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Продолжение содержания на 3 стр.

Symposium

„Petrogenetic aspects of ophiolites and similar complexes"

(Košice, September 27, 1983)



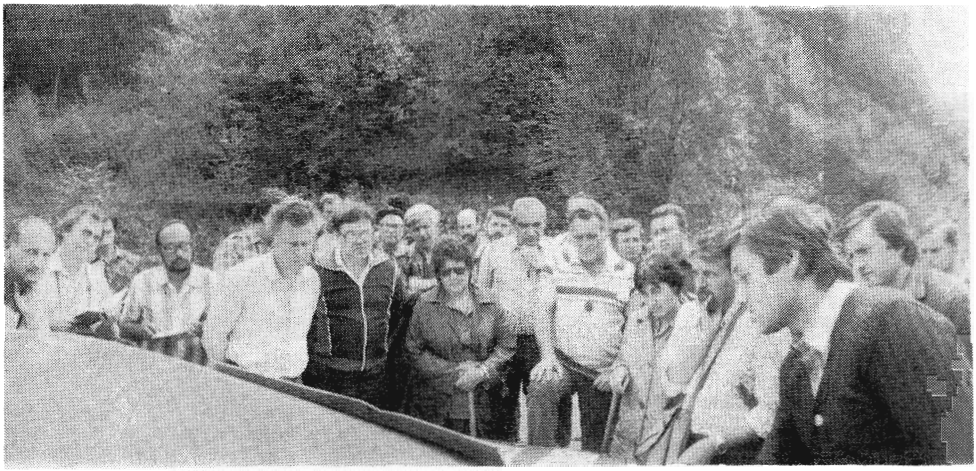
It is a well established tradition that in the frame of every year organized common fieldwork of the members of working groups, 2.1 and 2.2 of the Problem Commission IX of the multilateral agreements of Academies of Science of Socialist Countries, also thematic symposiums are being organized. Results of single working groups or, scientific achievments of larger working teams are presented. This kind of symposium devoted to the indicated theme was held in Košice on September 27, 1983. The majority of presented papers is included in this issue of the Mineralia Slovaca.

I am pleased to express, also in the name of the members of working groups 2.1 and 2.2, appreciations to the Editor of the journal and to its Editorial Board as well as to the members of redaction for the quick preparation of papers generated from the Symposium into a single, issue. Our thanks are so much sincere as materials are issued in the shortest time possible after the date of Symposium.

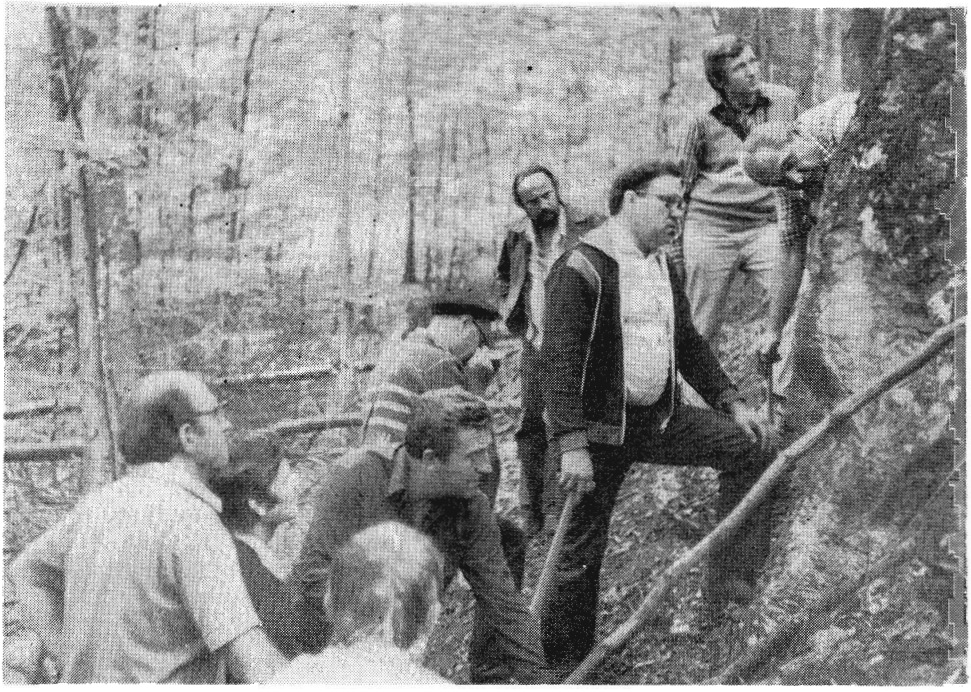
Stalo sa dobrou tradíciou, že sa v rámci každoročných spoločných terénnych prác členov pracovných skupín 2.1 a 2.2 problémovej komisie IX mnohostranných dohôd akadémií vied socialistických štátov organizujú aj tematické sympóziá. Prezentujú sa na nich výsledky prác členov skupín, resp. celých kolektívov. Takéto sympózium sa pod uvedenou ústrednou témou konalo aj 27. septembra 1983 v Košiciach. Prevažná časť referátov je zahrnutá do tohto čísla časopisu Mineralia slovaca.

V mene pracovných skupín 2.1 a 2.2 si dovoľujeme vysloviť poďakovanie vydavateľovi časoposu, jeho redakčnej rade a v neposlednom rade aj pracovníkom redakcie za zaradenie materiálov sympózia a ich prípravu do jedného čísla časopisu. Naša vďaka je o to úprimnejšia, že materiály sympózia vychádzajú v maximálne možnom krátkom termíne po konaní sympózia.

D. Hovorka



Účastníci sympózia pri výklade o geologickej stavbe zóny „blueschist" vo vnútorných Západných Karpatoch
Participants of the Symposium attending the explanation on the geology of the blueschist-zone in the Internal Western Carpathians



Účastníci sympózia pri štúdiu komplexu „blueschistu"
Participants of the Symposium examining an outcrop of blueschists

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Problem of the jadeite rocks, associating with ophiolites

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(5 figures and 1 table in the text)
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Problem of the jadeite rocks, associating with ophiolites

The importance of jadeite rocks as an indicator of high pressure in the Earth's crust was outlined by Sobolev. Jadeite is characteristic mineral of some glaucophane schist but pure jadeitite occurs only in serpentinite melange. In the Borus mélange (West Sayan) the origin of jadeitites during metasomatic alteration of eclogites was established (Figs. 1—3). Glaucophane schists with jadeitic pyroxenes were found as tectonic sheets at the base of ophiolite nappes or as zonal formations overlained by ophiolite nappes. They are examplified from Ural ophiolitic belts (Fig. 4). The jadeite-bearing glaucophane formation with essential over-pressure during metamosrphism (Fig. 5) may correspond to a specific version of the "contact metamorphism" under ophiolite plate with special fluid over-pressure regime.

The jadeite problem has almost simultaneously been outlined by V. S. Sobolev (1949, 1953, 1960) and H. S. Yoder (1950) in the 50-ies. H. S. Yoder concluded that only specific chemical or kinetic conditions are necessary for the jadeite origin and that "from the pressure one must take away cover of its mystical might". Sobolev suggested to use jadeite as a mineralogical indicator for the high pressures in the earth's crust. For the base of this conclusion Sobolev took the common crystallochemical rule that the change of Al from the fourfold co-ordination (in the albite and nepheline) into the sixfold one (in jadeite) takes place with the pressures increasing. On the basis of the preliminary thermodynamic calculations, he estimated that at $T = 600\,^{\circ}C$ this transition had to occur with the pressure over 7 kbars. Moreover, for the explanation of finding of the jadeite-bearing rocks at the moderate depths, V. S. Sobolev suggested that they were formed under the pressures exceeding the load pressure.

In different years, the author studied the jadeite-bearing rocks in the ultramafics (Dobretsov, 1962, 1963, 1964) and the jadeite-bearing glaucophane schists (Dobretsov, 1974; Dobretsov et al., 1973, 1979). This time the indicator role of jadeite is evidenced in particular, by numerous

experimental data (Kushiro, 1966; Currie — Curtis, 1976 et al.), refining the stability field of jadeite-bearing associations. Main difficulties arose in connection with relevant geological-petrological models to explain these high pressures. Just these difficulties led many investigators to the negation of the special role of the high pressure and to attempts to explain the formation of jadeite and glaucophane schists only by the geochemical factors (Marakushev, 1965; 1973; Gresens, 1969 et al.). From these positions, the relation of the jadeitic rocks and glaucophane schists with large overthrusts and the special role of the tectonic factor remained unnoticed or not explained, as it was underlined by authors (Dobretsov, 1963, 1964, 1974).

In the last 10—15 years, in connection with the development of the new global tectonics (or plate tectonics) it became universally recognized that the jadeite-bearing rocks, both the inclusions in the ultrabasites and the glaucophane schists, are indicators of specific tectonic processes such as subduction or obduction of oceanic plate on the active continental margins (Ernst, 1970). They are closely connected with the processes of the tectonic transportation of the ophiolites — sheets of ancient oceanic crust, and they are one of the important instruments of the reconstruction of geodynamic conditions (Dobretsov, 1979).

It became clear that the jadeite bodies in the ultrabasites are connected with definite type zones of serpentinite mélange, fixing abyssal thrusts of the ophiolite sheets. The bodies of jadeitites eclogites, glaucophane schists in such mélange present xenoliths of deep-seated rocks, entrapped in the tectonic transportation of the ophiolites. Probably, hole sheets (of) thickness from 100 m up to 1—2 km) consisting of glaucophane schists in the foot of ophiolite nappes (for example, around the western Pacific) play similar role. Finally, author (Dobretsov, 1979) tried to connect the genesis of California type belts of jadeite-bearing glaucophane schists with the model of multiphase obduction of island arcs rocks on oceanic plate margins. Within continental blocks tectonic zones of abyssal thrust were revealed which contain bodies of mantle eclogites and pyrope peridotites. Well known inclusions of the above-mentioned rocks in Central European crystalline massifs (i. e. Bohemian massif, Granulitegebirge, Sov'i Mts. and others), are receiving such interpretation (Dobretsov, 1982; Dobretsov et al., 1984).

Let us consider the evidences of these relations on the example of some jadeite-bearing complexes, studied by the author, and first of all those of them which are closely connected with the ophiolites. All the considered examples are related to the Urals — Mongolian folded system where the ophiolites and associated jadeite and glaucophane rocks are Riphean or Early Paleozoic in age (Dobretsov, 1974).

In the West Sayan Mts. two such ophiolite zones are known (Fig. 1) — (1) the Borus one, with jadeite-bearing rocks and eclogites in the serpentinite mélange, and (2) the Kurtushibin zone where a large ophiolite nappe is underlain by a mélange zone with eclogites inclusions as well as an independent sheet of jadeite bearing glaucophane schists.

The Borus zone is of complex imbricate structure. The zones of the serpentinite mélange of two types (Dobretsov, Tatarinov, 1983) were distinguished at the foot of large sheets. Jadeite rocks bodies described here previously (Dobretsov, 1963; Yudin, 1963) are associated, as it has been established, only with the mélange of the 1st type underlying the upper ultrabasite sheet with signs of the

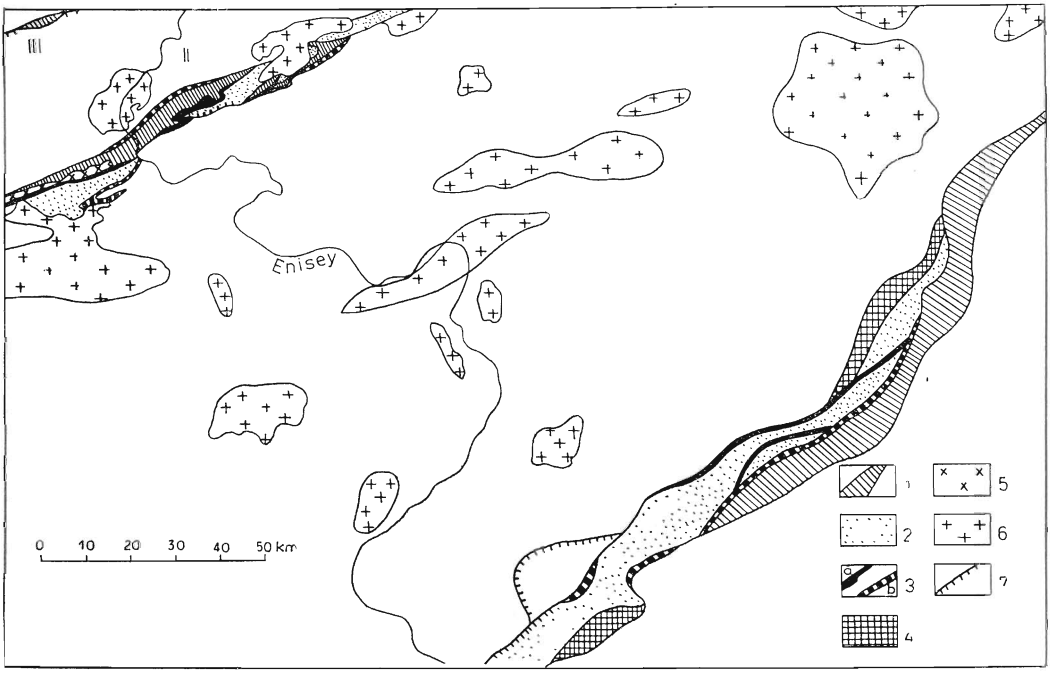


Fig. 1. Ophiolite belts of West Sayan (I Kurtushibin, II — Borus, III — North Sayan). 1 — ophiolites (ultramafics, gabbro, diabases), 2 — basalts and sediments, including olistostrom, 3 — I type melange with inclusions of eclogites, jadeite rocks and glaucophane schists (a), II type melange (b), 4 — glaucophane schists, 5 — diorite-plagiogranites, 6 — Paleozoic granites, 7 — overthrusts (without melange)

most continuous transportation. The strip of serpentinite schists with jadeite bodies in the middle part of the Kantegir river valley is an example of the mélange of the 1st type. It dips at 35—40° under the main ultrabasite body of the Borus range. The schistosity in the serpentinites is of the same orientation. The jadeitite and apojadeite-albitite bodies are of rounded shape and contain (1) relics of early high-temperature margins, torn off during the tectonic transportation, and (2) irregularly-developed low-temperature fringes, illustrating late reactions of the albitized jadeitites with the surrounding serpentinites. Both in the margins and in the body (itself) several stages can be outlined in the transformation of the primary coarse-grained jadeitites and the margins with diopside-jadeite and hornblende into the low-temperature associations with albite, analcime, late (frequently aegirine or jureite-bearing) diopside-jadeite, actinolite, mica, chlorite. Not long ago in a mélange zone in the south — western part of the Borus belt eclogite bodies were found (Fig. 2), which change into diopside-jadeite margin in the marginal part and are surrounded with small jadeitite bodies representing, seemingly, outer zone of the same those. These immediately-observed transitions prove that the jadeite rocks were formed during the metasomatism of the eclogites and are isofacial with them. In the central part of the Borus range jadeite-bearing albitite bodies were observed (with jadeite, aegirine-augite and quartz), which had originated at the ex-

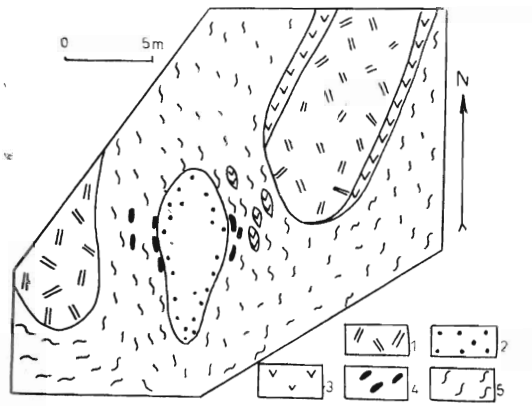


Fig. 2. The inclusions of eclogites and jadeitic rocks in the Borus melange. 1 — mica and albite-mica rocks; 2 — eclogites, 3 — garnet amphibolites, 4 — jadeite rocks, 5 — serpentinite schists

pense of acid dikes during one of the stages of the tectonic movements and the following metasomatism. The intrusion of the dikes, their metasomatism, the associations of the rocks, their relation with the serpentinites allow to distinguish at least 4 stages of tectogenetic processes and of regressive transformation of the abyssal xenoliths (table 1).

At all stages of the metasomatism mineral facies of higher alkality are characteristic with apo-eclogictic jadeitites (possibly, with nepheline admixture) at the expense of the eclogites (stage 1), aegirine-bearing or jureite-bearing jadeite, Na-amphibole, cancrinite (stage 2), aegirine-augite or chloromelanite, Na-amphibole, analcite, natrolite, schizolite (the stages 3 and 4). Rocks of normal alkalinity (eclogites, garnet amphibolites, epidote albitites, actinolitites etc.) coexist side by side with them.

The interaction with the magnesian medium of the filtrating solutions of normal alkalinity is contributed to the alkalies increasing as it was established previously (Dobretsov, 1964). Probably, solutions were generated from the buried sea waters and added from the continental "enclosing rock" at the stages II—IV. the K_2O and K_2O increasing, similar to the alkaline facies of the magnesian skarns (after Zharikov), took an additional effect in the last case. The higher pressure influenced only the specific mineral composition of the metasomatites as well as the higher solubility of Na-Al, Na-Cr, Na-Fe minerals (jadeite, juriite, aegirine, Na-amphibole, albite). For that reason, as well as, probably, because of the somewhat different composition of the solutions, in the mélange of the 2nd type, alkaline metasomatites are not typical, and slightly modified rocks (metagabbro, metabasalts, schists) and Ca-metasomatites (rodingites, nephrites) predominate being characterized also by very low potential of CO_2. It corresponds to the brucite appearance in the serpentinite mass of the 2nd type mélange in comparision to carbonates, usual in the mélange of the 1st type.

The variation of the conditions of the rock transformation specified the diversity of the mineral composition in the metasomatites and the combination of several stages in the same body. It is related not alone to the change of the secondary minerals (cancrinite, analcime, various Na-amphiboles, zeolites, rare sulphides and arsenides) but first of all to the variation of the jadeite pyroxene composition. As is seen from Fig. 3, the compositions of the pyroxenes include practically all the fields of the $NaAlSi_2O_6$ — $Na(Cr, Fe^{+3})Si_2O_6$ — — $Ca(Mg, Fe)Si_2O_6$ system. For the stage I the pyroxenes of the series jadeite-diopside-jadeite-omphacite are typical, being characterized by the small content of NaFe- and NaCr-components and some immiscibility between jadeite and diopside-jadeite. This immiscibility is due to the different structure of ordered diopside-jadeite (P/n unlike C/2n in jadeite) and

Stages of the jadeitites transformation

Table 1

Stage:	Facies:	Main mineral:	Valuation: T °C:	Valuation: P, kbars:	Tectonics:
I	Eclogitic	C/s jd + di — jd ± hrb, phl; omph + gr + hrb + rut.	600	10	Abyssal thrusts (subductions?)
II	Garnet-glaucophane and epidote-amphibolite	Aeg — di — jd, Cr — jd + ab + mc ± Na — amph, can; Na — hrb + gr + pl ± ± ep, sph.	550	8—10	1st stage moderate-abyssal trusts (obduction?) Intrusion of acid dykes
III	Green schist (and transitional)	Ab + Aeg — aug + + Anc + mc ± Na — — amph, schizolite; Ab + Ep + Na — — act + mc + sph	a) 400 b) 400	8—10 3—6	Main stage of mélange. Near-surface thrusts, main serpentinization.
IV	Low-temperature metasomatites	Ab + Aeg — jd + Na — — amph + anc ± ± natrolite, ± qz, Ab + anc, Ab + chl + carb	200—300	3—8	Repeated thrusts (mélange of the IInd type) The interaction with enclosing rocks.

Adopted abbreviations in the table and the text: Ab — albite, act — actinolite, aeg — aegirine, amph — amphibole, aug — augite, anc — analcite, gr — garnet, di — diopside, di-jd — diopside-jadeite, jd — jadeite, can — cancrinite, qz — quartz, omph — omphacite, pl — plagioclase, hrb — hornblende, rut — rutile, mc — white mica, sph — sphene, phl — phlogopite, ep — epidote.

depends on the high T, P, the kinetics of the crystallization, the NaFe and NaCr content (Dobretsov, 1962; Dobretsov et al., 1971; Carpenter, 1981). This immiscibility may disappear with increasing of temperature and Fe^{+3} — Cr content. At the first stage the oxygen potential and the interchange with the ultrabasites (the Cr supply) were not intensive. They sharply increase at the stage 2 where bright green pyroxenes of jadeitejurite or more rare aegirine-jadeite series appear in the bodies margins and veins. The latter are more typical for the stages III and IV whereas Cr enters mostly into Cr-chlorites or more rarely into Cr-bearing garnets and amphiboles. Similar regularities, as the formation of a wide range of aegirine-jadeite pyroxenes, are typical also for jadeite-bearing glaucophane schists (Essene, Fyfe, 1967; Dobretsov, 1974).

Temperature and pressure estimations presented in the table I and the Fig. 5, are made on the basis of mineral pairs such as gr-amph, gr-cpx, amph-cpx (Perchuk, 1970), data of jadeite-diopside-albite-quartz system (Kushiro, 1969; Currie, Curtis, 1976), and composition of white mica associating with albite and other Fe-Mg minerals (Dobretsov et al., 1976).

All the valuations of the rock generation and transformation in the 1st type mélange zones correspond to the oceanic geotherme. Most likely it means that all the stages of the abyssal thrusts occurred in the oceanic or intermediate environments, and the continental crust in which now the Borus ophiolite belt is situated, appeared only at the final stages due to thickening of the crust. Because of these stages (III and IV) in the 1st type mélange we observe the combination of the low and high pressure associations.

Rocks with glaucophane (stage III) and with aegirine-jadeite pyroxenes, analcite and zeolites including the association jad + anc + qz (the stage IV) are especially typical. One can suggest that the rocks with these associations are included at the stages III and IV from the underlying glaucophane schist zone, formed at the stages I—II. It is favourable from the availability of the jadeite-bearing glaucophane schist zone, at the foot of the ophiolite sheets of the related Kurtushibin belt (Fig. I). Here the 1st type mélange and glaucophane schist zones are also combined. In this mélange zone underlying the lowest sheet in the central part of the belt, inclusions of eclogites, garnet amphibolites, glaucophane schists are present, missing here "in situ". The mélange zones were not established at the periphery of the belt but large sheets of glaucophane schists are present here. A lawsonite-glaucophane and intermediate zone with jadeite-bearing rocks was mapped in the south Urbun area. (Petrologia..., 1979).

In the Polar Urals, a combination of glaucophane schists and 1st type mélange zones were recognized along the Main Urals thrust, dividing the myogeosynclinal belt of the western slope of the Urals and the ophiolite eugeosynclinal belt (Fig. 4).

In the massif Ray-Iz (Petrologia..., 1979; Kazak, 1980) at the foot of a large sheet-like ultrabasite body of more than 3 km in the thickness a mélange zone of the thickness over 100 m was recognized. Peridotites, pyrope pyroxenites, eclogites, jadeite rocks, vesuvianite, glaucophanites and other rodingites are present as inclu-

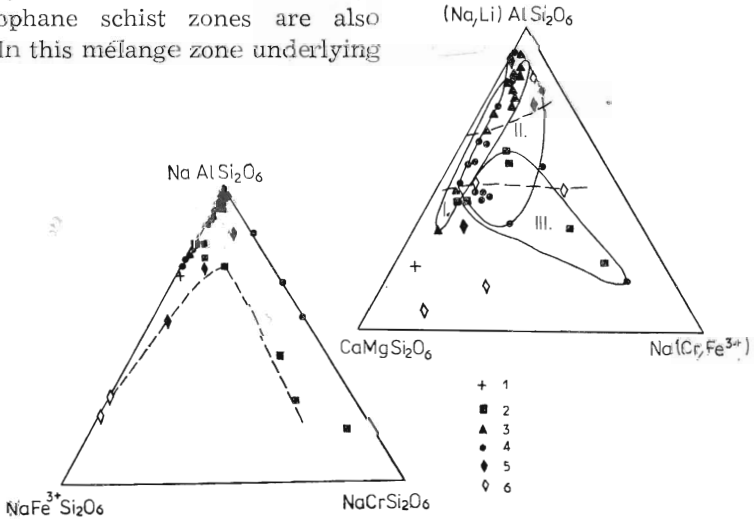


Fig. 3. Composition of jadeitic pyroxenes of the Borus melange Rocks: 1 — eclogites, 2 — jadeitic margins, 3 — jadeitites of 1st stage, 4 — jadeitic rocks and rims of 2nd stage, 5 — albites and (6) metasomatic rocks of 3rd stage (see Table 1)

sions in the mélange. 200 m-thickness separate sheets of glaucophane schists (below) and chloromelanite rocks are present above the mélange zone.

In the ophiolite massif Voikar-Synya glaucophane-jadeite rocks situated to the south the latter (Fig. 4A) are present at the foot of its western overturned part. Glaucophane and garnet-chloromelanite (eclogitic) rocks are formed at the cost of diabases and gabbros of an ophiolitic section including a change of anogabbroic blastomylonites (Petrology . . ., 1979; Lennykh et al., 1976). These rocks are tectonically boudinaged during the latest movements. The mélange zone with the inclusions of jadeitities, albitites garnet amphibolites is distinguished to the east, inside the ultrabasites of this massif. This zone and the jadeitites themselves are very similar to the above-discussed mélange zone of the 1st type of the Borus belt (Dobretsov, 1964, 1974).

The Salatin zone (Kozak, 1980) represents essentially a mélange-olistostrome zone. The serpentinite mélange bodies measuring from hundreds of meters up to 25 km^2 are included into the rock mass of the graphitic schists and quartzites. The ophiolites, dunites-harzburgites, gabbro-diabases bodies as well as these of eclogites, eclogite-like rocks, jadeitites, nephrites, rodingites are included in the serpentinite mélange but the glaucophane schists are absent. From the west this zone limits the green-stone rock masses of the Tagil synclinorium with dunite-pyroxenite-gabbroic bodies of the so-called platinum-bearing formation. Their attribution to the ophiolites is disputable but the bodies in the Salatim zone represent certainly the members of an ophiolitic as-

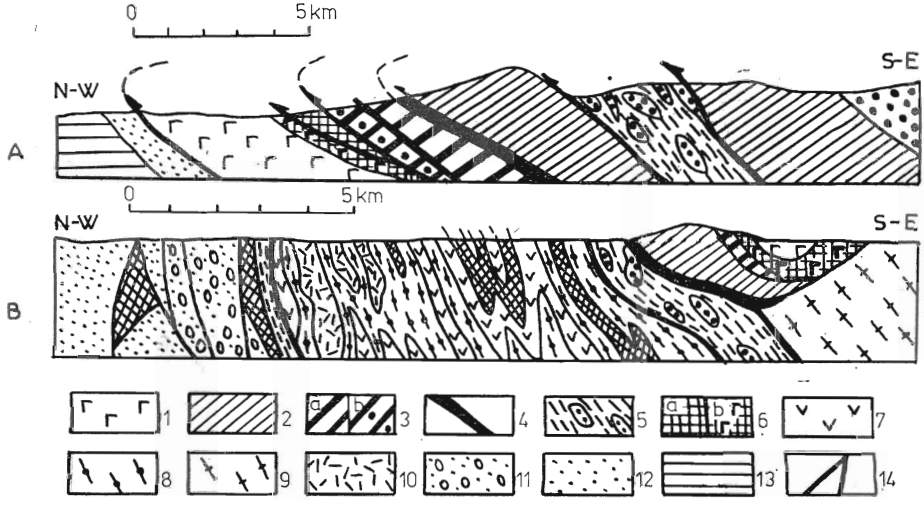


Fig. 4. Cross-section of Polar Ural glaucophane-ophiolite belts: Voikar-Synyk (A) and Syum-Ken (B). 1 — metabasalts and black schists, 2 — ultramafics, 3 — gabbro and diabases (a) and glaucophanized gabbro (b), 4 — serpentinitic melange, 5 — melange (at Fig. A) and blastomylonites (at Fig. B) with inclusions of metaperidotite, eclogite and jadeite rocks, 6 — glaucophane metadiabases (a) and glaucophane-lawsonite metabasalt, 7 — amphibolites with rare glaucophane, 8 — mica schists, 9 — gneisses with amphibolite and eclogite bodies, 10 — granito-gneiss olistoliths, 11 — metaconglomerates, 12 — metasandstones and quartzites, 13 — nonmetamorphosed Paleozoic sediments, 14 — faults

sociation. The mélange-olistostrome zone is evidently underlain by a zone of the glaucophane schists 2,5 km wide which changes little by little into the metavolcanogene green schists to the west.

In all above-described cases in the mélange were mainly present the more abyssal rocks (eclogites, jadeitites, garnet amphibolites), than the underlying glaucophane schists but those and others, as we saw in the example of the Borus belt, are united by the common oceanic geotherme and evidently characterize the different depth sections (and in some cases, and the different formation stages) of the common zone of the overthrusts characterizing a multistage obduction.

This multistage is the most brightly discovered in the zones of the California type with the jadeite-bearing glaucophane schists. The Maksyutov complex in the South Urals is an example of such types of zones. Here the situation is other than in the above-described cases (Dobretsov, 1974; Lennykh, 1977). Evidently, the Maksyutov complex presents a fragment of the more ancient basement, moved upon together with the underlying plates of the

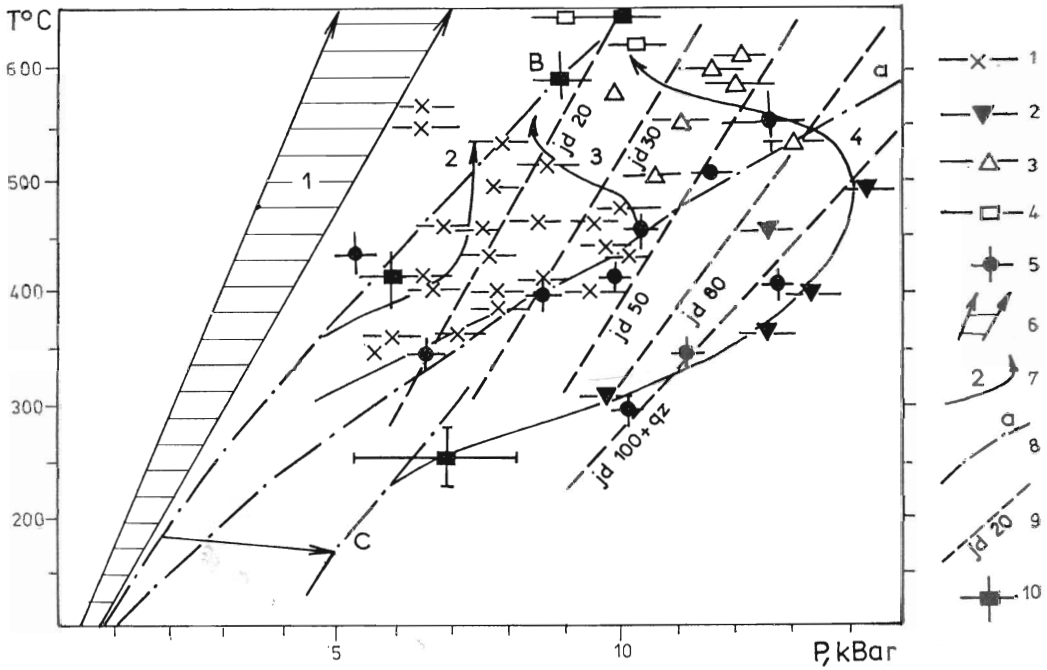


Fig. 5. P-T conditions of the formation of jadeite rocks, glaucophane schists and eclogites. 1—4 — average and limit origin conditions of glaucophane complexes (1), quartz-jadeite-bearing rocks (2), eclogites from glaucophane schists (3), eclogites from gneiss (4), 5 — some estimations from Alps, California, New Caledonia, Oregon with use of the oxygen isotope determinations (Brown, O'Neil, 1982; Dobretsov, 1974), 6 — interval of the usual greenschist and prehnite-pumpellyite metamorphism, 7 — curves of P-T evolution of the different types of metamorphism (2 — glaucophane-greenschist, 3 — lawsonite-glaucophane, 4 — jadeite-glaucophane), 8 — geothermes of the Precambrian shields (a), oceans (b) and geothermes in the subducted plates with fluid over-pressure (c), 9 — isolines of jadeite content in pyroxenes with albite and quartz, 10 — P-T conditions of rocks from the Borus melange

ophiolites to the east, to the green stone rock masses of the Magnitogorsk synclinorium and overlapped by the nappe of the green schists of the Suvanyak complex (species-the Lower Paleozoic ?). This plate is similar to the complex Seziya-Lanza in the Alps on his tectonic position, the composition of the rocks (the predominance of the acid rocks including the greywackes and arkoses) and on the maximum pressures obtained in the complexes of the glaucophane schist type. They are fixed on the mineral associations of the type 1) jad 90—100 + qz + alm + paragonite + + sch; 2) laws + alm + omph; 3) jad 80—100 + qz + glauc + sch. The association I is the most interesting in which the analyzed jadeite is very clear in the centre and is enriched in aegirine and diopsid (up to 10—15 %) only in the margins during diaphthoresis. These associations and the peculiarities of the composition of the minerals in the eclogites correspond to T = 500—550 °C, P = 14—15 kbars (Dobretsov, Sobolev, 1975; Dobretsov, 1974).

Combination of the California type jadeite-bearing glaucophane schist mélange and blastomylonite zone at the foot of ophiolite nappe can be seen at the northern part of Polar Ural near ultramafic Syum-Keu (fig. 4 B). Here from the SE to NW the following complexes are exposed: 1) basalts and metabasalts with lawsonite and glaucophane; 2) ophiolites plate (diabase, gabbro, ultramafic), 3) mélange; 4) blastomylonite zone with inclusions of eclogites and glaucophanites; 5) the jadeite-bearing glaucophane schist complex similar to Maksutov one; 6) metamorphosed olistostrom with olistolith of altered granites.

The lines of evolution of P-T conditions of glaucophane schists and jadeite rocks are drawn at Fig. 5. The line 2 (fig. 5) corresponding to glaucophane green schist metamorphism and jadeite rocks in ultramafics is close to the oceanic geotherme with the small surplus of pressure. The line 3 corresponding to lawsonite-glaucophane metamorphic rocks (with jadeite pyroxenes and quartz) is characterized by the essential overpressure. The line 4 with maximal overpressure corresponds to the eclogite-glaucophane complex of Californian type, containing jadeite-quartz association. The nature of this overpressure was explained by the combined tectonic model (Dobretsov, 1979, 1981).

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The Letovice dismembered metaophiolites in the framework of the Saxo-Thuringian zone of the Bohemian massif

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Разделённые метаофиолиты летовицкого кристалиника в строении саско-дуринской зоны Ческого масива

В кристалическом масиве района Летовице находятся нижние ультраосновные породы (тектониты), породы кумулативного комплекса, основные вулканиты и очень неравномерно породы жильного типа. Считаем их за метаморфованные члены разделенного класического офиолитового комплекса. Степень их региональной перемены переходит из фации зелёных сланцев до амфиболитовой фации. Геотектонические верхнепротерозойские летовицкие метаофиолиты являются частей саско-дуринской зоны среднеевропейских герцинид (варисцид). Могут сравниваться с породами марианско-лазенского комплекса, с офиолитами центрального саского линеамента, с метабазитами и ультрабазитами старомеcтского гнейсового пояса и с офиолитами на периферии Сових гор. Указанные офиолитовые комплексы возникли в геотектонической среде окрайового моря саско-дуринской зоны особенно в местах глубинных разломов.

The Letovice dismembered metaophiolites in the framework of the Saxo-Thuringian zone of the Bohemian massif

New geological and geochemical data are presented for basic and ultrabasic rocks of the Letovice crystalline complex. Lower ultrabasic rocks, cumulate rocks, basic volcanics and local basic dykes represent a dismembered ophiolite suite metamorphosed under conditions of amphibolite and greenschists facies. The geochemical features and differentiation trend correspond with those of other ophiolite complexes (e. g. Pindos, Bay of Island, Troodos, Oman, Papua etc.). Geotectonically, the Upper Proterozoic Letovice metaophiolites are a part of the Upper Proterozoic structural level of the Saxo-Thuringian subzone of the Hercynian (Variscan) fold belt. They are comparable with the Mariánské Lázně basic complex, with the ophiolites along the Central Saxonian Lineament, with the Staré Město ophiolite belt and the ophiolite complex at the border of the Sowie Góry Mts. All these ophiolite complexes could be formed in a marginal sea environment, following

internal rift depressions inside the Saxo-Thuringian zone. Considerable thinning of the Earth's crust, formation of a new ocean floor and deep faults are the most characteristic features of these depressions.

In the classical zoning of the Central European Hercynides, the Letovice crystalline complex belongs to the Saxo-Thuringian zone which is bordered by Moldanubian zone in the S and by Central German Crystalline Rise in the N (Fig. 1). All these three zones together with the Rheno-Hercynian zone are pinched together in the Moravian-Silesian fault zone (lineament) which may represent an important deep fault along the continental margin active in the Cadomian and Hercynian geotectonic cycles.

The tectonic development of the Saxo-Thuringian zone seems to be clearer from the time of the Hercynian than of the Cadomian geotectonic cycle. Paleozoic sediments unconformably cover the Proterozoic basement with geosynclinal sediments and volcanics (Barrandian basin). If metamorphosed they still differ quite distinctly from all Proterozoic sediments and volcanics in other parts of the Saxo-Thuringian zone (Erzgebirge). The Paleozoic formations do not contain any real ophiolites.

However, many metamorphosed basic and ultrabasic rocks can be found in the Pre-Hercynian structural level. Some of them are considered to be members of the classical ophiolite suite e. g. basic and ultrabasic rocks of the Mariánské Lázně complex, Letovice complex, Staré Město complex (Mísař et al., in press), other belong to the Upper Proterozoic volcano-sedimentary formation with spilites. Geosynclinal spilites together with graywackes and laminated shales, form a substantial part of the Central Bohemian Region (Fig. 1). The Upper Proterozoic age of some metamorphosed basic volcanics is documented by K/Ar isotope data in hornblende from the Mariánské Lázně complex (Gottstein, 1970). C. D. Werner (1981) mentions a transgression of Vendian conglomerates over metaophiolite in the area of the Saxonian granulite Mts.

During the past decade increased attention has been devoted to ophiolite complexes present in the continental crust. Classic ophiolites defined by G. Steinman (1927) commonly occur in alpine orogenic belts. Their age is mostly Jurassic to Cretaceous. Some older ophiolites were described in Hercynian belts e. g. the Ural or Tchien-Shan Mts., or in the Caledonian belts in Scotland, Norway, New Foundland, Mongolia etc. Pre-Cambrian ophiolites are relatively rare. There were described in the Panafrican orogenic belt by R. Black (1980) or in the Bajkal orogenic belt by N. L. Dobretsov (1982). The sequence of ultrabasic and basic metamorphosed rocks from the Cadomian basement of the Armoric massif could also be regarded as Pre-Cambrian metaophiolites.

