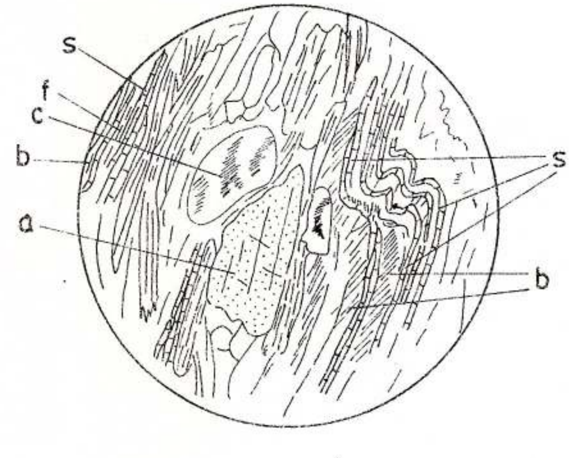

Fig. 13 - Biotite-sillimanite transition: s, sillimanite; f, fibrolite; c, cordierite; b, biotite; a, andalusite. Sillimanite micaschist, Valea Mălaia, Căpăţâna Mts.

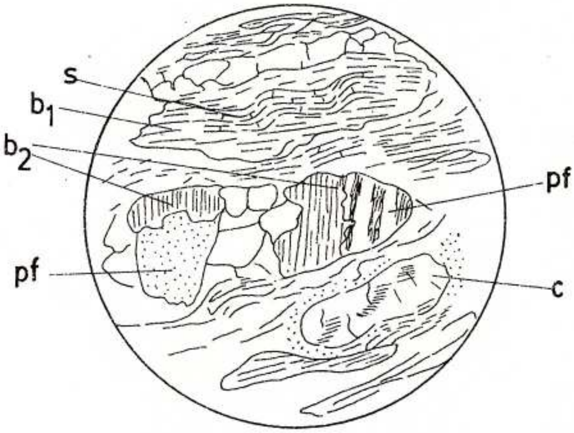

Fig. 14 - Two generations biotite: s, sillimanite; b_1,b_2, biotife; pf, plagioclase feldspar; c, cordierite. Cordierite-bearing gneiss, Valea Reci, Căpăţâna Mts.

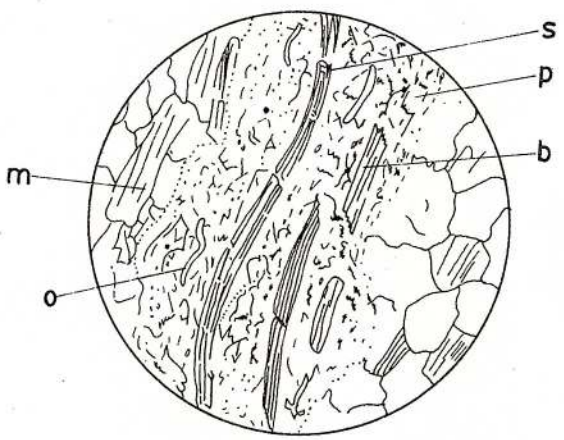

Fig. 15 - Selective alteration: m, muscovite; o, opaque mineral; s, sillimanite; p, pinnite; b, biotite. Sillimanite and cordierite bearing gneiss, Valea Mălaia,Căpăţâna Mts.

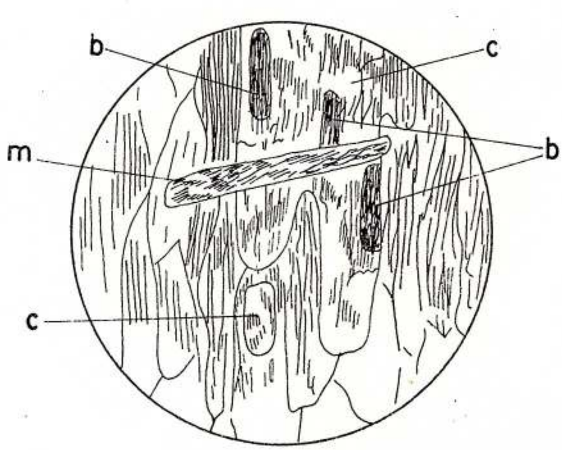

Fig. 17 - Cordierite substituting biotite: b, biotite; m, muscovite; c, cordierite. Cordierite-bearing paragneiss, Valea Craiova, Godeanu Mts.

The existence of two types of biotite can also be seen in Figure 12, where there also occurs a second generation of biotite, equally digested by andalusite and equally transversal on the rock schistosity. The andalusite also includes a sillimanite sheaf that extends beyond the edge of the andalusite crystal. We should mention the sillimanite seems to pseudomorphose the biotite noticed at the sheaf extremity included in the andalusite crystal. The sillimanite is also included in muscovite, but the two minerals can also be synchronous.

Figure 13 shows a close association between sillimanite and biotite. The contact between these two minerals can be direct but it is most times mediated by the so-called fibrolite.

As regards the frequent association of fibrolite with the deformation movements, the problem can also be put the other way round; either deformation determines fibrolitization or, fibrolite, being more plastic, yields more easily to deformation efforts.

A few optical determinations of fibrolite proved it to have properties of transition from sillimanite to biotite. Its refringence is closer to that of biotite and its birefringence resembles more that of sillimanite. The angle of the optical axes is very small or zero, like that of biotite, which sometimes behaves in this respect like an uniax mineral, but the optic sign of fibrolite is positive, just like that of sillimanite. In Figure 46 the contact between sillimanite and biotite can be more or less mediated by fibrolite.

Another proof regarding the existence of two biotite generations is shown in Figure 14. What differentiates the two biotites in time is that deformation did not affect both of them. So, at the upper part of the figure, the biotite along the foliation is slightly folded, at the same time with the incorporated sillimanite. Transversally, there is a second generation of biotite, not at all deformed, which digests the plagioclase feldspar.

The alteration of the minerals in the rocks under discussion can be selective. In Figure 15 sillimanite sheaves are seen, included in a pinnite mass; besides sillimanite, there are also biotite and opaque mineral crystals.

b) Godeanu Mountains. The surface on which host rocks of the three minerals examined here appear is restricted to the eastern part of the outlier of Getic metamorphic rocks in the Godeanu Mts, between the Cerna Valley to the east and a line running approximately SW–NE through the cental part of the Iauna, Craiova, Olanu, Balmoşu, Ivanu and Cărbunele Valley Basins (Bercia, 1975) (Fig. 16).

The andalusite, sillimanite and cordierite–bearing rocks include a large lithological and textural range, between biotitic plagiogneisses, micaceous plagiogneisses and micaschists as well as quartzo-feldspathic gneisses. Like in the Căpăţâna Mts, the mineralogical asociation in the studied rocks includes kyanite, besides the three minerals examined and the other minerals enumerated in the case of the Căpăţâna Mts. The significance of this mineral will be presented by the end of this chapter.

Cordierite seems to be more modestly represented than in the Căpăţâna Mts,

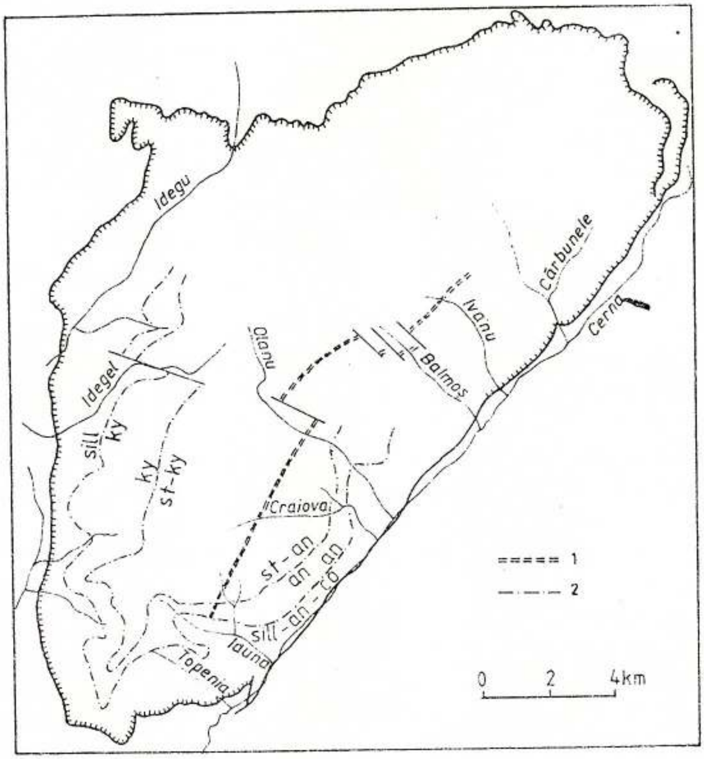

Fig. 16 – Metamorphic zonality in the Godeanu Mts (Bercia, 1975). 1, Boundary between various types of metamorphism; 2, Metamorphic isogrades.

but it is quite well developed so that it can be recognized as such with the naked eye and its relations with the other minerals can be examined under the microscope. In Figure 17 a cordierite phenoblast is presented, that includes three biotite crystals in reticular continuity with one another. Therefore it is possible for cordierite to replace a biotite crystal. It should be noticed the biotite within the cordierite crystal has the same orientation as the micas in the rock. Figure 18 shows the almost total inclusion of an andalusite crystal in a cordierite one. The latter also contains small andalusite relics with identical orientation against the big crystal. Therefore the replacement of andalusite by cordierite and a temporal sequence andalusite-cordierite has become certain. In the right side of the figure are situated, one next to the other, an andalusite crystal and a cordierite one. The andalusite crystal includes two small, identically oriented cordierite ones. It results that andalusite replaced cordierite and the cordierite-andalusite sequence becomes evident.

The two established sequences appear in obvious disagreement. There are three possible explanations for this situation:

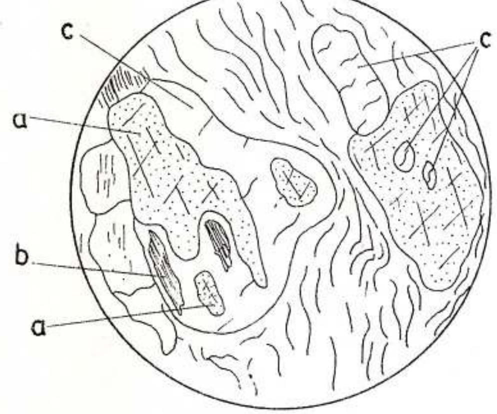

Fig. 18 – Andalusite-cordierite relation: c, cordierite; a, andalusite; b, biotite. Andalusite-bearing paragneiss, Valea Olanu, Godeanu Mts.

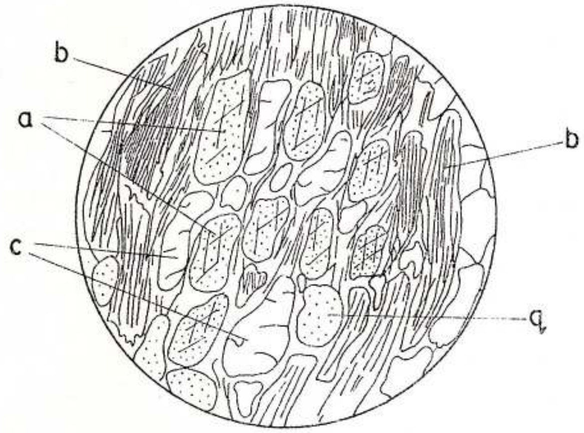

Fig. 19 – Andalusite-cordierite relation: b, biotite, a, andalusite; c, cordierite; q, quartz. Andalusite and cordierite micaschist, Valea Olanu, Godeanu Mts.

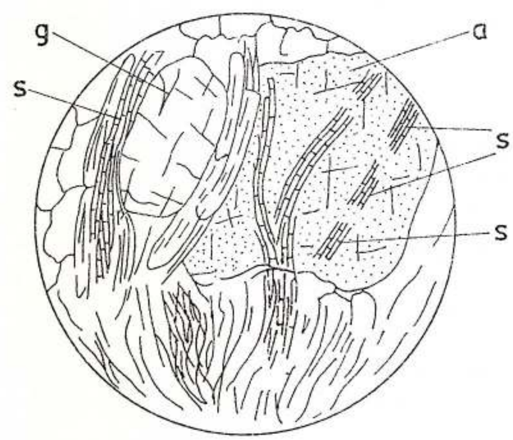

Fig. 20 – Possible substitution of sillimanite by andalusite: a, andalusite; s, sillimanite; g, garnet. Andalusite-bearing paragneiss, Valea Iauna Mică, Godeanu Mts.

a) the sequence starts with cordierite, is continued with andalusite and ends with a new generation of cordierite;

b) the sequence starts with a first generation andalusite, is continued with cordierite, followed by the second generation andalusite;

c) the andalusite and the cordierite are approximately synchronous.

This last explanation seems to reasonably suit the situation shown in Figure 19, where in a mosaic made up of andalusite, cordierite, quartz and, to a lesser extent, of micaceous minerals, the andalusite and cordierite crystals respectively built up groups with identical optical orientations. The part played by quartz in this assemblage is unclear, but it is likely to have appeared much more recently, in comparison with the other minerals. The advanced susceptibility of andalusite of being able to replace other minerals can probably apply to sillimanite too. So, in Figure 20 the relation between the two minerals can be observed. In the andalusite crystal there are three small sheaves of sillimanite with colinear disposition that seem to have belonged to a unique sheaf. The right extinction of sillimanite hinders us to examine the possible reticular relation that would have existed between the crystals of the three sheaves individualized by their digestion by andalusite.

The andalusite relative age can also be judged in relation with that of biotite. In Figure 21 two andalusite crystals are in relation with two types of biotite. At the upper side of the figure, two biotite crystals are included in andalusite, their optical orientation being identical. The cleavage traces are transversal on the schistosity direction of the rock and completely undeformed. At the lower side of the figure another andalusite crystal contains biotite crystals with identical orientation and elongated in the sense of the rock schistosity plane. Therefore the andalusite is younger than both types of biotite.

In Figure 22 one of the andalusite crystals includes micaceous minerals that would suggest the pre-existence in the area occupied at present by andalusite of a *decussate* structure. The replacement of staurolite by another andalusite crystal is worth mentioning. The preference of andalusite for incorporating staurolite does not seem to be accidental. The reason for this preference probably lies in the incorporated mineral itself – staurolite in this case – which supplies not only the material of the synthesis of andalusite but also suitable basis for its nucleation or possibly represents a good substratum for the latter's epitaxial growth.

The incorporation of various minerals in andalusite is maybe made even easier than the digestion. In Figure 23 such a crystal is shown, in which besides the graphite powder there occur crystals of biotite, opaque minerals (possibly magnetite, ilmenite), quartz as vermicles. It is difficult to assert if there is any reticular link between the opaque minerals. Vermicular quartz has no such linking or if there was, it was distrubed by certain deformation movements which fractured the andalusite – host and implcitly the incorporated quartz. The sillimanite nucleation is equally facilitated at the boundary of the mineral grains, as seen in Figure 24, where the sillimanite occurs among quartz grains on the one hand and feldspar ones on the other hand. It can't be said for certain if on the space occupied at present by sillimanite there wasn't biotite before and that biotite was the only

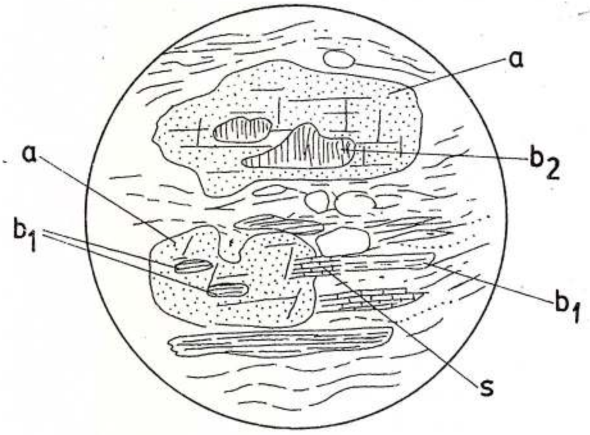

Fig. 21 – Substitution of both generations of biotite by andalusite: a, andalusite; b_1, b_2, biotite; s, silimanite. Andalusite-bearing micaschist, Valea Olanu, Godeanu Mts.

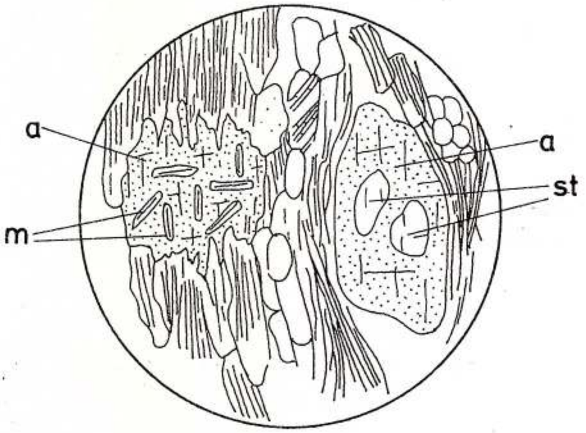

Fig. 22 – Facilitated andalusite blastesis: a, andalusite; m, muscovite and biotite; st, staurolite. Andalusite-bearing paragneiss, Valea Craiova, Godeanu Mts.

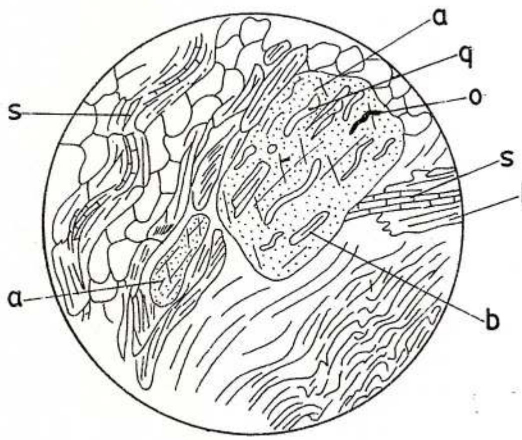

Fig. 23 – Inclusions in andalusite: s, sillimanite; a, andalusite; q, quartz; o, opaque mineral; b, biotite. Andalusite bearing micaschist, Valea Olanu, Godeanu Mts.

mineral permitting the sillimanite nucleation. Next to a sheaf of folded sillimanite there is a biotite one, folded parallelly to the former; in this context it is necessary to answer a question: why on such a limited space, "sillimanitization" took place selectively.

A similar situation can be identified in Figure 25, where, in the core of a fold, consisting of sillimanite sheaves, there is an unaffected (unfolded and undeformed) sillimanite sheaf. Therefore this sillimanite could have appeared postkinematically, which has already been asserted.

As its seems, sillimanite was also formed in several places, as in the case of other minerals. The relatively late appearance of sillimanite can also be observed in Figure 26 in which is presented a rock porphyroblasic in aspect as a result of the concentration of certain minerals in microlenticular spaces. At the upper side of the figure, the porphyroblast is made up of a garnet core surrounded by more or less orderly arranged biotite, followed by a sillimanite belt. At the lower side of the figure "the porphyroblast" seems more evolved, in the sense that the garnet is completely missing, being replaced by a biotite mass of *decussate* structure; this biotite is in its turn partially transformed in sillimanite. We consider therefore the formation succession to be garnet-biotite-sillimanite. The garnet substitution is even better expressed in Figure 27. In this case, biotite has probably filled a fissure, subsequently becoming a source or only a basis for sillimanite. Like in the previous case, at the outer part, the porphyroblast is bordered by a sillimanite belt which has probably totally replaced the initial biotite. It should be noticed that the sillimanite mass filling the void in the garnets shows the same decussate structure.

Form the data presented the conclusion can be drawn that it is not always possible to distinguish the digestion from the simple incorporation. In Figure 28 two clear situations of this processes are presented. At the lower side of the figure a rounded garnet crystal is partially replaced by biotite, so that the outer outline of the latter makes for the lack of the former. In its turn, the biotite is replaced by chlorite, so that the two minerals – biotite and chlorite – complete the missing garnet outline.

The case of a sure incorporation can be examined in the same figure, where an idiomorphic staurolite crystal is noticed, contained in an andalusite crystal. The digestion does not preserve the idiomorphism of the minerals, so that it can be asserted that no reaction took place between the two minerals. It results that, unlike in other situations, during the formation of andalusite, the staurolite was stable in relation with the andalusite. It became unstable quite late. In Figure 29 there coexist both the quasi-idiomorphic staurolite in a micaceous mass, with pressure shadows and that digested by the andalusite. Naturally, the questions arise:

– Why is staurolite only sometimes digested by andalusite?

– Does the idiomorphic staurolite represent another younger generation of this mineral ?

Anyhow, from what has been observed so far it results that both types of

,staurolite are pre-andalusitic. But this is only true provided that the andalusite should belong to only one generation.

A consequence of the reactions between minerals is the appearance of intergrowth structures, as is the case of simplictites. Such a structure is shown in Figure 30, at the contact between K plagiclase and sillimanite, in which it is difficult to establish the mineralogical composition. This section is of interest equally for the quite rare association of sillimanite with staurolite and of the latter with cordierite. We have to point out that in such situations one of the minerals appears in obvious imbalance or is very poorly represented, like in Figure 28, where the cordierite is partially pinnitized, or in Figure 30, where the staurolite occurs in very small crystals and the cordierite is totally pinnitized.

Figure 31 equally shows an assemblage lacking in equilibrium because of the appearance of kyanite close to the andalusite or even included in it. The latter is twisted and deformed, included in a muscovite mass. In certain cases, the kyanite is also accompanied by chlorite. In the same section the staurolite appears close to a pinnitized cordierite.

It is worth mentioning that although kyanite is an aluminium-silicate polymorph just like andalusite, no other passage from each other is noticed. That also appears in Figure 32, where the coexistence of the three Al_2SiO_5 polymorphs is presented.

c) Mehedinţi Mountains. The rocks bearing andalusite, sillimanite and cordierite in this massif can be grouped in two main categories: granoblastic, generally quartzo-feldspathic rocks that host especially cordierite and to a lesser extent sillimanite and andalusite, and so called pelitic rocks (metapelites), richly micaceous in which sillimanite and andalusite prevail, with granolepidoblastic or lepidoblastic texture. These rocks can sometimes have peculiar textures, like in the case of the ocular gneisses in the zone of the Mărăşeşti, Drăgheşti, Turbata villages, with nodules made up of sillimanite and cordierite, incorporated in a quartzo-feldspathic mass.

The rocks under discussion have a large distribution in the Mehedinţi Mts, occupying the largest part of the Bahna Outlier and a small part of the Severin Outlier. The minerals making up these rocks (especially the index minerals) have a zonal disposition, established on the basis of the microscopic study and observations of other scientists.

The mineralogical zonality in the Mehedinţi Mts is prolonged along the direction of the S_2 structure. Figure 33 shows this disposition, which suggests the existence of a relation between the spatial and the temporal position of the S_2 foliation and of the low pressure metamorphism in this massif.

Besides the minerals investigated here, in this zonality there are also other minerals, like K feldspar and staurolite. Kyanite associations have also been found, whose origin will be discussed.

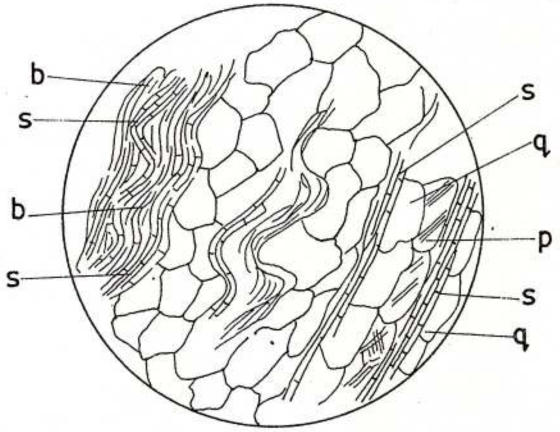

Fig. 24 Facilitated sillimanite blastesis: b, biotite; s, sillimanite; q, quartz; p, plagioclase. Sillimanite-bearing paragneiss, Valea Topenia, Godeanu Mts.

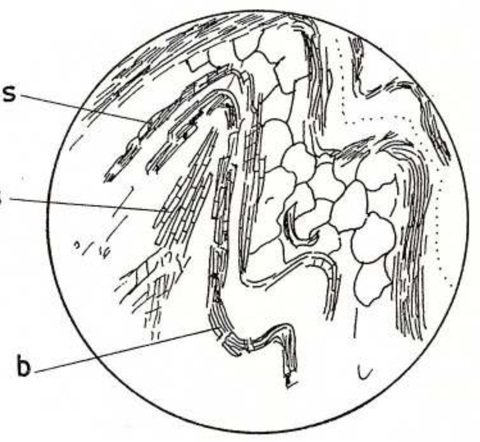

Fig. 25 – Sillimanite blastesis and folding: s, sillimanite; b, biotite; Sillimanite biotite gneiss, Valea Iauna, Godeanu Mts.

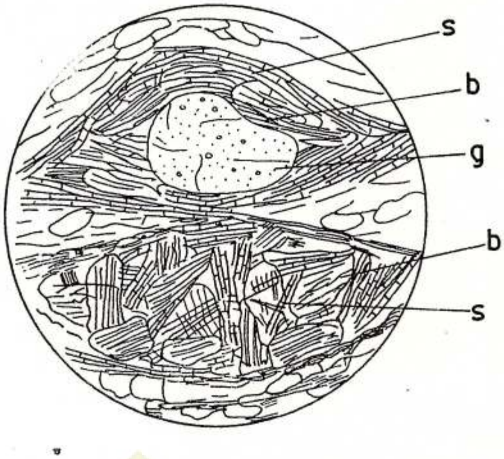

Fig. 26 – Crystallization sequence: s, sillimanite; b, biotite; g, garnet. Valea Iauna Mică, Godeanu Mts.

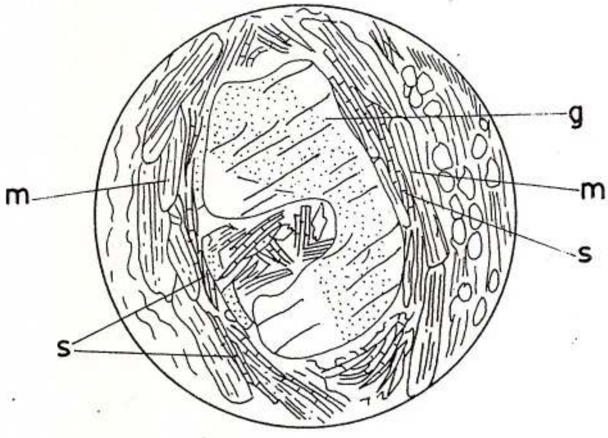

Fig. 27 – Substitution of garnet: m, muscovite, s, sillimanite; b, biotite; g, garnet. Sillimanite paragneiss, Valea Iauna, Godeanu Mts.

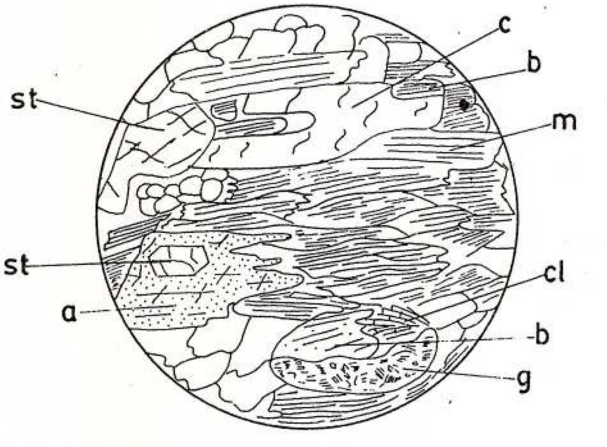

Fig. 28 – Substitutions and inclusions: st, staurolite; a, andalusite; c, cordierite; b, biotite; m, muscovite; cl, chlorite; g, garnet. Andalusite-bearing paragneiss, Valea Olanu, Godeanu Mts.

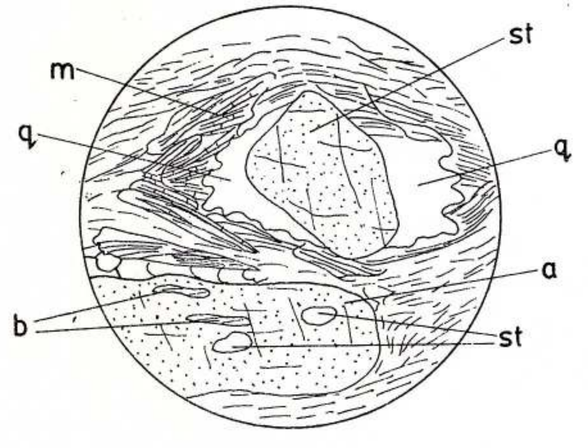

Fig. 29 – Pressure shadow: m, muscovite; q, quartz; b, biotite; st, staurolite; a, andalusite. Andalusite bearing micaschist, Valea Iauna, Godeanu Mts.

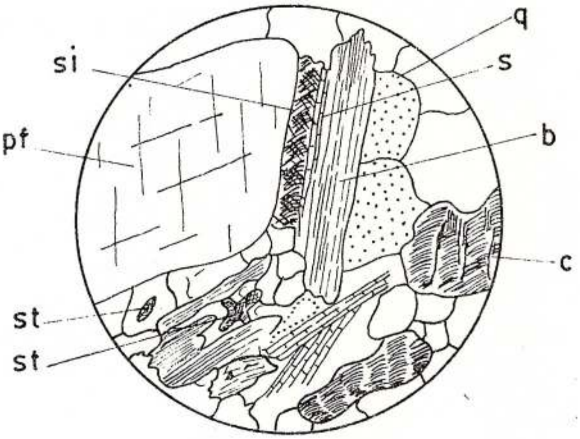

Fig. 30 – Simplectitic structure: pf, plagioclase feldspar; st, staurolite; q, quartz; s, sillimanite; si, simplectite; b, biotite; c, cordierite. Sillimanite-bearing paragneiss, Valea Iauna, Godeanu Mts.

