Slovak Geol. Mag., 11, 2 – 3 (2005), 143 – 153

Petrography and geochemistry of subvolcanic basalt bodies among the Upper Carboniferous sediments from the underlier of Muráň Mesozoic sequences (Slávča and Furmanec valleys, Western Carpathians)

RASTISLAV DEMKO and MÁRIO OLŠAVSKÝ

Geological Survey of Slovak Republic (ŠGÚDŠ), Kynceľovská 10, 97401 Banská Bystrica

Abstract: The dykes of basic rocks were found in several tectonic slices with the Upper Carboniferous clastic sediments in the underlier of the Muráň Mesozoic sequences, being located in the Slávča and Furmanec valleys north of the town Tisovec. The dykes consist of tholeiitic basalts with subophitic to intersertal texture. They are characteristic with the prior crystallization of plagioclase, which led to origin of plagioclase network, and subsequent crystallization of ilmenite and augite. The chemical composition of the rocks is influenced by the fractionation of penetrating melt through the plagioclase network, leading to high values of MgO, Ni, Cr and Al_2O_3. The basalts indicate partially the cumulate character.

The petrographic and chemical compositions correspond with the Permian dyke subvolcanic basalts from the Upper Carboniferous Nižná Boca Formation of Hronicum. Accordingly we assign the same petrogenetic conditions for the origin of basalts from Slávča, Furmanec as well as Hronicum. The same distribution of REE-HFSE as in the case of low-Ti flood basalts from the Paraná province (Brazil) and Noriľsk (Siberian traps) evokes the within-plate flood basalts environment for the origin of studied basalts.

Key words: *Permian volcanism, tholeiitic dykes, solidification, geochemistry*

Introduction

The Upper Carboniferous clastic sediments in the underlier of Muráň Mesozoic sequences are bearing already known occurrences of magmatic rocks, though without detail petrographic study. The bodies are compared with the potential Permian analogues of the vein bodies, being situated mainly in the Upper Carboniferous Nižná Boca Formation of the Ipoltica Group of Hronicum (Vozárová & Vozár, 1988). The enlistment of described occurrences to Hronicum mainly by their identical lithology was preferred already earlier (Zoubek, 1957; Biely, 1961, 1966). On the other side, their affinity to Gemericum was supposed by Kovařík et al. (1954), Klinec (1976) and Kamenický in Maheľ et al. (1967). In the last studies about the Carboniferous sequences in the underlier of Muráň Mesozoic in the Furmanec area (Vojtko, 2000; Plašienka & Soták, 2001) these isolated occurrences in the overlier of Veporicum and underlier of Silicicum nappes are understood by structural inventory as belonging to North-Gemeric.

The presented work gives the first detail petrographic description of rocks of subvolcanic bodies. This description, together with the geochemistry, analyses the genetic aspects concerning the solidification phase and paleotectonic regime of origin of parental magmas.

Geological setting

The lowermost element in the region with described localities (Fig. 1) is formed by the Hercynian crystalline basement – Veporicum, prevailingly composed from granitoids. The so-called Federáta sequence (Rozlozsnik, 1935) represents the cover of this basement and in its lower part it is formed mainly by the Permian-Triassic clastic sediments. The Permian sediments belong to Rimava Formation of the Revúca Group (Vozárová & Vozár, 1988). The preserved Triassic carbonate sedimentary succession according to Plašienka & Soták (2001) the best converges to so-called Tuhár Succession. The Carboniferous sediments from the Furmanec valley belong to two tectonic lenses. The upper clastic-carbonatic lens was correlated with the Lubeník Formation of the Ochtiná Group of Gemericum and its age was determined by biostratigraphy to Upper Visean (Plašienka & Soták, 2001). The lower slice is formed exclusively by the clastic sediments with basic volcanics designated as diorites. The listed authors (Plašienka & Soták, 2001) allocate both slices into the Furmanec partial unit, which is supposed to be a part of Gemericum. The clastic sediments of the Furmanec and Slávča valleys, composed of dark schists, greywackes, arkoses and locally conglomerates and accompanied with the bodies of basic volcanites, were mainly by lithological similarity supposed to be Upper Carboniferous (Stephanian) and correlated with the Nižná Boca Formation of Hronicum (Vozárová & Vozár, 1988). The relics of these Carboniferous sediments are tectonically superimposed by partial elements of Muráň nappe, composed of Mesozoic sequences of Silicicum (Lower Triassic-Lower Jurassic, Vojtko, 2000), but the author considers also the Turnaicum and Meliaticum.

Slovak Geol. Mag., 11, 2 – 3 (2005), 143 – 153

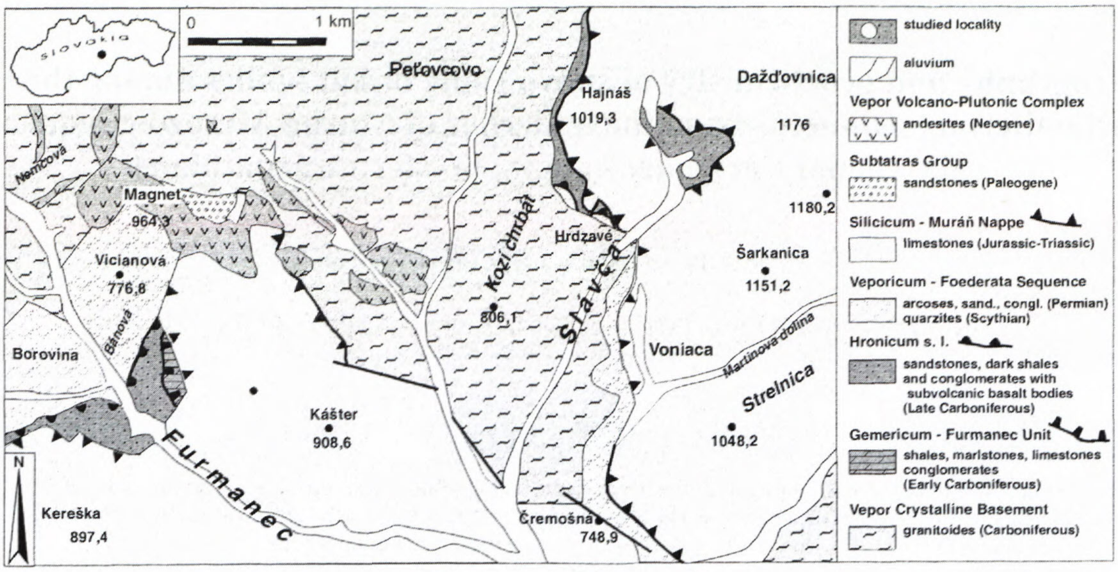


Fig. 1. Schematic geological map of the territory north of Tisovec describes the studied localities from the Furmanec and Slávča valleys. Compiled from the works by Klinec (1976), Vojtko (2000) and Plašienka & Soták (2001).

Analytical methods

The mineral phases were analysed by electron microprobe CAMECA SX-100 in Geological Survey of Slovak Republic (ŠGÚDŠ). Analytical conditions: accelerating voltage 15 kV, measured electric current 20 nA, the diameter of electron ray 5 μm. The selected analyses of clinopyroxene and amphibole are stated in Tables 1 and 2. The rock samples were manually purified from weathered parts and consequently analysed for essential silicates and selected trace elements in Geoanalytic laboratories of Geological Survey of Slovak Republic (ŠGÚDŠ) by the method of X-Ray Fluorescence spectrometry (XRF) and atomic emission spectrometry with inductively coupled plasma (AES-ICP). For the reasons of elimination of alteration (LOI) influence the analyses were recalculated for 100 % and water-free basis. The original analyses are stated in Tab. 3.

