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RELICS OF THE MELIATA OCEAN CRUST: GEODYNAMIC IMPLICATIONS OF MINERALOGICAL, PETROLOGICAL AND GEOCHEMICAL PROXIES

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Abstract: Relics of the oceanic crust of the Triassic-Jurassic Meliata Ocean are preserved as dismembered incomplete ophiolite sequences only in several small lithostratigraphic units mostly in the Inner Western Carpathians. The current data on these remnants with special emphasis on volcanic rocks are summarized in the present paper. Mafic volcanic rocks representing relics of the Meliata oceanic crust differ from each other by the following characteristics: (1) preservation of magmatic textures and structures, (2) geochemical type, (3) metamorphic evolution, (4) related sedimentary rocks and (5) recent tectonic position. On the basis of these differences, three groups of metabasalts related to the former oceanic floor can be discerned: (1) HP/LT metamorphosed basalts and dolerites with scarce gabbro as slices and small blocks in the Bôrka Nappe, (2) mostly LP/LT metamorphosed basalts and dolerites occurring as olistoliths in mélange in the Jaklovce, Meliata, Bódva Valley Ophiolite and Darnó Hill Formations, and (3) recycled, almost complete ophiolite magmatic rocks forming clasts in the Upper Cretaceous Gosau-type conglomerate from Dobšinská Ľadová Jaskyňa village. The distribution of relatively immobile trace elements (REE, HFSE) in metabasalts indicates their formation in the back-arc setting. In the initial stage of opening of the Meliata Ocean, the arc-like and back-arc basin basalts, erupted in the environment of carbonate or pelitic sediments, were generated. The evolved stage is characterized by generation of basalts close to the N-MORB type in association with abyssal sediments. Basalts close to E-MORB are assumed to be a melting product of an enriched mantle source probably locally present beneath the spreading basin. Closure of this ocean in the Middle Jurassic time was related to the subduction and formation of the accretionary prism. Mostly the relics of the marginal parts of the former oceanic basin were subducted and consequently exhumed, whereas the relics of central parts were preserved in the accretionary prism. The original location of the Meliata Ocean suture is not known. The present-day tectonic position of the oceanic crust relics in the Inner Western Carpathians is extremely complex as a consequence of the repeated nappe forming activity, erosion and plate kinematics. It seems likely that these relics represent a western continuation of the Hellenide-Dinaride ophiolites displaced by microplate motions in the Miocene.

Key words: Western Carpathians, Meliata Ocean, geodynamics, back-arc basin, oceanic crust.

Introduction

The opening and closing of the Meliata Ocean were important events, which substantially influenced the Mesozoic geological history of the Inner Western Carpathians. In spite of the fact that the Meliata Ocean is a frequently used term in many geodynamic, tectonic and petrological models and schemes, there are restricted data only related to the origin and structure of this former ocean. Such a situation is caused by the bad preservation of relics of the Meliata Ocean basin floor and its marginal sedimentary filling which form innumeral slices or olistoliths only. The aim of this paper is to summarize our current knowledge concerning real oceanic crust relics of the Meliata Ocean in the Western Carpathians realm as follows from the interpretation of mineralogical, petrological and geochemical data.

The Meliata Ocean — definition

The Meliata Ocean (or Meliata-Hallstatt Ocean) is the designation of a hypothetical oceanic basin in the Tethyan Realm, whose spreading was in progress during the Middle Triassic and closure in the Middle to Upper Jurassic time (Kozur 1991; Channell & Kozur 1997). It was deduced mostly from results of lithological and petrological investigations, which discovered abyssal sediments and various mélange types first in the Mesozoic units of the Inner Western Carpathians and then also in the Juvavic nappes of the Northern Calcareous Alps. The Meliata Ocean is regarded as a northwestern ending of the Tethys Ocean (Kovács 1997; Neugebauer et al. 2001), a basin connected with this ocean or an isolated active marginal basin (Stampfli 1996, 2000).

Regional distribution of the Meliata Ocean relics in the Alpine-Carpathian-Pannonian realm

Relics of the Meliata Ocean have been found as isolated occurrences along the northern and southern borders of the lithospheric block referred to as ALCAPA (Alpine-Carpathian-Pannonian), which included mainly the area of the Eastern Alps and Western Carpathians (Fig. 1). The prevailing part of relics of the Meliata Ocean near the northern border of ALCAPA block is located in the Northern Calcareous Alps. They are represented by Jurassic breccias and sedimentary mélanges containing redeposited marginal facies of the Meliata Ocean (Gawlick et al. 1999). Relics of the real oceanic crust are restricted to small bodies of metabasalts with the oceanic affinity in the Scythian shales (Kralik et al. 1984). In the Western Carpathians such relics are known in the form of recycled sedimentary material (clasts) in the Cretaceous conglomerates in the Klape Unit (Pieniny Klippen Belt; Ivan & Sýkora 1997). Near the southern border of the ALCAPA block the occurrences of oceanic crust relics of the Meliata Ocean have been found in the Medvednica Mts near Zagreb (Halamić et al. 1998, 1999), in the boreholes Inke-9 and Tóalmás-2 and -3 in the Pannonian Lowland (Harangi et al. 1996) and in the Inner Western Carpathians where the majority of such occurrences known at present are concentrated. In the last mentioned area most of the oceanic crust relics are located in its northern part where they occur in the Meliata Formation (Hovorka & Spišiak 1988, 1998), in the Bôrka Nappe (Ivan & Kronome 1996; Mazzoli & Vozárová 1998) and also in the Cretaceous conglomerates near Dobšinská Ľadová Jaskyňa (Hovorka et al. 1990; Fig. 2). In the southern part of the Inner Western Carpathians they were found in the Bódva Valley Ophiolite Formation and Darnó Hill Formation (Harangi et al. 1996).

Oceanic crust relics of the Meliata Ocean in the Inner Western Carpathians — a concise outline

A wide variability of such parameters as: (1) preserved magmatic structures and textures, (2) geochemical type of magmatic rocks, (3) metamorphic evolution, (4) related sedimentary rocks and (5) recent tectonic position, is typical for individual occurrences of the oceanic crust relics of the Meliata Ocean. Taking these differences into account, all the lithostratigraphic units containing oceanic crust relics of the Meliata Ocean can be divided into four groups: (1) units which experienced HP/LT metamorphism as a whole (units of the Bôrka Nappe), (2) units with LP/LT metamorphosed oceanic rocks only (Jaklovce Formation recently referred to the Meliata Formation, Meliata Formation s.s. and Darnó Hill Formation), (3) evaporitic mélange with low-grade metamorphosed oceanic rock fragments with rare indications of HP/LT event (Bódva Valley Ophiolite Formation) and (4) units with recycled oceanic crust material (Dobšinská Ľadová Jaskyňa conglomerate). A review of the lithology of these units and petrography of their oceanic rocks is summarized in Table 1.

The presence of basalts/metabasalts as the prevailing igneous rock types in all the mentioned groups allows a reliable testing of the oceanic geodynamic setting of their generation using trace element distribution or composition of preserved magmatic clinopyroxenes. The composition of selected relic magmatic clinopyroxenes is illustrated in Table 2, selected major and trace element analyses of the basaltic rocks represented in the Meliata Ocean crust relics from different lithostratigraphic units are summarized in Table 3.

Bôrka Nappe

The newly defined Bôrka Nappe (Mello et al. 1998) located in the northern part of the Slovenský kras Mts and in the west-

Table 1: Lithostratigraphical division of the Inner Western Carpathians and an overview of the formations with oceanic crust relics of the Meliata Ocean (see also Fig. 2).

A. Lithostratigraphy of the Inner Western Carpathians

GEMERIC UNIT (Gemericum)	
Early Paleozoic Formations	Štós Formation (Fm.), Gelnica Group (Gr.), Smrečinka Fm., Rakovec Fm., Klátov Fm.
Late Paleozoic Formations	Gočaltovo Gr., Rudňany Fm., Zlatník Fm., Hámor Fm., Krompachy Gr., Ochtiná Fm., Črmeľ Fm.
MELIATIC UNIT (Meliaticum)	
Bôrka Nappe Formations	Hačava Fm., Kobeliarovo Fm., Nižná Slaná Fm., Jasov Fm., Bučina Fm., Rudník Fm.
Meliata Supergroup	Jaklovce Fm., Meliata Fm. (s.s.), Bódva Valley Ophiolite Fm., Darnó Fm.
TORNAIC UNIT (Tornaikum)	
SILICIC UNIT (Silicicum)	
GOSAU GROUP	

Note: More detailed data to the individual units can be found in following papers and references herein: *Gemeric Unit* — Ivan (1996; 1997); *Meliatic Unit* — Mock et al. (1998), Mello et al. (1998), Ivan & Mello (2001); *Tornaic Unit* — Mello et al. (1997), Kozur & Mock (1997); *Silicic Unit* — Mello et al. (1997), Kozur & Mock (1997), Less (2000); *Gosau Group* — Mello et al. (2000).

