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TRIASSIC ADVANCED RIFTING RELATED AND JURASSIC OPHIOLITE-LIKE MAGMATIC ROCKS IN THE BÜKK UNIT, NE-HUNGARY – AN OVERVIEW

by

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Abstract

The Bükk Unit in north-eastern Hungary hosts both Triassic and Jurassic igneous rocks which are related to the different evolutionary stages of the Neotethys and are considered to be fragments of Dinaridic origin that had been displaced to northeast along the Periadriatic-Balaton-Darnó- and Mid-Hungarian Lines during the Oligocene-Early Miocene. The different magmatic blocks are found in the same accretionary mélange and this fact resulted in special scientific interest in the past few years in this region. Though a number of papers were published, controversial conclusions were drawn concerning the origin of these magmatic rocks. The igneous units involved in our current studies were submarine basaltic pillow lava units from the Darnó Unit and apparently similar pillow basalt blocks plus gabbro intrusions with plagiogranite at some places from the Szarvaskő Unit.

Re-evaluation of the previous results of studies from a new viewpoint and the overview of the most recent results of studies completed by the authors are presented in this paper. Major conclusions are that distinction can be made among the different basalt types on the basis of detailed mineralogical, petrological and geochemical studies and the origin of these rocks can be also distinguished.

Our volcanological study revealed that distal facies of basaltic lava flow complexes in relation to the submarine eruption centres are preserved in both the Triassic (Darnó) and the Jurassic (Szarvaskő) igneous units. The presence of the peperitic facies (lava-sediment mingling) supports this observation, however, in the case of the Triassic localities the occurring limey sediments confirm a shallower depth (above CCD) in relation to the Jurassic siliciclastic sediment-bearing peperites (below CCD).

The hydrothermal mineral paragenesis and the fluid inclusion study proved a more limited seawater-rock interaction in the case of the Jurassic basalts, though the influence of the seawater dominated at every locality.

Fluid-rock interaction related to the later Alpine (Cretaceous) regional metamorphism was traced in the Jurassic rocks; this kind of alteration can be clearly distinguished from the primary, hot basalt-seawater interaction related hydrothermal processes, as well as from the high temperature pegmatite related fluid-rock interaction in intrusive gabbroic rocks which also host small plagiogranite intrusions.

Results of the geochemical study confirmed that the Triassic basalts of the Darnó Unit were formed in a within-plate setting, so their relationship to the advanced rifting stage of the western Neotethys is the most probable scenario, while in the case of the Jurassic magmatites of the Szarvaskő Unit, a subduction related origin is suggested.

1. Introduction

The Bükk Mts. and its surroundings in NE-Hungary provide a unique opportunity for studies of igneous sequences which have been accumulated during different stages of the complex orogenic evolution of the Alpine-Carpathian-Dinaridic system. The special feature of this region is that the Mesozoic sequences of the Bükk Mts. can be correlated with the Dinarides (e.g. HAAS & KOVÁCS 2001). The recent setting of the Bükk Mts. is due to the northeastward "escape" of terranes from the Alpean collision zone during the Late Palaeogene – Early Neogene. This escape was caused by a right lateral displacement of about 300 km magnitude along the Mid-Hungarian Zone (CSONTOS & VÖRÖS 2004; SCHMID et al. 2008). This Tertiary structural evolution also generated the Carpathian subduction and opening of the Pannonian Basin. These latter processes also resulted in intense magmatism and the regionally distributed products of Neogene acidic calc-alkaline volcanism, cropping out along the southern and western forelands of the Bükk Mts.

As the results of the complex geological evolution, advanced rifting stage submarine basaltic volcanism of Triassic age and back-arc-basin volcanism related incomplete ophiolite-like magmatic series of Jurassic age of the Dinarides occur in the same mélange.

2. Regional geology

The basement of the Pannonian Basin consists of a mosaic-like pattern of allochtonous terranes derived from different parts of the Tethyan realm. The major structure of the basement is the Mid-Hungarian (Zagreb-Zemplén) Lineament which divides the Tisza Megaunit and the Pelso Megaunit (Pelsunia), a part of the ALCAPA (Fig. 1) (CSONTOS 1995).

Assemblages of each of these megaunits are related to the Cretaceous-Tertiary collision in the Alp-Carpathian system. The most noticeable character of the recent arrangement of these megaunits is that the Tisza Unit contains terranes of European Plate origin, whereas the Pelso Unit is more heterogeneous with terranes of South Alpine origin (Transdanubian Range Unit), Dinaridic origin (Bükk Unit) and blocks of mixed Alpine and Dinaridic affiliations (Sava and Aggtelek-Rudabánya Units) (HAAS 2001).

The Bükk Unit is a part of the Pelso Megaunit and is bounded by the Mid-Hungarian Lineament to the south and east and by the zone of the Diósjenő – Nekézseny Fault to the north. The boundary to Transdanubian Range Unit to the west is hard to define due to the Tertiary volcanic and sedimentary cover (Fig. 2, Fig. 3) (CSONTOS 1995).

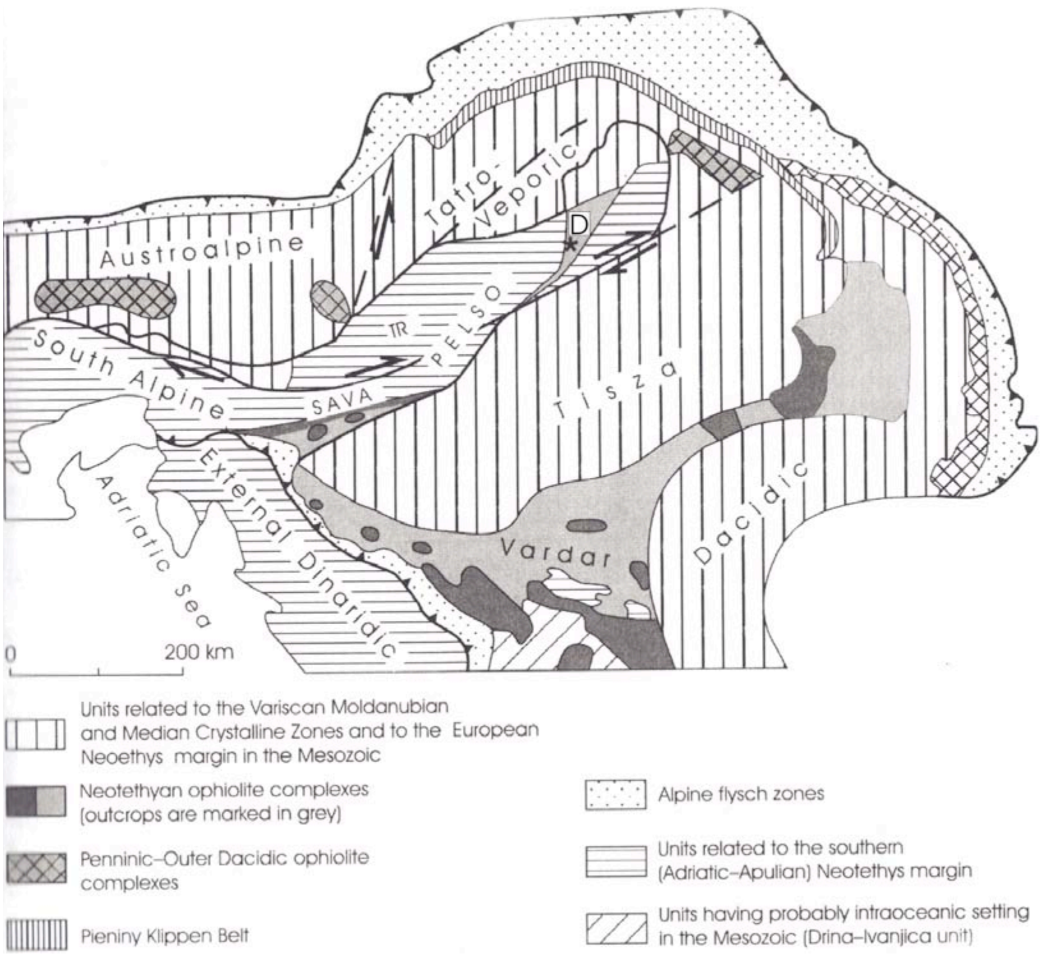

Figure 1
Tectonic sketch of the pre-Neogene basement of the Pannonian Basin and its surroundings (KOVÁCS et al. 2008). Letter "D" shows the Darnó-Szarvaskő area.

The pre-Tertiary sequences of the Bükk Unit compose a synformal structure built up by the Bükk Parautochton Unit and the covering nappes (CSONTOS 2000). The Bükk Parautochton (Fig. 3) is composed of formations ranging from the Middle Carboniferous (Variscan) flysch stage to the Late Jurassic ("Eohellenic") flysch stage (HAAS 2001) with continuous sedimentation from the Middle-Late Permian coastal plain setting trough the Permian-Triassic boundary and development of carbonate platforms in the southern margin of the Neotethys. The Lower-Middle Mesozoic sequence records the gradual development of the carbonate platform until the end of the Anisian, the Early Ladinian andesitic calc-alkaline volcanism, the resumption of the carbonate platforms and development of intraplatform basins during the Ladinian–Rhaetian and formation of deep-sea basins in the Jurassic (HAAS 2001; PELIKÁN 2005).

This sequence has suffered very low-grade Alpine metamorphism (ÁRKAI 1983) and has deformed into four E-W striking southward recumbent anticlines during the Late Jurassic-Cretaceous. The axes of these anticlines plunge to the west. The Kisfennsík Nappe in the northeastern Bükk Mts. has an undeformed/very weakly deformed Triassic sequence which is essentially identical to the sequence of the Parautochnous Unit.

