Basalt2017 Pre-conference fieldtrip: rift-flank volcanism in the Krušné hory/Erzgebirge Mts. area

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The Basalt2017 pre-conference field trip focuses on rift-flank volcanism exposed on the northern uplifted rift-shoulder, known as Krušné hory / Erzgebirge Mts. This excursion will lead us to two volcanoes on the edge of the uplifted rift-flank and two other volcanoes within the rift (fig. 1). During the field-trip, various volcanic rocks and volcaniclastic deposits will be observed demonstrating distinct settings on rift-flank and within the rift basins.

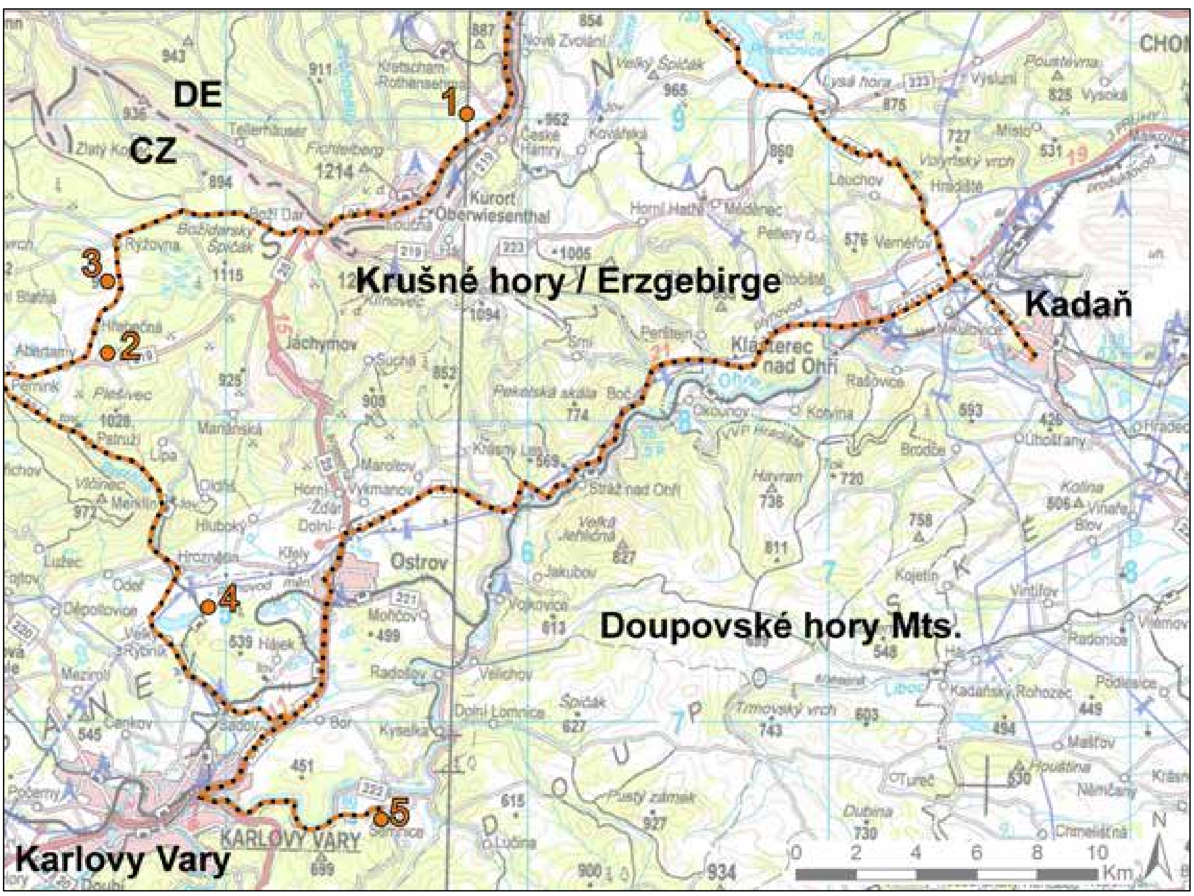


Fig. 1. Schematic sketch map of the pre-conference field-trip drive.

