PETROLOGICAL AND GEOCHEMICAL FEATURES OF THE MELIATA MAFIC ROCKS FROM THE SUTURED TRIASSIC OCEANIC BASIN, WESTERN CARPATHIANS

Shah Wali Faryad*, Ján Spišiak, Péter Horváth***, Dušan Hovorka****, Ivan Dianiška°** and **Sándor Józsa°°**

* *Institute of Petrology and Structural Geology, Charles University, Albertov 6, 12843 Prague 2, Czech Republic (Corresponding author, e-mail: faryad@natur.cuni.cz).*
* *Geological Institute of the Slovak Academy of Sciences, Slovak Republic.*
*** *Laboratory for Geochemical Research, Hungarian Academy of Sciences, H-1112, Budapest, Budaörsi út 45., Hungary.*
**** *Faculty of Natural Sciences, Comenius University, Slovak Republic.*
° *Mierova 16 Rožňava, Slovak Republic.*
°° *Department of Petrology and Geochemistry, Eötvös Loránd University, H-1088, Budapest, Múzeum krt. 4/a, Hungary.*

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ABSTRACT

Metabasites related to the Triassic Meliata oceanic basin occur along three tectonic zones in the Western Carpathians: (1) the Folkmár Zone, (2) the Rožňava Zone (Meliata Unit, s.s.) and the (3) Bódva valley - Darnó Hill Zone. The first two zones form the northern and southern boundary of the Paleozoic of the Gemericum (south-eastern Slovakia), respectively, and the latter is located south of the Meliata Unit, NE Hungary. All three zones contain metabasites. The serpentinites, radiolarian shales and cherts are considered to be complementary members of an ancient oceanic crust. Geochemical characteristics of metabasites from the Folkmár Zone indicate a MORB affinity. Metabasites from the Rožňava Zone have affinity between MORB and within plate basalts, but metagabbros comparable with alkaline basalts are also present. The Darnó Hill metabasites have MORB compositions and those from the Bódva valley are similar to the metabasites from the Rožňava Zone. The geochemical and petrographic features of these metabasites suggest a continental rift volcanism, followed by spreading of the Triassic Meliata oceanic basin. During the Middle Jurassic, part of the oceanic crust and adjacent passive continental margin underwent a subduction-related blueschist facies metamorphism afterwards they were exhumed within a mélange complex of the Meliata Unit in the southern part of Gemericum.

INTRODUCTION

Recently, a great progress has been made in understanding the paleogeography and tectono-metamorphic evolution of the Triassic Meliata oceanic basin (Dercourt et al., 1990; Dal Piaz et al., 1995; Kozur and Mock, 1997; Channell and Kozur, 1997; Marchant and Stampfli, 1997; Faryad and Henjes-Kunst, 1997; Plašienka, 1997). According to Stampfli et al. (2002), the Meliata Ocean opened from the Late Permian as back-arc basin within the Eurasian margin and Neotethys along the Gondwanian margin. Subsequent intra-oceanic subduction gave rise to the Vardar marginal ocean which was obducted in the Late Jurassic onto the Dinaro-Hellenic margin. During the late Early Cretaceous a NE-trending subduction generated the collision of an intraoceanic arc with the Austro-Carpathian and Balcanide Domains. The best evidence of this basin are ultramafic rocks and Middle Jurassic high-pressure metamorphic rocks which are exposed in the south-eastern part of the Western Carpathians, along the boundary with the Pannonian Basin. The oceanic rocks are represented by serpentinites, derived from harzburgite, lherzolite and rare dunite, metagabbro, dolerite dikes, tholeiitic basalts and radiolarites which are associated with shales, limestones and dolomites. Together with very low-grade metasediments, these rocks were included in the Lower Cretaceous accretionary mélange (Árkai et al., 2003) and exhumed along the Rožňava and Darnó tectonic zones (SE Slovakia and NE Hungary). As a whole, these rocks are believed to form an incomplete ophiolite sequence.

The mafic rocks investigated here occur as blocks within a tectonic mélange thrust onto the greenschist facies metamorphic volcano-sedimentary sequences of Paleozoic age which belong to the Gemericum. Petrological data are available for most of these metamorphic rocks and some geochemical data were also obtained from various occurrences of metabasites. Since these metabasites occur within different geological units and display various petrological and geochemical features, contrasting interpretations of their origin have been proposed by various Authors (Downes et al., 1990; Faryad, 1995; Ivan and Kronome, 1995; Harangi et al., 1996; Hovorka and Spišiak, 1998; Ivan, 2002). This study deals with the petrological and geochemical features of mafic rocks from all investigated localities in Slovakia and Hungary, also discussing their origin with respect to the geotectonic meaning of the Meliata Unit.

GEOLOGICAL SETTING

Tectonic blocks of ophiolites and deep sea sediments, representing relics of the Triassic-Jurassic Meliata oceanic basin, are well known from the inner Western Carpathians (Kozur and Mock, 1973; 1997; Hovorka, 1985; Harangi et al., 1996). In Slovakia, they occur along two tectonic zones: (a) the Folkmár Zone, which is parallel to or identical with the Margecany Zone, and (b) the Rožňava Zone. Both are separated by a Paleozoic block of the Gemericum which consists of a stake of metasedimentary and metavolcanic nappes (Fig. 1A). The Margecany Zone is a north-verging thrust system with Mesozoic and Upper Paleozoic sediments squeezed between the Gemericum and the underlying Veporicum (Fig. 1B, C).