B. Oceanic crust relics of the Meliata Ocean in the lithostratigraphic formations of the Meliatic Unit

FORMATION	OCEANIC CRUST RELICS	GEOLOGY	GEO-CHEMICAL TYPES OF BASALTS	METAMORPHIC ALTERATION
Hačava Fm. (Bôrka Nappe)	Basalts, dolerites, peridotites, cherts, (i-gabbro),	Olistoliths in tectonized olistostroma, tectonic slices →	IAT BABB→ N-MORB	(ORTM), (LP/LT), HP/LT (whole formation)
Kobeliarovo Fm. (Bôrka Nappe)	Fe-dolerites, basalts, peridotites, cherts	Olistoliths in tectonized olistostroma	IAT BABB	(HP/LT) → LP/LT-GS
Jaklovce Fm.	Basalts, peridotites, cherts	Olistoliths, in olistostroma, tectonic slices	BABB→ N-MORB	LP/LT-GS
Meliata Fm. (s.s.)	Basalts, peridotites, cherts	Olistoliths in olistostroma	BABB→ N-MORB	LP/LT-GS
Bódva Valley Ophiolite Fm.	Peridotites, gabbrodolerites, Fe-gabbrodolerites, dolerites, basalts, cherts	Olistoliths in a salinary mélange	E-MORB N-MORB	LP/LT-GS (ORTM) (HP/LT) → LP/LT-GS
Darnó Fm.	Basalts, dolerites, gabbrodolerites, cherts	Olistoliths in olistostroma	BABB E-MORB	LP/LT-GS
Gosau Group	Peridotites, i-gabbros, basalts, dolerites, cherts, c-gabbros, pyroxenites	Pebbles in conglomerate	BABB →N-MORB	ORTM LP/LT-PP,PA,GS HP/LT

Explanations: i-gabbros — isotropic gabbros, **c**-gabbros — cumulate gabbros, **(gabbro)** — scattered finding only, **IAT**— island arc tholeiite, **BABB** — back arc basin basalt, **N-MORB** — normal mid-ocean ridge basalt, **E-MORB** — enriched mid-ocean ridge basalt, **ORTM** — oceanic ridge-type metamorphism, **HP/LT** — high pressure/low temperature metamorphism (epidote-blueschist facies), **LP/LT** — low pressure/low temperature metamorphism, **PP** — prehnite-pumpellyite facies, **PA** — prehnite-actinolite facies, **GS** — greenschist facies, **(ORTM)** — indication of older ORTM-phase.

Table 2: Representative analyses of various magmatic clinopyroxenes from the metamorphosed oceanic basalts of the Meliata Ocean. Low aluminium and titanium clinopyroxene types are related to the early stage of basalt crystallization.

Sample	1 VVS16	2 VVS16	3 VVS16	4 VVS16	5 FJAK40	6 FJAK40	7 FJAK40	8 BRU1/b	9 BRU1/b	10 BRU1/b
SiO_2	54.12	54.31	52.90	50.75	52.60	49.28	47.88	53.28	50.42	49.59
TiO_2	0.36	0.54	0.78	1.00	0.39	1.51	2.03	0.62	1.13	1.56
Al_2O_3	1.90	1.62	3.59	3.54	1.59	3.90	3.45	1.60	4.06	3.12
FeO	5.72	8.83	5.98	7.67	10.05	10.15	15.35	9.14	7.71	14.09
MnO	0.22	0.29	0.13	0.09	0.00	0.00	0.39	0.31	0.30	0.32
MgO	17.78	17.14	16.66	15.86	19.59	14.39	11.88	17.47	15.36	12.38
CaO	19.67	17.83	20.18	21.48	15.22	19.77	18.17	17.51	20.17	18.44
Na_2O	0.28	0.34	0.33	0.46	0.30	0.34	0.30	0.21	0.31	0.38
Cr_2O_3			0.12	0.11					0.12	
Total	100.06	100.90	100.66	100.96	99.74	99.35	99.45	100.39	99.59	99.88
6 O										
Si	1.968	1.976	1.920	1.868	1.939	1.858	1.847	1.954	1.875	1.887
AlIV	0.032	0.024	0.080	0.132	0.061	0.142	0.153	0.046	0.125	0.113
AlVI	0.049	0.045	0.073	0.022	0.008	0.031	0.004	0.023	0.052	0.027
Ti	0.010	0.015	0.021	0.028	0.011	0.043	0.059	0.017	0.032	0.045
Fe	0.174	0.269	0.182	0.236	0.310	0.320	0.495	0.280	0.240	0.449
Mn	0.007	0.009	0.004	0.003	0.000	0.000	0.013	0.010	0.010	0.010
Mg	0.964	0.929	0.901	0.870	1.076	0.809	0.683	0.970	0.851	0.702
Ca	0.766	0.695	0.785	0.847	0.601	0.798	0.751	0.688	0.803	0.752
Na	0.020	0.024	0.023	0.033	0.022	0.025	0.023	0.015	0.022	0.028
Cr			0.003	0.003					0.004	

Note: VVS16 — HP/LT metamorphosed basalt of BABB type, Bôrka Nappe, Hačava Fm., loc. Radzim Mt.; FJAK40 — LP/LT metamorphosed basalt close to N-MORB type, Jaklovce Fm., loc. Margecany, quarry near lime factory; BRU-1a — LP/LT metamorphosed basalt close to N-MORB type, Meliata Fm., loc. Brusník village, borehole BRU-1, 781.5 m. Data sources: Vozárová & Vozár (1992) — BRU-1 and original data. Electron microprobe analyses of clinopyroxenes were carried out at Slovak Geol. Survey on a Jeol 733 microprobe using the following conditions and standards: 15 kV, 2×10^{-8} A, ZAFO; **Na, Al** — albite, **Ca** — wollastonite, **Mg** — MgO, **Mn** — willemite, **Fe,Cr** — chromite and **Ti** — TiO_2.

Table 3: Representative analyses of major and selected trace elements in the metamorphosed basalts forming the oceanic crust relics of the Meliata Ocean.

Sample	1 FBO-12	2 VVS-16	3 VHA-3	4 Jakl. (12)	5 Tk-2/254	6 VM-10	7 Szo-4	8 Dar-4	9 Rm-135
SiO_2	48.03	48.64	47.63	49.00	48.11	49.37	44.81	47.52	
TiO_2	3.23	1.62	1.95	1.37	1.15	1.63	3.69	1.82	
Al_2O_3	13.00	15.03	14.94	15.50	16.11	14.97	13.41	14.88	
Fe_2O_3	7.61	3.73	5.33	2.28	11.08*	5.20	7.54	10.96*	
FeO	6.38	6.39	6.86	6.35	-	5.14	6.61	-	
MnO	0.17	0.17	0.17	0.17	0.25	0.25	0.14	0.17	
MgO	5.06	6.69	6.46	7.05	7.41	5.07	6.12	7.51	
CaO	8.66	10.37	9.12	8.90	5.56	6.03	11.11	9.97	
Na_2O	3.13	3.64	3.30	4.15	5.11	6.94	3.02	3.30	
K_2O	1.23	0.02	0.27	0.54	0.33	0.03	0.50	0.59	
P_2O_5	0.04	0.17	0.17	0.18	0.12	0.29	0.32	0.21	
LOI	2.14	1.92	2.16	3.10	4.57	5.15	4.23	3.10	
Total	99.32	99.03	99.05	99.34	99.80	100.58	102.16	100.03	
Cr	28.6	191	455	98.0	413	270	210	329	310
Ni				145	156		81	92	112
Co	25.9	45.5	50.5	122	39	30.5	37		39
Sc	36.0	46.0	44.5	79.0		29.2	31	45	38
V	467	280	313	330	230	233	394	348	346
La	11.5	3.9	5.3	4.2	1.3	2.8	11.1	6.54	6.8
Ce	33.0	14.3	15.5	16.7	5.0	9.3	28.5	16.94	19.0
Nd	28.3	13.2	11.2	13.2		8.4		12.89	9.0
Sm	8.9	4.2	4.2	4.1		3.1	5.63	3.99	4.40
Eu	2.65	1.45	1.45	1.60	0.86	1.10	1.95	1.38	1.42
Tb	1.70	0.79	0.98	1.40		0.61			0.90
Yb	6.3	3.0	3.7	5.00	2.27	2.50	3.51	3.64	3.0
Lu	1.05	0.38	0.63	0.92	0.31	0.41	0.48		0.42
Hf	6.1	2.65	3.2	3.3	1.8	3.6	4.8		3.2
Ta	0.40	0.117	0.199		1.1	0.73	0.6		0.3
Th	2.05		0.58			1.10	0.7	0.6	0.6
Nb	6	1	2		1	11	10	8.7	1
Y	58	30	35		24	22	46	38.2	29
Zr	212	102	112		48	141	249	129	129
Ba	92	43	24	63	55	16	43	80	128

Note: Fe_2O_3* — total Fe like Fe_2O_3. 1–3 — Bôrka Nappe: 1 — HP/LT metamorphosed fractionated arc-like basalt, loc. Bôrka village; 2 — HP/LT metamorphosed basalt of BABB type, loc. Radzim Mt, 3 — HP/LT metamorphosed dolerite close to N-MORB type, loc. Hačava, ca. 1 km NW of village, 4 — Jaklovce Fm., LP/LT metamorphosed basalt close to N-MORB type, loc. Jaklovce village; 5 — Bódva Valley Ophiolite Fm., LP/LT metamorphosed dolerite close to N-MORB type, loc. Tornakápolna, borehole Tk-2, 254 m, 6 — LP/LT metamorphosed basalt of E-MORB type, loc. Tornakápolna, borehole Tk-3, 493.8-494.2 m; 7 — LP/LT metamorphosed coarse-grain dolerite of E-MORB type, loc. Szögliget, borehole Szo-4, 209 m; 8 — Darnó Hill Fm., LP/LT metamorphosed dolerite of transitional type between E- and N-MORB; 9 — Darnó Hill Fm., LP/LT metamorphosed coarse-grain dolerite close to BABB type, loc. Darnó Hill, borehole RM-135, 434 m. Data sources: Downes et al. (1990) -8, Hovorka & Spišiak (1993) -4, Harangi et al. (1996) -5,7 and 9, Horváth (2000) -7 (major elements) and original data. Analyses of REE, Cr, Co, Sc, Hf, Ta and Th in all samples were performed by the INAA (original analyses in laboratories of the company MEGA, Stráž pod Ralskem, Czech Republic); original analyses of other elements were carried out in Ecologic Laboratories Inc., Spišská Nová Ves, Slovak Republic using ICP OES method.

