Relict Magmatic Minerals and Textures in the HP/LT Metamorphosed Oceanic Rocks of the Triassic-Jurassic Meliata Ocean (Inner Western Carpathians)

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Abstract: High-pressure low-temperature (HP/LT) metamorphosed rocks of the Meliatic Unit (inner Western Carpathians) were formed during the Middle/Upper Jurassic subduction of the Mesozoic Meliata Ocean. They have been found in the form of variable in size bodies (from dm to km) in the mélange-like formations of the Bôrka Nappe (Hačava and Kobeliarovo Fms.), in the Bodva Valley Ophiolite Formation and also as recycled material in the Upper Cretaceous Gosau-type conglomerates from Dobšinská Ľadová Jaskyňa settlement.

Their original magmatic textures are observable due to selective replacement of magmatic minerals by metamorphic mineral assemblage or distribution of fine pigment of Fe-Ti oxides (ghost textures). Preserved textures suggest that most of these rocks were originally represented by basalts and dolerites, rarely even by gabbro, formed in the upper part of the oceanic crust of the Meliata Ocean. Lava solidification speed and the contact with the specific environment as well were the cause of variability in textures. In the basalts ophitic and subophitic textures were most widespread, furthermore glomeroophitic, intersertal, variolitic and vitritic textures have been identified. Rapid cooling mostly on the contact with water or rocks chilled margins or autoclastic lava breccia originated whereas on the contact with carbonaceous mud peperites and hyaloclastites occurred. Intrusive magmatic rocks had originally doleritic or gabbroic textures. Relic clinopyroxene is only preserved magmatic mineral. Its composition in accordance with whole-rock geochemical data indicates back-arc basin basalt (BABB) signature of these HP/LT metamorphosed basaltic rocks. The comparison of the magmatic clinopyroxene compositions from subducted (HP/LT metamorphosed) and obducted (LP/LT metamorphosed) basalts of the Meliatic Ocean confirmed results of previous geochemical study, that the crust of initial and early stages of the Meliata Ocean opening had been subducted while crust of evolved stage with basalts close to normal mid-ocean ridge basalt (N-MORB) had been mostly obducted. Identification of basalts, dolerites and also gabbros among the HP/LT metamorphosed rocks suggests for normal oceanic crust already in the early stage of Meliata Ocean opening. Traces of the oceanic ridge type metamorphism in dolerites and gabbros support this assumption. Metamorphic alteration of oceanic rocks in the subduction zone evolved progressively to HP/LT conditions, relic minerals of previous low-presure stages are rarely preserved. Only a part of them was retrogressed during exhumation.

Key words: Meliata Ocean, oceanic crust, blueschists, magmatic relicts

Introduction

The origin, opening and subsequent subduction of the Triassic-Jurassic Meliata Ocean represents events that have markedly influenced the Alpine history of Western Carpathians. Despite the fact that the Meliata (or Meliata-Hallstatt) Ocean occurs in many schemes of Mesozoic geotectonic evolution (Stampfli, 1996; Channell and Kozur, 1997; Plašienka, 2000; Golonka et al., 2000; Neugebauer et al., 2001, and others) detailed data about its origin and texture are still missing. Our knowledge comes out mostly from lithological and facial studies of sedimentary rocks (Kozur and Mock,1997; Channell and Kozur, 1997; Mello et al.,1997; Schweigl and Neubauer, 1997, and others). Less the knowledge is based on the understanding of the rocks, forming the sea-floor of this ocean – magmatic rocks of the oceanic crust. This is probably due to their relatively rare occurrence – oceanic crust rocks are preserved only as blocks of variable size in melanges or as small tectonic slices (Ivan et al., 1994 Furthermore shortly after their formation in an oceanic rift as well as during following accretion, eventually subduction, metamorphic processes modified their original petrographic and partially also their geochemical characteristics. Despite of this fact, also in some of the mostly altered rocks experienced metamorphic alteration in high-pressure low temperature conditions, relics of magmatic minerals and textures have been preserved. The aim of this study is to summarised data about relicts of the magmatic stage of evolution in HP/LT metamorphosed relicts of the Meliata Ocean oceanic crust and so to contribute to better knowledge of its geological history.

Geology of HP/LT metamorphosed oceanic rocks in the Meliaticum unit

Rock complexes of Inner Western Carpathians, related to the evolution of the Meliata oceanic basin, are

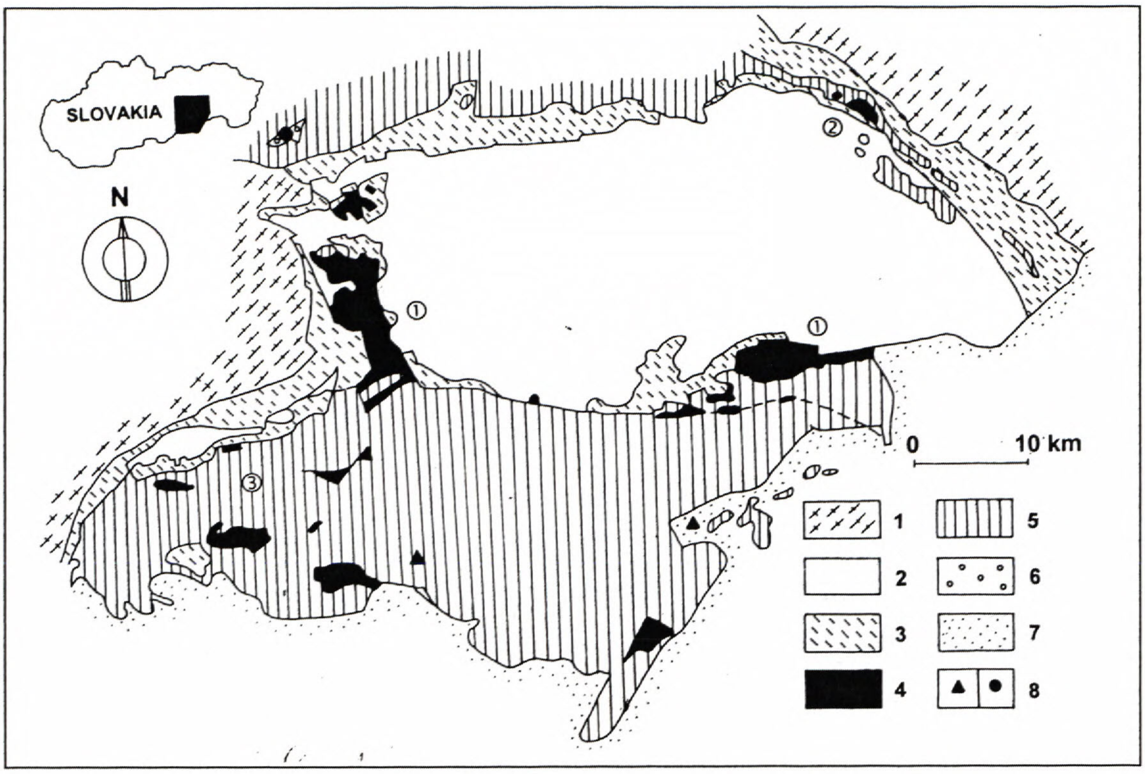


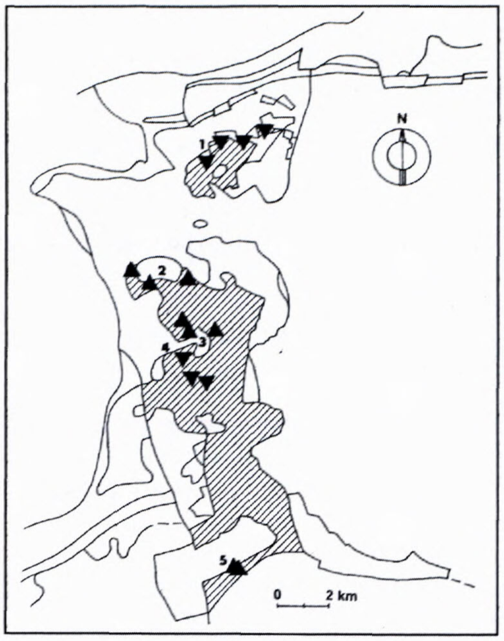
Fig. 1: Geological units with oceanic crust relicts of the Meliata Ocean in the Inner Western Carpathians.
Explanations: 1 – Veporicum unit, 2– Early Paleozoic of the Gemericum unit, 3 – Late Paleozoic of the GemericUnit, 4 – Formations with oceanic crust relicts of the Meliata Ocean (Meliatic Unit), 5 – other Mesozoic formations of the Inner Western Carpathians, 6 – Gosau-type Cretaceous conglomerates from Dobšinská ľadová jaskyňa settlement, 7 – Neogene, 8 – HP/LT metamorphosed oceanic rocks in boreholes (Bodva Valley Ophiolite Fm.; triangle) and in Cretaceous conglomerates (filled circle); 1 – Bôrka nappe, 2 – Meliata Fm., northern part in the neighbourhood of Jaklovce village, 3 – Meliata Fm.

refered as the Meliatic Unit. Relicts of the Meliata Ocean oceanic crust occur in two forms: either as (1) tectonic slices or blocks in nappe piles and melanges, or as (2) their redeposited material in the form of pebbles in conglomerates (Ivan, in press). Tectonic slices and blocks are a part of the Meliata unit s.s. in the area of Jaklovce and in broader surroundings of Meliata (Hovorka and Spišiak, 1998; Mock et al., 1998), Bodva Valley Ophiolite Formation (Harangi et al., 1996), Darnó Formation (Downes et al., 1990; Harangi et al., 1996) and Bôrka nappe (Ivan and Kronome, 1996; Mello et al., 1998). Oceanic crust rocks occur in the form of pebbles in Createcous Gosau-like conglomerates from the Dobšinská Ľadová Jaskyňa settlement (Hovorka et al., 1990; Ivan et al., 1998). Relicts of the Meliata Ocean oceanic crust came over variable geotectonic evolution that caused differences in their metamorphic alteration. Following its origin and subsequent metamorphism in the oceanic rift zone, a part of the oceanic crust was subducted, metamorphosed in HP/LT conditions during closing of the ocean and thereafter exhumed, while other part escaped the subduction and it was obducted or peeled in an accretion prism setting without any important metamorphic alteration. Oceanic rocks affected by HP/LT metamorphic alteration occur predominantly in the Bôrka nappe, but also as a relatively rare rock in the Bodva Valley Ophiolite Formation and in Cretaceous Gosau-type conglomerates (Fig. 1).