Field relations of the Letovice crystalline complex

The Letovice crystalline complex is located at the most eastern part of the Saxo-Thuringian zone where this approaches the Moravian-Silesian fault zone. The complex consists of mica schists, gneisses, metaquartzites (metalydites), amphibolites, metagabbros and metamorphosed ultrabasic rocks. The basic and ultrabasic rocks of the Letovice complex

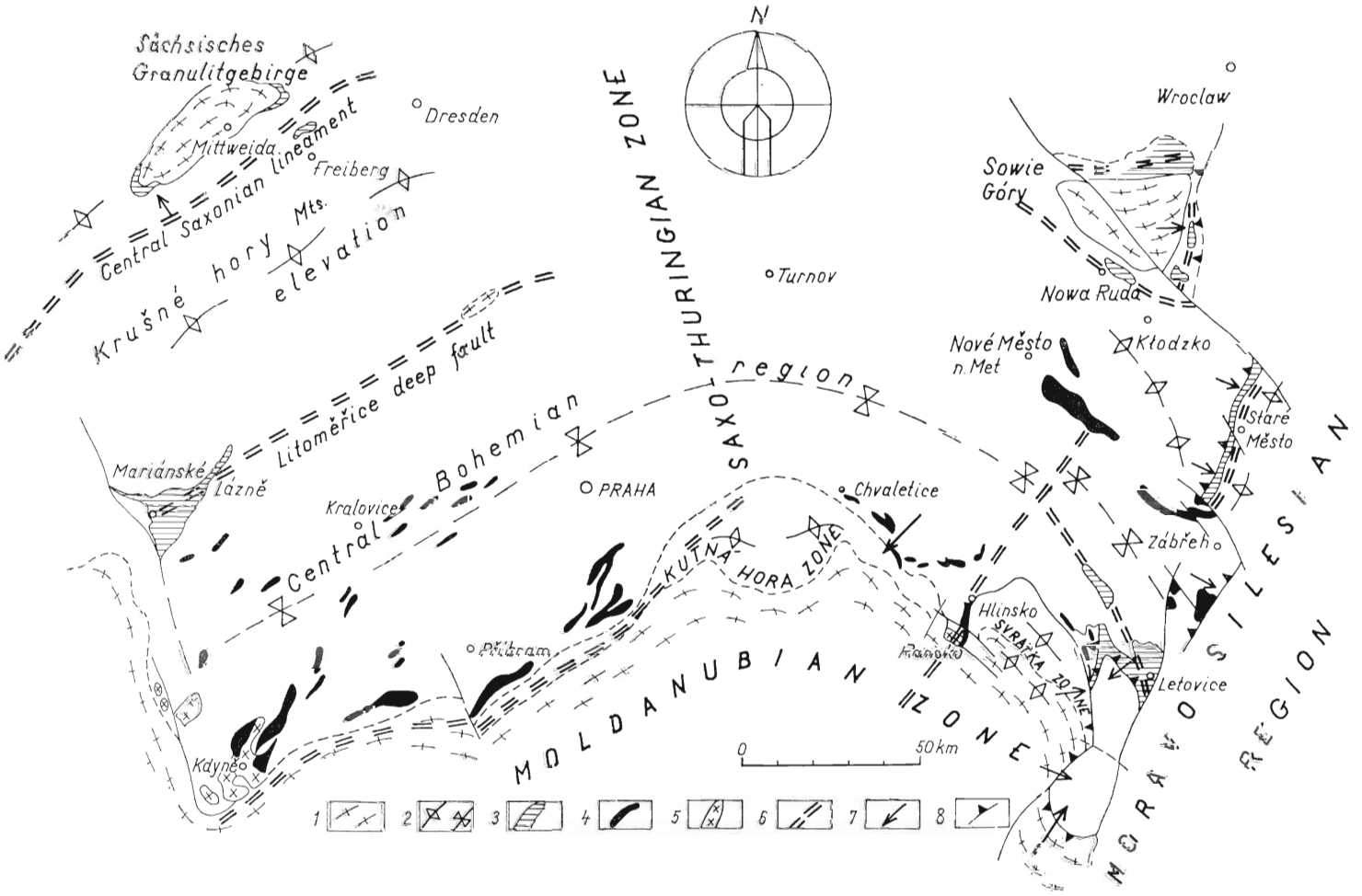


Fig. 1. Outline structural map with the distribution of Upper Proterozoic ophiolites and basic initialites in the Saxo-Thuringian zone of the Bohemian massif. 1 — Moldanubian region, 2 — axes of megastructures, 3 — Upper Proterozoic ophiolites, 4 — Upper Proterozoic basic volcanics and keratophyres, 5 — gabbro--periodite massifs, 6 — deep faults, 7 — direction of tectonic movements, 8 — Moravian-Silesian fracture zone

are a part of the Moravian-Silesian ophiolite belt (Mísař, 1979). Metasediments represent of about 30 per cent, amphibolites 30 per cent, metagabbros 30 per cent and ultramafic rocks about 10 per cent of the Letovice complex.

Z. Roth (1941) supposed the Letovice complex to be a large laccolith which had undergone gravity differentiation in situ. Diabases form the margin of the complex and ultramafic rocks the centre. J. Svoboda and V. Zoubek (1950) tried to compare the metabasite of the Letovice complex with the Upper Proterozoic spilites in the Barrandian area. The ultramafic bodies, amphibolites and mica schists have the same structural history.

Recently, D. R. Bowes et al. (1978, 1980) described the polyphase deformation of the Letovice amphibolites with dominant F_3 folds. Although the Letovice crystalline complex and the Moravian complex are in tectonic contact, they still have a comparable structural imprint for at least part of their history (Bowes et al., 1980).

Although the Letovice crystalline complex is overlain by a cover of Permian and Upper Cretaceous sediments, its amphibolites and ultrabasic rocks can be followed further to the NW to Svitavy using the gravimetry. Here, an ultrabasic body with dimension of about 10×0,5 km has been found by drilling.

The fundamental megastructures of the

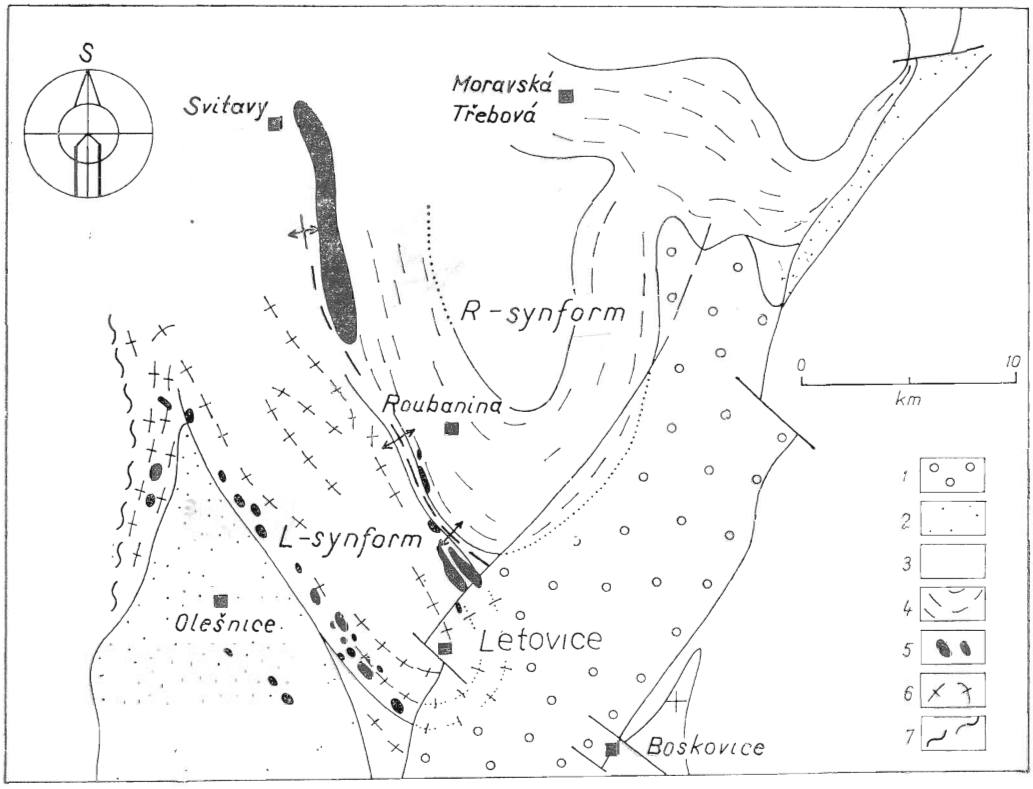


Fig. 2. Structural scheme of the Letovice crystalline complex. 1 — Permian sediments of the Boskovice furrow, 2 — Moravian metamorphic complex, 3 — mica schists and gneisses, 4 — amphibolites, 5 — ultrabasic rocks, 6 — megastructures as indicated by magnetic and gravity anomalies, 7 — mylonites

Letovice unit consists of two main synforms (Fig. 2): first is called the Letovice synform (= L-synform), the second, the Roubanina synform (= R-synform). The L-synform represents the leading megastructures of the Letovice complex exposed. To the west it joints the brachyanticlinal closure of the Moravian mica schist zone. The L-synform also closes near the deep fault zone of the Boskovice furrow. The internal dominating fold structures of the L-synform coincides perfectly with the corresponding dominating structures described in detail at the Bohuňov locality by D. R. Bowes et al. (1978).

The L-synform is separated from the R-synform by a narrow crest consisting of mica schists and quartzitic schists. Some NW—SE faults and mylonite belts also follow the boundary between both synforms.

The R-synform may be considered as a marginal structure of a large scale synform formed of Upper Proterozoic flysch-like sediments and basic volcanics (Fig. 2). Both rocks types, together with ultrabasic rocks and gabbros, are the main constituents of the R-synform.

Petrology of the Letovice crystalline complex

The petrological description of the rocks is mostly concerned with metamorphosed basic and ultrabasic rocks of the Letovice crystalline complex.

Ultrabasic rocks of several separated allochthonous bodies are situated at the boundaries between amphibolite and mica schists or are completely surrounded by amphibolites. The ultrabasic bodies are lenticular or slab-like with developed reaction zones at the contact with the country rocks. The largest exposed ultrabasic body is 1 km × 0,6 km in size.

There are some differences between the ultramafic rocks of the L- and R-synforms. The ultrabasic rocks of the L-synform are mostly serpentinites and strongly serpentinized peridotites, always with abundant spinel. The ultrabasic rocks of the R-synform are serpentinized peridotites, plagioclase peridotites and pyroxenites. The difference between two types of ultrabasic rocks may be also followed in the content and character of serpentine minerals (Fig. 3).

Some significant geochemical differences are observed between ultrabasic rocks of the R- and L-synforms. The concentration of alumina, calcium, titanium and vanadium is higher in the ultrabasic rocks of

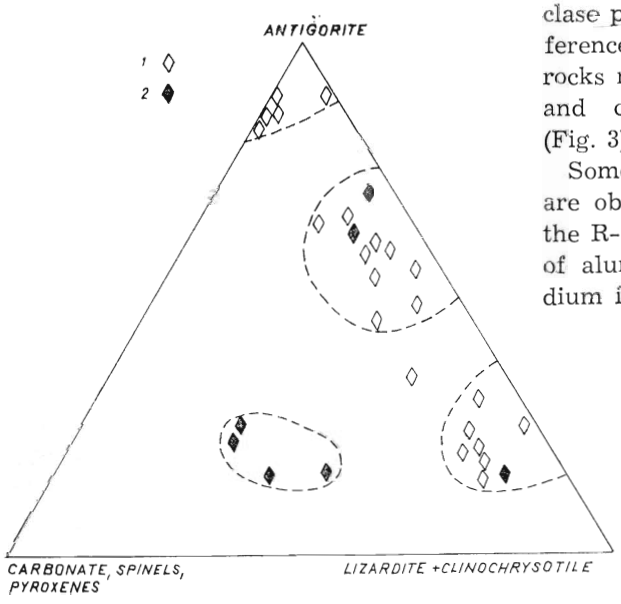


Fig. 3. Mineral content of Letovice ultrabasic rocks in a triangle antigorite — carbonate + spinel + pyroxene — lizardite + clinochrysotile. Mineral identification by differential thermal analyses-weight %. 1 — L-synform utrabasic rocks, 2 — R-synform ultrabasic rocks

the R-synform. This is mostly due to the presence of olivine cumulates and of pyroxene crystals in these rocks. The FeO^{tot}/MgO ratio is also different for the two rock groups.

According to the petrological and chemical character of the ultrabasic rocks of the L-synform these rocks are very similar to the lower ultrabasic rocks of any classical ophiolite suite. On the other hand, the ultrabasic rocks of the R-synform are reminiscent of cumulate ultrabasic rocks.

Metagabbros can be found in both synforms of the Letovice crystalline complex. However, they are more common in the R-synform where separate gabbroic bands (differing in composition and structures) can be mapped inside a larger gabbro body. From the geological and petrological point of view, the gabbro complex of the R-synform is strongly resembled of the layered gabbro complex of a typical ophiolite suite.

In spite of strong deformation the hornblende gabbro of the R-synform, it still contains visible relics of primary texture with larger crystals of hornblende and plagioclase.

The lowest members of the layered gabbro complex may be correlated with some horizons of the layered ultrabasic zone of the classical ophiolite sequence. This is reflected in the presence of cumulate olivine gabbro, troctolite and plagioclase-bearing peridotite and/or bands of dunite that are extremely rich in magnesium. The cumulate texture of these rocks with oval olivine and interstitial plagioclase and pyroxene is further evidence for this assumption. A peculiar rock type of the layered gabbro complex of the R-synform is "vesicular" peridotite in which lenses or spheres in the serpentine matrix are filled with talc. Geologicaly "vesicular" peridotite alternates in bands with pyroxenite.

A thin dyke of fine-grained diabas was found at only one place in the R-synform.

Metagabbros also occur in the L-synform. Here, they are very strongly sheared and metamorphosed under amphibolite metamorphic facies. The primary rock was very coarse-grained hornblende gabbro. Unfortunately, the relationship of gabbro to massive amphibolite in the L-synform is not sufficiently clear. However, D. R. Bowes et al. (1980) have described a fine-grained, basic dyke in coarse-grained metagabbro with a relic texture indicative of a plutonic origin.

Major and trace element chemistry were discussed in detail in the paper by E. Jelínek et al. (1984). Generally, the chemical criteria help to distinguish the gabbros of the R-synform from the gabbro of the L-synform. The L-synform gabbro has higher contents of Si, Fe, Na + K, and Ti compared with all types of gabbros of the R-synform. The chemistry of olivine gabbro is closely related to the chemistry of ultrabasic rocks of the R-synform (Fig. 4), characterized by a lower content of alkalines and lower Fe/Mg ratio compared with hornblende metagabbros. The enrichment of the olivine gabbro in Ni and Cr corresponds to a high degree with the higher content of these elements in ultramafic rocks of the R-synform.

Amphibolites are the most typical rocks of the Letovice crystalline complex. They form a substantial part of the L-synform. The lithology of the amphibolite bands is rather complex. Massive, fine grained, laminated and banded amphibolites can be distinguished. The amphibolite also differ in mineral assemblage. The most common amphibolites contain green hornblende and plagioclase. Others are richer in quartz, garnet, zoisite or epidote. Well-banded amphibolites and garnet

amphibolites represent good marker horizons in the north-western part of the L-synform.

The texture and metamorphic grade of amphibolites in both synforms seems to be different. Massive, fine-grained amphibolites and well-banded amphibolites and garnet amphibolites do not occur in the R-synform. Strongly sheared and metamorphosed gabbro with some relics of primary texture is also typical for the L-synform. Amphibolites of the R-synform are very fine-grained and finely laminated. Plagioclase and green hornblende classify these rocks as common amphibolites. The common amphibolites of both synforms seem generally to be identical. However, a small difference can be found in the magnesium content, which is higher in the amphibolites of the R-synform.

Garnet-epidote-zoisite amphibolites as a special variety of amphibolites of the L-synform are slightly enriched in Al, Ca and Mg and impoverished in alkalies, titanium and chromium.

Basic dykes are not very common elements in the amphibolites of either synform. In the R-synform at only one

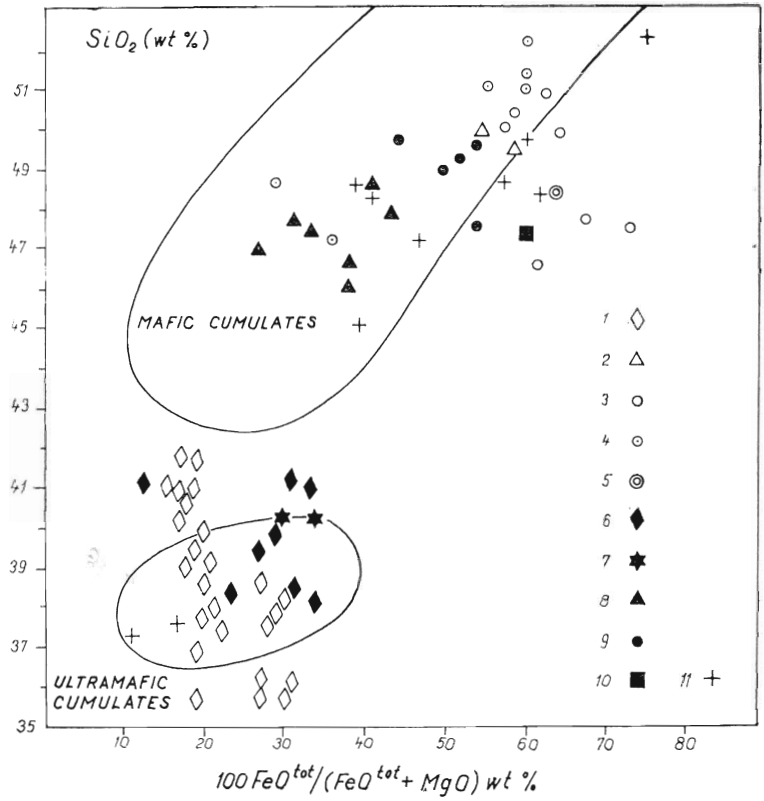


Fig. 4. Plot of SiO_2 versus 100 $FeO^{tot}/(FeO^{tot} + MgO)$ — Wt %. Rocks of the L-synform: 1 — ultramafic rock, 2 — gabbro, 3 — amphibolite, 4 — garnet (±zoisite) amphibolite, 5 — basic dyke. Rocks of the R-synform: 6 — ultramafic rock, 7 — olivine gabbro, 8 — hornblende gabbro, 9 — amphibolite, 10 — metadolerite. Others: 11 — ophiolite suite of Central Saxonian lineament according to C. D. Werner (1981). The field for ultramafic and mafic cumulates after R. C. Coleman (1977)

place, a small dyke has been found inside a layered metagabbro complex. The rock is fine to medium-grained with typical ophitic texture. Hornblende and plagioclase are the two main components. The chemistry of this rock (diabase) exhibits a marked contrast to all the gabbros and amphibolites described. The rock is extremely rich in Ti and Fe and very poor in Ni and Cr.

A thin basic dyke younger than the key fold structure F_3 was also found in metagabbros in the south-eastern part of the L-synform (Bowes et al., 1980). The dyke rock is black, very fine-grained and consists of hornblende and plagioclase. The preserved texture is microgabbroic.

Mostly monomineral rocks found at contacts between ultrabasic rocks and country rocks can be simply described as actinolitites, tremolitites, talc schists etc. A "band" found in the serpentine body at Letovice is rather strange and consists of chlorite and chlorite + vermiculite, probably replacing the primary mineral assemblage of pyroxenite.

Geochemistry

The results of geochemical research on basic and ultrabasic rocks of the Letovice crystalline unit may help to determine if these rocks are comparable with some members of the classical ophiolite sequence. In addition, the geochemical character of the rocks is a good base for discussion of the geotectonic environment in which these rocks originated. There are various methods and plots for expression of the chemical character of rocks. Some diagrams generally used for ophiolites are discussed in this chapter.

The lower ultrabasic members of the classical ophiolite sequence are represented by the ultrabasic rocks of the L-synform. Their magnesium content is higher than in the ultrabasic rocks of the R-synform (Fig. 4). The cumulate phase of the ophiolite layered complex is represented by ultrabasic rocks and gabbro of the R-synform. The major element chemistry and abundance of trace elements (Ti, V, Ni, Cr) show a systematic variation with the degree of differentiation: the Ni and Cr contents decrease, whereas the Ti and V contents increase with increasing Fe/Mg ratio (Fig. 6). Similar differences between lower and cumulate ultrabasic rocks are clearly demonstrated by the AFM plot (Fig. 7).

The chemistry of the upper members of the ophiolite sequence yields more information than that of the lower ones. The SiO_2 versus FeO^{tot}/MgO plot and also the plot of SiO_2 versus Cr (Miyashiro, 1975) indicate that all the metabasic rocks (amphibolites and metagabbros) are tholeiitic (Fig. 5).

It seems to be more difficult to interpret the results of the chemistry of ophiolite complexes in terms of their tectonomagmatic and geotectonic position, especially when the type of volcanism is concerned. Most of the discrimination plots are constructed on the basis of data from recent volcanic regions. The reliability of these methods when applied to rocks regionally metamorphosed has, however, not been verified.

The chromium, nickel and vanadium contents and Fe/Mg ratio of metabasic rocks of the L- and R-synform correspond to the average contents of these components in ocean floor basalts (Fig. 6). The Cr and Ti content distinguishes fields of lower ultrabasic rocks of the L-synform (extremely depleted in Ti) and the field of the R-synform ultrabasic rocks belonging to the lower part of the cumulate complex. The metagabbros of the R-synform are very similar to cumulate types, whereas the gabbros of the L-synform differ

from them in a much higher content of titanium.

Correlation of the Letovice basic and ultrabasic rocks with corresponding rocks of some classical ophiolite sequences (Pindos-Greece, Troodos-Cyprus, Bay of Island-New Foundland, or Sarmiento-Chile) reveals similar differentiation trends in the AFM diagram (Fig. 7). The position of the ultrabasic rocks of the L-synform in the diagram with that of the ultrabasic rocks from New Foundland, Oman and Papua. The gabbros of the L-synform (the cumulate type) are also in a good agreement with the gabbros of these ophiolite complexes. Gabbros of the L-synform may correspond to upper gabbros of the Pindos ophiolite suite or to volcanic rocks of the

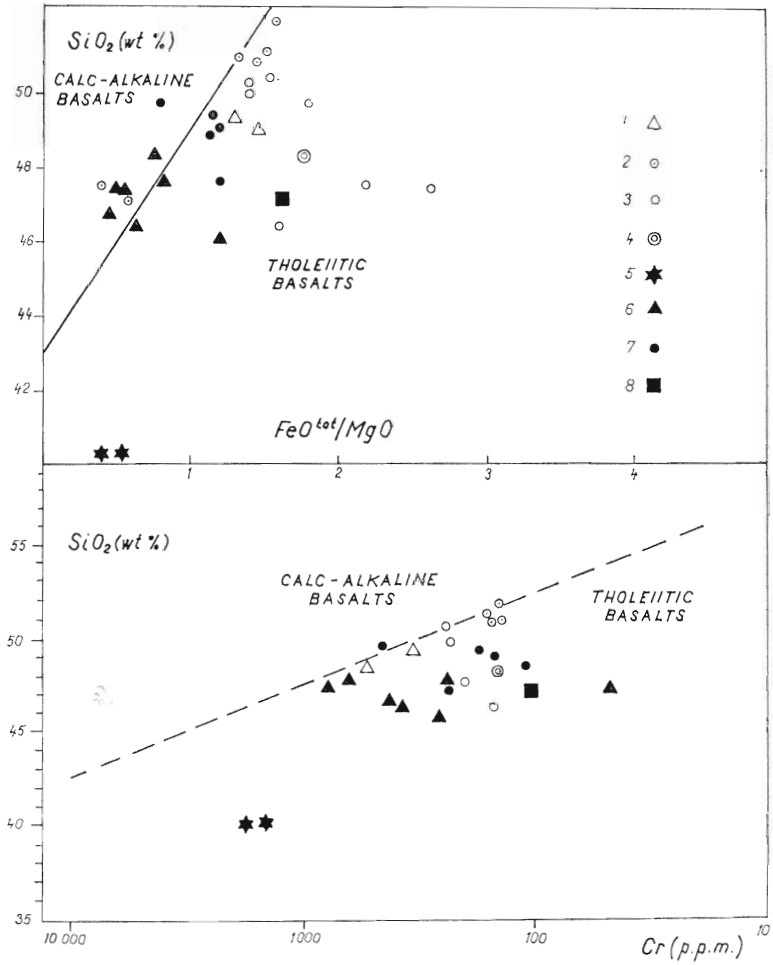


Fig. 5. The position of rocks of the Letovice complex in the diagrams of the L-synform: 1 — gabbro, 2 — amphibolite, 3 — garnet amphibolite, 4 — basic dyke. Rocks of the R-synform: 5 — olivine gabbro, 6 — hornblende gabbro, 7 — amphibolite, 8 — metadolerite

Papua and Oman ophiolites.

The general differentiation trend of the Letovice metaophiolites and of Pindos, Bay of Island and Sarmiento ophiolites expressed by relationship between the Solidification Index (SI) and the Ti/CrxNi ratio is shown in Fig. 8. Differentiation trends for the basic and ultrabasic rocks of the R-synform of the Letovice crystalline complex are comparable with the trends of the Pindos ophiolite suite. On the other hand, the gabbros as well as amphibolites of the L-synform follow the trend of Bay of Island and Sarmiento ophiolites.

The geochemical data for the Letovice metaophiolites are identical with the corresponding data for the Pindos, Troodos, Bay of Island and Papua ophiolites. Some similarities have been found also between the Letovice metaophiolite and Sarmiento ophiolite complexes in which not all the members of the typical ocean lithosphere occur (ultrabasic members are missing — Saunders et al., 1979).

Although the major and trace elements of the Letovice metaophiolite do not unequivocally determine their geotectonic position, they support the idea of a marginal sea basin or ocean floor environment for the origin of the Letovice metaophiolites.

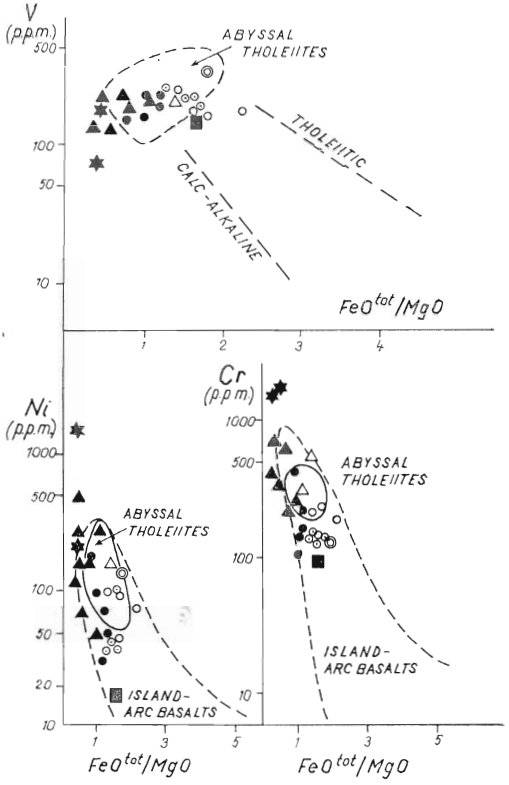


Fig. 6. Ni, Cr and V contents versus FeO^{tot}/MgO ratio plots of different rocks of the Letovice crystalline complex. Fields of abyssal tholeiites and island arc basalts as well as tholeiites and cacl-alkaline boundary after A. Miyashiro (1975). The symbols for the rocks of the L- and R-synforms as in Fig. 4

Regional geological aspects

The Letovice metaophiolite complex belongs to the Saxo-Thuringian zone of Central European Hercynides. In the Bohemian Massif, this zone is characterized by a thinner continental crust, as related to the Moldanubian zone and by the occurrence of Cadomian geosynclinal sediments and volcanics in larger, but narrow internal troughs. The Cambrium and, if it missing, the lower Ordovician sediments cover the folded Cadomian basement.

The morphological and structural subdivision of the Saxo-Thuringian zone and the deep fault zones strongly control the position of the metaophiolite complexes. The Letovice metaphiolite complex is located in the marginal area of the Central Bohemian region and closes at the Moravian-Silesian fault zone (Fig. 1).

Corresponding metaophiolite complex has been described by J. Tonika (1971) and in this sense also interpreted by Z. Mísař

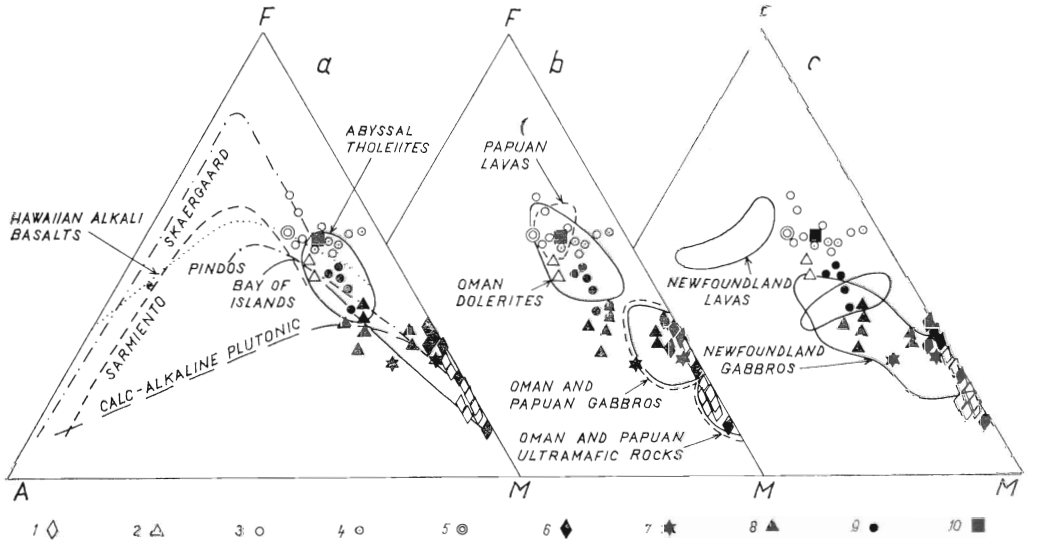


Fig. 7. Letovice metaophiolites in A-F-M plot as compared with trends of other ophiolite complexes [see corresponding data in Alleman and Peters (1972), Coleman (1977), Davis (1971), Montigny et al. (1973), Norman and Strong (1975), Saunders et al. (1979), and Suen et al. (1979)]. Rocks of the L-synform: 1 — ultramafic rock, 2 — gabbro, 3 — amphibolite, 4 — garnet amphibolite, 5 — basic dyke. Rocks of the R-synform: 6 — ultramafic rock, 7 — olivine gabbro, 8 — hornblende gabbro, 9 — amphibolite, 10 — metadolerite

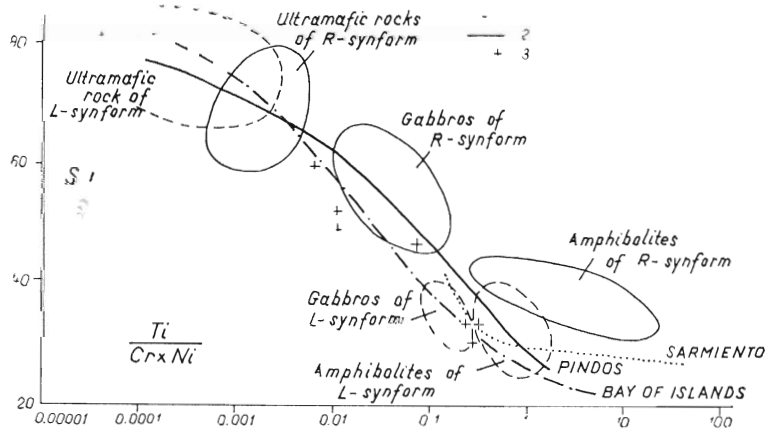


Fig. 8. Semilog plot of the Solidification Index (S. I.) (= 100 MgO/MgO + FeO + $+Fe_2O_3 + Na_2O + K_2O$) versus Ti/Cr×Ni for ophiolite members of the Letovice crystalline complex: a correlation with other ophiolite complexes. 1 — rocks of the L-synform, 2 — rocks of the R-synform, 3 — rocks of the ophiolite suite following the Central Saxonian Lineament (Werner, 1981)

et al. (in press) from the vicinity of Mariánské Lázně in Western Bohemia. The basic volcanics converted into many types of amphibolites (with garnet at some places) alternate with metagabbros. Along the central NE deep fault a larger ultrabasic body was emplaced. Nearly all members of the classical ophiolite suite are present in the Mariánské Lázně ophiolite complex, except probably of cumulate ophiolite complex. Geochemically the rocks of the Mariánské Lázně metaophiolite complex represent the metamorphic products of tholeiites and ocean floor basalts.

Upper Riphean ophiolite association of the Central Saxonian Lineament zone is made up of serpentinized dunites and peridotites, pyroxenites, several types of gabbros, amphibolites and less metamorphosed mafic and intermediate volcanics. There are sufficient geochemical data for correlation with the metaophiolites of the Letovice crystalline complex (Werner, 1981).

The ultrabasic rocks of the L-synform of the Letovice complex and the ultrabasic rocks of the Central Saxonian Lineament zone are practically identical: both correspond to the depleted mantle. C. D. Werner (1981) does not mention the cumulate ophiolite zone. However, Werner's analysed gabbros correspond to some extent with the cumulate gabbro of the R-synform (Fig. 4). The Saxonian metaophiolites are interpreted as ophiolite nappes with the homeland region along the Central Saxonian Lineament zone. They are unconformably overlain by sediments with basal conglomerates of Vendian age and by Paleozoic sediments.

A nearly complete ophiolite suite has been found at the margin of the faulted Sowie Góry Mts. (Maciewski, 1973). Abundant ultrabasic rocks are probably of two types (lower ultrabasic rocks and cumulate ultrabasic rocks with some concentration of chromite). The gabbros present are very probably also of two types. The gabbros at Nowa Ruda are closely connected with troctolite (classical locality of this rock) and olivine gabbro and obviously represent the rock of the cumulate zone. Another type of gabbro transgressive to ultrabasic rocks belongs to the upper gabbro zone of the complete ophiolite sequence. Basic volcanics are transformed into amphibolites. A sheeted dyke complex may be also present (Majerowitz, 1979; Narebski et al., 1982).

A metaophiolite complex, probably of Upper Proterozoic age, is also situated along the NNE—SSW contact between the Saxo-Thuringian and Moravo-Silesian regions (Mísař, 1979). The amphibolites represent metamorphosed mafic volcanic and strongly sheared gabbros. The banded harzburgite with pyroxenite layers (Mísař, 1966) and rhodingite are perhaps lower ultrabasic rocks — tectonites of mantle peridotites.

The described metaophiolite complexes of the Saxo-Thuringian zone of the Bohemian Massif are common in their structural position. They follow marginal zones of geosynclinal troughs and/or deep fault zones along the contact between troughs and internal elevations. The metaophiolite suite of dismembered type with a cumulate gabbro-peridotite zone is found only where the strike-slip deep fault zone inside the Saxo-Thuringian zone approaches the Moravian Silesian fault zone. The places may represent triple junctions from the time of the Cadomian geotectonic cycle — the Letovice ophiolite junction and the Sowie Góry Mts. junction.

The metaophiolite complexes of the Saxo-Thuringian zone also have some time and genetic relations to the abundant geosynclinal basic volcanism. The most representative of them are spilites and diabases of the Central

Bohemian region (Fig. 1). F. Fiala (1977) characterized the volcanics westerly of Prague as ocean floor basalts and those farther to the S of Prague as volcanics originated from calc-alkaline magma of the orogenic belt along the continental margin or an island arc. The metavolcanics (greenschists and amphibolites) of the Central Bohemian region (synclinorium) correspond to abyssal tholeiites described by M. Opletal et al. (1980).

All volcanic rocks of the Central Bohemian region alternate with geosynclinal greywackes and laminated pelites. These types of sediments with volcanic rocks are typical for marginal (back arc) basins or for basins between the outer and inner arcs (Mitchell and Garson, 1981). Some similarities may also be found in sedimentation and volcanic processes in a marginal sea of the Sarmiento type (Tarney-Dalziel and Wit, 1976).

Before passing the stage of compression, the marginal basin floor was influenced by crustal thinning, rifting, basic volcanism inside and island arc volcanism along the basin margins. All these processes may lead to formation of a new oceanic floor in the marginal sea.

The general character of the Saxo-Thuringian zone as a region that is strongly morphologically a structurally differentiated margin sea of Upper Proterozoic age seem also to be documented by new investigations of P. Jakeš et al. (1979) and J. Cháb et al. (1982). They concluded that the clasts in Proterozoic greywackes are largely derived from islad arc volcanic rocks and calc-alkaline volcanic rocks of continental margin but very rarely from ocean floor tholeiites. This paleogeographical scheme indicates that the ophiolite complexes of the Saxo-Thuringian zone were emplaced along deep faults (lineaments) inside the Saxo-Thuringian marginal sea and/or along its margins, especially where a triple junction can be assumed.

The sedimentary and volcanic rocks of the Saxo-Thuringian zone were affected by Cadomian metamorphism. The metamorphic mineral assemblage of the Letovice metaophiolite complex originated under conditions with a temperature of about 400—600 °C and a pressure of about 2—5 kb. These conditions do not exceed the limits of Cadomian metamorphism gived by J. Cháb and M. Suk (1977). Generally, the intensity of Cadomian regional metamorphism of rocks of the Saxo-Thuringian zone is not uniform. This is also true for the metamorphic grade of the Letovice crystalline complex. The rocks of the L-synform belong to the amphibolite facies (with garnet) whereas the rocks of the R-synform were metamorphosed under the conditions of green schists facies. This also seems to be very important if complex nappe tectonics is accepted for the Letovice crystalline unit.

Conclusions

The basic and ultrabasic rocks of the Letovice crystalline complex are considered to be members of dismembered ophiolites metamorphosed in amphibolite and green schist facies. Ultrabasic members most probably represent ultrabasic rocks "tectonites" in the L-synform and cumulate ultrabasic rocks in the R-synform. Metagabbros and metavolcanics (amphibolites) generally correspond to the rocks of the layered gabbro-peridotite zone and of the volcanics as seen in all classical ophiolite sections.

Paleotectonic analyses and general geochemical data allow interpretation of the Letovice metaophiolites as part of the Saxo-Thuringian zone developed as a complex, in strongly differentiated marginal sea.

The geotectonic position of the Letovice metaophiolite and other corresponding ophiolite complexes (Mariánské Lázně, Saxony area, Staré Město zone, Sowie Góry Mts.) is very probably controlled by deep faults (rifts) inside the Saxo-Thuringian zone and/or by the marginal faults especially when they approach the Moravian-Silesian fault zone. The metaophiolite complexes are in some way related to basic volcanic activity and greywacky sedimentation present (e. g. Barrandian Upper Proterozoic etc.) in the Saxo-Thuringian zone during the Cadomian geotectonic cycle.

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Rozdělené metaofiolity letovického krystalinika ve stavbě sasko-durynské zóny Českého masívu

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Nová geologická a geochemická data byla shromážděna z krystalinika v okolí Letovic. V krystaliniku se nacházejí spodní ultrabazické horniny (tektonity), horniny kumulátového komplexu, bazické vulkanity a velmi sporadicky i horniny žilného typu. Všechny tyto horniny lze považovat za metamorfované členy rozděleného klasického ofiolitového komplexu. Stupeň regionální přeměny zasahuje z facie zelených břidlic do facie amfibolitové v závislosti na pozici těchto hornin v základních megastrukturách letovického krystalinika. Geologické, petrografické i geochemické znaky i diferenciační trend bazických a ultrabazických hornin letovického krystalinika odpovídají ofiolitovým kon-

plexům např. lokalit Pindos, Bay of Island, Troodos, Oman, Papua a dalších.

Geotektonicky svrchnoproterozoické letovické metaofiolity jsou součástí svrchnoproterozoického strukturního patra sasko-durynské zóny střednoevropských hercynid (variscid). Jsou dobře srovnatelné s horninami mariánsko-lázeňského komplexu, s ofiolitovým komplexem centrálního saského lineamentu, s metabazity a ultrametabazity staroměstského svorového pásma a také s ofiolity v lemu kry Sovích hor. Všechny zmíněné ofiolitové komplexy patrně vznikaly v geotektonickém prostředí okrajového moře sasko-durynské zony zvláště v místech hlubinných zlomů sledujících okraje vnitřních depresí a elevací. Pro okrajová moře a vnitřní deprese jsou vedle hlubinných zlomů charakteristické znaky jako ztenčování zemské kůry a v konečném obrazu vytváření nové oceánské kůry. Tím se svrchnoproterozoické strukturní patro sasko-durynské zóny od paleozoického patra téže zóny velmi zřetelně odlišuje.

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Global evolution of the mafic magmatism with special regard to the rare earth elements

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Глобальное развитие мафического магматизма с особенным зрением на элементы редких земель.

Анализ глобального развития мафического магматизма основанного на, для этого пригодных картинах содержания элементов редких земель, позволяет различить его отношение к главным стадиям геодинамического режима в течении развития Земли. В результате понижения глобального теплотного течения и повышающегося разубаживания мантии о инкомпатибильные элементы явяются основным изменением состава мафических магматитов. Особенно интенсивные магматические процессы протекали к концу архея. Для отдельных эпох являются характеристическими специфические магматические циклы.

Global evolution of the mafic magmatism with special regard to the rare earth elements

The analysis of the global evolution of the mafic magmatism basing on the therefore especially suitable REE patterns makes recognizable a distinct connection to the main stages of the geodynamic regime with the progress of the earth's history. With decreasing global heat flow and increasing impoverishment of the mantle for the incompatible elements substantial modifications of the mafic igneous rocks result. Obviously, the decisive event seems to be at the end of the Archaean. Within the individual stages distinctly marked cycles are evident.

Some years ago, at the final session of the field works 1980 in Prague, our colleague prof. N. L. Dobretsov has proposed a model for the global evolution of ophiolites (Dobretsov — Kepezhinscas, 1981). Continuing his ideas, it shall made an attempt for the global evolution of mafic magmatism in general on the basis of the rare earth elements. The 14 naturally existing REE ($_{57}$La — $_{71}$Lu; $_{61}$Pm does not

occur because of its short half life period) are especially suitable for the substantial illustration of geologic events.

The variable distribution of the REE within the main mineral phases of the upper mantle (olivine, orthopyroxene, clinopyroxene and garnet) and whose different stability during partial anatexis in dependence of P and T enables to comprehend genetic events at the formation of mafic magmas in space and time. The secular diminuation of the thermal activity of the upper mantle with simultaneously decreasing on incompatible elements involve characteristic modifications of the mafic magmatites in the progress of the earth's history. They are especially marked during the Archaean.

Fig. 1 demonstrates the REE distribution between the primitive mantle (Mp) and the depleted mantle (Md) after the formal extraction of the present earth's crust (continental and oceanic; data from Wedepohl, 1981). The depleted mantle has a thickness of about 200 km, for strong incompatible elements considerably more (up to 900 km). The ratio LREE (La-Sm)/HREE (Eu-Lu) is distinctly higher in the crust and lower in the depleted mantle. The generation of mafic magmas should take place during the course of the earth's history from more and more depleted mantle areas apart from ranges with mantle metasomatism, mantle plumes, subduction and other disturbances.

In the following chapters all the rock types are demonstrated by their mean values, which enable a clearer comparison than by the range of scatter. The complete data will be published in a special paper (Werner, in press).