The Mónosbél Complex in the south western part of the Bükk Mts. (Fig. 3) is built up by stacking of the Mónosbél Unit (Jurassic sedimentary unit), the Szarvaskő Unit (Jurassic magmatic unit) and the Darnó Unit (Triassic-Jurassic sedimentary and magmatic unit) according to the most recent interpretations of KOVÁCS et al. (2008). Overthrusting of the Szarvaskő Nappe has taken place between 154-129 Ma and it was deformed together with the Bükk Parautochton Unit at around 126-115 Ma (ÁRKAI 1983). The recent position of the Bükk Mts. is due to the northeasternward escape of the ALCAPA terrane from the Alpean collision zone along the Periadriatic-Balaton Line during the Late Eocene-Oligocene (KÁZMÉR & KOVÁCS 1985; CSONTOS & VÖRÖS 2004; Fig. 1).

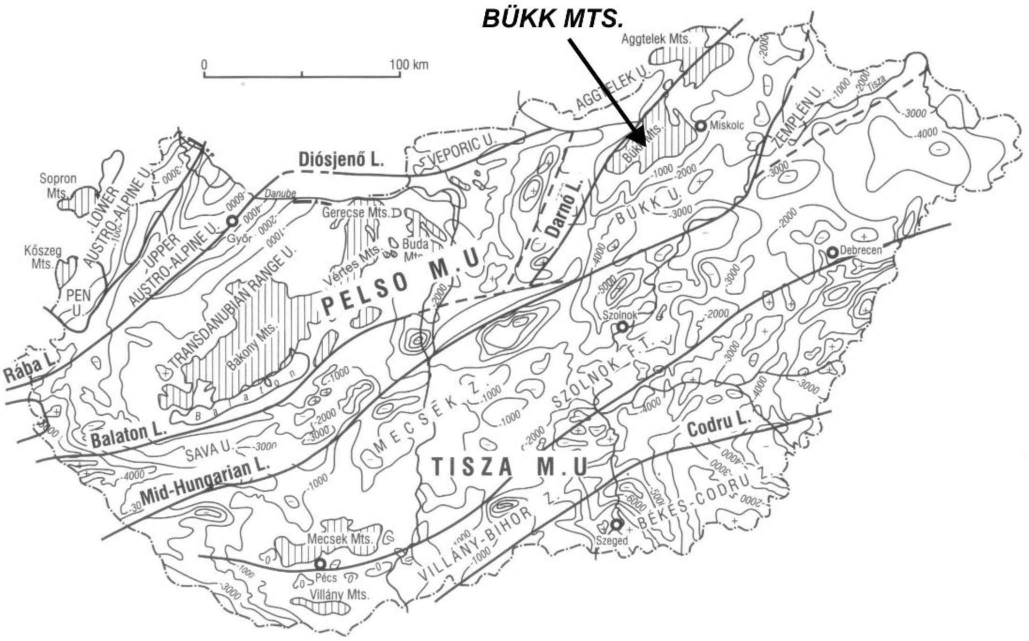

Figure 2

Pre-Tertiary structural units of Hungary and depth of pre-Tertiary basement (Legend: ruled area: pre-Tertiary rocks on the surface; numbers: depth of pre-Tertiary basement; thick line: structural unit boundary, dashed line: presumed structural unit boundary) (HAAS 2001).

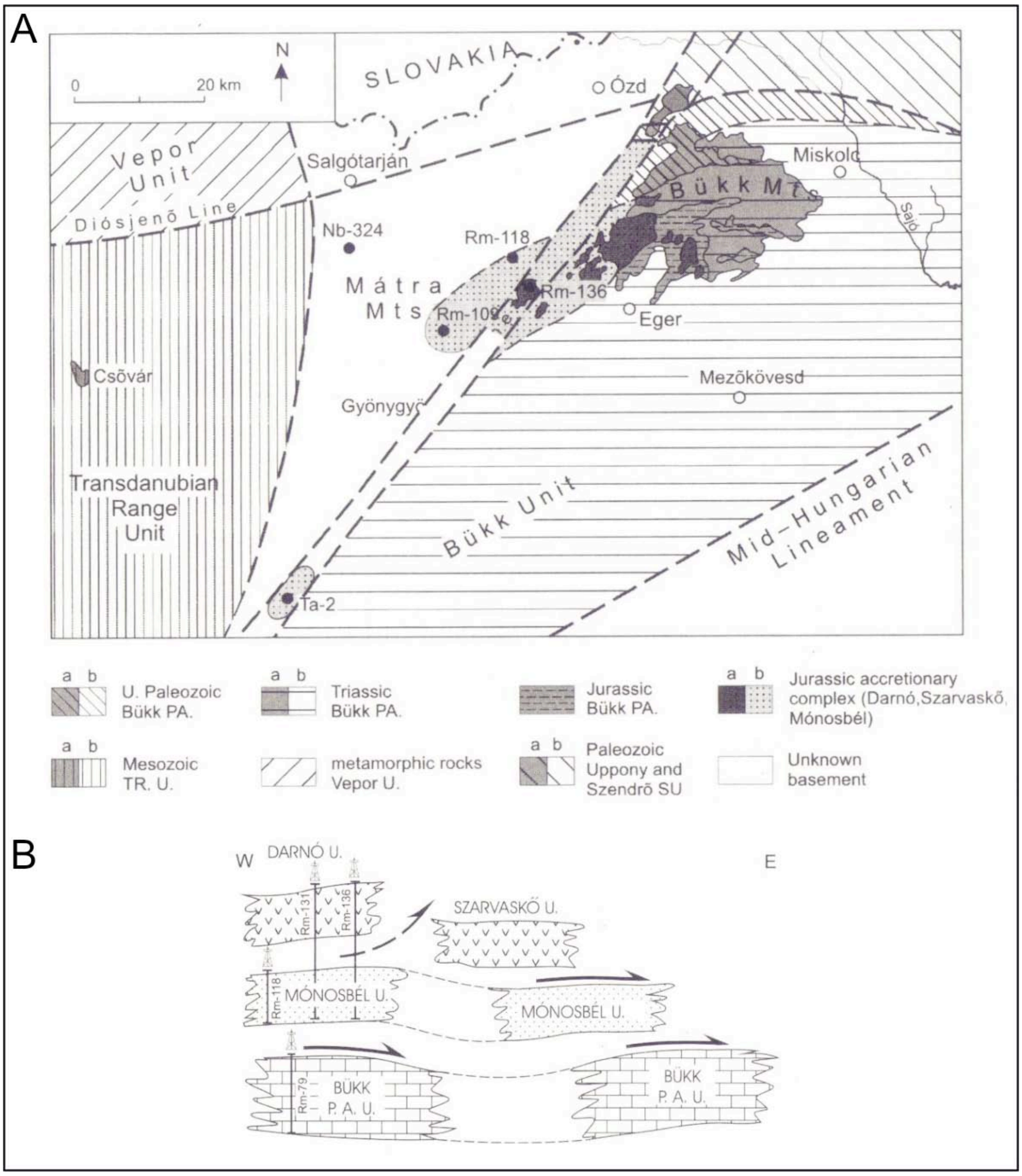

Figure 3

Simplified pre-Tertiary geological map (A) and tectonic reconstruction (B) of the Bükk Unit. (KOVÁCS et al. 2008).

3. The Darnó Unit

The Darnó Unit is located in NE-Hungary, about 120 km east of Budapest, along the western forelands of the Bükk Mts. (Fig. 3, 4). The Darnó Unit predominantly contains pillow basalts and some gabbro with minor amount of radiolarites, pelagic mudstones and siliceous shales (KOVÁCS et al. 2008; KISS et al. 2008; KISS et al. 2010). Radiolarians yielded both Triassic (Ladinian-Carnian) and Jurassic (Bathonian-Callovian) ages in different horizons of radiolarites, while only Jurassic (Callovian) ones occur in the shales. However, mingling of Triassic radiolarite with basalt also occurs at one locality of the Darnó Hill (GAWLICK et al. 2010).

Different kinds of basalts can be distinguished, from which amygdaloidal pillow basalts with peperites containing red and pink mudstone are considered to be advanced rifting related magmatites of Triassic age (KISS et al. 2008; KOVÁCS et al. 2008). These basalts are exposed in some quarries (e.g. Reszél Hill quarry) and outcrops throughout the Darnó Hill and its vicinity. The unit is underlain by the so-called Mónosbél Unit of Jurassic age containing dark grey shales with both pelagic and distal turbiditic characters, carbonate turbidites of distal character and debris flows with "microolistrostrome" character (Fig. 4). These units together with the Szarvaskő Unit are forming the so-called Mónosbél Complex which is a Jurassic accretionary complex. Some deep drillholes that have been completed during exploration of the Tertiary Cu-porphyry and skarn ores of Recsk area also encountered occurrences of the Bükk Parautochton Unit under the Mónosbél Complex (KOVÁCS et al. 2008).

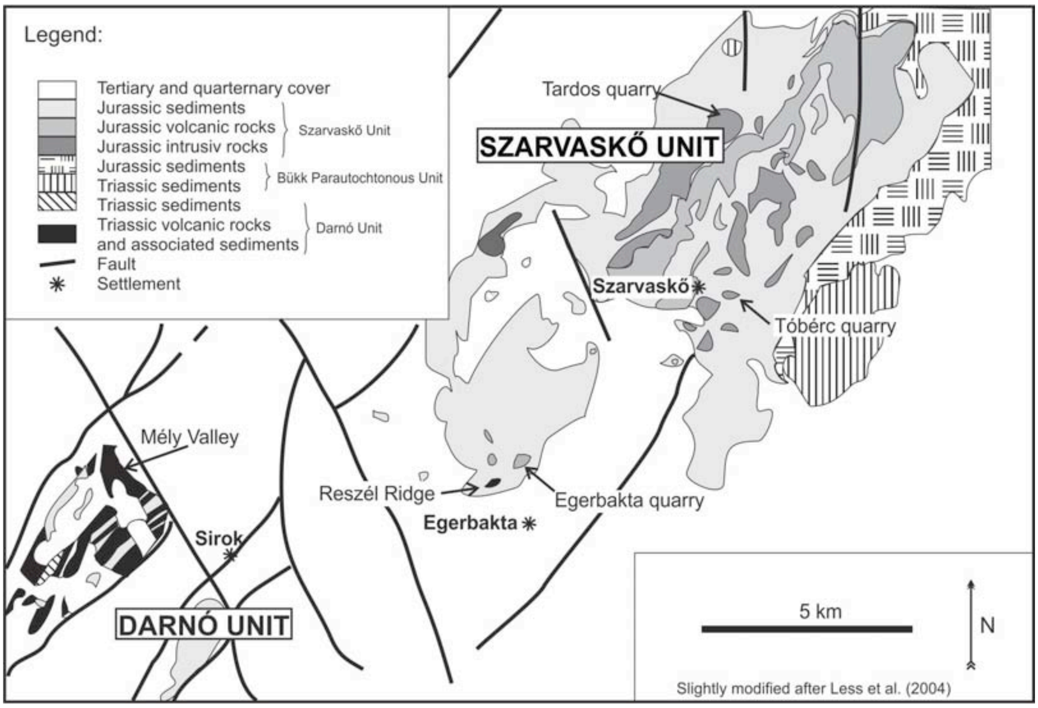

Figure 4

Geological sketch map of the Darnó and the Szarvaskő Units. Location of the below mentioned quarries is shown. Geology is modified after LESS et al. (2004).

