EXCURSION GUIDE

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Edited by P. Hanžl, R. Melichar and V. Janoušek

## MAGMATIC AND TECTONIC PHENOMENA OF THE SOUTHEASTERN MARGIN OF THE BOHEMIAN MASSIF

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MAGMATIC AND TECTONIC PHENOMENA
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# SHORT REGIONAL BACKGROUND TO THE FIELD TRIP

## Introduction

R. Melichar

The Field guide is focused on units situated in the southeastern margin of the Bohemian Massif and on their tectonic evolution. The **Bohemian Massif** is an elevation of crystalline rocks consolidated during the Hercynian Orogeny and surrounded by post-Hercynian sedimentary rocks. The elevation was formed in the Cenozoic era by combination of several tectonic events such as Saxonian reverse faulting, Neogene normal faulting etc.

The basement of the Bohemian Massif represents the easternmost part of the **Variscan orogenic belt** which is the Central-European segment of a large orogenic zone formed during the Hercynian Orogeny between Gondwana in the S and Laurussia in the N. The basement consists of several terranes derived from the northern rim of Gondwana typical by manifestation of the Cadomian Orogeny. These terranes were again juxtaposed and/or amalgamated into one orogenic belt during the Hercynian Orogeny (Matte et al. 1990; Winchester et al. 2002; Schulmann et al. 2009). Typical Hercynian internide zonation (Moldanubian and Saxo-Thuringian zones) coming from Iberian through Armorican to Variscan orogenic belts is ending at the eastern margin of the Bohemian Massif forming the so-called Lugodanubian Block (Stille 1951). This Block is here thrusted over the Brunovistulian Block along the Moldanubian thrust recognized by F. E. Suess long ago (1903).

The **Lugodanubian Block** consists of local units representing different terranes such as Moldanubicum (#7 in Fig. 1), Lugicum (#14) and Polička and Zábřeh units (#20). These terrains juxtaposed during Early Hercynian Orogeny were intruded by numerous bodies of plutonic rocks of Devonian and Permo-Carboniferous ages (#6; see Žák et al. 2014 for review). Voluminous Early Carboniferous (*c.* 354–346 Ma) arc-related syntectonic granitoids intruded into western part of the Moldanubicum (Holub et al. 1997a, b; Hrouda et al. 1999; Janoušek et al. 2000, 2004a, 2010b; Schulmann et al. 2005; Žák et al. 2005, 2011a). Then, at *c.* 350–330 Ma, followed ultrapotassic intrusions of melagranites to quartz melasyenites (Holub 1997; Holub et al. 1997a; Janoušek et al. 2000; Janoušek – Gerdes 2003; Verner et al. 2006, 2008; Janoušek – Holub 2007; Kotková et al. 2010). In the western Moravian Moldanubicum, even-grained two-pyroxene–biotite type forms the Jihlava Pluton and strongly Kfs-phyric amphibole–biotite one is typical of the Třebíč Pluton. This so-called “durbachite suite” is present in Variscides of Central and Western Europe (French Massif Central, Vosges, Schwarzwald, Corsica and Alps). Most of these plutonic suites share similar petrology and geochemical characteristics, as well as an intrusive age of *c.* 350–330 Ma (Holub 1997; von Raumer et al. 2014 for review). Lastly, the core of the Moldanubian Zone was intruded by the Moldanubian Plutonic Complex, dominated by voluminous ~330–320 Ma anatectic, S-type granites (Liew et al. 1989; Vellmer a Wedepohl 1994; Gerdes et al. 2003; Finger et al. 2009; Žák et al. 2011b; Verner et al. 2014).

The **Brunovistulian block** includes Brunovistulicum (#25) as a basement and covering Moravosilesioan Devonian and Lower Carboniferous sediments. In the Brno Massif, which represents the largest exposed part of the Brunovistulicum, there have been classically distinguished the more primitive eastern part (Slavkov Terrane) interpreted as having originated in an island-arc environment, and the more evolved western part (Thaya Terrane), including recycled cratonic material that is considered to have been originally part of the Neoproterozoic Gondwanan continental margin (Finger et al. 1995, 2000a). This unit can be traced towards the north, to the pre-Devonian basement of the Silesicum (Finger et al. 1995, 2000a; Kröner et al. 2000; Hanžl et al. 2007a). Much of the Brunovistulicum is concealed underneath Moravosilesian Devonian to Lower Carboniferous sediments (#24) and foredeep and flysch nappes (#27–#30) of the Outer Carpathian Belt (Dudek 1980; Jelínek – Dudek 1993). The Brunovistulian Block continues underneath the Lugodanubian Block towards the west, what is visible in the central parts of the Thaya and Svratka domes (Suess 1912; Stille 1951; Schulmann et al. 1991; Soejono et al. 2010).

The contact zone of these two blocks associated with the Moldanubian thrust is several kilometres wide and is referred to as the **Moravian Shear Zone**. It is typified by its inverse tectonics, flat foliation with stretching lineation in NNE–SSW direction and by dextral sense of movement with small thrust component. Minimum range of overthrusting based on geophysical data is as far as the Přibyslav Mylonite Zone near Jihlava (Guy et al. 2011; Babuška – Plomerová 2013). Strongly strained units in the Moravian Shear Zone are grouped into heterogeneous unit called Moravosilesicum (#23) that contains part of the Brunovistulicum and its Devonian cover, special unit (Moravicum) and sheared marginal parts of Lugodanubicum (known under the old name Moravian Mica-schist Zone, for example). These units crop out in central parts of three domes (Thaya, Svratka and Silesian). The Svratka Dome is the middle, the most complete and least eroded in comparison to the others.

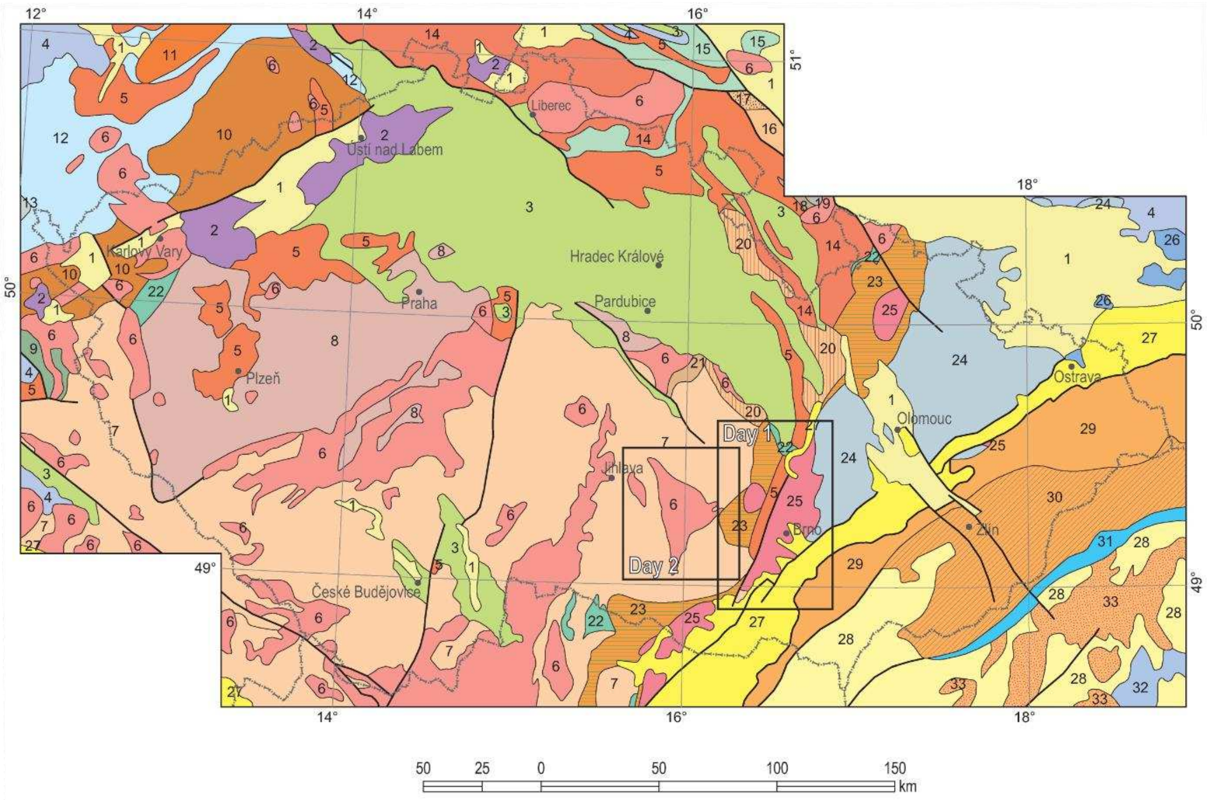


Fig. 1. Situation of excursion fields on geological scheme of the Czech Republic (Cháb – Stráník – Eliáš ed. 2007). **Bohemian Massif** and its overburden: 1 – Cenozoic sediments; 2 – Cenozoic volcanics; 3 – Upper Cretaceous Fm.; 4 – Upper Permian to Jurassic Fm.; 5 – Permocarboniferous rocks of intramountaneous depressions; 6 – Variscan granitoids; 7 – Moldanubicum; 8 – Bohemicum; 9 – Erbendorf-Vohenstrauss Units; 10 – Saxothuringicum; 11 – Saxon granulite platform; 12 – Palaeozoic of the Saxothuringian development; 13 – Palaeozoic of Bavarian development; 14 – Cadomian granitoids and metasediements of Lugicum; 15 – Palaeozoic metasediments of Lugicum; 16 – Góry Sowie Unit; 17 – Swiebodzice Unit; 18 – Kłodzsko Unit; 19 – Bardsko Unit; 20 – Polička and Zábřeh units; 21– Hlinsko–Skuteč Unit; 22 – Ophiolites; 23 – Moravosilesicum; 24 – Lower Carboniferous flysch; 25 – Brunovistulicum; 26 – Serpuchov and the Upper Carboniferous in the Brunovistulicum Foreland. **Western Carpathians**: 27 – Carpathian Foredeep; 28 –Intramountaneous basins; 29 – Outer Group of flysh nappes; 30 – Magura Group of flysh nappes; 31 – Klippen belt; 32 – Volcanics of the inner Carpathians.

The area affected by compressional evolution of Hercynian Orogeny associated with the Moldanubian thrust was in the latest Carboniferous (Gzhelian) changed by gravitational collapse. **Extensional stage** was manifested by origin of linear, tectonically based intramontane depressions with continental sediments (Jaroš – Malý 2001; McCann et al. 2006). A local representative of such basins (#5) is an asymmetric trough of the Boskovice Basin (named “Boskovice Furrow” in the past). The basin was filled by the Upper Carboniferous to Lower Permian shale, arkose, and conglomerate, which documents synkinematic filling of the basin. At its eastern edge, the basin is delimited by the Marginal Fault accompanied by brittle–ductile shear zone indicating dextral strike-slip to normal sense of movement. Such mylonite zone could be found in the nearby part of the Lugodanubian Block (Přibyslav Mylonite Zone and others).

## The Brno Massif

P. Hanžl, V. Janoušek, K. Hrdličková, R. Melichar

The Brno Massif as a part Brunovistulicum represents complex of predominantly magmatic rocks of Precambrian age. The massif crops out between Boskovice in N, Miroslav in S and Brno in E (Fig. 2). It is delimited by the Marginal Fault of Boskovice Basin from W, by the Devonian–Carboniferous rocks of Moravian Karst from E and by the Neogene sediments of the Carpathian Foredeep from SW. A few tectonic sheets of the Devonian limestones and Carboniferous greywackes are scattered along the contact of the Brno Massif and Boskovice Basin. Some Devonian clastic rocks and limestones were tectonically incorporated directly into granitoids of the Brno Massif.

The Brno Massif is composed of three tectonic units: Western and Eastern granodiorite complexes separated by the Metabasite Zone (MBZ; Hanžl – Melichar 1997). The **Metabasite Zone** of Tonian age (Tab. 1) is the oldest part of the Brno Massif. The zone is the N–S oriented belt of bimodal volcanic rocks cropping out between Brno-Petrov in the south and Černá Hora in the north. Metabasalts to basaltic metaandesites predominate in the bimodal MBZ accompanied by subordinate layers and boudins of metarhyolites. Primary volcanic textures have been mostly obliterated by deformation and low-grade metamorphism. Therefore, massive metabasalts passing to greenschists dominate the MBZ and pillow lavas are only exceptionally preserved. Amygdaloidal metabasalts and metadolerites are more common. Metarhyolites occurring as layers and sheets, several meters up to c. ten meters thick, are texturally variable. They occur as massive lavas, breccias, banded lithic-crystal tuffs and ignimbrites. The geochemical signatures of rocks of the Metabasite Zone suggest a direct derivation from a mantle source in an extensional setting (Hanžl et al. 2019).

The two **granodiorite complexes** are formed by calc-alkaline, mostly metaluminous plutonic rocks which differ from each other in petrography, petrophysical properties, geochemistry, mineralization and occurrence of metamorphic wall-rocks (Hanžl – Melichar, 1997; Leichmann – Höck 2008 for review) and correspond with the Thaya Terrane in W and the Slavkov Terrane in E. The age of granodiorite complexes is nearly the same, *c*. 600 Ma (Tab. 1).

The **Western Granodiorite Complex (WGC)** contains a large amount of wall-rock blocks of paragneisses, migmatites, calc-silicate rocks and diorites, which represent Cadomian orogenic complex intruded by different types of granodiorite. An interesting peculiarity of the wall rocks is more-or-less continuous Cryogenian **Diorite Zone** (*c*. 650–670 Ma) in the easternmost part of WGC. Hornblende and biotite–hornblende (meta-)diorites to quartz diorites dominate the DZ. They contain irregular bodies of coarse-grained (meta-)gabbros and rare serpentinite bodies. The geochemistry of rocks corresponds to evolution in geochemically primitive magmatic arc. The zone is intruded by Jundrov tonalite of nearly the same age (Hanžl et al. 2019).

Parallel position and basic composition of the Metabasite and the Diorite zones led authors to assume a genetic connection of these units to the Central Basic Belt (Zapletal 1928) or assigning them to a special ophiolite complex (Jaroš – Mísař 1976; Leichmann – Höck 2008). Tectonic setting and contacts enabled definition of the Metabasite Zone as a separated unit (Hanžl – Melichar 1997). This idea was recently proven by radiometric dating (Hanžl et al. 2019).

Based on all the available data, three successive tectono-magmatic stages have been identified in the Brno Massif in the Neoproterozoic times (c. 730–600 Ma), as products of a single long-lived, multi-stage subduction system (Soejono et al. 2017; Hanžl et al. 2019). The time of juxtaposition of individual units is unclear. Although exceptional granophyric microgranite forming a narrow body exposed along the contact of the Metabasite and the Diorite zones north of Brno (Hanžl – Hrdličková 2011) may indicate an early rendezvous, the Hercynian influence on tectonics of the Brno Massif is documented by tectonic slices of Devonian rocks incorporated to the interior of the massif.

Tab.1. Review of available radiometric dating from the Brno Massif

| **Method** | **Unit** | **Locality** | **Rock** | **Age (Ma)** | **Reference** |
|---|---|---|---|---|---|
| Ar–Ar (Amp) | EGC | Blansko | Diorite | 586 ± 0.5 | Fritz et al. (1996) |
| U–Pb LA-ICP-MS (Zrn) | EGC | Jehnice | Granodiorite | 595 ± 2 | Timmerman et al. (2018) |
| U–Pb LA-ICP-MS (Zrn) | EGC | Blansko | Tonalite | 597 ± 2 | Timmerman et al. (2018) |
| Conventional Zrn | WGC | Dolní Kounice | Quartz diorite | 601 ± 3 | Van Breemen et al. (1982) |
| U–Pb LA-ICP-MS (Zrn) | WGC | Anenský Mlýn | Quartz diorite | 601 ± 3 | Soejono et al. (2017) |
| Ar-Ar (Amp) | WGC | Anenský Mlýn | Quartz diorite | 596 ± 2 | Fritz et al. (1996) |
| U–Pb LA-ICP-MS (Zrn) | WGC | Jinačovice | Granite | 610 ± 4 | Timmerman et al. (2018) |
| WR–Grt Sm–Nd | WGC | Hlína | A-granite | 460 ± 6 | Leichmann et al. (2013) |
| U–Pb LA-ICP-MS (Zrn) | SM | Dolní Loučky | Metagranite | 634 ± 6 | Soejono et al. (2017) |
| Ar-Ar (Amp) | SM | Deblín | Metadiorite | 576 ± 2 | Fritz et al. (1996) |
| U–Pb LA-ICP-MS (Zrn) | DZ | Jundrov | Metadiorite | 655 ± 3 | Hanžl et al. (2019) |
| U–Pb LA-ICP-MS (Zrn) | DZ | Jundrov | Trondhjemite | 655 ± 4 | Hanžl et al. (2019) |
| U–Pb LA-ICP-MS (Zrn) | JT | Jundrov | Tonalite | 648 ± 5 | Hanžl et al. (2019) |
| Zrn evaporation | MBZ | Opálenka | Rhyolite | 725 ± 15 | Finger et al. (2000b) |
| U–Pb LA-ICP-MS (Zrn) | MBZ | Česká | Metarhyolite | 733 ± 5 | Hanžl et al. (2019) |
| U–Pb LA-ICP-MS (Zrn) | MBZ | Svinošice | Felsic metatuff | 726 ± 5 | Hanžl et al. (2019) |
| U–Pb LA-ICP-MS (Zrn) | MBZ | Sychrov | Felsic metatuff | 740 ± 4 | Timmerman et al. (2018) |
| U–Pb LA-ICP-MS (Zrn) | DY | Holedná | Rhyolite dyke | 594 ± 3 | Timmerman et al. (2018) |
| K–Ar | DY | Blansko | Porphyritic microdiorite | 309 | Šmejkal (1964) |
| K–Ar | DY | Lhota Rapotina | Porphyritic microdiorite | 324 | Šmejkal (1964) |

EGC – Eastern Granodiorite Complex, WGC – Western Granodiorite Complex, SM – Svratka Massif, DZ – Diorite Zone, JT – Jundrov tonalite, MBZ – Metabasite Zone, DY – dyke

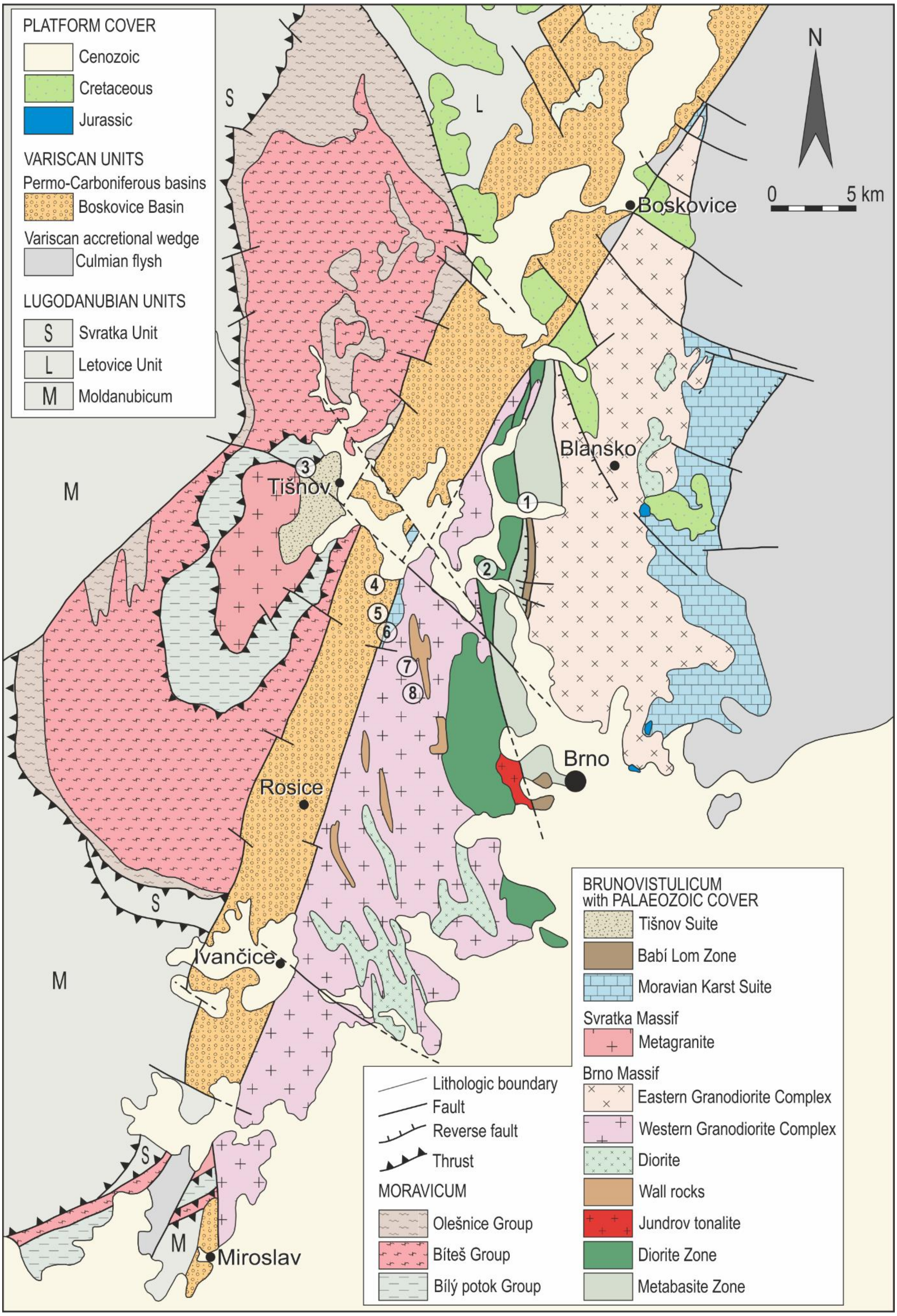


Fig. 2. Geological map of the Brno Massif and Svratka Dome with situation of first day localities.

## Moravo-Silesian Devonian to Lower Carboniferous sediments

T. Kumpan, R. Melichar, P. Špaček

The Devonian and Lower Carboniferous sedimentary rocks form the eastern part of the Rhenohercynian Zone were deposited on an eastern margin of Laurussia (Kalvoda et al. 2008). Besides the main outcrop areas, e.g. in Drahany Upland and Nízký Jeseník Mountains, small-scale tectonic fragments of these rocks occur in various positions between the Brno Massif and the Svratka Dome (Špaček et al. 2002; Leichmann et al. 2006), mostly along the Marginal Fault of the Boskovice Basin. Limestones dominate in these tectonic fragments, and are rarely accompanied by Lower Devonian clastics, and more frequently by greywackes, representing equivalent of the Lower Carboniferous Drahany Culm. Intensity of deformation differs for each fragment, but mylonitization often distinctively overprinted original fabric of the limestones. Despite the prevailing recrystallization, rare limestone relicts revealing primary fabrics occur.

