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SHAH WALI FARYAD*

METAMORPHIC EVOLUTION OF PARAGNEISSES FROM KLÁTOV REGION (LOWER PALEOZOIC OF GEMERIKUM)

(Figs. 12, Tabs. 6)

A b s t r a c t: Besides the mineral association plagioclase — biotite — hornblende — quartz (D i a n i š k a—G r e c u l a, 1979), the associations plagioclase — garnet — biotite — quartz and plagioclase — hornblende — cummingtonite — quartz were also determined in the studied rocks. Biotite and hornblende have high-temperature character with high stability field corresponding to biotite and hornblende originating in higher subfacies of amphibolite facies. Garnet is rich in the almandine component and no zonality was determined. For the determination of the temperature of metamorphism of the paragneisses the author used garnet-biotite and hornblende-biotite geothermometers. The studied rocks are polymetamorphic, while younger stages of metamorphism had tectonometamorphic character, leading to their weak retrograde alteration and mylonitization.

Р е з ю м е: В изучаемых парагнейссах были определены кроме минеральной ассоциации плагиоклаз-биотит-роговая обманка-кварц (D i a n i š k a — G r e c u l a, 1979) тоже ассоциации плагиоклаз-гранат-биотит-кварц и плагиоклаз-роговая обманка-куммингтонит-кварц. Биотит и кварц являются высокотемпературными минералми, они имеют высокие поле устойчивости, что соответствует биотиту и роговой обманке возникнувшим во высшей субфации амфиболитовой фации. Гранат является богатым алмандиновым компонентом и у него не была определена зональность. Для определения температуры метаморфизма парагнейссов автор использовал гранат-биотитовый и роговая обманка-биотитовый геотермометры. Изучаемые породы являются полиметаморфическими, причем более молодые этапы имели тектонометаморфический характер, что вызвало слабый ретроградный перемен и милонитизацию.

Metamorphic rocks of amphibolite facies of the Rakovec Nappe (according to the classification of G r e c u l a, 1982) are interesting not only from the point of view of their position in the gemericum structure, but also because of the character of their metamorphism. These rocks were studied in detail in the region of Dobšiná (R o z l o ž n í k, 1965), Rudňany (H o v o r k a et al., 1979) and Klátov-Košická Belá (D i a n i š k a—G r e c u l a, 1979).

Up to now, several opinions on their genesis have been expressed. According to R o z l o ž n í k (1965), these rocks originated by granitization caused by granitoid magma fluids on narrow zones of the Rakovec Group rocks. The origination of these rocks during regional thermal metamorphism is explained by G r e c u l a (1982). According to H o v o r k a et al. (1984), amphibolites, together with paragneisses and serpentinites, represent the upper part of oceanic crust, the metamorphism of which took place either in the obduction process or it corresponds to the metamorphism of transform faults region.

* S. W. F a r y a d, Geological Survey, nat. enterpr., Geological Region, Garbanova 1, 040 11 Košice.

The paragneisses of the Klátov-Košická Belá region have been studied for the first time by Dianiška and Grecula (1979), who distinguished paragneisses with mineral associations plagioclase + amphibole + biotite + + quartz and plagioclase + biotite + quartz. The authors (l.c.) pointed out at the same time the sedimentary origin of the studied rocks. In our work, except for the mineralogical study of these paragneisses, we concentrate also on paragneisses with the mineral association plagioclase + biotite + garnet + quartz, which were not described on this locality.

Geological position of the paragneisses

The amphibolite-gneiss complex in the Klátov region is a part of the Rakovec Nappe (Grecula, 1982). These rocks (l.c.) together with serpentinites and carbonate layers in amphibolites represent an incomplete part of an ophiolite suite. According to Hovorka et al. (1984), these rocks are, as to their composition and metamorphism, an equivalent of the amphibolites and paragneisses of the Rudňany and Dobšiná regions and they form one lithologic unit — the Klátov Group.

Amphibolites and paragneisses of the Klátov region occur superposed on black and green phyllites, the metamorphic conditions of which correspond to the greenschist facies (Fig. 1). Because of slice structure of this region, the relations of the lithologic members and different metamorphic rocks are mostly tectonic. Only locally it is possible to observe normal superposition of strata. The paragneisses are frequently in intimate contact with amphibolites and in some parts they form intercalations in these rocks (Dianiška—Grecula, 1979).

Petrography of the paragneisses

The paragneisses are fine- to medium-grained rocks; their colour varies depending on the quantity of dark minerals from greyish-green to dark green. Except schistose types, equigranular and augen gneisses with nodules of plagioclase of up to 5 mm in size are present. The paragneisses are mylonitized in some parts, so that they have the character of low-metamorphic rocks.

The main and frequently present component of the paragneisses is plagioclase. The contents of dark minerals in the rock is variable (Tab. 1). It is possible to distinguish following mineral associations according to dominant minerals:

plagioclase + biotite + quartz
plagioclase + biotite + hornblende + quartz
plagioclase + biotite + garnet + quartz
plagioclase + hornblende + cummingtonite + quartz

We have distinguished several types of texture in the paragneisses:

1. Porphyroblastic texture is characterized in equigranular types of gneisses by the presence of tabular plagioclase, rarely also garnet (Fig. 2). In compressed types, the porphyroblasts are surrounded by fine-grained matter.