During the earlier studies, BALLA et al. (1980) have found that the basaltic rocks of the Darnó Unit had possibly not formed in a MORB setting but an advanced rifting stage origin is more probable. DOWNES et al. (1990), DOSZTÁLY & JÓZSA (1992) and HARANGI et al. (1996) discussed that the age of the pillow basalts is Triassic, however they suggested mid-oceanic ridge origin. They also recognized that the rocks are olistolithes in an olistostrome formation of Jurassic age. According to JÓZSA (1999) the magmatic suite of the Darnó Unit was probably a part of the oceanic lithosphere of the hypothetical Meliata Ocean which opened in the Middle Triassic and then re-opened as back-arc-basin in the Jurassic. The recent works (HAAS & KOVÁCS 2001; DIMITRIJEVIĆ et al. 2003; KOVÁCS et al. 2008; KISS et al. 2008, KISS et al. 2011) have ruled out the Meliaticum of the West-Carpathians as the possible place of origin and have confirmed a correlation with similar basaltic units of the NW-Dinarides (e.g. Kalnik Mts., Croatia; Vareš-Smreka, Bosnia and Herzegovina).

According to these interpretations, the assemblage of the various units of the Darnó area is an accretional mélange or part of an accretional wedge in a nappe structure (DIMITRIJEVIĆ et al. 2003; HAAS 2004; KOVÁCS et al. 2008).

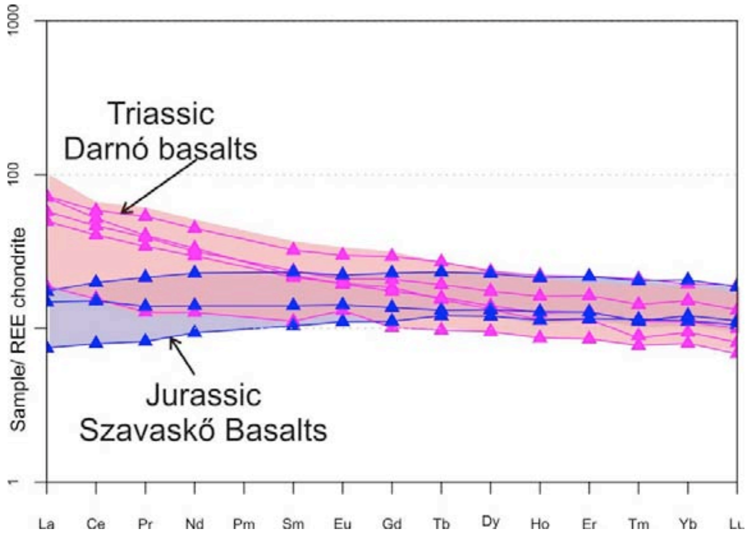

Figure 5
The chondrite normalized REE spider diagram of the Triassic and Jurassic basalts from different localities of NE-Hungary.
Note the differences among the Triassic Darnó basalts (pink) and the close Jurassic Szarvaskő basalts (blue) (slightly modified after KISS 2008).

Petrochemical characters of the Triassic basalts with carbonate peperitic facies of the Darnó Unit are well distinguishable from the Jurassic back-arc-basin-related pillow basalts of the Szarvaskő Unit. The chondrite-normalized (BOYNTON 1984) REE data are mainly around the 10x chondrite line for both types of basalts, however light enrichment from La to Nd is characteristic to Triassic basalts of the Darnó Unit (Fig. 5). On the 2xNb-Zr/4-Y discrimination diagram (MESCHEDE 1986), the analysed Triassic basalt samples are in the field of the within plate basalts and within plate tholeiites, whereas compositions for the Jurassic basalts of the Szarvaskő Unit are mainly in the volcanic arc and N-MORB fields (Fig. 6) (KISS 2008).

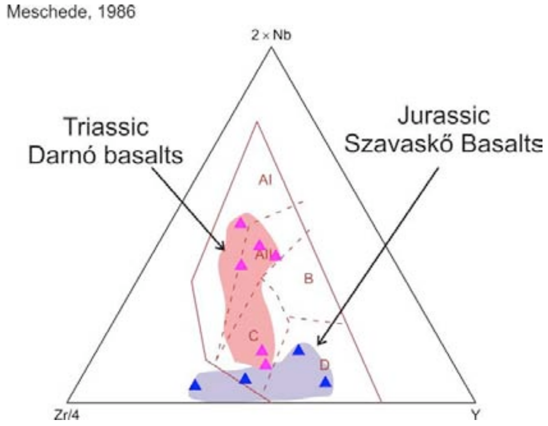

Figure 6
The Darnó and Szarvaskő basalts on the discrimination diagram of MESCHEDE (1984). The results support the rifting related origin for the Triassic basalts, as within-plate-basalt origin is the most probable. However, differences among Triassic and Jurassic basalts can be clearly seen (AI-AII: within plate alkaline basalt; AII-C: within-plate tholeiites B: P-type MORB; C-D: volcanic arc basalt; D: N-type MORB) (slightly modified after KISS 2008).

4. The Szarvaskő Unit

The Szarvaskő Unit is located in the southwestern part of the Bükk Mts., NE-Hungary and occupies an area of about 25 km^2 (Figs. 3 and 4). The magmatic sequence of the Szarvaskő Unit is quite uncommon and different units are missing in comparison to other well-known ophiolites (e.g. mantle section with ultramafic units is completely absent). Cumulate gabbro is abundant and it is accompanied by rare ultramafic cumulates (hornblendite, Fe-Ti- rich wehrlite) at some places. The upper part of the plutonic section with various gabbroic and related plagiogranitic rocks is the best preserved part of the unit (SZENTPÉTERY 1953; SADEK & ÁRKAI 1994) and crops out in the Tardos and Tóbérc quarries (Fig. 4). The area of Szarvaskő (Kecskefark Hill) is the locus tipicus of the wehrlit containing olivine, diallage, amphibole and magnetite (PAPP 2002). Nowadays, no good outcrops can be found to study this rock. The magmatic intrusions are hosted by a series of turbiditic shales and sandstones. The volcanic section is well developed; pillow basalts are exposed in many outcrops of the Szarvaskő Unit (SZENTPÉTERY 1953; BALLA 1984).

Recent geotectonic models favour that formation of the Szarvaskő Unit took place in the Vardar Ocean, where sea-floor spreading and magmatism lasted from the Middle Triassic until Late Jurassic/Early Cretaceous (PAMIĆ et al. 2002; CSONTOS & VÖRÖS 2004). A similar origin was suggested for some Dinaridic Ophiolite Zone (DOZ) ophiolites (PAMIĆ 1997). Radiometric age of the magmatic rocks of the Szarvaskő Unit is 166 ± 8 Ma (ÁRVÁNÉ SÓS et al. 1987), which is comparable with the ages of 189 ± 6.7 Ma to 136 ± 15 Ma obtained from ophiolitic rocks of the DOZ and also partly of the Vardar Zone (VZ) (PAMIĆ et al. 1998; PAMIĆ et al. 2002). According to CSONTOS & VÖRÖS (2004), the Vardar Ocean consisted of a Triassic-Jurassic plate and a Middle-Late Jurassic back-arc-basin, which could have been the original formation site of the Szarvaskő Unit. With the onset of Late Jurassic/Early Cretaceous intra-oceanic subduction of the Vardar Ocean (PAMIĆ et al. 2002; CSONTOS & VÖRÖS 2004), the Szarvaskő Unit became a part of the accretionary prism (CSONTOS 2000). Results of an early Alpine, low-grade metamorphism can be observed throughout the Szarvaskő Unit (ÁRKAI 1983; CSONTOS 1999). According to SADEK et al. (1996), this metamorphism was a low temperature anchizonal event (max. 250-300°C) corresponding to prehnite-pumpelleyite facies, with an illite-muscovite K/Ar age of about 120 Ma, which is in good agreement with the data of BELÁK et al. (1995) for the age of metamorphism in DOZ.

Petrochemical analyses of the mafic-ultramafic rocks of the Szarvaskő Unit revealed some differences from MORB and therefore a back-arc-basin or a marginal sea environment has been suggested to explain their formation (KUBOVICS et al. 1990; DOWNES et al. 1990; HARANGI et al. 1996; AIGNER-TORRES 1996; AIGNER-TORRES & KOLLER 1999). Some of the gabbros and the unusual ultramafic rocks, described originally as wehrlites, have rather low REE pattern and are regarded as cumulates (AIGNER-TORRES & KOLLER 1999). In any case, these samples represent a member of a classical tholeiitic fractionation trend with high Fe- and Ti-enrichment (Fig. 7). The low Cr- and high V-contents in contrast can only be explained by a fractionation from an evolved basic melt under rather high oxidation state. On the other hand, the plagiogranites show inverse pattern with overall high trace element contents and remarkable negative Eu anomalies. This sample suite with clear magmatic mineral assemblages cannot be related solely by fractionation of a common MORB source only. They represent a combination of a MORB-like fractionation of olivine + plagioclase + clinopyroxene ± chromite and a minor, but still important influence of assimilated terrigeneous sediments abundantly present in the area (AIGNER-TORRES 1996). The basalts and some of the gabbros show fractionated N-MORB-like patterns with a low ε_{Nd}, indicating a possible enriched source component.