The relatively best-preserved successions of Devonian and Lower Carboniferous rocks are in nappe relics situated along the western margin of the Brno Massif (Špaček et al. 2002). Several types of limestones were distinguished there, revealing affinity to limestones of the platform Moravian Karst, transitional Ludmírov and basinal Drahany facies domains of the Moravo-Silesian Palaeozoic (Chlupáč 1988; Kalvoda et al. 2008). Pale sparitic and micritic limestones yielded Middle to Upper Devonian (Eifelian–Frasnian) stromatoporoid and coral fauna, which enables correlation with the Macocha Formation of the Moravian Karst facies domain (e.g. Hladil 1979; Hladil – Lang 1985; Špaček 2001; Špaček et al. 2002). Darker micritic limestones with clayey intercalations yielded conodonts, foraminifers and corals of Late Devonian (Frasnian to Famennian) and Early Carboniferous (Tournaisian to Viséan) ages. These limestones are similar to carbonate turbiditic facies of the Moravian Karst (Vintoky Limestone, Hády-Říčka Limestone) or Ludmírov transitional facies domains (Jesenec Limestone; Bábek et al. 1995; Kalvoda et al. 1996; Špaček 2001; Špaček et al. 2002). The stratigraphically youngest unit of the Devonian–Carboniferous tectonic fragments of the western Brno Massif margin are greywackes with rare siltstones, which are equivalent to Lower Carboniferous syn-orogenic deposits of the Moravo-Silesian Palaeozoic (Špaček 2001).

Besides the Palaeozoic relics on the western Brno Massif margin, Devonian rocks are also exposed in the core of the Svratka Dome. Deformed Devonian limestones and clastics (sandstones and conglomerates) represent cover of the para-autochthonous Svratka Massif overthrusted by the Moravian nappes. Two sedimentary successions were distinguished from vicinity of Tišnov. The Závist succession is composed of 200 m thick conglomerates and quartzites at its base and by 100 m thick limestones and dolomites in its upper part. The Květnice succession has thinner basal clastic part (maximal thickness 100 m), which is overlain by 150 to 200 m of limestones and dolomites (Jaroš – Mísař 1976). A relatively rare stromatoporoid and coral fauna confirmed Devonian age of the limestones inferred previously from the tentative lithostratigraphic correlation with Moravian Karst limestones (Jaroš – Mísař 1968). However, the Devonian succession of the Svratka Dome differs from the Moravian Karst facies domain, and thus the Tišnov facies domain was established (Hladil 1992; Hladil et al. 1999).

## The Svratka Dome

K. Hrdličková, R. Melichar

The Svratka Dome is an excellent structure which allows us to see whole sequence of tectonic units in the Moravian Shear Zone. The lowermost part is formed by parautochthonous Brunovistulian rocks (here called the Svratka Massif) with the Devonian cover. The middle part named Moravicum consists of the Bílý potok Group ("*inner phyllites*" of Suess 1912), the Bíteš Group (mainly Cadomian orthogneisses) and the Olešnice Group ("*outer phyllites*" of Suess 1912). The upper part is represented by sheared Moldanubicum, Svratka and Letovice units.

**The Svratka Massif** is equivalent of Western Granodiorite Complex of the Brno Massif as shown by geochemical data (Hanžl et al. 2007b) and radiometric data (Tab. 2). Foliated medium-grained biotite metagranite is a dominating rock composed of altered feldspars, quartz and chloritized biotite. Epidotisation and carbonatization are common. Augen metagranites are exposed in the Loučka Valley and metadiorites NE of Deblín. Common aplite dykes were rotated to foliation well developed in metagranite. The Svratka Massif is imbricated with Devonian conglomerates and limestones. Devonian rocks are of Givetian–Frasnian age and belong to Tišnov development of Moravian-Silesian Palaeozoic in division of Hladil et al. (1999). They are represented by strongly deformed and slightly metamorphosed quartz conglomerates with sandstones and siltstone layers and limestones.

Tab. 2. Review of radiometric ages in Moravicum

| Method | Unit | Rock | Mineral | Age (Ma) | Reference |
|---|---|---|---|---|---|
| Rb–Sr | Bíteš Group (Thaya Dome) | Orthogneiss | WR | 796 ± 49 | Scharbert (1977) |
| Rb–Sr | Bíteš Group (Thaya Dome) | Orthogneiss | WR | 570 ± 44 | Morauf – Jäger (1982) |
| Rb–Sr | Bíteš Group (Thaya Dome) | Orthogneiss | WR | 480 ± 50 | Van Breemen et al. (1982) |
| Rb–Sr | Bíteš Group (Thaya Dome) | Orthogneiss | WR | 332 ± 17 | Morauf – Jäger (1982) |
| Rb–Sr | Bíteš Group (Thaya Dome) | Orthogneiss | Ms | 326 ± 7 | Morauf – Jäger (1982) |
| Rb –Sr | Bíteš Group (Thaya Dome) | Orthogneiss | Bt | 325 ± 7 | Morauf – Jäger (1982) |
| Ar–Ar | Bíteš Group (Thaya Dome) | Orthogneiss | Ms | 329 ± 1 | Dallmeyer et al. (1992) |
| Ar–Ar | Bíteš Group (Thaya Dome) | Orthogneiss | Ms | 329 ± 3 | Dallmeyer et al. (1992) |
| U–Pb | Bíteš Group (Thaya Dome) | Orthogneiss | Zrn | 586 ± 7 | Friedl et al. (2000) |
| U–Pb | Bíteš Group (Thaya Dome) | Orthogneiss | Zrn | 578 ± 7 | Friedl et al. (2000) |
| U–Pb | Bíteš Group (Svratka Dome) | Orthogneiss | Zrn | 568 ± 3 | Soejono et al. (2017) |
| Ar–Ar | Bíteš Group (Thaya Dome) | Orthogneiss | Ms | 325.1 ± 1 | Fritz et al. (1996) |
| Ar–Ar | Bíteš Group (Svratka Dome) | Orthogneiss | Ms | 326.6 ± 0.6 | Fritz et al. (1996) |
| U–Pb | Svratka Massif | Metagranite | Zrn | 634 ± 6 | Soejono et al. (2017) |
| Ar–Ar | Svratka Massif | Metadiorite | Amp | 575.6 ± 0.9 | Fritz et al. (1996) |
| Ar–Ar | Svratka Massif | Pegmatite | Ms | 565.3 ± 0.8 | Fritz et al. (1996) |
| Ar–Ar | Deblín Group | Amphibolite | Amp | 535 ± 0.9 | Fritz et al. (1996) |
| Ar–Ar | Outer Phyllites | Schist | Ms | 330.4 ± 0.5 | Fritz et al. (1996) |

The Moravicum is a Variscan geological unit set tectonically between Lugodanubicum in the hanging wall and Brunovistulicum with its cover in the footwall. Lower tectonic boundary was named by Jaroš – Mísař (1976) as Dřínová Fault, while the upper boundary is well-known Moldanubian thrust (Suess 1912), which was in west subsequently modified by younger Bíteš and Svojanov normal faults. The Moravicum was affected by the Hercynian Barrovian-type metamorphism (Höck 1995; Štípská – Schulmann 1995; Štípská et al. 2015), whereby the metamorphic inversion was caused by imbrication of crustal nappes (Suess 1912; Štípská – Schulmann 1995). The Bílý potok Group as tectonically lowermost part of Moravicum is dominantly composed of chlorite–sericite (± biotite), locally graphitic phyllite containing layers of greenschists, quartzite and limestones. The Bíteš Group forming sheet in hanging wall of Bílý potok Group is composed by lithologically monotonous, but texturally variable augen muscovite ± biotite orthogneiss. The Bíteš orthogneiss represents Late Proterozoic (Tab. 2) felsic peraluminous granites (Soejono et al. 2017) strongly reworked during the Hercynian Orogeny. In upper part, layers (sills) of amphibolite of within-plate setting geochemistry are common (Wilímský 2001). The uppermost part of Moravicum, the Olešnice Group is composed of micaschist and biotite gneiss metamorphosed under amphibolite-facies conditions. Marbles and strained gabbros are characteristic.

## Moldanubicum

K. Hrdličková, V. Janoušek, R. Melichar, V. Kusbach, P. Hanžl

Moldanubicum was defined by Suess (1903) as a unit of highly metamorphosed ("catazonal") rocks penetrated by a number of younger granitic intrusions in the area between Vltava ("Moldau") and Danube rivers. It was in contrast to the Moravian units with lower degree of metamorphism manifested by the muscovite presence.

Originally, the Moldanubicum was divided on the basis of lithology into Monotonous and Varied groups (Zoubek 1946, 1948). Later, the terms Ostrong, Drosendorf and Gföhl terranes were introduced (Fuchs 1976; Urban – Synek 1995). Currently Moldanubicum is subdivided into the **Drosendorf Assemblage** formed at middle crustal conditions, and the **Gföhl Assemblage** represented by the rocks exhumed from lower crustal levels (Franke 2000; Schulmann et al. 2008, 2009).

In the W Moravia, the Drosendorf Assemblage is represented by biotite ± sillimanite paragneisses, variously migmatitized. At the contact with the Třebíč Pluton, they locally contain cordierite, and also numerous anatectic granite bodies, thickness of which only rarely exceeds first meters and that are usually concordant with relatively flat foliation in wall rocks. The Gföhl Assemblage is dominated by the eponymous orthogneisses, which are quartzofeldspathic rocks of variable textures due to a different grade of migmatitization (Hasalová et al. 2008). The Náměšť Granulite Massif consists mainly of felsic, HP–HT granulite with serpentinized spinel and garnet peridotites, garnet pyroxenites, eclogites and amphibolites. Kusbach et al. (2015) described Náměšť granulite as an isochemically metamorphosed Ordovician–Silurian felsic magmatite, equivalent to other granulites of the Gföhl Unit (Janoušek et al. 2004b). The mineral association studied by Urban (1992) shows the peak conditions of 750°C and 11–14 kbar, followed by retrogression at 400°C and 3–5 kbar. The U–Pb SHRIMP data on zircon constrain the crystallization ages of the granulite protolith at 395.2 ± 4.4 Ma, high-grade metamorphic ages at 337.2 ± 1.7 Ma (Kusbach et al. 2015).

Ultrabasic rocks have also been studied by number of authors. Medaris et al. (2005) considered Moldanubian peridotites to be fragments of the depleted mantle, chemically corresponding to abyssal peridotites. On the other hand, Kovács (2010) suggested a relation to orogenic lherzolites. Peak metamorphic conditions were determined to 1120–1356°C; 27–29 kbar by Medaris – Jelínek (2004). Nakamura et al. (2004) presented values of 1050–1150°C, 45–49 kbar from Nové Dvory eclogite. Geochronological data are sporadic, 343 ± 17 Ma, Sm–Nd garnet–whole-rock age of uplift and cooling of peridotite body near Nové Dvory was calculated by Medaris et al. (1995). Based on geochemistry and P–T conditions, the garnet peridotites with eclogites were interpreted as subcontinental lithospheric mantle fragments, while the spinel- to garnet-bearing harzburgites are thought to reflect suboceanic lithospheric and asthenospheric origin (Nakamura et al. 2004; Medaris et al. 2005; Naemura et al. 2011).

The protoliths of Moldanubian rocks have originated at the northern margin of the Gondwana mainly in Neoproterozoic to Early Palaeozoic times and the Moldanubicum was assembled and metamorphosed during Hercynian Orogeny due to the collision of peri-Gondwana microcontinents with Avalonia and Baltica (Gebauer et al. 1988; Kröner et al. 1988; Friedl et al. 2000; Schulman et al. 2009; Pertoldová et al. 2009, 2014; Košler et al. 2014, Tab. 3). Rare exceptions represent the Paleoproterozoic (~2.1 Ga) Světlík orthogneiss in southern Bohemia (Wendt et al. 1993) and Mesoproterozoic (~1.38 Ga) Dobra orthogneiss in Lower Austria (Gebauer a Friedl 1994; Friedl et al. 2004).

Tab. 3. An overview of published zircon ages of the SE part of Moldanubicum

| Method | Unit | Rock | Locality | Age (Ma) | Reference | Dated event |
|---|---|---|---|---|---|---|
| U–Pb SHRIMP | Drosendorf | Orthogneiss | Weitenbach, Dobra Lake | c. 600 | Gebauer and Friedl (1994) | Metamorphism or remelting of older source |
| U–Pb ID TIMS | Drosendorf | Orthogneiss | Weitenbach, Dobra Lake | 1.38 Ga | Friedl et al. (2004) | Original granite protolith ? |
| U–Pb SHRIMP | Drosendorf | Orthogneiss | 3,5 km W of Spitz | 614 ± 10 | Friedl et al. (2004) | Magmatic age of granodioritic precursor |
| U–Pb ID TIMS | Drosendorf | Orthogneiss | 3,5 km W of Spitz | 629; 721 | Friedl et al. (2004) | Inheritance ? |
| U–Pb LA-ICP-MS | Drosendorf | Skarn | Rešice | ~ 325 | Pertoldová et al. (2014) | Metamorphism |
| U–Pb SHRIMP | Gföhl | Gföhl gneiss | Dürnstein | 488 ± 6 | Friedl et al. (2004) | Protolith crystallization |
| U–Pb ID TIMS | Gföhl | Gföhl gneiss | Dürnstein | 480–600 | Friedl et al. (2004) | Protolith crystallization |
| U–Pb SHRIMP | Gföhl | Gföhl gneiss | Dürnstein | c. 430 | Friedl et al. (2004) | Metamorphic event ? |
| Pb–Pb evaporation | Gföhl | Gföhl gneiss | Biskupice | 550.6 ± 1 | Schulmann et al. (2005) | Granitic precursor emplacement |
| Pb–Pb evaporation | Gföhl | Gföhl gneiss | Rokytka Valley | 394 ± 6 | Schulmann et al. (2005) | Protolith crystallization |
| U–Pb LA-ICP-MS | Gföhl | Migmatite gneiss | Raabs an der Thaya | ~ 340 | Košler et al. (2014) | Protolith crystallization |
| Pb–Pb evaporation | Gföhl | Migmatite gneiss | Loučka near Skryje | 353 ± 16 | Schulmann et al. (2005) | Partial melting |
| U–Pb SHRIMP | Gföhl | Granulite | 5 km SE of Krems | 2336 ± 23 | Friedl et al. (2004) | Inheritance |
| U–Pb SHRIMP | Gföhl | Granulite | 5 km SE of Krems | c. 450 | Friedl et al. (2004) | Original protolith forming event |
| U–Pb SHRIMP | Gföhl | Granulite | 5 km SE of Krems | 337.1 ± 2.7 | Friedl et al. (2011) | Metamorphism/ anatexis |
| U–Pb SHRIMP | Gföhl | Granulite | 5 km SE of Krems | 342.0 ± 3.0 | Friedl et al. (2011) | Metamorphism/ anatexis |
| Pb–Pb evaporation | Gföhl | Granulite | Loučka | 387 ± 14 | Schulmann et al. (2005) | Protolith crystallization |
| U–Pb SHRIMP | Gföhl | Granulite | Náměšť Massif | 470.1 ± 9.9 | Kusbach et al. (2015) | Protolith crystallization? |
| U–Pb SHRIMP | Gföhl | Granulite | Náměšť Massif | 395.2 ± 4.4 | Kusbach et al. (2015) | Protolith crystallization |
| U–Pb SHRIMP | Gföhl | Granulite | Náměšť Massif | 337.2 ± 1.7 | Kusbach et al. (2015) | HP–HT metamorphism |
| U–Pb SHRIMP | Gföhl | Granulite | Strážek Massif | 347 + 20/-9 | Kröner et al. (1988) | ? |
| Pb–Pb evaporation | Gföhl | Granulite | Strážek Massif | 340 ± 1 | Schulmann et al. (2005) | HP–HT metamorphism |

The Hercynian processes of the Moldanubian assemblage were associated with the HP–HT metamorphism at lower crustal conditions (~800–1000°C; 16–20 kbar: e.g. Štípská and Powell 2005; Racek et al. 2006; Tajčmanová et al. 2006). The HP–HT event was followed by rapid exhumation associated with LP–HT retrograde metamorphism under amphibolite-facies conditions of 750–700°C and 9–4 kbar (Štípská and Powell 2005; Tajčmanová et al. 2006), extensive anatexis and ductile deformation.

Deformation and metamorphic processes accompanying the Hercynian Orogeny resulted in convergence of rock complexes from different crustal to upper mantle levels, their metamorphism and formation of coexisting rock associations (Schulmann et al. 2005, 2008; Lexa et al. 2011). High degree of metamorphism, together with the presence of mantle rocks in the Gföhl Assemblage and affinity of the HP–HT granulites to Saxothuringian orthogneisses, are interpreted as the result of exhumation of the thickened orogenic root associated with Late Devonian Andean-type subduction (Schulmann et al. 2009), passing to deep underplating and relamination of the Saxothuringian, mostly felsic metaigneous material (Schulmann et al. 2014).

## Třebíč pluton

V. Janoušek, K.Hrdličková

The Třebíč Pluton (Fig. 3) intruded the contact between the Drosendorf and Gföhl units of the Moldanubicum (Schulmann et al. 2005; ~335 Ma, Tab. 4). It has approximately a triangular shape in map and it is divided by the E–W trending Třebíč Fault following the Jihlava River Valley to the Southern and Northern blocks. The Třebíč Pluton is a flat shallow body reaching the depth of mere 2 km according to geophysical data (Rejl – Sedlák 1987; Leichmann et al. 2015). With an areal extent of *c*. 540 km$^2$ it is the largest durbachitic outcrop in the Bohemian Massif. Endocontacts of the Třebíč Pluton with its Moldanubian country rocks are of various character. North-eastern contact is generally discordant to the regional metamorphic fabric; western contact is relatively flat, concordant with structures in migmatites and SE contact is steep, generally concordant but often reworked by younger faults.

Rocks of the Třebíč Pluton are petrographically variable quartz melasyenites to melagranites, but all are (ultra-)potassic, being characterized by high MgO and $K_2O$ contents together with low CaO and $Na_2O$. High abundances of LILE (Rb, Cs, Ba, K, Th and U), high radioactivity and Sr–Nd–Pb–Li isotopic signatures indicate crustal affinity of the melt. On the other hand, higher contents of Mg, Cr and Ni prove its mantle derivation (Holub 1997; Janoušek a Holub 2007; Janoušek et al. 2010a). During the Hercynian Orogeny, the originally depleted (harzburgitic) lithospheric mantle has been enriched and contaminated (Holub 1997; Becker et al. 1999; Janoušek a Holub 2007; Krmíček et al. 2016), most likely by fluids/melts derived from deeply subducted felsic metaigneous crust of the Saxothuringian provenance (Janoušek et al. 2004b; Schulmann et al. 2014).

The visited southern part of the Třebíč Pluton is lithologically homogenous, composed of coarse-grained, conspicuously Kfs-phyric amphibole–biotite quartz melasyenites to melagranites, the former denominated as durbachites s.s. At the body margins locally occur even-grained, or only weakly porphyritic varieties accompanied by aplitic granites of an anatectic character.

Numerous dykes of aplite, biotite granite to leucogranite and tourmalinic granite appear within the main durbachite body.

Two main magmatic fabrics are preserved in the Třebíč Pluton, one of them relatively steep, generally N–S trending, supposed to be relatively older (Lexa et al. 2007). Younger foliations, shallow-dipping generally to NE up to SE, were often influenced by younger metamorphic/ deformational fabric of similar orientation. The youngest structures are represented by localized brittle–ductile zones of S–N to NW–SE strike.

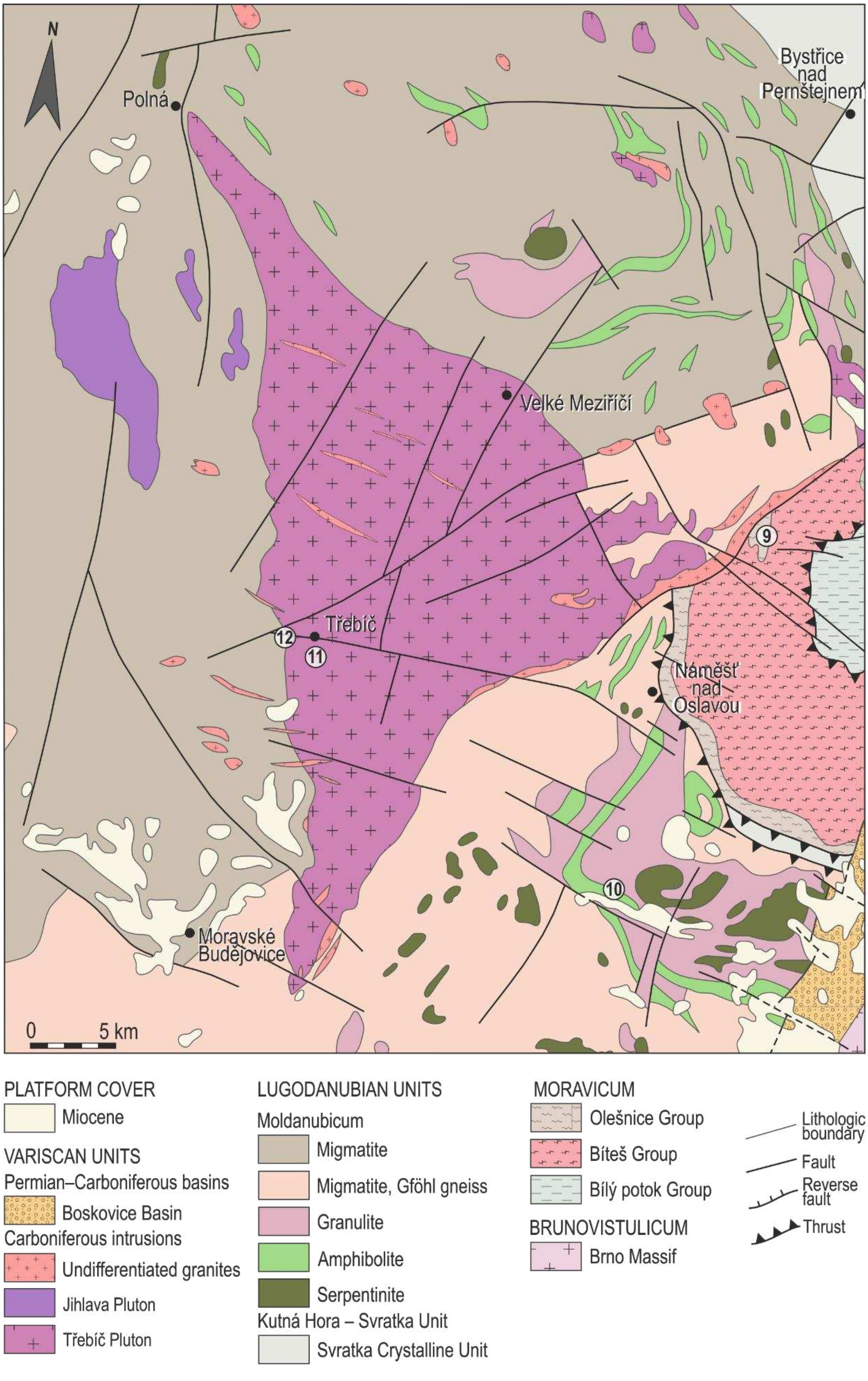


Fig. 3. Geological map of the Třebíč Pluton and surrounding units with situation of second-day localities.

