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# GLAUCOPHANIZED AMPHIBOLITES AND GNEISSES NEAR RUDNÍK (SLOVENSKÉ RUDOHORIE MTS.)

*(Figs. 10, Tabs. 2)*

Abstract: Amid low-metamorphic rocks of Mesozoic in the Rudník region, amphibolite and garnet-amphibole gneiss bodies occur having tectonic contact to the surrounding rocks, represented mostly by mylonitized serpentinite zones. By their metamorphic assemblage in amphibolite facies and common occurences with serpentinites they resemble metamorphites of amphibolite facies occuring the Rakovec Group (Lower Paleozoic of Gemericum). These rocks are slightly glaucophanized and sometimes also mylonitized. The intensity of their mylonitzation is lower than in glaucophane schists of Hačava region.

Резюме: Среди низкометаморфических пород мезозоя области с. Рудник встречаются тела амфиболитов и гранат-амфиболитовых гнейсов имеющих с вмешающими их породами тектонический контакт представлений прежде всего милонитизованными зонами серпентинитов. Их минеральной ассоциацией во фации амфиболитов и общими местонахождениями со серпентинитами они напоминают на метаморпфиты амфиболитовой фации встречающиеся в раковецкой группе (нижний палеозой гемерикума). Эти породы слабо глаукофанизованы и иногда тоже милонитизованы. Интенсивность процесса милонитизации в этих породах ниже чем в глаукофановых сланцах области с. Хачава.

As a result of detailed geological and petrographical studies, a number of amphibolite and gneiss occurrences have been discovered in the Spišsko-gemerské rudohorie Mts. region; this proved valuable for the explanation of metamorphic evolution of this region (Rozložník, 1965; Dianiška—Grecula, 1979; Hovorka et al., 1979; Bajaník—Hovorka, 1981). The coincidence of amphibolite and gneiss occurrences amid low-metamorphic Lower Paleozoic exclusively with Rakovec Group (Rakovec Nappe according to the classification of Grecula, 1982, or Klátov Nappe in the sense of Hovorka et al., 1984) makes at the same time their classification within the general geological structure of this region more difficult. As a result, several opinions on the genesis of these rocks have been expressed. A summary of the opinions can be found in the works of Hovorka et al. (1984) and Faryad (1986).

The glaucophanized amphibolites and gneisses described in this paper occur in the rocks of Meliata Group, which is a part of Inner West Carpathians. The position of Meliata Group is generally problematic. A number of glaucophane schist occurrences in this group (Kamenický, 1957; Reichwalder, 1973) classified according to their age together with crystalline limestones as Middle to Upper Triassic (Gall—Mello, 1983) point to low-tem-

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perature and high-pressure character of metamorphism. The marks of glaucophanization in the studied amphibolites and gneisses lead to the problem of the origin of glaucophane schists in this group, discussed as well in the following on the example of glaucophane schists near Hačava.

*Geological environment of glaucophanized amphibolites and gneisses*

The studied rocks occur south of the settlement Rudník (Fig. 1). They form a 200×80 m isolated isle jutting out of Neogene and Quarternary sediments.

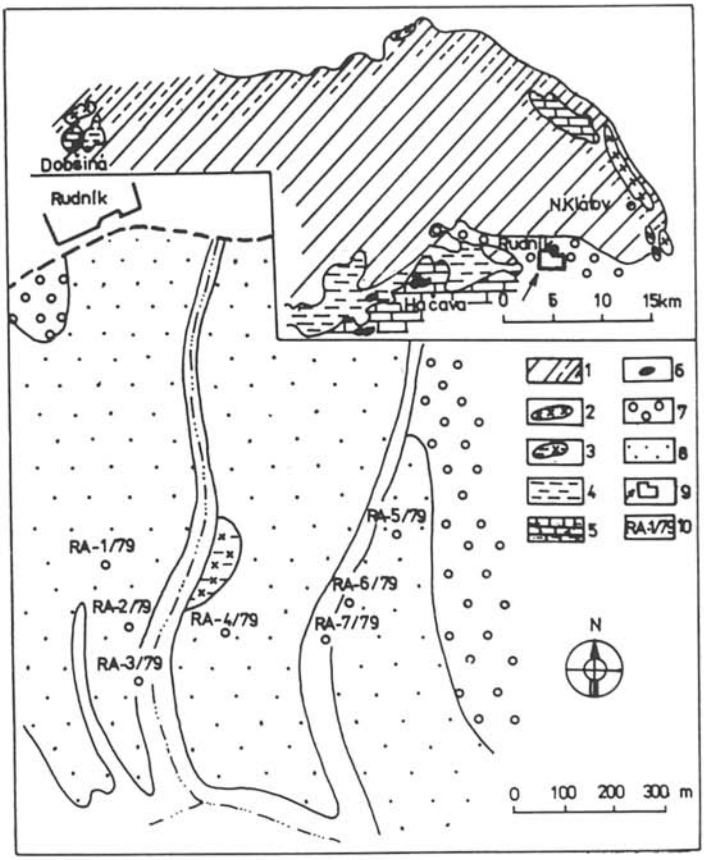


Fig. 1. A — Schematized geological map of Gemericum; B — Geological map of the studied region.

*Explanations:* 1 — Lower Paleozoic of Gemericum, dashed, Rakovec Group (Rakovec Nappe); 2 — amphibolites and gneisses of Rakovec Group; 3 — glaucophanized gneisses and amphibolites; 4 — Permian and Carboniferous together; 5 — Mesozoic in general; 6 — glaucophane schists; 7 — Neogene of Košice Basin; 8 — aluvium; 9 — studied territory; 10 — denotation of boreholes.

On existing geological maps these rocks have been denominated as Mesozoic serpentinites (P r í s t a š in B a j a n í k et al., 1984) or they have been assumed to be diabases of Meliata Group (B a c s o, 1980).