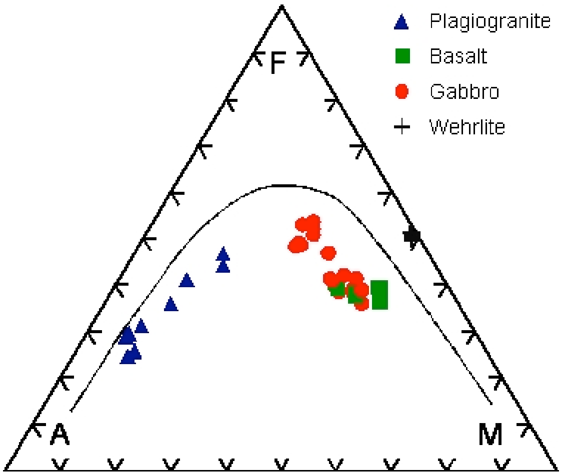

Figure 7
AFM diagram of various rock types from the Szarvaskő Unit (AIGNER-TORRES & KOLLER 1999).

5. Key localities in the Darnó and Szarvaskő area

5.1. The Reszél Hill quarry: an insight into the Triassic volcanism

In the Reszél Hill quarry (Fig. 4, 8) four different volcanological facies; the closely packed pillows with some “pyjamas-type” lava lobes, peperitic facies with red micritic limestones, in-situ and pillow fragmented hyaloclastite breccia facies are exposed. These volcanic facies are enclosed in the Jurassic Mónosbél Unit, represented by turbiditic shale (Mónosbél Formation) and re-sedimented bioclastic limestone (Oldalvölgy Formation). The contact of the basalt with the sedimentary units is clearly secondary, as there is no thermal effect on the sedimentary host rocks and hydrothermal features characteristic to the basalt (see below) are absent from the sediments. Also, occurrence of the red micritic limestone altered by the thermal effect of basalt is restricted to the peperitic facies. Thus the whole submarine volcanic unit is interpreted to be a large block which has been incorporated into the olistrostrome mélange of the Mónosbél Unit (KISS 2008, KISS et al. 2008 and 2010).

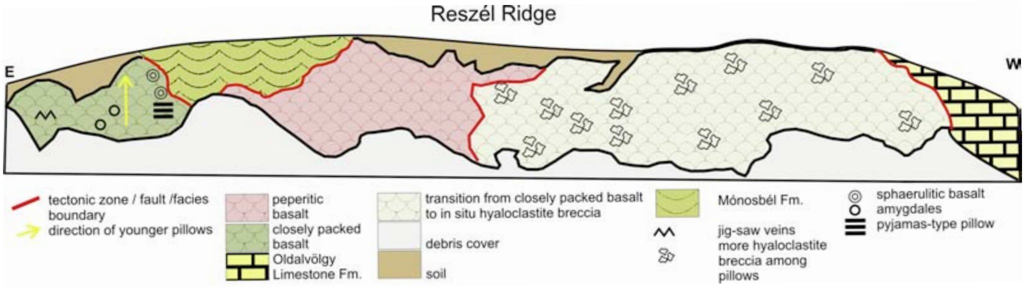

Figure 8
Sketch of the quarry at Reszél Ridge. Three different facies can be seen in the Jurassic mélange, which is represented by the Oldalvölgy and Mónosbél Formations (KISS, 2008).

According to KISS et al. (2008, 2010 and 2011), the peperitic facies (Fig. 9) forms a block of about 15 m in size. The so-called blocky peperite contains irregular-round shaped juvenile basalt fragments and sometimes even small recognisable parts of lava-lobes occur. The diameter of fragments and lave lobes is between 10 cm and 50 cm and they are hosted in red limestone matrix. The basalt fragments sometimes contain calcite-filled amygdales with 1-3 mm in diameter and are rich in 1-4 mm thick, mainly calcite-filled veins. Strong hematitization is also common, which seems to be typical to these basalts in peperitic facies, while it is not as common in the other volcanic facies of the studied localities. The basalt fragments of the peperite generally have variolitic texture. The basalt consists of skeletal crystals, mainly subhedral albite-rich plagioclase in glassy and microcrystalline material. Rock forming pyroxene is often pseudomorphosed by calcite and chlorite as the result of intense hydrothermal alteration. The limestone is the matrix of the basalt fragments, but it also occurs as infillings in jig-saw type cooling cracks with hydrothermal minerals that cut the basalt fragments. The limestone usually has micritic texture and often contains pieces of magmatic minerals, mainly plagioclase and is cut by 1-5 mm thick calcite-filled veins.

Figure 9
Peperitic facies in the Reszél Hill quarry. Red, micritic limestone is mingled with green basalt. Hydrothermal calcite is also common in this environment.

The closely packed pillow (Fig. 10) units contain lava lobes with diameters about 0.5 m. The marginal parts of the pillows may contain amygdales up to 1 cm in diameter, while sphaerolitic texture on the surface of pillows occur more often. The amygdales are filled up by calcite and other hydrothermal minerals. The lava lobes are also dissected by tortoise shell joints and jig-saw veinlets (formed obviously during the cooling of the basalt) with thickness from a few millimeters to about 2 centimeters. Other characteristic textures related to the solidification of the lava are the occurrences of "pyjamas-style" pillows and feeding channels in the cores of pillows. These features are also formed by rapid cooling of the basalt (PALINKAŠ et al. 2008). Both, the feeding channels and also the "pyjama" ribbons are geopetal structures with flat bottom of the vug and irregular-curving upper boundary. "Pyjamas-style" lava lobes are characteristic features of the lava pillows developed during obstructed propagation of lava into soft sediment thus their occurrences in the vicinity (a few meters) of the peperitic basalt facies is expected. In the block, the internal texture of individual pillows becomes variolitic whereas their rims are sphaerolitic towards the peperitic facies. Albite-rich plagioclase occurs in the microcrystalline, often chloritized groundmass and is sporadically accompanied by minor amount of clinopyroxene, as well as pyrite. Among the pillows, small amount of hyaloclastite breccia can be found in small pockets formed by joints of the pillows. The matrix supported breccia is made up of 2-5 cm large basalt and sideromelane shards, which are cemented by hydrothermal minerals (calcite, chlorite, epidote, hematite).

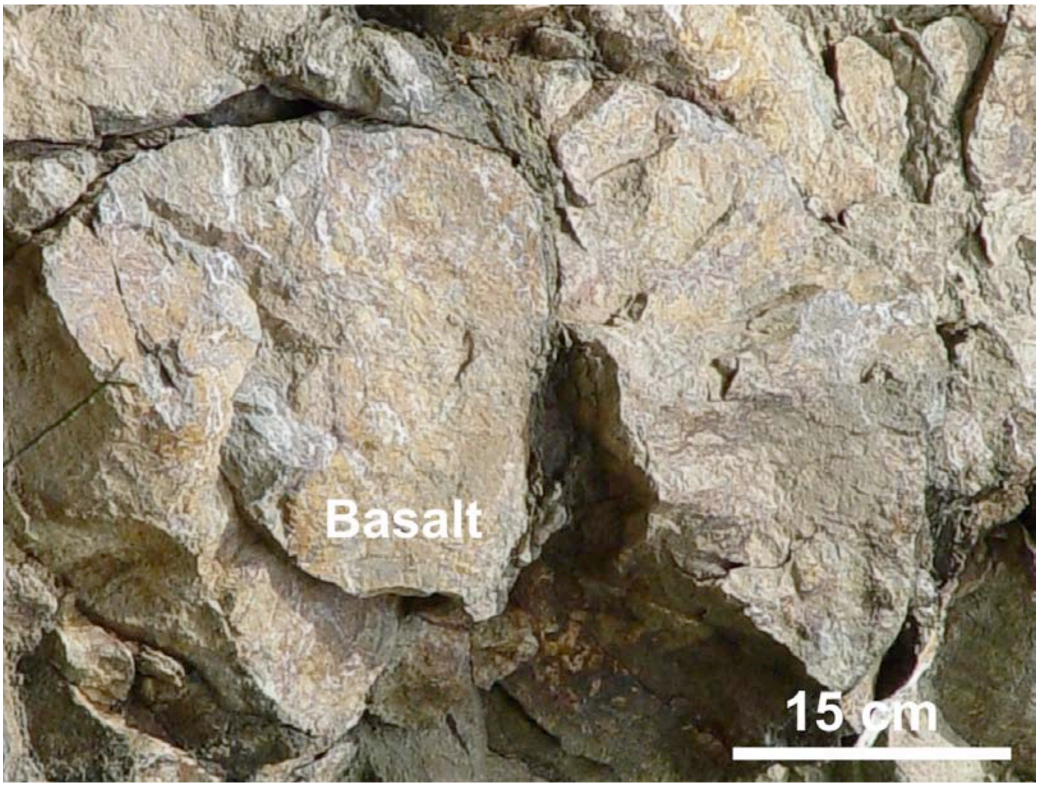

Figure 10
Closely packed pillow facies in the Reszél Hill quarry.

The in-situ hyaloclastite breccia and the pillow fragmented hyaloclastite breccia contains 10-50 cm large basalt fragments, which are cemented by the mixture of hydrothermal minerals (calcite, chlorite) and 0.5-2 cm large basalt, glassy basalt and limestone pieces. The textural characteristics of these rocks are similar to the above mentioned ones. More basalt fragments and less cement characterize the in-situ hyaloclastite facies, which grades continuously into the pillow fragmented breccia characterized by smaller and fewer glassy basalt fragments and more hydrothermal mineral cement.