Petrography

The rocks demonstrate the subophitic, or intersertal texture. The primary mineral composition consists of plagioclase, ilmenite, clinopyroxene and accessoric apatite. They are characteristic with the developed plagioclase skeleton, which documents the early extensive plagioclase crystallization. The skeleton is formed with numerous plagioclase crystals, being interconnected due to the minimalization of surface energy of plagioclase in host parental melt (Philpotts et al., 1998; Philpotts & Dickson, 2000). The plagioclase skeleton (PS) has a morphology of three-dimensional network and determines the next crystallization development of generating rock (Demko & Olšavský, 2005). The PS dictates the morphology and permeability of cell spaces infilled with melt. Locally the deformations of PS were observed, being the result of pushing up the plagioclase crystals due to the outer mechanical impulse – the stroking of dyke walls, compaction of dyke material, local thermal or compositionally induced convection. In rock the zones characteristic with the frequent occurrence of the subophitic clinopyroxene (Fig. 2) were observed, contrary to the zones with sporadically present clinopyroxene. The crystallization did not reach the phase of holocrystalline rock. Part of PS cells contains chlorite, which we suppose to be the product of volcanic glass alteration together with the mineral assemblage K-feldspar, albite and Fe-Ti oxide. The skeletal development of plagioclase margins in intersertal parts (Fig. 3) we suppose as a sign of the fast crystallization due to undercooling, which preceded the final overall frozing and the volcanic glass origin. The early crystallization of plagioclase prior the clinopyroxene is typical for tholeiitic crystallization trend with increase of FeO in residual melt during fractionation (Grove & Baker, 1984; Grove & Kinzler, 1986). The rock parts with the high degree of crystallinity dominantly contain the mineral association plagioclase, ilmenite, clinopyroxene and altered volcanic glass. In the case of crystallization of parental tholeiitic melt in closed system the increasing percentage of fractional crystallization would lead to crystallization of pigeonite and quartz with local granophyre development (l.c). The presence of parts without pigeonite and quartz we suppose to be an effect of cumulate process (Cox et al., 1979), in which the percolating melt in composition varied in phase volume of plagioclase and augite. The modified augite-poor and with pigeonite + quartz enriched melt was continuously displaced to effusive rock or quartz granophyre, which in locality was not observed. The rocks are penetrated with plagioclase veins of the thickness up to 2 cm - plagioclase pegmatites. These particular phenomena were firstly described by Šťastný (1927), later Vozár (1971) and analysed in details by Philpotts et al. (1996). They are the segregates of the melt from deformed PS by the process of filter pressing as a reason of pressing of the side walls of dyke and reduction of its volume, or by mechanical

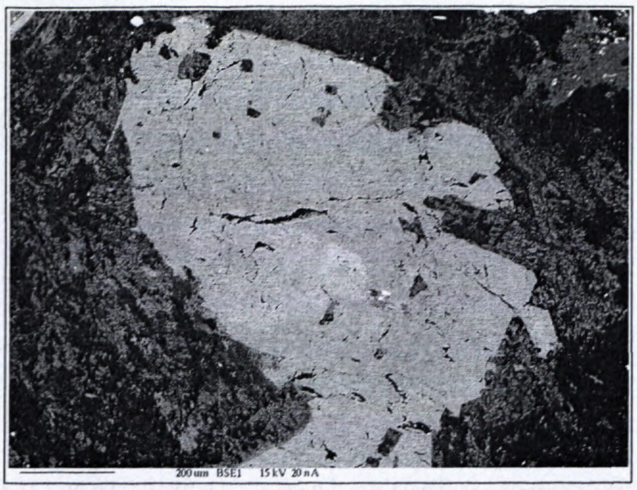


Fig. 2. Detail of subophitic cpx in plagioclase network. Plagioclases are strongly saussuritized. Clinopyroxene crystallized from the plagioclase surface towards the centre of PS cell. The light central part preserves the morphology of PS cell being dictated by the plagioclase configuration. BSE.

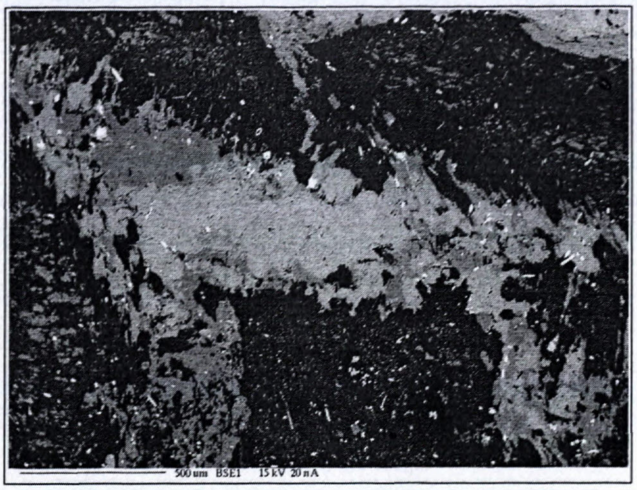


Fig. 3. Detail of relic thin channel in plagioclase network, being infilled with glass. The saussuritized plagioclase margins are bearing the traces of final undercooling with skeletal habit. Altered glass is transformed to mixture of chlorite, K-feldspar, albite and minute Fe-Ti oxide. BSE.

influence of a new melt injection into PS. The plagioclases in veins are of tabular morphology, variable dimensions, with locally observed phenomena of throttling of veinlet passage.

Chemical composition of clinopyroxenes and magmatic development of subvolcanic dykes

Clinopyroxenes (Tab. 1) are the only preserved minerals from the magmatic phase. According to classification by Morimoto et al. (1989) they are represented by augite to diopside. They can be divided into three groups: A) Cpx with composition **En**(49.3-40.6)**Fs**(15.2-6.1) **Wo**(46.7-40.9) **#Mg**(88.6-74.2). The monomineral clinopyroxene thermometer by Mercier (1976) demonstrates the temperatures in the range 1197-1039 °C. In the group the strong variations occur in the composition of Al_2O_3 (4-1.73 wt.%); TiO_2 (1.5-0.5 wt.%). Cpx associates with skeletal ilmenites, which mutual configuration in host cpx indicates the possible epitaxial relation. B) Cpx **En**(46.1-39.5)**Fs**(16.3-9.2)**Wo**(45.6-42.2) **#Mg**(83.3-71), temperatures 1196-1066 °C. The transitional group between the groups A) and C). The group C) with composition **En** (39.8-31.9)**Fs**(22.5-11.3)**Wo**(48.9-43.8) **#Mg**(77.9-58.6). The content of wollastonite component indicates their low-temperature origin (Mercier, 1976; Lindsley & Andersen, 1983). Differing from Cpx-A) the contents Al_2O_3 (0.55-0.24 wt.%), TiO_2 (0.2-0.06 wt.%) are low at variation MgO (14-10.9 wt.%), indicating the strong decrease of Al, Ti activities during the melt differentiation in PS (Fig. 5a, b). Cpx A, B, C occur in rock in tight spatial relation. They often form various composition zones of Cpx. The Cpx zonality types (core→rim) can be divided: A→B→C, A→C, but also A→C→B and C→A.

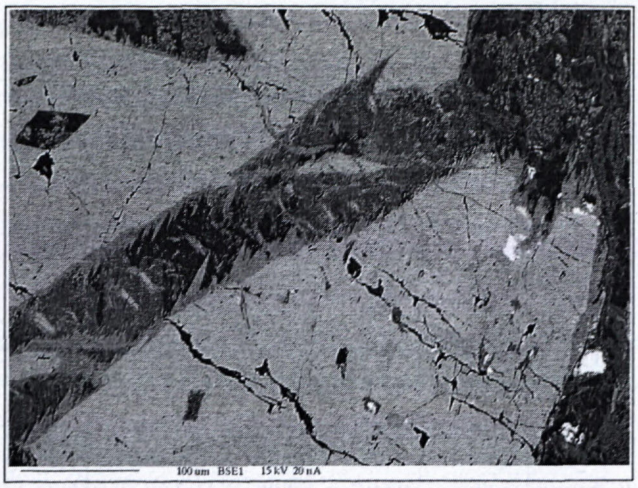


Fig. 4. Detail of obliquely cataclased clinopyroxene separated with antitaxial vein and with the development of directional metamorphic acicular actinolite. The picture documents the brittle deformation superimposed on phase of hydrothermal alteration (saussuritization of plagioclases). BSE.

The absence of pigeonite and quartz in PS cells, the former presence of glass in PS cells and low Al_2O_3 content in cpx can be explained by the flotation of melt through the PS skeleton. The penetrating melt was continually filtered by plagioclase component, pushing its composition into the phase volume of augite. Augites start to crystallize on plagioclases surface with the gradual infilling of PS cells and origin of subophitic texture. In this case the PS operates as catalyzer of cpx nucleation. The process causes the lowering of the ratio of intersertal texture towards the subophitic texture. The lowering of PS permeability leads to origin of partially closed microreservoirs of basaltic melt. The combined zonality of cpx is a result of crystallization with the increasing system undercooling (the heat conduction into the surrounding sediments) and interaction of chemically heterogeneous melts in PS (Demko & Olšavský, 2005).