Tab. 4. An overview of published zircon ages from the Třebíč Pluton

| Method | Rock | Locality | Age (Ma) | Reference |
|---|---|---|---|---|
| Pb–Pb evaporation | Quartz melasyenite | Chlumek | 340 ± 8 Ma | Holub et al. (1997) |
| U–Pb ID TIMS | Quartz melasyenite | Road cut E of Třebíč | 338 Ma | Kotková et al. (2003) |
| U–Pb ID TIMS | Quartz melasyenite | Road cut E of Třebíč | 332 Ma | Kotková et al. (2003) |
| U–Pb ID TIMS | Quartz melasyenite | Road cut E of Třebíč | 1.42 Ga (inheritance) | Kotková et al. (2003) |
| U–Th–Pb CHIME | Quartz melasyenite | Road cut NE of Velké Meziříčí | 347.8 ± 18.3 Ma | Kusiak et al. (2010) |
| U–Pb SHRIMP | Quartz melasyenite | Road cut NE of Velké Meziříčí | 341.6 ± 2.8 Ma | Kusiak et al. (2010) |
| U–Pb ID TIMS | Quartz melasyenite | Road cut E of Třebíč | 334.8 ± 3.2 Ma | Kotková et al. (2010) |
| U–Pb ID TIMS | Mafic enclave | Kožichovice | 341 ± 5 Ma | Kotková et al. (2010) |

## Boskovice Basin

H. Gilíková, K. Hrdličková, R. Melichar, P. Hanžl

The Boskovice Basin is a narrow, NNE–SSE trending asymmetrical basin between Miroslav in the S and Moravská Třebová in the N. It is approximately 100 km long and 3 to 10 km wide, filled with Carboniferous–Permian deposits. In the east, the basin is separated by dextral strike-slip structure of the Marginal Fault from the Brno Massif and Moravo-Silesian Palaeozoic rocks (Čepek 1946; Melichar 1995). Western, primarily transgressive contact of the Boskovice Basin with metamorphic complexes of eastern Bohemian Massif was tectonically modified by system of small normal faults (Jaroš 1961; Jaroš – Malý 2001). The bedding is generally gently dipping to the E and SE (Malý 1999). The total thickness of the sedimentary infill is assumed to reach 5000–6000 m, the geophysical profiles across the Boskovice Basin show the thickness of *c*. 3000 m (Štelcl et al. 1985; Jaroš – Malý 2001).

Sedimentation in the Boskovice Basin started in the Upper Carboniferous in the tropical humid paleoclimate, alternating episodically with dry climate periods and subsequently continued to the Permian with substantially dry and warm climate (Šimůnek – Martínek 2009). The Gzhelian deposition in the southern part of the Boskovice Basin (Rosice–Oslavany area) spread towards the S (Moravský Krumlov area) and towards the N and NE (Kalvoda et al. 2008).

Facially monotonous, poorly sorted **Rokytná conglomerates** sedimented at the eastern part, whereas heterogeneous **Balinka conglomerates** with well-rounded pebbles were deposited at the western slope of the Boskovice Basin. Both are interpreted as a product of alluvial deposition of Gzhelian to Asselian age (Jaroš 1961; Houzar et al. 2017). Together with the alluvial deposition from the marginal parts of basin the cyclic fluvial and fluvio-lacustrine sedimentation in the central (axial?) part was generated.

Sedimentary infill of the basin was divided into four formations which are, from the oldest to the youngest: Rosice–Oslavany Fm.; Padochov Fm.; Veverská Bítýška Fm. and Letovice Fm. (Fig. 4).

**Rosice–Oslavany Formation** is represented by cyclic sequence of siltstones, sandstones and shales of predominantly green colour. It contains three coal seams exploited from 1760 to 1992. Nehyba – Mastalerz (1997) described it as deposits of anastomosing fluvial system with channel and overbank sediments, swamp and lacustrine sediments (nearshore and delta plain sediments, swamp-lacustrine coal mudstone facies). Carboniferous–Permian boundary is placed at the roof of the Helmhacker Horizon between the Rosice–Oslavany and Padochov formations (Šimůnek 2003). Volcaniclastic rocks from the uppermost part of Rosice–Oslavany Fm. has been dated using U–Pb zircon method to 298.88 ± 0.09 Ma (Opluštil et al. 2017).

**Padochov, Veverská Bítýška** and **Letovice formations** of Asselian age are formed by complexes of arkoses, sandstones, siltstones and mudstones with layers of pelocarbonates – bituminous shales of fluvial, flood plain and lacustrine deposits. Pelocarbonates contain important plant fossils and, less frequently, fishes, amphibians and insects (e.g. Jaroš – Malý 2001; Šimůnek – Martínek 2009; Štamberg – Zajíc 2008).

Lately, during the compression stage of Hercynian Orogeny, the Brno Massif, locally together with its Devonian and Lower Carboniferous cover, was thrusted over the eastern edge of the Boskovice Basin. The sedimentary infill of the Boskovice Basin was deformed and thrust-related duplexes and folds developed in interior parts of the basin (Melichar 1995; Havíř 1997).

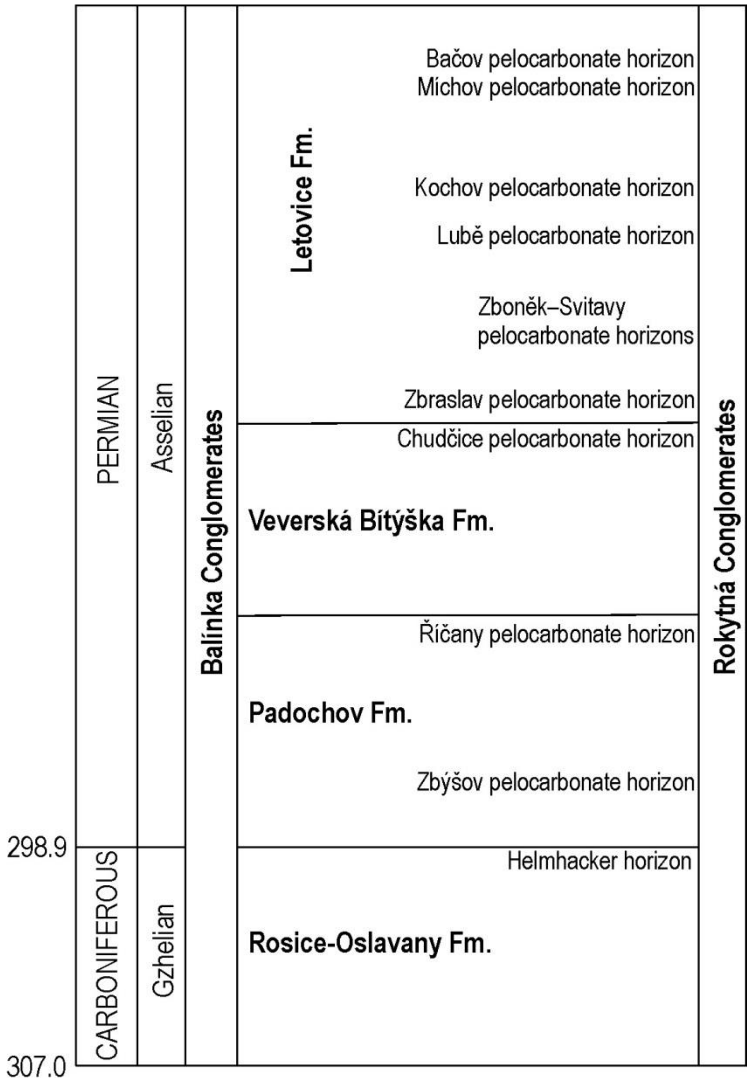


Fig. 4. Schematic lithostratigraphy of the Boskovice basin, simplified according to Štamberg – Zajíc (2008).

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# 1. SVINOŠICE, BIMODAL EXTENSIONAL VOLCANISM, METABASITE ZONE OF THE BRNO MASSIF

**P. Hanžl, V. Janoušek, R. Melichar, L. Mareček**

49.33510° N, 16.57286° E; small disused quarry behind municipal office

The rocks exposed in this quarry represent the Metabasite Zone (MBZ) of the Brno Massif which is up to two km wide N–S trending belt between the Eastern Granodiorite Complex and the Diorite Zone. On this site, layer of foliated and slightly metamorphosed lithic–crystal tuffs and ignimbrites of Late Tonian age (Hanžl et al. 2019) dominate and alternate with a greenschist exposed in the northern wall.

**Metarhyolite** is predominantly fine-grained, foliated or banded and light grey to yellowish in colour. Its groundmass is fine-grained to aphanitic, partly recrystallized, with or without feldspar and quartz phenocrysts (Fig. 1-1). It is dominated by albite, quartz, K-feldspar and sericite, with minor chlorite and/or epidote. Some parts of matrix resemble devitrified and recrystallized glass. The light grey ignimbrites display well-developed foliation with markedly flattened fiamme set in fine-grained matrix as well as deformed and rotated chess-boarded albite porphyroblasts. Small rhyolite clasts and rare basalts xenoliths (Fig. 1-2) occur locally in very fine-grained recrystallized matrix.

**Metabasalts to greenschists** as characteristic rocks of the MBZ are foliated grey–green to dark grey, fine- to medium-grained rocks. The original mineral composition is completely replaced by a low-grade metamorphic assemblage of albite, chlorite and/or epidote accompanied by variable amounts of amphibole, quartz and calcite. In relics, amygdaloidal and ophitic basalts are scattered within the MBZ (Fig. 1-3 and 1-4).


Fig 1-1 Quartz phenocryst with features of magmatic corrosion, photomicrograph in PPL.

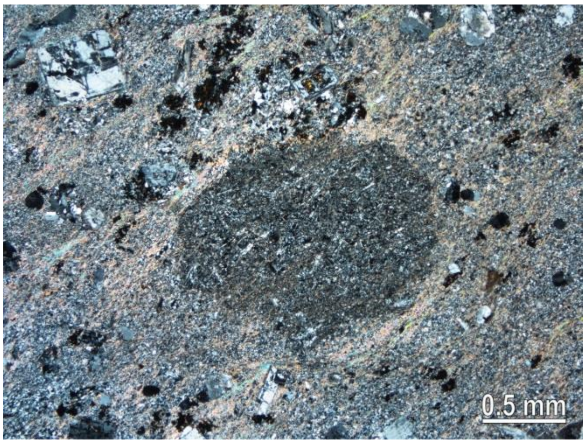


Fig. 1-2 Texture of rhyolite metatuff with chess board albite and oval basalt fragment, XPL.

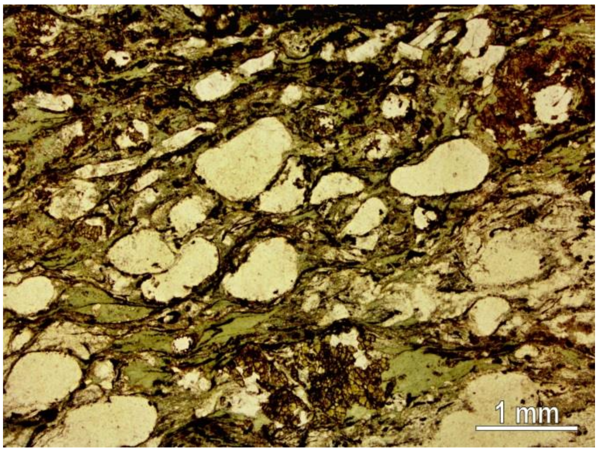


Fig. 1-3 Weakly deformed amygdaloidal metabasalts, photomicrograph in PPL.

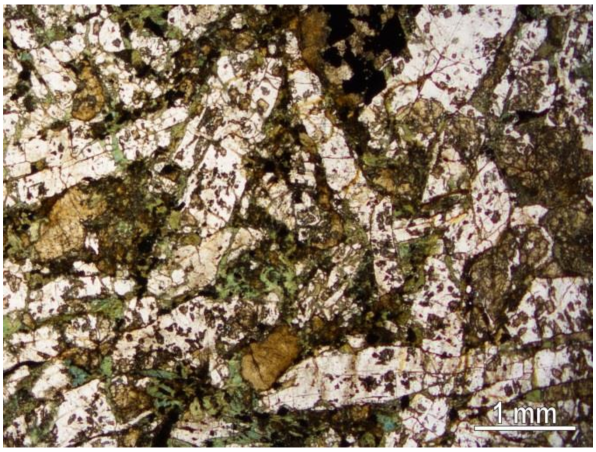


Fig. 1-4 Ophitic metabasalts, photomicrograph in PPL.

The zircon grains from lithic–crystal rhyolite metatuff show bimodal size distribution, but dating of the different size populations did not show any significant age differences. The CL imaging revealed that most of the crystals show well-developed magmatic oscillatory growth zoning with only slight alteration and unzoned homogenous cores. LA ICP-MS U–Pb dating of the zircons has given a concordia age of 726 ± 5 Ma (sample BM12-04, Hanžl et al. 2019). This magmatic age correlates well with Pb–Pb zircon evaporation data of Finger et al. (2000) from the Opálenka quarry (725 ± 15 Ma) and LA ICP-MS U–Pb dating of Timmerman et al. (2018) from the Sychrov Hill (740 ± 4 Ma).

Rhyolites of the Metabasite Zone are subalkaline (Fig. 1-5) with variable $K_2O$ (0.21–1.81 wt. %) probably reflecting the mobility of K during hydrous alteration and low-grade metamorphism. The total REE contents vary from 128 to 246 ppm and the chondrite-normalized patterns (Boynton, 1984; Fig. 1-6) are relatively flat and show pronounced negative Eu anomaly.

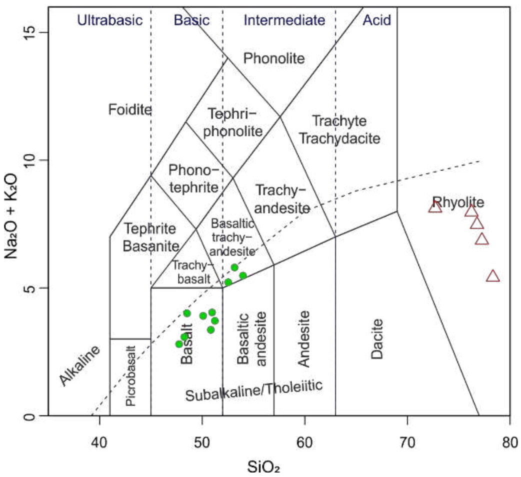


Fig. 1-5 Classification of volcanic rocks of MBZ in TAS diagram (Le Bas et al. 1986) with the alkaline/subalkaline boundary (dashed) of Irvine and Baragar (1971).

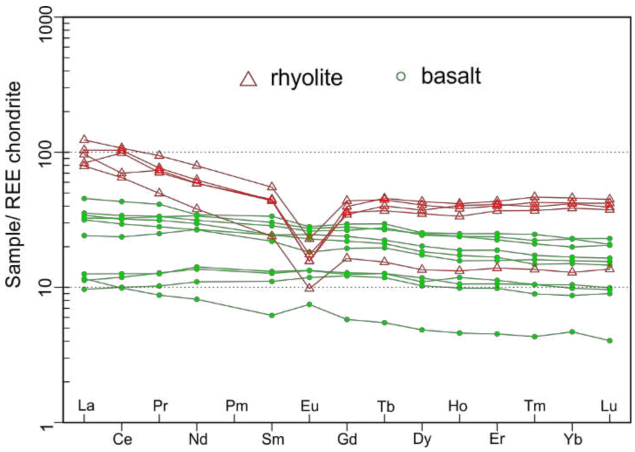


Fig. 1-6 Chondrite (Boynton 1984) normalized REE patterns for rocks of the MBZ.

In the mafic rocks from the MBZ, the $SiO_2$ ranges from 46.0 to 52.4 wt. % and individual samples can be classified as subalkaline basalt to basaltic (trachy-) andesite (Fig. 1-5) fitting a tholeiite series in the AFM plot by Irvine and Baragar (1971). Chondrite-normalized REE patterns divide the metabasalts into two distinct groups (Fig. 1-6). First one has flat trends with low total REE contents and slight depletion in LREE. The second group shows higher ΣREE and slightly fractionated trends.

Mafic metavolcanic rocks of the Metabasite Zone gave highly positive $\varepsilon_{Nd}^{725}$values of +7.8 to +6.9 ($T_{DM}^{Nd}$.2stg = 0.67 to 0.81 Ga). They therefore reflect most likely a direct derivation from a depleted mantle source. Two analysed metarhyolites from the Metabasite Zone yielded somewhat less positive $\varepsilon_{Nd}^{725}$ values of +6.0 and +5.7 ($T_{DM}^{Nd}$.2stg = 0.88 and 0.90 Ga).

The whole-rock geochemical character of the Metabasite Zone is compatible with a partial melting of lower crustal and relatively shallow (spinel stability field) upper mantle sources, probably triggered by heat contributed by rising asthenosphere, within an overall extensional setting. Geochemistry is in line with an idea of a back-arc basin (Hanžl and Melichar 1997; Finger et al. 2000). Besides that, another plausible scenario explaining the overall extensional setting and only weak subduction signal is a genesis within a (future) forearc region of an incipient subduction zone (Hanžl et al. 2019).

**Tectonics** of the rock in the quarry shows transition between two Hercynian deformational phases. Macroscopically eye-catching foliation in metarhyolite is steep NNE–SSW striking with dip to the WNW (Fig. 1-7). Associated stretching (aggregate) lineation is steeply plunging to the SW. Well-developed σ-type porphyroclast systems indicate normal faulting (Fig. 1-9). This deformation could be assigned to the late Hercynian extensional phase.

Similar orientation of foliation, e.g. subvertical N–S to NE–SW striking and dipping to W to NW, is typical of the older Hercynian deformation. The main difference is in associated lineation, which is usually subhorizontal. Microscopic asymmetric structures indicate sinistral strike-slip shearing. This older foliation is only poorly visible in the eastern part of the quarry; however it strongly dominates at other sites in the Metabasite Zone. Transitional reorientation of the old to new lineation could be seen in the AMS pattern (Fig. 1-8).

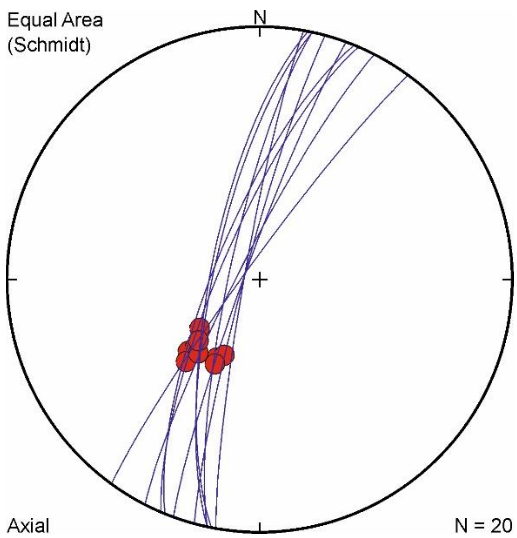


Fig. 1-7 Orientation of small-scale structures: foliation planes (great circles) and stretching lineation (dots).

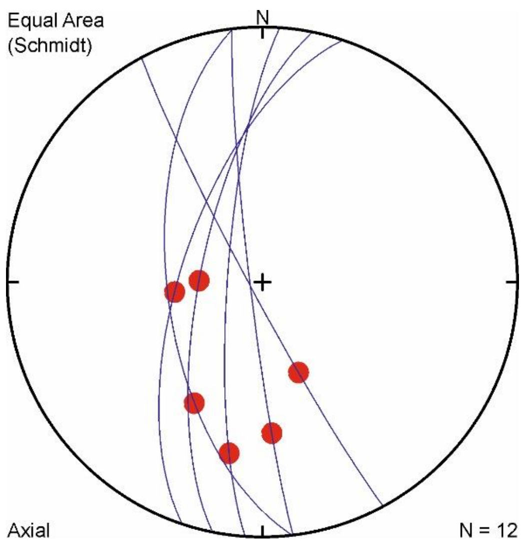


Fig. 1-8 Orientation of anisotropy of magnetic susceptibility (AMS): magnetic foliation (great circles) and magnetic lineation (dots).

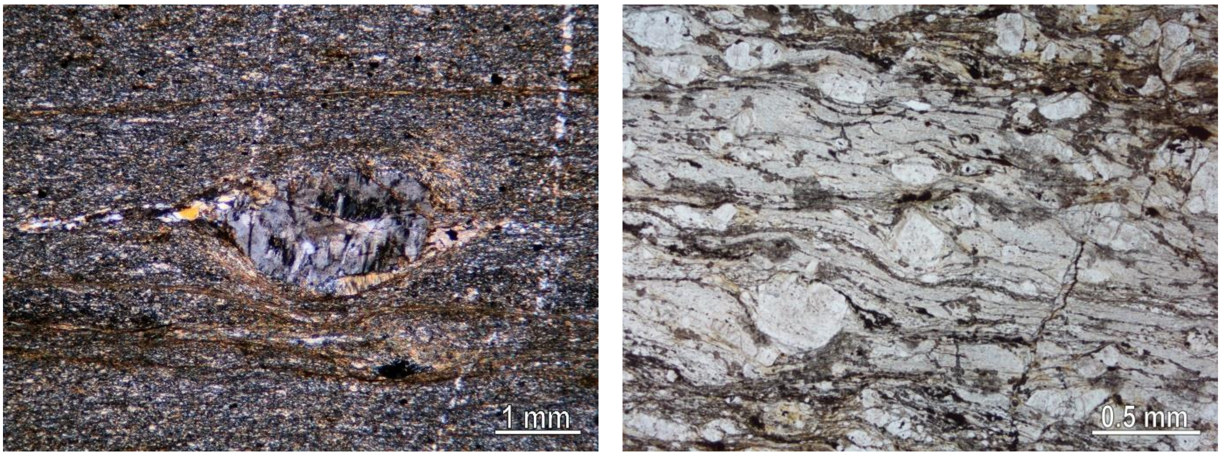


Fig 1-9 Feldspar forming σ-type porphyroclast system indicates normal shearing along originally steep westward dipping foliation. Photomicrographs in XPL (left) and PPL (right).

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# 2. KUŘIM, DIORITE ZONE OF THE BRNO MASSIF

**P. Hanžl, R. Melichar, V. Janoušek, K. Hrdličková, L. Mareček**

49.29881° N, 16.54857° E; abandoned quarry close to railway, east suburb

Locality represents the **Diorite Zone (DZ)** which is a plutonic part of the Central Basic Belt of the Brno Massif. The quarry enables to observe relationships among several types of rocks and alteration (Fig. 2-1). The most widespread rocks typical of the Diorite Zone are various types of diorites well documented in the Kuřim quarry. In places, the diorite varieties are cut by trondhjemite bodies which are represented here by dykes and boudins of several decimetres in thickness. All these Neoproterozoic rocks were metamorphosed and strained during Cadomian Orogeny and during polyphase compression in the Hercynian Orogeny that created foliation in diorite, chloritic mylonite zones and younger zones of epidotization. Subsequent, Late Hercynian extensional phase is manifested by intrusion of basaltic dykes (Fig. 2-1).