The exposed submarine volcanic facies in the Darnó Unit represent distal facies in relation to the major volcanic feeder zone (KISS et al. 2008, 2010 and 2011), as deduced from the absence of coherent pillow lava facies characteristic to the centre of a submarine volcanic dome in similar environments (e.g. Hruškovec quarry in the Kalnik Mts., Croatia; PALINKAŠ et al. 2008). This also invokes rapid cooling of the lava. Amygdales rimming marginal parts of the pillow lobes evidence degassing in a relatively shallow water; thus conditions enabled vesiculation of the basalt lava. The formation of the "pyjamas-type" 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.

Discovery of peperitic pillow facies in the submarine basalt formations of the Darnó Unit provides additional possibility for interpretation of the origin of the magmatism. The pillow lava extrusion was on the bottom of the sediment filled basin and not on the floor of an ocean at a mid-oceanic ridge, because basaltic lava penetrated into water soaked lime-mud above the CCD and this process resulted in development of the peperitic facies (KOVÁCS et al. 2010; KISS et al. 2008, 2010 and 2011; PALINKAŠ et al. 2008).

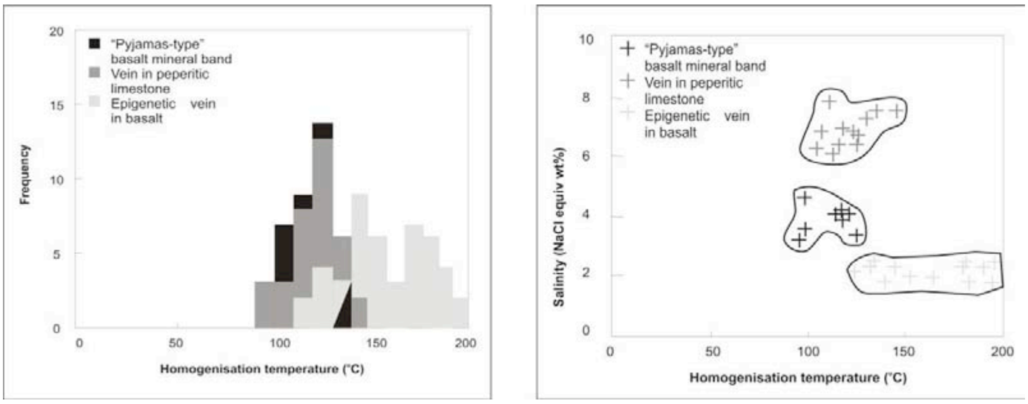

Figure 11

Results of fluid inclusion study in different kinds of calcite infillings from the Reszél Hill quarry. Precipitation of calcite from "pyjamas-type" infillings is related to the primary hydrothermal processes, while the veins in the limestone and other epigenetic veins in the basalt are corresponding to later processes (after KISS et al. 2008).

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-type" pillows and feeding channels in the centre of pillows. Temperature-salinity data (90-160°C, 3.2-5.6 NaCl equiv.wt.%) from primary fluid inclusions of calcite (Fig. 11) indicate that these hydrothermal processes also took place far from the major feeding zone of the volcanism (KISS et al. 2008). Similar results were obtained from the Triassic submarine basaltic dome of Hruškovec quarry, Croatia (BOROJEVIĆ et al. 2000; PALINKAŠ et al. 2008), where higher temperatures and salinities occur only close to the major feeding zone of the volcanism (e.g. in the coherent pillow lava facies). 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.

5.2. Egerbakta quarry: a unique Jurassic basalt locality

The quarry at Egerbakta belongs to the Szarvaskő Unit and exposes mainly pillow lavas. Among the closely packed pillows, a few dikes and local admixture of siliciclastic sediments into the pillow sequence and some pillow fragmented hyaloclastite breccias also occur in the western part of the quarry (Fig. 12, KISS 2008). The host Jurassic shale (part of the Mónosbél Formation Group) can also be observed in the quarry, just on the southwestern side of the lake. Alternative field locations of pillow basalts of the Szarvaskő Unit are the Várbérc Gorge north of the village of Szarvaskő or the Szarvaskő railway tunnel close to the station of Szarvaskő.

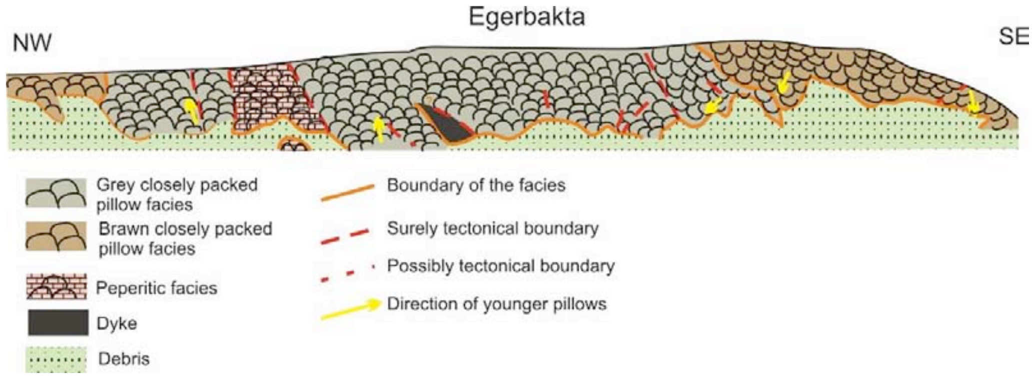

Figure 12
Sketch of the quarry of Egerbakta. Besides the closely packed pillow facies also peperitic facies (s.l.) and the pillow fragmented hyaloclastite breccia can be found there (KISS, 2008).

Most of the basalts belong to the closely packed pillow lava facies and are characterized mainly by intersertal texture with some porphyric characteristics (Fig. 13). Plagioclase and clinopyroxene occur as phenocrysts with a size up to 2 mm. Beside minor amount of Fe-oxide minerals (ilmenite and titanomagnetite), occurrences of olivine phenocrysts are rather rare.

The groundmass minerals are normally < 0.1 mm in size and are composed mainly of albite, augite and some oxides hosted by a glassy-microcrystalline material. Geochemically, all basalts can be derived form a similar tholeiitic source based on their homogeneous bulk and trace element data: the Ti/Zr ratio of 80-102, La/Ta (20-27), Th/Ta (1.25-2.09), a flat REE distribution pattern with slightly enriched normalized values around 10 (Fig. 5), homogeneous Zr/Y ratios around ~3 (Fig. 14) and Ti/V ratios around 40. The $^{87}Sr/^{86}Sr_i$ ratios of the basalts range between 0.7031 and 0.7035, while ε_{Nd} values are between +6.33-+6.64 (Fig. 15) (AIGNER-TORRES 1996; KISS, 2008).

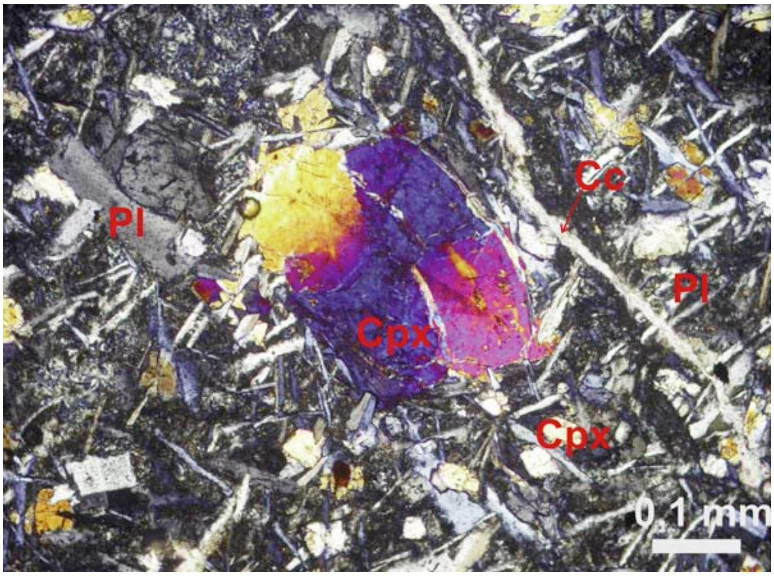

Figure 13
Microphotograph of the closely packed pillow basalt.

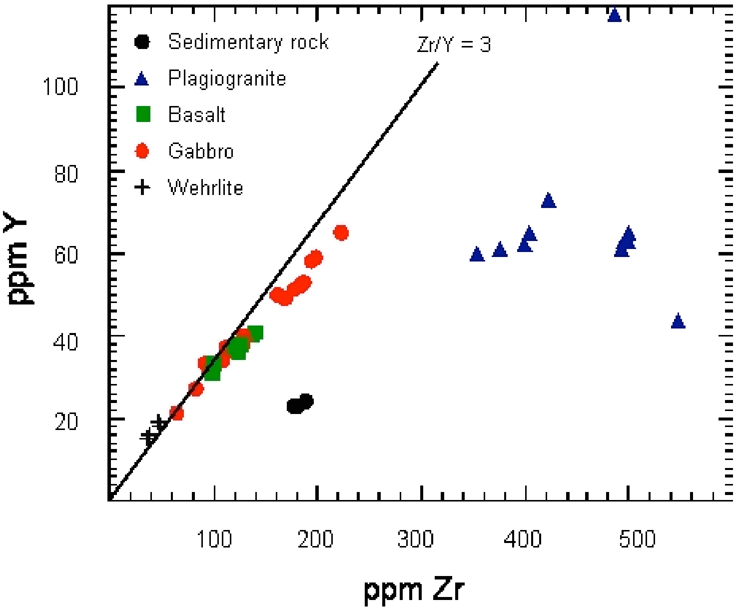

Figure 14
Diagram showing Zr and Y contents of the different kinds of magmatites at the Szarvaskő Unit (AIGNER-TORRES & KOLLER 1999).

