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STUDY OF AN EPIGENETIC COPPER OCCURRENCE AT THE DARNÓ HILL (NE HUNGARY) AND ITS CORRELATION WITH SOME DINARIDIC AND HELLENIDIC OCCURRENCES

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Abstract: The NE-Hungarian Darnó Unit hosts both Triassic and Jurassic pillow basalt blocks in an accretionary mélange. This Unit can be correlated with similar mélange complexes in the Dinarides and Hellenides. The studied epigenetic veins of the Darnó Unit are found in both Triassic and Jurassic basalts, however similar veins were recognized in the Triassic basalt of the Croatian Medvednica Mts. and in the Greek Stragopetra Mts., too. All studied veins contain mostly quartz and prehnite with a small amount of Cu- and Fe-bearing ore minerals. At the vein-basalt contact, clasts of the host rock and pumpellyite, chlorite, epidote are found. The primary ore minerals are chalcopyrite and bornite, but their alteration products also occur. Based on the fluid inclusion study of the quartz, the minimum formation temperature is between 169-228°C at the Darnó Hill, 110-212°C at the Medvednica Mts. and 183-259°C at the Stragopetra Mts. The salinity of the parent fluid was 2-3 NaCl equiv. wt% at both localities. Quantitative analysis of chlorite associated with the quartz allows calculating 228-258°C (Darnó Hill) and 212-216°C (Medvednica Mts.) as formation temperatures. Joint results of the above mentioned two methods define a pressure range of 10-110 MPa (Darnó Hill) and 55-245 MPa (Medvednica Mts.) for the vein formation. The observed characteristics suggest similar formation process in similar environment for both localities. The found p, T and salinity conditions, as well as the trace element composition of the ore minerals rule out the submarine hydrothermal process origin. The observed characteristics and the fact, that the veins are located in different aged basalts suggest an epigenetic process related origin. Based on earlier studies, an Alpine regional metamorphic process affected on the region and according to the results of the present research, the veins could form in the prograde or the retrograde phase of this metamorphism.

Keywords: pillow basalt, quartz-prehnite veins, copper occurrence, Alpine metamorphism

1. INTRODUCTION

The NE-Hungarian Darnó Hill geographically belongs to the Mátra Mts., but geologically it forms the uppermost nappe of the nappe system of the Bükk Unit. The geology of the Darnó Unit is very complex, as submarine volcanic rocks of different age (Triassic and Jurassic) and origin are found there together with Paleozoic, Mesozoic and Cenozoic sedimentary rocks. In the past centuries, a few ore indications (native copper, quartz and prehnite veins with chalcopyrite and galena, Fe-bearing sedimentary succession, copper shale) have been described in this area (Papp 1938; Mezősi & Grasselly 1949; Kiss 1958), but with the exception of the copper shale (Kiss & Zaccarini 2013), none of them were studied in details, with modern methodology. Thus, the aim of the research was to determine more precisely the formation circumstances of the Triassic and Jurassic basalt hosted epigenetic quartz-prehnite veins.

However, as pretty similar veins were found in the basalt of the geologically correlated Croatian Medvednica Mts. (Jurassic Ophiolite Melange) and in the Greek Stragopetra Mts. (Avdella Mélange), a comparison was also carried out among these areas, as it can contribute with a by far not examined aspect to this correlation.

2. GEOLOGICAL BACKGROUND

2.1. Regional geology

The basement of the Pannonian Basin consists of a mosaic-like pattern of allochtous terranes derived from different parts of the Neotethyan realm. The major structure of the Pannonian Basin is the Mid-Hungarian (Zagreb-Zemplén) Lineament which divides the Tisza Mega-unit and the Pelso Mega-unit (the latter is a part of ALCAPA - Alpine-Carpathian-Pannonian Mega-unit - Csontos 1995) (Fig. 1A). The most noticeable character that the Pelso Unit is more heterogeneous with terranes of South Alpine origin, Dinaridic origin (Bükk Unit) and blocks of mixed Alpine and Dinaridic affiliations (Haas & Kovács 2001). Middle to Late Jurassic closure of the Neotethys led to the development of a suture zone made up of subduction-related complexes that can be followed all along the strike of the Dinarides. During the Cretaceous compressional stages, nappe stacks were formed from the accretionary complex and the fragments of the previously disrupted passive margin. Eastward escape of the ALCAPA (Alpine-Carpathian-Pannonian) Mega-unit during the Oligocene to the Early Miocene led to large-scaled displacement of fragments of this nappe stack and transported them to their present-day position (Haas & Kovács 2001; Csontos & Vörös 2004; Schmid et al., 2008).

The NW-trending Neotethyan ophiolites in the Hellenides occur in two distinct zones bounding the Palegonian ribbon continent. The ophiolites to the west of the Pelagonian microcontinent, called the 'Western Hellenic Ophiolites', also known as 'External Hellenic Ophiolites' are nearly coeval or slightly older than those in the Vardar Zone ('Intermost Hellenic Ophiolites') and are spatially associated with Triassic–Jurassic volcano-sedimentary units and mélanges (Smith 1993; Robertson & Karamata 1994; Bortolotti et al., 2005; Dilek et al., 2005; Saccani & Photiades 2005).

2.2. The studied Hungarian occurrence - Darnó Unit

The studied Darnó Hill is located in NE Hungary, in the western forelands of the Bükk Mts. in the Darnó Unit. The Darnó Unit is a displaced fragment of the Dinarides, represents a relict of the Neotethyan accretionary complex (Dimtrijević et al., 2003) (Fig. 1A) and shows similarities to the Dinaridic Ophiolte Belt (Haas & Kovács 2001; Dimtrijević et al., 2003; Pelikán ed. 2005; Kovács et al., 2008; Haas et al., 2011; Kiss et al., 2012a).

The area is interpreted as a continuation of the structural elements of the nappe system of the Bükk Unit (Fig. 1C). The lowest two units are the "Bükk Paraautochton" and the Monosbél Unit, containing sedimentary formations. Above it, the Szarvaskő Unit forms an incomplete Jurassic ophiolitic sequence associated with deep-sea sedimentary succession. The uppermost Darnó Unit is made up of Triassic and Jurassic submarine volcanites and related sedimentary rocks (Csontos 1999; Haas & Kovács 2001; Kovács et al., 2008; Kovács et al., 2013) (Fig. 1C).

The Darnó Unit consists predominantly of pillow and massive basalts and subordinately of abyssal sediments: red radiolarite, pelagic mudstone and bluish gray siliceous shale (Dosztály et al., 1998; Kovács et al., 2005; Kovács et al., 2008). Basalts are of two types, the first type is early rift- type with peperitic facies of Triassic age, while the other type is similar to the Szarvaskő Basalt and is of Jurassic age (Kiss 2008; Kiss et al., 2008, 2010) (Fig. 1B).

The early stage alteration was the typical sea-floor hydrothermal alteration in basalts. However, the region suffered from a late alteration, too, related to the Alpine low-grade metamorphic event. This regional metamorphism is characterised by prehnite-pumpellyite facies in the SW Bükk Mts. (Árkai 1983; Árkai et al., 1995; Sadek Ghabrial et al., 1996) and by a maximum temperature of 250-300°C (Árkai et al., 1995), but the chlorite thermometers of Zang & Fyfe (1995) yielded 250-260°C (Péntek et al., 2006). The main minerals in the Alpine metamorphism related veins are prehnite, calcite and quartz, intergrown with fine-grained chlorite (Sadek Ghabrial et al., 1996).

The origin of the studied quartz-prehnite veins is not well documented. They were found in the 1940s and an exploration adit was also prepared. Mining never occurred in the area, due to the unpredictable ore content. Kiss (1958) discussed the submarine origin of the veins, but one decade later Félegyházy & Vecsernyés (1970) have found contact metamorphic origin and proved only 0.01-0.02% Cu content. Other theories suggested that the Darnó Hill was a deeper, while the Báj-patak (native copper occurrence) was a higher part of the same mineralisation, though did not draw any conclusions on their genesis. Later Mucsi (2009) suggested epigenetic origin of some only gangue mineral bearing veins, and proved that those veins were found in Triassic and Jurassic basalts, too.

