2^{nd} Central European Tectonics Group
9^{th} Meeting of the Czech Tectonic Studies Group
Lučenec, Slovakia, April 22–25, 2004

Excursion Guide

published in Prague, 2004

by the Institute of Geology,

Academy of Sciences of the Czech Republic

Pre-Conference Fieldtrip: Structure and Metamorphism of the Meliata Unit

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Blueschist facies rocks are known from two suture zones in the Western Carpathians, the Meliata unit and the Pieniny Klippen Belt. In the Meliata unit, blueschists are exposed on surface, but in the Klippen Belt only pebbles of different blueschist varieties were found in the Middle Cretaceous conglomerates. Based on paleogeographic reconstruction (Dercourt et al., 1990; Kozur and Mock, 1997; Channel and Kozur, 1996; Plašienka, 1997; Stampfli, et al., 1998; Neugebauer, 2001), the Meliata unit was formed by closure of the Triassic Meliata oceanic basin which was part or a westwards prolongation of the Vardar Ocean and bounded the Western Carpathian-Austroalpine block from southeast. Because of plate motion and rotation of crustal blocks during Cretaceous the Western Carpathian-Austroalpine block was convergenced with Tisza block, which formerly occurred northeast. The development of regional models contributes to our understanding of the Mesozoic orogeny in the European part of Tethys. The Klippen Belt, separating the Western Carpathians into outer and central units, is supposed to be a remnant of east-west trending pieninic basin, opened on the northern wedge of the Austroalpine-Slovak microcontinent which formed because of eastward driving of the Apulian promontory. Regarding paleogeographic situation (Dercourt et al, 1990), the Pieneny oceanic basin was opened due to the eastward motion of the Apulian promontory which resulted closure of the Meliata basin.

Geological setting

The Meliata accretionary wedge is situated along the the southern margin of the of the West Carpathians in Slovakia and northern Hungary (Fig. 1). It is thrust over the crystalline basement consolidated during Variscan orogeny. This crystalline basement is subdivided into northern high grade Vepor unit and low grade Gemer unit to the south. The later unit consists of Orodovician to Silurian volcano-sedimentary sequences unconformably overlied by late Carboniferous and Permian sediments. Apart from some amphibolite facies slices and blocks (the so-called Gneiss-amphibolite Complex) that occur along the northern and eastern parts of the Gemer complex, the basement rocks indicate only greenschist facies conditions. The Vepor unit consists of high grade gneisses and migmatites, barrovain schists and Paleozoic granitoids and was thrust over the Gemer complex during Paleozoic Variscan orogeny (Lexa et al. 2002). The present structure of the Meliata accretionary wedge is characterised by a complex stack of crustal and oceanic units, which is formed from bottom to top by:

1) Lower Thrust Sheet (LTS) composed of sub-blueschist facies quartz fyllite and conglomerate of Permian age (Faryad, 1995). These rocks are correlated with anchimetamorphosed autochthonous Permian cover of the Gemer basement. Upper Thrust Sheet (UTS) consisting of blueschist facies marble with metabasites and phyllites. According to Mello et al. (1997 these rocks represent passive margin of the European continent. Based on litho-stratigraphy (Kozur and Mock, 1997), the blueschist were formed by subduction of Triassic-Jurassic oceanic basin rocks. However, the presence of amphibolite-facies slices and blocks, overprinted by blueschist-facies metamorphism and the occurrence of relic low-Si muscovite in micaschists, which yielded 40Ar-39Ar age of ≥ 375–380 Ma suggest that continental basement units and/or sedimentary sequences were involved in subduction zone (Faryad and Henjes-Kunst, 1997).
2) Very low-grade Meliata Melange (MM) composed of Permian evaporates and Jurassic shells, marls and sandstones that contain blocks (olistolits) of Triassic radiolarites, cherts, limestones, serpentinites, gabbros and blueschists (Mock, 1978; Kozur and Mock, 1997; Mello et al., 1997 Faryad, et al. 2002). The presence of large amounts of ultramafic rocks in depth is indicated by geophysical data (Plančár et al., 1977).
3) Very low-grade Turna nappe formed by Triassic and Jurassic limestones, dark shales, sandstones and some volcanic rocks interpreted as the northern slope of the Apulian continent (Mello et al., 1997).
4) Silica nappe derived from Apulian shelf. The base of the nappe is composed by Upper Permian –Lower Triassic evaporites and shales followed by Middle and Upper Triassic carbonates. With exception of very low-grade rock in its lower part, the Silica nappe indicates no sign of metamorphism. Both the Silica and Turna nappes are correlated with similar rock sequences in the Bükk mountain in Hungary (Kozur and Mock, 1997; Mello et al., 1997 Vozárová – Vozár, 1992).

Petrology of rocks of the Meliata accretionary wedge

Sub-blueschist rocks of the LTS

Phyllites and phengite-bearing quartzite (free from glaucophane or Na-pyroxene) occur beneath the blueschist facies marbles and metabasites (UTS). The best exposures of these rocks occur in the eastern part of the Meliata unit (Fig. 1), where they are called as lower Complex. Sedimentary textures, mainly high amounts of quartz pebbles in metaconglomerates, suggest that the protoliths were shallow-water clastic sediments formed on a continental margin. As metamorphic minerals they contain chloritoid (X_{Mg} = 0.10 – 0.15), phengite (3.34 – 3.51 a.p.f.u.), paragonite, rarely albite and Chlorite (Faryad, 1995). Chloritoid forms radial aggregates or small porphyroblast that enclose rutile oriented parallel to schistosity. They are partly replaced by chlorite and mixed-layer silicate.

Blueschist facies rocks of the UTS

Regarding lithology and metamorphic history, several types of blueschist facies rocks that are derived from both oceanic and continental crusts can be distinguished: Metabasite (1) forming layers in marbles (2) exhibit composition between MORB and arc basalts with relatively high LREE contents (Faryad, 1995; Ivan and Kronome, 1995; Ivan, 2002). As primary igneous phase they may contain diopside, replaced by Na-pyroxene. Metamorphic minerals in metabasites are albite, blue amphibole (glaucophane, rarely riebeckite), epidote, titanite and rarely phengite, garnet, Na-pyroxene and paragonite. Na-pyroxene has composition ranging from aegirine augite, through omphacite to jadeite (Jd_{70}) (Faryad and Hoinkes, 1999). Albite coexists with Na-pyroxene of aegirine augite composition, but it is a retrograde phase in metabasites containing Na-(Na-Ca)-pyroxene of omphacite and jadeite composition. Blue amphibole reveals progressive zoning from riebeckite to glaucophane and garnet (Sps_{3-47}, Alm_{25-62}, Grs_{22-38}, Ad_{0-5}, Prp_{0-2}) has high Mn and low Fe and Mg contents in cores compared to the rims. Chlorite, actinolite, biotite and most albite are retrograde phases in metabasites. Pure marbles consist of calcite, but adjacent to sedimentary or volcanic rocks they contain blueschist facies minerals as well. Phyllites (3) usually occur in the lower part of slices or follow shear zones. They consist of quartz, white mica and may contain relics of one more of the minerals: chloritoid ($X_{Mg} = 0.1–0.2$), glaucophane, Na-pyroxene (aegirine-jadeite), garnet (Sps_{51-60}, Alm_{24-33}, Grs_{10-13}, Ad_{0-3}, Prp_{1-3}). Some black phyllites occurring in the lower part of slices are rich in graphite.

The continental basement rocks (4) are represented by metabasites and micaschists with relic amphibolite facies minerals. As pre-blueschist facies minerals, they contain tschermakitic hornblende and garnet in metabasites and muscovite in micaschists. Ar/Ar dating from relic muscovite in micaschists gave early Paleozoic (374 Ma) age (Faryad and Henjes-Kunst, 1997). Blueschist facies minerals are glaucophane, albite, epidote white micas, rutile and micaschists may additionally contain chloritoid. Cacic amphibole in amphibolites is rimed or overgrown by blue amphibole (Faryad, 1988). Although there are no geochronological data supporting Paleozoic age of amphibolite facies metamorphism, their possible correlation with the Gneiss-Amphibolite Complex that occur in the eastern and northern parts of the Gemericum is envisaged from their lithology and amphibolite facies mineralogy.

Meliata Melange

The melange matrix is represented by pelitic, silty, marly-pelitic, carbonatic and pelitic-cherty slates that display mostly irregular fracture cleavage arranged in two, crosscutting plane sets. The slates consist of quartz, white K-mica (illite-muscovite) and chlorite ± variable amounts of calcite, small amounts of albite and traces of rutile. In their < 2 μm grain-size fractions illite-muscovite predominates, chlorite and quartz are significant, while albite, calcite and rutile appear only in subordinate and trace quantities, often lacking in certain samples (Arkai et al., 2003). In addition, discrete paragonitic phase as well as mixed K-Na-mica are also found in subordinate quantities

Fragments and slices (cm up to few hundred meter in size) of serpentinized peridotites, basaltic rocks with pillow lava structure and gabbros occur, embedded tectonically in very low-grade sediment, including evaporitic-carbonatic rocks. Most of these rocks occur beneath Silica Nappe in Slovakia and northern Hungary (Bódva Valley and Darnó Hill zone and Szarvaskö). Some of these mafic and ultramafic rocks are imbricated along tectonic zone in the northern part of the Gemer unit. They associate with Anisian red pelagic limestones and Ladinian red ribbon radiolarites and red radiolarian shales (Kozur and Mock 1985). The metabasites may contain igneous dipside, but richterite or Ti-rich paragasite were also found. The metabasites have mostly MORB affinity (Réti, 1985; Harangi et al. ,1996; Horváth, 1997, 2000; Faryad et al., 2002), but those with rilict richterite and paragasite have character of alokaline basalts. The metabasites reveal different degrees of metamorphism. Some indicate only prehnite-pumpellyite facies ocean floor hydrothermal metamorphism, while other reached greenschist to amphibolite facies condtions (Árkai, 1983). Metabasalts and metagabbro with incipient blueschist facies metamorphism were found in boreholes SA-6 in Slovakia (Faryad and Dianiska, 1999) and Ko-11 in Hungary (Horvath, 2000). As metamorphic mineral they contains sodic amphibole (glaucophane or riebeckite), winchite, actinolite, albite, epidote, and phengite.