The Meliata Unit s.s. (called here the Rožňava Zone) is

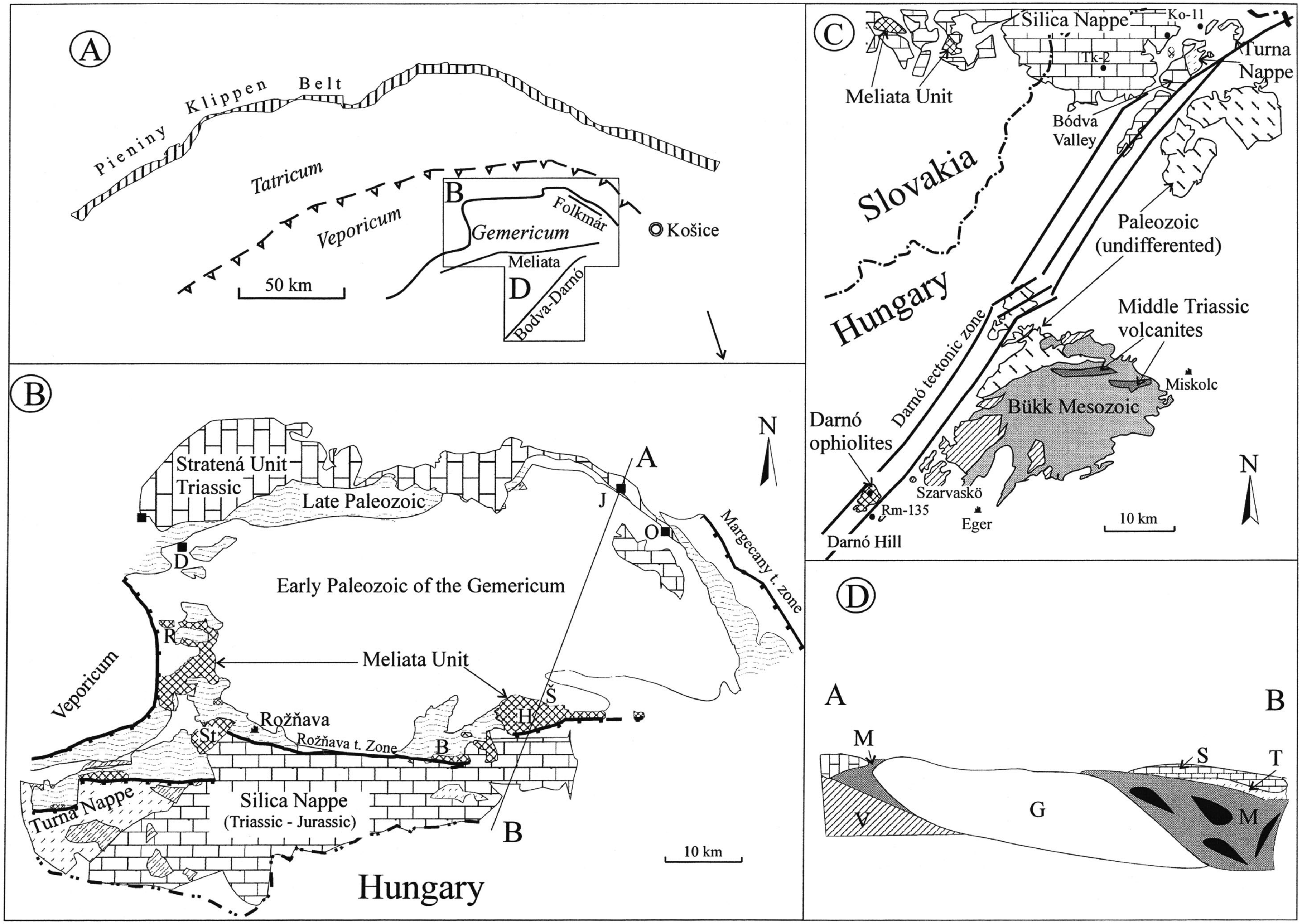

Fig. 1 - A) Geological position of the Meliata Unit in the Western Carpathians. B) The Gemericum unit with Flokmar (O- Opátka, J- Jaklovce, D- Dobšina) and Rožňava Zones (H- Hačava, B- Bôrka, Št- Štítnik, R- Radzim). C) The Meliata-related ophiolite complexes (Bódva Valley and Darnó Hills) in the NE part of Hungary. D) Schematic cross-section through the Gemericum and adjacent units.

located at the southern rim of the Gemericum (Fig. 1B) and is characterized by blueschist facies rocks (metabasites, marbles, phyllites, former amphibolite facies basement), serpentinites and very low-grade metasediments. They occur within the southward dipping zone located between the greenschist facies Paleozoic rocks of the Gemericum and the overlying very low-grade or not metamorphosed rocks of the Permian-Triassic Silica and Turna nappes (Fig 1C).

The Mesozoic ophiolites in the Bódva Valley - Darnó Hill Zone, NE Hungary, are known from boreholes and some outcrops (e.g., Darnó Hill) (Fig. 1D), usually covered by Tertiary sediments or tectonically overlain by the Silica Nappe. These tectonic fragments are referred to as a part of the Gemer-Bükk Unit of the Pelsonia composite terrane (Kovács et al., 1996; 1997), also named as the North Pannonian or ALCAPA Unit (Balla, 1982; Csontos et al., 1992) which was connected with other Western Carpathian units during the Miocene.

The Folkmár Zone

According to Kozur and Mock (1985), the Folkmár Zone is a tectonic suture which originated from the closure of the northern branch of the Meliata Basin. It extends from Jaklovce to Dobšina, where serpentinized peridotites occur (Hovorka et al., 1985). Characteristic rock types are Anisian red pelagic limestones and Ladinian red banded radiolarites and red radiolarian shales (Kozur and Mock, 1985), which can be observed along the entire suture zone (Kozur and Mock, 1997; Mock et al., 1998). Other rocks which may be correlated with the Meliata Unit are the Upper Triassic cherty limestones and Middle Jurassic deep water sediments represented by calcareous breccias with belemnites and shales and green to dark grey marly shales. Slightly recrystallized limestones of Early Anisian age, which originated during the pre-rift stage, are also present.

Numerous outcrops of serpentinite and basalt with poorly preserved pillow lava structures occur near Jaklovce and Opátka (Fig. 1B). These rocks are associated with fuchsite-bearing carbonate breccias (listvenites) derived from the hydrothermal-metasomatic alteration of serpentinites along tectonic zones. Most contacts among limestones and various ophiolitic bodies are tectonic.

The Rožňava Zone -Meliata Unit (s.s.)

The Meliata Unit is exposed in the southern part of the Gemericum. It is represented by a mélange complex (mostly low-grade metasediments with blocks of serpentinites and blueschists) below the Silica Nappe, and slices of blueschist facies rocks thrust onto the Gemericum. Based on recent structural and petrological analyses, the Meliata Unit consists of three thrust sheets (Faryad et al., 2003): the lower thrust sheet is represented by blueschist to sub-blueschist (transitional between low-temperature greenschist and blueschist) facies rocks derived from continental crust material (mostly quartz-rich metasediments); the middle thrust sheet contains a complex of blueschist facies marbles with metabasites and phyllites; the upper one consists of very low-grade metasediments of the mélange complex.

According to Kozur and Mock (1997), protoliths of the very low-grade metasedimentary sequence (dolomite, limestone, radiolarite, cherty limestone and cherty shale) are of Middle Anisian - Norian age and are related to the rifting that occurred after the break up of the Lower Anisian platform. The Jurassic sequence (Liassic-Bathonian) consists of silty shales with olistoliths of Triassic radiolarites, cherts, limestones, serpentinites, gabbros and blueschists. Mafic and ultramafic rocks are exposed in numerous localities along the southern border of the Gemericum Unit. The presence of large bodies of buried ultramafic rocks is supported by geophysical data (Plančár et al., 1977). The serpentinite bodies usually have a lenticular shape and occur in a schistose carbonate sequence under the Silica Nappe (Hovorka et al., 1985). They are derived from harzburgite, lherzolite and rare dunite. Some websterites occur in the eastern part of the Meliata Unit. Vozárová and Vozár (1992) reported the occurrence of olistostromes consisting of serpentinite and coarse-grained breccia within very low-grade laminated pelites and sandstones found in a borehole drilled in the western part of the Meliata Unit.

The blueschist facies rocks are represented by marbles with layers of metabasites (primary basaltic flows and pyroclastics), metapelites, metasandstones and metaconglomerates. In addition, amphibolite facies basement rocks with blueschist facies overprint are also present (Faryad, 1988). The blueschist facies rocks occur as tectonic slices in the Gemericum or as blocks in very low-grade metamorphic rocks (Fig. 1C) that bear evidence of accretionary metamorphism, represented by rocks exhumed from different depths of an accretionary wedge (Árkai et al., 2003). K-Ar and ^{40}Ar-^{39}Ar dating of metamorphic white mica indicates a Middle Jurassic (155-170 Ma) age for blueschist facies metamorphism and a Late Jurassic age (137-145 Ma) for accretionary metamorphism.

