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AN OUTLINE OF THE METAMORPHIC EVENTS RECORDED IN THE WESTERN CARPATHIANS (SLOVAKIA)

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PROJECT 276
Paleozoic of the Tethys

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Abstract: The main features of the Alpine and pre-Alpine metamorphisms in the Western Carpathians (WCp) are outlined in this paper, in order to give the basic information for interregional correlations within the ambit of the IGCP Project No. 276.
The WCp consists of three main Alpine structural zones. The outer zone is made up of non metamorphic sediments of the Flysch and Klippen Belts. The central zone includes three tectonic units: those comprising pre-Alpine complexes, the Tatricum, Veporicum, and Zemplinicum. The inner zone is the Gemericum. The Tatricum, Veporicum, Zemplinicum and Gemericum include metamorphic sequences of different age and petrological features. For each of these four structural domains, the available data concerning lithology, petrological features and chronological framework are critically summarized, and the main open problems are focused upon.
Due to the very complex history of the WCp, our present knowledge on the timing, regional distribution and petrological features of the variously aged metamorphic stages is sometimes not sufficient for presenting clear statements, notwithstanding the huge amount of new data published in the last ten years. Therefore, some aspects described in this paper are rather problematic.
However, the basic features of the Alpine and Variscan metamorphism are relatively clear. The Alpine metamorphism appears to be characterized by medium/high pressure and low to very-low temperatures. The Variscan event covers the whole range of metamorphic temperatures. It displays low-pressure conditions in certainly monometamorphic, low-grade sequences. In the high grade pre-Alpine terraines, barrovian-type conditions have also been reported as related to the Variscan event: however, they could also be a record of a pre-Variscan history, surviving after the prevailing Variscan effects, as some chronological data and geopetrographic hints may suggest.

Key words: Western Carpathians, pre-Alpine metamorphism, Alpine metamorphism, PT conditions.

Introduction

The main features of the Alpine and the pre-Alpine metamorphism in the Western Carpathians are outlined here, in order to give the basic information for interregional correlations within the ambit of the IGCP Project No. 276.

The geology of the Western Carpathians is very complex, due to a very strong Alpine deformation which variously reworked and disarticulated the Variscan basement and its Permo-Mesozoic cover, and dissected them in a system of Alpine nappes. Due to this very complicated history, our present knowledge on the timing, regional distribution and petrological features of the variously aged metamorphic stages is sometimes not sufficient for presenting clear statements, notwithstanding the huge amount of new data published in the last ten years. Therefore, some aspects described in this paper are rather problematic, and consequently they are presented and discussed here in a critical way, trying to point out the conflicting statements of the problems rather than conciliatory interpretations not strictly related to the available data.

For each of the main structural units making up the Western Carpathians, the lithology, the petrological features and the chronological framework are outlined here, and the main open problems are finally focused upon.

Mock (1978) and Maheľ (1986) following Kober (1931), divided the Western Carpathians into three domains (Fig. 1). The outer domain consists of non-metamorphic sediments of the Flysch and Klippen Belts. The central domain consists of three tectonic units which comprise the pre-Alpine complex: the Tatricum, the Veporicum and the Zemplinicum. The inner domain is the Gemericum. These domains differ from each other in lithology, tectonic structure and metamorphic evolution.

Tatricum

The Tatricum is presently the most external structural unit in the Central Western Carpathians. The so-called "core mountains" are megaanticlinal horsts with pre-Mesozoic complexes, surrounded by Mesozoic rocks. They are separated by Tertiary intramontane basins (Fig. 1).

The main core mountains are: Malé Karpaty Mts, Považský Inovec Mts, Tribeč Mts, Strážovské vrchy Mts, Malá and Veľká Fatra Mts, Tatry Mts, western part of the Nízke Tatry Mts.

Lithology. Numerous metamorphic rock types occur in the Tatricum. They include metapelites, metapsammites, basic metavolcanics and less abundant acidic metavolcanics, meta-

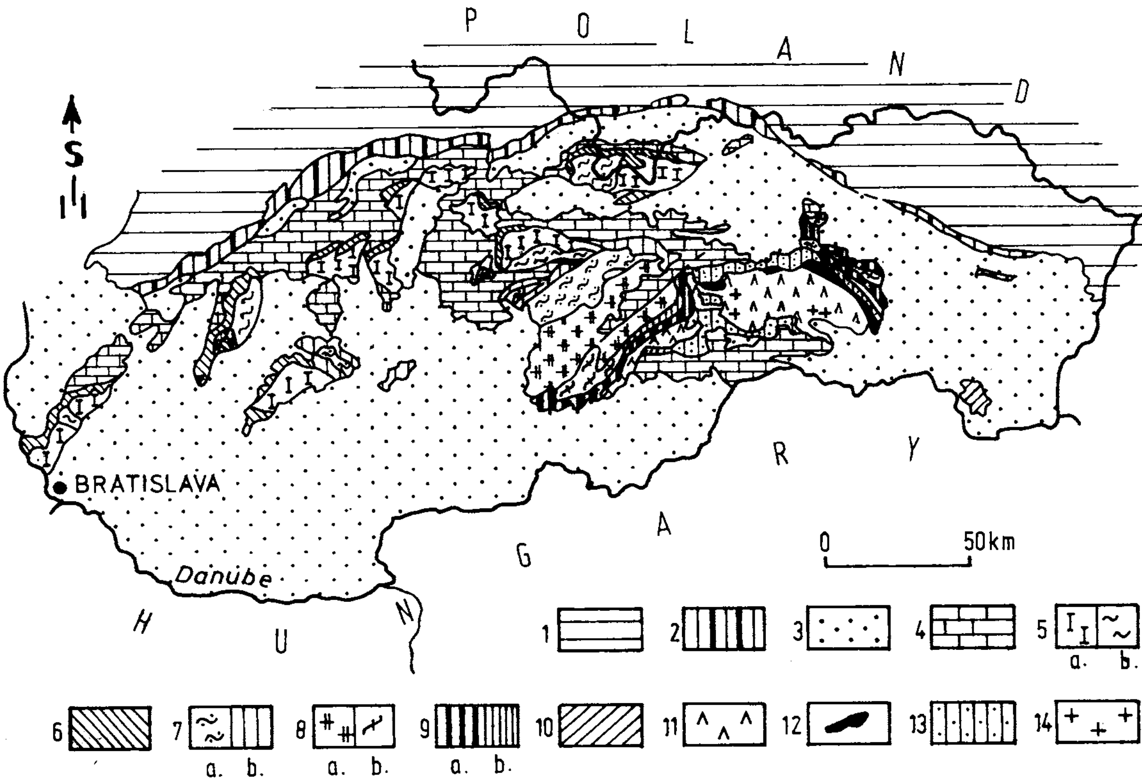

Fig. 1. Distribution of main tectonic units in the Western Carpathians.
1-2 - *Outer Western Carpathians*: 1 - Flysch Belt, 2 - Klippen Belt; 3 - *Tertiary sediments and volcanics*; 4 - *Higher nappes with Mesozoic sequences*; 5-10 - *Central Western Carpathians*: 5 - crystalline rocks of Tatricum: a - granitoids, b - metamorphites, 6 - Permian-Mesozoic envelope sequences of Tatricum, 7a - low- and high-grade crystalline complexes of northern Veporicum, 7b - Permian - Mesozoic envelope sequence of northern Veporicum, 8 - crystalline complexes of southern Veporicum: a - granitoids, b - metamorphites, 9a - Late Paleozoic - Mesozoic envelope sequence of southern Veporicum, 9b - ?Late Variscan-Alpine granitoids in tectonic contact between Gemericum and southern Veporicum, 10 - Zemplinicum - crystalline basement and Late Paleozoic - Mesozoic envelope sequence together; 11-14 - *Inner Western Carpathians*: 11 - low-grade metamorphites of Gemericum, 12 - high-grade metamorphites of Gemericum, 13 - Late Paleozoic and Mesozoic envelope sequence of Gemericum, 14 - granitoids in Gemericum.

ultramafics and marls, of various metamorphic grades. Due to amphibolite-facies metamorphism, these rock types are now gneisses, migmatites, amphibolites and calc-silicate rocks (Kamenický 1968; Maheľ 1986; Hovorka 1975; Spišiak & Pitoňák 1990). Low-grade rocks also occur, but as will be discussed later, it is questionable whether they are true phyllites or retrograded phyllonites (Molák et al. 1989).

Banded metabasites are very specific in the Tatry Mts, and sometimes they are associated with metaultrabasites in the Nízke Tatry Mts. They are characterized by a primitive REE distribution and show some affinity to the rock complexes of the island-arc initial stage. They may also represent a crustal fragment of oceanic affinity (Spišiak & Pitoňák 1991).

The whole rock sequence is cross-cut by post-metamorphic Variscan granitoids, which sometimes produce contact metamorphism in their country-rocks.

Petrologic features. The metamorphic history of these crystalline complexes is mainly Variscan. However, there are some hints of a pre-Variscan or early-Variscan stage (Spišiak & Pitoňák 1991), and Alpine reworking is also documented. The Alpine cycle produced mainly tectonic effects, but the occurrence of Alpine metamorphic overprints is also documented: they are confined within the anchizone and greenschist facies conditions and localized mainly within the shear zones.

As far as the pre-Alpine metamorphites are concerned, most of them belong to the garnet amphibolite facies, as the mineral assemblages clearly indicate (Fig. 2).

However, as above mentioned, lower-grade rocks of pelitic composition occur locally (in the Malé Karpaty Mts): some authors consider them to be true phyllites (Korikovsky et al. 1984), others as retrograde phyllonites formed from originally higher-grade rocks (Spišiak & Pitoňák 1990), as some high-temperature relics suggest. The main mineral assemblage is Chl + Bt + Ms + Ab + Qtz + Ilm in the metapelites, while Chl + Act + Ep + Ab + Qtz + Cc in the associated metabasites (symbol as in Kretz 1983).

The common mineral assemblages in the amphibolite-facies rocks are as follows (Cambel et al. 1981; Korikovsky et al. 1984, 1987a, 1987b; Janák 1991; Janák et al. 1988; Spišiak & Pitoňák 1990; Spišiak et al. in press):

1 - in gneisses: Pl + Kfs + Ms + Bt + Grt + Qtz;
2 - in Al-rich gneisses: Pl + Ms + Bt + Grt + St + Ky(Sil) + Qtz;
3 - in basic gneisses and amphibolites: Pl + Hbl + Cpx + Grt;
4 - in Ca-silicate rocks: Cpx + Hbl + Grt + Ep + Cc.

