

Metamorphosed igneous rocks study from Valea Satului (Almăj Mountains)

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Abstract

Based on mineralogical-petrographical studies made on samples of rocks taken from the field, we have made some genetical considerations on the “Valea Satului Diorite” and on the metamorphic rocks associated. “Valea Satului Diorite” is a microdiorite with hornblende and biotite and it is associated with poorly retromorphosed amphibolites. In this paper we propose a possible sequence of crystallization of main silicates from “Valea Satului Diorite”, and we also detect a series of transformations of metasomatic type.

Key words: Southern Carpathians, Danubian Autochthon, Valea Satului diorite, metamorphosed igneous rocks, mineralogical-petrographical observations

Introduction

In the slopes of Valea Satului river (Almăj Mountains- Southern Carpathians) downstream of Dubova (Mehedinți county), bordering on DN57 Orșova-Moldova Nouă, an igneous body of a few dozen meters thickness is present, which was described in the previous papers as being exclusively granodioritic [1, 2]. This body is intercalated between the Corbu phyllites unit and Neamțu unit, lithostratigraphical entities which belong to the Danubian Autochthon from a geological point of view.

The Corbu phyllites unit is described as being predominantly made up of tuffogenous and basic tuffogenic rocks with intercalations of terrigenous rocks, porphyrogenic rocks and limestones. The basic tuffogenous rocks which predominate here are greenschists with the following paragenesis: albite-epidote-chlorite±calcite±actinote (quartz-sphene). The terrigenous rocks are represented by quartzitic, sericito-chloritous schists, sericitous schists, graphitous schists. The area contains mostly the outcomes of an initial magmatism (basic tuffogenous rocks and porphyrogenic rocks). Under the conditions of the greenschists facies, the rocks were regionally metamorphosed into chlorite zone (quartz-albite-muscovite-chlorite subfacies) [1, 2, 3, 4].

The Neamțu crystalline unit mainly consists of fine granular gneisses with biotite and amphibolites, the latest being present at the contact with the Ogradena granite. The Neamțu zone consists of metamorphosed rocks under the conditions of amphibolites facies (the garnet zone) and in the conditions of the greenschists facies. In this area gneisses and amphibolites are widely developed. The first ones have a fine, parallel texture and consist of quartz, plagioclase (20-25% An) and micas. Between the gneisses there often appear lenticular intercalations of

amphibolites and amphibolic schists [1, 2, 3, 4]. According to [5] the Neamțu unit is affected by a typical amphibolitic-like metamorphism characterized by medium pressure/high temperature.

Measurements regarding the absolute age of the granitoidic bodies from the Danubian Autochthon indicated a large scale of values, the volcanic activity beginning in the Cadomian orogenesis (upper Proterozoic – lower Cambrian) and lasting until the end of Paleozoic. Thus, a part of the granitic bodies intrusive in the crystalline of the Danubian domain are neoproterozoic (Tismana, Șușița, Novaci, Olteț), and the other part are carboniferous (~300 Ma) (Ogradena, Cherbeazu, Sfârdinu, Muntele Mic, Retezat, Parâng, Buta, Frumosu, Furcătura) [6].



Fig.1 Igneous intrusion on the slope from the Valea Satului River.

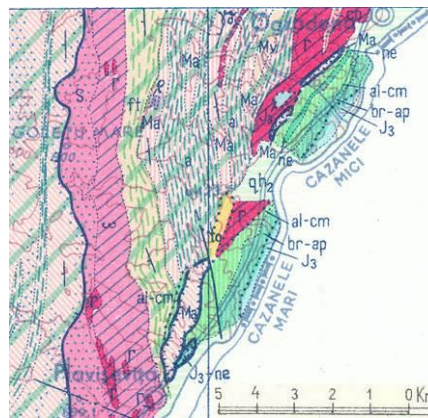


Fig.2 Geological map fragment in studied area (after Geological map of Romania, scale 1:200.000, Turnu Severin sheet, 1967).

In previous papers [1, 2], in the area studied by us, between the Corbu phyllites unit and the Neamțu crystalline unit were described some granodiorite bodies. The geological descriptions of the bodies suggest a unique homogenous body. In the outcrops which can be found between this two major unit it can be observed alternances of dark lithons (due to the prevalence of the mafic minerals, especially amphiboles and biotite) with lithons lighter in colour (richer in felsic minerals like quartz and feldspars).

In a previous field study made by our team on the Valea Satului river [7, 8], between the two major units, were sampled and identified several stratiform endogenous bodies having tectonic limits between them. Thus, from north-west to south-east, have been described in terms of mineralogical-petrographical point of view the following lithons: metatonalites with biotite, metagranites with chlorite, metagranites with muscovite and chlorite, mylonites from granitoides and granites, oligoclasite with chlorite, cataclasite from oligoclastic pegmatite, mylonites from diorites.

This paper is also about some endogenous rock bodies which are present between the two major crystalline units, and which have not been yet petrographically described in detail. We focus this study on two rock bodies: the first has a dark-green colour due to its high content of amphiboles, and the second has a dark grey colour. Both are present between the metatonalite zone and the oligoclasite zone.

We sampled this rock body and we found that it has in part some rock-components that are not granodioritic and are different from what we have previous described. We based our study on microscopical examination in polarized light of a series of thin sections made from our rock samples.

Mineralogical-petrographical investigations

After examining all the thin sections made we found four types of non-granodioritic rocks: diorites and amphibolites.

Type 1

The mineralogical composition: andesine, hornblende, biotite, sericite, chlorite, epidote, apatite, opaque mineral, calcite, titanite, zircon. The rock texture is non-oriented microgranular.