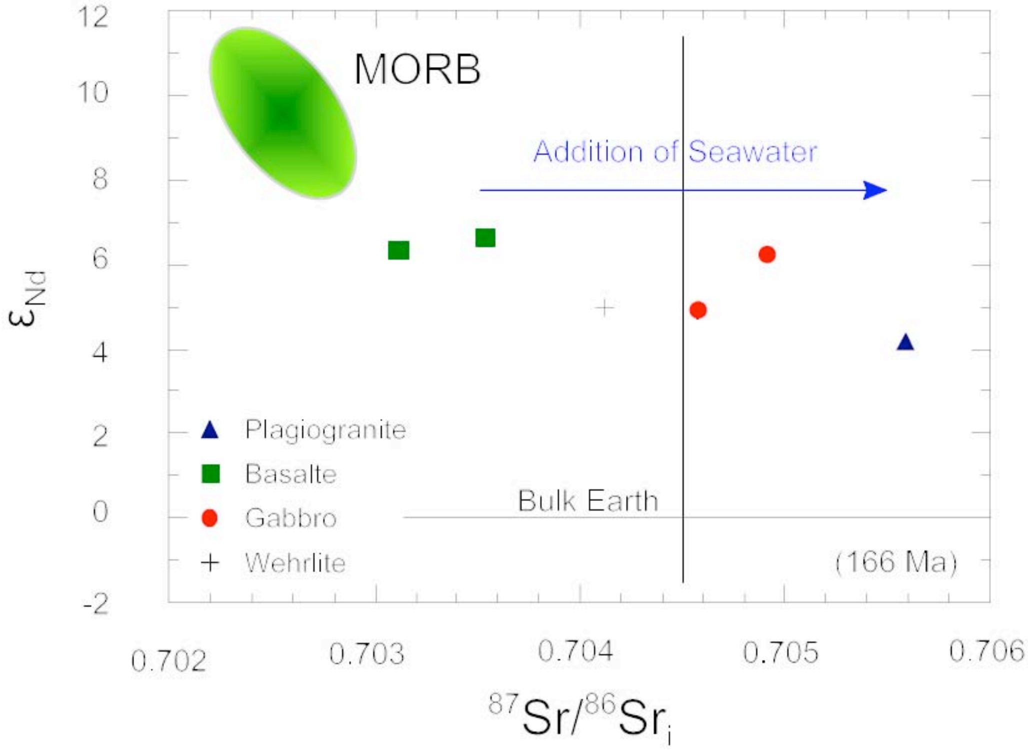

Figure 15
The $^{87}Sr/^{86}Sr_i$ ratio of the basalts of the Szarvaskő Unit (calculated of 166 Ma) (AIGNER-TORRES & KOLLER 1999).

Based on the closely packed pillow nature of the volcanic facies, the hydrothermal alteration took place under low fluid/rock ratio. This is deducted from the elevated salinities of primary fluid inclusions found in cross-cutting primary calcite veins. Salinities are from 4.5 to 9 NaCl equiv. wt.% and homogenization temperatures of fluid inclusions are between 110 and 150°C. Chlorite thermometry provided 150-160°C for temperature of alteration. Combination of fluid inclusion and chlorite thermometry data suggests about 5-6 kilometers deep seawater-cover at the time of cooling of the basalt (KISS 2008, Fig. 16).

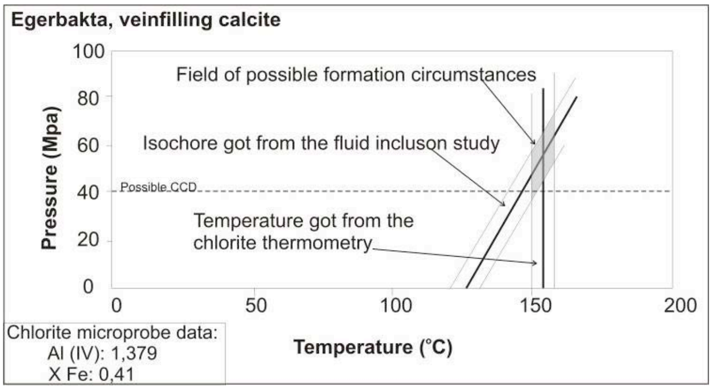

Figure 16
Results of fluid inclusion study and chlorite thermometry.

The peperitic facies (*s.l.*) (Fig. 17) can be found in the northwestern part of the section, with tectonic contact to the surrounding closely packed pillow facies (KISS 2008). The earlier siliciclastic sediment (aleuritic) is completely altered to hydrothermal minerals (mainly albite and quartz), but the sedimentary texture still remained. Pieces of this former sedimentary rock are mixed with the basalt; occurring between the pillows, in fractures and in the inter-pillow hyaloclastite breccia as well. The basalt of this facies bears similar characteristics to the above mentioned closely packed pillows, though more glassy parts occur along the contact with the sediment. Different stages of hydrothermal mineral precipitation can be traced in the basalt and in the altered sediment too (mainly albite, quartz, pumpellyite, chlorite, datolite and calcite formed in the groundmass and in different vein generations).

Figure 17
Peperitic facies in Egerbakta quarry. The black, fine grained absolutely altered siliciclastic material mingles with green basalt.

A few dikes occur in the middle of the quarry; to the northwest they have chilled contacts with the pillows, while to the southeast their contact is tectonic. The chilled margin is very fine grained, contains a lot of glassy and microcrystalline material (KISS 2008).

On the western side of the lake even an at least 5 m large block of pillow fragmented hyaloclastite breccia occur. The breccia contains 3-20 cm large basaltic and glassy fragments cemented by hydrothermal minerals (mainly quartz, chlorite and prehnite).

5.3. Tardos quarry: representatives of the lower levels of the Jurassic submarine volcanic system

The Jurassic Tardos Gabbro Formation of the Szarvaskő Unit is exposed in this quarry (Fig. 4). Here a variation of several types of gabbro can be found (Fig. 18). This gabbro is in relationship with the basalt of Szarvaskő; it represents a part of the intrusive sequence of the same magmatism. The gabbro shows variable texture depending mainly on the plagioclase-pyroxene ratio. There is a sharp contact between light and dark coloured varieties, further fine to coarse grained varieties and locally spotted types with up to 2 cm round dark inclusions may also be found. Some of these gabbros show a distinct orientation of plagioclase laths typical for layering, however, modal layering does not occur. Sheated (?) dykes are present in the middle of the quarry; the dykes of mainly dolerite composition have chilled margins against each other, though this phaenomena is lacking along the contact with the gabbro.

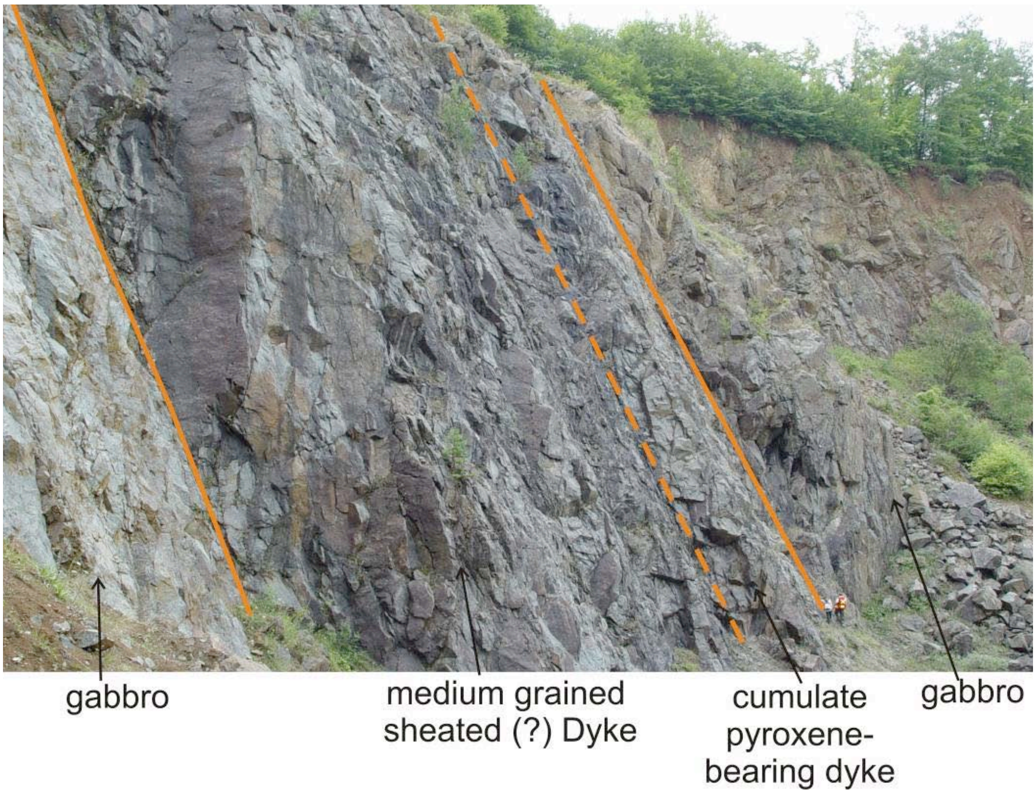

Figure 18
Different kinds of gabbros and dykes occur in the quarry of Tardos.

The gabbro contains plagioclase, clinopyroxene, amphibole and Fi-Ti-oxides, pyrite and pyrrhotite with minor or accessory phases of apatite, rarely zircon (Fig. 19). According to AIGNER-TORRES (1996), the composition of plagioclase ranges from $An_{0.60}$ to $An_{0.38}$ beside secondary albite, while the clinopyroxene composition ranges from $En_{44}Wo_{45}$ in fine-grained gabbros to $En_{37}Wo_{39}$ in cumulate gabbros.

Both olivine and orthopyroxene are preserved only in the wehrlite rock types, but dark and partly altered clusters and spots rise arguments of pre-existing olivine or orthopyroxene in the more mafic gabbros. Amphiboles are characterized by a composition from tschermakite to Mg- and Fe-hornblende. Amphibole-plagioclase thermometry based on HOLLAND & BLUNDY (1993) defines 920-850°C, as well as to 680-650°C crystallization temperatures in cumulate gabbros and pegmatitic gabbros, respectively (AIGNER-TORRES 1996). Secondary phases in basalts and gabbroic rocks are prehnite, pumpellyite, chlorite and albite as results of a low-grade Alpine metamorphic overprint.