Locality 1
Hammerunterwiesenthal, a maar-diatreme volcano with younger intrusions of phonolite and tephrite

The maar of "Hammerunterwiesenthal" is a compound monogenetic volcano (Kurszlaukis and Barnett, 2003) of Early Oligocene age located in the border region of Germany and the Czech Republic, in the so-called "Sächsisches Erzgebirge" (Saxonian Ore Mountains; Suhr and Goth, 1996). The Erzgebirge is a Hercynian folded and metamorphosed basement block, which consists of para- and orthogneisses, mica schists, amphibolites, phyllites, marbles and Permo–Carboniferous granites and rhyolites. In the Tertiary, a number of smaller volcanic eruptions occurred in this area. They are connected with the extensive volcanic activity in the Eger / Ohře rift southeast of the Erzgebirge Mts. These volcanic centres belong to the Central European Volcanic Province (Dézes et al., 2004) and the magmatic activity is connected with the Alpine orogeny. Since the Late Eocene, a dilating stress field caused the rift genesis in Central Europe. Different magma types erupted in the rifts. In the Eger / Ohře rift, there are two main volcanic centres – České středohoří Volcanic Complex and Doupovské hory Volcanic Complex.

The volcanic activity in Hammerunterwiesenthal area started in the Early Oligocene and continued till the Early Miocene. The palaeogeographic situation in the Early Oligocene, the starting time of volcanic activity, is characterised by a S-N directed drainage system (Suhr, 2003) with broad valleys and braided rivers. The marine realm of the "Palaeo-North Sea" reached far to south of the city of Leipzig and was accompanied by a belt of paralic swamps. A closer view on the locality of Hammerunterwiesenthal supports this general picture. The environment of the village of Hammerunterwiesenthal is characterised through the occurrence of several stone quarries and numerous former mining activities (Fig. 2). The quarries produced crushed phonolite, tephrite and amphibolite and, in former times, also some marble quarries were working. During the last 250 years, silver and uranium ores as well as fluorite and barite used to be mined. Today still two mines exist in near Hammerunterwiesenthal excavating marble and fluorite. The area is crossed by several hydrothermal veins of Mesozoic age (Fig. 3; Malásek et al., 1980). The weak zone along the veins in the country rocks later enabled a formation of a river valley from Late Eocene till Early Oligocene times. Remains of the fluvial sediments survived below a basalt flow some kilometres to the far north (Bärenstein, Pöhlberg and Scheibenberg; Suhr, 2008) and as loose quartzite blocks near the village Kovářská. The level of the fluvial erosion lays approximately a hundred metres above the recent surface. More than one hundred metres of rock material were eroded since the Erzgebirge Mts. block began to lift up in the Miocene.

About 30.5 Ma, a leucitite magma built up a dyke parallel to the hydrothermal veins. At the crossing point with the river valley, water could penetrate down and get in contact with the magma, causing phreatomagmatic explosions, which formed a huge maar-diatreme volcano ca. 1.7 km in diameter and with a crater depth of approximately 350 metres. The resulting circular depression is superbly visible in the recent morphology (Fig. 2). This form is caused by weathering-prone maar-crater sediments that are eroded more easily than the surrounding country rocks. It is clearly apparent how the recent valley is spreading on the place of the maar crater.

Quarry gateway at Height 890 - the margin of the maar crater is exposed at the entrance to the quarry at Height 890. At this locality (Figs. 4 and 5), the direct contact of the maar-lake sediments in marginal facies with the muscovite gneisses of the Erzgebirge Mts. can be observed. Some ten metres away from the contact, a phonolite intrusion is disclosed. This club-shape phonolite of the Height 890 intruded at the boundary between the marble and the muscovite gneiss. The entire intrusion is conspicuously exposed in the following abandoned quarry. The maar-lake sediments incline towards the centre of the maar crater in ca. 30° dip. This dipping results from the subsidence movements of the underlying diatreme (Suhr et al., 2006). The coarse sediments consist of phreatomagmatic ash and boulders of distinctive origins. Gneisses, marbles and crystals of augite are frequent. Jäger (1961; Fig. 5) described very similar relations from the dewatering gallery of the marble quarry II. Unfortunately, this outcrop is no longer accessible because it was filled up with debris.