The mineral proportions are: andesine + sericite 70-75%, hornblende 15-20%, biotite 3-5%, epidote 1-2%, opaque mineral 1-2%, calcite < 1%, apatite < 1%, titanite < 1%, zircon < 0,5%.

The andesine is present as crystals and twin crystals anhedral. It is locally replaced by sericite (fig. 3). It shows a diffuse zonality at the periphery. Most of the crystals have sizes between 0.50 and 0.90 mm. Hornblende is a common green variety. The crystals have an interstitial disposing of plagioclase (fig. 4). The crystal size is in the range 0.70-0.80 mm. The biotite mostly shares the place with hornblende and it is frequently replaced partially by chlorite (fig. 5). The sizes of the biotite crystals are in the range 0.12-0.25 mm.

The sericite exclusively substitutes the plagioclase and it appears especially on both sides of some microfissures (fig. 6). The chlorite is a pleochroic variety having anomalous birefringence colours. It resulted from the substitution of the biotite (fig. 7) or of the hornblende (fig. 10). The epidote is like chlorite, a secondary mineral. The crystals of epidote are usually located either next to those of opaque mineral (fig. 8), or near those of amphibole (fig. 9).

The opaque mineral appears as anhedral crystals, most of them sharing the space with mafic minerals. The calcite is found in two situations: (1) on microclasts associated with sericite of feldspar substitution, (2) in pseudomorphoses on the hornblende (fig. 10). The apatite is found as small anhedral or euhedral crystals, included in plagioclase or amphibole. The titanite also appears in two situations: (1) like small primary crystals usually included in plagioclase; (2) in a small proportion in the pseudomorphoses on the hornblende (fig. 10). The zircon was rarely found, as euhedral crystals, having sizes of 0.02-0.03 mm, enclosed in the hornblende.

Regarding this kind of rock the primary minerals are: andesine, hornblende, biotite, apatite, opaque mineral, titanite, and zircon.

Type 2

The mineralogical composition is: hornblende, oligoclase, sericite, chlorite, opaque mineral, apatite, titanite. The rock structure is schistose, microgranular.

The mineral proportions are: hornblende – 50-55%, oligoclase + phyllosilicate – 35-40%, chlorite – 3-5%, opaque mineral – 2-3%, epidote – 1-2%, apatite – 1-2%, titanite < 1%.

The hornblende is a common, green variety. The crystals are anhedral, most of them being preferentially oriented. The size of the crystals is about 0.25-0.40 mm (fig. 11). The oligoclase is found both as isolated crystals and as twin crystals. Their shapes are anhedral. This mineral is partly replaced by sericite (fig. 12). Most of the crystals and twin crystals have sizes ranging from 0.30 to 0.40 mm.

The sericite has optical features that are specific to muscovite and it partially replaces only the plagioclase crystals. The chlorite shows crystals with a high pleochroism and anomalous birefringence colours. Most of them are preferentially oriented.

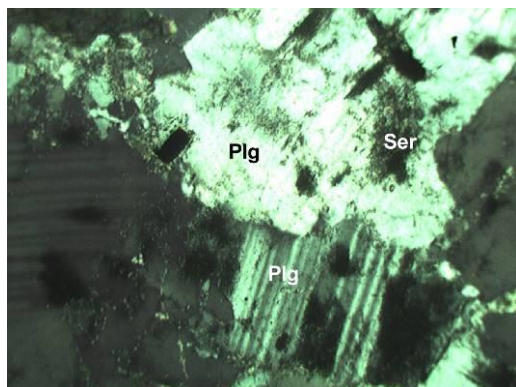


Fig.3 Andesine twins locally replaced by sericite (N+ 40x)

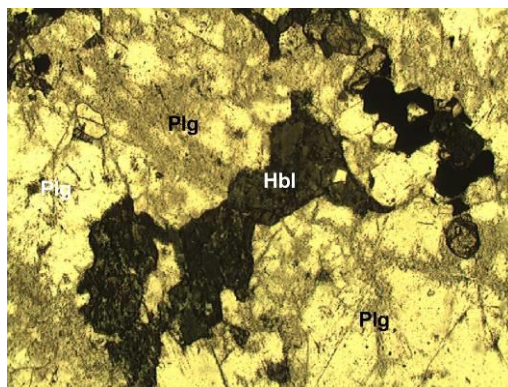


Fig.4 Hornblende having an interstitial position between the plagioclase crystals (N|| 40x).

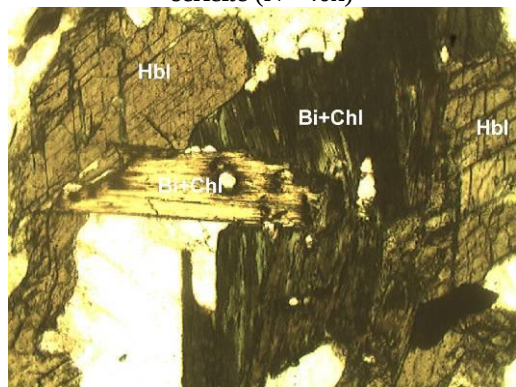


Fig.5 Partially chloritized biotite near hornblende (N|| 100x).