Bôrka nappe is located in western and southern part of the Spišsko-Gemerské Rudohorie Mts. It was thrusted over Gemeric Unit complexes, predominantly over the Early Paleozoic Gelnica Group or the Permian Gočaltovo Group. From the southern side the Bôrka nappe is limited by the Rožňava fault. The largest spread it reaches in western part, where it was saved from the erosion due to its position in the Nižná Slaná depression.

Bôrka nappe is buit up by several lithostratigraphic units (Ivan and Mello, 2001). Although all units came over HP/LT metamorphic stage, relicts of the oceanic crust of the Meliata Ocean or magmatic rocks related to initial stages of its formation are located just in two formations (1) Hačava Fm. and (2) Kobeliarovo Fm.

Hačava Fm. builds an important part of the Bôrka nappe in its western as well as eastern parts. Probably it represents tectonically reworked melange, which was metamorphosed in bulk in HP/LT conditions and quickly exhumed, so it does not have signs of retrogression. Relicts of magmatic rocks form tiny enclaves, bodies and tectonic slices of the magnitude from a few centimetres up to first hundreds of meters. The most important localities are the Radzim Hill near Vyšná Slaná village, southwards from the Ježovec Saddle NE from the Kobeliarovo village, eastwards from Štítnik village, between Lúčka and Bôrka villages, in Zádiel Valley and between the Hačava village and Šugov Valley (Fig. 2). Except of the Ježovec



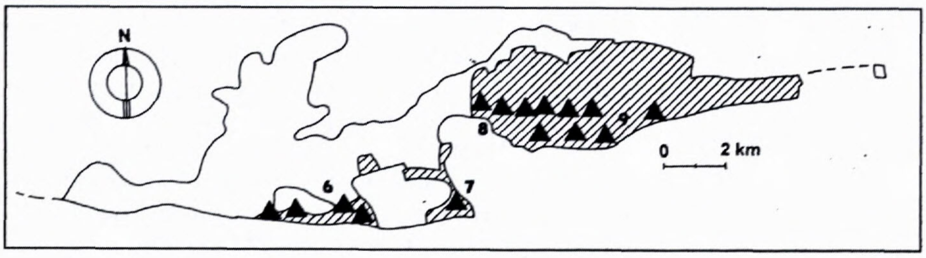


Fig. 2: HP/LT metamorphosed oceanic rocks of the Meliata Ocean in the Bôrka Nappe. A – western part of the Bôrka Nappe, B – eastern part of the Bôrka Nappe.
Explanations: triangles – Hačava Fm., inverted triangles – Kobeliarovo Fm. 1 – Dobšiná, 2 – Radzim Hill, 3 – Kobeliarovo village, 4 – Žiar Hill, 5 – Štítnik village, 6 – Lúčka and Bôrka villages, 7 – Zádiel Valley, 8 – Hačava village, 9 – Šugov Valley

Saddle and Zádiel Valley these rocks have been petrographically studied as glaucophanites in the classic study of Kamenický (1957). Occurrences are spatially (and in part also genetically) related to metamorphosed carbonates (middle part of the Šugov Valley, Bôrka) or to metapelites (Radzim, Ježovec Saddle, upper part of the Šugov Valley). At the Štítnik locality, apart from metamorphosed sediments, metamorphosed radiolarites have been also found in a close link to metamorphosed magmatic rocks.

Kobeliarovo Fm. builds the middle zone of western part of the Bôrka nappe, while in eastern part it is not present. Alike the Hačava Fm. it forms a melange of rigid blocks of metacarbonates (marbles) and metamorphosed magmatic rocks, predominantly in metapelitic matrix. It was metamorphosed in HP/LT conditions, but during exhumation it was subject to retrogression to greenschist facies. Metamorphosed magmatic rocks form tiny enclaves and thin layers (several centimeters thick) in carbonates, or small bodies (first tenths of meters) in metapelites in broader vicinity of the Žiar Hill. Identically metamorphosed magmatic rocks, that occur together with radiolarites in the form of bodies of the magnitude of first tenths up to hundreds of metres in the setting with various types of phyllites in the vicinity of Dobšiná, could also belong to the Kobeliarovo Fm. Hither to they have been regarded for a part of the Carboniferous of the Dobšiná Group of Gemericum (Rozložník, 1963). We have preliminary labelled them as a unique member (Steinberg member) of the Kobeliarovo Formation (Ivan and Mello, 2001).

Bodva Valley Ophiolite Formation represents salinary melange of rock fragments of the ophiolite association in evaporites (anhydrites) of Permian age (Réti, 1985; Harangi et al., 1996). HP/LT metamorphosed magmatic rocks are very rare here, identified just in two boreholes near the Komjáti village (borehole Ko-11; Józsa and Horváth, 1996; Horváth, 1997; 2000) and near the Bohúňovo village (borehole SA-6/82; Faryad, 1998). In the borehole near Komjáti, on the tectonic contact with underlying Perkupa Evaporite Fm. (Permian), about 200 m thick body of metamorphosed basic rocks has been found. In the borehole near Bohúňovo such a body sits directly in an evaporite melange and its thickness is just first tenths of meters.

In Cretaceous Gosau-type conglomerates near Dobšinská ľadová jaskyňa rare clasts of HP/LT metamorphosed basic rocks have been found in a unique type of conglomerates with prevailing rock clasts of the ophiolite sequence (Hovorka et al., 1990; Ivan et al., 1998).

Relict magmatic textures in HP/LT metamorphosed rocks of the Meliata Ocean

Already in the classic work of Kamenický (1957) the relict magmatic divergent-intersertal texture was ascribed to a part of the studied glaucophanites, alhough in the case of some the samples it was wrong (so called diabase porphyry). More recent studies (Reichwalder, 1973; Faryad, 1995a, 1997; Mazzoli and Vozárová, 1998), with exception of our study (Ivan and Kronome, 1996), do not present the phenomenon of relict magmatic textures.

Relict magmatic textures in the studied rocks are only rarely accompanied by original magmatic minerals. Usually, they are possible to identify just based on the distribution of secondary metamorphic minerals that specifically replace some of the original magmatic minerals, or they are preserved just as ghost, most often by distribution of fine pigment of Fe-Ti oxides. Abundance of rocks with preserved primary texture, as well as tiny details discernible in these rocks, indicate that in the HP/LT stage of metamorphism no significant deformation of rocks occurred and the signs of preferential orientation and veining reflect their previous metamorphic evolution. Metamorphosed magmatic rocks that associate with

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metapelites preserved their primary texture usually better than those localised in carbonates.

Relict magmatic textures determined in HP/LT metamorphosed oceanic rocks of the Meliata Ocean are shown in figures 3, 4 and 5.

Bôrka Nappe – Hačava Fm.

Significant differences in types of primary textures and grades of their preservation occur among individual localities of the Hačava Formation.

Radzim Hill

In the area of the Radzim Hill (southwards from the Vyšná Slaná village), at its western (Široké Pole Saddle) and southern slopes the original magmatic textures are very well preserved. Metabasalts with primary subophitic texture prevail but metabasalts with fine-ophitic, intersertal and variolitic textures are also relatively widespread. Rarely, fine-grained metabasalts, brecciated during solidification and subsequently pervasively veined, are present. Macroscopically, metabasalts with primary subophitic texture are massive rocks with dark speckles of mafic minerals. Microscopically, the primary subophitic texture is difficult to identify because the mineral, which has preserved the original habit and composition, is clinopyroxene (Fig. 3A). The characteristic identification feature – laths of plagioclases – is absent. During metamorphic stages preceding HP/LT metamorphism (prehnite-pumpellyite, eventually prehnite-actinolite facies) plagioclase in basalt was either replaced by fine-grained aggregate of white mica or by fan-shaped aggregates of prehnite. Chlorite eventually actinolite also originated, partially at the expense of clinopyroxene. Mostly idiomorphic crystals of ilmenite have been replaced by leucoxene. The rock replaced in this way was subject to compression and preferred orientation of variable intensity, during those the leucoxenised ilmenites have been often flattened up to elongate lenses and aggregates of mica or prehnite, so deformed that they partially flow of the grains of clinopyroxene, suggestive of the mylonite texture. In the high-pressure stage the magmatic clinopyroxene was totally or partially replaced by Na-pyroxene, prehnite by clinozoisite and subsequently by epidote, white mica obtained composition of fengite and chlorite and actinolite were replaced by glaucophane.