Alteration of subvolcanic dykes

Clinopyroxenes are the only preserved magmatic minerals. Plagioclases are saussuritized. The products of

Slovak Geol. Mag., 11, 2 – 3 (2005), 143 – 153

Table 1: EPM analyses of clinopyroxenes, recalculated to 6 oxygens. Fe^{3+} is obtained by charge balance calculation procedure of Papike et al., (1974; in Lindsley & Andersen, 1983).

	Cpx23	Cpx24	Cpx 38	Cpx 39	Cpx 45	Cpx 3	Cpx 9	Cpx 10	Cpx 20	Cpx 27	Cpx31
SiO_2	50,50	50,05	51,36	52,25	51,61	52,94	51,74	51,86	52,09	49,67	52,00
Al_2O_3	3,39	3,95	2,99	2,33	3,08	1,05	2,27	2,40	1,83	3,56	1,59
TiO_2	1,31	1,45	0,96	0,83	0,94	0,36	0,90	0,92	0,85	1,54	0,77
FeO	5,14	4,82	6,10	6,38	6,12	5,65	5,31	4,44	6,52	5,40	8,43
Fe_2O_3	2,60	2,69	1,57	0,87	0,98	1,85	2,03	2,40	1,45	3,06	1,62
MnO	0,21	0,27	0,19	0,24	0,25	0,24	0,24	0,22	0,33	0,23	0,35
MgO	15,29	15,25	15,48	15,20	15,38	15,80	16,25	16,40	16,37	15,14	14,99
Cr_2O_3	0,29	0,37	0,19	0,20	0,25	0,06	0,36	0,31	0,25	0,26	0,02
CaO	21,36	21,33	21,21	21,91	21,39	21,79	21,19	21,65	20,32	20,95	20,51
Na_2O	0,34	0,33	0,25	0,30	0,30	0,39	0,25	0,31	0,22	0,33	0,27
K_2O	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,02	0,00	0,01	0,00
Total	100,43	100,50	100,30	100,51	100,29	100,13	100,55	100,93	100,23	100,15	100,55
Si	1,862	1,843	1,893	1,922	1,900	1,951	1,899	1,892	1,920	1,841	1,928
Al (IV)	0,138	0,157	0,107	0,078	0,100	0,046	0,098	0,103	0,079	0,155	0,069
Fe^{3+} (IV)	0,000	0,000	0,000	0,000	0,000	0,003	0,003	0,004	0,000	0,004	0,003
Al (VI)	0,009	0,015	0,023	0,023	0,034	0,000	0,000	0,000	0,000	0,000	0,000
Fe^{3+} (VI)	0,072	0,075	0,044	0,024	0,027	0,048	0,053	0,061	0,040	0,082	0,043
Ti	0,036	0,040	0,027	0,023	0,026	0,010	0,025	0,025	0,024	0,043	0,022
Cr	0,009	0,011	0,005	0,006	0,007	0,002	0,010	0,009	0,007	0,008	0,001
Mg	0,840	0,838	0,850	0,834	0,844	0,868	0,889	0,892	0,899	0,836	0,828
Fe^{2+}	0,159	0,148	0,188	0,196	0,188	0,174	0,163	0,135	0,201	0,167	0,261
Mn	0,007	0,008	0,006	0,008	0,008	0,007	0,008	0,007	0,010	0,007	0,011
Ca	0,844	0,842	0,838	0,864	0,844	0,860	0,834	0,847	0,803	0,832	0,815
Na	0,024	0,024	0,018	0,021	0,021	0,028	0,018	0,022	0,015	0,024	0,020
K	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,001	0,000	0,001	0,000
cationes	4	4	4	4	4	4	4	4	4	4	4
Charge+	12	12	12	12	12	11,99	11,99	11,99	11,99	11,99	11,99
#Mg	0,841	0,849	0,819	0,809	0,818	0,833	0,845	0,868	0,817	0,833	0,760

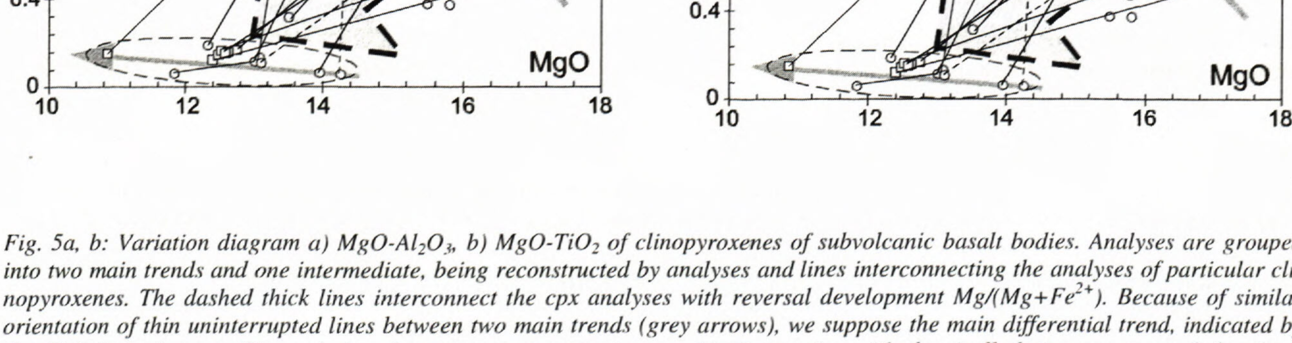


Fig. 5a, b: Variation diagram a) $MgO-Al_2O_3$, b) $MgO-TiO_2$ of clinopyroxenes of subvolcanic basalt bodies. Analyses are grouped into two main trends and one intermediate, being reconstructed by analyses and lines interconnecting the analyses of particular clinopyroxenes. The dashed thick lines interconnect the cpx analyses with reversal development $Mg/(Mg+Fe^{2+})$. Because of similar orientation of thin uninterrupted lines between two main trends (grey arrows), we suppose the main differential trend, indicated by the thick dashed arrow. The variation along two grey arrows is caused by interaction with chemically heterogeneous melt fractions, being a result of variable filtration effect of PS in zones with the variable permeability.

their alteration are dominantly the albite, prehnite and sericite. Ilmenite is altered. Phantoms after ilmenite are represented with pyrophanite, titanite, pyrrhotite, rutile and zircon. The volcanic glass is transformed to association chlorite, K-feldspar, albite and tiny Fe-Ti oxide (Fig. 3).

The unique feature of subvolcanic rocks at Slávča and Furmanec is the presence of actinolite, being specifically tied to the contact of relic clinopyroxene and chlorite (Fig. 4). It forms the tiny idio-hypidiomorphic individuals to aggregates of often orthorhombic habit. Analogical feature we have observed also in another occurrences of basalt rocks of Hronicum, namely in Lower Permian effusive basalt from Ipoltica valley and basalt lavas of the Čierny Váh valley. This phenomenon has probably validity for basalt rocks of the whole Hronicum. The rocks frequently contain also brown amphiboles, which, according to the approximation of minimum and maximum Fe^{3+} content in classification by Leak et al. (1997), represent the magnesiohornblende and magnesiohastingsite. They are a product of the high-temperature (probable synvolcanic) phase of hydrothermal alteration. They effectively consume the magmatic clinopyroxenes. Amphiboles form phantoms after subophitic clinopyroxenes, or reaction rims. In rock of Slávča locality their preferable concentration on the surrounding of plagioclase pegmatite was found. In strongly altered parts of rock the saussuritization reached the extreme extent. The phantoms after plagioclases are not present. The rocks are formed only by the angular clinopyroxenes with improper morphology, being inherited after the shape of PS cells. These clinopyroxenes are distributed in the plastic mixture formed by mineral association prehnite, albite and sericite.

