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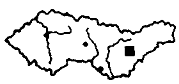
RETROGRADE METAMORPHISM OF STAUROLITE-GARNET-MICA SCHISTS OF THE KRAKĽOVSKÁ ZONE OF VEPORIDES

(3 Figs., 3 Tabs.)



Abstract: The mineralogy of retrograde alterations is studied on the example of medium-temperature staurolite-garnet-biotite schists of the Krakľovská Zone of the Vepor tectonic unit. In the secondary medium- and low-temperature alterations, three temperature grades alternating according to the decrease of temperature have been distinguished: muscovite stage (I), muscovite-chlorite stage (II) and sericite-chloritoid-chlorite stage (III). In these processes, biotite is replaced by muscovite or by muscovite and chlorite, plagioclase by muscovite and later by albite and sericite, garnet by chlorite and staurolite by sericite and chloritoid. Secondary tourmaline is formed as well. Chemical trends of retrograde metamorphism of all grades indicate that it is a metasomatic process of acid leaching, with a loss of Mg, Fe, Ca and Na. On the basis of several signs it was assumed that these secondary alterations originated in the retrograde stage of the Hercynian metamorphic cycle. Temperature values of progressive stage of metamorphism — 607 and 611 °C — are somewhat higher, probably due to high Mn contents in garnet which influence the data of geothermometry.

Резюме: Минералогия петроградного метаморфизма была изучена на приемере изменения среднетемпературных ставролит-гранат-биотитовых сланцев Кракловской зоны вепорид. Средне- и низкотемпературные изменения подразделяются на 3 температурные ступени, сменяющие одна другую по мере снижения температуры: мусковитовая (I), мусковит-хлоритовая (II) и серицит-хлоритоид-хлоритовая (III). При этом биотит замещается мускомитов, а затем — мусковитом с хлоритом, плагиоклаз-мусковитом, а затем альбитом и серицитом, гранат-хлоритом, и ставролит-серицитом и хлоритоидом. Вторичный турмалин кристаллизуется в условиях I и II ступеней. Химический тренд всех трех ступеней указывает, что ретроградный процесс является кислотным выщелачиванием, с выносом Mg, Fe, Ca и Na. На основании ряда критериев устанавливается, что все вторичные изменения связаны с ретроградной стадией герцинского метаморфического цикла.

Introduction

A characteristic trait of West Carpathian metamorphic terranes is an extensive presence of superimposed retrogressive alterations of medium- as well as of low-temperature type. Among them are the following ones: replacement of plagioclase, staurolite, biotite, kyanite as well as andalusite by coarse-flaked

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muscovite; formation (appearance) of fine-flaked clusters of secondary biotite replacing primary biotite with higher Ti-contents and garnet; replacement of biotite by coarse-flaked chlorite filled by sagenite needles and sphene grains; formation of chlorite or sericite-chlorite pseudomorphs after garnet and biotite; replacement of staurolite by sericite-chloritoid aggregate; saussuritization, sericitization or albitization of plagioclase etc...

These secondary replacements are connected with two different age periods: with the Hercynian retrograde stage and with Alpine diaphtoresis (Krist, 1962, 1980; Kamenický, 1962, 1967; Cambel—Korikovsky, 1986; Cambel et al., 1986 and others).

To determine criteria of these two different processes, complex geological-petrological studies are necessary, including the study of Variscan and Alpine dislocations and the connected tectonites, a comparison of the assemblages of the assumed Alpine diaphtorites in the crystalline complexes with progressively metamorphosed rocks of the mantle, further a study of the composition of Upper Carboniferous and Permian conglomerate pebbles as well as the determination of the isotopic age of the altered rocks by precise methods.

As far as the comparison of Alpine diaphthorite parageneses in the crystalline complexes with progressively metamorphosed rocks of the mantle is concerned, we shall present some microscopic observations obtained by this study.