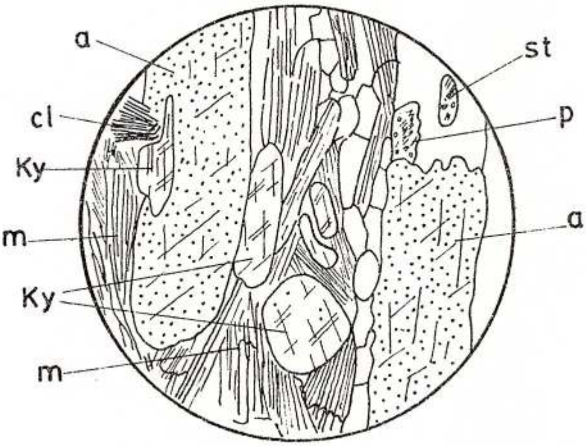

Fig. 31 – Coexistence of kyanite with andalusite: a, andalusite; cl, chlorite; ky, kyanite; m, muscovite; st, staurolite; p, pinnitized cordierite. Valea Iauna, Godeanu Mts.

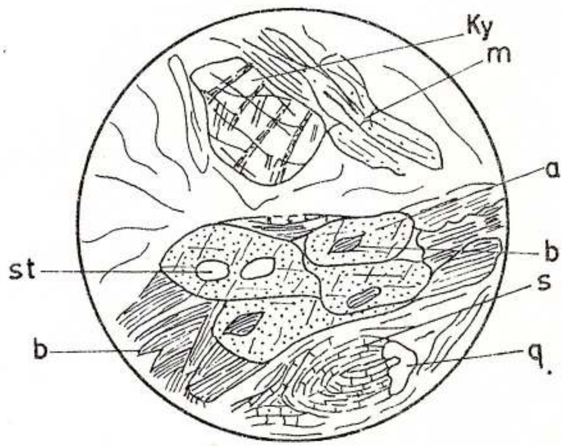

Fig. 32 – Coexistence kyanite-andalusite-sillimanite: st, staurolite; b, biotite; ky, kyanite; m, muscovite; a, andalusite; q, quartz. Andalusite-bearing micaschist, Valea Iauna, Godeanu Mts.

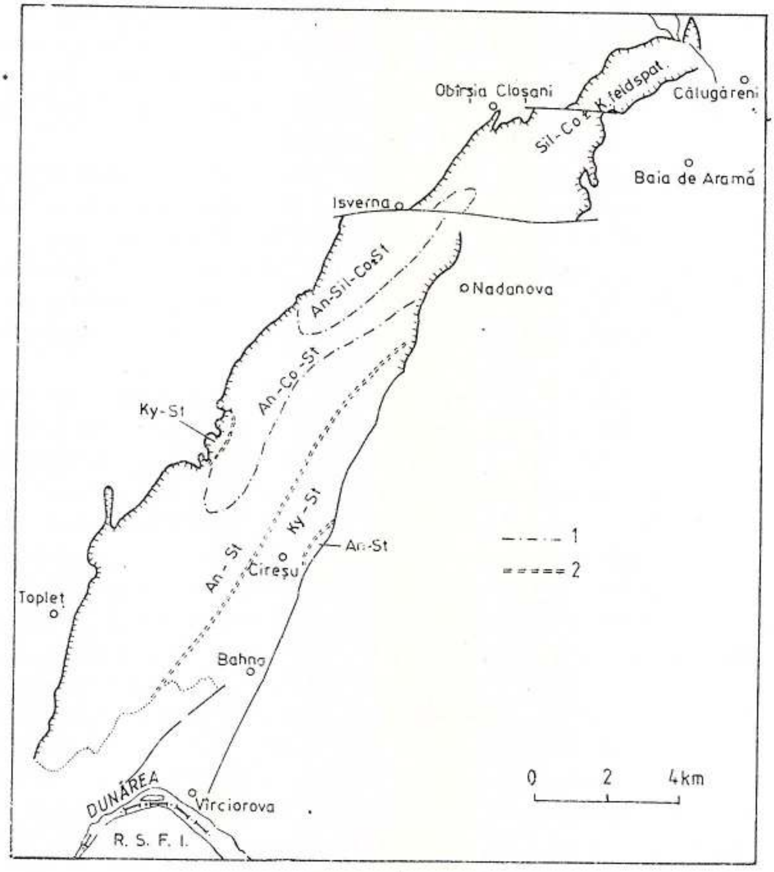

Fig. 33 - Metamorphic zonality in the Mehedinţi Mts (Hârtopanu, 1975):1, Zone boundary; 2, Domain boundary.

The age relations between various minerals, unlike the rocks in the Căpăţâna Mts, for instance, are clearer, probably equally due to the more abundant material at hand in the Mehedinţi Mts. In comparison with the Godeanu Mts, certain relations are not so clearly expressed and some others have an original character.

The relations of andalusite with cordierite appear, from the researches made so far, as simple incorporations of the latter by the former (Fig. 34). The cordierite incorporated in andalusite contains biotite relics and, probably at its expense, chlorite. The andalusite presented in this figure also includes garnet surrounded by a halo of undeterminable inclusions, possibly resulted in the process of the garnet digestion as well as staurolite occurring as relics with identical optic orientation.

In Figure 35 the same association of cordierite and andalusite is accompanied by the presence of intergrowths of simplectitic type that occur both at the cordierite-andalusite contact and between the two andalusite crystals. If we exclude the possibility that the cordierite crystal prolongs above or below the section plane, overlapping the two andalusite crystals, we must admit that for obtaing a simplectitic structure no mineralogical difference is necessary between the two crystals, that could belong to the same mineral species.

An important relation for the evolution of metamorphic crystallization is that between andalusite and biotite (Fig. 36). Like in the case of the other two massifs, there are two types of biotite, depending on the orientation in the schistosity plane or on the degree of deformation of this mineral. The biotite, which materializes this plane (in which it is situated) seems to be oldest, unlike the crystals of the same mineral which look fresh, undeformed and usually transversally disposed on the rock schistosity plane.

In Figure 36 the relations between andalusite and biotite II are of mutual interpenetration, both minerals sending amoeboidal prolongations towards the other. In this way it is difficult to decide which of the two develops at the expense of the other, and therefore, which is their relative age. The same kind of problem could arise for the situation in Figure 37. This time, in a mosaic-like quartz mass are situated a few andalusite crystals with common extinction. It is more difficult to appreciate if the quartz crystals show or showed reticular identity. Therefore, it is likely quartz has played the part of a substite of the andalusite. But the situation is complicated by the presence among the andalusite crystals of a sillimanite sheaf whose pole and position in metamorphic crystallization is difficult to establish.

In Figure 38, the presence of andalusite and sillimanite is partially related to that of biotite. At the upper side of the figure, a biotite rim separates an andalusite "core" whose reticular linking with the surrounding parental crystal is certain. In its turn, the latter is surrounded by another biotite rim suggesting the whole andalusite crystal partly replaced a biotitic porphyroblast. The sillimanite intergrows with the biotite, being partially digested by it.

Muscovite can also appear in a second generation as presented in Figure 39, where the digestion in relation with the andalusite could have taken place in both senses, and therefore, the interpretation of the texture presented is ambiguous. In exchange, the substitution of staurolite by andalusite is clear and that by garnet uncertain. In Figure 40 both micas of the second generation are shown, the biotite seeming to be, almost for certain, of a post-andalusitic age. As for the muscovite, its age can be assigned only in relation with the schistosity. But it seems strange that the andalusite relics at the bottom of the figure show traces of digestion by a muscovite oriented along the schistosity and which could therefore be of the first generation. It seems quite possible for the andalusite to have been replaced by muscovite of the second generation. But in Figure 41 the relation seems reversed, as transversal muscovite appears as relics in the mass of an andalusite crystal which seems to have grown from right to left, invading almost entirely the muscovite crystal.

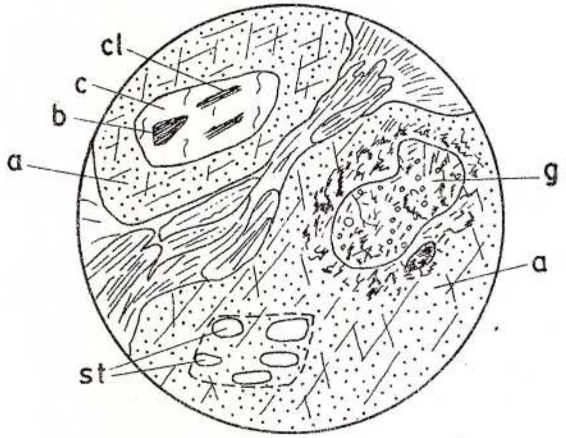

Fig. 34 – Inclusion and digestion of minerals: cl, chlorite; c, cordierite; b, biotite; a, andalusite; st, staurolite; g, garnet. Andalusite-bearing micaschist, Valea Topolniţa, Mehedinţi Mts.

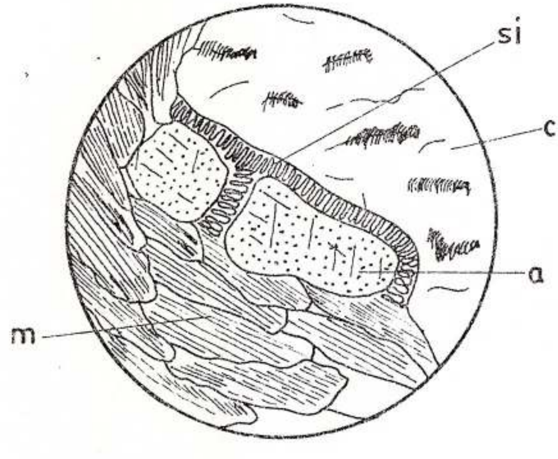

Fig. 35 – Cordierite-andalusite reaction: m, muscovite; c, cordierite; a, andalusite; si, simplectitic structure. Cordierite gneiss, Mărăşeşti, Mehedinţi Mts.

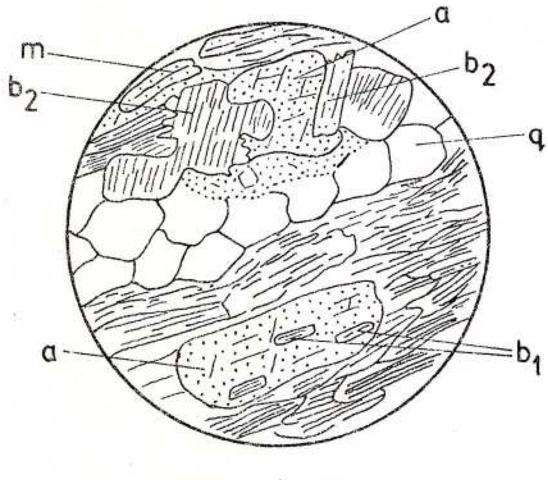

Fig. 36 – Relations between andalusite and biotite$_1$ and biotite$_2$: m, muscovite; b, biotite; a, andalusite; q, quartz. Andalusite-bearing paragneiss, Ogaşul lui Gurgui, Mehedinţi Mts.

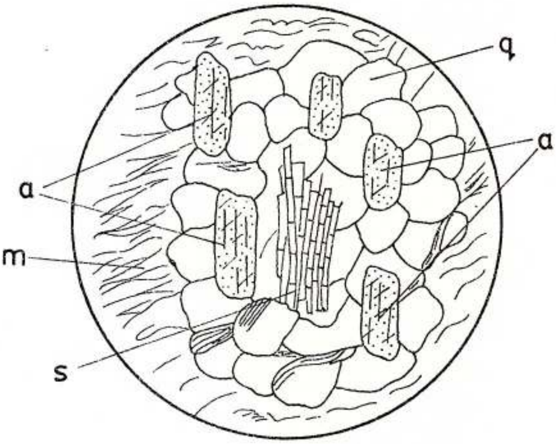

Fig. 37 - Substitution of andalusite by quartz: a, andalusite; m, micas; q, quartz; s, sillimanite. Andalusite-bearing micaschist, Turtaba, Mehedinţi Mts.

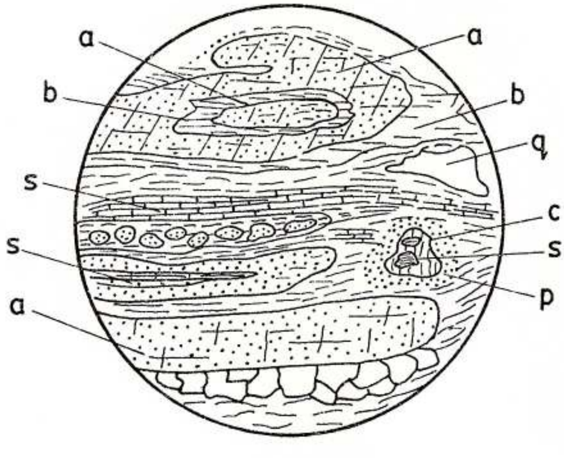

Fig. 38 - Inclusion and substitution relations: a, andalusite; b, biotite; s, sillimanite; q, quartz; c, cordierite; p, pinnite. Andalusite-bearing micaschist, Ogaşul lui Gurgui, Mehedinţi Mts.

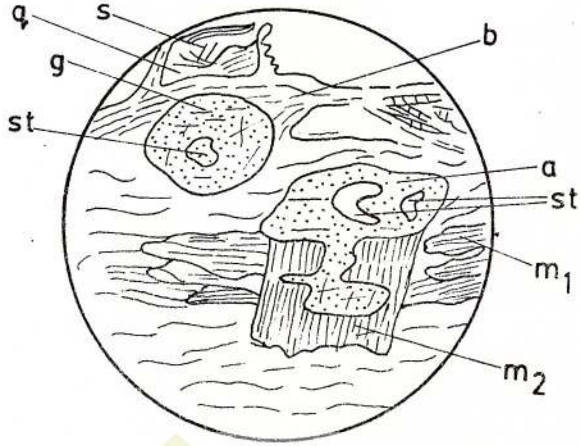

Fig. 39 - Successive substitutions: s, sillimanite; q, quartz; g, garnet; st, staurolite; b, biotite; a, andalusite; m, muscovite. Andalusite and sillimanite-bearing micaschist, Valea cu Peşti, Mehedinţi Mts.

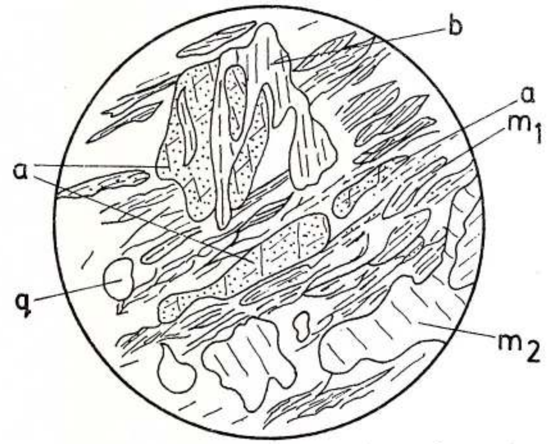

Fig. 40 – Second generation micas: a, andalusite; q, quartz; b, biotite; $m_{1,2}$, muscovite. Andalusite-bearing paragneiss, Valea Pietrele Albe, Mehedinţi Mts.

Fig. 41 – Substitution of muscovite by andalusite: a, andalusite; sq, sericite and quartz aggregate; a, andalusite; m, muscovite relict crystals. Andalusite-bearing micaschist, Mehedinţi Mts.

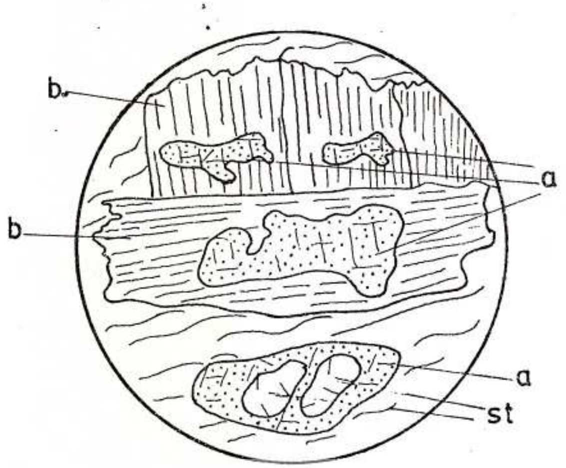

Fig. 42 – Biotite orientation and age: b, biotite; a, andalusite; st, staurolite. Andalusite and staurolite-bearing micaschist, Valea Topolniţa, Mehedinţi Mts.

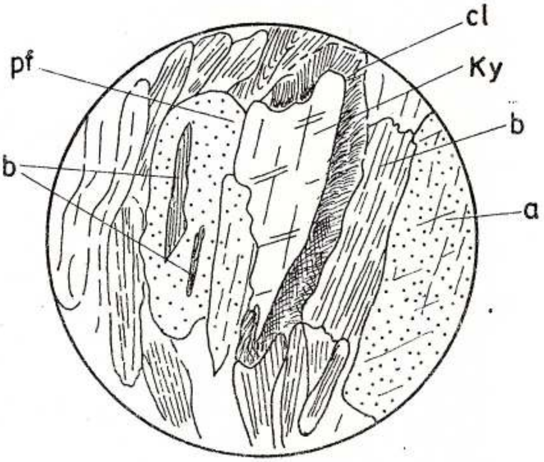

Fig. 43 – Andalusite-kyanite nonequilibrium association: ky, kyanite; b, biotite; pf, plagioclase feldspar; a, andalusite; cl, chlorite. Andalusite bering paragneiss, Valea Bolazu, Mehedinţi Mts.

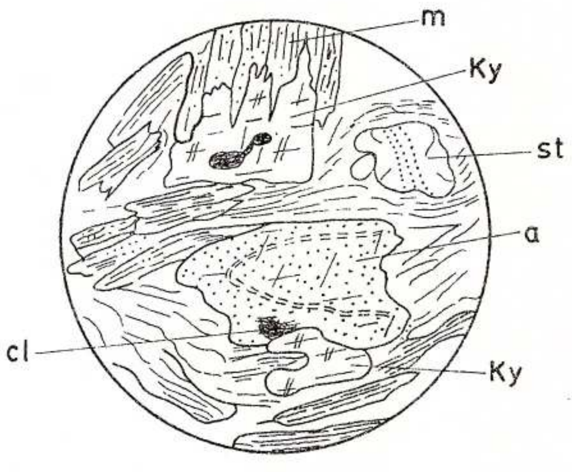

Fig. 44 – Coexistence kyanite-andalusite: m, muscovite; ky, kyanite; st, staurolite; a, andalusite; cl, chlorite; p, pinnite. Andalusite micaschist, Valea Topolniţa, Mehedinţi Mts.

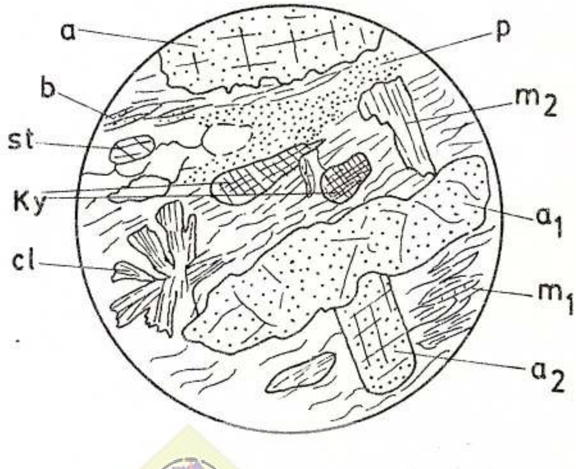

Fig. 45 – Two generations andalusite: a, andalusite; b, biotite; st, staurolite; ky, kyanite; c, chlorite; p, pinnite; m, muscovite. Andalusite bearing paragneiss, Valea Tăbuceaua, Mehedinţi Mts.

In the substitution of a mineral can participate not only one crystal but equally several crystals of the same mineral. So, in Figure 42, one andalusite crystal is partially replaced by three crystals of biotite, one of which is oriented along the foliation, although its morphology clearly indicates that it belongs to the late biotite generation.

One of the strange associations in the Mehedinţi Mts is given by the presence of kyanite as well as of andalusite and sometimes equally of sillimanite.

The association of sillimanite with kyanite and andalusite does not signify, in any case, that the conditions have been met for the triple point in the diagram of stability of the Al_2SiO_5 polymorphs. In our case, the kyanite is in an obvious state of lack of equilibrium with the rest of the rock. Its crystals are deformed, broken, bent and no longer in their originaly place. It is also intensely digested especially by muscovite, usually occurring as relics in a micaceous mass. In addition, as shown in Figure 43, quite close to the andalusite there occurs a kyanite crystal bordered by chlorite only where it comes close to the micas.

In Figure 44, in the kyanite/andalusite contact zone, chlorite appears, which is fibrous-radial but poorly developed. What is specific to the andalusite here is that its inclusions are disposed as folded trails, indicating the preservation of an old texture. The kyanite is visibly digested by the muscovite and its elongated part is transversal on the rock foliation. Therefore both the kyanite and the andalusite prove to have been engendered before the formation of the present foliation, and so is staurolite.

It result therefore that a generation of andalusite can be separated, older than what has been known so far. That can be seen more clearly in Figure 45 presenting two types of andalusite: one elongated along the schistosity, deformed and presenting trails of undulated or folded inclusions. In the proximity of the crystal there is another andalusite crystal, not at all deformed and clearer than the previous one and transversal on the schistosity. The transversal muscovite (of the second generation) seems to be of the same age with this last andalusite.

The kyanite with relic aspect and the staurolite are among the oldest minerals in the section.

The present rock schistosity has probably effaced the other S planes, so that at present, depending on "the deformation moment" we cannot separate in time "the kyanite moment" from "the moment of the first generation andalusite". It is only the difference of the alteration and of the deformation degree and the knowledge of the totally different conditions in which the two minerals can be formed that make it possible for us to separate them in point of chronology.

IV. MINERAL REACTIONS DEDUCED FROM TEXTURAL RELATIONS

The pointing out of the dynamic aspect of metamorphism is an important step in the knowledge of geological processes. Zwart (1962) was one of the first to make a remarkable analysis of the evolution of the metamorphism of a region, implying the minerals growth and decay in relation with the main deformation movements.

He also enriches the notion of metamorphism, underlining and giving arguments for the notions of synkinematic and static growth.

A further step was the recognition of the fact that certain older minerals or groups of minerals are related to younger ones by mineral reactions, the mentioned groups representing terms of these reactions.

Petrological observations made on rocks, especially in thin sections, have shown that during its history, the rock is subject to a series of transformations in what its mineralogical composition is concerned. Metamorphic rocks also show a legical tendency of developing mineral adaptations to the physical conditions which have been affected them since their formation. Excepting the rare cases when the adaptation remains isomineral or isopolymorphous, most mineral transformations occur as a mutual interaction between the minerals composing the rock: minerals newly formed at the expense of older ones, with a different individual chemistry than the latter. The realization of that fact led to the idea that minerals interreact under strict physical conditions, specific to each assemblage and in a general context of catalytic physical and/or chemical agents. It has also been established, both from microscopical observations and experimental researches, that mineral reactions, for being initiated, have to go beyond a certain barrier of free energy interposed between the reactants and the reaction products.

The experimental simulation of mineral reactions has showed they can be produced only under certain conditions that one association is stable with respect to the other when the relative value of its free enthalpy is smaller. Thus, the locus of the points equal free energy (Gibbs) represents the substantiation in a PT space of the reaction between the two assemblages.

At present the experimental determination of the various curves-reactions represents an important progress in the knowledge of the rock as a' mineralogical complex, the interdependence between the constituting minerals being well known.

The technical and material difficulties with which experiments are faced can often be compensated by the calculations of mineral equilibria or of mineral assemblages whose progress depends on the degree of knowledge and the amount of such data.

Our intention of making such calculations has been greatly hindered, as the values of the free energy of formation of cordierite, staurolite, biotite, almandine, of the enthalpy of their formation as well as the entropies of almandine, biotite and staurolite have not been calculated so far. These minerals participated to a great extent in the mineral reactions produced in the rocks investigated by us. That is why at present the most efficient possibility of establishing the conditions under which the main metamorphic events took place is that of identifying the most important reactions in the rock and of comparing them with the experimental ones. To the extent in which the latter are identified with the former, we shall have surer data on the conditions in which natural reactions took place.

The first phase leading to the establishment of metamorphic reactions is the knowledge of the various transitions (and appearance successions) between the minerals of the rock under study.

It can be noticed, of course, that all examples have been found exclusively in the zones where the intermediate, low pressure metamorphism was superposed on the Barrovian one.

In the other metamorphic areas of Barrovian type, although we equally recognize the existence of more than one metamorphic phase, the mineral equilibrium has been reached to a great extent, "frozen" mineral relations being found only in the isograde planes zones.

All relations signifying in most cases reactions between the minerals implied, have arisen the interest of those studying the conditions of metamorphism for a long time. Numerous such relations are ambiguous, to some others no significance has been given so far, and to others the law of the stoechiometric correspondence between terms has been applied, being expressed by chemical equations. Some of them have been checked up experimentally or on the basis of the knowledge of a few thermodynamic constants of the minerals in the reaction; the sense of reactions and the position in the PT space of the curves substantiating the reactions have been established by calculations.

Biotite, staurolite and andalusite participate in the most numerous relations observed. One of the relations between these minerals has been expressed by the equation:

Mg biotite + staurolite + muscovite + quartz → Fe biotite + Al_2SiO_5 + H_2O.

This equation justifies the possibility, suggested in the numerous microscopical observations, of andalusite formation equally at the expense of staurolite, under conditions of oversaturation in quartz. It also explains the seemingly paradoxical obsevation of the existence of biotite in both terms of the equation by the initial biotite being a flogopitic term and that in the second member of the equation an annitic term.

The cordierite formation can take place equally at the expense of staurolite, according to the equation:

Fe staurolite + quartz → Fe cordierite + andalusite + water justifying the numerous occurrences of cordierite and andalusite together, in the context of a total or almost total lack of staurolite.

A skematical reaction illustrating the sillimanite formation at the expense of biotite would be:

biotite + $5Al^{3+}$ + $3H_2O$ → 3sillimanite + K^+ + $3(Mg, Fe)^{2+}$ + $8H^+$

from which the necessity results of aluminium to gather and of potassium to be released. It is likely that aluminium should be released from another aluminium silicate and the potassium released should be fixed in a mica. This reaction shows why direct passages between aluminium silicates can be absent, such passages being possibly mediated by micas.

The andalusite formation at the expense of cordierite, as it has been suggested by a few textural situations can be expressed by the relation:

6 cordierite + $2O_2$ = 12 andalusite + 4 magnetite + 18 quartz

In its turn, cordierite can also be formed by the decomposition of almandine, which we have sometimes observed preceding the cordierite formation, according to the reaction:

54 almandine + O_2 → 2 Al_2SiO_5 + 4 magnetite + 4 quartz

The other way round, the related almandine formation can be expressed by the relation:

staurolite + quartz → almandine + Al_2SiO_5 + H_2O,

which would explain the frequent inclusion of staurolite in andalusite. Moreover, in this situation, staurolite can possibly create favourable conditions also to the andalusite nucleation.

It is only much rarelier that various researchers present reactions in which, besides the minerals investigated by us, micas also appear.

The biotite relics, often encountered in andalusite, the occurrence of a muscovite approximately at the same time with the andalusite, the staurolite relics in andalusite or even in garnet etc. could be justified by a reaction looking like:

18 staurolite + 19 biotite + 52 quartz → 31 almandine + 31 Al_2SiO_5 + 19 muscovite + 9 H_2O or a reaction of cordierite formation micas participate in would have the form:

32 staurolite + 20 biotite + 217 quartz → 62 cordierite + 20 muscovite + 16 H_2O, in which, besides cordierite, neoformation muscovite equally occurs.

Neoformation biotite could equally be born in a reaction of the type:

9 staurolite + muscovite + 5 quartz → 17 sillimanite + 2 garnet + biotite + 9 water

The decay of kyanite, that we have pointed to several times and at the expense of which muscovite is formed, could be rendered by the skematic reaction:

3 kyanite + 3 quartz + 2 muscovite + 2 H^+ → 3 sillimanite + 2 muscovite + 3 quartz

A few reactions resembling those above have been done experimentally (Richardson, 1968) and their progress as well as the minerals involved are altogether similar to what we have presented in the descriptive chapter. A characteristic feature of these reactions, resulted from the microscopic analysis is that most of them belong to the same mineralogical assemblage, are synchronous and implicitly took place in more or less the same physical conditions.

It results that, ideally, irrespective of the aspect of the curves representing the reactions under discussion, they must converge in a point or in a limited area, representing the conditions in which the association was in equilibrium. For accurately determining these conditions, it is suitable to combine a reaction sensible to pressure with one or others sensible to temperature.

We have represented in the same diagram (acccording to the scale of temperatures and pressures) three of these reactions, considered by us – from various intermineral relations – as possible to have taken place. These reactions have been produced experimentally by Richardson (1968) together with some others, in the same experiment conditions and using identical initial materials. The intersection of the curves reactions takes place almost in the same point (Fig. 46), corresponding to a temperature of about 680^0C and a pressure of the fluid of about 3.5 kbars. Therefore the thermobaric area in which the phenomena took place implied by the reactions presented above, must range around these values.

The domain and sense of metamorphism, judging after the sequence of mineralogical associations, can be expressed in a diagram showing stability domains of certain minerals or curves-reactions separating associations of various minerals.