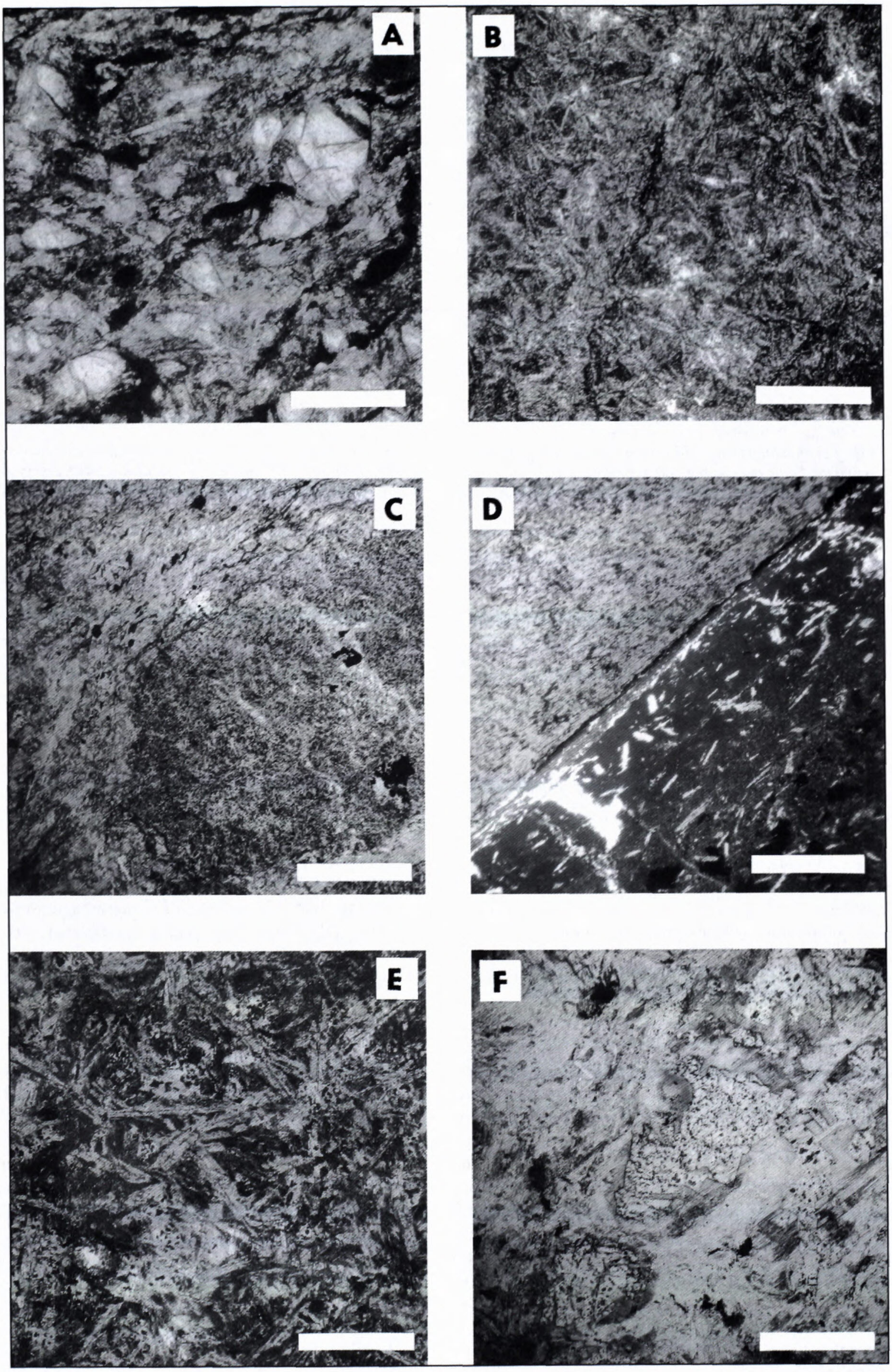
Glaucophanites with primary fine-ophitic to intersertal texture are markedly blue, fine-grained rocks, sometimes with isolated bright spots. In thin section they are characterised by preserved brown pigment after decomposed clinopyroxene or after volcanic glass, in which needles of the original plagioclase, arranged in ophitic texture, occur as ghosts (Fig. 3B). After solidification, the rocks with this texture were subject to low-grade alteration and pervasive veining with thin carbonate veinlets. In the proximity of veinlets they have been slightly replaced by albite and carbonate, while the remaining part was mostly chloritised. In the high-pressure stage of alteration chlorite was replaced by glaucophane, epidote. Fe-Ti pigment is also present. Relict clinopyroxene was altered through the intermediate stage of Na-pyroxene. Bright spots are composed of relict clinozoisite, less by albite and carbonate.

Variolitic texture in metabasalts from the Radzim Hill is preserved in the ghost form only. The original fan-shaped intergrowths of clinopyroxene and plagioclase are displayed by the distribution of Fe-Ti pigment. Chloritisation and pervasive veining of the rock by thin carbonate veinlets following the solidification are the reason why after HP/LT metamorphism the mineral composition is formed just by the pigment and by an aggregate of glaucophane, cut by a network of epidote veinlets.

Mechanical disintegration during solidification of metabasalts is manifested by the presence of rare metahyaloclastites to lava breccias, still with discernible ghost textures in individual fragments, such as fine-ophitic, intersertal and vitritic textures. The rock already contains just the assemblage of metamorphic minerals, where the fragments of the original basalt contain chlorite, albite and actinolite, minor glaucophane and carbonate, cemented by carbonate, albite, actinolite and glaucophane. Older actinolite is rimmed by glaucophane.

On the eastern end of the Radzim Hill (Hôra Saddle) and on the NE slope of the Spúšťadlo Hill (860.3m) a belt of HP/LT metamorphosed rocks is present, penetrated by a dense network of predominantly epidote veinlets. Microscopic study proved the preserved ghosts of primary vitritic

Fig. 3: Relict magmatic textures in metabasalts and metagabbro of the Hačava Fm. (Bôrka Nappe). Scale bar in all photos represents 1mm. A – Strongly deformed, formerly ophitic texture of metabasalt with preserved magmatic clinopyroxene (white crystals). Clinozoisite/epidote, glaucophane and leucoxenized ilmenite are other minerals composing this rock. Radzim Hill, sample VVS-6, II N. B – Relict intersertal texture in HP/LT metamorphosed fine-grained basalt. Radzim Hill, sample VVS-14, II N. C – Fine-grained basalt clast with originally intersertal texture in altered, strongly oriented, formerly mostly glassy basalt – probably quenched, most external part of a basaltic lava flow, metamorphosed in HP/LT conditions. Kobeliarovo village, 1 km N, sample VVS-127, II N. D – Basaltic lava chilled margin preserved on the contact of fine-grained basalt and probably altered surface of an older basalt, all metamorphosed in HP/LT conditions. Originally chilled margin with relict vitritic texture, containing sporadic plagioclase phenocrysts, is formed mostly by glaucophane. The rock on the contact is composed of glaucophane, epidote and white mica. Podježovec Saddle, sample VVS-142, II N. E – HP/LT metamorphosed basalt with ghost ophitic texture displayed mostly due to the fine Fe-Ti oxide pigment. Original magmatic assemblage was replaced by glaucophane, epidote and chlorite. Small amount of Na-Ca pyroxene as a transition metamorphic phase is also present. Štítnik village, 2 km NE, sample VVS-173, II N. F – Relict gabbro texture of HP/LT metamorphosed gabbro. Relict magmatic clinopyroxene was replaced by Mg-chlorite with impregnation of small titanite crystals. Older amphiboles, created at the expense of clinopyroxene, were replaced by glaucophane as well as plagioclase, replaced by fine-grained glaucophane aggregate. Šugov Valley, sample VHA-37, II N.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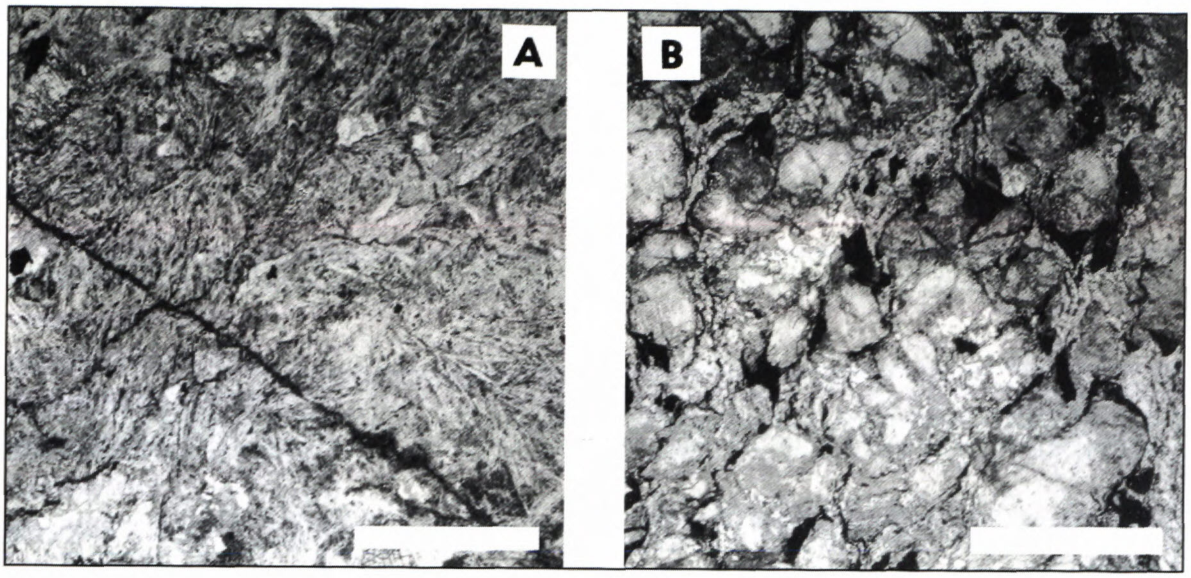