Glaucophanized amphibolites and gneisses have been reached by two boreholes (Fig. 2). They have tectonic contact with the surrounding rocks, represented by 2—7 m thick mylonite zones, mostly mylonitized serpentinites. The amphibolite and gneiss bodies, together with mylonitized serpentinite parts have contacts with two metamorphically different rock types. In the first case they are fine-grained crystalline limestones (borehole RA-7/79). These occured in some other boreholes too. In the second case they are sediments with a very low grade of metamorphic alteration (borehole RA-6/79). According to Z. B a c s o, all mentioned rock types are parts of Meliata Group. The structure of the region is tectonically complicated. It is difficult to construct a regular lithological succession of sediments in the studied region, in spite of a sufficiently dense net of boreholes.

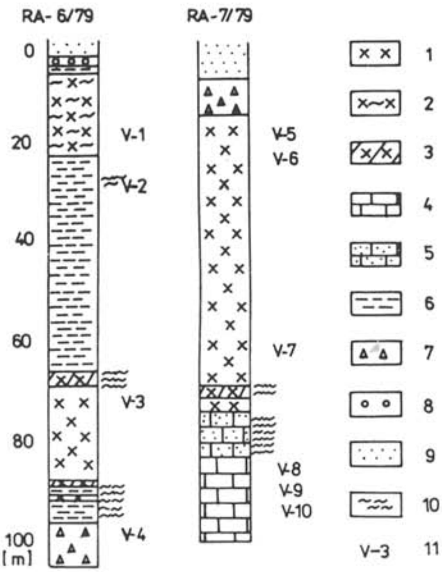


Fig. 2. Bore profiles (B a c s ó, 1980, adjusted).

*Explanations:* 1 — amphibolites; 2 — garnet-plagioclase gnenisses; 3 — serpentininites; 4 — crystalline limestones; 5 — carbonate schists (fine-grained crystalline limestones); 6 — green schists; 7 — breccias to graywackes; 8 — Neogene of Košice formation; 9 — alluvium; 10 — mylonitized zones; 11 — location and denotanion of thin section.

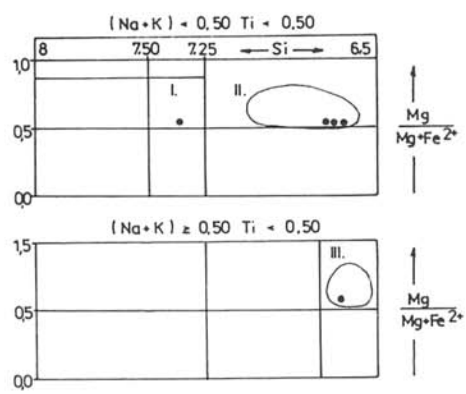


Fig. 3. Classification diagram of calcium amphiboles (L e a k e, 1978).

*Explanations:* The limited field marks hornblendes from garnet-amphibole gneisses from Rudňany region (data from the work H o v o r k a – S p i š i a k, 1981).

## Petrography

Except samples collected from surface by the authors, archival thin-section material from boreholes has been used as well for the petrographical study. The petrographic characterization deals above all with amphibolite facies metamorphites; we shall mention the character of surrounding rocks only briefly.

### *Amphibolite-facies metamorphites*

#### Glaucophanized garnet-amphibole gneisses

This rock type occurs on the surface and a substantial part of the islet in Quarternary sediments is formed by these rocks. They are fine- to medium--grained compact rocks of dark grey to grey colour, with a bluish shade, and not very pronounced schistose structure. The following minerals take part in the mineral composition: amphibole (hornblende + glaucophane, 40—60 %), plagioclase (20–30 %) and quartz (10—20 %), to a lesser extent garnet and accessories (apatite, zircon, epidote, chlorite, white mica ± biotite and ore minerals). The texture of these rocks is slightly oriented, nematoblastic.

Brown hornblende forms tabular to columnar shapes and sometimes it also encloses poikiloblastically garnet and plagioclase. The grain-size varies between 0.5—2.5 mm. Hornblende is often glaucophanized, even pseudomorphosed by glaucophane. The pseudomorphism of hornblende by glaucophane has topotactic character; it begins on grain rims and mostly it follows the direction of cleavage fissures. Glaucophane forms nomaxial grains with the c-axis of hornblende. In this alteration the original hornblende form is usually preserved. Its pleochroism changes to blue and numerous powder-like grains of ore minerals and titanite are formed in it. Relict hornblende islets are not clouded by ore pigment.

Glaucophanization is accompanied by ore-mineral exsolution. Idioblasts to hypidioblasts of glaucophane occur sporadically in veinlets with albite. Glaucophane has here bright blue pleochroism in ($\alpha$) direction and violet pleochroism in ($\gamma$) direction and it is not accompanied by ore mineral exsolution. This glaucophane type is in rare cases developed also on the rims of glaucophanized hornblendes but in this case it does not form individual crystals.

Garnet is a frequent mineral of these rocks. It forms irregular, rarely idioblastic grains. The grain-size varies between 0.5—2 mm. Garnets are usually cracked and chloritized along the cracks and rims. Infrequently garnet forms inclusions in glaucophanized hornblende. Its idioblastic form is here often preserved.

At least two plagioclase generations can be distinguished in these rocks. Older plagioclase forms irregular, more or less parallelly oriented grains, usually intensively sericitized, saussuritized and clouded. This plagioclase sometimes forms inclusions in hornblende. Second plagioclase type (albite) is represented by veinlets and in contrast to the previous type it is transparent and albitically lamelled.

Similarly as in the case of plagioclase, two generations of quartz can be distinguished. First generation forms elongated to lenticular grains and cumuloblasts in the direction of rock schistosity. It flows slightly around plagioclase as well as brown hornblende and occasionally it encloses them. All quartz grains have undulous extinction. The younger quartz generation forms independent veinlets. We have not succeeded in determining their succession relationship to the albite veinlets.

White mica is in the studied rocks present only in accessory quantities. It occurs most frequently in the form of sericite in plagioclase. White-mica idioblast inclusions up to 0.1 mm in size in glaucophanized hornblendes are sporadical. In both cases mica has random orientation of its flakes.