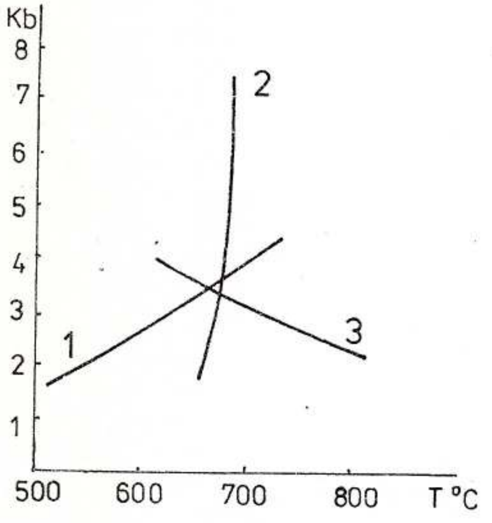

Fig. 46 – Equilibrium mineral reactions: 1, staurolite + quartz ⇌ cordierite + Al_2SiO_5; 2, staurolite + sillimanite ⇌ almandine + Al_2SiO_5; 3, almandine + sillimanite + quartz ⇌ cordierite + andalusite.

The (progressive or regressive) trend of the phase of metamorphism concerned is thus obtained, which can be expressed in quantitative parameters.

V. CONDITIONS OF METAMORPHISM

A. Arguments for the Existence of Metamorphic Entities

As already presented in the previous chapters, the area of metamorphic rocks belonging to the Sebeş–Lotru Series displays two types of metamorphism, in point of the mineral assemblages.

a) The metamorphism of Barrovian type is the most specifically represented in the Central South Carpathians as here there are no relations with the intermediate metamorphism that is so close in space, as in the case of the Godeanu, Căpăţâna and Mehedinţi Mts and neither is there such a "rapid" metamorphic zonality as in the Semenic Mts (Savu, 1970).

In the Central Carpathians, on a very large area there are only two metamorphic zones: the staurolite and kyanite-bearing zone – the largest in area – and the sillimanite one. The spatial position of the structure in relation with the isograde planes is directly responsible for this state of things, but we shall consider the situation as such, making use of the possibility of investigating on a large area small intervals in the metamorphism scale having affected the region under discussion.

Another element of interest is the polycyclic character of the metamorphism having affected the metamorphic rocks of the Sebeş–Lotru Series: which are the paragenetic elements that should be considered for establishing the physical conditions in which a certain metamorphic phase took place, as it is obvious that not all the minerals were formed during the same episode.

Fortunately, as shown, the two main metamorphic events are (in our opinion) produced at approximately the same intensity, so that when there are no relict elements of the old metamorphism we can firmlyely on the similitude of the intensities of the new metamorphism and the previous one.

The sequence of crystallization presented in chapter IV presupposes the appearance of minerals as an adaptation of the rocks to the conditions existing in the Earth crust at a certain moment. There is therefore, in this acceptation, a permanent concord between the physical conditions and the mineralogical assemblage existing at a certain moment. On the other hand, in the same environment conditions, at a certain initial chemistry, there occur the same minerals. Not only are they closely dependent on the outer environment but there is also an interdependence between the minerals themselves.

Therefore in a mineralogical assemblage an equilibrium is permanently maintained, irrespective of the sense of variation of the physical conditions, due to the mineral adaptation to these conditions. The sequence of crystallization presented in this paper is a consequence of the successive adaptations of the rock to the thermobaric conditions displayed by the rock crystallization environment. On the other hand, the source of material varies in composition in proportion with the formation of new minerals, so that there is a permanent dependence between minerals as they themselves can become the source of new transformations. That is therefore a skematic picture of the relations environment-rock, applicable, due to its general character, also to the rocks studied by us.

An important part of the history of aluminosilicate – bearing rocks has thus been unravelled just due to the presence of Al_2SiO_5 minerals, very much investigated and whose properties are established at least in broad lines.

The three polymorphous modifications themselves point to the metamorphism conditions, as they share a large range of *P-T* metamorphism conditions and especially the middle-high level one, which is also that of the rocks in our region of study.

The model of reversed *Y* diagrams, proposed for the first time by Miyashiro (1949) is a basic element for establishing the metamorphism conditions that affected the rock as a whole. For evaluating the conditions of metamorphism in the central zone of the South Carpathians, knowing that only the sillimanite and the kyanite (+ staurolite) metamorphism zones occur in the region, we shall use the information given by the monovariant equilibrium curve kyanite-sillimanite, as well as by the spatial position of the other two monvariant curves in the Al_2SiO_5

system. They will be correlated with the isograde curves of the first occurrence in the *P-T* field of certain minerals such as staurolite. We shall also use the empiric curves given by Wenk (1969) which show the hornblende stability with a coexisting plagioclase, of a certain anorthitic composition.

As in the region under discussion the kyanite-bearing rocks are bordered both to the north and to the south by sillimanite-bearing rocks (in this case the contacts between these zones are normal), it means that at least close to these boundaries the pressure is higher than that of the triple invariant point kyanite-andalusite-sillimanite. As in a kyanite rock sample in the Negovanu ore zone the assemblage of kyanite with a sillimanitic sheaf was found, we consider that in this zone the conditions of metamorphism were those in the region of the monovariant curve we have referred to. Therefore here as well, the pressure was higher than that characteristic of the invariant triple point (Fig. 47).

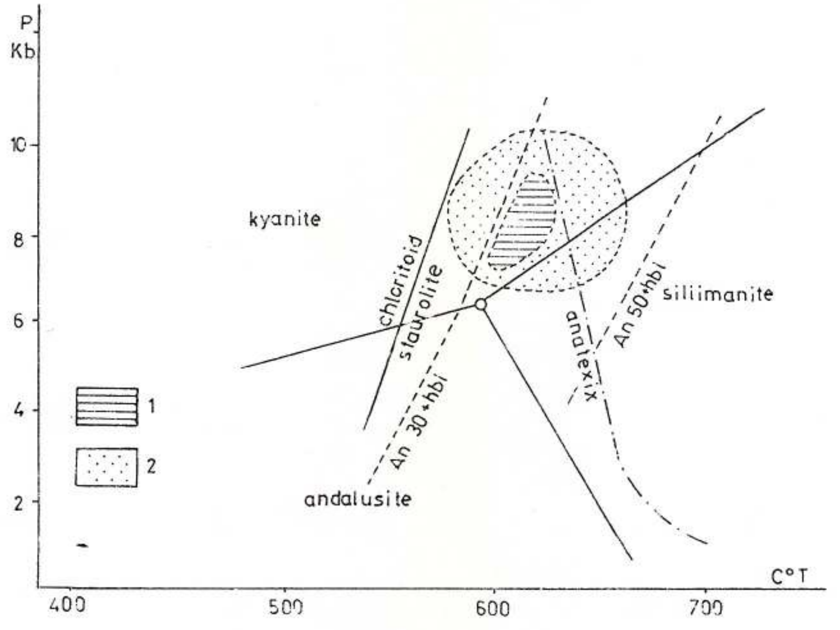

Fig. 47 – Domain of metamorphism in the Sebeş-Lotru Mts: 1 Thermo baric domain of metamorphism in the Negovanu area; 2 Thermo-baric domain of metamorphism in Sebeş-Lotru Mts.

Therefore, as a first step in the knowledge of the baric regime in which most of the mineral association in the aluminosilicate-bearing rocks was formed, it is also useful to know the quantitative aspect of the phase diagram of the Al_2SiO_5 polymorphs.

There are several ways of building up this diagram. The first was the Miyashiro's empirical method (1949), with a qualitative aspect, which only delineates the general outline of the limit of stability fields. The position of the triple point is established from the association with other minerals, with known stability field, therefore with the role of geologic thermometer, a possibility also used by Hietanen (1956).

Another approach is the experimental one, in which one of the polymorphs is subjected to pressure and/or temperature variations, following and registering (in the P-T coordinates) the moment of appearance of another polymorph from the pre-existing one.

An alternative of this method is that of the synthesis of one or the other of the polymorphs from the oxides constituting them (SiO_2 and Al_2O_3).

Finally, the third approach is that of building up a theoretical curve from the values of the state functions given in the tables of thermodynamic constants, elaborated by The U. S. Geological Survey at Reston, Virginia, by Robie and Waldbaum (1968) (Fig. 48).

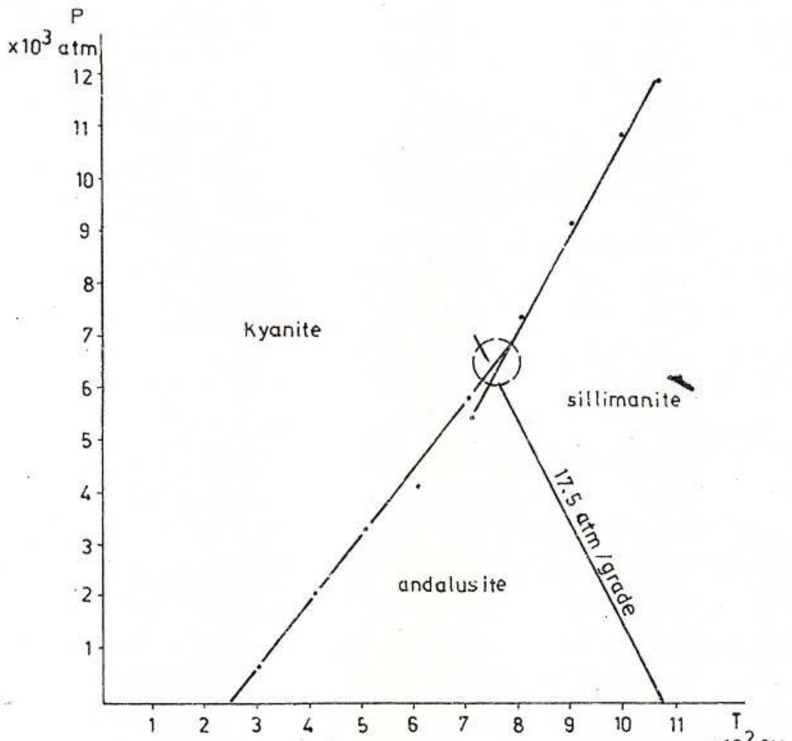

Fig. 48 - Phase diagram of the system Al_2SiO_5 (built up on the basis of thermodynamic data).

It can be noticed that the three monovariant curves are generally convergent, showing the tendency of meeting in a very limited area, encircled by us, indicating the approximate value of the triple point.

Comparing the position of the triple point obtained in this way with the data given by other modern authors who have studied the problem we can notice they give quite close pressure values, but the temperature obtained by our calculation is a little bit lower, of about 500^{0}C, quite close to the value given by Hietanen (1956) for the Idaho batholith zone. In the last period of time the tendency existed of narrowing the field of spatial variation of the triple point, the most reliable values being considered those of Althaus (1967), Richardson et al. (1969), who places the invariant point in various positions, Althaus – 6.5 kbars and 595^{0}C, Richardson – 5.5 kbars and 620^{0}C.

The diagram in Figure 47 shows the equilibrium curve of the Al_2SiO_5 system (according to Althaus, 1967), the stability curve of the association hornblende + plagioclase, the curve of the beginning of melting (anatexy in gneisses) and the chloritoid – staurolite equilibrium curve (according to Winkler, 1970).

The plagioclase in the amphibolites in the central zone of the South Carpathians and particularly that in the Negovanu zone, contains ca. 37 % An. That fact and what was asserted before, that the pressure in the investigated zone cannot be much lower than that of the triple point lead us to building up a rather limited *P-T* field of formation of the rocks under investigation. It is bounded by the An 30 + hornblende curve, by the kyanite-sillimanite univariant equilibrium curve and by the anatexy curve, as in the Negovanu zone no characteristic remelting processes have been observed. That is also true for the neighbouring regions, with the exception of those zones where important feldspathic remobilization processes are noticed, that can be compared with the anatexy as well as the zones with lower values of anorthite for the plagioclase in amphibolites. In this way, the field of metamorphism in the Central South Carpathians can also be extended to the *P–T* space and a little bit to the right of the curve of the beginning of anatexy as well as a little bit to the left of the An 30 + hornblende curve, up to the proximity of the chloritoid – staurolite equilibrium curve.

b) For the intermediate, low pressure metamorphism zones we have chosen as a prototype the zone of Getic metamorphic rocks in the Mehedinţi Mts, i.e. the Bahna Outlier, as, in comparison with the other zones with similar metamorphism (Godeanu and Căpăţâna) we are in possesion of field data rich in details.

At first our researches have established the following zonality: andalusite-staurolite zone, andalusite–cordierite–staurolite zone, andalusite–sillimanite–cordierite±staurolite zone and sillimanite–cordierite±Kfeldspar zone.

This zonality is disposed from south to north along the Bahna Outlier, the mentioned zones showing an obvious tendency of concentricity (Fig. 33).

In paragraph IIIB, concerning the evolution of metamorphic crystallization deduced from textures, we have described numerous intermineral relations suggesting a picture of metamorphic crystallization illustrated also in Figure 46.

The primary mineral paragenesis of the investigated rocks represents an assemblage (possibly two assemblages) characteristic of the Barrovian type of metamorphism. A second paragenesis represents an association typical of low pressure metamorphism. They are separated by a main deformation episode. Therefore each mineral assemblage represents a metamorphic episode. The second episode is superposed on the first one, on a part of the area of metamorphic rocks of the Bahna Outlier. On the area superposition, the minerals in the first episode partially preserved their individuality probably due to their tendency of persisting metastably in a field close to that which is characteristic of them but especially to the fact that the metamorphism in the second, static episode was not accompanied by deformation, which makes the mineral network very unstable. The temporal succession of the two periods of metamorphism is also demonstrated by direct relations between the minerals characteristic of each the two types of metamorphism. As noticed, andalusite has replaced kyanite (Fig. 49), andalusite has replaced staurolite (Fig. 40, 32, 39), and cordierite, kyanite (Fig. 50). In most cases, the direct relations between the above mentioned minerals are mediated by relations with other minerals,such as micas.

Starting from the premise that the spatial succession of mineral associations in the above mentioned zones represents in fact the sequence of their temporal formation, we have tried to place in a *P-T* diagram, the mineral associations in each zone described in the metamorphites of the Bahna Outlier (Fig. 51).

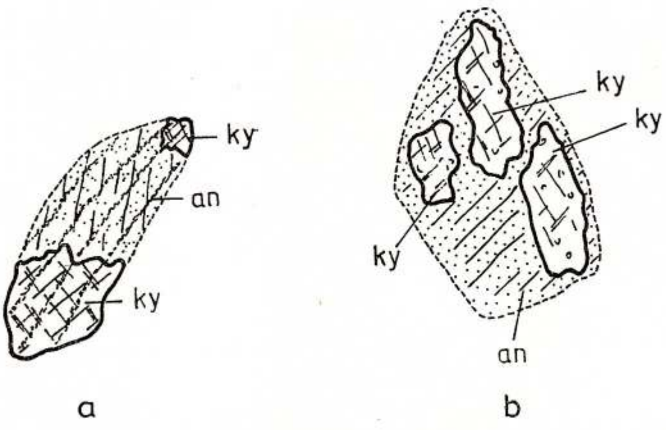

Fig. 49 - Substitution of kyanite by andalusite: an, andalusite; ky, kyanite.

In this synthetic diagram we have figured the equilibrium diagram of the Al_2SiO_5 polymorphs according to Richardson et al. (1969), the field of stability of staurolite and the staurolite + cordierite coexistence field according to Ganguly (1972) and the diagram of the phase relations in the K_2O - MgO - Al_2O_3 - SiO_2 - H_2O system according to Schreyer and Seifert (1969). In this synthetic diagram all the mineralogical associations encountered can be identified. In this way,

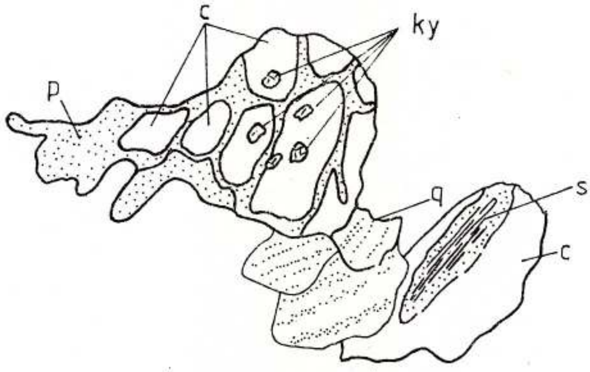

Fig. 50 – Substitution of kyanite by cordierite.
ky, disparate elements in a single kyanite crystal;
c, cordierite; s, sillimanite; q, quartz; p, pinnite.

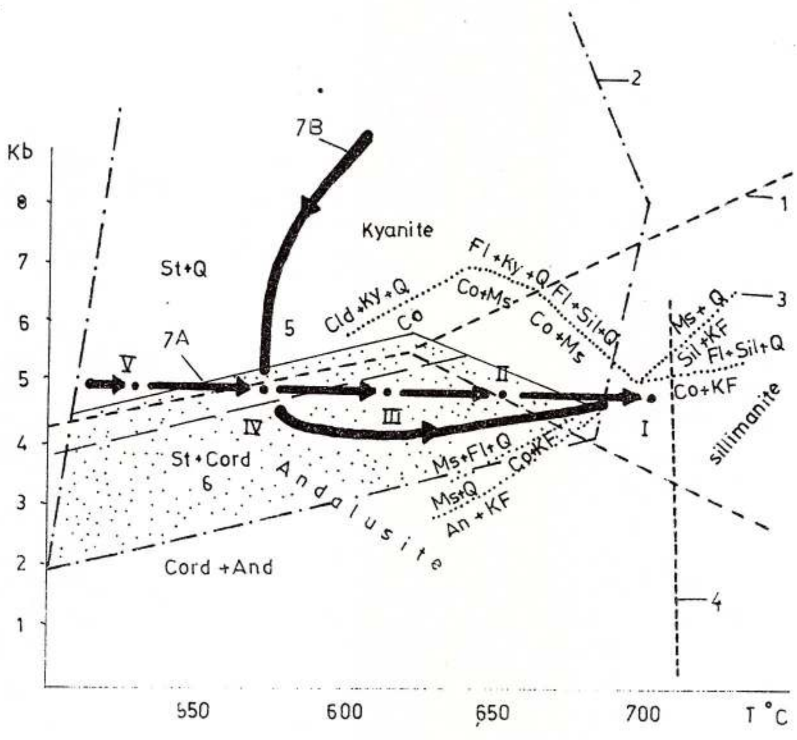

Fig. 51 – Probable evolution of metamorphism in the Mehedinţi Mts.

the sillimanite – cordierite ± K feldspar assemblage can be found in the sillimanite field under the univariant Co + KF line and left of the curve marking the beginning of melting (point I). To the left, the andalusite-sillimanite univariant equilibrium line will be intercepted, along which the minerals coexist. They also coexist along a certain distance on both sides of the line. In this way, in the zone concerned, the andalusite – sillimanite – cordierite ± staurolite association is obtained (point II). The staurolite occurrence is still accidental as we are still at the border of its field of stability under the conditions of oversaturation in quartz. Within the andalusite field, there will also appear staurolite, whose field of stability largely lies here, as well as cordierite, in the field of coexistence with staurolite, as deduced from Ganguly's data (1972). We have marked with III the figurative point of the andalusite – cordierite – staurolite assemblage. Towards the border of the andalusite field, close to the boundary with kyanite and at the periphery of the field of coexistence of the andalusite + cordierite association, the latter is diminished up to its disappearance, so that the specific assemblage in this zone is made up only of andalusite and staurolite (point IV). Towards the left part of the diagram, the field of the kyanite stability begins, superposed on that of staurolite, so that the characteristic assemblage is kyanite–staurolite (point V).

All the five points are approximately colinear, so that the passage from an assemblage to the other can be made at a constant pressure, only by temperature variations. The paradoxical situation occurred that the low pressure assemblage investigated here was the outcome not of a reduction in pressure but of an increase in temperature, under isobar conditions. The maximum temperature is reached in the sillimanite-cordierite±K feldspar zone, which close to the line where melting begins and which coincides with the appearance of the stromatic migmatites mapped by different authors.

An immediate consequence of the above reasoning is that the pressure of the metamorphic rocks outside the field under investigation is also low and that in fact a warming took place under relatively low pressure conditions. This increase in temperature can be accounted for by the appearance of a thermal dome with increasing values of the isotherms, from SW to NE, a dome which appeared after the main episode of deformation mentioned above.

Another course of the metamorphism could be imagined considering that the first deformation episode brought about a lowering of pressure in the kyanite field, up to intercepting the andalusite one, after which, at constant pressure, the gradual increase in temperature made possible the appearance of the sequence of mineral associations discussed. This last variant concords with the level of the Getic metamorphic rocks of Barrovian type, admitted in the neighbouring zones (Savu, 1970; Bercia, 1972) as being of about 8-10 kbars.

Considering also other variants , by other writers, of the fields of stability of the minerals implied, or curves-reactions separating assemblages of various minerals, we shall obtain the diagram in Fig. 52. It shows successive domains of P-T

conditions in which the rocks in the zones discussed are supposed to have passed.

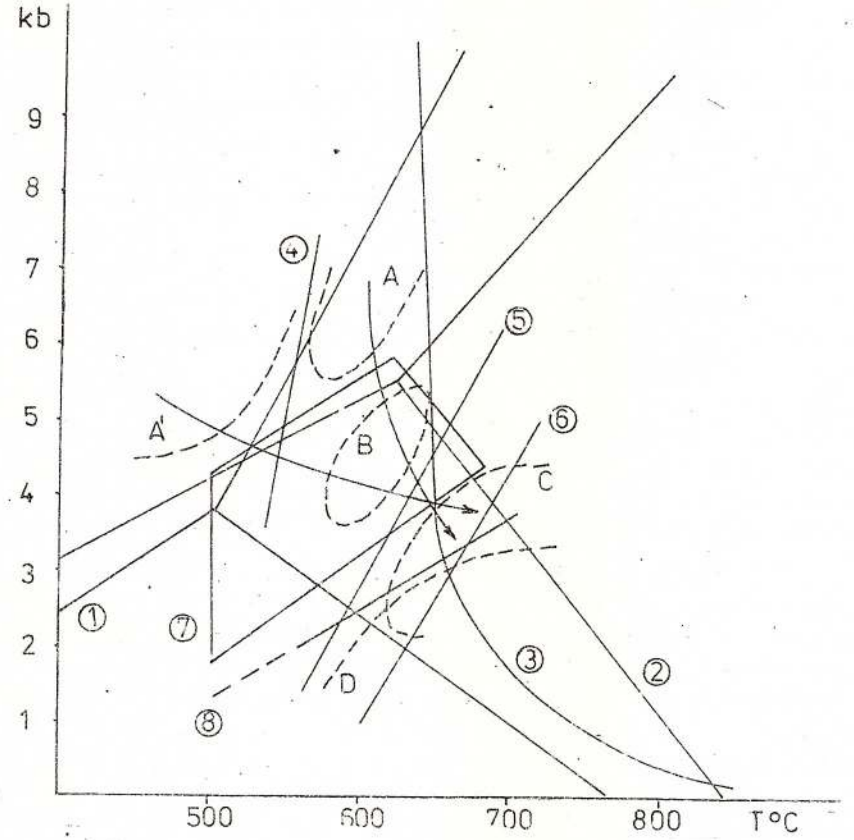

Fig. 52 - Possible domains of metamorphism in low pressure areas.

The normal course of metamorphism, deduced from the examined successions, is oriented towards the decrease in pressure and the increase in temperature. Curve 4 of the first appearance of staurolite at the expense of chlorite is the one which constraints the orientation of metamorphism in this way, whth the succession of domains especially in the sense of the pressure axis. In this way, the sense of the evolution of metamorphism is *A-B-C*. But considering that the field of stability of the staurolite + quartz assemblage also extends left of curve 4 and also that it is difficult to imagine the mechanism of the pressure decrease, in areal style, an *A'BC* sense can be imagined, prevailingly in the sense of the increase of temperature, that could be due, as has been said, to the intervention of a thermal dome.

B. Metamorphic Zonality

The study of the metamorphism in the South Carpathians has been a historical process that has needed a considerable physical and thinking effort from numerous specialists in metamorphic rocks. More and more geologists figure in the maps they build up, besides lithostratigraphic, tectonic elements, mineralizations etc isoconditions or isorelation lines of the metamorphism having affected the rocks under discussion. On the occasion of these actions, the researchers have been faced with important problems. Out of their most important elements we shall mention:

– selection of the most adequate mineral elemnts (index minerals) which, in the case of the aluminous metapelitic formations, have always included aluminium-silicates. Selection of a manner of representing metamorphism isogrades in the case of the formations lacking in aluminium-silicates,

– establishment of the relations between the isograde planes and structure. We consider the representation used so far, which conceives an almost perfect parallelism between the isograde plane and the lithostratigraphic markers, involves many exceptions worth considering in the future,

– mapping of the spatial relations between the areas with various types of metamorphism, which involves the making out of their genesis and sequence,

– mapping the sequence of metamorphism phases, of the paleoisogrades implicitly, which calls for a detail petrographic and petrogenetic study,

– establishment of the temporal relations between the main deformation moments and of the maximum mineral neoformation periods.

The metamorphic rocks of the Sebeş-Lotru Series, to which we have paid a special attention in this study are known, we could say, quite in detail as far as their metamorphism is concerned, which makes it possible for us to establish a metamorphic sequence considered to be rather up-to-date, based on both previous data and our own.

Our studies, concerning mainly rocks containing aluminium-silicates have contributed first of all to the research of the zonality in the zones of medium-high degree of metamorphism. According to the data at hand so far, it is only in the Semenic Mts that metamorphic zones upper than the staurolite + kyanite ones are known, due to Savu's contribution (1970). In the remaining part of the South Carpathians, between the Bârzava Valley and the Olt Valley, in the metamorphic rocks of the Sebeş-Lotru Series there only exist the sillimanite zones and the kyanite-staurolite one.

The kyanite zone, delimited as such by H.Savu in the Semenic Mts, is, in fact, according to our researches, a part of the kyanite and staurolite zone established by the above mentioned specialist. Our statement is based on field data, of frequent association, of kyanite and staurolite.

By detail sampling of the metapelitic rocks in this massif, we have also delineated a sillimanite-bearing zone within the staurolite and kyanite one, north of the Gărâna village.

In the Godeanu Mts, according to Bercia's researches (1975), two types of metamorphism are to be found, as already shown. The Barrovian metamorphism, situated in the western part of the massif, as the researches of the above mentioned author have pointed out, shows a zonality following the stratigraphic boundaries established by the author.

Consequently, the rock complexes lying at the base of the metamorphite pile will be subjected to a more intense metamorphism, mainly belonging to the sillimanite-bearing zone. This zone is followed in the southern and western part of the outlier, in the basins of the Topenia, Studina, Valea Moşului, Somogotin, Bandialu, Idegelu, Bărănelu, Baranu Valleys. The kyanite and staurolite zone goes beyond the Cerna-Timiş watershed, being situated in the upper course of the Iauna Mică, Craiova, Olanu and Balmoşu Valleys.

The intermediate, lower pressure metamorphism present in the eastern part of the outlier displays the follwing zonality: at the basal part, from the metamorphic point of view and in relation of superposition is the sillimanite+andalusite+cordierite zone, overlain by the andalusite zone, and, at the upper part, the andalusite-staurolite zone. All these lie on the right bank of the Cerna Valley, in the middle and lower basins of its tributaries: Iauna, Mihalca, Craiova, Olanu, Curmezişa, Naiba, Balmoşu and Ivanu Valleys. The boundary between the two types of metamorphism is drawn farther by Bercia to the north-east, through the middle course of the Cărbunele Valley, upstream its confluence with Radocheasa Valley. Our researches have so far confirmed to a great extent the zonality established by Bercia in the Godeanu Massif, particularly in the western part in the Barrovian metamorphism zone. In the eastern part, a notable exception from the zonality found for the intermediate type of metamorphism is the presence of kyanite – bearing rocks on the right bank of the Naiba Brook as well as in the zone of the hill with the same name.

The metamorphism zonality in the Mehedinţi Mts has been presented for the Bahna Outlier, the low pressure domain respectively. The Barrovian metamorphism is poorly represented in the zone, by two stripes, lying along the Bahna Outlier: the western one, situated west of the Podeni locality, in the upper course of the Grădejniţa, Buruiana and Camuna Valleys, up to the contact with the thrust line; the second stripe, in the east, partially runs through the lower course of the Bahna Valley, between the Ponorelu Valley to the north and the Tarovăţ Valley to the south, on the territory of the Cireşu, Moiseşti, Bunoaica, Bahna, Iloviţa localities. In the Porţile de Fier Outlier, the Barrovian metamorphism prevails. The kyanite zone is situated in the western part of the outlier, form the north – Ponoare locality – to the south – Godeanu locality. For the rest, the Barrovian metamorphism is represented by the sillimanite zone. As we have shown, the intermediate, low pressure metamorphism is poorly represented in this outlier, by an area situated in the Nevăţ Valley Basin – Bucureşti Hill.

In the Central South Carpathians, the kyanite – staurolite zone generally occupies the northern part, while the southern area is occupied by the sillimanite zone. Small "sillimanite islands" are also to be found within the kyanite – staurolite zone, in the upper course of the Godeanu Valley (Grădiştea de Munte), in the middle basin of the Cugir Valley, at the sources of the Miraş Valley, a left tributary of the Sebeş Valley, in the right slope of the Dobra Valley, on the Râul Mic al Cibinului Valley and on its right bank, in the Poiniţa zone. Such zones also exist in the upper course of the Dăneasa Valley – Păltiniş zone, north of the

Păltiniş resort, as the sources of Valea Mare and on the Reghina Valley, a left tributary of the Sadu Valley, in the proximity of the locality with the same name.

Most of these "islands" have been evidenced by our works and we shall give the explanation of their presence in the very zone with staurolite + kyanite in the chapter dealing with structure.