2.3. The studied Dinaridic occurrence – Medvednica Mts.

The Medvednica Mts. is located in northern Croatia, 10 km north from Zagreb; it is a part of the Zagorje-Mid-Transdanubian shear zone (ZMTZ) of the north-western Dinarides (Pamić & Tomljenović 1998) (Fig. 1D). In the Medvednica Mts., four of the main tectonostratigraphic units of the ZMTZ occur. From bottom to the top, the pre-Eocene structural assemblage of the Medvednica Mts. comprises the Medvednica Metamorphic Complex (MMC), the Jurassic Ophiolitic Mélange, and the Cretaceous-Paleocene Sequence (Tomljenović 2002; Tomljenović et al., 2008). In the southwestern part of the Medvednica Mts., a thick Triassic platform carbonate succession of the Žumberak Nappe represents the uppermost pre-Neogene structural unit (Šikić et al., 1977) (Fig. 1D).

Thrusted onto the MMC, the Jurassic Ophiolitic Mélange forms a chaotic assemblage of an accretionary wedge. It consists of fragments of metamagmatic rocks, graywacke, radiolarite and limestone, embedded in a sheared shaly-silty matrix (Pamić & Tomljenović 1998; Babić et al., 2002).

Halamić & Goričan (1995) and Halamić et al., (1999) documented Upper Ladinian to Carnian and Upper Bajocian to Lower Callovian ages for the radiolarites, while the age of the shaly-silty matrix was constrained as Lower Jurassic to Bajocian (Babić et al., 2002). From the end of the Triassic/beginning of Jurassic, the full extent of opening of the Dinaridic Neotethys took place, together with the formation of MORB and BAB/IAB-type magmatic rocks (Pamic et al., 1998, 2002). The Jurassic Ophiolitic Mélange is unconformably overlain by a diagenetically altered succession (Judik et al., 2004). Tomljenović et al., (2008) described four pre-Miocene deformational events in Medvednica Mts. (D1–D4).

Metamophic history of the Paleozoic and Mezozoic Sequence of Medvednica Mts. is well documented by Judik et al., (2004). Peak metamorphic temperatures of 190-220°C are estimated from representative samples of the Jurassic Ophiolite Mélange. The Jurassic Ophiolite Mélange was affected by a significantly lower thermal alteration like MMC (zeolite and prehnite-pumpellyite facies). (Judik et al., 2004; Tomljenović et al., 2008).

2.4. The studied Hellenidic occurrence – Stragopetra Mts.

The Stragopetra Mts. is located in NW-Greece, close to Perivoli and Avdella villages (Fig. 1E). It is found in the Pindos Zone, west of the Mesohellenic Trough Sediments and east from the External Hellenides. In the northern part of the Pindos Mountains, in the Pindos Zone, the following tectono-stratigraphic units are distinguished: Triassic rifting related basalt and sediments within tectonic-sedimentary mélange (Avdella Mélange in the northern Pindos Mountains); Middle Jurassic MORB-type and ophiolitic sequences (Dramala Complex in the northern Pindos Mountains); Mesozoic pelagic, platform-related sedimentary sequence and turbiditic slope sediments; Upper Cretaceous platform carbonates and uppermost Cretaceous-Eocene flysch (see e.g. Jones & Robertson 1991; Saccani et al., 2003 and the references cited therein).

The Avdella mélange crops out mainly in the area of Avdella village (Rassios & Grivas 1999). It is a Jurassic accretionary wedge exposed structurally beneath the Pindos Ophiolite Complex and it is placed over the Late Cretaceous – Middle Eocene Pindos fliysch. At places exceeding 1 km in thickness, it consists of blocks of primarily Late Jurassic to Middle Jurassic pelagic carbonates and cherts, within-plate basalt and mid-oceanic-ridge basalt (MORB) as well as ophiolitic fragments within a matrix of incompetent shaly marl and sandstone (Jones & Robertson 1991, Kiss et al., 2012a). Metamorphism is generally of zeolite facies, with only deep burial diagenesis and minor alteration. Close to the contact with the metamorphic sole and the ophiolite, however, lower greenshists facies metamorphism is characteristic (Jones & Robertson, 1991).

2.5. Correlation possibilities

Although there is a rich literature dealing with the ophiolite zones of the Balkan Peninsula, mostly concentrated on the ophiolite petrology and various plate tectonic reconstructions, only a few scientific works are focusing on Triassic advanced rifting-type basalt and associated deep-sea sediment occurrences.

According to Pamić (1997), the basaltic rocks of the Medvednica Mts. can be correlated with the Inner Dinaridic ophiolites. On the other hand, the Medvednica Mts. and the Darnó Unit can be also correlated, as both are representing the Dinaridic Ophiolitic Complex within a Jurassic olistostrome mélange (Pamić 1997; Kovács et al., 2010). Haas & Kovács (2001) suggested that the only 7 km^2 extending Darnó Unit is a dismembered fragment of the Dinarides and few years later Dimitrijevic et al., (2003) interpreted the Darnó Unit as a relict of a Neotethyan accretionary complex, which was displaced from the NW-Dinarides to NE-Hungary. According to Kovács et al., (2010) and Kiss et al., (2012a), the correlation can be extended to the Hellenides, because all of these localities belong to the western ophiolite belt of the Balkan Peninsula. The observed localities are found in the same ophiolite zone, which consists the Inner Dinaridic ophiolites in Croatia and Bosnia and Herzegovina, their continuation into Serbia and the Western Hellenidic ophiolites in Greece and Albania collectively from the Pindos Zone opholites in the western Balkan Peninsula (Ghikas et al., 2010; Robertson & Karamata 1994; Smith & Rassios 2003) (Fig. 1A).

3. ANALYTICAL METHODS

Field studies were carried out in outcrops of the Darnó Unit, NE-Hungary, the Medvednica Mts., N-Croatia and the Stragopetra Mts., N-Greece. Petrography of the collected samples was carried out with Nikon Alphaphot and Zeiss Axioplan polarizing microscopes with emphasis on texture of the host rocks and hydrothermal mineral parageneses of the veins. These studies were made to characterise the mineralogical–petrological features of the veins and demonstrate similarities and possible differences among the different localities.

Fluid inclusion petrography and microthermometric studies were carried out to help to describe the epigenetic process, which formed the studied veins. The observations were made on 80-100 µm thick double-polished sections of hydrothermal quartz of the veins, using Linkam FT-IR 600 type heating-freezing stage mounted on an Olympus BX-51 type polarizing microscope providing up to 1000 times optical magnification. The calibration of the stage was made by analysis of CO_2 and pure water synthetic fluid inclusions. The precision of the microthermometric measurements was ±0.1°C below 0°C, and ±1°C above it. Interpretation of the microthermometric data was carried out by a macro programme in MS Excel, developed in Visual Basic environment by G. B. Kiss, using the methods of Hall et al., (1988) and Zhang & Frantz (1987).

Preliminary investigations on the ore minerals of the studied veins were done using a scanning electron microscope equipped with an energy dispersive spectrometer at the Eötvös Loránd University, Budapest. The analysis were done with an AMRAY 1830 SEM+EDS instument, with 20 kV accelerating voltage and 1 nA beam current. The results of the measurements are qualitative results only, with a detection limit of 1000 ppm for the analysed metals.

Electron microprobe analysis of chlorite crystals cogenetic with the hydrothermal quartz and sulphide minerals was completed in the Eugen F. Stumpfl Microprobe Laboratory of the University of Leoben. Mineral chemistry of chlorite and trace elements of chalcopyrite were analysed by a Superprobe Jeol JXA 8200 type electron microprobe. The electron microprobe operated in the wavelength dispersive mode, with 15 kV accelerating voltage and 10 nA beam current. The detection limits (in ppm) during the chlorite analyses were 1227 for F, 184 for Cl, 130 for Si, 171 for Ca, 64 for K, 616 for Ba, 216 for Fe, 302 for Na, 181 for Ti, 184 for Mg, 187 for Mn, 141 for Al, 233 for Ni and 94 for Cr. The validity of the chlorite thermometry was proven by Kiss et al. 2012b for low grade alpine metamorphism related veins of the same region. The detection limits (in ppm) for the trace elements of the chalcopyrite were 180 for Fe, 330 for S, 267 for Cu, 363 for As, 346 for Ag, 180 for Co, 1827 for Pb, 639 for Au, 193 for Ni, 237 for Sb, 291 for Zn, 240 for Te, 1141 for Bi and 170 for Se.

4. RESULTS

4. 1. The studied occurrences

4.1.1. Darnó Hill, Hungary

The studied area is located in the Hosszú Valley in the vicinity of the Pollner Adit. Along the valley, several rock types can be observed on the surface: green and red basalt, grey and red shale/radiolarite and Neogene volcanism related rhyolite tuff. All of these rocks can be found in outcrops and as detrital fragments, too.