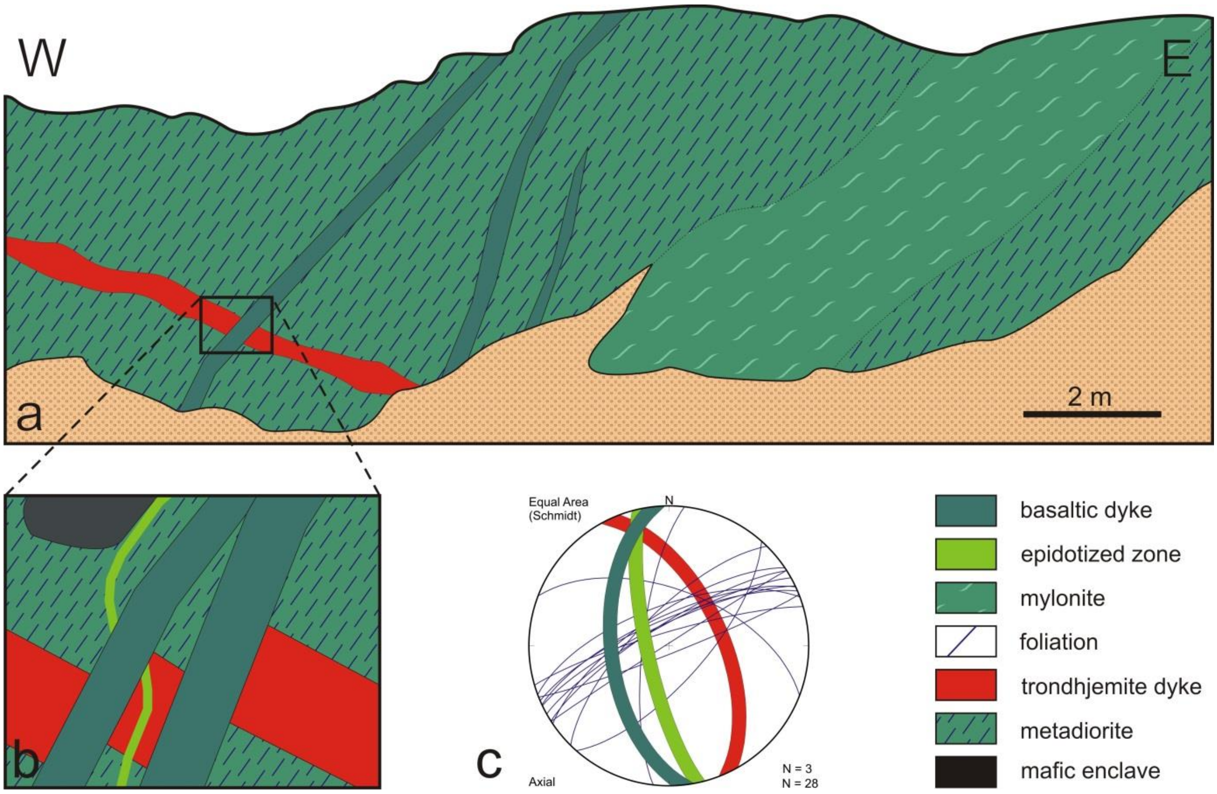


Fig. 2-1 Relationships among rock types and small-scale structures in the Kuřim quarry: (a) schematic drawing of the eastern half of quarry wall, (b) key part with cross-sections of dykes, (c) orientation of structural planes indicating relative ages.

**Biotite-amphibole (quartz) diorites** are dominating rocks exploited in the quarry, they are composed of plagioclase, amphibole, chlorite, altered biotite and epidote (Fig. 2-2). There is a great variation in modal composition and grain size among the samples. Fine-grained mafic enclaves are common (Fig. 2-3). Interstitial K-feldspar and/or quartz are sometimes found. Euhedral to subhedral plagioclases are heavily altered, making it difficult to identify their anorthite content. Primary calcic plagioclase is replaced by a mixture of zoisite, carbonate, prehnite, clay minerals and sodic plagioclase. Amphibole occurs as subhedral to euhedral crystals up to 1 cm long. They have usually a distinct zoning with actinolite to ferroactinolite cores and magnesiohornblende, tschermakite and pargasite rims. Strong epidotization is characteristic.

Medium- to coarse-grained, light grey **trondhjemite (leucotonalite)** forms dykes (Fig. 2-1) and boudins inside diorites. Plagioclase distinctively prevails in modal composition, it is zoned, with slightly more calcic cores composed by oligoclase ($An_{20–26}$); the rims have $An_{12–18}$. In cases, cores may be decomposed to an albite–sericite mixture. Quartz is undulose, ground, elongated to deformed ribbons. Samples include two chlorite generations. The earlier one, according to the appearance and textural characteristics, developed from the original biotite and was further decomposed to a quartz–epidote–muscovite mixture. Later chlorite accompanied by calcite is a product of hydrothermal processes. Original accessories are metamictized zircon and monazite, secondary is apatite grown from P-rich plagioclase and rutile in decomposed chlorite. Laser-ablation U–Pb zircon dating of metadiorite from Jundrov yielded a well-defined concordia magmatic age of 655 ± 3 Ma. Mean age of 655 ± 5 Ma is interpreted as magmatic formation age of the trondhjemite from the same locality (Hanžl et al. 2019).

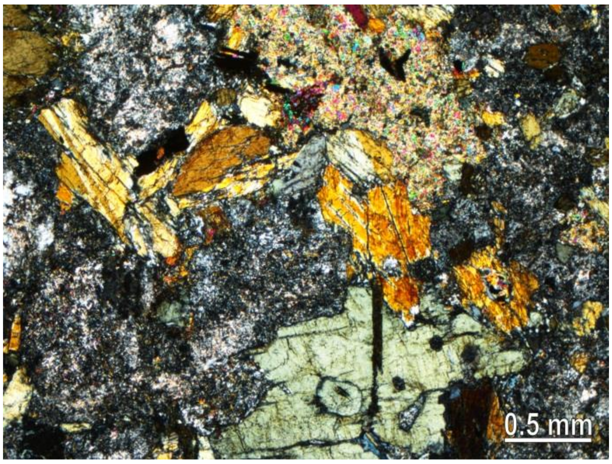


Fig. 2-2 Photomicrograph of altered biotite–hornblende diorite (XPL).

Fig. 2-3 Altered diorite with mafic enclave. Steep foliation, alteration and cataclasis effects are visible.

**Basaltic dykes** are characterized by fine-grained intersertal, often chloritized matrix formed by plagioclase laths and amphibole columns. Small phenocrysts of plagioclase and (exceptional) K-feldspar are rare (Fig. 2-4). Tiny amygdales are filled by carbonate or epidote. The dykes are calc-alkaline and trace-element contents indicate evolution in intra-plate extensional environment (Buriánek 2013).

**Foliation** in the quarry is developed to varying degrees: from hardly visible in metadiorite to well pronounced schistosity in the greenschist. Weak foliation dominant in the quarry strikes NE–SW and dips steeply to NW (Fig. 2-5). Marked schistosity with equivalent orientation is visible in the western edge of the quarry and beyond.

Geochemically the rocks from the Diorite Zone correspond almost exclusively to gabbros in the TAS diagram of Cox et al. (1979) with ultrabasic samples falling out of any fields. Based on the P–Q plot (Debon and Le Fort 1983, 1988) the rocks are quartz diorites–gabbros (Fig. 2-6).

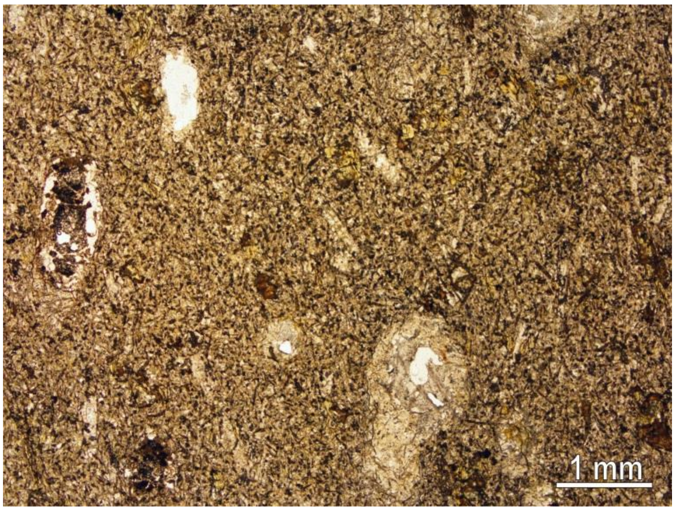


Fig. 2-4 Texture of basaltic dyke with tiny feldspar phenocrysts and amygdales. Photomicrograph in PPL.

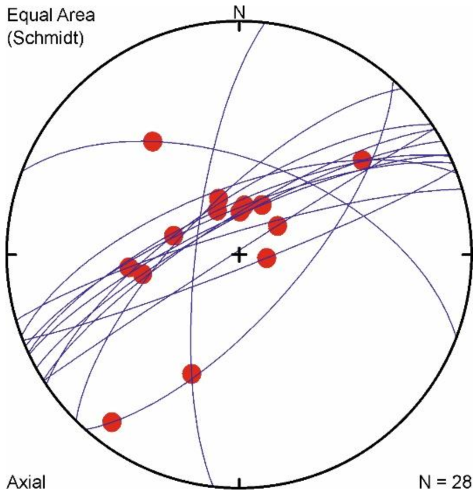


Fig. 2-5 Orientation of anisotropy of magnetic susceptibility (AMS): magnetic foliation (great circles) and magnetic lineation (dots).

The $SiO_2$ spans a range from ultrabasic to basic rocks (37.8 to 52.5 wt. %) that show a low- to normal-K calc-alkaline chemistry. For the samples least affected by the crystal accumulation and greenschist-facies overprint, NMORB-normalized spiderplots display patterns with a marked enrichment in Cs, Rb, Ba, K, Pb and Sr. All analyses are clearly depleted in Nb and Ta; some also in Zr and Hf (Hanžl et al. 2019). These LILE enrichments and negative anomalies for the HFSE are typical of arc-related magmas (Saunders et al. 1991; Pearce and Peate 1995; Tatsumi and Eggins 1995). Such a notion is also confirmed by geotectonic diagram of Pearce (2008; Fig. 2-7). The Diorite Zone is thought to have formed within a primitive magmatic arc during the Cryogenian (680–650 Ma: Hanžl et al. 2019).

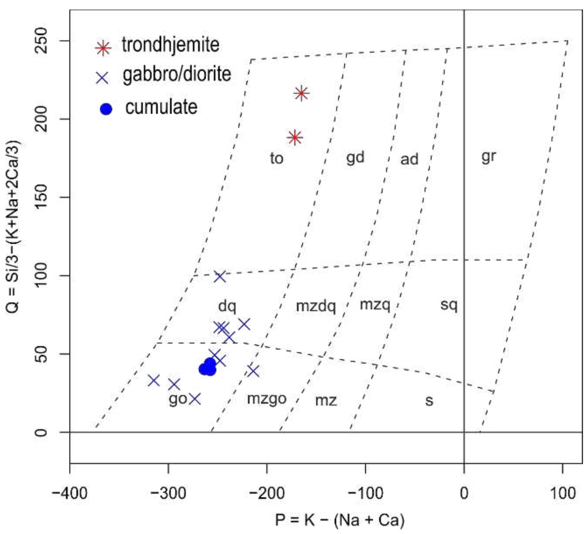


Fig. 2-6 Classification multicationic P–Q diagram of Debon and Le Fort (1983, 1988): gr = granite, ad = adamellite, gd = granodiorite, to = tonalite, sq = quartz syenite, mzq = quartz monzonite, mzdq = quartz monzodiorite, dq = quartz diorite, s = syenite, mz = monzonite, mzgo = monzogabbro, go = gabbro.

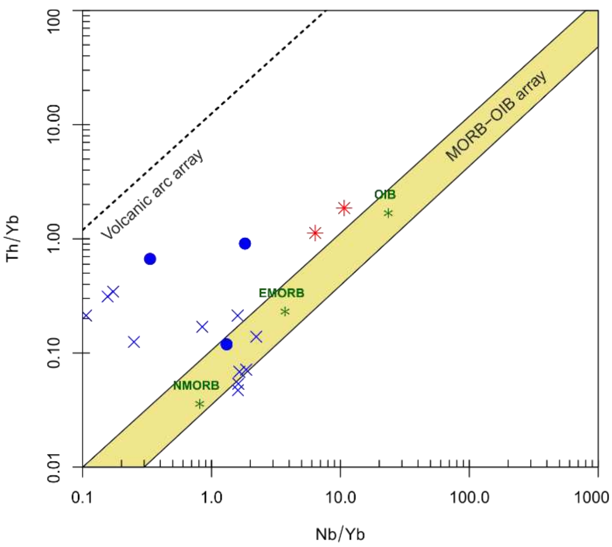


Fig. 2-7 Geotectonic discrimination diagrams for igneous rocks of the Diorite Zone. Nb/Yb vs. Th/Yb discrimination diagram of Pearce (2008). E- and N-MORB = Enriched and Normal Mid-Ocean Ridge Basalts; OIB = Oceanic Island Basalts.

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# 3. DŘÍNOVÁ HILL, THRUST TECTONICS MODIFIED BY SUBSEQUENT EXTENSIONAL FAULTING

**R. Melichar, D. Buriánek, T. Kumpan, K. Hrdličková, F. Bárta, M. Skoršepa**

49.36300° N, 16.40500° E; quarry on the southern slope of the Dřínová Hill, 3 km NW of the Tišnov

The Dřínová Hill was named after "dřín", which is Czech name for Cornelian cherry (*Cornus mas*), a shrub growing on arid calcareous soils. The quarry was originally opened for limestone mining, both the over- and the underlying non-lime rocks were exposed with the progress of the mining. Nowadays, the quarry is still active and produces different types of crushed stone, especially from the underlying granodiorite rocks.

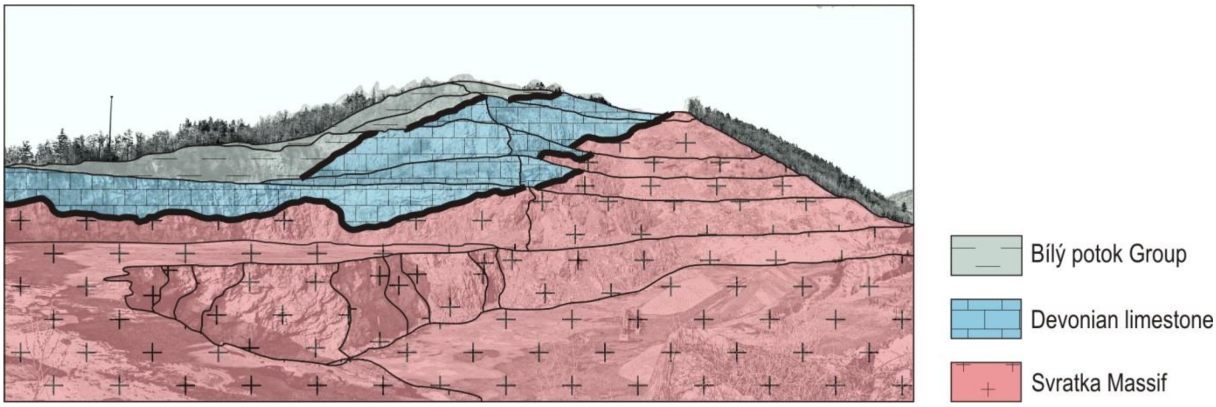


Fig. 3-1 Geological units exposed in the Dřínová quarry.

The quarry is situated in the central part of the Svratka Dome, where the lower part of sequence in the Moravian Shear Zone could be seen. Three units—three nappe sheets are lying here on top of each other: (1) the lowermost unit is the Svratka Massif, a sheared Brunovistulian basement; (2) the middle unit consists of the Devonian limestone (so called Tišnov development), and (3) the last, highest unit is a part of the Bílý potok Group, representning the lowermost member of the Moravicum (Fig. 3-1).

The Svratka Massif is exposed in the lower part of the quarry succession. Strongly mylonitized and hematized biotite metagranodiorite is typical rock of the massif (Fig. 3-2 and 3-3). Zircons from augen metagranite of the Svratka Massif were dated by LA ICP-MS to 634 ± 6 (Soejono et al. 2017); Ar-Ar data yieldes younger ages in the span of 575–535 Ma. Similarly as most of the Brunovistulian granitoids from Western Granitoid Area, these granitoids were formed during a major tectonothermal event at 596–610 Ma (van Breemen et al. 1982; Fritz et al. 1996; Soejono et al. 2017; Timmerman et al. 2018). Since the Devonian sedimentary rocks are incorporated into sheared Cadomian granitoids, the Svratka Massif cannot be autochthonous but at least parautochthonous.


Fig. 3-2 Sheared biotite granodiorite of the Svratka Massif.

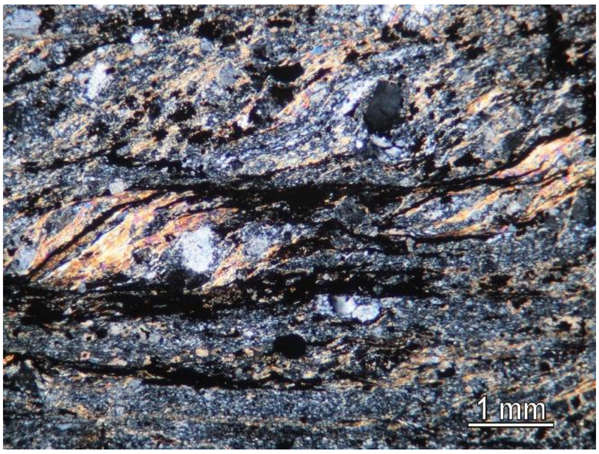


Fig. 3-3 Strongly sheared, recrystallized and haematized granodiorite with S-C structure.

Devonian sedimentary rocks are represented by different types of limestones which forms several tens metres thick layer. The Devonian basal clastics, so abundant elsewhere, are missing here, which is one of the evidence for tectonic detachment from the underlying unit. The Devonian limestone is pale to dark grey, sometimes reddish. Fine-grained texture and local lack of any fossils is a result of multi-phase shearing and recrystallization under very low-temperature conditions.

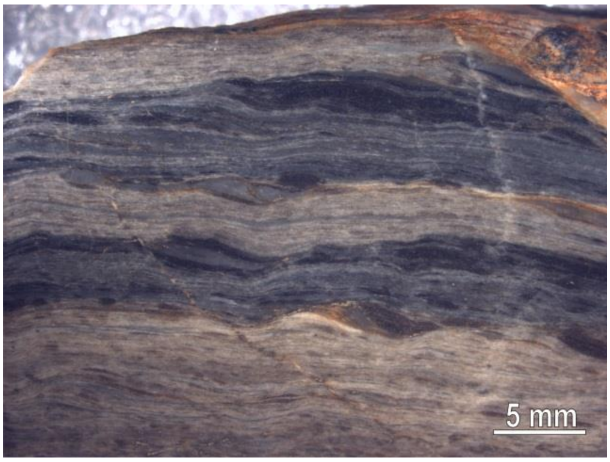


Fig. 3-4 Fine-rhythmic layering of sheared sandstone (pale), siltstone (grey) and pelite (dark grey).

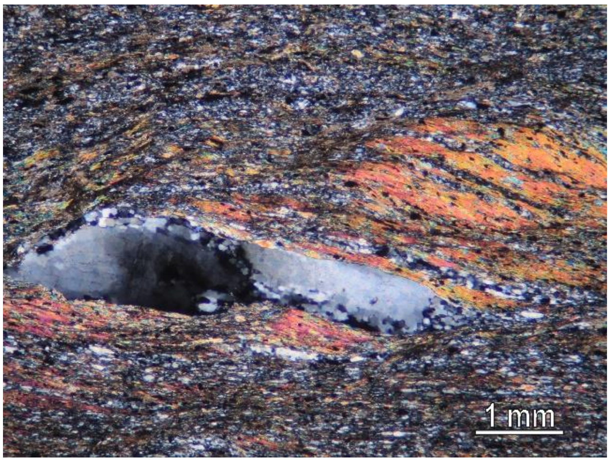


Fig. 3-5 Metapelite layer cut by stretched quartz vein (boudin).

The Bílý potok Group belonging to the Moravicum dominates in the western part of the quarry. This unit consists of different metasedimentary rocks with metavolcanic layers. The dominated rocks at the upper part of the quarry are metasandstones and metapelites with fine-rhythmic layering (Fig. 3-4). These rocks were metamorphosed to package of sericite and chlorite-sericite phyllites (Fig. 3-5). A layer of greenschist, about ten meters thick, is exposed in the uppermost quarry floor.

The Dřínová quarry is a type locality of so-called Dřínová overthrust (Jaroš – Mísař 1976), which is considered to be the main tectonic boundary between the allochthonous domain of the Variscan Orogen (Moravicum) and the Brunovistulicum with its sedimentary cover (Jaroš – Mísař 1976; Matte et al. 1990; Schulmann et al. 1991).

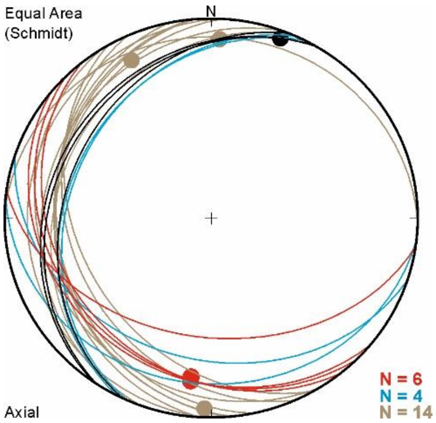


Fig. 3-6 Orientation of foliation (great circles) a lineation (dots): red – Svratka Massif; blue – Devonian limestone; brown – Bílý potok Group. Fault surfaces by black colour.

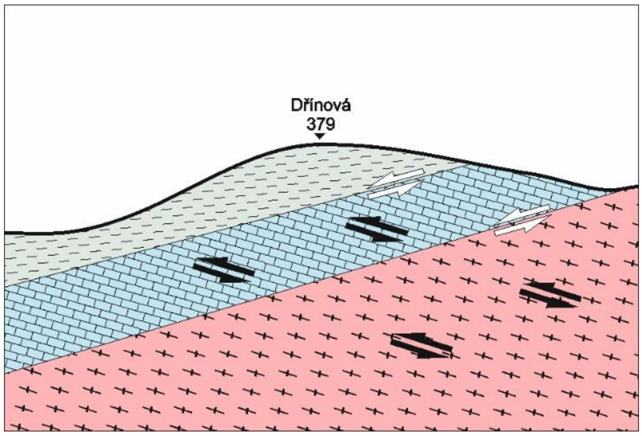


Fig. 3-7 Tectonic scheme of the Dřínová Hill with senses of movement. See Fig. 3-1 for colour explanation. Black arrow – thrust shearing, white arrows – Late-Hercynian extension.

Foliation planes in rocks of the Dřínová quarry are gently dipping and its dip direction varies from SW in the granodiorite and the Devonian limestone at the bottom to W–NW in the Devonian limestone and phyllite at the top of quarry (Fig. 3-6). Foliation dipping to SW is associated with the Variscan thrust tectonics (Moldanubian thrust). The age of cooling of the Moravian nappes equal to c. 330–325 Ma (Dallmeyer et al. 1992) is in good accordance with dating of compressional deformation of sediments in the Upper-Silesian Basin (Serpukhovian to Moscovian). West-dipping foliation is controlled by faults delimiting main units in the quarry. These structures might be connected to Late-Hercynian extension starting in Gzelian (Fig. 3-7). The Dřínová overthrust is thus an example of a thrust tectonics modified by subsequent extensional faulting. Character of fault cores indicates very young, probably Cenozoic reactivation of the faults.