The ultramafic rocks are represented by lizardite-chryzotile serpentinites that derived from dunites and harzburgites (Hovorka et al., 1985). Because serpentine minerals are stable at different P-T conditions and the serpentinites bodies are mostly mylonitized, it is not clear if some ultramafic rocks underwent blueschist facies metamorphism. Apart from lizardite and chrysotile they contain relic olivine, orthopyroxene and spinel. Some ultramafic rocks from the eastern part of the Meliata unit are classified as pyroxenite of websterite composition. Several boreholes from the Western sector of the Meliata accretionary wedge indicated the presence of olistostromes of serpentinites and coarse-grained breccia (Vozárová and Vozár, 1992).

Metamorphic conditions

Rocks of the Meliata accreationary wedge exhibit polyphase tectonometamorphic evolution where two even three major stages were recognized. The first metamorphic event is relictual and connected with peak pressure conditions attained during subduction event. The second metamorphism is widespread, retrograde with respect to the first event and associated with exhumation and differential obduction of detached slices. Retrogression of some blueschist could occur also during accretion that resulted deformation and partial recrystalization of melange matrix and of some blocks of blueschists at shallow crustal level.

Blueschist facies metamorphism

Glaucophane-free phyllites and quartzites of the Lower Thrust Sheet contain chloritoid and phengite (Si = 3.3–3.4 a.f.u.), paragonite and indicate pressure of 8-10 kbar at 350 °C (Fig. 2).

Textural relations and mineral zonation in metabasites and associated phyllites of the Upper Thrust Sheet indicate a progressive increase of pressures and temperatures during metamorphism (Faryad, 1995). Besides of common phases (glaucophane, epidote, albite and titanite), the blueschists may contain Na- and Na-Ca pyroxene (aegirine, jadeite and omphacite), phengite (Si = 3.3–3.5 a.f.u.) and garnet. No lawsonite or carpholite was found in the Meliata blueschists. Maximum P-T conditions of 13 kbar at 450 °C were calculated for these rocks, based on Jd_{70} contents in clinopyroxene and using TWQ and Thermocalc programs for blueschist facies mineral assemblages (Faryad 1995, Faryad and Hoinkes 1999).

A retrograde stage of blueschist facies metamorphism is recorded by the appearance of actinolite rimming blue amphibole and by formation of Act+Ab symplectites after glaucophane.

Consistent with textural relations and the actinolite having a smooth contact with blue amphibole represent post P-climax and retrograde phase for that 9–10 kbar at 400 °C were estimated (Faryad, 1995). Mylonitized blueschist facies phyllites with relic chloritoid (replaced by chlorite or by mixed layer phyllosilicate, Faryad, 1995) or metabasites with porphyroclasts of amphibole indicate ductile deformation associated with greenschist facies assemblages. Preservation of blueschist facies assemblages in most metabasites and locally in phyllites suggests a rapid uplift and/or a continuous cooling during exhumation of the Meliata blueschists.

Accretionary metamorphism

Low-grade rocks of the Meliata Melange contain metamorphic potassium white mica and locally pyrophyllite, which suggest temperature higher than 300 °C for this metamorphism. With exceptions of some coarse-grained muscovite that may have detritic origin, most potassium white micas from the studied rocks have phengitic composition with Si ranging between 3.2 and 3.4 a.f.u. and Fe+Mg = 0.4–1.2 a.p.f.u. Illite and chlorite crystallinity indices are rather homogeneous and indicate metamorphic conditions of ca 300–350 °C (Arkai et al., in press). Qualitative white K-mica b geobarometry shows moderate- to high- pressure metamorphism at (3–6 kbar at 300 °C) (Fig. 2). This prograde metamorphism in the melange matrix resulted in retrogression of blueschists budins at similar temperature. However, the pressure estimated by K-mica b geobarometry indicated 3 kbar for melnage matrix and 6 kbar for the blueschist boudins.

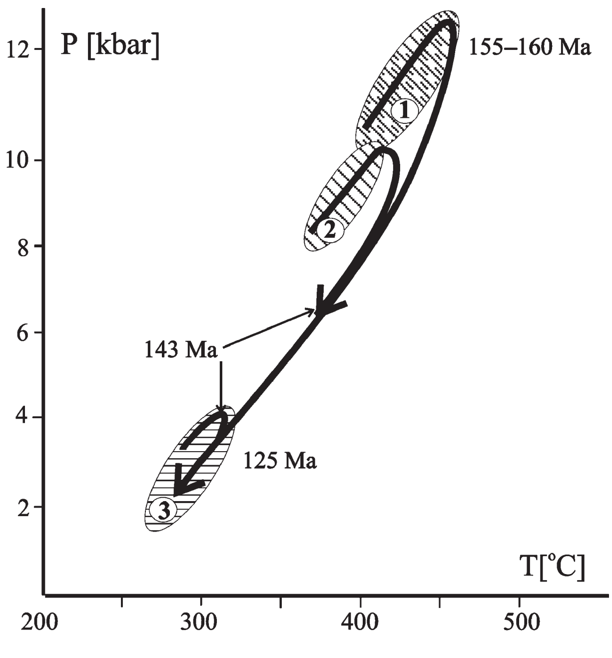

Fig. 2. Schematic P-T-t diagram for glaucophane-bearing blueschists (1), glaucophane-free chloritoid-bearing phyllites and quartzite of the lower Complex (2) and melange matrix (3) in the Meliata unit. P-T data are from Faryad (1995, 1995a and Faryad and Hoinkes, 1999).

4 Structures in the blueschist facies rocks

Structural evolution of Meliata accretionary wedge is characterized by fabrics testifying HP stage, retrogression during exhumation and emplacement of thrust sheets and late shortening of whole wedge due to buttressing.

D1- D2 deformation stages – HP and syn-foliation retrogression history

It is difficult to distinguish fabrics associated with development of HP assemblages from those related to retrogression and exhumation directly in the field. Most of original HP deformational fabrics are retrogressed and reactivated during exhumation history related to imbrication and emplacement of thrust sheets.

Deformation structures D1-2 are developed in all rocks of the Meliata accretionary wedge with different intensity. In the Permian clastics and shales of the LTS, the D1-2 is manifested by development of penetrative SE dipping metamorphic fabric, bearing intense stretching lineation plunging to the southeast. The latter is connected with sense of shear criteria as asymmetrical quartz pebbles and shear bands indicating top to the NW shearing. Late stage of deformation of quartz conglomerates is characterized by fracturing of stretched pebbles and growth of new quartz in tension gashes.

In the UTS the D1 and D2 can be distinguished as distinct deformational phases in suitable lithologies. D1 structures are essentially preserved in competent meta-basalts and marbles while in metasediments they are strongly reworked by subsequent retrogression. D1 deformation is not entirely penetrative in the meta-basalts where occur heterogeneous network of anastomose shear zones marked by growth of glaucophane. The S1 fabric is characterized by preferred orientation of glaucophane and phengite in phyllite and by the presence of inclusion-free glaucophane in the strain shadows of coarse-grained titanite-rich glaucophane in metabasites. Lath-shaped porphyroblasts or rosettes of chloritoid, which partly overgrow the S_1 foliation and some Na-pyroxene in glaucophane-bearing phyllites probably, formed during the final stage of D_1. Foliation S_1 is mostly parallel to bedding and generally dips at an angle of 20-50^o towards the E. WNW-ESE trending stretching and mineral lineation L_1 is only locally preserved. Shear sense criteria, such as asymmetric sheared clasts and pressure shadows around porphyroblasts, are consistent with a top to the WNW sense of shear. Up to 10 cm large σ- or δ-type clasts of basaltic composition mantled in carbonate matrix are other indicator of this thrusting periode.

D2 deformation is the most pronounced in the blueschist phyllites at the base of the UTS, where penetrative S2 foliation transposes earlier fabrics. The S2 fabric is axial planar to F2 isoclinal often rootless, recumbent folds. These west facing folds indicate top to the west oriented movements. Microfabrics and mineral assemblages connected with S2 cleavage suggest that D2 deformation evidences exhumation history accompanied by retrogression of blueschist to greenschist facies conditions. In some coarse-grained metabasites, the S2 fabric wrap around glaucophane porphyroclasts. Mylonitized black phyllites, which usually occur along thrust faults, contain σ-type mantled porphyroblasts of glaucophane pseudomorphs. The asymmetrical pressure shadows adjacent to porphyroclasts contain quartz and phengite. Late stages of D2 deformation in phyllites are connected with development of shear bands and pull-apart boudinage of albite porphyroblasts in calcite-rich phyllites.

The S1-2 metamorphic fabric in the Meliata melange is only preserved within competent Triassic marbles forming olistostomes. This fabric is discordant with respect to that developed in surrounding Jurassic shales.