In the Nízke and Vysoké Tatry Mts area, the banded amphibolites include dm to meter-size lenses, having zoned structure:

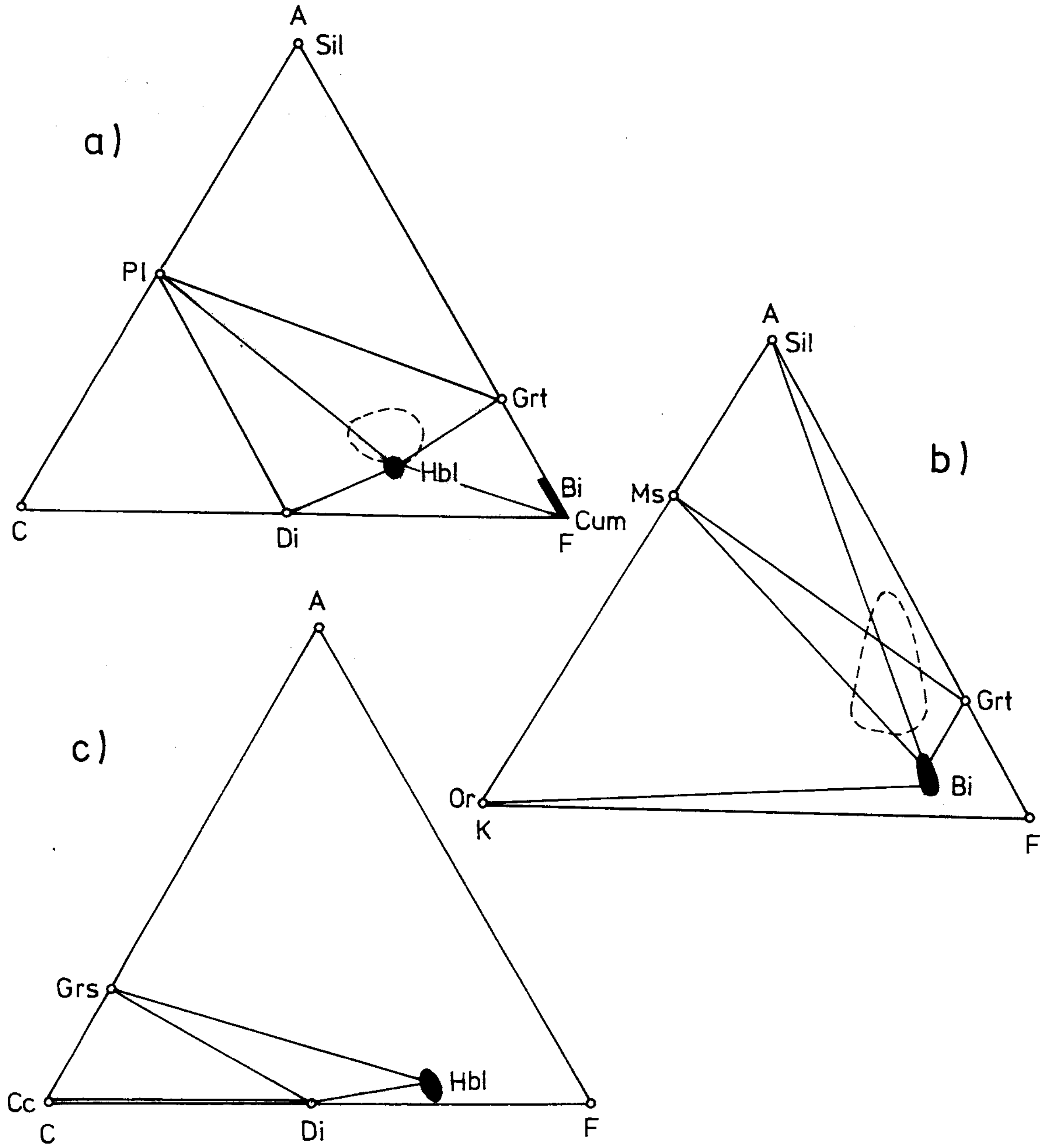

Fig. 2. Mineral compatibilities in the amphibolite facies of Tatricum: **a** - in metabasites; **b** - in metapelites; **c** - in Ca-silicate rocks. Dashed fields indicate the bulk chemical composition of rocks. Symbols as in Kretz (1983) in all diagrams of the paper.

1 - the core consists of Cpx + Grt + Hbl + Pl + Rt, and it is surrounded by a concentric zone consisting of Grt + Hbl + Pl + Qtz;

2 - the rim consists of Hbl + Pl + Qtz.

The symplectitic microstructure occurring in the core may suggest the original eclogitic nature of these lenses (Hovorka & Méres 1990; Spišiak & Pitoňák 1991).

On the basis of the whole set of petrological and field situations, the Tatricum metamorphic rocks can be divided into two groups:

1 - the first group includes the rock complexes in which temperature did not exceed below the granite solidus value, and the assemblage muscovite + quartz is stable (e.g. Malé Karpaty Mts, Považský Inovec Mts, Tribeč Mts);

2 - the second group consists of rock complexes in which the effects of partial melting are recorded, suggesting the availability of water and temperatures higher than the granite solidus (e.g. Malá Fatra Mts, Tatry Mts, Nízke Tatry Mts).

The above classification is a combined result of a regional metamorphic gradient and different levels of erosion within the individual core mountains.

As far as the metamorphic evolution of these rocks is concerned, Korikovsky et al. (1984, 1987 a,b) proposed isobaric prograde metamorphism, while other authors (Spišiak & Pitoňák 1990; Janák 1991) propose a metamorphic path controlled by increasing T and P (Fig. 3).

Another open problem is the possible presence of older high-temperature metamorphic relics (eclogites, granulites). The possibility of their presence was pointed out by Hovorka & Méres (1989, 1990).

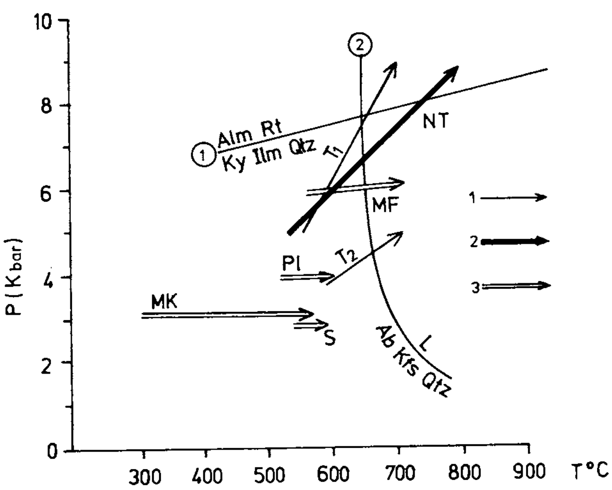

Fig. 3. Metamorphic gradients of the Variscan metamorphism of Tatricum reported in the literature.
Arrows are taken from: 1 - Janák (1991); 2 - Korikovsky et al. (1984, 1987) a, b; 3 - Spišiak (in press). Equilibrium curve of Rt-Grt-Pl-Ilm-Qtz in metabasites after Bohlen & Liotta (1984); beginning of melting in Ab-Or-Qtz system according to Ebadi & Johannes (1991).
MK - Malé Karpaty Mts, Pl - Považský Inovec Mts, S - Strážovské vrchy Mts, MF - Malá Fatra Mts, T_1 and T_2 - Tatry Mts, NT - western part of the Nízke Tatry Mts.

Chronological constraints. As regards the sedimentation age, biostratigraphic data are only known from the low-grade metamorphic sequences of the Malé Karpaty Mts and Nízke Tatry Mts. A Lower Devonian age has been proved in the former area (Čorná 1969, etc.), but an Upper Silurian - Devonian age in the Nízke Tatry Mts (Planderová 1986).

As far as the age of the regional metamorphism is concerned, a value around 380 Ma has been obtained from metamorphic rocks by means of Rb-Sr whole rock isochrons in the Malé Karpaty Mts (Bagdasaryan et al. 1983) and in the Tatry Mts (Burchart 1968), and from amphibolites by means of K-Ar whole isochrons (Burchart et al. 1987). However, it is a common opinion that the main metamorphism is Variscan, and these older age values may refer to a pre-Variscan event.

Granitoid plutons gave radiometric ages in a quite large interval (393 to 300 Ma, Cambel et al. 1990). Probably some of them (with the lowest age values) are Variscan, some are older. The radiometric age of the older ones may have been partially rejuvenated by the Variscan metamorphism.

Problems. As outlined above, the metamorphic history of the Tatricum crystalline rock is substantially Variscan, and it developed mainly under almandine-amphibolite facies conditions, but some hints of an Alpine overprint from one side, and a pre-Variscan (or Early Variscan) record from the other side exist. A better definition of this history requires on the one hand a convincing chronological framework, on the other hand, further geo-petrological work on specific problems. The following goals are suggested for future research:

1 - Rigorous definition of the metamorphic features and regional distribution of the Alpine metamorphic effects. Such problems also require some Rb/Sr age determinations of selected samples.

2 - Interpretation of low-grade rocks, in order to ascertain definitively whether they are prograde or retrograde products (or both).

3 - Further studies on banded amphibolites and related meta-ultrabasites, in order to better understand: a - the P-T path recorded in them; b - the age and geodynamic meaning of their protoliths.

4 - Further micro- and mesostructural studies on the relationships between deformation and crystallization of high grade rocks.

5 - Geochemical analyses and radiometric age determination of the anatectic effects recorded in some of the Tatricum crystalline complexes.

6 - Finally, a radiometric attempt should be made in order to ascertain whether the oldest metamorphic stage is early Variscan or older.

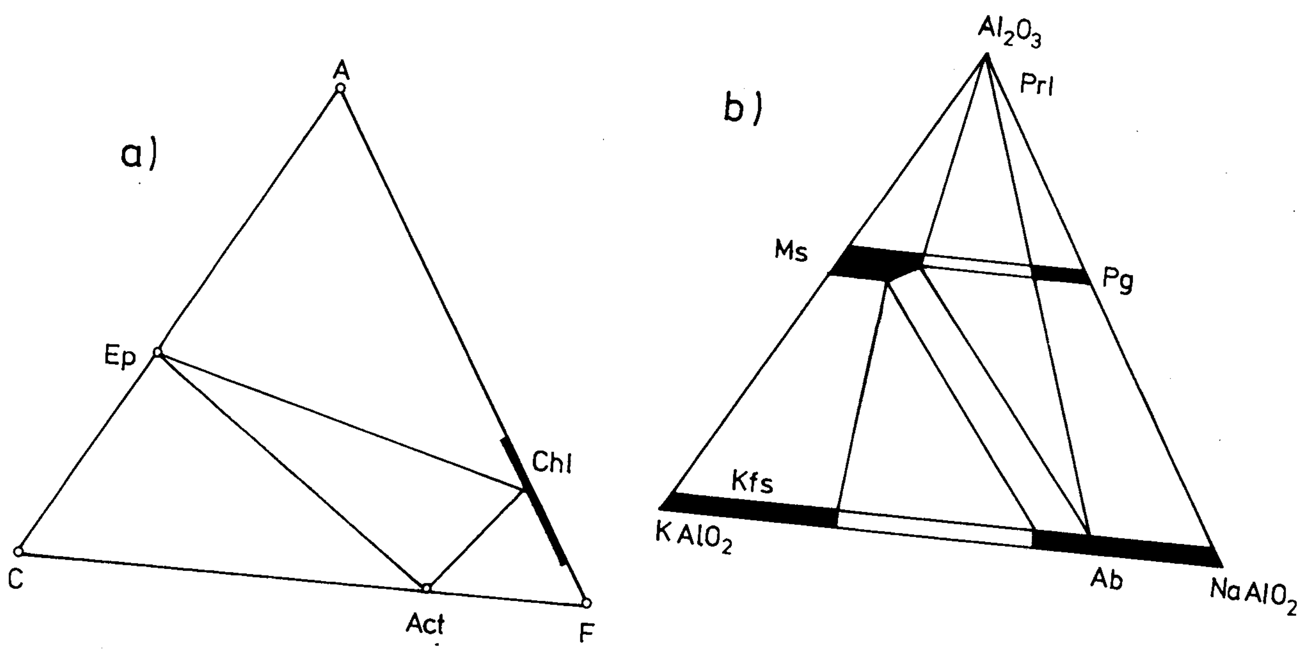

Fig. 4. Schematic diagrams showing the mineral compatibilities in greenschist facies of Veporicum: **a** - in metabasites; **b** - in metapelites.

