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Pre-Alpine Western Carpathians Basement Complexes: Lithology and Geodynamic Setting

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15 Text-Figures, 2 Tables

Contents

Voralpidisches Grundgebirge der Westkarpaten: Lithologie und Geodynamik

Zusammenfassung

Aufgrund der Lithologie, der Genese und der geodynamischen Position wurden im präalpidischen Untergrund der Westkarpaten vier Einheiten unterschieden:

1) Der Leptynit-Amphibolit-Komplex (LAC).
2) Ein altpaläozoischer Komplex (EPA).
3) Die präalpidischen Granitoide (PAG).
4) Ein jungpaläozoischer Komplex (LAP).

Der LAC, ein neudefinierter Komplex in den Westkarpaten, repräsentiert die polymetamorph umgebildete Kontinentalkruste. In diesem Komplex überwiegt eine ursprüngliche kumulative Abfolge: heute besteht sie aus Amphiboliten mit Leptynit-Einschaltungen. Örtlich wurden in diesem Komplex Enklaven amphibolitisierter Eklogite und Metaperidotite nachgewiesen, die wahrscheinlich Relikte einer überschobenen ozeanischen Kruste darstellen. Stellenweise ist der LAC durch Migmatisierung bis hin zu partieller Aufschmelzung modifiziert. Der LAC liegt tektonisch über den Metamorphiten des EPA, wobei die Basis des LAC „die variszische Hauptüberschiebungsfläche" darstellt.

Der EPA besteht aus vulkano-sedimentären Sequenzen mit einem variablen Anteil an Metasedimenten, sauren und basischen Metavulkaniten. Diese Abfolgen entstanden vor allem in den Randpartien eines back arc Beckens. Folgen mit vorwiegend Metabasiten repräsentieren Relikte der ozeanischen bzw. ozeanisierten Kruste dieses Beckens.

Die PAG stehen geochemisch den Graniten vulkanischer Inselbögen nahe. Ihr Intrusionsniveau, Fraktionierungsprozesse und die Kontamination durch Gesteine des LAC und EPA bedingen ihre variable Zusammensetzung. Die am geringsten differenzierten Granitoide sind räumlich an Gesteine des LAC gebunden, aus denen sie entstanden sind. Dies beweisen räumliche Beziehungen der Gesteine des LAC, Migmatite und Granitoide, festgestellte LAC-Xenolithe in den Granitoiden, REE–Werte und niedrige Isotopenverhältnisse in den Granitoiden. Granitoide, die im EPA auftreten, sind durch eine höhere Differentiationsstufe gekennzeichnet. In Xenolithen sind Metasedimente des EPA vertreten.

Der LAP repräsentiert vorwiegend Sequenzen mit Molasse-Charakter. Es überwiegen in ihnen Sedimente zumeist mit einem Delta-Ursprung. In untergeordneter Menge sind in diesen Sedimenten Vulkanite vertreten, die geochemisch den Vulkaniten destruktiver Plattenränder nahestehen. Die Entstehung eines geringeren Teils des LAP hinter einem Inselbogen ist möglich. Die zum LAP gehörenden Abfolgen sind in der Regel nur schwach metamorphisiert. Dies dokumentiert ihre konstante Position in der obersten Partie der kontinentalen Kruste.

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Abstract

The following units have been distinguished on the basis of lithology, genesis and geodynamic setting in the pre-Alpine basement of the Western Carpathians:

1) The Leptyno-amphibolite complex (LAC).
2) The Early Paleozoic complex (EPA).
3) The Pre-Alpine granitoids (PAG).
4) The Late Paleozoic complex (LAP).

The LAC has been newly defined in the Western Carpathians, representing polymetamorphic altered lower continental crust. This complex is dominated by an originally cumulate complex: now changed to amphibolites with leptynite intercalations. Local appearances of enclaves of metaperidotites and amphibolitized eclogites were verified in this complex. The latter most probably represents relics of subducted oceanic crust. The LAC is locally modified by migmatitization, or even partial melting. The LAC is in tectonic position with metamorphics of the EPA, while the basis of LAC represents "the main Variscan thrust plane".

The EPA is formed by volcano-sedimentary sequences with variable amounts of metasediments, acid and basic metavolcanics. These sequences were formed mainly in marginal parts of a back arc basin. Those with dominating metabasites represent the relics of oceanic, or oceanized crust of these basins respectively.

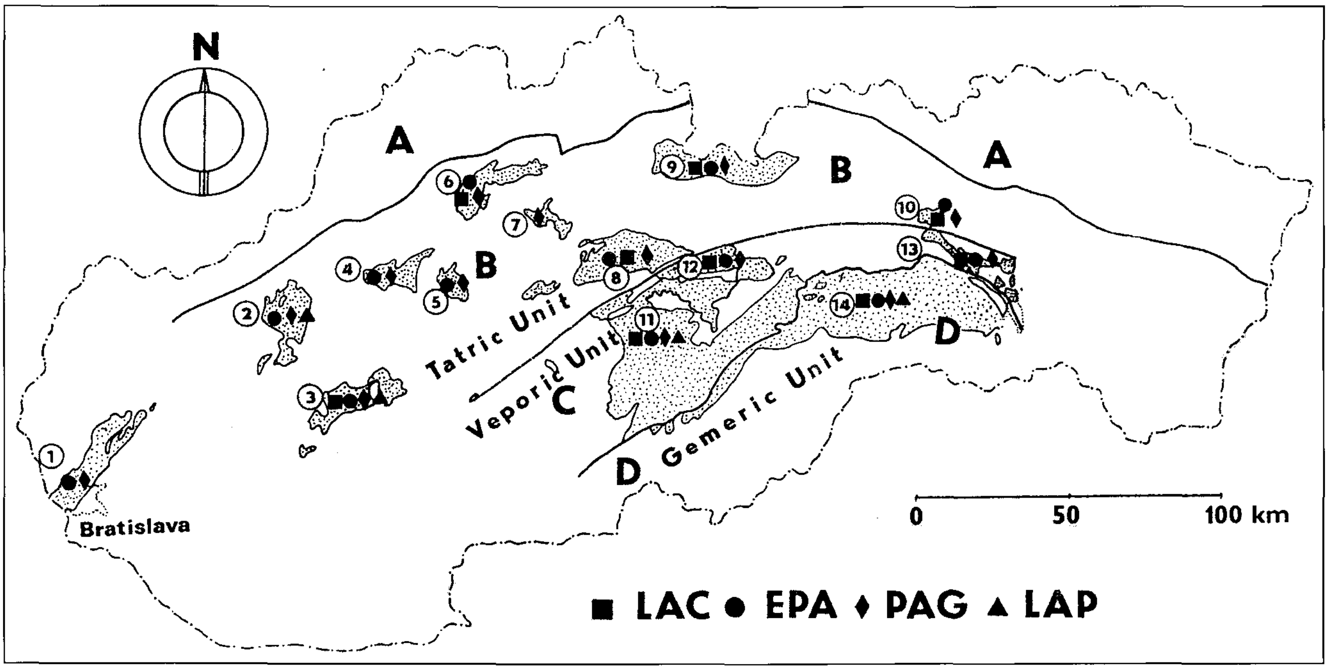
The PAG geochemically resemble granitoids of volcanic arcs. The level of their emplacement, the processes of fractional crystallization and contamination of the melts by the LAC and EPA are the conditioning factors of their variable composition. The least differentiated granitoids are spatially associated with the LAC, from which they were generated. It is documented by spatial relationships of the LAC, migmatites and granitoids, ascertained xenoliths LAC in granitoids, REE values and low isotope Sr ratios in granitoids. Granitoids which occur in EPA are characterized by a higher degree of differentiation. In xenoliths metasediments of the EPA are present.

The LAP represent mostly the molasse sequences. Detrital sediments are dominant, usually of deltaic origin. These sediments contain a subordinate amount of volcanics, geochemically similar to those of destructive margins. A back arc origin of a smaller part of LAP seems possible. The LAP sequences are usually only weakly metamorphosed. This documents their stable position in the upper part of the continental crust.

1. Introduction

The Pre-Alpine basement of the Western Carpathians takes part in all three structural-tectonic units: the Tatric Unit, Veporic Unit and Gemeric Unit (Text-Fig. 1). In the basement, the Tatric Unit and Veporic Unit, higher metamorphosed rocks and granitoids dominate. The basement of the Gemeric Unit consists mainly of weakly metamorphosed rocks. The complexes of the crystalline basement have hitherto been distinguished only according to regional criteria or on the basis of the intensity and character of metamorphic recrystallization. These complexes have generally been considered as metaclastics with subordinate metamorphosed basic volcanics. Marbles and graphitic rocks are also locally present (MÁŠKA & ZOUBEK, 1960; KAMENICKÝ, 1968).