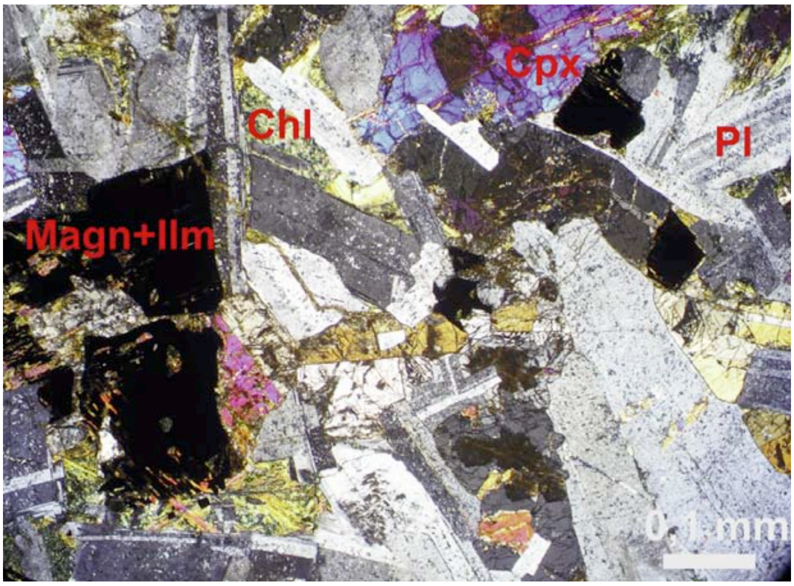

Figure 19
Microphotograph of the coarse grained gabbro.

Results of the geochemical studies show that the main characteristics of the basalt of Szarvaskő and the gabbro at Tardos and Tóbérc (see below) are similar; their slight negative anomaly at Nb and positive at Th and Ce are typical feature of the subduction related magmatism. The similar REE patterns also prove the common origin (Fig. 20).

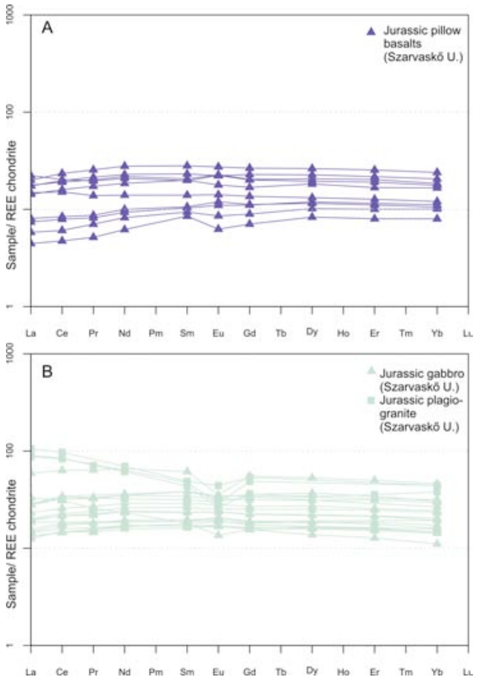

Figure 20
REE spider diagram of different Jurassic magmatites of the Szarvaskő Unit (A: basalts; B: intrusions).

5.4. Tóbérc quarry: gabbro pegmatite and plagiogranite in the Jurassic gabbro

Various gabbroic and related plagiogranitic rocks are exposed in Tóbérc quarry situated 1 km southeast of Szarvaskő village (Fig. 4). In the commonly coarse grained gabbroic rocks, quartz-dioritic varieties, intrusions of dikes and irregular bodies of plagiogranitic rocks locally also occur (Fig. 21). Detailed petrographic descriptions of the magmatic rocks were presented by SZENTPÉTERY (1953) and the plagiogranite was also studied by SADEK & ÁRKAI (1994).

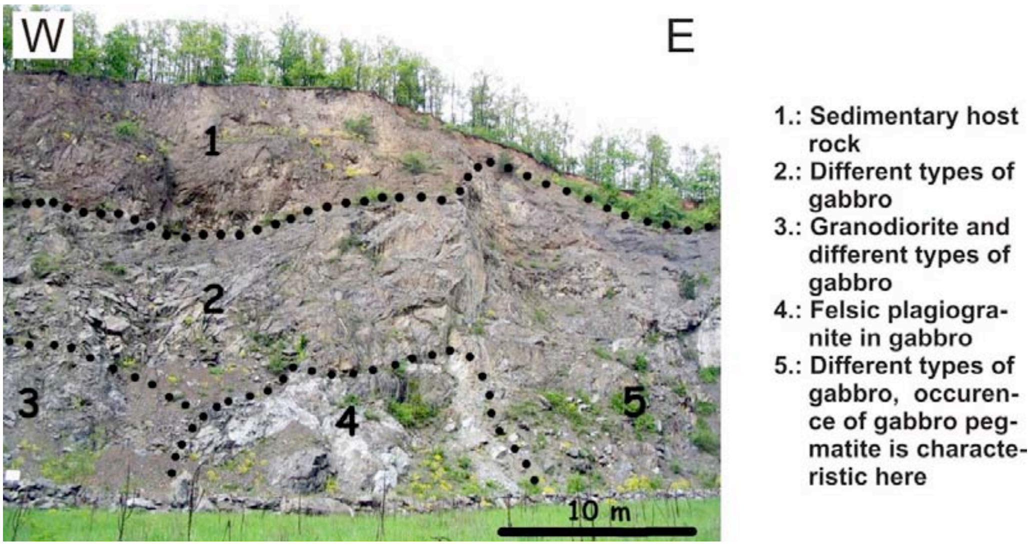

Figure 21
Various gabbroic and plagiogranitic rocks are exposed in the Tóbérc quarry (PÉNTEK et al. 2006).

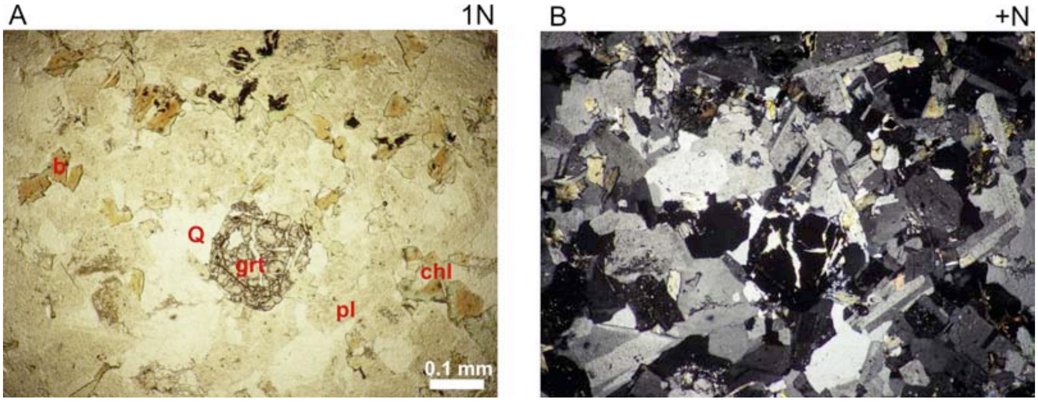

Figure 22
The plagiogranite in thin section. Plagioclase (pl), quartz (Q) highly chloritized (chl) biotite (b) are common and garnet (grt) can be also seen.

The plagiogranites are commonly equigranular in texture and contain ~65vol.% sodic plagioclase, 25-30 vol.% quartz and variable amounts of chlorite, garnet, allanite, zircon and apatite (Fig. 22). Garnet crystals up to 1 cm diameter are enriched in the border zones of its irregular or dike-like bodies towards the gabbro host (Fig. 23), but they are also present in the whole plagiogranite. The composition of the garnet is always almandine rich ($Alm_{61.6-77.4}Pyr_{2.6-17.1}Gros_{1.4-6.7}Spes_{5.4-34.3}$) but the crystals commonly show a strong zoning. Based on garnet-ilmenite geothermometric method (POWNCEBY et al. 1987 and 1991), magmatic temperatures in the range of 927-670°C from core to rim were calculated by AIGNER-TORRES (1996). Results of the geochemical studies revealed that the main characteristics of the basalt of Szarvaskő and the gabbro at Tardos and Tóbérc are similar, and suggest a subduction-related origin. However, the plagiogranites of this quarry behave a bit differently; from La to Sm they show a light enrichment, but decreasing tendency.

Figure 23
Plagiogranite in the Tóbérc quarry. 2-4 mm big reddish brown garnet is common in samples collected close to the border towards the gabbro.

According to PÉNTEK et al (2006), the host gabbro is very heterogenous, with medium to coarse grained texture. Coarsening of gabbro texture in irregular patches up to a few centimeter in diameter is a common feature of the rock. Clinopyroxene, plagioclase and amphibole are the major rock-forming minerals accompanied by Fe-Ti-oxides, biotite, apatite and rare orthopyroxene and sulphides.

Xenoliths of the host sediments are also abundant. These xenoliths were partly assimilated and recrystallized to coarse-grained massive quartz bodies with a plagioclase-rich granodioritic rim. Sulphide enrichments containing pyrrhotite, pentlandite and chalcopyrite in association with quartz and biotite can also be found along the contact of the gabbro with the shale. The gabbro is tectonically fragmented and fractures are filled with prehnite, calcite, chlorite and quartz.