In the upper most Turna and Silica units the S1-2 metamorphic flat-lying fabric is developed mainly in incompenet Lower Triassic calcareous shales of thrust sheets. The massive Middle to Upper Triassic carbonates which form the backbone of the Silica nappe are only affected by brittle faulting.

D3 deformation stage – buttressing

All thrust units forming Meliata accretionary wedge as well as the autochtonous Gemer basement are folded by steep N-S trending buckle folds during late buttressing stage. The large-scale buckles have wavelength of hundreds of meters to several kilometers and form open synclines and anticlines. There is also range of small-scale structures developed in individual units that accompany large-scale buckling.

The D3 structures are most intensively developed in Gemer Lower Palaeozoic slates in the footwall of the accretionary wedge. Here, steep N-S striking folds metre to several metres in size, refold bedding surfaces and are connected with development of steep ESE dipping slaty or spaced axial plane cleavage. In the Permian clastics of the LTS, the S1-2 foliation is locally refolded by open to close steep post metamorphic folds and kink bands centimetres to meters scale with N-S trending hinges. In the phyllites at the base UTS, these deformation phase leads to heterogeneous development of steep N-S trending cleavage.

In the Meliata Melange, D3 deformational fabric is heterogeneously developed. The matrix forming Jurassic shales show strong S3 planar fabric that is parallel to axial planes of open folds affecting metamorphic fabric S1-2 of Triassic olitstolithes. These buckle folds have steep axial planes and subhorizontal N-S trending hinges and indicate E-W compression.

Cretaceous overprint

Lexa et al., (2003) have shown that Cretaceous deformation in the studied area is a polyphase process controlled by indentation of southern block actively moving to the north. Complex structural evolution of Gemer slates and Mesozoic rocks is also governed by irregular shape of the Vepor promontories to the north. Consequently, the structures in the eastern part of Meliata accretionary wedge differ substantially from those in the west. We concentrate here on difference in contrasting Cretaceous structural evolution in respective areas with respect to previous Jurassic deformations.

The most important feature of Cretaceous shortening is the fact that it occurred at high angle of about 70° to direction of Jurassic accretion in the eastern part of the Meliata accretionary wedge.

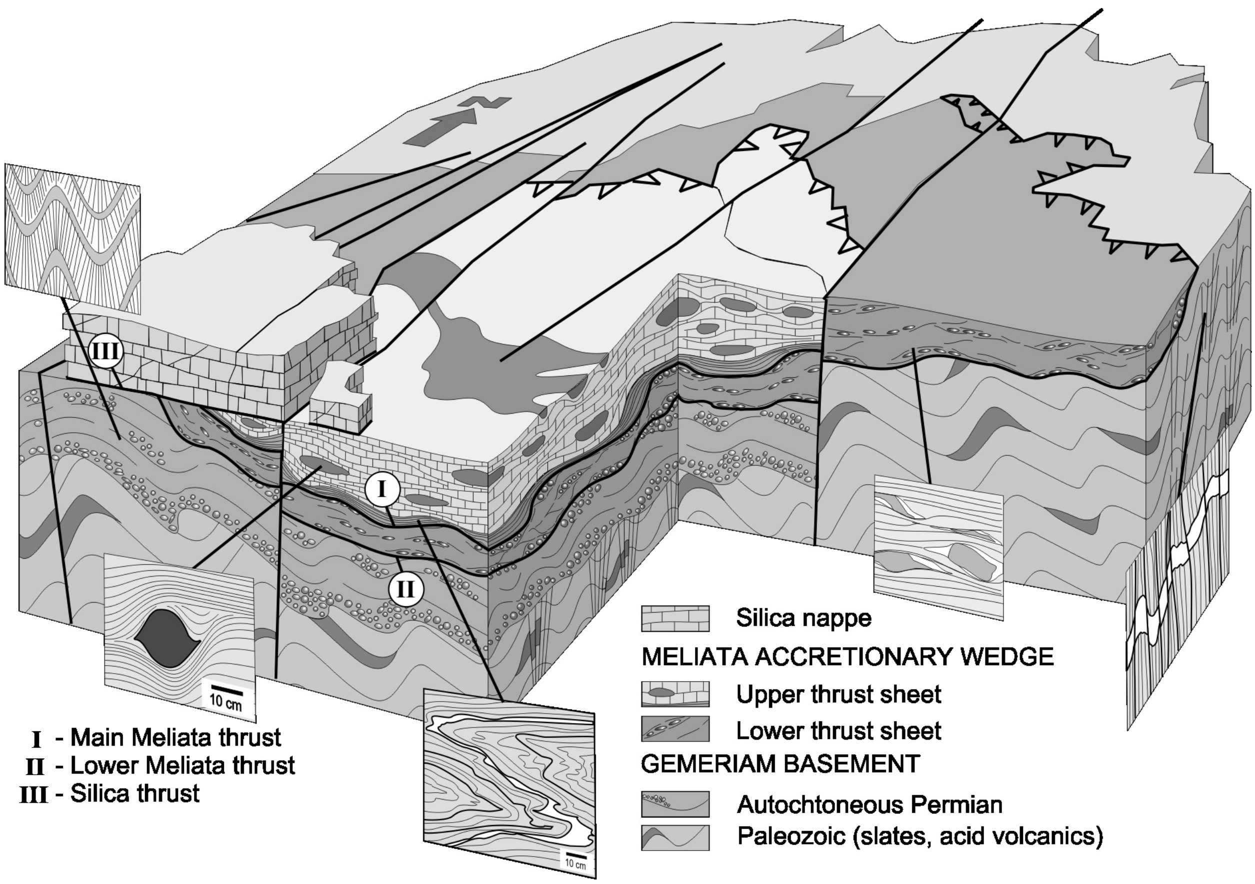

Fig. 3. Blockdiagram of the Southern part of the West Carpathians. The major tectonic units are listed.

Rationale and back-ground of excursion

Since Gilbert Wilson introduced the method of structural analysis of polyphased deformed metamorphic terrains, the method becomes widely used by structural geologists throughout the world. Subsequently, Turner and Weiss (1963) textbook deeply influenced structural geological community and the studies of deformations in poly-metamorphic terrains attracted a lot of interest in past decades. However, the techniques of structural analysis of polyphase deformations were often applied purely descriptively and therefore could not satisfy need of understanding of dynamics of continuous collisional processes resulting from existence of mechanical instabilities in progressively deforming rocks (Burg, 1999) as well as the role of superposed far field forces applied on metamorphosed units after significant periods of time.

This excursion is therefore planned as a discussion forum and an attempt is made to evaluate the age, succession and geometry of metamorphic fabrics in Mesozoic, Upper Paleozoic and Lower Paleozoic rocks of the Meliata accretionary wedge, Gemer and Vepor basement units. We would like to stimulate the discussion about possible extent of Jurassic obduction related fabrics of the Meliata wedge that was thrust onto Vepor and Gemer basement during Jurassic times. This discussion involves also the problem of age of main convergence and amalgamation of these two crystalline units before and/or during Cretaceous collision. The sequence of outcrops is selected so, that anybody can develop its own tectonic model and discuss the kinematic, dynamic and chronological significance of observed fabrics using the most basic geological observations.

During this workshop we wish to debate the meaning of geological structures as markers of heterogeneous strain field, finger prints of timely separated tectonic events developed during changes of far field forces in time and space and finally to show the beauty and difficulties of Carpathian geology, which makes this area attractive and desperately complex for generations of Slovak and Czech geologists.

Stop 1
Hill Mních Close to Rudná village

The first outcrop is represented by par-autochthonous Permian cover of the southern part of Gemer unit. These cover sediments in the studied locality mostly includes strongly deformed Permian quartz meta-conglomerates. Principal deformation is characterized by flat metamorphic schistosity dipping to the SE under shallow to intermediate angle. Foliation is defined by flattening of quartz pebbles and alignment of matrix minerals. Locally developed stretching lineation is associated with sense of shear criteria as asymmetric pebbles indicating top to the west shearing. This main schistosity is reworked by compressional kink-bands and chevron folds with subhorizontal NE-SW trending hinges suggesting ongoing NE-SW shortening related to late buttressing stage. Both metamorphic schistosity and kink-bands are refolded by late kink-bands and crenulation cleavage with axial plane steeply dipping either to the SSW or NNE. This deformation indicates generally N-S shortening of metamorphosed and folded Permian rocks exhibiting exceptionally high mechanical anisotropy in the outcrop scale. We argue that the first metamorphic fabric and E-verging buckling results from Jurassic emplacement of the Meliata accretionary wedge onto the Gemer basement and its par-autochthonous Upper Paleozoic cover. The greenschist facies thrusting was terminated during buttressing stage at lower greenschist conditions. Late compression occurred at right angle to Jurassic deformation and corresponds to major Cretaceous N-S shortening event.

Stop 2
Creek Valley East of Maša Community

The Meliata rocks are exposed in the lower part of Valley east of the Maša community (NE from Štítnik). The Upper sheet rocks are represented by metabasite, chloritoid schists and marbles that are tectonically overlain by limestone of the Turňa nappe. These rocks are exposed in the Valley and can be correlated with rocks that exposed on the northern and southern sides of Hončianský potok Valley. During the excursion we will see blueschist facies metabasites that partly contain calcitic marble. Fresh unfoliated metabasite contains glaucophane, albite and various amounts of epidote and titanite. These rocks show strong penetrative fabric developed during main HP event. The main metamorphic fabric contains numerous rootless folds and is refolded by recumbent folds connected with development of axial planar cleavage dipping to the SE. This later deformation event is interpreted to result from exhumation of HP unit associated with greenschist facies retrogression. We suggest that both main blueschist facies metamorphic fabric and greenschist facies reworking result from Jurassic subdution and obduction stage. The Cretaceous deformation event is also present and is manifested by large scale upright folding of the metamorphic sequence leading to the rotation of the whole metamorphic fabric.