The manifestations of Alpine metamorphism in the Kraklovská Zone crystalline complexes of Veporides have the character of diaphthoresis. In crystalline schists, phyllonite formation has been observed. A characteristic trait of the phyllonites is that they are fine-grained, thin-schistose, containing irregular lenses of secretion quartz as e. g. in the profile of Nový Krám (a part of the village Čierny Balog), in the direction towards the village Hronec.

Microscopically, the phyllonites of the crystalline schists have cataclastic-blastic textures with albite porhyroblasts (Fig. 2). Generally the mineral composition of the phyllonites is most frequently characterized by the newly formed assemblage Ser + Chl + Ab + Q*. Actinolite-chlorite to chlorite schists with the mineral assemblage Akt + Chl + Ep/Zs + Ab + Cc + Q were formed from basic rocks — amphibolites.

When observing the progressive character of the Alpine metamorphic cycle on Late Paleozoic and Mesozoic sediments, these appear to be also low-temperature alterations with a relatively intensive pressure factor. Thus, e. g. as a result of Alpine progressive regional metamorphism, Permian sediments in the NW part of the Vepor tectonic unit (Ľubietová Permian) acquired schistose structure. Sometimes there are only partly destructed and damaged clastic grains of the arenaceous fraction, or in some parts even cracked pebbles (Vozárová, 1979). In the most fine-grained members of the sedimentary complex, the low-grade metamorphic mineral assemblage Ser + Chl + Q ± Tour, Ru, Hem was formed. A similar mineral assemblage can be found also in the sediments

* Abbreviations of minerals: Ab — albite, Ap — apatite, Bi — biotite, Chl — chlorite, Chld — chloritoid, Fibr — fibrolitic sillimanite, Gr — garnet, Mu — muscovite, Pl — plagioclase, Q — quartz, Ser — sericite, St — staurolite, Tour — tourmaline, Akt — actinolite, Ep — epidote, Zz — zoisite, Cc — calcite, Ru — rutile, Hem — hematite.

of the Tribeč Mts. The complex of detrital sediments outcropping at the northern margin of the Ľubeník Line, denoted as the South Gemeride Permian (= Rimavica Formation, Vozárová—Vozár, 1982) displays also low-grade Alpine progressive regional metamorphism. Clastic sediments, above all of sand and silt grain-size, acquired the character of chlorite-sericite phyllite schists and chlorite-muscovite phyllites, with the most frequent mineral assemblages Ser + Chl ± Ep ± Ab + Q and (Mu) + Chl ± Gr ± Q.

The mantle Mesozoic was affected by low-grade Alpine progressive metamorphism as well. Thus, e. g. quartzites of Lower Triassic, as the lowermost member of the Veľký Bok Formation, display low-grade Alpine progressive metamorphism with the formation of the mineral paragenesis Ser + Chl + Q. The new-formed mineral assemblage Ser + Chl + Q can be found also in the quartz-sericite slates occurring above the epiquartzites. Weak recrystallization of matrix accompanied by the formation of the mineral assemblage Ser + + Chl + Q can be observed also in Keuperian variegated slates.

Thus it is clear that Alpine progressive metamorphism in the mantle rocks of the crystalline complexes and Alpine diaphthoresis of crystalline schists resulted in isofacial changes, i. e. the formation of a new mineral paragenesis characteristic for the sericite-chlorite subfacies of the greenschist facies. However, an important difference between Hercynian retrograde metamorphism and Alpine diaphthoresis is the presence of tectonic phenomenons in the Alpine diaphthoresis, an effect of which are the cataclastic-blastic or blastic-cataclastic textures. The relatively intensive kinetic factor in Alpine diaphthoresis was pointed out also by Krist (1980); together with the blastesis in the Kraklovská Zone phyllonites it resulted in the formation of rotated albite porphyroblasts.