Results of detailed studies on the gabbro-pegmatites of the Tóbérc quarry were presented by PÉNTEK et al. (2006). Pegmatitic structures were classified according to their textural and mineralogical properties. Pegmatitic patches, pockets (Fig. 24) and narrow dykes precipitated from a locally segregated hydrous melt, whereas thick and more felsic dykes were intruded later. Homogeneous pegmatitic pods crystallized simultaneously in contrast to zoned pods which indicate further differentiation of the hydrous melt. The formation temperatures of the pegmatites are difficult to determine, but their crystallization most probably occurred between 800 and 900°C. During the crystallization of the pegmatites a fluid phase separated, as indicated by granophyric textures and F-enriched apatite compositions. This magmatic fluid caused deuteric alteration of the primary pegmatitic assemblage. This is revealed by the alteration of magnetite and pyroxene, accompanied by formation of biotite and zoned amphibole showing the "pargasitic-trend" of compositions typical for this kind of amphiboles (Fig. 25).

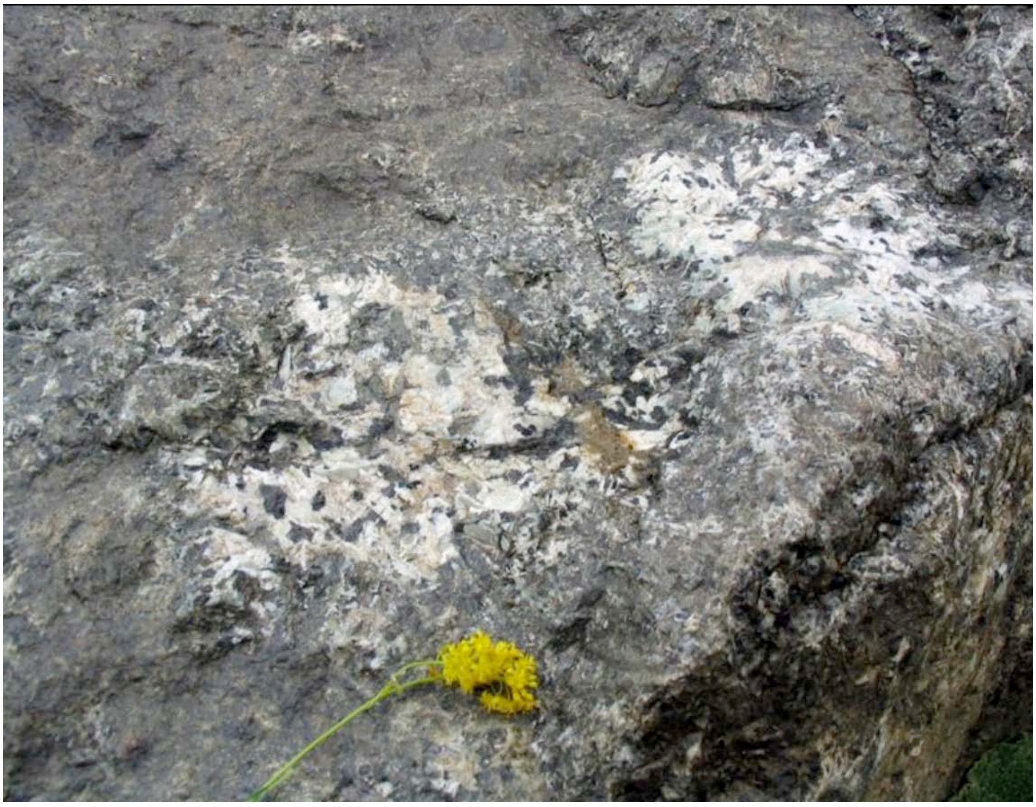

Figure 24
Pegmatitic pocket from Tóbérc quarry.

This process took place under continously cooling magmatic-submagmatic temperatures. The pegmatites and the host gabbro underwent postmagmatic alteration due to sea-floor hydrothermal activity: the responsible fluids were identified in two fluid inclusion generations. Typical to this process is the alteration of all primary phases and formation of actinolite, chlorite, clinozoisite and albite. Mineral assemblage, mineral- and fluid inclusion thermometry indicate a polyphase hydrothermal process between 250 and 400°C.

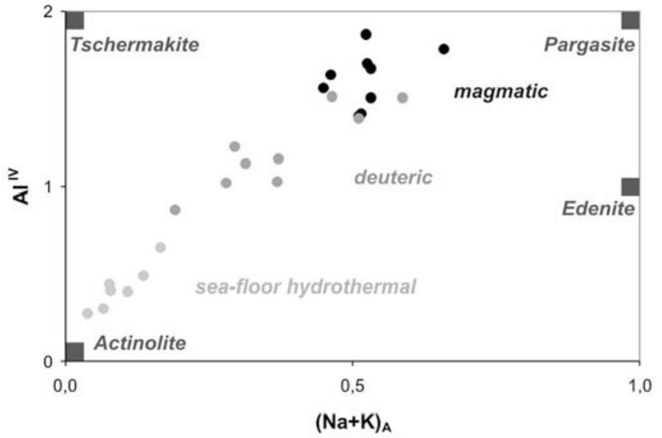

Figure 25
Compositions of the studied amphiboles from the Tóbérc quarry (PÉNTEK et al. 2006).

The Alpine regional metamorphism caused brittle and ductile deformation of the rocks discernible at outcrop- and microscopic scales. This deformation was accompanied by intense veining of a prehnite-chlorite-quartz-calcite-feldspar assemblage. This low-grade Alpine metamorphic overprint occurred at around 270-285°C at 1.5-2 kbars according to results of the fluid inclusion studies and the chlorite thermometry (Fig. 26).

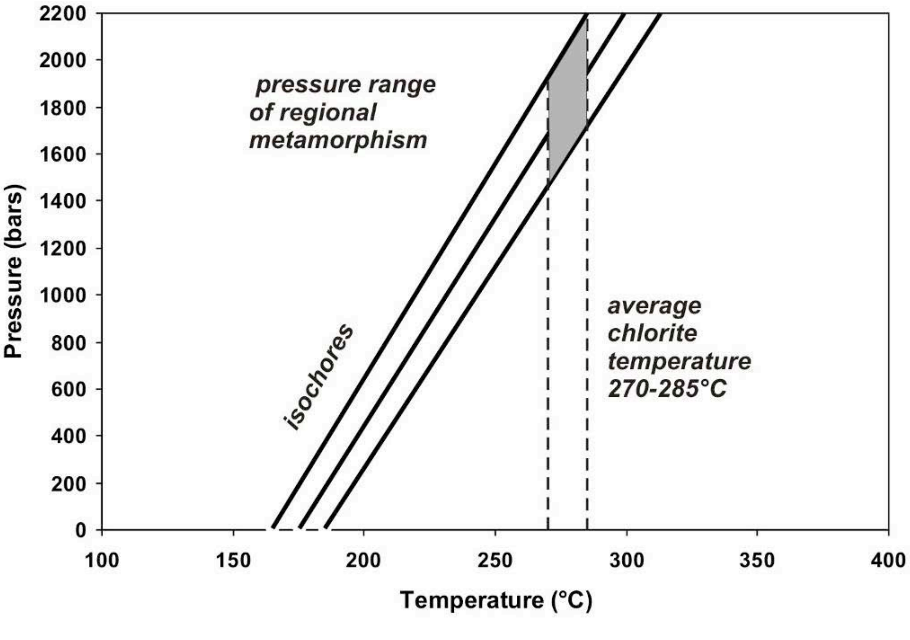

Figure 26
Pressure and temperature conditions of the low-grade Alpine metamorphic event was determined with the help of chlorite thermometry and fluid inclusion study (PÉNTEK et al. 2006).

6. Summary

In the Bükk Unit, detailed studies on Triassic, advanced rifting related volcanism and Jurassic, possibly back-arc-basin related magmatism were carried out in the past few years. Special interest has arisen concerning this region, because of the appearance of these different magmatites in the same mélange.

Though the Triassic and Jurassic basalts occur very close to each other in the field (sometimes only 200-1000 m far from each other), they can be distinguished with the help of careful macroscopic and microscopic observations. While porphyritic characteristics and well crystallized ground mass are common in the Jurassic basalt (even macroscopically visible), this feature is generally lacking in the Triassic ones. The occurrence of eu- and subhedral pyroxene is characteristic to the Jurassic basalts, while in Triassic rocks small pyroxene laths are rare.

Volcanic facies analysis was carried out on both types of lavas. The combination of this analysis and the fluid inclusion study revealed, that basaltic blocks of Triassic volcanism originated from distal parts of submarine lava flows, as no central facies was found, however, a very rapid cooling was proven. This origin is also suggested by mingling of unconsolidated reddish limey mud with the Triassic basalt (i.e. peperitic facies), which could have formed only as distal facies in a submarine lava flow. This facies is a typical feature of the Triassic localities and can be used as a great field indicator of that kind of basalt (KISS et al. 2011). However, results of lava-sediment mingling can be observed in the Jurassic pillow basalt blocks too, but there no limey mud, but black, very fine grained siliciclastic sediment mixed with the basalt (now altered to hydrothermal minerals). This can be regarded as peperitic facies *s.l.* and proves that Jurassic rocks formed much deeper, than Triassic ones, below the CCD, where no calcareous mud was presented.

At both localities, the seawater-rock interaction resulted in formation of hydrothermal mineral infillings (amygdale, jig-saw veins, feeding channels, pyjamas-type pillows) and the system was more likely seawater-dominated (as proven by fluid inclusion salinity data). However, in the case of the Jurassic basalts, this interaction was more limited, so a possibly lower water/rock ratio caused slight salinity increase.

Studies carried out on the Jurassic gabbros helped to understand better the Jurassic processes (e.g. to see the temperature circumstances) and to trace the origin of the magmatic suite. Results of a low-grade Alpine metamorphic overprint were found at every locality.

Data obtained from the geochemical studies show a clear difference among the Triassic and the Jurassic basalts' REE spider patterns. While Triassic samples reveal a slight enrichment from La to Sm, Jurassic ones show a tenfold enrichment compared to chondrite composition. These results reveal different geotectonic environments of the two types of basalts; Triassic ones formed most probably in an advanced rifting related environment, while Jurassic ones originated in an arc-related setting. The main characteristics of the Jurassic basalt of Szarvaskő and the gabbro at Tardos and Tóbérc are similar, which also proves a genetic relationship among them. However, their main REE characteristics suggest a subduction-related origin.

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