During the field work, quartz-prehnite veins with ore minerals were found in the waste dump of the adit, as well as in a trench above it and in several natural outcrops (Fig. 2. A). The observed veins occur in green basalt, and are characterised with a typical thickness of 1-10 cm, however, in the trench, a more than 50 cm thick vein is found. Both veins are N(NE)-S(SW) striking and are characterised with a nearly vertical dip. The veins contain only rarely ore minerals, mostly chalcopyrite occur primarily (Fig. 2D,E).

4.1.2. Medvednica Mts., Croatia

The exposure investigated in details is located in the NW side of the hill, along a road cut. Strongly tectonised pillow basalt crops out, though at several places, pillow lava structures and lava flows can be observed. The basalt is greyish-green in colour, which is caused by the appearing chlorite, the rock is densely cut by limonite veins, thus it is difficult to define its fabric. In some cases, the boundaries of the pillows are crossed by quartz-prehnite veins (Fig. 2B,F). The veins have a thickness of 0.5 to 10 cm, their characteristic orientation and inclination was not seen. Macroscopically no ore minerals were observable in the veins.

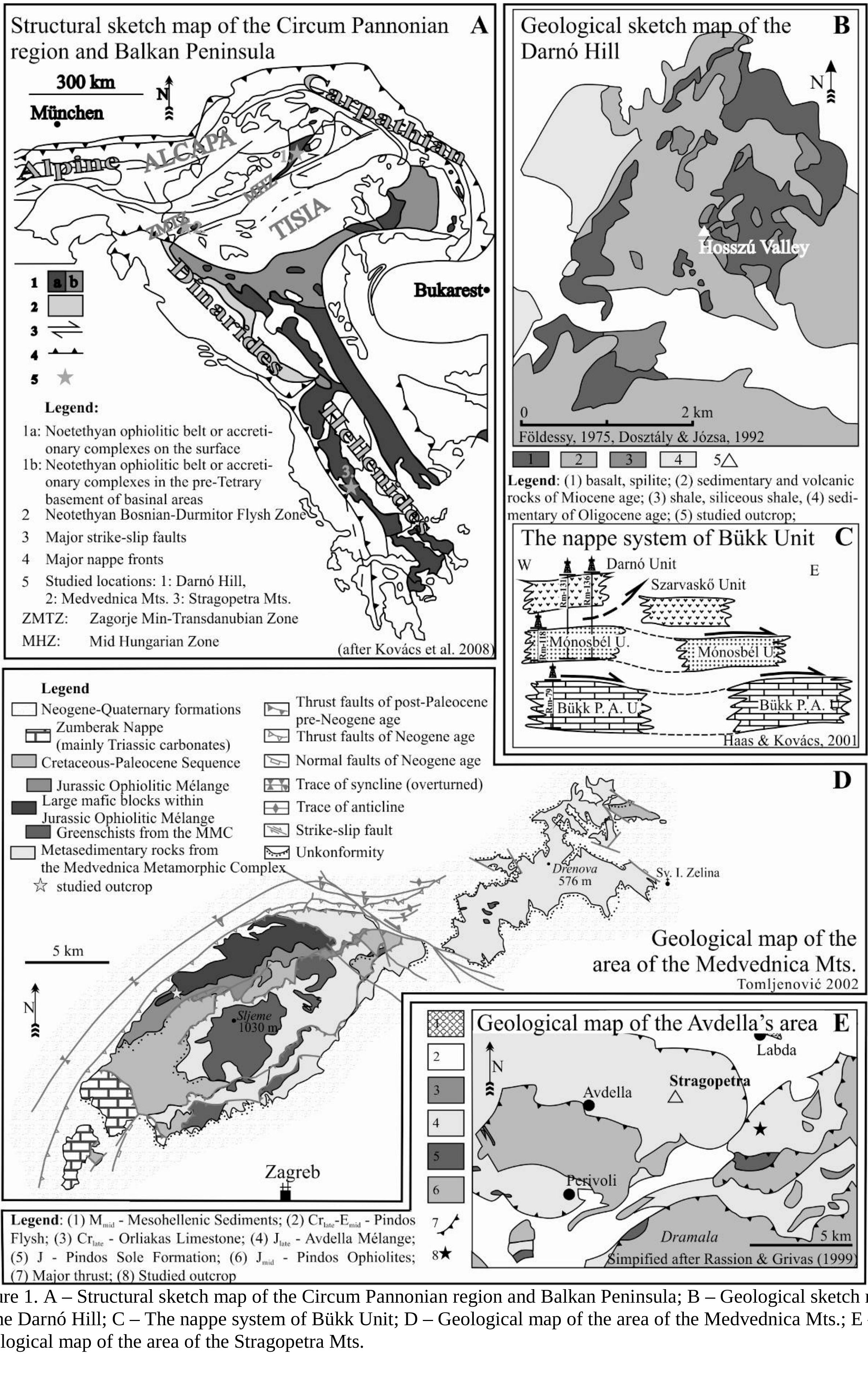

Figure 1. A – Structural sketch map of the Circum Pannonian region and Balkan Peninsula; B – Geological sketch map of the Darnó Hill; C – The nappe system of Bükk Unit; D – Geological map of the area of the Medvednica Mts.; E – Geological map of the area of the Stragopetra Mts.

4.1.3. Stragopetra Mts., Greece

Two outcrops were studied in details in the Stragopetra Mts. One of them is located on the E(SE) side of the hill. It is a 50 m long exposure, where different forms of lava flows and pillow basalt blocks are observable, however, among them a small amount of hyaloclastite breccia also appears. The samples are of Triassic age, representing the closely packed pillow lava facies (Kiss et al., 2012a). In this basalt, 290/65 and 285/85 dipping quartz-prehnite veins are found with a well observable greenish alteration halo.

The other studied locality is found on the E(SE) side of the hill, too. It is a 90 m long outcrop (road cut), in which red is radiolarite located on the SE part and going towards NE, it is tectonically in contact with closely packed pillow basalt. The closely packed basalt contains jig-saw veins of primary, cooling related origin and also the so-called "pyjamas-type" pillow occurs, as the result of the primary hydrothermal processes. This basalt block contains an approx. 30 cm thick quartz-prehnite vein with well observable greenish alteration halo, however, a later fault has moved its parts in the outcrop (Fig. 2C,G). The vein is 300/70 dipping and it contains no visible ore minerals.

4.2. Mineralogy, petrography and mineral chemistry

4.2.1. The basaltic host rock

At each studied locality, the basalt shows generally intersertal and variolitic texture (Fig. 2H,K). In some cases, porphyric characteristics were also observed at the Medvednica Mts. (Fig. 2J) and the Darnó Hill. The basalt consists mostly of skeletal crystal forming, subhedral plagioclase (0.2-1 mm), which is found in glassy and/or microcrystalline groundmass (30-40:70-60 ratio of matrix:crystals). The composition of the plagioclase is usually albitic, and it is partly or completely altered to clay minerals. Earlier rock-forming olivine (0.05-0.2 mm) is often pseudomorphosed by calcite and chlorite as the result of the primary hydrothermal alteration (Fig. 2K). Coarser-grained (~0.05 mm), well preserved augite occurs in the Medvednica Mts., while in some basalt blocks of the Stragopetra Mts., finegrained (0.05-0.2*0.02 mm), subhedral pyroxene laths are present (Fig. 2K). Fine grains of euhedral pyrite (0.1-1.0mm) (and chalcopyrite) occur rarely, while hematite pseudomorph after pyrite can be found more often. These opaque minerals occur in the altered groundmass and in the pseudomorphs of the altered mafic minerals.

Results of the primary, cooling related submarine hydrothermal alteration, like albitic composition of the plagioclase, chlorite in the groundmass and hydrothermal mineral infillings of the olivine pseudomorphs as well as cooling cracks and amygdales commonly occur at all the studied localities. These infillings are mainly composed of calcite, but some chlorite, hematite, epidote and prehnite also occur.

The alteration of the basalt is stronger in the vicinity of the studied veins. There the basalt shows chaotic texture and its original features, as well as its texture can be hardly recognised. The initial rock-forming minerals are not found and only secondary minerals present, such as chlorite and clay minerals (Fig. 2H). In some cases, completely altered plagioclase fragments can be observed, resembling to the original texture. At the basalt-vein boundary, fine-grained idiomorphic epidote, limonite patches and thin veinlets appear densely (Fig. 2L). These veinlets are in connection with the thick veins and are composed mostly of quartz, prehnite, pumpellyite, epidote and chlorite (Fig. 2I).