As it was pointed out earlier, in the case of Hercynian retrograde metamorphism the intensity of the tectonic factor was not sufficient for a stronger tectonization and thus for the formation of phyllonites. This was pointed out also by Krist (1971), who connected Hercynian retrograde alterations with the formation of garnet-biotite-muscovite or biotite-muscovite schists in the north-eastern part of the Tribeč Mts. crystalline complexes. Granoblastics-lepidoblastic texture can be found in these rocks as well, while the intensity of retrograde alterations corresponds to the classification of Korikovsky—Putiš (1986) and Cambel—Korikovsky (1986).

A few years ago, petrological criteria of Late Hercynian and Alpine retrograde alterations have been determined on material from the Malé Karpaty Mts. and Považský Inovec Mts. (Korikovsky—Putiš, 1986; Cambel—Korikovsky, 1986). In correspondence with these criteria, Late Hercynian retrograde processes taking place in a wide temperature interval (570—300 °C) were accompanied by an intensive crystalloblastesis, indicating a rich fluid influx, and from the chemical viewpoint they actually represent intensive acid leaching. In correspondence with these assumptions, Alpine diaphtoresis occurred in low-temperature conditions (300—350 °C). In Alpine tectonites mechanical crushing (cataclasis) with slight crystalloblastesis and a limited fluid influx was prevailing. As far as its chemistry is concerned, diaphthoresis is above all metamorphic dehydration with limited manifestations of acid leaching. These differences are connected with the differences in the fluid and thermal regime of the Hercynian and Alpine metamorphic cycle.

The presented criteria should be tested in various West Carpathian crystalline complexes. Besides this, it is necessary to study the composition of minerals forming in various temperature grades of the retrograde cycle and Alpine diaphtoresis.

In the presented paper, the mineralogy of retrograde alterations is studied on the example of medium-temperature staurolite-garnet-biotite schists from the Krakľovská Zone of Veporides. The authors have studied three samples. In two of them, primary minerals are represented by garnet, staurolite, biotite, muscovite, fibrolitic sillimanite, plagioclase and quartz. In the the third sample the primary minerals are garnet, biotite, muscovite, plagioclase and quartz.

Petrographical description of the studied rocks

The sample NT-10, was collected south of the village Beňuš, from the rocks underlying garnet amphibolite; it is a medium-grained schist, where the matrix is represented by sub-parallelly oriented intergrowths of biotite and muscovite with inclusions of small fibrolite clusters, plagioclase and quartz grains. Garnet occurs in the form of tiny idiomorphic grains which do not grow together to form large monocrystals. This is usually characteristic for Mn-enriched garnets; this assumption is confirmed by microprobe analyses (Tabs. 1 and 2). Staurolite forms also idiomorphic grains, with a size larger than that of garnets.

The signs of retrograde alterations are in these schists very weak and they are represented only by partial replacement of biotite by coarse-flaked muscovite. The size of such muscovite flakes is practically identical with that of primary muscovite, it is thus very difficult to asses the proportion of primary and secondary muscovite in the rock. Lower-temperature alterations have not been determined.

The sample FIL represents an analogous schists, but with very strong retrograde alterations. As in the sample NT-10, garnet is represented here as well by clusters of tiny idiomorphic crystalls and staurolite by slightly larger grains. Fibrolite is not present. Biotite is practically totally substituted by muscovite and chlorite.

Retrograde alterations in the sample FIL are in accordance with the classifications K o r i k o v s k y—P u t i š (1986) and C a m b e l—K o r i k o v s k y (1986) represented by three temperature grades. Biotite is substituted by coarse-flaked muscovite (stage I) and by intergrowths of coarse-flaked muscovite and chlorite (stage II). Their formation after biotite is corroborated by a large number of sagenite inclusions in chlorite. Inside the muscovite-chlorite aggregate, large newly-formed tourmaline crystalls can be found. Low-temperature alterations (stage III) are represented by the substitution of plagioclase by sericite and albite, of garnet by chlorite and of staurolite by a sericite-chloritoid aggregate. Sericite and chloritoid in these reaction rims around staurolite are represented by tiny crystals. It is important to note that the retrograde substitutions are not accompanied by any tectonization of the schists, but that they preserve their primary lepidogranoblastic texture. Medium-temperature secondary muscovite as well as chlorite are as a rule developed in the primary-schis-