This classic tectonic locality is also known as a mineralogical site. Late-Hercynian veining led to formation of relatively scarce dolomite vein (composed of Fe-dolomite and traces of sulphides) and especially abundant subvertical NW–SE trending up to 0.5 m thick hydrothermal veins with barite. Main constituents of the barite veins are white to pink coarse-grained barite, white to brown calcite (both forming often up to 10 cm large crystals in frequent drusy cavities, and locally also yellow fluorite, minor components are quartz, aragonite, goethite, hematite, malachite, and traces of sulphides (chalcopyrite, galena, pyrite; Dolníček – Buriánek 1997). Paleomagnetic dating of hematite-bearing samples showed an Upper Permian-Lower Triassic age for barite veins (Dolníček 2004). Fluid inclusion and stable isotope studies showed low fluid temperatures (<50°C to c. 120°C), variable salinities (0–24 wt. % NaCl eq.), low Cl/Br ratios (around 400; weight ratio), and low $\delta^{18}O$ values (−10 to +2 ‰ SMOW) of the parent Ca-Na-Cl aqueous fluids, whose origin is interpreted in terms of mixing of meteoric waters and basinal brines (Dolníček 2000, 2004). The youngest calcite-aragonite vein assemblage was formed during Cenozoic (as suggested from paleomagnetic data) under very low temperature conditions (<50°C; Dolníček 2004).

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# 4. VEVERSKÁ BÍTÝŠKA, VEVERSKÁ BÍTÝŠKA FORMATION IN BOSKOVICE BASIN

**H. Gilíková, K. Hrdličková, R. Melichar**

49.27847° N, 16.45221° E; outcrops and small abandoned quarries next to wastewater treatment plant, eastern periphery of the municipality

Chudčice pelocarbonate horizon, part of the Veverská Bítýška Fm. of the Asselian age, is exposed on small outcrops and in old quarries next to wastewater treatment plant on the left bank of the Svratka River east of Veverská Bítýška. It is represented by reddish grey and dark grey siltstones in the lower part of outcrop, passing into greenish grey micaceous siltstones deposited in the shallow lacustrine environment. Siltstones contain layers and lenses of light ochre silicified carbonaceous siltstones and concretions. Bedding is monoclinal, dipping to ESE under medial angles (Fig. 4-1), which corresponds well with the general structure of the whole middle and western parts of the Boskovice Basin. Slightly visible subhorizontal lineation trending NE–SW was formed during late Variscan compression.

Among the fragments and remnants of **plant fossils** (Fig. 4-2), Šimůnek and Martínek (2009) described four species of pteridosperms: *Neurodontopteris auriculata, Odontopteris subcrenulata, Odontopteris lingulata, Rhachiphyllum lyratifolia* (Goeppert) Kerp and eight species of conifers: *Culmitzschia angustifolia, Culmitzschia parvifolia, Culmitzschia speciosa, Ernestiodendron filiciforme, Otovicia hypnoides, Walchia goeppertiana* and *Walchia piniformis*.

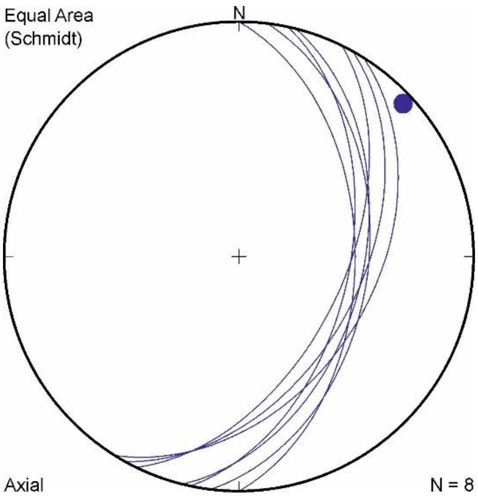


Fig. 4-1 Orientation of small-scale structures in siltstones: bedding (great circles), lineation (dot).

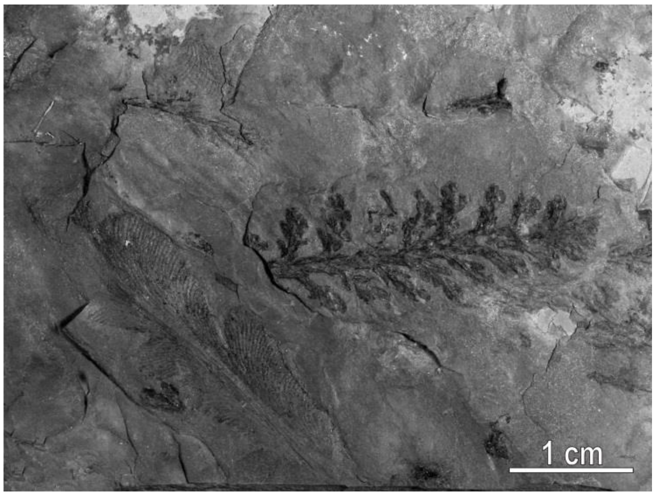


Fig. 4-2 Siltstone with fragments of *Rachyphyllum lyratifolia* and *Odontopteris lingulate*. Photo by Z. Šimůnek 2004.

Thin layers of volcaniclastic rocks are intercalated in lower part of the sequence exposed in the northern section of the defile. This rock is composed of quartz and feldspars set in the silicified matrix formed of quartz, feldspars and chlorite (Fig. 4-3). Isolated crystals of dolomite are relatively common. Volcaniclastic rocks have rhyolite/dacite composition (Fig. 4-4) in diagram by Pearce (1996). Even though the $K_2O$ contents are very low (0.13–0.43 wt. %, $Na_2O/K_2O$ ~ 17.5–65.5), rocks have alkaline affinity. Rhyolite layer from the uppermost part of Rosice–Oslavany Fm. was dated using the U–Pb method on zircon at 298.88 ± 0.09 Ma (Opluštil et al. 2017).

The sequence represents continental sediments deposited in a shallow lake in semi-humid climate.

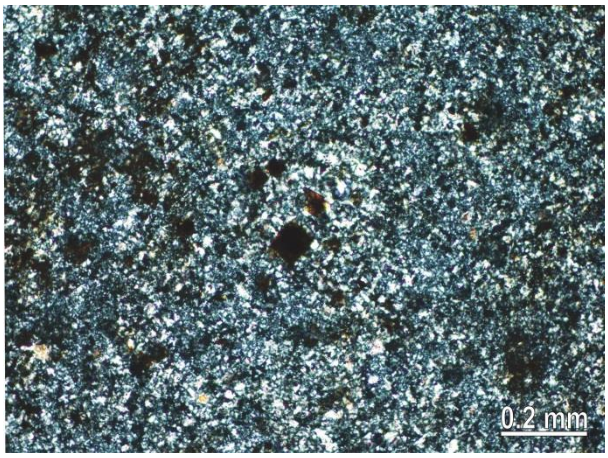


Fig. 4-3 Photomicrograph of a fine-grained silicified volcaniclastic rock of rhyolite/dacite composition.

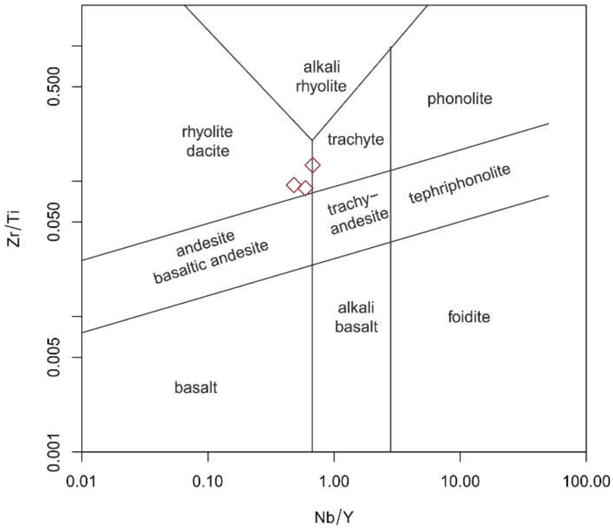


Fig. 4-4 Classification of volcaniclastic rocks of the Boskovice Basin in Nb/Y vs. Zr/Ti diagram of Pearce (1996).

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# 5. MEČKOV, ROKYTNÁ CONGLOMERATE IN BOSKOVICE BASIN, PERMIAN

**H. Gilíková, K. Hrdličková, R. Melichar, F. Bárta**

49.26771° N, 16.45288° E; series of large rock outcrops (The Mečkov Rock) at the right bank of the Svratka River

Rokytná conglomerates and breccias are grey to red, coarse- to very coarse-grained, clast-supported sediments (locally, the matrix-supported varieties may occur). They are poorly sorted with rounded to subangular pebbles, max. size of clast is about 50 cm (along the *a* axis). Conglomerates and breccias (Fig. 5-1) are facially monotonous, the material was derived from easterly situated geological units. Culmian rocks (greywackes, shales, conglomerates) dominate here (89–99 %), Devonian to Lower Carboniferous limestones (Špaček et al. 2002) are locally common (up to 6 %). Quartz, quartzite and magmatic rock clasts derived likely from the Brunovistulian units are variably distributed. They are exceptional at Mečkov, but could be relatively common (up 3 %) in other exposures of the Rokytná Conglomerate.

The bedding preserved in Rokytná Conglomerate close to the end of the Brno Lake is subvertical to steeply dipping to the W and NW (Fig. 5-2). Locally, due to thrusting of the Brno Massif over the sediments of the Boskovice Basin and associated transpression, the bedding is overturned and dips steeply to the E (118°/85°).

Rokytná Conglomerate was deposited along steep, tectonically active eastern edge of Brunovistulicum and its Palaeozoic cover (Fig. 5-3) in the Gzhelian to Asselian times. They were accumulated within alluvial fans (Jaroš 1961) as a product of episodic flood sedimentation (fan-conglomerates).

Fig. 5-1 Characteristic texture of Rokytná Conglomerate with a few limestone clasts and exceptional pebble of fine-grained granite.

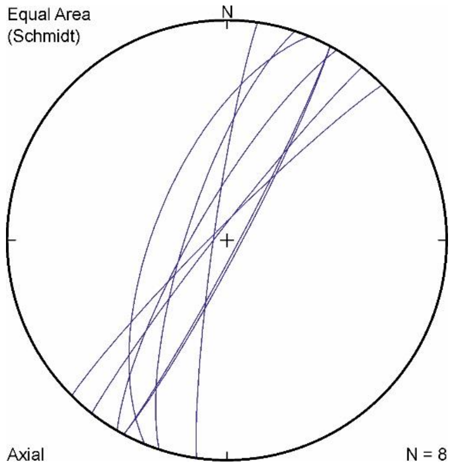


Fig. 5-2 Orientation of bedding in the Rokytná Conglomerate.

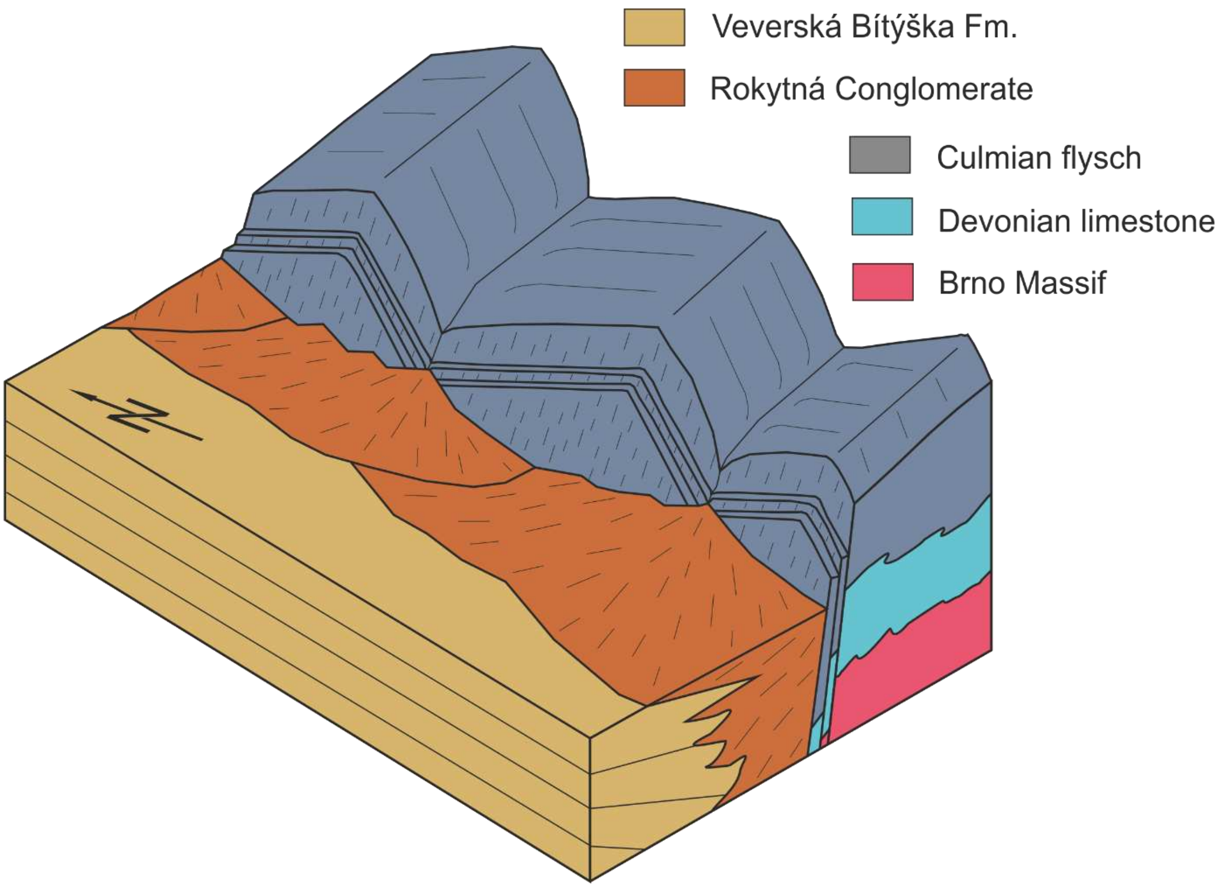


Fig. 5-3 The Rokytná Conglomerate originated along steep marginal fault of the Boskovice Basin with oblique dextral–normal sense of movement. Several branches of the marginal fault delimitate narrow fallen tectonic slices of the hanging-wall.

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# 6. NA SKALÁCH, DEVONIAN AND LOWER CARBONIFEROUS ROCKS OF THE MORAVO-SILEZIAN ZONE

**T. Kumpan, R. Melichar**

49.26350° N, 16.45729° E; outcrop on the left bank of the Svratka River

Cliffs on both banks of the Svratka River north of the Veveří Castle consist of Devonian and Lower Carboniferous rocks which are part of the Moravo-Silesian Zone. These rocks form nearly 9 km long and up to 900 m wide belt between Western Granodiorite Area of the Brno Massif in the east and the Rokytná Conglomerate of the Boskovice Basin in the west. The belt spans between the Čebínka Hill in the north and the Veveří Castle in the south, so this locality is situated at its southern tip.

The belt represents the largest relict of Devonian and Lower Carboniferous rocks preserved along the western rim of the Brno Massif and provides the most complete stratigraphic overview of considered Palaeozoic sequences that were described in detail by Špaček et al. (2002). Clastics belonging probably to the Basal Devonian Clastic Formation were documented in the northern part of the outcrop area. The major part of the sequence belongs to light coloured Givetian and Lower Frasnian limestones (Fig. 6-1) of platform facies with stromatoporoids (*Amphipora, Stachyodes, Trupetostroma),* corals *(Alveolites, Disphyllum, Scoliopora, Thamnopora, Thamnophyllum*) and brachiopods (*Stringocephalus*). The limestones are equivalent to the Vilémovice Limestone of the Macocha Formation of the Moravian Karst facies domain. The limestones are massive, cataclased, recrystallized and dolomitized (Fig. 6-2). The overlying darker micritic limestones (radiolarian lime mudstones, bioclastic packstones) with occasional shaly intercalations are exposed in the northern part of the outcrop area. This unit was interpreted as carbonate turbidites of Early Frasnian age based on rare conodonts (*Polygnathus cf. robustus, Polygnathus cf. dubius*).

Fig. 6-1 Pale grey Vilémovice limestone with preserved dendroid rugose corals and tabulate corals (*Disphyllum* sp., *Thamnophyllum* sp. a *Peneckiella*? sp., *Scoliopora denticulata* Hladil pers. com., 2008).

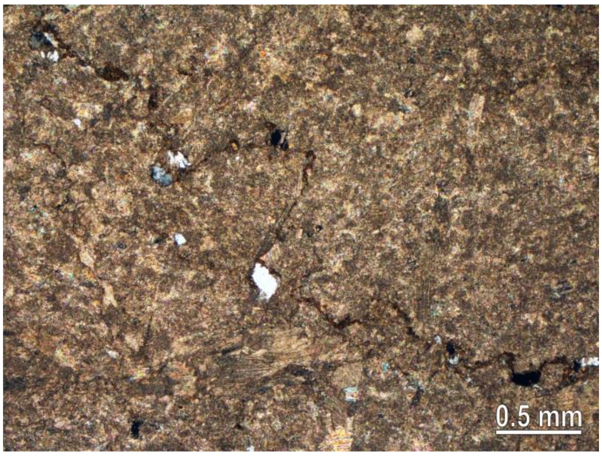


Fig. 6-2 Stylolite in recrystallized microsparite limestone. Photomicrograph in XPL.

The Lower Carboniferous greywackes and conglomerates are exposed west of limestones. Lithic medium- to coarse-grained greywacke contains angular fragments of quartzite, phyllite, shale and siltstone. The conglomerates include well rounded greywacke pebbles set in a greywacke matrix. These siliciclastic rocks represent equivalent of the Drahany Culmian flysch.

The Devonian and Lower Carboniferous sequences represent tectonic slices delimited by steep branches of the Marginal Fault of the Boskovice Basin. Brittle–ductile deformation along this fault indicates dextral strike-slip to normal sense of movement. The fault was active from the latest Carboniferous (Gzhelian) to Permian. Its activity was recorded by deposition of the Rokytná Conglomerates (locality 1-5 Mečkov) that document that the Brno Massif was more-or-less covered by Culmian flysh nappes at that time. Different degree of falling down of tectonic sheets thus kept the sequence from basement to cover now seen from east to west (see Fig. 5-3).

## Reference

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# 7. 'CYKLISTICKÁ' PORT, MYLONITE ZONES IN GRANITOIDS OF THE BRNO MASSIF

**R. Melichar, K. Hrdličková, P. Hanžl**

49.25801° N, 16.48129° E; road cut on the left bank of the Svratka River, Kůlny protected area

Down the Svratka river, ESE from the locality 6 'Na Skalách', the Svratka River forms several rectangular turns by using weakened tectonic zones. The 'Cyklistická' site provides a unique opportunity to observe these mylonite zones on the outcrop near the pier of the namesake boat stop. Here, the river valley is parallel to a younger WNW–ESE oriented fault accompanied by brittle-ductile mylonites to phyllonites locally developed. This mylonite zone cuts older N–S striking up to 100 m wide mylonite zone that the river follows during its next journey. The easternmost from these zones is observable at the stop 'Cyklistická' port.

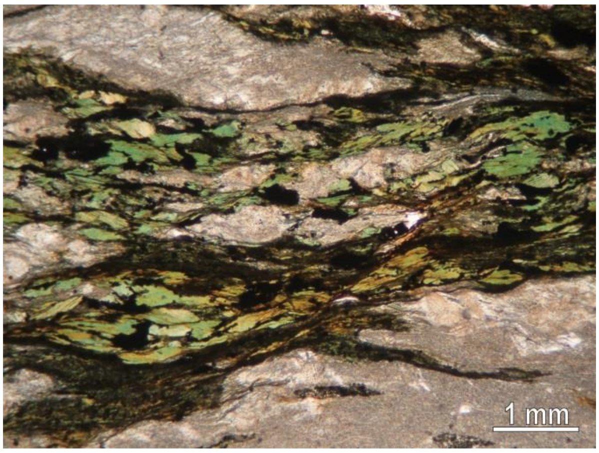


Fig. 7-1 Mylonitic texture of granodiorite with augen of quartz, fine-grained sericitized feldspars and chloritized biotite (PPL).


Fig. 7-2 Mylonitic texture of granodiorite with augen of quartz, fine-grained sericitized and kaolinized feldspars and chloritized biotite (XPL).

**Mylonite zones** are developed in biotite granodiorite of Western Granodiorite Area of the Brno Massif. Common biotite chloritization and feldspar sericitization allowed significant softening of the rock during deformation under conditions of greenschist facies (Fig. 7-1). Both chlorite and sericite define mylonitic foliation. Primary magmatic quartz grains were the most competent part of the rock during deformation. They usually keep their size and form σ-type porphyroclast systems (Fig. 7-2). In case of local brittle deformation they form book-shelf structures (Fig. 7-3). In addition to biotite granodiorite as the main parental rock, a red granite lenses and boudins can also be found. They probably represent dismembered younger dykes.


Fig 7-3 Partly hematized mylonite with synthetic book-shelf structure of large porphyroclast. Photomicrograph in PPL.

Fig. 7-4 Foliation in mylonite zone at the stop is steeply inclined to the E.

Steep **foliation** of the dominant mylonite zone strikes in N–S direction. Dip is changing from 50–90° E in the northern part of the zone (at the stop, Fig. 7-4) to 70–90° W (Fig. 7-5). Associated lineation and small fold axes are dominantly subhorizontal even though isolated steeper lineation may occur (Fig. 7-6). Almost identical orientation of the principal directions of orientation matrices for both surface and linear structures points to compatibility of these structures.

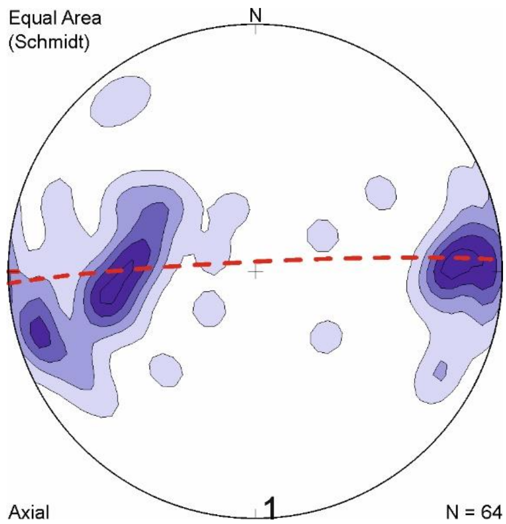


Fig. 7-5 Orientation of foliation in mylonite zone. Contour diagram of foliation poles, dashed line – $\pi$-circle, 1 – $\pi$-axis. Data by Jurníčková (2014).

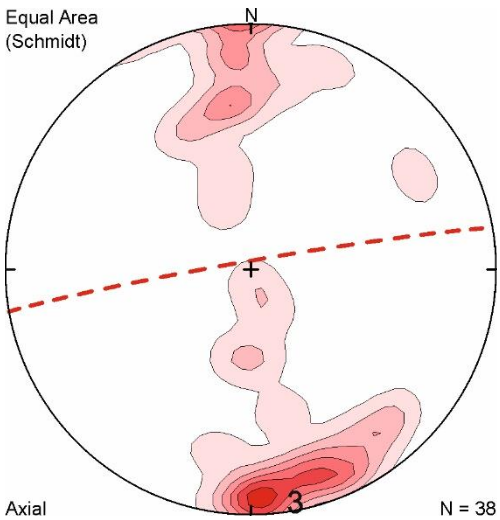


Fig. 7-6 Orientation of lineation in mylonite zone. Contour diagram, 3 – maximum principal axis and corresponding great circle (dashed). Data by Jurníčková (2014).