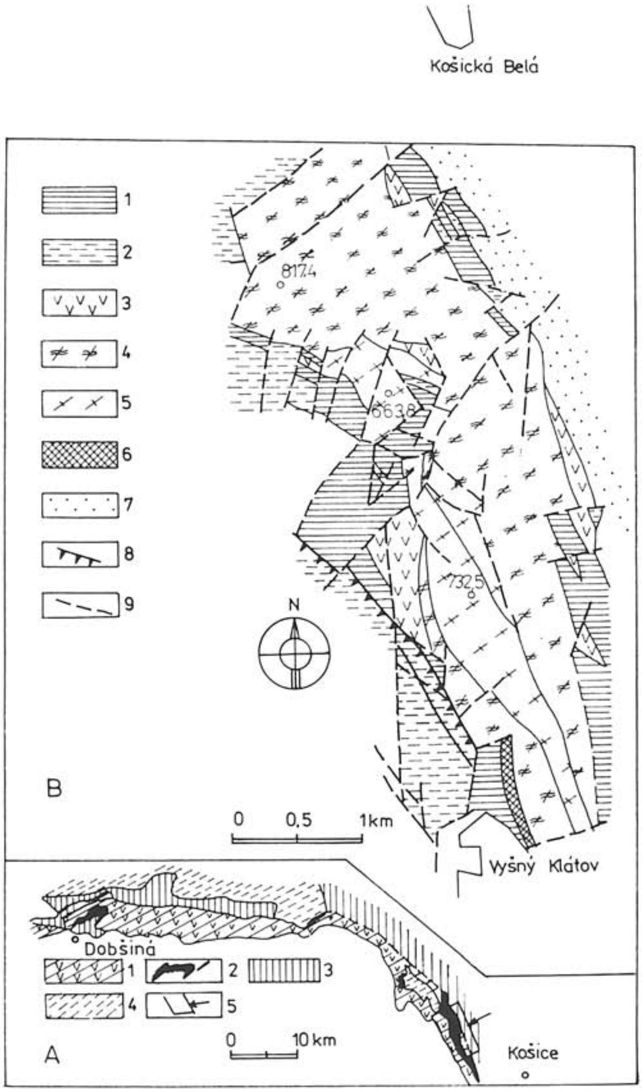

Fig. 1. A) A schematic geological map of the northern part of the Spišsko-gemerské rudohorie Mts.

Explanations: 1 — Rakovec Nappe; 2 — amphibolites and gneisses, components of the Rakovec Nappe (1—2 Lower Palaeozoic); 3 — Upper Palaeozoic; 4 — Mesozoic; — 5 — studied region.

Fig. 1. B) A geological map of the surroundings of Klátov (Dianiška — Hodermarský — Peterec, unpublished).

Explanations: 1 — graphite-sericite phylites; 2 — chlorite-sericite phyllites; 3 — metadiabases; 4 — amphibolites; 5 — paragneisses; 6 — serpentinites (1 — 6 Lower Palaeozoic); 7 — variegated schists, sandstones and graywackes (Permian); 8 — boundary of the Rakovec Nappe on the north and Mníšek Nappe on the south; 9 — faults.

Table 1

Chemical composition of paragneisses of the Klátov region

	FG-1/85	FG-85/85	FG-90/85	FG-134/85	FG-135/85	FG-140/85
SiO_2	56.31	59.93	60.82	61.27	57.83	55.60
Al_2O_3	15.65	16.45	14.09	15.63	17.92	15.58
Fe_2O_3	8.60	7.32	7.98	7.89	7.53	9.04
FeO	6.00	3.61	5.49	6.72	4.41	5.85
TiO_2	1.19	1.065	1.099	0.835	1.047	1.161
CaO	5.51	0.17	4.10	1.98	0.25	5.27
MgO	4.40	4.50	4.50	3.34	4.12	4.37
MnO	0.195	0.052	0.163	0.189	0.087	0.189
P_2O_5	0.19	0.18	0.22	0.22	0.14	0.29
Na_2O	4.25	2.96	2.30	3.12	2.36	3.38
K_2O	0.90	2.66	2.20	2.06	3.88	0.84
H_2O^+	0.31	5.52	0.25	0.43	0.30	0.33
H_2O^-	0.36	0.47	0.33	0.36	0.44	0.46
Total	100.5	99.15	100.57	99.14	99.78	99.18
Plagioclase	52	50	52	65	55	60
Quartz	25	30	35	15	15	10
Biotite	10	—	8	15	1	—
Hornblende	—	—	3	—	—	10
Garnet	8	—	—	3	—	—
Cummingtonite	—	—	—	—	—	5
Chlorite	3	20	+	2	30	10
Others	2	—	4	+	1	5

2. Lepidograno- and nematoblastic textures are typical for schistose paragneisses with the mineral association plagioclase + biotite ± hornblende + quartz.

3. Cataclastic texture is developed in mylonitized zones (Fig. 3).

Except the already mentioned mineral association and accessory apatite and zircon, secondary minerals take also part in the mineral composition of the paragneisses. Their quantity depends on the intensity of younger tectonometamorphic processes in the paragneisses and it varies from place to place. Frequent minerals of this type are white mica, chlorite, quartz, albite, rarely also epidote and biotite. Accessory tourmaline and a part of muscovite are in quartz ± albite veins. The rarely present graphite forms clusters and short scales in the direction of schistosity. Ore minerals (pyrite, chalcopyrite and others) are also present; their contents in the rock reach locally up to 1% of the rock volume (ore mineralization near Klátov was described by Grecula—Kucharski, 1981).

Mineralogy

Several minerals have been analyzed by electrone microprobe in the central laboratory of the Dionýz Štúr Geological Institute, Bratislava, with the aim of detailed petrographic study.

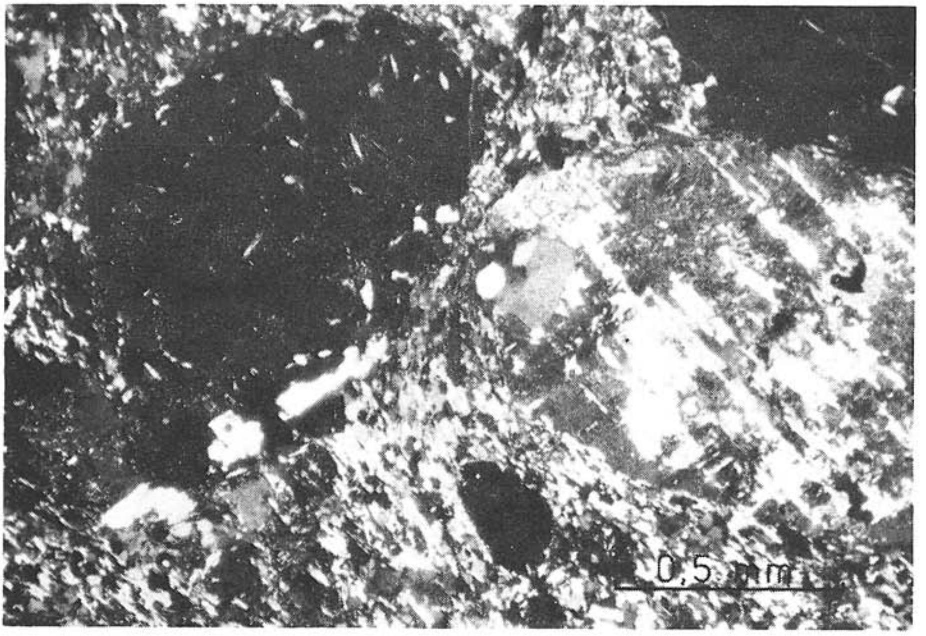

Fig. 2. Grains of plagioclase and garnet are slightly flowed around by biotite + quartz + plagioclase + matrix (Sample FG-1/85, X N).

