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Volcanic facies and hydrothermal processes in Triassic pillow basalts from the Darnó Unit, NE Hungary

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ABSTRACT

The Darnó Unit within the Zagorje-Mid-Transdanubian Megaunit is an allochtonous part of Dinarides in NE-Hungary and represents a relict of the Neotethyan accretionary complex. It contains blocks of submarine basalts of Triassic age in turbiditic sediments (olistrostrome) of Jurassic age. The lava clogged in the lime mud at the original site of volcanism and developed closely packed pillow, pillow fragment hyaloclastite breccia, and peperite facies. Interaction between the lava and the sea water produced mostly chloritic alteration of basalt and precipitation of hydrothermal calcite in amygdales, feeding channels of lava lobes and hyaloclastite breccia cements. Calcite is associated with chlorite, epidote, hematite and pyrite. Fluid inclusions in calcite infillings record conditions of fluid/rock interaction. Salinities of fluid inclusions (3.2–5.6 wt.% NaCl equiv. wt.%.) are close to the salinity of recent sea water and their homogenization temperatures are in the range of 80–150°C. Fluid inclusion data support interpretation that volcanic facies represent rapidly cooled distal zones away from the submarine volcanic centre. This is also confirmed by the comparison to the volcanic and hydrothermal alteration facies of the submarine basalt lava-flow complex and associated pillow lava formation of Triassic age in the Hruškovec quarry in the Kalnik Mts., NW-Croatia. The obtained data contribute to understanding of the early history of Neotethyan evolution, i.e. dilemma about rifting or oceanization in Triassic time and offer new aspects of correlation between units of Dinaridic origin which had been displaced from their original setting by large scale Tertiary tectonic processes.

Keywords: basalt pillow lavas, peperite, fluid inclusions, Triassic rifting, Darnó Unit, Zagorje – Mid-Transdanubian Megaunit, Dinarides, NE-Hungary, NW-Croatia

1. INTRODUCTION

The Darnó Hill is located in Northeast Hungary, in the western forelands of the Bükk Mountains (Fig. 1). The Reszél Hill and Mély Valley quarries are situated in this region, 10–15 km northwest from the town of Eger. The quarries expose pillow lavas, peperites and hyaloclastite breccias as a part of basaltic extrusions into deep water sediments.

A drilling project with three, 1200 m deep drill holes was completed in 1977–1979 in the Darnó Hill area. BALLA et al. (1980) found that the basaltic suite intercepted by those drillings is a result of an advanced rifting magmatism, rather than oceanization. DOWNES et al. (1990) discussed the Triassic age of the Darnó Hill igneous suite, and they distinguished it from the Szarvaskő Complex of Jurassic age in the Bükk Mountains (Fig. 1). DOSZTÁLY & JÓZSA (1992) argued that the age of the pillows is Triassic but the most probable option is their mid-oceanic ridge origin. The geochemical character of these mafic rocks is MORB-like, and the rocks are olistolithes in an olistostrome formation (HARANGI et al., 1996).

According to PAMIĆ (1997), the Kalnik Unit and the Darnó-Bükk Units can be correlated as a part of the Dinaridic ophiolitic complex within a Jurassic olistostrome mélange. DIMITRIJEVIĆ et al. (2003) interpreted the Darnó Unit as a

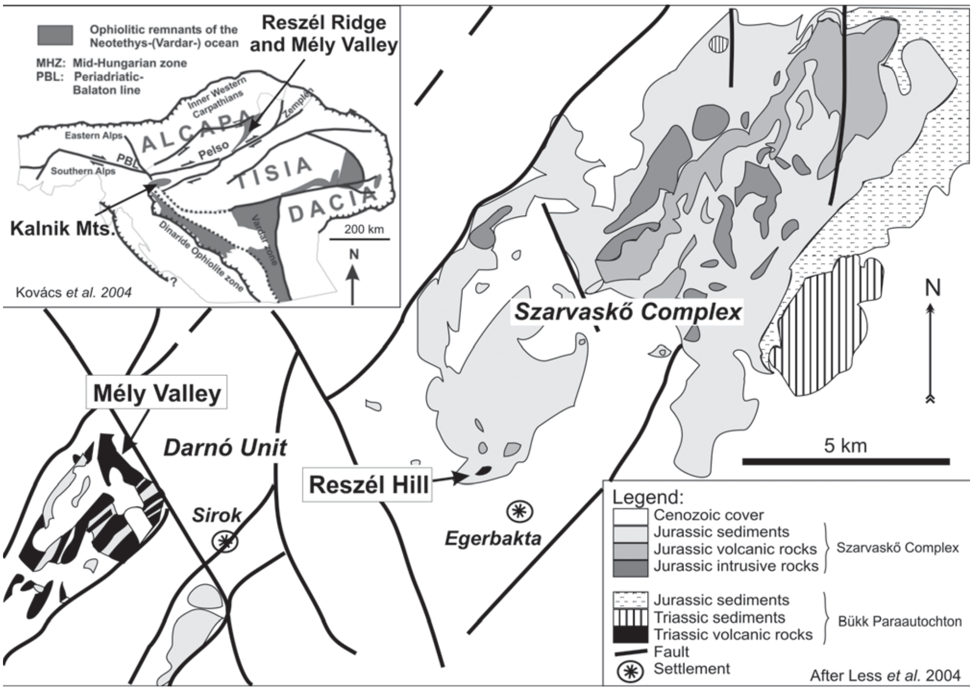

Figure 1: Sketch map of Zagorje-Mid-Transdanubian Mega-Unit, extruded along the two prominent regional fault lines, the Periadriatic-Balaton (PBL) and the Zagreb-Zemplén (ZZL) lineaments. Position of Reszél Hill and Mély-valley basaltic suites is within the Darnó Unit located in the western forelands of the Bükk Mts.

relict of the Neotethyan accretionary complex, which was displaced from the NW Dinarides to NE Hungary along the Zagreb-Zemplén Lineament; and shows similarity to the Dinaridic Ophiolite Belt (Fig. 1). Recent studies by HAAS et al. (2006) confirmed the earlier hypothetic palaeogeographical connection between these two regions during the Jurassic time. In addition, the possible correlation might be extended to the Hellenides (KOVÁCS et al., 2008).