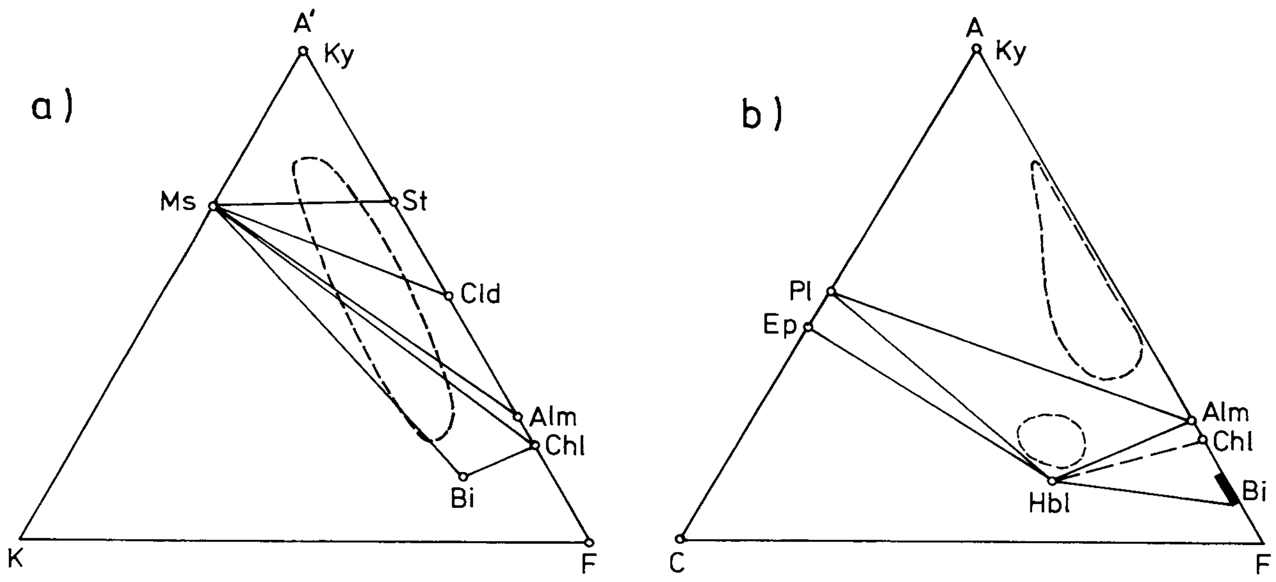

Fig. 5. Mineral compatibilities in upper greenschist - lower amphibolite facies of Veporicum: **a** - in metabasites; **b** - in metapelites. Dashed fields represent the main range of the bulk chemical composition of the rocks.

Veporicum

The Veporicum is an internal part of the central domain of the Western Carpathians (Fig. 1). It consists of several, variously-aged tectonic units grouped in three structural levels:

a - the structurally upper units are made up of Mesozoic and Upper Paleozoic complexes;

b - the structurally intermediate units consist of Early Paleozoic complexes;

c - the lower units consist of rocks of unknown age, which are believed to be pre-Paleozoic only because they can be distinguished from the Early Paleozoic units mainly due to their deeper structural position.

The pre-Upper Carboniferous complexes have different lithology and metamorphic features in the several tectonic units in which they occur. Their metamorphic history is Variscan, but some Alpine reworking is also recorded in them.

Lithology. Several rock types occur in the crystalline units of the Veporicum. Phyllites and associated acidic and intermediate metavolcanics occur in the Early Paleozoic sequences of northern Veporicum (Bajaník et al. 1979; Miko 1981), whereas mica-schists, subordinate amphibolites and albite-biotite gneisses occur in the southern Veporicum (Bezák 1989; Méres & Hovorka 1990). The albite-biotite gneisses have been interpreted as sedimentary mixtures of greywackes and intermediate volcanogenic materials (Bezák 1989).

The occurrence of Al-Fe-rich metasediments (interpreted as related to laterite-like protoliths: (Kováčik 1991), and the so-called Muráň orthogneisses (interpreted as an alternation of acidic and basic metavolcanics; Hovorka et al. 1987) are special types.

The rock types occurring in the Lower Carboniferous sequence of the southern Veporicum are different: they are metapelites, metabasites, metacarbonates, metagreywackes and metaconglomerates (Bezák 1989).

The rocks of the above mentioned, lowermost structural unit are mainly represented by gneisses. These occur as xenoliths in granitoids and are associated with migmatitic complexes. These gneisses may be related to greywacke protoliths, as indicated by geochemical data. Metamorphic Fe-ores of sedimentary origin should also be mentioned in this lower structural units (Korikovsky et al. 1989).

Petrologic features. As concerns Variscan metamorphism, amphibolite facies conditions have been recorded in some units and greenschist facies conditions in others.

In the greenschist facies terrains, as represented in Fig. 4, Qtz + Ab + Ms + Chl and Qtz + Ab + Ep + Bt are the common mineral assemblages in the metapelites of both the northern (Miko 1981) and southern Veporicum (Bezák 1991); and the occurrence of Pg has been reported in the Al-rich types (Mazzoli & Vozárová 1989).

The geobarometric estimations were based on the b values of muscovites from metapelites of the Northern Veporicum low-grade terrains. All data consistently indicate low-pressure conditions (T range of 350 - 430 °C) and thus relatively high thermal gradients, in the range of approximatly 40 - 45 °C/km (Mazzoli & Vozárová 1989: the Predná hola complex; Sassi & Vozárová 1991: Jánov Grúň complex).

In the lower amphibolite-greenschist facies terrains, as represented in Fig. 5, Alm_{60-80} + Bt + Ms + Pl_{15-20} + Qtz ± Chl is the most common mineral assemblage found in the mica-schists, while the occurrence of Ky + St(+Cld) has been reported in Al-rich metapelites (Korikovsky et al. 1989; Kováčik 1991). Data resulting from geothermometry (Grt-Bt and graphite thermometry), range usually from 450 °C to 530 °C (Bezák 1991; Putiš 1989).

The highest pre-Alpine temperatures are recorded in the gneisses of the lowermost units, where the assemblage Pl + Bt + Grt + Qtz ± Sil is common (Fig. 6). The pyrope content in garnet is 16 - 20 %, locally 26 %, and the anorthite content in plagioclase up to 33 %. Temperature values of 600 - 620 °C have been obtained by means of the graphite geothermometry, and higher values (T range 730 - 860 °C, P range 6 - 10 kbar) by the Grt-Bt and Grt-Bt-Pl-Sil geothermobarometry (Bezák 1991; Vozárová 1993).

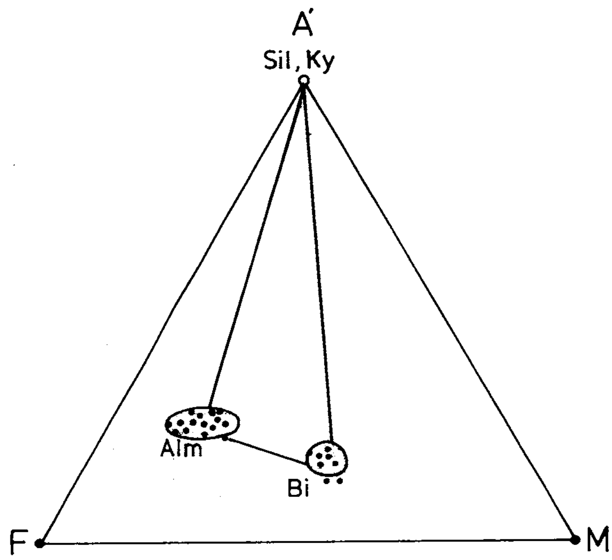

Fig. 6. Mineral compatibilities in high-grade gneiss complex of the Veporicum.
Dots represent the composition of mineral phases.

As concerns the Alpine overprint, it belongs to the lower greenschist facies (chlorite zone). This statement is consistent with the metamorphic effects recorded in the Mesozoic cover of northern Veporicum, in which temperatures in the range 300 - 350 °C have been estimated by means of illite crystallinity (Plašienka et al. 1989).

Qtz + Ms + Chl + Ep + Ab is the common mineral assemblage found in the lower Triassic metapelites of the southern Veporicum. The pressure character of this metamorphism was estimated by means of the b values of muscovites from paragonite-free metapelites. The analytical results correspond to the higher pressure range of the barrovian-type metamorphism (T range of 450 - 470 °C max.) and thus to a relatively low metamorphic thermal gradient, in the range 15 - 10 °C/km approx. (Mazzoli, Sassi R. & Vozárová 1992). This pressure estimation is consistent with the local occurrence of Ky + Cld (Vrána 1964).

The ?Late Variscan - Alpine granitoids produced in their country-rocks contact metamorphic effects which cover a relatively wide temperature range (e.g. Grt + Bt; Crd + Bt; Crd + And; Kamenický 1977; Vozárová & Vozár 1979; Korikovsky et al. 1986; Vozárová 1990).

Chronological constraints. As concerns the sedimentation ages, Lower Paleozoic biostratigraphic data (sporomorphs) have been obtained both in the northern Veporicum and in the southern Veporicum. In such a way, the Silurian - Devonian sedimentation age of the Predná hola and Jánov Grúň phyllites in the northern Veporicum and the Klenovec and Ostrá complexes in the southern Veporicum has been established (Klinec et al. 1975; Bajaník et al. 1979; Klinec & Planderová 1979).

As concerns the age of metamorphism, main metamorphism is believed to be Variscan due to structural-geological considerations and the fact that it affected early Paleozoic rocks.

Geological and radiometric data (K/Ar: 308 - 369 Ma; Rb/Sr: 319 Ma) confirm the Variscan age of the main metamorphism, but K-Ar ages of 500 Ma and higher were also obtained from hornblendes (Cambel et al. 1990). Further research is necessary in order to ascertain whether these old age values really indicate a pre-Variscan event or have no specific geological meaning.

As concerns the Alpine reworking, the occurrence of Alpine metamorphism is documented not only by geological features (it affected Mesozoic rocks), but also by some radiometric data (K/Ar; 94 ± 18 Ma: Burchart et al. 1987). Fission-track data indicate that the uplift of all the complexes is post-Cretaceous (Kráľ 1982).