4.2.2. Characteristics of the veins

On the basis of the field observations, the veins look similar to the well described alpine metamorphism-related veins of the Szarvaskő Unit, because at each studied locality, the veins show generally banded texture with increased, euhedral quartz crystals in cavities. From the vein-basalt contact, towards the centre of the vein, they contain clasts of the host rock (0.5-5 cm) (Fig. 2L,O) together with chlorite and some euhedral epidote (0.1-2 mm), but chlorite flakes and pumpellyite of acicular habit are also found. In the centre of the veins, mostly coarse-grained euhedral or subhedral quartz (trigonal elongated prisms of Dauphiné-type habit) (0.1 mm - 2.5 cm) and prehnite (0.05-5 mm) crystals are found together (Fig. 2M,N). The veins contain chalcopyrite and its alteration products (malachite, azurite, cuprite and covellite), together with hematite and pyrite in the Darnó Hill (Fig. 2E). Near to the boundary with the host rock, usually within the veins, chalcopyrite and its alteration products are found. The ore minerals are located between the prehnite and quartz crystals and the cavities, but the chalcopyrite and pyrite can be observed as inclusions in quartz with some hematite (Fig. 2P), too. In the Medvednica Mts., the veins contain chalcopyrite, pyrite and hematite in similar textural positions, like at the Darnó Hill (Fig. 2T). The veins from the Stragopetra Mts. are also similar in appearance to the above mentioned ones, but they do not contain chlorite, however, the amount of pumpellyite is much higher, and as ore mineral, in these veins bornite is found (Fig. 2V,W,X).

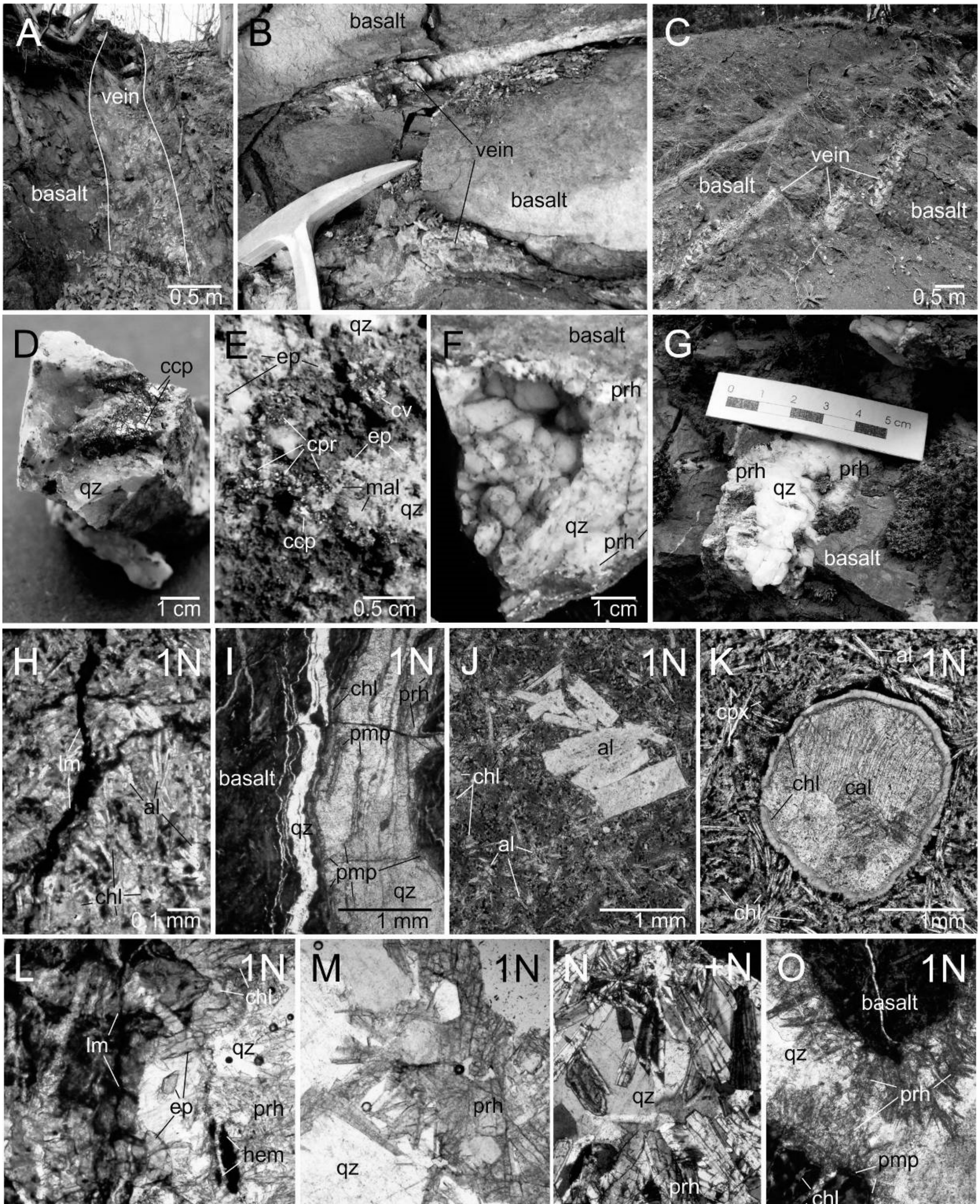

Figure 2. A – Quartz-prehnite veins in Hosszú Valley; B – Quartz-prehnite veins at Medvednica Mts.; C – Tectonised quartz-prehnite veins at Stragopetra Mts.; D – Calcopyrite in quartz-prehnite veins from Darnó Hill; E – Calcopiryte and that alteration products (Darnó Hill); F – Quartz-prehnite veins with cavity (Medvednica Mts.); G – Quartz-prehnite vein in basalt (Stragopetra Mts.); H – Microscopic picture of altered basalt (close to the vein) (Darnó Hill); I – Microscopic picture of some thin quartz-prehnite veins in basalt (Medvednica Mts.); J – Microscopic picture of porphiric albite containing 'unaltered' basalt (Medvednica Mts.); K – Chlorite and calcite infillings of amygdales (Stragopetra Mts); L – Microscopic picture of vein-basalt contact (Darnó Hill); M – Microscopic picture of the quartz-prehnite vein (Darnó Hill); N – Microscopic picture of zonated quartz-prehnite vein (Stragopetra Mts.); Basalt clasts in vein (Darnó Hill).