Phonolite quarry Richter - A cross section through the western part of the maar-structure (Fig. 6) shows the sedimentary filling of the maar-lake topping the diatreme breccias. In the phonolite quarry, the so-called quarry Richter, named after its former owner, there are outcrops of the maar-lake sediments (Fig. 7) below and above the younger phonolite intrusion. Primarily, the sediments consist of turbidites and debris flow deposits. The turbidites show all characteristic features (Fig. 8) such as grading of the grain size, fine-grained tops, sole marks, rip-up structures etc. More to the deeper parts of the quarry, other types of maar-lake sediments are observable: Black, fine-laminated limestones form typical meromictic lake sediments without any body fossils (Fig. 9). The limestones are partly silicified and similar to chert. In the deepest level of the outcrop, peperites appear (Skilling et al., 2002), representing marginal parts of leucitite intrusions. These blocky peperites consist of a mixture of maar-lake sediments and patchy blocks (Fig. 10) of leucitite with the size of up to 20 cm in diameter (pseudopillows after Tucker and Scott, 2009). In contrast to debris-flow deposits, which also occur in the record, they consist only of fine-grained maar-lake sediments and leucitite blocks often showing chill crusts and cooling fissures. The debris-flow deposits comprise a broader spectrum of different rock debris.

In the maar-lake sediments some small intrusions of leucitites occur. They belong to the first volcanic phase of the maar formation. The thin-sections of leucitite samples display the characteristic picture of foiditic rocks including big nephelinite crystals and large amounts of leucite in the groundmass. K/Ar ages of the leucitite are ca. 30.5 Ma (Suhr and Goth, 1996) defining the upper time limit for the maar genesis.

Finer-grained turbiditic layers contain little flora (Sittner, 1985) with Lower Oligocene leaves and fruits (Fig. 11) fitting very well to the isotopic ages. Walter (1998) described these plant remains in a monographic paper and classified them as volcanic floras. Weinlich (1979) determined the coalification degree of some wood fragments as lean coal. In the same layer, remains of the endemic amphibian *Archeotriton basalticus* (Böhme, 1998; Böhme and Rößler, 2002) have been observed. This species has its endemic occurrences only in the environment of the Eger / Ohře rift and is typical for the Oligocene age. The remnant of a corselet of a turtle (Fig. 12) was found in 2014 in debris-flow deposits of the 3rd level of the Richter quarry. As meromictic lake sediments had been deposited under oxygen-free conditions, it is surprising that trace fossils occur in the black lacustrine limestones (Fig. 13). However, a closer view reveals that the observed traces are always connected with turbiditic intercalations. Obviously, the turbidity currents transported enough oxygen into the deeper water of the lake permitting higher life forms in the sediments for a short time interval. These conditions correspond to the *Mermia* ichnofacies (Buatois and Mángano, 2008), which is characteristic for lacustrine turbidites. The traces on the picture (Fig. 13) show *Vargorichnius ichnosp.*, a characteristic species of the *Mermia* ichnofacies.

The second magmatic event started at 28.4 Ma (Suhr and Goth, 1996) with the intrusions of three discrete phonolitic domes. Two of them intruded into the soft and moist maar-lake sediments and created typical laccoliths. The third one took place in the boundary zone between the muscovite gneiss and the marble surrounding the maar structure, and it shows a club-like form. The map of magnetic anomalies (Fig. 14) clearly displays these three intrusive bodies and their relation to the maar structure. The cross section shows two different shapes of the phonolitic intrusive bodies. The club-shaped phonolite of the Height 890 is exposed in an abandoned quarry at Height 890 (see Fig. 6).

In the Richter quarry, another kind of intrusive body (laccolith) with a flat shape was formerly quarried. The thin-section of the phonolite samples from this locality shows the typical fluidal texture of the groundmass with a large amount of sanidine feldspar. In some parts of the Richter quarry amygdales filled with zeolites, e.g., natrolite and thomsonite, occur frequently. For collectors, the quarry was famous for its minerals. The boundaries of the intrusive phonolite are partly exposed along the quarry walls (Fig. 16). On the top of the intrusion, baked maar-lake sediments survived as pocket fillings (Fig. 16). These rocks are reddish in colour and show a clear thermometamorphism. The more lateral and lower boundaries of the laccolite are characterised by a low thermal influence, only affecting the marginal areas of the sediments (cm-scale). Phonolite columns, representing cooling structures, are well-visible along the footwall boundary. It is possible, that water from underlying moist sediments has been involved in the formation of the columns.