Most of exposed mafic rocks along the Rožňava Zone form up to 0.5 x 3 km bodies of basalts and basaltic tuffs embodied within limestones and also associated with pelites. They form slices, partly thrust onto the Paleozoic sequences of the Gemericum. Tectonic blocks of metagabbros with very low-grade to blueschist facies overprint were found in a Permian evaporite-carbonate sequence of the Turna Nappe (Faryad and Dianiška, 1999).

Bódva Valley - Darnó Hill Zone

The Meliata rocks, occurring south of the Rožňava Zone, are known only from boreholes beneath the Silica Nappe (Fig. 1D). A sedimentary complex, mostly represented by shales, pelites and sandstones, contains blocks of Ladinian-Carnian reddish cherty limestones associated with basalts. Mafic and ultramafic rocks occur as isolated blocks and olistoliths in the Jurassic olistostrome series with radiolarian fauna (Réti, 1985; Dosztály and Józsa, 1992). In the Bódva Valley, blocks of chrysotile serpentinite, metabasalt and metagabbro (cm to a few hundreds of meters in size) are tectonically embedded in a non metamorphic evaporitic matrix of the Upper Permian Evaporite Formation. A Middle Triassic age of these rocks is assumed, based on sporadic biostratigraphic data on radiolarites believed to be contemporaneous with the pillow basalts (Kozur and Réti, 1986; Dosztály and Józsa, 1992).

The Jurassic Szarvaskö ophiolite complex (not investigated here) is exposed in the NE part of the Bükk Mts., northern Hungary. It mostly consists of a series of ultramafic and mafic rocks (Balla et al., 1983; Aigner-Torres and Koller, 1999) transected by acidic dykes and veins. The surrounding rocks are terrigenous sediments.

PETROGRAPHY AND GEOCHEMISTRY OF METABASITES

Major, trace and rare elements of metabasites were analyzed by XRF and neutron activation methods at the universities of Bochum (Germany), Budapest (Hungary), Vienna and in a laboratory at Stražské pod Ralskem (Czech Republic). The metabasites suffered various degrees of alteration and metamorphism, which may have affected major element contents in the rocks. Major components can therefore be used only for classification and comparison among metabasites from different tectonic units and localities. In order to compare geochemical features and to define the geotectonic position and magma generation process, some trace element and REE were used. As chemical analyses of metabasites were done in different laboratories, some trace and rare elements were not detected. In addition to the new analyses presented in this work, some published data were used for regional correlations of the Meliata mafic rocks. Major and trace element analyses of the studied metabasites are presented in Table 1.

The Folkmár Zone

The very low-grade metabasalts from Jaklovce are massive fine-grained rocks with rare amygdules of maximum 1 mm size. Some ophitic varieties can also be observed in the core of some thick lava flows or in subvolcanic bodies. Relatively large (to 2 mm) phenocrysts of albitized plagioclase and rare clinopyroxenes are present in some porphyric varieties. The clinopyroxene is a diopsidic augite similar to that from alkaline and subalkaline rocks (Fig. 2). Metamorphic minerals are albite, carbonate, epidote, chlorite and titanite.

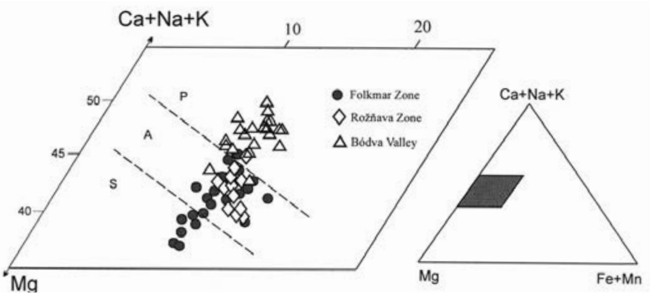

Fig. 2 - Pyroxene composition of the Meliata metabasites plotted in the Mg: Ca + Na + K: Fe + Mn (Le Bas, 1962) diagram. The S, A and P fields correspond to clinopyroxenes from subalkaline, alkaline and peralkaline rocks.

Based on major element composition, mainly SiO_2 and Na_2O+K_2O, the mafic rocks from Jaklovce and Opatka correspond to basalts which plot close to the field of basaltic andesite (Fig. 3). The CaO and MgO contents, consistent with isopleths given in the SiO_2-Na_2O+K_2O plot (Fig. 3), range between 7.9-10.2 and 6.4-8.1 wt %, respectively. The Zr, Y and Nb contents indicate their affinity with MORB (N/P-MORB) basalts (Figs. 4, 5). The chondrite normalized REE distribution shows a flat pattern (Fig. 6a) with weak fractionation, $(Ce/Yb)_n$ = 1.1-1.7 and $(La/Sm)_n$ = 0.6-0.9.

The Rožňava Zone

The most common metabasites in this zone occur in layers and lenses within blueschist facies marbles. Small amounts of very low-grade metabasites, associated with radiolarites and shales, occur in the mélange matrix. They are rather badly exposed and therefore geochemical data are unsuitable.

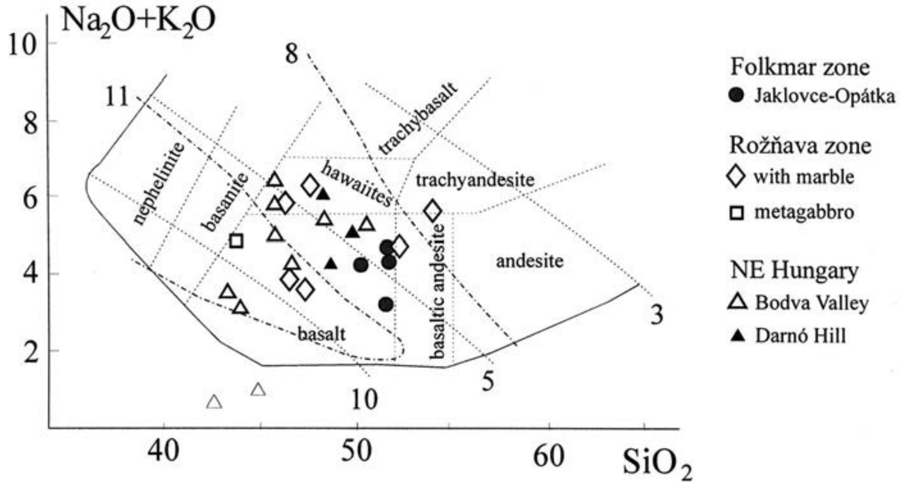

Fig. 3 - K_2O+Na_2O:SiO_2 diagram for the Meliata metabasites (LeMaitre, 1989). Isopleths of CaO and MgO after Cox et al. (1993).

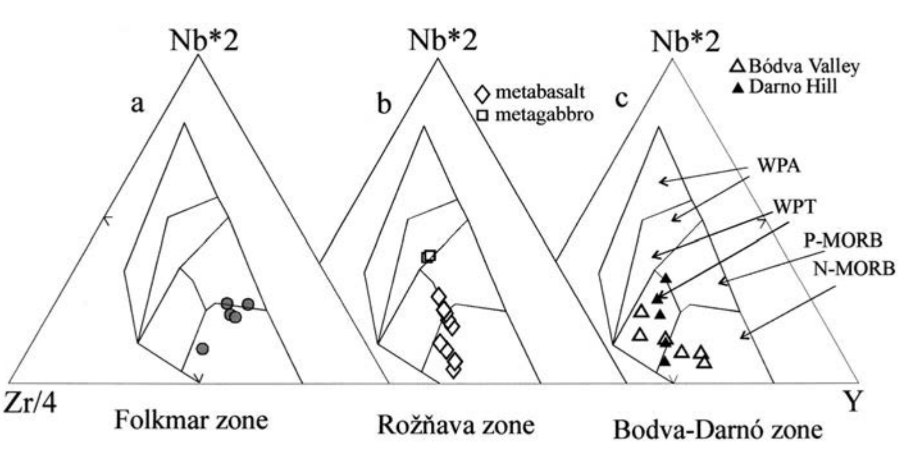

Fig. 4 - Ternary plots for the Meliata metabasites: 2Nb:Y:Zr/4 (Meschede 1986).