Geochemical and petrological studies of the metavolcanics and metasediments of the pre-Alpine basement have brought new insight into their genesis. These data indicate that the sequences, or lithological groups respectively, present in the pre-Alpine basement of the central and inner Western Carpathians, share a great deal of identical, but at the same time, also very different genetic features.



Text-Fig. 1.
Distribution of the pre-Alpine Western Carpathians basement complexes.
A = *outer Western Carpathians*, B + C = *central Western Carpathians*, D = *inner Western Carpathians*.
(1) = Malé Karpaty Mts., (2) = Považský Inovec Mts., (3) = the Tribeč Mts., (4) = Strážovská hornatina Upland, (5) = Žiar Mts., (6) = Malá Fatra Mts., (7) = Velká Fatra Mts., (8) = Ďumbier zone of the Nízke Tatry Mts., (9) = Tatry Mts., (10) = Branisko Mts., (11) = Slovenské rudohorie Mts., (12) = Veporic Unit of the Nízke Tatry Mts., (13) = Čierna hora Mts., (14) = Spiš and Gemer Ore Mts.

2. Pre-Alpine Complexes

Since the last published works on the geology and division of the pre-Alpine Western Carpathians complexes (MÁSKA & ZOUBEK, 1960; KAMENICKÝ, 1968) a wealth of new, mainly analytical results have been published. In the following chapters an attempt to their synthetization is presented. Based on their lithology, geodynamic setting, metamorphic recrystallization and age, the following four complexes may be distinguished in pre-Alpine basement of the Western Carpathians:

1) The Leptyno-amphibolite complex (LAC).
2) The Early Paleozoic complex (EPA).
3) The Pre-Alpine granitoids (PAG).
4) The Late Paleozoic complex (LAP).

The common presence of the four complexes provides some evidence for a complicated evolution of the pre-Alpine basement of the Western Carpathians.

2.1. Leptyno-Amphibolite Complex (LAC)

LAC is a newly defined pre-Alpine basement complex. It has been found in all structural-tectonic units of the basement – in the Tatric, Veporic and Gemeric Units. In the Tatric Unit it forms a part of the crystalline complex of several mountain ranges (Text-Fig. 1). Its typical development is known from the Nízke Tatry Mts. ("banded amphibolite rocks" according to SPIŠIAK & PITOŇÁK, 1992), Tatry Mts. and Malá Fatra Mts. In the Veporic Unit it occurs mainly in its northern part. In the Gemeric Unit, the LAC forms a part of the sequence designated as the Klátov Group (HOVORKA & MÉRES, 1993; IVAN, in print).

LAC is represented by the following rock-types*):

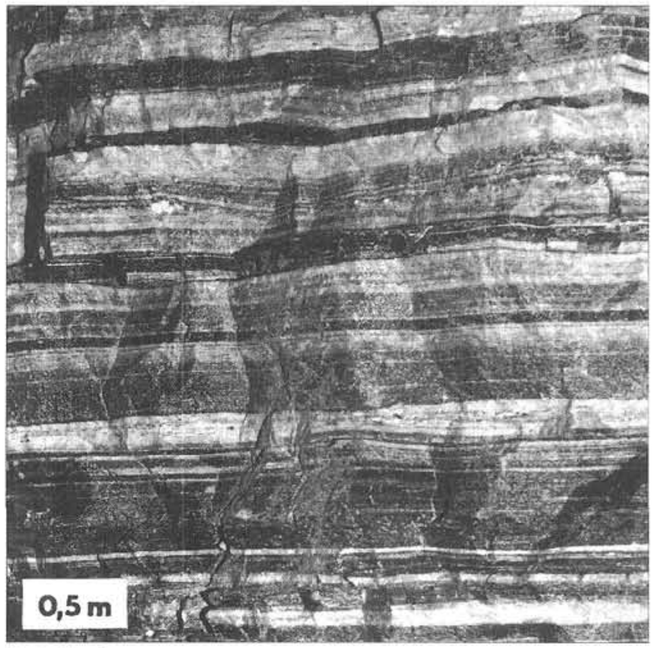
a) amphibolite (Hbl > Plg ± Gar ± Bt)
b) leptynite (Plg > Qtz ± Gar ± Hbl ± Bt)
c) enclaves – metaperidotites (Ant + Tre + Chl ± Tlc) and amphibolitized eclogites (Rtl + Cpx + Gar + Hbl ± Plg).

In the LAC rocks with a conspicuously banded structure dominate (Text-Fig. 2). Their fabrics show as the main textural element multiple alteration of light and dark bands, different in thickness. In the light bands, plagioclase is dominant. The dark bands have amphibole as the most widespread mineral. Transitional types with different amounts of plagioclase, amphibole and other minerals, are also frequent. Bands appear in millimetre to tens of metres in thickness. Their strike can be followed for hundreds to thousands of metres. Both main lithologies – the light retromorphically recrystallized leptynites and also the dark amphibolites – share a characteristic fine-grained structure and sharp boundaries. The difference in composition of the dark and light bands is represented in Text-Fig. 3.

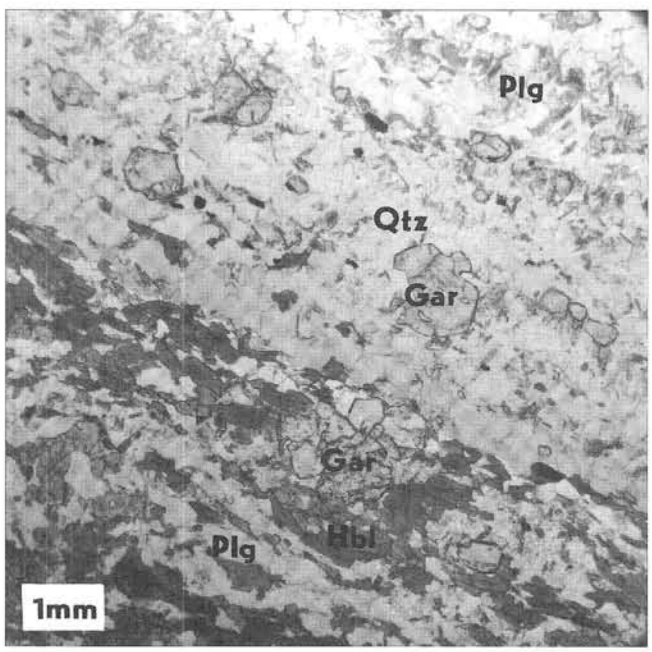
The enclaves are represented by metre to decametre sized lenses of metaperidotites and amphibolitized eclogites of lower crust/upper mantle provenance. Enclaves of metaperidotites are mainly represented by antigorite serpentinites, but also by tremolite + chlorite + talc + antigorite schists (HOVORKA et al., 1985). Enclaves of amphibolitized eclogites (HOVORKA & MÉRES, 1990; HOVORKA et al., 1992) display a markedly zonal structure. The centre of the enclaves is mainly metabasites containing Rtl + Gar + Cpx + Hbl (Text-Fig. 4). Based on the symplectitic textures (Cpx + Hbl, Cpx + Plg, Hbl + Plg) it can be assumed that the central parts of the lenses represent the product of the beginning stage of metamorphic equilibration of the former association Omph + Gar under hydrated amphibolite facies conditions. The margins of lenses include mineral assemblages identical with those of the surrounding amphibolite facies metamorphics. These assemblages (Hbl + Plg) have revealed schistose structure at the margins of these bodies.

In the course of a complicated ascent of LAC into its present position, it was subjected to the following processes:

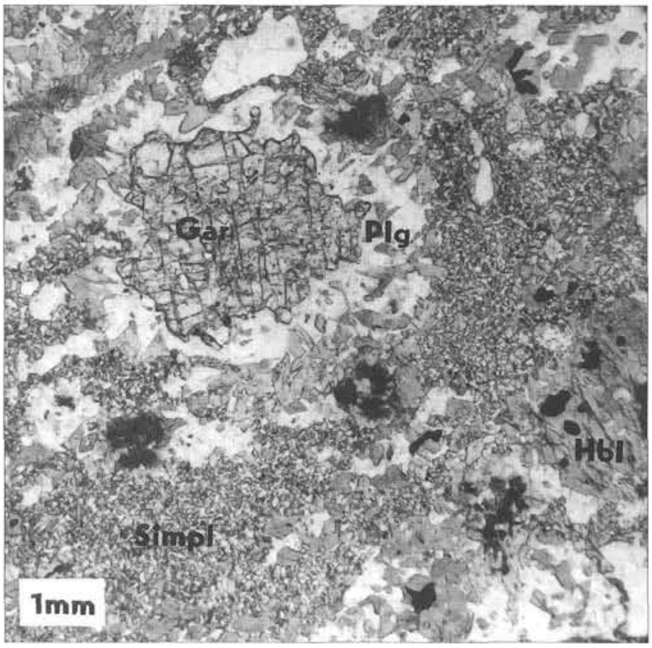
*) Abbreviations: Plg – plagioclase, Hbl – amphibole, Gar – garnet, Qtz – quartz, Rtl – rutile, Bt – biotite, Chl – chlorite, Ant – antigorite, Tlc – talc, Tre – tremolite, Cpx – clinopyroxene.