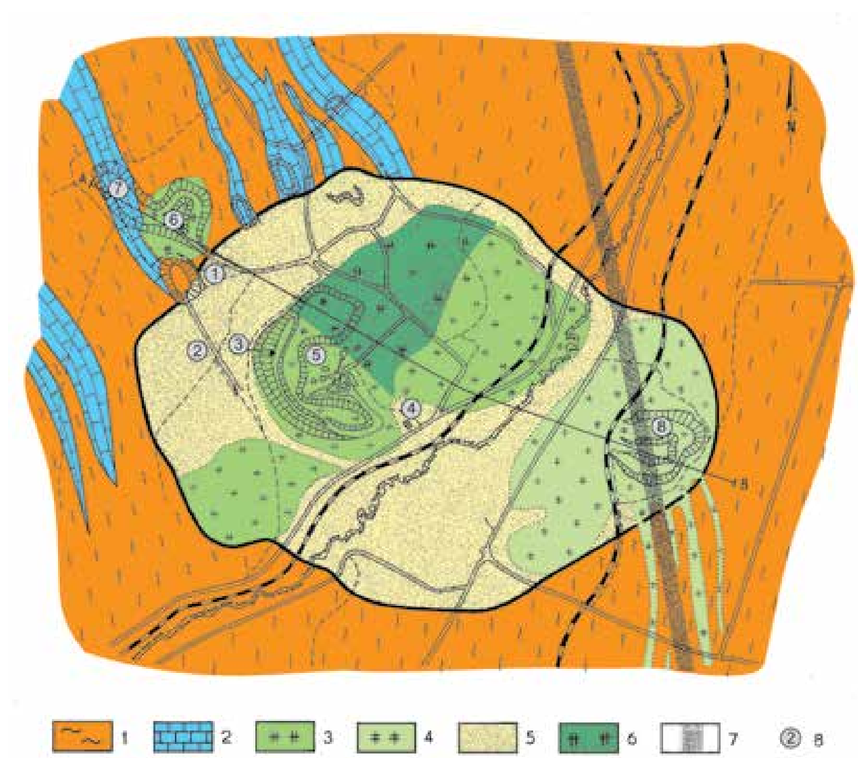
Sometimes peperite structures of subordinate extension are observed along the lateral boundary zones of the phonolite body. Here, a quick cooling is evident for the development of a chill crust between the phonolite and the peperite (Fig. 14).

Very shortly after the phonolite intrusion, a camptonite dyke penetrated the still-plastic phonolitic material (Fig. 17). A small bubble-like intrusion of phonolitic material was squeezed into the dyke, proving that both rock materials were still liquid. Unfortunately, the described outcrop is under water now because the quarry dewatering is out of work for some years.

The third magmatic event in the area of Hammerunterwiesenthal occurred at 22.8 Ma. At this time a pine-shaped tephrite body intruded into the maar-lake sediments of the eastern part of the structure. The tephrite body was accessible in an abandoned quarry at the Czech side of the border, but in the last years the quarry has been filled up with waste. The shape of the intrusion was well explored by the mining and drillings (Malásek et al., 1980). The K/Ar isotopic dating implies a significantly younger age than that of the phonolites. The maar-diatreme volcano of Hammerunterwiesenthal has a very complex history with three distinct magmatic events between 30.5 and 22.8 Ma. Every event has its own petrographic fingerprint. The maar-forming magma was of leucititic composition and is accessible as blocky fragments in a peperite in the maar-lake sediments. The main intrusion phase took place at least two million years after the maar-forming eruptions and culminated in phonolitic intrusions into the maar-lake sediments and into the gneisses of the surrounding area. The last magmatic event, 22.8 Ma ago, is represented by a tephrite intrusion in the eastern part of the maar.

Starting in the Miocene, the Erzgebirge Mts. lifted up and at the same time erosion of the maar filling as well as of the intrusive bodies begun. Today, the intrusions are exhumed and form small hills (Fig. 2). The thalweg of the Pöhlbach cuts a deep valley into the maar structure.