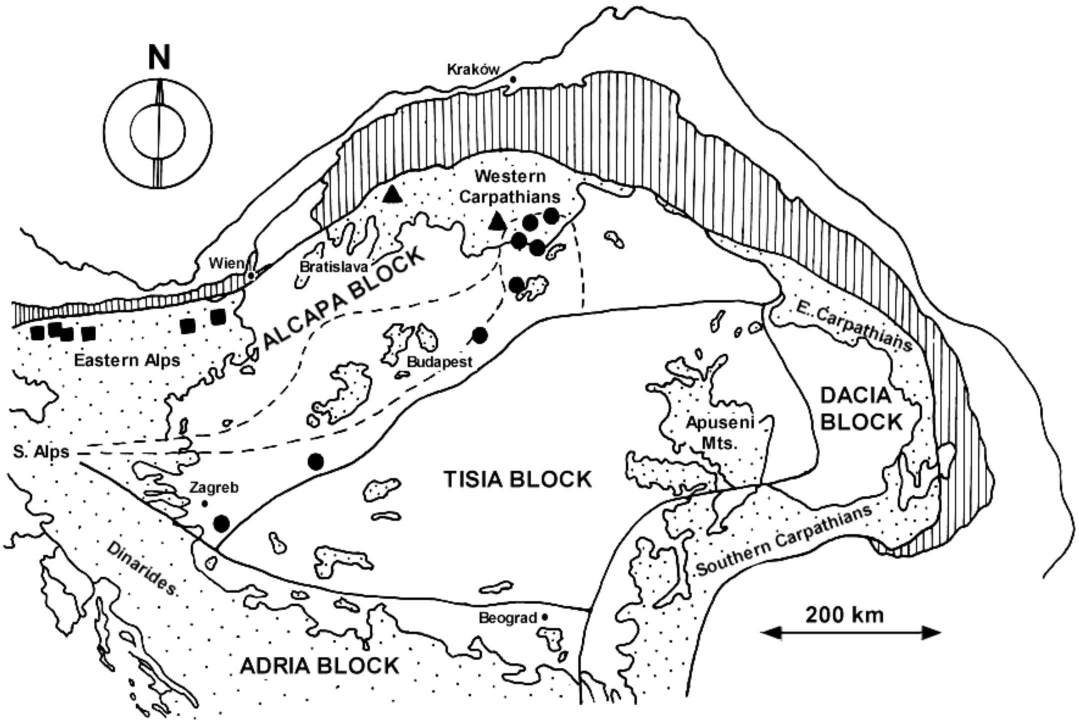

Fig. 1. Localization of the Meliata Ocean remnants in the Alpine-Carpathian-Pannonian area. Explanations: circles — oceanic crust relics (olistoliths), triangles — recycled relics of the oceanic crust relics as pebbles in the Cretaceous conglomerates, squares — relics of marginal facies of the MHO resedimented into Jurassic basins in the Northern Calcareous Alps. Structural units were taken from the paper by Harangi et al. (1996).

ern part of the Spišsko-gemerské rudohorie Mts (Fig. 2), is composed of several partial nappes or slices formed by different lithostratigraphic formations all metamorphosed in HP/LT conditions. Two of them, preliminarily referred to as the Hačava and Kobeliarovo Formations, differing from each other by the metamorphic P–T conditions, contain oceanic crust relics of the Meliata Ocean, the others comprise rocks of non-oceanic origin only.

Oceanic crust relics in the Hačava Formation, formed by tectonic slices and olistoliths of metabasalts, metadolerites and rarely also metagabbros, underwent progressive metamorphic evolution from prehnite-pumpellyite through greenschist to epidote blueschist facies conditions. Vestiges of the former ocean-ridge type metamorphism have been found in the dolerites and gabbros (Ivan, in press). The original magmatic mineral associations were replaced by the association composed of Na-amphibole (glaucophane) and epidote with variable amounts of Na-pyroxene (acmite), clinozoisite, albite, titanite, white mica and garnet (Faryad 1995a; Mazzoli & Vozárová 1998). Relics of magmatic clinopyroxene and amphibole of former metamorphic stages have been found locally. Clinopyroxene composition (Fig. 3) fully conforms to the geochemical type of basalt (BABB type mentioned below). In spite of metamorphic recrystallization the magmatic textures are still recognizable and hyaloclastic, variolitic, intersertal, ophitic, doleritic and gabbroic textures have been identified together with the former glassy chilled margins (Ivan, in press). Such a variability of magmatic textures in metabasalts indicates that basalts originally formed lava flows with glassy or lava breccia rinds and probably also pillow lavas.

The study of the distribution of REE and other relatively immobile trace elements revealed that the geochemical types of metabasalts vary from typical oceanic N-MORB (normal mid-ocean ridge basalt) type through transitional BABB (back-arc basin basalt), both with flat primitive REE patterns (Fig. 4) to arc-related types with distinct deficit of the SZC (subduction zone component — e.g. Ta — Fig. 6) and LREE enrichment (Ivan & Kronome 1996). Arc types of metabasalt were erupted in a carbonaceous environment (now transformed to marbles) whereas BABB types seem to be related to metamorphosed pelitic rocks and a type close to N-MORB is even accompanied by dark metamorphosed radiolarite.

The Kobeliarovo Formation lithologically resembles the Hačava Formation. Oceanic crust relics occur in association with metamorphosed carbonates (marbles) forming olistoliths in the metapelitic (phyllitic) matrix. They are represented by dolerites and smaller amounts of basalts with still preserved dolerititic or ophitic textures, which are geochemically close to fractionated arc-related basalts. Hyaloclastites, intensively altered and recrystallized together with the surrounding carbonate rocks, have also been found. Magmatic rocks in the Kobeliarovo Formation were originally metamorphosed in epidote blueschist metamorphic conditions and later retrogressed to greenschist conditions. Actinolite, chlorite, albite, octahedron-forming magnetite and titanite compose the most common mineral assemblage.

The age of oceanic crust relics is not exactly known in the Bôrka Nappe, it is supposed to be Triassic. The age of HP/LT metamorphic stage was dated by the $^{40}Ar/^{39}Ar$ method on fengite to 150–160 Ma (Maluski et al. 1993; Dallmeyer et al.

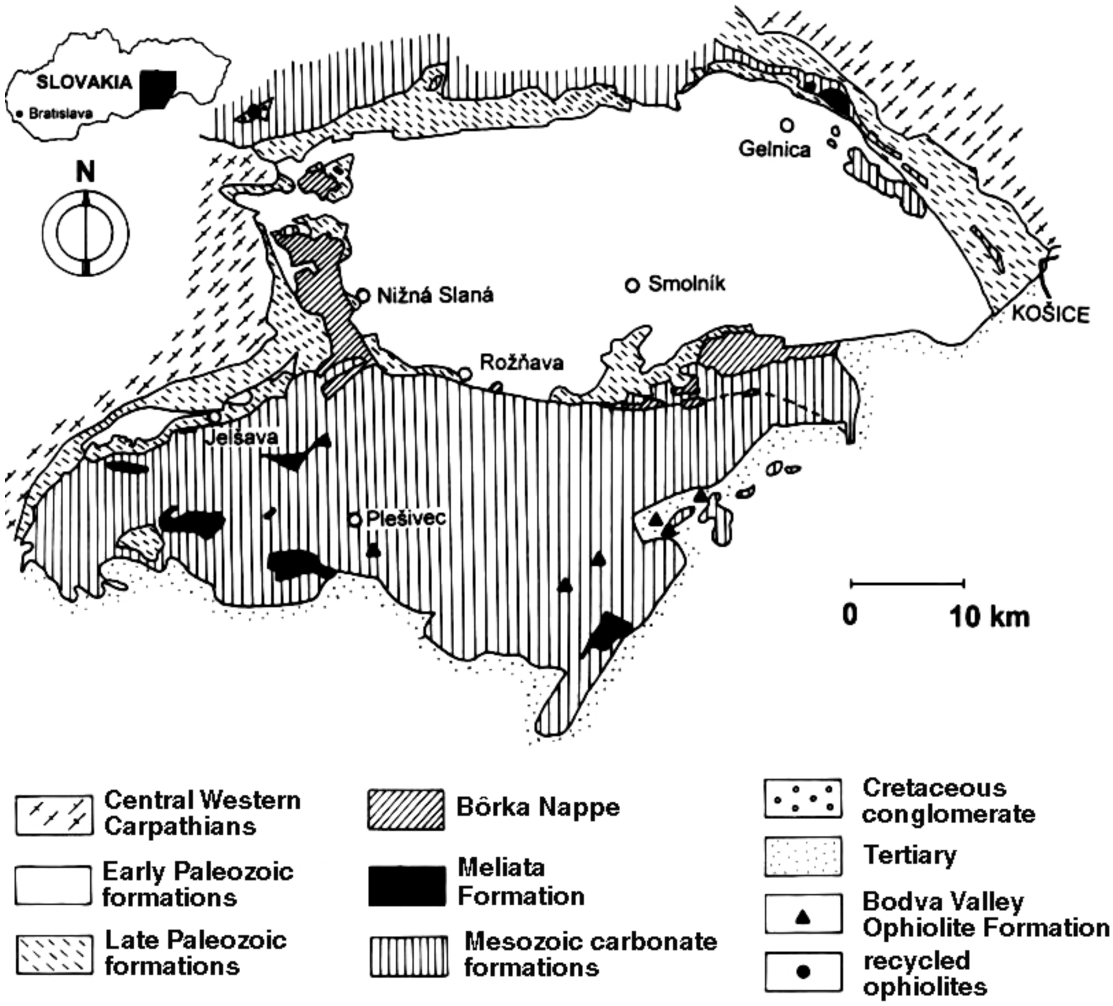

Fig. 2. Geological sketch-map of the Inner Western Carpathians. Oceanic crust relics of the Meliata Ocean have been found in the Bôrka Nappe, Meliata Formation (displayed together with Jaklovce Formation located NE of the town of Gelnica), Bódva Valley Ophiolite Formation (in boreholes only) and in the Darnó Formation (off the displayed area). Cretaceous Gosau-type conglomerates contain recycled material of the Meliata Ocean crust. Early and Late Paleozoic formations belong to the Gemeric Superunit, Mesozoic carbonate formations to the Silicic Unit partly also to the Turnaic Unit.