Table 1

Compositions of minerals in staurolite-garnet schist (sample NT-10)

Minerals	Gr		St	Bi	Pl
	centre	rim			
SiO_2	32.27	37.39	28.43	36.32	64.60
TiO_2	0.05	0.05	—	1.62	
Al_2O_3	20.92	21.22	54.78	19.92	22.43
FeO	30.80	31.81	12.45	17.70	—
ZnO	0.02	—	0.50	—	—
MnO	5.86	5.49	0.40	0.16	—
MgO	3.89	4.13	1.47	11.42	—
CaO	1.41	1.13	—	0.04	3.55
Na_2O	—	—	0.07	0.30	10.20
K_2O	—	—	0.06	8.76	0.08
Total	100.22	101.22	98.16	96.24	100.86
$\frac{Fe}{Fe + Mg}$, %	81.6	81.2		46.5	16 %
$\frac{Fe + Mn}{Fe + Mn + Mg}$, %	84.3	83.5	83.0		
Garnets:					
Alm	68	69			
Spes	13	12			
Pr	15	16			
Gros	4	3			

Paragenesis: Bi + Gr + St + Mu + Pl + Q + Ap;
Retrograde alterations: Bi → Mu

tosity plane and low-temperature sericite or sericite-chloritoid aggregates have pseudomorphic character. They copy the contours of the substituted plagioclase and staurolite grains.

The sample 3-2 from the Veľký Zelený creek valley collected south-east of the sample NT-10 belongs to medium-grained garnet-biotite-muscovite schists. It differs from the earlier described two samples by the absence of staurolite as well as of sillimanite (fibrolite) relics. Medium-temperature alterations can be in this sample characterized as well by muscovitization of biotite and by the formation of large tourmaline crystals (stage I), as well as by the formation of smaller muscovite flakes with chlorite forming often irregular clusters (stage II). Low-temperature alterations are characterized by the substitution of plagioclase by sericite and of albite and garnet by chlorite. Retrograde alterations are also in this case not accompanied by tectonization of the schist, as indicated by its lepidogranoblastic texture.

Table 2

Composition of primary and secondary minerals in retrograde-altered staurolite-garnet schist (sample FIL)

Minerals	Progressive stage			Retrograde stage						
	Gr		St	stage II			stage III			
	centre	rim		Mu	Chl	Tour	Chl	Ab	Ser[1]	Ser[2]
SiO_2	38.01	38.01	28.17	46.90	26.53	38.46	27.04	69.43	46.39	46.18
TiO_2	—	0.03	0.52	0.50	0.08	0.57	0.03	—	0.15	0.06
Al_2O_3	20.56	21.25	55.86	37.79	23.97	34.59	44.55	19.47	35.78	38.16
FeO	30.74	30.35	10.81	2.47	25.41	8.44	24.12	—	1.57	1.45
ZnO	0.07	0.07	2.09	—	0.04	0.04	0.02	—	—	—
MnO	5.19	4.87	0.35	0.01	0.27	0.4	0.89	—	0.01	0.01
MgO	3.93	4.15	1.00	0.69	12.91	6.02	2.24	—	0.70	0.61
CaO	1.81	1.49	—	—	—	0.92	—	—	—	—
Na_2O	—	—	—	1.57	—	2.04	—	10.78	0.84	0.95
K_2O	—	—	—	9.17	0.08	0.04	0.07	0.06	10.54	9.71
Total	100.51	100.22	98.80	97.10	89.29	91.16	98.96	99.74	95.98	97.13
$\frac{Fe}{Fe + Mg}$, %	81.4	80.4			52.4	44.0	85.8			
Garnets:										
Alm	68	68								
Spes	12	11								
Pr	15	17								
Gros	5	4								

Primary paragenesis: Gr + Bi ± Mu + Pl + Q + Ilm
Retrograde alterations: Grade II: Bi → Mu + Chl, Gr → Chl
Graade III: St → Ser[2] + Chld, Pl → Ab + Ser[1], Gr → Chl

Composition of minerals

Minerals of the prograde as well as of the retrograde stage in the samples NT-10 and FIL have been analysed with the help of the microprobe analyzer CAMECA MS-46. The results are presented in Tabs. 1 and 2. Microprobe analyses of muscovite in the sample 3-2 have been carried out on the microanalyser JEOL Superprobe 733 and they are presented in Tab. 3.