The sillimanite – bearing zone in the southern part of the Central South Carpathians dips east-west, with a characteristic bent in the Sebeş Mts, the Taia and Strei Valleys basins penetrating like a wedge northward, up to the Comărnicelu Peak zone.

In the Căpăţâna Mts, the metamorphic zonality is again complicated just like in the Godeanu and Mehedinţi Mts, by the presence of the second, intermediate, low pressure metamorphism, superposed on the Barrovian one. Our researches in this massif are not so much detailed. In the low pressure metamorphism zone, situated in the western part of the Getic metamorphic rocks in the Căpăţâna Mts we have evidenced the following zonality: sillimanite ± cordierite in the central area, followed towards the outer part by the andalusite + sillimanite ± cordierite zone. This type of metamorphism disposed mainly on the southern slope of the massif also passes in the northern slope, in the basin of the Mălaia and Repedea Valleys (Fig. 70). The Barrovian type of metamorphism situated east of the previous one has been presented in detail on the 1 : 200 000 map. Hann's studies (1978) and our own have led to an image different from the known one. The most important area of Barrovian metamorphism is occupied by the sillimanite zone. It contains the kyanite zone, cut off to the west by the boundary between the two types of metamorphism, to the east looking like a lobe. It is surrounded by the sillimanite zone, which is totally novel for the metamorphism in our country and probably represents only a stage in the knowledge of the metamorphism in this massif.

C. Discussions Concerning the Mineral Relations at the Isograde Plane and at the Boundary Between Areas with Different Types of Metamorphism

The evolution of metamorphic crystallization as presented in a previous chapter can be deduced from the relations between various minerals belonging to different moments of crystallization, between the phases of deformation and mineral neoformation etc.

Unfortunately, these relations are hard to preserve and they can be found only in isolated cases, so the evolution of metamorphism is in fact a sequence of reconstructions of isolated phases, followed by a collage that can often be subjective.

In the actual situation of the South Carpathians the Barrovian metamorphism is at a disadvantage in this respect in comparison with the Pirinean type, as in the first case it is likely that the slow evolution of metamorphism conditions has led to a mineral equilibrium accompanied by the accomplishment of mineral reactions. The fact that "the frozen reactions" have lasted – and they have been found out only after being repeatedly and systematically searched – is in this case only a matter of circumstances. As for the intermediate, low pressure metamorphism, these relations are much more frequent.

We have supported the two types of metamorphism with arguments approximately equal quantitatively only for the sake of a balanced presentation.

In the case of the Barrovian type of metamorphism, it could be expected that the interval of transition between the metamorphic zones could contain elements of disappearance and of first appearance of the two neighbouring zones. This statement contains in itself the idea of the movement of the isograde plane in time. "Does the pattern of metamorphic zones that may be mapped in space correspond to the time sequence of change at any one point, while the metamorphic conditions were slowly intensifying ? If so, then each mineral assemblage will form directly from assemblage that precedes it in the spatial sequence of zones, by means of the chemical of reaction that *relates* the two zones, and the isogrades will migrate slowly through the rock body, keeping pace with rising temperature and pressure." And as a possible alternative: "Clearly, any attempt to correlate the physical conditions of metamorphism with natural metamorphic assemblages is futile if the natural metamorphic reactions are too sluggish to keep pace with rising temperature."

Many scientists speculated on the modalities in which a low-grade mineral assemblage passes to a higher-grade one, and conversely, the type of reactions varies considerably.

Certain investigators assert that it is in fact not at all important for which reactions we opt, if the initial and the final member have a correspondant in the mineral association in the two adjacent metamorphic zones. We have been concerned with finding "frozen" reactions in the isograde plane zone. A first remark we can make is that in the kyanite-sillimanite isograde we are studying (wthin the area of metamorphism of Barrovian type) we have never found direct relations between the disappearing mineral (kyanite) and the newly appeared one (sillimanite). But two important situations have been observed.

a) the case in which the two index minerals, kyanite and sillimanite (having therefore the certainty that they are situated in the isograde plane) were accompanied by adjacent mineral relations which involved them partially.

b) the case in which in the absence of direct relations between the two index minerals and of other relations of substitution between the other accompanying minerals, kyanite and sillimanite coexist unchanged, in separate adjacent thin beds, at distances of the order of millimeters (Fig. 53). In the section across the isograde line, only the disappearance of one of the two minerals is observed, alongside the development and the spreading of the other.

In the first case, the most frequent way in which kyanite disappears in the isograde plane zone is its replacement by muscovite. Plate X, Figure 1, shows a fragment of a thin section in which kyanite coexists with sillimanite. Having the concrete proof that things happen in the isograde plane, it results that at least in this section, the mineral relations identified are specific to this plane. A big kyanite crystal is observed, from which muscovite has detached by digestion two small fragment with the same optical and crystallographic orientation.

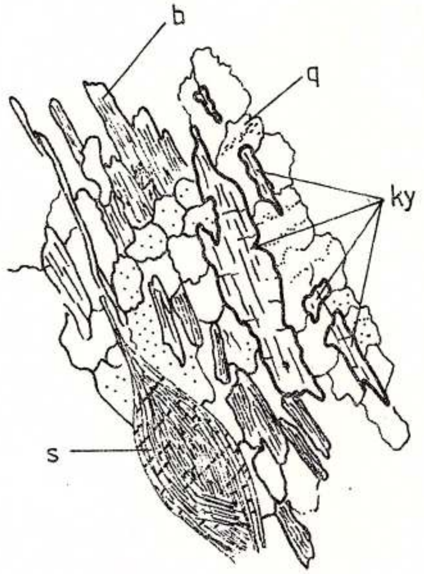

Fig. 53 – Coexistence of kyanite with sillimanite: s, sillimanite; ky, kyanite; q, quartz; b, biotite.

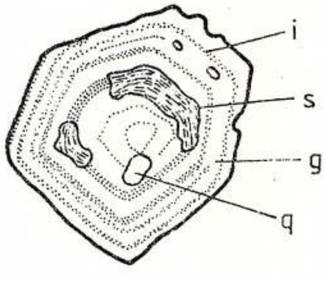

Fig. 54 – Substitution of garnet by sillimanite: s, sillimanite; g, garnet; q, quartz; i, trails of inclusions.

The situation shown in Figure 54 has equally been found in the section menioned above, where an almost idiomorphic, concentrically zoned garnet crystal ontains a sillimanite sheaf, of the same shape as the microscopic inclusions. Therefore sillimanite has not been included mechanically, but having a mimetic shape, it replaces garnet. The way in which this replacement took place is suggested by the detailed examination of the sillimanite sheaf in which typical sillimanite is associated with biotite and fibrolite, the last seemingly deriving from biotite, as already happened in numerous situations. So, the substitution of garnet by sillimanite is preceded by the biotitization of the former. The potassium released by the transformation of biotite in sillimanite is likely to represent the source of the formation of the muscovite that substitutes kyanite. But, in this case, sillimanite is formed a moment before the disintegration of the kyanite. This sequence in time would justify, from a point of view, the spatial coexistence along a certain distance in the isograde plane zone, of the two index minerals.

The sequence mentioned above seems contradicted by the situation in Figure 55, where the kyanite is substituted by "the collaboration" of biotite and muscovite. In this case as well it is possible for muscovite to follow biotite but the general aspect of the association suggests rather a simultaneous growth.

Fig. 55 – Substitution of kyanite by biotite and muscovite: b, biotite; m, muscovite; ky, kyanite.

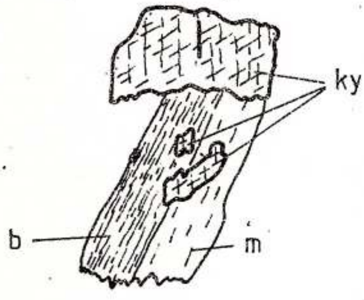

Figure 56 equally shows the kyanite substitution, this time by chlorite: in the left side the incipient phase of substitution, a partial digestion respectively, and in the right side the total detachment (at least at the level of the section) of two relics from a single kyanite crystal. The physiographic character of the chlorite in this figure clearly suggests its generation from biotite, which reduces the present situation at the already described substitution of kyanite by biotite.

Finally, a last case of kyanite substitution at the level of the isograde plane is that by plagioclase feldspar. Two crystals of such a mineral claim the digestion of a single kyanite crystal, from which only six relict fragments have remained, identically oriented from the optical point of view (Fig. 57).

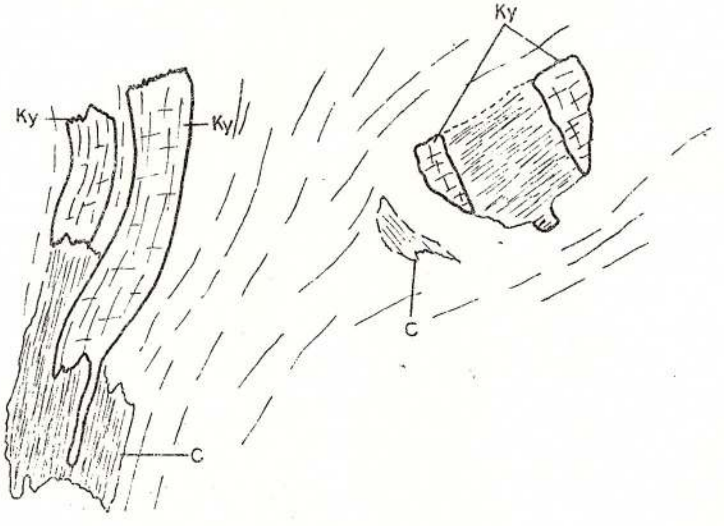

Fig. 56 – Substitution of kyanite by chlorite: ky, kyanite; c, chlorite.

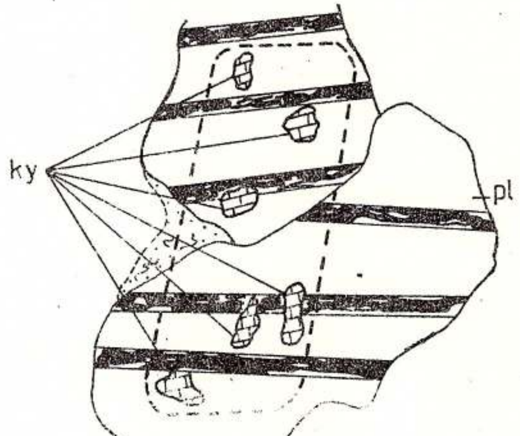

Fig. 57 – Substitution of kyanite by plagioclase: ky, kyanite; pl, plagioclase.

In the case of the intermediate, low pressure metamorphism of Pirinean type, developed, as shown, in the Godeanu, Mehedinţi and Căpăţâna Massifs, the mineral relations in the isograde plane or at the contact with the Barrovian metamorphic area much more intricate, as these planes are defined by several associated minerals. The relation between this type of metamorphism and the Barrovian one has given us the possibility of observing the only direct relation between aluminium-silicates, that is the substitution of kyanite by andalusite.

The metamorphic zonality by various authors presented in another chapter would suggest the possibility of identifying "frozen" reactions in the plane of these isogrades.

Unfortunately, it is only in the Mehedinţi Mts that we have succeeded to present in detail the relations in the isograde plane, at least in relation with the zonality built as such (Hârtopanu, 1975).

In comparison with the data from the sketch with the Metamorphism Isogrades (Bercia 1975) for the Godeanu Mts, in which the metamorphic zonality is obtained by uniting the areas including identical mineral associations, the situation in the Mehedinţi Mts is much less suitable for building up such a zonality. Studying the distribution of various minerals on a high density of thin section (Figure 58) we have found out that the mineral associations previously described by us (Chap. III B 2 and Fig. 33) show an altogether restrictive distribution. These mineral associations have been separated on a map showing the distribution of the most important minerals, the areas of superposition of the domains of individual existence of two, three or several minerals. In Figure 59 one can notice the area of coexistence of andalusite, sillimanite and cordierite is extremely discontinuous, in very small islands. The sillimanite and andalusite area is even smaller, occupying five small separate zones, and the cordierite and andalusite one occupies three separate zones. The only continuous area is that of the sillimanite – cordierite assemblage, only little superposed on the andaluiste one. It results the zonality drawn up by us before in this massif has been too much indebted to interpolations and the metamorphic zonality in the Godeanu Mts has no correspondent in the Mehedinţi Mts as regards the mineral associations used by Bercia (1975).

The superposition of K feldspar remains identical with that separated by us in previous papers, possibly prolonging farther to the south of the Isverna locality.

Taking all this into account it seems natural to us to simplify the zonality presented before (Fig. 33) according to the reality in the field, considering in the area of low pressure metamorphism of the Mehedinţi Mts, only two zones, i.e. the andalusite-bearing zone in the east and the cordierite + sillimanite + K feldspar zone in the west.

As shown before, the zones represented by the andalusite + sillimanite + cordierite or the sillimanite + andalusite or cordierite + andalusite assemblages are quite discontinuous and we can consider them isograde plane associations containg elements of two adjacent metamorphic zones.

Considering this situation and the intermineral relations presented in the chapter referring to textures, we have thought useful a spatial representation of various mineral relations, the most frequent and illustrative ones for the area under discussion.

On a map presenting the areas of existence of various index minerals, we have also figured the following mineral relations (Fig. 60):

– the relation of substitution of staurolite by andalusite occupies an area outside

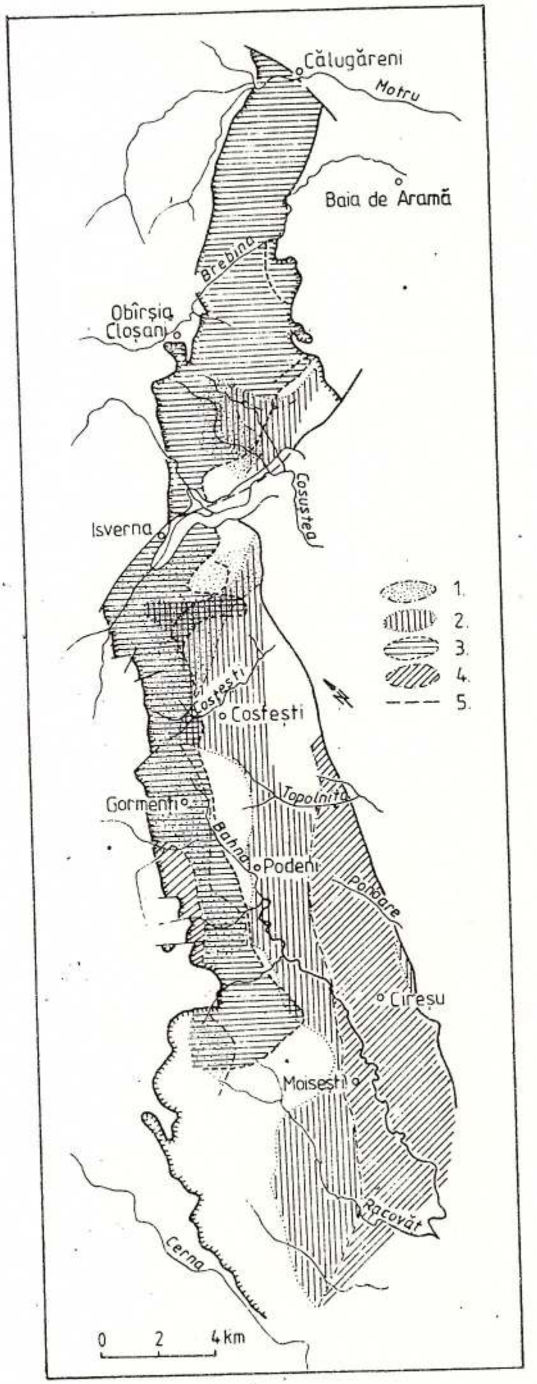

Fig. 58 – Area of distribution of index minerals in the crystalline rocks of the Bahna Outlier: 1, Area of cordierite distribution; 2, Area of andalusite distribution; 3, Area of sillimanite distribution; 4, Area of kyanite distribution; 5, Western boundary of K-feldspar distribution area.

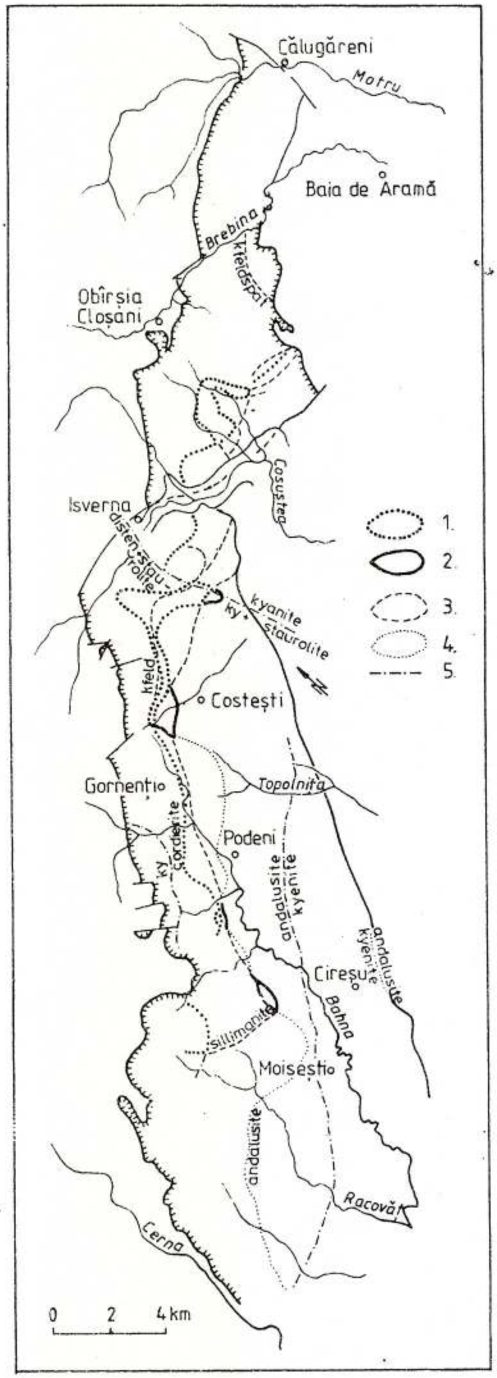

Fig. 59 – Area of coexistence of index minerals in the crystaline rocks of the Bahna Outlier: 1, andalusite, sillimanite, cordierite; 2, sillimanite, andalusite; 3, cordierite, andalusite; 4, sillimanite, cordierite; 5, paleoisograde (relict isograde).

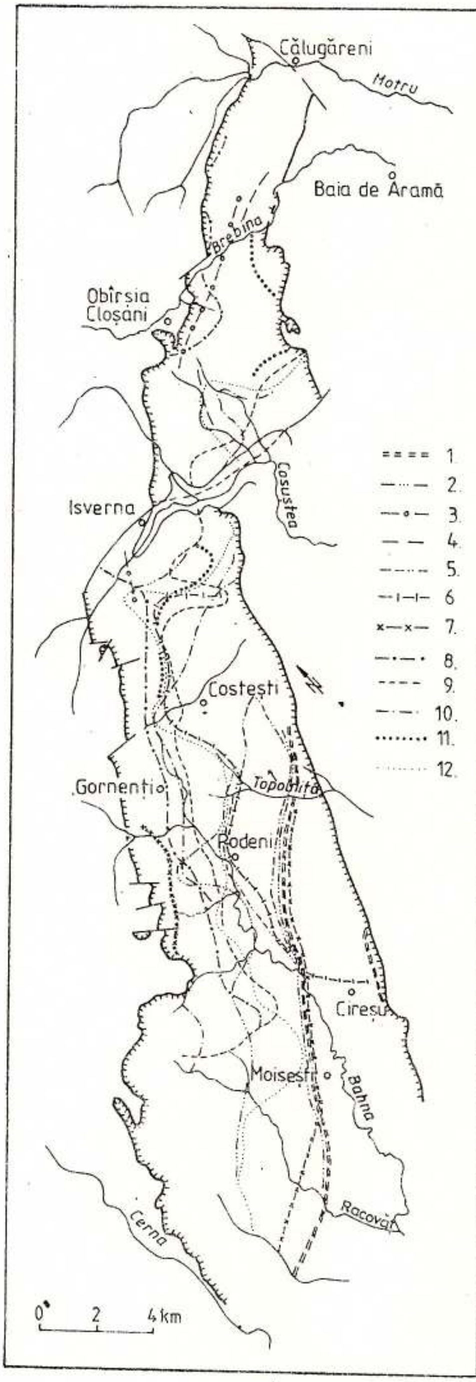

Fig. 60 – Map of mineral isorelations in the crystalline rocks of the Bahna Outlier: A. Substitution relations: 1, kyanite/andalusite 2, garnet/biotite; 3, kyanite/plagioclase; 4, kyanite/cordierite; 5, staurolite/andalusite; 6, biotite/andalusite; 7, kyanite/muscovite; B. Nucleation or intergrowth relations: 8, biotite-sillimanite; C. Eastern boundary of last occurrence: 9, sillimanite; 10, cordierite; 11, K-feldspar; D. Western boundary of last occurrence; 12, andalusite.

which the respective relations have not been encountered. This area coincides at its eastern boundary with an eastern portion of the low pressure metamorphism area.

– the relation of substitution of garnet by biotite is equally spread in the area, with part of the eastern portion common with the area of the previous relation;

– the relation of substitution of biotite of an older generation by andalusite takes place in a plane whose trace is sinuous, but with general orientation resembling that of the previous areals;

– the sillimanite – biotite relation, oriented in the same direction with the preceding ones, represents an area bounded to the east by a plane figured on the map and to the west by the anomalous contact of the thrust line or by the boundary with the area of Barrovian metamorphism. This relation is somehow ambiguous and we have to show from the very beginning that we included here either the intimate association of biotite with sillimanite and fibrolite, (the derivation of the last two by the first being uncertain),or the relation of obvious derivation of sillimanite (or fibrolite) from biotite.

The general orientation of the traces of these planes (Fig. 60) is NNE – SSW, with certain local exceptions. A notable one is found south of the Isverna locality, where the boundaries of the sillimanite, andalusite areas, of the biotite – andalusite and sillimanite – biotite relations are subject to a definite ENE – WSW reorientation and the area of the garnet – biotite relation is interrupted. It is equally here, superposed on these inflexions or breaks that we have drawn the boundary of the area (of disappearance) of staurolite, which, in the acceptation of the present paper, has an exclusively relict character. In this case, we have granted this boundary the value of a paleoisograde which separates the kyanite and staurolite paleozone in the south from the kyanite paleozone in the north.

Like in the case of the Barrovian metamorphism, the relation marking the disappearance of kyanite is that of the substitution of this mineral by muscovite. It coincides with the line by which we marked the relation of substitution of kyanite by andalusite. It is only in the eastern part that it has been possible to draw these lines.

In the western part of the contact between the area of intermediate, low pressure metamorphism and the Barrovian area, between the "sillimanite + cordierite zone" and the kyanite + staurolite or kyanite zone respectively, there were no longer any relations marking the disappearance of kyanite through its definite substitution by sillimanite, but, only in places, relations indicating the substitution kyanite – cordierite and kyanite – plagioclase that could mediate the passage from specific minerals to the two types of metamorphism.

All the relations presented above as well as the spatial disposition of the lines marking mineral isorelations suggest possible metamorphic reactions that could favour the passage from one type of metamorphism to another and within the same type of metamorphism from one metamorphic zone to another, respectively.

So, for the eastern boundary between the low pressure area and the Barrovian metamorphism area, the most frequent relations of sustitution are: kyanite →

andalusite; garnet → biotite; staurolite → andalusite; biotite → andalusite.

They can be encountered immediately south of the middle part of the Bahna Outlier which we consider to be the zone with the most complicated but also with the most constant mineral relations. Those relations would suggest reactions of the type:

a) kyanite + garnet + staurolite + biotite → andalusite + biotite.

This reaction would obviously point to the conditions that would accompany the passage from the Barrovian metamorphism to the low pressure one. Within the low pressure metamorphism area the isograde plane between the two metamorphic zones could be materialized by the raction:

b) andalusite + biotite → sillimanite + cordierite + K feldspar

that has the quality of being ubiquitous due to the permanent existence of the final members of the two adjacent metamorphic zones.

Considering the western proximity of the Barrovian metamorphism area, it is probable that the second term of the reaction *b* should also originate in a reaction of the type:

c) kyanite + staurolite + biotite → sillimanite + cordierite + K feldspar

We are of the opinion that these reactions, very simplified, of course, represent a reality in the field and can be used for establishing the physical conditions in which they took place. Unfortunately they imply, besides the Al_2SiO_5 minerals, also some others with variable chemistry and therefore with different values of the thermodynamic parameters. Nevertheless it would be possible to calculate these parameters but, as already shown, only when it is possible to achieve the punctiform chemical analysis of the minerals in the reaction.

By discussing the mineral relations at the boundary between the two types of metamorphism, their temporal sequence has been established. It has also been discussed that within the area with Barrovian metamorphism, two important metamorphic phases or moments can be distinguished, their polycyclic character being thus demonstrated.

Within the area of intermediate, low pressure (Pirinean) metamorphism, the existence of the two Pre-pirinean Barrovian cycles has no longer been registered.

Of course, that situation could be explained by the fact that, in the case of so many superpositions of mineral deformation and neoformation events, it is difficult to separate all the paragenetic individualities.

There are, however, a few facts we consider worth mentioning here and that could shed a new light on the temporal sequence of the main metamorphic events.

The main finding at the examination of a map containing the low pressure metamorphism areas and the Barrovian type ones is the coincidence between plane S_2 (recognized by us as belonging to moment 2 of the Barrovian type of metamorphism) and the looks of the isograde planes in the domain of Pirinean metamorphism and even partially with the boundary between the two types of metamorphism.

We have recognized the static postkinematic character of the crystallization of this type of metamorphism and at the same time have demonstrated diagramatically its prevailingly thermal genesis. Consequently, a relation results between the deformation moment D_2(that generated the foliation S_2) and the moment of intermediate, low pressure metamorphism, in the sense of their association, even if the general tendency of the latter is that of blurring the foliation S_2.

Another observation concerns the differences between minerals (and their relations) formed during the second, Barrovian metamorphism phase and those specific to intermediate, low pressure metamorphism. In this context it is worth mentioning the possibility of a mineral species, formed in two different moments, to include itself. We should also remember some minerals in the second phase, of Barrovian metamorphism, were idiomorphic in character, which attests their late postkinematic crystallization.

All these relations or the marked idiomorphism of certain minerals are no longer found in the metamorphism area of Pirenean type but persist in the adjoining zones of Barrovian metamorphism. At the same time, as already presented, in "the Pirenean area" numerous relics of "Barrovian" minerals have been identified, which makes us suggest we are in the presence of a synchronism of metamorphism moments, i.e. between the second moment of Barrovian metamorphism and the Pirinean metamorphism moment. In other words, the intermediate, low pressure metamorphism represents a peculiar manifestation of the second phase of Barrovian metamorphism, i.e. by the occurrence of a thermal dome by the end of the kinematic phase of moment M_2.

It results therefore that the whole metamorphic area in the Sebeş-Lotru Series has been subject to two important moments of metamorphism, the first being very homogeneous, with a constant syncrhronism of the mineral deformation and neoformation moments throughout its whole area, accompanied, no doubt, by a heat flow which facilitated the blastesis that probably took place at very deep levels.

The second moment of metamorphism also affected less deep zones (which would explain more simply " the character of high temperature of the low pressure parageneses") being also characterized by the lack of coincidence of the moment of thermal apex with the moment of deformation, the latter preceding the former in time.

VI. OPINIONS ON THE STRUCTURE OF THE METAMORPHIC ROCKS OF THE SEBEŞ-LOTRU SERIES IN THE SOUTH CARPATHIANS, AS A CONSEQUENCE OF THE POLYCYCLICITY OF METAMORPHISM

In the last decades, structural geology, on the one hand, and the study of metamorphism, its polycyclic character respectively, on the other hand, knew remarkable progress. This is not the case with its concrete use, in the geological mapping of metamorphic fields. That can be accounted for by objective and subjective factors.

The discussion of the structural consequences of the polycyclic character of metamorphism, which we have tried to demonstrate in this paper, in a way goes beyond the scope and competence of our work. But we consider necessary to express our opinion in this respect, for underlining the complexity of the deciphering of the structural-metamorphic evolution in the metamorphic fields in our country.

We shall approach this problems for more restricted areas than that of the South Carpathians as it was not possible to carry out petrographical-petrogenetical and structural studies of great detail at such a scale.

For the beginning we chose for exemplification the Central South Carpathians, that is the Sebeş-Lotru Series in the Sebeş and Cibin Mts.

Our argumentation will follow the scheme:

A) General aspect of lithologically contrasting rocks

B) General orientation of schistosity foliations and lineations, the position of the synkinematic garnet in the zone of their maximum convergence

C Microstructural elements supporting the polycyclicity of the Sebeş-Lotru Series

D The vertical distribution of the main lithological (complex) formation, the relations between the lithological boundaries and other *S* planes, visible in the field at a regional scale

E) Alignments of blastomylonites. Their spatial and temporal position

F) Structural consequences.

A. General Aspect of Alignements of Rocks with Contrasting Lithology

A lithological map of the Central South Carpathians (Figure 61) shows a surprising image for this unity, considered until recently an example of lithological and structural monotony of the Romanian Carpathians. Indeed, at a first examination it can be noticed that there is a well expressed lithological content, represented by plagiogneisses (paragneisses) and micaschists, monotonous enough to permit the separation by contrast of certain formations altogether subordinate in point of quantity, of various petrographies. These formations are generally carbonate rocks and manganiferous rocks and less characteristically, amphibolites.