Fig. 2. Oblique aerial photo of the maar-diatreme volcano Hammerunterwiesenthal (viewing direction NE). 1 – Phonolite quarry Richter; 2 – Phonolite quarry Height 890; 3 – Former tephrite quarry České Hamry; 4 – Amphibolite quarry Stümpel; 5 – Thalweg of the Pöhlbach; 6 – Thalweg of the Bílá Voda brook; red line: contour of the maar crater.

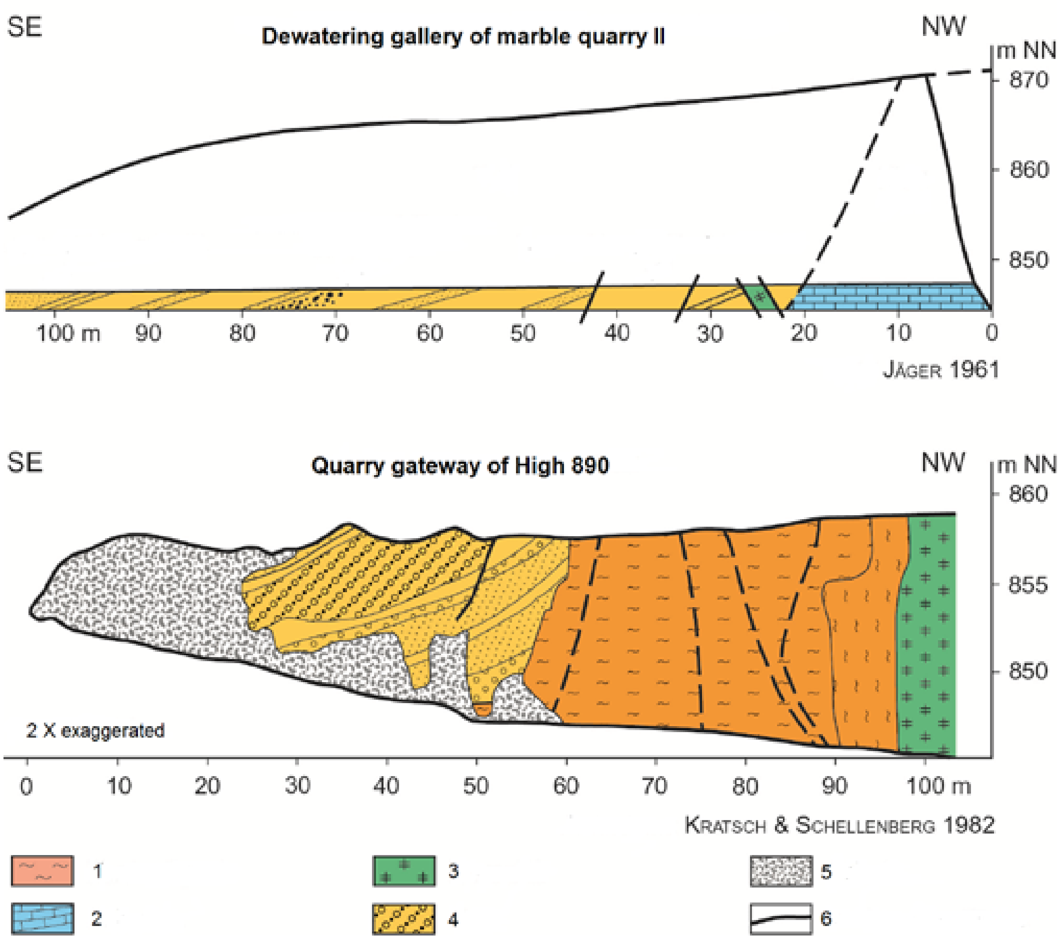


1 – Muscovite gneiss;
2 – Marble;
3 – Phonolite;
4 – Tephrite;
5 – Maar-lake sediments;
6 – Phonolite overlain by maar-lake sediments;
7 – Mesozoic hydrothermal vein;
8 – Localities:
1 – Quarry gateway at Height 890;
2 – Dewatering gallery of marble quarry II;
3 – Quarry Richter
4 – Gully near the church;
5 – Crushing plant;
6 – Phonolite quarry Height 890;
7 – Marble quarry III;
8 – Former tephrite quarry České Hamry.