Stop 3
Baťa Quarries Northwest of the Roštár Village

The Upper sheet rocks are here represented by coarse grained crystalline marbles associated with metabasite boudins tectonically overlain by the weakly metamorphosed limestone of the Turňa nappe in the southern part of studied section. The marbles show well equilibrated recrystallised structure and weak layering underlined by different colours of inpure calcite layers. Locally it bears strong mineral lineation plunging to the SE. The metabasites are represented by retrogressed blueschists that exhibit strong metamorphic fabric. In some places isoclinally folded metabasite fabric indicate complete transposition of blueschist facies fabric during retrogression associated with exhumation of HP unit.

Importantly the Upper sheet rocks west of Roštár directly overlying the Vepor Palaeozoic cover that exhibit concordant metamorphic fabric with that of hangingwall Meliata rocks.

Stop 4
Creek Valley Southwest of the Hanková Village

The studied outcrop is represented by meta-grauwackes (metasandstones) and meta-semipelites of the Upper Carboniferous Slatvina formation. These rocks are affected by greenschist facies metamorphism. The most characteristic feature is a NE-SW trending steep fabric that is refolded by recumbent folds. These NE-SW trending subhorizontal folds rework the metasedimentary unit with variable intensity leading locally to complete transposition of early metamorphic? fabric.

In this outcrop we shall examine the character of folding and development of penetrative and sub-horizontal metamorphic foliation. The discussion is focused on the existence of steep NE-SW trending fabric in the Vepor cover and timing of its reworking by flat thrust related foliation and folding. We underline, that the kinematics and orientation of both steep and flat fabrics are not consistent with generally accepted model of top to the north oriented Cretaceous shortening.

Stop 5
Valley East of the Hanková Village

This outcrop is developed in weakly metamorphosed laminated quartz-mica phyllites of the Gelnica group of the Gemer unit. The metamorphic conditions related to the main compositional layering correspond to lower greenschist conditions typical for this part of the Gemer unit.

The key structure in this outcrop is the existence of steep compositional metamorphic layering reworked by flat crenulation cleavage. The new cleavage is penetrative, clearly compressional and results most likely from tangentional movements. Study of Lexa et al., (2003) did not demonstrated such a structural succession in the Gemer complex and neither Cretaceous structural fan, nor the Trans-Gemer shear zone may be responsible for development of both kinds of fabrics.

The motivation for visiting this outcrop is the discussion of age of steep fabric in the Gemer unit, timing and kinematics of development of the late flat cleavage. Clearly highly anisotropic and already metamorphosed Gemer metasediments are reworked during late subhorizontal shearing with axis which is not consistent with Cretaceous N-S shortening.

Stop 6
Creek Valley North of the Hanková Village

Series of outcrops is developed in Permian conglomerates and metasediments overlying the Vepor basement unit. These rocks are marked by presence of chloritoid, kyanite and phengite mineral assemblage in lower part that is interpreted to result from Cretaceous thickening and MP-MT metamorphism (Vrána, 1964, 1966; Lupták et al., 2000, Janák et al., 2001). Janák et al., (2001) consider the metamorphic fabric of this unit to represent a vestige of Cretaceous metamorphism associated with thickening of the Vepor basement. The visited outcrop does not exhibit above mentioned mineral assemblage but reveals interesting succession structures. First metamorphic fabric is penetrative and related with flattening of quartz pebbles and alignment of fine-grained white mica. This fabric is affected by heterogeneous shear zones developed at acute angle to the main metamorphic schistosity. These shear zones are commonly interpreted to result from late extensional unroofing of the Vepor basement. Locally all deformation fabrics are reworked by steep folds with N-S trending hinges clearly indicating late E/W shortening of highly anisotropic flat fabric. We would like to stimulate discussion here about the possible significance of early flat fabric, kinematic and dynamic framework of extensional unroofing of the Vepor basement and subsequent E-W shortening related to ??.

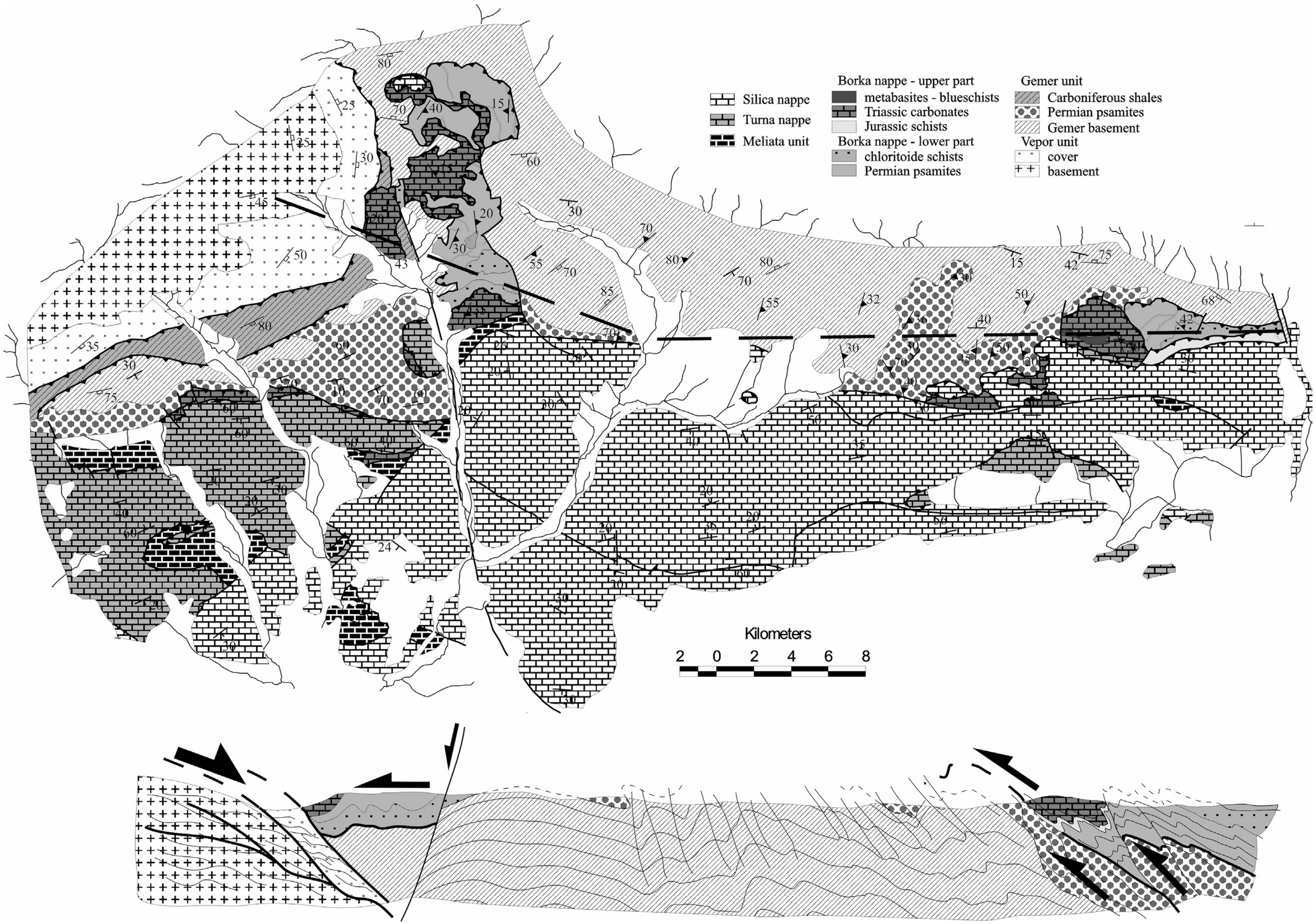

Fig. 1. Outline map and cross-section of the Southern part of the West Carpathians. The major tectonic units are listed.

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Post-Conference Fieldtrip: Volcanic and Subvolcanic Lava Bodies – Structural Aspects

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Introduction

Alkali basalt and andesite volcanic formations of southern and central Slovakia provide an opportunity to continue our studies of various lava bodies with a special attention paid to structural aspects like jointing and magmatic fabric. During the post-conference fieldtrip we shall visit five localities – three in the surroundings of Fiľakovo and two south of Zvolen. Localities have been selected to demonstrate differences among shallow intrusive bodies (laccolites and sills) on one side and surficial extrusive bodies (extrusive domes and lava flows) on other side.

Localities Šiatorošská Bukovinka south of Fiľakovo as well as Sasa and Breziny south of Zvolen are andesite laccolites respectively extrusive dome (Breziny). They are a part of the early phase of garnet-bearing andesites that initiated the Middle Miocene andesitic volcanic activity in central and southern Slovakia (Konečný et al., 1995a). Volcanic activity was related to the youngest evolutionary stage of the Carpathian arc and the intra-Carpathian basins, with subduction, extension and asthenospheric upwelling as the main driving mechanisms (Lexa & Konečny, 1998). Magma generation itself was initiated by decompression partial melting of the enriched asthenosphere and/or lithosphere, due to asthenosphere upwelling and/or related lithosphere delamination. Rocks are mostly of the medium to high-K type, showing compositional features comparable with andesites of continental margins. Interpretation of trace element contents and Sr, Nd, Pb and O isotopic compositions (Salters et al., 1988; Downes et al., 1995) demonstrates a primary basaltic magma source in the enriched asthenosphere or lithosphere, with subsequent contamination by crustal materials. Further evolution of magmas involved high- and low-pressure fractionation, assimilation and mixing (Lexa et al., 1998).