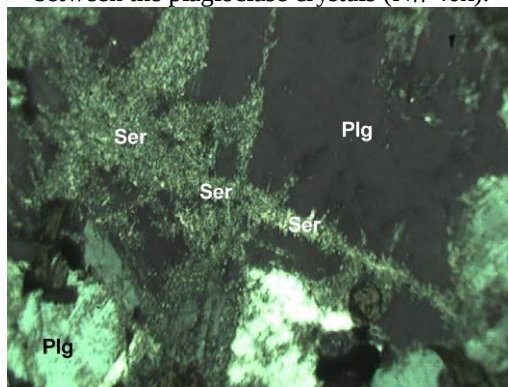


Fig.6 Sericite formed by plagioclase replacement, this replacement started from the joints (N+ 40x).

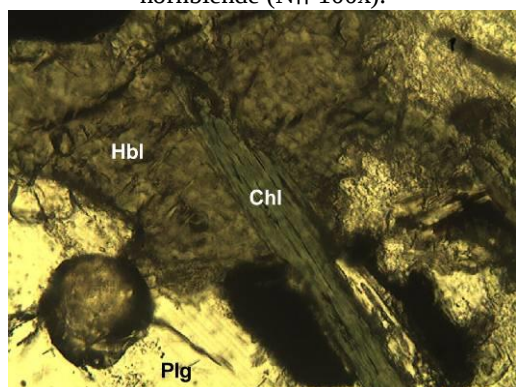


Fig.7 Chlorite partially included in hornblende; this chlorite is formed by a complete replacement of biotite (N|| 250x).

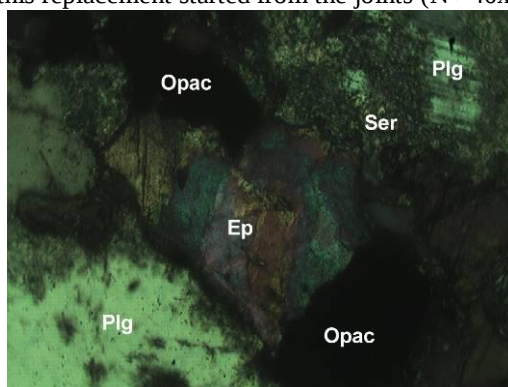


Fig.8 Epidote near the opaque crystals (N+ 100x).

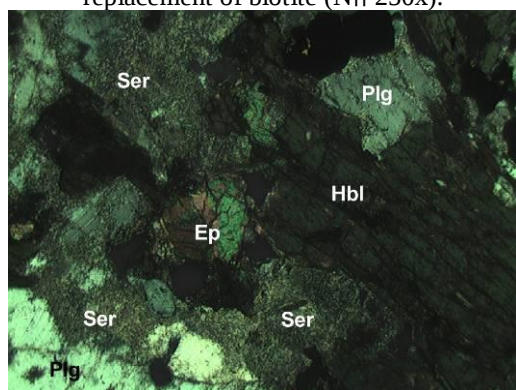


Fig.9 Epidote near the hornblende crystals (N+ 40x).

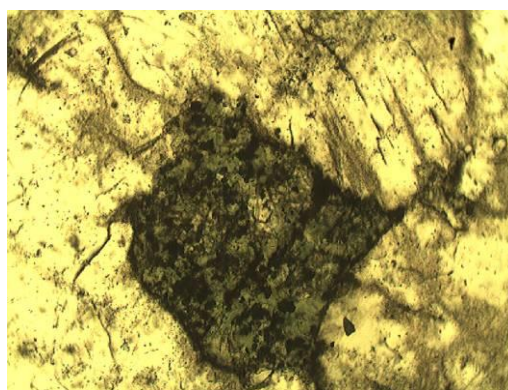


Fig.10 Calcite, chlorite and titanite pseudomorph after hornblende (N|| 100x).

The epidote is very rarely found like some small polycrystalline groups (fig. 13). The opaque mineral was determined by the use of microscopy in reflected light. It is ilmenite. The crystals are anhedral and partially replaced by titanite at the periphery (fig. 14). These crystals are uniformly disseminated in the whole mass of the rock.

The titanite appears in three situations: (1) like crowns on the ilmenite, resulting from a retromorphic reaction; (2) like anhedral crystals usually included in plagioclase and more rarely in amphibole; (3) like some small inclusions in chlorite.

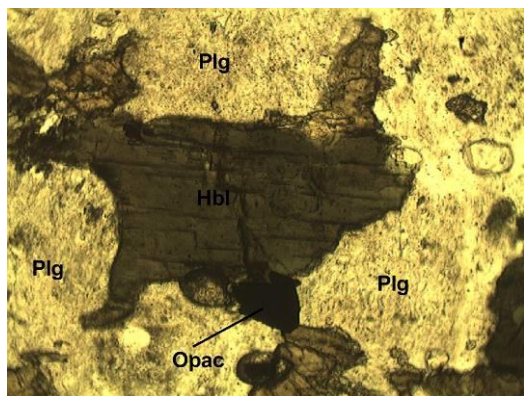


Fig.11 Anhedral crystal of green hornblende (NII 100x).

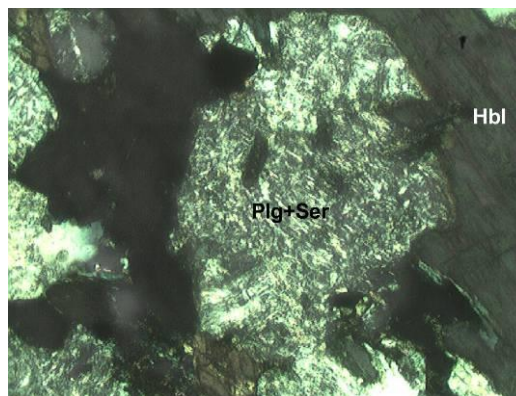


Fig.12 Plagioclase crystal almost completely replaced by sericite (N+ 100x).