Fig. 3. Geological map of the environment of Hammerunterwiesenthal.

Fig. 4. Margin of the maar crater in the quarry gateway of Height 890.

Fig. 5. Cross sections of the quarry gateway Height 890 and of the dewatering gallery of marble quarry II.



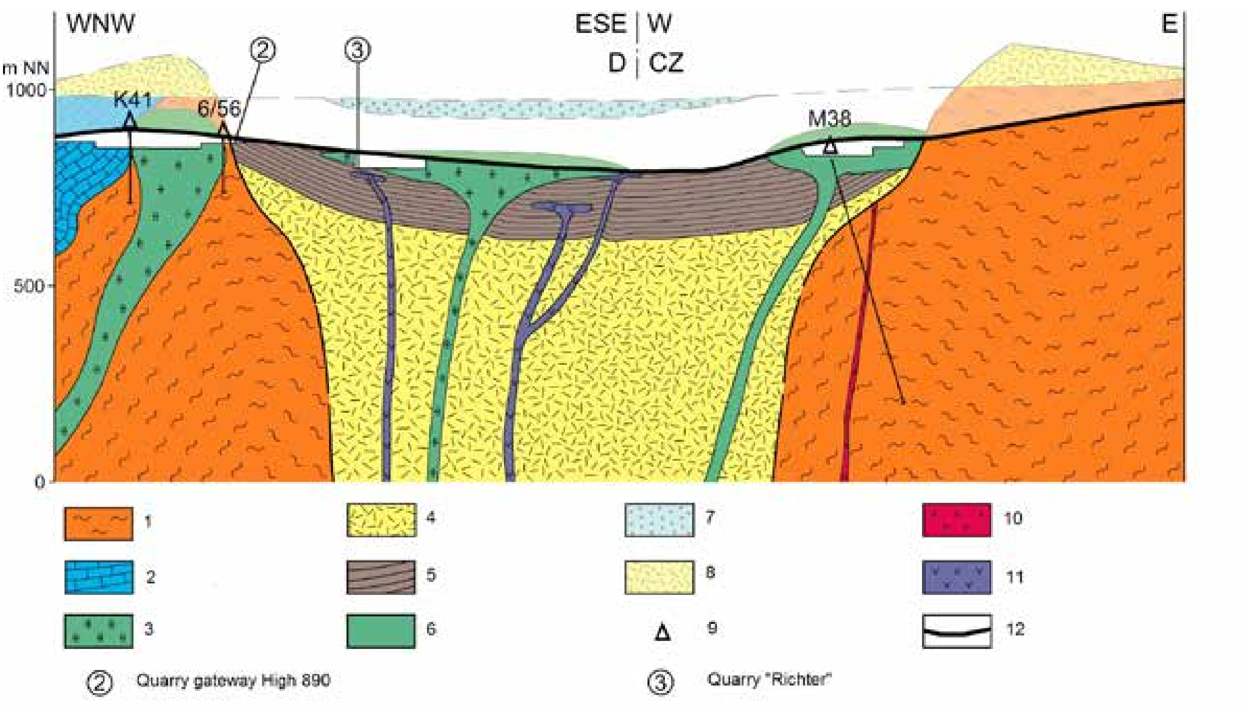


Fig. 6. Cross section of the maar Hammerunterwiesenthal.

1 – Muscovite gneiss;
2 – Marble;
3 – Phonolite;
4 – Diatreme breccia;
5 – Maar-lake sediments;
6 – Tephrite;
7 – Former fluvial gravels;
8 – Former tephra ring of the maar crater;
9 – Drill holes;
10 – Mesozoic hydrothermal vein;
11 – Leucitite intrusions;
12 – Recent surface.

Fig. 7. Profile of the maar-lake sediments in the phonolite quarry Richter.