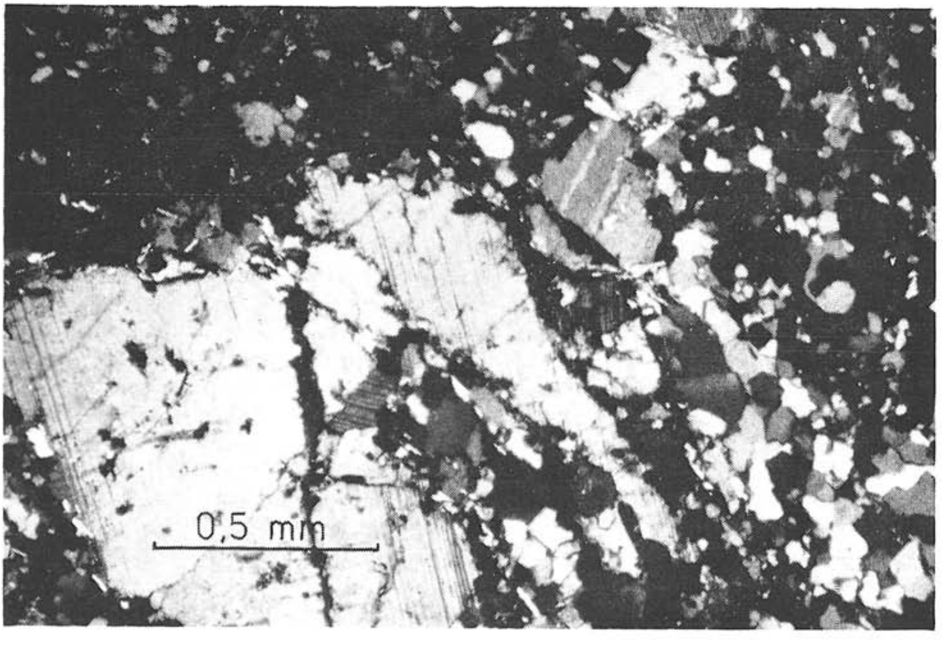

Fig. 3. Cataclastic texture of paragneiss. (Sample 16/095, X N).

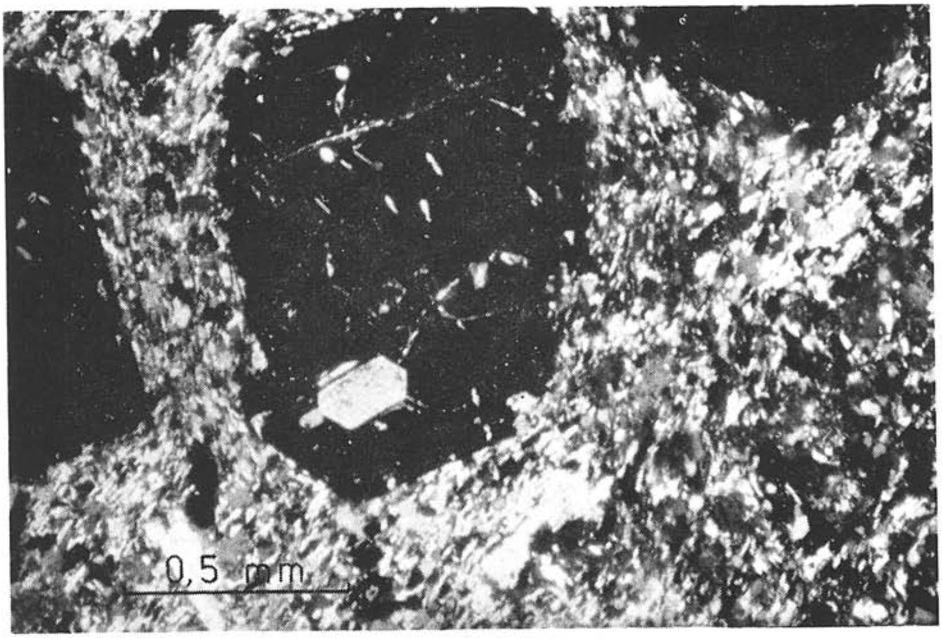

Fig. 4. Idioblast of biotite in garnet. (Sample FG-1/85, X N).

Biotite: In association with hornblende, biotite forms coarse flakes (up to 1 mm) or clusters, frequently directed along schistosity. Biotitization of hornblende is rare. In association with garnet, biotite is present in two forms:

1. Well developed, sometimes even idioblastic crystals of biotite; they form inclusions in garnet, rarely also in plagioclase (Fig. 4). Biotite in garnet reaches the size of up to 1 mm. Reddish-brown colour is typical for this biotite.

2. Biotite in the matrix is, like other minerals, fine-scaled. Frequently it is oriented and of greenish-brown colour. It appears that this biotite originated by recrystallization of originally reddish-brown biotite during younger tectonometamorphic processes.

We have analyzed biotites in association with hornblende (Aph II, see amphiboles) and garnet. There are no substantial differences in the chemical composition of both types. They are rich in Ti, what points to high stability field of biotite (Dymek, 1983). According to Edward et al. (1984), the content of Ti in biotite is dependent on the grade of metamorphism and not on the activity of Ti, as Ti contents in ilmenite and rutile are equal. In the diagram of octahedral ions: Ti/6 (Holdway, 1980), the projection points of the studied biotites coincide with the average composition of biotites from three regions correspond, according to metamorphism, gradually to staurolite + sillimanite and sillimanite + K-feldspar zones (Fig. 5).