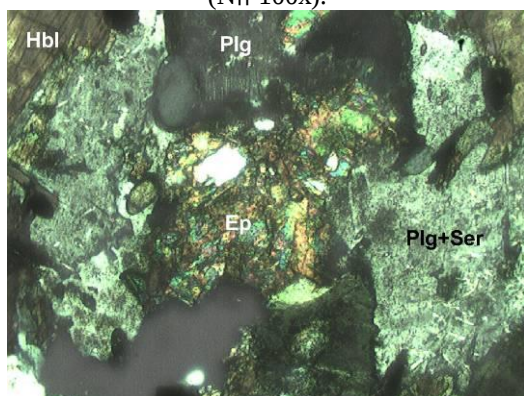


Fig.13 Group of anhedral crystal of epidote (N+ 100x).

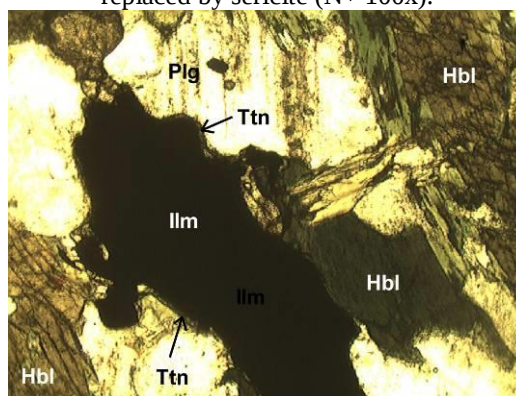


Fig.14 Ilmenite marginally replaced by titanite (NII 100x).

Type 3

The mineralogical composition is: plagioclase, green hornblende, chlorite, sericite, albite, titanite, epidote, opaque mineral. The structure is non-oriented inequigranular, allohipidiomorphous. The mineral proportions are: plagioclase + sericite – 60-65%; hornblende – 20-25%; chlorite – 10-15%; the rest of minerals < 5%.

The microscopic study using polarized light allowed from the beginning the distinction of two categories of minerals: primary (igneous) and secondary (metamorphic). The primary minerals are represented by plagioclase, hornblende, opaque mineral, and apatite. The secondary minerals are represented by chlorite, sericite, albite, titanite, and epidote.

The plagioclase is an oligoclase. The content of An optically determined with the method of extinction angles is 28%. It is present in some parts of crystals or twin crystals which were not substituted by the secondary minerals (fig. 15). The original sizes of twin crystals and plagioclase crystals ranged between 0.90 and 1.40mm. A part of the initial plagioclase twin

crystals are poikilitic, with intrusions inclusions of hornblende, chlorite and, subordinately, titanite (fig. 16).

The hornblende is a common green type. Most of the crystals are anhedral. A small part of these crystals are found like simple twin crystals (fig. 17). The size of the crystals ranges between 1 and 3mm. Generally the hornblende is not replaced by secondary minerals.

A local exception is represented by the titanite. The opaque mineral and the apatite are primary minerals accessories. The opaque mineral appears in the shape of minerals, frequently included in chlorite (fig. 18). It is a mineral previous to chlorite and it was included in the mineral replaced by the chlorite. The apatite is present like small anhedral crystals (< 0,4mm). It appears as inclusions usually in plagioclase (fig. 19) and more rarely in hornblende and chlorite.

Chlorite is a high pleochroic variety with anomalous birefringence colours (fig. 19). All the chlorite in the rock is created by the pseudomorphoses of a previous biotite (fig. 20). Rarely, in the case of chlorite pseudomorphoses, there were noticed areas where the replacement process is incomplete, which is illustrated by birefringence colours that are not specific to chlorite and that are close to those of the biotite (fig. 21). The sizes of chlorite pseudomorphoses and implicitly of the previous crystals of biotite generally belong to the interval 1.50-2.20mm.

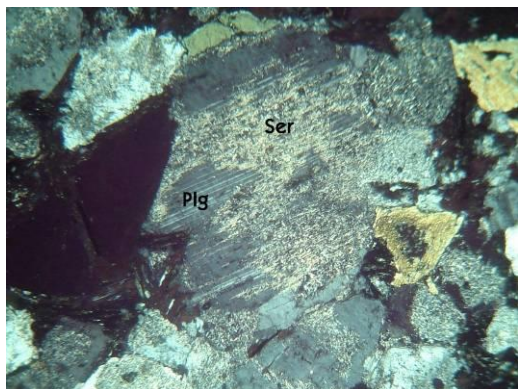


Fig.15 Primary relict microdomains of oligoclase near other microdomains which are replaced by sericite (N+ 40x)

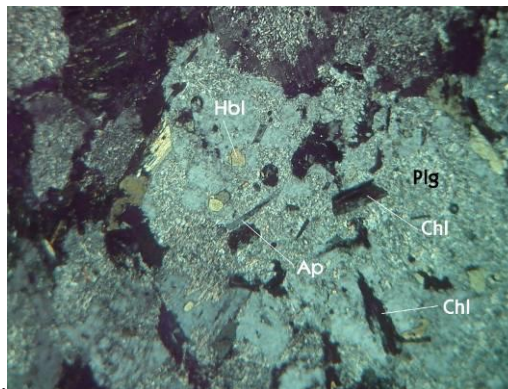


Fig.16 Poikilitic twins of plagioclase having hornblende, chlorite and apatite inclusions (N+ 40x)

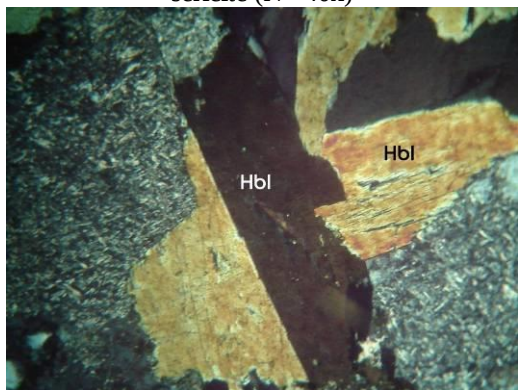


Fig.17 Simple hornblende twin (100 as twin plane) near sericite-albite domains (N+ 100x).