1996; Faryad & Henjes Kunst 1997) and its peak P–T conditions as 12 kbar at 400–460 °C (Faryad 1995a, 1997).

Jaklovce Formation

The Jaklovce Formation is situated in the eastern part of the North Gemeric Zone, which is an area of peculiar geological structure on the northern border of the Inner Western Carpathians (Fig. 2). According to Mock et al. (1998) it is formed by mélange with claystone, siliceous shales, argillites and sandstone matrix and olistoliths of pale shallow-water limestones (Honce limestones), pelagic cherty limestones, dolomites, radiolarites and clastic sediments. Pale-green keratophyre and massive pink rhyolite olistoliths have been found as well. An important component of the mélange are also olistoliths or tectonic slices of basalts usually spatially related to red radiolarites or red abyssal pelitic sediments (Kamenický 1957; Hovorka & Spišiak 1988, 1993, 1997). The Jaklovce Formation has recently come to be regarded as a part of the Meliata Formation.

Magmatic textures and partly also primary mineral composition of basalts are well preserved. Observed glassy, intersertal, variolitic, glomeroophitic and ophitic textures (Kamenický 1957) reflect variations in the cooling rate of the basaltic melt. Lava breccias indicate direct contact with water. Basalts erupted probably in the form of sheet lava flows; pillow lavas have not been reliably proved. The primary mineral association comprises clinopyroxene, plagioclase and small amounts of olivine and ilmenite. Low-grade metamorphic alteration (in greenschist facies conditions) mostly affected the vicinity of tectonic fissures causing saussuritization and local albitization of plagioclase, chloritization of olivine and partly also of clinopyroxene and formation of small chlorite-epidote-albite-pyrite veins.

Magmatic clinopyroxene composition (Fig. 3) as well as the distribution of REE and other relevant trace elements indicate that the basalts of the Jaklovce Formation are close to N-MORB having typical flat chondrite normalized REE patterns with characteristic LREE depletion (Fig. 4). Nevertheless, the still identifiable effect of the subduction zone component (SZC) in the mantle source on the composition of the basalts

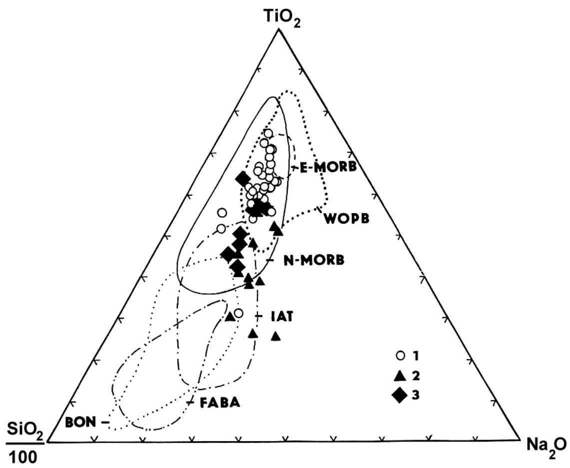

Fig. 3. TiO_2-SiO_2/100-Na_2O discriminate diagram (Beccaluva et al. 1989) for relic magmatic clinopyroxenes from ophiolitic basalts representing former oceanic crust of the Meliata Ocean. More "arc-like" character of the metabasalts from Radzim Mt (Bôrka Nappe) seems to be evident. Explanations: **1** — Jaklovce area (Jaklovce Formation), **2** — Radzim Mt (Bôrka Nappe), **3** — BRU-1 borehole (Meliata Formation), **E-MORB** — enriched mid-ocean ridge basalts, **N-MORB** — normal mid-ocean ridge basalts, **WOPB** — within oceanic plate basalts, **IAT** — island arc tholeiites, **FABA** — intra-oceanic fore-arc basaltic andesites and andesites, **BON** — boninites. Data sources: Hovorka & Spišiak 1988; Vozárová & Vozár 1992 and unpublished data.

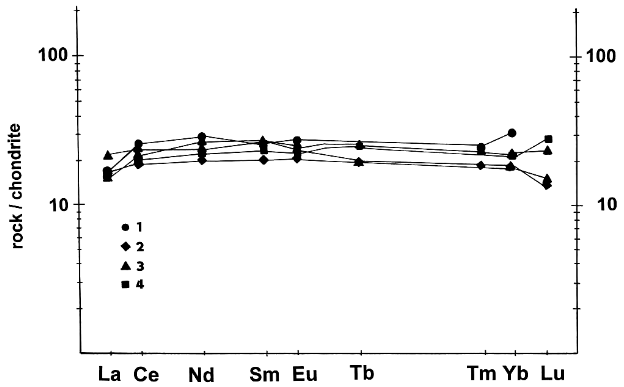

Fig. 4. Chondrite normalized REE patterns for metabasalts and metadolerites representing Meliata Ocean relics in the northern part of the Inner Western Carpathians. Note primitive flat shape of patterns typical for oceanic rocks. Explanations: **1** — Jaklovce Formation, **2** — Meliata Formation, **3** — Bôrka Nappe, **4** — Dobšinská Ľadová Jaskyňa conglomerates. Normalization by Evensen et al. (1978). Data sources: Ivan & Kronome (1996), Hovorka & Spišiak (1993) and unpublished data.

(deficit of Ta together with Th enrichment) is important evidence for generation in the back-arc setting (Fig. 6). Some the basalt samples of this formation crystallized from fractionated magmas as follows from the elevated total REE content and positive Eu anomaly, both a potential consequence of cumulate gabbro formation in the rift zone.

The age of oceanic crust relics in the Jaklovce Formation, that is basalts and related red radiolarites and radiolarian schists, was determinated paleontologically as Triassic (Ladinian; Kozur & Mock 1985) whereas the age of mélange forming is Middle Jurassic (Bathonian?; Kozur & Mock 1995).

Meliata Formation

The Meliata Formation is exposed on the surface in several small outcrops — tectonic windows — in the northern part of the Slovenský kras Mts to the south of an important fault zone — the Rožňava Line (Fig. 2). Under the surface the Meliata Formation forms footwall of the carbonate Silica Nappe and it has been recorded in several boreholes (Vozárová & Vozár 1992). The lithology of this unit is similar to the previously mentioned Jaklovce Formation (and partly also to the Bódva Valley Ophiolite Formation), which is the reason for their classification as a single unit by some authors (e.g. Mello et al. 1997). The Meliata Formation, like the Jaklovce Formation, is a mélange with mostly carbonate olistoliths (or tectonic slices) in a matrix composed of deep-water shales with sparse thin intercalations of breccias, sandstones and thin-bedded radiolarites (Mock et al. 1998). Rhyolite olistoliths have also been found together with oceanic crust relics represented by small bodies of red radiolarites, fully serpentinized spinel peridotites and metabasalts. Effusive types often with volcanic glass as a substantial component originally dominated among the metabasalts. The primary textures such as brecciate, intersertal or variolitic are still recognizable (Kantor 1955) in spite of the intensive metamorphic alteration to greenschists composed of albite, chlorite, carbonate and a smaller amount of ilmenite and titanite. A unique occurrence of the basalt with glassy to variolitic texture with preserved magmatic clinopyroxene crystallized in direct contact with black chert has been also found.

Limited geochemical data indicate close similarity to N-MORB type for metabasalts from the Meliata Formation (Figs. 4, 6).

The Triassic age (Ladinian) of the oceanic crust relics in the Meliata Formation is derived from the paleontologically proven age of red radiolarites (Dumitrica & Mello 1982). The mélange was formed in Jurassic time (Upper Callovian to Lower Oxfordian or Middle Bathonian to Lower Callovian) as follows from paleontologically dated radiolarites from the matrix (Kozur et al. 1996; Mock et al. 1998).

Bódva Valley Ophiolite Formation (BVOF)

BVOF has been found in the boreholes only in the Bódva valley SE of the Slovenský kras/Aggtelek Mts (northern Hungary). It is represented by slices or small fragments of ophiolitic rocks (from dm to 100 m in scale) embedded into ductile Upper Permian evaporitic rocks (Réti 1985; Harangi et al. 1996; Horváth 1997). The formation comprises serpentinized spinel peridotites and metamorphosed gabbrodolerites, ferrogabbrodolerites and basalts. Variable textures — variolitic, hyalopilitic, intersertal to ophitic — are typical for the basalts. According to Harangi et al. (1996) the majority of the basalts were originally pillow lavas and lava breccias formed as products of submarine eruptions. Magmatic rocks of the BVOF underwent multi-stage metamorphic alteration resulting in transformation of magmatic minerals (clinopyroxene, plagioclase, ilmenite and olivine) to a diverse association of metamorphic minerals such as Ca amphiboles (pargasite, magnesiohornblende, actinolite), Na-amphibole (riebeckite), Na-Ca amphibole (winchite), albite, chlorite, epidote, biotite, titanite, carbonates and ore minerals (Horváth 1997, 2000). The succession of the mineral growing indicates at least three stages of metamorphism: (1) oceanic ridge metamorphism overprinted by (2) HP/LT stage followed by (3) retrogression in greenschist facies conditions, although there is an alternative interpretation (e.g. Horváth 2000).