Problems. A better understanding of the metamorphic evolution of the Veporicum requires from one side further geochronological radiometric research, from the other further petrological work oriented on specific goals.

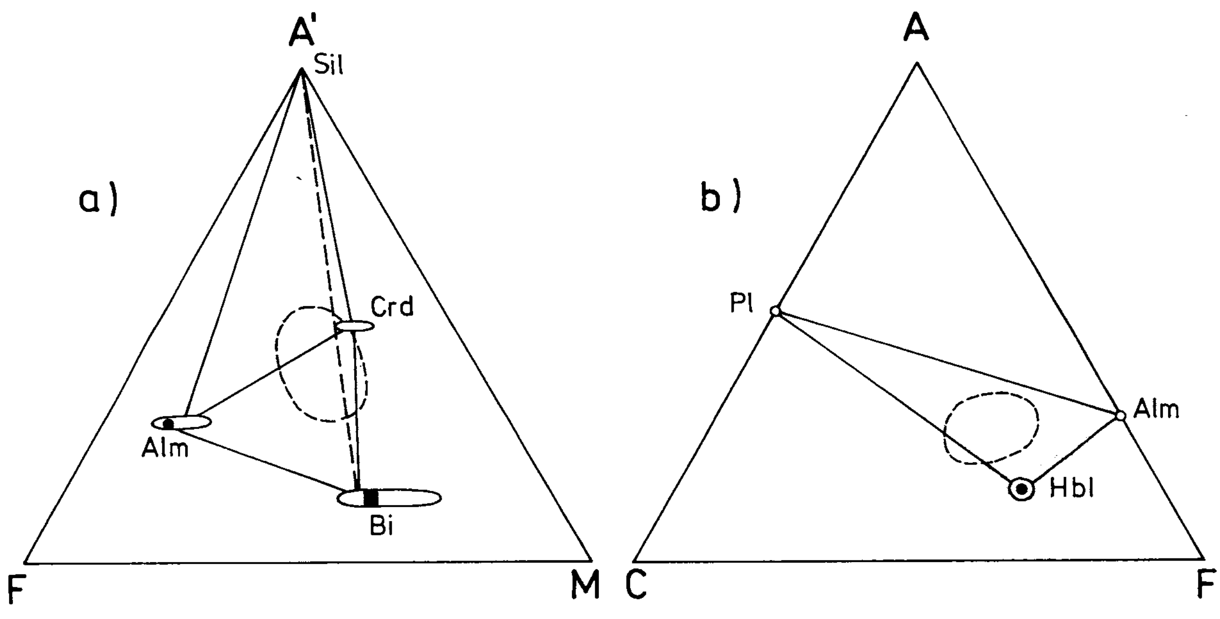

Fig. 7. Mineral compatibilities in high-grade amphibolite facies of the Zemplinicum.
Full points and square indicate the average mineral composition. Dashed fields show the bulk chemical composition of rocks.

From the geochronological point of view, ascertaining whether or not records of a pre-Variscan history is certainly a preferential target with greatest priority. In fact, the hornblende K/Ar age of more than 500 Ma presently available in the literature is not sufficient for admitting a pre-Variscan event. On the other hand, the timing of the Variscan metamorphism as well as that of the Alpine overprint also need further investigation: the chronological framework available at present is not sufficient for interregional comparisons.

From the petrological point of view, one of the most appealing goals is the geothermobarometry in the gneisses of the lowermost unit. Moreover, comparative microtextural analyses of these rocks and similar rock types in other units could supply data concerning differences and identities of the crystallization/deformation pre-Alpine history in different structural units. A possible pre-Variscan record could be recognized in such a way.

Zemplinicum

The Zemplinicum is a tectonic unit occurring in the southernmost part of Eastern Slovakia. It was recognized by Slávik (in Fusán et al. 1971) and defined as a part of the Central Carpathians (Fig. 1).

The crystalline rocks of the Zemplinicum make up a tectonic horst having NW - SE direction, which continues on Hungarian territory, on the NE side of the Tokaj Mts. The existence of these rocks is detectable mainly from the boreholes and from their pebbles occurring in the Stephanian - Permian conglomerates (Grecula & Együd 1982; Vozárová & Vozár 1988).

Lithology. The Zemplinicum includes pre-Mesozoic and Mesozoic rock complexes, which are unconformably covered by Tertiary and Quaternary sediments.

On Slovak territory, only high-grade metamorphic rocks belong to this unit. They are the gneisses, amphibolites and migmatites forming the Bytča Formation (Vozárová 1991). Cataclastic deformations of various intensities are common in these rocks.

Pelites, graywackes with tholeiitic andesite-basalts and their volcanoclastics made up the protoliths of these crystalline rocks. Minor acidic metavolcanics occur. On the basis of bulk chemical composition and the average REE content in amphibolites, some affinity with the initial stage of island arcs cannot be excluded (Vozárová 1991). It should also be mentioned, that in the Stephanian - Permian conglomerates granitoid pebbles have been found.

In Hungary, a more complex situation has been recognized by means of boreholes. A medium- to high-grade and a low-grade sequence have been distinguished, the mutual relation of which was interpreted as a Late Variscan, south-vergent thrust (Pantó 1965). Upper Carboniferous sediments cover both sequences (evidence in boreholes). The Late Variscan age of this thrust is confirmed by the occurrence of both low-grade and high-grade metamorphic rocks as pebbles within the overlying Stephanian - Permian conglomerates.

Metapelites and acidic metavolcanoclastics make up the greenschist facies complex (Pantó 1965). It should be noted that these rocks are considered by Kishazi & Ivancsics (1988) to be retrograde, cataclastic gneisses. Pelitic and semi-pelitic rocks with sandy intercalations, basic horizons and granitoids made up the protoliths of the higher-grade rocks on Hungarian territory (Lelkes-Felvári & Sassi 1981).

Petrologic features. The following mineral assemblages occur in the different rock types (Fig. 7):

- Kfs ± Sil + Bt + Alm ± Pl in the gneisses
- Hbl + Pl ± Ilm + Spn in the amphibolites
- consistent assemblages in the migmatites, i.e. Kfs + Pl + Bt + Qtz + Alm in the leucosomes and Hbl ± Bt ± Alm + Pl in the melanosomes.

The stability of Kfs + Sil + Alm and destabilization of Ms + Qtz + Pl, are worthy to be stressed in the gneisses. They indicate medium pressures and temperatures of 650 - 680 °C. Similar temperature estimates have been obtained from the Hbl-Pl geothermometer, but the low Na content in the M_4 site of hornblende suggests low pressure conditions (Brown 1977). Consistent P-T estimates have been obtained from the chemistry of leucosomes within the Qtz-Ab-Or-An system at $P = 5$ kb (Winkler & Breitbar 1978).

The crystalline rocks of the Zemplinicum show, in the character of their protolith and mineral assemblages, distinct similarity with the higher-grade rocks of the Tatricum and Veporicum (Vozárová 1991). Ky + St + Sil were described on Hungarian territory. This mineral assemblage corresponds to above mentioned physical conditions (MP, T close to 670 °C; Lelkes, Felvári & Sassi 1981).

Chronological constraints. The pre-Alpine age of the main metamorphism is documented by the geological situation described at the beginning of this section: pebbles of the described metamorphic rocks are included in the Stephanian - Permian conglomerates.

A better chronological classification is not possible due to lack of radiometric data. The age values of 960 - 980 Ma reported by Pantó et al. (1967) require confirmation, and are not sufficient for assuming the Late Proterozoic age of the metamorphism.

Later overprint is suggested by the K/Ar age values (258 - 262 Ma of whole rocks: Pantó et al. 1967; 229 Ma of muscovite and 307 of amphibole: Lelkes-Felvári & Sassi 1981).

Problems. The main problem to be solved in the Zemplinicum is related to the chronology of the main events: specific radiometric research should be attempted in order to ascertain whether the age of this metamorphism is Variscan, as interregional correlations may suggest, or older.

Gemericum

The Gemericum is in the inner domain of the Western Carpathians (Fig. 1). It shows a complicated Variscan structure, with fold and thrusts. Three main Early Paleozoic complexes have been distinguished so far in it: the Gelnica Group, the Rakovec Group and the Klátov Group.

The mutual relations of all these Early Paleozoic complexes are mostly tectonic. According to Grecula (1982), several Variscan nappes have been defined inside them. However, normal stratigraphic contacts have also been reported within single Early Paleozoic complexes (Bajaník et al. 1983).

Besides the three above mentioned groups, another two Lower Carboniferous sequences have been reported in the literature: the Ochtiná Formation and the Črmel Group.

Lithology. The Gelnica Group (Andrusov & Matějka 1931) is probably the oldest rock sequence in the Gemericum. It consists of low-grade, flysch-type metasediments in which there are interlayers of mainly acidic metavolcaniclastics. The metasediments are characterized by mesorhythmic alternation of metasandstones and metapelites, and sporadic occurrence of