Table 1 - Selected chemical analyses rocks from the Meliata Unit.

	Folkmár Zone				Rožňava Zone				NE Hungary				
	Jaklovce		Opatka		metabasalt			gabbro	Bódva V. Ko-11		Darnó Hills Rm-135		
sample	Jakl-13	Jakl-15	Opa-1	Opa-2	1991	9025	FBO-12	Sa-470.3	204 G	235G	254G	44B	514G
SiO_2	49	48.11	49.05	50.53	53.90	52.2	48.03	43.86	46.35	45.46	48.11	48.60	44.65
TiO_2	1.37	1.79	1.32	1.64	2.44	3.14	3.23	2.88	3.22	4.28	1.15	1.85	1.18
Al_2O_3	15.5	14.57	13.77	13.94	12.40	12.9	13.00	15.37	12.78	12.80	16.11	13.90	12.64
Fe_2O_3	2.28	4.52	1.54	2.23	6.20	5.14	7.61	4.97	8.59	7.74	11.08	11.98	17.46
FeO	6.35	6.1	7.43	6.64	9.27	8.68	6.38	7.05	6.05	6.56	-	-	-
MnO	0.17	0.2	0.18	0.19	0.45	0.25	0.17	0.13	0.19	0.32	0.25	0.20	0.29
MgO	7.05	6.86	8.09	6.44	2.68	3.3	5.06	7.43	6.10	4.88	7.41	7.16	10.07
CaO	8.9	9.17	10.2	9.79	4.36	7.24	8.66	10.21	9.20	8.67	5.76	8.65	6.79
Na_2O	4.15	3.62	3.03	4.45	3.09	3.11	3.13	3.83	3.70	4.31	5.11	4.26	0.86
K_2O	0.54	0.68	0.17	0.26	2.65	1.55	1.23	0.74	0.68	0.70	0.33	0.10	0.06
P_2O_5	0.18	0.4	0.26	0.38	0.78	0.62	0.04	0.24	0.36	1.19	0.12	0.22	0.18
LOI	3	2.7	3.41	2	2.11	2.44	2.14	2.86	1.83	1.73	4.57	3.13	5.82
Total	98.49	98.72	98.45	98.49	100.33	100.57	99.32	99.57	99.81	99.48	100.00	100.05	100.09
La	4.15	6.57	5.53	6.49	26	23	11.5	9.5	11	32.60	1.3	6.7	4.1
Ce	11.86	18.62	15.54	16.77	66	51	33.0	30.5	27	77.2	5	18	12
Nd	10.06	15.43	13	12.46	42	35	28.3	19.2	-	42.9	-	9	9
Sm	4.13	5.81	4.99	4.62	12	10	8.9	4.5	6.23	13.9	-	4.77	2.97
Eu	1.22	1.65	1.48	1.29	3	3	2.65	1.55	2.1	4.66	0.86	1.54	1.01
Gd	5.08	7.23	6.54	5.79	14	11	-	7.7	-	-	-	-	-
Dy	5.42	7.53	6.55	5.67	15	11	-	-	-	-	-	-	-
Er	3.22	4.31	3.88	3.18	8	7	-	-	-	-	-	-	-
Yb	2.9	3.62	3.11	2.5	7	6	6.3	2.8	3.96	7.71	2.27	3.4	2.2
Lu	0.37	0.47	0.38	0.33	1	1	1.05	0.49	0.61	1	0.31	0.38	0.29
Y	28.13	37.91	34.25	30.07	88	71	58	27	54	150	27.7	30	22
Ba	56	183	436	78	78	186	92	118	-	-	64.3	26	5
Co	54	71	70	49	69	36	25.9	52	37	22	39	49	78
Cu	102	41	24	80	-	43	-	80	-	-	-	-	-
Nb	6	9	7	8	33	19	6	20	-	13	0.1	9	1
Ni	123	83	109	62	-	10	-	65	59	11	156	198	679
Sc	32	35	32	32	-	-	36.0	31	44	44.5	41.7	37.3	27
Sr	183	151	358	316	-	190	-	127	-	-	193	344	55
V	332	435	373	337	-	351	467	290	408	292	251.7	340	223
Zn	104	122	131	326	-	157	-	281	-	-	-	-	-
Zr	71	73	82	78	320	259	212	130	212	395	48.1	134	93
Hf	-	-	-	-	-	-	6.3	3.8	5.80	8.90	1.8	3.6	2.1
Ta	-	-	-	-	-	-	0.4	0.57	0.64	1.41	1.1	1	0.3
Th	-	-	-	-	-	-	2.05	0.55	-	0.89	-	0.7	0.6
Cr	-	-	-	-	-	15	28.6	157	67	-	413	404.0	920.0
Tb	-	-	-	-	-	-	1.7	0.88	1.31	2.67	-	0.6	0.6
Rb	-	-	-	-	-	63	-	12.2	-	-	5.6	1	0
Ce/Yb	1.07	1.35	1.31	1.76	2.48	2.23	1.31	2.86	1.79	2.63	0.58	1.39	1.43
La/Sm	0.63	0.71	0.69	0.88	1.36	1.44	0.81	1.32	1.11	1.47	-	0.88	0.87

For the Darnó Hill metabasites FeO = FeO, Samples FBO-12 and 414 G are from Ivan (2002) and Harangi et al. (1996), respectively.

Blocks of very low-grade to blueschist facies metagabbros are present in the evaporite mélange beneath the Silica Nappe. The blueschist facies metabasites in marbles usually are weakly or non foliated and may preserve pillow lava, amygdules, variolites and ophitic structures. As relics of igneous phases they contain diopside, which plots in the field of alkaline basalts (Fig. 2). The most common metamorphic mineral assemblage is glaucophane + epidote + albite + titanite, but in some cases also glaucophane + albite + omphacite + epidote +phengite or glaucophane + aegirine/jadeite + garnet+ phengite can be present. Maximum P-T conditions of 13 kbar at 450 °C were obtained for the blueschist facies metamorphism that was followed by a greenschist facies retrograde event (Faryad, 1995; Faryad and Hoinkes, 1999).