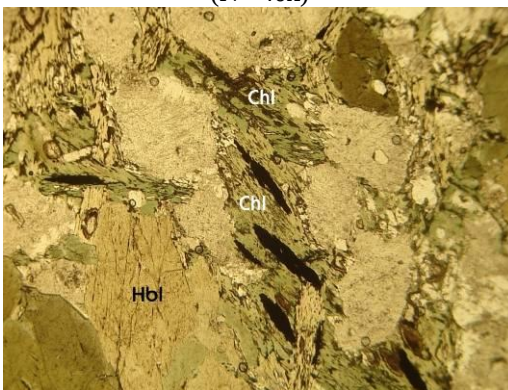


Fig.18 Pronounced anisometric crystals of opaque mineral included in chlorite (N|| 40x).

The sericite and the albite are found closely associated, being formed by substitution of plagioclase. Almost with no exception the substitutions are partially, so that the areas with albite and sericite are present on the space of the former crystals and twin crystals of plagioclase, adjacent to the relict plagioclase (fig. 22). The sericite has optical characteristics similar to those of muscovite, the birefringence being slightly lower.

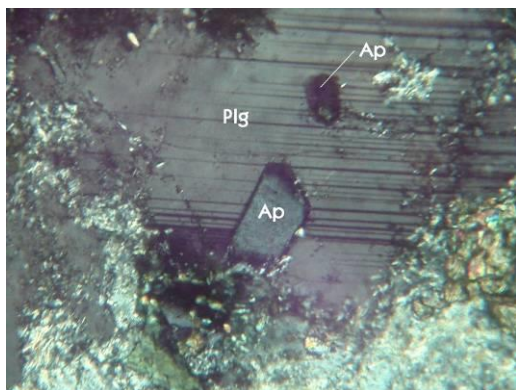


Fig.19 Apatite crystals included in plagioclase (N+ 250x)

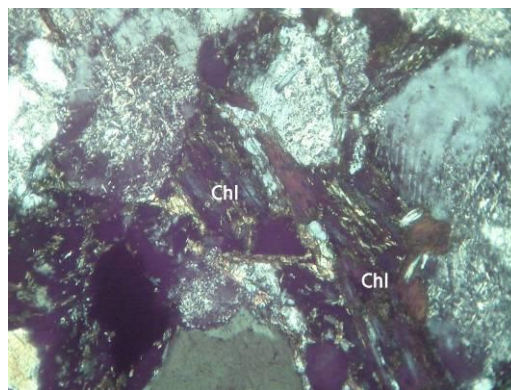


Fig.20 Relict biotite layers within chlorite pseudomorphs (N+ 100x).

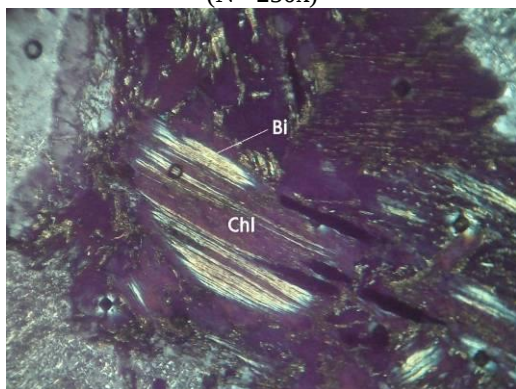


Fig.21 Chlorite crystals with anomalous birefringence colors (N+ 100x).

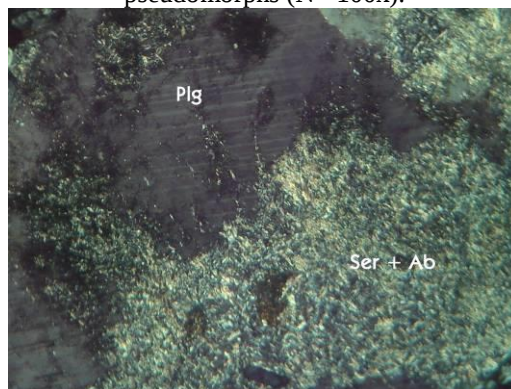


Fig.22 Albite-sericite microdomain located near a relict plagioclase (N+ 100x).

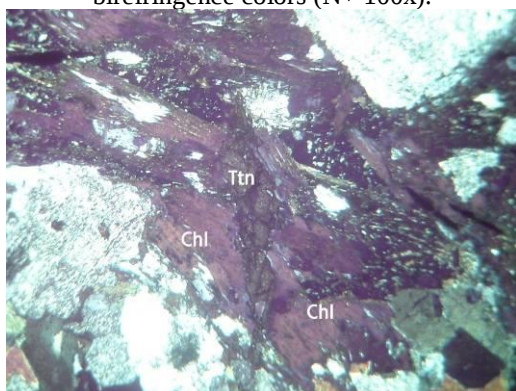


Fig.23 Secondary titanite present near the chlorite crystals (N+ 100x).