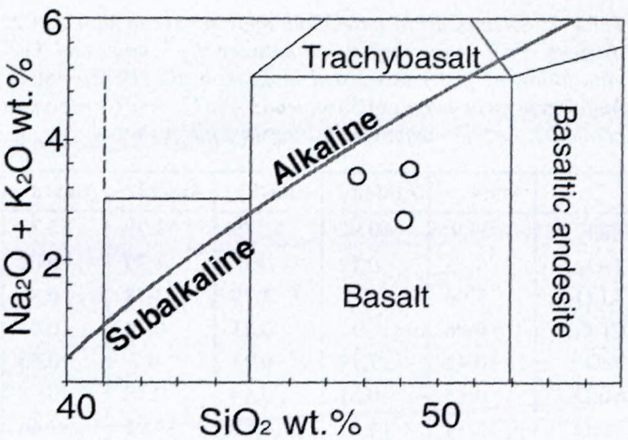


Fig. 6. Classification diagram for effusive rocks (sensu Le Maitre et al., 1989). The curve discriminating the alkaline and subalkaline rocks is according to Irvine & Baragar (1971). Analysed samples represent the subalkaline basalts.

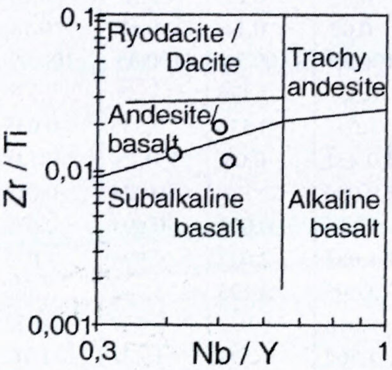


Fig. 7. Complementary classification diagram for altered and metamorphic rocks according to Winchester & Floyd (1977). Analysed samples belong to the subalkaline basalts to andesites.

Rock classification

Because the studied rocks represent the shallow-intrusive or subvolcanic equivalents of basaltic melt, they can be classified by TAS diagram (Le Maitre et al., 1989; Fig. 6). Analyses cluster into the basalt field beneath the discrimination curve defining the subalkaline rocks (sensu Irvine & Baragar, 1971). The superimposed hydrothermal alteration of rocks led to decomposition of primary plagioclase and ilmenite (sea the paragraph about the rock alteration). Because of this fact the redistribution of alkalis can be expected and consequently the subalkaline basalt character of rocks can be simulated. The complementary classification diagrams Nb/Y-Zr/TiO_2 and Zr/TiO_2-SiO_2 (Winchester & Floyd, 1977) designated for altered and metamorphic rocks confirm the basic subalkaline character of rock (Fig. 7).

The petrography and composition of clinopyroxenes demonstrate the partially cumulative character of rocks. The origin of plagioclase network and course of cumulative process distinctly affected the chemical composition of subvolcanic body. Analysed MgO varies in interval 9.09–11.26 wt.%, at #Mg/(Mg+Fe*) 70.55-67.8. The contents Ni 283-181 ppm and Cr 472-343 ppm reach values for primitive undifferentiated basalts Ni > 200 ppm and Cr > 400 ppm (Tatsumi & Eggins, 1995). The absence of olivine or its phantoms in plagioclase network demonstrates the relative advanced differentiation of parental basalt magma, away of normative olivine phase volume. The high MgO content is then the result of adcumulative effect of through flow fractionation of augite and closed basic glass (the product of its alteration is mainly the abundant chlorite above 20 wt.% MgO). The content of Al_2O_3 in interval 12.93–15.84 wt. % converges to values for highly aluminium basalts ($\geq$ 16 wt.%). The high Al_2O_3 content is a result of cumulative effect of plagioclase. The closed crystallization of melt would lead to crystallization of pigeonite and quartz (Grove & Baker, 1984; Grove & Kinzler, 1986), but they were not observed. This phenomenon can be explained by continuous removal of differentiated melt into associated effusion or by continuing part of unseen subvolcanic body. The rocks therefore do not represent clearly effusive members. The early crystallization of plagioclase (origin of plagioclase network) before the augite clinopyroxene proves the tholeiitic character of magmatic differentiation (Grove & Baker, 1984; Grove & Kinzler, 1986).

The applying of stated principles we suppose the studied rocks as a differentiation product of a tholeiitic basalt melt. Despite influencing the composition by cumulate process, the rocks have a character of subalkaline tholeiitic basalt.

Slovak Geol. Mag., 11, 2 – 3 (2005), 143 – 153

Table 2: Selected EPM amphibole analyses recalculated to 22 oxygens. Fe^{3+} is average value between Fe^{3+} max. and Fe^{3+} min. following procedure listed in Leak et al., (1997). Amf4a, Amf-5 represent magnesiohornblend; Amf12, Amf18 represent actinolite, Amf4a – magnesiohastingsite / pargasite.

	Amf4	Amf4a	Amf-5	Amf12	Amf18
SiO_2	43,9	50,92	51,79	51,79	55,78
TiO_2	4,15	0,72	1,4	1,29	0,02
Al_2O_3	9,94	3,1	3,79	3,78	0,85
Cr_2O_3	0,08	0	0,21	0,14	0,01
FeO*	10,42	17,11	9,11	9,7	10,55
MnO	0,15	0,31	0,14	0,18	0,18
MgO	15,34	14,27	17,81	17,92	17,46
CaO	11,39	10,13	11,99	11,53	13,24
Na_2O	2,72	1,15	1,13	1,23	0,08
K_2O	0,65	0,28	0,36	0,4	0,02
H_2O	2,05	1,90	1,99	2,01	2,03
F	0,02	0,21	0,1	0,16	0,17
Cl	0,02	0,14	0,17	0,14	0,01
total	100,85	100,36	100,35	100,09	100,48
Si	6,339	7,476	7,38	7,379	7,899
Al	1,692	0,536	0,636	0,635	0,142
Ti	0,451	0,08	0,15	0,138	0,002
Cr	0,009		0,024	0,016	0,001
Fe^{3+}	0,175	0,074	0,091	0,079	0,006
Fe^{2+}	1,083	2,027	0,994	1,077	1,243
Mg	3,302	3,123	3,783	3,806	3,686
Mn	0,018	0,039	0,017	0,022	0,022
Ca	1,762	1,594	1,831	1,76	2,009
Na	0,762	0,327	0,312	0,34	0,022
K	0,12	0,052	0,065	0,073	0,004
total	15,713	15,329	15,283	15,324	15,036

Geochemistry of subvolcanic dykes

The basalt subvolcanic dykes in localities Slávča and Furmanec are characteristic with low SiO_2 47.82-49.33 wt.%, high MgO 12,18-9,69 wt.%, high Al_2O_3 16,89-13,99 wt.% and FeO* 9.06-7.63 wt.%. In the frame of basalt rocks it represents an extreme composition, being influenced by the cumulative process. The TiO_2 contents vary in interval 0,91-1,71 wt.% and P_2O_5 in interval 0,16-0,23 wt.%. The main bearer of Ti is a skeletal, partially corroded ilmenite, crystallizing as a second mineral after plagioclase. Phosphorus is tied on apatite, which distribution in rock is not unambiguously specific. The high LOI (3.84-3.06 wt.%) is a result of synvolcanic hydrothermal alteration modification. In comparison with the genetically related Permian basalts of Hronicum (Dostál et al., 2003) the subvolcanic dykes at Slávča and Furmanec have more primitive contents Cr 511-365 ppm, Ni 306-193 ppm, V 172-90 ppm and Sc 43-29 ppm.

The subvolcanic dykes are typical with enrichment by Rb, Ba, Th, with moderate development of Ba-anomaly, which is one of typical features of basalts from Hronicum (Fig. 8). The influence of plagioclase fractionation for Ba and Sr contents (the distinctive deficit of Permian basalts) in conditions of plagioclase network of

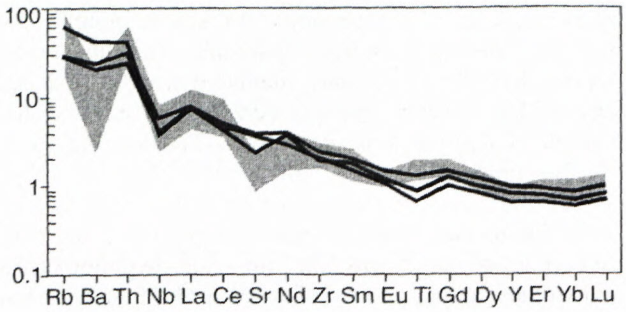


Fig. 8. NMORB normalized abundance patterns of elements of subvolcanic dykes from Slávča and Furmanec (curves) and analyses of genetically related Permian basalts and basaltic andesites of Hronicum, grey area. Taken from Dostál et al. (2003). NMORB normalized values are from Sun & McDonough (1989).