Although, the correlation has been recognised, and confirmed by tectonical and geological evidences during earlier studies, we present a new approach of matching Triassic basalts of the Kalnik Mts. and Darnó Unit in this paper. The comparison is based on features pertained to the Darnó Hill area with those in the Hruškovec quarry, Kalnik Mts. (HALAMIĆ & GORIČAN, 1995; PALINKAŠ et al., 1998, 2000, 2008) and includes description of various facies of submarine basaltic volcanism and P-T-X characteristics of hydrothermal processes associated with the emplacement of basaltic rocks. This work offers a clue to the dilemma, whether the Darnó Hill basalts belong to the advanced rifting process or to the progressive oceanization of the Tethys in Triassic time.

2. METHODS OF STUDY

The major aspects of field studies were the reconstruction of the pillow lava complex, recognition of different submarine volcanic and hydrothermal facies as well as representative sampling of recognized environments. The field observations were supplemented by the study of rocks and hydrothermal mineral parageneses in polished thin sections.

X-Ray Powder Diffraction (XPD) method was used to determine some mineral phases using a Siemens D-5000 type, Bragg-Brentano geometric diffractometer emission (Θ-Θ working method, Cu Kα (λ=0.154178 nm), secondary graphite crystal monochromator and scintillation detector.

Fluid inclusion petrography and microthermometric study was carried out on 100 μm thick, double polished sections of hydrothermal calcite from various volcanic and hydrothermal facies of basalt using a Chaixmeca type heating freezing stage mounted on an Olympus BX-51 type polarizing microscope providing 1000 times magnification. The precision of the microthermometric measurements was ±0.1°C below 0°C, and ±1°C above it. The calibration of the instrument was made by analysis of CO_2 and pure water synthetic fluid inclusions. Interpretation of microthermometric data were carried out by the BULK 01/03 and the ISOC 01/03 software (BAKKER, 2003).

3. FIELD OBSERVATIONS

The Reszél Hill quarry has three volcanic facies comparable with the known facies in the Hruškovec quarry (Kalnik Mts., Croatia; PALINKAŠ et al., 1998, 2000, 2008). These are the closely packed pillows with some "pyjamas-style" lava lobes, the peperitic facies with red micritic limestones and the pillow fragment hyaloclastite breccias. These facies gradually developed sequentially from NE to SW along the profile of the quarry, and all of the units are enclosed in the Mónosbél Complex represented by turbiditic shale (Mónosbél Formation) and bioclastic limestone (Oldalvölgy Formation) in the quarry (Fig. 2). The age of the Mónosbél Complex is Jurassic and consists of olistrostrome and re-sedimented carbonates. Contacts of the basalt with the sedimentary units of Jurassic age are evidently tectonic as there is no thermal effect on the sedimentary host rocks. Hydrothermal features developed on the basalt (see below) are absent, but also in the sediments as well. Also, occurrence of red micritic limestone, thermally affected by basalt lava is restricted to the peperitic facies and similar type of carbonates are absent in the surrounding sedimentary host rocks. Thus the whole submarine volcanic unit is interpret-