Geochemical signatures of basic magmatic rocks of the BVOF vary between N-MORB and E-MORB (Harangi et al. 1996). E-MORB type displays mildly dipped chondrite normalized REE pattern (Fig. 5) and enrichment in HFSE in relation to N-MORB (Fig. 7).

The age of magmatic rocks of the BVOF was interpreted as Triassic (Ladinian) on the basis of paleontological dating of red radiolarites (Kozur 1991). Direct geochronological dating of gabbrodolerites indicates some older age, probably lowest Triassic (Horváth 2000).

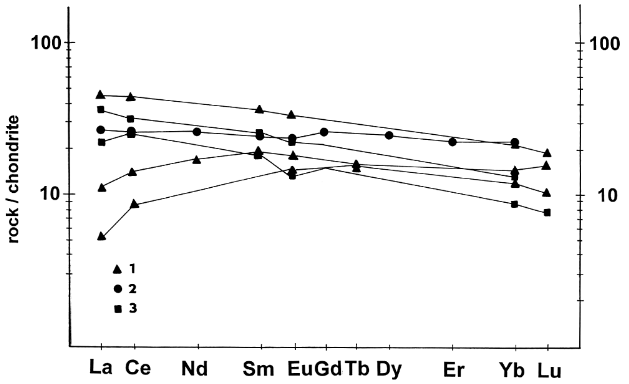

Fig. 5. Chondrite normalized REE patterns for metabasalts and metadolerites — relic of the Meliata Ocean from the southern part of the Inner Western Carpathians. Patterns with differentiated LREE/HREE enrichment belong to the E-MORB type. Explanations: **1** — Bódva Valley Ophiolite Formation, **2** — Darnó Hill Formation, **3** — Inke and Tóalmás boreholes. Normalization by Evensen et al. (1978). Data sources: Downes et al. (1990), Harangi et al. (1996) and unpublished data.

Darnó Hill Formation

The Darnó Hill Formation crops out as a small (several km^2) area SW of the Bükk Mts. It represents, similarly to the Meliata Formation, a mélange of olistoliths of abyssal sediments and ophiolitic rocks in the turbidity sediment matrix (Kozur 1991). According to Downes et al. (1990) the ophiolitic olistoliths are composed of basalts, dolerites and gabbrodolerites. In spite of the varying intensity of LP/LT alteration (spilitization), the original magmatic structures and textures are well preserved. Basalts erupted as pillow lavas or sheet lava flows. Clinopyroxene, plagioclase, ilmenite and rare olivine are the main constituents in the fresh basalts. In altered varieties they are replaced by chlorite, albite, epidote, carbonate and leucoxene.

Two trends are observable in the chemical composition of basalts: some of them are geochemically close to E-MORB types (Downes et al. 1990) similar to BVOF basalts, other ones remind of BABB type (cf. Harangi et al. 1996) similar to the Meliata Unit basalts (Fig. 5, Fig. 7).

The age of ophiolitic rocks, supposed to be Triassic (Ladinian), is based on paleontological dating of red radiolarites (De Wever 1984), whereas the age of the mélange matrix was reported by analogical method as Middle Jurassic (Kozur & Mock 1988; Dosztály & Józsa 1992).

Dobšinská Ľadová Jaskyňa conglomerates (DLJC)

The most complete evidence for the oceanic crust composition of the Meliata Ocean comes from the Upper Cretaceous Gosau-type conglomerates from Dobšinská Ľadová Jaskyňa village (Slovenský raj Mts). The Cretaceous formation at this locality is composed of conglomerates, sandstones, marly slates and limestones. Conglomerates build up the lowermost part of the sequence and are represented by two types with the different clastic material. Ophiolitic rocks are the principal clast type in one of them only. They are accompanied here also by subordinary amounts of marble, cherts, sandstone, calc-alkaline basaltic andesite and rhyolite clasts. All clasts are differentially rounded in accordance with their resistance. The conglomerate is poorly sorted and it has serpentine matrix (Hovorka et al. 1990).

Almost all the components of the typical ophiolite sequence (e.g. Moores 1982) have been found among clasts of this conglomerate type: radiolarites, basalts, dolerites, isotropic gabbros, cumulate gabbros, cumulate pyroxenites and spinel peri-

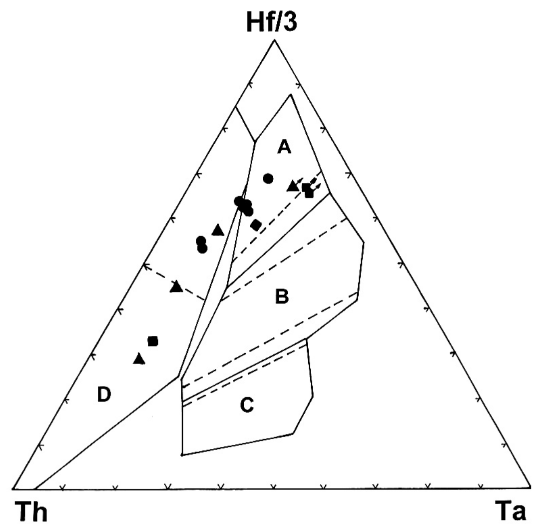

Fig. 6. Hf/3-Th-Ta diagram (Wood 1980) for metabasalts and metadolerites representing Meliata Ocean relics in the northern part of the Inner Western Carpathians. Mixing trend between N-MORB and arc characteristics is typical for several recent back-arc basins (e.g. Falloon et al. 1992). Explanations: symbols — see Fig. 4; **A** — N-MORB, **B** — E-MORB, **C** — WPB (alkali), **D** — basalts of destructive plate margin (IAT and CAB). Data sources: Ivan & Kronome (1996) and unpublished data.

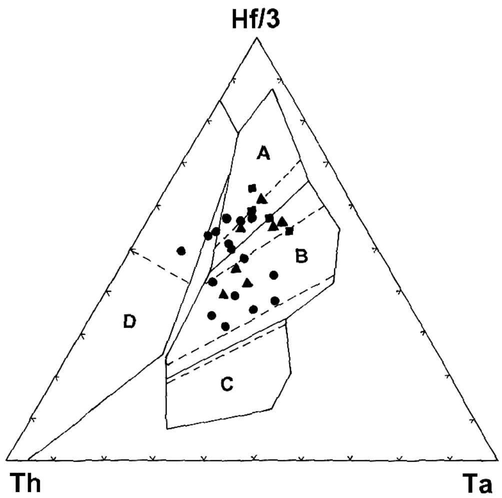

Fig. 7. Hf/3-Th-Ta diagram (Wood 1980) for metabasalts and metadolerites — relic of the Meliata Ocean from the southern part of the Inner Western Carpathians. Explanations: symbols — see Fig. 5; **A** — N-MORB, **B** — E-MORB, **C** — WPB (alkali), **D** — basalts of destructive plate margin (IAT and CAB). Data sources: Harangi et al. (1996) and unpublished data.

dotites (Ivan et al. 1998). Basalt clasts with glassy, intersertal, variolitic, subophitic or ophitic textures were initially composed of clinopyroxene, plagioclase and volcanic glass with a lesser amount of olivine and ilmenite. The same association (except glass) has been found in dolerites, whereas the association in gabbros comprises orthopyroxene, clinopyroxene, plagioclase and ilmenite. As a result of the metamorphic alteration, these associations were variably replaced by Ca-amphiboles (often gradually changed from pargasite through magnesiohornblende to actinolite with decreasing of temperature in gabbros), albite, chlorite, epidote, prehnite, pumpellyite, grossularite, carbonate and smectite. Pyroxenites were almost fully transformed to actinolite rocks, peridotites to lizardite-chrizotile or rarely to antigorite serpentinites. Metamorphic alteration evolving from the amphibolite (in gabbros only) to lower greenschist facies conditions resembles typical oceanic-ridge type metamorphism. Relatively numerous metagabbro clasts with grossularite, pumpellyite, actinolite and prehnite do not exclude later overprint by a very low-grade metamorphic stage. Blueschist clasts, rarely found in conglomerate as a product of HP/LT metamorphism, are composed of Na-amphibole (glaucophane), Na-Ca-amphibole, actinolite, epidote, albite and titanite. Some of them only seem to have originated from ophiolite protolith.

Trace element distribution in several studied basaltic clasts indicates their similarity to N-MORB, although arc-like signature has been also identified in basalt forming small (several meters) body located near the base of the conglomerate layer. The geochemical characteristics of gabbros are similar to those from oceanic floor with positive Eu anomaly for cumulate gabbro.

The Triassic age of ophiolite clasts in Cretaceous DLJC is most probable because they are associated with red radiolarite clasts of the paleontologically proven Triassic age (Múčková 1989).