To avoid environmental influences of the original composition of the rocks where originated biotite, we compared the biotite composition of the studied paragneisses with biotites from low-potassium metapelites of the Buulgena

Table 2

Chemical composition of co-existing garnet and biotite (Sample FG-1/85)

	Garnet				
	1[1]	2[1]	3[1]	4[1]	5[1]
SiO_2	38.24	38.34	39.33	39.13	39.52
TiO_2	—	—	—	—	—
Cr_2O_3	—	—	—	—	—
Al_2O_3	21.84	22.19	22.02	22.20	22.53
Feo	31.89	29.60	29.21	29.75	28.99
MnO	4.20	6.64	3.08	3.0	3.0
MgO	5.87	4.63	4.96	4.82	4.87
CaO	1.03	1.32	1.4	1.1	1.09
Na_2O	—	—	—	—	—
K_2O	—	—	—	—	—
Total	101.1	102.0	100.00	100.00	100.00
Calculation of structure formula to the base 12 (0)					
Si	2.9548	2.9748	3.004	3.003	3.007
Al^{IV}	0.0452	0.0252	—	—	—
Al^{VI}	1.9436	2.000	2.0285	2.0481	2.0679
Ti	—	—	—	—	—
Cr	—	—	—	—	—
Fe^{2+}	2.04	1.9204	1.9094	1.9476	1.8881
Mn	0.274	0.4366	0.2039	0.1989	0.1979
Mg	0.676	0.537	0.5779	0.5624	0.5654
Ca	0.085	0.11	0.1172	0.0922	0.090
Na	—	—	—	—	—
K	—	—	—	—	—
Al	66.5	63.80	67.98	69.52	68.81
PY	21.8	17.9	20.57	20.00	20.6
SP	8.8	14.68	7.26	7.10	7.2
An	0.6	—	—	—	—
Gr	2.7	3.6	2.02	3.3	3.3

series, USSR (Shengelia—Kechobeli, 1982). These rocks are chemically similar to our paragneisses and they were metamorphosed by low- to medium--pressure metamorphism in biotite-staurolite-sillimanite to migmatite zones. The projection points of our biotites in the Ti-Al^{VI} diagram (Fig. 6) fall near staurolite-sillimanite zone. It is necessary to add that low-potassium metapelites of the Buulgana series, although they occur in the staurolite-sillimanite zone, frequently contain the mineral association garnet + biotite + plagioclase + quartz + graphite ± staurolite. In contrast to the biotites from the Rudňany region, the studied bioties are richer in the annite-phlogophite component (Fig. 7).

Continuation of Tab. 2

	Biotite						
	1[1]	2[1]	3[1]	4[2]	5[2]	6[2]	7[2]
SiO_2	36.684	36.992	35.674	36.50	36.51	35.09	36.17
TiO_2	1.754	2.218	2.829	2.76	2.77	3.12	3.40
Cr_2O_3	0.000	0.032	0.072	—	—	—	—
Al_2O_3	18.176	18.356	19.109	18.55	18.23	18.00	18.09
FeO	18.7	17.175	18.607	17.34	18.10	20.01	19.47
MnO	0.000	0.41	0.221	—	—	—	—
MgO	10.67	11.345	9.787	10.17	10.68	10.32	9.17
CaO	0.000	0.000	0.004	—	—	—	—
Na_2O	0.000	0.242	0.378	—	—	—	—
K_2O	9.459	9.393	9.555	9.69	9.70	8.64	9.71
Total	95.443	96.105	97.235	95.00	96.11	96.00	96.00
	Calculation of structure formula to the base 22 (0)						
Si	5.5385	5.51364	5.3108	5.508	5.476	5.411	5.465
Al^{IV}	2.4615	2.48636	2.6892	2.524	2.524	2.589	2.534
Al^{VI}	0.7727	0.73818	0.6636	0.807	0.698	0.608	0.687
Ti	0.1991	0.2486	0.3285	0.312	0.311	0.353	0.385
Cr	—	0.003	0.008	—	—	—	—
Fe^{2+}	2.361	2.1408	2.3166	2.188	2.270	2.522	2.459
Mn	0.000	0.0517	0.0279	—	—	—	—
Mg	2.4015	2.5275	2.17206	2.287	2.388	2.318	2.064
Ca	0.000	0.000	0.0006	—	—	—	—
Na	0.000	0.053	0.1	—	—	—	—
K	1.821	1.78596	1.8145	1.865	1.856	1.661	1.871

Notes: 1 — minerals analyzed by the microanalyzer JEOL 733; 2 — minerals analyzed by the energy-dispersion analyzer EDAX; Al — almandine; PY — pyrope; SP — spessartite; An — andradite; Gr — grossular.

G a r n e t: Garnet forms porphyroblasts of up to 3 mm in size in the rock. Except irregular shapes, odioblasts of garnet are also frequent. In some parts, garnet contains inclusions of biotite and quartz. Garnet is allways cracked and sometimes along the cracks even totally chloritized. Garnet is not zonal, neither have we determined any difference in the composition of idioblasts and xenoblasts of garnet. It is rich in the almandine component (Tab. 3). On Fig. 8 it is possible to see that the studied garnets correspond quite well to the garnets of the paragneisses from the Rudňany region, which have the same lithologic environment (S p i š i a k—H o v o r k a, 1985). On the contrary, garnets from amphibolites are different (Fig. 9).

A m p h i b o l e s: We have distinguished several types of amphiboles in the paragneisses:

1. The most common amphibole of the paragneisses is hornblende (Aph I). It has greenish-brown to brown pleochroism and it forms tabular crystals with typical amphibole cleavage. We have studied this kind of amphibole in

amphibolites (F a r y a d—G r e c u l a, in press); according to its composition it corresponds to low-ferrian pargasitic hornblende to magnesio-hornblende.

2. Interesting in the paragneisses is brown to reddish-brown hornblende (Aph II), which forms irregular tabular shapes of up to 3 mm in size, and in contrast o to Aph I its cleavage is weakly developed. According to its composition it corresponds to magnesium hornblendes, while it differs from the hornblende Aph I by its lower contents of Al, Fe, Na and K and higher contents of Mg and Si.