1. Manganiferous Rocks. As the area we refer to is quite large (about 55 km E-W and 30 km N-S) it gave us the possibility to follow at a regional scale the main alignments of manganiferous rocks and to distinguish two sections of such alignments:

– western section, bounded to the east by the Cugir Valley – Sebeş Valley inerfluve. Westwards, this section prolongs close to the boundary metamorphic rocks-sedimentary rocks of the Petroşani and Haţeg Basins.

– eastern section, between the eastern boundary on the preceding section and the basin of the East Sadu Valley.

The western section seems to have the most complicated aspect. It looks like a sheaf, divergent to south-west, being made up of three, four distinct alignements, all of them converging towards the confluence zone of the Cugir Valley, with its left tributary, Boşorog Valley (Fig. 61).

The first alignement, the most northern one, can be followed from Poiana Omului to the west, on the bank of the Godeanu Valley (Grădiştea de Munte Zone), passing by the Cugir Valley Sources up to the Canciu Zone (Cugirul Mare – Valéa Boşorog confluence). That alignment is quite discontinuous and is prevailingly made up of spessartitic rocks.

The second alignment is the most important, also including the Pravăţ – Bretan ore deposits. It is strongly bent from the Jigureasa Valley Basin (left tributary of the Strei Valley) northwards, bending again north-eastwardly in the Pravăţ zone and then eastward in the zone of the Strei Valley Sources (Rovina Valley basin) up to Canciu.

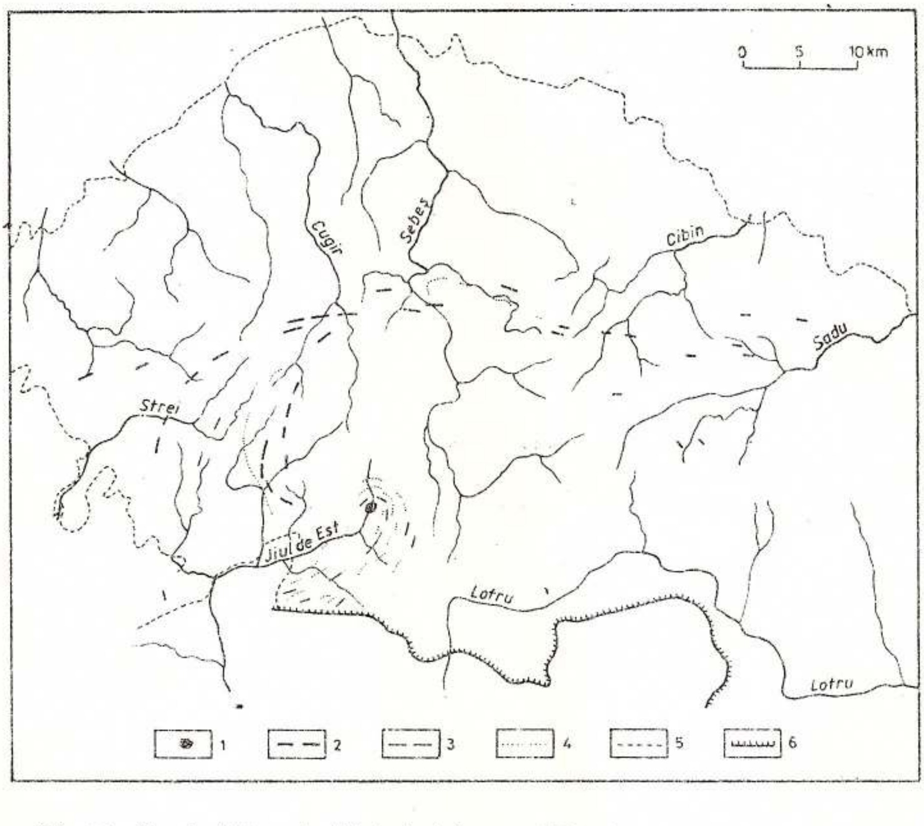

Fig. 61 – Sketch of the main lithological elements in the Central South Carpathians: 1, Synkinematic granites; 2, Manganiferous rocks; 3, Carbonate rocks; 4, Amphibolites; 5, Boundary of the Sebeş-Lotru Series; 6, Thrust plane.

The third alignment can be considered a replica of the fourth. It can be followed from Valea Răscoala (right tributary of the East Jiu Valley) north-eastwards, up to the Auşelu Valley (Taia Valley Basin) and then northwards, on the left bank valley.

The fourth alignement is less bent, starting in the middle course of the Auşelu Valley and advancing northwards through the Dobraia Valley and Summit; it meets the third alignement in the Pârva Summit and the Pârva and Gropşoara Valleys Basin and prolongs north-northeast, up to Canciu.

In point of mineralogy, in the second alignement a very great variety is observed, besides spessartite being described tephroite, pyroxmangite, rhodonite as well as other minerals common to all the alignments: rhodocrosite, dannemorite.

Alongside these four alignments we should also mention the isolated occurrences of manganiferous rocks in the zone of the Aninoasa locality and of the Cimpa Valley Basin, at Plaiul lui Glod, which, in our opinion can be correlated with the second alignement, by its strong bending south-east and east.. We have equally succeeded to identify the most eastern occurrence of manganiferous rocks in the southern part of the Sebeş Mts, in Valea Bilele Basin, that we consider to belong to alignment 3 or 4.

The eastern section has the same fasciculated aspect as the western one, but keeps a constant orientation approximately east-west, between the Cugir Valley and the Sadu Valley, a certain divergence occurring in the Sadu Valley zone due to the bending of a supposed alignment of manganiferous rocks to the south, towards the Lotru Mts and farther to the south-west, in the Căpăţâna Mts (Recea Valley Basin).

Finally, a small alignment can be traced more southward, on the right bank of the Sadu Valley, between the northern points Stefleşti Peak – Conţu Valley – Sădurel Valley, trending east – west.

2. Carbonate Rocks. In the Central South Carpathians there are, generally, few carbonate rocks. They are more largely spread in the northern part of the Sebeş Mts, interbedded in the epimetamorphic schists of the Cărpiniş – Căpâlna Series.

In the Sebeş – Lotru Series, the largest distribution of carbonate rocks is found in the southern part of the Sebeş Mts, in the East Jiu Valley Basin. Paliuc (1937) was the first to map them, followed by Pavelescu, Pavelescu (1966), being represented by a ENE – WSW alignment, south of and parallel with the East Jiu Valley.

In point of chemistry and mineralogy, the carbonate rocks are represented by slightly dolomitic limestones, calcareous dolomites or pure dolomites (according to the Vişneacov cell). Subordinataly, the manganiferous ankerites or the manganodolomites in these rocks can show local chemistry variations.

Our researches of great detail, have succeeded in identifying, besides the main known alignment, its prolongation that bends northwards, somehow discontinously, crossing the Fetiţa Mică and Sterca Valleys, then north-westwards, crossing Valea Bârlogu Mare and farther west, up to Valea Bilele.

A characteristic of the carbonate rocks alignment is its centrifugal character, with a center of convergence that can be situated in the very zone in which the synkinematic granite body at Voevodu crops out, at the confluence of the Bârlogu Mare – Bârlogu Mic Valleys. A second character of this alignment is (like in the case of manganiferous rocks) its fascicular character with an equally centrifugal tendency, the more so as we go farther from the zone of maximum convergence.

Crossing the Petroşani Basin, carbonate rocks occur more discontinuously and with much more modest development, in the crystalline rocks of the Sebeş – Lotru Series of the Aninoasa Valley Basin. Farther north they are encountered again in the upper course of the Galbena Valley (south of the Sebeş Mts) continuing farther north, on the right slope of the Sasu Valley, in the central part of the Sebeş Mts.

Finally there is another lens of carbonate rocks in the Cibin Main Summit, in the proximity of the Niculeşti Summit.

3. **Amphibolic Rocks.** Although more numerous and more difficult to correlate, numerous amphibolite bodies are disposed similarly with the carbonate rocks and the manganiferous rocks. The most "suggestive" alignment seems to be that which surrounds the granite body at Voevodu, starting north of it (Cândreşu Valley), then north-east and east, beyond the Bârlogu Mare, Bârlogu Mic and Pârâul lui Grivei Valleys, bending again south-west and west, beyond the Fetiţa, Sterminosu and Lolaia Valley. This alignment is situated at the outer part of this carbonate rocks alignment.

Another important alignment is that situated in the Taia Valley Basin,starting south of the confluence Taia – Auşelu and advancing north-west and north, up to the proximity of the Titiana Summit.

Unlike these "aligned" rocks, which we consider a consequence of an advanced transposition, following the last important deformation plane, S_2, there are equally situations of a striking unconformity at a macro and mesoscopic scale between the disposition of certain rock bodies and foliations S_2. Without entering into details, we mention the amphibolic rock bodies on the left bank of the Jigureasa Valley, in the Piatra Tomnatec zone and on the right bank of the Gâlceag Valley, which seem to trend transversally on the structure, as it is conceived so far.

The microcline rocks (migmatites) show the same character of alignment, with a general centrifugal aspect. But they could have been formed more recently than the rocks discussed above, their probable age being that of S_2 and therefore their aspect is normal in this structure context.

B. General Trend of Schistosity Foliations and of Lineations, Position of Synkinematic Granite in their Zone of Maximum Convergence

A general examination of a map of the Central South Carpathians which contains planar elements (foliations) and linear ones (lineations) leads to the conclusion that the structure of this zone generally trends east – west with important re-bendings in the central and southern zone of the Sebeş Mts, which was first suggested by Ghica-Budeşti (1939). The lineations, that are, with certain exceptions, approximately parallel with the foliations strikes indicate the same thing.

The foliations and the lineations show a feature quite similar to that of the alignments of rocks with contrasting lithology, equally bending in the zone of maximum concentration around the Voevodu Granite. This granite can be considered a crucial point of the structure of the region.

Areal statistical diagrams of the foliations, for almost the whole zone under investigation (Pl. I), mainly indicate a "faint" aspect of these elements in the northern part of the investigated zone, with unidirectional lineations, corresponding with the general trend of the structure (east-west) and foliations with small dips, preserving at large the strike suggested by the lineations.

As we go far from the zone of the Cibin Mts westward (up to the Cugirul Mare Valley) and then south of the Sebeş Massif, we notice a gradual rotation of the linear elements to the south-west, south, south-east and east as well as a straightening of the dips (towards the vertical) of the planar elements.

The foliations equally show re-bendings, towards the nodal point of the Voevodu Granite, the curvature radius of the lines that would unite these foliations being smaller and smaller as we draw near the granite body.

The Voevodu Granite was described by us (Hârtopanu et al., 1969) as having a shape slightly elongated ENE – WSW and termed at the moment gneissic or anatectic granite. In the granite body amphibolic or metapelitic rock enclaves have been described. From the chemical point of view, the granite is intermediate, at the upper limit towards alkaline rocks, being a salic rock.

Microscopic textural relations have pointed to three main features:

– the existence during or immediately after the formation of this type of rocks of active movements that led to breaks, cracks and bendings of minerals:

– the marked and long-lasting mobility of microcline; the relatively more reduced mobility of other minerals such as quartz, plagioclase;

– metasomatic replacement of various minerals such as plagioclase by albite, biotite by plagioclase etc.

The analysis of the author's map shows that the schistosity foliations of the crystalline rocks adjacent to the granite body mould its shape, being permanently parallel with the lithological contact plane granite – metamorphic rocks. This character as well as the linear (deformational) structure of granite which is slightly elongated east – west points to its synkinematic character. It has also been supported by Savu et al. (1977), the granite being considered by them to represent the Dalslandian synorogen magmatism.

As the synkinematic character of the granite is not doubted (with the exception of the papers by Pavelescu and Pavelescu, 1974, – the most recent being the geological map of Romania, 1 : 50,000, Vârful lui Pătru Sheet – who consider it metatectic migmatite), the problem arises of the connection of its emplacement with a certain deformation episode. In our opinion, it is connected with the last episode that generated plane S_2 and lineation L_2. The granite penetration was accompanied by a considerable uplift of the suprajacent rock mass. We consider the apex of the granite body is to be found in the zone where it crops out at present. The ascending of the rock mass over the granite was not a solidary vertical one, but was produced differentiatedly, one of the factors that hindered the ascensional movement being the friction between the crystalline rocks at a long distance from the granite and those already moving with the granite. Movement was probably transmitted after a hyperbolic curve, being quite active close to the granite and gradually diminishing with the distance.

Another movement worth considering is that of the crystalline rock mass in plane S_2 of the schistosity foliations, visible at present. Examining the rotation angles of variuos minerals grown synkinematically – of which garnets are the commonest – we can get an idea of the proportions of this movement.

It is easy to imagine that in the region under discussion the movements to which the rocks have been subject were due to the combination of at least the two movements discussed above. It seems logical to admit the maximum effect of the combination of the two movements is achieved quite close to the granite body; moving away from it, the effect of ascending movements, behind the scenes, tends to be extinguished. The only constant movement – deformation is that produced at the level of S_2, being possibly considered a background for the deformation brought about by the ascending of the granite.

The fact that the highest values of the curvature and therefore of the discussed alignments are to be found quite close to the granite body, that these deformations diminish with the distance, leads to the conclusion that at least the deformation materialized in these curvatures was due mainly (probably not exclusively) to the ascending movement and the shape of the granite body. They also account, in our opinion, for the straightening of the foliations in the proximity of the granite body, observed from the spatial statistical analysis of planar elements.

The rocks adjacent to the granite body have been subject to a large range of deformations, from ductile to brittle, probably due to the movement of the granite body that also continued after it reached a viscous state. That is why the granite itself has been subject to a brittle deformation.

C. Microstructural Elements Supporting the Hypothesis of the Sebeş-Lotru Series Polycyclicity

Our works in the Central South Carpathians and in most of the crystalline areas of the Sebeş-Lotru Series have offered us evidences concerning the existence in the course of the history of the rocks under investigation of at least two important movements of deformation – reorganization, attesting their polymetamorphic character.

The arguments we possess so far in the metamorphic fields in the South Carpathians are related to microstructural aspects of rocks (presented in the chapter dealing with textural relations).

Geological practice has succeeded in establishing certain criteria for identifying recyclings, such as the stratigraphic unconformities and the accompanying conglomerates, the interference of folding patterns, the polymetamorphic characters, the distribution of lithophile elements, absolute age datings, (Den Tex E., 1974).

In our opinion, a phenomenon such as polymetamorphism cannot be demonstrated by only one of the methods above. At the same time we think it is not at all advisable to ignore the microstructural evidences (for the time being the only ones applicable on a large scale), the relations among minerals or among minerals and the S planes of rocks.

The methods used for evidencing the superposition of certain distinct metamorphic events and which we presented in a previous chapter, consisted in the study of the intermineral relations as well as in the relations among various minerals and the deformation-event. We consider deformation an outcome of differential movements on equivalent surfaces (S planes), materialized in the growth of phylosilicate minerals or in submicroscopic inclusions disposed on these planes.

The purpose of the study of mineral relations and of the relation mineral deformation – neoformation is to establish paragenetic entities characterized by a specific mineralogy or individual physiographic characters, different from one paragenesis to another.

The polycyclic character of the metamorphic formations of the crystalline rocks of the Sebeş-Lotru Series has been discussed in the chapter treating of metamorphism.

D. Vertical Distribution of the Main Lithological (Complex) Formations, Relations among Lithological Boundaries and other S Planes Discernible in the Field on a Regional Scale

As seen in the introductory chapter, many formations making up the crystalline rocks of the Sebeş-Lotru Series are represented by a range of transitions between two main types of rocks, which we can consider extremes: quartzo-feldspathic, granoblastic rocks of granitoidic type in which K feldspar has an important part and metapelitic rocks of the type of kyanite-bearing micaschists. Between them are included the rocks generally termed micaceous plagiogneisses (paragneisses), with or without garnets, staurolite, kyanite.

On a largest part of the area under dicussion our researches together with those of the geologists-prospectors who worked in the region have evidenced a certain vertical sequence of geological formations which does not at all correspond with the geological boundaries and structure in general, if they are built up in keeping with foliations S_2.

It is worth noticing that for a large part of the area under discussion, although not necessarily for the whole of it, there exists a statistically registered regularity of the vertical distribution of the main geological formations mentioned above. Thus, for the zone between the Godeanu Valley (Grădiştea de Munte) to the west and the Sadu Valley – Hoteagu Valley to the east, a remarkable "preference" is obvious of the aluminous rocks (kyanite – bearing micaschists and rarelier plagiogneises) of occupying the highest summits, giving the impression of a plate or a roof, intensely fragmented by the hydrographic network (Pl. I). The boundaries of these types of rocks, as presented in this plate, mediate between the numerous lenses of kyanite-bearing micaschists.. We should point out that the orientation of these individual lenses has been represented by different authors in keeping with foliations S_2 with the general orientation east - west. In our acceptation, the initial boundary of the aluminous rocks under discussion could have had the outline we have given it. The effect of the deformation and transposition by S_2 has given a false image of the orientation of the major rock bodies and a real reorientation of the small rock bodies, as seen on the outcrop scale.

A second formation presenting a preferential position in the vertical plane is that of the granitoidic gneisses. They are granoblastic microcline gneisses, with generally massive structure. They occur on the bottom of more important deeper valleys, and equally on some of their tributaries. They have been described under various names: microcline gneisses, granitized gneisses, migmatites.

Considering the remarkable structural - textural and compositional convergences between various types of granitoid rocks, we have not yet succeeded to differentiate these rocks from one another, to give a differentiated physiographic description of the granitoids we discuss and of those subject to a lithostratigraphic control depending on foliation S_2.

It is the granitoid rocks on the Frumoasa and Curpătul Valleys - right tributaries of the Sebeş Valley -, those on the Lotru Valley upstream and downstream the Vidra Lake, and on the Sadu Valley, continuing the ones on the Frumoasa Valley, that are the most important, interesting and consistent in opposing a stratigraphic control following plane S_2. In the Sebeş Mts we have encountered such situations on the Auşelu Valley and its left tributary, the Clăbucet Valley; on the Strei and Taia Valleys. The disjuntive tectonics frequently interrupts the continuity of these rocks.

An association that occurs quite regularly for being characteristic is that with amphibolic rocks.

Between the two types described, with an intermediate position from the altitudinal and lithostratigraphic point of view, there are various types of plagiogneisses, with or without microcline, with or without kyanite, but frequently with garnets and staurolite.

This lithologic sequence, applicable to the area of metapelitic rocks (with Al_2SiO_5 minerls) seems to represent an interval from the standard lithogeometric column of the Sebeş-Lotru Series in the South Carpathians, that is the upper metapelitic complex and the middle one, of quartzo-feldspathic gneisses and amphibolites.

E. Blastomylonite Alignments. Their Position in Space and Time

The existence in the area of the Central Carpathians of highly deformed rocks, very different in physiographic aspect, has made it necessary to discerin the field and in laboratory, the physical conditions that contributed to its birth, the rocks' birth implicitly.

An altogether general classification can appreciate that the deformations of this type are:

1. **Brittle** due to recent faults or to faults in the superficial zones of the earth crust, which produced cataclasites, mylonites and pseudotachylytes on their way:

2. **Ductile** produced at high temperature and pressures, implying the plastic flow of individual grains, which slightly fragmented or without fracturing, according to Vernon (1974) it is normal for these rocks to have a compositional bedding, which is parallel to the XY plane of the finite strain ellipsoid. Katz (1968) suggested that the recrystallized feldspar porphyroblasts in certain deformed granulites at Quebeck occupy the same relative position and volume as those of the parental rocks preceding deformation.

In what follows we shall treat of these ductile deformations which we have followed along certain alignments, terming the resulting rocks blastomylomites.

Unlike mylonites and cataclasites, blastomylonites are not clearly distinct from surrounding rocks. They show a foliation which, in the zone under discusssion has the property of being approximately conformable with foliation S_2 of the adjacent rocks. A first conclusion deriving from here is the possible synchronism between the blastomylonite foliation and plane S_2. But it seems most likely for the blastomylonite deformation planes to have adopted – as being easier – planes S_2. In any of these situations, the deformations to which the minerals of the non-mylonitic rocks were subject, are similar but slighter. The most visible effects of the process under discussion are the shearings, the laminations and the mineral neoformations.

Shearing affects only certain minerals, especially the less ductile ones, under the conditions in which the phenomenon is produced.

In Plate X., Figure 2 we can see a kyanite crystal clearly cut along planes parallel to the blastomylonite foliation plane. Deformation has equally caused the mechanical twinning of the kyanite crystal.

Two planes S and succession relations among them (Pl. XI, fig. 1) are noticed in the mylonite planes. In this case we consider the affected foliation is relict S_2 and therefore mylonitization was subsequent to the deformation moment D_2 and was produced along S_2 planes.

But, in most cases, this sequence is not observed, an indication of the synchronism of the two planes, of oné being mimed by the other (coplanarity) or of the advanced transposition of the old S after the new one. In any case, "the bedding" effect is quite visible, starting with the purely mechanical one (Pl. XI, fig. 2) where, at the level of the shearing plane, the minerals (especially quartz) are quite crumbled, forming thin microgranular "schliereh", with less deformed "bands" in between, made up mainly of quartz, with undulatory extiction and apparently developed in the shearing plane.

In the rocks more heterogeneous from the mechanical point of view a lamination effect is produced. We can thus notice slides at the level of micaceous minerals (Pl. XII, fig.1), a mechanical segregation of minerals being thus brought about. A rock with bedded aspect results, which is in fact an effect of the strong transposition of an older bedding, visible in the right bottom corner of the photo.

Another product of the shearings and laminations we are dealing with is the porphyroclastic structure. In Pl. XII, fig. 2 the porphyroclasts are small polycrystal quartz aggregates included in a fine micaceous matrix, the phylosilicate minerals probably being mineral neoformations accompanying lamination.

Besides quartz polycrystal porphyroclasts, phenoblasts can be equally represented by micas (Pl. XII, fig. 2). In this case, micas can possibly be neoformed, accentuating the blastic character of the mylonite under consideration.

Finally, another specific character of the blastomylonites is the postkinematic formation of new minerals that did not exist before deformation. Chloritoid is the most characteristic mineral of this kind. The prismatic chloritoid crystals are disposed at random in the schistose textural assemblage of mylonite. Our researches (Hârtopanu I., Hârtopanu P., 1976) established that chloritoid – bearing rocks range along two important alignments and the conditions of the chloritoid appearance are mainly the previous existence of an aluminosilicate mineralogic background, the absence of K feldspar and the incompatibility of the association of biotite which, in presence of chloritoid, is broken down.

In Plate XIII, Figure 1 in a finely micaceous schistose mass there are a few chloritoid bars randomly oriented and in Plate XIII, Figure 2 the chloritoid crystals include sillimanite needles, with which they coexist (without the latter's decomposition). This is also true for kyanite, which is partially substituted by chloritoid, but with which it can coexist. A phase diagram (Holdaway, 1971) has already been established, showing the coexistence of kyanite and chloritoid on a large area, the latter being equally found on a small zone in the field of sillimanite, in the proximity of the triple point.

Equilibrium textural relations for the kyanite – chloritoid assemblage have been observed by several authors, of which we mention Vrána (1964) for the Alpine metamorphism in Slovakia.

All this makes us conclude that the degree of metamorphism in the ductile mylonitization zones was equal or a little bit lower than that in the adjacent rocks, deformations being not accompanied by retrograde replacements of minerals such as micas, garnets, aluminiumsilicates, feldspars etc. These minerals appear in rounded grains, in a laminated, finely granulated matrix, (especially) with strongly recrystallized quartz.

The zones adjacent to the planes of ductile mylonitization also show the symptoms of similar deformations with *S* planes crossing certain minerals porphyroblastically developed or with proofs of their rotation. The mechanism of producing these deformations is probably similar with that admitted to have taken place when metamorphic nappes were formed (Zwart, 1974).

An important mass of rocks is subject to the deformations occurring at the level of these nappes, with the highest strain at the base of the slided mass. Unlike them, the non-metamorphic nappes have the movement localized at the level of the basal pushing plane.

As already shown, the blastomylonites investigated by us can be followed on a few alignments, two of which are more important: one in the East Jiu Valley

Basin, trending NNW – ESE, re-bending then towards ESE and a second one trending E – W, crossing the Sadu, Cibin (in the neighbourhood of the Păltiniş resort), Sebeş, Cugir Valleys.

Besides the phenomena taking place at the level of this plane, we can also point to the fact that along it, zones of different metamorphism come into contact: staurolite + kyanite and sillimanite, the last one being superposed on the first (Pl. I).

In the Caledonides where this superposition has also been noticed, the metamorphic nappes have represented the most acceptable solution for explaining this relation. That is why we consider that in certain places the blastomylonite plane can have the value of an overthrust plane, synchronous with or immediately post-dating the last metamorphic event in the region.

F. Structural Consequences

The above presentation of structural elements has tried to point out the rocks alignment and the structure on much of the studied area has a spiral look, which, in our opinion, represents the effect of at least two coupled movements along different directions. The strongest effect of the combination of movements was encountered in the Voevodu Zone, close to the synkinematic granite, described in a previous chapter. The maximum bending of the foliation directions in this zone indicates the influence of the granite movement was the decisive factor in creating the tectonic style in this zone. The degree of plasticity of the granite, as seen from the observed mineral relations, was diminished especially because of the insufficient amount of water in the granitic magma (which was deduced from the maximum amount of hydroxyl minerals in the granitic rock). At the same time, the temperature of the granitic magma was high enough to correspond to the metamorphic environment of the rocks in which granite is an intruder. The intrusion of granite, viscous enough, was accompanied by the involvement through friction, during the ascending movement, of the adjacent-rocks, especially in the zone of granitic apex but also in that of the global uplifting of an important mass of crystalline rocks situated at its top.

We can therefore imagine that a huge granitic cone was formed, wrapped in a still bigger one, of crystalline rocks, with a common summit (in the apex zone) (Fig. 62), making up together an immense dome.

Another element worth considering is the synkinematic character of the granite, that is of its permanent deformation during intrusion, but equally that of the deformation of the country rocks following plane S_2 which acted after the directions suggested by the mineral lineations, transition movements being equally produced at the level of this plane. We are therefore in the presence of two continuous synchronic movements, the spiral aspect of the lithologically contrasting formations being a consequence of the combination of the ascending movement of the granite and of their own movements in plane S_2, also demonstrated by the synkinematically grown mineral relations. The spiral aspect of the manganiferouis rocks in the north – western part of the zone under study, complementary to the equally spiral look of the carbonate rocks in the south , probably equally represents an effect of the relief which descends from the granite southwards and soars northwards, up to the main summit of the Sebeş- Cibin Mts. The disappearance of the spiral character of the alignment of manganiferous rocks in their northern part can be explained by the extinction of the effect of the granite uplifting, the rocks in this area remaining exclusively under the influence of the movements at the level of plane S_2.

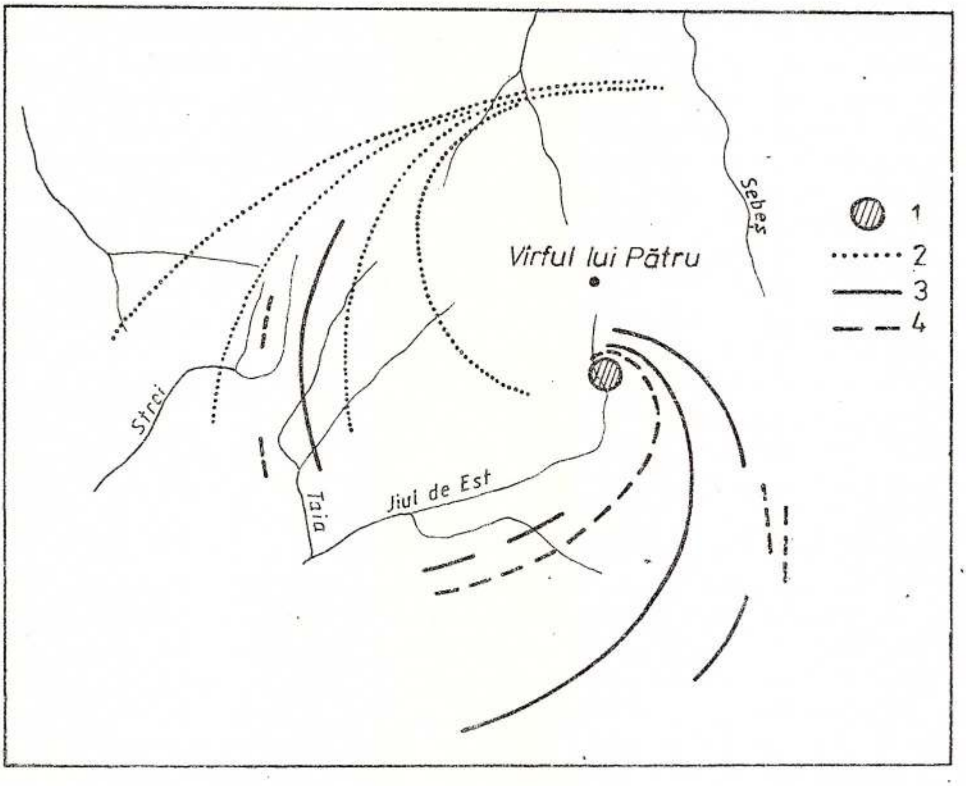

Fig. 62 – Idealized sketch of the orientation of the main lithological elements in the Sebeş-Cibin Mts: 1, Synkinematic granite; 2, Manganiferous rocks; 3, Amphibolites; 4, Carbonate rocks.

The recurrence or the fasciculation of manganiferous rocks, carbonate rocks, amphibolites, and all the other crystalline rocks, more monotonous from the lithologic point of view, can be explained especially by the grand effect of transposition of deformation movement D_2, in planes S_2 – generally unconformable against the primary lithological boundaries.

The displacement planes at the level of blastomylonites can have a spectacular effect, generating important doublings of certain lithological alignments or even overthrustings of the lower formations by the upper ones. Finally, another cause has to be considered – the only one invoked so far – that of primary recurrences of the formations concerned.