Localities Šiatorošská Bukovinka – Mačacia and Bulhary are alkali basalt lava flows, respectively a shallow laccolite. Activity of alkali basalt volcanism started in the area of central Slovakia during the Pannonian time (8.0 Ma). Subsequently it moved into the region of southern Slovakia. Initial volcanic products of the Pontian age (around 6.5 Ma) are located in the NW part of the region (Podrečany Formation). The following volcanic activity during the Pliocene to Early Pleistocene time (5.5 – <1.0 Ma) was confined to the Cerová vrchovina highland area, which went through a contemporaneous uplift. The youngest alkali basalt volcanic activity of the Late Pleistocene age (around 150 Ka) took place again in the region of central Slovakia. Alkali basalt volcanic activity in southern Slovakia created a typical monogenous volcanic field of numerous necks, diatremes, maars, tuff cones, scoria cones and lava flows (Konečný te al., 1995b). Alkali basalts as a group of rocks includes nepheline basanites, tephrites, alkali olivine basalts, trachybasalts and trachyandesites. All mentioned rock typess are Si-undersaturated with normative nepheline implying predominance of Na_2O over the K_2O. Petrologic aspects of alkali basalt volcanics in the Carpatho-Pannonian region were recently evaluated on the basis of geochemical and isotopic data by Embey-Isztin et al. (1993) and Dobosi et al. (1995). Alkali basalts and nepheline basanites are products of partial melting in depleted asthenospheric mantle with a slight relict (especially isotopic) subduction signature. Lithospheric component plays a subordinate or even negligible role. Composition of magmas was controlled mostly by a degree of partial melting, processes of fractionation were less important. Recent processes of diapiric uprise in the mantle related to generation of alkali basalts in southern Slovakia are indicated by PT conditions of mantle xenoliths equilibration, which fall on the adiabatic trend in the depth interval 50–90 km (P. Konečný et al. 1995). Rare extreme fractionation and limited crustal contamination of ponded alkali basalt magma in lower crust have been recently described by Huraiová et al. (1996).

Localities

1. Šiatorošská Bukovinka: Garnet-bearing andesite laccolite in Early Miocene sedimentary rocks

Neogene calc-alkali volcanism is represented in southern Slovakia by intrusive bodies of garnet-bearing andesites (Fig. 1). One of the andesite laccolites (or thick sills) is exposed in the visited abandoned quarry. Due to favourable jointing it has been used extensively to produce dimension stone, including famous curb stones and pavement cubes. Age of the laccolite is

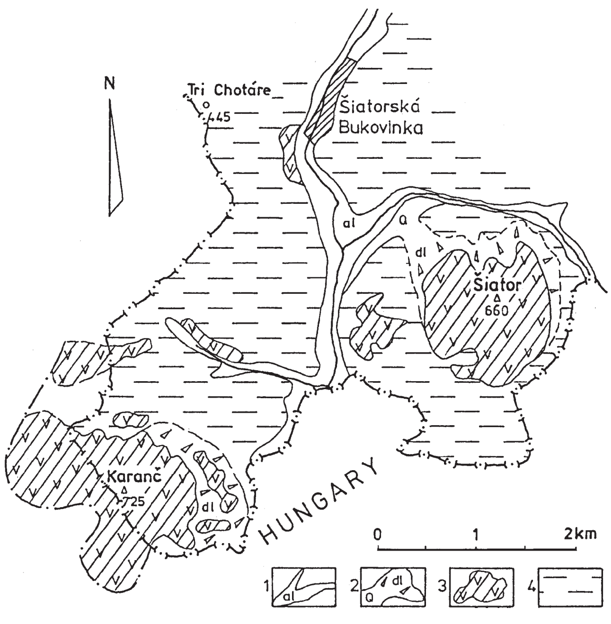

Fig. 1. Scheme of the Šiator intrusive complex. 1 – fluvial deposits (Quaternary), 2 – deluvial deposits (Quaternary), 3 – garnet-bearing andesites (lacoliths and sills), 4 – Early Miocene (Eggenburgian) sedimentary rocks.

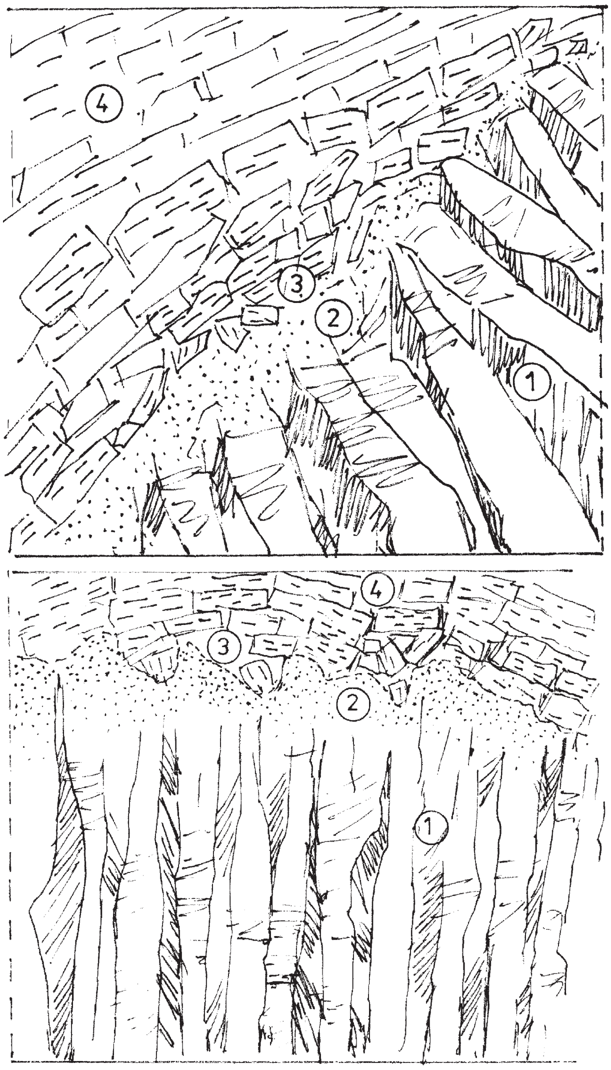

Fig. 2. Quarry Šiatorošská Bukovinka – intrusive contact of garnet-bearing andesite with Early Miocene sandstones. 1 – andesite with blocky to columnar jointing, 2 – zone of andesite vesiculation and brecciation, 3 – disturbed sandstones affected by contact metamorphism, 4 – undisturbed sandstones.

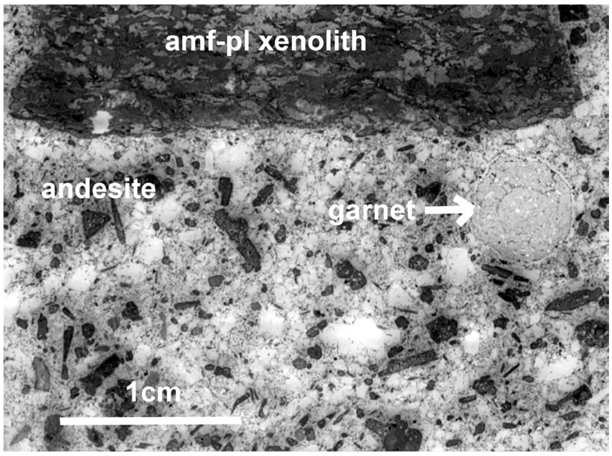

Fig. 3. Microphotograph of garnet-bearing pyroxene-hornblende andesite with „amphibolite" xenolith.

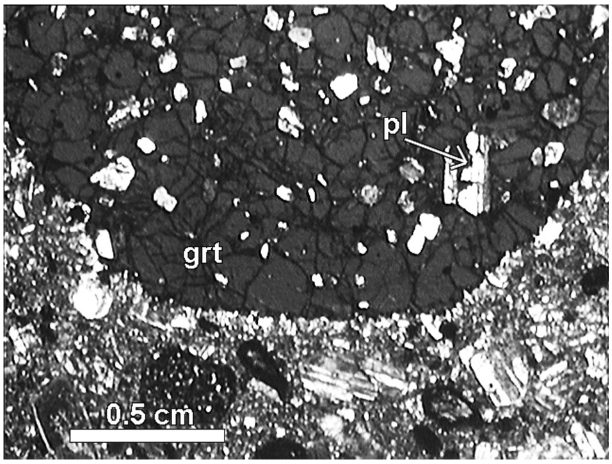

Fig. 4. Microphotograph of a large garnet phenocryst enclosing smaller plagioclase phenocrysts.

16.4 Ma (K/Ar dating, Pécskay unpublished), corresponding to the age of garnet-bearing andesites at other localities of central and southern Slovakia. The laccolite about 600 m in diameter and 60–80 m in thickness was emplaced into a monotonous succession of Fiľakovo Formation sandstones (Eggenburgian). It is build of massive andesite with blocky to columnar jointing. At the contact with sediments, which are broken and displaced (Fig. 2) andesite is brecciated and/or vesiculated, including carbonate veinlets.