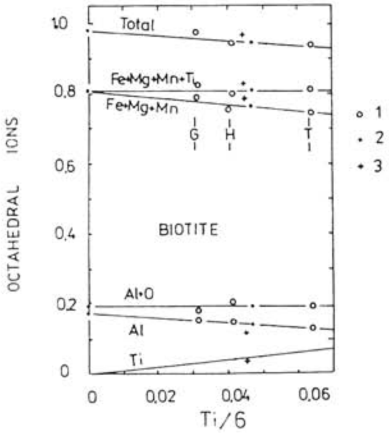

Fig. 5. Site occupancy of octahedral ions in relation to Ti content in biotite (H o l d w a y, 1980).
Explanations: 1 — average values of biotite from three regions: G — staurolite-sillimanite zone, H — sillimanite-K-feldspar zone and T — K-feldspar zone; 2 — total average composition and composition adjusted to zero value of Ti according to the valid module of solid solution; 3 — average values of octahedral ions of the biotites from the Klátov paragneisses.

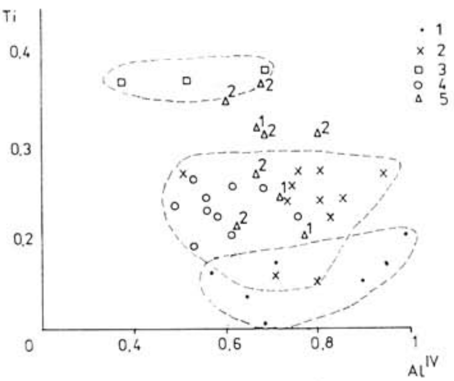

Fig. 6. Correlation of the contents of Ti: Al^{VI} in biotite.
Explanations: 1 — staurolite zone; 2 — sillimanite zone; 3 — migmatite zone (1 — 3: data from the work of S h e n g e l i a — K e c h o b e l i, 1982, see text); 4 — biotites from the Rudňany paragneisses (data from the work S p i š i a k — H o v o r k a, 1984); 5 — biotites of the Klátov paragneisses (Indices 1 and 2 as in Tab. 2).

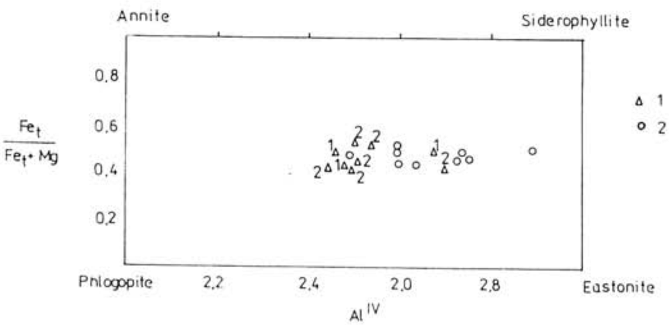

Fig. 7. Composition of biotite of the Klátov paragneisses (1) and Rudňany paragneisses (2).
Explanations: Indices 1 and 2 as in Tab. 2.

Table 3

Chemical composition of amphiboles and biotites

	MG-4/81		FG-90/85			
	Hornblende		Hornblende		Biotite	
	1[1]	2[1]	1[2]	2[2]	1[2]	2[2]
SiO_2	41.76	42.02	45.67	44,83	35.07	36.87
TiO_2	2.69	2.19	1.87	1.90	1.85	1.39
Cr_2O_3	0.09	0.00	—	—	—	—
Al_2O_3	11.64	11.75	8.72	8.85	18.82	17.55
FeO	18.26	18.78	14.61	14.83	19.13	16.53
MnO	0.24	0.25	1.10	—	—	—
CaO	10.46	10.47	10.34	10.39	—	—
MgO	8.52	8.41	11.39	11.86	12.93	11.60
Na_2O	1.60	1.45	0.79	0.75	—	—
K_2O	1.25	1.18	0.52	0.62	7.21	10.07
Total	96.52	96.51	95.00	94.00	95.00	95.00
Calculation of crystalochemical formula to the base						
	23 (0)				22 (0)	
Si	6.404	6.450	6.916	6.851	5.281	5.559
Al^{IV}	1.596	1.550	1.083	1.148	2.718	2.440
Al^{VI}	0.510	0.571	0.472	0.445	0.622	0.678
Ti	0.310	0.252	0.212	0.217	0.209	0.270
Cr	0.010	0.000	—	—	—	—
Fe^{3+}	0.250	0.220	0.018	0.018	—	—
Mg	1.951	1.923	2.570	2.701	2.902	2.606
Fe^{2+}	2.090	2.189	1.83	1.877	2.409	2.089
Mn	0.031	0.032	0.141	—	—	—
Ca	17.20	1.721	1.677	1.70	—	—
$Na^{M(4)}$	0.101	0.100	0.221	0.42	—	—
K	0.244	0.231	0.1	0.116	1.384	1.845
Na	0.374	0.331	0.01	0.18	—	—

3. Cummingtonite (Aph III), in association with Aph II, is developed as well. It has yellow-brown pleochroism and lower relief than magnesium hornblende. Its typical characteristics is twin lamelling. We have observed a transition from magnesio-hornblende (Aph II) to cummingtonite in a single grain. The borderline between both amphibole types is sharp.

4. Actinolite (Aph IV) is developed in some parts as a secondary mineral, in association with hornblende (Aph I). While studying amphibolites, we described three forms of actinolite (F a r y a d—G r e c u l a, in press).

The transition of one type of amphibole into another is an important phenomenon of the change of metamorphism grade. The difference in chemical composition of Aph I and Aph II points to the fact that Aph II is richer