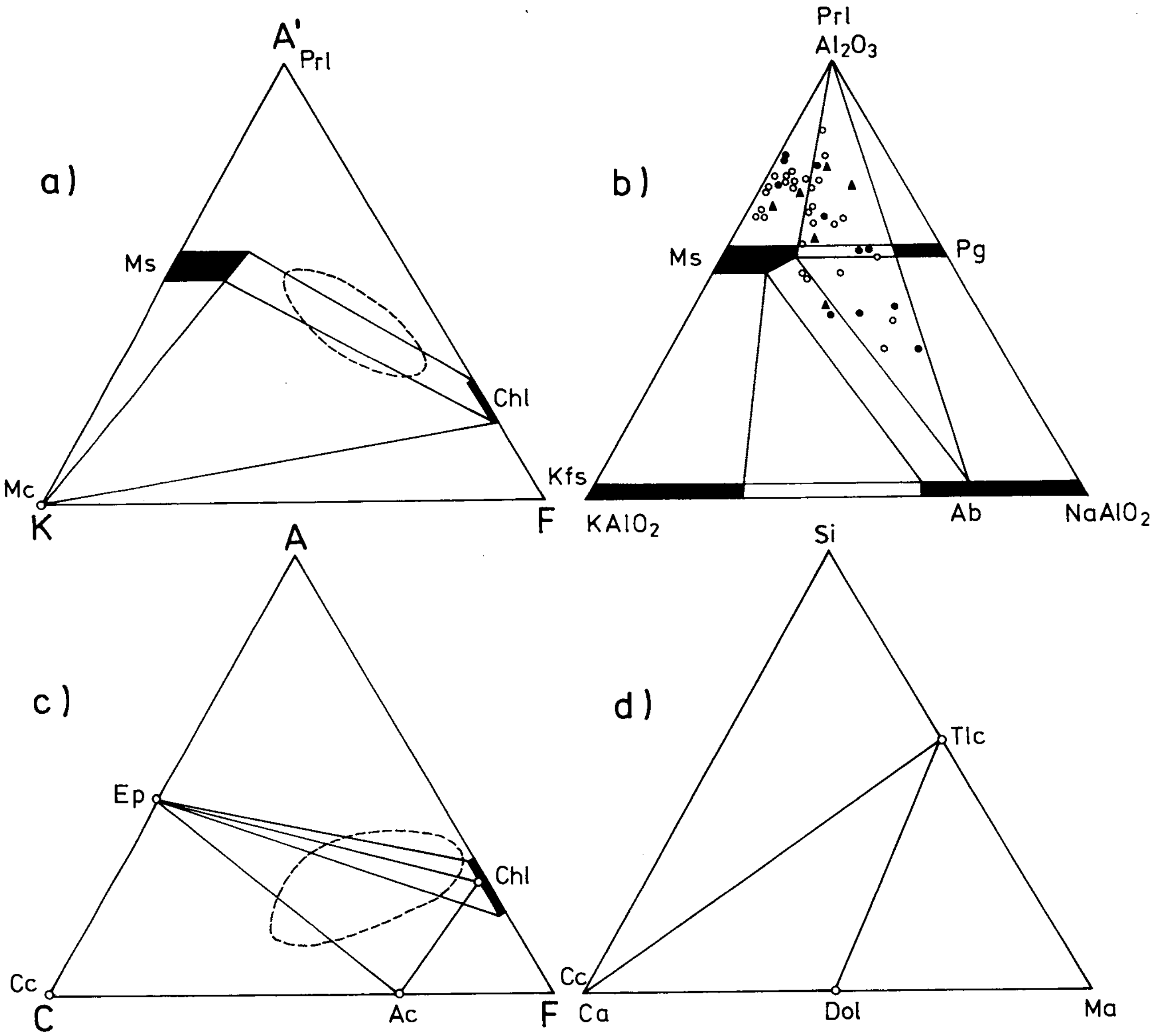

Fig. 8. Mineral compatibilities in the low-grade greenschist facies of Gemericum: **a** - in metasemi-pelitic rocks and acid metavolcanoclastics; **b** - in metapelites; **c** - in metabasites; **d** - in carbonate rocks.
Dashed fields indicate the bulk chemical composition of rocks. Symbols in diagram **b** show bulk chemical compositions of phyllites: full circle - Črmeľ Gr., open circle - Gelnica Gr., full triangle - Rakovec Gr.

allodapic carbonate and lydite intercalations in the upper part. As concerns the metavolcaniclastics, besides the prevailing acidic types, intermediate and rare basic compositions also occur. Their chemistry prevailingly displays a calc-alkaline affinity (Snopko & Ivaniška 1978; Grecula & Hovorka 1987).

The Rakovec Group (Andrusov & Matějka 1931) is characterized by a finer grain-size of the occurring metasediments and a huge amount of basic metavolcanics and metavolcanoclastics. The metamorphic grade is also low in this group. As regards the metasediments, metasiltstones and variegated to graphitic shales prevail, fine-grained metasandstones and metacarbonates being less frequent. As regards the metavolcanics and metavolcanoclastics, a tholeiitic affinity has been ascribed to the basic types, and the occurrence of rare layers of intermediate and acid compositions has also been reported (Bajaník 1976).

The Klátov Group (Spišiak et al. 1985) consists of higher-grade metamorphic rocks of various compositions which, during the pre-Westphalian tectogenesis, were tectonically incorporated as slices on the low-grade terrains of the Rakovec Group. They are: gneisses (assumedly related to greywacke protoliths), amphibolites, serpentinized spinel peridotites, and rare marbles and Ca-silicate rocks (Hovorka et al. 1989). Pebbles of these amphibolites and gneisses have been found within the Westphalian conglomerate which unconformably covers both the Rakovec and the Klátov Group (Rozlozsnik 1935; Rozložník 1965; Vozárová 1973). The metaultrabasites have been considered to be a part of a dismembered ophiolite suite related to a marginal (fore-arc?) basin (Hovorka & Ivan 1985).

As regards the Ochtiná Formation and the Črmel Group, they display a similar rock sequence, with some peculiarities in each

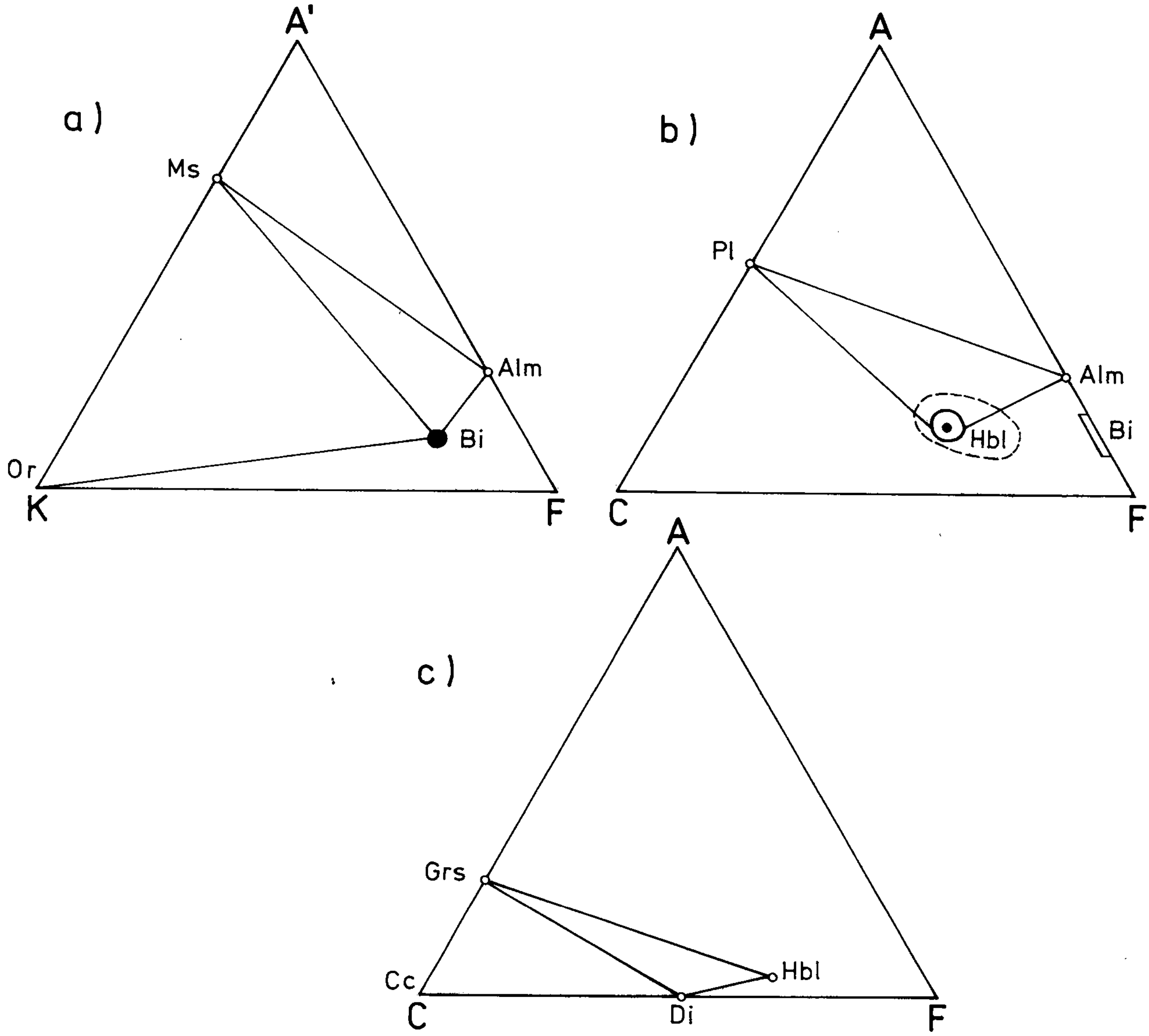

Fig. 9. Mineral compatibilities in the amphibolite facies of the Gemericum (Klátov Group): **a** - in metasediments; **b** - in metabasites; **c** - in Ca-silicate rocks.
Dots: average composition of hornblendes. Dashed: field of bulk rock chemical composition.

of them. They mainly consist of metasediments, and display a low metamorphic grade. The lower part of both sequences is made up of flysch-like metasediments, with a prevalence of fine-grained siliciclastic rocks at the bottom, where basic metavolcanics displaying a tholeiitic affinity also occur (Vozárová & Vozár 1988). Acidic metavolcanics were only found as intercalations within the lower part of the Črmel Group, while 10 to 100 m thick intercalations of marbles occur only in the uppermost part of the Ochtiná Fm. Their compositional range is very large: they include layers related to calcitic, dolomitic and magnesitic protoliths.

Petrologic features. As above mentioned, the Variscan metamorphic grade in the Gemericum is systematically low, with the only exception in the Klátov Group.

The common mineral assemblages in the more abundant rock types of the Gelnica, Rakovec, Ochtiná and Črmel sequences are (Bajaník et al. 1983; Varga 1973; Faryad 1991, and others):

- in metapelites: Qtz + Ab + Ms ± Pg + Chl and various amounts of graphite
- in acidic metavolcanics: Qtz + Ab ± Kfs ± Ms ± Chl
- in basic metavolcanics: Chl + Ab + Ep ± Act ± Ms ± carbonates
- in impure carbonates: Cc + Dol + Qtz ± Ms ± Chl ± Tlc; Mgs + Tlc
- in Mn-carbonates: Rdn + Sps + Pxm.

These mineral compatibilities (Fig. 8) clearly refer to the lower-temperature part of the greenschist facies: biotite and Al-silicates never occur, suggesting temperatures in the range 350 - 370 °C.

The pressure character of the Variscan metamorphic climax in the Gemericum has been estimated by means of the values of the muscovites b cell parameter in metapelites of suitable composition (Sassi & Vozárová 1987; Mazzoli & Vozárová 1989). The analytical results indicate low-pressure conditions, and a metamorphic thermal gradient of approx. 40 °C/km.