Except zircon and apatite which form inclusions in hornblende and plagioclase, other accessories like epidote, chlorite, titanite etc. are secondary minerals in these rocks and they are irregularly dispersed in them.

We have not found wholly preserved biotite in the studied rocks. Only in one sample, in which there is a relatively lower content of glaucophanized hornblende and higher content of garnet, there are biotite relics. It is thus possible to assume that biotite occurrences are connected only with parts poor in hornblende and rich in plagioclase and quartz. Only in the middle of a chlorite crystal there are relics of greenish-brown biotite. Ti-minerals (leucoxene and titanite) concentrate along cleavage fissures of chlorite. Original crystal forms are preserved during the alteration of biotite to chlorite; they flow often around garnet and plagioclase. Sporadical flakes of already chloritized biotite occur along the rims of hornblende grains. These were probably formed by the replacement of hornblende.

### Amphibolites

Amphibolites have been found in the boreholes RA-6/79 (V-3) and RA-7/79 (V-7). They occur on the surface only to a lesser extent.

In contrast to glaucophanized gneisses they form only smaller fragments, often weathered. They are dark blue in colour and macroscopically fine-grained. The mineral composition of amphibolites consists of hornblende and plagioclase, to a lesser extent of epidote, chlorite and accessory apatite, titanite, quartz, actinolite and in the sample (V-7) also galucophane. The rock texture is slightly oriented, granonematoblastic. Brown to greenish-brown hornblende forms tabular grains chloritized along cleavage fissures and rims. In one sample, (V-7), very faint glaucophanization signs are present. Similarly as in glaucophanized gneisses, pseudomorphs of glaucophane after hornblende are present here as well, with simultaneous forming of powder aggregate, probably of titanite. Except for these preudomorphism, glaucophane forms here also individual crystals in veinlets with albite. In the sample (V-3), in place of glaucophane after hornblende pseudomorphs, deep-green amphibole with bluish shade was formed as an accessory. Most probably it is sodium-calcium amphibole.

Plagioclase grains (first generation) are intensively saussuritized and clouded. They often form inclusions in hornblende. Younger plagioclase — albite (second generation) — is present as well. Albite veinlets occur along various directions and they are sometimes accompanied by actinolite needles.

### Chlorite-epidote schists

They were probably formed as a result of mylonitization of amphibolites. This rock type corresponds to the upper part of amphibolite body in the borehole RA-7/79 (V-5 and V-6). They are rocks consisting mostly of chlorite, epidote, plagioclase, accessory apatite, quartz, titanite and other ore minerals. Plagioclase is similarly saussuritized as in amphibolites, but fresh plagioclases here dominate, forming veinlets and clusters in the rock.

Chlorite often forms aggregates with tabular form (size up to 1 mm) with dispersed fine grains of titanite, sporadically also carbonate. Similar tabular forms in amphibolites correspond to glaucophanes or bluish-green amphibole (not determined more precisely) and they were formed by pseudomorphism after hornblende. The rock is generally interveined by albite, chlorite, albite + + calcite, calcite + haematite veinlets.

### Garnet-plagioclase gneisses

This rock type occurs in the borehole RA-6/79 (6—23 m) (V-1). The rock is formed by plagioclase, chlorite, garnet and ore minerals. Plagioclase is absolutely predominant in this rock. It forms either saussuritized grains in the rock or fresh grains in veinlets and nests. Garnet is strongly chloritized to pseudomorphosed by chlorite, only sporadically it is preserved as a relic in chloritized formations. The original contents of garnet in the rock can be estimated as 5 % of rock volume. The rock is penetrated by albite veinlets and no forms after pseudomorphosed amphibole or other dark mineral can be found.

### *Rock types in the surrounding of glaucophanized amphibolites and gneisses*

On the basis of borings (Bacso, 1980) and our petrographical studies, the following rock types have been distinguished in the studied region: limestones, clay schists, black schists, violet schists, breccias to graywackes, green schists, serpentinites, crystalline limestones and rocks of gabbroid character. Individual rock types do not form regular stratigraphical strata succession in the boreholes. Rocks observed in one borehole are frequently lacking in the neighbouring one.

Breccias to graywackes (V-6), but other sedimentary rock types too, display a very low alteration grade. Fine sericite flakes, chlorite (after clastic biotite decomposition) and ore pigment are formed in these rocks. In green schists, the newly formed mineral assemblage consists of chlorite, albite, carbonate, quartz and ore mineral. Original dark minerals have here not been preserved.

Crystalline limestones (V-8-10) are interesting by the fact that except calcite (grain size 0.1 mm) they contain xenoblasts to poikiloblasts of plagioclase. This rock type, but with a more coarse-grained character and perfect recrystallization, has been described also in the proximity of glaucophane schists in the area of Hačava (Reichwalder, 1973).

*Chemical composition of minerals*

Analyses of minerals have been carried out on the automatized microanalyser ARL-SEMQ in the Central Geological Institute, Prague, using a programme modified by Ing. K o t e r b a and Ing. R y b k a. We have analysed several minerals from glaucophanized gneisses. For the purpose of comparison we have also analysed some minerals of glaucophanites from the Hačava region, which were petrographically already evaluated by J. K a m e n i c k ý (1957) and R e i c h w a l d e r (1973).

1. H o r n b l e n d e

In two analysed samples of glaucophanized garnet-amphibole gneisses, three analyses correspond to magnesian hornblendes (Fig. 3). One analysis has relatively higher Na contents which is characteristic for edenitic hornblende. Another analysis has Si contents corresponding to actinolitic hornblende. Both analyses are from a single sample (Fg-70/85) and we do not exclude the possibility that such an increase of Na and Si contents is secondary, since glaucophanization is here more intensive than in the sample Fg-158/85 (Fig. 4).