Due to the thermal effect of the intrusion sediments are metamorphosed under conditions of the hornfels facies. Assemblage of newly formed minerals is diopside-plagioclase-orthoclase-quartz (locality Šiator). Subsequent hydrothermal activity, which involved meteoritic water, was responsible for alteration and formation of secondary minerals. These show a pronounced zonal arangement with increasing distance from the contact. In order of descending temperature there are distinguished mineral assemblages: biotite, quartz-carbonate-epidote, chlorite-sericite, apofylite-skolecite-epistilbnite-laumontite-heulandite-chabazite-stilbite-quartezite-smectite (Hojstričová et al., 1995).

Andesite is medium to coarse grained, porphyritic, light green to dark green in colour. It contains phenocrysts of plagioclase, hypersthene, amphibole and scarce biotite. Characteristic there are garnet phenocrysts, up to 1 cm in diameter. Garnets are of almandine compositon, showing well developed zonality and rarely also enclosed plagioclase phenocrysts. The presence of garnet phenocrysts implies a high pressure crystallisation prior the magma upraise to the surface, most probably at the base of the Crust. Groundmass shows a variable texture. It is granular microallotriomorphic in the central parts of intrusive bodies, while it is felsitic-microlitic in marginal parts. Owing to autometamorphic processes (subsolidus reactions with fluids) mafic minerals are hematitized, chloritized and replaced by secondary carbonate and quartz. Andesite contains a number of xenoliths. The most frequent there are xenoliths of crystalline schists, gneisses, banded gneisses, amphibole gneisses, amphibolites, migmatites and granitic rocks (Hovorka and Lukáčik, 1973). Some of these xenoliths are supposed to represent pieces of the lower crust in the time of their entrapment.

2. Šiatorošská Bukovinka – Mačacia: Abandoned quarries in alkali basalt lava flows

Extensive quarries at the locality Mačacia northeast of Šiatorošská Bukovinka expose a succession of alkali basalt lava flows. Basalt was used for the production of curb stones and pavement cubes. Its exploitation took place mostly in the second half of 19th and first half of 20th century. Lava flows are a part of a lava plateau surrounding a still recognizable scoria cone Medvedia výšina (Medves) (Fig. 5). According to K/Ar dating the age of lava flows is 2.61 ± 0.19 Ma (Konečný et al., 1995c). Three superimposed lava flows have been recognized, separated by zones of vesicular basalt and lava breccias and by a discontinuous horizon of distal facies tuffs and fluvial deposits. The uppermost lava flow is 20–30 m thick. At its base there is a narrow zone of vesiculated breccia, showing eventually features of hyaloclastite and/or peperite breccias. Breccia passes upward into platy jointing following uneven underlying surface. Internal parts of the lava flow show a characteristic thick platy jointing passing upward into poorly developed columnar jointing. Vesicular scoraceous breccias are also at the top of the lava flow. Only those parts of the lava flow with the regular thick platy jointing could be used for production of pavement stones.

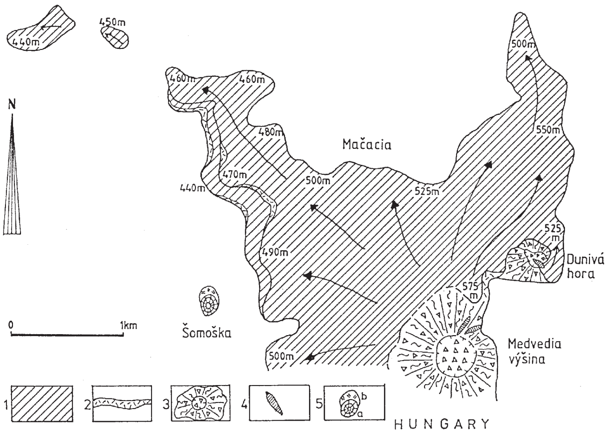

Fig. 5. Basalt plateau of Mačacia. 1 – alkali basalt lava flows, 2 – horizons of tuffs, 3 – scoria cones, 4 – dykes, 5 – lava neck Šomoška composed of basalt showing columnar jointing (a) and explosive breccia (b).

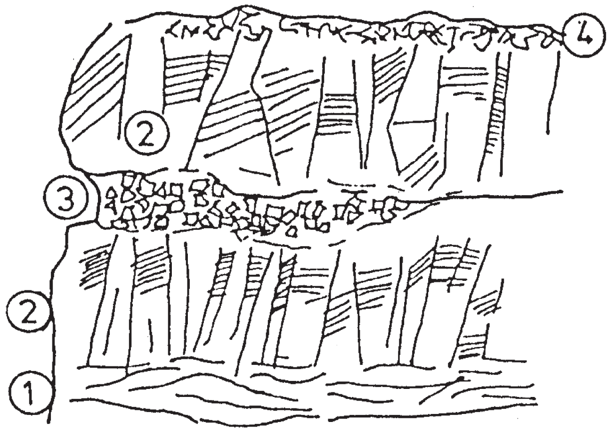

Fig.6. Lava flows at the locality Mačacia. 1 – platy jointing at the lower part of the flow, 2 – columnar jointing, 3 – vesicular breccia at the base of the upper flow, 4 – vesicular breccia at the top of the flow.

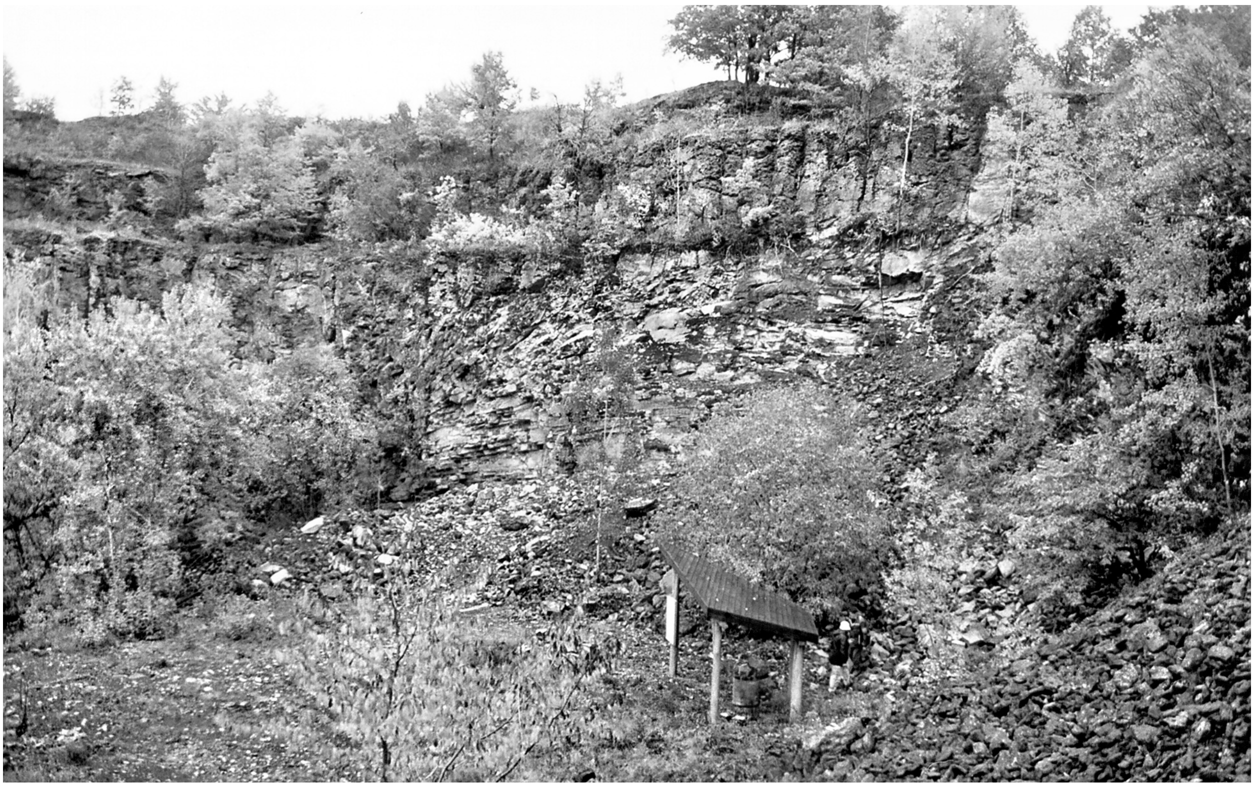

Fig. 7. Upper lava flow at the locality Mačacia. Note platty jointing in the lower part of the flow passing upward into columnar jointing (upper level of the quarry).

Fig. 8. Base of the lava flow at the locality Mačacia. Note platy jointing parallel with the contact and a local evolution of hyaloclastite/peperite breccia at the base of the flow. Succession of underlying tuffs is explained in the fig. 9.

According to low content of modal olivine the alkaline basalt at this locality is classified as tephrite. It has microcrystalline to glassy groundmass formed by plagioclase, anorthoclase, clinopyroxene, Fe-Ti oxides and glass. Fenocrysts of clinopyroxene and olivine can be easily recognized in the hand specimen as well as mantle pyroxene xenocrysts and lherzolite nodules. Upper mantle fragments represented by spinel lherzolites are angular to less rounded in shape with average size about 1 to 2.5 cm. Lherzolites are distinguished by typical pale-green color. Wide range of textures has been identified, from protogranular, porphyroclastic to equigranular and secondary recrystallized texture indicating a complex evolution of the upper mantle in this region.