The massive granodiorites forming the main part of the Brno Massif were little-sensitive to deformations with small differential stress. In the mylonite zones and their surroundings, this sensitivity has been greatly increased, and so structures unseen therein, such as kink bands and folds have been preserved (Fig. 7-7, 7-8). Described mylonite zones are accompanied on Trnůvka Hill NE of the visited site by huge quartz dykes interpreted as Late Hercynian based on hydrothermal fluid study (Přichystal – Slobodník 2011).

Fig. 7-7 Kink-band developed in foliated mylonite zone.

Fig 7-8 Younger faults in mylonite zone.

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# 8. ROKLE, MAGMATIC AND WALL ROCKS OF THE WESTERN GRANODIORITE AREA, BRNO MASSIF

**K. Hrdličková, P. Hanžl, F. Bárta**

49.24939° N, 16.48798° E; canyon-like valley between 'Cyklistická' and 'Rokle' ports, Brno Lake (Prýgl in local slang)

Large cliffs on banks of the Brno Lake expose rocks of the Western Granodiorite Area (WGA; part of the Thaya Terrane *sensu* Finger et al. 1989) of the Brno Massif. Neoproterozoic biotite and amphibole–biotite granodiorite with common mafic (microdiorite and biotite–amphibole quartz diorite) enclaves. The felsic and mafic magmas have mutually interacted with each other forming magma mingling textures (Fig. 8-1, 8-2). Magmatic foliation is steep and NW–SE trending (Fig. 8-3). Country-rock xenoliths, e.g. fine-grained banded amphibolite with thin pegmatite and granite veins (Fig. 8-4), could be found in outcrops on the left bank. Foliation in xenoliths is of similar orientation as is the magmatic one in the granodiorite.

Fig. 8-1 Foliated diorites intruded by biotite granodiorite.

Fig. 8-2 Cauliflower texture at contact of biotite–amphibole diorite and biotite granite.

**Biotite to amphibole–biotite granodiorite** as dominant rock is medium- to coarse-grained, grey to reddish grey, composed of plagioclase, K-feldspar, biotite ± amphibole. Plagioclase is homogenous oligoclase ($An_{22–25}$), locally albitized, preferably along rims or in small "perthite-like" ribbons. Orthoclase is also partly albitized and contains common perthites. Alterations to sericite in plagioclase and to clay minerals in both feldspars is widespread. Biotite with $X_{Fe}$ = 0.44–0.46; $Al^{IV}$ = 1.27–1.65 apfu and Ti = 0–0.14 apfu is often chloritized. Amphibole corresponds to magnesiohornblende with frequent inclusions of magnetite, ilmenite, apatite and titanite. Zircons from the equivalent rock, located in the Anenský Mlýn quarry to the south, was dated to 601 ± 3 Ma by U-Pb LA-ICP-MS method (Soejono et al. 2017).

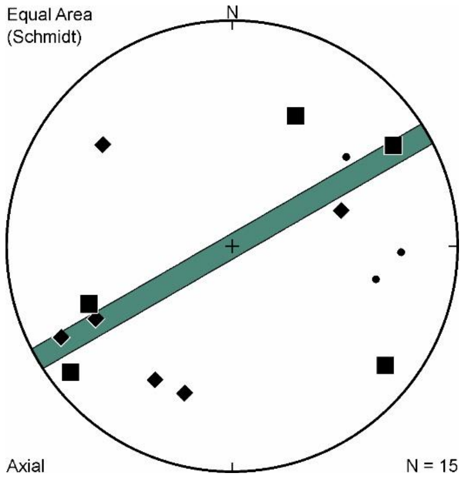


Fig. 8-3 Orientation of small-scale structures: foliations: magmatic (squares), metamorphic (diamonds), and low-temperature mylonitic (dots); basaltic dyke (green belt).

Fig. 8-4 Open fold in fine-grained amphibolite with pegmatite injections.

**Diorite** is medium-grained, grey to dark grey rock composed of plagioclase, amphibole and biotite. Magnetite, ilmenite, rutile, titanite, zircon and apatite are accessoric. Plagioclase is andesine ($An_{38–39}$), exceptionally anorthoclase may be present, amphibole is magnesiohornblende ($X_{Fe}$ = 0.48), biotite has $X_{Fe}$ = 0.51. Chloritization of amphibole and biotite is, in contrast with other granitoid rocks of the Brno Massif, only minor.

**Dark grey amphibolite** in xenoliths is fine to very fine grained, injected by granodiorite melt along foliation. Modal composition includes amphibole (magnesiohornblende), plagioclase (andesine $An_{37–41}$), quartz and accessoric titanite and apatite. Secondary epidote is common in net of tiny veins.

From metamorphic wall rocks of the Western Granodiorite Area, Buriánek (2010) described effects of regional metamorphism $M_1$ (~700°C, 6–7 kbar), overprinted by a younger thermal metamorphism (680–780°C, 3–5 kbar).

**Geochemistry:** Intrusive rocks of the Western Granodiorite Area of the Brno Massif form a series from quartz monzodiorite to granodiorite and granite in P–Q classification diagram (Fig. 8-5a) of Debon – Le Fort (1983).

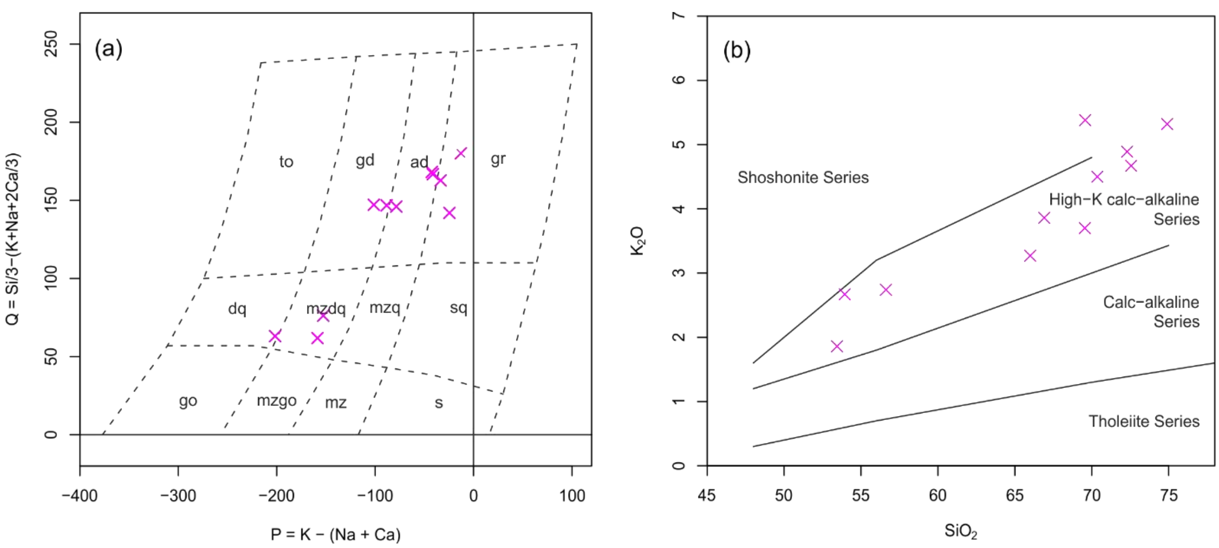


Fig. 8-5 Classification of granitoids from the WGA of the Brno Massif in diagrams of (a) Debon – Le Fort (1983), (b) Peccerillo – Taylor (1976). Unpublished data of Czech Geological Survey.

They are high-K calc-alkaline (Fig. 8-5b) with $SiO_2$ ranging from 53.4 to 74.9 wt. % comprising a wide range from metaluminous to peraluminous rocks (A/CNK = 0.7–1.2).

Chondrite-normalised (Boynton 1984) REE patterns (Fig. 8-6) show a fair degree of fractionation in LREE while HREE are relatively flat. Negative Eu anomalies are pronounced (Eu/Eu* = 0.2–0.8) with one sample featuring a positive one. The NMORB-normalized (Sun – McDonough 1989) spider plot displays marked depletion in Nb, P and Ti (Fig. 8-7). The LILE are generally strongly enriched and some samples show weak positive anomaly of Pb and Nd.

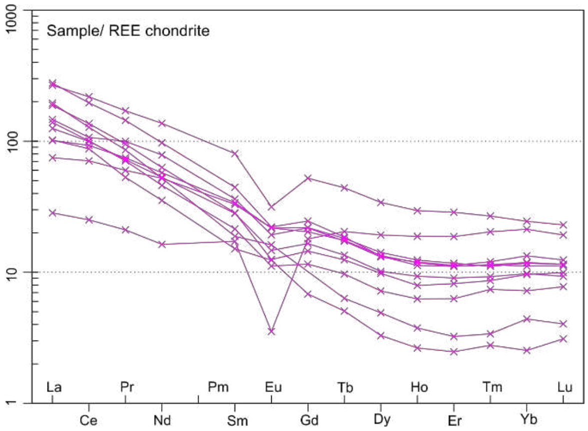


Fig. 8-6 Chondrite (Boynton 1984) normalized REE patterns for granitoids of the WGA.

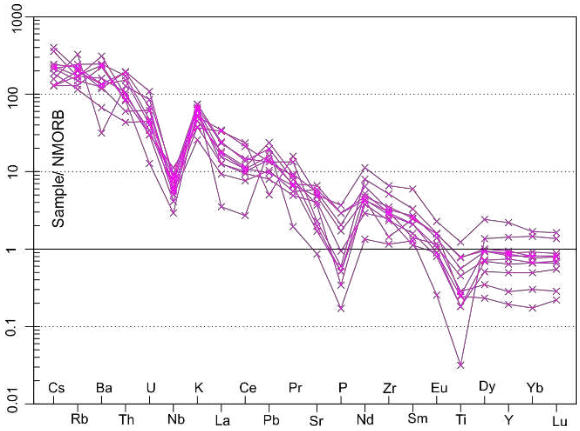


Fig 8-7 NMORB normalized trace-element patterns (Sun – McDonough 1989) of the WGA granitoids.

The NMORB-normalized spider plots resemble trends typical of igneous rocks from continental arcs (e.g. Saunders et al. 1991; Pearce – Parkinson 1993). A continental-arc setting (Fig. 8-8) is also indicated by geotectonic discrimination diagrams of Pearce et al. (1984) and Schandl and Gorton (2002).

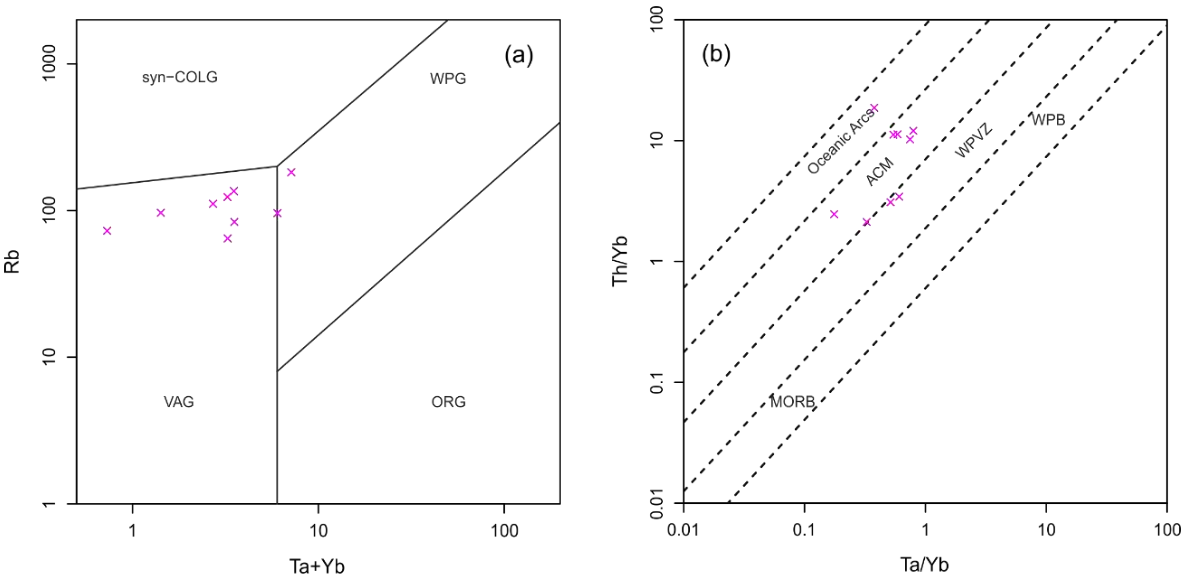


Fig. 8-8 Geotectonic discrimination diagram for granitoid rocks of the WGA: (a) Pearce et al. (1984), (b) Schandl – Gorton (2002).

Origin of the Brunovistulian granitoids in the magmatic arc was suggested previously (e.g. Dudek 1980; Finger et al. 1989; Jelínek and Dudek 1993; Hanžl and Melichar 1997; Finger et al. 2000; Leichmann and Höck 2008). The high-K calc-alkaline character and trace-element patterns of granitoids from the WGA correspond well with the idea of Finger et al. (1989, 2000) of the dichotomy of the Brno Massif: primitive volcanic-arc granodiorites occur in the east (Slavkov Terrane) and more evolved continental-arc granodiorites in the west (Thaya Terrane). According to Soejono et al. (2017) these arcs were one of the manifestations of a long-lived, episodic magmatism along the northern Gondwanan active margin.

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# 9. KŘOVÍ, FOLDING IN BÍTEŠ GNEISS OF MORAVICUM

**R. Melichar, K. Hrdličková, P. Hanžl**

49.29924° N, 16.25577° E; active quarry 2 km NE of the Velká Bíteš

The active quarry in valley on junction of the Bítýška and Bílý Potok creeks exposed upper part of the Bíteš Unit of Moravicum where Bíteš orthogneiss alternates with layers of paragneiss and amphibolite (Fig. 9-1).

**The Bíteš Gneiss** is the lithological type variable in texture, grain size and mineralogy. Bíteš orthogneisses are light grey, grey, greenish grey, ochre or pinkish, mostly fine- to medium-grained rocks with characteristic augen textures (Fig. 9-2) passing to planar or, locally, blastomylonitic ones. Modal composition includes quartz, plagioclase and K-feldspar in variable proportions. Muscovite and/or biotite and, alternatively sericite and/or chlorite, are common in most varieties, rarely also garnet may be present. Common accessories are zircon, xenotime, monazite, magnetite, apatite and titanite. Plagioclase has albite to oligoclase composition ($An_{2–28}$), K-feldspars also include small amounts of albite component ($Ab_{7–9}$). Chlorite and sericite are relatively commonly present, dispersed as small flakes and leafs. Muscovite and biotite ($X_{Fe}$ = 0.57–0.79), if present, they form flakes and ribbons parallel to foliation or porphyroblast-like nests. Garnet, present in grains of several mm in size, is often brittle deformed with fissures infilled by chlorite. Garnet ($Alm_{74–78}Sps_{10–18}Pyr_{3–9}Grs_3$) is zoned with rimward decreasing almandine and pyrope and increasing spessartine components; grossular does not show any zoning.

Fig. 9-1 Intercalations of dark amphibolite in pale Bíteš orthogneiss.

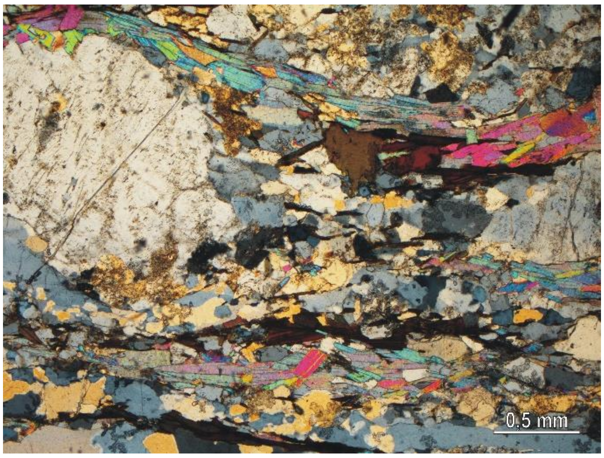


Fig. 9-2 Photomicrograph of the Bíteš Gneiss with characteristic augen texture. XPL.

Layers of fine-grained, banded granoblastic to lepidogranoblastic gneisses alternate with the Bíteš Gneiss in the Křoví quarry. Two petrological types could be recognised:

- dark-grey biotite gneisses composed of quartz, plagioclase, K-feldspar, biotite ± garnet ± sillimanite ± muscovite,
- amphibole–biotite gneisses to biotite amphibolites composed of quartz, plagioclase, biotite, amphibole ± garnet.

Garnet–biotite thermometry of garnet–biotite gneisses from Křoví using garnet cores and biotite inclusions yielded temperatures of 520–535°C, whereas garnet rims and biotite in contact gave 630–650°C and 5–6 kbar.

**Amphibolites** of the Bíteš Group occur along the western rim of the unit and form layers/sill subparallel with foliation. According to Wilimský (2001), they represent petrographically and geochemically a relatively homogenous group, the precursor of which could correspond to transitional tholeiitic to slightly alkaline basalts of within-plate origin (Fig. 9-3).

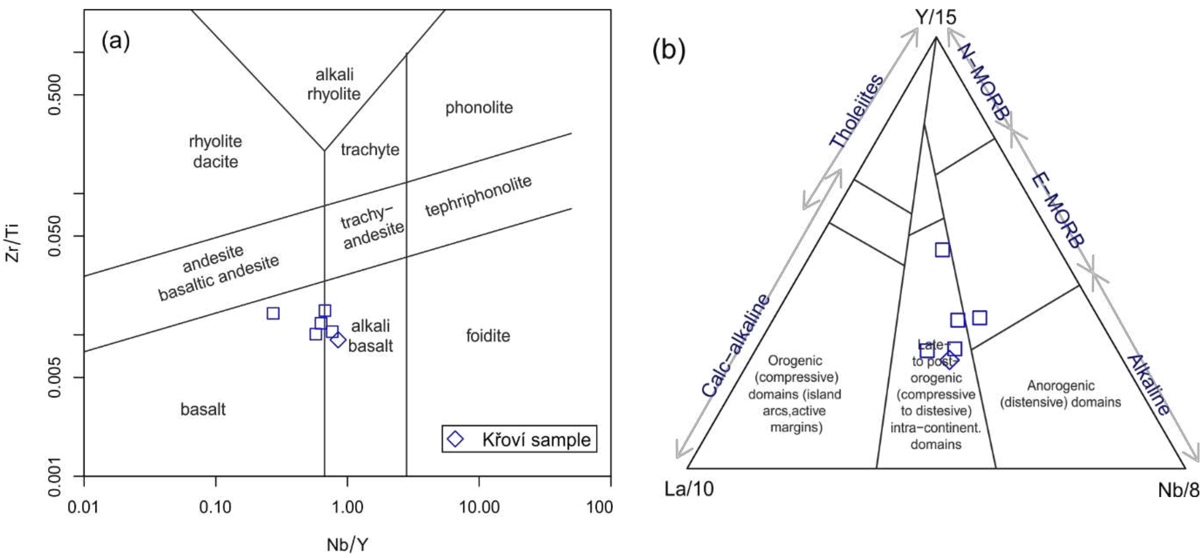


Fig. 9-3 Classification of amphibolites from the Bíteš Group of Svratka Dome. Data from Wilimský (2001). (a) Nb/Y vs. Zr/Ti diagram of Pearce (1996), (b) La/10–Y/15–Nb/8 plot of Cabanis and Lecolle (1989), where the Y/Nb serves as the "alkalinity index" and La/Y as the "calc-alkaline index".

The **Bíteš Gneiss** is geochemically homogenous rock of granodiorite to adamellite composition (Fig. 9-4) with $SiO_2$ of *c.* 71–74 wt. %. It is peraluminous, calk-alkaline to high-K calc-alkaline with $K_2O/Na_2O$ = 1.1–1.2. The NMORB-normalized spider plot (Fig. 9-5) displays marked depletion in Nb, La, Ce and Ti. The LILE are generally strongly enriched and some samples show weak positive anomaly of Pb. Sum of REE is quite variable, but chondrite normalized patterns are mutually comparable, slightly fractionated with pronounced negative Eu anomaly (Eu/Eu* = 0.66–0.84). The Bíteš Gneiss corresponds to volcanic-arc granite in diagram of Pearce et al. (1984) and to active continental margin setting in diagram of Schandl – Gorton (2002).

Friedl et al. (1998, 2004) dated the Bíteš Gneiss from the Thaya Dome to *c.* 585 Ma (SHRIMP). Many inherited zircons with Mesoproterozoic and Early Palaeoproterozoic ages of *c.* 1.2, 1.5 and 1.65–1.8 Ga, indicate a derivation from the South American part of Gondwana (Friedl et al. 2000, 2004). The age supports previous concepts (Waldmann 1951) that the Bíteš Gneiss nappe represents a deformed, former western part of the Thaya Batholith (Friedl et al. 2004). On the other hand, no inherited zircons were described in Thaya Batholith, dated by Svojtka et al. (2017) to 603 ± 3 Ma (LA-ICP-MS). Soejono et al. (2017) interpreted a concordia age of 568 ± 3 Ma (LA-ICP-MS) of the Bíteš Gneiss from the Svratka Dome as the Late Proterozoic crystallization age of the magmatic protolith. Dating of the frequent inherited cores shows a range of ages between c. 1.1 and 2.1 Ga and two dates at c. 2.5 Ga and c. 2.7 Ga. It together with geochemical data indicates, that the orthogneiss of the Moravicum was generated from an ancient, mature crustal segment.

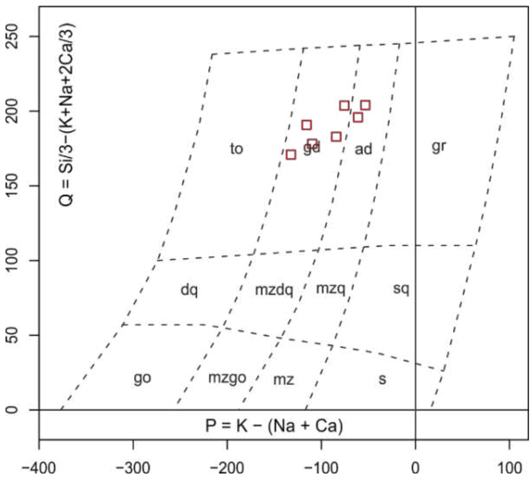


Fig. 9-4 Classification of the Bíteš Gneiss in diagram of Debon – Le Fort (1983) .

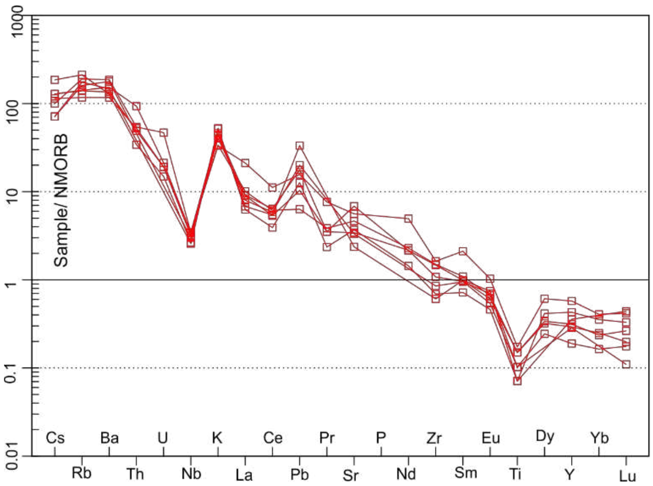


Fig. 9-5 NMORB normalized trace-element patterns (Sun – McDonough 1989) of the Bíteš gneiss.