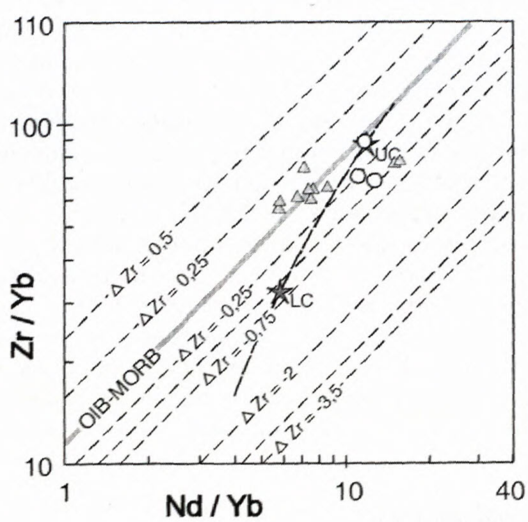


Fig. 9: Diagram Nd/Yb-Zr/Yb characterizing the development of Zr-anomaly. The values Δ Zr were taken by recalculation after Pearce et al. (1999). The negative values characterize the development of negative Zr anomaly, the positive values the development of positive anomaly. Grey OIB-MORB line is calibrated by average OIB-MORB values from Sun & McDonough (1989) and represents the rock members without development of Zr-anomaly. Triangle symbols represent the analyses of genetically related Permian basalts of Hronicum sensu Dostál et al. (2003). The asterisks represent the average values of lower (LC) and upper crust (UC; taken from Taylor & McLennan, 1985). The curve cutting the points of lower and upper continental crust represents the mixing between these end members.

subvolcanic dykes is clearly hypothetical. The more distinctive deficit of Ba and Sr in Permian basalts we connect with the more intensive hydrothermal alteration, which the studied rocks suffered. The subvolcanic basalts have at enrichment by LREE developed the negative HFSE-anomalies: Nb_N/La_N[1] 0.46-0.67 and Δ Zr in interval (–0.03-0.44)[2], (Fig. 9).

[1] PM normalized values after Sun & McDonough (1989)

[2] Values of Zr-anomaly are characterized using the method by Pearce et al. (1999).

Table 3: Whole rock analyses of subvolcanic basalts. Samples MP-01-2 and MP-01-3 belong to Slávča locality, and MP-s belongs to Furmanec locality. Detailed localisation is presented in schematic map, Fig 1.

	MP-01-2	MP-01-3	MP-s		MP-01-2	MP-01-3	MP-s		MP-01-2	MP-01-3	MP-s
SiO_2	50,26	49,22	50,64	Sc	29	41	28	La	19	20	20
TiO_2	0,889	1,640	1,171	V	86	165	116	Ce	37	39	35
Al_2O_3	16,14	14,46	13,31	Cr	349	432	486	Nd	21	29	29
Fe_2O_3	1,726	1,919	1,668	Co	37	34	43	Sm	4,1	5,6	5,0
FeO	5,74	6,21	7,12	Ni	184	191	291	Eu	1,12	1,55	1,28
MnO	0,117	0,148	0,139	Rb	35	17	17	Gd	3,7	5,6	4,8
MgO	9,26	9,38	11,59	Sr	335	358	220	Tb	0,7	1,0	0,8
CaO	7,74	9,43	6,62	Ba	269	155	132	Dy	3,8	5,6	4,7
Na_2O	2,41	2,85	2,09	Th	5	4	3	Ho	0,8	1,2	0,9
K_2O	1,15	0,61	0,6	Hf	3	3	4	Er	2,0	2,9	2,4
P_2O_5	0,15	0,22	0,19	Nb	9	14	10	Yb	1,8	2,6	2,2
LOI	3,68	3,06	3,84	Zr	160	181	150	Lu	0,33	0,47	0,38
H_2O -	0,41	0,37	0,45	Y	18	27	24				

The chondrite normalized REE patterns are characteristic with the extreme fractionation La_n/Sm_n 2.51-2.31 at relatively flat development of Tb_n/Yb_n 1.77-1.65 (Fig. 10). The La_n values reach 88,7-83,9 at content 21,02-19,88 ppm. Eu/Eu* varies in the range 0.88-0.8. The effusive rocks of this character do not occur in the environment of oceanic crust, NMORB-EMORB-OIB types.

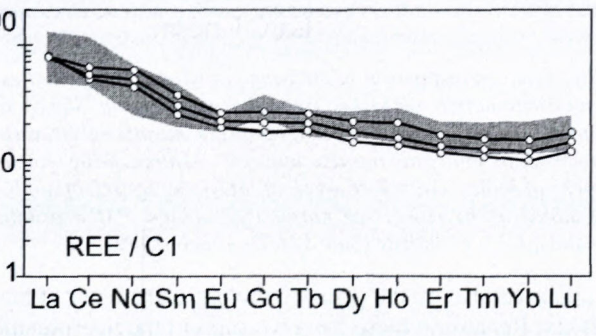


Fig. 10: Chondrite normalized REE patterns. The normalized values for Cl are taken from Sun & McDonough (1989). The grey field represents the comparing analyses of genetically related Permian basalts of Hronicum. Taken from Dostál et al. (2003).

The preservation of relatively constant course of normalized content Tb_n/Yb_n at fractionation La_n/Sm_n requires the presence of garnet and amphibole in magmatic source. The garnet alone has a tendency to fractionate La-REE-Yb as a whole without selective fractionation of MREE. The amphibole fractionates MREE and causes the concave depletion by MREE. The combination of garnet and amphibole allows the selective enrichment by LREE in level of La-Sm at flat development Gd/Yb, Tb/Yb, during which it need not be a single-shot event, but also the polystadial fractionation. This normalized REE course is characteristic for continental crust (Taylor & McLennan, 1985) and for some active continental margins, for example central and southern Andes or Kamchatka - the volcanoes Kluchevskoy, Achtang (Churikova et al., 2001).

The process of modification of mantle melts in the environment of thick continental crust is analysed by Hildreth & Moorbath (1988), presenting the MASH hypothesis based on the composition of volcanic rocks of Chilean active margin. The MASH represents the combined process of melting, assimilation, storage and homogenization. Process is directly in the field observed for example on gabbroid intrusion Fiambalá in NW Argentina (DeBari, 1994). The modification of mantle melts in continental crust is solved by the numerical model of RTF magmatic reservoir (analogical to process MASH) by Wooden et al. (1993) for the basalts of Siberian traps.

The function of MASH process is tectonically controlled. The enhancing extension expands the percentage of the adiabatic decompression melting of the mantle and consequently the bigger volume of the melt. The bigger amount of melt has thereafter the tendency to penetrate the continental crust with shortening of time of its remaining in the crustal magmatic reservoirs and lowering the possibility of current hybridization. The transport of the bigger amount of basic melt through the continental crust uses the dyke system which manifests the lower reaction surface and assimilation potential contrary to the transport of volume lower melt fractions, where the transport by porous flow occurs (one of the MASH requirements). Because of La/Sm fractionation at flat Tb/Yb of studied basalt subvolcanic rocks we suppose the function of MASH process, as a modification agent of primary basalt magmas, being produced by volume weak partial melting of subcontinental lithospheric mantle as a consequence of indistinct extension.

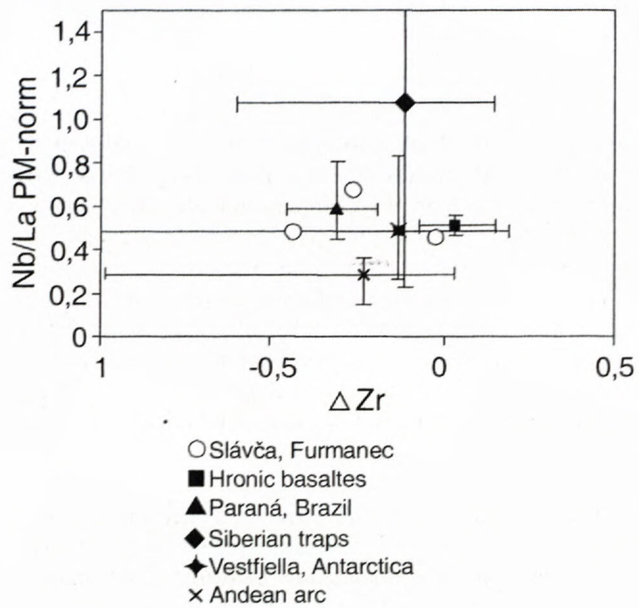
Geodynamic environment of origin of subvolcanic basalt dykes

For reconstruction of geodynamic environment of the basalt origin the principal factor is the relative distribution of REE-HFSE, indicating the strong resistance against the mobilization during hydrothermal alteration processes (e.g. Humphris, 1984; Rollinson, 1993).