Text-Fig. 2.
Banded structure of the LAC.
Light bands = leptynites; dark bands = amphibolites.
Tatric Unit, Nízke Tatry Mts., Jasenie.



Text-Fig. 3.
Banded structure of the LAC.
Light bands have the composition Gar + Qtz + Plg, dark ones Gar + Plg + Hbl.
Veľký Zelený potok, Veporic Unit; polars //.

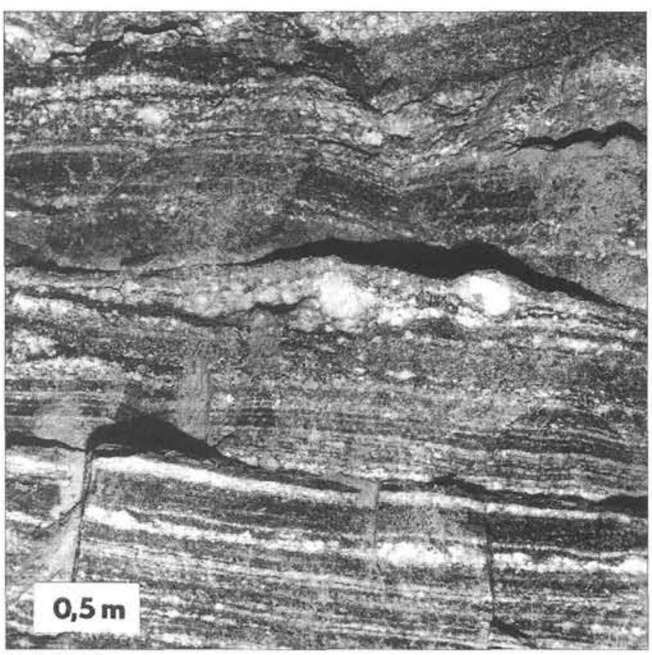


Text-Fig. 4.
Plg + Gar + Cpx + Hbl metabasite: enclave of amphibolitized eclogite in the LAC.
Simpl = simplectite of Hbl + Cpx + Plg.
Malá Fatra Mts., Tatric Unit; polars ‖.

a) a polyphase recrystallization:as a consequence of pressure release and migmatitization/anatectic melting (HOVORKA & MÉRES, 1991; HOVORKA et al., 1992);
b) a blastomylonitization of regional extent.

The recrystallization of LAC occurred under high-grade amphibolite to granulite facies conditions. This process was substituted by recrystallization in lower PT conditions.

The migmatitization and anatectic melting resulted in the origin of lenses and even irregular nests formed by albite and quartz. These attained decimetre thickness (Text-Fig. 5). The amphibolites are recrystallized into coarse-grained aggregates thereby increasing the amount of plagioclase. The advanced stages of anatexis resulted in a mobilization of the melt phase. The consolidated melts formed veins and nest-like aggregates. Their genetic association with LAC is documented by the presence of dykes connecting the LAC with the overlying migmatites. Anatectic melting can be observed in many places of LAC, as for example in the Tatry and Malá Fatra Mts.



Text-Fig. 5.
Beginning stage of the LAC migmatitization.
Jasenie, Nízke Tatry Mts., Tatric Unit.

Blastomylonitization of LAC causes the equilibration of the original mineral assemblage under low-grade ambibolite to greenschist facies conditions. The process is attributed to the Variscan (?), and in the Veporic Unit also to the Alpine age. Retrogressive metamorphic recrystallization yielded different types of phyllonites with chlorite, and white mica respectively, as significant phyllosilicates.

The thickness of LAC varies within a few hundred metres. LAC has most frequently horizontal/subhorizontal layering.

2.2. Early Paleozoic Complex (EPA)

The Early Paleozoic complex is present in all three structural-tectonic units of the pre-Alpine basement, in the Tatric, Veporic and Gemeric Units (Text-Fig. 1). It is formed by volcano-sedimentary sequences with variable representation of metavolcanics and metavolcaniclastics.

Differences appear also in the metamorphic grade. In the Tatric unit medium-grade metamorphics are prevailing, whereas in the Veporic and Gemeric Units low grade metamorphics dominate. These differences allow the following classification of the most characteristic sequences in EPA:

1) Metabasalt-metagreywacke sequence.
2) Metarhyolite-metapelite sequence.
3) Variegated sequence.
4) Metarhyolite sequence.
5) Metabasalt sequence.

2.2.1. Metabasalt-Metagreywacke Sequence

This sequence is in its typical development only known from the Tatric and Veporic Units, where it occurs in the form of an envelope of Variscan granites. In this sequence migmatites are also developed locally. Amphibolite facies metabasalts in gneisses attained metre to decametre thickness. Preliminary geochemical studies suggest alkaline basalts as protoliths.

Gneisses constitute a dominating member of this sequence. Their protolith were greywackes (HOVORKA, 1975). A continental crust of granodiorite-tonalite composition was their source area. They were deposited most probably in a back-arc basin (HOVORKA & MÉRES, 1991). Metamorphism reached the conditions of high grade amphibolite facies. Typical development of the amphibolite-gneiss sequences is mainly observed at the Strážovská hornatina Upland and Malá Fatra Mts.

2.2.2. Metarhyolite-Metapelite Sequence

This sequence consists of the two main lithotypes: metarhyolites (HOVORKA et al., 1987; MÉRES & HOVORKA, 1992) and metapelites (BEZÁK, 1989; MÉRES & HOVORKA, 1990, 1991a).

Intercalations of the following rocks occur: metacarbonates, black shales-metalydites, serpentinites, basic metavolcanics and carbonate phyllites. The precursor of the garnet micaschists is represented by geochemically mature sediments (claystones), in which fine-grained quartz (most probably of volcanic provenance) had been present in variable amount.

An Early Paleozoic age of metarhyolite/metapelite sequence is indicated by:

a) geological arguments (the presence of their gravels in Upper Carboniferous metaconglomerates);
b) Early Paleozoic palynomorphs in the intercalations of the micaschist complex (KLINEC et al., 1975);
c) geochronological data (CAMBEL et al., 1990).

Acidic metavolcanics of the Tatric and Veporic Units mostly appear discordantly to their basement which was metamorphosed in high-grade conditions. In the case of the metarhyolite-metapelite sequence of the Kohut crystalline complex within the Veporic Unit, two metamorphic events are distinguished. The older Variscan is characterized by a medium/low pressure amphibolite facies conditions. The younger Alpine is characterized by medium to high pressure metamorphic recrystallization up to the kyanite isograde (VRÁNA, 1964; MÉRES & HOVORKA, 1991a,b).

2.2.3. Variegated Sequence

Apart from the Early Paleozoic sequences with definite (and at the same time, only slightly varied) rock association in the Tatric and Veporic Units, there also exist sequences with a varied rock association. Their composition is made up of metasediments such as metagreywackes, phyllites, metacarbonates, quartzites and metavolcanics (metarhyolites as well as metabasalts). This group of Early Paleozoic sequences includes the following complexes:

The Predná hola complex, located in the easternmost part of the Nízke Tatry Mts., was described and distinguished by BAJANÍK et al. (1979). It is mainly composed of clastic metasediments, acid and basic metavolcanics and metashales. Geologically it is a part of the Veporic Unit.

The Jánov Grúň complex (MIKO, 1981) is mainly formed by prevailing acid/intermediate, also basic metavolcanics and phyllites, occuring only in negligible amount. Tourmaline-rich rocks are characteristic members of this unit. This complex is emplaced on the southern slopes of the eastern part of the Nízke Tatry Mts.

The representative of this sequence in the Malé Karpaty Mts, is the Harmónia formation. Metabasalts, present in this formation as lava flows and hyaloclastites, are geochemically similar to the E-type MORBs (IVAN, unpublished data). The protoliths of the metasediments were greywackes and pelites. It is possible to observe an admixture of organic matter and sporadic lenses of metamorphosed carbonates occur. Metamorphic alteration of the Harmónia sequence proceeded into the greenschist facies. It is partly affected by overlying periplutonic metamorphism.