The natural question arisen by so many previsible effects of the mentioned movements is that of the primary structural aspect of the rocks in the investigated zone. The answer - if not simplistic - must take into account the movements involved in the structure completion. At the same time it is difficult to represent the composite of the movements having acted on the pre-existing lithological elements, in order to identify, starting from the effects observed today, its primary structure. The major difficulty lies in the strong transposition effect of planes S_2. The microscopic and mesoscopic relations between plane S_2 and older deformation planes (possibly the planes of primary bedding too) have only a qualitative value, showing only that they have existed and not their initial position. It is the figuring on the map of the main major lithological elements of a complex type (or formation) that can give valuable information. In our zone of research we have thus established the boundaries between these formations to have a quasihorizontal position, the pelitic formations investigated by us being situated in the central part of the area of the Sebeş and Cibin Mts, in the zones of greatest height, the vertical descendence coinciding with the crossing of more and more feldspathic complexes, first plagioclase and then microcline ones.

The zone of disappearance of the kyanite – bearing rocks in the south of the Sebeş Mts coincides with the zone of active influence of the uplifting of the granitic mass at Voevodu. The substitution of the kyanite in the north by the sillimanite in the south (even if the latter knows higher concentrations in certain spots) is not equivalent with the identification in the south of the pelitic zone present in the north, which was probably uplifted and eroded.

The fan-like aspect of the sillimanite zone in the Sebeş Mts, whose shape and general look seem to be equally related to the granitic body can also raise questions: is there any genetic relation between the intruded granitic body and the sillimanite genesis? Is that mineral and the metamorphism zone related to it of the age of S_2? For the time being, it is difficult to give an answer as in the zone quite close to the granitic apex, besides the important deformations mentioned above there also exist mineral neoformations of the kyanite type, including an older kyanite. We consider the last generation of kyanite was formed in the context of the combined deformations between planes S_2 and those which accompanied the ascending movement of the granite.

The major problem of this chapter is in fact the primary structure and the resulting one in the zone under investigation. From the above presentation it has resulted that the spiral look of various lithological formations, of the main blastomylonite alignments and maybe even of the sillimanite metamorphism zone is the outcome of the mentioned combination of movement.

But what was the structural background against which these movements occurred ?

The regulate bends for various elements under consideration, the quasi – horizontal planar position of the clearly individualized metapelitic rocks in the northern part of the zone – where the effect of the granite uplifting ceases to be felt – make us assert the structures under consideration can result only from the joint action of the mentioned movements, on an initially planar, quasi – horizontal background. In fact this structure is not novel for the Sebeş – Lotru Series; it was demonstrated by Bercia (1975) in the Godeanu Mts and Hârtopanu, Iancu, Hârtopanu in Stănoiu et al. (1979) in the Mehedinţi Mts. The resulting local structure we have dealt with in this chapter is domal and all the geometrical elements concerning the spatial orientation of the formations affected by its genesis lead to this conclusion.

Conclusions

In the present paper we have tried to carry out a detail microscopic study of the metapelitic rocks metamorphosed to a medium – high degree and to transpose our observations and relations in the field. The complexity of the problems have made us restrict our study to the Sebeş – Lotru Series.

In this series we have investigated two important types of metamorphism, the Barrovian metamorphism and the intermediate, low pressure (Pirinean) one. For both types we have tried to demonstrate the polycyclic character of metamorphism. By studying the mineral relations in the zone of transition between the two types of metamorphism an attempt has been made to establish their temporal relations. In particular, for each type the specific physical conditions that determined the formation of the metamorphites concerned have been indirectly investigated.

One of the achievements of this paper is the mapping of intermineral relations and of the sequence of metamorphisms, succeeding in drawing a paleoisograde in the crystalline rocks area of the Mehedinţi Mts.

By drawing on the map the line of mineral isorelations we consider we have established more objectively and closer to the reality in the field, the areas of physical isoconditions governing the metamorphism process in the region. That has also led to a new picture of the metamorphic zonality of the Bahna Outlier, previously established equally by us, but on relatively simpler criteria.

The final part of the paper represents a structural essay concerning the metamorphites in the Central South Carpathians, through the polycyclic character of the metamorphism and as one of its consequences. On this occasion we point out that deformation as an element always presenting regional metamorphism can bring about major changes in the shape of rock bodies – at mesoscopic level – and in the character of the boundaries between the major rock bodies, due to transposition. Blastomylonite alignments are evidenced that impose the idea of very old disjunctive tectonics.

The discussions leading to the conclusion of the structural domal model of the central zone of the South Carpathians have represented our way of approaching the study of the structure of an intensely and repeatedly metamorphosed region.

The dynamic character of metamorphisms, the temporal sequence of certain metamorphic phases or cycles are not confirmed so far for the zone under study by reliable investigations of absolute ages. However the variety of K – Ar datings on minerals or rocks belonging to the metamorphites of the Sebeş - Lotru Series as well as the alternative offered by U - Pb dating on zircons (Pavelescu et al., 1979) made on ocular gneisses at Căpâlna (intercepted in two points of the Concordia curve) make us be optimistic as regards our modality of research, in our opinion, the only one possible on a big scale and with modest financial support.

Taking into account the space at our disposal and the conditions of rapidly perishable ideas, that is what is meant to be my contribution to this extremely fertile subject. I think I am not wrong to consider it "a collective paper", as at this time of rapid circulation of information, it is difficult to conceive"a spontaneous generation" of ideas. The paper appears to be a distillate of the conceptions of the present day generation of Romanian geologists - and to the extent of its receptivity - of contemporaneous ideas circulating on the subject concerned. As for the unanswered questions, they are all mine. And so are certain solutions or verdicts that should be taken as personal reactions to the complexity of nature.

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EVOLUŢIA POLIMETAMORFICĂ A SERIEI DE SEBEŞ-LOTRU (CARPAŢII MERIDIONALI) REZULTATĂ DIN STUDIUL METAPELITELOR CU ALUMINO-SILICAŢI

(Rezumat)

I. PROBLEMATICA STUDIULUI

Lucrarea de faţă este dedicată problemelor de metamorfism pe care le ridică rocile metapelitice ce conţin în mod frecvent disten sau andaluzit şi/sau sillimanit. În aria de care ne ocupăm, aparţinând cristalinului seriei de Sebeş-Lotru, intensitatea metamorfismului este apreciată a se situa în faciesul amfibolitelor cu almandin.

Abordarea studiului metamorfismului a fost făcută pe tipuri de metamorfism: metamorfismul barrovian şi metamorfismul intermediar, de presiune coborâtă.

Studiul texturilor metamorfice din rocile metapelitice a pus în evidenţă caracterul dinamic, permanent schimbător, al acestor roci, rolul pe care l-au îndeplinit mişcările de deformare în facilitarea diferitelor transformări, pe de o parte, dar şi în departajarea celor câteva evenimente metamorfice, pe de altă parte. O importanţă majoră a relaţiilor texturale este aceea că ele semnifică reacţii minerale. Depistarea acestor reacţii, dacă este făcută corect, reprezintă pasul cel mai sigur spre stabilirea condiţiilor metamorfismului, sensul lor reprezentând sensul metamorfismului.

Consecinţa condiţiilor specifice în care s-a desfăşurat metamorfismul este, în primul rând, crearea unor entităţi metamorfice. În cadrul fiecărui tip de metamorfism există o zonalitate ce exprimă poziţia în spaţiu a gradienţilor de condiţii fizice.

Prin studiul relaţiilor minerale, din zona planelor izograde sau la limita dintre tipuri diferite de metamorfism, se pot depista modalităţile de transformare minerală prin care se face trecerea de la o zonă de metamorfism la alta, sensul prograd sau retrograd al metamorfismului şi relaţiile temporale dintre diferitele tipuri de metamorfism.

Un ultim capitol al lucrării este dedicat consecinţelor structurale ce derivă din caracterul policiclic al metamorfismului, cu o exemplificare concretă pentru zona Carpaţilor Meridionali centrali.

Gradul ridicat al metamorfismului ce a afectat rocile masivelor muntoase ale Carpaţilor Meridionali, gama variată de condiţii fizice precum şi fondul litologic adecvat au făcut posibilă larga răspândire a mineralelor aluminiu-silcatice, uneori fiind concentrate până la nivel de interes economic. Masivele cristaline cercetate în mod special, au fost cele apaţinând seriei de Sebeş-Lotru din domeniul Getic (Căpăţâna, Lotru Cibin, Sebeş, Godeanu, Mehedinţi, Ţarcu) pentru că acestea întrunesc cele mai favorabile dintre condiţiile enunţate.

II. METAMORFISMUL

A) Tipuri de metamorfism. Repartiţia lor areală

Examinarea asociaţiilor mineralogice din rocile metapelitice ale seriei de Sebeş-Lotru a evidenţiat o bipolaritate paragenetică:

- asociaţii minerale din care nu lipseşte andaluzitul şi/sau cordieritul, ambelor putându-li-se asocia sillimanitul,
- asociaţii minerale cu disten $\pm$ staurolit sau cu sillimanit.

Această din urmă asociaţie are cea mai largă răspândire şi este specifică aşa zisului metamorfism de tip barrovian, confundându-se aproape în totalitate cu aria de răspândire a seriei de Sebeş-Lotru. Pe teritoriul acestui tip de metamorfism a fost supraimpus un alt tip, intermediar, de presiune coborâtă (pirinean), în poziţie subsecventă faţă de primul şi răspândit în partea de est a peticului de acoperire Godeanu, pe cea mai mare parte a peticului de Bahna (insular şi în peticul Porţile de Fier) şi în zona central-sudică a munţilor Căpăţânii.

B) Evoluţia cristalizării metamorfice dedusă din texturi

În scopul efectuării unei analize cronologice privind formarea şi creşterea mineralelor principale ale rocii, este necesar a se departaja în timp mineralele sau grupele de minerale ce s-au format aproximativ în aceeaşi perioadă de timp.

Care sunt elementele care le departajează ?

Sistemul de referinţă cel mai important, deformarea, este o mişcare diferenţială pe suprafeţe echivalente. În raport cu acest element, formarea mineralelor poate avea loc în timpul sau după mişcările de deformare.

Cristalizarea sintectonică sau sindeformaţiomală a fost cercetată în special în legătură cu mineralele care cresc porfiroblastic şi cu forme în general izometrice. Este probabil că acestea nu sunt singurele care s-au format în acest timp ci mai trebuie luate în considerare şi mineralele ce alcătuiesc matricea rocei (mice, cuarţ, feldspaţi) care au o pondere volumetrică importantă. Mişcările de deformare le privim ca pe un prilej şi ca pe o sursă energetică pentru neoformarea masivă a mineralelor ce materializează planele S născute prin deformările invocate. Mineralele neoformate "ţin pasul" în mod permanent cu deformarea, astfel că la încetarea acesteia ele reprezintă produsul ei ultim şi alura poziţiei finale în care ea s-a manifestat. În acest fel, aceste minerale nu vor fi ele însile deformate ci vor fi doar imaginea ultimă a mişcării.

Alte elemente de departajare în timp a mineralelor dintr-o rocă:

- relaţii de substituţie
- gradul de idiomorfism
- gradul de deformare

Se admite că determinarea succesiunii de cristalizare într-o rocă metamorfică este o operaţie la care trebuie luate în considerare mai mult de unul din criteriile subliniate mai sus.

Pentru examinarea succesiunii de cristalizare din rocile cu minerale aluminosilicatice au fost cercetate în mod diferenţiat zonele de metamorfism pe tipuri.

1. Aria metamorfică de tip Barrovian. Rocile metapelitice aparţinând acestei arii dispun de o asociaţie minerală relativ simplă, cu minerale micacee+cuarţ – cu rol de matrice –, în care sunt implântate porfiroblaste de granat, staurolit, disten, plagioclaz.

Pentru a surprinde caracterul evolutiv al rocilor cercetate au fost folosite relaţiile interminerale şi relaţia mineral – eveniment deformaţional. În acest context au fost deosebite trei grupe de minerale: relicte, remobilizabile şi tardiv formate.

Mineralele relicte s-au format probabil în timpul unui eveniment metamorfic mai vechi. Specia acestor minerale se poate forma şi post sau sin-deformare. Sunt reprezentate prin disten, staurolit, granat, biotit, putând apare ca relicte în zona de metamorfism disten+staurolit. Ele sunt total distruse la actualul nivel de metamorfism al silimanitului.

Mineralele remobilizabile sunt cele cu o capacitate ridicată de reorganizare în timpul mişcărilor de deformare, imprimând rocii o nouă textură cu tendinţa accentuată de a şterge pe cea veche. Această reorganizare implică în special minerale micacee şi cuarţ dar poate angrena şi alte minerale precum granatul, distenul, staurolitul, care prezintă în acest caz caractere morfologice şi relaţii ce demonstrează neoformarea lor.

Grupa mineralelor tardiv formate include în sistematica ce o prezentăm, acele minerale care cristalizează static, după încetarea principalelor mişcări de deformare. Au o orientare indiferentă în textura rocii sau cristalizează mimetic.

Mineralele relicte se pot recunoaşte prin gradul de deformare ridicat, spre deosebire de cele aparţinând ultimelor două categorii.

Indicii ajutătoare pentru ierarhizarea mineralelor mai vechi în funcţie de vechime ne sunt furnizate şi de gradul mai avansat de digerare al mineraleor în comparaţie cu cele noi, de digerarea primelor de către ultimele, de gradul de idiomorfism şi de poziţia conformă sau nu în textura orientată a rocii.

Putem considera că posibilitatea păstrării unor minerale relicte în contextul unei neoformări minerale masive este dificilă şi se poate imagina că depinde de viteza de creştere a paragenezei noi şi de amploarea deformării care a provocat distrugerea paragenezei vechi.

Pentru exemplificarea afirmaţiilor de mai sus a fost prezentată o textură particulară considerată de noi ca un rezultat al cuplării fenomenelor deformare-neoformare minerală, într-un grad foarte avansat. Rezutatul conlucrării acestor două fenomene este o rocă megaporfirică alcătuită dintr-o matrice cuarţ-micacee, izotropă textural şi din megablaste de disten ce au o bordură de staurolit concrescut epitaxial cu distenul. Se mai găsesc de asemenea granaţi cu sau fără structură atol. Naşterea acestui tip de rocă a fost dedusă examinând relaţiile sale cu roca înconjurătoare şi fenomenele care au loc în zona de contact, plecând de la premisa că succesiunea spaţială a fenomenelor o reproduce pe cea în timp.

Din examinarea acestei texturi particulare, precum şi din consideraţiile prezentate mai înainte, se desprind unele caractere ale rocilor cristaline aparţinând domeniului barrovian din seria de Sebeş-Lotru. O primă observaţie este că mineralele pot fi departajate în funcţie de vechimea lor după gradul diferit de deformare şi digerare. Reacţia lor în afară de deformarea propriuzisă a fost de "distrugere" însoţită de o permanentă neoformare minerală. Neoformarea minerală reprezintă un procent însemnat din masa rocii, regenerată în acest episod de deformare, fapt care ne determină să considerăm că din punct de vedere cantitativ, transformările suferite de rocă sunt comparabile cu cele admise că se petrec într-un eveniment metamorfic major. Punerea sa în evidenţă a fost şi mai este încă dificilă, tocmai datorită amplorii desfăşurării sale în spaţiu, a reorganizării aproape integrale a mineralelor micacee şi, desigur, vechimii sale, care face extrem de dificilă identificarea ciclului geotectonic corespunzător evenimentului în discuţie. Intensitatea acestui nou eveniment metamorfic poate fi judecată după tipul de mineral index neoformat. S-a constatat că există dovezi de neoformare minerală până la nivelul sillimanitului, ceeace ne face să considerăm că nivelul maxim atins este comparabil cu cel definit de vechea asociaţie. Este puţin probabil ca poziţia zonelor metamorfice să fie aceeaşi, suprapunându-se arii cu intensitate diferită. Consecinţele acestui fapt, în mod previzibil, sunt: amestecul de minerale index (de intensităţi diferite sau de vârste diferite), complicarea fenomenelor petrecute la planul izograd, pierderea caracterului tranşant dintre vechile zone metamorfice. O altă consecinţă priveşte determinările de vârstă absolută, în special cele efectuate asupra mineralelor micacee proaspete. Vârstele determinate în acest caz sunt cele ale ultimului eveniment ce a generat micele proaspete şi nu ale celui în care s-a format majoritatea mineralelor de tip disten, staurolit şi granat. O ultimă consecinţă pe care o amintim este aceea care priveşte operaţia de cartare geologică, cu scopul său final de a stabili geometria corpurilor de rocă. Deducerea sa pe baza măsurătorilor foliaţiilor cel mai bine exprimate, în speţă S_2, pune sub semnul întrebării coincidenţa dintre acest plan şi limitele litologice primare S_0 sau foliaţia S_1 a primului metamorfism. De aici rezultă pericolul construirii limitelor corpurilor de rocă pe baza unor elemente geometrice diferite poziţional faţă de limitele iniţiale ale complexelor litologice şi pe baza unor limite litologice transpuse, aparţinând unor corpuri de rocă diferite.

2. *Aria metamorfică de tip intermediar.* Mineralele caracteristice acestui tip de metamorfism sunt andaluzitul, cordieritul şi sillimanitul. Ariile în care au fost întâlnite parageneze ce includ mineralele de mai sus sunt situate în munţii Godeanu, Mehedinţi şi Căpăţâna. Mineralele rocilor metapelitice care conţin aluminosilicaţi şi/sau cordierit se află în numeroase cazuri în relaţii reciproce, observabile la scară microscopică. Ele se pot raporta la mişcările de deformare care au creat textura foliată a rocilor sau la mineralele ce aparţin tipului de metamorfism barrovian, pe care le-au substituit în cea mai mare parte. Relaţiile cu acestea din urmă pot fi cercetate doar în zona de contact dintre ariile cu aceste două tipuri de metamorfism.

Analiza relaţiilor minerale din rocile aparţinând metamorfismului de tip intermediar denotă câteva trăsături:

a) mineralele index citate au o blasteză predominant statică, subsecventă ultimului eveniment deformaţional, cu tendinţa de a estompa foliaţia principală a rocii.

b) relaţiile dintre mineralele caracteristice tipului intermediar şi celelalte minerale sunt:

- substituţia staurolitului prin andaluzit
- biotitizarea granatului
- incompatibilitatea cordieritului cu staurolitul
- substituţia biotitului şi muscovitului de primă generaţie prin andaluzit şi/sau cordierit
- dezvoltarea sillimanitului din biotit, concreşterea frecventă între aceste minerale.

Toate aceste relaţii vor fi ulterior completate cu cele din zona de contact dintre cele două tipuri de metamorfism.

III. REACŢII MINERALE DEDUSE DIN RELAŢII TEXTURALE

Un pas important în sesizarea dinamicii metamorfismului l-a reprezentat recunoaşterea faptului că unele minerale sau grupe de minerale mai vechi sunt legate de cele mai noi prin reacţii minerale, grupele amintite reprezentând termeni ai acestor reacţii. În momentul de faţă posibilitatea cea mai eficientă de a stabili condiţiile în care au avut loc principalele evenimente metamorfice este aceea de a identifica cele mai importante reacţii care s-au petrecut în rocă.

Prima etapă care duce la stabilirea reacţiilor metamorfice este cunoaşterea diferitelor treceri (şi succesiuni de apariţie) între mineralele rocilor cercetate. Au fost selectate cele mai reprezentative relaţii minerale observate la microscop, exclusiv din zonele în care metamorfismul intermediar, de presiune coborâtă s-a suprapus peste cel de tip Barrovian. Aceste zone beneficiază de o conservare apreciabilă a numeroaselor relaţii minerale, fapt care derivă probabil din specificitatea celui de-al doilea tip de metamorfism şi, poate, din intervalul de timp mai scurt în care el a acţionat. Relaţiile minerale identificate semnifică în majoritatea cazurilor reacţii între mineralele implicate. O caracteristică a acestor reacţii, rezultată din analiza microscopică este aceea că apaţinând aceleiaşi asociaţii mineralogice sunt sincrone şi implicit, au avut loc în aceleaşi condiţii fizice. Rezultă că, în mod ideal, curbele trebuie să concure într-un punct sau o arie restrânsă, care reprezintă condiţiile în care asociaţia a fost în echilibru. Am reprezentat trei din aceste reacţii deduse din relaţiile interminerale, reacţii care au fost realizate experimental de către Richardson (1968). Intersecţia acestor curbe-reacţii are loc la cca 680^0 C şi la o presiune de 3,5 kbari. Deci aria termobarică în care au avut loc fenomenele implicate de reacţiile pomenite, trebuie să graviteze în jurul acestor valori.

IV. CONDIŢIILE METAMORFISMULUI

A) Argumente pentru existenţa entităţilor metamorfice

Condiţiile fizice din cele două mari domenii de metamorfism, pot fi cunoscute sub aspect cantitativ, folosind procedeul suprapunerii diferitelor diagrame de stabilitate (corespunzătoare unor minerale, asociaţii minerale sau relaţii dintre acestea) într-un acelaşi spaţiu P–T.

Pentru metamorfismul de tip barrovian a fost construită diagrama din fig. 47. Zona reprezentativă pentru acest tip de metamorfism este aceea a Carpaţilor Meridionali Centrali – munţii Lotrului. Domeniul de formare minerală din această arie este îngrădit de curba An_{30} + hornblendă, de linia de echilibru monovariant disten-sillimanit şi de curba anatexiei.

Pentru zonele de metamorfism de tip intermadiar, de presiune coborâtă am ales zona munţilor Mehedinţi (petecul de Bahna). A fost stabilită aici o zonalite metamorfică cu dispoziţie concentrică. Plecând de la premiza că succesiunea spaţială de asociaţii minerale din zonele amintite reprezintă succesiunea formării lor în timp, am situat într-o diagramă P–T (fig. 51) asociaţiile de minerale din fiecare zonă pe baza unor curbe de echilibru bine stabilite. Asociaţiile de minerale au fost figurate prin 5 puncte dispuse colinear, paralel cu axa temperaturii. Rezultă, în mod paradoxal, că metamorfismul de presiune coborâtă cercetat aici s-a realizat printr-o creştere de temperatură în condiţii izobare, fapt ce s-ar putea datora unui dom termic.

Succesiune în timp a celor două tipuri de metamorfism a fost demonstrată prin succesiunea paragenezelor specifice cât şi prin relaţii directe de substituţie a distenului prin andaluzit sau cordierit, a staurolitului prin andaluzit.

B) Zonalitatea metamorfică

S-a schiţat o zonalitate metamorfică pentru fiecare tip de metamorfism. Metamorfismul de tip barrovian, cu excepţia masivelor Semenic şi Godeanu, nu conţine decât două zone metamorfice: zona cu sillimanit şi zona cu disten+staurolit.

O caracteristică a modalităţii de reprezentare a izogradelor de metamorfism, aşa cum au fost înţelese până în prezent, este paralelismul aproape perfect între planele izograde şi planele litostratigrafice primare (S_0). Considerăm că acest fapt implică numeroase excepţii.

Metamorfismul intermediar, de presiune coborâtă comportă şi el o zonalitate metamorfică, faţă de care zonalitatea de tip barrovian este o paleozonalitate.

În munţii Godeanu, Bercia (1975) a stabilit că izogradele de metamorfism sunt concentrice, urmărind limitele litostratigrafice cvasiorizontale. Rezultă o zonalitate metamorfică în relaţii de superpoziţie: zona cu sillimanit+cordierit+andaluzit la partea inferioară, zona cu anadaluzit într-o poziţie mediană iar la partea superioară zona cu andaluzit+staurolit.

Zonalitatea din munţii Mehedinţi va fi prezentată şi explicată într-un capitol următor.

În munţii Căpăţânii am evidenţiat următoarea zonalitate (areală): zona cu sillimanit+cordierit în partea centrală şi zona cu andaluzit+sillimanit+cordierit la exteriorul primei.

C) Relaţiile minerale la planul izograd şi la limita dintre ariile cu tipuri diferite de metamorfism

Evoluţia cristalizării metamorfice dedusă din relaţiile minerale este de fapt o succesiune de reconstituiri de secvenţe izolate, pentru că acestea sunt, cel mai adesea, greu păstrate.

În cazul metamorfismului de tip barrovian este previzibil că intervalul de tranziţie dintre zonele metamorfice conţin elemente de dispariţie şi de primă apariţie ale celor două zone vecine. Preocupările noastre au vizat găsirea unor reacţii "îngheţate" din zona planului izograd. La izogradul disten-sillimanit nu au fost găsite relaţii directe între aceste două minerale. S-au putut observa însă două situaţii:

a) Cele două minerale index sunt însoţite de relaţii minerale adiacente care le implică. Cel mai frecvent mod de dispariţie al distenului este prin substituţia sa de către muscovit. Ca o relaţie complementară se remarcă biotitizarea granatului şi transformarea biotitului în sillimani. Distenul mai este substituit de către biotit sau plagioclaz.

b) Distenul şi sillimanitul coexistă netransformate, în strătuleţe individuale, adiacente, la distanţe milimetrice sau submilimetrice.

În cadrul metamorfismului de presiune coborâtă au fost efectuate detalieri importante în ce priveşte zonalitatea metamorfică, fiind în prezent în măsură să dăm o zonalite mai simplă pentru petecul de Bahna şi mai conformă cu realitatea terenului. Am separat astfel doar două zone: zona cu andaluzit în est şi zona cu cordierit+sillimanit+feldspat potasic în vest. Zonele cu asociaţiile andaluzit+sillimanit+cordierit sau sillimanit+andaluzit sau cordierit+andaluzit, destul de discontinue le putem considera asociaţii de plan izograd, conţinând elemente a două zone metamorfice adiacente.

Relaţiile minerale mai importante din această regiune au fost figurate pe o hartă, fie prin arii de izorelaţii minerale, fie prin linii, după cum urmează: relaţia de substituţie a staurolitului prin andaluzit; relaţia de substituţie a granatului prin biotit; relaţia sillimanit-biotit; (areale) şi relaţia de substituţie a biotitului de o generaţie mai veche prin andaluzit (lineară). Orientarea generală a acestor linii sau arii de izorelaţii minerale este NNE–SSW. La sud de localitatea Izverna am trasat limita ariei (de dispariţie) a staurolitului, pe care noi îl considerăm exclusiv relict. În acest caz, acestei limite i-am acordat valoarea unui paleoizograd ce desparte paleozona cu disten şi staurolit din sud. de paleozona cu disten din nord.

Toate aceste relaţii expuse mai sus, precum şi dispoziţia spaţială a liniilor ce marchează izorelaţii minerale, sugerează reacţii metamorfice posibile care ar fi putut prilejui trecerea de la un tip de metamorfism la altul şi respectiv, în cadrul aceluiaşi tip de metamorfism, de la o zonă la alta. Astfel, pentru limita estică a ariei de presiune coborîtă cu aria de metamorfism Barrovian, cele mai frecvente relaţii de substituţie sunt: disten → andaluzit; granat → biotit; staurolit → andaluzit; biotit → andaluzit.

Aceste relaţii ar sugera reacţii de forma:

disten + granat + staurolit + biotit → andaluzit + biotit

Această reacţie ar materializa condiţiile care ar însoţi trecerea de la tipul Barrovian la cel de presiune coborâtă de metamorfism.

În interiorul ariei cu metamorfism de presiune coborâtă, planul izograd dintre cele două zone metamorfice ar putea fi materializat prin reacţia:

andaluzit+biotit → sillimanit+cordierit+feldspat potasic,

reacţie ce are însuşirea de a fi omniprezentă prin permanenta existenţă a membrilor finali în cele două zone metamorfice adiacente.

Este probabil că termenul al doilea al racţiei a doua, în vecinătatea vestică a zonei de metamorfism Barrovian, poate proveni de asemenea printr-o reacţie de tipul:

disten+staurolit+biotit → sillimanit+cordierit+feldspat potasic

Considerăm că aceste reacţii, desigur foarte simplificate, reprezintă o realitate a terenului şi pot fi folosite pentru stabilirea condiţiilor fizice în care s-au desfăşurat, deşi, din păcate, ele implică şi minerale cu chimism şi respectiv parametri termodinamici variabili.

D) Comentarii asupra relaţiilor dintre cele două tipuri metamorfice

Reamintim că în cadrul ariei metamorfice barroviene au fost stabilite momente importante. În cadrul ariei de metamorfism de tip intermediar, de presiune coborâtă, nu a mai fost depistată existenţa celor două momente amintite mai sus. O primă explicaţie ar fi aceea a dificultăţii conservării individualităţilor paragenetice în cazul suprapunerii atâtor evenimente deformaţionale şi de neoformare minerală.

O altă explicaţie care aruncă o lumină nouă asupra succedării principalelor evenimente metamorfice ar consta din coincidenţa dintre planul S_2 barrovian şi alura planelor izograde din aria cu metamorfism de tip intermediar. Aceasta sugerează o legătură între deformarea D_2 şi metamorfismul de tip intermediar în sens asociativ.

Numeroase relaţii minerale sau alte caractere ale mineralelor din aria barroviană nu mai sunt întâlnite în aria de presiune coborâtă iar relictele barroviene din acesată din urmă arie par a fi de tipul barrovian vechi (momentul I).

Toate acestea sugerează ideea unui sincronism între al doilea moment barrovian şi momentul de tip intermediar, de presiune coborâtă.

Cu alte cuvine, metamorfismul de tip intermediar (pirinean) reprezintă un mod particular de manifestare a fazei a doua de metamorfism din domeniul barrovian. În opinia noastră, aria metamorfică aparţinând seriei de Sebeş-Lotru, a suferit două momente importante de metamorfism din care primul a fost foarte omogen cu un sincronism al momentelor deformare-neoformare minerală pe toată aria sa. Al doilea moment a afectat şi zone mai puţin profunde (ceeace ar explica mai simplu "caracterul de înaltă temperatură al paragenezei de joasă presiune"), caracterizându-se şi prin lipsa de coincidenţă a momentului de apex termal cu momentul deformării, acesta din urmă precedându-l pe primul.