Fig. 4: Relict magmatic textures in metabasalts of the Hačava Fm. (Bôrka Nappe) formed on the contact with carbonaceous sediment. Scale bars in both photos represent 1 mm. A – Ghost variolitic texture in the basalt from the contact with carbonaceous sediment, fully replaced by carbonate. Lúčka village, 1 km E, sample FBO-40, II N. B – HP/LT metamorphosed peperite. Clasts of basaltic glass were chloritised (light grey) or devitrified (grey, pigmented) and then partly replaced by glaucophane (medium grey). Carbonate matrix was mostly replaced by epidote. Zádiel Valley, sample FBO-34, II N.

texture of basalt (mostly by the distribution of fine Fe-Ti pigment), locally with tiny fragments of fine-crystalline basalt. The subsequent hydrothermal alteration caused pervasive veining probably with carbonate veinlets and, in part, also the deformation of the rock. Glassy parts were replaced by chlorite. During high-pressure stage an aggregate of fine individuals of Na-amphibole (glaucophane) with divergent arrangement originated instead of chloritised glass. In fine-crystalline fragments albite, together with glaucophane, also originated. Carbonate in veinlets was prevailingly replaced by epidote. Similar rocks have been found as enclaves in sericite phyllites in the area northwards from the Kobeliarovo village (Fig. 3C).

Ježovec Saddle (NW of Kobeliarovo village)

Relict magmatic textures of HP/LT metamorphosed basalts from this locality are close to textures from the Radzim Hill. Medium- and fine-grained subophitic/ ophitic texture, intersertal texture and chilled margin with vitritic texture and with tiny sporadic phenocrysts of plagioclase, originally formed at the contact with thin layer of sediment or heavily altered basalt, were identified (Fig. 3D). Textures of fine-grained rocks are preserved just as ghosts by the distribution of Fe-Ti pigment, more coarse-grained rocks also with a specific distribution of metamorphic minerals. Original clinopyroxenes were pseudomorphosed by chlorite, in which glaucophane crystals occur as blasts. Plagioclase laths were replaced by albite, clinozoisite/epidote and fine-grained aggregate of white mica. Compared to rocks from the Radzim Hill, in the period before high-pressure phase these rocks were metamorphosed in the greenschist facies coupled with moderate spilitisation.

Štítnik village

In the area eastward from the Štítnik village two small bodies of HP/LT metamorphosed basic rocks are known. The rocks of the more eastern body are represented by HP/LT basalts with the best preserved relict textures among the all studied localities. Glomeroophitic, intersertal and variolitic textures have been determined. They have been identified based on the distribution of Fe-Ti pigment as well as products, that replaced the original magmatic clinopyroxenes – e.g. relicts of Na-Ca pyroxenes. Basalts with glomeroophitic texture were composed of laths of skeletal plagioclase up to 3 mm long, among whose fan-shaped aggregates of clinopyroxene were present (Fig. 3E). More fine-grained varietes had analogous texture; however, they contained sporadically present phenocrysts of plagioclase. Even more fine-grained rocks were characterised by variolitic, locally also intersertal textures with sporadic phenocrysts of plagioclase and scattered gas cavities. Metamorphic texture, on which mostly glaucophane, less also epidote and chlorite participated, does not respect the original texture. HP/LT metamorphosed radiolarites also occur with metabasalts. It seems that before the high-pressure stage of metamorphism basalts were affected just by minimum alteration. In the more western body pervasive veining and alteration caused that magmatic textures were obliterated.

Lúčka and Bôrka villages

In the area between the Lúčka and Bôrka villages HP/LT metamorphosed magmatic rocks are represented by basalts, those effusions occurred in an environment with carbonate sedimentation. Extensive hydrothermal alteration was the reason for an apparent recrystallisation and the origin of metamorphic textures during the HP/LT stage of alteration. Relict breccia-type texture of lavas or variolitic texture (Fig. 4A) were preserved just thanks to the nearly total replacement by hematite or carbonate on the contact of the lava with carbonaceous mud, probably immediately after solidification. Rarely identified primary ophitic or subophitic texture in the centre of bigger bodies can be predicted based on spatial distribution of albite and epidote crystals and white mica, partially following the original plagioclase.

Zádiel Valley

HP/LT metamorphosed rocks from this locality are a direct eastern continuation of the occurrences near the Bôrka village. From the relatively well preserved primary texture it is clear that peperite, pervasively veined and hydrothermally altered still before the high-pressure stage of metamorphism, was their protolith. Differences in the mode of crystalisation and alteration are the reasons for the current variable composition of individual clasts (Fig. 4B).

Hačava village

The biggest body of HP/LT metamorphosed magmatic rocks of the Meliatic Unit is located northwards from Hačava. Primary magmatic textures are preserved especially in its western part, while the recrystallisation and preferential orientation increase in direction to the east, so that the original textures can be difficult to identify. The body was originally composed mostly of doleritic basalts with subophitic texture. In massive varieties with relict subophitic texture also laths after original plagioclase, up to 3 mm large, are macroscopically observable. The texture is noticeable also macroscopically, despite its complex metamorphic evolution (Ivan and Kronome, 1996). The spaces after original laths of plagioclase are usually filled by aggregate of short columnar crystals of epidote, in some samples also by fine-laminar aggregate of mica. Spaces between the laths (also between the epidote crystals) are filled mostly by glaucophane. In a part of the epidote aggregates fan-shaped aligned pigment is preserved, indicating the original replacement of plagioclase by prehnite. Glaucophane among the original laths is extensively variably coloured. Dark blue parts rich in riebeckite often have subhedral habitus and enclose needles and pigment of Ti-minerals (originally sagenite). They probably originated after older, Ti-bearing, amphiboles and are enclosed or overgrown by pale blue glaucophane. Bright glaucophane also replaces older actinolite and chlorite. Magmatic clinopyroxene is preserved just rarely in the form of relicts, partially replaced by metamorphic pyroxene – aegirine (c.f. Faryad, 1997). Ilmenites usually preserved their primary magmatic shape, but they were totally replaced by leucoxene. Preferentially oriented types of glaucophanites originated by the deformation of basalts still in the time, when they contained plagioclase replaced by prehnite. They contain garnet, formed at the expense of clinozoisite which was created after prehnite during the metamorphic evolution.

Occasionally, metabasalts with primary vitritic texture, probably representing metamorphosed chilled margin of a basalt body, have been found. Petrographically, these rocks are identical to the above-described case. Chilled margins appear to have been created at the contacts with older basic magmatic rock.

Šugov Valley

The bodies of HP/LT metamorphosed rocks, located in the northern part of the Hačava Fm. belt, are represented by metabasalts that erupted into carbonate environment and similarly, as in the case of the locality Bôrka, the primary magmatic textures are not preserved due to the extensive hydrothermal alteration. Fine fragments and short lenses of basic material of centimetres size, conformably embedded in massive carbonates, were subject to extensive recrystallisation (Reichwalder, 1973). Just in rare cases, in samples heavily impregnated by hematite pigment, it was possible to find out that they originally represented strongly fractured and brecciated basalt with vitritic to intersertal texture.

In the southern part of the Hačava Fm. rock belt metamorphosed doleritic basalts occur with heavily deformed subophitic texture. They represent eastern continuation of the analogous rocks from Hačava. Relatively coarse-grained rocks (grain size 6 mm), originally with gabbroic texture, have been determined here too. Magmatic mineral assemblage in this rock was originally composed of pyroxene, plagioclase and ilmenite. Relicts of brown, green and colourless amphibole are the result of rock alteration accompanied by decreasing temperature during the oceanic ridge type of metamorphism, still before the high-pressure stage of metamorphism. The crystallisation of amphiboles occurred on intergranulars and fissures in direction towards the interior of clinopyroxene crystals. The relicts of clinopyroxenes werefinally chloritised. During the HP/LT metamorphism a part of the amphiboles (actinolites) were replaced by glaucophane. The aggregate of fine needles of glaucophane together with brownish pigment, replaces also the original plagioclase (Fig. 3F). The rock also contains small grains of ilmenite, replaced by leucoxene, and accessory zonal turmaline. In the belt of HP/LT metamorphosed phyllites and black shales also a small body of fine-grained metabasalt with well-preserved subofitic texture was found. Plagioclase laths were replaced by finegrained aggregate of clinozoisite/epidote. Clinopyroxene was replaced by glaucophane.

Bôrka Nappe – Kobeliarovo Fm.