From primary minerals of the samples NT-10 and FIL we have analysed garnet, staurolite, biotite and plagioclase. The composition of garnets is in both samples almost identical. They contain relatively high amounts of Mn and Mg and little Ca. It is important to note that in samples with low (NT-10) and very high (FIL) retrograde alteration grade garnets preserve the prograde type

Table 3

Composition of muscovites in garnet-biotite-muscovite schist (sample 3-2, Veľký Zelený creek, South of Beňuša)

Mineral	Mu	Mu
SiO_2	48.93	48.55
TiO_2	0.80	0.72
Al_2O_3	84.01	34.73
FeO	1.44	1.46
MnO	—	0.02
MgO	0.95	
CaO	—	
Na_2O	0.77	0.71
K_2O	7.95	7.85
	94.85	95.07
Calculation to 22 oxygens		
Si	6.415	6.350
Al^{IV}	1.585	1.650
Al^{VI}	3.661	3.697
Fe	0.142	0.143
Ti	0.131	0.071
Mn	—	0.002
Mg	0.185	0.197
Ca	—	0.002
Na	0.195	0.181
K	1.328	1.308
Fe/Fe + Mg	0.43	0.42
Na/Na + K	0.13	0.12

Primary paragenesis: Gr + Bi + Mu + Pl + Ilm
Medium-temperature alteration: Mu + Chl + Tour
Low-temperature alteration: Ser + Ab + Chl (Gr → Chl)

of zoning — an increase of Mg contents and decrease of Mn and Ca contents as well as of the ratio Fe/Fe + Mg from centre to rim.

Staurolites contain varying but increased quantities of Zn. Biotite has a composition usuall for biotites from medium-temperature assemblages with low Ti contents. Plagioclases are represented by oligoclase containing 16 % of anorthite molecule.

The determination of the progressive-stage metamorphic temperature in the sample NT-10 on the basis of the biotite-garnet thermometer of Aranovich (1983) gives the value 607 °C. According to the thermometer of Ferry—Spear (1978) the temperature is 611 °C. Taking into consideration that the mineral assemblages in the sample NT-10 indicate the staurolite-sillimanite subfacies of progressive metamorphism, the calculated temperatures appear to be a little too high. It is possible that this is connected with the high Ti contents in garnets affecting the data of the geothermometers. The composition of primary muscovites from the sample 3-2 (Tab. 3) indicates that the progressive stage of metamorphism took place in the staurolite zone, thus influencing their projection points on the diagram with the coordinates FeO_{tot}: Al_2O_3 (Fig. 2). This fact would also indicate that the schists described from this part of the Krakľovská Zone are not of diaphthoritic origin (schists formed from paragneisses) but they are progressive-metamorphic rocks affected after the culmination of the progressive stage of the Hercynian metamorphic cycle by retrograde alterations of the same cycle connected only with fluid influx.

The composition of retrograde minerals has been studied in the sample FIL (Tab. 2). Large chlorite and muscovite flakes and tourmaline grains in equilibrium with them are related to the second temperature stage. Stage III was ascribed to sericite (Ser^1) and albite which replaced plagioclase, as well as to chloritoid and sericite (Ser^2) from reaction rims aroud staurolite. A part of the large-flaked muscovite could possibly be formed in the conditions of Stage I, but morphologically it does not differ from muscovite forming intergrowths with chlorite.