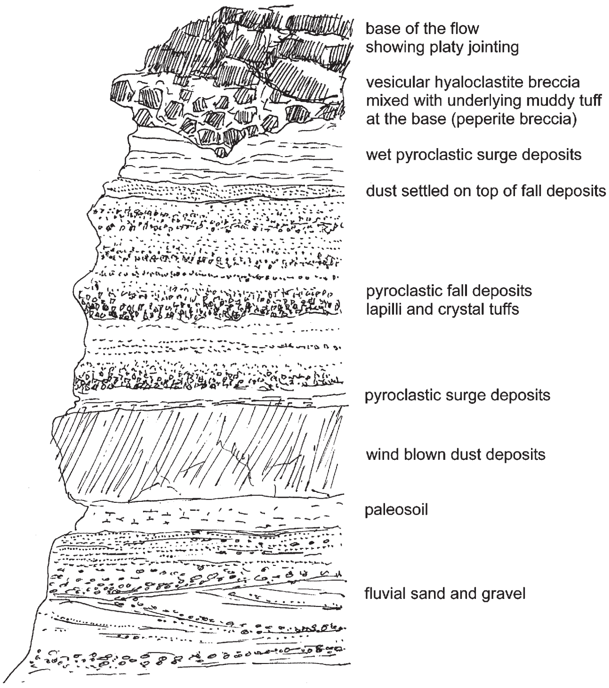

Fig. 9. Interpretation of the outcrop in the fig. 8.

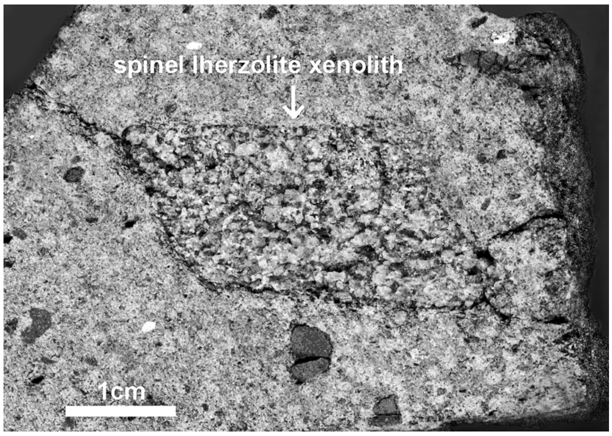

Fig. 10. One of the lithospheric mantle xenoliths in alkali basalt from the locality Mačacia.

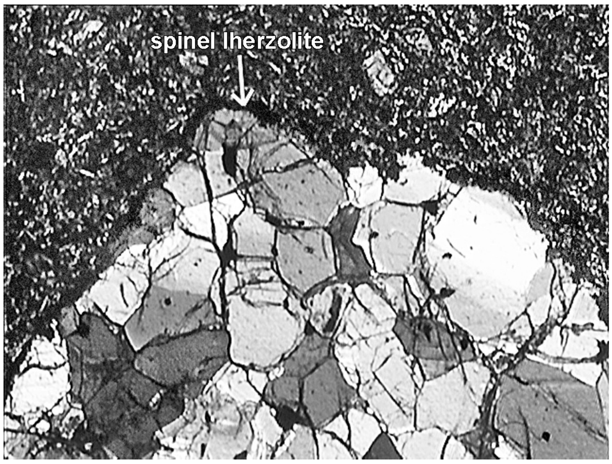

Fig. 11. Microphotograph of a lithospheric mantle xenolith in alkali basalt from the locality Mačacia.

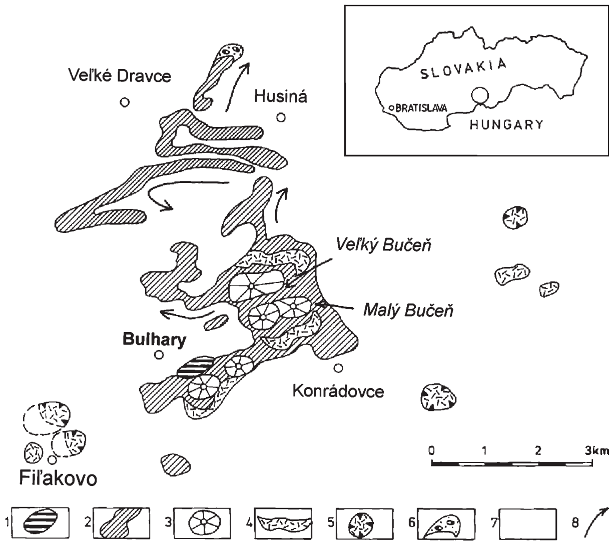

Fig. 12. Scheme of the NW part of the Southern Slovakia Alkali Basalt Field. 1 – Bulhary maar, 2 – lava flows, 3 – scoria cones, 4 – palagonite tuffs, 5 – maars, 6 – fluvial gravel, 7 – Early Miocene sedimentary rocks, 8 – flow direction.

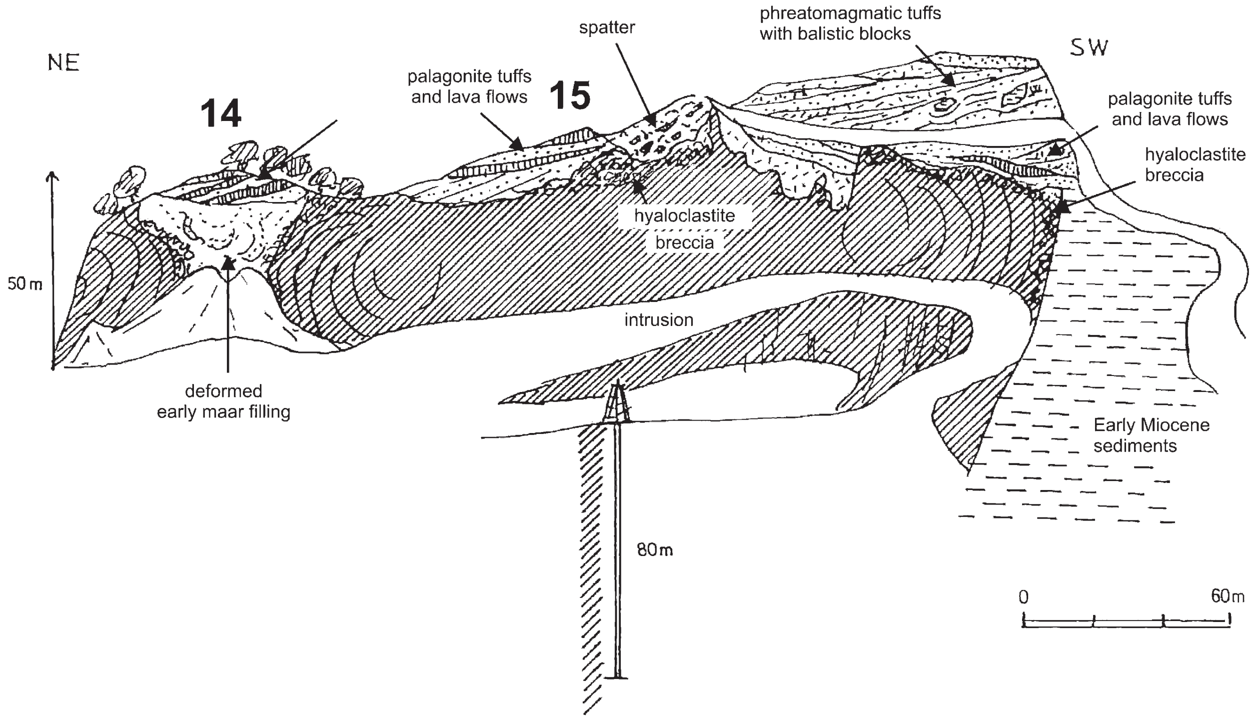

Fig. 13. Panoramatic scheme of quarries in the Bulhary maar, looking from the Northwest. Numbers indicate position of the fig. 14 and 15.

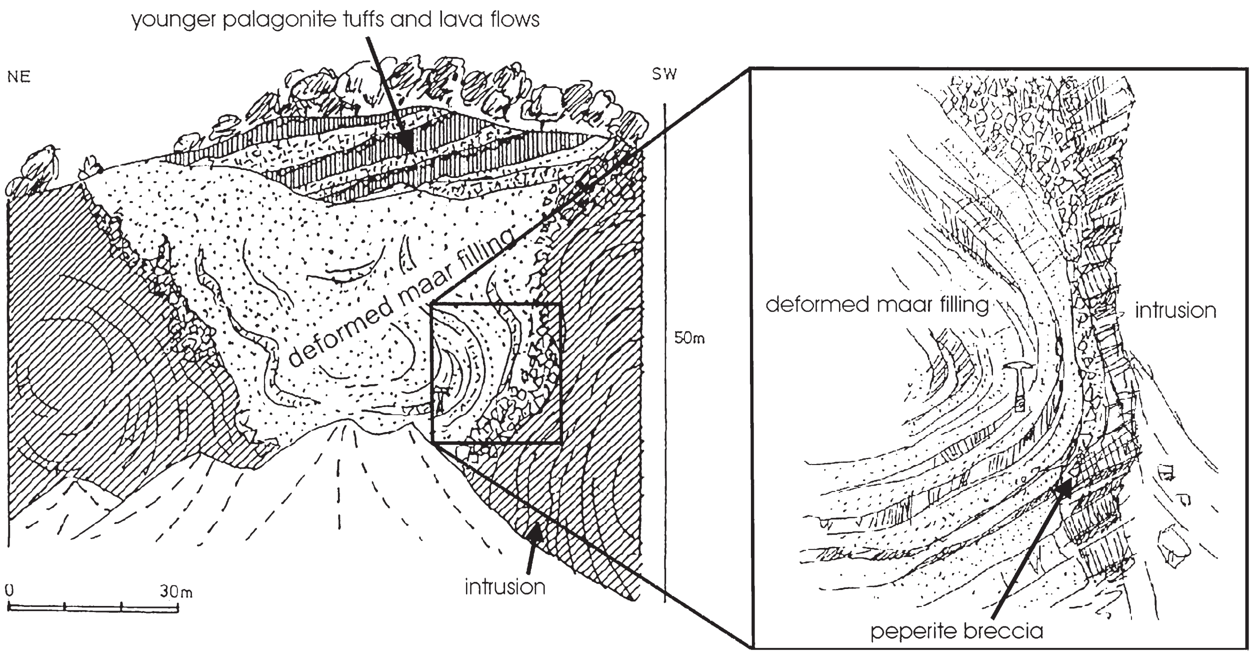

Fig. 14. A view of the NE part of the quarry showing the intrusion invading deformed palagonite tuffs of the early maar/diatreme filling and the younger succession of palagonite tuffs and lava flows.