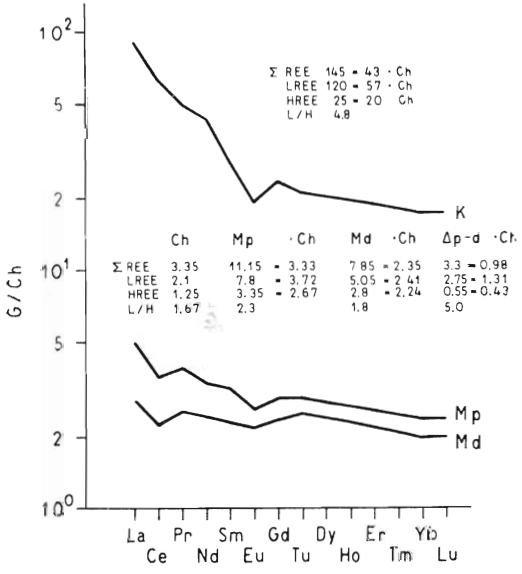


Fig. 1. Chondrite-normalized REE patterns for primitive (Mp) and depleted (Md) upper mantle and crust (K). REE data in ppm; Ch = average of the C1-C3 chondrites from the data of MASON (1979)

The Archaean komatiite-tholeiite sequence

From the first primitive basic to anorthositic crust of the earth, formed directly after the condensation of the earth's matter and the formation of the core, we don't know certain relics. As the oldest know mafic rocks the komatiitic-tholeiitic series of the greenstone belts appear, mainly evident on a sialic basement. Two main cycles may be distinguished:

3.5—3.3 b. y. (Barberton/RSA, Sargur/India, Pilbara/West Australia),

2.7—2.5 b. y. (Zimbabwe, Dharwar/India, Yilgarn/West Australia, Canada, Karelia/Finland-USSR).

A third cycle is known only relictic as enclaves in the 3.8 b. y. old Amitsoq gneisses from West Greenland. It may have an age of approximately 4 b. y.

The komatiites are predominantly effusive, partly explosive volcanics with mostly subaquatic emplacement and large thickness of the complexes. Generally,

they contain olivine, orthopyroxene and plagioclase, but no clinopyroxene. The melting rate at the formation of the komatiitic magmas is very high: 40—70 % at high temperatures (more than 1650 °C) and low H_2O contents.

Fig. 2 demonstrates the REE patterns for some rock types of the three cycles. The oldest one (~ 4 b. y.) displays no big differences between peridotitic and basaltic komatiites. However, both the types are clearly enriched in face of the Mp. The second cycle (3.5—3.3 b. y.) is distinguished by a strong differentiation between PK and BK, and the PK patterns lie near by the Mp one. Within the third cycle, PK and BK are impoverished in LREE with lower contents of the hygromagmaphile REE (La-Pr) in the PK against Mp. Tholeiites and andesites on the other hand, which occur more frequently in the third cycle, possess considerably higher contents of LREE.

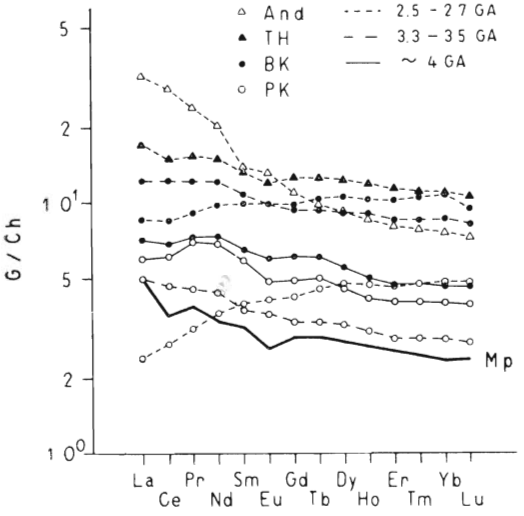


Fig. 2. Chondrite-normalized REE patterns for the Archaean komatiite-tholeiite association. PK — peridotitic komatiites, TH — tholeiites, BK — basaltic komatiites, AND — andesites

An explanation for the retrogression of the LREE contents in the youngest komatiites may lie in the progressive impoverishment on clinopyroxene in the upper mantle. This is made likely by the bulk chemistry of the komatiites, too, especially by the ratio CaO/Al_2O_3. These ratios change from 2—3 (1st cycle) over 1—2 (2nd cycle) to 0.6—1.2 (3rd cycle).

Continental tholeiites

With the third cycle of the komatiitic-tholeiitic igneous event in the greenstone belts, at the border Archaean/Proterozoic, above all the thermal activity of the upper mantle seems to be exhausted widely. The magmatism is now of the type of the continental tholeiites. An old variant are the locally occurring cumulative complexes of the types Stillwater (2.7 b. y.), Great Dyke (2.5 b. y.) and Bushveld (2 b. y.).

A second cycle of the continental tholeiites we can find in the Late Precambrian, for instance in the Keweenawan and the Coppermine districts, North America (1.1 b. y.). At last, the plateau basalts of Mesozoic-Cenezoic age occur: Sibirian traps (250—220 m. y.), Karroo dolerites (200—165 m. y.), Paraná Basin (150—120 m. y.), Deccan traps and Thule Province (65—50 m. y.), and the Columbia River Province (15—10 m. y.). The main part of the Variscan initialites in Western and Central Europe belongs to this type, too (Werner, 1982). These two cycles are connected with intracontinental rift, resp. arcogene events, in parts joint with the separation of Gondwana, resp. the north drift of India.

Apart from the Keweenawan andesites and the Deccan traps with a certain alkaline tendency, the continental tholeiites (fig. 3) show relatively constant REE patterns over a time distance of more than

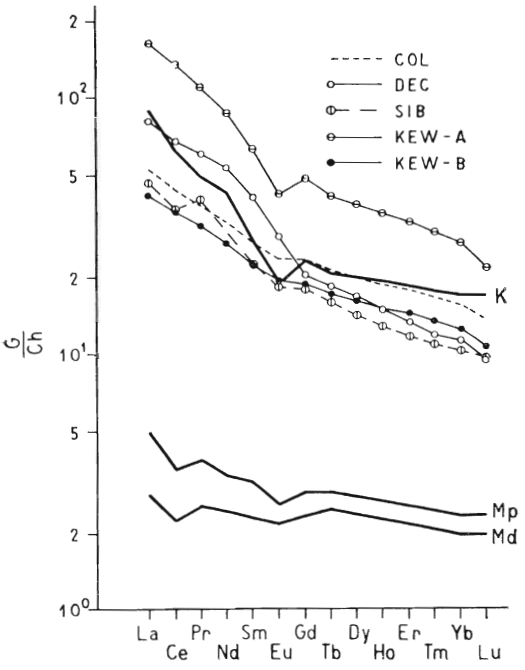


Fig. 3. Chondrite-normalized REE patterns for the continental plateau basalts. COL — Columbia River, Province, DEC — Deccan. SIB — Sibiria, KEW — Keweenawan, A — andesites, B — basalts

1 b. y. This may be the expression of comparable conditions of magma generation at 1200—1300 °C and 10—15 kbars in the presence of some water from a nearly homogeneous mantle composition. The somewhat elevated LREE contents could be the result of a supply of LREE enriched fluid phases from greater depths, possibly from the lower mantle. This can be derived from the Nd isotopes, too.

Oceanic tholeiites and ophiolites

The mass of the ophiolites is much larger than that of all post-Archeaen continental mafics together. The oldest known ophiolite complex is dated with 1.8—2 b. y. (Baykal-Muya Zone, Dobretsov — Kepezhinscas, 1981), however, ophiolites occur more and more from the Upper Proterozoic (Polar Urals, Central Europe) and the Cambrian (Northern Europe and Northern America), and reach their maximum during the Meso-Cenozoic with the formation of the recent oceans (about 2×10^9 km^3 basalts in 200 m. y.).

The oceanic tholeiites can be divided into three types, especially distinct at the REE: a primitive type (P), a 'normal' (N) and an enriched type (E). The prevailing N-type is mainly connected with the mid-ocean ridges. Elemental variations are depending from differing spreading rates, differing melting rates and the varying depth levels of the partial anatexis as well as from certain mantle inhomogeneities. The E-type is often connected with fractures zones and hot spot oder plume areas resp., combined with possibly anomalous mantle composition or fractionation in shallow-level magma chambers.

These three types are demonstrated in fig. 4. Gabbros and diabases can be divided into three types, too, but with distinctly lower enrichment of the LREE. This means originally primary differences between the intrusive and the extrusive melts. The positive Eu anomaly of the gabbros is involved by their higher plagioclase contents.

For the ultramafic members of the ophiolites there exist only few analyses. Due to their refractory or restitic character, they should be strongly impoverished in LREE. Actually, they show a more or less strong ascent of the LREE, very likely as the effect of the hydrothermal sub-sea floor serpentinization.

Oceanic island basalts

Within the oceanic lithosphere plates an igneous rock association with a completely

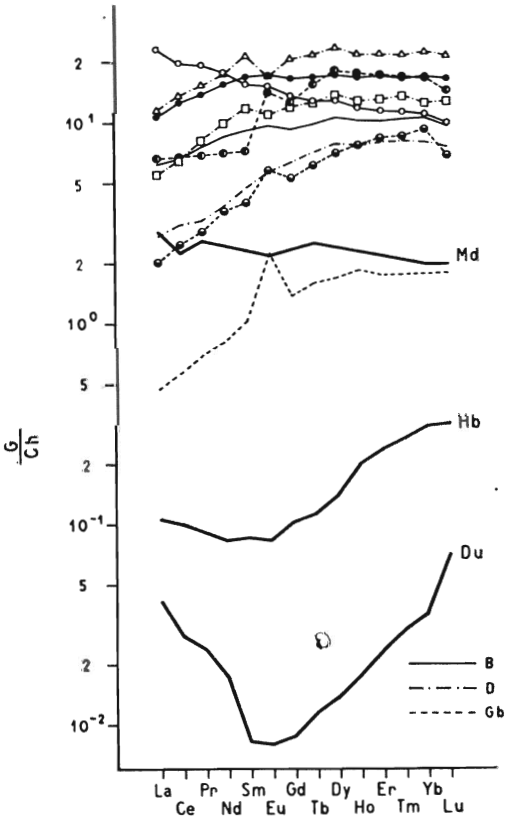


Fig 4. Chondrite-normalized REE patterns for the ophiolite association, B — basalts (tholeiites), Hb — harzburgites, D — dolerites ("diabases"), Du — dunites. Gb — gabbros

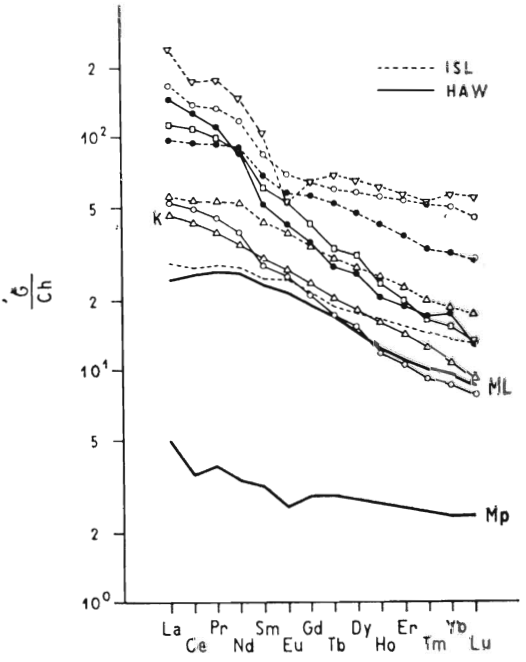


Fig. 5. Chondrite-normalized REE patterns for the oceanic island volcanic association. HAW — Hawaii, ML — Mauna Loa tholeiites, □ hawatites + mugearites, K — Kilauea tholeiites, ○ trachytes, △ alkali olivine basalts, ISL K Iceland (Tertiary) without signs — H-Mg tholeiites, △ — H-Fe tholeiites, ○ — icelandites, ● andesites, ▽ — rhyolites

differing petrochemical character occurs, but similar to continental within-plate mafic and alkaline rock series. It is connected with local hot spots in the mantle during the last 70 m. y., where the oceanic islands and seamounts were formed. Besides prevailing tholeiites, alkaline mafics and of minor importance felsic rocks, too, are evident.

Fig. 5. shows two examples, from Hawaii and from the Tertiary Iceland. The latter is conventionally looked as a part of the Thule Province, but on an oceanic basement. For each region a progressive increase in LREE is typical in the mafic to felsic sequence. The somewhat flatter ascent of the Iceland rocks may be the result of a less deep melting level. Because of the generally higher contents in incompatible elements compared with oceanic tholeiites, their parent melts must be originated in greater depths. From isotopic conditions the lower mantle is even thought by some authors.

Island arc igneous rocks association

Spreading within the oceanic lithosphere plates is necessarily connected with the subduction of oceanic crust on converging

plate boundaries. In these regions the generation of characteristic igneous rock series takes place. They are of the Andean or of the island arc type. Only the latter may be regarded here. Three or four magmatite series can be divided: TH, CA, H-K, and SHO, and in each series we have basalts and andesites, apart from some other rock types.

Fig. 6 demonstrates clearly the increasing REE contents with increasing depth levels of the anatectic magma generation, and with the increasing K contents of the series. For comparison the mean values for the boninite/H-Mg andesite association are given.

Boninite/H-Mg andesite association

The first description of a boninite dates from 1890, but at first in the last five years these rocks have found a special interest. They are high-Mg (> 9 to more than 20 % MgO) plagioclase-free andesites with 56—58 % SiO_2, very poor in Ti, but considerably high in Ni and Cr. The boninites s. str. are tied to intra-oceanic island arcs (Bonin-Mariana arc), mainly as pillow lavas with olivine, chromite, clinoenstatite, H-Mg orthopyroxene, pigeonite, clinopyroxene and amphibole in a H_2O-rich glassy matrix. Other types are the H-Mg andesites from continental island arcs (Papua-New Guinea; Japan). All they are of late Mesozoic to Cenozoic age, older occurrences with a boninite tendency are known, for example, from the upper pillow lavas of the Troodos Massif, and within the ophiolites of Othris/Greece, Betts Cove/Newfoundland and Victoria/Australia. The boninites occur preponderantly in a fore-arc position with island arc tholeiites

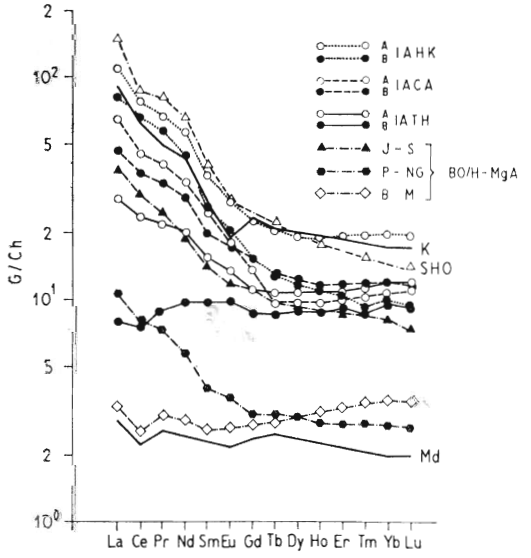


Fig. 6. Chondrite-normalized REE patterns for the island arc igneous rocks association. A — andesites, B — basalts, BO/H-MgA — boninite — H-Mg andesite series (mean values, explanation see fig. 7)

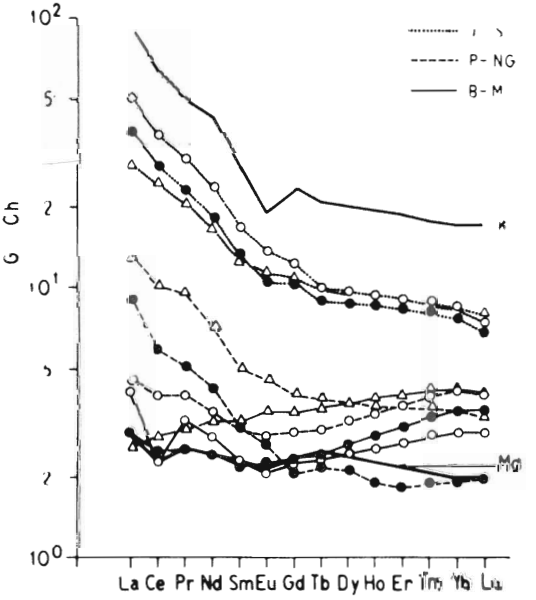


Fig. 7. Chondrite-normalized REE patterns for the boninite — H-Mg andesite series. J-S — Japan (Setouchi), B-M — Bonin-Mariana Arc, P-NG — Papua-New Guinea

as basement, and overlained by oceanic tholeiites.

Three sub-types of boninites are demonstrated in fig. 7. The most primitive REE pattern is in the rocks with the comparatively highest REE content. However, it is clearly lower than in normal island arc and oceanic tholeiites. Within the sub-type with the lowermost REE content, there is a typical V-shape pattern.

The H-Mg andesites from Cape Vogel (Papua-New Guinea) lie somewhat higher than the boninites, but in the main type with V-shape pattern, 'too. The Setouchi-H-Mg andesites from Japan possess no clinoenstatite, but orthopyroxene and olivine, and have clearly higher REE contents, somewhat differing from normal island arc volcanics, however.

Comparison of main types of mafic igneous rocks

If we compare the main types of mafic igneous rocks (fig. 8), clear differences with respect to the REE patterns are relevant. The poorest and youngest rocks are the boninites, generated from depleted mantle material with a relatively high melting rate. Then the oldest rocks (Archaean komatiites) succeed with very high melting rates in a ± primitive mantle. The striking similarity between basaltic komatiites and IATH gave rise to the models of Archaean subduction by some authors, but the rock association and the produced magma volumes are not comparable.

The highest REE enrichment show the oceanic and continental tholeiites, but with a different pattern. The first one were produced from a LREE depleted mantle, the second one from a possibly primitive mantle in a deep level or from a partially depleted, but somewhat metasomatized mantle. In table 1 some REE data for all main types are compiled.

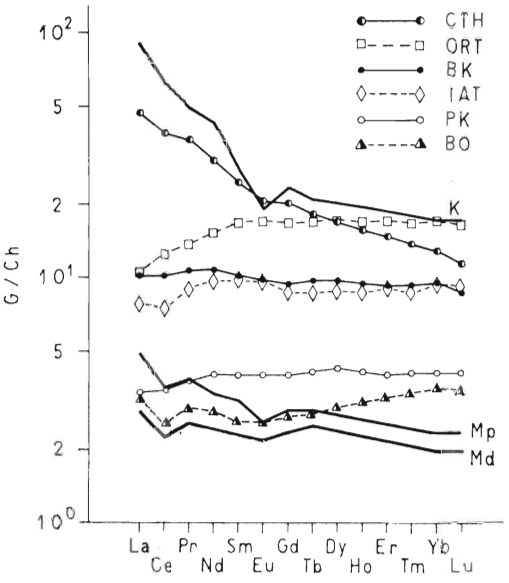


Fig. 8. Chondrite-normalized REE patterns for the main types of mafic igneous rocks. CTH — continental tholeiites, ORT — ocean ridge tholeiites, BK — basaltic komatiites, IAT — island arc tholeiites, PK — peridotitic komatiites, BO — boninites

Conclusions

In fig. 9 the occurrence of the main groups of mafic igneous rocks is time-scaled. After the condensation stage of the earth (A) with core formation, mainly degassing and a first primitive crust the stage of microplate tectonics (B, after Goodwin, 1981) follows with the komatiites during the Archaean. Here, the main formation of the earth's crust took place (Dobretsov, 1980; McLennan — Taylor, 1982). The three komatiitic cycles are clearly different. During the stage of the within-plate tectonics (C) in the Lower and Middle Proterozoic with only small crustal growth and intracontinental for-

mation of troughs and protogeosynclines the continental tholeiites occur, which are generated in the next stage, too.

The final stage (D) started in the Late Precambrian with the ophiolites and the macroplate tectonics in more rigid plates, joint with ocean-floor spreading and subducion on Benioff zones. Connected with the ophiolites is the island arc magmatic activity. The within-plate alkaline igneous rocks belong to this stage, too, but their volume is very small, and to a certain extend they are 'exotic' rocks. The youngest formations are the boninite series, coupled with island arcs, but substantially and petrogenetically independant.

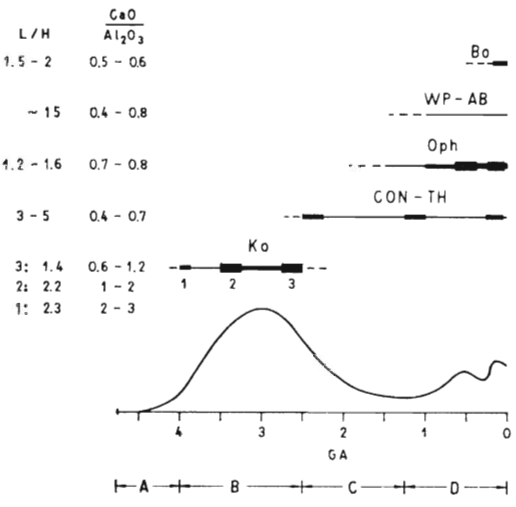


Fig. 9. Historical diagramm for the evolution of mafic magmatism compared with the crust formation (after Dobretsov, 1980) and the stages of the earth's evolution (after Goodwin, 1981). BO — boninites, WP-AB — within-plate alkali mafics, Oph — ophiolites, CON-TH — continental tholeiites, Ko — komatiites, A-D — evolution stages of the earth (see text)

REE mean values for the main types of mafic igneous rocks

Table 1

n	CTH	ORT	BK	IAT	PK	BO
	183	92	101	11	44	14
La	15.05	3.34	3.25	2.51	1.10	1.06
Ce	33.9	10.7	8.7	6.51	3.08	2.19
Pr	4.35	1.61	1.21	1.06	0.46	0.35
Nd	17.85	9.05	6.2	5.73	2.42	1.71
Sm	4.85	3.37	1.94	1.93	0.81	0.52
Eu	1.50	1.25	0.68	0.71	0.30	0.19
Gd	5.69	4.69	2.54	2.45	1.14	0.77
Tb	0.87	0.81	0.44	0.42	0.20	0.135
Dy	5.26	5.34	2.89	2.74	1.34	0.92
Ho	1.16	1.24	0.66	0.64	0.31	0.23
Er	3.05	3.55	1.81	1.88	0.85	0.68
Tm	0.44	0.53	0.28	0.28	0.13	0.11
Yb	2.46	3.27	1.71	1.82	0.80	0.69
Lu	0.37	0.54	0.28	0.30	0.14	0.115
Σ REE	96.8	49.3	32.6	29	13.1	9.7
LREE/HREE	3.65	1.32	1.89	1.58	1.51	1.52
La/Yb	6.12	1.02	1.90	1.38	1.38	1.54
$(La/Sm)_N$	1.94	0.62	1.05	0.81	0.85	1.27
$(La/Yb)_N$	3.69	0.62	1.15	0.83	0.83	0.93

We can perceive a congruency between the mafic magmatism and the crustal growth. The differing ratios of LREE/HREE and CaO/Al_2O_3 are the expression of an increasing depletion of clinopyroxene and incompatible elements within the upper mantle with more and more reduced melting rates. Especially clear is this tendency during the Archaean with three komatiitic cycles.

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White's clinopyroxene diagram applied to the differentiation of the eclogite and granulite facies

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(2 figß. and 1 tab., in the text)

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К проблематике применения диаграмма Уайте (White) **клинопироксенов для отличия эклогитовой и гранулитовой фации**

При сравнении химизмов клинопироксенов (омфацитовых салитов) из омфацитовых гранулитов в Чешском массиве была применена диаграмма Уайте с целью выяснения метаморфной фации. Было утверждено мнение, что диаграмм клинопироксенов Уайте (Уайте, 1964) для отличия их возникновения в гранулитовой или эклогитовой фации имеет ограниченное употребление. Омфацитовые гранулиты содержат большое количество ядеитовой молекулы, что не отвечает результатам диаграмма Уайте. Для отличия гранулитовой фации от фации эклогитовой является выгоднейшим установление соотношения FeO : MgO : 2 Na_2O или Mg : FeO : CaO пироксенов.

White's clinopyroxene diagram applied to the differentiation of the eclogite and granulite facies

White's clinopyroxene diagram has been tested for differentiating the granulite and eclogite metamorphic facies in the Bohemian Massif. It has been stated, however, that the omphacite granulites have clinopyroxenes with a large content of jadeite molecule, which does not agree with White's diagram. The validity of White's diagram is obviously limited. More suitable for differentiating the granulite and eclogite facies using the chemistry of pyroxenes is the FeO : MgO : 2 Na_2O or FeO : MgO : CaO diagram.

A. J. R. White (1964) proposed the possibility of distinguishing between the eclogite and the granulite facies on the basis of the content of jadeite and Tschermak molecules in clinopyroxenes. From the presented diagram it follows that omphacites do not exist in granulites. In examining an orthopyroxene-bearing granulite from the borehole near Tirschheim in the Saxonian Granulitgebirge (Mathé, 1969)

noted the presence of omphacite and questioned the validity of White's diagram. He emphasized that to differentiate eclogites and granulites according to the composition of clinopyroxenes, the Fe/Mg ratio is much more important than the Na content. J. Fiala et al., (in print) found omphacites in dark granulites near Nové Vilémovice in the Rychlebské hory Mts. These omphacite-bearing granulites accompanied by predominating light-coloured "acid" granulites extend from Czechoslovakia to the Gieraltów area in Poland, where they were described in detail by (Kozlowski, 1965), (Smulikowski and Bakun-Czubarowa, 1973). They were assigned by these authors to a transitional facies between granulites and eclogites, and in 1980 Smulikowski used the term omphacite granulite for them, but only in parantheses. The third occurrence of omphacite granulite in the Bohemian Massif was assessed by Paděra in the Čáslav crystalline complex near Běstvina in the Železné hory Mts. (Dudek — Fediuková, 1974) considered the Běstvina omphacite granulite to be an eclogite. All these omphacite granulites are accompanied by predominant light-coloured "acid" granulites (see Mathé, 1969, Matějovská, 1970, Zoubek et al., 1977, etc.).

The omphacite granulites contain major amounts (15—30 %) of primary plagioclase (oligoclase — andesine) and quartz (15—20 %). Potassium feldspar is absent or present in a small amount. Other essential components are metacrystals (poikiloblasts) of garnet (20—35 %) and omphacite (20—50 %). It is the presence of a major amount of primary plagioclase that distinguishes the pyroxene and omphacite granulites from eclogites in which a considerable content of primary plagioclase is exceptional.

Chemical analyses of omphacites from the omphacite granulites of the Bohemian Massif are given in Table 1. They are taken from the papers of (Kozlowski, 1965), (Mathé, 1969), (Smulikowski and Bakun-Czubarowa, 1973), (Dudek — Fediuková, 1974), (Fiala — Paděra, 1981). The clinopyroxenes analyzed contain 2.8 to 5.1 Na_2O and White's diagram projects them to the field of eclogites (Fig. 1). The question arises whether this diagram is only of partial validity, or whether the rocks are eclogites or, possibly, rocks formed in the transitional granulite-eclogite facies. The presence of accompanying light-coloured granulites, which have been formed in conditions of the granulite-facies or transitional between the amphibolite and the granulite facies, provides evidence

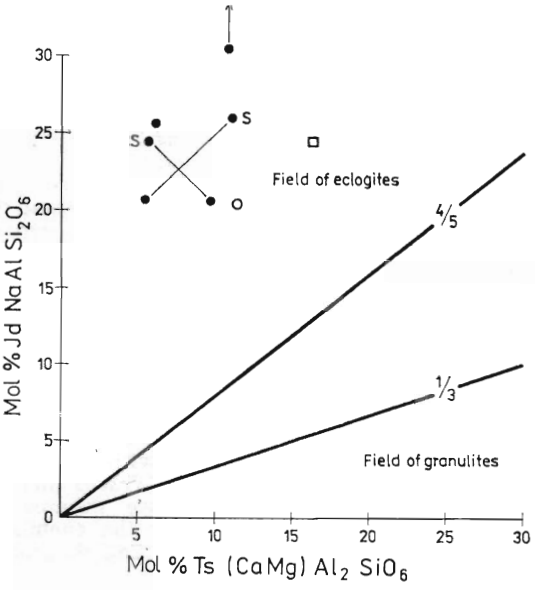


Fig. 1. White's diagram of clinopyroxenes for the distinction of eclogite and granulite metamorphic facies. Projections of clinopyroxenes from omphacite granulites of the Rychlebské hory Mts. are marked by small full circles. Straight lines connect centres of the analyzed omphacite grains (marked S) with grain margins. The open circle corresponds to omphacite from Tirschheim and open square to omphacite from Spačice

Chemical analyses of clinopyroxenes (omphacites) from omphacite granulites of the Bohemian Massif

Tab. 1

Analyst	Tirschheim Posner	Spačice Fediuková*	Kozlowski	Rossol	Rychlebské hory Mts. Fiala* centre	margin	centre	margin
SiO_2	50.0	50.41	52.76	51.49	51.91	53.40	53.35	52.39
TiO_2	1.9	3.09 ?	0.23	0.48	0.66	0.46	0.56	0.52
Al_2O_3	8.8	11.64	8.11	11.80	11.13	6.88	8.49	8.30
Fe_2O_3	0.4	—	1.88	1.36	—	—	—	—
FeO	9.4	9.03	6.50	7.02	7.32	8.01	7.01	7.27
MnO	0.2	—	0.02	0.06	0.06	0.05	0.08	0.06
MgO	9.0	8.10	8.81	8.45	8.77	10.44	10.18	10.56
CaO	15.6	14.58	17.90	13.26	16.41	18.40	16.97	18.06
Na_2O	2.8	3.34	3.58	5.11	3.82	2.93	3.41	3.00
K_2O	0.3	—	0.37	0.12	0.01	0.01	0.00	0.01
	98.4	100.19	100.16	99.15	100.09	100.58	100.05	100.17
Si	1.89	1.84	1.94	1.89	1.89	1.95	1.95	1.91
Al (IV)	0.11	0.16	0.06	0.11	0.11	0.05	0.05	0.09
Al (VI)	0.28	0.34	0.29	0.41	0.37	0.25	0.32	0.27
Ti	0.05	0.09	0.01	0.01	0.02	0.01	0.02	0.01
Fe^{3+}	0.01	—	0.05	0.04	—	—	—	—
Fe^{2+}	0.30	0.28	0.20	0.22	0.22	0.25	0.21	0.22
Mn	0.01	—	0.00	0.00	0.00	0.00	0.00	0.00
Mg	0.51	0.44	0.48	0.46	0.48	0.57	0.55	0.57
Ca	0.63	0.57	0.70	0.52	0.64	0.72	0.66	0.71
Na	0.20	0.24	0.26	0.36	0.27	0.21	0.24	0.21
K	0.01	—	0.02	0.01	0.00	0.00	0.00	0.00

* determined by electron microprobe
all Fe determined as Fe^{2+}

that the omphacite granulites themselves also originated in granulite facies conditions. The solution to the problem of whether or not the rocks in question should be assigned to the granulite facies is facilitated by using the triangular diagram of Mg, Fe and Na oxides in clinopyroxenes from the omphacite granulites described from the Bohemian Massif. The comparison of the composition of clinopyroxenes from the eclogites of adjacent areas, i. e. the Góry Snieźnickie Mts. in Poland, and in the Moravian and Bohemian parts of the Moldanubicum (Fig. 2) is also useful. The twofold exaggeration of the sodium content was chosen so as to enhance the differences between the clinopyroxenes. Partial chemical analyses of clinopyroxenes from the eclogites of the Góry Snieźnickie were taken from the paper of (Smulikowski, 1967) and chiefly from that of (Bakun-Czubarowa, 1968), where 36 partial analyses of clinopyroxenes from the eclogites at the Nowa Wieś locality are given. Chemical analyses of clinopyroxenes from the eclogitic rocks (griquaites and garnet pyroxenites) of the Bohemian and Moravian parts of the Moldanubicum were taken mainly from the publication of (Dudek — Fediuková, 1974) and completed by data (Paděra, 1971) and many other as yet unpublished chemical analyses. The diagram permits the distinction of clinopyroxenes in omphacite granu-

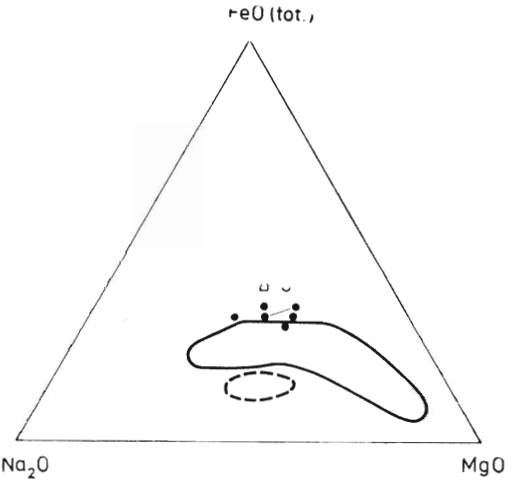


Fig. 2. Comparison of partial analyses of clinopyroxenes from omphacite granulites of the Bohemian Massif with clinopyroxenes from eclogitic rocks (griquaites, garnet pyroxenites) of the Bohemian and Moravian parts of the Moldanubicum (solid line) and with omphacites from eclogites of the Góry Snieźnickie Mts. (dashed line). Full circles represent partial analyses of omphacites from the Rychlebské hory Mts., the small open circle corresponds to omphacite from Tirschheim and the open square to omphacite from Spačice

lites of the Bohemian Massif from those of the eclogitic rocks in the Moldanubicum, and indicates a striking difference between the latter and the eclogites of the Góry Snieźnickie. It also shows that the sodium content in clinopyroxenes is not as important in distinguishing the eclogite facies from the granulites as previously thought. Of primary importance for genetic conclusion is the Fe/Mg ratio in clinopyroxenes, which was also stressed by (Mathé, 1969). White's diagram of clinopyroxenes is obviously only of partial validity for distinguishing the eclogite and the granulite facies.

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Petrology and geochemistry of the layered dike of Almaş-Sălişte (Mureş zone, Romania)

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Петрология и геохимия магматически складчатой дайки месторождения Алмас-Салисте (мурешская зона, Румыния)

Габроидная дайка месторождения Алмас-Салисте установлена в центральной части мурешской зоны (южной Апусени). Была объявлена Саву (1953-непубликованные данные) и позже описано её магматически складчатое строение и соответствующие петрографические фации Циофликом и Саву (1963). Изучение структурных петрохимических и геохимических аспектов этой дайки привело к составлению этой работы.

Petrologie et géochemic de le dykes stratitifié d'Almaş-Sălişte (Zone de-Mureş, Roumanie)

Le dyke stratifié d'Almaş Sălişte se trouve dans le complexe des basaltes de fond océanique (O_1) de la zone de Mureş. A sa partie supérieure, les trois zones suivantes se sont formées par différentiation gravitationelle (in situ): (1) la zone supérieure constituée d'anorthosites à niveaux de gabbros; (2) la zone médiane gabbroïde, à alternances de leucogabbros et de roches mélanocrates et ferrogabbros; (3) la zone inférieure surtout gabbroïde. Dans la zone supérieure se sont concentrés Al, Ca, Na, Sr et Ba et dans la zone médiane Fe, V et Co. La zone inférieure est moins différenciée. Les derniers différenciés du magma tholéiitique sont les plagiaplites filoniennes.

The gabbroic dike of Almaş-Sălişte is situated in the central part of the Mureş zone (Southern Apuseni Mts.). It was discovered by H. Savu in 1953 (unpublished data) and later described with respect to the layered structure and the petrographic facies by G. Cioflica and H. Savu (1963). Subsequently it was mentioned in various correlation papers.

In 1979, when the investigations in the

Almaş-Sălişte region were resumed (Savu et al., 1983), the gabbroic body was studied from the structural, petrochemical and geochemical points of view. The data obtained allowed the drawing out of the present paper.

Structure of the Gabbroic Body

The gabbroic body is hosted in the ocean floor basalt complex (0_1) of the Alpine ophiolitic series (J_1—J_2) in the Mureş zone (Savu, 1983). This complex consists of basalts, hyalobasalts, anamesites and variolites in pillow lava facies, in which dolerite sills are intercaled (Fig. 1) as well as small gabbro bodies and a body of ultrabasic rocks (Savu et al., 1983). The layered gabbroic dike trends NE—SW, being of 2.6 km in length and reaching the maximal width of 1 km. In the upper part, where the dike gets wider, the boreholes showed that it has a rhythmic layered structure (Wager — Brown, 1968) within which three zones can be distinguished (Fig. 1); upper, median and lower (Cioflica — Savu, 1963). Only the first two zones crop out, the third one being reached by boreholes at the depth of 200 m under the level of the Almaş Valley.

The rock structure in the three zones is highly irregular both vertically and horizontally due to the extremely varied dimensions and frequency of crystals, the rocks consequently showing a structure in bands, schlieren and successive lenses with thicknesses ranging from a few centimeters to a few decimeters or meters.

1. The Upper Zone consists of anorthosites with gabbro intercalations. Anorthosites are leucocrate rocks formed of plagioclase (> 90 %), sometimes partially albitized, and low amounts of clinopyroxene, titanite, rutile and magnetite or ilmenite. Plagioclase (An 55) shows on the margins an andesine zone (An 34); diopside ($c > Ng = 38,5°$) is xenomorphic and is associated with magnetite. The late magmatic solutions from the deuteric stage, which led to the formation of the plagioclase marginal zone, determined also the recrystallization of some clinopyroxene crystals. The gabbro rhythms occurring in anorthosites in the eastern part of the dike consist of plagioclase (An 55—48) and diopside replaced by a brown hornblende (Ng = brown; Nm = dark brown; Np = yellowish-brownish; $c\ Ng = 20°$) < at the expense of which there form a green-bluish hornblende and then actinolite.

2. The Median Zone, within which G. Cioflica and H. Savu described the rhythmic layering in 1963, consists mainly of diopside gabbros, four horizons being distinguished: (a) an upper horizon formed of gabbros with thin levels (rhythms) of leucogabbros with diopside and quartz, and hypersthene gabbros; (b) three horizons situated in the lower part of the zone. All the horizons form a structure with rhythmic layering, the concavity of which being upward (Fig. 1.)

a. The leucogabbros and gabbros from the upper horizon are rocks rich in slightly zoned plagioclase (64—54 %), within which clinopyroxene is accompanied by hypersthene and quartz.

b. The three lower horizons consist of microrhythms of rocks varying in structure and composition (dolerites, hypersthene gabbros, hyperites, gabbros with vanadium titanomagnetite etc.). These horizons are thicker on the south-eastern margin of the body, where higher vanadium magnetite concentrations (5—15 %) are found. The gabbros in this zone consist of 50 % plagioclase (An 52), but in some schlieren the rocks tend to enrich in clinopyroxene and brown-greenish deuteritic hornblende which occurs also on the fis-

sures (Photo 1); other schlieren consist of pegmatoid gabbros.

The rocks of the three lower horizons with rhythmic layering differ from the other gabbros by the more elongated aspect of the plagioclase crystals and the divergent structure. One should mention the hyperites that consist of 54 % plagioclase (An 58), 14 % diopside, 15 % hypersthene, 6.5 % olivine, 7 % deuteritic hornblende and 3 % biotite. The xenomorphic diopside presents pigeonite exsolution in the form of little plates. Hypersthene shows the following characteristics: Ng = slightly greenish, Np = slightly reddish; it is replaced by bastite on the fissures. Olivine, which forms small and idiomorphic crystals included in pyroxenes,

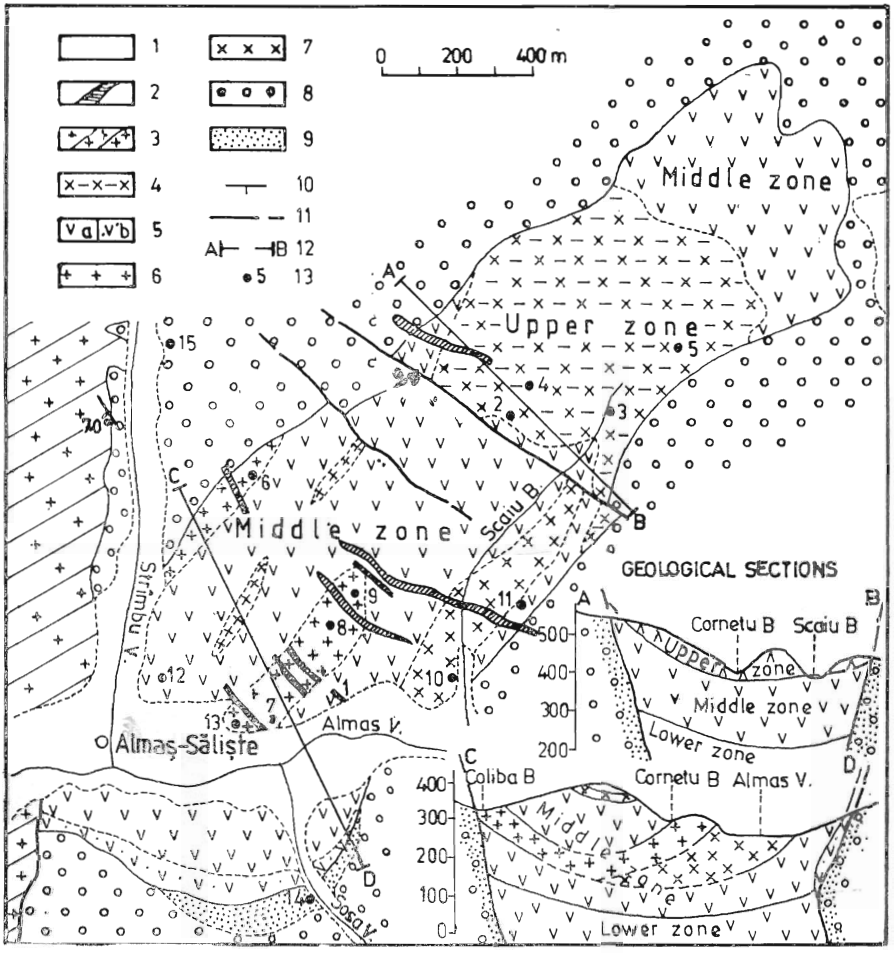


Fig. 1. Geologic map of the layered gabbroic dike of Almaș-Sălișteа. 1 — alluvia, 2 — vein rocks, 3 — granites and granodiorites (Cerbia massif), 4 — anorthosites, 5a — gabrros with diopside ± quartz, 5b — microgabbros, 6 — ferrogabbros, 7 — gabbros with hypersthene, hyperites, ferrogabbros, 8 — basalts and anamesites, 9 — basic hornfelses, 10 — granite/basalt contact, 11 — fault, 12 — geological section, 13 chemical and spectral analysis

is frequently replaced by bowlingite. The most characteristic rocks in this zone are ferrogabbros or gabbros with vanadium titanomagnetite; the latter mineral is usually xenomorphic and contains ilmenite exsolutions.