The analyses show differences in the composition of three white-mica generations. Coarse-flaked muscovites from the sample 3-2 contain more Ti than coarse-flaked muscovites of the retrograde stage (Stage II) in the sample FIL which contain a high proportion of paragonite molecule (21 %). Ti contents of sericites are much lower and the admixture of the paragonite molecule is 11—13 %. The content of the phengite component is in all white micas low.

Oligoclase was replaced by pseudomorphs of practically pure albite with sericite.

Trends of rock-composition changes in retrograde metamorphism

The changes of mineral parageneses during retrograde recrystallization of staurolite-garnet-mica schists can be demonstrated on the diagrams (K, Na) — (Mg, Fe, Mn, Zn) — Al (Fig. 1). The compositions of the analysed minerals are marked on these diagrams by black points. Since muscovites of the retrograde metamorphic Stage I are very difficult to distinguish from progressive-metamorphic muscovites, we shall dicuss only Stage II and Stage III alterations, most markedly manifested in the sample FIL.

Dominant minerals of the primary composition of the garnet-staurolite-mica schists are garnet, biotite and plagioclase. Staurolite is present only in small quantities. The composition of the rock can be thus represented approximately by the point 1 (Fig. 1, 1). The replacement of biotite by muscovite and chlorite, of plagioclase by muscovite with simultaneous tourmaline crystallization indicates that the critical paragenesis for the second stage of retrograde metamorphism is Mu + Chl + Tour (depicted on Fig. 1, 1; dotted). Thus the general rock composition will, according to the development of the process, approach the point 2.

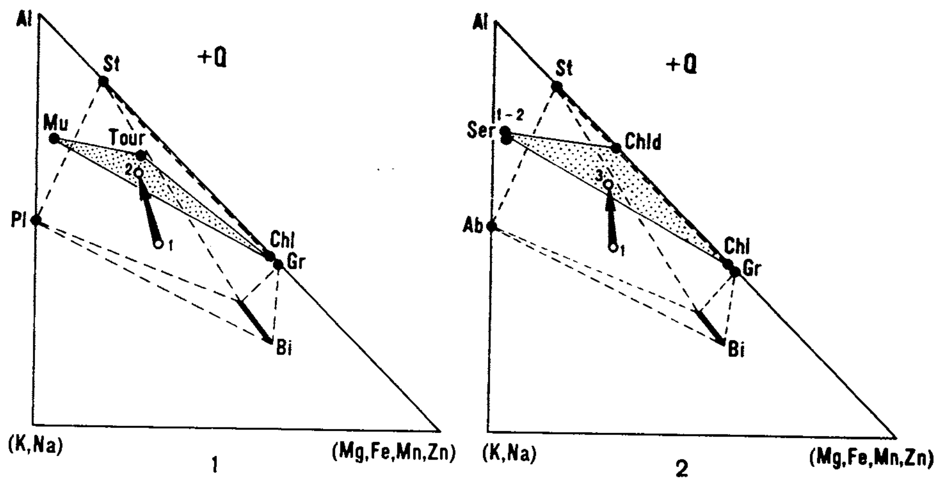

Fig. 1. Trends of composition changes of staurolite-garnet-biotite schists during their retrograde metamorphism.

Explanations: Newly formed assemblages are denoted by dotting.
1 — muscovite ± tourmaline — chlorite stage (II) (average compositions: 1 — staurolite-garnet-biotite schist, 2 — secondary assemblage muscovite + tourmaline + + chlorite). Analyses of minerals are in Tabs. 1 and 2.
2 — sericite-chlorite stage (III) (3 — average composition of the secondary assemblage sericite + chloritoid + chlorite). Analyses of minerals are in Tab. 2.

With a further temperature decrease in the conditions of the retrograde-metamorphic Stage III, due to the abovementioned replacements, the critical paragenesis Ser + Chld + Chl + Ab was formed. In this case the composition of the primary schist will be transposed from point 1 to point 2 (Fig. 1, 2).