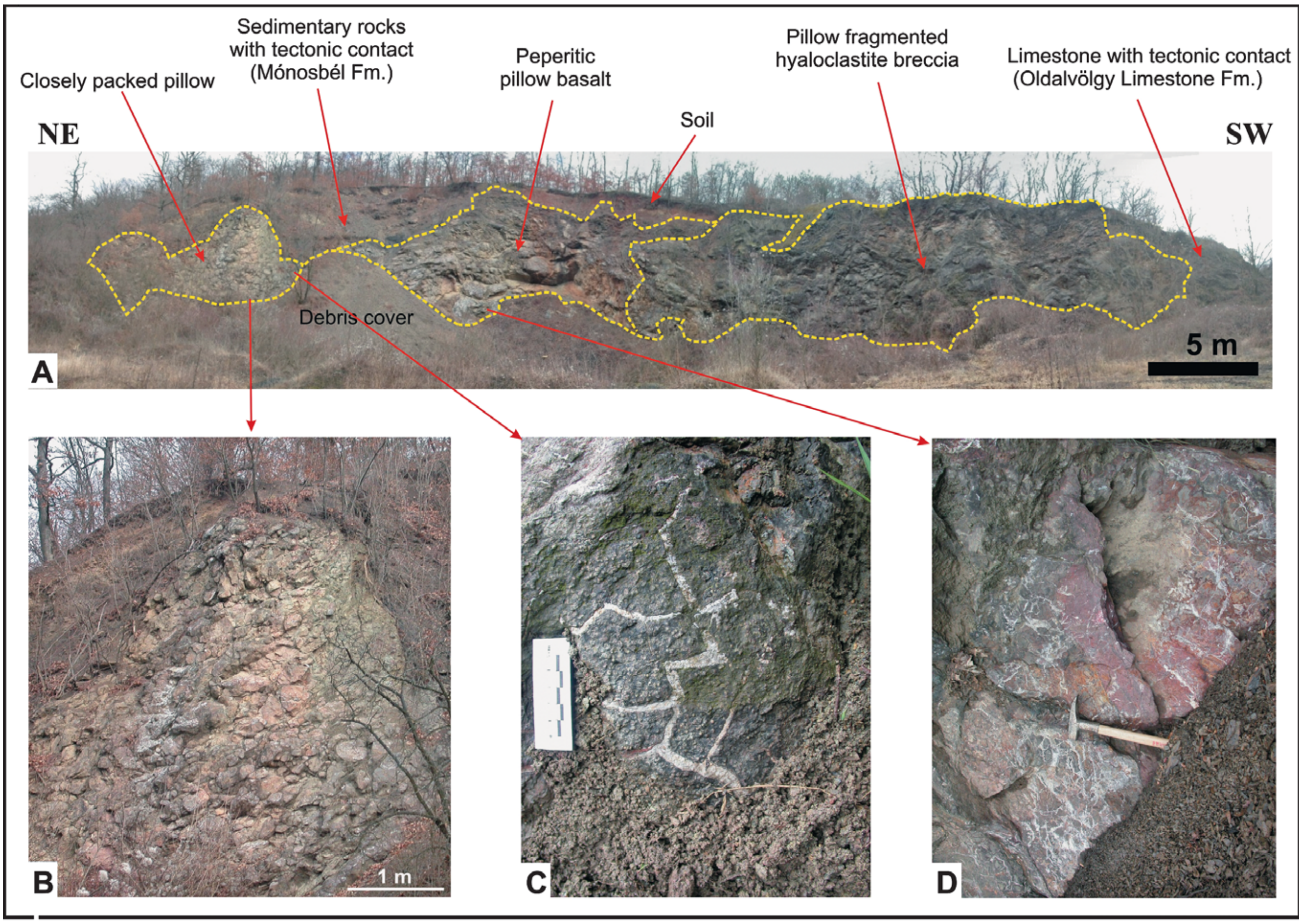

Figure 2: Occurrences of submarine volcanic facies in the quarry of Reszél Hill. **A** – Panoramic view of the quarry. **B** – Closely packed pillow facies. **C** – Spherulitic surface and jigsaw fractures of a pillow in the transition zone between the closely packed pillow and peperitic pillow facies. **D** – Peperitic pillow facies with red limestone mixed up with fragmented basalt.

ed to be a large block (olistolite) which has been incorporated into the olistrostrome mélange of the Mónosbél Complex.

The Mély Valley quarry also reveals distinctive submarine volcanic facies of basalt resembling to those in the Reszél Hill quarry. These are closely packed pillows, occasionally with calcite-filled feeding channels within the individual pillows and "pyjama-style" lava lobes and peperite with red micritic limestone. These facies are strongly dissected and tectonically fragmented and also intercalated partly with Langobardian radiolarites and cherty limestone, proving the possible Middle Triassic age of the submarine volcanic activity (DOSZTÁLY & JÓZSA, 1992; DOSZTÁLY et al., 1998) The basaltic units together with their sedimentary intercalations form 15–20 m long and several metres thick blocks in the olistostrome mélange (Mónosbél Complex) of Jurassic age. Hydrothermal features, characteristics of the basalt, are absent in the Jurassic sedimentary units which also supports that basalts are exogeneous blocks (olistolithes) in the sedimentary host.

4. PETROGRAPHY OF THE SUBMARINE BASALTIC FACIES

4.1. Closely packed pillow lava facies

The closely packed pillow units contain lava lobes with diameters about 0.5 m (Fig. 2B). The marginal pars of pillows are rich in amygdales with size up to 1 cm. These amygdales are filled with calcite and other hydrothermal minerals. The lava lobes are also dissected by tortoise shell joints and jigsaw veinlets with thickness from a few millimetres to about 2 centimetres (Fig. 3A). The veins are within the pillows, and they do not cross the pillow's boundaries, so it is obvious that they are primary ones, and they were formed during the cooling of the pillows. Other characteristic textures related to the solidification of the lava are the occurrences of "pyjama-style" pillows and feeding channels in the cores of pillows (Figs. 3B and 4A). These features are also formed by rapid cooling of the basalt: in the place of "pyjama" ribbons and feeding channels, the lava was still molten when the crust has already been solidified and outpouring of lava from these parts left behind open tubes in which calcite and other hydrothermal minerals were instantaneously precipitated from the heated sea water. In the case of the "pyjama-style" pillows, this process repeated in sequence several times and contemporaneous flattening of the semi-consolidated lava lobe resulted in flat voids with thickness about 2–3 cm and width up to several tens of centimetres. Both the feeding channels and "pyjama" ribbons are geopetal structures with flat bottom of the vug and irregular-curving upper boundary. "Pyjama-style" lava lobes are characteristic features of the lava pillows developed during ob-