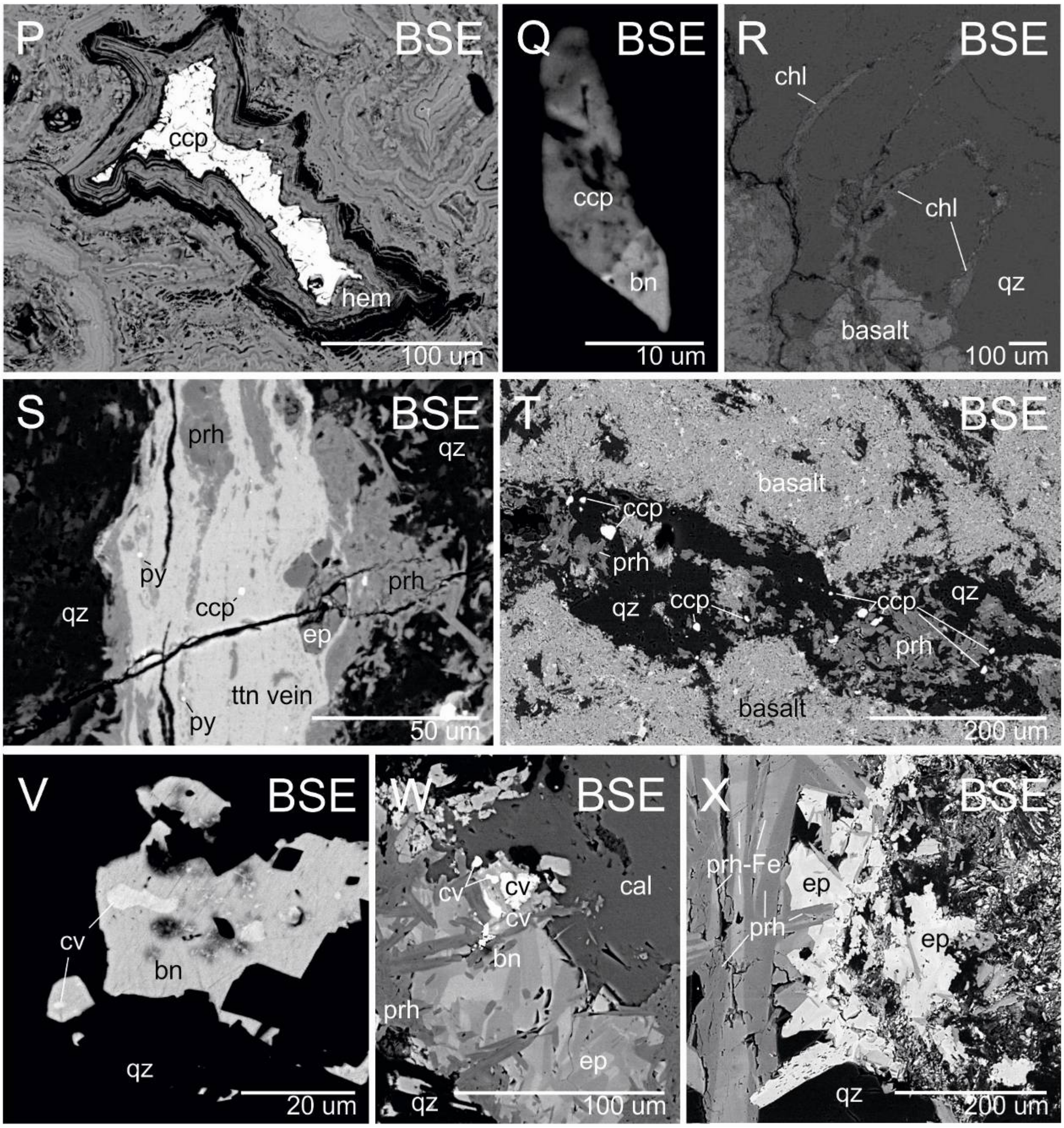

Figure 2. (continuation): P – Hematite around the chalcopyrite (Darnó Hill); Q – Bornite on the rims of chalcopyrite (Darnó Hill); R - chlorite crystals cogenetic with the hydrothermal quartz (analysed with EPMA) (Darnó Hill); S – titanite veins with ore minerals (Medvednica Mts.); T – chalcopyrite grains in a thin quartz-prehnite vein (Medvednica Mts.); V – Bornite with covellite in quartz (Stragopetra Mts.); W – Covellite amongst prehnite and epidote crystals (Stragopetra Mts.); X – vein-basalt contact BSE image from Stragopetra Mts., also shown the zonation of prehnite. Used acronyms (after Whitney et al. 2010): ab-albite, cal-calcite, ccp-calcopyrite, chl-chlorite, cv-covellite, cpr-cuprite, cpx-clinopyroxene, ep-epidote, hem-hematite, lm-limonite, mlc-malachite, prh-prehnite, prh-Fe-Fe-rich prehnite, pmp-pumpellyite, py-pyrite, qz-quartz, ttn-titanite.

Results of the scanning electron microscopy analyses (SEM+EDS) of the ore minerals from the Darnó Hill revealed that the chalcopyrite is found as destructed grains, rimmed with hematite. Besides the earlier mentioned alteration products, primary bornite was also identified with the help of the SEM analyses, which was never described from the area before (Fig. 2Q). However, further textural features of the ore minerals, like almost completely hematitized pyrite were also observed. The results of the SEM measurements on the samples from the Medvednica Mts. revealed that prehnite grains have zonation; the internal parts of the crystals are more enriched in iron. Titanite was also identified, occurring with ore minerals, like pyrite, chalcopyrite and hematite (Fig. 2S). Furthermore, chalcopyrite and pyrite inclusions in quartz and in some cases almost completely hematitized pyrite grains were observed. The prehnite grains from the Stragopetra Mts. are also characterised with zonation; the internal parts of the crystals is more enriched in iron (Fig. 2X). These veins also contain titanite, but no ore minerals were found in association with them. Besides the earlier mentioned alteration products, covellite on the rims of the bornite crystals was identified here (Fig. 2V). However, bornite was found not only among the quartz grains, but also as inclusions in quartz.

4.2.3. Results of the electron microprobe analyses

The composition of chlorite and the trace element content of chalcopyrite from the Darnó Hill (Fig. 2R) and the Medvednica Mts. were analysed. Results of electron microprobe analysis of all chlorite grains cogenetic with the quartz crystals of the studied veins correspond to Type 1, Fe-chlorite according to the nomenclature of Zane & Weiss (1998). The Al(IV) values of the chlorite crystals varied between 1.063-1.145 (Darnó Hill) and 0.736-0.753 (Medvednica Mt.) while the XFe values were between 0.359-0.517 (Darnó Hill) and 0.520-0.521 (Medvednica Mt.). These data can be used for chlorite thermometric calculations, as they fit into the method of Kranidiotis & MacLean (1987) and Zang & Fyfe (1995), respectively. According to these calculations, a formation temperature of 228-258°C was calculated in the case of the Darnó Hill and 212-216°C in the case of the Medvednica Mts. (Table 2).

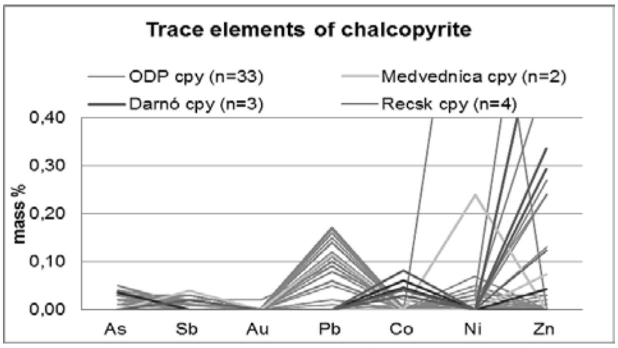

Figure 3. Trace element content of chalcopyrite from the studied localities. As a comparison, chalcopyrite analyses data from the Ocean Drilling Program (Lawrie & Miller 2010) and from Recsk (well-known epithermal-Cu-porphyry mineralisation near the Darnó Hill, Turi, 2012) are also plotted on the diagram.

Based on the EPMA measurements, the chalcopyrite grains of the Darnó Hill always contain a small amount of Co (0.028-0.06 mass%), sometimes As (<0.035 mass%), Zn (<0.43 mass%), and Te (<0.031 mass%) also occur, but never contains Pb and Ni. The chalcopyrite grains of the Medvednica Mts. may contain some Sb (<0.039 mass%), Pb (<0.144 mass%), Ni (<0.024 mass%) and Zn (<0.073 mass%) (Fig. 3).

4.3. Fluid inclusions

At each studied locality, fluid inclusion study was carried out on the primary, two-phased (liquid and vapour) fluid inclusions of the quartz crystals. These inclusions were about 5-10 micrometre in size; the ratio of vapour phase was always about 20%, thus a homogenous parent fluid is suggested. The inclusions behave often metastable; therefore their measurement was often difficult or impossible (Table 1).

Table 1. Results of the fluid inclusion microthermometry

	Darnó Hill	Medvednica Mts.	Stragopetra Mts.
Inclusions type	P (L+V)	P (L+V)	P (L+V)
n	20	30	11
Min. Th	169	110	183
Max. Th	217	212	259
Te	-21,5	-	-21,8
Min. Tm	-1,8	-1,5	-1,8
Max. Tm	-1,3	-1,2	-1,5
Min. salinity	2,24	2,07	2,57
Max. salinity	3,06	2,57	3,06

Temperature is given in °C,
Salinity is given in NaCl equiv. mass%.

Based on the measured homogenisation temperatures, the minimum formation temperature of the quartz crystals of the Darnó Hill (i.e. the homogenisation temperature of the fluid inclusions) was between 169-228 °C, while based on the final melting temperatures, the calculated salinity of the parent fluid was 2.24-3.06 NaCl equiv wt% (Table 1) (Fig. 4). The homogenisation temperatures of the primary fluid inclusions from the quartz of the Medvednica Mts. were between 110-212 °C, and the calculated salinity of the parent fluid was 2.07-2.57 NaCl equiv wt% (Table 1.) (Fig. 4).