Microgabbros are found on the southern margin of the body (Fig. 1).

3. The Lower Zone seems to be more homogeneous as it consists of diopside gabbros, within which rare thin levels of hypersthene gabbros can be separated.

The ocean floor basalts were thermally metamorphosed at the contact with the gabbro body and transformed into hornfelses with the plagioclase-clinopyroxene-amphibole-magnetite paragenesis. This paragenesis formed under the conditions of the hornblende hornfelses facies at about 700 °C, the temperature at which, as established by H. Savu and C. Udrescu in 1967, the gabbro body was also formed. Like the whole ophiolitic series in the Mureș Zone, the effusive and intrusive rocks at Almaș-Săliște ere also subjected to ocean floor metaborphism processes in the albite-epidote-amphibolitic, greenschist and zeolitic facies (Savu, 1967; Coleman, 1977).

The gabbro body is crossed by dolerite and albitic plagiaplite dikes (Photo 2) of the concanguineous ophiolitic series, island arc basalt, rhyolite and orthophyre veins (J_3—Cr_1) and by porphyries connected with the Cerbia acid body.

Petrology and Geochemistry

The chemical composition of gabbros is rather similar to that of the tholeiitic basalt (Table 1, № 15) except for the ferrogabbro, which is richer in iron (Table 1). Leucogabbros are marked by higher Al_2O_3 and CaO amounts, while anorthosites are richer in SiO_2, Al_2O_3, CaO and Na_2O, but they are poor in iron and MgO. The albitic plagiaplites, which are the last differentiates of the tholeiitic magma, are the richest in SiO_2, Na_2O, Y and Yb.

The minor elements show a similar behaviour to the major ones, with which they are closely connected. Vanadium, which is of about 250 ppm in most rocks (Kraft — Schindler, 1961), reaches 730—1,000 ppm in the ferrogabbros and leucogabbros rich in magnetite from the Median Zone. The Cr-Ni correlation is positive, while the Cr/Ni ratio decreases from gabbros (3.5—2 ppm) to anorthosites

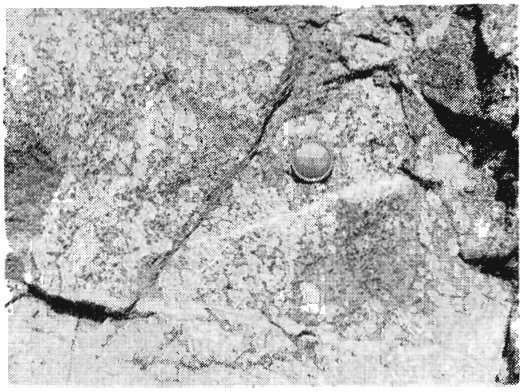


Photo 1. Gabbro with diopside and deuteritic hornblende. Almaș Valley

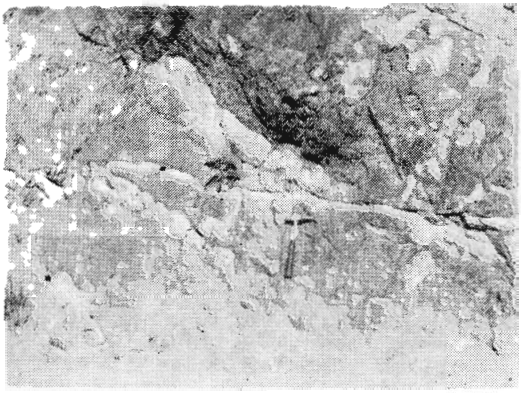


Photo 2. Plagiaplite veins in gabbro. Almaș Valley

Major and trace elements analyses

Table 1

Sample / Element	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SiO_2	52.57	51.98	51.53	50.20	51.71	48.13	47.96	47.37	46.85	46.20	45.94	45.58	46.20	48.79	48.45
Al_2O_3	19.80	23.20	20.90	21.50	15.81	19.14	16.64	21.80	22.85	16.65	18.31	20.42	16.65	14.74	14.84
Fe_2O_3	1.08	0.57	0.88	0.87	2.39	2.13	2.72	3.36	2.45	3.77	2.39	3.05	3.77	5.99	3.61
FeO	1.86	0.59	0.76	1.58	3.79	3.52	3.98	4.07	3.11	4.80	3.45	4.21	4.80	4.78	5.30
MnO	0.08	0.05	0.06	0.10	0.13	0.13	0.15	0.13	0.11	0.15	0.13	0.15	0.15	0.09	0.20
MgO	3.68	2.58	3.44	4.90	8.91	4.09	8.66	3.71	4.15	8.30	6.67	8.79	8.30	5.85	7.43
CaO	11.10	14.17	15.27	15.03	11.79	15.04	14.34	13.38	15.15	15.61	15.72	13.62	15.61	12.87	13.01
Na_2O	4.62	3.22	3.50	2.95	2.35	2.95	1.70	2.25	1.80	1.40	2.25	1.80	1.40	2.79	2.30
K_2O	0.40	0.30	0.10	0.01	0.25	0.45	0.53	0.50	0.45	0.15	0.20	0.65	0.15	0.20	0.55
TiO_2	1.39	1.18	1.36	0.98	0.70	1.44	0.48	0.71	0.52	0.57	1.68	0.62	0.57	1.65	1.22
P_2O_5	0.67	0.21	0.51	0.27	0.31	0.77	0.05	0.42	0.20	0.06	0.33	0.11	0.06	0.27	0.26
CO_2	0.30	0.30	—	—	—	1.07	0.62	—	0.59	0.40	0.69	0.30	0.40	—	—
H_2O+	1.78	0.97	1.19	1.01	1.89	1.70	1.58	1.64	1.19	1.36	1.62	0.99	1.36	1.38	2.31
S	0.07	0.07	0.06	0.06	0.07	0.07	0.07	0.09	0.08	0.08	0.06	0.06	0.08	0.18	0.07
Fe(S)	0.06	0.06	0.05	0.05	0.06	0.06	0.06	0.08	0.07	0.07	0.05	0.05	0.07	0.15	0.06
Total %	99.46	99.46	99.61	99.42	100.16	100.69	99.54	99.41	99.57	99.56	99.51	100,40	99.56	99.73	99.60
Ni	55	14	32	48	210	44	100	44	28	180	130	67	75	77	70
Co	17	6	9.5	14.5	43	28	33	40	22	55	31	40	50	30	46
Cr	42	4.5	14	75	550	17	145	17	38	420	34	160	12	225	260
V	250	230	440	420	310	520	215	320	250	400	1000	350	730	430	290
Sc	29	14	30	30	36	44	38	30	19	45	65	39	44	44	35
Zr	67	66	66	57	115	55	38	50	20	35	80	53	72	120	110
Y	38	13	20	17	17	30	11	16	< 10	10	16	12	12.5	39	27
Yb	4.7	2.5	2.3	3.4	2.7	5	1.8	2.3	1.1	1.5	4.7	2.1	2.3	6	4.6
Nb	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	10	< 10
Ba	190	140	90	65	190	85	120	160	190	75	160	100	92	26	44
Sr	70	480	400	420	520	480	360	550	480	340	550	440	370	160	290
Ga	22	23	22	17	14.5	18.5	15	20	16	14.5	19	17	21	23	12
Cu	11	7	5	6.5	8.5	13	14	70	17	22	28	38	115	29	30
Pb	5.5	5	5.5	2	3.5	3.5	3	5	2.5	3.5	10	9	4.5	< 2	3.5
Sn	3.5	< 2	< 2	< 2	2	2.5	3	< 2	< 2	2	< 2	2	3.5	< 2	< 2

Anorthosites: 2, 3, 4; gabbro in anorthosites: 5; leucogabbros: 6, 7, 8, 9; magnetite leucogabbro: 11; hyperite: 10; gabbro: 12; magnetite gabbro: 13; basalt: 15; basic hornfelse: 14; plagiaplite: 1.

(1—0.3 ppm). Ferrogabbros and some leucogabbros contain a low amount of Cr, a reason why the Cr/Ni ratio is round 0.3. The Co values greatly decrease from gabbros to anorthosites (Table 1).

Zr, Y and Yb have a positive correlation with Ti (Fig. 2), which shows that the parental magma underwent a differentiation process. The Ba contents range between 26 and 120 ppm in gabbros and basalts, but in most rocks rich in plagioclase they are above 120 ppm. Sr shows much higher values than in the ocean floor rocks, its concentration being favoured by the plagioclasic character of the Ca-rich rocks that resulted from the accumulation of the plagioclase crystals in the upper part of the dike.

The gabbroic dike started at the level of the sheeted-dike complex (O_2) of the Mureș Zone or even at a lower level. At the moment of the intrusion the parental magma, the composition of which was similar to that of the tholeiitic basalt (Fig. 3), had already undergone a certain differentiation in the magmatic chamber situated in the mantle, under the spreading zone or in an intermediary one, so that it had become somewhat richer in aluminium and calcium.

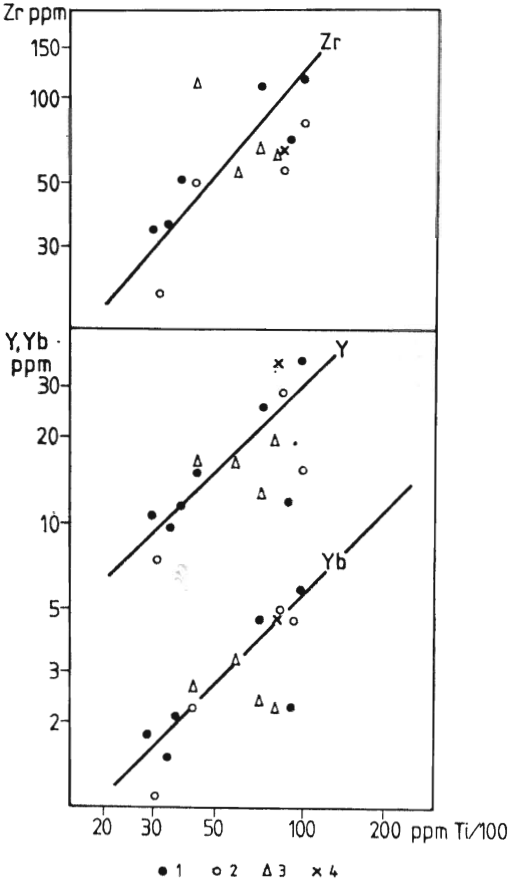


Fig. 2. Zr, Y, Yb-Ti diagram. 1 — basalts and gabbros, 2 — leucogabbros, 3 — anorthosites, 4 — albitic plagiaplites

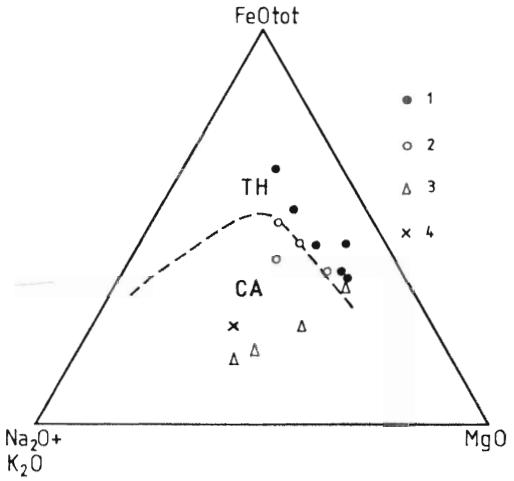


Fig. 3. FeO (tot) — MgO — $Na_2O + K_2O$ diagram (after Irvine and Baragar, 1971). Legend from Figure 2

The more aluminous magma character allowed first the crystallization of the plagioclase, which floated towards the upper part of the intrusion, forming the anorthosite zone and the leucogabbro rhythms beneath it. Under these conditions iron (Kennedy, 1948) and magnesium

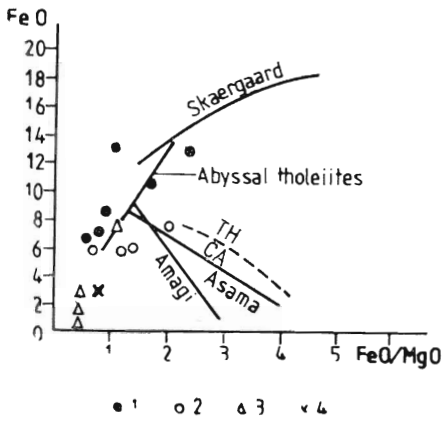


Fig. 4. FeO (tot) — FeO (tot)/MgO diagram (after Miyashiro, 1975). Legend from Figure 2

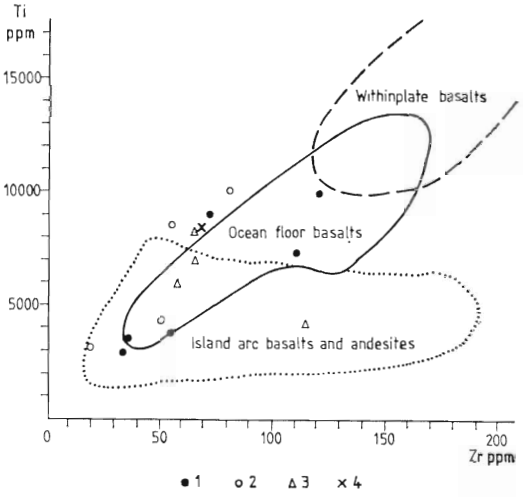


Fig. 5. Ti-Zr diagram (after Pearce and Gale, 1977). Legend from Figure 2

accumulate in the lower horizons with rhythmic layering from the Median Zone, there resulting more melanocrate rocks and ferrogabbros. This phenomenon seems to be slightly manifested in the Lower Zone, in which only rare rhythms of hypersthene gabbros form.

Thus the intrusion undergoes a gravitational differentiation (in situ) through fractional crystallization, under the control of the variable tension of the volatiles, especially of the PH_2O and the mean oxidation degree of the magma (W — 0,42). Nevertheless most rocks preserve the charaster of ocean floor tholeiites of the ophiolitic series in the Mureş (Figs. 4 and 5), excepting, as in Figure 3, the cumulates rich in plagioclase and the plagiaplites.

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Intracrustal manifestations of the basalt layer in the development of the Moravian block

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Интракрустальные проявления базальтового этажа в развитии Моравского блока

Если обсуждаем возможность наличия базальтов и ультрабазальтов в пространстве моравского блока с точки зрения геологического синтеза, устанавливаем их прямое отношение к тектогенезу и одновременно формовочному анализу базальтового этажа. И по геофизическим данным является пространственное размещение очевидное в зонах тектонической передиспозиции и назначает возможность — если берём во внимание близость поверхностного действия периферии ледницкого и пржибиславского разлома — транспорта этих ультрабазитов в интракрустальные, или даже в субпракрустальных частей земной коры моравского блока. Поэтому является заметным, что основные и ультраосновные породы юговосточной части Ческого массива имеют тесное отношение к базальтовому этажу или верхнему плащу.

Intracrustal manifestations of the basalt layer in the development of the Moravian block

Considering the occurrences of basic and ultrabasic rocks in the area of the Moravian block from the viewpoint of its general structure, a close relation may be deduced between tectogenesis and shape properties of the basalt layer. Geophysical data confirm the disposition of basites along tectonic zones and point to the transport of ultrabasites into intracrustal and, eventually, even supracrustal levels along the Lednice and Přibyslav deep-seated faults. Hence the basic and ultrabasic rocks along the SE periphery of the Bohemian mass reveal close relations to the basalt layer or eventually to the upper mantle.

The Earth's crust overtakes crucial function in endogenous processes. Decisive role is played by dynamics of intracrustal portions in the crust so in relation to deep-seated processes as by the generation of tectonic discontinuities originating ex-

clusively in supracrustal parts of the Earth.

Characteristics of the basalt layer

The part of the Earth's crust occurring between the C- and M-discontinuities is called the basalt (or gabbro) layer in the literature. Its behaviour is known mainly from geophysical data whereas the geological nature is approached by a whole set of models.

According to geophysical data, this basalt layer appears heterogenous as is the whole crust composed of low and high velocity zones or channels of both horizontal and vertical attitude. The usually indicated span of seismic wave velocities between the lower and upper boundary of this layer (neutrally assigned using the Bullen's model sometime as the A_2 layer) is 6.1—7.1 km . s^{-1} for P-waves and 3.6—4.2 km . s^{-1} for S-waves. The boundary towards the higher layer is not everywhere pronounced and there are already several examples when the Conrad-discontinuity may not be identified (e. g. for Czechoslovak territory; Zoubek — Vyskočil, 1971, Beránek et al., 1971). Views appeared in this connection that the layer may be composed of more peridotitic rocks than basalts. The basic division of the basalt layer as done by H. H. Hess (1955) distinguished four models: peridotite — gabbro, peridotite — amphibolite, peridotite — granulite and granulite — eclogite. The nature of the basalt layer is usually explained setting out from its physical properties but even more from its composition. From the compositional point of view, the basalt layer is assumed to represent a complete ophiolite suite *sensu* Peive (1974) or Coleman (1977). This view is substantiated by concrete data obtained through ocean floor dredging and, peculiarly, by the detailed knowledge of rocks drilled by the deep drilling on Kola peninsula in the USSR.

Practical experience leds us to an important problem: seismic horizons with boundary velocities of 6.6—7.2 km . s^{-1} contradict, even in well distinguished places, to the presumed attitude of the upper boundary of the basalt layer. Downwards from this boundary, there are layers in the crust in which seismic velocities correspond still to granite. Therefore the distinction of the upper boundary of the basalt layer is made using the elastic but not boundary velocities.

Seismic horizons with elastic wave velocities of 6.5—7.2 km . s^{-1} may directly not be ascribed to the Conrad-discontinuity but to layers of overwhelmingly basic rocks. Therefore if seismic horizons with velocities of 6.6—7.2 km . s^{-1} do not reflect the upper boundary of the basalt layer then, in fact, may represent some of crustal horizons vhere the composition is still granitic nevertheless already considerable amounts of basic or ultrabasic rocks occur. Seismic velocity values are usually not high enough to presume a general continuity between such zones and the upper mantle. Namely this pattern is pointed out by Wyllie (1976) who strongly disputes the presumption that each gabbroic body, or even every inclusion of basic and ultrabasic composition, could be derived from a mantle source. Rather a crustal origin is maintained and substantiated also by geochemical aspects (Weiss 1971).

It may be supposed that more properly are the factological data (attenuated crust, presence of ultrabasics, thickening of the basalt layer, gravimetric and frequently even magnetic highs) deduced from seismic indications and interpreted by the means of lamellae (Meissner, 1967) or pillows (Khropotkin, 1973, Moisseenko, 1975) cha-

racterizing different (more dense or quick) physical parameters.

In analogy to the Earth's crust, also in the case of basalt layer, two subtypes are distinguished: continental and oceanic one. In the continental type of basalt layer, also comprimed types of acidic plutonites and metamorphics are present whereas rocks of the ophiolite suite prevail in the oceanic one. Nor the presence of acid volcanites may be excluded from the latter.

In the continental type, physical manifestations of a two-layer basaltic crust occur in Europe and America mainly in areas of crustal thickening (e. g. beneath the Alps). P-wave velocities are here about 7 $km.s^{-1}$ or sometime higher. The layer usually is assigned as a "high-velocity" one. Probably, basic rocks participate on its composition namely basaltoids splitted from the mantle and creating the pillow-shaped bodies mentioned. Basalts as rocks of lighter densities in comparison with the deeper mantle may heighten the overlying crustal blocks and so induce rejuvenated lifting of units earlier stabilized. It may not be excluded that the high velocity layer is part of the upper mantle from the time of differentiaton. The residual heavy masses occur, after the splitting of basaltoids, in greater depths and are reflected by "normal" mantle velocities of P-waves. Evidently, the crust does not consist only of a layered basalt seam filling up the whole space between C- and M-discontinuities. Under the rocks of basaltic, or according to velocities of similar, composition and situated near to the C-discontinuity, there also rocks of granitic character appear in crustal sections. This pattern substantiated in the Ukrainian shield and Bohemian mass or elsewhere is not a local symptom but evidently a certain rule. Hence this aspect must be kept in mind even when investigating the nature of the basalt layer in the Moravian block.

Geological interpretation

The increased accumulation of ultrabasite bodies in the Moldanubicum of the Moravian block reflects processes within its infracrustal portion. Results of recent seismic and gravimetric investigations allow to interpret the spatial distribution of ultrabasite bodies in relation to the shape of the basalt layer or, eventually, with the upper boundary of the upper mantle.

The vertical infracrustal model of the Moravian block reveals variegated and specific distribution of velocities (Beránek et al., 1975). Velocity gradient in the Moravian block may be observed near to its western and eastern margin. The cause is that a layer of higher velocities has been found from the Přibyslav deep-seated fault eastwards emerging further towards the western margin of the Moravicum up to about 15 km depth. Beneath this zone, a layer of lower velocities occurs again. Therefore the apparent increased thicknes of the basalt layer is here compensated by low-velocity channels situated, in the Moravian part of Moldanubicum, in 22—34 km depths. Below the zone of high velocities, rocks of lower velocities (6.6 $km.s^{-1}$) may be observed along the western periphery of the infracrustal part of the Moravian block what points to the presence of sialic rocks under the rocks of the basalt layer. An analogy with the Ivrea zone is therefore highly probable. Differences in contrast with the position of the latter are only that rocks of the basalt layer did not emerge into high crustal positions as is the case in the Ivrea zone (Weiss, 1977).

Velocity distribution models of the crust in the Bohemian mass and West Carpathians (Beránek, 1975) together with results of geophysical investigations along their

contact (Beránek — Adam, 1975) allow to interpret piling up of basic and ultrabasic rock masses in relation with the Lednice deep-seated fault. The basites represent rocks dredged tectonically or magmatic masses intruded into higher levels along the disjunctive structure represented by the Lednice deep-seated zone.

Adam et al. (1976) assumed the Lednice deep-seated fault to have characteristic pattern of a fault limiting megablock margin: it acquires linearity of mobile belts and spatially broadens its mobility (occurence of basics and ultrabasics). The fault is characteristic also by marginal depressions in the Alpine-Carpathian foredeep (Upper Morava dales) developing allways upon consolidated blocks. A pronounced downfaulting of the autochtonous basement relief is indicated by both refractive and reflexion profile data from the supracrustal portions. Northeasternly from this structure, the autochtonous basement is interpreted in about 2 km depth whereas it merges gradually into more than 7 km southeastwards. This merging is due to the function of the Lednice deep-seated fault.

Owing to the anomalous distribution of velocities, the dragging out of the Carpathian basalt layer is interpreted, on Czechoslovak territory, in the space of the Lednice deep-seated fault (Beránek — Dudek, 1977, Beránek, 1978). The obduction of the Carpathian basalt layer may be caused by the subduction movement of the Bohemian mass. According to the authors indicated, apical portions of the basalt layer occur in 10 km depth below the recent surface and only 2 km below the surface of the crystalline basement.

Hence the belt of higher velocities related to supracrustal parts of the Lednice deep-seated fault zone may be explained by the presence of rocks of the basalt layer. The disturbed magnetic field correlates even well with such meaning. The Lednice fault is also indicated by a sharp change in thicknesses of flysch nappes deduced from both refractive and reflexion seismic profile data.

The geological model of the Moravian block (fig. 1) reveals southeastward attennuation of the crust whereas the Moho-discontinuity strongly rises. In the western part of the Moravian block, rocks with higher velocities already characteristic for the basalt layer occur in 15 km depth. Underneath again rocks of granitoid character appear in the velocity pattern. The feature may be explained by upthrusting of the Moldanubian block over the Moravian one whereas rock masses of the basalt layer have been squeezed-out into the uper portions of the downfaulted Moravian block. The oncoming of the basalt layer into upper crustal levels may be placed in the space between the eastern margin of the Třebíč durbachite massif and Brno massif. Besides velocity data, this solution is substantiated even by densities (gravimetric high) and, particularly, by the extensive regional positive magnetic anomaly in the 1 : 1.000,000 scale aeromagnetic map. All data coincide well with the frequency of ultrabasite occurrences in supracrustal portions of the Moravian block here.

The main distribution of NW—SE trending elevation and depression structures appears even in the general geological picture. Gravimetric data prove the coincidence of elevation structures (western part of the Moldanubicum, Krušné hory Mts.) with gravimetric minima and that of depressions (Barrandian, Saxothuringian) with gravimetric highs (Beránek et al., 1980). The character of such regional gravimetric anomalies is influenced just by changing thicknesses of the basalt layer. Its dissected upper boundary and proximity to the recent surface is conspicuous along the eastern margin of the Molda-

nubicum where the coincidence with frequent occurrences of basite and ultrabasite bodies allows to assume a collision belt of the Variscan orogen with the older crystalline of Brunovistulicum.

The large regional anomaly along the contact of the Bohemian mass and West Carpathians could be interpreted as being related to the emplacement of ophiolite suite rocks along the Lednice deep-seated fault into supracrustal levels. This fault so represents a peripherial structure to the Bohemian megablock unit and to the Central European Epivariscan platform.

Manifestations of the basalt layer

Several bodies of basic and ultrabasic rocks contained in the Moravian block represent in fact segmented and metamorphosed members of originally ophiolitic associations derived from oceanic crust and upper mantle. If based on relations between the pyrope peridotites and eclogites in the Moravicum, it may be further deduced their pertaining to a metaophiolite association and together with the latter allways to a continental crust.

An exception to this rule is represented particularly by the position of the Letovice synform (Mísař, 1979) consisting unambiguously of rocks of tholeiitic magma affinity where distributions of Ti and Cr point to ocean floor basalts (Jelínek et al., 1978). According to the mafic index and silica content, ultrabasites fall into the field of ultrabasic cumulates or gabbros whereas the majority of amphibolites has figurative points in the field of basic cumulates of typical ophiolite complexes. Accordingly, basites and ultrabasites of the Letovice crystalline may be regarded, with high probability, to represent members of a metamorphosed ophiolite suite of Proterozoic age (Mísař, 1966, 1979).

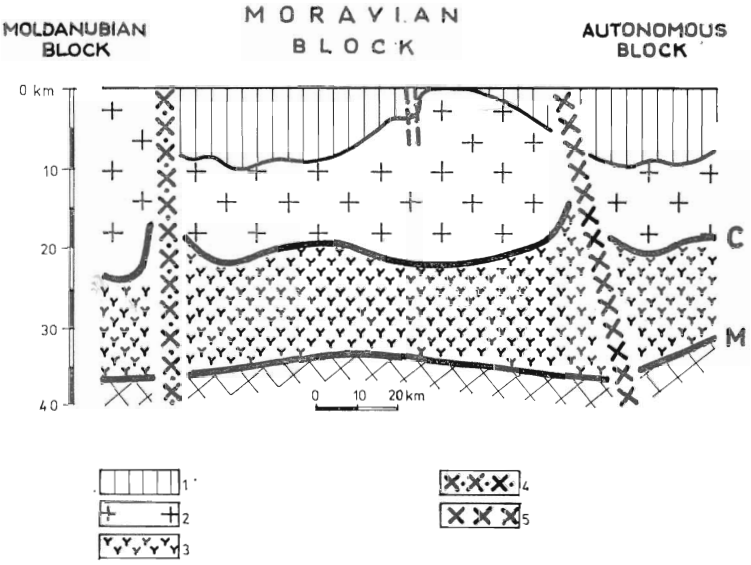


Fig. 1. Geological model of the Moravian block. 1 — crystalline complex, 2 — 2 — granit layer, 3 — basalt layer, 4 — Přibyslavice deep fault, 5 — Lednice deep fault

The Moravian block is limited from the west by the Přibyslav deep-seated fault. The existence of this fault, creating eastern marginal fault to the Central Moldanubicum mass, is definite according to seismic and gravimetric data. With the highest probability, the upvaulting of the basalt layer is also due to this deep-seated fault representing by its main characteristics a crucial marginal zone of the Moravian block of intra- to subcrustal range. In surficial crustal portions, it is accentuated by mylonites associating, besides ultrabasic rocks, also with eclogites and amphibolites. The Přibyslav deep-seated fault is of general metallogenetic importance as proved by numerous ore manifestations in Czechoslovakia (near Staré Ransko), Austria (Waldkirchen) and even in Poland.

Ultrabasites present in the central part of the Moravian block complicate the pattern of the magnetic field by reaching amplitudes up to several hundreds γ (Šalanský et al., 1967, Šalanský, 1972). This intricated pattern and sharp gradients of the field together with frequent superposition of magnetic sources in several levels result in such configuration of isoanomalies which, as the rule, could by no means completely reflect the cartographically ascertained surficial distribution of ultrabasite bodies. It is however really to assume considerably larger extent of ultrabasics in supracrustal levels e. g. westernly from Jevišovce, near Dukovany (Weiss, 1975) or near Dalešice (Weiss, 1971).

These relations are reflected also by the more dissected course of the basalt layer upper boundary, by its gradual eastward thickening and approaching the surface-near parts of the crust. In this case hence the interconnection of single ultrabasite occurrences in the depth is provable. What concerns the original continuity of basic and ultrabasic rock bodies to the upper mantle, a certain criterion may be their greater frequency in the Moldanubic part of the Moravian block. Results of detailed airborne geophysical measurements drew attention, besides numerous geophysical data, also to the regular distribution of ultrabasites within the Moravian block. Ultrabasite bodies appear as well expressed anomalies in the aeromagnetic picture. In the case of areally larger bodies (Bory, Borovník, Březí and Mohelno), data may be deduced for their depthward extension, dip etc. Besides these, geophysical data allow to trace some further occurrences within tectonic zones, namely the blind bodies without surficial outcrops due to their occupation of deeper crustal levels in the enclosing metamorphics or covered by thicker sediments of Quarternary or less Cenozoic age. Such ocurrences are namely in the Moldanubicum near Strážek.

The examination of geophysical results and recent geological data allow to assume effects of subsequent deformations on ultrabasite massifs expressed mainly by faulting (tectonic contours of some bodies are evidently observable) and vaulting (undulations) induced probably by folds of great amplitude and small heigh index.

The basite body on Moravské kopce locality westernly from Olešnice in Moravia consists, from petrographical point of view, of different amphibolite varieties (located in uppermost levels of the gneiss complex according to Mísař, 1966) and olivine gabbros. The presence of the latter is of peculiar meaning when assuming the model of deep origin for the Olešnice dome. Olivine gabbros from the Olešnice area represent, by internal fabric and geological setting, equivalents of analogous basic magmatites in the Moravian block (Weiss, 1957). A certain similarity in structural position may be observed by the

Uherčice gabbro (Němec, 1935) or by the olivine gabbro body in Železné near Tišnov (Rosický, 1926).

Westward from the Boskovice furrow, the lower boundary of the granite layer rises continuously to 15 km whereas the lower boundary of the basalt layer occurs in almost 35 km depth. The Boskovice furrow, in analogy with the Blaník one, has but supracrustal range though some authors assumed it to be reflection of a deep-seated fault (Jaroš — Mísař, 1965, 1967, Zeman, 1974, 1975. Such explanation seems to be supported by the sharp submergence of the Moho westernly from the furrow into almost 37 km level at the western margin of the Lednice deep-seated fault.

Granitoids of the Brunnia mass composing the Brno massif proper and creating part of the substructure in the entire eastern margin of the Moravian block as far as the Lednice deep-seated fault originated in the time of Cadomian orogenic cycle. Most of magnetic anomalies are created by intermittently magnetized horizons in the area. Anomalous belts, part of which is dissected into the mosaic of blocks, point to strong faulting and accomodate to, in a certain degree, the function of the Lednice deep-seated fault. The strike of single belts is not constant and, also due to the shattering of single block units, a gradual bending from N—S to SE is observable, i. e. into the area of the Carpathian foredeep.

From a regional point of view, such magnetized horizons in the Brno massif and representing more or less altered basic and ultrabasic rock varieties, are spatially cumulated in a metabasite belt. Some authors relate this weakened zone to gabbroic rock occurrences the Svitavy anomaly including (Čuta et al., 1964) in contrast to others denying relations with the Svitavy magnetic anomaly and, namely, with the gravimetric high (Mísař et al., 1972, Weiss, 1977).

In the eastern part of the Moravian block but mainly in the autochtonous block unit covered by Paleozoic, Jurassic and mostly Cenozoic sediments of the Carpathian foredeep or partly even by overthrust of Outer Carpathian nappes, ultrabasic rocks are not too much known. More frequent occurrences are preferredly restricted to the Upper Morava dales where hidden bodies have been discovered by numerous hydrocarbon and other drillings. Bodies of a gabbro-peridotite complex occur near Vlkoš allways together with a set of secondary alterations (mainly amphibolization, chloritization and steatitization). In analogy, the Rusava ultrabasite (gabbro-norite) massif occurs along the Holešovice fault system in spatial proximity with teschenite occurrences (Dudek in Weiss et al., 1978). Rocks of the teschenite association represent, substantially, the continuation of both intrusive and effusive members of the metaophiolite complex.

A gravimetric low may be interpreted in the Vienna basin area caused by superposition of more shallow (15 to 25 km depth) and deeper (35 km) sources. In the area of Upper Morava dales, a body inducing negative disturbance of the gravity field is assumed having its upper boundary in 35 km depth and the centre of gravity about 45 km below the recent surface. The main source of the negative anomaly along the boundary of the Bohemian mass and West Carpathians is usually explained by the basalt layer and the relief of the Moho-discontinuity. These factors are multiplied by the influence of inhomogeneities in the basalt layer itself and, obviously, by interferences of light sedimentary masses in supracrustal portions.

Ultrabasics and related rocks are

confined, in the Brunnia mass, to the Brno massif and its crystalline envelope. The geotectonic position of the Brno massif in the area of strong Variscan tectogenesis together with its Assyntian age (Štelcl et al., 1978, Štelcl — Weiss, 1983) create entirely different conditions for the distribution of the metaophiolite complex.

Basite and ultrabasite bodies of the Brno massif are spatially confined to a metabasite zone running in belt-like shape, broad about 10 km and almost 50 km long, through the central part of the massif. The metabasite zone may be divided into two subzones (Mísař, 1980). The westernly metadiorite subzone is relatively thicker and is composed of even xenoliths, diorite, gabbro (even olivine-bearing) and ultrabasite in the crystalline envelope namely in the southern part of the Brno massif. The eastern part is created by discontinuous metadiabase subzone.

Ultrabasite bodies in the metabasite zone are less frequent (Moravany, Želešice, Bystrc, Kohoutovice, Milonice, Jinačovice and Kuřim localities). Probably, the entire metabasite belt creates an assymetric synform structure. Such arrangement results from interpretation of the gravity field in the northern part of the zone (Skácelová — Weiss, 1978). Obviously, the metabasite zone continues accross the Želešice magnetic hight to SE into the Carpathian foredeep.

Contrary to the ultrabasics, gabbroid rocks are not so strictly confined to the zonality of the metabasite zone though generally reveal also a N-S spatial distribution (Kamenný vrch, Podskalský mlýn and Kounice localities). Such distribution is well expressed by the appearance of the metabasite zone in geophysical data. In gravity maps, the zone creates a relatively broad belt of positive anomalies of NNE-SSW strike arching into NW—SE direction in its southern part. Such course is reflected by pronounced magnetic pattern (Šalanský et al., 1965) and converging also with the continuation of this abundantly differentiated belt southwards.

Conclusions

Evaluating the presence of basics and ultrabasics in the Moravian block from the viewpoint of synthetic geological approach and existing geophysical data, their immediate relation to tectogenesis and, namely, to the shape pattern of the basalt layer may be deduced. Geophysical data disclose their spatial distribution into the belts of tectonic predisposition and point to the possibility, assuming also the proximity of surficial manifestations along the periphery of the Lednice and Přibyslav deep-seated faults, that these ultrabasites have been transported into infracrustal or even supracrustal situations within the Moravian block. Hence, the prevailing close relation of basic and ultrabasic rocks to the basalt layer of the crust or even to the upper mantle becomes evident in the southwestern part of the Bohemian mass.

Several from the previous conclusions have the nature of working hypotheses as the Conrad-discontinuity occurs in about 20 km depths in this crustal area (fig. 1). In spite of its location in such considerable depth, data allow to deduce the characteristics of the crust and pose a set of problems to be solved in the future. In the case if some of previous conclusions are pertinent, possibilities arise to the knowledge of processes taking place within the Earth's crust since accumulations of mineral raw materials are immediately depending on the type of crust.

Translation by I. Varga

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Intrakrustální projevy bazaltového patra ve vývoji moravského bloku

JAROSLAV WEISS

Posuzujeme-li možnosti existence bazitů a ultrabazitů v prostoru moravského bloku z hlediska geologické syntézy a dosavadních geofyzikálních výsledků, zjišťujeme jejich přímý vztah k tektogenezi a zejména tvarové analýze bazaltového patra. I z geofyzikálních materiálů je prostorové rozmístění na zónách tektonické predispozice zřejmé a naznačuje možnosti — bereme-li v úvahu těsnou blízkost povrchových projevů periférie lednického a přibyslavského hlubinného zlomu — transportu těchto ultrabazitů do infrakrustálních, popřípadě až suprakrustálních částí zemské kůry moravského bloku. Je tedy evidentní, že bazické až ultrabazické horniny jihovýchodní části Českého masívu mají převážně úzký vztah k bazaltovému patru, případně svrchnímu plášti.

Mnohé z uvedených závěrů mají charakter pracovní hypotézy, poněvadž, jak vyplývá ze základního obrázku č. 1, se Conradova hranice pohybuje v této části zemské kůry průměrně okolo — 20 km. I když je tato úroveň poměrně ve velkých hloubkách, přesto si můžeme jednak vytvořit určitý obraz o geologickém charakteru zemské kůry, jednak před nás předstupuje celá řada otázek, které je nutno v budoucnu řešit. V případě, že některé závěry ve výše uvedeném textu jsou správné, otevírají se nám možnosti poznání charakteru procesů probíhajících v zemské kůře, poněvadž na jejím typu je přímo závislá přítomnost kumulací rudních i nerudních ložisek.

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Петрология метаморфизованных ультрабазитов забырденского района (Центральные Родопы, Болгария)

КРИСТИНА КОЛЧЕВА, МАРИЯ ЖЕЛЯЗКОВА-ПАНАЙОТОВА, ЖИВКО ИВАНОВ

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(2 рис., 5 табь. в тексте)

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Петрология метаморфизованных ультрабазитов забырденского района (Центральные Родопы, Болгария).

В нижней части метаморфитов среднеродопской группы обнажаются несколько линзевидных тел ультрабазитов. Тело на вершине Ченгене кёшк представлено гарцбургитами с переходом в дуниты. Тело „Балабан" имеет выразительно полосчатое строение (полосы дунито-гарцбургитового и оливино-пироксенового сложения). Для всех тел характерным является низкая степень серпентинизации; в их составе принимают участие ассоциации высокотемпературных минералов. Тела ультрабазитов первоначально представляли олистолиты в осадочной секвенции, вместе с которой были метаморфированные и затем частично серпентизированные

Petrology of metamorphosed ultrabasites from the Zabărdo village area (Central Rhodope Mts., Bulgaria)

In the lower part of metamorphites in the Central Rhopode group, several lense-shaped ultrabasite bodies do occur. The body on Tshengene kemk hill consists of harzburgite passing into dunite whereas the Balaban body reveals well expressed banded structure with bands of dunite-harzburgite and olivine pyroxenite. All bodies are characterized by only low degree of serpentinization and the high-temperature mineral assemblages are preserved. Originally, ultrabasite bodies created olistoliths in the sedimentary sequence and underwent metamorphic alteration together with the enclosing rocks. The slight serpentinization is a subsequent phenomenon.

В ряде районов Центральных Родоп, в нижних частях разреза метаморфитов Центральнородопской группы, представлены включения изолированных линзообразных ультрабазитовых тел. Так например, в окрестностях с. Забырдо (Смолянский округ) были установлены две более круп-

ные и несколько более мелкие тела (рис. 1). Вмещающие ультрабазитов породы представлены главным образом биотитовыми гнейсами, мигматизированные в различной степени, с прослоями относительно маломощных пачек амфиболитов в графит- и флогопитсодержащих мраморов. Они обособлены в т. н. Посестримской мраморно-гнейсовой свиты (Иванов и др., 1983).