Primary textures of metamorphosed magmatic rocks of the Kobeliarovo Fm. are usually well identifiable, although these rocks, compared to Hačava Fm. rocks, were furthermore affected by retrogression up to the greenschist facies conditions. Their characteristic features are massive texture, blue-green to green colour and impregnation by magnetite octahedrons up to 1 mm in size.

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Žiar Hill

Relict magmatic textures of majority of the studied basic rocks from this area are manifested also macroscopically (Fig. 5A). Subophitic and doleritic textures are dominant, but hyaloclastites have been also found. Metabasalts to dolerites, that had primary clinopyroxene-plagioclase composition with abundant content of ilmenite, have also a similar association of metamorphic minerals. Original plagioclase laths are replaced by aggregate of randomly oriented epidote columns of no preferential orientation, albite and white mica in interstices. On the place of the original clinopyroxene, aggregate of bluish actinolite, rich in Na, with minor chlorite and relict riebeckite, are present. Primary euhedral ilmenite is totally replaced by leucoxene. Small aggregates of albite grains, rare stilpnomelane and carbonate are also present. Magnetite forms individual octahedrons of various sizes, less often their aggregates (Fig. 5B). Some rocks were subject to more extensive albitisation or carbonatisation probably still before the HP/LT metamorphism. Metamorphosed basic rocks located in carbonates did not preserve relicts of primary magmatic textures. Hyaloclastites with ghost texture, formed by tiny crystals of magnetite, are an exception (Fig. 5C).

Dobšiná town

Unlike the Žiar Hill area, relict magmatic textures preserved in rocks from the vicinity of the Dobšiná town are more variegated and indicate an important abundance of fine-grained basalts. Subophitic, glomeroophitic and variolitic textures have been determined. Similarly as in the above cases, they are usually preserved just as ghost textures, displayed by the distribution of Fe-Ti pigment as well as by metamorphic minerals. The metamorphic mineral assemblage is identical to the previous case, but instead of riebeckite, relict glaucophane is present. Basalts were metamorphosed together with associated radiolarites.

Bodva Valley Ophiolite Fm.

Mineralogical, petrographical and metamorphic characteristics of multistage metamorphosed basic rocks of this formation were published by of Horváth (1997; 2000). Primary magmatic textures, such as gabbrodoleritic, doleritic and subophitic, are well preserved despite complex relations among associations of metamorphic minerals, produced by several metamorphic stages (Fig. 5D). Laths and columns of magmatic plagioclase consist of relicts of prehnite and fine-grained clinozoisite to epidote replacing the prehnite, further accompanied by albite. Aggregate of uralite, impregnated by small grains of magnetite, is probably the result of direct alteration of clinopyroxene relicts. However still before, during the oceanic ridge metamorphism, clinopyroxene was extensively overprinted by several generations of amphibole (brown, greeen, greenish) in direction from intergranulars grains. The growth of amphiboles continued also during the HP/LT metamorphic stage, but owing to the retrogression just riebeckite was preserved and glaucophane was replaced by bluish actinolite with higher. Na content. Mainly at contacts of the original plagioclase and pyroxene newly formed chlorite, epidote and titanite are present. Abundant euhedral crystals of primary ilmenite are totally replaced by leucoxene.

Gosau-type conglomerates

In Cretaceous conglomerates from the Dobšinská Ľadová Jaskyňa settlement eight pebbles of HP/LT metamorphosed basic rocks have been already found, from which only two have preserved the primary magmatic texture. Ophitic texture of the first one is possible to identify based on the arrangement and unequal size of original plagioclase laths, replaced by fine-grained aggregate of clinozoisite/epidote, albite and glaucophane in variable ratio (Fig. 5F). Clinopyroxene was replaced by amphibole still before the high-pressure stage of alteration, because between original plagioclase laths zoned

Fig. 5: Relict magmatic textures in metabasalts of the Kobeliarovo Fm., Bodva Valley Ophiolite Fm. and Gosau-type Cretaceous conglomerates from Dobšinská Ľadová Jaskyňa settlement. Scale bars in all photos (except A) represent 1 mm.
A – Macroscopic visible relict doleritic texture of multi-stage metamorphosed dolerite of the Kobeliarovo Fm. Žiar Hill, sample VVS-47. B – relict ophitic texture preserved in HP/LT metamorphosed basalt, retrogressed into LP/LT conditions. Original plagioclase laths are replaced by aggregate of albite and plenty of small columnar crystals of epidote. Bluish actinolite, chlorite, white mica, leucoxene and magnetite are also present. Žiar Hill, sample VVS-46, II N. C – Metahyaloclastite composed of originally glassy clasts with sporadic plagioclase and/or clinopyroxene phenocrysts in carbonaceous matrix, fully transformed into magnetite-chlorite-albite-carbonate rock. Žiar Hill, sample VVS-99, II N. D – Multi-stage metamorphosed gabbro-dolerite of the Bodva Valley Ophiolite Fm. with relict dolerite texture. Magmatic plagioclase laths or columns were replaced by prehnite which is further transformed into clinozoisite/epidote and albite. Clinopyroxene is replaced by several types of amphibole and partly also by chlorite. Szögliget, borehole Szö-4, 154.8 m, sample VM-21, II N. E – HP/LT metamorphosed fine-grained basalt with ghost intersertal texture, displayed by distribution of Fe-Ti oxide pigment. Small laths of original plagioclase are still discernible. Clast in Cretaceous conglomerate. Dobšinská Ľadová Jaskyňa settlement, sample DĽJ-52, II N. F – HP/LT metamorphosed basalt with relict ophitic texture. Clinopyroxene was replaced by chlorite and actinolite, and then actinolite was rimmed by glaucophane during high-pressure metamorphic stage. Plagioclase laths were replaced by glaucophane, clinozoisite/epidote and albite. Primary ilmenite crystals were leucoxenized (black). Clast in Cretaceous conglomerate, Dobšinská Ľadová Jaskyňa settlement, sample DĽJ-63, II N.

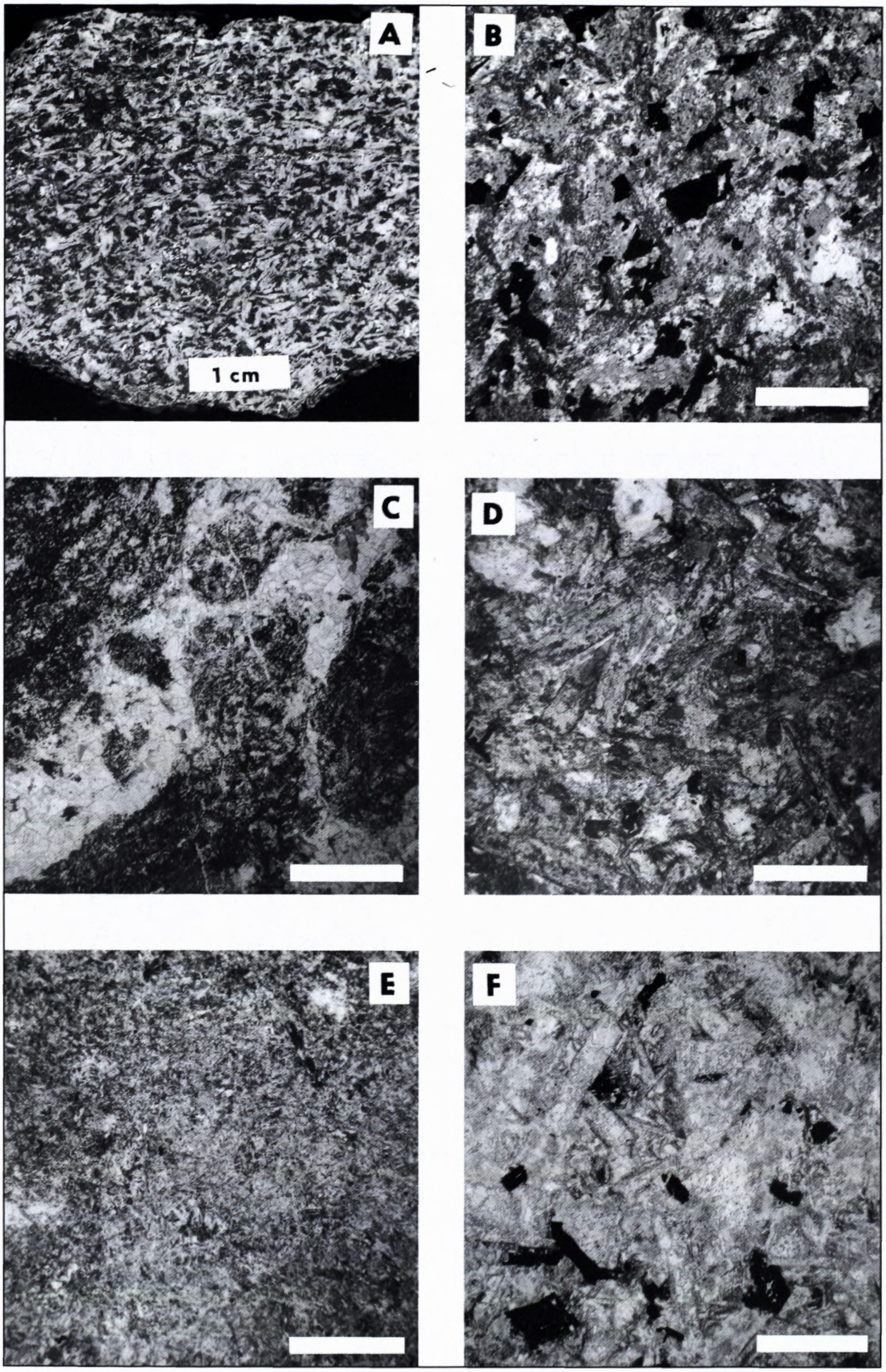
A
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Table 1: Analyses of relict magmatic clinopyroxenes from HP/LT metamorphosed basalts from the Radzim Hill (Hačava Fm., Bôrka Nappe). Analysis of a metamorphic Na-Ca pyroxene is added for comparison (analysis no. 15).