Slovak Geol. Mag., 11, 2 – 3 (2005), 143 – 153

Tab. 4. Comparison of range of HFSE anomalies. The ratios Nb_n/La_n are normalized for the primitive mantle (according to Sun & McDonough, 1989). The numbers stated in table correspond in order to maximum, average and minimum value. The data about Permian basalts of Hronicum were taken from Dostál et al. (2003); Paraná - low titanium basalts (Peate & Hawkesworth, 1996); Siberian traps – Noril'sk (Wooden et al., 1993). Basalts of province Vestfiela, Antarctica (Luttinen & Furnes, 2000). The basic calk-alkaline volcanic rocks of Andes (source: web geochemical database GEOROCK). Zr anomaly is computed using the method by Pearce et al. (1999). The lower value ΔZr, the more intensive negative Zr anomaly, resp. deficiency against REE. The values REE are normalized to chondrite according to Sun & McDonough (1989).

	Nb_n/La_n	Δ Zr	La_n/Sm_n	Tb_n/Yb_n	La_n
Slávča, Furmanec	0,67 – 0,46	-0,03 až –0,44	2,5 – 2,3	1,8 – 1,7	88,7 – 83,9
Hronic basaltes	0,56 / 0,51 / 0,46	0,15 / 0,03 / -0,07	2,9 / 2,5 / 2,1	1,7 / 1,4 / 1,3	126,6 / 80,8 / 46,4
Paraná, Brazil	0,8 / 0,59 / 0,45	-0,17 / -0,31 / -0,42	2,8 / 2,1 / 1,3	1,6 / 1,4 / 1,3	135,9 / 76,8 / 34,6
Siberian traps	3,28 / 1,07 / 0,23	0,15 / -0,11 / -0,6	3,2 / 1,9 / 1,2	1,9 / 1,3 / 0,9	145,6 / 48,1 / 19,7
Vestfjella, Antarctica	0,83 / 0,49 / 0,26	0,19 / -0,13 / -1,49	2,71 / 1,55 / 0,83	2,16 / 1,84 / 1,67	86,2 / 45,82 / 15,15
Andean arc	0,36 / 0,29 / 0,15	0,03 / -0,23 / -0,99	3,1 / 2,2 / 1,4	2 / 1,4 / 1	92,8 / 58,3 / 25,3



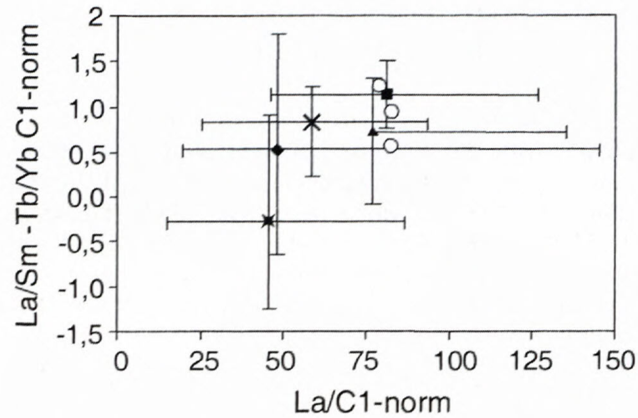


Fig. 11a, b. Comparison of the range of Nb and Zr anomalies a) and fractionation of LREE b) in basalt dykes at Slávča and Furmanec with genetically neighbouring basalts of Hronicum, inner-plate tholeiitic basalts and calk-alkaline basic volcanic rocks of Andes with 49-56 wt.% of SiO_2. The source of analyses is stated in the text. Used normalized values: PM = primitive mantle, C1 = chondrite (Sun &McDonough, 1989).

The basalts have developed negative HFSE anomalies, which is a typical feature of the volcanic rocks of convergent boundaries of lithospheric plates (e.g. Pearce & Peate, 1995). The negative HFSE anomalies are present also in the case of basalts of inner-plate provinces, though of lower intensity (Wooden et al., 1993; Molzahn et al., 1996; Peate & Hawkesworth, 1996; Luttinen & Furnes 2000). The next feature is represented by the selective fractionation LREE from HREE ($La_n/Sm_n >> 1$, $Tb_n/Yb_n \approx 1$). This phenomenon is present only in the case of volcanic rocks generated in the environment with evolved continental crust. As an example there serve the volcanic rocks of Andes and Kamchatka (volcanoes Kluchevskoy, Achtang; Churikova et al., 2001), being tied to convergent tectonic regime. In the case of inner plate volcanic provinces this specific distribution is observed in the case of some Siberian trap basalts – the Noril'sk province (Wooden et al., 1993) and at low-Ti basalts of Paraná province (Brazil). The comparison of distribution of HFSE anomalies and REE is summarized in Tab. 4 and graphically depicted in Fig. 11 a, b.

The comparison of REE-HFSE distribution (Tab. 4; Fig. 11a, b) confirms the affinity of dykes basalts from Slávča and Furmanec to inner-plate basalts. This fact is supported also by the primary tholeiitic character of basic dykes. Regarding these facts we support the interpretation of inner-plate geodynamic regime of the origin of basalts, being present in localities Slávča and Furmanec.

Discussion

The investigated rocks, owing their characteristic appearance also from further occurrences, were generally classified as diorites - veiny diorite porphyrites (Šťastný, 1927; Vozár, 1967), gabbrodiorite porphyrites (Vozár, 1976), or also as augite/quartz/gabbro porphyrites (Tulis & Novotný, 1998). The detail petrographic investigation from several localities of Western Carpathians has manifested, that these rocks represent the subvolcanic basalts without the presence of porphyric intratelluric mineral phases, which means the crystallization of all rock-forming minerals in situ inside the dyke. The found subophitic texture is characteristic for tholeiitic subvolcanic basalts with the specific development of crystallization (Philpotts et al., 1998; Philpotts & Dickson, 2000; Demko & Olšavský, 2005). The rocks manifest the transitional character between effusive basalts and gabbro cumulates. From effusive basalts they differ by continual removal of more differentiated pigeonite–quartz normative melt fraction, which was probable transferred to associated effusion, or unwatched part of subvolcanic body of granophyre composition (plagioclase + quartz) as we observed for example in the locality SE of Hranovnica (the Nízke Tatry Mts.). From the cumulate gabbro they differ by the presence of intersertal glass, being the result of rapid final undercooling in superficial conditions. The specific petrographic character and peculiar chemical composition of dykes, being identical with the Permian basalts in Hronicum (Dostál et al., 2003), requires to allocate the studied rocks to mentioned tectonic unit. In the locality Furmanec there is biostratigraphically dated only the upper tectonic slice with carbonatic development of Upper Visean age affiliated to Gemericum (Plašienka & Soták, 2001). The lower lens we understand as the Upper Carboniferous of Hronicum - the Nižná Boca Formation. As one of arguments against the competency to Hronicum there was stated the following fact: *"these magmatic rocks are mylonitized and recrystallized in greenschist facies, so they cannot be correlated with the Nižná Boca diorites"* (Plašienka & Soták 2001). We can agree with the metamorphism of studied rocks, but especially this metamorphism proves the identical character of rocks with analogical occurrences in Hronicum.

Based on following facts we can exactly state that petrogenetic and metamorphic development of subvolcanic rocks was identical as in Hronicum.

- The similar position of subvolcanic basalt bodies among clastics of Upper Carboniferous sediments with the same lithology
- Identical primary petrographic character as in the case of bodies from Hronicum: Dikula, Podbrezová, Nižná Boca, Vernár - Barbolica (the Nízke Tatry Mts.), Žiare (Tríbeč Mts.) as well as from locality Spálený vrch (the Čierna hora Mts., Faryad et al., 2005)
- Identical metamorphism of subvolcanic bodies (saussuritization of plagioclase, presence of prehnite, pumpellyite, actinolite), as well as basalt bodies from Hronicum (Ipoltica, Čierny Váh)
- Identical courses of normalized contents of trace elements (Figs. 8 and 10).