Geodynamic and tectonic implications

In all the above-mentioned formations a fragmentary character of oceanic crust relics of the former Meliata Ocean is a typical feature. The relics of the Meliata Ocean can be referred to as incomplete dismembered ophiolite sequences including only deep-sea sediments, pillow lavas and sheet lava flows, in smaller amounts also subvolcanic members (from the sheeted dyke complex?) and scattered isotropic gabbros. All the above mentioned rocks belong to the uppermost part of the oceanic crust. The presence of the real complete oceanic crust in the Meliata Ocean, produced in a zone similar to the mid-ocean ridge, follows from the association of magmatic rocks in the DLJC. In spite of this fact the Meliata Ocean was never a wide ocean separating large continents. The variability of basalt composition from the arc-like types through geochemical types close to BABB up to almost typical N-MORBs is identical with the products of magmatic evolution during opening and spreading of recent back-arc basins (e.g. Price et al. 1990; Gribble et al. 1996, 1998). Arc-like or back-arc basin basalts are related to the carbonate or clastic deposition (Bôrka Nappe), whereas the types approaching typical N-MORB occur together with black cherts or red radiolarites. This change in sediment type can also be interpreted as a result of basin spreading and deepening. E-MORB types or transitional types between E- and N-MORB, identified in the BVOF and Darnó Hill Formation, are also known from recent back-arc basins where they are interpreted as a result of the partial melting of mantle sources previously affected by older mantle plumes and generated in the initial stages of the basin opening (Falloon et al. 1992; Wendt et al. 1997; Ewart et al. 1998). There is evidence for the existence of such types of mantle sources also from Early Paleozoic and Carboniferous volcanic rocks of the Inner Western Carpathians (Ivan et al. 1994; Ivan 1997).

The maximum extent of the Meliata Ocean is related to the Middle Triassic time, when it could have reached a width approximately several hundreds km. This estimation is based on basalt geochemistry, sediment lithology and analogies to recent back-arcs (cf. Gribble et al. 1996, 1998).

Formation of the Meliata Ocean as a back-arc basin had to be related to the subduction or early post-orogenic settings. It seems likely that the Meliata Ocean was founded and opened inboard of the Permian volcanic arc, the vestiges of which are traceable in the Inner Western Carpathians (Krompachy Group) or southern Central Western Carpathians (Permian formations of the Veporic Unit) in the form of subaerial calc-alkaline volcanism producing lavas from basic to acid in composition (Vozárová & Vozár 1988; Ivan 1996). The products of such a volcanic activity have been also found together with HP/LT metamorphosed basalts of BABB signature and the Meliata Ocean affinity forming clasts in the Cretaceous conglomerates of the Klape and Manín Units of the Pieniny Klippen Belt (Ivan et al. 1999). Late Permian opening of the Meliata Ocean on the active continental margin was supposed by Stampfli (1996, 2000) in his global plate tectonic reconstructions. Following the dynamics of a back-arc basin opening at the present time (cf. Doglioni et al. 1999) it seems to be possible that the dipping of the subduction zone, above which the Meliata Ocean was opened, was to the west. This idea seems to be supported by the paleomagnetically proven original position of all future small lithospheric segments of the Alpine-Carpathian-Pannonian realm, which probably formed together with Adria, Sardinia, Corsica and Greece a compact piece of land of south-north orientation adjacent to the eastern side of the French Massif Central during the Permian (Neugebauer et al. 2001).

The closure of the Meliata Ocean resulted from its subduction connected with the formation of the accretion wedge of Franciscan type (Kozur 1991). The first to be consumed were the oldest sedimentary complexes with some volcanic rocks (arc-like or BABBs) from the basinal margin. They underwent subduction-related HP/LT metamorphism followed by exhumation and now they represent the substantial part of the high-pressure metamorphosed relics of the Meliata Ocean. Low-grade (LP/LT) metamorphosed relics were originally generated mostly during a more developed stage of the Meliata Ocean opening (basalts similar to N-MORB). They were accreted into mélanges probably by peeling of the upper part of the oceanic crust in accretionary prism because many analogies in geological structure between such terrain (see Kimura & Ludden 1995) and particularly the Jaklovce Formation can be found. There is indirect evidence only for the obduction of the complete oceanic crust sequence onto arc crust following from the petrographic variability of clasts in the DLJC. The closure of the Meliata Ocean was dated as Middle Jurassic (Bathonian to Callovian/Oxfordian;) using the paleontologically estimated age of radiolarites of the mélange matrix (Kozur 1991; Mock et al. 1998).

The recent tectonic position of the Meliata Ocean crust relics is extremely complex because the pile of nappes and slices created in the Jurassic accretion wedge was involved in the repeated nappe structure formation during the Cretaceous (cf. Plašienka 1997). The latter event is also responsible for the formation of salinar mélanges by tectonic mixing of oceanic crust relics with Permian evaporites (Kozur 1991). The erosion of nappes containing the rocks of the former Meliata Ocean in the Upper Cretaceous led to their recycling into Gosau-type conglomerates.

The complicated tectonic position of the relics of the Meliata Ocean floor and marginal rocks render difficult a reconstruction of the paleogeography, subduction trend or original position of the suture of the Meliata Ocean. According to Neubauer et al. (1999) this suture was situated between the Austroalpine units on the one side and the Southalpine or Tisia units on the other side. Direct evidence concerning the geological structure of the former continental margins of the Meliata Ocean derives from olistoliths or clasts of arc-related magmatic rocks (rhyolites, calc-alkaline basalts probably Permian or Triassic in age) in the Meliatic Fm. or in the DLJC and also from HP/LT metamorphosed non-oceanic rocks in the Bôrka Nappe — material of the overriding lithospheric plate located immediately above the subducting oceanic plate or a continental margin temporarily involved into the subduction zone (e.g. Chemenda et al. 1996). These rocks are represented by metamorphosed clastic sediments with sporadic rhyolites (Permian?; Faryad 1995b) and calc-alkaline basic volcanic rocks interlayered by pelitic sediments (Ivan 1999) or amphibolites and gneisses with HP/LT overprint (Faryad 1988), both probably Early Paleozoic in age.

Several controversial models of the paleogeographical evolution of the Tethyan Realm during the Mesozoic time including also the Meliata Ocean (Kozur 1991; Michalík 1994; Neubauer 1994; Stampfli 1996; Channel & Kozur 1997; Kovács 1997; Zacher & Lupu 1998; Gawlick et al. 1999; Neugebauer et al. 2001) have been proposed. Among these models the conception by Stampfli (1996, 2000), which interpreted the Meliata Ocean as an individual back-arc basin separated by a Permian island arc from Paleotethys, seems to be, from the geodynamic point of view, in good accordance with the results obtained from the geological study of the Mesozoic oceanic crust relics in the Inner Western Carpathians. But the extent and spatial position of this back-arc basin to the coeval large oceans referred to as Paleotethys and Neotethys still remains unclear and, the alternatives of its continuation in the Inner Hellenides, Inner Dinarides, Transylvanides and Northern Dobrogea, are a matter of discussion (e.g. Zacher & Lupu 1999). New light could be cast on this problem by kinematical reconstructions of the ALCAPA and Tisia block movements, which indicate important dextral displacement of the ALCAPA block to the NE along the Middle Hungarian Zone connected with the transport of some structural units of South Alpine-Dinaridic affinity as far as the Bükk Mts — Inner Western Carpathians area during the Tertiary (Fodor et al. 1998; Haas et al. 2000). If such an interpretation is correct, then the Meliata Ocean relics could be directly related to Hellenide-Dinaride ophiolites and could represent their original northwestern continuation. The same idea was formerly supported by Kovács (1997), who argued for it pointing out the presence of oceanic basalts associated with the Ladinian/Carnian red radiolarites in both the above mentioned ophiolitic complexes. Unfortunately lack of reliable data on the magmatic rock geochemistry, geological structure and evolution of the Hellenide–Dinaride ophiolite belts do not allow us to trace the position of the Meliata Ocean relics herein. The majority of ophiolitic rocks of these belts are supposed to be Jurassic in age and they are interpreted as relics of one or two oceans (e.g. Vardar and Pindos Oceans; Channells & Kozur 1997) younger than the Meliata Ocean. Jurassic magmatic rocks with MORB signature were also found in the close neighborhood of the southernmost Meliata Ocean relics in the Bükk Mts, but the relation of this incomplete ophiolite complex to those in the Dinaride belts is still unclear (Downes et al. 1990; Aigner-Torres & Koller 1999). According to Pearce et al. (1984) the Dinaride ophiolites were formed in a supra-subduction zone geodynamic setting, because they are geochemically more variable in comparison to typical oceanic rocks (or Alpine ophiolites) including not only MORB but also IAT (island arc tholeiite) or boninitic types. Although such a characterization of Dinaride ophiolites may be too generalized (e.g. Bosnian ophiolites belong wholly to the N-MORB, exceptionally to the E-MORB type — Trubelja et al. 1995), it is fully applicable also for the Meliata Ocean relics. Speculation, that the Meliata Ocean relics together with Hellenide-Dinaride ophiolite belts are really remnants of one or more (parallelly opened?) back-arc basins, seems to be reasonable, but the incompatibility of the plate-tectonic models of the Mesozoic-Tertiary evolution of the western Tethyan Realm including its small oceanic basins clearly indicates that a great amount of exact data is still missing.