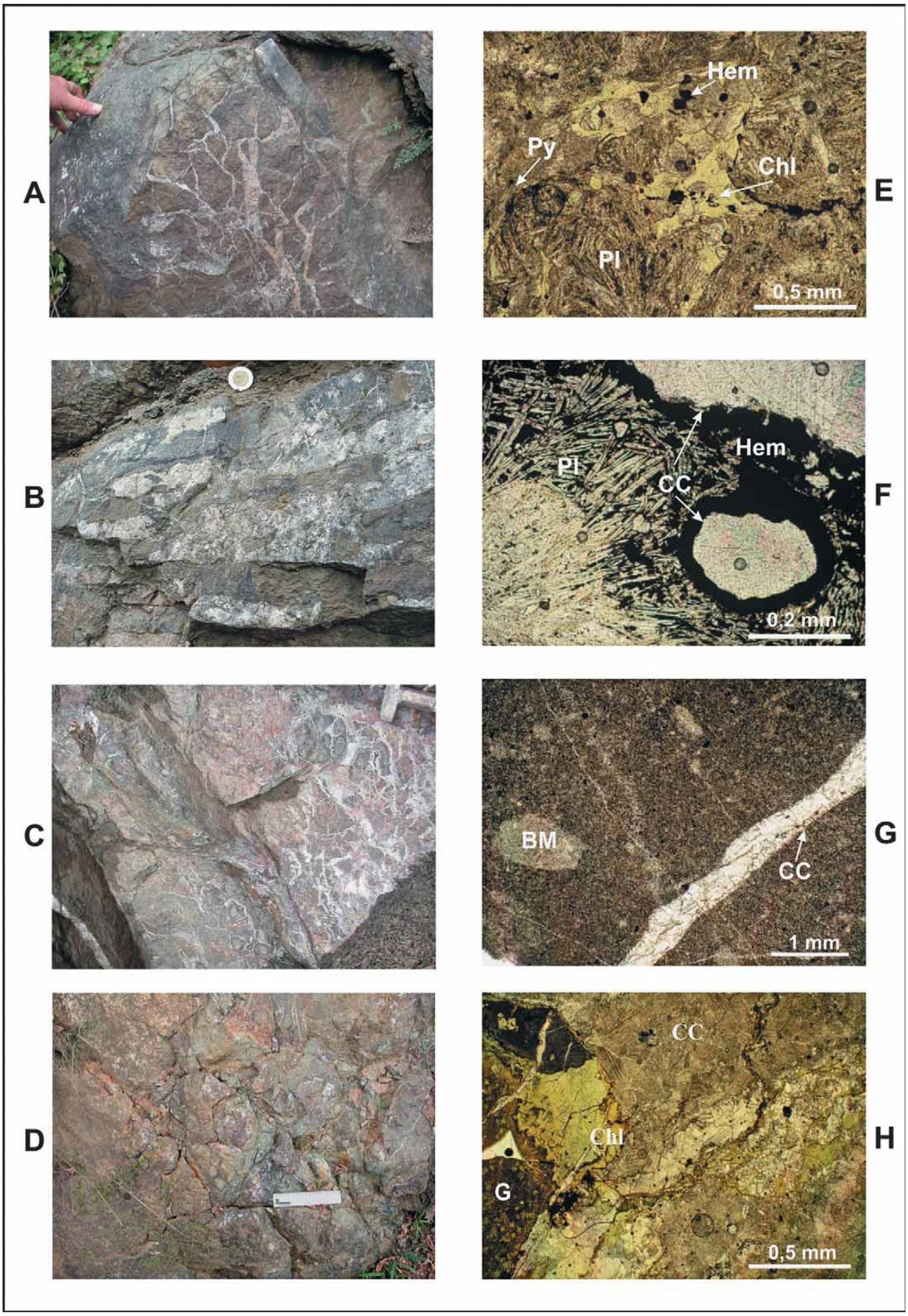

Figure 3: Macroscopic and microscopic features of different volcanic facies, Reszél Hill, Darnó Unit. **A –** Lava lobe in the closely packed pillow facies with tortoise shell joints and jigsaw veins filled up by calcite. **B –** Pyjama-style pillow basalt. This characteristic feature of the submarine lava developed during obstructed propagation of lava into a soft sediment. Flat vugs developed during this process have been filled up by hydrothermal calcite which was the object of fluid inclusion studies. **C –** Peperitic facies; blocks of reddish limestone within fragmented basalt pillows. **D –** Pillow fragment hyaloclastite breccia. **E –** Microphotography of closely packed pillow with acicular plagioclase (Pl) in bundles and radial arrangements, submerged in a groundmass of glass, chlorite (Chl) and accessories like hematite (Hem), pyrite (Py), (1N). **F –** Microphotography of the basalt wall of the "pyjama-style" shelf and white infillings of hydrothermal calcite. The basalt in the wall has variolitic texture made of radiating acicular plagioclase (Pl) and oxidized to hematite (Hem). Amygdale and the inner compartment of the shelf are rimmed with hematite and sparry calcite (CC), (1N). **G –** Microphotography of recrystallized reddish micritic limestone, the matrix of the peperitic breccia. Sparry calcite (CC) in a cross-cutting vein and a biomold (BM). **H –** Microphotography of hyaloclastite breccia. Fragments of basalt (left corner) in the matrix of chlorite (Chl) and basaltic glass (G). The matrix is cemented by sparry calcite (CC), (1N).