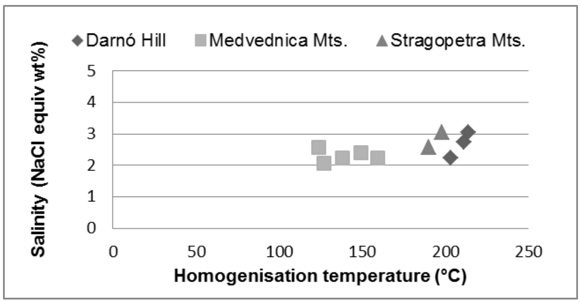

Figure 4. Results of the fluid inclusion microthermometry Homogenisation temperature versus salinity diagram.

Table 2. Representative results of the electron microprobe analyses of chlorite

	Medved-nica - 1	Medved-nica - 2	Medved-nica - 3	Medved-nica - 4	Medved-nica - 5	Medved-nica - 6	Medved-nica - 7	Medved-nica - 8	Darnó - 1	Darnó - 2	Darnó - 3
SiO_2	39,105	30,288	29,258	31,519	31,156	27,511	33,100	33,535	26,711	27,600	26,298
TiO_2	0,067	0,037	0,087	0,056	0,040	n.a.	0,056	0,064	0,038	0,113	0,018
Al_2O_3	10,921	15,500	14,903	15,225	13,745	12,141	13,835	14,200	17,236	17,919	17,760
Cr_2O_3	0,031	0,039	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	0,043	0,024
FeO T	20,727	26,034	25,546	23,613	24,294	21,929	22,222	22,826	26,999	27,952	19,271
MnO	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	0,919	0,897	0,846
MgO	11,124	13,096	12,744	12,285	13,867	10,001	13,189	12,601	13,632	13,553	18,754
CaO	3,694	0,461	0,678	1,006	0,624	1,052	0,772	1,029	0,020	0,142	0,115
Na_2O	0,225	0,022	0,019	n.a.	0,040	0,058	0,011	0,027	0,028	n.a.	n.a.
K_2O	0,099	0,036	0,066	0,139	0,061	0,169	0,212	0,228	0,010	n.a.	0,008
Cl	n.a.	0,013	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	0,020	n.a.	0,031
Total	*85,993*	*85,526*	*83,301*	*83,843*	*83,827*	*72,861*	*83,397*	*84,510*	*85,613*	*88,219*	*83,125*
Calculated cation numbers (14 oxygene)											
Si (IV)	4,031	3,264	3,247	3,414	3,397	3,469	3,566	3,573	2,929	2,937	2,855
Al (IV)	-0,031	0,736	0,753	0,586	0,603	0,531	0,434	0,427	1,071	1,063	1,145
Total (IV)	*4,000*	*4,000*	*4,000*	*4,000*	*4,000*	*4,000*	*4,000*	*4,000*	*4,000*	*4,000*	*4,000*
Al (VI)	1,358	1,233	1,197	1,357	1,163	1,274	1,322	1,356	1,156	1,183	1,127
Ti	0,005	0,003	0,007	0,005	0,003	n.a.	0,005	0,005	0,003	0,009	0,001
Cr	0,003	0,003	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	0,004	0,002
Fe	1,787	2,346	2,371	2,139	2,215	2,312	2,002	2,033	2,476	2,487	1,749
Mn	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	0,085	0,081	0,078
Mg	1,709	2,104	2,108	1,983	2,254	1,880	2,118	2,001	2,228	2,149	3,035
Ca	0,408	0,053	0,081	0,117	0,073	0,142	0,089	0,117	0,002	0,016	0,013
K	0,013	0,005	0,009	0,019	0,008	0,027	0,029	0,031	0,001	n.a.	0,001
Na	0,045	0,005	0,004	n.a.	0,008	0,014	0,002	0,006	0,006	n.a.	n.a.
Total (VI)	*5,328*	*5,752*	*5,777*	*5,620*	*5,725*	*5,649*	*5,567*	*5,549*	*5,958*	*5,929*	*6,007*
vacancy	0,672	0,248	0,223	0,380	0,275	0,351	0,433	0,451	0,042	0,071	-0,007
XFe	0,458	0,521	0,520	0,505	0,488	0,534	0,476	0,490	0,517	0,525	0,359
Mg+Fe total	3,496	4,450	4,479	4,122	4,469	4,192	4,120	4,034	4,704	4,636	4,784
Al+vacancy	2,030	1,481	1,420	1,738	1,438	1,624	1,755	1,807	1,198	1,254	1,120
Classification (Zane & Weiss 1998)											
Type	Type 1	Type 1	Type 1	Type 1	Type 1	Type 1	Type 1	Type 1	Type 1	Type 1	Type 1
Name	Fe-chlorite	Fe-chlorite	Fe-chlorite	Fe-chlorite	Mg-chlorite	Fe-chlorite	Mg-chlorite	Fe-chlorite	Fe-chlorite	Fe-chlorite	Mg-chlorite
Calculated crystallisation temperature											
T°C (K&ML)		*212,653	*216,125						283,403	282,434	287,370
T °C (Z&F)		156,870	160,526						228,480	226,045	258,940

* Results differs slightly from the criteria of the thermometry methods, but can be still used according to Frimmel (1997)

(dark grey) Results useable for thermometry calculation

(light grey) analyses results do not fit into the criteria of any known thermometry method

(K&ML): Kranidiotis & MacLean 1987

(Z&F): Zang and Fyfe 1995

Homogenisation temperatures of the primary fluid inclusions from the quartz of the Stragopetra Mts. were between 183-259 °C. Salinities calculated based on the final melting temperature of the fluid inclusions were between 2.57-3.06 NaCl equiv. wt% (Table 1.) (Fig. 4).

At every studied locality, the homogenisation temperature data show a large scattering, which may be caused by the fact that the different bands of the veins could form at slightly different temperatures and the studied quartz crystals represent these different parts of the veins (Table 1.) (Fig. 4).

5. DISCUSSION

5.1. Origin of the veins

5.1.1. Darnó Hill

The studied veins are found in basalt blocks of the accrétionary mélange complex of the Darnó Hill. As the characteristics of the different basalt blocks (i.e. Triassic, rifting-related and Jurassic, back-arc-basin or marginal-basin opening related) are well described in this region (see e.g. Harangi et al., 1996; Aigner-Torres & Koller 1999; Kiss 2008, 2012; Kiss et al., 2008, 2010, 2011, 2012a and the references cited therein), it is possible to figure out, whether the studied veins are found in Triassic or Jurassic basalts. Based on the comparative petrographical study, it can be concluded, that veins are found in both kind of basaltic blocks.

According to the results of Kiss (1958), the found ore mineral paragenesis can be well explained by a series of alterations at the Darnó Hill. The present research has confirmed the presence of chalcopyrite, cuprite, malachite, azurite, pyrite, hematite and goethite, however, a new mineral; the bornite was also identified in the area. Our results confirm and specify the earlier assumptions; i.e. it can be supposed that together with the chalcopyrite, the bornite is also primary ore mineral, and all the others are the alteration products of them.

Based on the measured homogenisation temperatures of the fluid inclusions, the minimum formation temperature of the quartz crystals was between 169-228°C, while based on the final melting temperatures, the calculated salinity of the parent fluid was 2-3 NaCl equiv wt%. Quantitative analysis of chlorite cogenetic with quartz allows calculating a formation temperature of 228-258°C.

Joint results of the fluid inclusion study (using the defined isochore) and the chlorite thermometry define a pressure range of 10-110 MPa for the formation of the veins (Fig. 5).

By first approximation, the submarine hydrothermal origin cannot be ruled out, as the host rock is pillow basalt, the observed gangue mineral paragenesis is similar to those systems, as well as the chalcopyrite is frequent mineral in the stringer zone of the submarine volcanogenic massive sulphide deposits. The found pressure (10-110 MPa), formation temperature (228-258 °C) and salinity (2.24-3.06 NaCl equiv. wt%) conditions would be possible in a VMS system, if we take into consideration the fact of the possible phase separation (thus the presence of the low salinity fluids, see e.g. Foustoukos & Seyfried 2007) and the possible overpressure phenomenon (caused by self-sealing of the veins, Sherlock et al., 1999).However, the field occurrence of the veins does not support this idea. Thus, the EPMA measurement of the trace element content of the chalcopyrite grains was used as further proof. Those results showed that the chalcopyrite from the Darnó Hill always contains a small amount of Co, sometimes As, Zn and Te also occur, but never contains Pb and Ni. This pattern is different from that of found in a typical VMS deposit in a mid-oceanic ridge environment (Fig. 3, Lawrie & Miller 2010), hence the submarine hydrothermal origin can be ruled out.