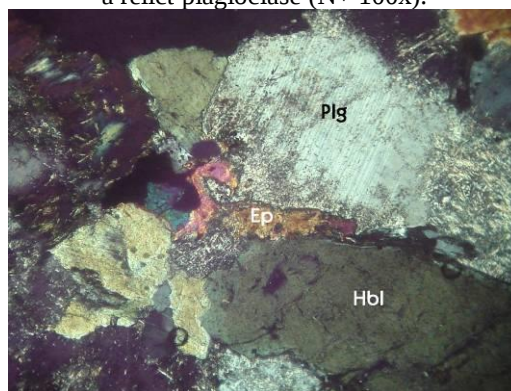


Fig.24 Secondary epidote at the plagioclase-hornblende border (N+ 40x).

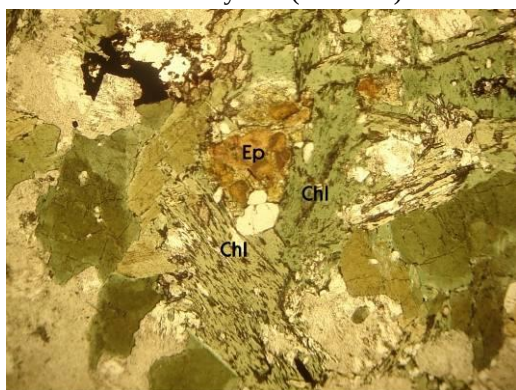


Fig.25 Secondary epidote surrounded by chlorite (N|| 40x).

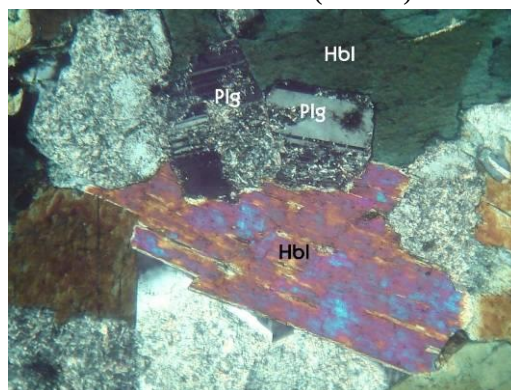


Fig.26 Hypidiomorphic microtextures: euhedral plagioclase twins included in hornblende (N+ 100x).

The titanite is found like anhedral crystals, sometimes surprisingly bigger in comparison to the rock granulation, being located inside or next to other mafic minerals (fig. 23). The epidote is very rare. The crystals are anhedral and relatively small ($< 0,02\text{mm}$). They appear either bordered by chlorite (fig. 24), or at the boundary between plagioclase and hornblende (fig. 25). The ones bordered by chlorite have a high pleochroism.

Type 4

The mineralogical composition is: plagioclase, green hornblende, biotite, opaque mineral, chlorite, sericite, epidote and apatite.

The mineral proportions are: plagioclase + sericite – 55-65%, green hornblende– 25-30%, biotite + chlorite – 5-10%, opaque mineral– 2-3%, sericite + epidote + apatite $< 5\%$.

The rock structure is grano-nemato-lepidoblastic, from micro to medium granular, poorly schistose. There can be noticed a moderate preferential orientation of the amphibole and biotite crystals.

The plagioclase is an andesine present as twin crystals or simple crystals, both anhedral. It is locally substituted by sericite (fig. 27). The poor undulose extinction of the twin crystals and the slight curvature of twin crystals planes (fig. 28) show that the rock suffered a deformation and that this mineral is prekinematic. The sizes of the plagioclase grains range between 1 and 2mm.

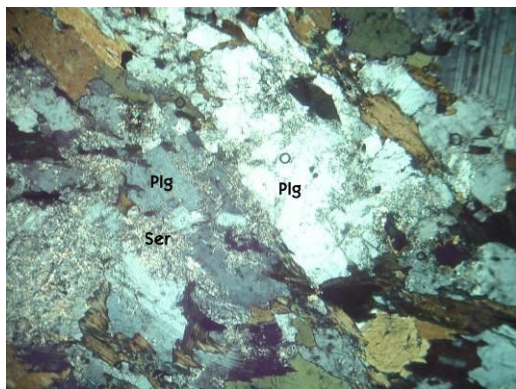


Fig.27 Plagioclase twins partially replaced by sericite (N+ 40x).

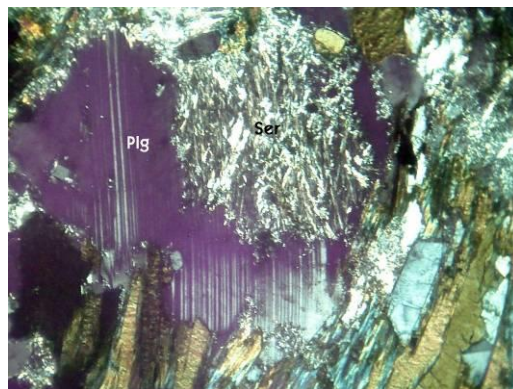


Fig.28 Weakly strained plagioclase twins locally replaced by sericite (N+ 100x).