As the geodynamic environment of origin of Permian basalts of Hronicum Vozár (1997) determined the inner-continental rifts, Ivan et al. (2002) affiliated basalts of Hronicum with calk-alkaline series of the convergent boundaries of lithospheric plates, Dostál et al. (2003) associated the geodynamic regime with that of the inner-plate volcanic province Basin and Range (U.S.A.). Because of distinct similarity of chemical composition with tholeiitic basalts of Paraná volcanic province and Siberian traps we support the interpretation of their inner-plate origin. Tholeiitic and alkaline volcanisms are related on the range of adiabatic decompression melting being controlled by the degree of extension (McKenzie & O'Nions, 1991; Kinzler, 1997; Niu, 1997; Takahahshi et al., 1998). The lower degree of extension results in lower extent of mantle melting and specific geometry of melted space (O'Hara, 1985). It results also in the higher percentage of melt from the field of grt-lherzolite stability. As an example there is stated the NMORB/EMORB distribution in oceanic basalts, or distribution of tholeiitic and alkaline rift zones in Africa (Wilson, 1989). The products are the alkaline rocks. The high degree of extension leads to higher percentage of total melting and higher percentage of melt from the stability field of sp-lherzolite. The products of this melting are tholeiites.

The degree of extension of continental crust connected with the basalt volcanism had to fulfil the conditions of tholeiite generating and simultaneously the course of MASH process (La/Sm fractionation in flat development of Tb/Yb). It means that extension should be bigger than for the alkaline volcanism and at the same time the lower than for the ideal tholeiite volcanism. The increase of extension would lead to depletion by LREE with transition to $La_n/Yb_n \leq 1$ and to erasure of HFSE anomalies.

Conclusions

The subvolcanic bodies in Carboniferous sediments at Slávča and Furmanec represent the dykes of tholeiitic basalts. These subophitic to intersertal basalts are formed by the dominant network plagioclases, skeletal ilmenite, clinopyroxene of augite to diopside composition and glass. The rocks are penetrated with thin plagioclase pegmatites, being a product of segregation of melt from plagioclase network as a result of compaction. The rocks are altered. Alteration affected dominantly the plagioclase (saussuritization). The intersertal glass is altered to chlorite, Fe-Ti oxides, K-feldspar and albite. Clinopyroxene is locally consumed by brown amphibole, or tiny needles of metamorphic actinolite. The particular character of former mineralogy of dykes - plagioclase, ilmenite, clinopyroxene, complicated composition of relic clinopyroxene, absence of pigeonite with quartz, high content of MgO, Cr, Ni, demonstrate the role of flow cumulated process in dykes genesis. The character of distribution of trace elements corresponds with the same character and distribution in Permian subvolcanic and effusive basalts of Hronicum. The dykes were probable the feeding channels of these basalts (aphyric). Chemical composition of studied rocks is similar with the composition of some inner-plate basalts (Siberian traps, Paraná). Weakly developed negative Nb-, Zr- anomalies, the distinct fractionation of LREE and tholeiitic character correspond with inner-plate volcanism, being connected with the relatively low extension of continental crust. The stated localities in underlier of Muráň Mesozoic we suppose to be the analogues of Upper Carboniferous Nižná Boca Formation with the presence of the vein basalt bodies of the Permian age.

Acknowlwdgement

We are grateful to Dr. P. Konečný for the useful suggestions and for critically reading of the manuscript.

This work originated as a part of the project of Ministry of Environment of Slovak Republic No. 130 *Tectogenesis of sedimentary basins.* It was also supported by the project No. 27 98 *Geological map of Slovak Republic in scale 1 " 200 000.*

References

Biely, A., 1961: Remarks to geology of Mesozoic of root zones in Veporides. *Geol.* Práce, Zpr., 21, 109-125. (In Slovak.)

Biely, A., 1966: To the problem of boundary of Gemerides and the Choč nappe. Geol. Práce, Zpr., 40, 171-172. (In Slovak.)

Biely, A., Beňuška, P., Bezák, V., Bujnovský, A., Halouzka, R., Ivanička, J., Kohút, M., Klinec, A., Lukáčik, E., Maglay, J., Miko, O., Pulec, M., Putiš, M. & Vozár, J., 1992: Geological map of the Nízke Tatry Mts. 1:50 000. Geol. Úst. Dionýza Štúra, Bratislava. (In Slovak.)

Biely, A., Bujnovský, A., Vozárová, A., Klinec, A., Miko, O., Halouzka, R., Vozár, J., Beňuška, P., Bezák, V., Hanzel, V., Kubeš, P., Liščák, E., Lukáčik, E., Maglay, J., Molák, B., Pulec, M., Putiš, M., Slavkay, M., (Biely & Bezák edit.) 1997: Explanations to geologickej map of the Nízke Tatry Mts. 1 : 50 000. Geol. Úst. Dionýza Štúra, Bratislava, 7-232 (In Slovak).

Cox, K. G., Bell, J. D. & Pankhurst, R. J., 1979: The interpretation of igneous rocks. G. Allen & Unwin (publishers), London, 450.

DeBari, S. M., 1994: Petrogenesis of the Fiambalá gabbroic intrusion, North-western Argentina, a deep crustal syntectonic pluton in a continental magmatic arc. J. Petrol., 35, 679-715.

Demko, R. & Olšavský, M., 2005: Subophitic clinopyroxenes of basic subvolcanic bodies in the Upper Carboniferous sediments of Western Carpathians. Min. Slovaca, 37, abstrakt, 477. (In Slovak).

Demko, R. & Olšavský, M., 2005: Petrography and geochemistry of subvolcanic basalt bodies among the Upper Carboniferous sediments from the underlier of Muráň Mesozoic sequences (Slávča and Furmanec valleys, Western Carpathians), Slovac Geol. Mag., 11, 2-3, Bratislava, 143-153.

Dostál, J., Vozár, J., Keppie, J. D. & Hovorka, D., 2003: Permian volcanism in the Central Western Carpathians (Slovakia): Basin-and-range type rifting in the southern Laurussian margin. Geol. Rundsch., 92, 27-35.

Faryad, S. W., Ivan, P. & Jacko, S., 2005: Metamorphic petrology of metabasites from the Branisko and Čierna Hora Mountains (Western Carpathians, Slovakia), Geol. Carpathica, 56, 3-16.

Hildreth, W. & Moorbath, S., 1988: Crustal contributions to arc magmatism in the Andes of Central Chile. Contrib. Mineral. Petrol., 98, 455-489.

Humphris, S. E., 1984: The mobility of the rare earth elements in the crust. In: Rare earth element geochemistry. Henderson P. (ed.), British Museum, London, 317-340.

Irvine, T. N. & Baragar, W. R. A., 1971: A guide to the chemical classification of the common volcanic rocks. Can. J. Earth Sci., 8, 523-548.

Ivan, P., Demko, R., Rojkovič, I. & Vozár, J., 2002: Geochemistry and geodynamic setting of the Permian volcanism in the Western Carpathians: A review. Special issue of Geologica Carpathica (CD), 53, 1335-0552.

Georock, internet geochemical database, Max Planck Institute in Mainz, http://georock.mpch-mainz.gwdg.de

Grove, T. L. & Baker, M. B., 1984: Phase equilibrium controls on the tholeiitic versus calc-alkaline differentiation trends. J. Geophysic. Res., 89, 3253-3274.

Grove, T. L. & Kinzler, R. J., 1986: Petrogenesis of andesites. Ann. Rev. Earth Planet. Sci., 14, 417-454.

Churikova, T., Dorendorf, F. & Wörner, G., 2001: Sources and fluids in the mantle wedge below Kamchatka, evidence from across-arc geochemical variation, J. Petrol., 42, 1567-1593.

Kinzler, R. J., 1997: Melting of mantle peridotite at pressures approaching the spinel to garnet transition: Application to mid-ocean ridge basalt petrogenesis. J. Geophys. Research, 102, 853-874.

Klinec, A., 1976: Geological map of the Slovak Ore Mts. and the Nízke Tatry Mts. Geologický Ústav Dionýza Štúra. Bratislava. (In Slovak).