2.2.4. Metarhyolite Sequence

Early Paleozoic acid/intermediate metavolcanics are known from the central and inner zone of the Western Carpathians. Metarhyolites (+ metavolcaniclastics and metaignimbrites) formed the rock association of the Gelnica Group of the Gemeric Unit. They display the main geochemical features of calk-alkaline effusives. Black shales, metapelites and metacarbonates are subordinate. Sporadically metamorphosed intermediate volcanics occur. Metabasalts are geochemically close to the E-type MORB, in the northern part of the Gelnica Group also CAB and N-type MORB (IVAN et al., 1992; IVAN, in print) are also present. Palynological data support the stratigraphic position of the rock complex being of Silurian to Lower Devonian in age (SNOPKOVÁ & SNOPKO, 1979).

Radiometric age data (Pb/U) from zircons of a quartz-porphyry of the Gelnica Group offer a wide span of ages: 355–520 Ma (GRECULA, 1982).

2.2.5. Metabasalt Sequence

A total dominance of metabasalts over metapelites is typical for this sequence. It comprises in the Tatric Unit the Pernek formation (in the Malé Karpaty Mts.) and in the Gemeric Unit the Rakovec Group.

The Rakovec Group contains metabasalts with preserved volcanic features (pillow lavas, agglomerates). Subvolcanic members appear more rarely. Intermediate and acid metavolcanics are rare. The Rakovec Group underwent polymetamorphic recrystallization; original medium to high pressure recrystallization was followed by greenschist facies metamorphism (HOVORKA et al., 1988; IVAN et al., 1992).

The Pernek formation is formed by dominating metabasalts and metagabbros appear in lower amounts. Primarily the upper part of the sequence was formed by siliceous black shales with pyrite. The Pernek formation is polymetamorphosed in a similar way as the Rakovec Group. The final stage of metamorphism was periplutonic. The age of the Pernek formation has yet to be determined.

2.3. Pre-Alpine Granitoids (PAG)

Variscan granites are present in the Tatric and Veporic Units of the central zone, as well as in the Gemeric Unit (Text-Fig. 1). In the central zone they form the backbone of the individual mountain ranges, whereas in the inner zone, they only form smaller massifs. Together they cover 11–12 per cent of the total area of Slovakia.

Most part of the Variscan granite massifs of the central zone have a rootless position and represent a part of the Variscan/Alpine nappes. Gravimetric modelling of the shape and size of granite bodies allows us to define them as tabular or lenticular bodies with the maximal thickness of 4–6 km. Within the central Western Carpathians zone they dip to S, SE or SW (TOMEK et al., 1989). The lowermost hitherto seismically detected boundary of the granitic bodies seems to be not deeper than 7 kilometres from the present surface.

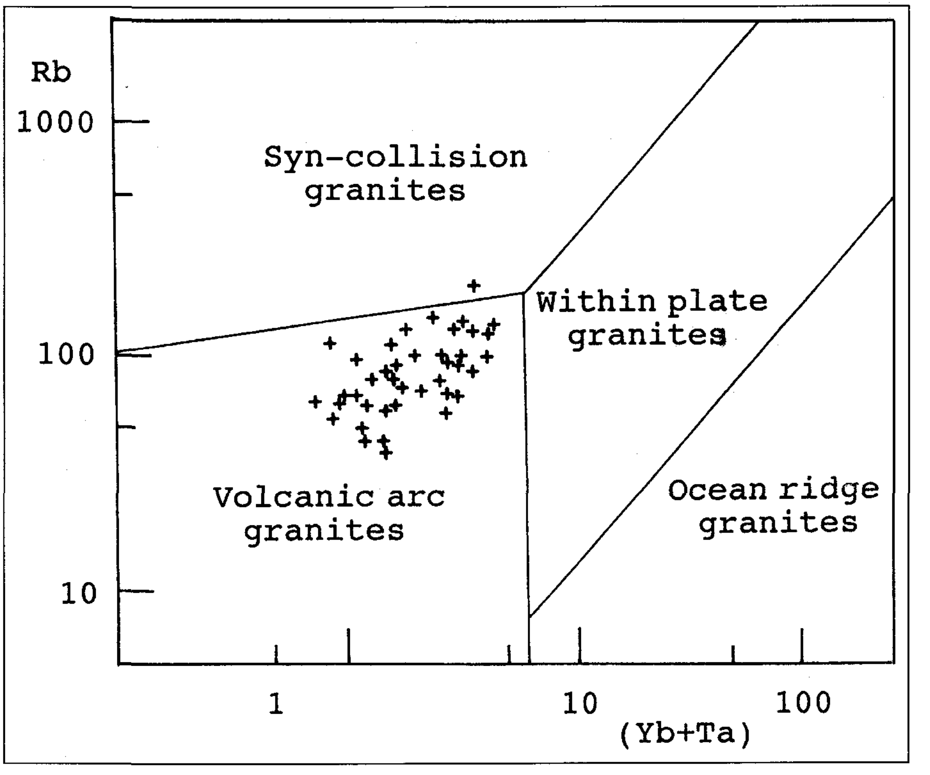
Western Carpathian Variscan granitic massifs share a most common feature of generally narrow range of composition and differentiation (65–74 % SiO_2). The dominant dark mineral is biotite and in more leucocratic types primary muscovite is present. For the majority of the Variscan granites the dominance of natrium over potassium is a characteristic feature. Parts of the granite massifs have A/CNK>1, that indicates they have a peraluminious character. No enclaves have yet been found of this type. The composition is reflected by the presence of magmatic garnet, sillimanite, muscovite (HOVORKA & FEJDI, 1983). Other main types – biotite tonalites and biotite granodiorites – attain the value A/CNK ≈ 1.

A highly fractionated REE pattern of the granite massifs (La_N/Yb_N = 40–16, HOVORKA & SPIŠIAK, 1983; HOVORKA & PETRÍK, 1992) and low HREE contents and Rb/(Yb + Ta) ratios (Text-Fig. 6) assign the massifs to the VAG granites.

Field and laboratory studies in the last few years indicate the presence of two genetic granite types:

1) Granitic (s.l.) bodies with enclaves of leptyno-amphibolite complex (amphibolites, metaperidotites). Within massifs of this type "ghost" palimpsestic (banded) struc-

Text-Fig. 6.
Rb – (Ta + Yb) discrimination diagram (PEARCE et al., 1984) for Variscan granitoids (PAG).
Data according HOVORKA & PETRÍK (1992).



tures are observable locally. Lower $^{87}Sr/^{86}Sr$ ratios (<0.706) are characteristic (KRÁL, 1992). Many of their features are similar to I-types granites.

2) The second type of granites constitutes more differentiated massifs. They often contain xenoliths (assimilated to different degree) of EPA metamorphics. Gradual transitions into Early Paleozoic complexes are frequent, the connecting zone is represented by migmatites. Granites of this group are characterized by higher initial $^{87}Sr/^{86}Sr$ ratio (<0.706; KRÁL, 1992) and by the properties attributing them to S-type granites. They usually intruded into higher crustal levels causing contact-thermic aureoles.

Rb/Sr whole rock analyses as well as U/Pb data on zircons allowed the classification of the Variscan Western Carpathian granites into the following groups (PETRÍK et al., in print):

1st group: Lower Carboniferous (350–330 Ma),
2nd group: Upper Carboniferous (310–290 Ma),
3rd group: Permian (280–250 Ma).

2.4. Late Paleozoic Complex (LAP)

The late Paleozoic complex is present in all units of the pre-Alpine basement (Text-Fig. 1). It is most widespread in the Gemeric Unit. For the Late Paleozoic complexes which are divided into several groups and formations (VOZÁROVÁ & VOZÁR, 1988), the following main characteristics can be summarized.

Within the individual sedimentation basins of the Carboniferous and Permian, variable quantitative amounts of sedimentary and volcanic material is known. Generally terrigenous sediments prevail over evaporites. Among volcanics, both basalts and rhyolites, are substantially present in some lithostratigraphic units. Mostly low structural and mineralogical maturity is characteristic for the sediments. Provenance of the detritic material is represented by the uplifted basement of crystalline complexes of the Early Paleozoic (Precambrian ?).

For the sedimentation, a change from the shallow-marine, deltaic-marine and deltaic environment to fluvial and fluvial-lacustrine occur (VOZÁROVÁ & VOZÁR, 1988). The deposition of Late Paleozoic sediments proceeded under humid and warm semiarid to arid climatic conditions. For both, Carboniferous and Permian sediments, the horizons with faunal remnants are very sporadic. As these complexes have never reached the conditions of elevated temperatures, their metamorphic recrystallization proceeded under anchizone to low grade greenschist facies conditions.

A part of the LAP has a different evolution in the Gemeric unit. The sequences of Carboniferous age contain basic metavolcanics, geochemically close to BABB (IVAN et al., 1992). In the Ochtina formation, metaclastics and metacarbonates prevail over metabasalts. On the contrary, the Zlatník formation is characterized by metabasalts and metagabbros prevailing over black shales. Permian sequences contain the products of intensive calc-alkaline volcanism.