Continuation of Tab. 3

	FG-140/85						
	Hornblende			Cummingtonite			
	1^2	2^2	7^2	3^2	4^2	5^2	7^2
SiO_2	45.01	46.39	45.19	53.88	54.48	54.42	54.52
TiO_2	2.30	2.15	2.34	—	—	—	—
Cr_2O_3	—	—	—	—	—	—	—
Al_2O_3	9.25	9.96	10.14	1.31	2.12	2.73	1.46
FeO	13.65	13.81	13.80	21.10	21.55	20.27	20.94
MnO	—	—	—	0.45	0.34	0.13	0.34
MgO	11.24	11.12	11.33	16.09	15.09	15.40	16.29
CaO	11.11	10.29	10.70	1.79	1.42	2.16	1.47
Na_2O	0.65	0.73	0.68	0.14	—	—	—
K_2O	0.80	0.55	0.83	0.24	—	—	—
Total	94.00	95.00	95.00	95.00	95.00	96.00	95.00
	Calculation of crystalochemical formula to the base 23 (0)						
Si	6.853	6.936	6.776	8.025	8.000	7.954	8.001
Al^{IV}	1.146	1.063	1.223	0.000	0.000	0.045	0.000
Al^{VI}	0.513	0.691	0.615	0.229	0.369	0.424	0.238
Ti	0.262	0.241	0.263	—	—	—	—
Fe^{3+}	0.020	0.014	0.016	0.132	0.015	0.112	0.064
Mg	2.550	2.477	2.531	3.572	3.336	3.354	3.596
Fe^{2+}	1.715	1.712	1.776	2.495	2.658	2.365	2.529
Mn	—	—	—	0.056	0.041	0.015	0.041
Ca	1.874	1.782	1.719	0.285	0.225	0.338	0.233
Na	0.191	0.211	0.08	—	—	—	—
K	0.154	0.104	0.158	—	—	—	—
Na		—	0.117	—	—	—	—

in the cummingtonite component. Such changes are a reflection of increasing grade of metamorphism (Miyashiro, 1974; Fabriés, 1963, 1968; Bossiere, 1980 and others). The origination of cummingtonite to the detriment of hornblende points to a substantial increase in the grade of metamorphism. This change takes place according to the following reaction (Miyashiro, 1974):

7 tchermakite + 10 quartz = 3 cummingtonite + 14 anorthite + H_2O

The changes of chemical composition before and after the reaction are similar to the above described changes of Aph I and Aph II or Aph II and Aph III.

Muscovite: White mica is a rare mineral in paragneisses. The most frequent and many times the youngest form of this mica is sericite, which originates in the process of mylonitization and it occurs in the form of oriented scales in the matrix, or it forms inclusions in plagioclase. A part of muscovite occurs together with tourmaline near quartz veins in the rock. Fluids which filled the opened fissures in the rock probably took part in the origination of this mica. The third, relatively oldest form of light mica is represented by regular scales of muscovite (up to 0.3 mm) developed in the fine-grained matrix of the paragneisses with the association plagioclase + biotite + garnet + quartz. We connect the genesis of white mica with younger tectono-metamorphic processes (see later).

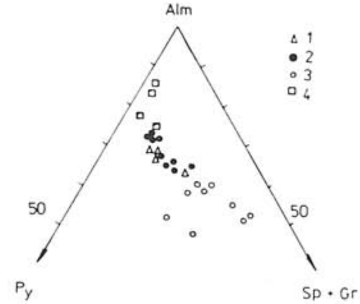

Fig. 8. Composition of garnet from the paragneisses.
Explanations: 1 — Klátov region; 2 — Rudňany region; 3 — garnets from amphibolites of the Rudňany region (2 — 3: data from the papers Spišiak — Hovorka, 1984 and Hovorka — Spišiak, 1981); 4 — garnets of low-pressure K-metapelites (Shengelia — Kechobeli, 1982, see text).

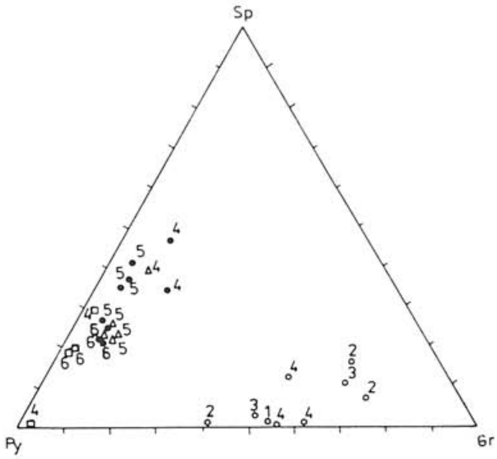

Fig. 9. Contents of the Py-Sp-Gr components in garnet.
Explanations: The numbers express the content of the almandine component in garnet: 1 (45—50), 2 (50—55), 3 (55—60), 4 (60—65), 5 (65—70), 6 (70—75). Other indices as in Fig. 8.

The latest described form of mica was analyzed by electrone microprobe. We can see on the diagram K-Al-Mg, Fe (Fig. 10) that the projection points of this mica are richer in the fengite component than the muscovites of the staurolite-sillimanite zone of the Buulgena series, i.e. they have lower contents of Al^{VI} and higher contents of Fe and Mg. The contents of the celadonite component in the analyzed mica change from 17%to 23% and the contents of the paragonite component is about 6%.

Plagioclase: The content of plagioclase in the rock is 50—70% of the rock volume. In the case of non-compressed augen types of paragneisses, the plagioclase forms regular tabular shapes. In contrast to the plagioclase of amphibolites, where epidotization is frequent, sericitization and clouding of plagioclase by a clay mineral are here dominant. Plagioclase suffered in the matrix of augen paragneisses from alteration earlier than the augens. The basicity of plagioclase is frequently about An_{5-13}, only rarely it reaches the values of An_{19-23} in fresh grains. Except fine grains of plagioclase in matrix, which are younger than porphyroblasts, albite is also present in veinlets with quartz.

Geothermometry

The ratio of Fe to Mg contents in garnet and biotite is a good indicator of the grade of metamorphism. These data were experimentally verified by several authors. Ferry—Spear (1978), Thompson (1976) and Goldman—Albee (1977) used the distribution of Fe^{+} and Mg between co-existing garnet (Alm and Py) and biotite (Ann and Phl) as a starting point

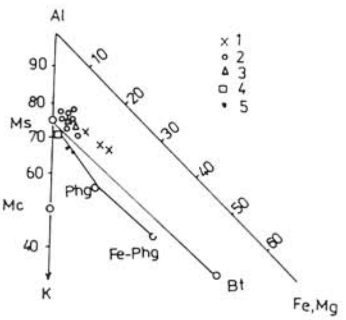

Fig. 10. K-Al-Fe, Mg diagram for muscovite.
Explanations: 1 — biotite zone; 2 — staurolite zone; 3 — sillimanite zone (1—3: Shengelia — Kechobeli, 1982); 4 — muscovite of the staurolite zone (according to Holdway, 1980); 5 — muscovites of the Klátov region paragneisses.