Ультрабазиты окрестностей с. Забырдо относятся к выделенной ранее группе родопских дометаморфических ультрабазитов (Желязкова-Панайотова и др., 1977). Пока что этот район является единственным, где в наиболее древней ультрабазитовой группе установлены наряду с линзами метаморфических перидотитов (фрагменты нижнего уровня офиолитового разреза) еще и блоки разлоенного комплекса, при том довольно крупных размеров.

Одно из более крупных ультрабазитовых тел района расположено в 500—600 м северозападнее вершины Ченгене кёшк, а второе на расстоянии 1 км восток-североточнее от этойже вершины, в местности „Балабан" (рис. 1).

Первое тело в плане имеет почти изометрическую форму, размерами 450×500 м и пересекается в северной части пегматитовой жилой, мощностью около 5 м. Ультрабазитовое тело сложено перидотитами, переходящими в дуниты. Породы темносерого коричневатого цвета, мелкозернистые. В отдельных участках на мелкозернистом фоне выделяются крупные, до 1—2 цм, кристаллы ортопироксена. Характерна сферическая поверхность выветривания, очень хорошо выражен-

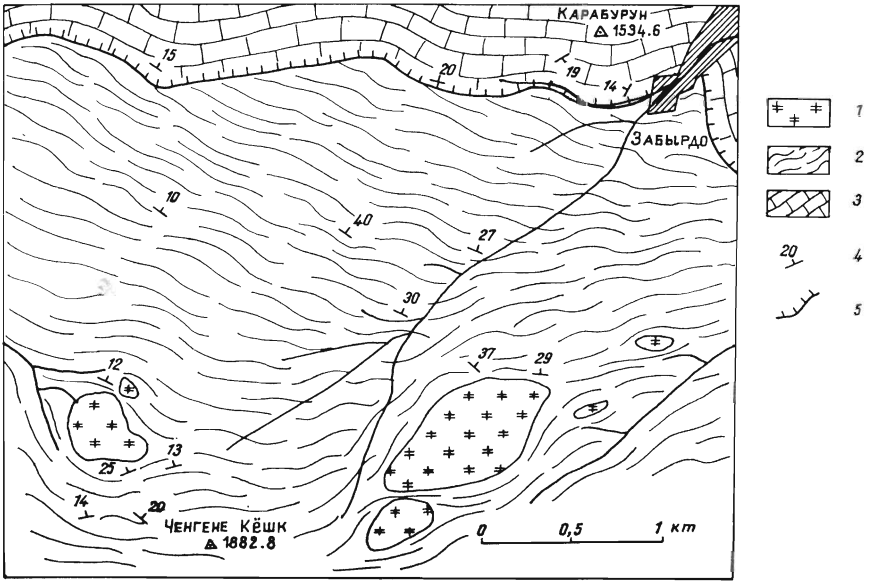


Рис. 1. Схематическая геологическая карта района с. Забырдо. 1 — ультрабазитовые тела, 2 — биотитовые до двуслюдянные гнейсы с прослоями амфиболитов и мраморов (Посестримская свита), 3 — мраморы (Добростанская свита), 4 — элементы залегания, 5 — надвиг

ная в отдельных участках, а также сланцеватость, конформная сланцеватости вмещающих метаморфитов. Степень рассланцевания сильно уменьшается к центральной части тела.

Ультрабазитовые тела в местности „Балабан" имеют более удлиненную линзовидную форму. Наиболее крупное из них достигает 1 км в длину, а в ширину — 600 м. Почти прямым продолжением от него, отделенном тонкой амфиболитовой прослойкой, прослеживается более мелкое тело размером 300×200 м. Ультрабазитовые тела очень мелких размеров наблюдаются несколько восточнее. Они сильно гидротермально изменены и характеризуются асбестовой и тальковой минерализацией. Более крупные тела в местности „Балабан" отличаются полосчатым строением. Полосы сложены двумя главными типами пород: дунитами, переходящими в гарцбургиты и оливиновыми пироксенитами. Мощность полос изменяется от 10 до 20—30 цм. Дунитовые полосы коричневато-серого цвета, мелкозернисты, характеризуются шаровидным выветриванием. В прослойках клинопироксенитов на сером мелкозернистом фоне выделяются темно-зеленые короткопризматические зерна клинопироксена, длиной обычно 0,3—0,5 цм, в отдельных случаях до 1 цм. Сферическая поверхность выветривания для них не характерна, что еще более подчеркивает полосчатое строение пород. И в этом случае ультрабазитовые породы рассланцованы. В особености ясно выражено рассланцевание в периферических зонах, кде процессы перекристаллизации проявлены наиболее ярко, вплоть до перехода ультрабазитов в тремолит-актинолитовые сланцы.

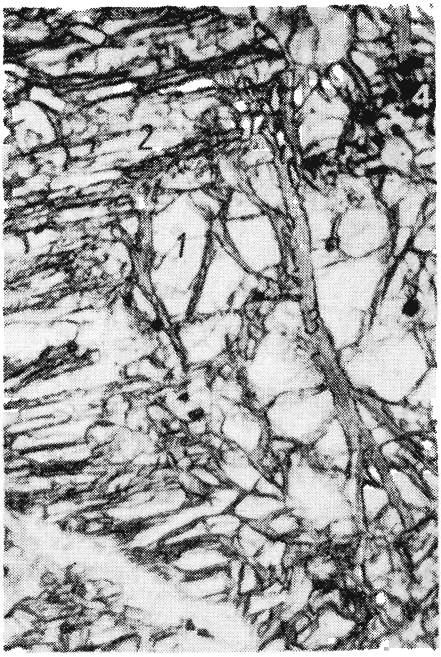
Ддя ультрабазитов в районе с. Забырдо характерны высокотемпературный минеральный парагенезис и очень слабая степень серпентинизации. Последняя проявлена локально и определенно приурочена к поздним тектоническим зонам.

Ультрабазитовое тело, вскрытое на северозападе от вершины Ченгене кёшк, отличается относительно монотонным петрографическим составом. Главным породообразующим минералом является оливин, количество которого изменяется от 98—95 до 60 %. В связи с этим выделены дуниты и богатые оливином гарцбургиты, количественно преобладающие (табл. I-1).

Оливин ($2V_z = 80—88°$) представлен как более крупными, так и мелкими зернами, всегда очень свежими. В периферических частях зерен и вдоль трещин в них развит тонко-петельчатый серпентин. Ддя более крупных зерен оливина иногда характерна хорошо выраженная спайность (табл. I-2), которая некоторыми авторами принимается как признак метаморфического происхождения.

Ортопироксен ($2B_x = 80—86°$) участвует в подчиненных количествах. Наблюдается в виде крупных до очень крупных призматических зерен, иногда слагающих веерообразно разветвленные агрегаты. Частично замещается серпентином или тальком. Нередко в крупных зернах ортопироксена включены мелкие пойкилобласты оливина.

Местами в породах наблюдается также тремолит в виде относительно крупных зерен призматического габитуса. Вторичная ассоциация минералов, включающая тонко игольчатый тремолит, серпентин, тальк и хлорит, замещает оливин, ортопироксен и крупнозернистый тремолит и имеет очень ограниченное распространение



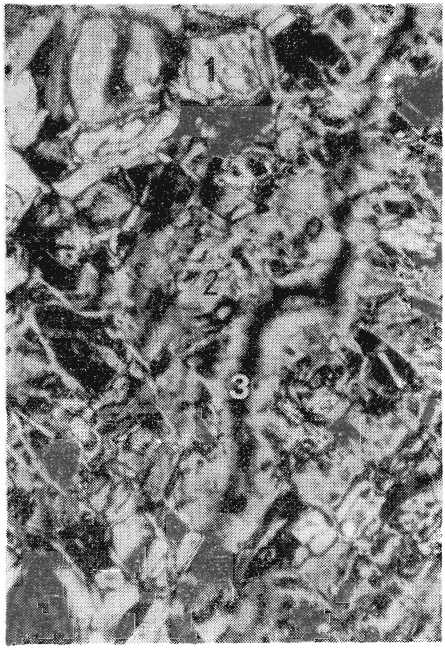
CH. 1



CH. 2



CH. 3



CH. 4

(обычно 5—10 % объема породы). Локально, вдоль трещин, узкие зоны пород подвергнуты интенсивной серпентинизацией (табл. I-3). Рудные минералы представлены хромшпинелидами (1—2 %), которые в дунитах образуют гнездовидные и полосчатые скопления (табл. I-4). Изучение их состава показало, что они относятся к редким видам шпинелидов с повышенной железистостью. Исследование двух мономинеральных проб позволило установить следующие кристаллохимические формулы:

$(Fe_{0.61}Mg_{0.39})\ (Cr_{1.21}Al_{0.44}Fe_{0.35})\ O_{4.00}$* и $(Fe_{0.66}Mg_{0.34})\ (Cr_{1.11}Fe_{0.51}Al_{0.38})\ O_{4.00}$.

Как было уже отмечено ультрабазитовые тела местности „Балабан" имеют ритмично полосчатое строение, обусловленное чередованием дунит-гарцбургитов с оливиновыми клинопироксенитами.

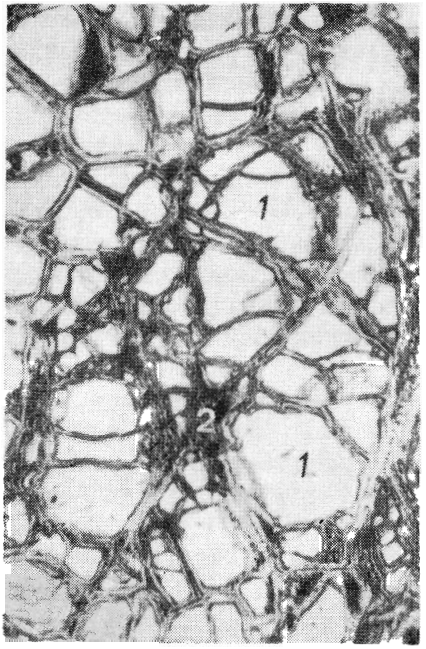
Минеральный состав в количественные соотношения породообразующих и акцессорных минералов дунит-гарцбургитов (табл. II-1) такиеже как и в породах выше описанного ультрабазитового тела около вершины „Ченгене кёшк".

В оливиновых клинопироксенитах главным породоовразующим минералом является клинопироксен. Он представлен двумя генерациями. Клинопироксен — I ($2V_z = 53—58°$) наблюдается в виде крупных до очень крупных (2—3 см) зерен. Под микроскопом устанавливается, что очень часто эти зерна изогнуты и трещиноваты (табл. II-2). Клинопироксен — II развит в виде мелкозернистого агрегата вдоль трещинок или в виде гнезд в крупных кристаллах клинопироксена — I (табл. II — 2, 3, 4). В отличие от клинопироксена — I, который содержит очень мелкие включения „рудной пыли", придающие ему мутный облик, клинопироксен II очень свежий и прозрачный. Выделения мелкозернистого рудного вещества наиболее хорошо выражено в центральных частях крупных зерен или вдоль спайности, что являются результатом частичной перекристаллизации клинопироксена — I. В состав породы входят также оливин и тремолит, которые слагают вместе с клинопироксеном — II мелкозернистую основную массу, окружающую или пересекающую в виде прожилков крупные помутневшие зерна клинопироксена — I (табл. II — 3, 4). Оливин обычно представлен в виде удлиненных линзовидных агрегатов (табл. II — 4). Очень часто на периферии зерен развиты боулингит-иддингситовые тонкочешуйчатые агрегаты, иногда полностью замещающие оливин. Наиболее хорошо в этом парагенезисе представлен тремолит-ак-

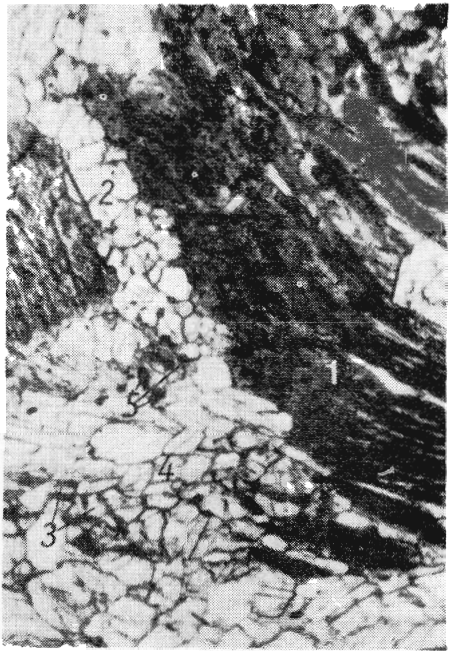
* a_0 — 8.32 Å, D — 4.60, n — 2.20, R — 14.4 %. H — 1080 кГс/мм², неферромагнитен (при 18 °C), содержание хрома изменяется зонально — в центральных частях зерен — 31,2 %, в периферических — 28.8 %.

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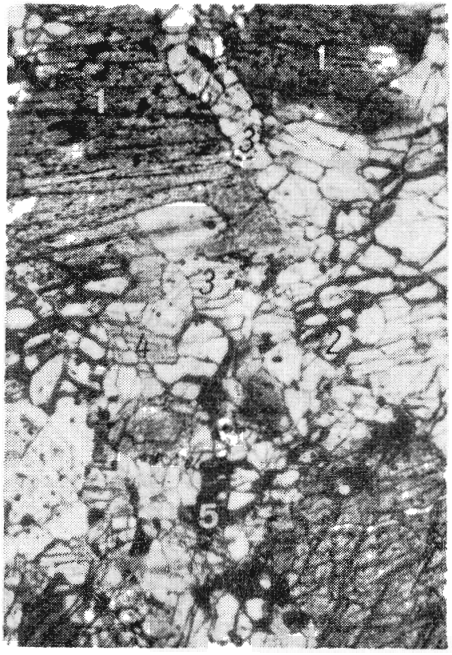
Таблица I. сн. 1 — Гарцбургит, Ченгене кёшк. 1 — оливин; 2 — ортопироксен; 3 — серпентин, 4 — железистый хромшпинелид. N II, увел. 60. сн. 2 — Дунит, Ченгене кёшк. 1 — оливин с ясно выраженной спайностью; 2 — серпентин; 3 — железистый хромшпинелид. N II. увел. 60. сн. 3 — Частично серпентинизированный дунит с рудной минерализацией, Ченгене кёшк. 1 — оливин; 2 — железистый хромшпинелид; 3 — хлорит; 4 — серпентин. N II, увел. 60. сн. 4 — Сильно измененный перидотит, Ченгене кёшк. 1 — реликты оливина; 2 — серпентин; 3 — серпофит. N +, увел. 60



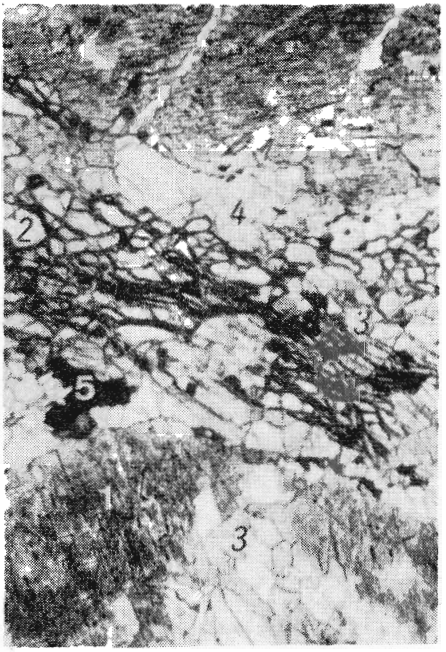
CH. 1



CH. 2



CH. 3



CH. 4

тинолит ($2V_x = 78—85°$), количество которого обычно возрастает к периферии ультрабазитового тела.

Кумулятивные структуры в исследованных породах не наблюдаются.

По химическому составу породы, слагающие ультрабазитовое тело северозападнее вершины Ченгене кёшк, очень близки (табл. 1). Как по числовым значениям характеристики Хесса М/Г, варирующей от 7.30 до 9,91 (среднее из 15 определений — 8.35), так и по содержанию TiO_2 (менее 0.16 %, а в большинстве случаи ниже 0.01 %) они определенно относятся к перидотитовым производным (Желякова-Панайотова и др., 1978[б]) или к метаморфическим перидотитам по Колману (1979). По сравнению с аналогичными метаморфизованными перидотитами Ардинского района (Колчева, Желязкова-Панайотова, 1982) они содержат больше воды, в связи с более высокой степенью серпентинизации, однако при сопоставлении с постметаморфическими перидотитами (Желязкова-Панайотова и др., 1978[а]) они относительно более „сухие". По нор-

Химический состав пород ультрабазитового тела северозападнее вершины „Ченгене кёшк"

Таблица 1

№ обр. / Элементы	233[а]/65	5435	152[а]/65	238/65	255/65	163/65	5434
SiO_2	35,47	36,60	37,37	37,95	37,99	38,04	38,23
TiO_2	0,08	0,16	сл.	сл.	сл.	0,06	0,14
Al_2O_3	0,38	0,99	0,70	0,82	0,77	0,41	1,12
Fe_2O_3	4,80	5,40	6,09	7,41	5,97	6,73	4,55
FeO	3,40	4,70	3,93	4,30	3,08	2,15	3,68
CaO	0,56	0,50	0,83	0,83	0,91	0,78	0,28
MgO	42,95	43,28	40,67	39,67	41,62	39,45	43,21
Na_2O	0,07	0,02	0,07	0,13	0,07	0,07	0,02
K_2O	0,12	0,01	сл.	сл.	сл.	сл.	0,01
MnO	0,13	0,14	0,17	0,17	0,15	0,13	0,10
P_2O_5	0,09	0,06	0,02	0,03	0,03	0,03	0,07
H_2O-	0,63	0,32	0,69	0,36	0,36	0,78	0,41
H_2O+	9,60	7,32	8,66	7,66	8,40	10,50	7,94
Cr_2O_3	0,25	н. о.	0,32	0,31	0,19	0,16	н. о.
NiO	0,23	0,238	0,24	0,10	0,22	0,26	0,262
CoO	0,004	0,020	0,02	0,012	0,02	0,01	0,012
CO_2	0,56	0,33	нет	нет	0,41	нет	0,20
SO_3	0,20		0,28	0,28	0,20	0,18	0,14
сумма	99,52	100,178	100,05	100,03	100,37	99,74	100,374

◀

Таблица II. сн. 1 — Дунит, масть. „Балабан". 1 — оливин; 2 — серпентин. N II, увел. 60. сн. 2 — Оливиновый клинопироксенит, масть. „Балабан". 1 — изогнутое зерно клинопироксена — I; 2 — прожилка клинопироксена — II, секущая клинопироксен — I; 3 — оливин — II; 4 — тремолит; 5 — магнетит?. N II, увел. 60. сн. 3 — Оливиновый клинопироксенит, масть. „Балабан". 1 — клинопироксен — I; 2 — оливин — II; 3 — клинопироксен — II; 4 — тремолит; 5 — магнетит?. N II, увел. 60. сн. 4 — Оливиновый клинопироксенит, масть. „Балабан". 1 — клинопироксен — I; удлиненные агрегаты оливина (2), клинопироксена — II (3) и тремолита (4) с магнетитом (5.) N II, увел. 60

Таблица 1 (продолжение)

№ обр. Элементы	156б/65	224/65	115/65	158/65	114/65	139/65	160/65	212/65
SiO_2	38,28	39,03	39,71	41,27	41,40	40,34	42,59	44,53
TiO_2	сл.	0,06	сл.	сл.	0,13	0,11	сл.	сл.
Al_2O_3	2,24	1,12	1,11	0,99	0,70	1,04	1,00	1,06
Fe_2O_3	5,29	4,84	5,03	5,78	4,89	4,88	5,22	3,67
FeO	2,52	3,72	3,33	2,54	4,10	4,35	2,78	3,62
CaO	1,05	0,74	1,68	2,60	3,30	0,98	2,53	0,84
MgO	38,17	41,90	40,82	36,54	36,12	39,85	36,96	39,20
Na_2O	0,07	0,06	0,09	0,09	0,14	0,07	0,13	0,07
K_2O	сл.	сл.	сл.	сл.	сл.	сл.	сл.	сл.
MnO	нет	0,11	0,13	0,13	0,15	0,13	0,14	0,09
P_2O_5	0,09	0,03	0,04	0,03	0,02	0,04	0,04	0,03
H_2O^-	0,79	0,52	0,27	0,52	0,66	0,69	0,56	0,48
H_2O+	10,20	6,98	6,96	8,41	7,11	5,80	7,41	5,40
Cr_2O_3	0,32	0,18	0,17	0,13	0,43	0,27	0,20	0,19
NiO	0,26	0,19	0,26	0,21	0,18	0,29	0,15	0,22
CoO	0,05	0,006	0,01	0,006	0,01	0,009	0,01	0,01
CO_2	нет	нет	нет	0,29	нет	0,76	нет	нет
SO_3	0,22	0,08	0,54	0,26	0,34	нет	0,22	0,84
сумма	99,55	99,57	100,15	99,79	99,68	99,61	99,94	100,25

Все анализы выполнены в химической лаборатории специальности Геохимии, Софийского университета. Аналитики: Е. Ланджева, К. Георгиева, Т. Куртева, Р. Спасова.

мативному составу эти породы в основном попадают в поле дунитов и богатых оливином гарцбургитов и лишь единичные пробы соответствуют лерцолитам, близким к гарцбургитам (рис. 2).

По петрохимическим особенностям породы, слагающие ультрабазитовые тела местности „Балабан", четко разграничиваются в две группы, соответствующие двух типам полос, слагающих полосчатый комплекс (табл. 2). Породы дунит-гарцбургитовых полос целиком попадают в соответствующее им поле и не отличаются от пород, слагающих ультрабазитовое тело окрестности Ченгене кёшк. Оливиновые клинопироксениты попадают, с небольшим разбросом, в своем поле (рис. 2). Для них характерно повышенное содержание TiO_2 (около 0.30 %)

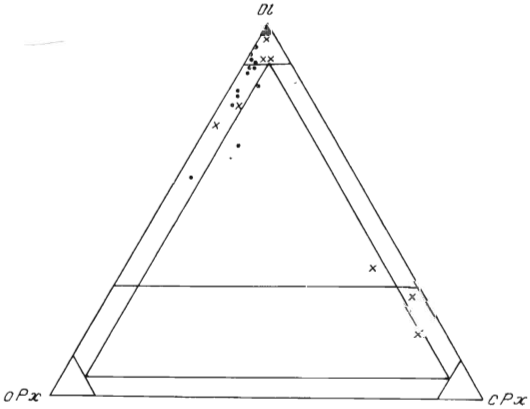


Рис. 2. Диаграма количественно-минералогической номенклатуры ультрабазитов Забырденского района (по нормативному минеральному составу). Ol — оливин, oPx — ортопироксен, cPx — клинопироксен; 1 — породы ультрабазитового тела северозападнее вершины Ченгене кёшк, 2 — породы ультрабазитового тела местности „Балабан"

и очень низкое содержание воды (табл. 2).

Наиболее существенной особенностью характеризуемых ультрабазитовых пород является их слабая степень серпентинизации. Они сложены высокотемпературным минеральным парагенезисом. Нахождение их в виде отдельных изолированных линз, хаотически разбросанных в определенных уровнях разреза метаморфитов Центральнородопской группы, свидетельствует о том, что они оказались в этой среде в виде блоков (олистолитов) еще во время отложения первичных осадочных пород.

Минеральный состав и петрохимические особенности отдельных блоков ультрабазитов, как уже было отмечено, показывают, что первоначально формирование этих пород происходило, по всей вероятности, в условиях верхних частей верхней мантии или в самых нижних отделах земной коры. Подъем в верхние части земной коры, их дробление и попадание в осадочном комплексе бессомнено сопровождалось серпентинизацией ультрабазитовых пород. При этом, только клинопироксен почти полностью сохранился. Частично или полностью серпентинизированные блоки ультрабазитов вместе с включающими их осадками были подвергнуты динамотермальному метаморфизму в амфиболитовой фации. В этих условиях происходили десерпентинизация и формирование высокотемпературных ассоциаций оливин+ортопироксен±тремолит в дунит-гарцбургитах и оливин+клинопироксен+тремолит в оливиновых клинопироксенитах. В последних, наряду

Химический состав пород ультрабазитового тела местности „Балабан"

Таблица 2

	Дунит-гарцбургитовые полосы					Оливин-клинопироксенитовые полосы		
№ обр. Элементы	40/65	54/26	34/65	5423^{Г}	5292^{А}	5424	5423^{В}	5424^{А}
SiO_2	35,78	37,73	38,50	38,81	39,64	47,83	49,39	51,26
TiO_2	сл.	0,18	0,07	0,13	0,06	0,27	0,28	0,30
Al_2O_3	0,31	0,87	0,60	0,61	0,45	2,98	2,28	2,38
Fe_2O_3	4,88	8,62	7,02	4,93	6,42	3,53	3,99	2,87
FeO	5,15	4,92	0,71	3,70	2,34	2,41	2,83	2,48
CaO	1,02	1,23	0,51	1,21	1,20	14,60	17,95	19,78
MgO	42,51	38,58	37,65	42,93	39,70	24,77	20,84	19,48
Na_2O	0,07	0,09	0,07	0,04	0,09	0,24	0,35	0,32
K_2O	сл.	0,02	сл.	0,02	0,02	0,02	0,06	0,02
MnO	0,21	0,20	0,08	0,13	0,15	0,10	0,12	0,11
P_2O_5	0,04	0,08	0,02	0,09	0,07	0,06	0,08	0,09
H_2O^-	0,32	0,28	0,88	0,24	0,55	0,08	0,14	0,08
H_2O^+	8,51	6,72	12,93	6,34	9,00	2,50	0,96	0,55
Cr_2O_3	0,19	н. о.	0,29	н. о.	0,21	н. о.	н. о.	н. о.
NiO	0,20	0,131	0,25	0,255	0,15	0,10	0,042	0,034
CoO	0,02	0,017	0,004	0,014	0,009	0,008	0,002	0,006
CO_2	0,69	0,08	нет	0,41	нет	0,14	0,30	0,01
SO_3	0,34	0,23	нет	0,15	0,025	0,54	0,49	0,12
сумма	100,24	99,978	99,58	100,009	100,084	100,178	100,104	99,980

Таблица 3

Этапы	Разновидности пород	Минеральные ассоциации
I. Формирование ультрабазитов (верхняя мантия — нижняя часть земной коры)	Метаморфические перидотиты —	**Ol-I** + oPx-I + Shp-I
	1. дунит — гарцбургиты	**Ol-I** + oPx-I + Shp-I
	Кумуляты (расслоенные)	Ol-I + **cPx-I** + Shp-I
	2. дунит — гарцбургиты	
	3. Ol — клинопироксениты	
II. Подъем в земную кору и серпентинизация	1. Серпентинизированные дунит — гарцбургиты	**Spn**±рел. Ol-I, oPx-I и Shp-I
		Spn±рел. Ol-I, oPx-I и Shp-I
	2. Серпентинизированные дунит — гарцбургиты	Spn±рел. Ol-I, и Shp-I + **cPx-I**
	3. Серпентинизированные Ol — клинопироксениты	
III. Дробление и попадание в виде олистолитов в осадочный комплекс, серпентинизация	1. Серпентиниты	**Spn** и сопровождающие минералы
	2. Серпентиниты	**Spn** и сопровождающие минералы
	3. Серпентинизированные Ol — клинопироксениты	Spn + **cPx-I**
IV. Метаморфизм совместно с парасланцевым комплексом в амфиболитовой фации, десерпентинизация	1. Десерпентинизированные дунит-гарцбургиты	**Ol-II** + oPx-II + Tr-I — + Shp-II
		Ol-II + oPx-II + Tr-I —
	2. Десерпентинизированные дунит-гарцбургиты	Ol-II + **cPx-I** + **cPx-II** + Tr-I
	3. Десерпентинизированные Ol-клинопироксениты	
V. Локальная тектоническая и гидротермальная обработка, локальная серпентинизация и оталькование	1. Слабо серпентинизированные дунит — гарцбургиты	Ol-II + oPx-II + Tr-I + Shp-II + + Spn-II + Tr-II + Tc
	2. Слабо серпентинизированные дунит — гарцбургиты	Ol-II + oPx-II + Tr-I + + Spn-II + Tr-II + Tc
	3. Слабо серпентинизированные Ol — клинопироксениты	Ol-II + Spn-II + cPx-I + cPx-II + + Tr-I + Act

Примечания: Ol — оливин, oPx — ортопироксен, cPx — клинопироксен, Shp — хромшпинелид, Tr — тремолит, Act — актинолит, Spn — серпентин, рел. — реликты.

с клинопироксеном-II сохранились изогнутые и помутневшие реликты клинопироксена-I.

Из расчетов изореакционград системы CaO — MgO — SiO_2 — H_2O (Evans and Trommsdorff, 1970) минеральные ассоциации оливин+ортопироксен+тремолит и оливин+клинопироксен+тремолит стабильны при T = = 700—720 °C и P > 2 кб.

Существенной особенностью, свидетельствующей о метаморфическом происхождении высокотемпературных минералов, является полное отсутствие характерных для кумулятов гипидиоморфнозернистых структур пород, хотя полосчатое строение сохранилось. По существу „исчезла" и т. н. „рудная пыль", сопутствующая процессов серпентинизании. Метакристаллы железистых хромшпинелидов, собранные в виде прожилок, струй или небольших гнезд образовались в результате перекристаллизации в указанных условий распыленного рудного вещества. Наряду с этим необходимо отметить, что в периферических частях отдельных блоков протекали биметасоматические реакции. В результате поздних, локально проявленных тектонических и гидротермальных воздействий имели место низкотемпературные преобразования, приведшие к частичной и даже полной серпентинизалии ранее десерпентинизированных ультрабазитовых пород, а также отальковании и асбестообразованию. Эти процессы привели к полному преобразованию небольших тел и к частичному изменению вдоль тектонических нарушений в пределах более крупных из них.

Общий ход и последовательность преобразований ультрабазитовых пород с формированием соответствующих характерных для новых P-T условий ассоциаций минераллов можно иллюстрировать следующим образом (табл. 3).

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Petrology of metamorphosed ultrabasites from the area of the village of Zabărdo (Central Rhodope Mts., Bulgaria)

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Several lenticular bodies of ultrabasites have been found in the area of the village of Zabărdo in the lower levels of the metamorphic profile of the Central-Rhodope group. Two of the bodies are larger — one of them occurs northwest of the Chengene-Kyoshk Peak (450/500 m), and the other in the Balaban locality (1000/600 m). The former body consists of harzburgites blending into dunites, and the other one has a distinct banded structure of dunite-harzburgite and olivine-clinopyroxenite bands, respectively.

The rocks are characterized by a low degree of serpentinization. They consist of high-temperature mineral parageneses. Their occurrence as separate isolated denses, scattered randomly in definite levels to the metamorphites from the Central-Rhodope paraschist group, shows that they were brought there as olistoliths already during the sedimentation of the primary rocks. After that all of them were metamorphosed into amphibolite facies, the olistolith suffering deserpentinization. The general course and sequence of transformation of the ultrabasic rocks and the formaiton of the parageneses characteristic of the respective P-T conditions are given in Table 3.

In their geological occurrence, mineral composition and petrochemical characteristic the ultrabasic rocks belong to the group of the Rhodope premetamorphic ultrabasites distinguished in an earlier work (Zhelyaskova-Pananyotova et al., 1977). So far this is the first locality where blocks of a layered complex have been found to occur besides the lenses of metamorphic peridotites, i. e. from the lower levels of the ophiolithic sections.

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Nappe with the amphibolite facies metamorphites in the Inner Western Carpathians — its position, origin and interpretation

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(4 figures and 1 table in the text)

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Покров с метаморфическими породами амфиболитовой фации внутренних Западных Карпат, его позиция, возникновение и интерпретация

Совместно с вышезалегающими анхиметаморфизованными породами добшинской группы досреднекарбонские метаморфические породы амфиболитовой фации метаморфизма внутренних Западных Карпат представляют аллохтон. Означаем его как „клатовский покров". Самыми распространёнными досреднекарбонскими породами покрова являются амфиболиты, парагнейсы и в меньшинстве даже антигоритовые серпентиниты и кристалические карбонаты. Предполагаемые горные породы представляют метаморфически перекристализованный протолит океанического дна, в составе которого в большом количестве принимал участие и материал коры континентального типа. Метаморфическая перекристализация нижнепалеозойских членов клатовского покрова произошла в зоне трансформного разлома или в почве обдукованного офиолитового комплекса.

Nappe with the amphibolite facies metamorphites in the Inner Western Carpathians — its position, origin and interpretation

Together with overlying anchi-metamorphites of the Dobšiná group (Carboniferous), the pre-Middle Carboniferous metamorphites of amphibolite facies of the Inner Western Carpathians (the Gemericum) form the allochthon — which is designated as the "Klátov nappe". The most wide-spread pre-Middle Carboniferous members of the nappe are gneisses and amphibolites, to a lower degree also antigorite serpentinites and crystalline carbonates. They have originated via metamorphic recrystallization of the ocean-floor protolith; the material of continental crust represents a considerable amount in its composition.

In the zone of transform fault or in the basement of obducted ophiolite complex there has taken place the metamorphic recrystallization of the most probably Early Paleozoic nappe members.

The Western Carpathians are in the north-southern direction divided as follows: a) Outer and Inner; or b) Outer, Central and Inner. In the sense of the latter division (Mock, 1978), the Inner Western Carpathians comprise the units which occur and/or are generated south of the "Margecany — Lubeník lineament".

Also during the period when the concept of the nappe structure of the Outer and Central Western Carpathians was dominant, the area of the Inner Western Carpathians was considered to be autochthon with eventual local shifts of partial units. It was not until the 70-ies when D. Andrusov (1968) illuminated some older concepts claiming the allochthonous position of the Inner Western Carpathian units and he designated them "Gemericum" (contrary to older usage of "Gemerides"). The assignment of Paleozoic units occurring south of the Margecany — Lubeník lineament to the Gemericum has been generally accepted. Also the place of origin as well as the tectonic assignment of certain Mesozoic units appearing in the present relief south of the given lineament remain still a nagging question work (Kozur — Mock, 1973, Maheľ, 1975, 1983).

According to P. Grecula (1973), the Early Paleozoic of the Gemericum originally divided into two superpositional groups, the Gelnica and Rakovec groups, forms the group with the same development as that of the Gelnica and Rakovec ones (Upper Ordovician — Devonian?). These lithofacial developments are regarded as the partial nappes (Grecula — Varga, 1979), and the above-mentioned authors (l. c.) placed the Rakovec partial nappe on the basis and the Gelnica nappe into its overlying layers. The allochthonous character of the Gemericum as a unit has recently been emphasized by B. Leško — I. Varga (1980). The problem of the structure of the Gemericum has not been definitely solved, also at present, certain authors (Bajaník — Vozárová — Reichwalder, 1981) support the idea viewing the Gelnica group on the basis and the Rakovec group within its overlying layers. Also M. Maheľ (1983) considers the most part of Paleozoic rock complexes to be autochthonous.

The Gelnica group (nappe) is represented by volcanic — sedimentary sequence of the flysch type. Pelitic — micropsammitic sediments (schists, sandstones) are dominant, with locally present abundant silicites and limestones partly ankeritized to sideritized are in small amounts. Quartz porphyres (and quartz keratoporhyres) and corresponding volcanoclastics are dominant volcanic members. As for the Rakovec group (nappe), within the lower part of the sequence weakly-metamorphosed clastogenous members (quartz-sericite phyllites) are dominant. The upper part is abundant in basic volcanites and volcanoclastics, amongst sedimentary members — sericite chlorite and sericite — quartz phyllites. Also small bodies of basic intrusives are known to appear.

Metamorphic recrystallization of Early Paleozoic rock complexes is considered to be a consequence of Late Caledonian, and/or Bretonian phase of folding and metamorphism (Kamenický, 1968), or a product of Alpine metamorphic-recrystallization processes (Varga, 1973), and/or a

product of polymetamorphic Late Caledonian, Bretonian and Alpine processes (Fusán. 1968, in Maheľ — Buday et al., 1968).

On Early Paleozoic groups (nappes), discordantly in autochthonous (subautochthonous) position, there appear sediments and basic volcanites of Middle and Upper Carboniferous to Permian. Mesozoic members of the Inner Western Carpathians are assigned, at the same time, into several tectonic units.

Metamorphites of higher grade

Complexes of metasediments and metaeruptives in the Inner Western Carpathians (and namely Paleozoic complexes) have in the past been generally and definitely assigned among metamorphites which have originated in the greenschist facies conditions (Kamenický, 1968, Kamenický — Krist, 1969, Kamenický, 1969 in Maheľ, 1969, Varga, 1973). Generally accepted scheme of intensity and type of metamorphism of pre-Middle Carboniferous rock complexes in Gemericum is not supported by the results of L. Rozložník (1965) from the area of Dobšiná. This author (l. c.) described a complex of amphibolite facies metamorphites from the mentioned area. The higher grade of metamorphic recrystallization took place in narrow tectonically predisposed zones, due to the effects of granitizing fluids. Among amphibolite facies metamorphites he presented mainly different types of amphibolites and gneisses. Totally different views on the genesis of pre-Middle carboniferous rock complexes in the Dobšiná area were held by L. Kamenický — M. Marková (1957) and J. Ilavský (1957). The former authors (l. c.) distinguished "hornblende gabbro" in the area of Dobšiná. They described it as magmatically preferrentially oriented intrusion of diabase magma, and "amphibole-biotite diorite" which they regarded as later differentiate of the mentioned basic magma which was cooling after the release of pressures. In the view of J. Ilavský (l. c.) the origin of amphibolites can be explained by assimilation of diabase. He considered diorite the product of assimilation of Carboniferous greywackes by granite intrusion.

In recent years, the rocks of higher metamorphic recrystallization grade have been introduced by J. Popreňák et al. (1973) from the area of Rudňany. Their main characteristics (composition, position) and arguments in favour of their metamorphic origin can be found in the work of D. Hovorka et al. (1979). Metamorphites of similar type were described also from the area of Vyšný and Nižný Klátov (Dianiška — Grecula, 1979) and other areas (Bajaník — Hovorka, 1981, Hovorka et al., in print).

Apart from the characteristics of the main rock types comprised in the metamorphite complex of amphibolite facies and their geological position, recent years have brought some attempts to interpret mainly the temperature conditions of the origin of the mentioned rocks via the study of coexisting metamorphic minerals (Hovorka — Spišiak, 1981, Bajaník — Hovorka, 1981, Hovorka et al., in print, Spišiak — Hovorka, in print). These studies also provided evidence for the Variscan metamorphic recrystallization of the discussed rock complex. Also radiometric age determinations of the rocks under consideration (Cambel et al., 1980, Bajaník et al., 1981, Kantor, 1981) point to the Variscan metamorphic recrystallization to have taken place. Although the limitations due to the used method and the character of the used analyzed mineral are considerable, and they also cause that the results suffer from the accuracy (differences in determining the age of gneisses and amphi-

bolites), yet, the metamorphic processes are undoubtedly pre-Middle Carboniferous.

Rock filling

Although there are known in detail different rock types in dependence on the degree of natural, and/or artificial outcrop in different areas where the rocks of amphibolite facies occur, yet, the main rock filling is identical for the whole characterized complex.

Paragneisses are the main rock type in the upper part of the discussed complex, while laterally and vertically they are alternated by metabasites. Their main mineral association: quartz — plagioclase (An_{18-30}) — biotite ± garnet ± amphibole ± muscovite, is often hydrothermally destructed. On the basis of geochemical criteria (Hovorka — Spišiak, in print), original sediments of paragneisses corresponded to pelitic — psammitic sediments and they also did not show geochemically mature character (rocks close to greywackes). Plagioclase biotite paragneises locally pass into quartz-rich types of paragneisses. Rocks of this group have mostly porphyroblastic structures with porphyroblasts of plagioclase and garnet, banded textures are frequent. High portion of plagioclase porphyroblasts (and at the same time, low mica contents) cause that sections perpendicular to the rock schistosity shows macroscopically massive appearance of these rocks. Also in such cases microscopical development of mineral association provides the evidence for its metamorphic-recrystallization origin. In the case of gneisses, to a lower degree also in amphibolites, there can be seen zones of intensive Na-metasomatosis (albitization), which is older than the siderite-sulphide mineralization wide-spread in the discussed areas. Local presence of nests and irregular positions of mineral associations of granitic pegmatites, and albite-quartz nests which are probably the result of mobilization and segregation during metamorphic recrystallization. Chemical composition of the main types of gneisses can be found in Table 1.

Amphibolites are another substantially present rock type and in the directions towards the basis of the complex they are becoming dominant. Specifically, it is the rocks of the association: amphibole + plagioclase ± garnet. They are mostly fine to medium-grained, markedly schistose and quasi-massive, homogeneous and slightly (locally) banded. Bands are formed by plagioclase-quartz aggregate. In the case of amphibolites, several types can be distinguished. Their varied mineral associations are mainly due to lithological and chemical differentiation of educt. Pyroxene garnet, epidote and epidote-zoisite amphibolites were identified. The latter represent more-or-less the transition to the rocks of greenschist facies. It is interesting that the spatial occurrence of the given types is usually differentiated which can be best seen in the area of Dobšiná. Centric structures are characteristic for garnet amphibolites. By increase of quartz content, amphibolites gradually pass into amphibole gneisses. According to presently used geochemical discrimination criteria, original volcanics were similar to ocean-floor tholeiites by their composition (Hovorka — Spišiak, in print).