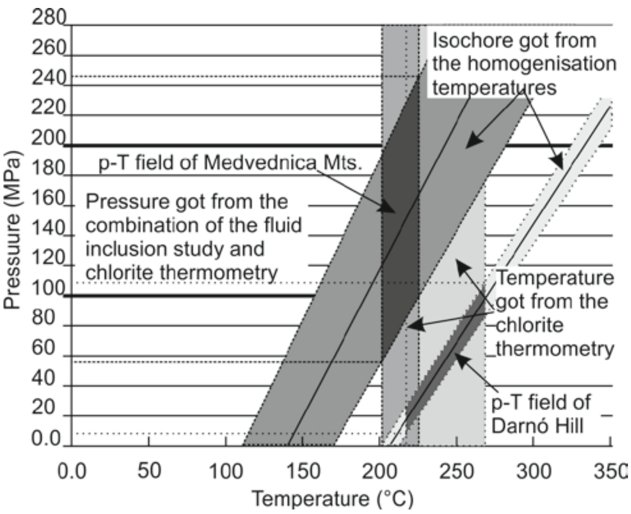

Figure 5. Result of the fluid inclusion microthermometry and the chlorite thermometry: Result of the chlorite thermometry and the fluid inclusion study defines a pressure range (Zhang & Frantz 1987)

The study of Mucsi (2009) has suggested an epigenetic origin for veins with similar gangue mineral paragenesis (without any ore minerals) in the region. He has proven that the vein formation happened obviously after the host rock formation, as the veins are found both in Triassic and Jurassic basalts and a strong alteration zone at the vein-basalt contact can be also observed. However, no conclusion about the origin or age of that epigenetic process was drawn.

Based on the local geology, as well as the fact, that this epigenetic process had effect on both Triassic and Jurassic rocks, two processes have to be taken into consideration; the low-grade Alpine regional metamorphism and the somewhat younger formation of the Recsk Ore Complex. The latter would be an obvious solution, as the western side of the Darnó Hill is found only 2 km far from the easternmost occurrences of the Recsk Ore Complex. In the closest locations of the Palaeogene epithermal and Cu-porphyry Recsk Ore Complex, the gangue minerals are mainly barite, quartz, calcite and clay minerals while the ore minerals are composed mostly of Cu, Fe, Zn, Au, Ag, Pb, Se, Bi and Sb (Sztrókay 1940; Baksa et al., 1974, Baksa 1983; Gatter et al., 1999; Seres-Hartai 2000; Seres-Hartai & Földessy 2001; Földessy et al., 2008; Molnár 2007; Molnár et al., 2008; Takács et al., 2013). This paragenesis is not in a good agreement with the one found at the Darnó Hill, as there the gangue minerals are quartz, prehnite, epidote and chlorite and the element association contains Cu and Fe only. To prove this conclusion, the trace element content of the chalcopyrite grains was compared, too (Fig. 3). They show significantly different patterns, highlighted by lower Zn content in the Darnó Hill and lower As content at Recsk. Thus, based on the observed mineral assemblages as well as the trace element content of the chalcopyrite grains, this possible connection can be ruled out.

The above mentioned Alpine regional metamorphism had an effect on the region, with a peak of 150-200 MPa and 270-280°C estimated to the SW Bükk Mts. (Árkai 1983, Árkai et al., 1995; Sadek Gabrial et al., 1996; Árkai 2001; Péntek et al., 2006). The observed gangue mineral paragenesis is similar to the typical mineral paragenesis of the low grade metamorphism, however similar copper mineralisation associated with low grade metamorphism is also known at other localities, though not in the Alpine metamorphic zone (Wilton & Sinclair, 1988). In the close vicinity of the studied veins, earlier researchers have performed detailed study on some hydrothermal veins representing the prograde or the retrograde phase as well as the peak of this low-grade Alpine metamorphism (Péntek et al., 2006; Kiss et al., 2012b). They have described a similar fluid composition, than found in the recently studied veins. The recently obtained formation temperature and pressure data are lower than the ones found by Péntek et al., (2006) at the peak of the metamorphism. However, it can be concluded, that the veins were formed in the prograde or the retrograde phase of the same process, similarly as shown for a nearby locality by Kiss et al., (2012b) (Figs. 6-7).

5.1.2. Medvednica Mts., Croatia

The geology of the Medvednica Mts. is correlated with the Darnó Hill area as well as with the NW part of the Dinarides (Pamić 1997; Pamić & Tomljenović 1998; Haas & Kovács 2001; Dimitricevic et al., 2003; Karamata 2006; Kovács et al., 2008). The basaltic rocks of the Medvednica Mts. can be correlated with the Inner-Dinaridic ophiolites (Pamić 1997). Thus, similar origin and possible relationship between the submarine basaltic rocks can be assumed in the Darnó Hill and in the Medvednica Mts., i.e. the presence of both Triassic rifting-related and Jurassic MOR-type basalts is possible. The petrographic studies of the host rock of the veins have supported this correlation. Based on their similarities (texture, rock forming minerals, characteristic pseudomorps after olivine) it can be suggested, that the studied locality comprises of basalt formed during the rifting of the Neotethys in the Triassic period.

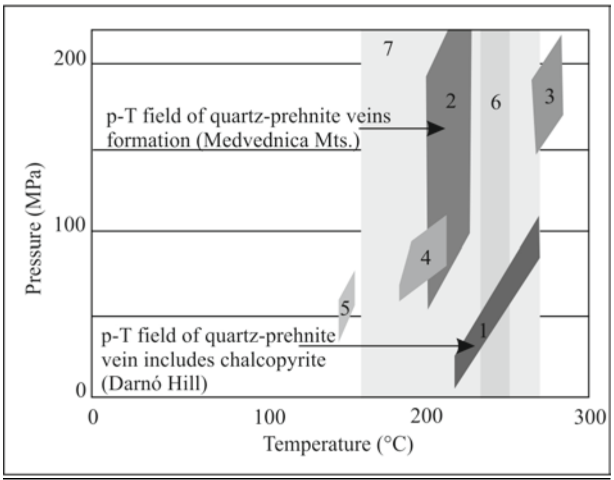

Figure 6. Entrapment conditions (p-T) of the studied primary fluid inclusions. 1: p-T field of chalcopyrite containing quartz veins (Darnó Hill); 2: p-T field of quartz-prehnite veins (Medvednica Mts.); 3: p-T field of the peak of low-grade Alpine metamorphism (SW-Bükk) (Sadek Ghabrial et al. 1996; Péntek et al., 2006); 4: p-T field of Alpine metamorphism related datolite formation (Kiss et al., 2012b); 5: p-T field of primary submarine hydrothermal calcite formation (Szarvaskő Unit, Kiss et al., 2011); 6-7: T peak of low-grade Alpine metamorphism in the Medvednica Mts. from composition of chlorite-like phases (6) and vitrinite reflexion (7) (Judik et al., 2004).

The studied veins look symmetrical and banded, in which the previously mentioned pumpellyit-epidote-prehnite-quartz mineral zonation appears. Beginning from the thicker veins, several thin veins are running into the host rock basalt. Their mineral composition is similar to the thicker veins, but chlorite appears in them, too. On the basis of the textural position it can be assumed, that the chlorite is formed as a result of the same process, than the other vein-filling minerals. Furthermore, it is conceivable that the mineral zonation of the veins is connected to the cooling of the mineral forming fluid. In the central part of the veins, titanite grains can be found, which presumably represent the last stage of the vein formation and contains some pyrite, chalcopyrite and hematite, too. On the basis of the petrographic observations, the opaque minerals of the veins are chalcopyrite, pyrite and hematite pseudomorps after pyrite, which appear together with the vein forming quartz and prehnite as well as inclusions within them, thus, they formed at the same time.