The diagrams of Fig. 1 indicate that the chemical trends of Stage II and III retrograde metamorphism are identical and they shift the primary schist composition towards the Al-corner of the diagram. The replacement of biotite by muscovite with chlorite and of plagioclase by albite and sericite is accompanied to a certain extent by an increase of K content, and by a loss of a part of Mg, Fe, Ca and Na, and thus by an increase of the general ratio Al/Mg + Fe + + Ca + Na in the rock. This type of metasomatism represents the process of

Fig. 2. Albite porphyroblasts. Phyllonite, Hrončok, Krakľovská Zone, Veporides. Photo E. Krist.

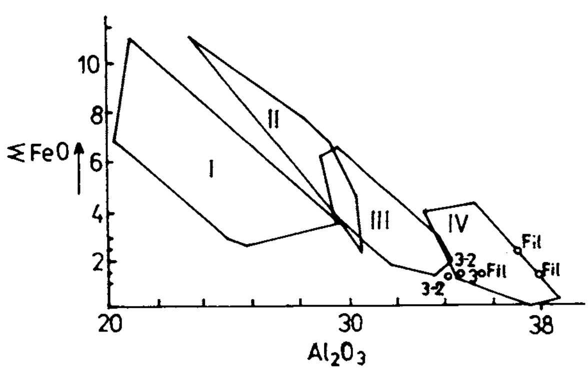

Fig. 3. Relationship of muscovite compositions and metamorphic grade of staurolite-garnet-biotite and garnet-biotite-muscovite schists of the Krakľovská Zone, according to Butler (1967).

Explanations: I — Blueschist facies, II — chloritoid and biotite zone, III — almandine zone, IV — staurolite zone.

acid leaching the substance of which has been already discussed in greatest detail in the work Cambel—Korikovsky (1986).

The characteristics of the retrograde alterations of the staurolite-garnet-mica schists of the Krakľovská Zone lead to the following conclusions:

1. The process took place in a wide interval of decreasing temperatures and it can be divided into three subsequent stages:
— muscovite
— muscovite-chlorite
— sericite-chloritoid-chlorite.

2. The chemical trends af all three stages are that of acid leaching; as a result the rock colour becomes lighter, since potassium mica — muscovite or sericite — becomes the principal mineral. This indicates that the fluids were saturated by potassium.

3. In medium-temperature stages of the retrograde process, an increased activity of B in fluids has been observed.

4. Secondary alterations took place in all stages without any superimposed tectonization, in the conditions of perfect crystalloblastesis.

These trends correspond to the criteria which, according to Cambel—Korikovsky (1986), are characteristic for Hercynian retrograde metamorphism. It is indicated by the newly-formed tourmaline, a typical accessory mineral of many Hercynian granite types, often formed also in external contact aureoles of these granitoids in zones of metasomatic muscovitization.

Important is also the fact that similar retrograde rocks — muscovitized, chloritized and tourmalinized gneisses, migmatites and granites occur as pebble material in Lower Carboniferous and Permian conglomerates in the Považský Inovec Mts. (Kamenický, 1958; Putiš, 1981; Korikovsky—Putiš, 1986).

All this indicates that the studied medium- and low-temperature secondary alterations of staurolite-garnet-mica schists as well as of garnet-mica schists of the Krakľovská Zone are most probably connected with the retrograde stage of the Hercynian metamorphic cycle.

Conclusion

Three temperature stages alternating according to temperature decrease have been distinguished in secondary medium- and low-temperature alterations of staurolite-garnet-mica schists: muscovite (I), muscovite-chlorite (II) and sericite-chloritoid-chlorite (III). In these processes, biotite is replaced by muscovite or by muscovite with chlorite, plagioclase by muscovite and later by albite and sericite, garnet by chlorite and staurolite by sericite and chloritoid. Secondary tourmaline is formed as well. The minerals have been studied with the help of microprobe.

The chemical trends of retrograde metamorphism of all grades indicates that it is a process of acid leaching with a loss of Mg, Fe, Ca and Na. On the basis of several characteristics it is assumed that these secondary alterations took place in the retrograde stage of the Hercynian metamorphic cycle.

Translated by K. Janáková

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