The study of chemical composition of main mineral phases of amphibolites and paragneisses (amphibole — garnet — biotite — plagioclase) with the aid of electron microprobe (Hovorka — Spišiak, 1981, Spišiak — Hovorka, in print) as well as calculated distribution coefficients of Fe, Mg and Ca in mineral pairs (l. c.) in amphibolites and paragneisses allow to reconstruct the origin of these mineral associations (rocks) in the conditions of

low-temperature parts of amphibolite facies (T = 530—620 °C). This finding, together with characteristic vertical and lateral alternation of the mentioned and other rock types, in this way document the temperature conditions under which the whole discussed complex has originated.

Ultramafites appearing in the form of small to fine bodies (hundreds of meters to cm dimensions) in the gneiss — amphibolite complex are its characteristic rock member. They have the character of antigorite serpentinites (Dobšiná — Tešnárky, Rudňany, Klátov, Bukovec). Spinel peridotites were original rocks. Meta-ultramafites appear either directly in gneisses and amphibolites as small, often isometric bodies (ultramafic balls), or as larger lenses on the contact with the Rakovec group. In the first case they were a part of the complex before its metamorphic recrystallization and were metamorphosed together with the complex (the formation of blackwall). Similar evidences if any at all, claiming the pre-metamorpfic presence of ultramafites in the pre-underlying part of the complex, are still missing. They are overprinted with intensive tectonometamorphic and hydrothermal alteration. In the tectonic transport of the metamarphic complex of amphibolite facies were tectonized ultramafic bodies incorporated into tectonic discontinuities not

Chemical composition of the Klátov nappe main rock types

Table 1

	1	2	3	4	5	6
SiO_2	47,96	46,22	49,42	67,20	60,86	39,34
TiO_2	1,14	2,31	1,83	0,63	1,05	0,17
Al_2O_3	16,19	12,51	13,66	14,26	13,24	1,81
Fe_2O_3	1,74	5,06	2,96	0,88	2,87	6,69
FeO	6,64	9,04	10,69	4,13	6,76	2,71
MnO	0,12	0,22	0,24	0,10	0,14	0,07
MgO	9,86	7,10	7,01	2,80	3,77	36,67
CaO	10,22	11,55	6,42	1,80	2,80	0,87
Na_2O	2,28	3,40	2,51	2,72	2,68	0,10
K_2O	0,35	0,44	1,07	2,45	1,84	0,10
P_2O_5	0,15	0,19	0,19	0,10	0,49	0,10
H_2O^-	0,34	0,34	0,32	0,14	0,22	6,61
H_2O^+	2,86	1,65	3,87	2,75	2,54	11,02
Suma	99,72	100,03	99,64	100,04	99,26	100,05
V	174	220	336	128	—	89
Cr	331	205	83	48	—	1610
Co	15	76	8	12	—	89
Ni	69	127	10	17	—	1690
Li	34	—	33	38	—	—
Rb	8	—	23	75	—	—
Cs	2	—	2	5	—	—
Sr	185	—	262	170	—	—
Ba	50	—	400	380	—	—
Zr	38	—	354	84	—	—

1 — Rudňany, drill Ry-IV-Z/393,5 m: augen anmphibolite, 2 — Kušická Belá, drill SGR-V-9/9,4 m: epidote amphibolite (Dianiška — Grecula, 1979), 3 — Rudňany, drill Ry-Z-58/21,0 m: banded garnet amphibolite, 4 — Rudňany, drill Ry-Z-58/40,3 m: plagioclase paragneiss, 5 — Dobšiná, biotite-plagioclase paragneiss (Rozložník, 1965), 6 — Dobšiná — Tešnárky: antigorite serpentinite (Hovorka — Ivan, 1981, FD-103)

only in the complex itself, but also in the overlying rocks of the Dobšiná group (Dobšiná, Mlynky, Mišíkova skala, Gretla, Rudňany, Košické Hámre). On favourable tectonic structures, when overlying hydrothermal processes took place, the bodies of metaultramafites represented primary concentrators of Ni, and Co of hydrothermal vein occurrences of arsenides of nickel and cobalt (the "Dobšiná type", Ivan — Hovorka, 1980, Hovorka — Ivan, 1982).

Carbonates are present in the facies of crystalline limestones and dolomites, associating mostly with amphibolites. They form the layers which attain the thickness of several cm to several m. Original clastic admixture at metamorphic recrystallization gave rise to tremolitic amphibole, garnet, mineral of clinozoisite-epidote group, plagioclases and others. They were identified in Dobšiná (P. Rozlozsnik, 1935, L. Rozložník, 1965), Rudňany (Kusák — Hurný, 1981), Klatov (Dianiška — Grecula, 1979). Due to successive hydrothermal processes they are sometimes altered into ankerite and siderite, respectively.

The group of seldom rock members of the metamorpfite complex under consideration includes also the layers of monomineral pyroxene rocks and pyroxene amphibolites from the area of Dobšiná described by P. Rozlozsnik (1935). Layers of tremolite schists, and/or rocks with fibre-like terminating amphibole, discovered by L. Rozložník (1965), most probably represent (uralitized) derivatives of pyroxene rocks. The group of rarely occurring rocks comprises also garnet-pyroxene rocks described by L. Rozložník (l. c.) within the area of Dobšiná. They have also been discovered recently at Langenberg near Dobšiná (Hovorka — Spišiak, in preparation).

In concluding the characteristics of the most wide-spread rock types of metamorphite complex of amphibolite facies, it must be emphasized that the mentioned rock types are intensively tectonically, but mainly hydrothermally-metasomatically altered namely in ore fields at Rudňany and Dobšiná. For that reason, it is difficult to identify their originally metamorphic character in places.

Geological position

Amphibolite facies metamorphites occurrences in the Inner Western Carpathians are concentrated exclusively in the north-Gemeride zone. This is the designation of the zone of individual structural-tectonic development which connects the contact of the Inner Western Carpathians represented by the Gemericum — and the units of the Central Western Carpathians — the Veporicum and Tatricum.

Until now, the following areas of occurrence of amphibolite facies metamorphites are knon from the north — Gemericum zone (Fig. 1): Rejdová — Táfliová, Dobšiná, Mlynky, Rudňany, Slovinky, Kojšov, Klátov. In the mentioned areas, the rocks at the same time assigned among metamorphites of amphibolite facies, were identically regarded as the part of Early Paleozoic Rakovec group.

The main geological characteristics of the mentioned occurrences are in all cases considerably similar. The most typical common feature is the morphology of the given rock complex. It represents tabular bodies attaining the maximum thickness of the first hundreds of meters. Their underlying layer is usually the Rakovec group in the development of chlorite-sericite phyllites. The contact is tectonic; the contact zone is indicated by strong tectonic mixing and there are localized lense-shaped bodies of antigorite serpentinites. The overlying layers of gneiss-amphibolite complex are within the most of mentioned

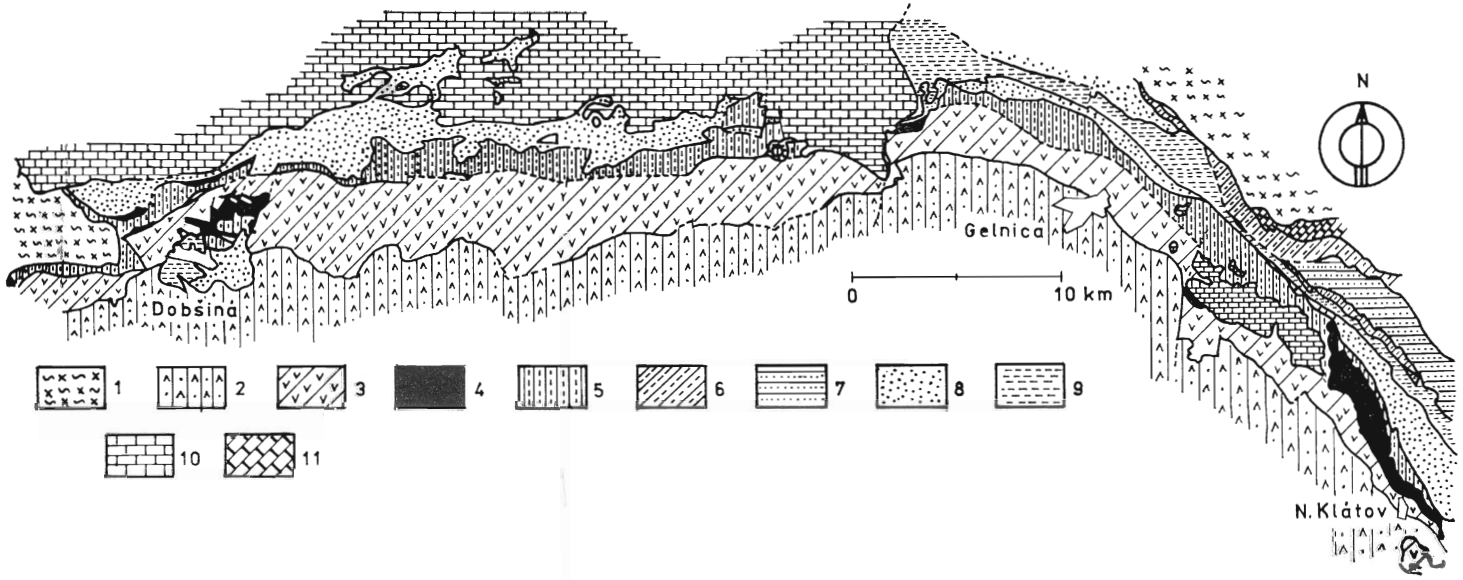


Fig. 1. Geological map of the northern part of the Inner Western Carpathians (compiled on the base of Bajaník's, Grecula's, Mahel's, Snopko's and others geological maps). 1 — Pre-Carboniferous units of the Central Western Carpathians, 2 — Gelnica Group, 3 — Rakovec Group, 4 — Klátov Group, 5 — Dobšiná Group (except of the Ochtiná Beds), 6 — Ochtiná Beds, 7 — Črmel Group, 8 — Krompachy Group, 9 — Lower Triassic of schistose development, 10 — North Gemeric Mesozoic in carbonate rock development, 11 — Mesozoic envelope of the Central Western Carpathians, core mountains

occurrences, formed by coarse-grained anchimetamorphosed metaclastics of the Dobšiná group (Carboniferous). Most of the pebble material of polymict conglomerates to breccias are formed by rocks of the direct underlying layers (gneisses, amphibolites; Rozložník, 1965, Vozárová, 1973). The presence of sandstones and greywackes can also be seldom noticed in the overlying layers of the complex under consideration. On the basis of above-mentioned facts, the position of the rocks within Dobšiná group in the overlying metamorphites of amphibolite facies, can by designated paraautochthonous.

The present morphological form and areal distribution of amphibolite facies metamorphites represents the final result of several Hercynian and Alpine folding phases which have effected them. Besides lithological and geological-tectonic factors, its position and localization was effected by the difference in physical and mechanical properties of the rock complexes involved. In comparison with greenschist facies rocks of the Rakovec group, gneisess and amphibolites behave as a rigid body.

According to L. Rozložník (1965), this has found reflection in the geological structure of the Dobšiná area. Occurrences of discussed metamorphites are concentrated in narrow zones of reverse fault type of NE—SW direction (Fig. 2), appearing in the middle of the Rakovec group rocks. The zones express the imbricate structure of the area which has formed as a result of compensation of Alpine N—S compressional motions (l. c.). L. Rozložník (l. c.) considers the relief reverse fault of the discussed complex through the rocks of the Rakovec group in the area N of Dobšiná, to be a special case. The reverse fault plain, with respect to the morphology occupies relatively flat position, only slightly dipping to the S, and in that way, amphibolite facies metamorphites, together with overlying Dobšiná group, are exposed on the area reaching several km^2. Their position in regional tectonic depression saved them from erosion (Rozložník, 1965). The whole rock complex under consideration is strongly tectonically limited. The E and W terminals are provided by faults of the shift character, the S and N terminals are represented by outcrops of overthrust plane — the Georgi and Kor-

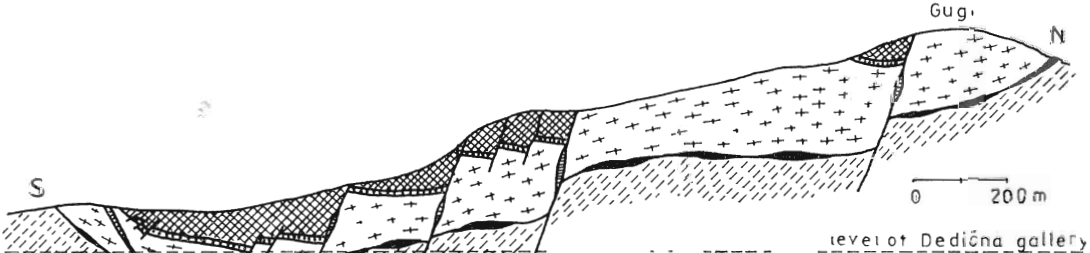


Fig. 2. Schematic geological cross section northward of Dobšiná. 1 — Rakovec group, 2 — metamorphites of the amphibolite facies (Klatov Group), 3 — conglomerates, 4 — pelitic schitic schists and limestones (3 + 4 Upper Carboniferous of the Dobšiná Group), 5 — metaultramafites associated with amphibolite facies (Klatov Group) metamorphites, 6 — metaultramafites tectonically protruded into overlying rock sequences

nélia lineaments (Rozložník, 1965, Hovorka — Ivan, 1981). Both lineaments are noted for strong expressions of destruction, the presence of antigorite serpentinite lenses and successive hydrothermal activity. The study of small-scale tectonic elements of the body testifies to its shift from the S to N (Rozložník, 1965). Spatial and genetic relation of gneiss amphibolite complex with overlying Dobšiná group is characteristic, in which the layers starting with conglomerates with pebbles of the overlying rocks. The continuation of Mlynky zone at the W is the occurrence of amphibolite metamorphites described from the bore-hole BM-1 near Mlynky (Bajaník — Hovorka, 1981). Geological situation is analogical with that in the area N of Dobšiná. With respect to the presence of the rocks of the Dobšiná group in the area NE to E of Mlynky, the complex of highly-metamorphosed rocks seems to continue in the depth in that direction.

In the area of the Rudňany ore-field, the discussed rocks practically do not appear on the surface-data on their geological position are based on mining and prospection works. In fact analogical structure as that in Dobšiná has been verified there. The complex of amphibolite metamorphites facies forms tabular body. Its thickness probably increases towards the N. The contact with underlying layers is tectonic and is formed by chlorite-sericite phyllites, often hydrothermally altered, to a lower degree also graphite phyllites (tectonite?) and green schist. Due to the low degree of knowledge, there does not exist any definite evidence about the presence of ultrabasites in contact zone. The overlying layers of gneiss-amphibolite type rocks are mostly formed by polymict conglomerates, more rarely sandstones. Within conglomerates the clastic material of direct underlying layers is dominant. On the contrary to the conglomerates from Dobšiná, they exhibit higher thicknesses with tendency of fine-grained clastic material towards the overlying layers.

Due to bad exposure and small areal extent, metamorphites of amphibolite facies in Slovinky and Kojšov have been discovered only recently (Bajaník — Hovorka, 1981). They appear close to, or directly on the overthrust plane of younger Mesozoic carbonate sediments on the Rakovec group. In the area of Slovinky, direct overlying layers are built up of polymict conglomerate of the Krompachy group (Permian). The most probable underlying layers in both mentioned areas are formed by chlorite-sericite phyllites, to a lesser degree also by metavolcanoclastics.

The esternmost as well as areally largest occurrence of amphibolite facies metamorphites is represented by the localities in the area of Vyšný and Nižný Klátov (Fig. 3). Its length exceeds 10 km and false thickness on the surface reaches 2 km. In comparison with occurrences in the western part of the North-Gemericum zone it appears as in the reverse position. The overlying layers form sericite-chlorite phyllites of the Rakovec group. The contact is tectonic, phyllites are separated from the complex of higher metamorphosed rocks by a thin position of graphite-sericite phyllites (tectonites ?) and lense-shaped bodies of antigorite serpentinite. The underlying layers are formed by the rocks of the Dobšiná group: graphite-sericite phyllites and dark schists with carbonates (Dianiška — Grecula, 1979).

Discussion and Interpretation

The presence of rocks of higher metamorphic recrystallization grade within the frame of structurally-tectonic unit charac-

terized by generally only a low grade of metamorphic recrystallization (greenschist) represents a phenomenon which is difficult to interpret. Conceptions proposed until now can fall into 4 groups:

1) The origin of amphibolite facies metamorphites via granitization processes in narrow zones of the Rakovec group. Processes are determined by penetration of granitization fluids derived from more intensive hypothetical massif of plutonites in the underlying layers (Rozložník, 1965). The age of metamorphism: Hercynian.

2) The origin of the complex due to compressional movements and the change of p-t conditions of the Rakovec group rocks within Jurassic-Cretaceous. The Rakovec group itself corresponds to the ophiolite suite of oceanic rift which has been deformed and disintegrated into melange during Paleo-Alpine obduction (Dianiška — Grecula, 1979).

3) Metamorphic recrystallization in conditions of amphibolite facies was conditioned by elevated heat flow taking place during the intrusions Late Variscan (Permian) granites of the Gemericum which was active in the rock assemblage situated between two geochemical and heat barriers-positions with abundant graphite schists and graphite quartzites (Hovorka et al., 1979).

4) The rocks metamorphosed in the conditions of amphibolite facies are not a part of the Gemericum, but they represent the tectonic wedge from the neighbouring structurally-tectonic unit of the Veporicum (conceptions of some authors — not published yet).

In comparison with some other Western Carpathian metamorphic areas, the expressions of metamorphic recrystallization in the conditions of amphibolite facies within the Gemericum exhibit peculiarites which indicate a different mechanism of metamorphic recrystallization. The most important features which should be mentioned and taken into consideration when interpreting the genesis, follow like this:

a) certain affinity of metamorphic

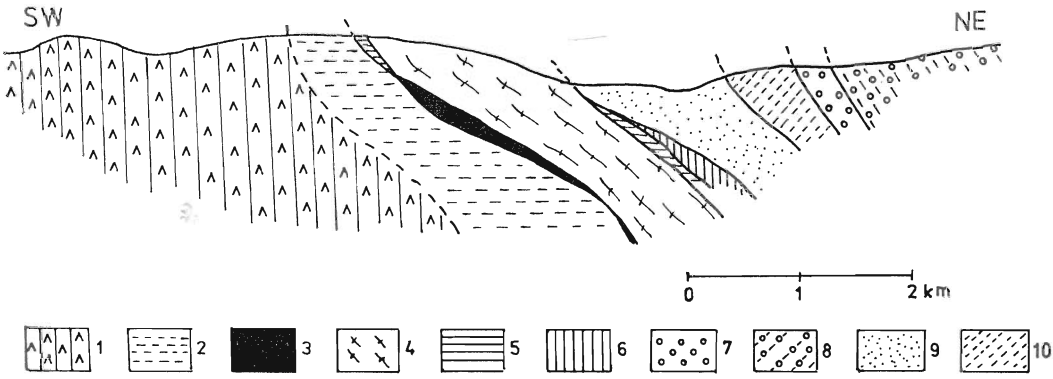


Fig. 3. Geological cross section of the amphibolite facies metamorphites (Klátov area; Dianiška — Grecula, 1979 — adopted). 1 — graphite — sericite schists (tectonites?), 2 — chlorite — sericite schists of the Rakovec group, 3 — metabasalts of the Gelnica group, 4 — amphibolite facies metamorphites, 5 — Gelnica group (metasediments and acid metavolcanics), 6 — Krompachy group (variagated sandstones and shales — Permian), 7 — dark shales with carbonate intercalations (Carboniferous), 8 — conglomerates (Permian), 9 — metaultrabasites, 10 — faults; a — detected, b — supposed

alteration to linear tectonic elements (noticed by Rozložník, 1965), which is expressed by morphological delimitation of metamorphosed complex;

b) discovered features of zoning of the intensity of metamorphic recrystallization within the frame of the given rock complex-from the rocks of typical amphibolite facies to the rocks of lower metamorphic recrystallization grade, locally even to metamorphites of higher-temperature areas of greenschist facies. Although the areal occurrence of metamorphites of the given grades is to certain extent tectonically separated at the present stage of knowledge, it is supposed that the change of the grade of metamorphic recrystallization took place only on small distances;

c) "quasi-statical" character of metamorphic alteration. In comparison with Variscan metamorphites of equivalent grade in the Tatricum and Veporicum, the rocks under consideration are characteristic by only slight role of dynamic phenomena during metamorphic recrystallization of the complex.

d) Narrow areal linkage of metamorphites with ultrabasic material as an undoubt part of the metamorphosed complex.

e) On the contrary to the conceptions presented by I. Dianiška — P. Grecula (1979), lithological and geochemical character of protolith (Fig. 4) does not represent (in the same way as the Rakovec group) a typical ophiolite sequence. It rather corresponds to the material of oceanic crust effected by clastic materials of close block with the continental crust. In the case of the Rakovec group, it can not be assigned to typical ophiolite suite: volcanoclastic are dominating over effusions of basalts, which are of island-arc tholeites trend.

Analysis of the mentioned problems leads to the conclusion that the origin of amphibolite facies metamorphites could be regarded as a result of the effect of elevated heat flow upon the rocks, using well-defined linear element having relation to oceanic crust to penetrate the recrystalling complex.

Present views on geodynamical conditions of metamorphism of oceanic (suboceanic respectively) crust offer in this case the two following models as being the most probable: 1) metamorphism conditioned by obduction of ophiolite plate, and 2) metamorphism in the zone of transform fault. At metamorphism through obducting ophiolite plate, due to its residual heat and that originated from friction, there originates tabular body of metamorphites below the shift plane. In this body, the intensity of metamorphism

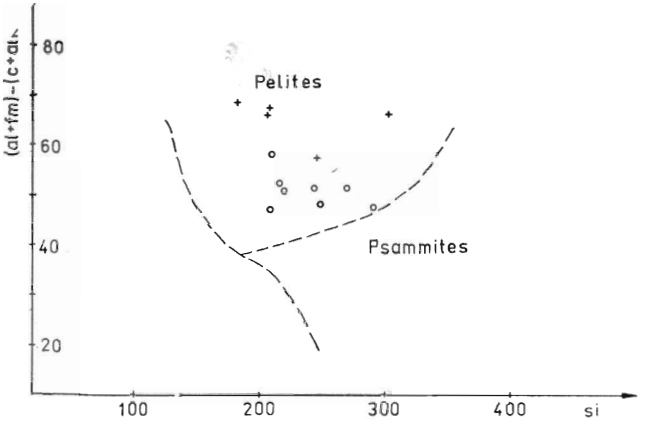


Fig. 4. Projections of the amphibolite facies metamorphite of the Klátov nappe (o) and greenschist facies metamorphites of the Rakovec Group (+). Analytical data in Hovorka — Spišiak (in print); Simonen's diagram (1953)

decrease on a small distance from granulite facies to greenschist facies (Karamata, 1968, Ghent— Stout, 1981, Spray — Roddick, 1980). During tectonic movements the blocks can be separated according to individual facies. In the case of metamorphites under consideration, this way of origin could be indicated by the expressions of higher grades of metamorphic recrystallization (pyroxene amphibolites to monomineral pyroxene rocks).

Metamorphism in the zone of transform fault originates as a consequence of the shifted segments of oceanic ridges contacting with the rocks which are more distant from the ridge and therefore also cooler. In the same ways as in the case of metamorphism at obduction, tabular body is being formed along the fault plane of transform fault. The intensity of metamorphism usually attains only middle grade, while decreasing outwards of the fault (Spray — Roddick, 1981).

The rocks with pyroxenes, discovered also in these conditions, were interpreted as products of Ca-metasomatosis by the authors mentioned above (l. c.). Analogical possibility can not be excluded also in the case of Gemericum metasomatites. Metamorphites originating in the zone of transform faults also exhibit areal relation to ultrabasites penetrating as protrusions along fault planes. The discussed metamorphites got into the structure of continental crust by successive processes of obduction type.

The age of higher-grade metamorphism in the Gemericum is definitely Hercynian (pre-Middle Carboniferons). It is supported also by K-Ar ages of metamorphites and the presence of detrites of amphibolites and gneisses in Middle Carboniferons clastics of the Dobšiná group. The presence of ultrabasic material in conglomerates confirm their genetic relation (Hovorka — Ivan, 1983).

As mentioned above, the protolith of amphibolite facies metamorphites were rocks probably forming in the upper parts of oceanic crust under the effects of clastogeneous material from the block with continental-type crust. In the case that the metamorphites under consideration originated via obduction mechanism, their material has already been in allochthonous positions probably in accretion prism of ocean arc. In the case that metamorphites originated in the zone of transform fault, they have been successively obducted also on the ocean arc (?). The final form as appearing in partial nappe was gained during intensive re-construction of tectonic plan of the Inner Western Carpathians during Alpine age.

Translations by H. Budajová

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Покров с метаморфическими породами амфиболитовой фации во внутренных Западных Карпатах — его позиция, возникновение и интерпретация

ДУШАН ГОВОРКА — ПЕТЕР ИВАН — ЯН СПИШЯК

Для внутренних Западных Карпат (южнее маргецианско-любеницкого линнеамента) домезозойские комплексы представлены метаэффузивами и метаосадочными породами. Степень их метаморфизма отвечает фации зеленых сланцев барровианского типа. В течение последних лет в этой зоне были обнаружены породы значительно более высоких ступеней (Розложник, 1965, Говорка и др., 1978; Дианишка—Грецула, 1978, Говорка—Спишяк, 1980), вплоть до амфиболитовой фации. Эти метаморфические комплексы, совместно с вышележащими слабо метаморфизованными осадками добшинской группы (карбон) образуют аллохтон. Мы называем его „клатовский покров". Самыми распространенными породами дасреднекарбоновых метаморфитов амфиболитовой фации являются гнейсы и амфиболиты, в меньшей степени антигоритовые серпентиниты и кристаллические мраморы. Эти типы пород возникли при метаморфической перекристаллизации как протолита океанического дна, так и материала континентальной коры. В зоне трансформного разлома или в подстилающих комплексах обдуктированных офиолитов произошла метаморфическая перекристаллизация пород вероятнее всего нижнепалеозойского возраста. Клатовский покров в целом не имеет признаков, характерных ддя типичных офиолитов.

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The PT — conditions of equilibrium for some pyrope peridotites and country rocks in the Moldanubian area at Mohelno (Eastern Moravia, Czechoslovakia)

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Температурные условия и условия давления при возникновении пироповых перидотитов и их вмещающих пород в молданубику в районе Могелна

Индексовые минералы пироповых ультрабазитов и вмещающего гранулита изучались при использовании микросонды. На основании полученных данных и при использовании различных геотермических отношений и давления разных авторов были вычислены соответствующие температурные условия и условия давления возникновения этих пород. Минералогические ассоциации гранатовых перидотитов соответствуют условиям их эквилибрации при температуре 1123—1060 °C при давлении приблизительно 18 килобар. Пироксены встречаются и в других ультраосновных породах пришли в состояние равновесия при температурных условях ниже 200 °C. Сложной является интерпретация полученных данных соответствующих минералогических пар для пород, которые возникли биметасоматическим процесом между перидотитом и гранулитом. На выбранном разрезе района Могелна были изучены те породы, которые содержат амфибол, биотит, гранат и местами клинопироксен. Раздельные величины эквилибрации возможно получить различными методами. Например по Перчуку (1970) условия равновесия бы возникли при температурах приблизительно 600° даже 650 °C, по методу Гангулиго (1979) температурные величины значительно выше.

The PT-conditions of equilibrium for some pyrope peridotites and country rocks in the Moldanubian area at Mohelno (Eastern Moravia, Czechoslovakia)

Pt-conditions were calculated for mineral assemblages of garnet peridotite and country granulite and biotite gneiss at the Mohelno locality in the eastern Moldanubian area. The mineral association of garnet peridotite originated at a temperature of 1123—1060 °C and a pressure of about 18 kbar. The temperature found using two different

thermometers for formation of the banded granulite and granulite gneiss with hornblende and biotite were from 600 (650) °C to 800 (850) °C, respectively. The conditions for the origin of bimetasomatic reaction rocks with garnet, clinopyroxene and hornblende correspond either to a temperature of 600—650 °C using Perchuk's method (1970) or to 860—910 °C using Ganguly's method (1979).

The presence of pyrope peridotite and eclogite bodies in the crystalline schists and gneisses is one of the characteristic features of the Moldanubicum of the Bohemian Massif. The largest peridotite and eclogite bodies are very often surrounded by granulite and granulite gneiss. Similar relations have been described in the Central Massif in Kazachstan, the Muyun-Kum Massif in the USSR Tchein-Schan and the Uralian Ufalei in the USSR, etc.

It follows from petrographical and mineralogical data that the pyrope peridotite often corresponds to the conditions in the upper mantle (temperature up to 1200 °C, pressure up to 25—30 kbar) when the temperature in the crust is less than 700—800 °C and the pressure less than 10 kbar. However, it is more difficult to explain the structural and metamorphic history of polymetamorphosed and polyphase deformed terrains, to which the Bohemian Massif belongs, see e. g. the memory age of Gföhl gneiss (1813 Ma) and its Hercynian age 341 ± 4 Ma of its monazite or the surprising lower age of the granulite = 345 ± 5 Ma (O. van Breemen et al. 1982). Therefore it would seem to be usefull to carry out systematical structural (Bowes-Hopgood and Mísař, in press) and petrological (this article) studies of peridotite bodies and their surroundings.

A unique possibility in this respect is offered by a very well exposed section along the Jihlava river near Mohelno. There many peridotite bodies are infolded in granulite formations, biotite gneisses and Gföhl gneiss and migmatites. A classical deep metamorphic contact of bimetasomatic character between garnet peridotite and country granulite and gneisses was found by Z. Mísař (1980) and shown to participants of the working group "Ophiolites". N. L. Dobretsov collected the main varieties of rocks from this section and, together with E. V. Popov, carried out the microprobe analyses in the laboratory of the Geological Institute of the Academy of Sciences in Novosibirsk.

Geology

The Mohelno peridotite body, together wiht garnet amphibolite, granulite and granulite gneiss, forms a complicated structural unit overthrusted on the Moravicum. The western and southern margin of this "peridotite-granulite" unit is of tectonic character with mylonite and ultramylonite. The Mohelno peridotite body and surrounding granulite represent a local synform with steeply dipping metamorphic foliation along the western margin but with nearly horizontal planes in the east. In the internal structure of the Mohelno peridotite body, the banded and laminated textures (alternating bands of harzburgite differing in the amount of pyroxene and olivine, and dunite bands) do not correspond to the predominant structures of the country rocks. New structural investigations (Bowes-Hopgood and Mísař, in press) have indicated that the peridotite body and the

granulite were folded togeter during some later folding phase. Simoultaneously, a new distinct metamorphic foliation with garnet, hornblende and biotite in the granulite rocks and metamorphic foliation with stretched pyropes in peridotite were developed.

The contact between the peridotite and the granulite, studied at this first step only along the road cut by Mohelno, is marked by a complex rock association of high temperature metamorphic-bimetasomatic origin. Some of the contact rocks, e. g. biotite schist, hornblende-biotite schist, biotite-hornblende-garnet schist were studied and their PT conditions of equilibration were calculated from the microprobe data. However, amphibolites, garnet amphibolites, spotted amphibolites, and many rock varieties of diorite, granite and gabbro composition have been found at other parts of the contact (Fig. 1). All bimetasomatic reaction rocks forming the contact and its petrological and geochemical character are now being studied by Dudek, Mísař and Jelínek.

Microprobe mineral analyses and conditions for the origin of rocks

The index minerals from pyrope peridotite of the Mohelno body and minerals from some country rocks, as well as the minerals of some bimetasomatic reaction rocks from the contact zone were analysed by the microprobe method. All secondary minerals and low temperature minerals were omitted.

Minerals of pyrope lherzolite and harzburgite

The main mineral components of the Mohelno peridotite (Table 1-1) are pyrope,

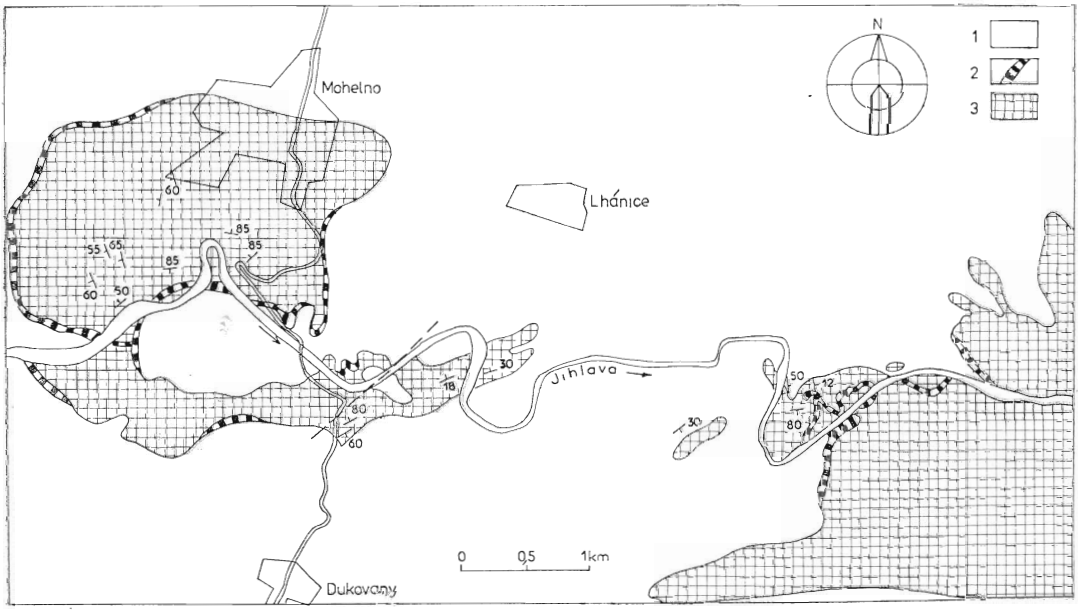


Fig. 1. Geological scheme of the Mohelno area. Original map of Dudek, Mísař, and others. 1 — granulite and granulite gneiss, 2 — high temperature reaction zone at the contact between peridotite and granulite, 3 — garnet peridotite

Chemical analyses of minerals form Bohemian pyroxenites and peridotites

Tab. 1

Components	Gar	Cpx	Opx	Gar	Cpx	Opx	Gar	Cpx	Gar	Opx
	Mohelno (1)			Staré, (Fiala — Paděra 1977) (2)			Horní Bory (3)		Paděra (1980) Mohelno (4)	
SiO_2	39,3	51,8	54,2	40,89	53,18	56,14	41,23	52,72	42,21	54,72
TiO_2	0,33	0,69	0,19	0,49	0,46	0,16	—	—	0,01	0,00
Al_2O_3	22,0	7,11	5,07	21,14	3,74	1,45	23,29	6,00	22,59	3,84
Cr_2O_3	1,33	—	—	1,66	0,81	0,09	—	—	0,15	0,33
FeO	8,13	2,69	7,02	10,22	2,90	7,03	12,94	5,53	14,20	10,25
MnO	0,25	0,09	0,12	0,31	0,11	0,15	0,41	—	0,23	0,11
MgO	20,30	13,9	31,7	20,54	17,10	30,98	15,56	14,28	15,62	29,7
CaO	5,07	19,9	0,86	4,45	19,31	1,30	5,98	19,62	4,18	0,13
Na_2O	—	2,18	0,12	—	2,42	—	—	1,40	0,00	0,03
K_2O	—	0,0	0,0	—	0,12	—	—	—	—	—
Total	96,71	98,36	99,28	99,70	100,26	100,30	99,41	99,68	99,19	99,11
Si	3,028	1,900	1,892	2,940	1,920	1,940	3,009	1,925		
Ti	0,018	0,019	0,005	0,026	0,013	0,004	—	—		
Al	1,854	0,370	0,209	1,790	0,160	0,060	2,006	0,259		
Cr	0,075	—	—	0,096	0,023	0,003	—	—		
Fe	0,487	0,083	0,205	0,573	0,087	0,168	0,788	0,169		
Mn	0,015	0,003	0,004	0,022	0,004	0,004	0,026	—		
Mg	2,124	0,759	1,649	2,190	0,920	1,751	1,690	0,776		
Ca	0,389	0,781	0,032	0,374	0,746	0,048	0,469	0,765		
Na	—	0,155	0,008	—	0,169	—	—	0,101		
Total	7,990	4,005	4,003	8,111	4,042	3,978	7,988	3,995		
$\frac{Fe + Mn}{Fe + Mn + Mg}$	19,1	10,2	11,2	21,8	8,66	10,2	32,5	17,9		
1)	—	1043			1092					
2)	1123			1128			1022			
3)	—	820			1070					
4)	1066			1087			934			

Estimation of temperature according to: 1) Perchuk, 1977; 2) Ganguly, 1979; 3) Davis, Boyd, 1966: 4) Ellis, Green, 1979;

clinopyroxene and orthopyroxene. The result of microprobe analyses of garnet-clinopyroxenite (3) from the quarry near Bory, of "garnet orthopyroxenite" (from a larger inclusion (4) in the Mohelno peridotite — Paděra, 1980, in Mísař ed 1980) as well as the pyrope peridotite (2) from the Staré bore hole (Fiala and Paděra, 1977) are also added for comparison.

The analyzed pyroxenes and pyrope of the Mohelno peridotite are analogous to those in the pyrope lherzolite from bore hole T-7 as described by J. Fiala and K. Paděra (1977). The equilibration of two-pyroxene association indicated by Perchuk's (1977) thermometer corresponds to a temperature close to 1100 °C. Boyd's thermometer (Davis and Boyd, 1966) indicates a temperature 820 °C and 1070 °C probably due to the higher content of sodium in clinopyroxene. Mysen's clinopyroxene-garnet thermometer-barometer

(Mysen and Heier, 1972) shows the conditions of equilibration of the garnet — clinopyroxene pair at a temperature 1150 °C and at a pressure of 18 kbar (Fig. 2). These

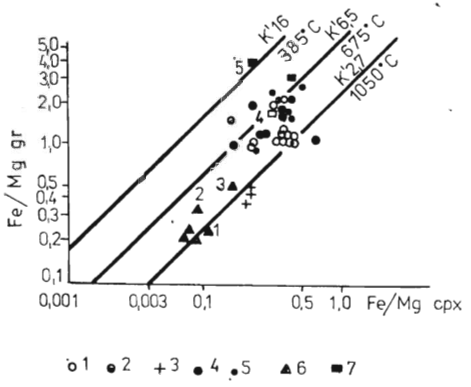


Fig. 2. Distribution of Fe and Mg between coexisting garnet and clinopyroxene in Moldanubian eclogites and pyrope peridotites (Dudek and Fediuková, 1974). 1 — eclogites inside of peridotite bodies surrounded by granulite, 2 — eclogites of "deep fault zones", 3 — pyrope-almandin eclogites in gneisses, 4 — eclogites in gneiss complex together with peridotite, 5 — pyrope-almandin-grossular eclogites in gneisses and migmatites, 6 — pyrope peridotite, 7 — eclogite-like rocks in gneisses. Points 1—3 correspond to garnet peridotite od Mohelno and Staré and to garnet clinopyroxenite of Bory (tab. 1) points 4 and 5 to the rocks of the tab. 2

data are similar to those found by Ganguly (1979) and Ellis and Green (1979). The calculated temperature and pressure for Mohelno peridorite seem to be slightly lower than for pyrope peridotite from inclusions in granulite of Bory (Mísař — Jelínek — Jakeš, 1984) and slightly higher than the data of J. Fiala and K. Paděra (1977). For the garnet peridotite of Bory the calculated temperature is 1190—1278 °C at an assumed pressure of 35 kbar. The PT-conditions calculated for Bory banded peridotite containing olivine, clinopyroxene and orthopyroxene are of a temperature 990 °C—1170 °C and pressure of 23 kbar. Many garnet pyroxenites from the locality Bory were studied by Z. Mísař — E. Jelínek and P. Jakeš (1984). They show the temperature of the origin to be 320 °C (average) at a calculated pressure of 23 kbar. The data for the some Bory garnet pyroxenite (table 1) are higher than Ganguly's (1979) or Ellis and Green's thermometers are used. See also new data of Šanc and Rieder (1983) for the PT-conditions of equilibration of garnet ± orthopyroxene lamellae in clinopyroxene (940 ± 20 °C—3,6 ± 6 kbar).

Minerals of country gneiss and granulite

Of the minerals of the contact bimetasomatic rocks (5) garnet, hornblende and rare clinopyroxene were analysed (Table 2). In addition to these minerals biotite of banded granulite gneiss and gneiss were also studied by the microprobe method (6, 7).

Perchuk's (1970) clinopyroxene-hornblende thermometer indicates a rather lower temperature for the origin of the mineral pair (600—650 °C). Gangluly's garnet-clinopyroxene thermometer indicates a higher temperature for the same rocks (T — 879—916 °C at 10 kbar). According to Ellis and Green's thermometer the temperature is 775 °C.

The interpretation of the given PT-conditions of equilibration for the bimetasomatic rocks at the contact between the peridotite and granulite is not unambiguous as different thermometers were used. However, it is also primarily more complicated because of the bimetasomatic origin of these contact rocks and their unequilibrated mineral assemblage.

Some estimates are also made for the PT-conditions of the origin of banded granulitic rocks (Table 2) containing garnet, clinopyroxen, hornblende, biotite and sometimes orthopyroxene (not analysed).