Conclusions

Mineralogical, petrological and geochemical data concerning the Meliata Ocean crust relics together with their geodynamic implications led us to the following conclusions:

- Oceanic crust relics of the Triassic-Jurassic Meliata Ocean are represented by dismembered ophiolites forming slices and blocks in Jurassic olistostroma and mélanges or recycled material in conglomerates
- Metamorphosed basalts and dolerites from the upper part of the former oceanic crust dominate within the Meliata Ocean crust relics
- Variations in basalt composition from arc-like types through BABBs to the types similar to N-MORB together with the changing of enclosing sediments from carbonate to deep-sea ones in the Meliata Ocean relics are related to the same magmatic and sedimentary evolution operating in the course of the opening and spreading of recent back-arc basins
- Jurassic subduction and the following exhumation was experienced mostly by the marginal parts of the Meliata Ocean with magmatic rocks of the initial stage of opening, whereas magmatic rocks of the evolved stage were usually obducted or accreted in an accretion wedge
- The Meliata Ocean ophiolite suture in its original position was destroyed by the following tectonic processes and nappe formation in the Cretaceous time
- The Meliata Ocean was probably opened as a back-arc basin inboard of a Permian magmatic arc, the vestiges of which are traceable in the nappe piles on both sides of the Inner and Central Western Carpathian boundary
- Continental margins of the Meliata Ocean comprised in their geological structure Permian(?) arc-related volcanic rocks together with an arc-related volcano-sedimentary complex, amphibolites and gneisses all probably Early Paleozoic in age
- The Meliata Ocean relics could be directly related to Hellenide-Dinaride ophiolites representing originally their northwestern continuation displaced into their present-day position by microplate motions in the Miocene

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References

Aigner-Torres M. & Koller F. 1999: Nature of the magma source of the Szarvaskő complex (NE-Hungary): Petrological and geochemical constraints. *Ofioliti* 24, 1–12.

Beccaluva L., Macciotta G., Piccardo G.B. & Zeda O. 1989: Clinopyroxene composition of the ophiolite basalts as petrogenetic indicator. *Chem. Geol.* 77, 165–182.

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

Chemenda A.I., Mattauer M. & Bokum A. 1996: Continental subduction and mechanism for exhumation of high-pressure metamorphic rocks: new model and field data from Oman. *Earth Planet. Sci. Lett.* 143, 172–182.

Dallmeyer R.D., Neubauer F., Handler R., Fritz H., Muller W., Pana D. & Putiš M. 1996: Tectonothermal evolution of the internal Alps and Carpathians: Evidence from $^{40}Ar/^{39}Ar$ mineral and whole rocks data. *Eclogae Geol. Helv.* 89, 203–227.

De Wever P. 1984: Triassic radiolarians from the Darnó area (Hungary). *Acta Geol. Hung.* 27, 295–306.

Doglioni C., Harabaglia P., Merlini S., Mongelli F., Peccerillo A. & Piromallo C. 1999: Orogens and slabs vs. their direction of subduction. *Earth Sci. Rev.* 45, 167–208.

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

Downes H., Pantó G., Árkai P. & Thirlwall M.F. 1990: Petrology and geochemistry of Mesozoic igneous rocks, Bükk Mountains, Hungary. *Lithos* 24, 201–215.

Dumitrica P. & Mello J. 1982: On the age of the Meliata Group and Silica Nappe radiolarites (localities Držkovce a Bohúňovo, Slovak Karst). *Geol. Práce, Spr.* 77, 17–28.

Evensen N.M., Hamilton P.J. & O´Nions R.K. 1978: Rare earth abundances in chondritic meteorites. *Geochim. Cosmochim. Acta* 42, 1199–1212.

Ewart A., Collerson K.D., Regelous M., Wendt J.I. & Niu Y. 1998: Geochemical evolution within the Tonga-Kermadec-Lau arc-back arc systems: the role of varying mantle wedge composition in space and time. *J. Petrology* 39, 331–368.

Falloon T.J., Malahoff A., Zonenshain L.P. & Bogdanov Y. 1992: Petrology and geochemistry of back-arc basin basalts from Lau Basin spreading ridges at 15, 18 and 19-degrees S. *Mineral. Petrology* 47, 1–35.

Faryad S.W. 1988: Glaucophanized amphibolites and gneisses near Rudník (Slovenské rudohorie Mts). *Geol. Zbor. Geol. Carpath.* 39, 747–763.

Faryad S.W. 1995a: Phase petrology and p,T conditions of mafic blueschists from the Meliata Unit, West Carpathians, Slovakia. *J. Metamorph. Geol.* 13, 701–714.

Faryad S.W. 1995b: Petrology and phase relations of low-grade high-pressure metasediments from the Meliata unit, Western Carpathians, Slovakia. *Eur. J. Mineral.* 7, 71–87.

Faryad S.W. 1997: Lithology and metamorphism of the Meliata unit high-pressure rocks. In: Grecula P., Hovorka D. & Putiš M. (Eds.): Geological evolution of the Western Carpathians. *Miner. Slovaca, Monogr.* 131–144.

Faryad S.W. & Henjes-Kunst F. 1997: Petrologic and geochronological constraints on the tectonometamorphic evolution of the Meliata unit blueschists, Western Carpathians (Slovakia). In: Grecula P., Hovorka D. & Putiš M. (Eds.): Geological evolution of the Western Carpathians. *Miner. Slovaca, Monogr.* 145–154.

Fodor L., Jelen B., Márton E., Skaberne D., Čar J. & Vrabec M. 1998: Miocene-Pliocene tectonic evolution of the Slovenian Periadriatic fault: Implications for Alpine-Carpathian extrusion models. *Tectonics* 17, 690–709.

Gawlick H.J., Frisch W., Vecsei A., Steiger T. & Böhm F. 1999: The change from rifting to thrusting in the Northern Calcareous Alps as recorded in Jurassic sediments. *Geol. Rdsch.* 87, 644–657.

Gribble R.F., Stern R.J., Bloomer S.H., Stuben D., O´Hearn T. & Newman S. 1996: MORB mantle and subduction components interact to generate basalts in the Southern Mariana Trough back-arc basin. *Geochim. Cosmochim. Acta* 60, 2153–2166.

Gribble R.F., Stern R.J., Newman S., Bloomer S.H. & O´Hearn T. 1998: Chemical and isotopic composition of lavas from the northern Mariana Trough: Implications for magma genesis in back-arc basins. *J. Petrology* 39, 125–154.

Halamić J., Goričan Š., Slovenec D. & Kolar-Jurovšek T. 1999: A Middle Jurassic radiolarite-clastic succession from the Medvednica Mt, (NW Croatia). *Geol. Croatica* 52, 29–57.

Halamić J., Slovenec D. & Kolar-Jurovšek T. 1998: Pelagic Triassic limestones in pillow lavas in the Orešje quarry near Gornja Bistra, Medvednica Mt (northwest Croatia). *Geol. Croatica* 51, 33–45.

Harangi S., Szabó C., Józsa S., Szoldán Z., Árva-Sós E., Balla M. & Kubovics I. 1996: Mesozoic igneous suites in Hungary: Implications for genesis and tectonic setting in the northwestern part of Tethys. *Int. Geol. Rev.* 38, 336–360.

Haas J., Mioč P., Pamić J., Tomljenović B., Árkai P., Bérczi-Makk A., Koroknai B., Kovács S. & Felgenhauer E.R. 2000: Complex structural pattern of the Alpine-Dinaridic-Pannonian triple junction. *Int. J. Earth Sci.* 89, 377–389.

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.

Horváth P. 2000: Metamorphic evolution of gabbroic rocks of the Bódva Valley Ophiolite Complex, NE Hungary. *Geol. Carpathica* 51, 121–129.

Hovorka D., Ivan P., Mock R., Rozložník L. & Spišiak J. 1990: Gosau-type sediments near Dobšinská Ľadová Jaskyňa: topics on non-traditional interpretation. *Miner. Slovaca* 22, 519–525 (in Slovak).

Hovorka D. & Spišiak J. 1988: Mesozoic volcanism of the Western Carpathians. *Veda*, Bratislava, 1–263 (in Slovak with English summary).

Hovorka D. & Spišiak J. 1993: Mesozoic volcanic activity of the Western Carpathian segment of the Tethyan belt: Diversities in space and time. *Jb. Geol. Bundesanst.* 136, 769–782.

Hovorka D. & Spišiak J. 1998: Mesozoic Meliata ocean dismembered ophiolites. In: Rakús M. (Ed.): Geodynamic development of the Western Carpathians. *Geol. Survey Slovak Rep.*, Bratislava, 81–88.

Ivan P. 1996: Problems of geodynamic evolution and geological structure of the Paleozoic Gemeric Unit (Inner Western Carpathians) as inferred by magmatic rock study. *Slovak Geol. Mag.* 3–4/96, 239–244.

Ivan P. 1997: Rakovec and Zlatník Formations: two different relics of the pre-Alpine back-arc basin crust in the inner Western Carpathians. In: Grecula P., Hovorka D. & Putiš M. (Eds.): Geological evolution of the Western Carpathians. *Miner. Slovaca, Monogr.* 281–288.

Ivan P. 1999: HP/LT metamorphosed calc-alkaline basalts of the Bôrka Nappe: a significant rock type for the knowledge of the subduction mechanism and tectonic evolution of the Western Carpathians. In: Ďurža O. & Rapant S. (Eds.): Geochemistry 1999. *Konf. Symp. Sem., Geol. Survey Slov. Rep.*, Bratislava, 49–52 (in Slovak).

Ivan P. in press: Relic magmatic minerals and textures in the HP/LT metamorphosed oceanic rocks of the Triassic-Jurassic Meliata ocean (inner Western Carpathians). *Slovak Geol. Mag.*

Ivan P., Demko R. & Sýkora M. 1999: Calc-alkaline basalts and basaltic andesites in the Cretaceous conglomerate of the Klape Unit (Pieniny Klippen Belt) — problem of the source area and its geodynamic setting. In: Ďurža O. & Rapant S. (Eds.): Geochemistry 1999. *Konf. Symp. Sem., Geol. Survey. Slov. Rep.*, Bratislava, 115–119 (in Slovak).