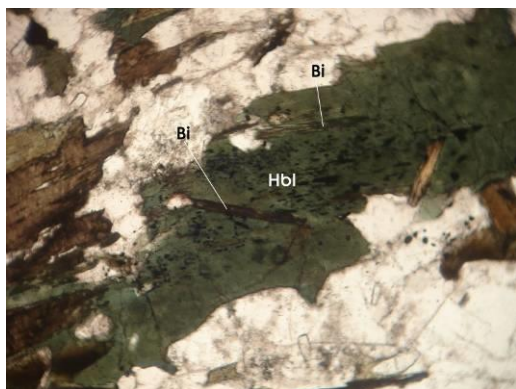


Fig.29 Hornblende including biotite and a lot of tiny opaque mineral crystals (N+ 40x)

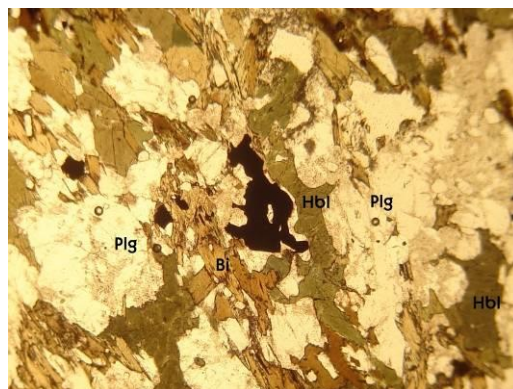


Fig.30 Anhedral crystals of opaque minerals (N+ 40x).

The hornblende is a green variety, strongly pleochroic. All crystals are anhedral. Rarely there are also found twin crystals, sometimes even polysynthetic. Sometimes the hornblende partially includes crystals of biotite. Some hornblende crystals have fine inclusions of opaque mineral (fig. 29). The sizes of the crystals are usually between 1.2 and 2mm.

The biotite is a brown variety, strongly pleochroic. The crystals are preferentially situated next to hornblende or they are included in it.

The opaque mineral is present as anhedral crystals. By the study of the polished sections in microscopy in reflected light, there was found that the opaque is a pyrite partially substituted by magnetite on the margin. The crystals sizes are variable, the maximum size observed being of 1.8mm. A part of these crystals partially or totally include the plagioclase (fig. 30).

Chlorite is a variety with anomalous blue birefringence colours. It locally and partially substitutes the crystals of biotite (fig. 31). The sericite is exclusively present as a substitute for plagioclase. The sericitisation is poorly and it has a prominently local character. The epidote is present on a very small scale, as anhedral crystals formed on the plagioclase area (fig. 32). The apatite is present as inclusions, frequently anhedral and subhedral, especially in plagioclase.

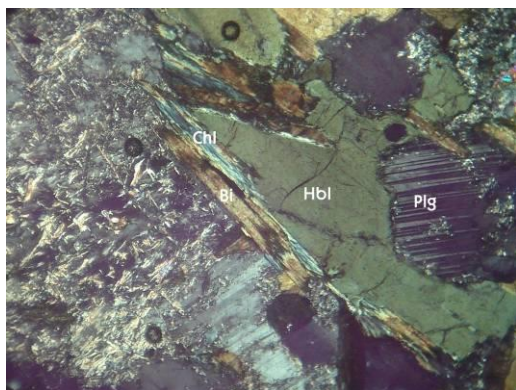


Fig.31 Anomalous birefringence chlorite replacing biotite crystals at their margins (N+ 100x).

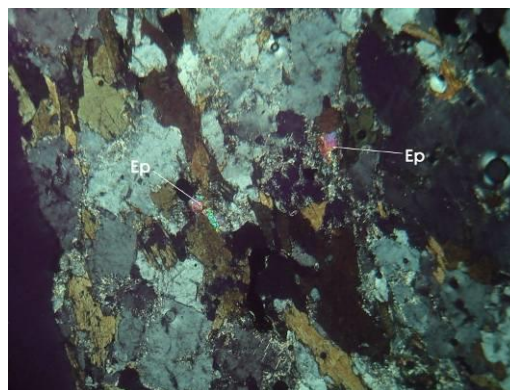
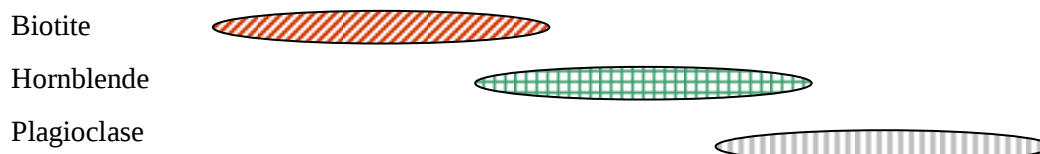


Fig.32 Epidote crystals nucleated near hornblende (N+ 40x).

Genetical remarks

Type 1

We distinguish in this type of rock a primary igneous mineral association: plagioclase + biotite + hornblende + titanite + zircon. For these primary minerals, according to the deductions resulted from the study of microstructures, we figured out the most probable succession of crystallization:



Taking into account the nature of the primary minerals, the size of their crystals and the lack of crystal orientation, we can conclude that this type of rock is a **microdiorite with hornblende and biotite**.

The post magmatic transformations of these primary minerals are: (1) the biotite chloritisation; (2) hornblende substitution by the association: calcite + chlorite + titanite; (3) the local sericitisation of plagioclase; (4) the forming of epidote. Thus, a second generation of minerals, the secondary ones are: chlorite, calcite, sericite, epidote.

Type 2

In this case of this rock we have also made the separation between two generations of minerals, both being metamorphic. The first generation are those formed in amphibolitic facies: plagioclase, hornblende, biotite, apatite and ilmenite. The second generation are those formed by retromorphic processes in the greenschist facies: chlorite, sericite, epidote, and titanite.

The chlorite and sericite are formed through a complex retromorphic metasomatic reaction, which implied addition of water:



The epidote could form due to the calcium and aluminum which were released after the decomposition of the anortitic component of plagioclase, due to the iron released from the annitic component in biotite and to the silica released from the above reaction.