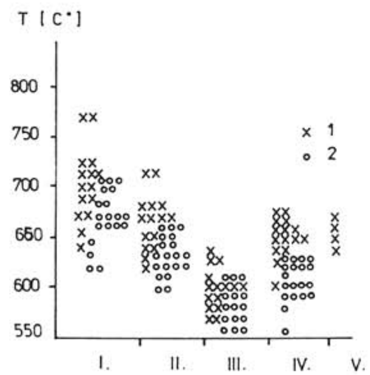

Fig. 11. Diagram of temperatures obtained by the use of the garnet-biotite and hornblende-biotite geothermometers. *Explanations:* I — Ferry—Spear, 1978; II — Thompson, 1975, III — Guidotti et al., 1977; IV — Perchuk—Riabchikov, 1976; V — Perchuk—Riabchikov, 1970 (hornblende-biotite geothermometer); 1 — temperatures for the Klátov paragneisses; 2 — temperatures for the Rudňany paragneises.

for their calculations of the temperature of metamorphism. Because the contents of Fe^{2+} and Fe^{3+} in biotite vary very much, the use of these methods for biotites analyzed by a microanalyser does not provide reliable results. In spite of the fact that we have substracted the values of Fe^{3+} 0.2—0.41 (calculated on the basis of normalization and neutralization of cations and anions) from the total iron, the resulting temperatures calculated by the method of Ferry—Spear (1978) are high compared with the paragenesis of the studied rocks (Tab. 5, Fig. 11). Similar high temperatures (up to 821° C) were calculated by Shengelia—Kechobeli (1982) in the metapelites metamorphosed in the staurolite isograde using the garnet-biotite thermometer according to Ferry—Spear (1978). For this reason, the use of this method and interpretation of its results should be done with great caution.

Table 4

Chemical composition of plagioclase and muscovite

	Plagioclase		Muscovite	
	P/6	P/7	M/8	M/9
SiO_2	60.282	61.709	48.297	47.22
TiO_2	—	—	0.061	0.982
Al_2O_3	26.187	24.05	33.22	33.54
CrO	0.16	0.008	—	—
FeO	0.003	0.172	1.670	1.46
MnO	—	0.132	—	—
MgO	0.008	0.064	1.098	0.898
CaO	7.221	5.465	—	—
Na_2O	7.652	8.330	0.407	0.51
K_2O	0.047	0.035	9.309	9.89
Total	100.91	99.96	94.692	94.5
	Calculation of the structure formula to the base 12 (0)		22 (0)	
Si	2.649	2.924	6.3885	6.3125
Al^{IV}	—	—	1.6115	1.6875
Al^{VI}	1.356	0.998	3.5676	3.5983
Ti	—	—	0.0687	0.0987
Fe^{2+}	—	—	0.1854	0.1637
Mn	—	0.00	—	—
Mg	0.0	0.0	0.2165	0.1791
Ca	0.34	0.277	—	—
Na	0.652	0.692	0.1044	0.1322
K	0.003	0.05	1.5788	1.6869
An	23.75	18.30		
Ab	75.90	76.20		
Or	0.35	5.05		

The temperatures received on the basis of phase equilibrium of garnet and biotite and hornblende with biotite (Perchuk—Riabchikov, 1976) have the same upper limits (675° C), which are also high for paragneisses. The lower temperature limit obtained by the use of the garnet-biotite thermometer (Perchuk—Riabchikov, 1976) and temperatures calculated by the method of Goldman—Albee (1977) correspond to the mineral paragenesis in the studied rocks. In comparison with the paragneisses from the Rudňany region, the temperatures calculated on the basis of garnet-biotite thermometer for the paragneisses of the Klátov region are relatively high (Fig. 11).

Interesting is the discovery of cummingtonite, which points to a certain increase in the grade of metamorphism. Because the study of cummingtonite and its paragenetic relations is now going on, we do not discuss this problem at this time in more detail.

Table 5

Temperatures calculated on the basis of the phase equilibrium garnet-biotite

Sample	ln K	X^{Mg}_{Gr}	X^{Mg}_{Bi}	T_1	T_2 v (°C)	T_3	T_4
1—1	—1.23	0.224	0.504	772	710	627	675
1—2	—1.35	0.224	0.535	715	674	605	665
1—3	—1.24	0.224	0.480	770	711	627	600
2—1	—1.40	0.227	0.504	691	650	590	660
2—2	—1.52	0.227	0.535	642	630	570	650
2—3	—1.40	0.227	0.535	691	650	590	675
3—1	—1.32	0.214	0.504	727	681	615	665
3—2	—1.44	0.214	0.535	675	640	580	625
3—3	—1.33	0.214	0.480	726	676	607	650
4—1	—1.37	0.207	0.504	705	673	603	650
4—2	—1.49	0.207	0.535	655	625	575	640
4—3	—1.37	0.207	0.480	704	673	603	655
5—1	—1.34	0.213	0.504	722	675	607	650
5—2	—1.45	0.213	0.535	670	641	581	640
5—3	—1.34	0.213	0.480	721	676	607	655

Notes: Temperature values: T_1 — according to Ferry — Spear, 1978; T_2 — according to Thompson, 1975; T_3 — according to Goldman — Albee, 1977; T_4 — according to Perchuk — Riabchikov, 1976;
ln K = ln $(Mg/Fe^{2+})_{Gr}$: $(Mg/Fe^{2+})_{Bi}$; X^{Mg}_{Gr} = Mg : (Mg+Fe+Mn); X^{Mg}_{Bi} = Mg : : (Mg+Fe+Mn); Gr — garnet; Bi — biotite.