A multistage development of the Variscan metamorphism has been reported in the metabasalts of the Rakovec Group (Ho-

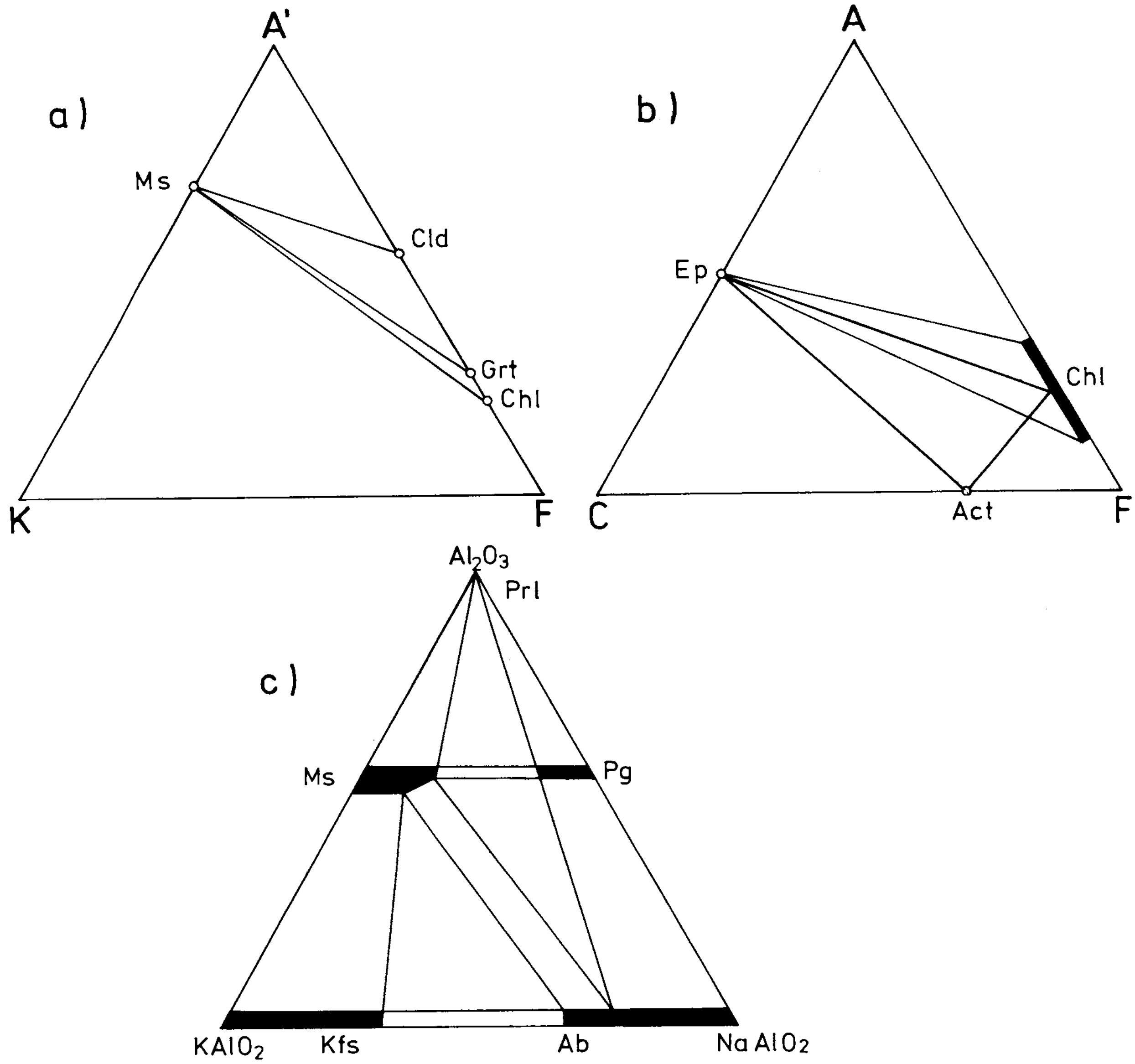

Fig. 10. Mineral compatibilities in the Alpine greenschist facies of the southern Gemericum.

vorka et al. 1988). Specifically, cores of barroisitic composition have been found within the actinolite crystals, and interpreted as relics of a high-pressure, early metamorphic stage: according to Hovorka et al. (1988), these findings record an evolution from blueschist to greenschist facies.

As concerns the higher grade rocks of the Klátov Group (Fig. 9), the following mineral assemblages have been reported (Dianiška & Grecula 1979; Bajaník & Hovorka 1981; Hovorka & Spišiak 1981):

- in paragneisses: Bt + Alm + Pl_{20-30} ± Ms ± Qtz ± Hbl
- in amphibolites: Hbl + Pl_{30-35} ± Grt
- in Ca-silicate rocks: Grt + Cpx.

Geothermometric estimates based on various mineral pairs (Grt-Bt, Grt-Hbl, Grt-Pl) gave temperature values in the range 550 - 630 °C, suggesting intermediate pressure (Hovorka & Spišiak 1981; Spišiak & Hovorka 1981; Faryad 1990; Radvanec 1992).

As concerns the Alpine overprint, it affected mainly rocks along strike-slip faults, overthrusts and shear zones. The physical conditions of the Alpine overprint reached from the anchizone to lower greenschist facies.

Alpine regional metamorphism affected tectonically thrusted sheets of late Paleozoic and Mesozoic rocks in the southern Gemericum. The following metamorphic mineral assemblages (Fig. 10) have been determined (Reichwalder 1970; Howie & Walsh 1982; Árkai & Kovács 1986):

- in metapelites: Qtz + Ab + Ms ± Chl, and the occurrence of Pg and Prl has also been reported
- in Al-Fe rich metapelites: Ctd + Chl + Ep ± Pg ± Qtz ± Ms
- in metabasites: Gln + Ep + Ab.

These mineral assemblages indicate the high-pressure greenschist facies. The pressure character of the Alpine metamorphic climax in the southern Gemericum has been also confirmed by means of the b cell dimension of muscovites. The analytical results indicate medium/high pressure metamorphism, and a thermal gradient of approx. 10 °C/km (Mazzoli et al. 1992).

Thermal overprint in the central part of Gemericum is the result of ?Late Variscan - Alpine granitoid magmatism. Three zones of contact metamorphism (Chl, Bt, And) can be distinguished in metasedimentary rocks (T range 350 - 550 °C; Faryad 1991).

Chronological constraints. As concerns the sedimentation age, biostratigraphic data are very few, but sufficient to ascribe Paleozoic pre-Westphalian age to the sedimentary protoliths of large parts of the Gemericum.

Palynological findings show that the sedimentary protoliths of the Gelnica Group range from Upper Cambrian to Lower Devonian (Snopková & Snopko 1979). No biostratigraphic data are so far available for the Rakovec Group: however, the occurrence of fragments of their rocks as pebbles within the Westphalian conglomerate indicates that the sedimentation age of their protoliths and their metamorphism are pre-Westphalian.

Lower Carboniferous sediments occur in the Ochtiná Fm. and in the Črmel Group, as shown by palynological findings (Bajaník & Planderová 1985; Bajaník et al. 1986). However, the uppermost part of the Ochtiná Fm. is Upper Visean - Serpuchovian, as shown by conodont fauna (Kozur et al. 1976).

As far as the age of metamorphism is concerned, several geological features clearly indicate that it is pre-Westphalian:

- as above mentioned, pebbles of amphibolites and gneisses from the Klátov Group and greenschist facies rocks of the Rakovec Group occur in the Westphalian conglomerate (Rozlozsnik 1935; Rozložník 1965; Vozárová 1973);
- rock fragments of the Črmel Group occur within the Westphalian conglomerate (Vozárová 1973);
- pebbles of the Gelnica Group were found in the Stephanian - Permian conglomerate (Vozárová 1973).

Taking into consideration the regional context, a Variscan age may be deduced from the above geological data. This hypothesis is confirmed by a few radiometric data in the range 320 - 350 Ma.

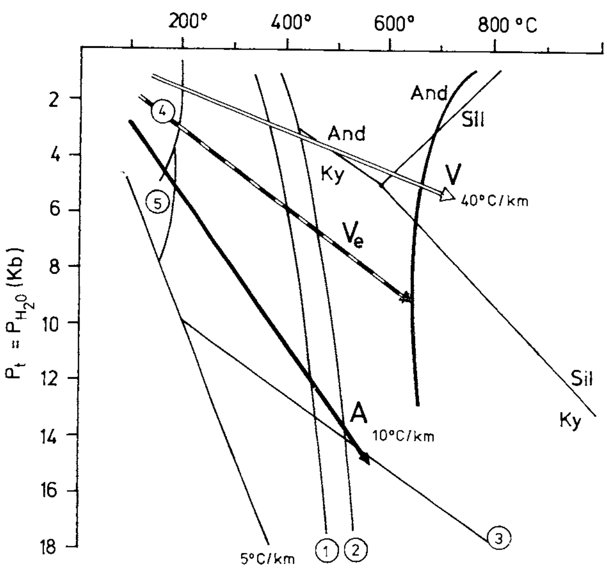

Fig. 11. Metamorphic gradients estimated for Alpine (A), Variscan (V) and possible Early Variscan (V_e) metamorphism in the Western Carpathians.
Curve 1 - dehydration of kaolinite (Thompson 1971); curve 2 - dehydration of pyrophyllite (Kerrick 1968); curve 3 - stabilization of glaucophane (Carman & Gilbert 1983); curve 4 - Anl+Qtz Ab (Thompson 1971); curve 5 - Hln→Lws+Qtz (Nitsch 1968). Al_2SiO_5 tripple point: Greenwood (1976). The lenghth of the arrows shows the temperature range.

However, the available isotopic data vary in a relatively wide range (320 - 448: Cambel et al. 1980; Kantor 1980; Kantor et al. 1981), so that their interpretation is difficult. Some problematic zircon ages (reflecting ages of source rocks) are also available, and fall into the range 945 - 660 Ma (Bagdasaryan et al. 1977).

As concerns the age of magmatism in the central Gemericum, a wide dispersion of radiometric data has been reported (K-Ar: 98 - 140 Ma, Rb-Sr: 159 - 269 Ma, Cambel et al. 1990; Rb-Sr: 346 Ma, Kovach et al. 1986).

Problems. It seems to be clear, from the above data, that the pre-Alpine metamorphic history of the Gemericum is Variscan. However, considering that the presently available chronological framework is rather poor, a strong effort is necessary in order to:

a - clearly establish the age of Variscan metamorphism;

b - check further data about the zonation of Alpine metamorphic overprints;

c - ascertain the possible existence of pre- Variscan metamorphic records (i.e. clarify whether the age values reported in the literature in the range of 350 - 450 Ma are confirmed or not);

d - clearly establish the age of magmatism (i.e. clarify whether the age values reported in literature belong to two magmatic events etc.).

As concerns the above problem under point a), further petrologic, microstructural and microprobe work is necessary for a better understanding of the multistage development of the Variscan metamorphism, and a reconstruction of a P-T-t path well supported by chronological data.

Regarding the above problem under point c), systematic microstructural analyses of low-grade rocks from the Klátov Group could help us to understand the crystallization-deformation relationships in the high-grade realm of the Gelnica Group better.

Finally, a new extensive geochronological study on zircons should be useful for a better characterization of the chronology of the source area of the clastic zircons.

Concluding considerations

As readers may have realized from the above pages, the amount and quality of data produced in the last decade are sufficiently high to make proposed general outlines possible. Notwithstanding the need for a further, significant effort in radiometric geochronology, and further petrological work oriented towards specific goals, the presented scenarios are relatively well framed in each of the four main structural units, and the main points of the evolutionary trends in the metamorphic complexes are basically clear. They are:

a - the sedimentation is pre-Westphalian Paleozoic in age;

b - the main metamorphism is Variscan;

c - Alpine overprints occur locally, although they may be more widespread than presently known;

d - the occurrence of pre-Variscan metamorphic records cannot be excluded, but requires confirmation;

e - the Variscan metamorphism covers the whole temperature range, from the lower greenschist facies to the upper amphibolite facies, locally reaching anatectic, migmatite-producing conditions;

f - the Variscan metamorphism turns out to have had a multistage development, with complex relationships between crystallization and deformation;

g - the Variscan metamorphic climax recorded in the low grade terrains took place under relatively low pressure conditions, related to a metamorphic thermal gradient of approx. 40 °C/km (see review in Sassi R. & Vozárová 1991);

h - the Alpine metamorphic climax recorded in compositionally similar low grade terrains took place under relatively high pressure conditions, related to a metamorphic thermal gradient lower than 15 °C/km (Mazzoli et al. 1992).