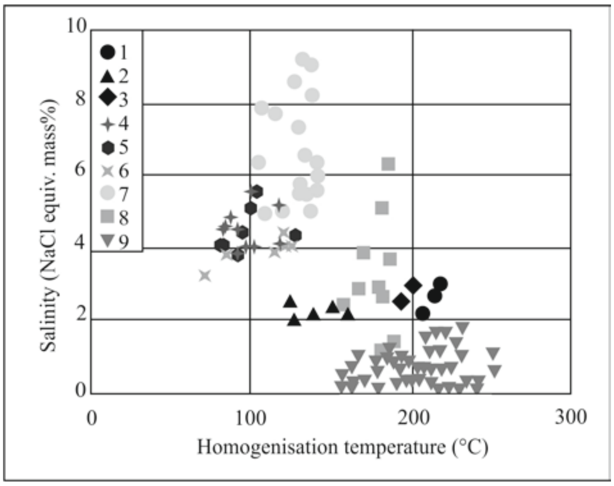

Figure 7. Homogenisation temperature versus salinity diagram of the fluid inclusions. 1: chalcopyrite containing quartz-prehnite veins (Darnó Hill); 2: quartz-prehnite veins (Medvednica Mts.); 3: quartz-prehnite veins (Stragopetra Mts.); 4: Calcite filling amygdales (Darnó Hill) (Kiss 2012); 5: calcite infilling of pyjamas-type pillows (Darnó Hill) (Kiss 2012); 6: calcite of jigsaw-type veins (Darnó Hill) (Kiss 2012); 7: primary submarine hydrothermal process related calcite veins (Szarvaskő Unit, Kiss et al., 2011); 8: low-grade Alpine metamorphism related quartz and calcite (Péntek et al. 2006); 9: low-grade Alpine metamorphism related datolite (Kiss et al., 2012b).

Based on the measured homogenisation temperatures, the minimum formation temperature of the quartz grains was between 110-212°C, while based on the final melting temperatures, the calculated salinity of the parent fluid was 2.07-2.57 NaCl equiv wt%. Quantitative analysis of chlorite grains cogenetic with quartz allows calculating a formation temperature of 212-216°C. Combination of the results of these two methods (fluid inclusion study and chlorite thermometry) defines a pressure range of 55-245MPa.

The field appearance of the veins (they crosscut the pillow margins and significant alteration halo occurs in the host basalt along the veins) suggest that the vein formation happened after the host rock formation. Based on the mineral paragenesis of the veins and the found physico-chemical parameters of the vein forming fluid, their formation can be connected either to submarine hydrothermal or to low grade metamorphic process. The observed gangue mineral paragenesis and the trace element content of the chalcopyrite grains cannot rule out the submarine hydrothermal origin. On one hand, the mineral paragenesis is similar to those systems, on the other hand, the trace element content of the chalcopyrite does not show characteristic difference compared to the data from the ODP drillings (Lawrie & Miller, 2010) (Fig. 3).

However, if the geological correlation with the Darnó Hill is taken into consideration, as well as the significantly similar morphological appearance of the veins, the latter option seems to be more possible. The Medvednica Mts. suffered from a complex metamorphic history, as described by Judik et al., (2004). However, in the studied part of the mountains (Jurassic Ophiolite Melange), the low-grade Alpine regional metamorphism had its effects (peak: 230-250°C from vitrinite reflexion and 160-270°C from composition of chlorite-like phases, Judik et al., 2004). The composition of the veins is characteristic to the low-grade metamorphic minerals, and the obtained P and T values fit into the metamorphic history of that part of the Medvednica Mts (Figs. 6-7).

5.1.3. Stragopetra Mts., Greece

As seen above, the Medvednica Mts. and the Darnó Unit can be correlated, as both are representing different blocks of the Jurassic ophiolitic mélange (Haas & Kovács 2001; Dimitricevic et al., 2003; Kovács et al., 2008, 2010; Kiss 2008, 2012). According to Kovács et al., (2010) and Kiss et al., (2012a), this correlation of the ophiolitic mélange complexes can be extended to the Hellenides, till e.g. the Avdella Mélange, cropping out in the area of the Stragopetra Mts.. This correlation possibility is supported by several other authors (e.g. Robertson & Karamata 1994; Robertson 2002; Smith & Rassios 2003; Karamata 2006; Smith 2006; Robertson et al., 2009; Ghikas et al., 2010), as the continuation of the Inner Dinaridic Ophiolites till the Western Hellenidic Ophiolites is well traceable. The host rock of the studied veins has significant similarities to the Triassic rifting-related basalts, as described by Kiss (2012, Kiss et al., 2012a), which has to be taken into consideration, while evaluating the obtained results.

The appearance of the veins is similar to the previous two localities; however chlorite does not appear as vein-filling mineral, and pumpellyte is found in much greater quantities. Inside the veins, titanite grains can be found, which are presumably representing the last stage of the vein formation. The veins contain opaque minerals too, which are mainly bornite and its alteration product, covellite. These minerals occur always together with the vein forming quartz and prehnite and probably formed together with them.

Fluid inclusion study of the vein filling quartz gave a minimum formation temperature of 183-259°C, while the calculated salinity of the parent fluid was 2.57-3.06 NaCl equiv wt%. As these veins contained no measurable chlorite grains, the real formation temperature, as well as the formation pressure was not possible to determine.

Based on the observations about the field appearance (veins cross-cutting the pillow margins and alteration halo around them), the mineral paragenesis, as well as the formation circumstances, the veins could form either during submarine hydrothermal or low-grade metamorphic processes. As the host rock is pillow basalt, and the observed gangue mineral paragenesis (quartz, prhenite, epidote, pumpellyte) as well as the ore minerals (bornite, covellite) can form during submarine hydrothermal processes, its possible effect cannot be ruled out. However, the lack of chalcopyrite, which appears typically in those systems, can be a sign of a possible different process.

As the mineral paragenesis is similar to the typical mineral assemblage of the low grade metamorphism, using the analogy of the above mentioned localities, the possible role of a low-grade metamorphic process was also taken into consideration. According to Jones & Robertson (1991), a very low-grade to low-grade metamorphism was typical in this area, which is in good agreement with the found characteristics.

5.2. Large-scale correlation possibilities

In the first half of 20th century, intensive studies were carried out on the basalt of the Darnó Hill, since native copper and other ores were found in veins of the area (Papp 1938; Mezősi & Grasselly 1949; Kiss 1958). Although the quartz-prehnite dominated veins were discovered, only limited conclusions on their genesis were drawn. The later investigations concentrated mostly on the petrography, primary hydrothermal processes and geochemical characteristics of the basic volcanic rocks found in the accrétionary mélange and conclusions were drawn about their Neotethyan rifting-related origin and the Dinaridic-Hellenidic correlation possibilities (Dimitrijević et al., 2003; Kovács et al., 2008, Kiss 2012).

As a contrary, the studied ore mineral containing veins were not described earlier from the studied blocks of the Medvednica Mts. and the Stragopetra Mts., although a similar mineral paragenesis forming regional Alpine metamorphic process was mentioned at each area (Judik et al., 2004; Jones & Robertson 1991).

The studied veins formed after the host rock formation, most likely during a regional scaled process, which may be the low-grade Alpine metamorphism. The source of the metals was most probably the basaltic host rock, as it is generally enriched in Cu (Levinson, 1974), and the metamorphic-hydrothermal fluid could enrich and precipitate them as ore minerals.

The observed mineral paragenesis, the obtained parent fluid properties as well as the temperature and pressure ranges correspond most likely to the characteristics of the prograde or retrograde phase of the low-grade, very low-grade metamorphism, which affected on both studied areas. This work contributes to our knowledge on that regional metamorphic process, as products of an earlier not well described phase (the prograde/retrograde phase of the metamorphism), as well as its ore-forming potential were documented. However, the fact, that this phenomenon is present in the dismembered fragment of the Dinarides (i.e. the Darnó Hill), in the Dinarides as well as in the Hellenides may contribute to the regional scaled correlation with a new aspect.

6. CONCLUSIONS

The studied epigenetic veins are located in Triassic advanced rifting related and occasionally in Jurassic pillow basalt blocks of Neotethyan accrétionary mélange complexes. The macroscopic and microscopic characteristics of their textures are very similar to each other, as well as their gangue and ore mineral paragenesis. The veins formed most likely at a temperature of 210-260°C from a low salinity (below average seawater) parent fluid, at a pressure higher, than expected on the seafloor. Some of the observed features have ruled out the submarine hydrothermal origin, and an epigenetic, low-grade metamorphic process related origin was suggested. More precisely, the veins were formed most likely during the prograde or the retrograde phase of the regional Alpine metamorphism. This finding not only contributes to the geological correlation of the studied areas, but –in spite of the relatively low ore mineral content of the studied veins– also draws the attention to the possible ore-forming role of the low-grade, regional Alpine metamorphic process.

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