In some sedimentation basins extensive volcanic activity supplied volcaniclastic material alternating with or passing gradually into sandstones. The gradual change from the uppermost Permian to the lowermost Triassic shale sediments is evident in some vertical sections.

3. Discussion

Pre-Carboniferous complexes of the central Western Carpathians metamorphosed to amphibolite facies were in the past designated as the Tatra (MÁŠKA & ZOUBEK, 1960) or Jarabá series (KAMENICKÝ, 1968). The protolith (Early to Middle Proterozoic?) of this series was considered to be a complex of pelitic and pelitic-psammitic sediments with local basic volcanism. The stratigraphic superimposed sequences of the Jarabá series includes the Kohút (Late Proterozoic?; MÁŠKA & ZOUBEK, 1960) or the Kokava series (KAMENICKÝ, 1968). This division was based on different lithology and intensity of metamorphic recrystallization.

In the Early Paleozoic of the Gemeric Unit, the Gelnica and Rakovec series were distinguished. In those days there were no detailed petrological and geochemical data from the individual rock types available. Therefore, the complexes classified in the past also included lithological types whose present geological position and often also metamorphism (as a consequence of polymetamorphic evolution) suggest their common genesis. However, geochemical criteria and recent petrological data in several cases exclude an identical environment of their origin. This aspect is, in our view, one of

Table 1.
Representative chemical analyses of rocks of the leptyno-amphibolite complex.
Location of samples: ZT-15A = leptynite, ZT-15B = amphibolite, Žiarska dolina, Tatry Mts., Tatric Unit; ZP-301 = amphibolite, ZP-302 = leptynite, Veľký Zelený potok, Slovenské rudohorie Mts., Veporic Unit: MF-315 = amphibolitized eclogite, N-MORB type, Malá Fatra Mts., Tatric Unit; VV-45 = amphibolitized eclogite, E-MORB type, Hel'pa, Nízke Tatry Mts., Veporic Unit.
Major oxides in wt. %, trace elements in ppm,.
Fe_2O_3* = total iron content; LOI – loss on ignition (1100°C); ND = not detectable.
Trace elements have been determinated using INAA techniques at the MEGA laboratory, Stráž pod Ralskem, Czech Republic.

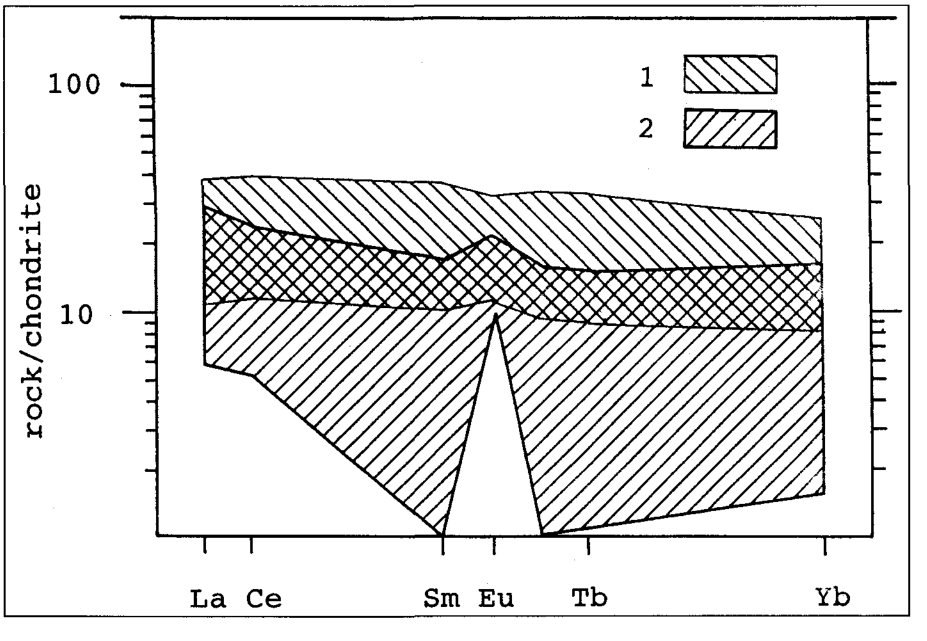
	ZT-15A	ZT-15B	ZP-301	ZP-302	MF-315	VV-45
SiO_2	70.47	54.52	50.69	76.83	50.60	49.47
TiO_2	0.39	0.80	1.06	0.10	1.59	2.12
Al_2O_3	14.63	14.99	15.19	13.33	13.54	11.06
Fe_2O_3*	5.01	11.53	10.61	0.80	13.15	12.07
MnO	0.13	0.19	0.15	0.02	0.23	0.18
MgO	0.89	6.20	7.65	0.22	6.71	11.43
CaO	2.36	7.56	10.09	3.20	10.57	12.03
Na_2O	4.47	3.30	3.04	4.35	2.36	1.02
K_2O	0.69	0.67	0.27	0.34	0.52	0.53
P_2O_5	0.08	0.06	ND	ND	ND	0.18
LOI	0.76	1.13	0.76	0.32	0.23	0.78
Total	99.88	100.95	99.51	99.51	99.50	100.87
Rb	27.6	30.0	<7.9	12.7	10.6	<7.2
Hf	2.1	1.20	2.7	2.8	2.6	3.5
Sc	15.9	38.5	39.5	0.83	46.0	29.0
Ta	0.084	0.05	0.169	0.42	0.129	0.94
Th	1.05	0.53	1.75	1.15	<0.106	1.15
La	5.0	2.7	5.7	1.5	2.6	13.2
Ce	13.6	7.6	12.2	4.2	9.5	35.5
Sm	1.95	1.55	2.65	0.3	3.2	4.5
Eu	0.59	0.66	0.96	0.97	1.35	1.55
Tb	0.35	0.34	0.71	0.082	0.81	0.66
Yb	1.70	1.4	2.85	0.34	3.4	1.40

the main reasons of the wide scattering of geochronological data known (CAMBEL et al., 1990) that was in the past assigned to this complex. Mutual interaction within a specific time span between the rocks of the LAC, EPA and PAG connected mainly by PAG in fact covered their main differences. Our suggested criteria testify to different evolutions in their initial stages and enable their independent definition with significant consequences for stating the geodynamic evolution of the pre-Alpine basement of the Western Carpathians.

Petrological and geochemical data obtained from "banded amphibolites", the discovery of enclaves of amphibolitized eclogites (HOVORKA & MÉRES, 1989; HOVORKA et al., 1992) in these amphibolites allowed the authors to distinguish the leptyno-amphibolite complex (LAC) in the basement of the Western Carpathians (HOVORKA et al., 1992).

REE-normalized patterns of amphibolites and leptynites (Text-fig. 7 and Tab. 1) indicate their probable cumulate origin in the lower continental crust. REE pattern of the best preserved leptynites is similar to cumulate gabbros because of their low REE content and often positive Eu-anomaly. Considerable variability of REE pattern is most probably caused by variations in the amount of fractionated plagioclase, and/or postmagmatic alterations (mainly migmatitization). REE contents in amphibolites are higher, Eu-anomalies (positive and negative) are either not pronounced or are missing. This may lead to a conclusion that a part of the amphibolites represent rocks, the protolith of which had originated from weakly fractionated magma. Testing of the composition of amphibolites in discrimination diagrams such as Th – Hf/3 – Ta (Text-Fig. 8) and La/Th – Sc (Text-Fig. 9) indicates their possible affinity to two groups of basic magmas:

1) calcalkaline magma, or
2) magma generated in back-arc basins.

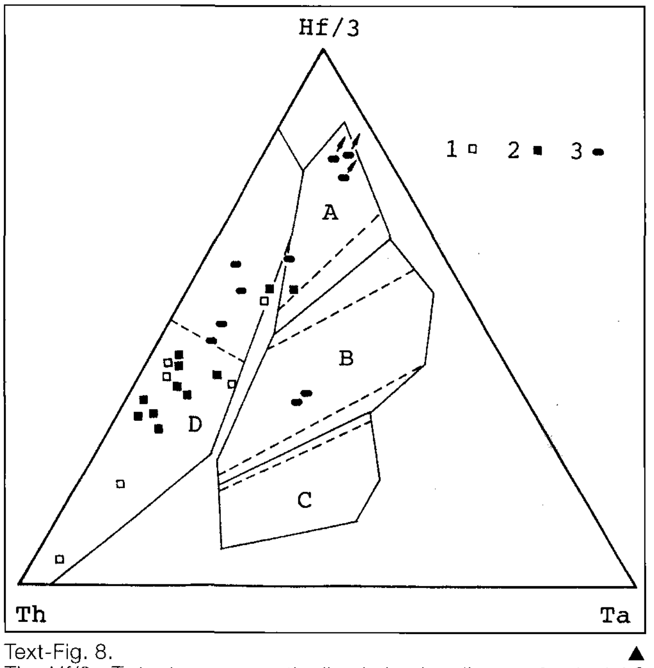


Text-Fig. 7.
Chondrite normalized REE patterns of the LAC (Tatric and Veporic Units; unpublished data).
Normalization after EVENSEN et al. (1978; all data in this paper).
1 = amphibolite, 2 = leptynite.