Sample	VVS-6								VVS-16						
Analysis	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SiO_2	54.42	51.46	53.02	51.02	51.22	50.96	50.90	53.17	53.03	49.60	52.90	54.12	54.31	53.30	56.13
TiO_2	0.46	1.06	0.35	0.84	0.94	1.07	0.83	0.41	0.55	1.52	0.78	0.36	0.54	0.59	0.08
Al_2O_3	1.68	3.33	1.91	3.82	3.67	4.17	4.15	2.21	1.68	3.74	3.59	1.90	1.62	1.74	6.76
FeO^t	7.43	8.60	6.16	6.98	7.85	7.07	6.74	6.60	8.62	10.90	5.98	5.72	8.83	9.89	9.95
MnO	0.20	0.21	0.24	0.00	0.00	0.00	0.00	0.00	0.27	0.27	0.13	0.22	0.29	0.31	0.15
MgO	18.22	15.23	18.22	15.56	15.66	15.58	15.68	17.52	16.52	13.94	16.66	17.78	17.14	16.20	6.94
CaO	17.88	19.13	18.14	21.20	20.69	20.91	20.73	19.64	18.28	18.62	20.18	19.67	17.83	16.56	12.34
Na_2O	0.26	0.46	0.49	0.61	0.43	0.53	0.54	0.46	0.32	0.49	0.33	0.28	0.34	0.39	8.17
K_2O	0.00	0.00	0.00	0.08	0.12	0.09	0.09	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cr_2O_3	0.00	0.00	0.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.00	0.00	0.00	0.00
Total	100.55	99.48	98.75	100.11	100.58	100.38	99.66	100.12	99.27	99.08	100.67	100.05	100.90	98.98	100.52
Si	1.973	1.913	1.956	1.884	1.887	1.876	1.883	1.945	1.966	1.876	1.920	1.968	1.976	1.982	2.004
Al^{IV}	0.027	0.087	0.044	0.116	0.113	0.124	0.117	0.055	0.034	0.124	0.080	0.032	0.024	0.018	0.000
Al^{VI}	0.045	0.059	0.039	0.050	0.046	0.057	0.064	0.040	0.039	0.043	0.073	0.049	0.045	0.058	0.285
Ti	0.012	0.030	0.010	0.023	0.026	0.030	0.023	0.011	0.015	0.043	0.021	0.010	0.015	0.017	0.002
Fe^t	0.225	0.267	0.190	0.216	0.242	0.218	0.209	0.202	0.267	0.345	0.182	0.174	0.269	0.307	0.297
Mn	0.006	0.006	0.008	0.000	0.000	0.000	0.000	0.000	0.009	0.009	0.004	0.007	0.009	0.010	0.005
Mg	0.985	0.844	1.002	0.857	0.860	0.858	0.865	0.955	0.913	0.786	0.901	0.964	0.929	0.898	0.369
Ca	0.695	0.762	0.717	0.839	0.816	0.825	0.822	0.770	0.726	0.755	0.785	0.766	0.695	0.660	0.472
Na	0.019	0.033	0.035	0.044	0.031	0.038	0.039	0.033	0.023	0.036	0.023	0.020	0.024	0.028	0.566
K	0.000	0.000	0.000	0.004	0.005	0.004	0.004	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cr	0.000	0.000	0.006	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.000	0.000	0.000	0.000

Note: Analyses were performed by electron microprobe Jeol 733 (Geological Survey of the Slovak Republic) using following conditions for measuring: 15 kV, 2 . 10^{-8} A, ZAFO; standards Na,Al- albite, Ca- wollastonite, Mg- MgO, Mn- willemite, Fe,Cr- chromite, Ti- TiO_2.

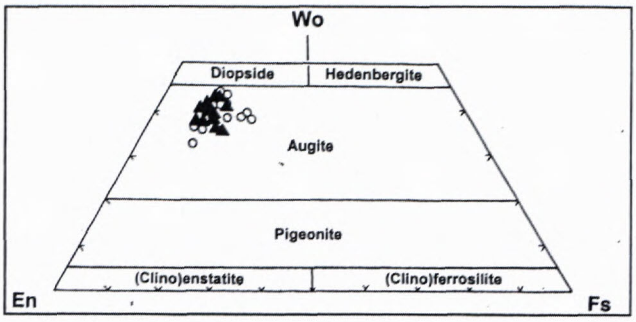

Fig. 6: Relict magmatic clinopyroxenes from HP/LT metamorphosed oceanic basalts of the Bôrka Nappe in the classification diagram by Morimoto et al. (1988). Clinopyroxenes from LP/LT metamorphosed oceanic basalts of the Meliata Unit from Jaklovce (Hovorka and Spišiak, 1988) are displayed for comparison (empty circles).

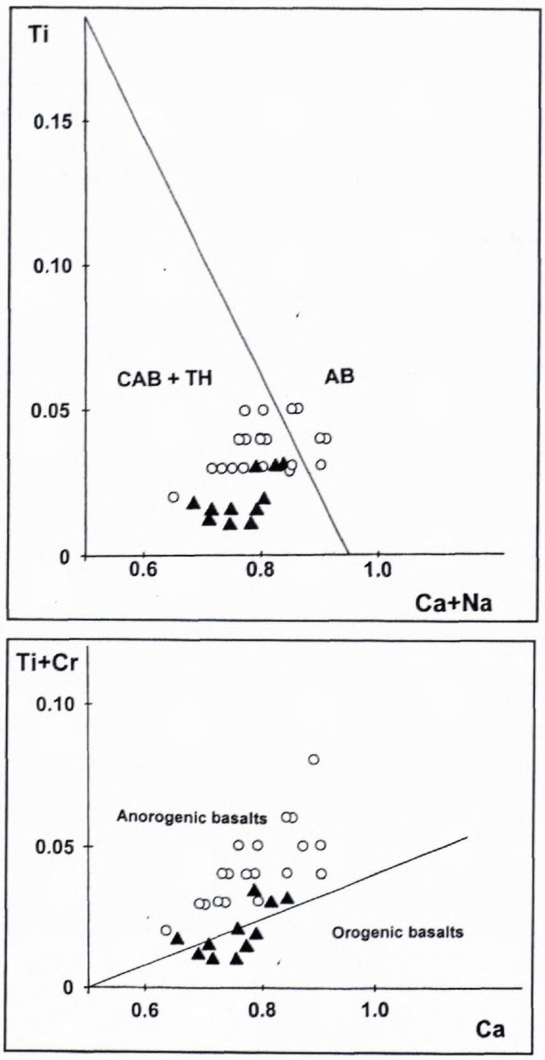

Fig. 7: Relict magmatic clinopyroxenes from HP/LT metamorphosed oceanic basalts of the Bôrka Nappe in discriminative diagrams by Leterrier et al. (1982). Clinopyroxenes from LP/LT metamorphosed oceanic basalts of the Meliata Unit from Jaklovce (Hovorka and Spišiak, 1988) are displayed for comparison (empty circles). A – Diagram Ca+Na vs. Ti (p.f.u.) discriminating clinopyroxenes from alkali basalts (AB) and calc-alkaline/ tholeiitic basalts (CAB/TH). B – Diagram Ca vs. Ti+Cr (p.f.u) for discrimination of clinopyroxenes from anorogenic and orogenic basalts.

amphibole crystals are predominantly presented. Actinolite in the centre rimmed by darker glaucophane with small inclusions of titanite is fringed by pale glaucophane without inclusions. Euhedral magmatic ilmenites were cataclastically deformed and affected by decomposition to leucoxene and magnetite.

Basic rock, forming the other rounded pebble, has preserved intersertal ghost texture (Fig. 5E). Major part of the rock is formed by metamorphic glaucophane.

Relict magmatic minerals in HP/LT metamorphosed rocks of the Meliata Ocean

Clinopyroxene is the only preserved magmatic mineral in HP/LT metamorphosed rocks of the Meliata Ocean. It was found on the localities Radzim Hill (Ivan and Kronome, 1996; Mazzoli and Vozárová, 1998) and Hačava village (Faryad, 1997). We have studied it in detail on the locality Radzim Hill.

Analyses of selected clinopyroxenes are shown in table 1. According to the classification of Morimoto et al. (1988) pyroxenes display augite composition (Fig. 6) identical to the composition of clinopyroxenes from the best preserved LP/LT metamorphosed oceanic basalts of the Meliata Ocean from Jaklovce (Meliata Fm.). Some of the clinopyroxene grains shows zoning; slightly increased contents of Al_2O_3 and TiO_2 are typical for grain margins.