The metagabbro blocks in the evaporites from Bohúňovo are characterized by relics of igneous Ti-rich richterite, which is preserved as relatively coarse crystals. Its Ti content ranges between 0.20 and 0.31 a.p.f.u. (Fig. 7), but if compared with richterite from potassium-rich alkaline rocks (Mitchell, 1985; Wagner and Velde, 1986; Konzett et al, 1997) it has lower potassium (0.10-0.18 a.p.f.u.) with K/Na = 0.08-0.12. Most analyses indicate insufficient Si+Al, and thus some Ti^{4+} occurs in tetrahedral site. Richterite of similar composition but with high fluorine content was described by Leake et al. (1995) in a basalt lava flow from Wild Dog Well, Roy Hill (Western Australia). The majority of richterite analyses indicates $X_{Mg} > 0.5$ (0.50-0.55), but some analyses having $X_{Mg} = 0.47$ correspond to ferrorichterite (cf. Leake et al., 1997). The Na contents in B and A sites are 0.9-1.0 and ca 0.6 a.p.f.u., respectively. In some cases the yellow tabular crystals of richterite have yellow-green domains of metamorphic edenite or magnesiohornblende composition. Along the contact with richterite, these domains show relatively high Ti = 0.8-1.3 (Fig. 7) and Na^{M4} = 0.1-0.3 a.p.f.u and A site is occupied by 0.4-0.52 Na+K a.p.f.u. Compared with richterite they also have higher Al^{IV} = 0.7-0.9 a.p.f.u. and X_{Mg} = 0.7-0.8 and lower K (0.01-0.02 a.p.f.u.). Other metamorphic minerals in the rock are phengite, albite, chlorite, titanite and adularia forming veinlets. Estimated P-T conditions of the metamorphic mineral assemblage in metagabbros are 0.8 GPa at 300-330 °C (Frayad and Dianiška, 1999).

Most analyses of blueschist facies metabasite in marbles plot in the basalt field (Fig. 3); those in the hawaiite field are due to high K_2O probably of secondary origin. The metagabbro from Bohúňovo, containing relict richterite, has normative nepheline and plots close to the basanite field. Using the

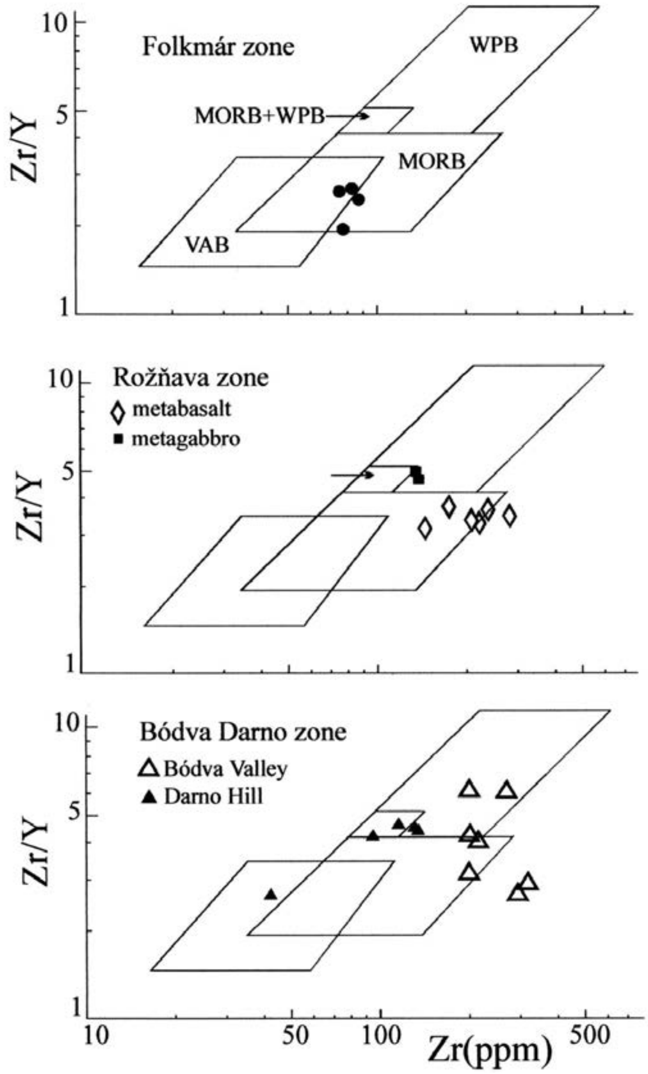

Fig. 5 - Zr/Y - Zr discrimination plot (Pearce and Norry, 1979) for the Meliata metabasites.

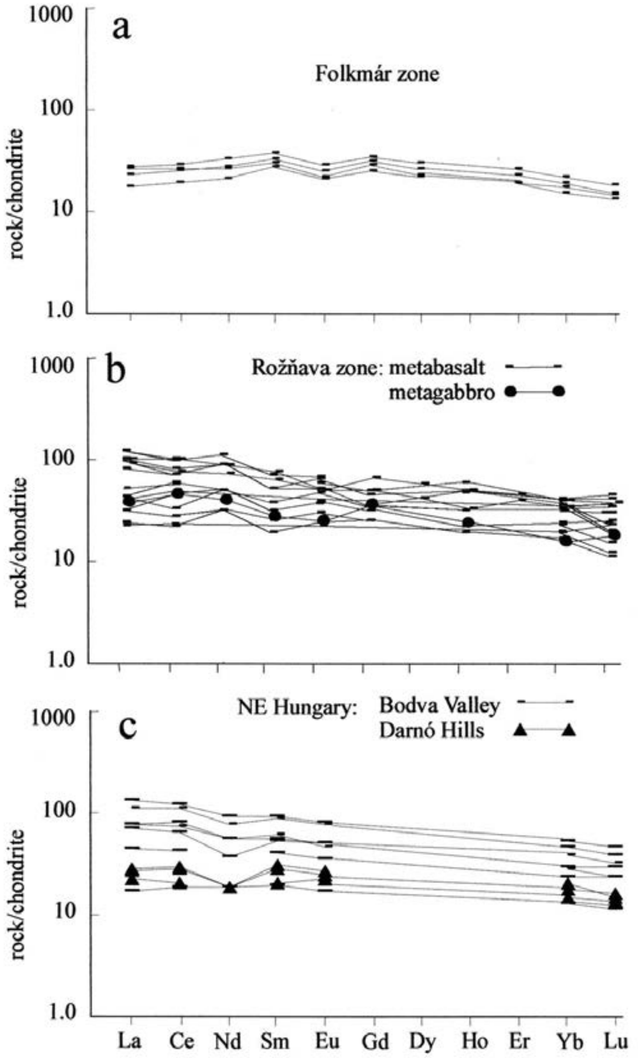

Fig. 6 - Chondrite normalized REE (McDonough and Frey, 1989) pattern of mafic rocks from the Meliata unit. Group 1 metabasites in Fig b includes also analyses published by Mazzolli and Vozárová (1998), and Ivan (2002).

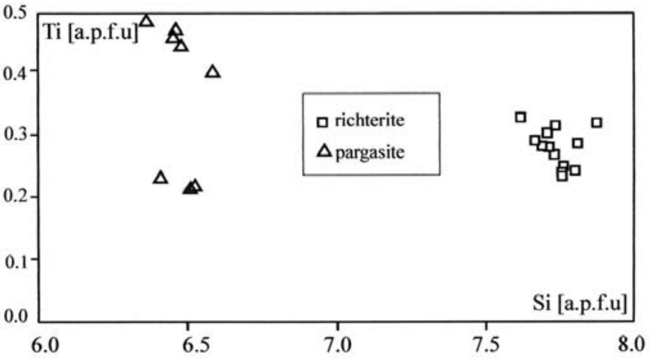

Fig. 7 - Ti content in a richterite from Bohúňovo and a pargasite from the Bódva Valley

Zr:Y:Nb diagram (Figs. 4, 5), the metabasites correspond to MORB with transition to within plate basalts. The metagabbro plots in the field of within plate basalts. When compared with metabasalts from the Folkmár Zone, the Rožňava Zone rocks show higher REE (Fig. 6) and are LREE enriched [$(Ce/Yb)_n$ = 2.2-2.5 and $(La/Sm)_n$ = 1.3-1.4].