All these features and situations clearly show strong analogies between the Western Carpathians and other Alpine-Mediterranean mountain chains: the features ascertained in the Western Carpathians are similar to those in the other mountains chains, and most of the problems which are unsolved in the Western Carpathians concern situations which are also problematic in the other mountain chains. The specific targets of greatest priority suggested above for further research have been specifically selected in order to provide more facts for interregional comparisons and correlations, and to fill the gap of knowledge which still persists concerning specific aspects or problems relevant at the scale of inter-regional comparisons.

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References

Andrusov D. & Matějka A., 1931: Guide des excursion dans les Karpathes occidentales etc. *Knih. St. geol. úst.*, 13 A, Praha, 1 - 397.

Árkai P. & Kovács S., 1986: Diagenesis and regional metamorphism of the Mesozoic of Aggtelek-Rudabánya Mountains (Northeast Hungary). *Act. Geol. Hung.*, 29, (3 - 4), 349 - 373.

Bajaník Š., 1976: To petrogenesis of Devonian volcanic rocks of the Spišsko-gemerské rudohorie Mts. *Západ. Karpaty, sér. min., petr., geoch., lož., GÚDŠ*, 2, 75 - 94.

Bajaník Š., Biely A, Miko O & Planderová E., 1979: A Paleozoic volcanosedimentary complex of Predná hoľa (Nízke Tatry Mts.). *Geol. Práce, Spr., GÚDŠ*, 73, 7 - 28.

Bajaník Š. & Hovorka D, 1981: The amphibolite facies metabasites of the Rakovec Group of Gemericum (the West Carpathians). *Geol. Zbor. Geol. carpath.*, 32, 6, 679 - 705.

Bajaník Š., Hanzel V, Ivanička J., Mello J., Pristaš J., Reichwalder P., Snopko L., Vozár J. & Vozárová A., 1983: Explanations to the geological map of Slovenské rudohorie Mts., eastern part, 1 : 50 000. *GÚDŠ*, Bratislava, 7 - 223 (in Slovak).

Bajaník Š. & Planderová E., 1985: Stratigraphical position of lower part of the Ochtiná Formation of Gemericum between Magnezitovce and Magura. *Geol. Práce, Spr., GÚDŠ*, 82, 67 - 76 (in Slovak).

Bajaník Š., Snopková P. & Vozárová A., 1986: Litostratigraphy of the Črmeľ Group. *Reg. geol. Západ. Karpát, Správy o geol. výsk., GÚDŠ*, 21, 65 - 68 (in Slovak).

Bagdasaryan G. P., Cambel B., Veselský J. & Gukasyan R. Ch., 1977: Kalium-argon age determination of the rocks of Western Carpathians crystalline complexes and presumably interpretation of results. *Geol. Zbor. Geol. carpath.*, 37, 3, 219 - 242 (in Russian, English abstract).

Bagdasaryan G P., Gukasyan R. Ch., Cambel B. & Veselský J., 1983: Results of Rb-Sr age determination of metamorphic rocks of the Malé Karpaty Mts. crystalline complex. *Geol. Zbor. Geol. carpath.*, 34, 4, 387 - 397 (in Russian, English abstract).

Bezák V., 1989: Pre-metamorphic rock character of Kohút zone of the Veporicum. *Miner. slovaca*, 21, 247 - 250 (in Slovak).

Bezák V., 1990: Metamorphic evolution of the Veporicum (Contribution to possible correlation with the Eastern Alps). In: Minaříková D. & Lobitzer H. (Eds.): *Thirty years of geological cooperation between Austria and Czechoslovakia.* Prague, 254 - 255.

Bezák V., V. 1991: Metamorphic conditions of the Veporic unit in the Western Carpathians. *Geol. Carpathica*, 42, 4, 219 - 222.

Bohlen S. R. & Liotta J. J., 1986: A barometer for garnet amphibolites and garnet granulites. *J. Petrology*, 27, 1025 - 1056.

Brown E. H., 1977: The crossit content of Ca-amphibole as a guide to pressure of metamorphism. *J. Petrology*, 18, 1, 53 - 72.

Burchart J., 1968: Rubidium-strontium isochron ages of the crystalline core of the Tatra mountains, Poland. *Amer. J. Sci.*, 266, 895 907.

Burchart J., Cambel B. & Kráľ J., 1987: Isochron reassessment of K-Ar dating from the West Carpathians crystalline complex. *Geol. Zbor. Geol. carpath.*, 38, 2, 131 170.

Cambel B., Bagdasaryan G. P., Veselský J. & Gukasyan R. Ch., 1980: To problems of interpretation of nuclear-geochronological data on the age crystalline rocks of the West Carpathians. *Geol. Zbor. Geol. carpath.*, 31, 1-2, Bratislava, 27 - 48.

Cambel B., Dyda M. & Spišiak J., 1981: Thermodynamic measurement of origin of minerals in metamorphites in the area of crystalline of Malé Karpaty Mts. *Geol. Zbor. Geol. carpath.*, 32, 6, 745 768.

Cambel B., Kráľ J. & Burchart J., 1990: Isotope geochronology of the Western Carpathian crystalline. *VEDA*, Bratislava, 183 (in Slovak).

Carman J. H. & Gilbert M. C., 1983: Experimental studies on glaucophane stability. *Amer. J. Sci.*, 283 A, 414 - 437.

Čorná O., 1969: Bemerkungen zur Verbreitung Palynologischer Mikrofosilien vom Präkambrium bis zum Unter-Karbon. *Geol. Zbor. Geol. carpath.*, 20, 2, 399 416.

Dianiška I. & Grecula P., 1979: Amphibolite-gneiss complex as a part of ophiolite suite of the Rakovec Nappe. *Miner. slovaca*, 11, 405 - 427 (in Slovak).

Ebadi A. & Johannes W., 1991: Beginning of melting and composition of first melt in the system Qtz-Ab-Or- H_2O-CO_2. *Contr. Miner. Petrol.*, 106, 286 - 295.

Faryad S. W., 1990: Gneiss-amphibolite complex of Gemericum. *Miner. slovaca*, 22, 4, 303 - 318.

Faryad S. W., 1991: Metamorphism of the Early Paleozoic sedimentary rocks in Gemericum. *Miner. slovaca*, 23, 4, 315 - 324.

Fusán O., Ibrmajer J., Plančár J., Slávik J. & Smíšek M., 1971: Geological structure of the basement of covered area of southern part of the Inner Western Carpathians. *Západ. Karpaty, GÚDŠ*, 15, 5 - 173 (in Slovak).

Grecula P., 1982: Gemericum - a segment of riftogene basin of the Paleotethys. *Alfa*, Bratislava, 1 - 236 (in Slovak).

Grecula P. & Együd K., 1982: Litostratigraphy of the Early Paleozoic and Lower Triassic of the Zemplínske vrchy Mts. *Miner. slovaca*, 14, 3, 221 - 239 (in Slovak).

Grecula P. & Hovorka D., 1987: Early Paleozoic volcanism of the Western Carpathians. In: Flügel H., Sassi F. P. & Grecula P. (Eds.): Pre-Variscan and Variscan events in the Alpine-Mediterranean mountains belts. *Miner. slovaca*, Monogr., 251 - 270.

Greenwood H. J., 1976: Metamorphism at moderate temperatures and pressures. In: Bailey D. K. & McDonald R. (Eds.): *The evolution of the crystalline rocks. Academic Press*, London.

Hovorka D., 1975: The litology and chemical composition of the metasediments of the Jarabá group (West Carpathians). *Krystalinikum*, 11, 87 99.

Hovorka D. & Spišiak J., 1981: Coexisting garnets and amphiboles of metabasites from Rudňany area (the Paleozoic, the Spišsko-gemerské rudohorie Mts., the Western Carpathians). *Miner. slovaca*, 13, 6, 509 - 525.

Hovorka D. & Ivan P., 1985: Meta-ultrabazites in the Paleozoic of the Inner Western Carpathians: implications for the reconstruction of the tectonic evolution in this region. *Ofioliti*, 10 (2/3), 317 - 328.

Hovorka D., Dávidová Š., Fejdi P., Gregorová Z., Határ J., Kátlovský V., Pramuka S. & Spišiak J., 1987: The Muráň Gneisses - the Kohút crystalline complex, the Western Carpathians. *Acta Geol. Geogr. Univ. Comen., Geol.*, 42, 5 - 101.

Hovorka D., Ivan P., Jilemnická L. & Spišiak J., 1988: Petrology and geochemistry of metabasalts from Rakovec (Paleozoic of Gemeric unit, Inner Western Carpathians). *Geol. Zbor. Geol. carpath.*, 39, 4, 395 - 425.

Hovorka D. & Méres Š., 1989: Relicts of high-temperature metamorphics of the Tatro-Veporicum crystalline of the Western Carpathians. *Miner. slovaca*, 21, 193 201 (in Slovak).

Hovorka D. & Méres Š., 1990: Clinopyroxene-garnetic metabasites of the Tribeč Mts. *Miner. slovaca.*, 22, 6, 533 - 538 (in Slovak).

Howie R. A. & Walsh J. N., 1982: The geochemistry and mineralogy of an epidote-glaucophanite from Hačava, Spišsko-gemerské rudohorie Mts., West Carpathians, Czechoslovakia. *Geol. Práce, Spr., GÚDŠ*, 59 - 64.

Jacko S., Korikovsky S. P. & Boronikhin V. A., 1990: Equilibrium associations from gneisses and amphibolites of Bujanová complex (Čierna hora Mts.). *Miner. slovaca*, 231 - 239 (in Slovak).

Janák M., 1991: Petrology of metamorphic rocks of the Western Carpathians and High Tatras Mts. crystalline. Manuscript, Geofond, Bratislava, 244 (in Slovak).

Janák M., Kahan Š. & Jančula D., 1988: Metamorphism of pelitic rocks in SW part of Western Tatra Mts. crystalline complex. *Geol. Zbor. Geol. carpath.*, 39, 4, 455 488.

Kamenický J., 1968: Some problems of the West Carpathians crystalline complex. *Geol. Zbor. Geol. carpath.*, 19, 1, 7 - 20.

Kamenický J., 1977: Contact metamorphism in the aureole of the Rimavica granite (West Carpathians Mts.). *Miner. slovaca*, 9, 3, 161 - 184.

Kantor J., 1980: To the problem of the metamorphism age of amphibolites in the Rakovec Group of the Gemeric from Klatov - Košická Belá. *Geol. Zbor. Geol. carpath.*, 31, 4, 451 - 456.

Kantor J., Bajaník Š. & Hurný J., 1981: Radiometric dating of metamorphites of amphibolite facies from the Rudňany deposit, Spišsko-gemerské rudohorie Mts. *Geol. Zbor. Geol. carpath.*, 32, 3, 335 - 344.

Kerrick D. M., 1968: Experiments on the upper stability limit of pyrophyllite at 1.8 and 3.8 kb water pressure. *Amer. J. Sci.*, 266, 204 - 214.