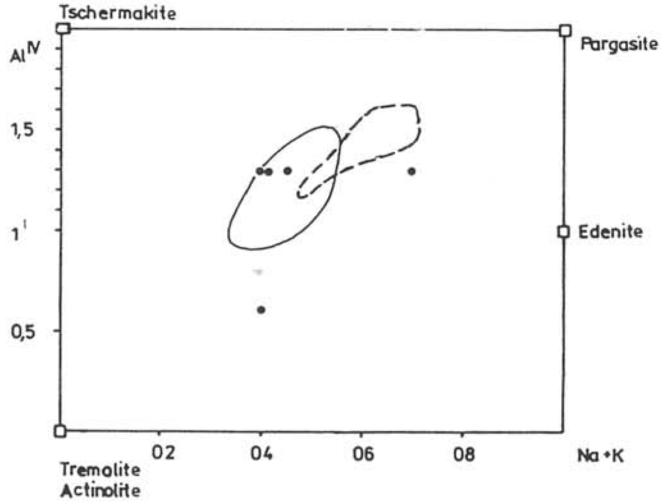


Fig. 4. $Al^{IV}$: Na + K diagram for calcium amphiboles.
*Explanations:* Dashed field marks hornblendes of amphibolites from Klátov region. The rest as in Fig. 3.

2. G l a u c o p h a n e

In the classification diagram (M i y a s h i r o, 1957), the analysed glaucophanes from glaucophanized gneisses and amphibolites concentrate on the border between Fe-glaucophane and glaucophane (Fig. 5). In contrast to the samples from Rudník region, glaucophanes from glaucophanites near Hačava concentrate in the field of Fe-glaucophane. There remains the problem of estimation or calculation of $Fe^{3+}$ and $Fe^{2+}$ contents from analyses carried out by a microanalyser. E.g., glaucophanes from glaucophanites of Hačava region analysed by the classical method (H o w i e—W a l s h, 1982) correspond to crossite and the determined $Fe^{3+}$ contents in them vary between 0.9—0.8 %. Glaucophanes from this locality, analysed by microanalyser, as already mentioned, correspond to Fe-glaucophanes. We have calculated their maximum $Fe^{3+}$ contents (0.52) with the help of the method suggested by P a p i k e et al. (1974).

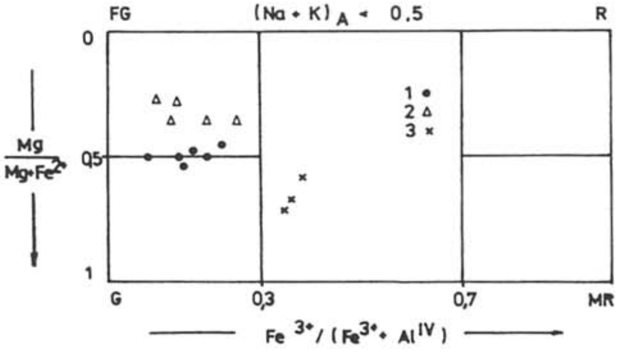


Fig. 5. Classification diagram of alkali amphiboles (M i y a s h i r o, 1957) for Na-amphiboles.

*Explanations:* Na-amphiboles from 1 — glaucophanized gneisses and amphibolites; 2 — glaucophanites from Hačava region; 3 — glaucophanites from Hačava region (data from the work H o w i e — W a l s h, 1982; see text).

Glaucophanes from amphibolites and gneisses of Rudník region differ from glaucophanes from glaucophane schists near Hačava by an increased amount of actinolite component $Ca/(Ca + Na) = X_{Ca}$. In the first case $X_{Ca}$ is less than 0.9, but in two analyses as low as 0.11. In the second case is this quantity usually lower than 0.05. It is necessary to add that in glaucophane from glaucophane schists of Tavsanli region (north Turkey) where other high-pressure minerals are present as well, the actinolite component contents are under 0.1 (O k a y, 1980).

3. G a r n e t

In glaucophanized garnet-amphibole gneisses, garnet is rich in almandine component. Weak progressive zoning is development from the core to the rim of grains (Figs. 6, 7).

Garnet from glaucophanites near Hačava analysed for the purpose of a possible reconstruction of the glaucophanization process has a very different chemistry from the previous one. It is rich in the almandine-spessartite component and has a pronounced progressive zoning (Figs. 8 and 9). Thus we can see that these garnets are by far not connected only with a single type of metamorphism.

4. White mica

As already mentioned, white mica is fine-flaked in the glaucophanized gneisses. We have analysed three mica flakes forming clusters beside glaucophane. The contents of muscovite component vary between 60—80 %, the content of fengite component is 15—40 %. From petrographical characteristics it is not possible to tell whether white mica was formed in these rocks simultaneously with glaucophanization or it is still younger.

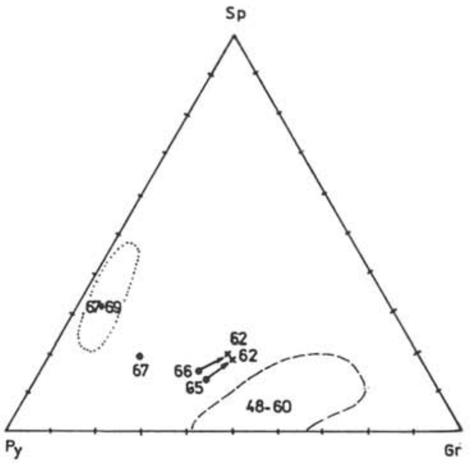


Fig. 6. Composition of garnet from glaucophane schists and amphibolites.
*Explanations:* Full circles — core of garnet, crosses — rim of garnet. The numbers signify the contents of almandine component (rounded off). Dashed field are garnets from garnet-amphibole gneisses (Rudňany) and dotted from garnet-biotite gneisses (Klátov).

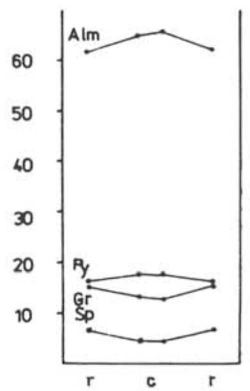


Fig. 7. Zonning of garnet from glaucophanized gneisses.