Este evident că "soluţia termică" ce explică apariţia metamorfismului de presiune coborâtă pe aria seriei de Sebeş-Lotru, trebuie argumentată şi prin alte metode.

V. OPINII STRUCTURALE PRIVIND SERIA DE SEBEŞ-LOTRU

Pentru descifrarea evoluţiei structurale şi petrologice în terenuri cristaline intens şi repetat metamorfozate, am ales spre exemplificare aria Carpaţilor Meridionali centrali, respectiv seria de Sebeş-Lotru din munţii Sebeş şi Cibin.

A) Alura aliniamentelor de roci cu litologie contrastantă

În contrast cu fondul litologic monoton (plagiognaise şi micaşisturi), în aria discutată se pot separa unele formaţiuni litologic contrastante: roci carbonatice, roci manganifere, amfibolite.

Rocile manganifere se dispun pe câteva aliniamente în două tronsoane:
- tronsonul de vest are un caracter fasciculat, cu aspect general de jerbă divergentă spre sud-vest, fiind alcătuit din 3–4 aliniamente ce converg în zona văii Cugirului;
- tronsonul de est prezintă acelaşi caracter fasciculat dar îşi păstrează o orientare generală est-vest.

Rocile carbonatice sunt răspândite în special în partea de sud a ariei discutate, în bazinul văii Jiului de est. O caracteristică a aliniamentului de roci carbonatice este caracterul său centrifugal, cu un centru de convergenţă în zona în care aflorează corpul de granit sincinematic de la Voevodu. Un alt caracter este fascicularizarea sa, cu tendinţă de asemenea centrifugală, mai accentuată pe măsura depărtării de zona de convergenţă maximă.

Rocile amfibolice sunt mai numeroase şi mai dificil de corelat, numeroasele corpuri de amfibolite dispunându-se cu aceeaşi alură.

B) Orientarea generală a foliaţiilor de şistozitate şi a lineaţiilor, plasarea granitului sincinematic în zona de maximă convergenţă a acestora

Aceste elemente planare şi lineare au aceeaşi recurbare în zona de maximă concentrare de la Voevodu, astfel încât granitul situat în această zonă poate fi considerat ca un punct nodal al structurii. Acest granit are o compoziţie intermediară spre alcalină. Conţine enclave de roci amfibolice sau metapelitice. Foliaţiile rocilor cristaline adiacente mulează forma corpului granitic, însuşi granitul având un caracter slab foliat şi linear. Are o formă alungită est-vest. Aceste caractere pledează pentru un caracter sincinematic în raport cu momentul D_2. Mişcarea masei de roci de deasupra granitului a fost ascensională, ca şi a acestuia iar frecarea dintre granit şi şisturile cristaline adiacente sau dintre acestea şi altele mai îndepărtate, a prilejuit o transmitere a mişcării după o curbă hiperbolică.

O altă mişcare este aceea efectuată în planul S_2 al foliaţiei de şistozitate, amploarea sa fiind apreciabilă, putând fi dedusă din unghiul de rotaţie al mineralelor sincinematice.

Deci mişcările suferite de rocile din această zonă reprezintă un rezultat al acţiunii combinate a celor două mişcări-deformări: cea care s-a manifestat la nivelul planului S_2 (constantă şi generală), pe fondul căreia s-a desfăşurat mişcarea-deformarea provocată de deplasarea ascensională a granitului.

C) Elemente microstructurale în sprijinul policiclicităţii

La capitolul de metamorfism am adus dovezi despre existenţa a cel puţin două momente de deformare-reorganizare importante ce au afectat seria de Sebeş-Lotru. Accentuăm că neoformarea şi deformarea la nivelul unui plan S produce un important fenomen - transpoziţia - care modifică radical orientarea corpurilor de roci la nivel mezoscopic.

D) Distribuţia pe verticală a complexelor litologice

În mod statistic există o distribuţie în plan vertical a celor două entităţi litologice (rocile cuarţo-feldspatice şi metapelitele), precum şi a tranziţiilor dintre acestea. Se remarcă o "preferinţă" a rocilor aluminoase (micaşisturi cu disten+granaţi) de a ocupa crestele cele mai înalte. Limitele acestui tip litologic reprezintă o mediere a numeroaselor lentile de micaşisturi cu disten. Efectul deformaţional şi de transpoziţie al lui S_2 a creat o reorientare reală a corpurior mici de roci, la nivel mezoscopic.

Gnaisele cuarţo-feldspatice au dimpotrivă o "preferinţă" statistică pentru zonele mai coborâte, aflorând pe fundul văilor mai adânci. Cu poziţie intermediară, altitudinal şi litostratigrafic se află diferite tipuri de plagiognaise cu granaţi, staurolit, ±disten±microclin.

E) Aliniamentele de blastomilonite. Poziţia lor în spaţiu şi în timp

În aria cercetată s-au evidenţiat câteva aliniamente de roci ultradeformate ductil. Foliaţia lor concordă parţial cu S_2. Neoformarea minerală din aceste roci este reprezentată prin mice şi cloritoid. Minerale ca granaţii, aluminosilicaţii, feldspaţii au supravețuit ca relicte într-o matrice fin cristalizată. Se poate deduce că gradul metamorfismului din aceste zone de milonitizare ductilă a fost egal sau puţin mai coborât decât cel din rocile adiacente.

Se remarcă faptul că în lungul planului de blastomilonite vin adesea în contact zone de metamorfism diferite: staurolit+disten şi sillimanit, cea din urmă situându-se geometric, uneori, peste cea dintâi. Considerăm deci că în unele locuri planul de blastomilonite poate avea valoarea unui plan de încălecare sincron sau mai tardiv în raport cu S_2.

F) Consecinţe structurale

A reieşit din cele prezentate că alura spiralată a diferitelor formaţiuni litologice, rezultă din combinarea de mişcări citată.

Dar pe ce fond structural s-au manifestat aceste mişcări?

Alura foarte regulată a curbării diverselor elemente urmărite, faptul că în partea de nord a zonei cercetate, unde se stinge efectul ridicării granitului, rocile metapelitice au o poziţie cvasiorizontală şi planară, ne face să afirmăm că structurile urmărite nu pot rezulta decât prin acţiunea cuplată a mişcărilor citate, pe un fond iniţial planar şi cvasiorizontal. Structura locală rezultată de care ne-am ocupat aici este o structură domală, având apexul în zona de aflorare a granitului de la Voevodu.

INSTRUCŢIUNI PENTRU AUTORI

Vor fi acceptate numai lucrările originale care prezintă concis şi clar informaţii noi. Manuscrisul va fi supus lecturii critice a unuia sau mai multor specialişti; după a doua revizie nesatisfăcătoare din partea autorilor va fi respins definitiv şi nu va fi înapoiat.

Manuscrisele trebuie prezentate, de regulă, în engleză sau franceză; cele prezentate în limba română trebuie să fie însoţite de un rezumat, în engleză sau franceză, de maximum 10 % din volumul manuscrisului.

Lucrările trebuie depuse, în două exemplare, la secretariatul Comitetului de redacţie, inclusiv ilustraţiile în original. Manuscrisul trebuie să cuprindă: textul (cu o pagină de titlu, care este şi prima pagină a lucrării), bibliografie, cuvinte cheie, abstract, ilustraţii, explicaţii ale figurilor şi planşelor, şi un sumar cu scop tehnic.

Se va adăuga o filă separată cu un sumar, în care se va indica ierarhia titlurilor din text în clasificarea zecimală (1; 1.1; 1.1.1), care nu trebuie să depăşească patru categorii.

Textul va fi dactilografiat la două rînduri (31 rînduri/pagină şi 64 semne/rând), pe o singură parte a colii, cu un spaţiu liber de 3–4 cm în partea stângă a paginii şi nu trebuie să depăşească 20 pagini dactilografiate (inclusiv bibliografia şi figurile).

Prima pagină a textului va cuprinde: a) titlul lucrării (concis, dar informativ), cu un spaţiu de 8 cm deasupra; b) numele întreg al autorului (autorilor); c) instituţia (instituţiile) şi adresa (adresele) pentru fiecare autor sau grup de autori; d) colontitlu de maximum 60 semne. Notele de subsol se vor numerota consecutiv.

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Abstractul, maximum 20 rânduri, trebuie să fie în limba engleză şi să prezinte pe scurt principalele rezultate şi concluzii (nu o simplă listă cu subiecte abordate).

Cuvintele cheie (maximum 10) trebuie să fie în limba engleză sau franceză, corespunzător limbii în care este lucrarea (sau abstractul, dacă textul este în română), prezentate în succesiune de la general la specific şi dactilografiate pe pagina cu abstractul.

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Exemple:

a) jurnale:

Giuşcă, D. (1952) Contributions à l'étude cristallochimique des niobates. *An. Com. Geol.*, XXIII, p. 259–268, Bucureşti.

– Pavelescu, L. (1954) Contribuţii la studiul mineralogic al zăcământului de la Muşca. *Comm. Acad. Rom.*, IV, 11–12, p. 658–991, Bucureşti.

b) publicaţii speciale:

Strand, T. (1972) The Norwegian Caledonides. p. 1–20. In: Kulling, O., Strand, T. (eds.) Scandinavian Caledonides, 560 p., Interscience Publishers.

c) cărţi:

Bălan, M. (1976) Zăcămintele manganifere de la Iacobeni. Ed. Acad. Rom., 132 p., Bucureşti.

d) hărţi:

Ionescu, I., Popescu, P., Georgescu, G. (1990) Geological Map of Romania, scale 1:50,000, sheet Câmpulung. Inst. Geol. Geofiz., Bucureşti.

e) lucrări nepublicate sau rapoarte:

Dumitrescu, D., Ionescu, I., Moldoveanu, M. (1987) Report. Arch. Inst. Geol. Geofiz., Bucureşti.

Lucrările sau cărţile publicate în rusă, bulgară, sârbă etc. trebuie menţionate în bibliografie transliterând numele şi titlurile. Exemplu:

Krasheninnikov, V. A., Basov, I. A. (1968) Stratigrafiya kainozoia. Trudy GIN, 410, 208 p., Nauka, Moskow.

Ilustraţiile (figuri şi planşe) trebuie numerotate şi prezentate în original, pe coli separate (hîrtie de calc), bune pentru reprodus. Dimensiunea liniilor, a literelor şi simbolurilor pe figuri trebuie să fie suficient de mare pentru a putea fi citite cu uşurinţă după ce au fost reduse. Dimensiunea originalului nu trebuie să depăşească suprafaţa tipografică a paginii: lăţimea coloanei 8 cm, lăţimea paginii 16,5 cm, lungimea paginii 23 cm, pentru figuri, iar pentru planşele liniare nu trebuie să depăşească dimensiunile unei pagini simple (16,5/23 cm) sau duble (23/33 cm) şi trebuie să fie autoexplicativă (să includă titlul, autori, explicaţie etc.). Scară grafică obligatorie.

Ilustraţiile fotografice (numai alb-negru) trebuie să fie clare, cu contrast bun şi grupate pe planşe de 16/23 cm. In cadrul fiecărei planşe numărătoarea fotografiilor se repetă (de. ex. Pl. I, fig. 1, Pl. II, fig. 1).

Tabelele vor fi numerotate şi vor avea un titlu. Dimensiunea originală a tabelelor trebuie să corespundă dimensiunilor tipografice menţionate mai sus (8/16,5 sau 16,5/23).

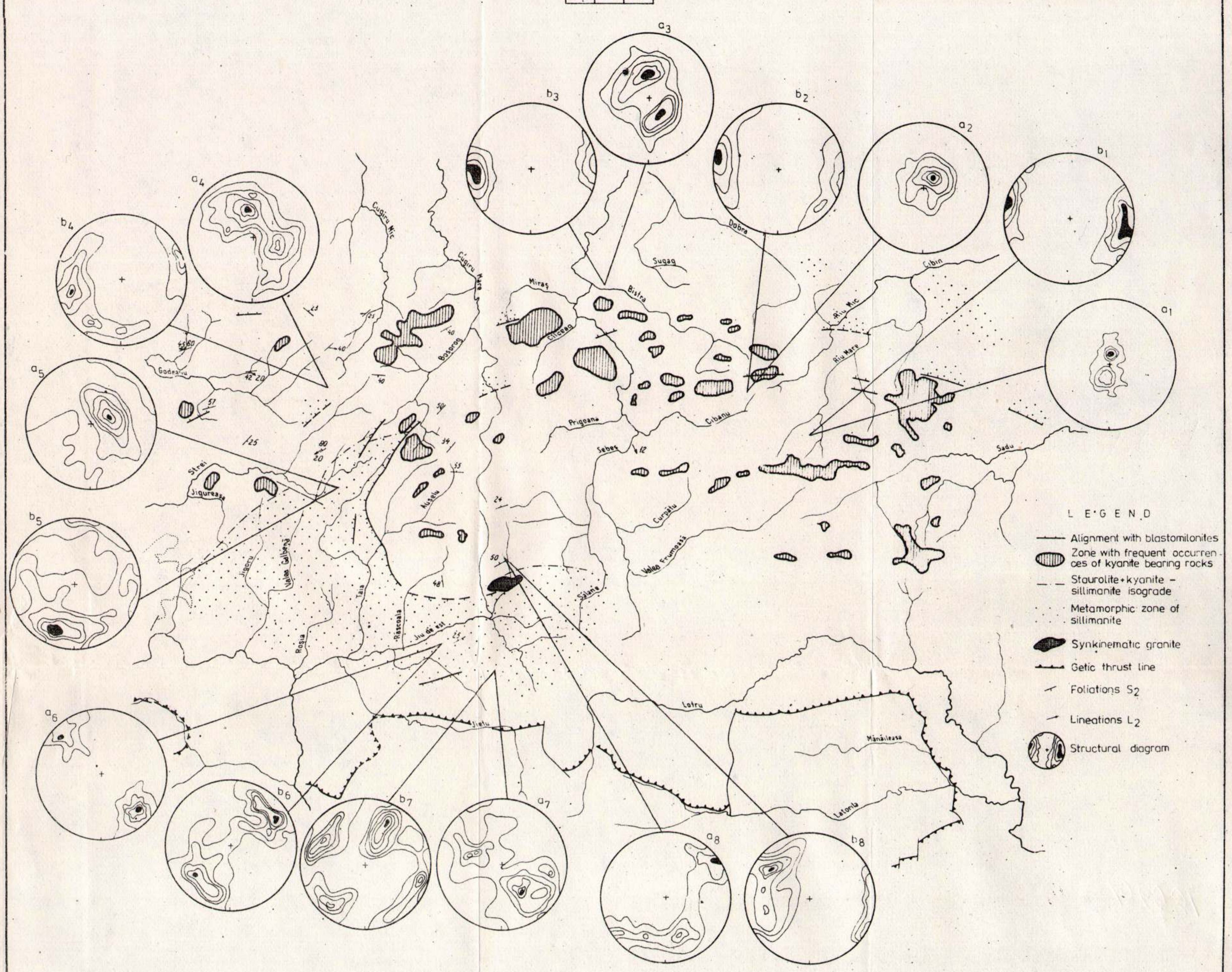
Autorii vor primi un singur set de corectură, pe care trebuie să-l înapoieze, cu corecturile corespunzătoare, după 10 zile de la primire. Numai greşelile de tipar trebuie corectate; nu sînt acceptate modificări.

Autorii vor primi gratuit 30 de extrase pentru fiecare lucrare.

Comitetul de redacţie

SKETCH MAP SHOWING STRUCTURAL AND METAMORPHIC FEATURES OF CENTRAL SOUTH CARPATHIANS

0 2 4 6 km



LEGEND OF STRUCTURAL DIAGRAMS

Homogeneous structural areas for axis B_2

1. Niculeşti - Bătrina - Riul Mare
   - a_1 foliations: 250 measurements 0.5-4-8-11 %
   - b_1 lineations: 87 measurements 1-3-6-11 %
2. Valea Bistra - Strimba Mare
   - a_2 foliations: 130 measurements 0.3-2.5-5-7.5-14-17-24 %
   - b_2 lineations: 130 measurements 0.7-3.5-10.5-15 %
3. Valea Bistra - Valea Sebeş
   - a_3 foliations: 820 measurements 1-3-5-7.5-8 %
   - b_3 lineations: 88 measurements 1-3.5-10-17 %
4. Strei - Grădiştea de Munte
   - a_4 foliations: 461 measurements 0.5-1-3-5-8-10 %
   - b_4 lineations: 315 measurements 0.5-1-3-4.5-7 %
5. Valea Taia - Valea Sasului
   - a_5 foliations: 760 measurements 0.1-0.5-1-2-4-6-8-10-15 %
   - b_5 lineations: 420 measurements 0.2-0.5-1-2-4-6-8-10 %
6. Valea Sterminosu - Valea Jiul de Est
   - a_6 foliations: 340 measurements 0.5-1-2-3-4-5-6-7-8 %
   - b_6 lineations: 109 measurements 1-2.5-3.5-4-6-7 %
7. Valea Cimpa - Capra
   - a_7 foliations: 347 measurements 0.6-1-2-3-4-5 %
   - b_7 lineations: 72 measurements 1-2-3-4-5-6-9 %
8. Valea Voevodu - Valea Bilele
   - a_8 foliations: 170 measurements 1-2-3-6-8-10 %
   - b_8 lineations: 49 measurements 1.2-2.5-5-7.5-10-20 %

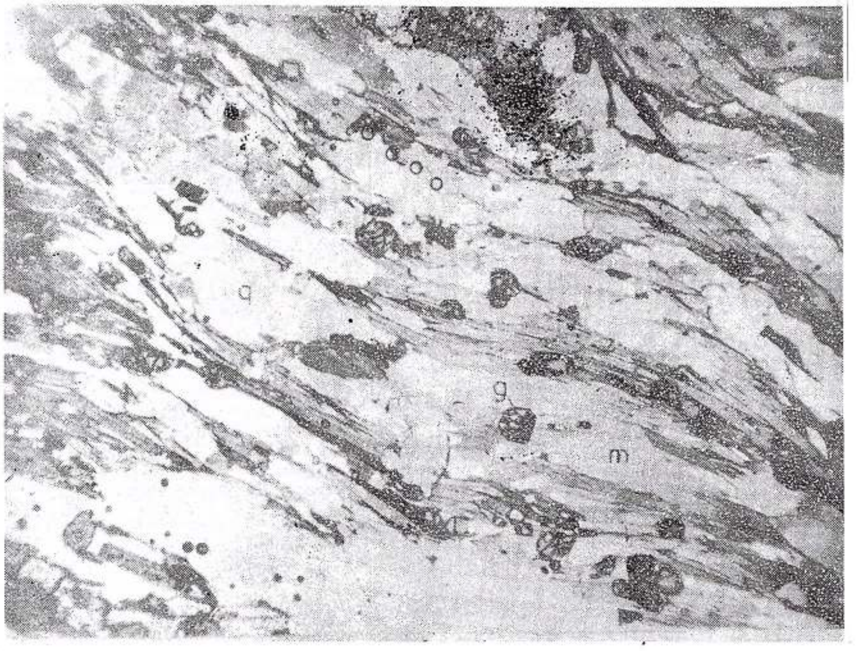


Fig. 1 Amply folded michaschist with rectilinear micas and broken garnets. N|| , 75X; g-garnet, q-quartz, m-micas.

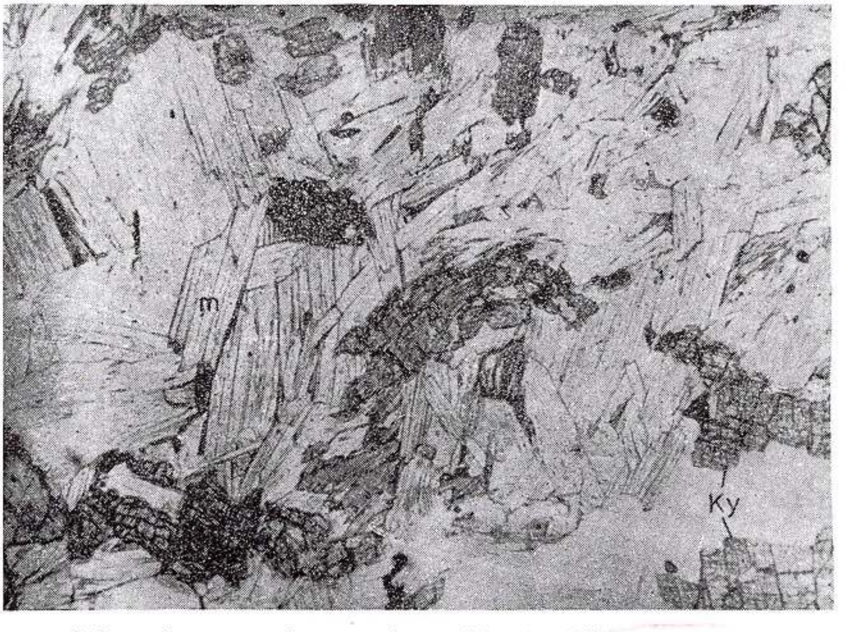


Fig. 2 - Deformation contrast between micas and kyanite. N||, 75X; m-micas, ky-kyanite.

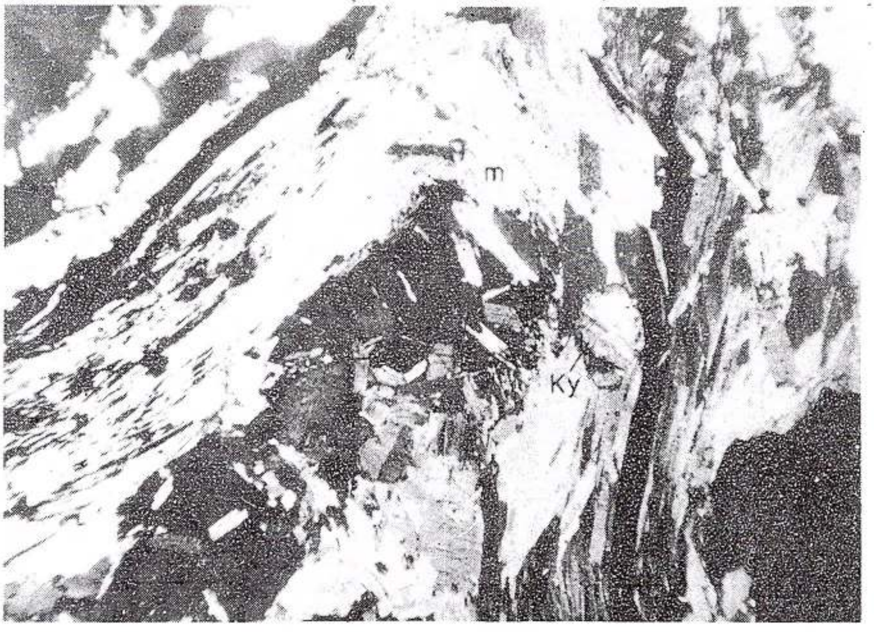


Fig. 1 – Rectilinear segments of micaceous minerals making up a fold. N+ ; 75X, m–micas. ky deformed kyanite crystal.

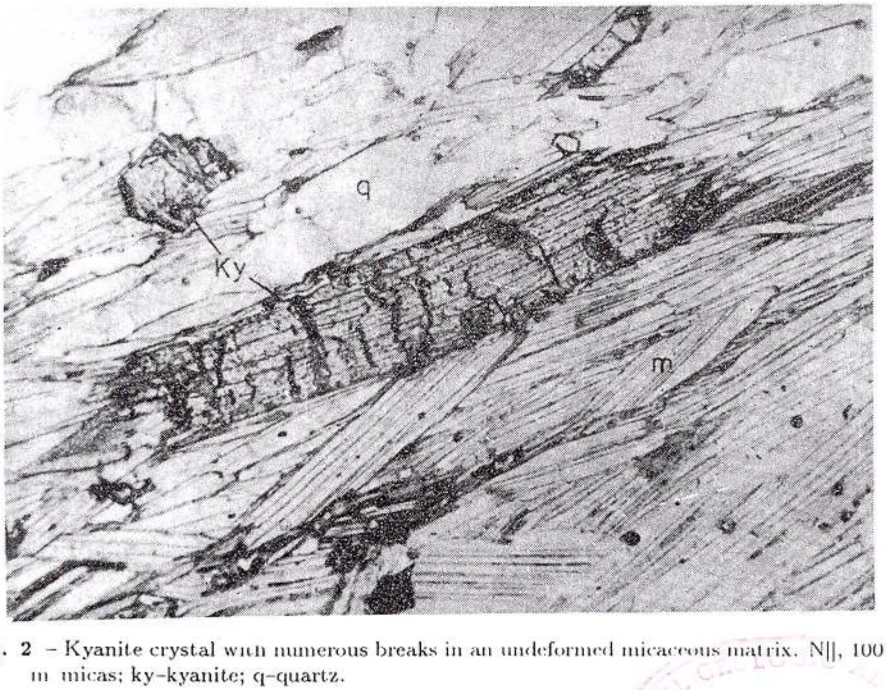


Fig. 2 – Kyanite crystal with numerous breaks in an undeformed micaceous matrix. N||, 100X; m micas; ky–kyanite; q–quartz.

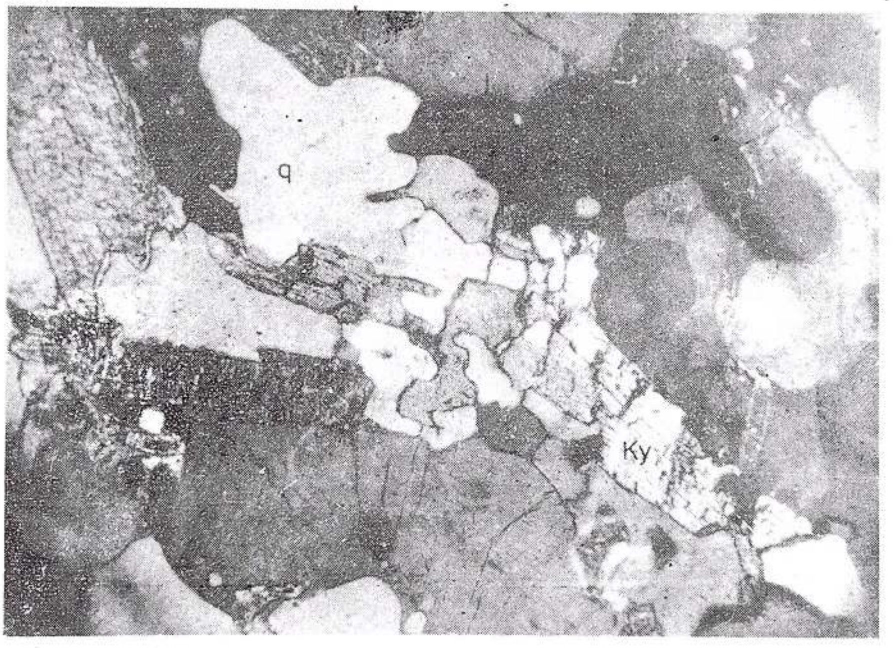


Fig. 1 – Kyanite crystal partially digested by quartz. The kyanite is bent and included in an undeformed quartzo-micaceous matrix. N+, 75X; ky–kyanite; q–quartz.

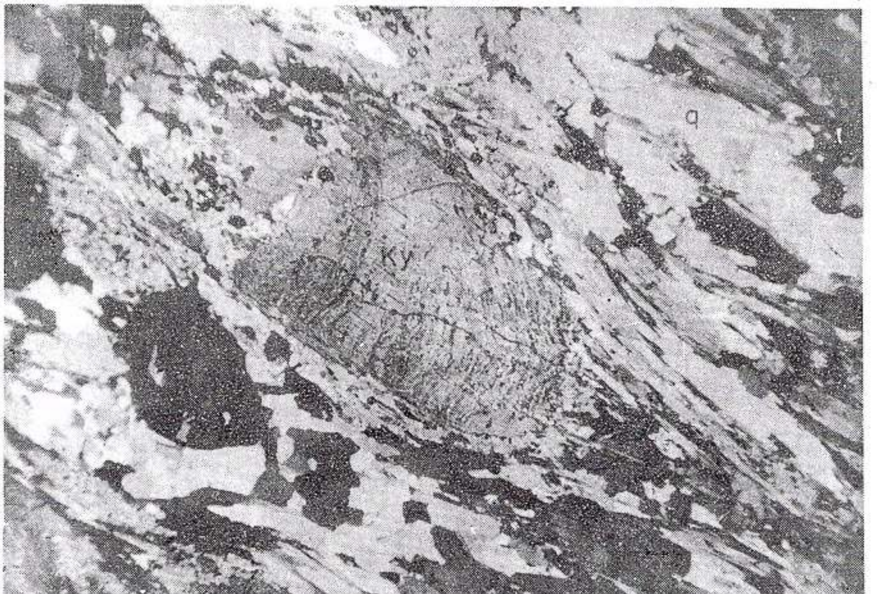


Fig. 2 – Trails of kyanite inclusions (Si), transversally disposed on foliation (Se). N+, 75X; ky–kyanite; q–quartz.