Microprobe analysis of minerals from country gneisses of the Mohelno peridotites

Tab. 2

	Contact bimetasomatic zone (5)					Banded granulite gneiss (6) melancratic band				
Components	Gar-2	Gar-1	Cpx	Hb-1	Hb-2	Gar I	Gar II	Cpx	Hb	Bi
SiO_2	38.7	38.8	51.8	47.2	44.5	39.2	38.9	51.6	45.2	35.8
TiO_2	0.55	0.46	0.42	0.92	1.64	0.22	0.40	0.46	1.84	3.19
Al_2O_3	20.7	21.2	2.84	5.65	10.02	21.1	21.4	3.21	9.43	14.9
FeO	26.2	24.6	9.73	11.5	13.9	26.5	24.9	8.85	13.7	18.9
MnO	0.56	0.44	0.10	0.09	0.06	0.52	0.39	0.15	0.08	0.10
MgO	6.99	7.91	13.3	12.9	13.2	7.57	8.96	13.1	13.0	12.6
CaO	6.70	6.49	20.8	17.2	11.4	5.42	6.21	21.5	11.5	0.29
Na_2O	—	—	0.75	0.88	1.83	—	—	0.80	1.72	0.12
K_2O	—	—	0.11	0.17	0.50	—	—	0.01	0.69	9.08
Total	100.40	99.90	99.85	97.21	97.05	100.53	100.16	99.68	97.16	94.98
Si	3.000	2.997	1.937	7.092	6.602	3.023	2.987	1.931	6.701	2.742
Ti	0.032	0.027	0.012	0.103	0.184	0.013	0.023	0.013	0.205	0.184
Al	1.886	1.925	0.125	0.985	1.755	1.913	1.934	0.142	1.648	1.347
Fe	1.707	1.589	0.304	1.426	1.733	1.708	1.599	0.277	1.704	1.212
Mn	0.037	0.029	0.003	0.011	0.008	0.034	0.026	0.005	0.010	0.006
Mg	0.808	0.910	0.743	2.837	2.924	0.869	1.024	0.729	2.868	1.433
Ca	0.556	0.537	0.835	2.722	1.807	0.447	0.429	0.860	1.821	0.024
Na	—	—	0.055	0.253	0.528	—	—	0.058	0.496	0.017
K	—	—	0.005	0.031	0.095	—	—	0.001	0.130	0.888
Total	8.025	8.014	4.018	15.443	15.642	8.007	8.023	4.015	15.583	7.853
(Fe + Mn) . 100 / Fe + Mn + Mg	68.3	64.0	29.2	33.6	37.3	66.7	61.3	27.9	37.4	45.9
T °C*	600			650		650		800	700	725
T °C**	369—916					356—858				

* Perchuk (1970), assemblage Gar-Bi, Gar-Hb, Gar-Cpx); ** Ganguly (1979)

Clinopyroxene-garnet association corresponds to 856—858 °C according to Ganguly's method and to 742 °C according to the Ellis and Green thermometer. For the clinopyroxene hornblende, clinopyroxene-garnet and hornblende-biotite pairs the calculated temperature is 700—800 °C (Perchuk, 1970). The minerals of the leucocratic bands of the same rock and of the granulite with cyanite (8) might have equilibrated under lower conditions (600—650 °C according to the Perchuk thermometer).

Conclusions

The deepest PT-conditions for the origin are fixed in the garnet-clinopyroxen-orthopyroxen mineral assemblage of the Mohelno peridotite. They correspond to the Pt-conditions in the upper mantle. The country banded granulite gneiss and some gneisses, because of their polyphase origin, still contain some relics of older granulite metamorphic association equilibrated at a temperature of cca. 700—900 °C. The garnet-biotite pair of biotite gneisses indicates

leucocratic band		Biotite gneiss (7)		Leptinite (granulite) with kyanite)	
Gar	Bi	Gar	Bi	Gar	Bi
38.1	36.7	37.2	32.9	37.4	33.8
0.21	0.90	0.003	2.70	0.13	2.49
20.7	15.1	20.1	14.0	20.7	19.6
29.7	15.6	33.2	29.2	35.8	21.5
0.79	0.01	1.88	0.18	1.16	0.04
5.54	15.0	1.61	8.25	3.68	7.46
5.07	0.49	5.94	0.17	1.13	0.16
—	0.04	—	0.09	—	0.09
—	6.75	—	7.91	—	8.82
100.11	90.79	99.93	95.40	100.00	93.96
3.003	2.850	3.016	2.646	3.007	2.656
0.012	0.053	0.000	0.163	0.008	0.147
1.922	1.379	1.918	1.325	1.959	1.809
1.956	1.015	2.250	1.965	2.413	1.408
0.053	0.001	0.129	0.012	0.079	0.003
0.650	1.733	0.194	0.989	0.441	0.873
0.427	0.041	0.517	0.015	0.098	0.013
—	0.005	—	0.015	—	0.013
—	0.669	—	0.811	—	0.887
8.024	7.745	8.025	7.941	8.005	7.709
75.5	37.0	96.2	66.6	85.0	61.8
600		400 (?)		650	

only a temperature of 600—650 °C. Similar data are valid for granulite with cyanite occurring inside the granulite formation near the contact with the Mohelno ultrabasic body.

The PT-conditions for equilibration of bimetasomatic rocks at the contact between the peridotite and granulite might be reflected in a higher temperature (granulitic) mineral assemblage and in probably younger and lower (amphibolite facies) mineral assemblage with hornblende and biotite.

The mineral association of garnet pyroxenite (eclogite) inside the Mohelno garnet peridotite and also other focalities is a special problem. The PT-conditions of the origin of these rocks are about 200 °C and by 23 kbar lower than the PT-conditions of equilibration in the upper mantle garnet peridotite (Mísař — Jelínek and Jakeš, 1984). Therefore these pyroxenites may be formed in the uppermost part of the upper mantle or in the lower level of the continental crust.

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Tlakové a teplotní podmínky vzniku pyropových peridotitů a jejich okolních hornin v moldanubiku v okolí Mohelna

N. L. DOBRETSOV — Z. MÍSAŘ — E. V. POPOV

Indexní minerály pyropových ultrabazik a okolních granulitů byly studovány na mikrosondě. Podle získaných dat a použití různých geotermických a tlakových vztahů různých autorů byly vypočteny příslušné teplotní a tlakové podmínky vzniku těchto hornin. Minerální asociace granátických peridotitů odpovídá podmínkám jejich ekvilibrace za teploty 1123—1060 °C při tlaku kolem 18 kilobar. Pyroxenity vyskytující se i v jiných tělesech ultrabazických těles se dostaly do rovnovážného stavu za teplotních podmínek asi o 200 °C nižších. Nejsložitější se jeví interpretace získaných dat příslušných minerálních párů pro horniny, které vznikly bimetasomatickými pochody mezi peridotitem a granulitem. Z vybraného profilu u Mohelna byly zatím studovány ty, které obsahují amfibol, biotit, granát a sporadicky klinopyroxen. Rozdílné hodnoty ekvilibrace lze u nich obdržet podle různých metod. Např. podle Perčuka (1970) by podmínky rovnovážného stavu nastaly přibližně za teplot kolem 600 až 650 °C, podle metody Gangulyho (1979) jsou teplotní hodnoty podstatně vyšší.

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Минералого-петрологический очерк магматических пород окрестностей Сарвашкё (горы Бюкк, Северная Венгрия)

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Минералогическо-петрологическая характеристика магматических пород окрестностей Сарвашкё (горы Бюкк, Северная Венгрия)

Базальты окрестностей Сарвашкё очень похожи базальтам океанического дна, но всречаются в большой толщи теригенных свит. Представляют верхнюю часть серии, которая с точки зрения петрологии является офиолитовой; с геологической точки зрения эти породы приурачиваем к компликованным осадочным породам. Первоначальная магма возникала с нормального или слабо разубоженной мантии; имела пикритическое сложение, причем подвергалась диференциации в магматическом очаге за счёт возникновения базальтовых пород офиолитового характера. Базальтовые расплавы выливались очень медленно в результате существующего мощного осадочного комплекса; в следующем развитии базальтовые расплавы были опять последственно диференцированные. С точки зрения расположения и геохимии габра и перидотиты являются еквивалентными комплексу паралельных даек, причем представляют силивые формы в осадочных породах в почве базальтового горизонта. Они возникли из базальтовых расплавов, которые подверглись следующей диференциации после еффузии базальтов. Поэтому содержат повышенное количество железа и титана. В средней стадии кристализации эти расплавы подверглись оксидации а то в результате трансвапоризации ин ситу.

Mineralogic and petrogenetic outline of magmatic rocks from Szarvaskó (Bükk Mts., North Hungary)

Basalts from Szarvaskó are very similar to ocean floor ones but ley within a thick terrigenous sequence. They represent upper part of a series which is ophiolitic in petrological sense but is "diluted" by sediments in geological one. The primary magma originated from normal or slightly depleted mantle, was of picritic composition and suffered differentiation in a magma chamber of ophiolitic type generating basaltic melts. These melts ascended relatively slowly because of the existence of a sedimentary cover and were differentiated further.

Gabbro and peridotites are equivalents of sheeted dykes in view of their position and geochemistry but form sills within sediments beneath

the basalt horizon. They originated from the basaltic melts which suffered further differentiation after the basalt eruptions and or this reason were elevated in Fe and Ti. In middle stages of crystallization the melts became oxidized because of in situ transvaporization.

В юго-западной части гор Бюкк (рис. 1) находится одно из немногих полей развития основных и ультраосновных магматических пород Карпатского региона. В результате полевых геологических (Balla et al., 1980), затем лабораторных исследований (Balla et al., 1980), были выяснены основные черты стратиграфии, петрохимии и геохимии этих образований. Было установлено, что базиты представлены как в эффузивной, так и интрузивной фациях, залегая внутри терригенной толщи значительной мощности и слагая вместе с ней систему покровов; смятую в синформу сложного строения.

Эффузивный горизонт мощностью 300—500 м сложен подушечными лавами базальтового состава. Отсутствие концентрической зональности и пузырей или миндалин в подушках, а также монотонный глинистый состав преобладающей части осадков при турбидитном происхождении песчано-алевритовых прослоев среди них можно считать признаками глубоководного происхождения разреза.

Все интрузивные тела представлены силлами, причем степень раскристаллизации и дифференцированности пород закономерно увеличивается при удалении от эффузивного горизонта вниз по разрезу (рис, 1). В то время как породы самых верхних силлов почти не отличаются от эффузивных базальтов в самых глубоких силлах наблюдаются средне- и крупнозернистые габброиды, местами расслоенные, с более основными дифференциатами вплоть до перидотитов, местами со шлирами средних и с дайками кислых дериватов вплоть до плагиогранитов.

По составу базальты Сарвашкё близки к океаническим толеитам, но по сравнению с их средним типом в 1,5—2 раза обогащены элементами как с низкими (Na, K, Rb, Ba, Sr, Zr, Y, La, Ce), так и с высокими (Cr, Ni) коэффициентами распределения между Fe-Mg силикатами и расплавом. Выяснение причин этой двойственности равнозначно выяснению происхождения исходной магмы и хода ее дифференциации. Наиболее надежным методом в этом отношении является анализ состава минералов. Ввиду того, что подобные исследования проводились впервые, внимание было сконцентрировано на двух типах магматических пород района Сарвашкё: на базальтах их подушечных лав, являющихся самыми распространенными породами всей магматической серии и в то же время менее всего дифференцированными ее членами, и на габбро и перидотитах из расслоенных участков сильно дифференцированного силла, представляющих собой крайние продукты дифференциации. в которых ярче всего отражена главная особенность магматических пород всей серии — их обогащенность железом и титаном и обедненность магнием.

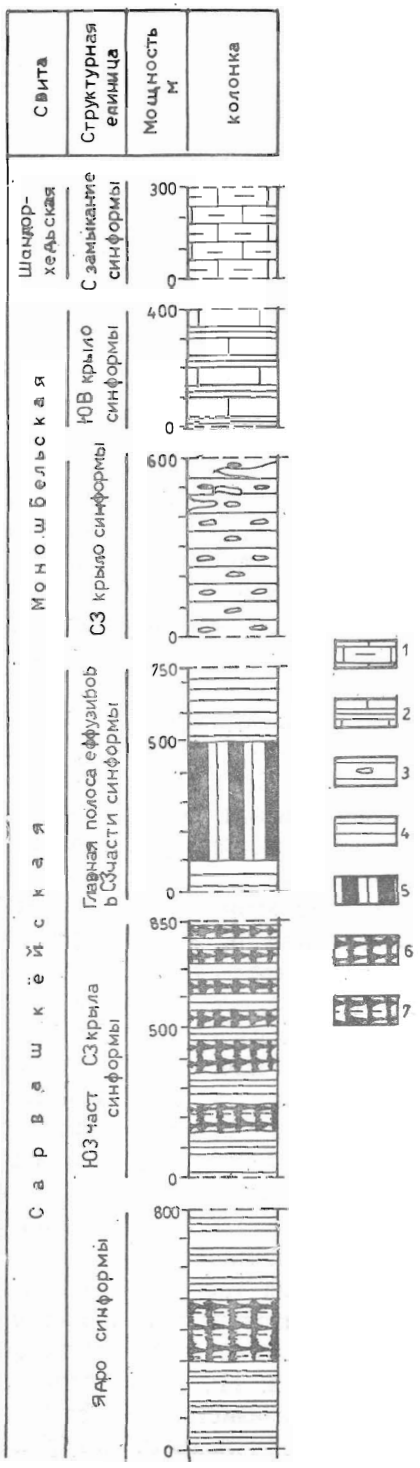
В клинопироксенах из базальтов на основании морфологических особенностей и состава были выделены: (1) протокристаллы размером до 5 мм, большей частью резорбированные, высоко- и низкохромистые, (2) каймы,

обрастающие протокристаллы, реликтовые и дорастающие, (3) микрофенокристаллы размером до 0,5 мм, идиоморфные, не сросшиеся с плагиоклазом, и (4) пироксены основной массы — отдельные микролиты или чаще — тонкие срастания с плагиоклазом игольчатого или радиально-лучистого облика, представляющие собой продукты одновременной и быстрой крис-

Рис. 1. Сводная стратиграфическая колонка Сарвашкёйской синформы (по Balla et al., 1983). Слева: положение Сарвашкёйской синформы в географической схеме Венгрии (вверху) и схема поперечного разреза синформы (внизу). Условные обозначения: 1 — известняки, сланцы кремнистые и глинистые в частом переслаивании или чередовании в виде пачек, в основном красные до розовых, 2 — известняки серые, часто с кремнями, обычно плитчатые, с прослоями светлых глинистых сланцев, 3 — глинистые сланцы, темносерые до светлосерых, местами с олистолитами известняков, в верхней части с линзами известняков с кремнями, местами с прослоями кремнистых или кремнисто-глинистых сланцев, 4 — глинистые сланцы, темносерые до светлобурых, 5 — глинистые сланцы, алевролиты, песчаники, 6 — подушечные лавы базальтов, 7 — слабо дифференцированные силлы (базальты, мелкозернистые габбро), 8 — сильно дифференцированные силлы (габбро, гипербазиты, диориты и т. п.)







таллизации эвтектического типа.

По составам и трендам их изменения выделенные объекты могут быть объединены в три группы, каждая со своим трендом (рис. 2): (А) высокохромистые ядра протокристаллов и реликтовые каймы, (Б) низкохромистые ядра протокристаллов, дорастающие каймы и микрофенокристаллы, наконец, (В) пироксены основной массы. Эти три группы можно рассматривать в качестве продуктов трех этапов кристаллизации.

Первый этап, соответствующий группе А (протокристаллизация) характеризуется тем, что в процессе кристаллизации при практически постоянной железистости клинопироксена резко уменюшаются Cr, Al, Ti и особенно Ca, и возрастает Si. Можно предположить, что этот этап протекал при высокой температуре в равновесии с оливином (псевдоморфозы: Balla et al., 1983), хромитом (высокое содержание Cr) и ортопироксеном (предельно низкая концентрация Ca), то есть кристаллизация происходила из пикритовой или близкой к ней магмы.

В ходе второго этапа, фиксируемого группой Б, железистость пироксена возрастает от 15 до 30 % с одновременным возрастанием Al и Ti и уменьшением Si, Ca и Cr. Возрастание Cr и Mg в начале этапа по сравнению с заключительной стадией протокристаллизации можно объяснить тем, что в это время стали неустойчивыми хромит и оливин, которые как бы „растворились" во вновь кристаллизующемся клинопироксене.

Во время третьего этапа (группа В) кристаллизовалась большая часть породы, в частности, не менее 80—90 % пироксенов. На этом этапе с возрастанием железистости (f) от 25 до 45 % резко увеличивалось содержание Ca, несколько снизилось содержание Al при почти постоянных Si, Ti и Cr.

Составы клинопироксенов выделенных трех этапов кристаллизации базальтов Сарвашкё имеют свои аналоги в других районах (рис. 3). Высокая степень их сходства с толеитами океанического дна наводит на мысль о возникновении этих пород тем же механизмом, что и офиолитовые серии. Сущность этого механизма заключается в наличии промежуточной магматической камеры, выравнивающей составы отделяющихся от нее базальтовых расплавов (Dobretsov and Kepezhinscas. 1981). Протокристаллы можно рассматривать в качестве продуктов кристаллизации внутри этой камеры, а их сходство с клинопироксенами мантийных пород Лесото можно считать следствием конвергенции, обусловленной сходными в обоих случаях высокими температурами магмы, обычными в офиолитовых камерах (Бакуменко и др., 1976).

Сходство характера изменения составов клинопироксенов из базальтов Сарвашкё с таковыми в трапповых сериях, скорее всего, является следствием того, что по сравнению с обычными офиолитовыми сериями путь (и соответственно время) подъема магмы Сарвашкё был удлинен на мощность осадочной толщи, подстилающей эффузивный горизонт.

Состав магмы, исходной для базальтов Сарвашкё можно оценить на основании предположения, что базальтовый расплав сформировался из нее путем удаления протокристаллов оливина и клинопироксена. Расчеты велись для разных количеств и соотношений этих минералов с учетом всех петротенных окислов и важнейших из микроэлементов. Результаты сравнивались с составами наиболее вероят-

ных аналогов исходной магмы офиолитовых серий — различных пикритов (Dobretsov and Kepezhinscas, 1981). Оказалось (Балла и Добрецов, 1984), что наилучшего соответствия пикриту можно добиться при осаждении примерно 20 % оливина и 10 % клинопироксена на глубине. Полученная таким путем исходная магма обладает повышенными содержаниями Ti, Zr, Sr, Rb и Na, что свидетельствует о повышенной щелочности и может быть объяснено малой степенью плавления нормальной или слабо истощенной мантии.

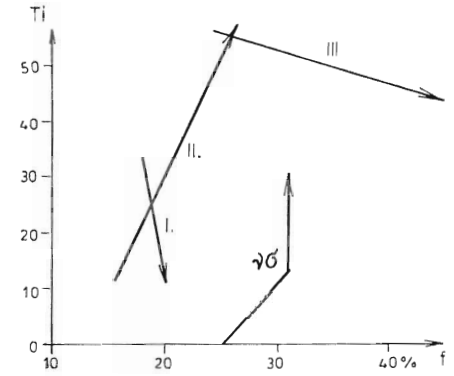
Таким образом, генезис базальтовой магмы Сарвашкё определяется тремя главными факторами: (1) офиолитовой природой базальтового расплава (его возникновением из пикритовой магмы в камере офиолитового типа), (2) существенно удлиненным путем его подъема к поверхности и (3) происхождением исходной магмы из нормальной или слабо истощенной мантии. В целом магматические породы района Сарвашкё представляют собой верхнюю часть такого разреза, который в петрологическом смысле является офиолитовым, но в геологическом отношении как бы „разбавлен" осадками и оторван ими от более глубоких габбро-перидотитовых уровней офиолитовой серии — продуктов затвердевания собственно офиолитовой магматической камеры.

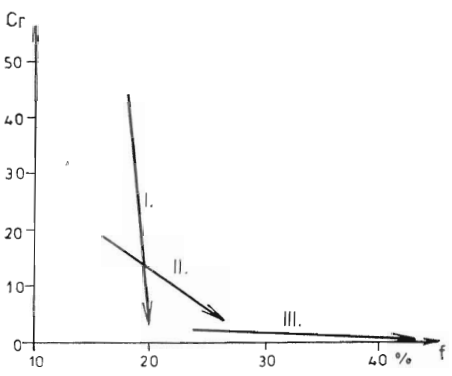
Габбро и перидотиты из силлов окрестностей Сарвашкё никак не могут отождествлятся с обычными офиолитовыми габбро и перидотитами, поскольку по отношению к эффузивному горизонту они залегают на уровнях, соответствующих комплексу параллельных даек офиолитовых серий, обладая рядом геохимических черт именно даек, а не более глубинных габбро (Balla et al., 1983).

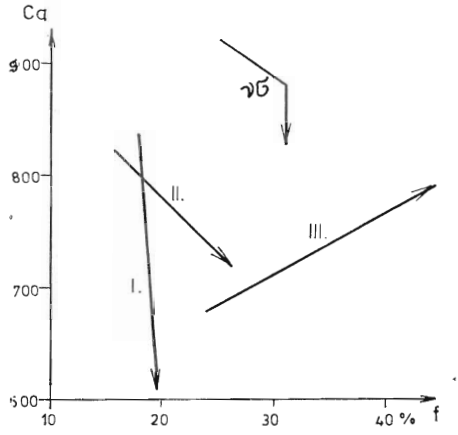
В ультраосновных породах окрестностей Сарвашкё выделяются три генерации минералов: (1) кумулятивные оливин и ильменит, (2) посткумулятивный клинопироксен (± ортопироксен, ± плагиоклаз) и (3) поздняя бурая роговая обманка (± титаномагнетит, ± биотит). В начальные этапы кристаллизации (кумуляты железистого оливина и ильменита) расплав был восстановленным. Его железистость и титанистость, скорее всего, слабо менялись при кристаллизации. Появление вместо железистого оливина и ильменита значительно менее железистого и низкотитанистого клинопироксена, вероятнее всего, связано с окислением расплава и с появлением в нем трехвалентного железа.

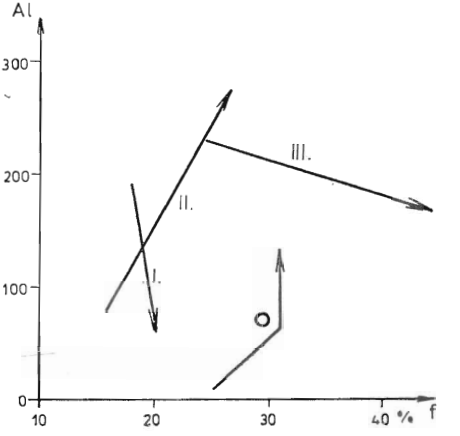
В начальные стадии окисления трехвалентного железа было мало для образования самостоятельных твердых фаз, и оно оставалось в расплаве. Существенное замедление роста железистости клинопироксена (рис. 2) могло быть связано с появлением минералов, обогащенных трехвалентным железом: бурой роговой обманки и ти-магнетита. Кристаллизация на этой стадии значительных количеств водных минералов: амфибола и биотита — доказывает связь окисления с поступлением воды в расплав. Основная масса железа выделилась в виде магнетита не в начале окисления, фиксируемого резким падением железистости силикатной фазы (с 50 % в оливине до 25 % в раннем клинопироксене), а лишь тогда, когда окислительный потенциал достиг необходимого для этого уровня.

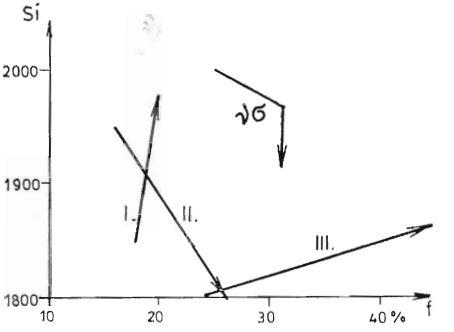
Этот момент наступил на довольно поздней стадии кристаллизации силикатов, после выделения основной мас-

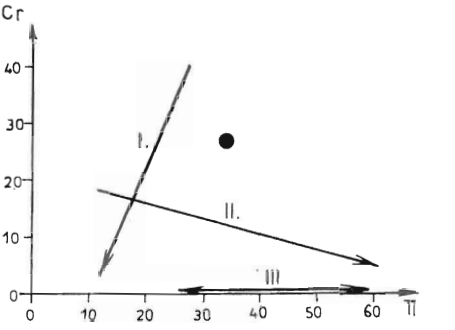

Ti
50
40
30
20
10
0
10
20
30
40 %
f
I.
II.
III.
∇σ


Cr
50
40
30
20
10
0
10
20
30
40 %
f
I.
II.
III.


Ca
900
800
700
600
10
20
30
40 %
f
∇σ
I.
II.
III.


Al
300
200
100
0
10
20
30
40 %
f
I.
II.
III.
σ


Si
2000
1900
1800
10
20
30
40 %
f
∇σ
I.
II.
III.


Cr
40
30
20
10
0
0
10
20
30
40
50
60
Ti
I.
II.
III.

E D C B A

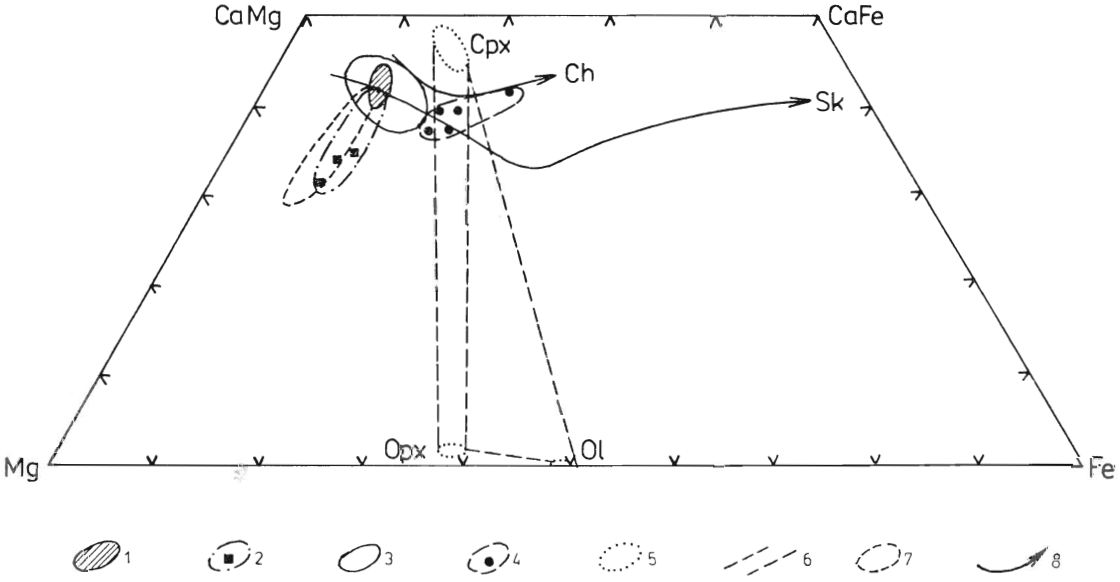
4 3 2 1

Рис. 2. Схема изменения составов клинопироксенов при кристаллизации, I, II, III — этапы кристаллизации в базальтах, уб — габбро и перидотиты, Ti, Cr, Ca, Al и Si — в формульных единицах, f = $FeO^t/(Fe\,O^t+MgO)$; $Fe\,O^t$ — $FeO+0{,}9\,Fe_2O_3$. Тренды проведены на основании 68 микрозондовых анализов, выполненных в Будапеште (Геохимический институт ВАН) и в Улан-Удэ (Геологический институт Бф СО АН СССР). Фактический материал см. в статье З. Балла и Н. Л. Добрецова (1984)

◀

сы клинопироксена и примерно совместно с кристаллизацией роговой обманки. Повышенную титанистость амфибола и магнетита можно считать следствием накопления титана в расплаве при кристаллизации силикатов. Об этом накоплении свидетельствует характер изменения состава клинопироксена (рис. 2).

Таким образом, для понимания процессов формирования расслоенных габбро и перидотитов окрестностей Сарвашкё ведущими являются следующие обстоятельства: (1) происхождение исходного расплава из магмы базальтов, (2) повышенная железистость расплава с самого начала его кристаллизации и (3) окисление расплава в ходе его кристаллизации. Возникновение необычных интрузивных



▲

Рис. 3. Составы железо-магниевых минералов в минальных координатах. Условные 6 — условные линии, соединяющие минералы перидотитов и габбро, 7 — поле составов клинопироксенов первого этапа кристаллизации в базальтах, 3 — то же, второго этапа, 4 — то же, третьего этапа, 5 — поля составов кристаллов из рудных перидотитов и габбро (Cpx — клинопироксен, Opx — ортопироксен, Ol — оливин), 6 — условные линии, соединяющие минералы перидотитов и габбро. 7 — поле составов клинопироксенов из глубинных включений в кимберлитах Лесото (по Boyd and Nixon, 1973), 8 — тренды изменения составов клинопироксенов из дифференцированных траповых интрузий: Ch — Чинейский плутон (Конников, 1982), Sk — Скаергардская интрузия (Brown, 1957. Brown and Vincent, 1963)

пород из магмы офиолитовых базальтов можно считать следствием дальнейшей дифференциации исходного расплава в той же глубинной камере. Она не отразилась на составе базальтов, следовательно, произошла позже их излияний. Окисление в ходе кристаллизаци могло быть связано с поступлением воды из вмещающих пород, то-есть с трансвапоризацией расплава в камере силла.

В результате проведенных исследований выявлена главенствующая роль глубинной камеры офиолитового типа в формировании расплавов, из которых образовались магматические породы района Сарвашкё. Оказалось, что „разбавление" верхних горизонтов магматической серии осадочными породами создало особые условия для кристаллизации и дифференциации расплавов, что позволяет считать данный разрез особым типом офиолитовых серий.

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Metasomatites (listvenites) replacing ultrabasics (Paleozoic, Inner Western Carpathians)

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Метасоматиты (листвениты) по ультрабаитам. (Палеозой, внутренние Западные Карпаты)

В палеозоическом вулкано-осадочном комплексе, который до сих пор относили к раковецкой группе, был определён целый ряд метасоматитов по ультрабазитах (*лиственитах*) в прошлом с большей части интерпретированных как метасоматические анкериты или магнезиты. В их составе принимают участие: бреуннерит, железистый доломит, кварц, хлорит, фухсит, хромспинелид, магнетит, гематит и другие минералы. Наличие лиственитов повышает металогенетическую перспективность этой территории и свидетельствует о материалах океанической коры в геологическом строении региона.

Metasomatites (listvenites) replacing ultrabasics (Paleozoic, Inner Western Carpathians)

Several occurences of metasomatized ultrabasic rocks (listvenite) have been found to occur in volcano-sedimentary complexes of Paleozoic age ranged hitherto among the Rakovec group. The bodies have been formerly assumed to represent metasomatic ankerite or magnesite. Mineral assemblages are composed of breunerite, Fe-dolomite, quartz, chlorite, fuchsite, chromspinelids, magnetite, hematite and others. The presence of listvenites increases metalogenetic perspectives of the entire area.

The North-Gemeric zone is a belt of peculiar structural edifice bordering the northernmost structural-tectonic unit of the Internal West Carpathians, the Gemeric unit, in places of its contacts with more northernly units of the Central West Carpathians. The belt is built prevailingly by Paleozoic and but less Mesozoic complexes. Paleozoic age have the Rakovec (Devonian ?), Dobšiná (Middle to Upper Carboniferous) and Krompachy groups (Permian, fig. 1). From all these units, the

Rakovec group has the largest areal extent and, from the viewpoint of reconstruction of the geotectonic development, it appeared hitherto as the most important in the area. The majority of authors is inclined in assuming it to represent an incomplete ophiolite sequence or, at least, agrees with its generation upon a suboceanic crust (Dianiška — Grecula, 1979, Grecula — Varga, 1979, Bajaník — Hovorka, 1981, Maheľ, 1981 a. c.). An important stimulus to such interpretation was the finding of metaultrabasite bodies near Vyšný Klátov, Bukovec and Dobšiná-Tešnárky localities (Dianiška — Grecula, 1979. Hovorka — Ivan, 1981a) as members of the Rakovec group. The present paper gives evidence on rich representation of ultrabasic masses at least in the part of complexes ranged into the Rakovec group.

From the wider surroundings of Košické Hámre locality, several bodies of ankerite and dolomite-magnesite composition have been described by J. Ilavský — R. Ďuďa (1970) and R. Ďuďa (1976). Carbonates contain subordinated quartz, chlorite, fuchsite, sericite and ores as pyrite, chalcopyrite, tetrahedrite and cinnabar. Bodies were regarded to represent metasomatic analogues of quartz-ankerite (± sulphides) veins developed in suitable environment "of carbonatic to diabasic composition" (Ďuďa, l. c.). Results of own investigations of the author point to different mineral composition of these bodies substantiating also different genetic interpretation. Structural, mineralogical and geochemical features allow to interpret them as hydrothermally altered ultrabasics i. e. as metasomatites of listvenite type.

Geological characteristics

Listvenites in the surroundings of Košické Hámre occur exclusively in Paleozoic volcano-sedimentary complex represented by multiply alternating epimetamorphic and pelitic sediments. Moreover, also sesediments with carbonate admixture and

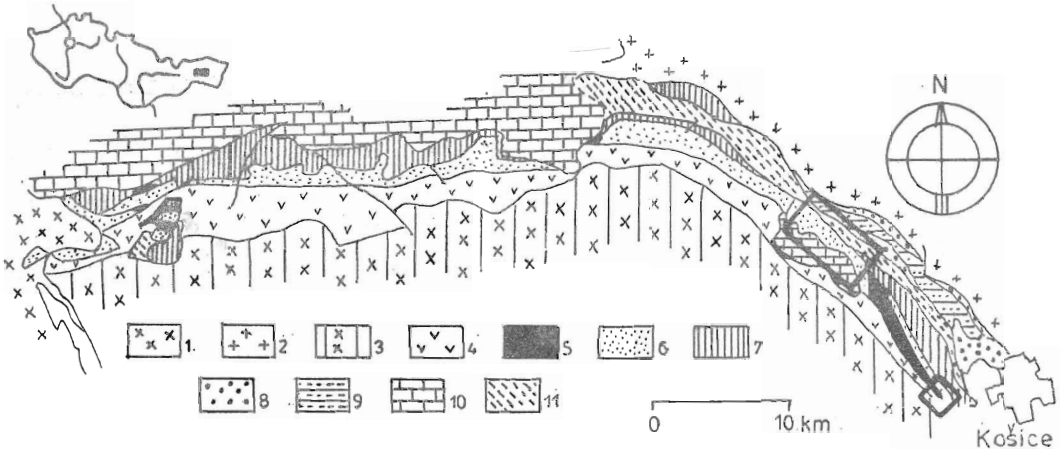


Fig. 1. Geological sketch-map of the Spišsko-gemerské rudohorie Mts. Framed areas of metasomatite occurences after ultrabasite rock. 1 — Veporic, 2 — Tatric (1—2 units of the Central West Carpathians), 3 — Gelnica group, 4 — Rakovec group, 5 — complex of higher-metamorphic rocks (Klátov group), 6 — Dobšiná group (except of the Ochtiná member), 7 — Krompachy group, 8 — Ochtiná member, 9 — Črmeľ group (3—9 — Paleozoic of the Gemeric unit), 10—11 — Mesozoic of the Gemeric unit

graphite phyllite are present. The whole complex has been ranged to the Rakovec group by M. Maheľ (1954).

All listvenite occurrences concentrate into several parallel belts of NW—SE strike conciding with the general structural pattern of the area (fig. 2). Listvenites

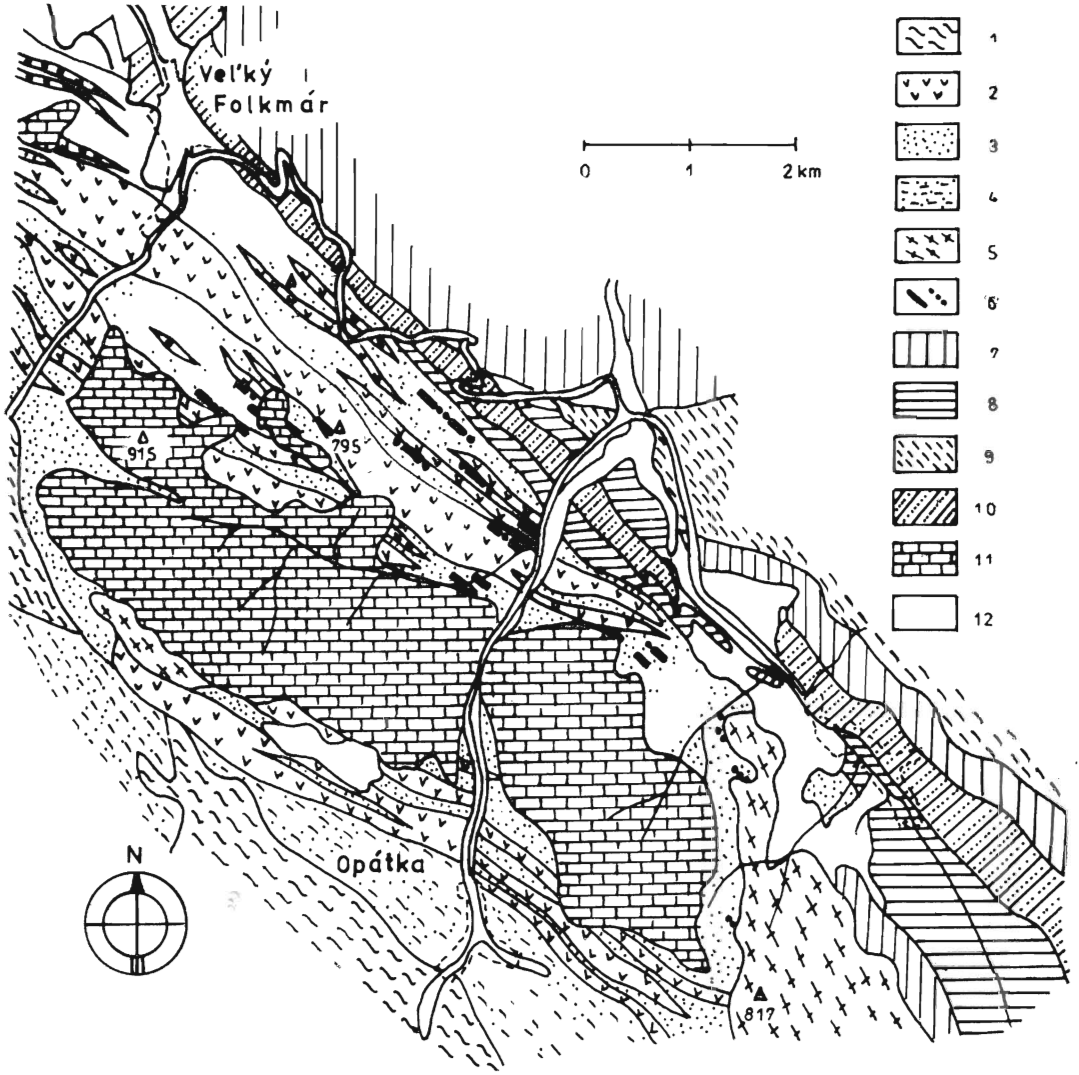


Fig. 2. Geological map of the surroundings of Košické Hámre (modified after Snopko et al., 1973). 1 — Gelnica group, 2 — epimetamorphosed basalt, tuff and spilite, 3 — green phyllite with epimetamorphosed tuff and tuffite layers (2—3 — Rakovec and Dobšiná group undifferentiated), 4 — laminated green chlorite-sericite phyllite (Rakovec group), 5 — rocks of higher metamorphic degree (mainly gneiss and amphibolite, Klátov group), 6 — listvenite body known and presumed, 7 — Ochtiná member, 8 — Krompachy group, 9 — Črmeľ group, 11, 12 — Mesozoic of the Gemeric unit

after ultrabasics create lense-shaped bodies of various size. Names of single occurrences and their more detailed geographic location are in fig. 3. Commonly, thicknesses do not surpass 20 m, the strike lengths attain first hundred metres.

On the most of localities, listvenites appear sharply in morphology creating cliffs several metres high above the terrane or boulder outcrops among the enclosing rocks. Boundaries of bodies toward the enclosing rocks are sharp. In the exocontact zone, features of phyllonitization and subsequent hydrothermal alteration are observable to some metres distance. Anchimonomineral chlorite rock preserved only locally and represent the product of contact-metasomatic reactions between serpentinized ultrabasite and enclosing rocks still before listvenitization.