5. Plagioclase

Older plagioclase is always substituted by another mineral. Several grains of second-generation plagioclase have been analysed. In all cases it was albite.

*Metamorphic mineral assemblages*

Mineral assemblage of amphibolite facies

In the studied amphibolites and gneisses this assemblage is characterized especially by the forming of brown hornblende, plagioclase and garnet. Plagioclase, as mentioned above, is subsequently always substituted by other minerals. We have based our estimation of amphibolite facies metamorphic temperature on hornblende and garnet relics in these rocks. Slight regressive zoning is developed in garnet. Temperatures obtained on the basis of phase equilibrium garnet-hornblende (P e r c h u k, 1978) vary between 625 °C for the core and 595 °C for the rim of garnet.

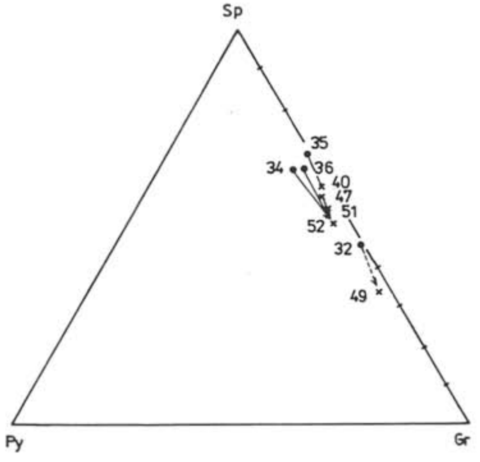


Fig. 8. Composition of garnet from glaucophane gneisses.

*Explanations:* Dashed arrows connect core and rim of garnet from blue schists of Tavsanli region (Turkey, O k a y, 1980)

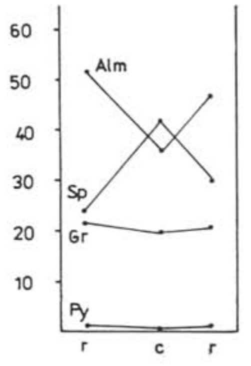


Fig. 9. Zoning of garnet from glaucophanites of Hačava region.

Regressive zoning in garnet, signs of substitution of hornblende by biotite and above all the same saussuritization to kaolinization character of plagioclase (in glaucophanized amphibolites and gneisses as well as in amphibolites and gneisses with no signs of glaucophanization) could be proofs of regressive alteration of these rocks. Most probably it took place after the reaching of culmination point of amphibolite facies metamorphism.

### Mineral assemblages of glaucophane schists

The intensity of glaucophanization is in amphibolites and gneisses very variable. The most affected rocks are garnet-amphibole gneisses. The glaucophanization itself has metasomatic character. During this alteration, topotactic substitution to pseudomorphism of hornblende took place and the structure of amphibolite facies metamorphites remains unaltered. The suggestion of Na-metasomatism is supported also by the occurrence of albite ± glaucophane veinlets in these rocks and new plagioclase in surrounding carbonates.

We base our assesment of metamorphic conditions of glaucophane schist mineral assemblage formation on some common petrographic signs in rocks of

Rudník and Hačava regions, which could be the proofs of a possible similarity of glaucophanization process in both localities. The development of glaucophane is in both cases mostly directionless and the rocks are massive. Original texture and structure characteristics are mostly preserved. Similarly as in Hačava region, recrystallized limestones with plagioclase xenoblasts to poikiloblasts occur sporadically also on the locality Rudník. In this case lower recrystallization grade of limestones is in accordance with the intensity of glaucophanization this locality.

The cause of the formation of glaucophane schists is assumed to be the subduction process (Ernst, 1971 and others) or overpressure of tectonic origin (Coleman — Lee, 1962 and others). The presence of veinlets of blue amphibole, jadeite and lawsonite in Franciscan formation in California as well as in other regions point to the possibility of effects of fluid pressure of tectonic origin (Roever, 1972). Misch (1962, 1969) suggests syntectonic origin of these veinlets: i. e. crystallization during the opening of fissure. The minerals ususally crystallize from solution.

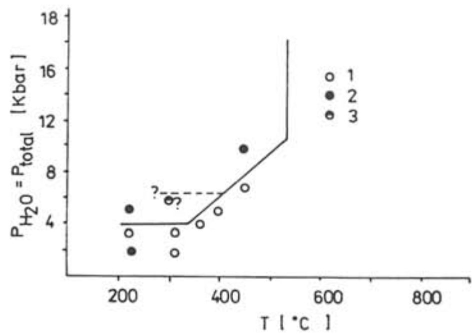


Fig. 10. Maximal possible stability field of glaucophane (Maresch, 1977).

*Explanations:* 1 — decomposition of glaucophane, 2 — glaucophane without changes, 3 — ambiguous result (see text).

The problem of the conditions of glaucophane formation has been in the last time the centre of attention of several experimental works (Ernst, 1961, 1963; Liyama, 1963; Roever, 1967; Carman, 1969, 1974; Maresch, 1973, 1974, 1977 and others). The maximal stability field $P_{H_2O}$ — T of natural glaucophane has been studied by Maresch (1977). This author established that at $P_{H_2O}$ under 4 kbar, at temperatures under 350 °C, glaucophane is not stable any more (Fig. 10). The ambiguous result obtained from the new phase corresponding to less than 3—4 % of the total matter, at 300 °C and 6 kbar $P_{H_2O}$ signifies the upper limit of low-pressure stability. According to some authors, (Roever, 1972 and others), the low-temperature limit of glaucophane formation is at pressures of 4—5 kbar and more 200 °C. Na-metasomatism alone, without high $P_{H_2O}$, hardly leads to the formation of glaucophane.