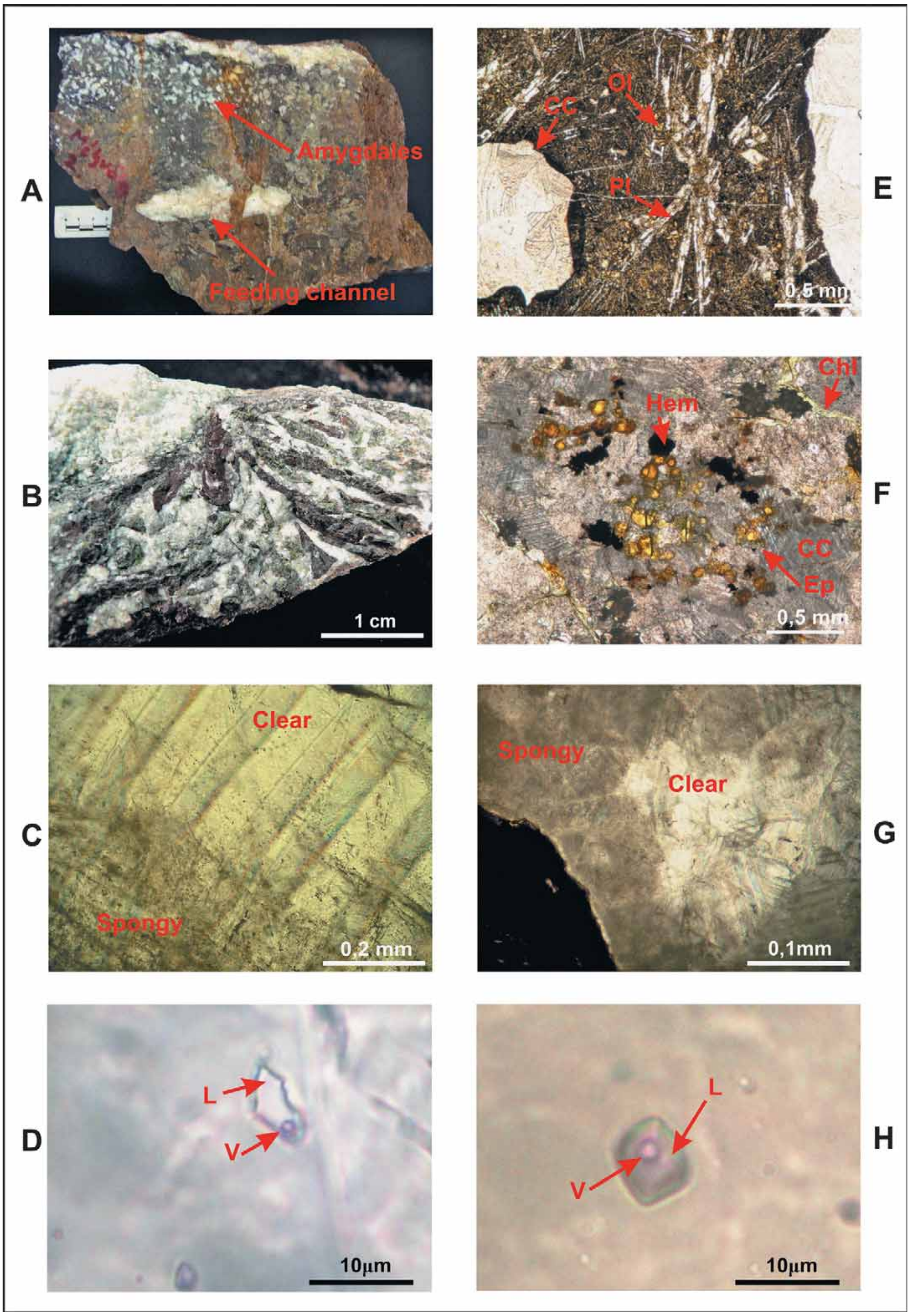

Figure 4: Macroscopic and microscopic features of different volcanic facies, Reszél Hill and Mély Valley, Darnó Unit. **A –** Pillow lobe with a circling belt of amygdales along the rim. In the centre of the lobe there is a feeding magma channel. Amygdales and feeding channel are filled up by hydrothermal calcite, the object of fluid inclusion studies. Mély Valley. **B –** Hyaloclastite breccia consists of basalt fragments and sideromelane shards cemented by hydrothermal minerals (mostly calcite). Mély Valley. **C –** Microphotography of spongy and water-clear calcite from the white part of the "pyjama-style" pillow shelf, the object of the fluid inclusion study. Reszél Hill, (1N). **D –** Primary fluid inclusion with liquid (L) and vapour (V) phases in the water-clear calcite of the "pyjama-style" pillows. Reszél Hill, (1N). **E –** Aphyric to microporphiritic texture of basalt with amygdales from the closely packed pillow facies. The plagioclase (Pl) laths occur in bundles, often as skeletal crystals, sporadically accompanied by probably olivine (Ol), and opaque minerals, such as pyrite (Py) and hematite (Hem). The amygdales are filled with sparry calcite (CC). Mély Valley, (1N). **F –** Microphotography of the hyaloclastite breccia matrix. The matrix contains tiny fragments of oxidized basalt, hematite (Hem), chlorite (Chl), and epidote (Ep) cemented by sparry calcite (CC). Mély Valley, (1N). **G –** Microphotography of sparry calcite from the amygdales – the object of the fluid inclusion study. Calcite in the outer parts of amygdale has spongy appearance due to large amount of fluid inclusions whereas it is water clear in the centre. Mély-valley, (1N). **H –** Primary fluid inclusion in the sparry, water-clear calcite of the amygdales. Mély Valley, (1N).

structed propagation of lava into soft sediment (PALINKAŠ et al., 2008), thus their occurrences in the vicinity (a few metres) of the peperitic basalt facies is expected.

The basalt in the closely packed pillow facies is aphyric to microporphiritic, with abundant microcrysts. Plagioclase laths (0.1–1.5 mm) occur in bundles, often as skeletal and radially arranged crystals, submerged in the glassy matrix (Figs. 3E and 4E). Plagioclase is sporadically accompanied by fewer amounts of altered olivine and clinopyroxene, as well as pyrite. In the coherent basaltic block of the Reszél Hill quarry, internal texture of individual pillows becomes variolitic whereas their rims are spherulitic towards the coherent peperitic facies (Fig. 2C).

Among the pillows, minor amount of hyaloclastite breccia can be found in small pockets formed by joints of the pillows. The breccia is made of basalt fragments and sideromelane shards which are cemented by hydrothermal minerals. The shards are brown or brownish green, with rare crystallites. The opaque minerals are mostly hematite and thus basalt fragments are characterized with reddish colour due to oxidation attained during emplacement in the sea water. Textures of basalt fragments are identical to the pillows.

4.2. Peperitic pillow basalt facies

The peperitic facies developed by intrusion of lava into the soft, water soaked lime mud. The result was quench fragmentation of the lava, and formation of blocky peperites, supported by matrix of reddish micritic limestone (Figs. 2D and 3C). The peperitic facies form up to 3–5 m large irregular bodies in both quarries and it appears to have a transitional position between the closely packed pillows and pillow fragmented hyaloclastite breccia at the Reszél Hill quarry (Fig. 2).

The originally micritic limestone is mainly recrystallized therefore it has a sparry texture especially in biomolds (Fig. 3G). Biomolds gradually develop into sparry recrystallized limestone without bioclasts in irregular patches. Texture of the basalt is variolitic-intersertal. The glassy groundmass contain prismatic, occasionally skeletal plagioclase (albite–oligoclase, 0.2–0.8 mm) occurring in small radial knots at some places. The groundmass also contains abundant disseminations of fine grained (0.01–0.02 mm) hematite pseudomorphs after pyrite in the red-coloured parts of basalt. A few altered mafic minerals, most probably former clinopyroxene is also present in the rock.