3. Bulhary: Laccolite-like alkali basalt intrusion emplaced in a maar fill

The Bulhary maar-diatreme volcano 1 km in diameter forms a part of a more extensive complex of maars, cinder cones and lava flows 3 km NE of Fiľakovo (Fig. 12). Radiometric dating of the maar-related intrusion by K/Ar method has given the result 1.60 ± 0.15 Ma (Konečný et al., 1995c, 2002). Internal parts of the Bulhary maar and underlying diatreme are accessible thanks to extensive quarries opened to extract high quality stone of the laccolite-like intrusion (used to produce curbstones and old-fashioned pavement cubes). The Bulhary maar/diatreme complex demonstrates a multistage evolution, governed by the water/magma interaction in the depth as well as in the maar lake. The volcano evolved in 5 stages (Konečný and Lexa, 2003): (1)

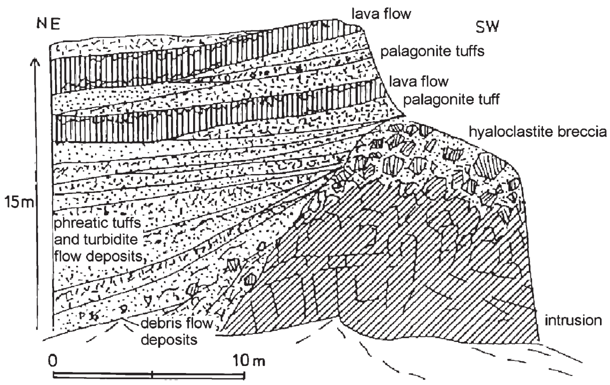

Fig. 15. Scheme of the outcrop at the SE edge of the quarry, showing hyaloclastite breccias and related onlapping succession of reworked material (mostly fines carried out of the breccia by boiling and phreatic explosions).

Fig. 16. Locality Sasa. Blocky to columnar jointing of pyroxene-amphibole andesite laccolite.

maar formation by phreatomagmatic eruptions; (2) emplace-

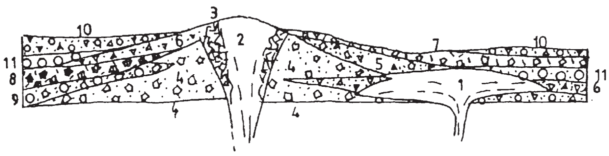

Fig. 17. Structure of the Neresnica Formation. 1 – laccolite, 2 – extrusive dome, 3 – extrusive breccia, 4 – coarse to blocky epiclastic volcanic brecccia, 5 – epiclastic volcanic breccia, 6 – fine epiclastic volcanic breccia, 7 – mudflow deposits, 8 – breccia flow deposits, 9 – coarse to blocky epiclastic volcanic breccia/conglomerate, 10 – epiclastic volcanic breccia/conglomerate, 11 – coarse epiclastic volcanic conglomerate.

ment of a laccolite-like intrusive body into maar/diatreme filling; (3) creation of hyaloclastite breccias and phreatomagmatic tuffs with spatter due to a direct contact of magma with water in the maar lake; (4) several cycles of the Surtseyan and Hawaiian type eruptions giving rise to overlying lava flows alternating with palagonite tufs; (5) final Hawaiian type eruptions responsible for to the capping horizon of cinder and spatter.

The central part of the maar/diatreme complex is occupied by an extensive laccolite-like intrusion. Platy to blocky jointing shows the onion-like internal structure, implying ballooning as the principal mode of its emplacement. At the SW it is in a direct contact with surrounding Early Miocene sedimentary rocks. Thermal effect of the intrusion on sedimentary rocks is almost negligible, limited to a meter or two of induration. Insulation of sedimentary rocks has been provided by a zone of peperitic and

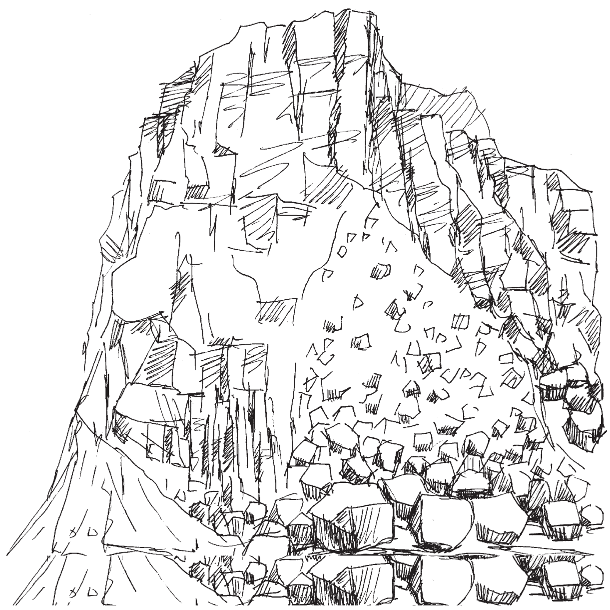

Fig. 18. Locality Breziny. Internal part of the extrusive dome showing blocky jointing.

hyaloclastite breccias, implying a presence of water.

At the NE the situation is different. Here the intrusion has invaded palagonite tuffs of the early maar/diatreme filling. Close to the contact basalt shows a distinct platy jointing, parallel with the contact. At the contact itself, there is a zone 0.5 – 5 m thick, formed of slightly vesiculated hyaloclastite and/or peperite breccia, implying a saturation of the maar/diatreme filling by water in the time of the intrusion emplacement.

The apical part of the intrusion is exposed at the upper levels of the SE wall of the quarry. Apparently the intrusion at this place went into a direct contact with water in the maar lake as it is capped by a thick zone of greenish to reddish vesiculated hyaloclastite breccia. Variegated colors and the presence of nontronite and hematite imply a boiling system.

At the SW wall of the quarry the intrusion passes upward into several lava tongues separated by thick accumulations of hyaloclastite breccia. Lava of the intrusion was at this place in a direct contact with water of the maar lake.

The intrusion is formed of nepheline basanite with phenocrysts of olivine, clinopyroxene, plagioclase and rare opacitized amphibole in microdioritic to microlitic groundmass rich in nepheline and ore pigment. Aragonite and/or zeolite might be present in vesicules close to margins of the intrusion.

4. Sasa: Pyroxene-amphibole andesite laccolite

Laccolite exposed in an abandoned quarry between the villages Sasa and Babiná belongs to the Neresnica Formation of the early Middle Miocene age. It has been emplaced more or less at the contact of basement rocks and overlying volcanic complex of the Neresnica Formation (Fig. 17). The laccolite form of the lava body is reflected in well developed regular blocky jointing showing loally features transitional to columnar jointing (Fig. 16). Andesite is porphyritic with phenocrysts of plagioclase, amphibole, augite, hypersthene and very rare garnet in pilotaxitic groudmass composed of plagioclase, pyroxenes and magmatite. Mafic minerals are replaced partially by fine grained magnetite pigment (opacitization due to reaction with steam at subsolidus conditions). Rare miarolitic cavities are filled by analime. Andesite contains inclusions of sedimentary and crystalline basement rocks. F. Fiala (1955) has described cordierite-plagioclase hornfelses rich in corrund.

5. Breziny: Garnet-bearing andesite extrusive dome

Extrusive dome is a part of the Neresnica Formation south of Zvolen, which is composed mostly of andesite extrusive domes, related coarse to blocky extrusive breccias and reworked epiclastic rocks (Fig. 17). Fission-track dating has given results 16.1 ± 0.3 Ma and 15.9 ± 0.5 Ma corresponding to early Middle Miocene. Extrusive dome exposed in the abandoned quarry next to Breziny is elongated in the NNE-SSW direction and surrounded by accumulations of coarse breccias. Andesite shows an irregular blocky jointing (Fig. 18) and steeply dipping or vertically oriented flow banding, implying a fan-like internal structure of the dome. Plagioclase and amphibole phenocrysts show a preferential orientation parallel to flow banding. Andesite is coarse porphyritic with phenocrysts of plagioclase, pyroxenes, amphibole and rare biotite, quartz and garnet. The phenocryst assemblage implies a high pressure crystallization prior the extrusion of magma upon the surface. Groundmass shows microlitic to hyalopilitic texture.

Andesite contains inclusions of sedimentary and crystalline basement rocks. F. Fiala (1955) has described cordierite-sillimanite hornfelses rich in garnet and pleonaste, diopside erlane and dioritic rock with garnet and cordierite.

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