Kishazi P. & Ivancsics J., 1988: Contribution to the petrology of crystalline schists in the Zemplén structure. *Bull. Hung. Geol. Soc.*, *2*, 109 - 124.

Klinec A., Planderová E. & Miko O., 1975: Late Paleozoic age of the Veporic Hron complex. *Geol. Práce, Spr., GÚDŠ*, 9, 95 - 104 (in Slovak).

Klinec A. & Planderová E., 1979: Paleozoic metamorphics from Hnúšťa area. *Geol. Práce, Spr., GÚDŠ*, 72, 194 - 196 (in Slovak).

Kober L., 1931: Das alpine Europa und sein Rahmen. Berlin (Borntraeger), 1 - 310.

Korikovsky S. P., Cambel B., Miklóš J. & Janák M., 1984: Metamorphism of the Malé Karpaty Mts. crystalline complex: events, zonality, relation to granitoids. *Geol. Zbor. Geol. carpath.* 35, 4, 437 462 (in Russian, English abstract).

Korikovsky S. P., Janák M. & Boronikhin V. A., 1986: Geotermometry and changes of mineral equilibria during crystallization of garnet-mica schists in cordierite gneiss in the auoreole of the Rochovec granites (Slovenské rudogorie Mts., region Rochovce-Chyžné). *Geol. Zborn. Geol. carpath.*, 37, 5, 607 - 633 (in Russian, English abstract).

Korikovsky S. P., Kahan Š., Putiš M. & Petrík I., 1987a: Metamorphic zonality of the Suchý crystalline and high-temperature autometamorphism in peraluminous granitoids of the Strážovské vrchy Mts. *Geol. Zbor. Geol. carpath.*, 38, 2, 181 203 (in Russian, English abstract).

Korikovsky S. P., Kamenický L., Macek J. & Boronikhin V. A., 1987b: PT conditions of metamorphism of Malá Fatra Mts. gneisses (area of Mlynský potok brook). *Geol. Zbor. Geol. carpath.*, 38, 4, 409 427 (in Russian, English abstract).

Korikovsky S. P., Krist E. & Boronikhin V. A., 1989: Staurolite-chloritoid schists from the Klenovec region: Prograde metamorphism of high-alumina rocks of the Kohút zone - Veporides. *Geol. Zbor. Geol. carpath.*, 39, 187 - 200.

Korikovsky S. P., Dupej J. & Boronikhin V. A., 1989: High-ferruginous metasediments from Kokava nad Rimavicou (Veporicum). *Miner. slovaca.*, 21, 251 - 258 (in Slovak).

Kováč A., Svingor E. & Grecula P., 1986: Rb-Sr isotopic ages of granitoids from the Spišsko-gemerské rudohorie Mts., Western Carpathians, Eastern Slovakia. *Miner. slovaca*, 18, 1, 1 - 14.

Kováčik M., 1991: High Al and Fe micaschists from the southeastern Veporicum: protolith and regional metamorphism. *Miner. slovaca*, 23, 23 - 32 (in Slovak).

Kráľ J., 1982: Dating of young tectonic movements and distribution of uranium in apatite of granitoid and metamorphosed crystalline rocks of the West Carpathians. *Geol. Zbor. Geol. carpath.*, 33, 5, 663 - 664.

Kretz R., 1983: Symbols for rock-forming minerals. *Amer. Mineral.*, 68, 277 - 279.

Lelkes-Felváry Gy. & Sassi F. P., 1981: Outlines of the pre-Alpine metamorphism in Hungary. In: Karamata S. & Sassi F. P. (Eds.): *IGCP No. 5, Newsletter*, 3, Beograd, 89 - 99.

Maheľ M. 1987: Geological structure of Czechoslovak Carpathians. Paleoalpine units - I. *VEDA*, Bratislava, 7 - 478 (in Slovak).

Mazzoli C. & Vozárová A., 1989: Further data concerning the pressure character of the Hercynian metamorphism in the West Carpathians (Czechoslovakia). *Rend. Soc. It. Miner. Petr.* (Milano), 43, 635 - 642.

Mazzoli C., Sassi R. & Vozárová A., 1992: The pressure character of the Alpine metamorphism in the Central and Inner Western Carpathians (Czecho-Slovakia). In: Vozár J. (Ed.): *Special volume of IGCP Project No. 276. GÚDŠ*, Bratislava, 109 - 117.

Méres Š. & Hovorka D., 1990: REE, U, Th and K geogeochemistry of the mica schists (the Kohút Crystalline Complex, the Western Carpathians). *Geol. Zbor. Geol. carpath.*, 41, 4, 415 - 426.

Miko O., 1981: Middle Paleozoic vocano-sedimentary Jánov grúň complex in Veporic crystalline of the Nízke Tatry Mts. *Geol. Zbor. Geol. carpath.*, 32, 4, 465 - 474 (in Russian, English abstract).

Mock R., 1978: New knowledge about southern parts of the Western Carpathians. In: Vozár J. (Ed.): *Paleogeographical development of the Western Carpathians. GÚDŠ*, Bratislava, 321 - 342 (in Slovak).

Molák B., Buchardt B., Vozárová A., Ivan J., Uhrík B. & Toman B., 1989: Carbonaceous matter in some metamorphic rocks of the Nízke Tatry Mts. (West Carpathians). *Geol. Zbor. Geol. carpath.*, 40, 2, 201 230.

Nitsch K. H., 1968: Die stabilität von Lawsonit. *Naturwiss*, 55, 388.

Pantó Gy.,1965: Pre-Tertiary development of the Tokaj Mts. *Magyar állami Földt. int., Évi jelent. az 1963,* Budapest, 227 - 241 (in Hungarian).

Pantó Gy., Kovács A., Balogh K. & Sámsoni Z., 1967: Rb-Sr check of Assyntian and Caledonian metamorphism and igneous activity in NE Hungary. *Acta Geol. Acad. Sci. Hung.*, 11, 1-3, 279 - 282.

Planderová E., 1986: New remarks about the ages of metasediments from the Ďumbier crystalline (Jasenie area). *Miner. slovaca*, 18, 3, 237 251 (in Slovak).

Plašienka D., Janák M., Hacura A. & Vrbatovič P., 1989: First data about the illite crystallinity from the Alpine metamorphosed rocks of Veporicum. *Miner. slovaca*, 21, 1, 43 - 51 (in Slovak).

Putiš M., 1989: Structural and metamorphical development of the eastern part of the Nízke Tatry Mts. crystalline. *Miner. slovaca*, 21, 217 - 224 (in Slovak).

Radvanec M.,1992: Zoning, low-pressure and polyphase metamorphism in open fluid system in gneiss-amphibolite complex. *Miner. slovaca*, 24, 3-4, 175 - 196 (in Slovak).

Reichwalder P., 1970: Some remarks to the occurrence of glaucophane rocks at Hačava region. *Geol. Práce, Spr., GÚDŠ*, 3, 157 - 166 (in Slovak).

Rozlozsnik P., 1935: Die geologischen Verhältnisse der Gegend von Dobšiná. *Geol. Hung., Ser. geol.*, 5, 1 - 118.

Rozložník L., 1965: Petrographie der granitisierten Gesteine der Rakovec Serie in der Umgebung von Dobšiná. *Sborn. Geol. Vied, Západ. Karpaty*, 4, 142 - 144.

Sassi F. P. & Vozárová A., 1987: The pressure character of the Hercynian metamorphism in the Gemericum (West Carpathians, Czechoslovakia). *Rendiconti Soc. Ital. Min. Petr.*, 42, 73 - 81.

Sassi R. & Vozárová A., 1991: Pressure character of the Variscan metamorphism in the Gemericum and Veporicum (Western Carpathians, Czecho-Slovakia). *Boll. Soc. Geol. Ital.*, 110.

Snopko L. & Ivanička J., 1978: Considerations about paleogeography of the Late Paleozoic of Spišsko-gemerské rudohorie Mts. In: Vozár J. (Ed.): *Paleogeographical development of the Western Carpathians. GÚDŠ*, Bratislava, 269 - 279 (in Slovak).

Snopková P. & Snopko L., 1979: Biostratigraphy of Gelnica Series of Spišsko-gemerské rudohorie Mts on the basis of palynological study. *Západ. Karpaty, sér. geol.*, *GÚDŠ*, 5, 57 - 102 (in Slovak).
Spišiak J. & Hovorka D., 1984: Coexisting biotites and garnets of paragneisses from the Rudňany area (the Paleozoic, the Spišsko-gemerské rudohorie Mts., the Western Carpathians). *Acta Geol. Geogr. Univ. Comen., Geol.*, 4, 61 - 78.
Spišiak J., Hovorka D. & Ivan P., 1985: Klatov Group - the representative of the Paleozoic amphibolite facies metamorphites on the Inner Western Carpathians. *Geol. Práce, Spr.*, *GÚDŠ*, 82, 205 - 220.
Spišiak J. & Pitoňák P., 1990: Nízke Tatry Mts. crystalline complex new facts and interpretation (Western Carpathians, Czechoslovakia). *Geol. Zbor. Geol. carpath.*, 41, 4, 377 392.
Spišiak J. & Pitoňák P., 1991: Banded amphibolitic rocks ancient Oceanic Crust? Conference Abstracts "Malé Karpaty Mts. - Geology of the AlpineCarpathian junction". Smolenice 1991.
Spišiak J., Janák M. & Pitoňák P.: Metamorphism of the Tatric part of the Western Carpathians. Kongres KBGA, Beograd (in press).
Thompson A. B., 1971: Analcite-albite equilibria at low temperatures. *Amer. J. Sci.*, 271, 79 - 92.
Varga I., 1973: Mineralogical associations of the regional metamorphism and their zonality at Spišsko-gemerské rudohorie Mts. *Miner. slovaca*, 5, 115 - 134 (in Russian).
Vozárová A., 1973: Pebbles analysis of the Lower Paleozoic conglomerates of the Spišsko-gemerské rudohorie Mts. *Západ. Karpaty*, *GÚDŠ*, 18, 7 - 98 (in Slovak).
Vozárová A., 1990: Development of metamorphism in the Gemeric/Veporic contact zone (Western Carpathians). *Geol. Zbor. Geol. carpath.*, 41, 5, 475 - 502.
Vozárová A., 1991: Petrology of Zemplinicum crystalline rocks. *Západ. Karpaty, sér. min., petr., geoch., met.*, *GÚDŠ*, 14, 7 - 59 (in Slovak).
Vozárová A., 1993: Thermodynamic conditions of metamorphism of the crystalline rocks in northern part of the Branisko Mts. *Geol. Zbor. Geol. carpath.*, 43, 5.
Vozárová A. & Vozár J., 1988: Late Paleozoic in West Carpathians. Monograph. *GÚDŠ*, Bratislava, 7 - 314.
Vrána S., 1964: Chloritoide and kyanite zone of Alpine metamorphism on the boundary of the Gemerides and the Veporides (Slovakia). *Krystalinikum*, 2, 125 - 143.
Winkler H. G. F. & Breitbar R., 1978: New aspects of granitic magmas. *Neu. Jahr. Min. Monatsch.*, 463 - 480.