Taking into account the texture, mineral composition and the mineral reactions, we conclude that this rock is a **poorly retromorphosed amphibolite**.

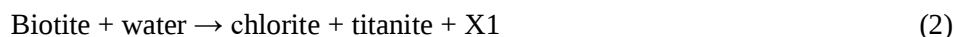
Type 3

The isotropic structure and the hipidiomorphic aspects indicate the fact that the rock is of magmatic origin. Taking into account the characteristic and the proportion of the primary minerals one can conclude that the rock was initially a **diorite with hornblende and biotite**. The content of An found in the relict plagioclase (28%) allows the differentiation from gabbros. In addition, the presence in high proportions of the biotite (at present substituted by chlorite) is specific to diorites.

The post magmatic subsolidus transformations were made in a static pattern which allowed the conservation on a big scale of the initial structure as well as of the mentioned hipidiomorphic aspects.

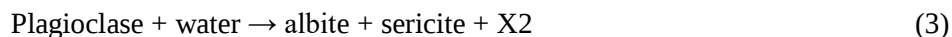
These transformations consist in reactions between the primary minerals and a aqueous fluid. The most important transformation consists in the biotite chloritisation.

Regarding the space of the biotite crystals, the reaction can be charted as follows



where X1 is the substance entered/levigated in/from the area of these crystals.

On the space of the plagioclase crystals the following reaction took place:

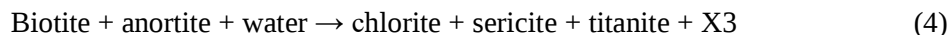


where X2 is the substance entered/levigated in the area of these crystals.

The exact specification of the substances corresponding to X1 and X2 cannot be made without knowing the composition of the initial and final solid terms belonging to the reactions. Yet, it

can be specified that during the reaction (2) there produced a releasing of K because the element is not found in the reaction products and that in reaction (3) an addition of K was necessary.

Thus, it can be interpreted that it was possible for the reactions (2) and (3) to take place together.



On biotite the reaction of chloritisation is almost complete due to the fact that the space occupied by the areas where substitution was incomplete is insignificant. But the reaction on plagioclase is partially developed, the primary oligoclase still being present in a high proportion. The incomplete substitution of the primary plagioclase by sericite can be correlated with the depletion of the source providing K, due to the fact that the initial proportion of biotite is at least 3 times smaller than that of plagioclase. Also this incomplete substitution can be correlated with the depletion of the water for reactions, a fact that, in its turn, would plead for the magmatogenous nature of the water. It is obvious that the primary magma was hydrated due to the presence of primary hydroxylated mafic minerals.

Finally, the forming of titanite can be related with the reactions (2) and (3), the ion of Ca coming from the anortitic component of the primary plagioclase and that of Ti from the primary biotite, chloritised at present.

Type 4

The amphibolite resulted from the sincinematic izomineral recrystallization of a dioritic rock (the same kind with the rock which represented the protolite of type 3). This recrystallization leads to the apparition of the schistose structure.

During the recrystallization the primary minerals generally have poor mobility. An exception is made by biotite. This has developed preponderantly along the shearing surfaces, penetrating the hornblende crystals and sometimes those of plagioclase. This way there can be explained the enclosing of biotite crystals by hornblende, which was previously described. The most inert to mobility was the apatite, which kept his initial forms, predominantly anhedral.

Just like in the case of type 3, in this amphibolite with a dioritic protolite, there are found some changes caused by the reaction with water, but much more reduced. This fact is correlated with the loss of magmatogenous water through the foliation surfaces generated by the shearing.

The slight transformations of biotite by chloritisation could not release, in the case of this rock body, the quantity of K necessary forming the sericite. Thus, it is sure that the process of seriticisation took place with an external addition of K.

The rock diagnosis is ***amphibolite with biotite***.

Conclusions

The endogenous body on Valea Satului River (Almăj Mountains) is now in spatial relationship with the formations of the metamorphic series, classically known as the Corbu phyllites unit and the Neamțu crystalline unit, respectively.

This polilithonic rock body that appears to be petrographically homogenous in the field, is in fact made up of both igneous and metamorphic rocks. On a closer examination of the outcrop we can distinguish a component part of the polilithonic rock body, which is a green-gray compact mediogranular lithon having igneous origin (according to its texture and mineralogical composition). This igneous rock is a *diorite with hornblende and biotite*. For this lithon, not described in previous literature, the name “Valea Satului Diorite” was proposed.

Based on the mineralogical-petrographical observations made on the rock samples taken from the outcrop, in this paper there are presented genetical considerations on the “Valea Satului Diorite” and the associated metamorphic rocks.

According to the inferences resulted from the study of microstructures in “Valea Satului Diorite”, the most probable sequence for the crystallization of the primary main silicates was: biotite → hornblende → plagioclase.

The study of the associated amphibolites showed that they also resulted from the metamorphosation of some rocks of an initially dioritic facies. We have also noticed that the studied rocks were affected by characteristic metasomatic processes.

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Studiul magmatitelor metamorfozate din Valea Satului (Munții Almăjului)

Rezumat

Pe baza observațiilor mineralo-petrografice efectuate asupra probelor de roci prelevate din teren, în lucrare se fac considerații genetice referitoare la “dioritul de Valea Satului” și la metamorfitele asociate. Dioritul de Valea Satului este un microdiorit cu hornblendă și biotit și este asociat cu amfibolite slab retromorfozate. În lucrare a fost propusă o succesiune posibilă a cristalizării principalilor silicați, fiind decelate și o serie de transformări de natură metasomatică.