The Bíteš Gneiss was recrystallized during overthrusting by Moldanubian Unit under MT–MP conditions (amphibolite-facies) and LT–LP event (greenschist-facies) accompanied with a thin-skinned northward-oriented nappe emplacement over the para-autochthonous Svratka Massif (Schulmann et al.1991). Post-metamorphic cooling related with these events in the Bíteš Gneiss of the Svratka Dome were dated to 326 ± 1 Ma using $^{40}Ar/^{39}Ar$ on muscovite (Fritz et al. 1996).

The Moldanubian overthrusting led to the formation of metamorphic foliation, which is generally flat and folded. Poles to foliation surfaces are arranged to great π-circle (Fig. 9-6) what is typical for cylindrical structures. Some steep orientation is a result of complex folding to large overturned or recumbent folds (Fig. 9-7). Associated π-axis representing averaged fold axes correspond with stretching lineation (Fig. 9-6). This demonstrates simple shear mechanism under ductile conditions for folds' origin.

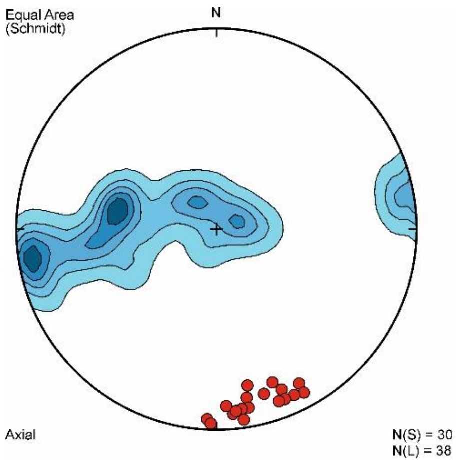


Fig. 9-6 Orientation of metamorphic foliation (blue contours of poles) and stretching lineation (red points).

Fig 9-7 Alternating Bíteš orthogneiss and amphibolite in southern quarry wall. Note foliation gently dipping to the E and open folds with eastward vergence.

Two mechanically very different materials have allowed to record different **stages of deformation**. We can recognize two phases of folding in minimum. The older fold system is characterized by closed to isoclinal folds, whose fold axial surfaces are cut by brittle–ductile faults. These faults may have been formed in the end of the old folding, when lower limbs of these folds were turned to thrusts. Young fold system refolded both old fold axial surfaces as well as old thrusts (Fig. 9-8). As the fold axes are parallel, the coaxial refolding is evident and therefore the refolded folds could be identified as type 3 by Ramsay classification (Ramsay – Huber 1987).

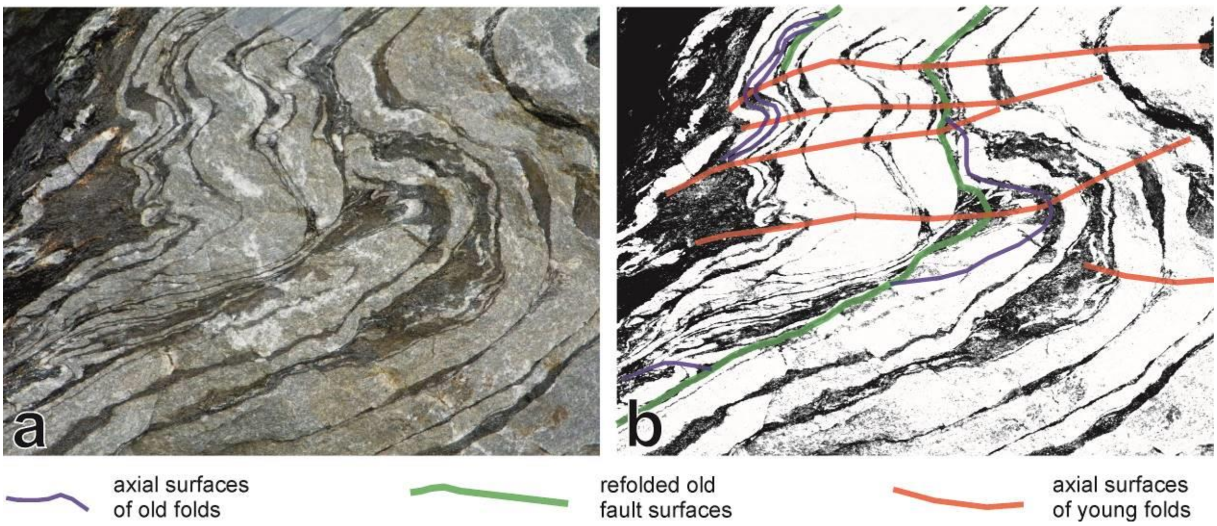


Fig. 9-8 Refolded faults and fold from the Křoví quarry: (a) a part of the rock block with alternation of competent pale Bíteš orthogneiss and incompetent dark amphibolite, (b) structural interpretation indicates co-axial refolding.

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# 10. RABŠTEJN, AMPHIBOLITE ENVELOPING THE NÁMĚŠŤ GRANULITE MASSIF

**V. Kusbach**

49.09726° N, 16.15259° E; castle ruins close to Mohelno Lake

Felsic high-pressure granulite massifs enclosing volumetrically minor, but petrogenetically important, fragments of "orogenic peridotites" (garnet or spinel peridotite, pyroxenite and associated eclogite), are typical of the high-grade core of the European Variscan Belt. The Moldanubian Zone in the Bohemian Massif is no exception (Medaris et al. 1995, 2005; O'Brien and Rötzler 2003). Here, the granulite massifs are concentrated in the high-grade Gföhl Unit, which represents the most metamorphosed part of this internal orogenic zone. The granulite massifs are commonly surrounded by a rim of garnetiferous amphibolites bearing relics of retrogressed eclogites and banded amphibolites called collectively the "Begleit Series" (Accompanying Series; Finger and Steyrer 1995; Fritz 1995). In the Moravian Moldanubicum, the largest granulite body with common peridotites and amphibolites is the Náměšť Granulite Massif (NGM).

At Rabštejn site, located SW of the Mohelno peridotite body, granulite is exposed on the rocky view point, but coarse-grained amphibolite with garnets up to several centimetres dominates. Large garnet porphyroclasts with amphibole and quartz inclusions are recrystallized into amphibole–feldspar symplectite with abundant accessory opaque minerals (Fig. 10-1d). Both feldspars and amphibole from the fine-grained structures around garnet are segregated into monomineralic bands parallel with garnet structures elongation. These rocks experienced high-grade metamorphism at granulite-facies conditions with primary mineral assemblage clinopyroxene, plagioclase, garnet ± orthopyroxene and rutile (Matějovská 1987; Němec 1996). During amphibolite-facies retrogression, HP mineral assemblage was replaced by an association of amphibole, plagioclase, biotite ± garnet, ilmenite and quartz.

The amphibolites of the so far unknown protolith age show generally MORB-type geochemistry (Šichtařová 1981) and are sometimes interpreted as a relic of a Silurian–Devonian (Rheic) Ocean separating the Moldanubian continental domain from the Brunia Continent (Finger et al. 2007). The amphibolite envelope is also commonly associated with eclogite boudins testifying shared HP and retrograde evolution of felsic granulites and mafic rocks. The most likely protolith corresponded to EMORB-like, within-plate tholeiitic basalts, having originated most likely during Early Palaeozoic rifting or back-arc spreading.

Foliation in amphibolite outcrops with the castle ruins is subhorizontal, towards south it gets steeper. Petro-structural study (Kusbach et al. 2012) revealed that the tectonic history of granulites can be described by a succession of three main metamorphic fabrics. (1) Coarse-grained granulitic S1 fabric is characterized by a granulite-facies mineral assemblage of garnet, kyanite, ternary feldspar and rutile (Fig. 10-1a) and is preserved only in low-strain domain within the internal part of the peridotite megafold. (2) Ultramylonitic granulite S2 fabric shows also granulite-facies mineral assemblage with ternary feldspar preserved only as inclusions in garnet. The S2 fabric was associated with emplacement of the peridotite sheet into the orogenic root and initiation of the granulite complex exhumation (Fig. 10-1b). (3) The amphibolite-facies S3 fabric was associated with partial melting forming foliation-parallel leucosomes (Fig. 10-1c). Granulites with S3 fabric are strongly retrogressed as shown by a syn-D3 growth of sillimanite and biotite as well as accumulation of elongated lenses of granitic melt.

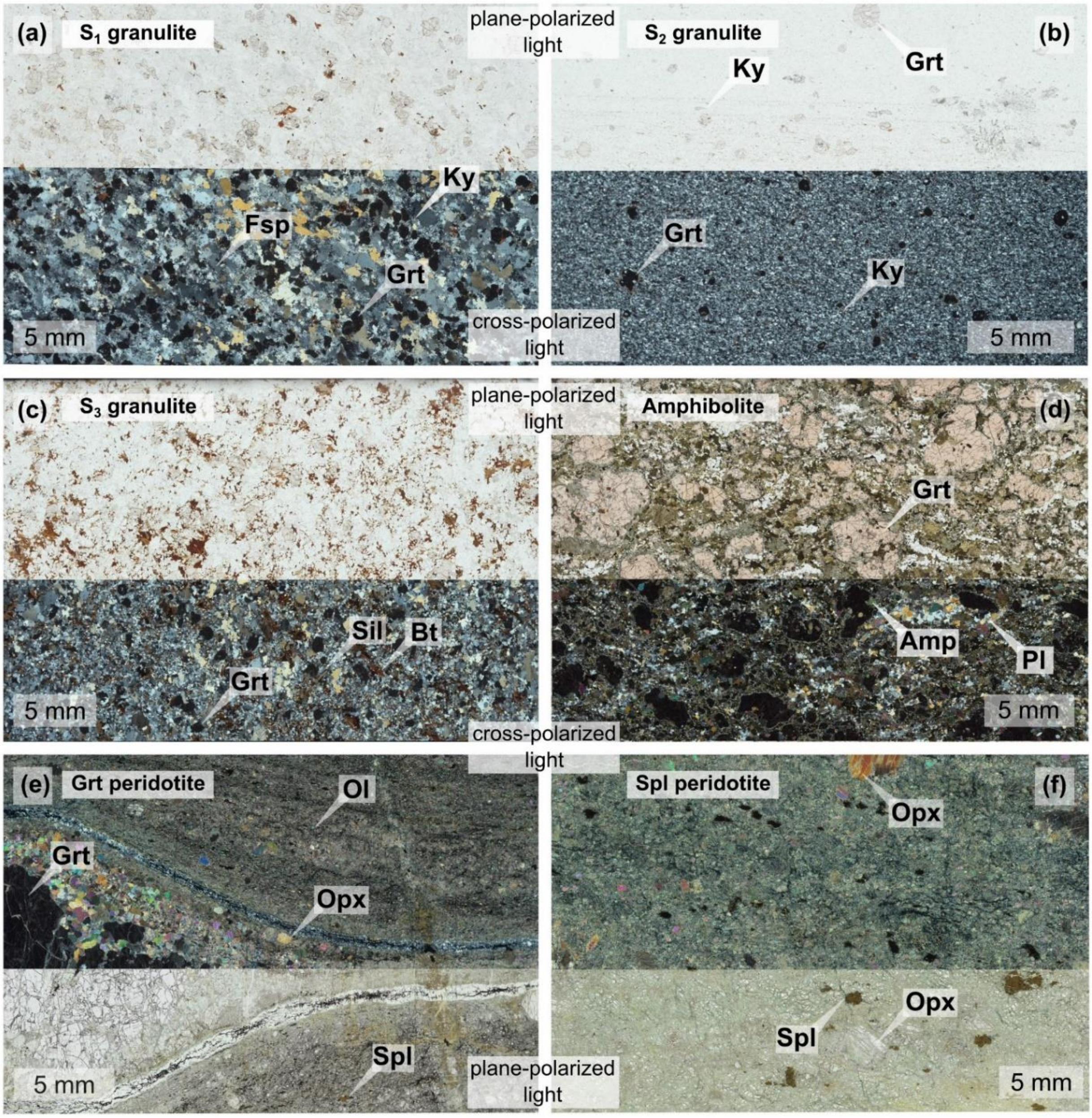



Fig. 10-1. Examples of mineral associations and microtextures in granulites (a–c), amphibolite (d) and peridotites (e–f) of the Náměšť Granulite Massif.

Amphibolites were classified based on presumably immobile elements (HFSE). The subalkaline basaltic affinity of the NGM amphibolites is clearly visible from diagram Nb/Y–Zr/Ti (Fig. 10-2a). The multicationic Al–(FeT + Ti)–Mg diagram of Jensen (1976) confirms high-Mg tholeiite basalt compositions (Fig. 10-2b). The amphibolites are geochemically rather primitive with low $SiO_2$ (41.6–46.1 wt. %), high MgO (6.1–8.9 wt. %) and fairly high mg# (44.7–58.3). The Normal Mid-Ocean Ridge Basalt (NMORB; Sun and McDonough 1989) normalized spiderplot (Fig. 10-3a) shows a variable enrichment in the LILE. Patterns for all samples are more or less delimited by pattern of Ocean Island Basalt (OIB) on the top and Enriched Mid-Ocean Ridge Basalt (EMORB) on the bottom for range of less mobile REE and HFSE (except of depletion in Nb, Zr and Ti). Generally, the hydrous fluid mobile elements (e.g., Cs, Rb, Ba, K, Pb and Sr) are several times enriched over the NMORB, but variations are most likely due to the high-grade metamorphism. The total REE concentrations vary between 52.2 and 169.5 ppm. The REE are all slightly enriched if compared with previously reported analyses of amphibolites from this region (René 2008, 2009; Fig. 10-3b). The chondrite-normalized trend for one of the amphibolites matches very well NMORB pattern, only slightly depleted in LREE

($La_N/Yb_N$ = 0.9, $La_N/Sm_N$ = 0.6). The remaining patterns resemble those of EMORB or OIB with variable degree of enrichment in LREE and MREE over the HREE, but all are relatively flat ($La_N/Yb_N$ = 2.4–4.5, $La_N/Sm_N$ = 1.0–3.7). Three amphibolite samples span from 0.7047 to 0.7070 in $^{87}Sr/^{86}Sr_{340}$ ratios and between +5.9 and –2.0 in $\varepsilon_{Nd}^{340}$ values. The single-stage Depleted-Mantle (DM) Nd model ages range from 0.77 to 1.91 Ga.

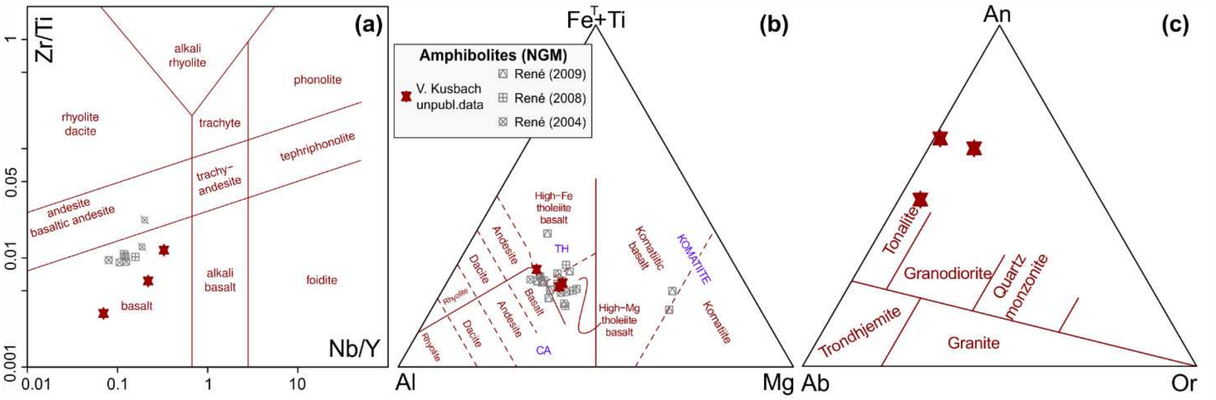
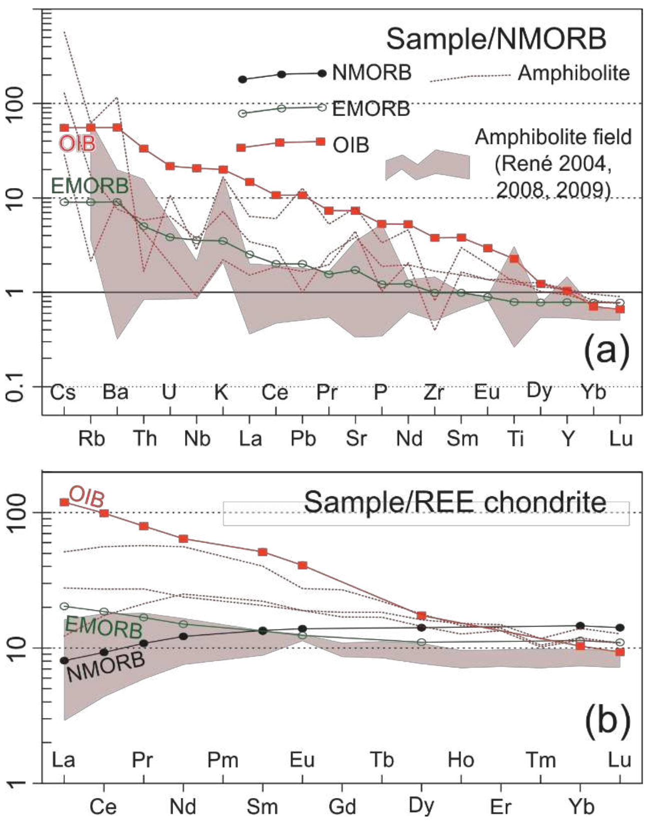



Fig. 10-2 Classification of Náměšť amphibolite in diagrams of (a) Pearce (1996), (b) Jensen (1976), (c) Barker (1979).

Three (SHRIMP) U–Pb zircon ages obtained from the amphibolite zircons spread from 349.2 ± 7.3 Ma to 324 ± 7.3 Ma. The 343–349 Ma U–Pb ages for Náměšť amphibolites record almost certainly the Variscan high-grade metamorphism (unpublished data and Kusbach et al. 2015). The younger analysis (~324 Ma) could reflect the presence of the crack in zircon. On the other hand, the lowest among Depleted Mantle Nd model ages (0.77 Ga) can be taken as a maximum age of the basaltic protolith (Janoušek et al. 2008). Useful information on protolith and likely geotectonic setting can be provided by relatively immobile trace elements (especially HFSE and REE), even for rocks with strong metamorphic overprint (Pearce 1996). In the Th – Zr/117 – Nb/16 classification diagram (Fig. 10-4) the amphibolites plot into the field of EMORB/Within-Plate Tholeiite. Taking also into account the Sr–Nd isotopic data, the most likely seems continental-rift or back-arc setting.

The Mohelno peridotite seems to correspond to suboceanic depleted mantle variably refertilized, probably under a Late Devonian slow-spreading ridge. This resulted in considerable heterogeneity of the relatively shallow mantle. The local lithospheric mantle could have been contaminated by the passage of deeply subducted felsic metaigneous material in Early Carboniferous times (< 354 Ma as shown by the metamorphic ages from the NGM granulites).



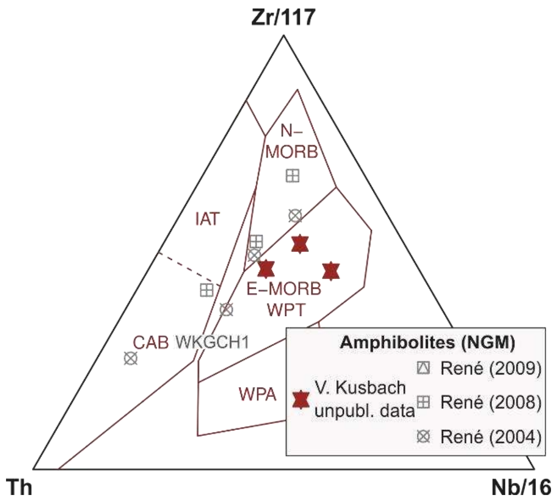




Fig. 10-4 Geotectonic classification of Náměšť amphibolite in diagram of Wood (1980).

Fig. 10-3 Trace-element patterns of Náměšť amphibolite in NMORB-normalized (Sun and McDonough 1989) spiderplot (a) and chondrite-normalized (Boynton 1984) REE diagram (b).

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# 11. ULTRAPOTASSIC PLUTONIC ROCKS OF THE TŘEBÍČ MASSIF, SOUTHERN SUBURBS OF TŘEBÍČ

**V. Janoušek, F. V. Holub†, P. Hanžl, R. Melichar, M. Svojtka, J. Hora, K. Hrdličková, L. Mareček, D. Hlávka**

49.19933° N, 15.88914° E; parking lot next to the Kaufland supermarket in southern suburb

The Třebíč Pluton represents the largest outcrop of ultrapotassic plutonic rocks of the 'durbachite series' *sensu* Holub (1997) in the Bohemian Massif. These dark rocks with conspicuous whitish phenocrysts represent an iconic building stone used in the Třebíč region since the medieval times. Modal compositions vary from durbachite *s.s.* (Sauer 1893) with 40–50 vol. % of phlogopite and actinolitic hornblende and only sporadic quartz (~ 5 vol. %) to durbachitic melagranite containing *c.* 20–25 % of the same mafic minerals (dominated by phlogopite) and more than 20 % of quartz. K-feldspar (Fig. 11-1) prevails over relatively sodic plagioclase (oligoclase–andesine). The most common accessories are apatite, zircon, thorite and sulphides (pyrrhotite, arsenopyrite, chalcopyrite and sphalerite); frequently occur also sphene, allanite or, locally, monazite (Goliáš 1995). Foliated durbachites with common microdiorite enclaves (Fig. 11-2) are exposed in rocky walls surrounding the parking lot.


Fig. 11-1 Zonal K-feldspar in amphibolite-biotite melagranite. Photomicrograph in PPL.

Fig. 11-2 Foliated porphyritic amphibole–biotite melagranite with MME.

Durbachitic rocks at the locality are quite strained to form flat foliation gently dipping to the E. Associated lineation is subhorizontal trending NNW–SSE. The brittle–ductile deformation by simple shear produced coarse S-C to S-C' structures (Fig. 11-3) and shear bands with top-to-the SSE sense of movement. The shear bands are best visible if they cut some mafic enclave (Fig. 11-4).

Fig. 11-3 Foliated melagranite with S-C structure produced by simple shearing.

Fig. 11-4 Sheared mafic enclave indicating top-to-the SSE sense of movement.

The durbachite series of the Třebíč Pluton covers a wide compositional range from c. 52 % $SiO_2$ and 10 % MgO in the most mafic durbachites up to 67 % $SiO_2$ and 3.2 % MgO in the most felsic melagranites (Fig. 11-5a). High contents of $K_2O$ and high $K_2O/Na_2O$ ratios (Fig. 11-6) are combined with relatively low CaO. The compositional variations are, however, mostly simple and characteristic linear trends can be observed in various element–element plots. All the rocks are highly magnesian with mg#, i.e. 100×Mg/(Mg + Fe), ranging between 75 and 62 (Fig. 11-5b).