The recrystallized limestone and pillow basalts are both cut by tortoise or jigsaw-like cooling related fractures (2–6 mm thickness) filled up by calcite (Fig. 2D).

4.3. Pillow fragment hyaloclastite breccia facies

The pillow fragment (hyaloclastite) breccia is matrix supported. Basalt and sideromelane shards, as well as very rare limestone fragments occur as clasts, varying in size between 2 mm and 5 cm (Figs. 3D and 4B). The colour of the glass shards is usually brown-green, containing sporadic crystallites of plagioclase. The breccia matrix contains calcite cement, represented by the two varieties, accompanied by rare anhedral chlorite, epidote and hematite (Figs. 3H and 4F). The earlier generation calcite has a larger grain-size and cloudy appearance, while the younger one, determined with certainty as vein-filling, is entirely water-clear.

Fragmented pillow basalt in the hyaloclastite breccia displays similar textural and mineralogical variations as observed in the closely packed pillow and peperitic facies.

5. FLUID-ROCK INTERACTION AND HYDROTHERMAL MINERALIZATION

5.1. Features of fluid rock interaction and hydrothermal minerals

As one of the main results of the fluid-rock interaction, the very rapid cooling of basalt resulted in the specific textures observed. That is why a high amount of glassy material, sometimes spherulitic, often variolitic, variolitic-intersertal and microporphyritic texture has been developed. Skeletal growths of plagioclase, occurrences of radial knots of plagioclase in glassy groundmass, as well as alteration of mafic rock forming minerals into chlorite and less frequently epidote and hematite is also the result of the vigorous interaction between the hot basalt and sea water.

The plagioclase of basalt in various facies has albite–oligoclase composition and it is in contrast with common basalts, with Ca-rich plagioclase. The hydrothermal alteration which happened because of the fluid-rock interaction changed the plagioclase composition. During the process Ca has been released and then blocked in calcite and rarely epidote in the veins, amygdales, and in the hydrothermal cementation of the hyaloclastite breccia. Additional source of Ca for the voluminous formation of carbonate and Ca-rich silicates is the seawater itself.

Chlorite also occurs as a result of the wide-spread submarine hydrothermal alteration. During this process original silicates of the basalt (e.g. clinopiroxene, rarely olivine), even some parts of the glassy groundmass turned into chlorite, while SiO_2 has been released. That is why even quartz can be found in the veins or in the cement of the hyaloclastite breccia at some places.

A specific form of precipitation of hydrothermal calcite is in the bands of the “pyjama-style” pillows. Calcite has two generations in the infillings: one is a water-clear and sparry and the other is spongy calcite containing abundant fluid inclusions (Fig. 4C). The spongy calcite occurs mostly at the margins of the white bands, so this should be the older generation. Beside calcite, also chlorite, hematite and epidote are scarcely present in the bands with hydrothermal minerals (Fig. 3F). The sparry calcite shows deformational structures (bending of cleavage planes), developed by numerous tectonic phases which affected the mélange formation. Feeding channels in the center of pillows and amygdales along the rim of pillows have similar infillings to the bands in the “pyjama-style pillows”. Along the walls of the feeding channel and amygdales, calcite is spongy but it is water-clear in the middle of the infillings. Epidote and chlorite are present as well (Fig. 4G).

Formation of jigsaw veins within pillow lava lobes is the result of cracking of the already solidified rock during fast cooling. Upheated sea water leaching out metals from the altered basalt plus components from the sea water precipitated mostly anhedral calcite grains (up to 1–2 mm size) with minor amount of quartz in these veins. Chlorite is also a common mineral in these veins with some rare epidote.

The matrix of hyaloclastite breccia also mostly contains fine grained (0.5–1.5mm) calcite associated with lesser amount of rounded aggregates of epidote, quartz–chalcedony and flakes of chlorite and fine grained hematite. Calcite also has two generations in the breccia matrix: an early calcite with larger (>1mm) grain-size and cloudy-spongy appearance due to large amount of fluid inclusions and a younger water-clear vein filling generation (Fig. 3H).

5.2. Fluid inclusions in calcite

In the calcite infillings of the "pyjama-style" pillows of the Reszél Hill quarry, the early spongy and the late water-clear calcite contain rarely liquid and vapour (L+V) two-phase primary inclusions with about 5–10 µm sizes (Fig. 4D). The primary origin of inclusions is evidenced by their three dimensional and sometimes zoned distributions independently from cleavage planes. The vapour phase fills up about 5 vol.% of the inclusions on room temperature. There also are very small (<5 µm size) secondary L+V and L only inclusions in healed microfractures of calcite; these inclusions were excluded from microthermometric studies.

Primary fluid inclusions in the water-clear calcite, in the spongy calcite and within the transition zone between the two calcite phases, homogenized into the liquid phase most commonly between 100 and 120°C (Fig. 5). Freezing measurements encountered problems of metastability in the inclusions, expressed by disappearance of the vapour phase and its late showings at around +1 to +2°C during fast melting of ice. The problem was overcome by careful stretching of inclusions prior to the freezing runs. The eutectic temperature determined on the artificially stretched inclusions were around –20.8°C, suggesting a NaCl–H_2O type model composition. Ice melting temperatures correspond to salinities of 3.2 and 4.6 wt.% NaCl equiv. wt. % (Fig. 5.).

Fluid inclusion studies were carried out from calcite from the amygdales and the feeding channels of the closely packed pillows facies from the Mély Valley quarry. Primary L+V fluid inclusions about 5 vol.% V phase on room temperature in the amygdales are about 5 µm in size (Fig. 4H), and show steady decrease in the homogenization temperature from about 150°C at the rim to about 110°C at the centre of calcite infilling (Fig. 5). The eutectic temperature is between –20.5 and –22.1°C, while salinity also shows a decreasing trend from the rim (5.6 NaCl eq. wt%) to the central zone (3.2 wt.% NaCl equiv.wt.%). In the feeding channel, the homogenisation temperatures are slightly lower in comparison to amygdales, and they are between 80°C and 100°C. The eutectic temperature is between –20.4 and –21.1°C, while the mean salinity is around 3.9 wt% NaCl equiv. wt% (Fig. 5).