Bódva Valley - Darnó Hill Zone

The metabasites in this zone are represented by pillow lavas, massive basalts and gabbros of various grain size. The metagabbro, which has a geological position like that of the Bohúňovo drill hole, contains relics of igneous pargasite with high Ti content (ca 0.5 a.p.f.u., Fig. 7). Igneous clinopyroxene from this locality has high Na+Ca+K and Ti+Cr contents, and falls in the peralkaline field (Fig. 2). The metabasites underwent a polyphase metamorphism, first in blueschist and then in greenschist facies conditions (Horváth, 1997; 2000). The metabasites from the Darnó Hill show a prehnite-pumpellyite facies ocean floor hydrothermal metamorphism, while the related sedimentary rocks only suffered a diagenetic alteration (Árkai, 1983).

The gabbroic rocks of the Bódva Valley have high TiO_2 contents (up to 6 wt%), and are similar to the metagabbros from Bohúňovo, close to basanite (Fig. 3). Based on trace element contents (Figs. 4 and 5), they correspond to MOR basalts. However, some analyses plot in the within plate tholeiite field. The position of the Bódva Valley mafic rocks is not clear in the Zr:Zr/Y diagram, since they lie both in MORB and WPB fields, and some also outside (Fig. 5). The analyzed metagabbro has a composition similar to that from the Rožňava Zone, being relatively high in REE and LREE enriched [$(Ce/Yb)_N$ = 1.8-2.6, $(La/Y)_N$ = 1.1-2.5].

Metabasites from the Darnó Hill plot both in the N-MORB and WPT fields (Figs. 4a and 5c). However, they show a REE distribution similar to that of the Folkmár Zone. When compared with the Bódva Valley ones they display lower $(Ce/Yb)_n$ = 0.6-1.4 and $(La/Sm)_n$ = 0.8 contents. Some gabbros from this locality have high MgO values (10-16 wt%) due to high olivine content (Harangi et al., 1996; Józsa, 1999).

Based on geochemical data, Balla et al. (1983), Dobosi (1986) and Downes et al. (1990) assume an oceanic tholeiitic nature of the Jurassic Szarvaskö metabasites, whereas Harangi et al. (1996) favored a back-arc origin. Aigner-Torres and Koller (1999) documented that the basalts and some gabbros have fractionated N-MORB-like trace element patterns. However, their low e_{ND} values, may suggest the involvement of an enriched source component.

DISCUSSION AND GEOTECTONIC IMPLICATION

The association of sediments, basalts, dolerite dykes, gabbros and mantle peridotite-serpentinites found in the Meliata Unit clearly recalls an oceanic suite. However, the petrographic and geochemical data on metabasites discussed in this work, combined with the lithological characteristics of blueschist facies rocks, highlight some critical problems of their pre-orogenic environment. The major contribution of this work is the discovery of continental crust rocks (metaconglomerates, metapsammites-metapelites and amphibolite facies basement rocks), which underwent a blueschist facies metamorphism (Faryad, 1995). Compositional variations within very low-grade and blueschist facies metabasites provide information on the development of the Meliata oceanic basin and its closure.

Varieties and relationships among metabasites

The very low-grade metabasalts from the Folkmár Zone reveal a N-MORB composition (Figs. 4 and 5) with only slight degree of fractionation [$(Ce/Yb)_n$ = 1.1-1.7 and $(La/Sm)_n$ = 0.6-0.9]. These metabasalts, together with serpentinites and radiolarites, are a good evidence of an ophiolite suite already assumed by Kozur and Mock (1985; 1997). In contrast to the Folkmár Zone, the blueschist facies metabasites of the Rožňava Zone have a compositional range from MORB to within-plate basalts and the majority of the studied samples display high total REE contents with fractionated indices of [$(Ce/Yb)_n$ = 1.3-2.5, $(La/Sm)_n$ = 0.8-1.4]. The difference between these rocks and MOR type basalts is also supported by the richterite-bearing metagabbro of Bohúňovo which plots in the field of plateau basalts. All these rocks bear no stratigraphic relation to the very low-grade metabasites, associated with radiolarites and serpentinites occurring along the Rožňava Zone.

Petrological and geochemical signatures of the Bódva Valley metabasites are similar to those of the Rožňava Zone. They plot both in the MORB and WPB fields, with relatively high REE contents (Fig. 6) and [$(Ce/Yb)_n$ = 1.7-2.8 and $(La/Sm)_n$ = 1.1-1.3]. The Ti-pargasite metagabbro of the Bódva Valley is similar in geochemical composition to the richterite-bearing metagabbro of Bohúňovo. Both contain relics of igneous amphiboles and occur in the Permian evaporite mélange. When the composition of relict clinopyroxene is compared, the metabasites indicate a transition from peralkaline members in the Bódva Valley to alkaline ones in the Rožňava Zone. They differ from clinopyroxenes from the Folkmár Zone that show a subalkaline character of the basaltic magma (Fig. 2). Regarding the REE pattern, the Darnó Hill metabasites are similar to those of the Folkmár Zone. They show a flat distribution with a slight degree of fractionation $(Ce/Yb)_n$ = 0.9-1.4 and $(La/Sm)_n$ = 0.8.

Geotectonic interpretation

According to Harangi et al. (1996), the mafic and ultramafic rocks of Darnó Hill originated along a mid-oceanic ridge system, whereas Downes et al. (1990) argued for their continental margin or oceanic island arc setting. Based on data published by Aigner-Torres and Koller (1999), the Jurassic Szarvaskö Complex would be a dismembered ophiolite sequence of back-arc basin affinity. These ophiolitic rocks mostly recorded a very low-grade metamorphism (Árkai and Kovács, 1986). By contrast, the blueschist facies metabasites of the Rožňava Zone and Bódva Valley show a within-plate affinity, particularly because of the presence of metagabbro with Ti-rich amphibole. Richterite and Ti-rich pargasite are usually known from alkaline basalts in oceanic island or continental rift environment. According to Bailey (1974), all the clearly defined nepheline basaltic rocks are confined to anorogenic sectors of the lithosphere, either in ocean basins or in stable continents. In the first case they are known from volcanic islands of the Atlantic and Pacific oceans. In the second case, the outstanding development of nephelinites and related plutonic suites can be seen in the African continent, particularly along the rift zones. The origin of alkaline rocks, including nepheline basalts, is related to magma generated in the astenospheric mantle (Harris and Bailey, 1974).