Except the presence of glaucophane and albite ± glaucophane veinlets, another sign analoguos for glaucophanites of Hačava region and blue schists (Okay, 1980) is the presence of markedly zonal garnet (Fig. 9). Similar garnet types rich in spessartite component and very poor in pyrope component are frequent in the Franciscan complex (Ernst et al., 1970) and in New Cale-

Table 1

Chemical composition of minerals from glaucophanized gneisses and amphibolite

| | Hornblende | | | | | Garnet | | | | | Glaucophane | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Fg-158/85 | | Fg-70/85 | | | Fg-158/85 | | | | | Gg-71/85 | | Fg-70A/85 | | Fg-70B/85 | |
| | 1r | 2c | 3c | 5 | | 1c | 2r | 3c | 4r | 5 | 1 | 2 | 3 | 4 | 5 | 6 |
| $SiO_2$ | 44.60 | 44.33 | 44.47 | 43.95 | 49.31 | 38.43 | 38.34 | 38.38 | 38.55 | 37.90 | 53.18 | 53.47 | 54.17 | 50.25 | 51.03 | 55.30 |
| $TiO_2$ | 1.26 | 1.29 | 1.13 | 0.74 | 0.77 | 0.05 | 0.07 | 0.04 | 0.05 | 0.00 | 0.41 | 0.08 | 0.22 | 0.27 | 0.27 | 0.00 |
| $Al_2O_3$ | 11.51 | 11.68 | 11.22 | 12.16 | 10.45 | 21.42 | 21.34 | 21.62 | 21.65 | 21.19 | 8.58 | 5.22 | 6.14 | 9.91 | 9.49 | 6.70 |
| $FeO_t$ | 16.37 | 16.45 | 16.40 | 16.30 | 14.59 | 30.05 | 28.34 | 30.34 | 28.76 | 30.84 | 16.64 | 20.40 | 17.97 | 17.28 | 16.49 | 18.23 |
| MgO | 10.81 | 10.44 | 10.72 | 10.56 | 9.42 | 4.40 | 4.16 | 4.54 | 4.12 | 5.25 | 8.64 | 7.96 | 9.10 | 8.81 | 8.94 | 7.97 |
| MnO | 0.35 | 0.38 | 0.32 | 0.27 | 10.33 | 1.99 | 2.86 | 2.03 | 2.97 | 2.39 | 0.16 | 0.14 | 0.23 | 0.13 | 0.21 | 0.10 |
| CaO | 10.35 | 10.19 | 10.00 | 8.23 | 7.17 | 4.73 | 5.55 | 4.54 | 5.49 | 2.62 | 1.39 | 0.94 | 0.50 | 1.06 | 1.56 | 0.23 |
| $Na_2O$ | 1.15 | 1.13 | 1.31 | 2.20 | 1.17 | 0.00 | 0.04 | 0.00 | 0.00 | 0.00 | 5.96 | 6.06 | 5.86 | 5.54 | 6.00 | 7.07 |
| $K_2O$ | 0.52 | 0.52 | 0.50 | 0.33 | 0.33 | 0.00 | 0.09 | 0.00 | 0.00 | 0.00 | 0.05 | 0.01 | 0.03 | 0.06 | 0.07 | 0.00 |
| Total | 96.91 | 96.41 | 96.06 | 94.75 | 93.55 | 101.07 | 100.60 | 101.43 | 101.60 | 100.29 | 95.01 | 94.28 | 94.03 | 93.31 | 93.99 | 95.61 |
| | Calculation of cathions to the base | | | | | | | | | | | | | | | |
| | 23 (0) | | | | | 12 (0) | | | | | 23 (0) | | | | | |
| Si | 6.66 | 6.65 | 6.69 | **6.68** | **7.37** | 3.00 | 3.00 | 2.99 | 3.00 | 2.99 | 7.82 | 8.00 | 8.00 | 7.57 | 7.62 | 8.00 |
| $Al^{IV}$ | 1.34 | 1.35 | 1.31 | 1.32 | 0.63 | 0.00 | 0.00 | 0.01 | 0.00 | 0.01 | 0.18 | 0.00 | 0.00 | 0.43 | 0.38 | 0.00 |
| $Al^{VI}$ | 0.68 | 0.72 | 0.68 | 0.86 | 1.22 | 1.97 | 1.97 | 1.98 | 1.99 | 0.00 | 1.31 | 0.93 | 1.10 | 1.33 | 1.29 | 1.16 |
| Ti | 0.14 | 0.14 | 1.13 | 0.08 | 0.08 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.04 | 0.01 | 0.02 | 0.03 | 0.03 | 0.00 |
| $Fe^{+}$ | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.03 | 0.28 | 0.29 | 0.27 | 0.23 | 0.11 | 0.28 |
| $Fe^{+}$ | 2.04 | 2.06 | 2.06 | 2.07 | 1.83 | 1.96 | 1.85 | 1.98 | 1.98 | 0.61 | 1.77 | 2.29 | 1.96 | 1.95 | 1.94 | 1.96 |
| Mg | 2.40 | 2.33 | 2.40 | 2.39 | 2.10 | 0.51 | 0.48 | 0.52 | 0.47 | 1.16 | 1.39 | 1.79 | 2.02 | 1.98 | 1.99 | 1.74 |
| Mn | 0.04 | 0.05 | 0.04 | 0.03 | 0.04 | 0.13 | 0.19 | 0.13 | 1.19 | 0.22 | 0.02 | 0.02 | 0.00 | 0.02 | 0.03 | 0.01 |
| Ca | 1.66 | 1.64 | 1.61 | 1.34 | 1.15 | 0.39 | 0.45 | 0.38 | 0.45 | 0.00 | 0.22 | 0.15 | 0.08 | 0.17 | 0.25 | 0.04 |
| $Na^{M4}$ | 0.04 | 0.04 | 0.03 | 0.21 | **0.33** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.40 | 1.49 | 1.55 | 1.30 | 1.36 | 1.81 |
| $Na^{A}$ | 0.29 | 0.28 | 0.32 | 0.44 | **0.00** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.24 | 0.26 | 0.14 | 0.32 | 0.38 | 0.20 |
| K | 0.10 | 0.32 | 0.10 | 0.06 | **0.06** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.01 | 0.01 | 0.00 |
| Alm. | | | | | | 65.18 | 61.87 | 65.73 | 62.36 | 66.95 | r — rims | | | | | |
| Pyr. | | | | | | 17.17 | 16.25 | 17.26 | 15.91 | 20.31 | | | | | | |
| Gross. | | | | | | 13.22 | 15.51 | 12.54 | 15.19 | 7.25 | | | | | | |
| Spess. | | | | | | 0.40 | 6.25 | 4.40 | 6.51 | 5.47 | | | | | | |