6. DISCUSSION

The Darnó Unit is correlated with similar units of the NW-Dinarides (PAMIĆ, 1997; DIMITRIJEVIĆ et al., 2003) among which the Kalnik Mts. contain a well exposed submarine basaltic volcanic centre of Triassic age in the Hruškovec quarry. In the case of the subaqeous basalt lava-flow complex of the Kalnik Mts., six different facies were described by PALINKAŠ et al. (1998, 2000, 2008). The major lava feeder in the centre of the low-aspect pseudo-cryptodome consists of coherent pillow lava facies which is laterally followed by closely packed pillows, "in situ" hyaloclastites, isolated pillow breccias, pillow fragment hyaloclastite breccias and peperitic hyaloclastites within red micritic limestone and red shale. In the Darnó Unit, there have been recognized only three of these submarine volcanic facies (closely packed pillow, peperitic pillow and pillow fragmented hyalocclastite breccia) in a large olistholite of the Mónosbél Complex. However, there is enough data which enable convincing correlation and comparison between the two Triassic volcanic complexes.

The exposed submarine volcanic facies in the Darnó Unit represent distal facies in relation to the master feeder zone, as deduced from the absence of coherent pillow lava facies, characteristic to the centre of the dome in the Hruškovec quarry. This also invokes that cooling of lava was rapid, and this is manifested by sideromelane shards and skeletal plagioclase microcrysts in the basalt groundmass. Amygdales rimming marginal parts of the pillow lobes evidence degassing in relatively shallow water, what enabled vesiculation of the basalt lava.

The formation of the "pyjama-style" pillows and feeding channels invokes rapid cooling as well, due to subsequent precipitation of hydrothermal minerals in the space liberated by draining of lava from already solidified crust of the pillow lobes. Spherulites on the crust of the pillow lobes experienced slower cooling in the isolated mud environment, within the place of the pillows accommodation.

Physico-chemical characteristics of the hydrothermal water in the "pyjama-style" pillows were determined by fluid inclusion microthermometry in calcite. Vapour film around the chilling basalt, supported by relatively high hydrostatic pressure, created low temperature hydrothermal fluids. Homogenization temperature of the uniformly filled primary fluid inclusions (constant phase ratio), provided the minimum formation temperature of the host mineral. Determination of the true formation temperature (trapping temperature) requires knowledge on concomitant pressure. Estimation of pressure without an independent isotope or other geothermometer is just an approximation, and was done by the presence of the micritic limestone in the peperitic facies only. Sedimentation of the limestone certainly took place above the carbonate compensation depth (CCD). The depth of the CCD is variable in the oceans in time and space. On the base of DSDP results, the CCD is known only till the Jurassic back in time, and was about 4–4.5 km below the sea level (VAN ANDEL TJEERD, 1975). BALLA et al. (1980) also appraise 4–4.5 km deep water for the basaltic volcanism of the Darnó Hill. A water col-