Kovařík, J., Kužvart, M., Pouba, Z., 1955: Report about geological mapping in surrounding of Tisovec and Muráň. *Zprávy o geol. výskumech v roku 1954. ÚÚG, Praha.* (In Czech).

Leake, B. E., Woolley, A. R., Arps, C. E. S., Birch, W. D., Gilbert, M. C., Grice, J. D., Hawthorne, F. C., Kato, A., Kisch, H. J., Krivovichev, V. G., Linthout, K., Laird, J., Mandarino, J., Maresch, W. V., Nickel, E. H., Rock, N. M. S., Schumacher, J. C., Smith, D. C., Stephenson, N. C. N., Ungaretti, L., Whittaker, E. J. W. & Youzhi, G., 1997: Nomenclature of amphiboles: Report of the Subcommittee on amphiboles of the International Mineralogical Association commission on new minerals and mineral names. Mineral. Mag., 61, 295-321.

Le Maitre, R. W., Bateman, P., Dudek, A., Keller, J., Lameyre, Le Bas, M. J., Sabine, P. A., Schmid, R., Sorensen, H., Streckeisen, A., Woolley, A.R. & Zanettin, B., 1989: A classification of igneous rocks and glossary of terms. Blackwell, Oxford.

Le Bas, M. J. et al., 2000: IUGS Reclassification of the high-Mg and picritic volcanic rocks. J. Petrol., 41, 1467-1470.

Lindsley, D. H. & Andersen, D. J., 1983: A two-pyroxene thermometer. J. Geophys. Res., 88, A887-A906.

Luttinen, A. V. & Furnes, H., 2000: Flood basalts of Vestfjella: Jurassic magmatism across an Archaean-Proterozoic lithospheric boundary in dronning Maund Land, Antarctica. J. Petrol., 41, 1271-1304.

McKenzie, D. & O'Nions, R. K., 1991: Partial melt distributions from inversion of rare earth element concetrations. J. Petrol., 32, 1021-1091.

Mercier, J-C. C., 1976: Single-pyroxene geothermometry and geobarometry. Amer. Mineralogist, 61, 603-615.

Molzahn, M., Reisberg, L. & Wörner, G., 1996: Os, Sr, Nd, Pb, O isotope and trace element data from the Ferrar flood basalts, Antarctica: Evidence for an enriched subcontinental lithospheric source. Earth Planet. Sci. Lett., 144, 529-546.

Morimoto, N., 1989: Nomenclature of pyroxenes. Canadian Mineralogist, 27, 143-156.

Níu, Y., 1997: Mantle melting and melt extraction processes beneath ocean ridges: Evidence from abyssal peridotites. J. Petrol., 38, 1047-1074.

O'Hara, M. J., 1985: Importance of the "shape" of the melting regime during partial melting of the mantle. Nature, 314, 58-62.

Pearce, J. A., Kempton, P. D., Nowell, G. M. & Noble, S. R., 1999: Hf-Nd element and isotope perspective on the nature and provenance of mantle and subduction components in Western Pacific arc-basin systems. J. Petrol., 40, 1579-1611.

Pearce, J.A. & Peate, D.W., 1995: Tectonic implications of the composition of volcanic arc magmas. Annu. Rev. Earth Planet. Sci. 251-285.

Peate, D. W. & Hawkesworth, Ch. J., 1996: Lithospheric to asthenospheric transition in low-Ti flood basalts from southern Paraná, Brazil. Chem. Geol., 127, 1-24.

Philpotts, A. R., Carroll, M. & Hill, J. M., 1996: Crystal-mush compaction and the origin of pegmatitic segregation sheets in a thick flood-basalt flow in the Mesozoic Hartford basin, Connecticut. J. Petrol., 37, 811-836.

Philpotts, A. R., Shi, J. & Brustman, C., 1998: Role of plagioclase crystal chains in the differentiation of partly crystallized basaltic magma. Nature, 395, 343-346.

Philpotts, A. R. & Dickson, L. D., 2000: The formation of plagioclase chains during convective transfer in basaltic magma. Nature, 406, 59-61.

Plašienka, D. & Soták, J., 2001: Stratigraphic and tectonic position of Carboniferous sediments in the Furmanec valley (the Muráň plain). Min. Slov. 1/33, 29-44. (In Slovak.)

Rollinson, H. R., 1993: Using geochemical data: Evaluation, presentation, interpretation. Longman Scientific & Technical, 352.

Rozlosznik, P., 1935: Die geologischen Verhältnisse der Gegend von Dobsina. *Geologica hung., Ser. Geol. Palaeont., 5, 1-118.*

Šťastný, V., 1927: Study about so-called melaphyres in the Low Tatra Mts. in Slovakia. Rozpravy II. tr. ČA 36, č.29. (In Czech.)

Sun, S.-s. & McDonough, W. F., 1989: Chemical and isotopic systematics of oceanic basalts: Implications for mantle composition and processes. From Saunders A. D. & Norry M. J. (eds): Magmatism in the ocean basins. Geological Society Special Publication No. 42, 313-345.

Takahahsi, E., Nakajima, K. & Wright, T. L, 1998: Origin of the Columbia River basalts: Melting model of a heterogeneous plume head. Earth Planet. Sci. Lett., 162, 63-80.

Tatsumi, Y. & Eggins, S., 1995: Subduction zone magmatism. Cambrige (Ma.), Blackwell Sci. Publ., 248.

Taylor, St. R., McLennan, S. M, 1985: The continental crust: Its composition and evolution. Blackwell Scientific Publications. Geoscience texts.

Tulis, J. & Novotný, L., 1998: Evaluation of geological works for U ore in the Upper Paleozoic of Hronicum in the northern part of the Nízke Tatry Mts. and Kozie chrbty. Geofond 144 s. (In Slovak).

Vojtko, R., 2000: Are there tectonic units derived from the Meliata-Hallstatt trough incorporated into the tectonic structure of the Tisovec karst? (Muráň karstic plateau, Slovakia). Slovak Geol. Mag., 4/2000, 335-346.

Vrána, S., 1966: Alpidische Methamorphose der Granitoide und der Foederata Serie im Mittelteil der Veporiden. Sbor. Geol. Vied, rad ZK 6, Bratislava

Vrána, S. & Vozár, J., 1969: Mineral assemblage of pumpellyite-prehnite-quartz facies in the Nízke Tatry Mts. Geol. Práce, Správy, 49, 91-99. (In Slovak).

Vozár J., 1967: Der permische Vulkanismus in der Choč-Decke (Westkarpaten). Geologické práce, Správy 42. Bratislava.

Vozár, J., 1971: Multiphase character of Permian volcanism of the Choč Unit in the Nízke Tatry Mts. Geol. Práce, Správy, 55, 131-137. (In Slovak).

Vozár J., 1976: Permian volcanites of the Choč Unit in the Tríbeč Mts. Záp. Karpaty, sér. Miner., petrol., geoch., lož., 1, Geol. Úst. Dionýza Štúra, Bratislava, 151-187. (In Slovak).

Vozárová, A. & Vozár, J., 1988: Late Paleozoic in the West Carpathians. Geol. Úst. Dionýza Štúra, Bratislava, 7-314.

Vozár, J., 1997: Rift-related volcanics in the Permian of the Western Carpathians. In: Grecula, P., Hovorka, D. & Putiš, M. (eds.): Geological evolution of the Western Carpathians. Min. Slovaca – Monograph., 225-235.

Wilson, M., 1989: Igneous petrogenesis. London, Unwin Hyman, 466 p.

Winchester, J. A. & Floyd, P. A., 1977: Geochemical discrimination of different magma series and their differentiation products using immobile elements. Chem. Geol., 20, 325-343.

Wooden, J. L., Czamanske, G. K., Fedorenko, V. A., Arndt, N. T., Chauvel, C., Bouse, R. M., King, B. W., Knight, R. J. & Siems, D. F., 1993: Isotopic and trace-element constraints on mantle and crustal contributions to Siberian continental flood basalts, Noril'sk area, Siberia. Geoch. Cosmoch. Acta., 57, 3677-3704.

Zoubek, V., 1957: Report about geological investigation in the Vepor Mts. in surrounding of Tisovec town. Zpr. Geol. Výzk. V roku 1965, Praha, 201-203. (In Czech.)