Ivan P., Hovorka D. & Spišiak J. 1998: Complete ophiolites as clasts in the Gosau-type Cretaceous conglomerates from Dobšinská Ľadová Jaskyňa (Gemeric Unit, inner Western Carpathians). In: *Carpath.-Balcan Geol. Assoc. XVI. Congress. Abstracts. Geol. Survey Austria,* Vienna, 233.

Ivan P. & Kronome B. 1996: Protolith and geodynamic setting of the HP/LT metamorphosed basic rocks from the northern margin of the Bôrka nappe (Meliatic Unit, Inner Western Carpathians). *Slovak Geol. Mag.* 3–4/96, 331–334.

Ivan P., Méres Š. & Hovorka D. 1994: Oceanic crust in geological history of the Western Carpathian orogeny. *Acta Geol. Hung.* 37, 19–32.

Ivan P. & Sýkora M. 1997: HP/LT metamorphosed magmatic rocks in the conglomerates of Klape and Manín Units (Pieniny Klippen Belt, Western Carpathians). In: Plašienka D., Hók J., Vozár J. &. Elečko M. (Eds.): Alpine evolution of the Western Carpathians and related areas. *Abstracts, D. Štúr Publ.*, Bratislava, 20–21.

Kamenický J. 1957: Serpentinites, diabases a glaucophanitic rocks from the Triassic of the Spišsko-gemerské rudohorie Mts. *Geol. Práce, Zoš.* 45, 5–108 (in Slovak).

Kantor J. 1955: Diabases of Mesozoic of the southern Slovakia. *Geol. Práce, Zoš.* 41, 77–99 (in Slovak).

Kimura G. & Ludden J. 1995: Peeling oceanic crust in subduction zones. *Geology* 23, 217–220.

Kovács S. 1997: Middle Triassic rifting and facies differentiation in Northeast Hungary. In: Sassi F.P & Papanicolaou D. (Eds.): Geodynamic domains in Alpine-Himalayan Tethys. *Oxford & IBH Publ. Co. Pvt. Ltd.*, New Delhi - Calcutta, 375–397.

Kozur H. 1991: The evolution of the Meliata-Hallstatt ocean and its significance for the early evolution of the Eastern Alps and Western Carpathians. *Palaeogeogr. Palaeoclimat. Palaeoecol.* 87, 109–135.

Kozur H. & Mock R. 1985: Erster Nachweis von Jura in der Meliata Einheit der südlichen Westkarpaten. *Geol. Paläont. Mitt.* 13, 223–238.

Kozur H. & Mock R. 1988: Deckenstructuren im südlichen Randbereich der Westkarpaten and Grundzüge der alpidischen Entwicklung in den Westkarpaten. *Acta Geol. Geogr. Univ. Comen., Geol.* 44, 5–100.

Kozur H. & Mock R. 1995: First evidence of Jurassic in the Folkmar Suture Zone of the Meliaticum in Slovakia and its tectonic implications. *Miner. Slovaca* 27, 301–307.

Kozur H. & Mock R. 1997: New paleogeographic and tectonic interpretations in the Slovak Carpathians and their implications and correlations with Eastern Alps and other parts of the Western Tethys. Part II: Inner Western Carpathians. *Miner. Slovaca* 29, 164–209.

Kozur H., Mock R. & Ožvoldová L. 1996: New biostratigraphic results in the Meliaticum in its type area around Meliata village (Slovakia) and their tectonic and paleogeographic significance. *Geol. Paläontol. Mitt.* 21, 89–121.

Kralik M., Koller F. & Pober E. 1984: Geochemie und K-Ar alter der Diabasvorkommen von Annaberg (Nördliche Kalkalpen, Niederösterreich). *Mitt. Österr. Geol. Gesell.* 77, 37–55.

Less G. 2000: Polyphase evolution of the structure of the Aggtelek-Rudabánya Mountains (NE Hungary), the southernmost element of the Inner Western Carpathians — a review. *Slovak Geol. Mag.* 6, 260–268.

Maluski H., Rajlich P. & Matte P. 1993: ^{40}Ar-^{39}Ar dating of the Inner Carpathians Variscan basement and Alpine mylonitic overprinting. *Tectonophysics* 223, 313–337.

Mazzoli C. & Vozárová A. 1998: Subduction related processes in the Bôrka Nappe (inner Western Carpathians): a geochemical and petrological approach. In: Rakús M. (Ed.): Geodynamic development of the Western Carpathians. *Geol. Survey Slovak Rep.*, Bratislava, 89–106.

Mello J., Elečko M., Pristaš J., Reichwalder P., Snopko L., Vass D., Vozárová A., Gaál Ľ., Hanzel V., Hók J., Kováč P., Slavkay M. & Steiner A. 1997: Explanations to the geological map of the

Slovenský kras Mts 1: 50,000. *D. Štúr Publ.*, Bratislava, 1–255 (in Slovak).

Mello J., Filo I., Havrila M., Ivan P., Ivanička J., Madarás J., Németh Z., Polák M., Pristaš, J., Vozár J., Vozárová A., Liščák P., Kubeš P., Scherer S., Siráňová Z., Szalaiová V. & Žáková E. 2000: Explanations to the geological map of the Slovenský raj Mts, Galmus Mts and Hornád depression 1: 50,000. *D. Štúr Publ.*, Bratislava, 1–303 (in Slovak).

Mello J., Reichwalder P. & Vozárová A. 1998: Bôrka Nappe: high-pressure relic from the subduction-accretion prism of the Meliata ocean (Inner Western Carpathians, Slovakia). *Slovak Geol. Mag.* 4, 261–273.

Michalík J. 1994: Notes on the paleogeography and paleotectonics of the Western Carpathian area during the Mesozoic. *Mitt. Österr. Geol. Gesell.* 86, 101–110.

Mock R., Sýkora M., Aubrecht R., Ožvolďová L., Kronome B., Reichwalder P. & Jablonský J. 1998: Petrology and petrography of the Meliaticum near the Meliata and Jaklovce Villages, Slovakia. *Slovak Geol. Mag.* 4, 223–260.

Moores E.M. 1982: Origin and emplacement of ophiolites. *Rev. Geophys. Space Phys.* 20, 735–760.

Múčková B. 1989: Radiolarites from pebbles of Senonian conglomerates near Dobšinská Ľadová Jaskyňa. *Master thesis, Comenius Univ.*, Bratislava, 1–69 (in Slovak).

Neubauer F. 1994: Kontinentkolision in den Ostalpen. *Geowissenschaften* 12, 136–140.

Neubauer F., Dallmeyer R.D. & Takasu A. 1999: Conditions of eclogite formation and age of retrogression within the Sieggraben unit, Eastern Alps: Implications for Alpine-Carpathian tectonics. *Schweiz. Mineral. Petrogr. Mitt.* 79, 297–307.

Neugebauer J., Greiner B. & Appel E. 2001: Kinematics of the Alpine-West Carpathian orogen and palaeogeographic implications. *J. Geol. Soc.* 158, 97–110.

Pearce J.A., Lippart S.J. & Roberts S. 1984: Characteristics and tectonic significance of supra-subduction zone ophiolites. In: Kokelaar B.P. & Howells M.F. (Eds.): Marginal basin geology. *Geol. Soc. London Spec. Publ.* 16, 77–94.

Plašienka D. 1997: Cretaceous tectonochronology of the Central Western Carpathians, Slovakia. *Geol. Carpathica* 48, 99–111.

Price R.C., Johnson L.E. & Crawford A.J. 1990: Basalts of the North Fiji Basin: the generation of back-arc basin magmas by mixing of depleted and enriched mantle sources. *Contr. Mineral. Petrology* 105, 106–121.

Réti Z. 1985: Triassic ophiolite fragments in an evaporitic melange, northern Hungary. *Ofioliti* 10, 411–422.

Stampfli G.M. 1996: The-Intra Alpine terrain: A Paleotethyan remnant in the Alpine Variscides. *Eclogae Geol. Helv.* 89, 13–42.

Stampfli G.M. 2000: Tethyan oceans. In: Borkurt E., Winchester J.A. & Piper J.D.A. (Eds.): Tectonics and magmatism in Turkey and surrounding area. *Geol. Soc. London Spec. Publ.* 173, 1–23.

Trubelja F., Marchig V., Burgath K.P. & Vujović Ž. 1995: Origin of the Jurassic Tethyan ophiolites in Bosnia: A geochemical approach to tectonic setting. *Geol. Croatica* 48, 49–66.

Vozárová A. & Vozár J. 1988: Late Paleozoic in West Carpathians. *D. Štúr Geol. Inst.*, Bratislava, 1–314.

Vozárová A. & Vozár J. 1992: Tornaicum and Meliaticum in borehole BRU-1, southern Slovakia. *Acta Geol. Hung.* 35, 97–116.

Wendt J.I., Regelous M., Collerson K.D. & Ewart A. 1997: Evidence for contribution from two mantle plumes to island-arc lavas from northern Tonga. *Geology* 25, 611–614.

Wood D.A. 1980: The application of a Th-Hf-Ta diagram to problems of tectonomagmatic classification and to establishing the nature of crustal contamination of basaltic lavas of the British Tertiary Volcanic Province. *Earth Planet. Sci. Lett.* 50, 11–30.

Zacher W. & Lupu M. 1998: The oceanic puzzle of the Alpine-Carpathian orogenic belt. *Jb. Geol. Bundesanst.* 141, 97–106.

Zacher W. & Lupu M. 1999: Pitfalls on the race for an ultimate Tethys model. *Int. J. Earth Sci.* 88, 111–115.