The variation of serpentinites derived from harzburgite, lherzolite and dunite (Hovorka et al., 1985) appears to be a fair evidence of contrasting sources. For instance, the lherzolites from the External Ligurides (Northern Apennines, Italy) are interpreted as slices of subcontinental lithospheric mantle emplaced at the surface during an early stage of rifting before the opening of the Jurassic Ligurian ocean (Rampone et al., 1995). Besides the possible interpretation of tectonic emplacement of these mafic and ultramafic rocks in the Meliata mélange complex, the presence of metabasites with varying geochemical compositions (MORB, within plateau or arc basalts) may suggest a heterogeneous crust that is characteristic of a back arc basin (Hawkins and Allan, 1994). Recent studies on the origin of many ophiolites have favored a marginal basin or arc-related setting rather than a major oceanic basin environment (Taylor et al., 1992). The presence of alkaline rocks, such as metagabbros in the Bódva Valley and Bohúňovo, is likely to be related to rifting and opening of a back-arc basin. Taking into account the varieties of metabasites from all three zones and the intraoceanic subduction model for the Meliata Basin (Stampfli et al., 2002), the pre-orogenic environment is thought to have been a continental wedge with rift-related igneous rocks. During exhumation, the blueschist units were brought together with ophiolitic rocks from the internal parts of the oceanic basin. Taking into consideration the three thrust sheets structure of the Meliata Unit (the upper thrust sheet with very low-grade Meliata mélange and the medium and lower thrust sheets with blueschist and sub-blueschit facies rocks, respectively) (Faryad et al., 2003), the rocks with ophiolitic signature belong to the upper thrust sheet mostly occurring south of the blueschist/sub-blueschist facies rocks. The ophiolitic rocks from the Folkmár Zone may therefore be interpreted as part of the upper thrust sheet, which was displaced to the north during the Upper Cretaceous orogeny, and sandwiched between the Gemericum and Veporicum Units along the Margecany or Folkmár Zones.

Conclusion

The geochemical and petrological characteristics of the several varieties of metabasite under study can be summarized as follows:

1. The metabasites from the Rožňava Zone and from Bódva Valley are more similar to plateau basalts than to middle ocean ridge basalts. This is also supported by the composition of relict clinopyroxenes and Ti-rich amphiboles showing affinity to alkaline rocks.
2. The presence of older basement rocks with blueschist facies overprint and geochemical characteristics of the studied metabasites suggest subduction of continental crust with rifting-related magmatic rocks.
3. Ophiolitic rocks (peridotite, gabbro, dolerite dykes and basalts of MORB composition, radiolarian shales and cherts) occur mostly within the accretionary wedge south of the blueschist facies thrust sheets.
4. Based on geochemical properties, the very low-grade metabasites occurring in the Folkmár Zone together with serpentinites, radiolarites and cherts, are similar to the Darnó Hill metabasites. This suggests a single oceanic suture and a southern origin of the Folkmar rocks that were then imbricated along the Margecany Zone during Cretaceous tectonic events.

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REFERENCES

Aigner-Torres M. and Koller F., 1999. Nature of the magma source of the Szarvaskö Complex (NE-Hungary): Petrological and geochemical constraints. Ofioliti, 24: 1-12.

Árkai P., 1983. Very low- and low-grade Alpine regional metamorphism of the Paleozoic and Mesozoic formations of the Bükkium, NE-Hungary. Acta Geol. Hungar., 26: 83-100.

Árkai P., Faryad S.W., Vidal O. and Balogh K., 2003. Very low-grade metamorphism of sedimentary rocks of the Meliata unit, Western Carpathians, Slovakia: implications of phyllosilicate characteristics, Int. Rev. Earth Sci., 92: 68-85.

Árkai P. and Kovács S., 1986. Diagenesis and regional metamorphism of Aggtelek - Rudabánya Mountains (Northern Hungary). Acta Geol. Hungar., 29: 349-373.

Bailey D.K., 1974. Nephelinites and ijolites. In: Sorensen H. (Ed.), The alkaline rocks. John Wiley and Sons, London, p. 53-66.

Balla Z., 1982. Development of the Pannonian basin basement through the Cretaceous-Cenozoic collision: a new synthesis. Tectonophysics, 88: 61-102.

Balla Z., Hovorka D., Kuzmin M. and Vinogradov V., 1983. Mesozoic ophiolites of the Bükk mountains (North Hungary). Ofioliti, 8: 5-46.

Channell J.E.T. and Kozur H.W., 1997. How many oceans? Meliata, Vardar, and Pindos oceans in Mesozoic Alpine paleogeography. Geology, 25: 183-186.

Cox K.G., Bell J.D. and Pankurst R.J., 1993. The interpretation of igneous rocks. Chamann and Hall, 450 pp.

Csontos L., Nagymarosy A., Horváth F. and Kovác M., 1992. Tertiary evolution of the Intra-Carpathian area: a model. Tectonophysics, 208: 221-241.

Dal Piaz G.V., Martin S., Villa I.G., Gosso G. and Marschalko R., 1995. Late Jurassic blueschist facies pebbles from the Western Carpathian orogenic wedge and paleostructural implications for Western Tethys evolution. Tectonics, 14: 874-885.

Dercourt J., Ricou L.E., Adamia S., Császár G., Funk H., Lefeld J., Rakús M. et al., 1990. Anisian to Oligocene paleogeography of the European margin of Tethys (Geneva to Baku), Mém. Soc. Géol. France, 154: 159-190.

Dobosi G., 1986. Clinopyroxene compositions of some Mesozoic igneous rocks of Hungary: the possibility of identification of their magma type and tectonic settings. Ofioliti, 11: 19-34.

Dosztály L. and Józsa S., 1992. Geochronological evaluation of Mesozoic formations of Darnó Hill at Recsk on the basis of radiolarias and K-Ar data. Acta Geol. Hungar., 35: 371-394.

Downes H., Pantó Gy., Árkai P. and Thirlwall M.F., 1990. Petrology and geochemistry of Mesozoic igneous rocks, Bükk Mountains. Lithos, 24: 201-215.

Faryad S.W., 1988. Glaucophanized amphibolites and gneisses near Rudnik (Gemericum). Geol. Zbornik Geol. Carpathica, 39 (6): 747-763.

Faryad S.W., 1995. Phase petrology of mafic blueschists of the Meliata Unit (West Carpathians)-Slovakia. J. Metam. Geol, 13: 432-448.

Faryad S.W. and Dianiška I., 1999. Metagabbro with relic richterite from the Permian evaporite mélange near Bohúňovo (Western Carpathians). 77 DMG conference, MinWin 1999. Vienna, Beiheft Europ. J. Mineral., 11: 68.

Faryad, S.W. and Henjes-Kunst F., 1997. Petrological and K-Ar and ^{40}Ar-^{39}Ar age constraints for the tectonothermal evolution of the high-pressure Meliata Unit, Western Carpathians (Slovakia). Tectonophysics, 280: 141-156.

Faryad, S.W. and Hoinkes, G., 1999: Two contrasting mineral assemblages in the Meliata Blueschists, Western Carpathians, Slovakia. Mineralogical Magazin,

Faryad S.W., Schulmann K. and Lexa O., 2003. Evolutionary model of the Meliata blueschist accretionary wedge (Western Carpathians, Slovakia). Geophys. Res. Abstr., 5: 05617.

Harangi Sz., Szabó Cs., Józsa S., Szoldán Zs., Árva-Sós E., Balla M. and Kubovics I., 1996. Mesozoic igneous suites in Hungary: Implications for genesis and tectonic setting in the northwestern part of Tethys. Intern. Geol. Rev., 38: 336-360.

Harris P.G. and Baily D.K., 1974. Origin of alkaline magmas as result of anatexis and melting in the mantle and deep crust. In: Sorensen H. (Ed.), The alkaline rocks. John Wiley and Sons, London, p. 427-442.