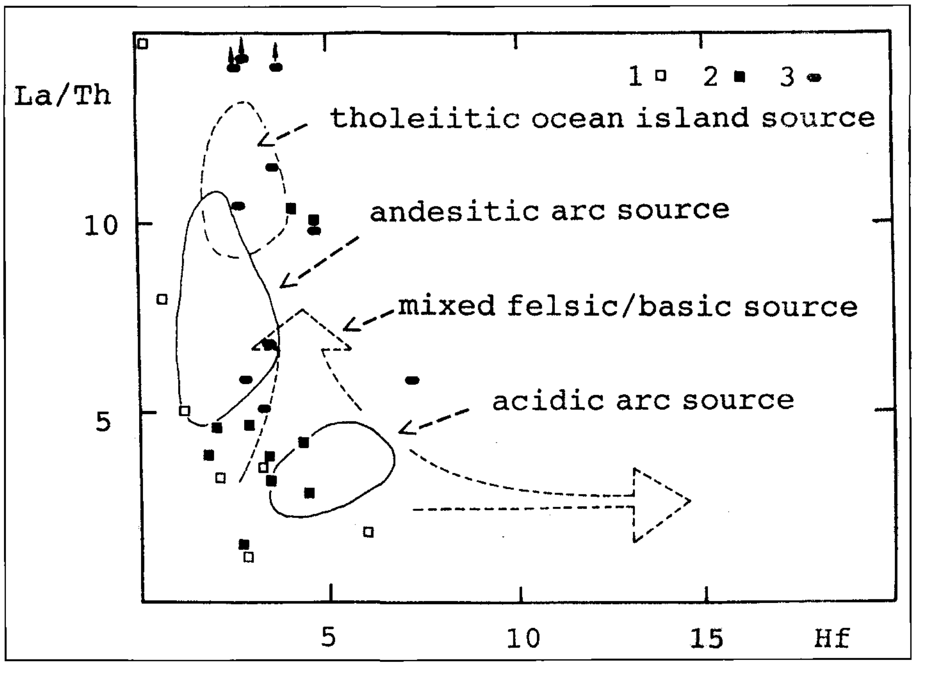
On the basis of geochemical characteristics it is possible to make a preliminary classification of the enclaves of amphibolitized eclogites into three groups:

Table 2.
Representative chemical analyses of rocks of the Early Paleozoic complex.
Location of samples: VMK-45 = metabasalt (greenstone), N-MORB type, Borinka, Malé Karpaty Mts., Tatric Unit; BSV-36 = metabasalt, E-MORB/OIT type, Gelnica Group, Gemeric Unit; RMK-33 = gneiss (metagreywacke), Malé Karpaty Mts., Tatric Unit; SY-9 = mica schists (metapelite), Kohút zone, Veporic Unit; AVG-58 = acidic metavolcanics, Gemeric Unit.
Major oxides in wt. %, trace elements in ppm.
Fe_2O_3* = total iron content; LOI = loss on ignition (1100°C); ND = not detectable.
Trace elements have been determinated using INAA techniques at the MEGA laboratory, Stráž pod Ralskem, Czech Republic.

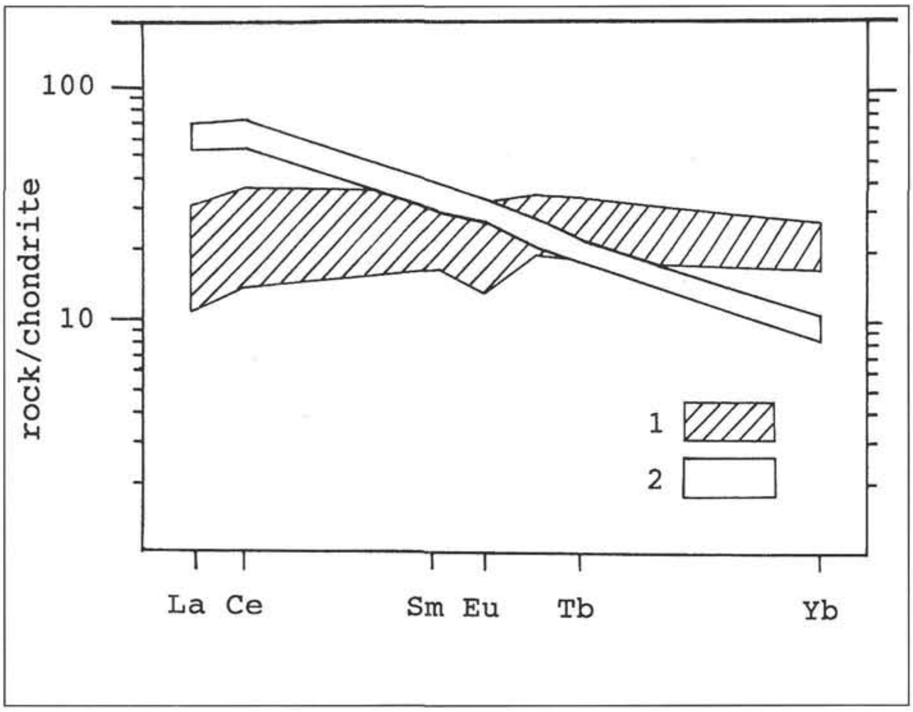
	VMK-45	BSV-36	RMK-33	SY-9	AVG-58
SiO_2	48.95	47.48	62.25	57.40	73.80
TiO_2	1.99	2.10	0.75	1.11	0.40
Al_2O_3	14.69	15.49	17.43	21.59	13.51
Fe_2O_3*	11.47	11.58	7.51	8.38	3.30
MnO	0.22	0.20	0.12	0.14	0.02
MgO	7.11	7.02	2.88	0.78	0.54
CaO	9.25	6.91	1.71	1.81	0.10
Na_2O	2.52	4.29	2.89	1.32	4.59
K_2O	1.08	0.23	2.28	4.23	2.23
P_2O_5	0.18	0.29	0.17	0.14	0.11
LOI	2.28	3.89	1.69	2.63	0.93
Total	99.74	99.78	99.68	99.53	99.53
Rb	49	ND	93.5	199	75.5
Hf	3.3	2.3	4.7	10.2	7.1
Sc	46.5	43.5	20.7	22.5	7.7
Ta	0.236	0.58	0.75	1.25	0.86
Th	0.34	0.64	8.1	20.8	17.6
La	5.4	14.5	26.6	68.5	25.5
Ce	17	27.8	61	130	77.5
Sm	4.3	4.6	5.7	10.7	5
Eu	1.5	1.15	1.3	2.15	0.57
Tb	0.99	0.91	0.83	1.4	0.93
Yb	3.5	2.05	2.9	4.4	3.7



Text-Fig. 8.
Th – Hf/3 – Ta tectonomagmatic discrimination diagram for the LAC rocks.
1 = leptynites, 2 = amphibolites, 3 = amphibolitized eclogite enclaves from LAC.
Fields after WOOD (1980): A = N-MORB type; B = E-MORB type; C = within plate alkali basalts; D = destructive plate/margin basalts.



Text-Fig. 9.
La/Th – Hf discrimination diagram (after FLOYD & LEVERIDGE, 1987) with projections of the LAC rocks.
1 = leptynites, 2 = amphibolites, 3 = amphibolitized eclogite enclaves.



Text-Fig. 10.
Chondrite normalized REE patterns of amphibolitized eclogite enclaves of the LAC.
1 = N-MORB and IAT types, 2 E-MORB types.

1) N-MORB,
2) IAT and
3) E-MORB.

The first two groups show relatively low total contents of REE and flat REE patterns (Text-Fig. 10) and usually a modest negative Eu-anomaly. Enclaves similar to E-MORB show enrichment in LREE, differentiated LREE/HREE pattern and are without an Eu-anomaly. In the Gemeric Unit there are, on the basis of our preliminary results, only enclaves with a composition similar to E-type MORB and in the Veporic Unit only the ones close to E-type MORB as known. So far, the Tatric unit is concerned, within the LAC enclaves of N-type MORB have hitherto been identified and enclaves with a composition close to IAT.