Table 2

Chemical composition of minerals from glaucophanes of Hačava region

| | Garnet | | | | | | | Glaucophare | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | K-1A/54 | | | K-1B/54 | | | | K-1A/54 | | K-1B/54 | | |
| | 1r | 2c | 3r | 4 | 5c | 6c | 7r | 1 | 2 | 3 | 4 | 5 |
| $SiO_2$ | 37.27 | 37.36 | 37.45 | 37.70 | 37.21 | 37.40 | 37.47 | 55.53 | 55.36 | 55.89 | 55.77 | 55.77 |
| $TiO_2$ | 0.16 | 0.30 | 0.16 | 0.13 | 0.29 | 0.24 | 0.32 | 0.07 | 0.03 | 0.08 | 0.10 | 0.05 |
| $Al_2O_3$ | 20.35 | 19.75 | 20.42 | 20.59 | 19.87 | 20.20 | 20.12 | 7.94 | 9.73 | 0.19 | 10.56 | 9.71 |
| $FeO_t$ | 20.66 | 15.94 | 22.79 | 22.89 | 16.85 | 15.70 | 17.91 | 20.40 | 20.23 | 21.25 | 20.08 | 18.19 |
| MgO | 0.23 | 0.17 | 0.23 | 0.29 | 0.18 | 0.16 | 0.21 | 5.24 | 4.92 | 4.48 | 4.07 | 5.22 |
| MnO | 13.27 | 18.16 | 10.55 | 11.87 | 17.73 | 19.10 | 15.74 | 0.21 | 0.18 | 0.08 | 0.27 | 0.06 |
| CaO | 7.41 | 7.20 | 7.68 | 7.16 | 7.74 | 7.20 | 8.19 | 0.38 | 0.33 | 0.51 | 0.75 | 0.14 |
| $Na_2O$ | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 6.15 | 7.04 | 6.65 | 6.65 | 6.82 |
| $K_2O$ | 0.00 | 0.00 | 0.00 | 0.00 | 0.02 | 0.00 | 0.00 | 0.07 | 0.02 | 0.00 | 0.06 | 0.00 |
| Total | 99.35 | 98.88 | 99.34 | 100.63 | 99.89 | 100.01 | 99.96 | 96.09 | 97.84 | 98.16 | 98.32 | 96.00 |
| | Calculation of cathions to the base | | | | | | | | | | | |
| | 12 (0) | | | | | | | 23 (0) | | | | |
| Si | 3.00 | 3.05 | 3.05 | 3.01 | 3.00 | 3.01 | 3.01 | 8.00 | 7.82 | 8.00 | 7.98 | 8.00 |
| $Al^{IV}$ | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.18 | 0.00 | 0.02 | 0.00 |
| $Al^{VI}$ | 1.95 | 1.90 | 1.95 | 1.95 | 1.90 | 1.93 | 1.92 | 1.37 | 1.44 | 1.56 | 1.76 | 1.66 |
| Ti | 0.00 | 0.02 | 0.00 | 0.00 | 0.02 | 0.01 | 0.02 | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 |
| $Fe^{3+}$ | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.14 | 0.52 | 0.26 | 0.20 | 0.25 |
| $Fe^{2+}$ | 1.41 | 1.09 | 1.54 | 1.54 | 1.14 | 1.06 | 1.21 | 2.16 | 1.92 | 2.30 | 2.20 | 1.96 |
| Mg | 0.03 | 0.02 | 0.04 | 0.03 | 0.02 | 0.01 | 0.02 | 1.16 | 1.06 | 0.96 | 0.86 | 1.13 |
| Mn | 0.91 | 1.26 | 0.72 | 0.81 | 1.22 | 1.31 | 1.08 | 0.02 | 0.18 | 0.01 | 0.03 | 0.01 |
| Ca | 0.64 | 0.63 | 0.66 | 0.61 | 0.67 | 0.62 | 0.71 | 0.05 | 0.05 | 0.08 | 0.01 | 0.02 |
| $Na^{M4}$ | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.75 | 1.97 | 1.82 | 1.81 | 1.92 |
| $Na^{A}$ | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.03 | 0.03 | 0.00 |
| K | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 |
| Alm. | 46.99 | 36.37 | 52.05 | 51.36 | 37.39 | 35.20 | 40.00 | | | | | |
| Pyr. | 0.93 | 0.68 | 1.16 | 1.14 | 0.70 | 0.60 | 0.80 | | | | | |
| Gross. | 21.50 | 20.95 | 22.38 | 20.49 | 22.02 | 20.70 | 23.40 | | | | | |
| Spess. | 30.53 | 41.97 | 24.40 | 26.97 | 39.86 | 43.40 | 35.60 | | | | | |

donia (B l a c k, 1973). The increase of almandine and pyrope contents from the core of garnet to its rim signifies an increase of temperature during its crystallization.

If we base our considerations on the results of the existing experimental works on glaucophane stability and some analogies (the development of rock texture and its mineral composition) of the studied rocks with high-pressure rocks, then the most probable process of formation of glaucophane schists and crystalline limestones is low-temperature, medium-pressure metamorphism. Most probable appear to be the values of $P_t = P_{H_2O}$ pressure (in temperature interval 200—350) 0.4 to 0.6 GPa (upper low-pressure limit of glaucophane stability).