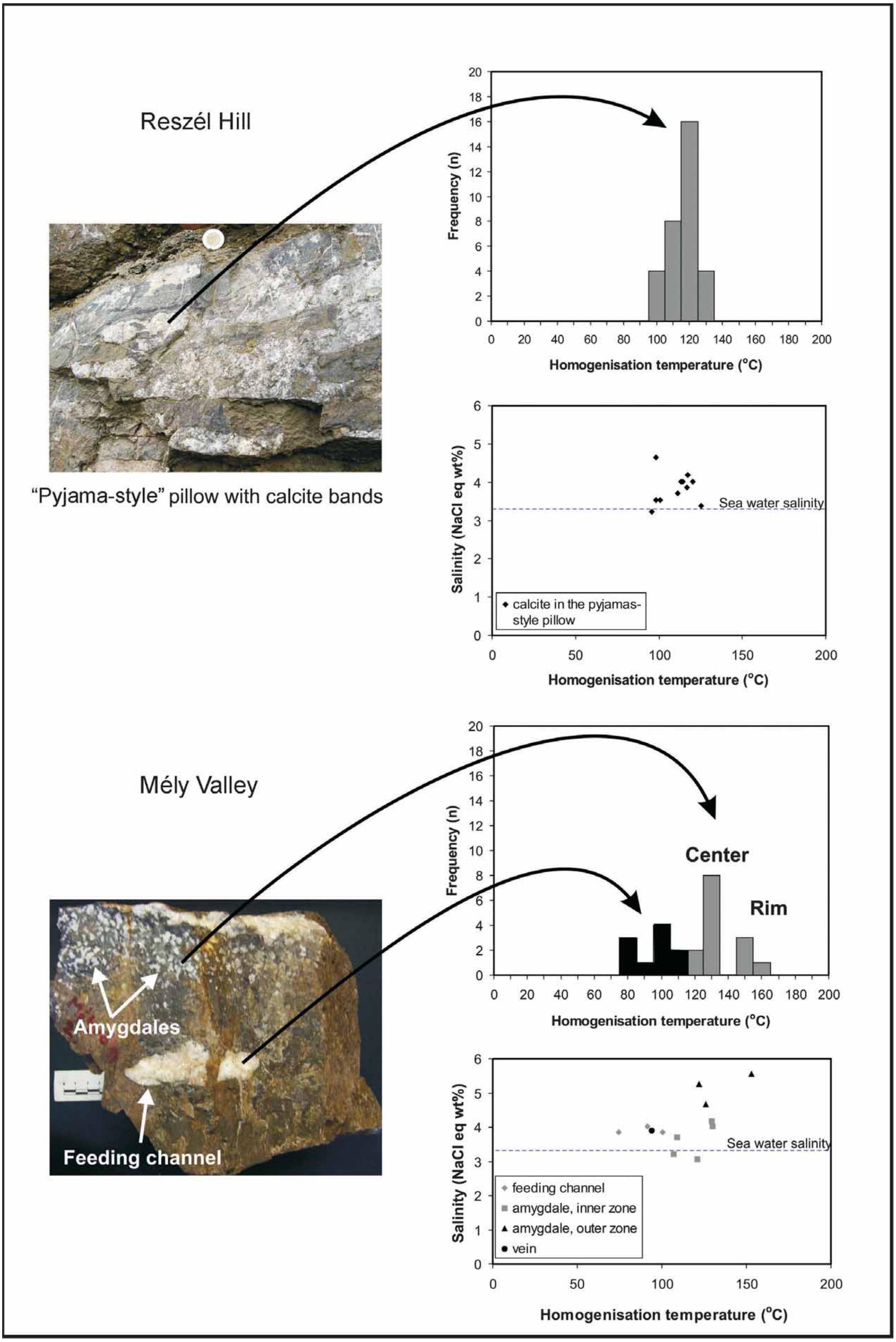

Figure 5: Results of fluid inclusion microthermometry carried out on samples from the Reszél Hill and Mély Valley, Darnó Unit.

umn of 4 km exerts a pressure of 400 bars (40 MPa). Using the estimate of the maximum pressure, the trapping temperature was determined by intercepts of this pressure with the isochors of fluid inclusions. This approach gives negligible pressure corrections of homogenization temperatures in the range of 8–10°C. Therefore calcite precipitation in the "pyjama-style" pillows took place at 110–140°C from hydrothermal solutions slightly more saline (3.2–4.6 wt.% NaCl equiv. wt.%) than the sea water. This result excellently matches with the fluid inclusions data for calcite in the "pyjama-style" pillows in the Hruškovec lava-flow complex, where BOROJEVIĆ et al. (2000) determined 110–160°C and 1.4–4.6 wt.% NaCl equv.wt.% salinities.

Rapid cooling of heated sea water from about 160°C to 120°C is recorded by fluid inclusions in amydales, followed by the lowest temperature (90–110°C) mineralization in the feeding channel in the closely packed pillow facies of the Darnó Unit. The rapid cooling process was associated with decreasing of salinities from 5.6 to 3.2 wt.% NaCl equiv.wt.% in the amygdales. This decreasing trend is a result of the fluid-rock interaction. The loss of water due to formation of secondary hydrous silicates and retrograde dissolution of transient hydroxy-chloride phases may not substantially change salinity in an open system. In a restricted, semi-closed environment like vesicules, however, it may come in effect during early encrustation stage, and the lower (sea water) salinity is attained during recharge of the cooler sea water.

Fluid inclusion data on hydrothermal minerals formed in restricted, semi-closed environments, like amygdales are similar to some data from the Hruškovec quarry, Kalnik Mts. (BOROJEVIĆ et al., 2000). The discrepancies arise, however, with temperature and salinity data from open vein systems crosscutting pillow lava formation in the Hruškovec lava-flow. Salinities for that environment are in the range of 3–16 wt.% NaCl equiv.wt.%, and presence of halite cubes in some rare fluid inclusions in calcite (not measured due to decrepitation) indicates even higher salinities. Temperatures as high as 300 °C were recorded for this stage of hydrothermal activity, invoking substantial magmatic heat source due to the vicinity to the central feeder zone. Similar high temperature conditions could not be recognized in the hydrothermal environments of the Darnó Unit's basalts which is consistent with their distal/peripheral position in the submarine volcanic system.

7. CONCLUSIONS

Submarine basaltic blocks of Triassic age enclosed in the olistrostrome of the Monosbél Complex of Jurassic age, consist of closely packed pillow, peperitic pillow and pillow fragmented hyaloclastite breccia facies in the Darnó Unit, NE-Hungary. This is also confirmed by comparison of volcanic facies with those observed in the architecture of the well preserved subaqueous basalt lava-flow complex of Triassic age in the Hruškovec quarry, Kalnik Mts., NW-Croatia.

Discovery of peperitic pillow facies in the submarine basalt formations of the Darnó Unit provides additional possibility for interpretation of the origin of magmatism. The pillow lava extrusion was on the bottom of the sediment filled basin and not on the ocean's floor at a mid-ocean ridge because basaltic lava penetrated water soaked lime-mud existed above the CCD and this process resulted in the development of the peperitic facies. The intensive lava vesiculation recorded in the pillows also prefers shorter water column and lower hydrostatic pressure exerted on the lava.

Hydrothermal processes associated with the submarine volcanic activity resulted in formation of abundant calcite infillings together with accessory chlorite, epidote, quartz, pyrite, hematite in amygdales, and vugs of pyjamas pillows and feeding channels in the centre of the pillows. Temperature-salinity data (90–160°C, 3.2–5.6 wt.% NaCl equiv.wt.%) from primary fluid inclusions of calcite indicate that the hydrothermal processes also took place far from the master feeding zone of the extrusion where higher temperatures and salinities occur, as evidenced by data from the Hruškovec quarry. Decreasing temperatures and salinities from rim to core of calcite infillings in amygdales suggest short-term interaction between the rapidly cooling lava and seawater in a semi-closed fluid-rock system.

Comparison of the obtained data between the Darnó Unit, NE-Hungary and those on the Hruškovec lava-flow of Kalnik Mts., NW-Croatia, both situated in the Zagorje-Mid-Transdanubian Megaunit, a part of Dinarides, with similar magmatic complexes along the Dinarides, Hellenides and even further to the east, would constrain more precisely timing of rifting and oceanization in the Neotethyan evolution.

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