Metasomatic rocks of analogous type have also been found near to the eastern termination of the Rakovec group near Bukovec village (fig. 1). Listvenites occur along the margins of antigorite serpentinite body confined to the contact of epimetamorphites of the Rakovec group with the gneiss-amphibolite complex. Due to

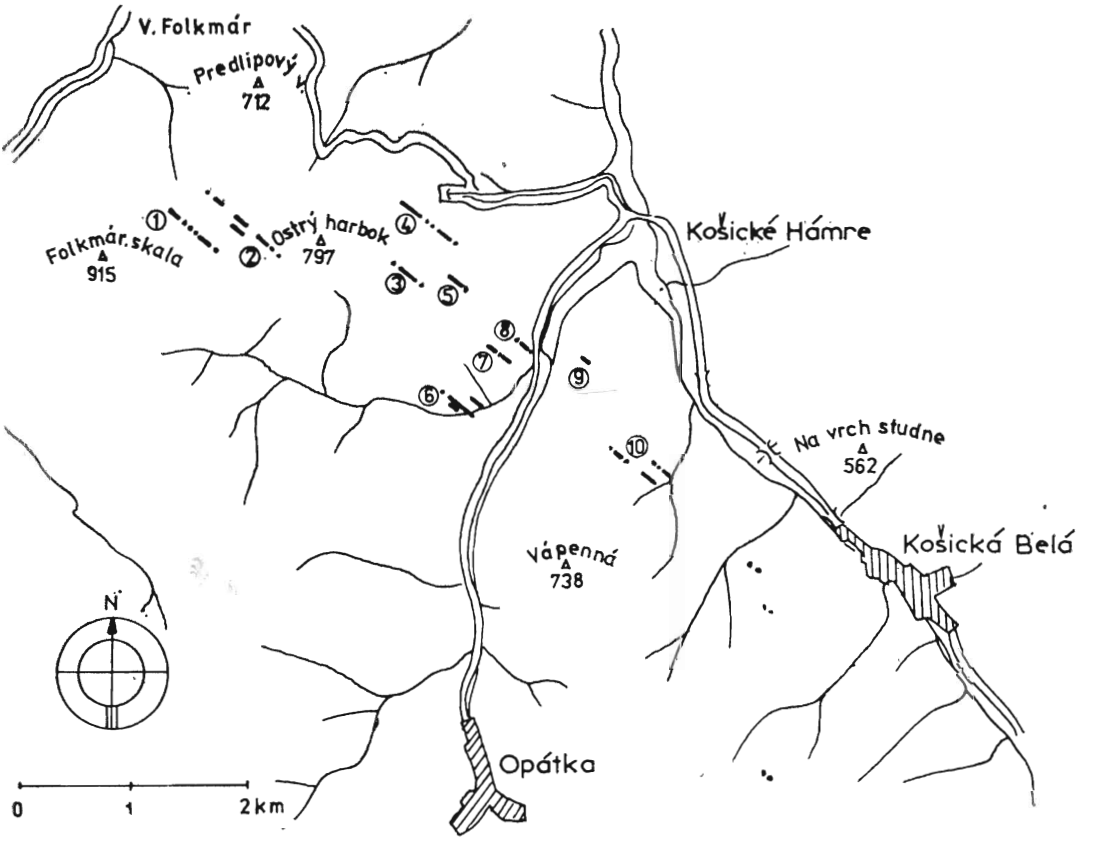


Fig. 3. Distribution of metasomatites after ultrabasics (listvenite) in the surroundings of Košické Hámre. Localites: 1 — Folkmárska skala cliff, 2 — Ostrý harbok, 3 — Rimasgrund, 4 — Teplý potok, 5 — Predné nové, 6 — Zlatník, 7 — Za Prieložky, 8 — Nad Prieložky, 9 — Roveň, 10 — Slatviny

bad outcrops, the occurrence has not been examined in detail.

Petrography and mineralogy

Results of petrographic investigations revealed variable mineral composition of listvenites from the area so in qualitative as in quantitative proportions. In the whole, rock varieties may be classified into several well defineable basic types. Unambiguously, metasomatites after ultrabasics are represented by rocks of the following composition: talc + carbonate, chlorite + quartz + carbonate (breunnerite), chlorite + quartz + charbonate (Fe-dolomite) and fuchsite + quartz + carbonate.

If compared with the original ultrabasite, the talc-carbonate rocks underwent the less alterations. These are rocks foliated to various degrees and, by nacked eye, of brownish-grey to brownish-yellow colours. As a rule, the rocks are composed of fine flaky talc aggregate enclosing idioblasts or clusters of irregular carcarbonate grains (breunerite or breunerite + Fe-dolomite) in various proportions. From the primary minerals of ultrabasics, only chomspinelids are preserved as disseminated grains retaining original idiomorphic shapes and but slightly altered by cataclasis (fig. 4a). Chromspinelids, however, mostly altered in the course of metamorphic alterations as they lost transparency and a chlorite rim developed around the grains indicating the depletion of Al and simultaneously even of Mg with their substitution by iron. Talc-carbonate rocks do not create considerable masses but as small enclaves (2—3 m) occur within other metasomatic rock types on Ostrý harbek, Rimasgrund and Slatviny localities.

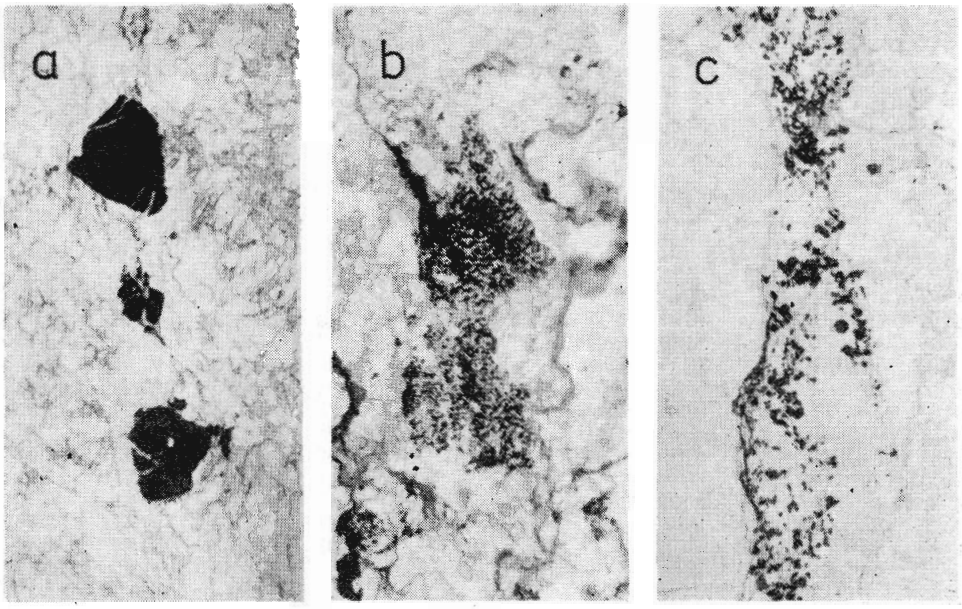


Fig. 4. Increase of chromspinelid cataclasis with increasing degree of metasomatic alteration. a — sample FKH-16, talc-carbonate listvenite, b — sample FKH-57, chlorite-quartz-carbonate (dolomite) listvenite, c — sample FKH-54, fuchsite-quartz-carbonate (dolomite) listvenite, magn. ×48, parallel nicols, photo by L. Oswald

Rocks of chlorite-quartz-carbonate composition are already products of more intense alteration originated at the expense of ultrabasics. This variety is genetically related to the previous one as proved by intermediate parageneses of chlorite + talc quartz + carbonate. Mostly talc underwent alterations being itself substitued by quartz-carbonate mass where usually quartz creates isolated domains of fine-grained development in panxenomorphous carbonate aggregate.

Quartz pseudomorphoses after chlorite are less frequent. Chromspinelid grains are strongly cataclased and together with chlorite rims rolled-out into planar surfaces yielding to the rock a preferredly oriented appearance and even slaty parting (fig. 4b). According to the species of the chlorite and carbonate present, several subtypes may be distinguished.

The most common subtype contains at most exclusively breunerite (up to 50 %) whereas Fe-dolomite is contained maximally in some per cents (tab. 1.).

The content of emerald-green Mg-chlorite is characteristic in this subtype; its Ni-content is higher (2,000 p. p. m.) and contains, as colouring element, chromium (over 1 p. c.). Macroscopically, the rocks have bright yellow colour and contain emerald-green chlorite stripes together with black disseminated chromspinelid grains (fig. 5). The variety composes the majority of listvenite bodies with the exception of the Slatvina locality.

Chlorite-quartz-carbonate (Fe-dolomite) metasomatites containing lesser amounts of greyish-green Mg-chlorite, in thin section almost colourless, have been found as minor enclaves in the previous breuneritic metasomatite. Manometric analyses (tab. 1) point to but subordinated amounts of breunerite and overwhelming Fe-dolomite in the rock. This variety is remarkable by strongly varying colours (dark-grey to

Composition of the carbonate constituent in listvenites from the surroundings of Košické Hámre

Tab. 1

	Loc.	Sample	Type	Breunerite	Dolomite	NZ	Σ	Λ
1	3	FKH-36	$(Ch^1) + T + K$	50,71		47,52	98,33	1,77
2	2	FKH-17	$(Ch^1) + T + K$	46,23		52,20	99,43	0,57
3	6	FKH-2	$Ch^1 + T + Q + K$	44,08		54,25	98,33	1,67
4	6	FKH-4	$Ch^1 + T + Q + K$	26,28	3,14	56,25	85,67	14,33
5	1	FKH-68	$Ch^2 + Q + K$	64,87		32,33	97,60	2,40
6	6	FKH-5	$Ch^2 + Q + K$	42,84	4,42	44,70	91,96	8,04
7	2	FKH-15	$Ch^2 + Q + K$	61,71	2,51	34,95	99,17	0,83
8	4	FKH-62	$Ch^2 + Q + K$	39,34	3,56	53,37	96,27	3,73
9	10	FKH-9	$Ch^3 + Q + K$		49,68	49,32	99,00	1,00
10	10	FKH-12	$Ch^3 + Q + K$		53,86	45,57	99,43	0,57
11	4	FKH-60	$F + Q + K$		37,15	58,65	95,65	5,11
12	1	FKH-67	$Q + K$	17,61	32,15	49,45	99,21	0,79
13	2	FKH-27A	$(Ch^1) + Q + K$	4,58	54,44	38,12	97,14	2,86
14	2	FKH-27B	$(Ch^2) + Q + K$	36,47	25,05	33,37	94,87	5,11
15	10	FKH-28	$Se(?) + Q + K$	68,05		26,68	94,73	5,27

Analyses made by manometric method, analyzed by J. Turan, L. Turanová, Geological Institute, Comenius University, Bratislava. NZ — insoluble residue, Λ — soluble noncarbonatic constituent. Locality number as in fig. 3, metasomatite type as in tab. 3

greenish-white) and banded structure.

A peculiar subtype of chlorite-quartz-carbonate metasomatite has been found on the Slatvina locality being characterized by dark-green Fe, Mg-chlorite (strongly pleochroic in thin section) and rich disseminated hematite. By nacked eye, the rock reminds the previous subtype, it is of greyish-green colour and has well expressed banded structure.

Fuchsite-quartz-carbonate rocks are, when comparing with the other types, less frequent products of ultramafite alteration. Their largest occurrence is in the western part of the Teplý jarok locality where this type prevails. The variety creates only enclaves in chlorite-quartz-carbonate rock on the Zlatník and Rimasgrund localities. The rock is massive, greyish-green and has but slightly expressed banded structure. The fuchsite content is low, not concentrated into bands but mainly scattered. The microscopic composition is the same as in previous cases: carbonate mostly prevails in aggregates or single grains with authomorphic shapes towards quartz. The last mineral occurs as typical fine-grained aggregate (0.0X mm), fuchsite is present in minor flakes or short lense-like veinlets predominantly in quartz. Chromspinelid grains are strongly cataclased and scattered (fig. 4c). Peculiar feature is the locally rich tetrahedrite dissemination.

Listvenite bodies in the surroudings of Košické Hámre are rimmed by various metasomatic rock types originated synchronously with the listvenite through alteration of metabasites and their tectonites. Nevertheless, only anchimonomineral chlorite rocks are mentioned here because these represent the single variety related, from genetic point of view, to the ultrabasics. The last rocks originated by contact-metasomatic processes along the contacts of ultrabasite bodies with the

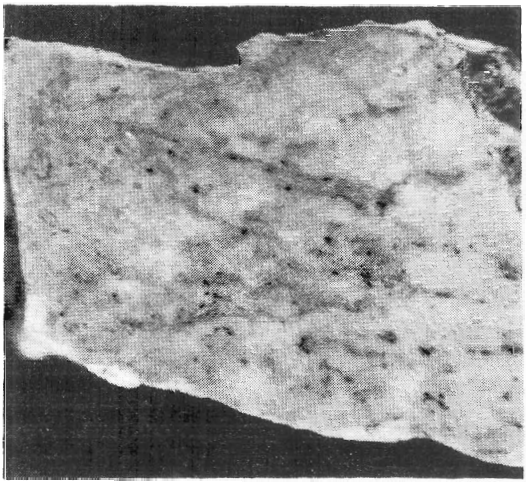


Fig. 5. Chlorite-quartz-carbonate (breunerite) listvenite. Black grains are chromspinelids, greyish stripes composed of emerald-green chlorite, sample FKH-15, magn. ×1.5, photo by L. Oswald

surrounding rock still before the listvenization. The variety underwent but limited hydrothermal-metasomatic alterations so that creates relics inside and along the margins of listvenite bodies. The rock is massive and dark-green, consisting of, almost exclusively, Mg-chlorite and but subordinated apatite, carbonate, rutile and pyrite. Most common occurrences are on Zlatník and Ostrý harbek localities.

Chemical characteristics

The chemical composition of metasomatic rocks resulted from two antagonistic tendencies: one tending to maintain the pecularities of composition of the educt and another expressed by the tendency of alterating hydroterms to modify the original composition. The rate of the second tendency grows by the alteration degree. The rules indicated influence also the composition of investigated samples. Listvenites originating at the expense of ultra-

basites from the surroundings of Košické Hámre preserved the pattern of their origin in contents of petrogenous as well as trace elements. The characteristic traits of ultrabasics, the high MgO and Al_2O_3 content, remain namely in products of initial alteration stages i. e. in talc-carbonate and chlorite-quartz-carbonate (breunerite) rocks (tab. 2, fig. 6). Later metasomatite types, namely the final fuchsite-quartz-carbonate rocks reflect the introduction of calcium by the development of dolomitic carbonate with simultaneous decrease of their magnesium content. Even alkalies then appear owing to the development of fuchsite. From trace elements, high concentrations of chrome characterize all metasomatite types (tab. 3). Certain cases of low chromium concentrations result from the partial destruction of its main carrier, the chromspinelids. Early stages of metasomatic alteration are characterized also by the preservation of original high nickel concentrations. In final products, the fuchsite-quartz-carbonate rocks, the amount of nickel is considerably lower (tab. 3). Similar behaviour characterizes even cobalt contents. Low concentrations of titanium and vanadium are sensible indicators of the original ultrabasic nature of listvenites. In anchimonomineral chlorite rocks confined to the rims of listvenite bodies, concentrations of Ti and V are higher what points to enrichment at the expense of enclosing metabasites.

The comparison of listvenite composition with Uralian listvenites *(locus typicus)* revealed almost perfect similarity (tabs. 2 and 3, fig. 6). Owing to the same original rocks (serpentinized alpinotype ultrabasite), this similarity is proof for a generally valid geochemical nature of listvenization processes.

Chemical composition of metasomatites after ultrabasite from the surroundings of Košické Hámre

Tab. 2

	1	2	3	4	5	6	7	8
SiO_2	34,22	24,94	43,77	55,03	30,92	32,73	40,81	33,25
TiO_2	0,03	0,03	0,02	0,02	0,22	1,46	0,01	0,01
Al_2O_3	1,19	1,61	1,62	1,41	17,50	19,38	1,84	0,45
Cr_2O_3	0,20	0,23	0,17	0,11	0,13	0,03	0,32	0,24
Fe_2O_3	0,65	0,52	2,39	0,38	0,52	0,10	4,17	1,72
FeO	5,31	6,06	3,55	3,50	6,06	6,55	4,16	3,67
MnO	0,12	0,16	0,30	0,16	0,04	0,01	0,06	0,09
NiO	0,20	0,20	0,12	0,00	0,31	0,35	0,23	0,17
MgO	32,15	29,90	10,84	7,59	28,23	25,40	36,00	29,18
CaO	0,18	0,30	14,51	12,84	0,10	0,28	0,61	0,40
Na_2O	>0,01	0,04	0,10	0,08	0,10	0,08	<0,1	0,07
K_2O	>0,01	0,05	0,09	0,28	0,03	0,04	<0,1	0,05
H_2O^-	0,23	0,24	0,41	0,36	0,24	0,32	0,34	0,03
H_2O^+	23,29	35,56	20,60	18,26	15,06	13,12	11,40	1,00
CO_2								29,46
P_2O_5	0,01	>0,01	0,01	>0,01	>0,01	0,26	>0,1	0,02
S	0,01	>0,01	0,05	0,03	>0,01	0,01	—	0,01
Σ	97,79	99,84	98,55	100,05	99,46	100,21	99,93	99,83

Analyses made in laboratories of Geologický prieskum Spišská Nová Ves, 1 — FKH-17, 2 — FKH-15, 3 — FKH-12, 4 — FKH-60, 5 — FKH-3, 6 — FKH-18, 7 — A, 8 — B, other data in tab. 3

The origin of listvenites

To the contrary to classical Uralian localities, a well expressed metasomatic zonality lacks in listvenites from the eastern part of the Gemeric Paleozoic. This is due to small size of single bodies as well as to the high intensity of hydrothermal activity. The development sequence of single mineral types of listvenites in the area investigated, and by that also the general trend of chemical changes, may be stated only on the base of rarely observable

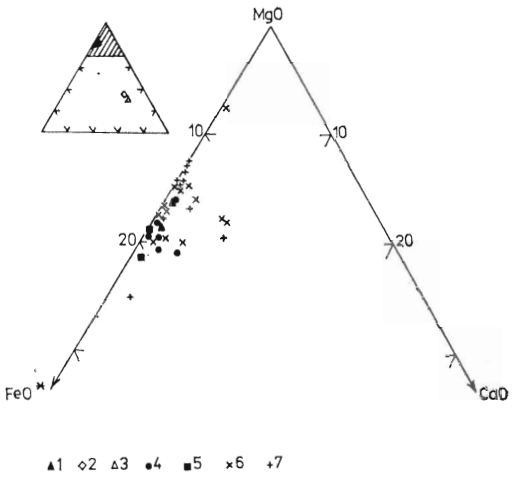


Fig. 6. Variations of FeO* contents (total Fe as FeO), MgO and CaO in various types of metasomatite after ultrabasite (listvenite) and in their educts from the surroundings of Košické Hámre and Ural Mts. (latter data from Sazonov, 1978). 1 — breunerite-bearing listvenite (talc-carbonate and chlorite-quartz-carbonate rock), 2 — chlorite-quartz-carbonate (dolomite) listvenite, 3 — fuchsite-quartz-carbonate (dolomite) listvenite, 4 — serpentinite from the Paleozoic of the Gemeric unit, 5 — anchimonomineral chlorite rock, 6 — listvenites from the Ural Mts. (breunerite-bearing types), 7 — serpentinites from the Ural Mts.

Contents of some typomorphic elements in listvenites from the surroundings of Košické Hámre

Tab. 3

	Loc.	Sample	Type	Ni	Co	Cr	V	Zn	Ni/Co
1	2	FKH-69	T + K	1250	90	2170	30	111	13,89
2	2	FKH-17	Ch^1 + T + Q + K	2020	84	2025	32	100	24,05
3	2	FKH-15	Ch^2 + Q + K	1590	74	1560	39	50	21,49
4	1	FKH-68	Ch^2 + Q + K	1100	60	1250	30	52	18,33
5	2	FKH-14	Ch^2 + Q + K	940	26	1485	35	100	36,15
6	6	FKH-65	Ch^2 + Q + K	935	41	1320	35	109	22,80
7	10	FKH-12	Ch^3 + Q + K	30	40	1140	35	23	19,36
8	4	FKH-35	(Ch^1) + Q + K	8	910	1730	47	405	11,41
9	4	FKH-58	F + Ch^1 + Q + K	46	194	1220	17	39	17,00
10	4	FKH-60	F + Q + K	153	9	750	25	87	6,00
11	6	FKH-3	a. Ch^1	2460	82	870	156	600	30,00
12	2	FKH-18	a. Ch^1	2780	150	211	259	200	18,53
13		A	Serp	1806	80	2190	54		22,58
14		B	F + Q + K	1200	70	1450	30		17,14

Analyses made in Laboratories of Geologický prieskum Spišská Nová Ves, locality number as in fig. 3. Single metasomatite types are characterized by typical mineral assemblages: K — carbonate, Q — quartz, Ch^1 — greyish-green Mg-chlorite, Ch^2 — emerald-green Mg-chlorite, Ch^3 — black-green Fe, Mg-chlorite, (Ch) — chlorite in subordinated amounts, F — fuchsite, Se — sericite, Serp — serpentine, a. Ch — anchimonomineral chlorite rock, A — serpentinite from the Paleozoic of the Gemeric unit (average of 16 analyses), B — fuchsite-quartz-carbonate (breunerite) listvenite from the Ural Mts. (average of 9 analyses, data from Sazonov, 1978)

structural and textural relations between different metasomatite types.

Basic data allow to assume four stages of alterations of original ultrabasites. The first stage is explained by the generation of talc-carbonate rocks at the expense of serpentinite. This stage of alteration has been completed in the whole volume of single bodies therefore serpentinite did not preserve neither as relics and the newly generated carbonate was breunerite. The development of chlorite-quartz-carbonate (dolomite) metasomatites may be assigned as the second stage of alteration. The rate of its development on localities investigated is various being the dominant one on Slatvina locality. This stage was peculiar for high activity of calcium and is reflected by the generation of exclusively dolomitic carbonate. During the third stage, the alteration acquired regressive character and the development of chlorite-quartz-carbonate (breunerite) metasomatites resulted in enrichment of magnesium. The accumulation of such metasomatites occurred at the expense of both older products reflecting, according to the view of the author, the bound of calcium into dolomitic carbonate due to the continuing alterations in deeper portions of original ultrabasite bodies. This led to sharp decrease of calcium activity in hydrothermal solutions when, simultaneously, considerable amounts of magnesium have been released and mobilized.

In the majority of bodies, alteration processes accomplished by the development of chlorite-quartz-carbonate (breunerite) metasomatite. Only to a certain degree and in some cases, fuchsite-quartz-carbonate (dolomite) metasomatites originated in the final progressive stage of alteration. The variety occurs, as a rule, in veinlets or irregular nodule-like chambers. More continuous partions of fuchsite-quartz-carbonate (dolomite) metasomatite occur only on Teplý potok locality.

The alteration stages indicated may not be understood as independent phases limited in time but as products of more or less continuous development when the whole alteration process was governed by a unique hydrothermal system. Such deduction is unambiguously proved by very near carbon and oxygen isotopic compositions in chlorite-quartz-carbonate (breunerite) and fuchsite-quartz-carbonate metasomatites (sample FKH-15: $\delta^{13}C$ —5.25 per milles PDB, $\delta^{18}O$ +19.15 per milles SMOW; sample FKH-60: $\delta^{13}C$ —4.45 per milles PDB, $\delta^{18}O$ +20.07 per miles SMOW). The hydrothermal water responsible for metasomatite generation was obviously of magmatic or metamorphic origin. A more exact evaluation, due to incertainities in the assessment of temperatures responsible for metasomatite generation and in the determination of the fractionation coefficient for the carbonate/water system, is impossible.

The metasomatic paragenesis found in listvenites in the area investigated corresponds to the development sequence of classical Uralian listvenites. Moreover, also the regression stage, producing chlorite-quartz-carbonate (breunerite) listvenites has its analogies in so called "yellow listvenites" (comp. Sazonov, 1975, 1978). However, it is to be mentioned that not all rocks in the area and composed, as the main constituent, of breunerite and/or dolomite represent in fact altered ultrabasite. Several cases have been found (Slatviny and Košická Belá localities) where the metasomatic alterations occur in sedimentogeneous carbonate situated near to structures carrying the ultrabasites. Besides mineral and chemical characteristics, there are also pronounced differences in carbon isotopic composition (e. g. the breunerite rock from Slatviny, sample

FKH-28 has the $\delta^{13}C$ value equal to —1.8 per mille PDB).

Metallogenic importance of listvenites

The metallogenic meaning of listvenites lies (i) in their collector properties for specific mineralization types and (ii) in their function as mobilization environment for primary ore element concentrations accumulated, as a rule, already in their educts (Ivan, in print).

Listvenite bodies in the eastern part of the North-Gemeric Paleozoic belt are remarkable mainly for their collector properties containing locally small amounts of disseminated mercury ore and a stockwork to disseminated copper-antimony mineralization. The mercury mineralization is very irregular bound mainly to dolomitic metasomatite and disseminatons of cinnabar are only rarely observable. The copper-antimony mineralization is represented by tetraedrite impregnations in metasomatites or as chambers or quartz veinlets (Ďuďa 1976) being related to final stage of listvenite development as deduced by its occurrence only in fuchsite-quartz-carbonate rock. In breuneritic metasomatite, tetrahedrite is concentrated into younger quartz veinlets.

Indications of ores which could represent mobilization products from listvenites or from their educts (serpentinite) have hitherto not been found in the area. Mainly ores of cobalt-nickel arsenides known near Dobšiná have to be taken in consideration (Hovorka — Ivan, 1981b, Ivan, in print) or, eventually, also mineralizations of gold (Clark, 1979, Zhelobov, 1979). Up to present, none of indicated ores related otherwise to listvenites in the area have economic value. Nevertheless, these may indicate considerable accumulations related to tectonic surfaces in the depth.

The meaning of listvenites for stratigraphy and tectonics

The assessment of ultrabasite origin of listvenites (serpentinite) motivated the reevaluation of stratigraphic and tectonic schemes used formerly for the area. Ultrabasites occur in Paleozoic complexes of the Gemeric unit in two different forms: (i) as constituent of a higher metamorphosed unit composed mainly of gneiss and amphibolite as well (ii) as tectonic implantate from this unit into the stratigraphically higher complex of the Dobšiná group (Hovorka — Ivan, in print). From this aspect, it is highly probable that the epimetamorphic volcano-sedimentary sequence in the area investigated does not belong to the Rakovec group but, from lithological point of view, corresponds to the very similar constituent of the Dobšiná group, the Zlatník member *sensu* Š. Bajaník et al. (1981). Also the presence of graphiteous shales, otherwise unknown from the Rakovec group, speaks in favour of such interpretation. Therefore, in tectonic respect, the area considered does not belong to the Rakovec partial nappe *sensu* P. Grecula — I. Varga (1979) but to the newly defined Klátov partial nappe (Hovorka et al., in print) including rocks of the so called gneiss-amphibolite complex (Rakovec group up to recently) and also part of the Dobšiná group (Rudná and Zlatník members).

Conclusions

Geological and mineralogical investigations of metasomatic rocks from wider surroundings of Košické Hámre known hitherto as metasomatic ankerite bodies proved that

1) the majority of rocks represents hydrothermally altered ultrabasite,

2) by composition, both mineralogical and

geochemical, the metasomatites correspond to listvenites and are very similar to their Uralian analogies,

3) listvenites in the area carry poor disseminated mercury mineralization and stockwork to disseminated tetrahedrite ore,

4) the presence of ultrabasites altered to listvenite within the Paleozoic epimetamorphosed volcano-sedimentary complex casts doubts on its hitherto used ranging into the Rakovec group and, obviously, the complex participates on the Zlatník member of the Dobšiná group creating, the newly defined, Klátov partial nappe.

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Translation by I. Varga

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Alkaline ultrabasic rocks and associated silicocarbonatites in the NE part of the Transdanubian Mts. (Hungary)

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(2 figs. and 2 tables in the text)

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Алкалические ультраосновные породы и с ними связанные силикатокарбонатиты в северной части Задунайских холмов (Венгрия).

Алкалические ультраосновные породы и с ними связаные силикато — карбонатиты были установлены в районе между горами Веленце и Буда. Представляют самостоятельные дайки или обнажаются в виде роя даек в верхне карбонских гранитах или в верхне пермских и верхне триасовых карбонатах. Их обнажение на поверхности в настоящее время известно только в упомянутых горах; остальные обнажения были обнаружены скважинами. Толщи известных обнажении этих дискутированных пород имеют северо-южное простирание, что входит в соотношение с залегающими элементами отдельных даек, которые измерялись на обнажениях (изображение № 1). Мощность даек колеблется в пределах 0,2—5 м. Всего было установлено больше чем 40 даек. Их наличие потверждает начало рифтогенеза в период верхнего мела.

Alkaline ultrabasic rocks and associated silicocarbonatites in the NE part of the Transdanubian Mts. (Hungary)

Alkaline ultrabasic rocks and associated silicocarbonatites have been found in the area between Velence and Buda Mts. The rocks occur in single dykes or create dyke swarms within granite of Upper Carboniferous age or Upper Permian and Upper Triassic carbonate host rock. Beside the surficial outcrops, further bodies are known from drillings. The entire zone of occurrences creates a N-S trending belt. Thicknesses of single dykes vary between 0.2—5 m the number of dykes found hitherto exceeds 40. Alkaline ultrabasics point to beginning rifting during Upper Cretaceous time.

The existence of alkaline lamprophyres described below has not been known previously in Hungary.

The occurence of this rock association is important because it may indicate a special geotectonic setting — the early phase

of continental deep faulting or perhaps that of a rifting event in late Upper Cretaceous time.

This rock association has been found in the area between the Velence and Buda Hills as single dykes, dykelets or dyke swarms in Upper Carboniferous granite and Upper Permian to Upper Triassic carbonates. Their outcrops are only known in the Velence and Buda Hills the other occurrences are from deep drillings. The zone of all occurrences in the area has a N—S strike, which is similar to that measured in the outcrops. (Fig. 1.) The thickness of the dykes is from 0.2—5 m. More than 40 dykes and dykelets have so far been found in the area.

The petrological characteristics are as follows: This lamprophyric rock association consist of many varieties of rocks differing more or less from each other. The monchiquite can be considered the basic rock type in the area investigated. Its outcrop can be studied in the Velence Hills. On the base of its composition an extreme end member of this association is a silicocarbonatite which was indentified studying core samples (St-1. Di-1.).

These alkaline ultrabasic rocks are of dark grey and reddish brown colours, of porphyritic structure and they often contain ocelli of carbonate and silicate composition, as well as glass. They sometimes show flow structure. The rocks are often strongly altered.

The mineralogical composition of the

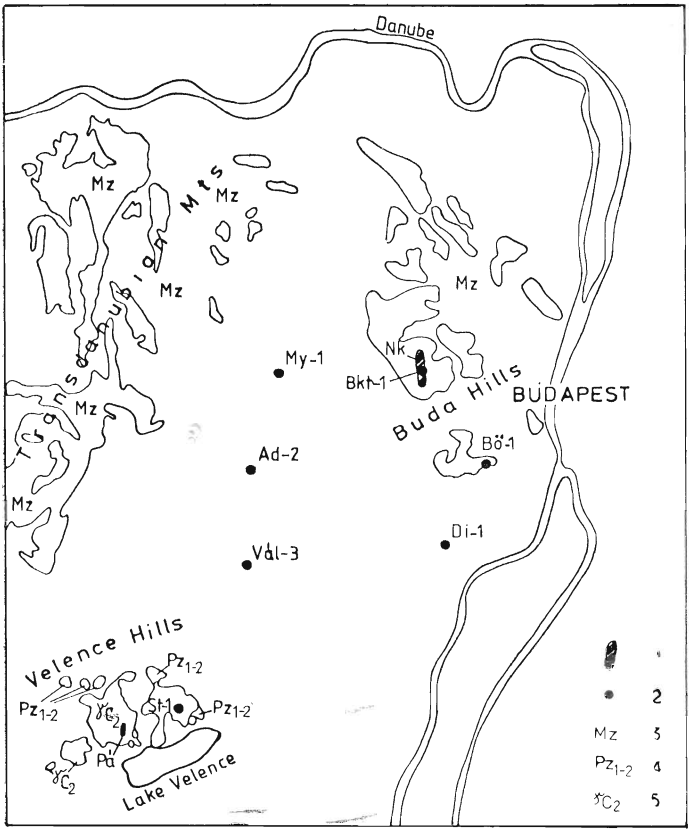


Fig. 1. Location map of the alkaline ultrabasic dykes. 1 — outcrops, 2 — drill holes, 3 — mesozoic carbonates, 4 — paleozoic schites, 5 — upper carboniferous granite

rocks is shown qualitatively on Table 1. The microprobe data showed the olivine to be of 85—90 % forsterite content. It is always of phenocryst appearance. The olivine can be found in every variety of rock, generally as pseudomorphs — it is substituted by the following alteration products or infillings: serpentine, smectite, sericite, dolomite and ankerite. The clinopyroxenes of diopsidic composition and the Ti rich phlogopites — which often have biotite rim-appear as phenocrysts and can be seen in the groundmass as well as in the ocelli. Some of the ocelli contains biotite. The variable amount of carbonate minerals is the product of the primary magmatic crystallization — the carbonates are emplaced in the groundmass, in the place of olivine and clinopyroxene phenocrysts and in the ocelli. There are rock varieties where sodalite, melilite and garnet appear and in some of the ocelli alkalic amphibole, aegirine and analcime can also be identified.

The main petrochemical features of the investigated rock suits follow roughly outlined (Table 2).

Chemical composition of some of the rock studied

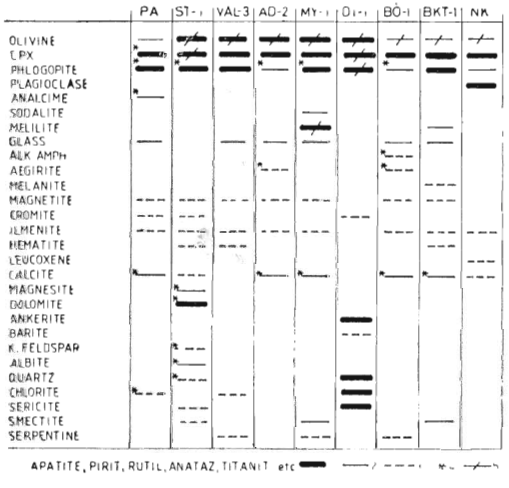
Table 2

	Pá	St-1.	Vál-3.	Bkt-1.
SiO_2	36.2	28.8	38.3	34.3
TiO_2	2.21	1.99	2.13	1.67
Al_2O_3	9.51	6.39	7.84	8.59
Fe_2O_3	4.74	2.57	4.13	4.72
FeO	6.10	6.33	6.17	3.13
MnO	0.20	0.29	0.13	0.18
CaO	13.80	12.60	9.73	17.20
MgO	11.50	13.10	17.90	8.32
Na_2O	1.22	0.83	0.66	0.33
K_2O	1.84	3.24	1.52	1.55
P_2O_5	1.38	0.97	1.14	0.10
CO_2	5.54	20.40	1.64	10.90
$+H_2O$	3.59	2.50	4.52	4.50
$-H_2O$	1.08	0.31	3.48	3.57

For localities see Fig. 1.

The minetralogical composition of dyke rocks

Table 1



Explanation: 1 — over 15 %, 2 — between 5—15 % lower than 5 %, 4 — the mineral can be found in the ocelli too, 5 — occurs as pseudomorph. For locality see Fig. 1

The silica content may be from 29 up to 42 %, the alkali content ranges from 2—5 %, the rocks are always potassic in character. The water content is from 1—4.5 %. The total iron content in FeO is from 9—12 %. The MgO, in agreement with the mineralogical composition varies from 8—18 %. The rocks have high content of volatile and for instance the CO_2 content of monchiquite type rocks ranges from 1—10 % and that of silicocarbonatites from 20 to 28 %. This rock association has specific trace elements content. The distribution of rare earth elements (Fig. 2) and in certain cases the high content of Nb and Th are worth mentioning because of their diagnostic value. The total content of rare earth elements in these rocks reaches up to 800—1000 ppm. The deep — seated origin of CO_2 has been proved by carbon isotope data. The δ 13 C ‰. PDB is

from —1 to —5 ‰, with a mean of —3 ‰ which is characteristic for deep seated igneous rocks and carbonatites and distinct from the values of the surrounding sedimentary carbonate rocks. As a conclusion it can be stated that by the data of the different geological and instrumental analyses the unusual appearence of monchiquite, silicocarbonatite, polzenite, alkaline picrite porphyry and in one place microgabbro (Nk) in this area is now established. The K-Ar radiometric method from fresh phlogopite has given the following values for 2 occurrences: 69 and 77 m. y. which indicate late Creta-

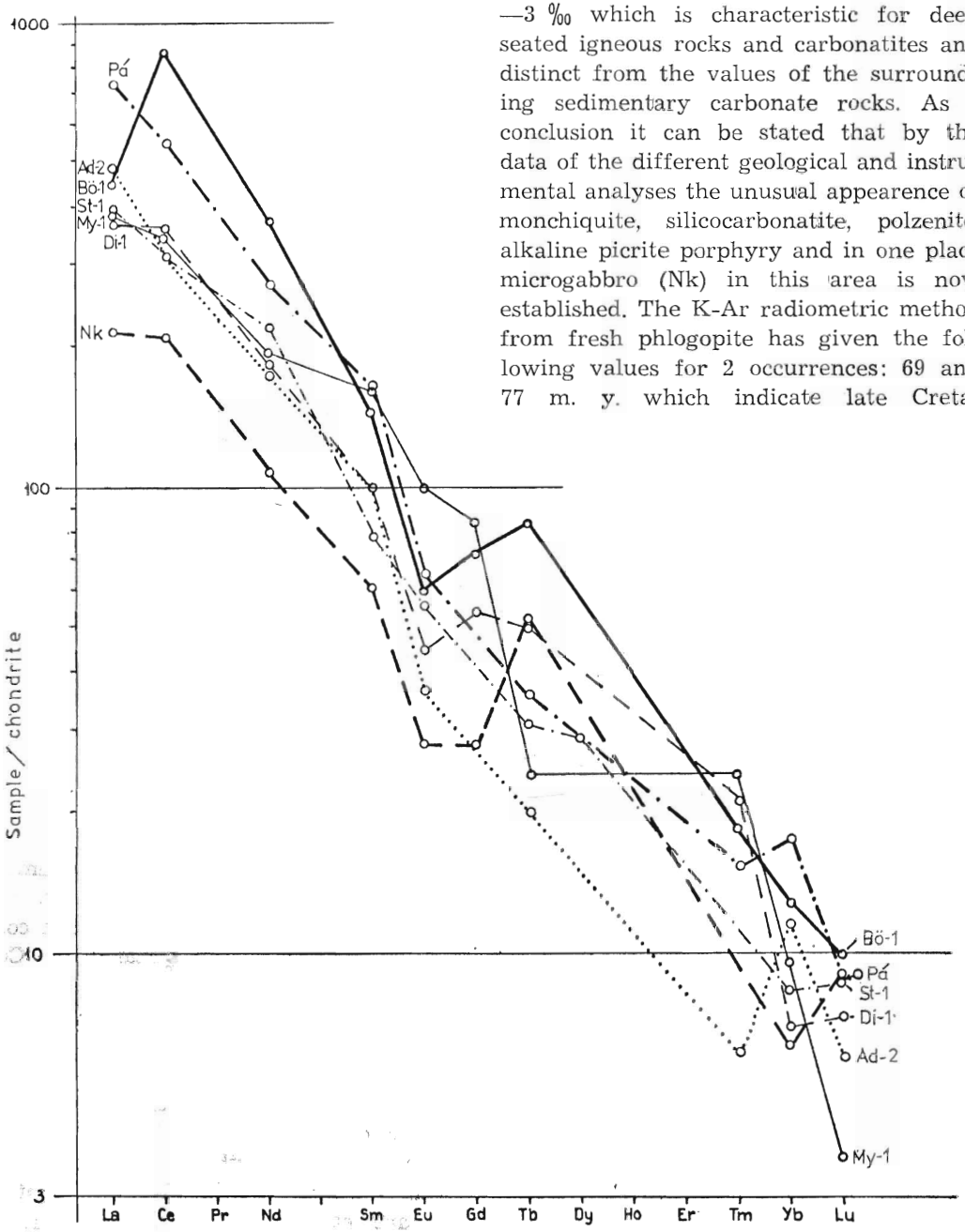


Fig. 2. Chondrite normalized REE pattern for the alkaline ultrabasic dykes. INAA made by J. Bérczi (Technical Univ. of Budapest). See Fig. 1 for localities

ceous period. These age data seem to be reliable but the understanding of the position of this type of magmatism in the structural development of the area needs further studies. It is known from the literature that among the dyke rocks of the alkaline — ultrabasic — carbonate association rocks similar to those described above are widespread. They also seem to appear independently from each other along major linear tectonic features.

The intrusive formations of this dyke rock association were not found so far in the studied area.

Alkalické ultrabazické horniny a s nimi späté silikokarbonatity v severovýchodnej časti Zadunajských vrchov (Maďarsko)

ISTVÁN HORVÁTH — LÁSZLÓ ÓDOR

Alkalické ultrabazické horniny a s nimi späté silikokarbonatity sa zistili medzi vrchmi Velence a vŕškami Buda. Tvoria izolované dajky, resp. vystupujú v podobe roja dajok vo vrchnokarbónskych granitoidoch, príp. vo vrchnopermských a vrchnotriasových karbonátoch. Ich výskyty na povrchu sú dnes známe iba v uvedených vrchoch. Ostatné výskyty boli zistené vrtmi. Zóna známych výskytov sledovaných hornín má priebeh S—J, čo je v súlade s úložnými pomermi dajok meraných vo východoch (obr. 1). Mocnosť dajok varíruje od 0.2—5 m. Celkove sa zistilo vyše 40 dajok.

Výskyt uvedených hornín je dôležitý najmä z geotektonického hľadiska, pretože indikuje počiatočné štádiá vzniku hlbokých zlomov v kontinentálnej kôre, resp. počiatočné štádiá riftogenézy v období vrchnej kriedy.

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