Table 6

Temperatures obtained on the basis of phase equilibrium between biotite and hornblende (Perchuk — Riabchikov, 1976) (FG-90/85)

	X^{Mg}_{Hb}	X^{Mg}_{Bi}	T (°/₀)
1—1	0.58	0.54	645
1—2	0.58	0.55	640
2—1	0.59	0.54	670
2—2	0.59	0.55	660

The manifestations of younger tectonometamorphic processes in the paragneisses

Petrographical and mineralogical study of the paragneisses has shown that the grade of metamorphism of the studied rocks is not uniform. A certain zoning of the metamorphism grade is characterized by a change in the composition of amphiboles and sometimes as well by the origination of garnet. Such

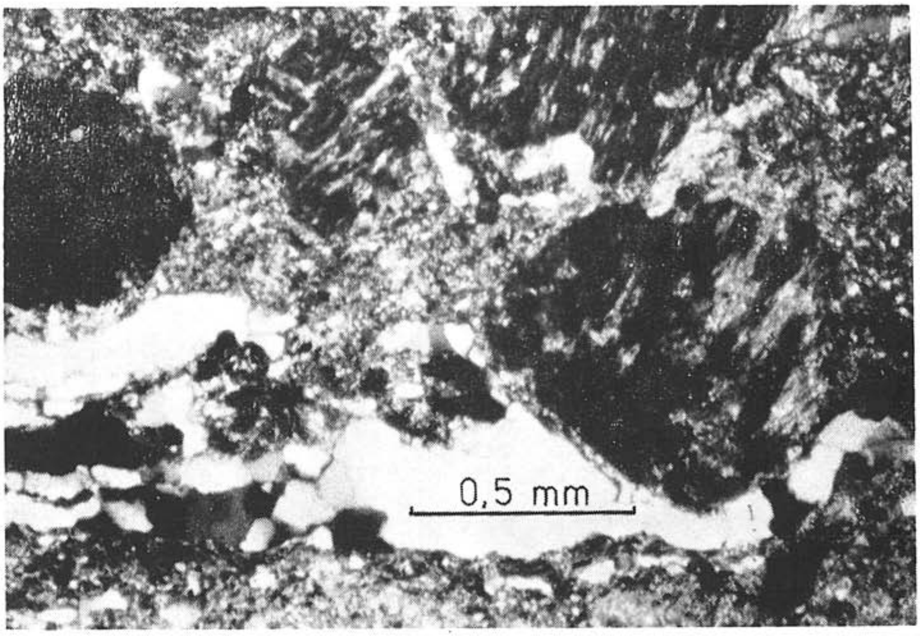

Fig. 12. Grains of plagioclase and garnet surrounded by mobilisates of quartz flowing around the grains. (Sample 15/098, XN).

changes in the grade of metamorphism could sometimes be the result of tectonic approachment of differently metamorphosed rocks. Differently metamorphosed rocks played a role to a certain extent also in younger tectonometamorphic processes. In most cases, paragneisses of lower grade of metamorphism are most strongly affected by these processes. A good example of such selective mylonitization and diaphtoresis are amphibolites from this region, which, as rigid rocks, are preserved better than paragneisses. As a result of strong compression, the paragneisses often decompose into small pieces and are secondarily cleavaged. It is possible to record within one body a transition from compact paragneisses to schistose parts, where the rock gets the character of rocks metamorphosed in greenschist facies. Such changes are not always only a reflection of different grades of metamorphism, as it is evidenced in the region of Dobšiná (Rozložník, 1965) and Rudňany (Rozložník et al., 1981 etc.), but they are also the result of later tectonometamorphic processes.

On the basis of microscopic study it is possible to distinguish several genetic types of individual minerals originating during different metamorphic processes. For example, quartz enclosed in garnet and associated with biotite and plagioclase appears to be the oldest one. A second type of quartz forms short veinlets or elongated clusters, rarely also lenticular grains oriented along the schistosity of the rock, which „flow" around plagioclase porphyroblasts (Fig. 12). Some of the quartz veinlets suffered in the direction across schistosity from younger tectonic processes, i.e. the veinlets are broken and quartz grains stick-like lamelled. The youngest ype of quartz forms veinlets, sometimes in association with albite. This type of quartz forms veins with sulphides in amphibolites.

We consider regular crystals of muscovite in fine-grained matrix of compact garnet-biotite paragneisses to be the oldest ones. A different type of muscovite is represented by crystals developed together with tourmaline near quartz veinlets. The youngest type of muscovite forms oriented scales flowing around cataclasts or inclusions in plagioclase.

We have pointed out three different types of biotite in the mineralogical description: Primary biotite with hornblende and sometimes with garnet forms coarse flakes. The second type of biotite was formed by biotitization of hornblende and garnet. Fine flakes of biotite associating with garnet are the youngest ones. We have distinguished four types of amphiboles while studying amphiboles in amphibolites (Faryad—Grecula, in press). Except tabular plagioclase, there are also present fine grains of albite in the matrix and in veinlets with quartz.

The younger metamorphic processes led together to the destruction and restructuring of minerals and textures of the paragneisses. The intensity of these processes differs within single paragneiss body. The study of mutual relations and associations of minerals makes it possible to connect the forming of individual mineral types with three tectonometamorphic stages. The first stage had the character of diaphtoresis, the second corresponds to hydrothermal alterations and the third one to mylonitization.

It is not sufficiently clear whether hydrothermal metamorphism is a part of diaphtoresis, which is more probable, or it represents an independent stage. The manifestations of diaphtoresis are in the paragneisses evident: the formation of new biotite, muscovite, quartz, epidote, chlorite, albite and maybe actinolite. Vein quartz, partly graphite, tourmaline and muscovite near the veinlets were formed as well especially during hydrothermal alteration.

We consider mylonitization to be the youngest process. During this process were destructed not only the paragneisses, but also minerals and veinlets formed during diaphtoresis and hydrothermal alterations.

Conclusions

The petrographical and mineralogical study of the paragneisses has shown that these rocks had undergone complicated metamorphic processes. Paragneisses in the amphibolite facies were formed by the oldest metamorphism. They are represented by high-temperature minerals (biotite and amphibole). The high-temperature stability field for these minerals and at the same the absence of Al-silicates in the paragneisses is probably a reflection of the chemical composition on primary rocks.

The metamorphic temperatures calculated by the method of Ferry—Spear (1978) and Thompson (1975) are too high for the studied rocks. According to the mineral assemblage in the paragneisses and in the surrounding amphibolite we suppose that the temperatures of the oldest metamorphic stage did not exceed 580—627 °C. These temperatures have been calculated by the method of Goldman—Albee (1977). Lower temperature values calculated on the basis of the garnet-biotite geothermometer (Perchuk—Riabchikov, 1976) correspond as well with this temperature.

Younger tectonometamorphic processes led to changes in the oldest and at the same time high-temperature mineral assemblage. On the basis of the hitherto made study of the succession of mineral formation it is possible to distinguish also a second stage of metamorphism (which had in these rocks the character of diaphtoresis), hydrothermal alterations and mylonitization.

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