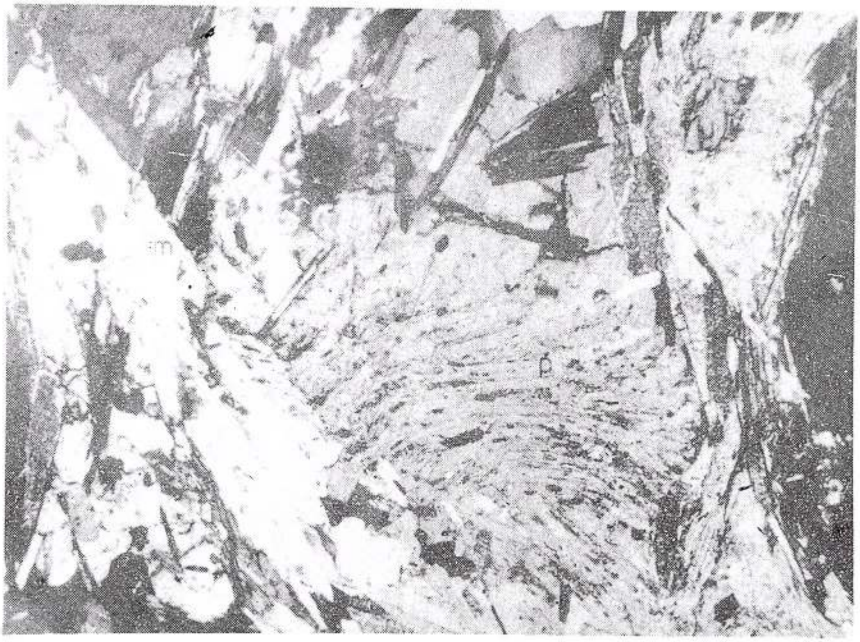


Fig. 1 – Si/Se unconformity; the trails of inclusions in feldspar are disposed in a fan. N+, 100X; p–plagioclase; m–micas.

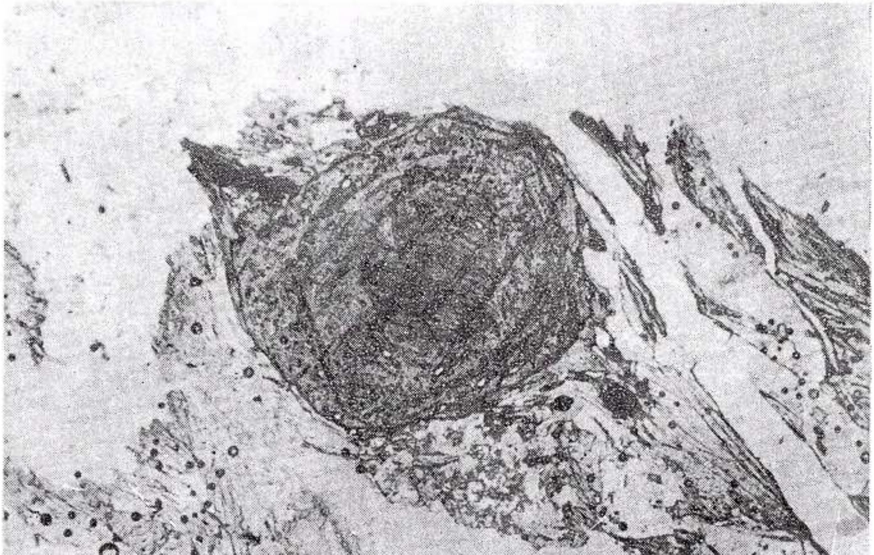


Fig. 2 – Blastesis movement relation materialized in a garnet crystal. N||; 100X.

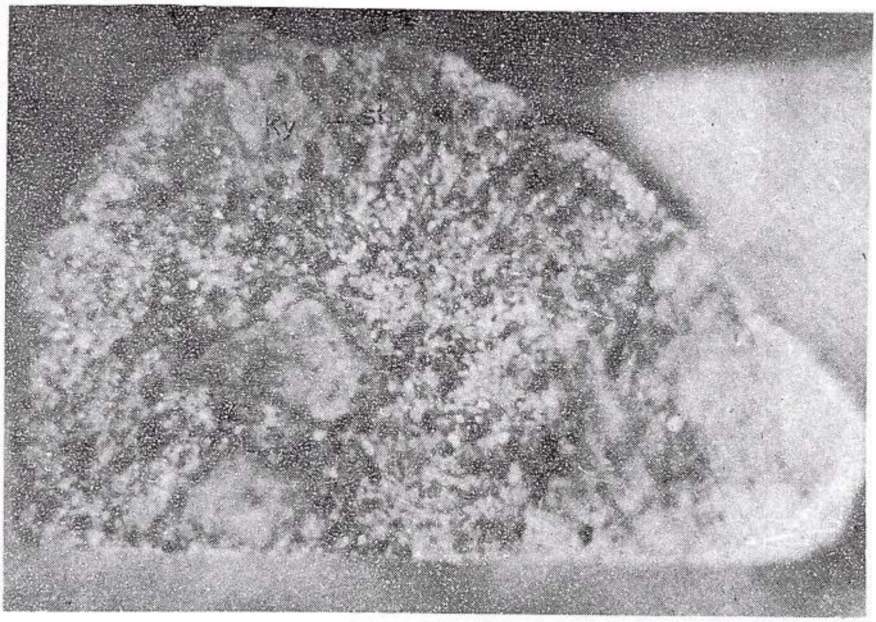


Fig. 1 – Massive texture in a metamorphic rock F (photo of sample). ky–kyanite, st–staurolite crystal border.

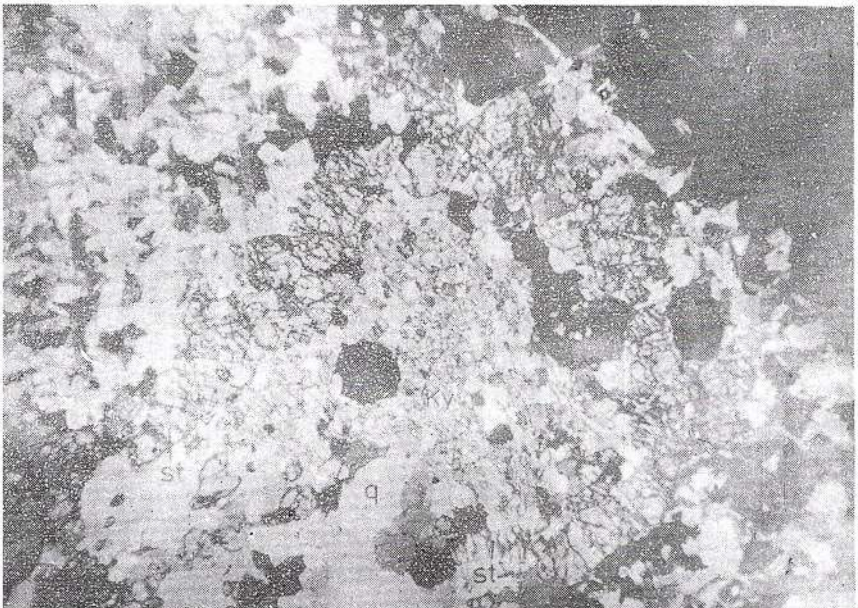


Fig. 2 – Staurolite epitaxial intergrowth on kyanite. Partial substitution of kyanite by quartz. N+, 75X; ky–kyanite; st–staurolite; q–quartz.

Fig. 1 – Differentiated evolution of the garnet included in kyanite and of that in the matrix.

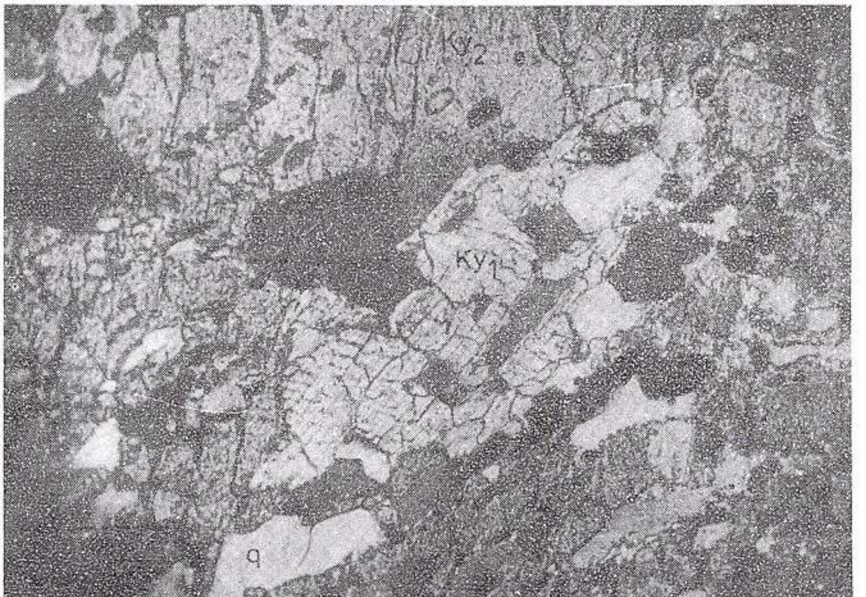


Fig. 2 – Temporal relations in kyanite blastesis. ky_1–1^{st} generation kyanite; ky_2–2^{nd} generation kyanite; q–quartz. N+, 150X.

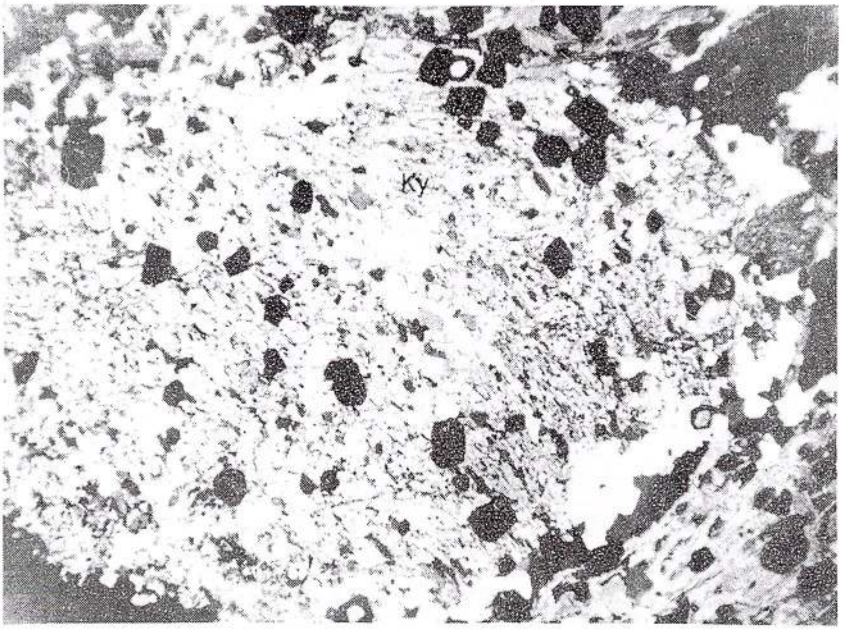


Fig. 1 – Unconformable position of the trails of inclusions in kyanite against the foliation of the near by matrix. N+, 100X; ky–kyanite.

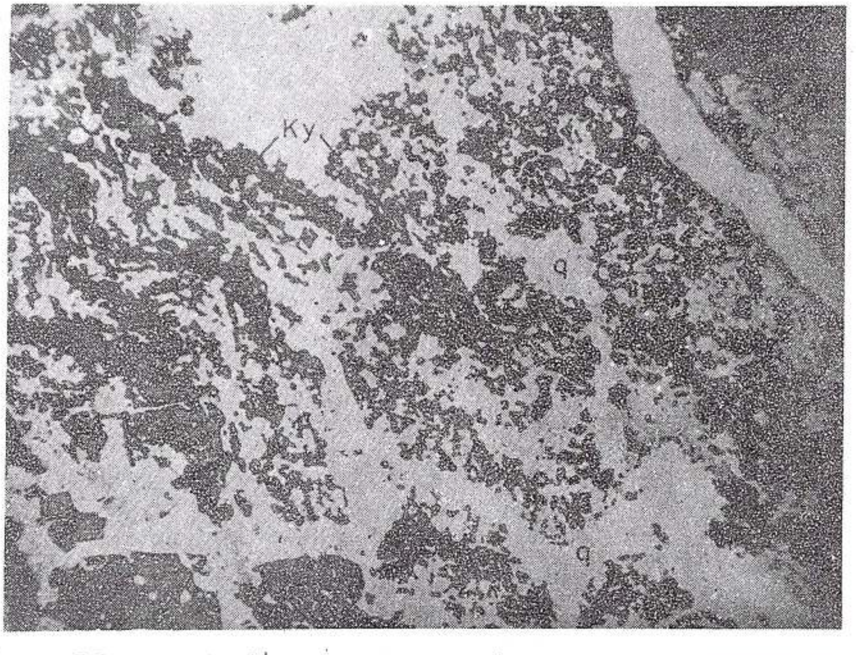


Fig. 2 – Paleotexture in 2^{nd} generation kyanite. N||, 75X; ky–kyanite; q–quartz.

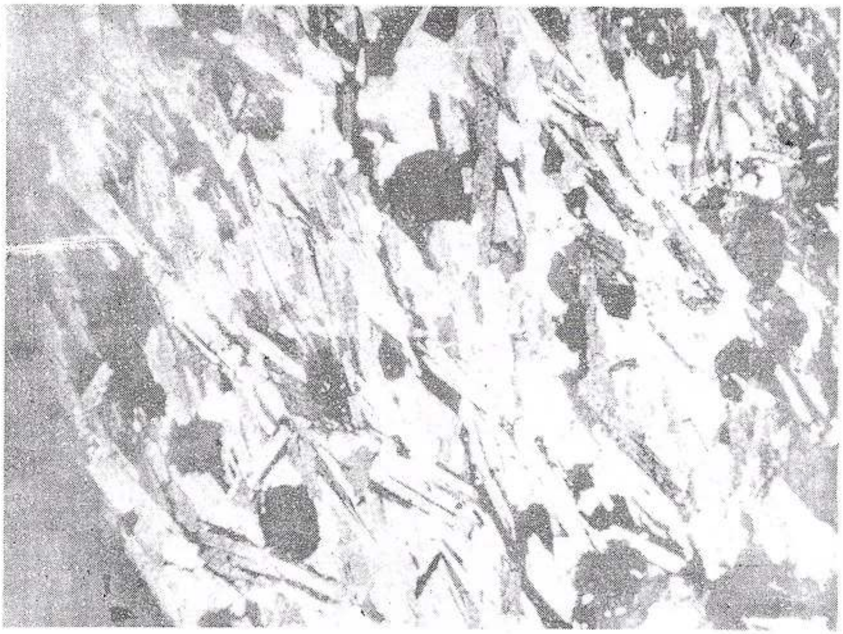


Fig. 1 – Orientation of micas in the matrix after at least two directions. N+, 75X.

Fig. 2 – Metastable persistence of staurolite in the sillimanite zone. N||, 75X; st–staurolite; s–sillimanite.

I. HÂRTOPANU – Aluminium Silicate-Bearing Rocks in the South-Carpathians

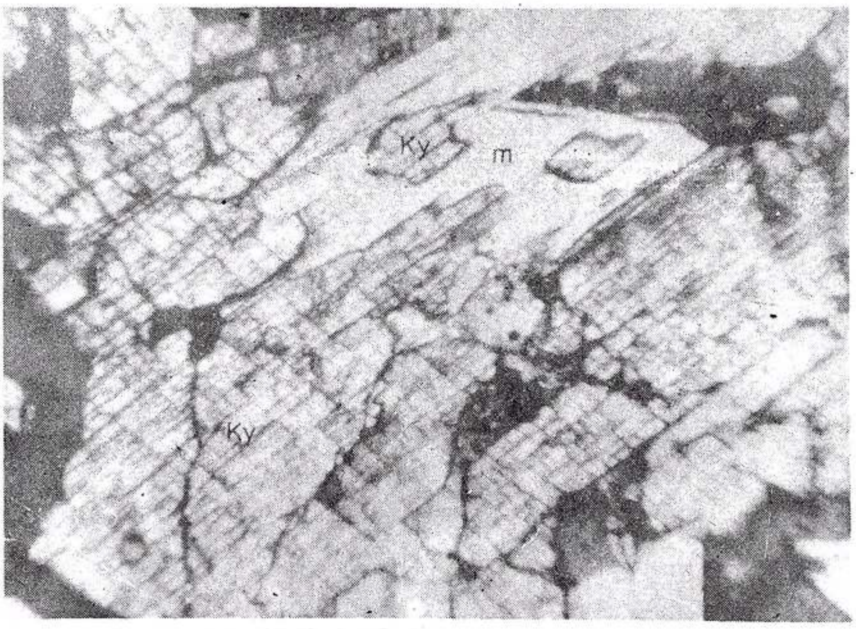


Fig. 1 – Substitution of kyanite by muscovite. N+, 100X; ky-kyanite; m-muscovite.

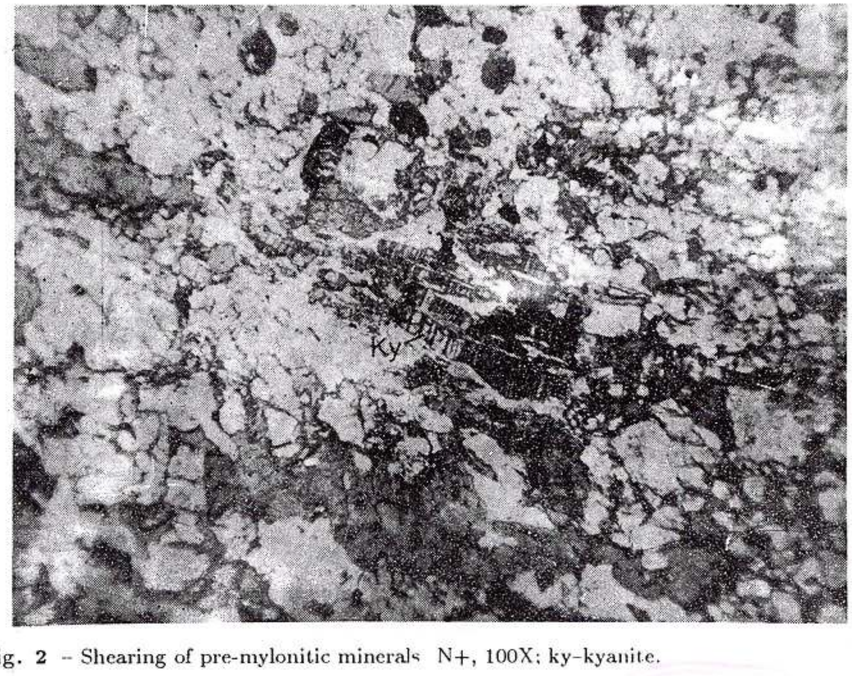


Fig. 2 – Shearing of pre-mylonitic minerals N+, 100X; ky-kyanite.

I. HÂRTOPANU – Aluminium Silicate–Bearing Rocks in the South–Carpathians

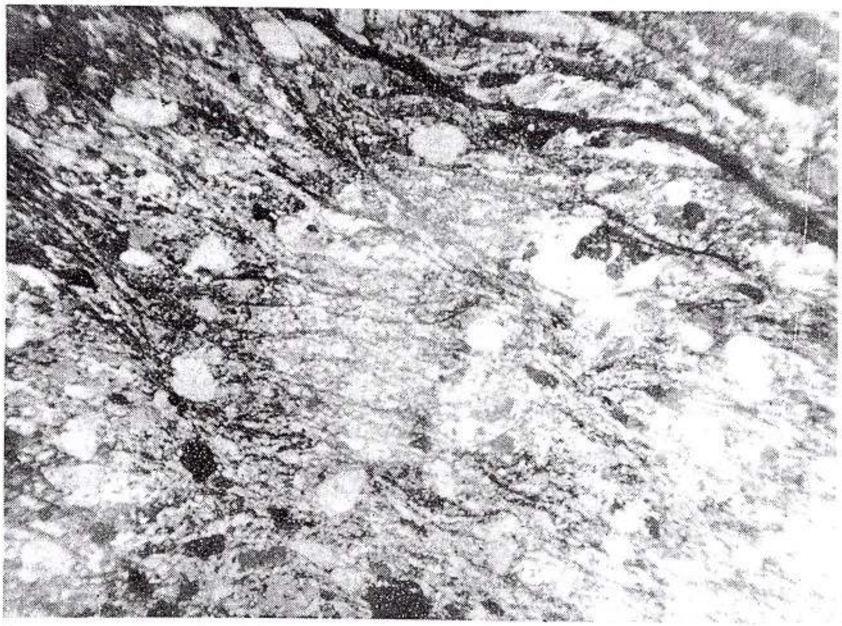


Fig. 1 – Relations of succession between planes S visible in blastomylonites. N+, 100X.

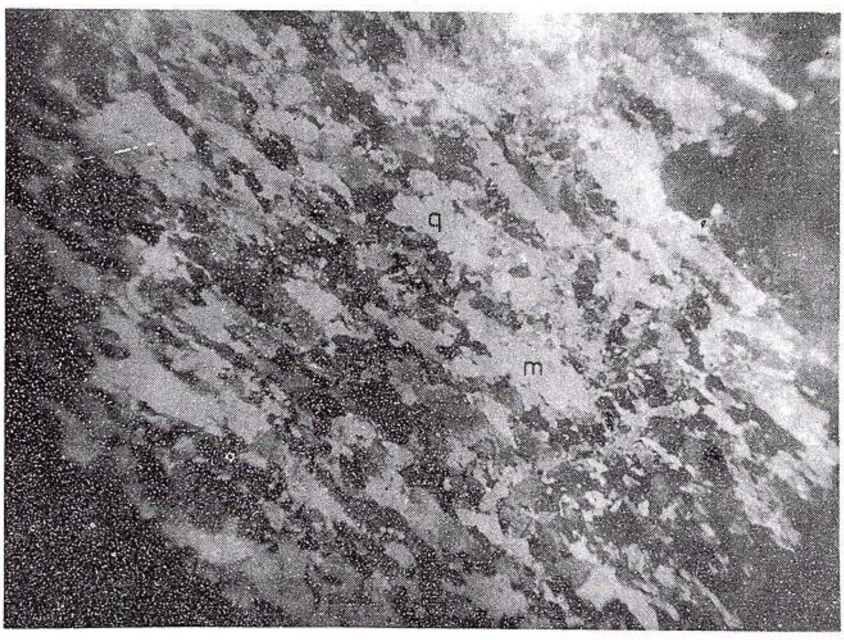


Fig. 2 – Mechanical "bedding" produced by the shearings accompanying mylonitization. N+, 100X; m–micas; q–quartz.

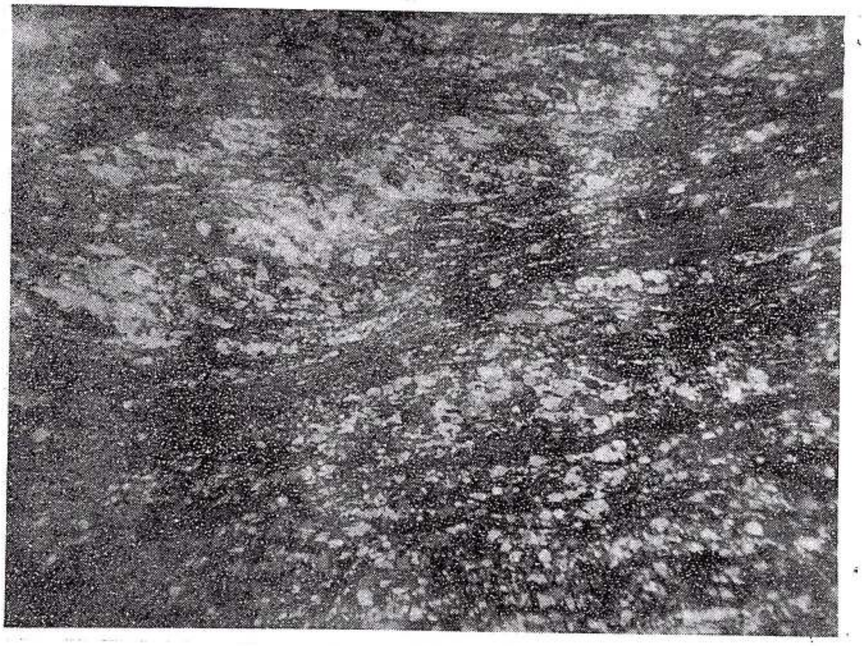


Fig. 1 Differentiated and relict laminations in pre-mylonitic S planes.

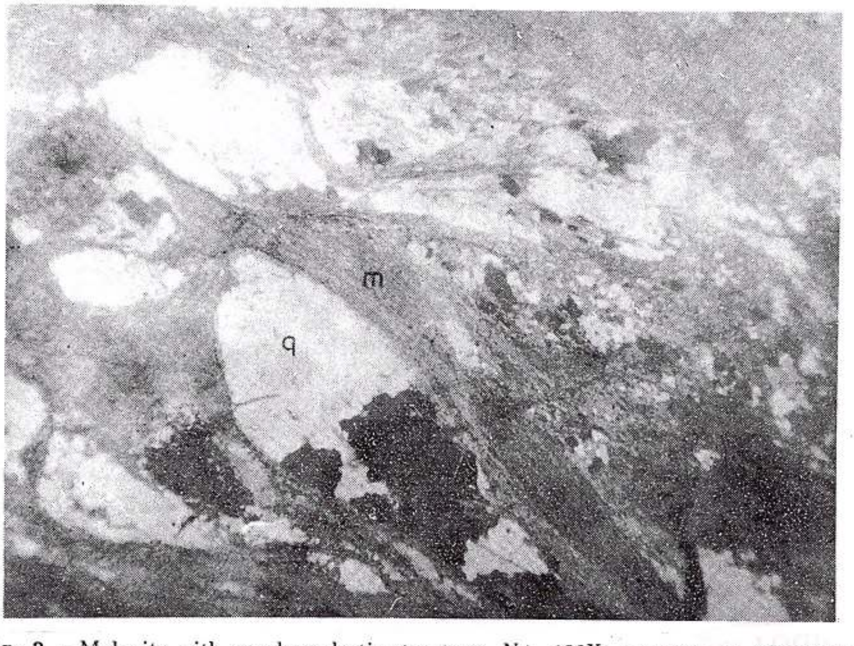


Fig. 2 - Mylonite with porphyroclastic structure. N+, 100X; q-quartz; m-micaceous aggregates.

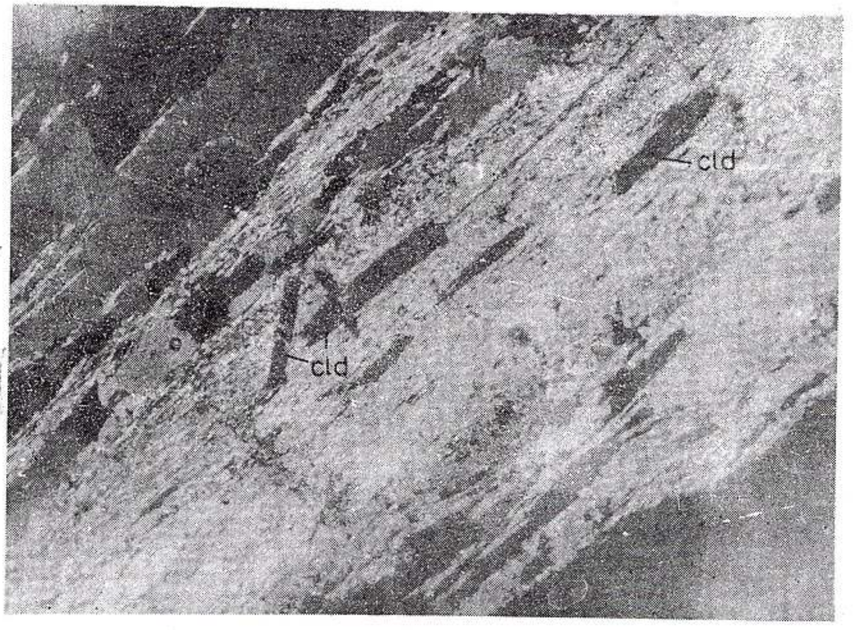


Fig. 1 – Blastomylonite with chloritoid neoformation, N+, 150X; cld–chloritoid.

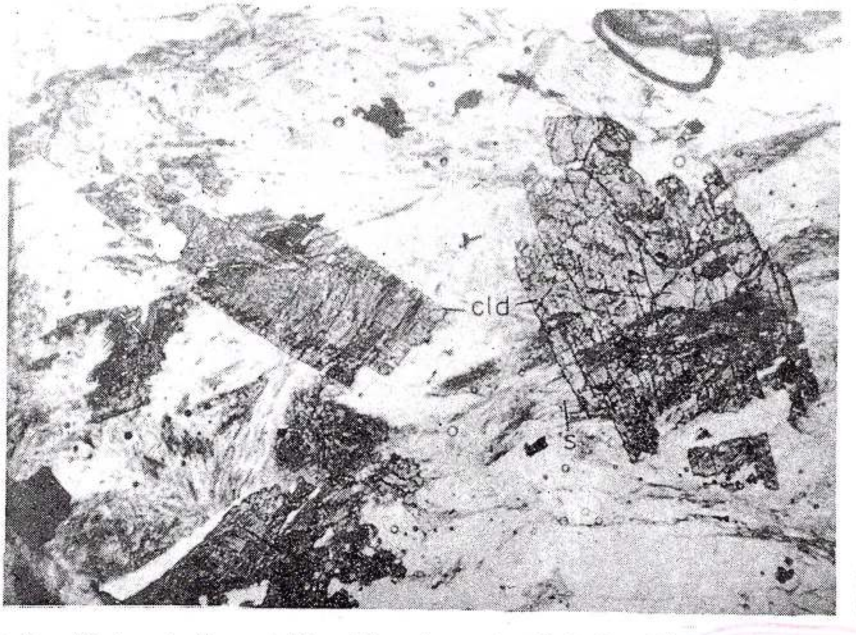


Fig. 2 – Blastomylonite containing sillimanite and chloritoid. N||, 100X; cld–chloritoid; s–sillimanite.