The application of discriminative diagrams by Leterriér et al. (1982) showed that pyroxenes from both compared localities have composition closer to pyroxenes

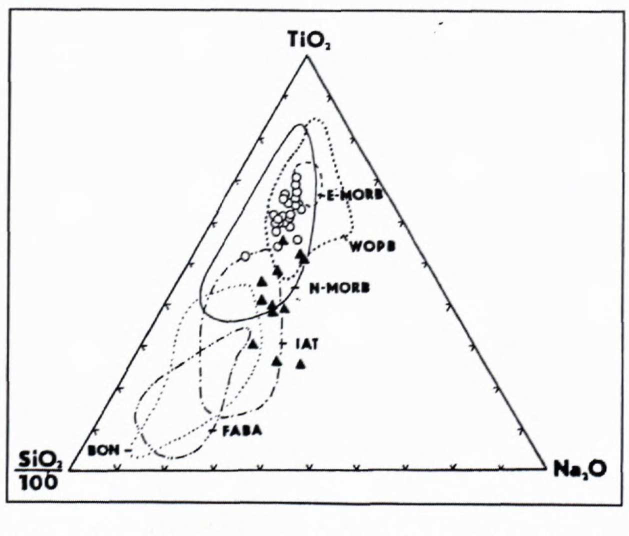

Fig. 8: Relict magmatic clinopyroxenes from HP/LT metamorphosed oceanic basalts of the Bôrka Nappe in TiO_2-$SiO_2/100$-Na_2O discriminative diagram (Beccaluva et al., 1989). Clinopyroxenes from LP/LT metamorphosed oceanic basalts of the Meliata Unit from Jaklovce (Hovorka and Spišiak, 1988) are displayed for comparison (empty circles). More „arc-like" character of metabasalts from the Bôrka Nappe seems to be apparent. Explanations: E-MORB- enriched mid-ocean ridge basalts, N-MORB- normal mid-ocean ridge basalts, WOPB- within oceanic plate basalts, IAT- island arc tholeiites, FABA- intraoceanic fore-arc basaltic andesites and andesites

from tholeiite or calc-alkaline basalts than to pyroxenes from alkaline basalts (Fig. 7A). In a similar way, pyroxenes from the Radzim Hill appear to be closer in composition to pyroxenes from orogenic basalts, in comparison to clinopyroxenes from the Meliata Fm. which are similar respond to pyroxenes of anorogenic basalts (Fig. 7B).

In the discriminative diagram of Beccaluva et al. (1989) clinopyroxenes from the Radzim Hill are projected more to the field of island-arc tholeiites (IAT), while clinopyroxenes from the Meliata Fm. respond to normal basalts of mid-oceanic ridges, although an overlap with the field of within-ocean plateau basalts (E-MORB) occurs here too.

Differences in composition between relict magmatic augites and metamorphic acmites are apparent from table 1 and they are most evident in Na and Ti contents.

Discussion

HP/LT metamorphosed rocks, as a reliable indicator of subduction, have been extensively studied especially during the last three decades. Despite of that, references about preserved primary magmatic textures and minerals in these rocks are not very frequent. For instance, they are known from Franciscan melange (California), already described by Coleman and Lee (1963) and later also by Maruyama and Liou (1987, 1988) and Liou and Maruyama (1987). According to Coleman and Lee (1963), in the HP/LT metamorphosed rocks, pillow structures are preserved with hyalophitic to subophitic texture in the centre of pillows and variolitic and tachylitic texture on their rims. In Sanbagawa belt (Japan) Maruyama and Liou (1985) found well preserved not only the original volcanic rocks (pillow lavas, hyaloclastites and feeding dykes) but also original textures (ophitic, subophitic, intersertal and intergranular). Similar phenomenons are also known from HP/LT metamorphosed rocks from Mikabu and Chichibu belts (Japan; Suzuki and Ishizuka, 1998), from Susunai complex (SE Sachalin, Sakakibara et al., 1997), from Betic cordillera (Spain, Morata et al., 1994) and others. Furthermore, similar textures were also preserved in HP/LT rocks from Mariana forearc, that are the only example of high-pressure metamorphosed rocks in recent subduction zones so far Yamamoto et al. (1995). In all the above mentioned examples relict magmatic clinopyroxenes are also presented.

Relict magmatic textures, well preserved in most of the HP/LT metamorphosed basic rocks of the Hačava and Kobeliarovo Formations of the Bôrka Nappe, allow exact characteristic of the magmatic protolith of these rocks, the setting where they cooled and also their positions in the original Meliata Ocean basin. The composition of relict pyroxenes together with whole-rock geochemical data specify the geodynamic setting of magma generation. These data together with the determined details on metamorphic evolution significantly contribute to solving of complicated problems of origin, evolution and cessation of the Meliata Ocean.

Based on the above data the studied HP/LT metamorphosed rock can be divided into two different groups, formed in two different stages of opening of the Meliata Ocean. Metabasalts from the localities Šugov Valley, Zádiel Valley, Lúčka and Bôrka and occurrences on the western slope of the Žiar Hill belong to the first group that erupted synchronously with carbonates sedimentation. Magma extrusions into the environment of carbonaceous mud caused mechanical disintegration of the quickly cooling lava and the generation of hyaloclastites. Carbonaceous setting was the reason for extensive subsolidus alteration, related to the crystallisation of hematite. These basalts appear formed in initial stages of opening of the Meliata Ocean to be which was interpreted as a back-arc basin (c.f. Stampfli, 1996; Ivan and Kronome, 1996). This is also supported by their geochemical characteristics that suggest the origin from a fractionated basaltic lava of arc signature (Ivan, 2000; Ivan, in print).

The second group is formed by rocks that originated in more advanced (early) stage of opening of the back-arc basin, when the basin already started to be deeper, probably below to the level of CCL. In the basin they originated as a component of the upper part of a magmatic crust which was similar by its features to the typical oceanic crust produced in oceanic rifts. Metabasalts at the localities Radzim Hill, Ježovec Saddle, Štítnik and Dobšiná originated as the uppermost part of the oceanic crust rock sequence of the Meliata Ocean basin. Variegated magmatic textures, preserved in relicts in HP/LT metamorphosed basalts in the western part of the locality Radzim Hill, and their changes observable within a single sample indicate that these basalts were probably extruded as pillow lavas. Vitritic to breccia-type textures in the eastern part of this locality would suggest that thin lava floods and/or ropy lavas were also probable. The composition of relict pyroxenes, compared to pyroxenes from LP/LT metamorphosed basalts of the Meliata Fm. from Jaklovce, indicate a still apparent influence of the arc-like mantle source on the composition of the parent rock. Identical results have been also obtained based on the study of the distribution of trace elements: while metabasalts from Radzim Hill can be still classified as BABB, those from Jaklovce are already close to typical oceanic N-MORB (Ivan, 2000; Ivan, in print). Similar conclusions are valid also for the other mentioned localities. While on the localities Radzim Hill and Ježovec Saddle no sedimentary rocks, originated simultaneously with metabasalts, have been proved, at the localities Štítnik and Dobšiná they accompany metamorphosed radiolarites that prove deep-sea setting of their origin.

Metamorphosed doleritic basalts from the area of Hačava originated in subvolcanic conditions. Sporadic occurrence of samples, representing original chilled margins, indicates that these basalts could originate as a part of a sheeted-dyke complex. This assumption is also supported by indications of the metamorphism of oceanic ridge type. Geochemically, they can be characterised as close to BABB (Ivan, 2000; Ivan, in print). Metadolerites from the area of Žiar Hill also crystallised in subvolcanic conditions from a fractionated basaltic magma, but necessary data for a closer identification of the setting of their origin are still missing.

Among the studied samples, metagabbros from Šugov Valley represent the relatively deepest part of the oceanic rock sequence of the Meliata Ocean crust. Their relict texture and composition remind of isotropic ophiolite gabbros from the upper part of the gabbro complex. Such an origin is also suggested by the well-preserved manifestations of the metamorphism of oceanic ridge type.

All the presented differences among individual occurrences of HP/LT metamorphosed magmatic rocks of the Hačava and Kobeliarovo Formations of the Bôrka nappe confirm that they represent independent fragments of the Meliata Ocean basin floor. The presence of just the upper parts of the oceanic crust in these fragments can be the result of their peeling in an accretion prism by a mechanism similar to that described by Kimura and Ludden (1995). In both formations not only magmatic rocks but also all other rocks i.e. pelitic sediments, carbonates or radiolaritic cherts were affected by HP/LT metamorphism (c.f. Faryad, 1995b). Therefore it seems to be probable that in this case a melange, formed in an accretion prism, was subject to metamorphism in the subduction zone. Than, different conditions of exhumation caused that a part of the melange does not take any signs of retrogression (Hačava Fm.), while an another part was equilibrated in greenschist facies conditions (Kobeliarovo Fm.).

Fragments of metamorphosed dolerites to gabrodolerites from the Bodva Valley Ophiolite Formation, incorporated into evaporites, differ from metamorphosed basic rocks from the Bôrka nappe by their geochemical characteristics – they represent the products of a fractionated magma close to the enriched, mid-oceanic rift basalts (E-MORB). Furthermore, geochronological data from analogous rocks of this formation, that do not contain relicts of high-pressure phase minerals, suggest an older age of metamorphism than it is the supposed Middle Triassic age of the opening and spreading of the Meliata Ocean (Horváth, 2000). It can not be excluded that they represent inicial stage products of the origin of this ocean.