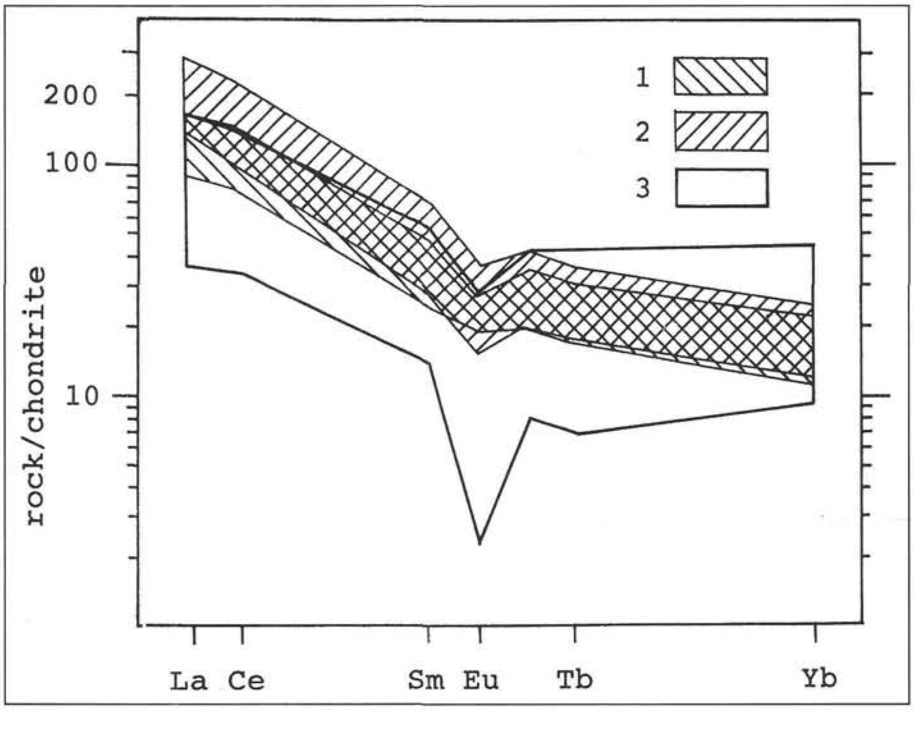
A part of the Klátov group in the Gemeric Unit resembles LAC described from the central zone, because of its properties (enclaves of metaperidotites, amphibolitized eclogites, banded texture). Geochemical characteristics of this group resemble of the crust of an island arc basement (IVAN, in print).

Geochronological dating has not been applied to the rocks of the LAC. On the basis of geochronological data interpretation (CAMBEL et al., 1990) from the rocks genetically related to the LAC, we assume the age of the complex to be higher than 400 Ma.

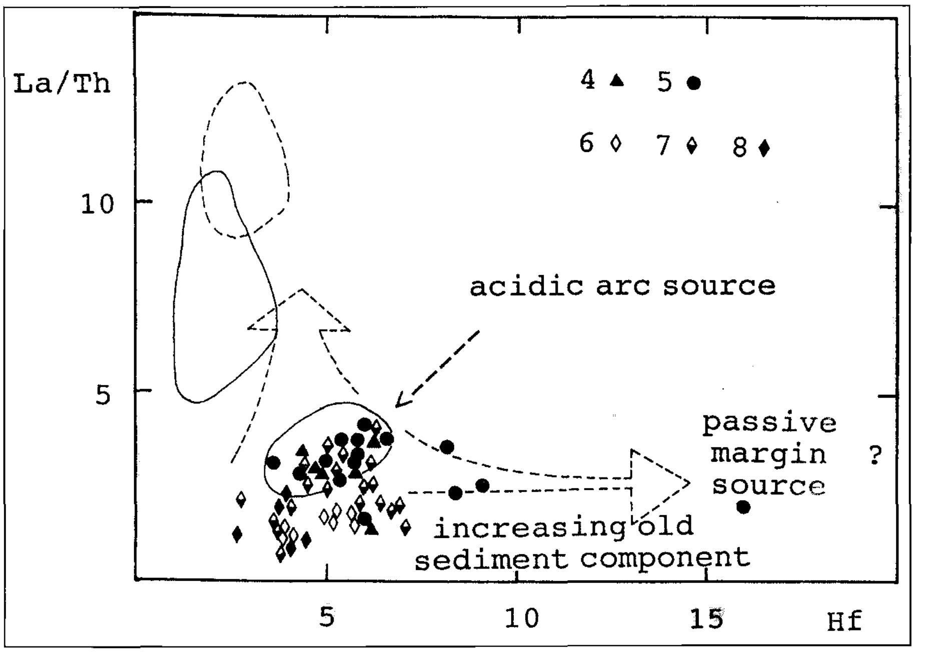
One of the common five features hitherto characterizing the Early Paleozoic (EPA) sequences is their volcano-sedimentary character and the evidence for their formation in back arc basins. They differ mainly in lithology, or in markedly distinct presence in the amount of rock types respectively. Metamorphic development and the intensity of metamorphic recrystallization are another criterion for distinction.

Sequences with a variable amount of sediments and acid volcanics originated in marginal parts of a back arc basin. Sequences with dominating metabasites probably represent the relics of oceanic crust in these basins (IVAN, 1989; IVAN et al., 1992). The first two sequences reached PT conditions of the central part of the continental crust in the course of their development, the final three sequences are characterized by their recrystallization in PT conditions of the upper part of the continental crust. The type of the recrystallization under HP-LT conditions in the sequences with dominating metabasites (HOVORKA et al., 1988) indicate metamorphic recrystallization in a subduction zone.

The different compositions (Tab. 2) of the most widespread EPA rock sequences (Text-Figs. 11, 12, 13 and 14) reflect the character of their protolith. Metapelites (mica



Text-Fig. 11.
Chondrite normalized REE abundances from EPA rocks.
1 = gneisses (metagraywackes) from the Tatric Unit (data HOVORKA & MÉRES, 1991); 2 = micaschists from the Veporic Unit (data MÉRES & HOVORKA, 1990; 1991a); 3 = acidic metavolcaniclastics/metavolcanics from the Tatric Unit = Tribeč Mts. (data MÉRES & HOVORKA, 1992); Veporic Unit = Muráň orthogneisses (data HOVORKA et al., 1987) and Gemeric Unit (unpublished data).



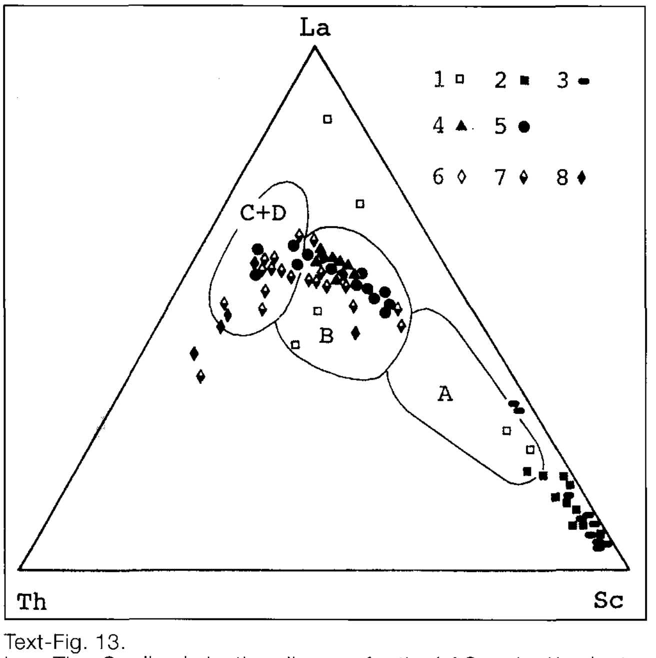
Text-Fig. 12.
La/Th – Hf discrimination diagram (after FLOYD & LEVERIDGE, 1987) with projections of the EPA rocks: 4 = micaschists; 5 = gneisses.
Acidic metavolcaniclastics/metavolcanics from: 6 = Tatric Unit (Tribeč Mts), 7 = Gemeric Unit, 8 = Veporic Unit (Muráň orthogneisses).

schists) and metagreywackes (gneisses) are evidently generated from acidic arc sources (Text-Fig. 12) similar to the acid metavolcanics. The chemical discrimination diagram La – Th – Sc (Text-Fig. 13) shows that the tectonic environment of metapelites and metagreywackes is a continental island arc and for the acid metavolcanics and metavolcanoclastics, a continental sland arc and a passive/active continental margin.