Hawkins J.W. and Allan J.F., 1994. Petrologic evolution of Lau Basin sites 834 through 839. Proceed. DDP Sci. Results, 135: 427-470.

Horváth P., 1997. High-Pressure metamorphism and P-T path of the metabasic rocks in the borehole Komjáti-11, Bódva Valley area, NE Hungary. Acta Mineral.-Petrogr., Szeged, 38: 151-163.

Hovorka D., Jaroš J., Kratochvíl M., Reichwalder P., Rojkovič I., Spišiak J. and Turanová L., 1985. Ultramafic rocks of the Western Carpathians, Czechoslovakia. Geol. Instit. Dionýz Štúr, Bratislava, 258 pp.

Hovorka D. J. and Spišiak J., 1998. Mesozoic Meliata Ocean dismembered Ophiolites. In: Rakús M. (Ed.), Geodynamic development of the Western Carpathians. D. Štúr Publishers, GSSR Bratislava, p. 81-88.

Ivan P., 2002. Relics of the Meliata ocean crust: geodynamic implication of mineralogical, petrological and geochemical proxies. Geol. Carpathica, 53: 245-256.

Ivan I. and Kronome B., 1996. Predmetamorfný charakter a geodynamické prostredie vzniku vysokotlakovo metamorfovaných bázitov meliatskej jednotky na lokalitách Radzim, Bôrka, Hačava a Rudník. Mineralia Slovaca, 28: 26-37.

Józsa S., 1999. Petrological and geochemical study of the Darnó Hill ocean floor magmatic rocks. Unpubl. PhD. Thesis, ELTE, Budapest, (in Hungarian with English summary).

Konzett J., Sweeney R.J., Thompson A.B. and Ulmer P., 1997. Potassium amphibole stability in the upper mantle: An experimental study in a peralkaline KNCMASH system to 8.5 GPa. J. Petrol., 38: 537-568.

Kovács S., 1997. Middle Triassic rifting and facies differentiation in Northeast Hungary. In: A.K. Sinha, F.P. Sassi and D. Papanikolaou (Eds.), Geodynamic domains in Alpine-Himalayan Tethys. Oxford and IBH Publ., p. 375-397.

Kovács S., Szederkényi T., Árkai P., Buda Gy., Lelkes-Felvári Gy. and Nagymarosy A., 1996-97. Explanation to the terrane map of Hungary. Ann. Géol. Pays Hellén., 37: 271-330.

Kozur H. and Mock R., 1973. Die Bedeutung der Trias-Conodonten für die Stratigraphie und Tektonik der Westkarpaten. Geol. Paläont. Mitt. (Innsbruck), 3 (2): 1-14.

Kozur H. and Mock R., 1985. Erster Nachweis von Jura der Meliata-Einheit der südlichen Westkarpaten. Geol. Paläont. Mitt. (Innsbruck), 13 (10): 223-238..

Kozur H. and Mock R., 1997. New paleogeographic and tectonic interpretations in the Slovakian Carpathians and their implications for correlations with the Eastern Alps and other parts of the Western Tethys, Part II: Inner Western Carpathians. Miner. Slovaca, 29 (3): 164-209.

Kozur H. and Réti Zs., 1986. The first paleontological evidence of the Triassic ophiolites in Hungary. N. Jb. Geol. Paläont. Mh., 5: 284-292.

Le Bas M.J., l962. The role of aluminium in igneous clinopyroxenes with relation to their parentage. Am. J. Sci., 260: 267-288.

Leake B.E, Farrow C.M. and Towned R., 1995. K-poor titanian four-richterite from near Nulagine, Western Australia. Am. Mineral., 80: 162-164.

Leake B.E., Woolley A.R., Arps C.E.S., Birch W.D., Gilbert M.C., 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. and Youzhi G., 1997. Nomenclature of amphiboles. Europ. J. Mineral., 9: 623-651.

LeMaitre R.W., 1989. Classification of igneous rocks and glossary of terms. Blackwell, Oxford, 112 pp.

Marchant R.H. and Stampfli G.M., 1997. Subduction of continental crust in the Western Alps. Tectonophysics, 269: 217-235.

Mazzolli G. and Vozárová A., 1998. Subduction related processes in the Bôrka nappe (Inner Western Carpathians): a geochemical and petrological approach. In: M. Rakús (Ed.), Geodynamic development of the Western Carpathians. Dionýz Štúr Publ., p. 89-106.

McDonough W.F. and Frey F.A., 1989. Rare earth elements in upper mantle rocks. In: B.R. Lipin and G.A. McKay (Eds.), Geochemistry and mineralogy of rare earth elements. Rev. Mineral., 21: 99-145.

Mello J., Elečko J., Pristaš J., Reichwalder P., Snopko L., Vass D. and Vozárová A., 1997. Vysvetlivky k geologickej mape slovenského krasu, mireka 1: 50 000. GUDŠ, Bratislava.

Meschede M., 1986. A method of discriminant between different types of mid-ocean-ridge basalts and continental tholeiites with the Nb-Zr-Y diagram. Chem. Geol., 56: 207-218.

Mitchell RH, 1985. A review of the mineralogy of lamproites: Trans. Geol. Soc. South Africa, 88: 411-437.

Mock R., 1978. Niektoré nové poznatky o južnej časti Západných Karpát. In: J. Vozár (Ed.), Paleogeografický vývoj Západných Karpát Geologický ústav. Dionýza Štúra, Bratislava, p. 322-341.

Mock R., Sýkora M., Aubrecht R., Ožvoldová L., Kronome B., Reichwalder P. and Jablonský J., 1998. Petrology and stratigraphy of the Meliaticum near the Meliata and Jaklovce villages, Slovakia. Slovak Geol. Mag., 4: 223-260.

Pearce T.H. and Norry M.J., 1979. Petrogenetic implication of Ti, Zr, Y and Nb variations in volcanic rocks. Contr. Mineral. Petrol., 69: 33-47.

Plašienka D., 1997. Cretaceous tectonochronology of the Central Western Carpathians, Slovakia. Geol. Carpatica, 48: 99-111.

Réti Zs., 1985. Triassic ophiolite fragments in an evaporitic melange, Northern Hungary. Ofioliti, 10: 411-422.

Rampone E., Hofmann A.W., Piccardo G.B., Vannucci R., Bottazzi P. and Ottolini L., 1995. Petrology, mineral and isotope geochemistry of the External Liguride peridotites (Northern Apennines, italy). J. Petrol., 36: 81-105

Stampfli G.M., Borel G.D., Marchant R. and Mosar J., 2002. Western Alps geological constraints on western Tethyan reconstructions. J. Virtual Explorer, 8: 77-106

Taylor R.N., Murton B.J. and Nesbitt R.W., 1992. Chemical transects across intra-oceanic arcs: implications for the tectonic settings of ophiolites and their modern oceanic analogues. Geol. Soc. London Spec. Publ., 60: 117-132.

Vozárová A. and Vozár J., 1992. Tornaicum and Meliaticum in borehole Brusnik BRU-1, Southern Slovakia. Acta Geol. Hangar., 35: 97-116.

Wagner Ch. and Velde D., 1986. The mineralogy of K-richterite-bearing lamproites. Am. Mineral., 71: 17-37.

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