Clasts of HP/LT metamorphosed rocks from the Createcous Gosau-type conglomerates occur together with clasts of rocks of virtually complete ophiolite sequence, but also with rhyolites and calc-alkaline basaltic andesites. The nappes of the Jurassic melange of an analogous type as it represents the Meliata Fm. were probably the source of this recycled material (Ivan et al., 1999).

Conclusions

Based on the detailed study of HP/LT metamorphosed basic magmatic rocks, regarded as relicts of oceanic crust of the Triassic-Jurassic Meliata Ocean, the following conclusions have been attained:

- Relicts of primary magmatic textures in HP/LT metamorphosed basic rocks of the Hačava and Kobeliarovo Formations of the Bôrka Nappe, Bodva Valley Ophiolite Formation and pebbles of these rocks from Cretaceous conglomerates near Dobšinská Ľadová Jaskyňa are mostly well preserved.
- In these rocks magmatic textures are preserved as ghost textures, mainly formed by distribution of fine Fe-Ti pigment, less often by a specific distribution and orientation of metamorphic minerals.
- The obliteration of magmatic textures is the result of extensive hydrothermal alteration and pervasive veining shortly after the solidification or deformation during initial low-pressure stages of metamorphism in the subduction zone.
- The identified relict textures (gabbroic, doleritic, ophitic, subophitic, glomeroophitic, intersertal, variolitic, vitritic) reflect exclusively the variable speed of solicification of basaltic magma, while breccia-type and hyaloclastite textures are the result of the contact with a specific environment.
- The Bôrka Nappe contains two groups of magmatic rocks, originally related to the origin of the Meliata Ocean: (1) volcanic rocks, syngenetic with the carbonate sedimentation, related to the initial stage of the oceanic basin opening and (2) magmatic (volcanic, subvolcanic and intrusive) rocks, related to the more advanced (early) stage of the opening; volcanic rocks can be accompanied by radiolarites.
- Magmatic rocks of the more advanced stage probably already formed an oceanic type of crust with common magmatic stratification.
- Magmatic rocks of the Bôrka Nappe related to the Meliata Ocean formation were metamorphosed in HP/LT conditions in the form of blocks in mélange and were exhumed by two different ways.

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References

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.W., 1997: How many oceans? Meliata, Vardar, and Pindos oceans in Mesozoic Alpine paleogeography. Geology, 25, 183-186.

Coleman R.G. & Lee, D.E., 1963: Glaucophane-bearing metamorphic rock types of the Cazadero area, California. J. Petrology, 4, 260-301.

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

Faryad, S.W., 1995a: Phase petrology and P-T conditions of mafic blueschists from the Meliata Unit, West Carpathians. 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: Geological evolution of the Western Carpathians. Grecula P., Hovorka D. & Putiš M. (eds.):. Bratislava, Mineralia slov., Monogr., 131-144.

Faryad W.S. (1998): High-pressure metamorphic rocks of the Meliata Unit vs. Bôrka Nappe: Their correlation with blueschist pebbles in conglomerates from the Klape Unit of the Klippen Belt. (In Slovak with English summary). Mineralia slov., 30, 235-240.

Golonka J., Oszczypko N. & Ślączka, A., 2000: Late Carboniferous-Neogene geodynamic evolution and paleogeography of the circum-Carpathian region and adjacent areas. Ann. Soc. Geol. Polon., 70, 107-136.
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.
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. Geologica carpath., 51, 121-129.
Hovorka D., Ivan P., Mock R., Rozložník L. & Spišiak, J., 1990: Sediments of Gosau type near Dobšiná Ice Cave: ideas for their non-traditional interpretation. (In Slovak). Mineralia slov., 22, s. 519-525.
Hovorka D. & Spišiak J., 1988: Mesozoic volcanism of the Western Carpathians. (In Slovak with English summary). Bratislava, Veda, 264 p.
Hovorka D. & Spišiak J., 1998: Mesozoic Meliata ocean dismembered ophiolites. In: Geodynamic development of the Western Carpathians. M. Rakús edit. Bratislava, Geol. Survey Slovak Rep., 81-88.
Ivan P., 2000: Geochemical types of the basic metavolcanic rocks in the Meliatic Unit (inner Western Carpathians). (In Slovak). In: Geochemistry 2000. O. Ďurža a S. Rapant (eds). Konf. Symp. Sem., Bratislava, D. Štúr Publ., 31-34.
Ivan P., in print: Relicts of the Meliata ocean crust: An overview of the results of mineralogical, petrological and geochemical data and their geodynamic implications. Geologica carpath.
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. & Mello J., 2001: Tectonic subunits in the Bôrka Nappe (inner Western Carpathians): Their lithostratigraphy and original position in the structure of the ancient Meliata ocean basin. Geolines, 13, 64-65.
Ivan P., Méres Š. & Hovorka D., 1994: Oceanic crust in geological history of the Western Carpathian orogeny. Acta geol. Hung., 37, 19-32.
Józsa S.& Horváth P.,1996: Preliminary report on the metamorphic evolution of the Vardar-Meliata ophiolites, Bódva Valley area, NE Hungary. Abstract. In. Terranes of Serbia. The formation of the geologic framework of Serbia and adjacent regions. V. Knezevič & B. Krstič eds., Belgrade, 227-228.
Kamenický J., 1957: Serpentinites, diabases a glaukophanitic rocks from the Triassic of the Spišsko-gemerské rudohorie Mts. (In Slovak). Geol. Práce, Zoš., 45, 5-108.
Kimura G. & Ludden J., 1995: Peeling oceanic crust in subduction zones. Geology, 23, 217-220.
Kozur H. & Mock R., 1997: New paleogeographic and tectonic interpretations in the Slovakian Carpathians and their implications and correlations with the Eastern Alps and other parts of the Western Tethys. Part II: Inner western Carpathians. Mineralia slov., 29, 164-209.
Leterrier, J., Maury, R.C., Thoron, P., Girard, D. & Marchal, M. 1982: Clinopyroxene composition as a method of identification of the magmatic affinities of paleovolcanic series. Earth planet. Sci. Lett., 59, 139-154.
Liou J.G. & Maruyama, S., 1987: Parageneses and compositions of amphiboles from Franciscan jadeite-glaucophane type facies series metabasites at Cazadero, California. J. metamorph. Geol., 5, 371-395.
Maruyama S. & Liou J.G., 1985: The stability of Na-Ca pyroxene in low-grade metabasites of high-pressure intermediate facies series. Amer. Mineralogist, 70, 16-29.
Maruyama S. & Liou J.G., 1987: Clinopyroxene – a mineral telescoped through the processes of blueschist facies metamorphism. J. metamorph. Geol., 5, 529-552.
Maruyama S. & Liou J.G., 1988: Petrology of franciscan metabasites along the jadeite-glaucophane type facies series, Cazadero, California., J. Petrology, 29,1-37.
Mazzoli C. & Vozárová A.,1998: Subduction related processes in the Bôrka Nappe (inner Western Carpathians): a geochemical and petrological approach. In: Rakús M. (edit.): Geodynamic development of the Western Carpathians. Bratislava, Geol. Survey Slovak Rep., 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. (In Slovak). Bratislava, D. Štúr Publ., 1-255.
Mello J., Reichwalder P. & Vozárová A., 1998: Bôrka Nappe: high-pressure relict from the subduction-accretion prism of the Meliata ocean (Inner Western Carpathians, Slovakia). Slovak geol. Mag., 4, 261-273.
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.
Morata D., Puga E. & Aguirre, L., 1994: Na-metamorphic pyroxenes in low-grade metabasites from the External Zones of the Betic Cordilleras (southern Spain): influence of rock chemical composition on their formation. Rev. geol. Chile, 21, 269-283.
Morimoto, N. et al., 1980: Nomenclature of pyroxenes. Mineral. Petrology, 39, 55-76.
Neugebauer J., Greiner B. & Appel E., 2001: Kinematics of the Alpine-West Carpathian orogen and palaeogeographic implications. J. geol. Soc., 158, 97-110.
Plašienka D., 2000: Paleotectonic controls and tentative palinspastic restoration of the Carpathian realm during the Mesozoic. Slovak geol. Mag., 6, 200-204.
Reichwalder P., 1973: Geology of the Late Paleozoic of the southwestern part of the Spišsko-gemerské rudohorie Mts. (In Slovak). Západné Karpaty, 18, 99-139.
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.
Sakakibara M., Ofuka H., Kimura G., Ishizuka H., Miyashita S., Okamura M. & Melnikov O.A., 1997: Metamorphic evolution of the Susunai metabasites in southern Sakhalin, Russian Republic. J. metamorph. Geol., 15, 565-580.
Suzuki S. & Ishizuka H., 1998: Low-grade metamorphism of the Mikabu and northern Chichibu belts in central Shikoku, SW Japan: implications for the areal extent of the Sanbagawa low-grade metamorphism. J. metamorph. Geol., 16, 107-116.
Schweigl J. & Neubauer F., 1997: Structural evolution of the central Northern Calcareous Alps: Significance for Jurassic to Tertiary geodynamics in the Alps. Eclogae geol. Helv., 90, 303-323.
Yamamoto K., Asahara Y.m, Maekawa H. & Sugitani K., 1995: Origin of blueschist-facies clasts in the Mariana forearc, Western Pacific. Geochem. J., 29, 259-275.