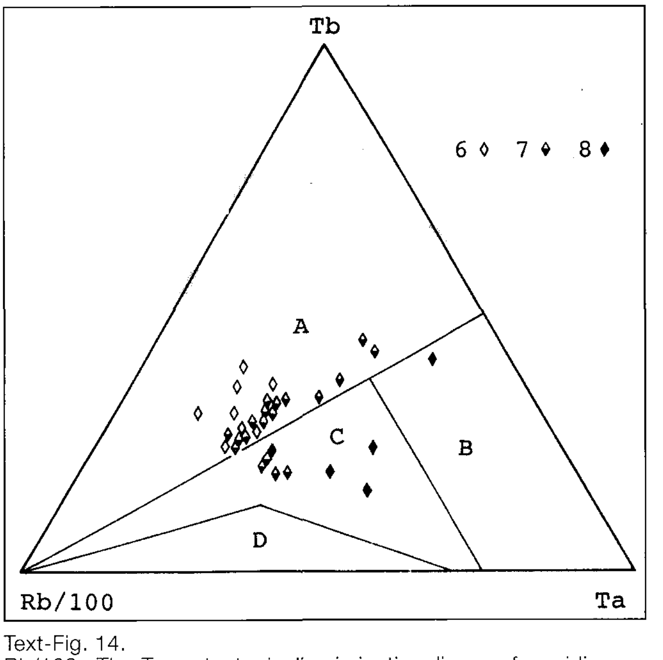
The Gelnica Group, a typical representative of the metarhyolite sequence, was formed at the margin of a back arc basin, on the slope of an ensialic island arc. It is supported by the prevalence of acid metavolcaniclastics, flysch-like sediments and the presence of minor basic calc-alkaline volcanics with metabasalts of E-type MORB. The presence of bodies of N-type MOR metabasalts at the northern margin of the group indicates the introduction of back arc spreading associated with the formation of oceanic crust. A part of the Early Paleozoic sequences within the central and inner zones of the Western Carpathians was metamorphosed to greenschist facies conditions.

The geotectonic conditions that generated the Early Paleozoic acidic volcanics in the Gemeric Unit are interpreted in a different way. Based on geochemical studies we correlate these metavolcanics with anorogenic volcanic activity (Text-Fig. 14) in a tensional environment.

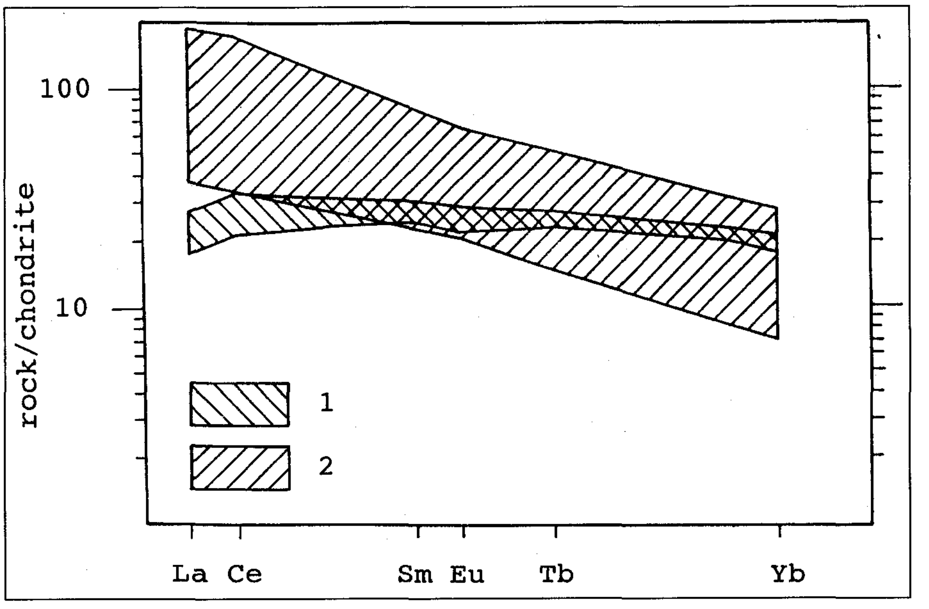
The metabasalt sequence was formed in the initial stages of the evolution of back arc basin. It is testified by the presence of E-type MOR basalts among prevailing metaclastics: metapsammites and metapelites. The absence of acid volcaniclastic material in this sequence indicates the sedimentation occur outside of the accretion zone relative to the magmatic arc.



Text-Fig. 13.
La – Th – Sc discrimination diagram for the LAC rocks (1 = leptynites, 2 = amphibolites, 3 = amphibolitized eclogite enclaves) and for the EPA rocks (4 = micaschists; 5 = gneisses; 6–8 = acidic metavolcaniclastics/metavolcanics from: 6 = Tatric Unit – Tribeč Mts; 7 = Gemeric Unit, 8 = Veporic Unit – Muráň orthogneisses).
Fields after BHATIA & CROOK (1986): A = oceanic island arc; B = continental island arc; C + D = active and passive continental margin.



Text-Fig. 14.
Rb/100 – Tb – Ta geotectonic discrimination diagram for acidic metavolcanics/metavolcaniclastics of the EPA rocks.
6 = Tatric Unit (Tribeč Mts), 7 = Gemeric Unit, 8 = Veporic Unit (Muráň orthogneisses).
Field of acidic magmatic suites after THIÉBLEMONT & CABANIS (1990): A = anorogenic non-peralkaline suites, B = anorogenic peralkaline suites, C = post-collision and syn-subduction suites, D = syn-collision suites.



Text-Fig. 15.
Chondrite normalized REE patterns of the EPA rocks metabasalts sequence.
1 = N-MORB type metabasalts from the Tatric Unit (Malé Karpaty Mts; IVAN, unpublished data); 2 = E-MORB/OIT type metabasalts from the Gemeric Unit (Rakovec Group).
Data: HOVORKA et al. (1988).

The Rakovec Group with prevalence of E-type MOR metabasalts (HOVORKA et al., 1988) rather corresponds to early stages of the opening of back arc basin. The Pernek formation with N-type MOR metabasalts and metagabbros (Text-Fig. 15) is a product of a developed back arc spreading. Sediments are in both cases pelitic.

The pre-Alpine granitoids of the Western Carpathians (PAG) show a genetic association with LAC and EPA. It is manifested by gradual transitions from LAC rocks through migmatites into only slightly differentiated granitoids (type 1). We assume these massifs were generated from LAC (HOVORKA et al., 1992). The transition into this type of granites proceeds through the zone of the 1st type migmatites. Processes of anatexis (= migmatitization) of the LAC are demonstrated by gradually increasing grain-size within the light and dark bands, too. Migmatites of this type resemble geochemically (including REE) the granites. The granitic melts leave the LAC in the form of discordant veins.

Properties of the 2nd type granitoids are influenced by the interaction of the melt which has already undergone the process of fractional crystallization, with the rocks of the volcano-sedimentary sequences (EPA). Contamination of the melt by EPA rocks (mainly metasediments) influences the geochemical characteristics of these granitoids. The intrusion of Variscan granitoids is time related also with younger metamorphic recrystallization of metasediments and metabasites of EPA in amphibolite facies conditions.

The Late Paleozoic complexes of the Western Carpathians represent the sequences deposited/erupted in a transition time span between the main sedimentation/ magmatism/metamorphism period of the Variscan and the Alpine orogeny. The Late Paleozoic sequences reflect the processes of the closure of the Variscan mobile belt. They are generally accepted as being the "Variscan molasse". The Late Paleozoic complexes originated after the deposition, folding and metamorphic recrystallization of the Early Paleozoic complexes. LAP complexes are mostly in allochthonous position being members of the Alpine nappes. Extensive molasse formations included into the Late Paleozoic complex indicate stabilization of the Variscan crust and denudation of its upper parts. The acid and rarely also basic volcanism is probably linked to subduction volcanism known from Late Paleozoic of the Gemeric Unit and Choč nappe.

4. Conclusions

The following four main complexes of pre-Alpine basement may be distinguished at the present erosion section of the Western Carpathians:

1) The leptyno-amphibolite complex (LAC).
2) The Early Paleozoic complex (EPA).
3) The complex of granitoids (PAG).
4) The Late Paleozoic complex (LAP).

These complexes are distinguished, in principle, in the rock types and the environment in which they were generated. A summary of existing petrological and geochemical data indicate the following complexes as being responsible for the composition of the pre-Alpine basement of the Western Carpathians:

a) complexes of oceanic crust of back arc basins (the Rakovec and Pernek Groups/Formations);
b) complexes generated in the lower continental crust (LAC of the Tatric and Veporic Units, and probably 1st type granitoids), or in the lower part of an ensialic island arc (the Klátov Group of the Gemeric Unit);
c) complexes that underwent metamorphic recrystallization processes corresponding to the central part (1st and 2nd sequences of EPA) and mainly the upper part of the continental crust (3rd and 4th sequences of EPA and LAP).

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