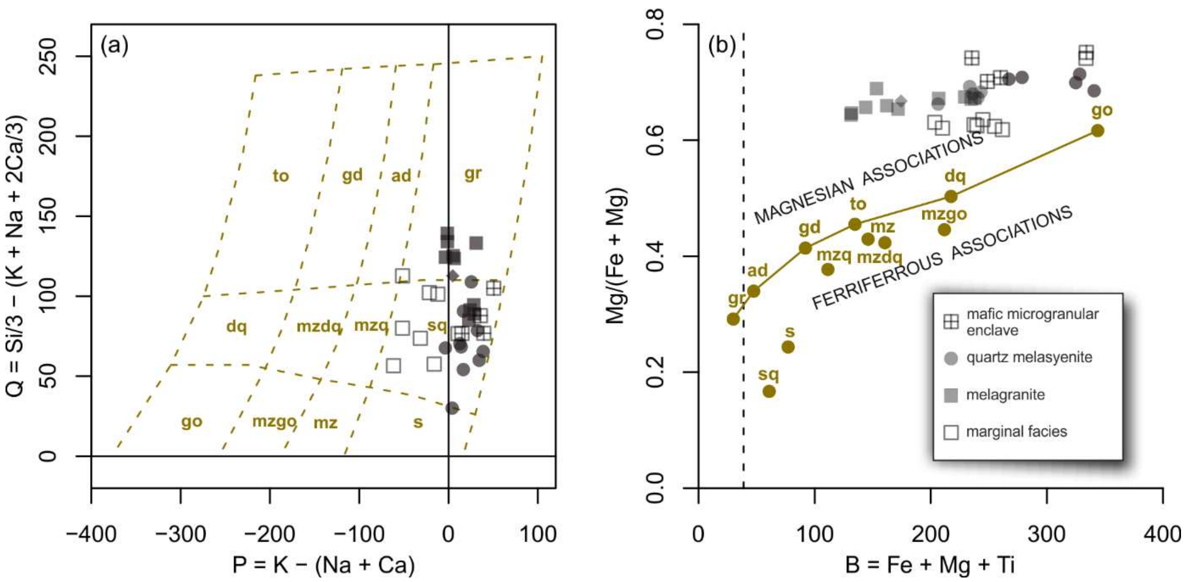


Fig. 11-5 Multicationic classification diagrams for rocks of the durbachite series from the Třebíč Pluton. (a) Diagram P (proportion of K-feldspar to plagioclase) vs. Q (quartz content; Debon–Le Fort 1983), (b) Diagram B (maficity) vs. mg# (Debon – Le Fort 1988). Model compositions of the following rock types are also plotted: gr = granite, ad = adamellite, gd = granodiorite, to = tonalite, sq = quartz syenite, mzq = quartz monzonite, mzdq = quartz monzodiorite, dq = quartz diorite, s = syenite, mz = monzonite, mzgo = monzogabbro, go = gabbro.

High contents of Cr are typical, reaching *c*. 600 ppm in durbachites and going down to *c*. 200 ppm in the most acid varieties, and display linear co-variations with major elements like MgO (Fig. 11-7). Incompatible elements of the LILE group (except for Sr) as well as Th and U are highly enriched, resulting, together with high K contents, in the high radioactivity of the durbachitic rocks (Lexa et al. 2011; Leichmann et al. 2017). Moreover, the Primitive Mantle-normalized patterns are characterized by negative anomalies of elements with a high ionic potential (HFSE) and Sr. The total REE contents are variable, but usually high (135–355 ppm). Chondrite-normalized REE patterns are mostly subparallel and steep ($La_N/Yb_N$ = 6.9–21.1). with characteristic negative Eu anomalies (Eu/Eu* = 0.92–0.46). The whole-rock Sr and Nd isotopic compositions of the Třebíč Pluton resemble those of mature continental crust ($^{87}Sr/^{86}Sr_{337}$ = 0.7104–0.7124; $\varepsilon_{Nd}^{337}$ = –7.7 to –6.5).

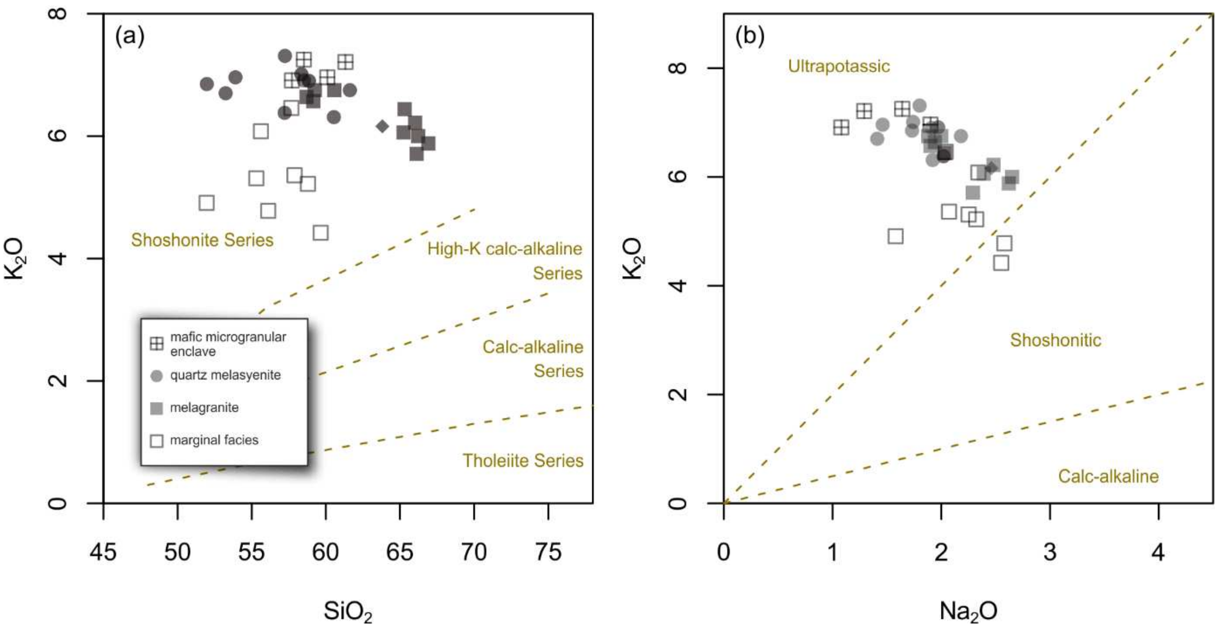


Fig. 11-6 (a) Binary plot $SiO_2$ vs. $K_2O$ wt. % (Peccerillo – Taylor 1976), (b) Binary plot $Na_2O$ vs. $K_2O$ wt. %. Ultrapotassic rocks are defined as having MgO > 3 wt. %, $K_2O$ > 3 wt. % and $K_2O$/ $Na_2O$ > 2 by weight (Foley et al. 1987).

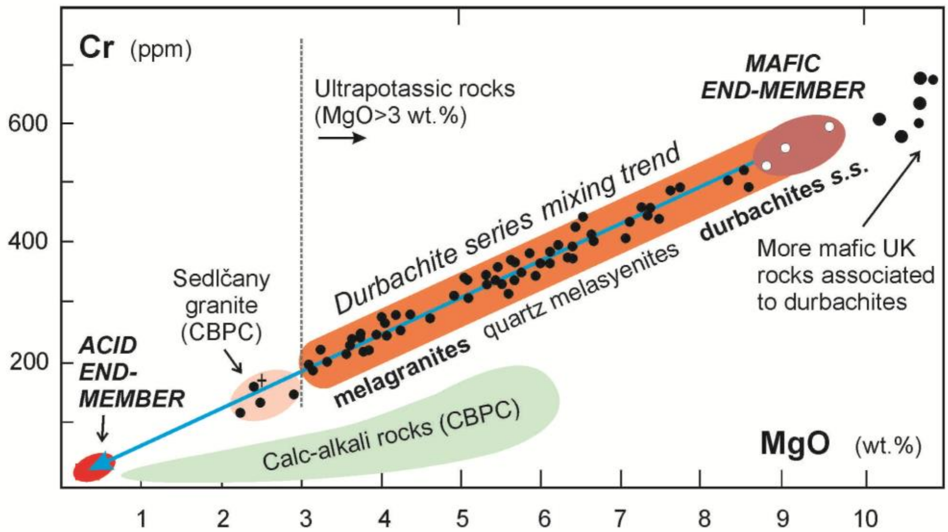


Fig. 11-7 Plot of MgO vs. Cr for ultrapotassic rocks of the durbachite series with the mixing trend between durbachite *sensu stricto* as the mafic end-member and a hypothetical acid end-member.

Durbachites *sensu stricto* probably represent primitive, mantle-derived ultrapotassic magma that could have been only slightly modified by processes of fractionation and/or bulk assimilation of crustal rocks. Their composition is far from those originating from typical mantle lherzolite, but requires a phlogopite-bearing source poor in clinopyroxene, probably corresponding to phlogopite harzburgite. Such a rock could be present within some parts of the lithospheric mantle that have been modified, sometime in their history, by a strong depletion in "basaltic" components but, subsequently, enriched in a broad spectrum of hygromagmatophile elements (Holub 1990; 1997; Wenzel et al. 1997; Becker et al. 1999). Very high concentrations of alkalis, Th and U as well as the high initial $^{87}Sr/^{86}Sr$ and highly negative $\varepsilon_{Nd}^{337}$ values imply a significant contribution from subducted continental crust. The local lithospheric mantle was likely strongly modified by direct contamination by subducted metaigneous crust or fluids/melts derived from such a source in course of the Variscan HP granulite-facies metamorphism (Janoušek – Holub 2007; Lexa et al. 2011; Schulmann et al. 2014).

Geochemical characteristics of the more acidic members of the durbachite series, namely the high Mg and Cr, linear trends in simple variation diagrams (and only weak decrease in the mg# with increasing silica; Fig. 11-5b), are compatible with an origin by mixing of the durbachite magma with crustal (leuco-)granitic melts (Holub 1990; 1997; Gerdes et al. 2000). The latter could have been derived from crustal rocks undergoing anatexis during their rapid decompression. Both the end-members were rich in LILE, such as K, Rb, Cs, U and Th but the acid one was significantly lower in Sr, Ba, Zr, Hf and Nb. The mixing hypothesis is supported by the broad variation in the Sr–Nd isotopic compositions as well as the presence of pilitic pseudomorphs after Mg-rich olivine phenocrysts even in the most acid durbachitic rocks with up to 66 wt. % $SiO_2$.

Some local deviations from the simple two-member mixing trend are explainable by limited fractionation, interactions with mingled portions of geochemically more variable ultrapotassic magmas (now represented by microgranular enclaves), and assimilation of various crustal rocks (such as stopped gneiss xenoliths; Holub 1997).

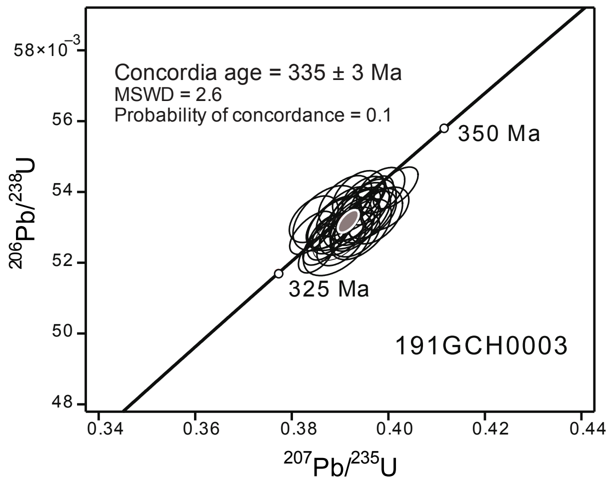


Fig. 11-10 Concordia diagram for melagranite from the current locality (Hanžl et al. 2017).

Zircon from a Kfs-phyric Amp–Bt melagranite of the current locality has been dated at 335 ± 3 Ma by LA ICP-MS U–Pb method (Fig. 11-10). This datum corresponds well to two of the previously determined zircon ages from the Třebíč Pluton –conventional 334.8 ± 3.2 Ma (Kotková et al. 2010) and, within the error, evaporation 340 ± 16 Ma (Holub et al. 1997). Somewhat older U–Pb zircon age of 341.6 ± 2.8 Ma obtained Kusiak et al. (2010) by the SHRIMP method; also U–Pb zircon dating of a mafic enclave by Kotková et al. (2010) gave 341 ± 5 Ma.

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# 12. TŘEBÍČ, WESTERN CONTACT OF THE TŘEBÍČ PLUTON AND MOLDANUBICUM

**R. Melichar, K. Hrdličková, L. Mareček, F. Bárta, F. V. Holub†**

49.21346° N, 15.87053° E ; road cut on the crossing of Sucheniova and Dr. Ant. Hobzy streets, Třebíč

A long outcrop situated next to the Sucheniova St. shows the character of the western edge of the Třebíč Pluton with its Moldanubian host rocks (Fig. 12-1). Country rocks of the western margin of the Třebíč Pluton are represented by migmatized biotite paragneiss to stromatitic migmatite of the Moldanubian Monotonous Group, commonly cordierite-bearing, sporadically, and only locally, also sillimanite and exceptionally garnet were described in this rock (Kala – Lacinová 1990). The dominant igneous rocks of Třebíč Pluton are coarse-grained Kfs-phyric amphibole–biotite melagranite to quartz syenite (‘durbachite’). Other rock types of the Třebíč Pluton are less common and are represented by the so-called “marginal facies” of syenite to granite and biotite granite.

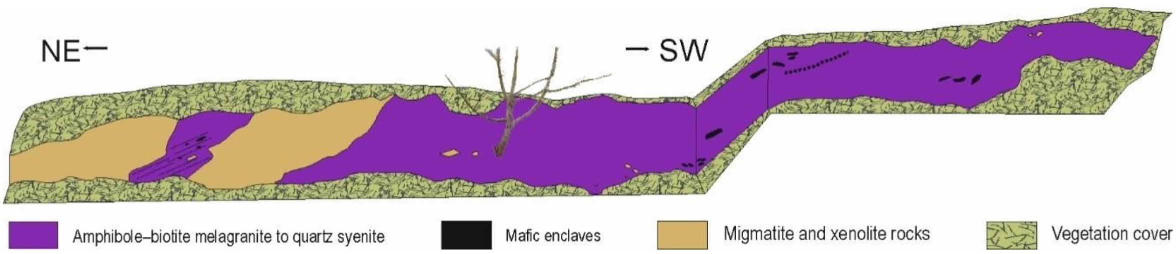



Fig. 12-1 A schematic view of the outcrop in Sucheniova St., Třebíč. Foliated durbachite with wall-rock xenoliths and mafic microdiorite enclaves alternates with partially melted country rocks (migmatite) of Moldanubicum.

**Migmatitized paragneiss** is a fine-grained, ochre to greyish brown rock, banded, locally even with augen texture. The modal composition generally includes quartz, feldspars and biotite. Muscovite, sillimanite and cordierite may be also present. Accessories are apatite, zircon, monazite and a scarce ilmenite. Secondary chlorite and muscovite are common. K-feldspar is slightly perthitic, with the composition of $Or_{9–95}Ab_{8–5}$, often with domains and small veins enriched by Ba. Plagioclase is oscillatory zoned or rarely shows sector-like zoning, whereby the cores or other more calcic domains correspond to oligoclase $An_{20–31}$, rims or more sodic domains are albites $An_{7–8}$. Both feldspars disintegrate along cleavage to clay minerals. Micas are of two types. Primary muscovite and biotite ($X_{Fe}$ = 0.40–0.55) are preserved scarcely. Muscovite is, however, generally rather exceptional and primary biotite is severely chloritized. Secondary micas, muscovite and biotite of $X_{Fe}$ = 0.45, have originated by disintegration of the original cordierite. The original cordierite is preserved in relics only and it corresponds to Fe-cordierite–sekaninaite. Apatite up to 500 μm across is a dominant accessory; prominent are also zircon grains up to 100 μm. Younger allanite enclosed by biotite provides an evidence for likely input of fluids enriched in REE. The presence of cordierite (and sillimanite) is apparently a result of thermal metamorphism during the Třebíč Pluton intrusion. The P–T conditions were estimated using Thermocalc to 690–770 °C and 3.6–4.5 kbar.

**Coarse-grained Kfs-phyric amphibole–biotite melagranite to quartz syenite (‘durbachite’)** is black or dark grey rock with characteristic pale phenocrysts of K-feldspars, several centimetres in size. Modal composition includes K-feldspars, amphibole and biotite. Plagioclase and quartz are minor.

Apatite, titanite, ilmenite and zircon are common accessories. Potassium feldspars are optically zoned; chemical zonation in main oxides or trace elements was not found. Chemical composition corresponds to orthoclase with up to $Ab_9$. Perthites are common. Amphibole is homogenous magnesio-hornblende ($X_{Mg}$ = 0.9). Biotite in reddish brown lamellae of $X_{Fe}$ = 0.34 is common. Plagioclase ($An_{43–51}$) is relatively homogenous or distinctively zoned, whereby the basicity decreases to rims to oligoclase–andesine ($Ab_{18–24}$); rarely, albite rims may be present.

**Tectonic modification** of the primarily magmatic boundary between melagranite and migmatite septa is evident. The rocks are strongly foliated along the contacts and foliations in both migmatite and melagranite are parallel in fact. Likewise, orientation of rock contacts and mafic enclaves positions in durbachites are also parallel to the foliation which is dipping to E–SE under *c*. 30°, stretching lineation is subhorizontal very gently plunging to SSE (Fig. 12-2).

Studied anisotropy of magnetic susceptibility (AMS) comprises not only the orientation of the fabric, but also the degree of anisotropy. Magnetic fabrics as well as compass data from western part of the Třebíč Pluton show very unified pattern in its attitude (Fig. 12-4a). Magnetic foliation is gently dipping to the E–SE, magnetic lineation is very gently plunging to the SSE. This pattern is almost identical to the orientation of foliation and lineation in the Moldanubian metamorphic rocks west of the Třebíč Pluton (Fig. 12-4b). Considering asymmetrical structures and top-to-the SSE sense of movement described at Locality 11 we may conclude, that both units were deformed by same simple shear regime. The degree of AMS increases to the western margin of the Třebíč Puton. It could be presumed that this fabric reflects shallow eastern-dipping shear zone that limits the western boundary and shallowly cuts off the Třebíč Pluton. Inhomogeneous shearing led to tectonic mingling and alternation of igneous and wall rocks (Fig. 12-1).

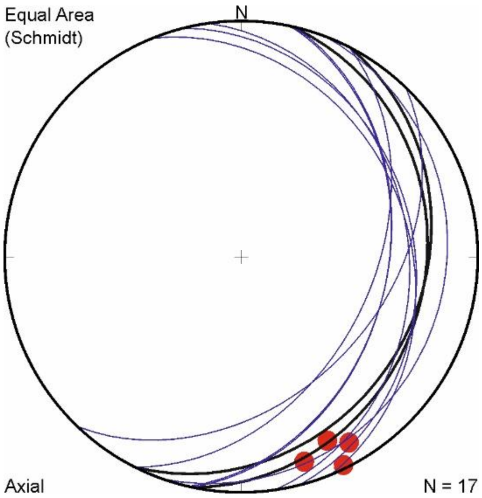
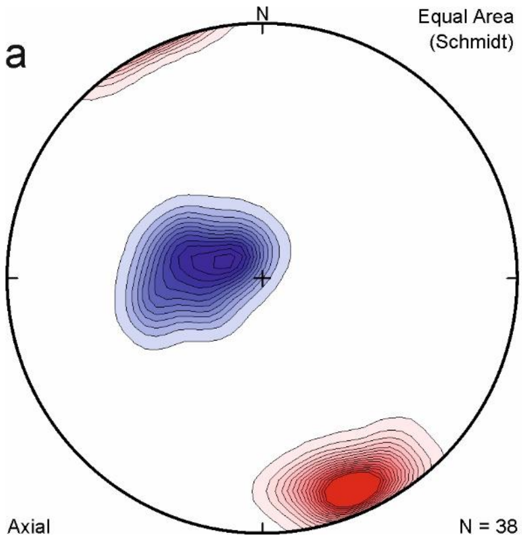



Fig. 12-2 Orientation of structures at the locality: navy blue great circles – foliation, red dots – stretching lineation; thick black great circles – rock boundary.

Fig. 12-3 The town of Třebíč is situated in the Jihlava River Valley predisposed by the Třebíč Fault. The two towers on the left show the location of the St. Procopius Basilica built of the ultrapotassic rocks.

The Jihlava River Valley follows brittle-ductile to brittle structure known as the **Třebíč Fault** (Fig. 12-3) manifesting itself by expressive facets on both slopes of valley. The fault is steep, striking in nearly E–W direction. The fault zone is up to several hundereds meters thick and it is accompanied by distinct mylonitization, cataclasis and strong chloritisation of durbachites. Indications of sense of movement by offset are in contrast: some markers suggest sinistral strike slip, or uplift of the southern wall; the presence of abundant relics of the Neogene sediments on the southern wall indicates its subsidence in the Late Neogene or Pleistocene. The fault separates geologically and geophysically different blocks (Bubeníček 1968,  Leichmann et al. 2016), what also indicates vertical component of the movement along it. In E close the Vladislav village, the fault terminates in "horse tail structure", minor faults of variable length continuing to SE. The master fault is accompanied by pennate structures of the NW–SE directions along the Jihlava River.



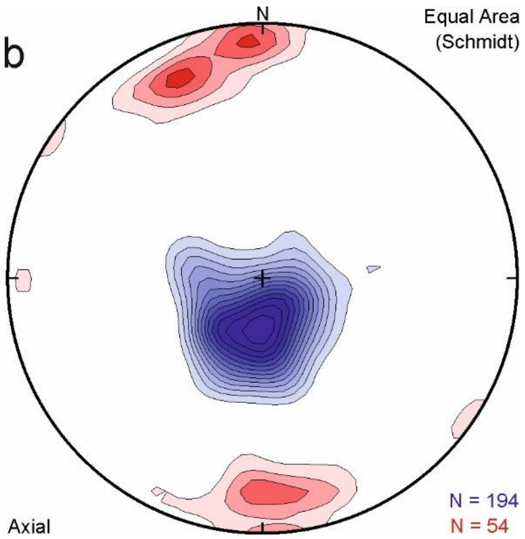




Fig. 12-4 Attitude of principal structural anisotropy in Moldanubian and durbachitic rocks: (a) poles to magnetic foliation (navy blue) and magnetic lineation (pink) from western part of the Třebíč Pluton (Bárta 2018), (b) poles to metamorphic foliation (navy blue) and stretching lineation (pink) from the Moldanubicum west of the Třebíč Pluton (Melichar 1985).

Open valley, where Jihlava River turns to west, has been inhabited since ancient times, and the surrounding massive ultrapotassic melagranites have been used as a well-processable stone for the construction of sacred buildings. One of such buildings is St. Procopius Basilica, a part of the Benedictine Monastery founded in 1101 (Fig 12-5). The basilica ranks among the pearls of medieval architecture. Its Romanesque style shows also some Gothic elements. The basilica was built in the early 13th century originally and—as the abbot's church—initially dedicated to Virgin Mary. The church was damaged much when Třebíč was besieged by Matthias Corvinus' army in 1468, and was then used for secular purposes for more than two centuries. After its renovation by Frantisek Maxmilian Kanka in 1725–1731, it was used again for sacral purposes and dedicated to St. Procopius. In 2003, the ensemble of the Jewish Quarter, the old Jewish cemetery and the Basilica of St. Procopius in Třebíč were added to the UNESCO World Heritage List (https://whc.unesco.org/en/list/1078).

Fig. 12-5 Photographs of the St. Procopius Basilica in Třebíč built from the durbachites of the Třebíč Pluton.

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