*Mineral assemblage formed predominantly by dislocation metamorphism*

It is difficult to distinguish the products of this alteration from the previous ones in the solid and massive amphibolites and gneisses. It is possible only to notice sericite flakes occurring sometimes in younger albite which forms veinlets and clusters in the rock. In mylonitized parts, sericite, chlorite and epidote are formed simultaneously with cataclasis. Chloritization of glaucophane took here place as well.

*Discussion and interpretation of results*

1. The earliest metamorphic process is amphibolite-facies metamorphism which caused the formation of the studied amphibolites and gneisses. In its concluding phase, weak regressive alteration most probably took place as well.

2. Crystalline limestones with plagioclase xenoblasts occurring next to amphibolites and gneisse in the Rudník region are not metamorphic equivalents of the amphibolites and gneisses, but they have higher recrystallization grade than the surrounding limestones and other sedimentary rock types. It is probable that the crystalline limestones were formed simultaneously with amphibolite and gneiss glaucophanization. The relatedness of the formation of glaucophane schists and crystalline limestones can be supported by the presence of crystalline limestone intercalations in peripheral parts of glaucophane schists in the region of Šugovská Valley.

3. The recent position of the rocks leads us to assume that glaucophanized amphibolites and gneisses reached the environment of limestones and other sedimentary rocks by the means of tectonic displacement. Tectonic position of glaucophane schists and crystalline limestones to the surrounding rocks and signs of younger deformation elements in glaucophane schists themselves are well documented in the Hačava region (R e i c h w a l d e r, 1973).

The process of glaucophanization in Gemericum is considered to be of Alpine age as Mesozoic rocks are affected by this process. However, there remains the problem of the age determination of amphibolite facies. Before we should state our standpoint in this question, it is appropiate to mention a few similarities of the studied amphibolites and gneisses with amphibolites and gneisses from Klátov and Rudňany regions, in spite of their independent position (the occurrence of amphibolites and gneisses in Mesozoic rocks without the presence of other rocks of Rakovec Group where these rocks are known to occur). The similarity of amphibolites and gneisses from Rudník region with amphibolites and gneisses of Klátov and Rudňany regions consists in:

a) Lithological rock types. Similarly as in Klátov, Rudňany and Dobšiná regions, amphibolites occur here next to gneisses, which have similar mineral and possibly also chemical composition. Serpentinites found in boreholes next to glaucophanized amphibolites and gneisses have not been yet petrographically and mineralogically evaluated. It is not known whether they correspond, according to their mineral and chemical composition, to serpentinites from amphibolite and gneiss complexes known to occur in the Rakovec Group, or to Mesozoic serpentinites from southern part of Gemericum.

b) Character and grade of metamorphism. The similarity of character and grade of metamorphism is apparent from the same texture and mineral development and mutual phase equilibrium between the minerals. However, it is true that the original rock composition plays an important role in the forming of metamorphic mineral assemblages. In our case it is possible to compare the studied gneisses with garnet-amphibole gneisses of Rudňany region, where similar mineral assemblage can be distinguished (comp. Hovorka — Spišiak, 1981). The composition of hornblendes from of both localities falls into the same fields (Figs. 3, 4).

More recent petrological investigations (Hovorka et al., 1984; Spišiak — Hovorka, 1985) show that amphibolites, gneisses and serpentinites (rocks of the Klátov Group) together with the rocks of the Dobšiná Group represent an individual nappe, the so-called Klátov Nappe. According to the above-mentioned authors, the rocks of Klátov Group represent the upper part of oceanic crust metamorphosed either in the area of transform faults or in the process of their obduction.

The presence of glaucophanized amphibolites and gneisses and fine-grained crystalline limestones in low-metamorphic sediments and the presence of mylonitized serpentinites in Meliata Group near Rudník resemble tectonical melange.

With regard to the geological position of glaucophanized amphibolites and gneisses and their metamorphic, possibly also lithological (?) similarity with metamorphites of amphibolite facies from Rakovec Group, it is possible to explain the origin of these rocks in two ways:

a) Amphibolites and gneisses are together with serpentinites a part of Meliata Group. If this is true, we must however admit that rocks of Meliata Group were affected by amphibolite facies metamorphism even before the process of low-temperature, medium-pressure metamorphism. It is necessary to add that there are no signs of amphibolite facies in the glaucophanites of Hačava region. On the contrary, there are frequently present textures and structures pointing to their origination from basalts and their tuffs containing sometimes carbonate beds.

b) The studied rocks come from the same complex as amphibolite, gneiss and serpentinite bodies occurring in peripheral parts of Lower Paleozoic (Rakovec Group). These rocks were together with rocks of Meliata Group affected by subsequent low-temperature and medium-pressure metamorphism.

So far we cannot answer this question unambiguously, because there are missing geochronological data about the studied rocks and our petrological investigations are only in the beginning stage. However, if we consider the existing observations, lithological and metamorphical relatedness of these rocks with amphibolites and gneisses occurring in Rakovec Group is most probable.

## *Conclusion*

Glaucophanized gneisses and amphibolites in Mesozoic rocks of Rudník region appear to be, from the viewpoint of petrography and mineralogy, metamorphic and possibly also lithological (?) equivalents of amphibolite facies metamorphites occurring along Rakovec Group. The calculated metamorphic temperatures of these rocks vary between 595—625 °C. According to the mineral assemblages in the amphibolites and gneisses, the most probable temperatures of formation of these rocks appear to be a little lower (570—600 °C).

Except amphibolite facies metamorphism and regressive alteration, it is possible to distinguish in the studied rocks the following succession of events:

1. Low-temperature, medium-pressure metamorphism of amphibolites and gneisses from Mesozoic limestones took place most probably at temperatures of 200—350 °C and pressures $P_t = PH_2O = 0.4 - 0.6$ GPa. The intensity of this alteration was in the rocks of Rudník region lower than in Hačava region.
2. Transportation of glaucophanized rocks and crystalline limestones into their recent environment, their mylonitization and forming of tectonic slices.

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