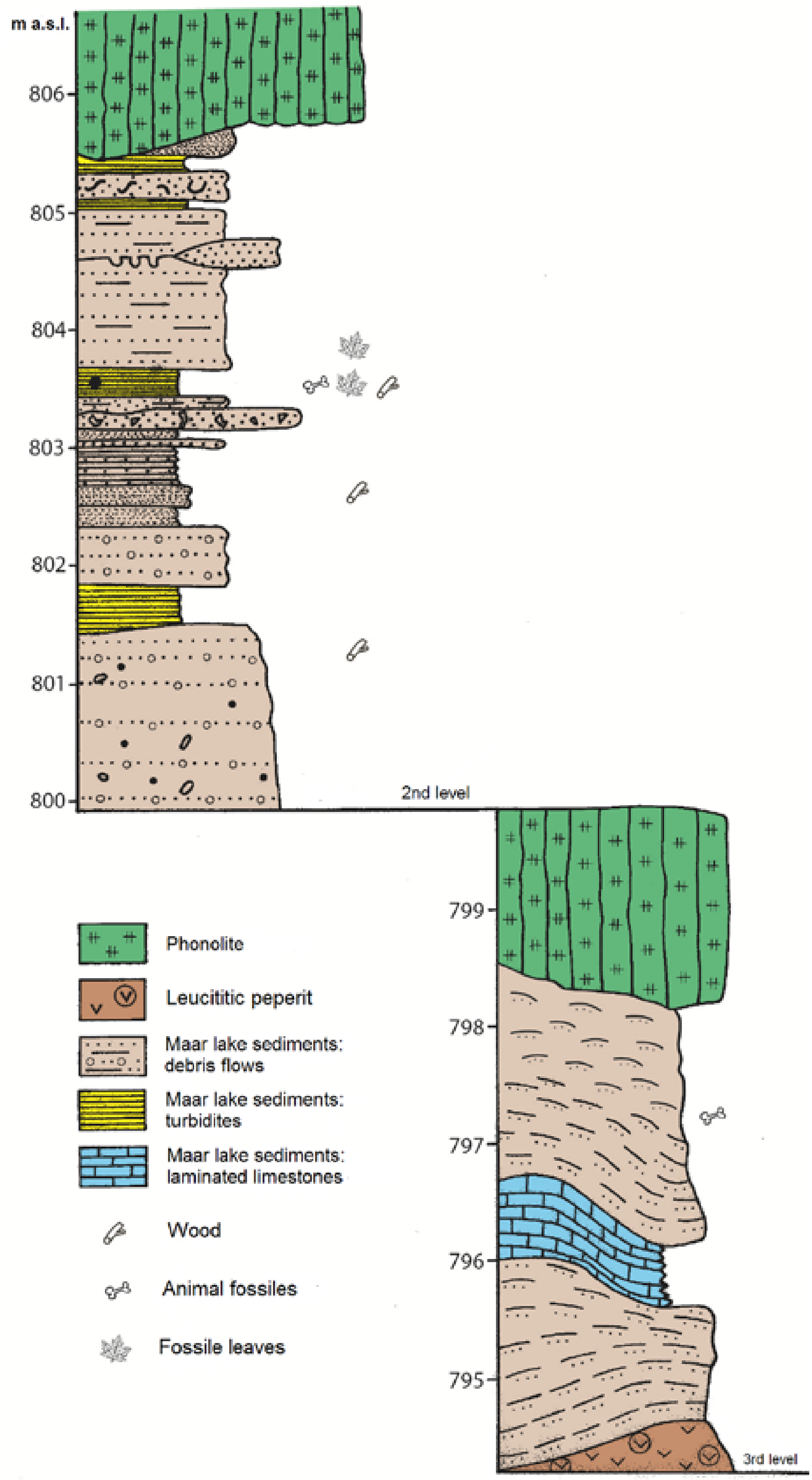


Fig. 8. Examples of turbiditic layers within the maar-lake sediments. Above: Coarse-grained turbidite with load casts; below: thick (12 cm) turbidite with rip-up structure.

Fig. 9. Outcrop of black lacustrine carbonates, partly silicified. The contact to the phonolite is visible on the right of the picture.

Fig. 10. Big pseudopillow of leucitite in peperitic rocks.

Fig. 11. Maar-lake sediment with flora of low diversity.

Fig. 12. Remnant of a corselet of a turtle in debris-flow sediments.

Fig. 13. Vagorichnius ichnosp. at the top of a turbiditic layer.

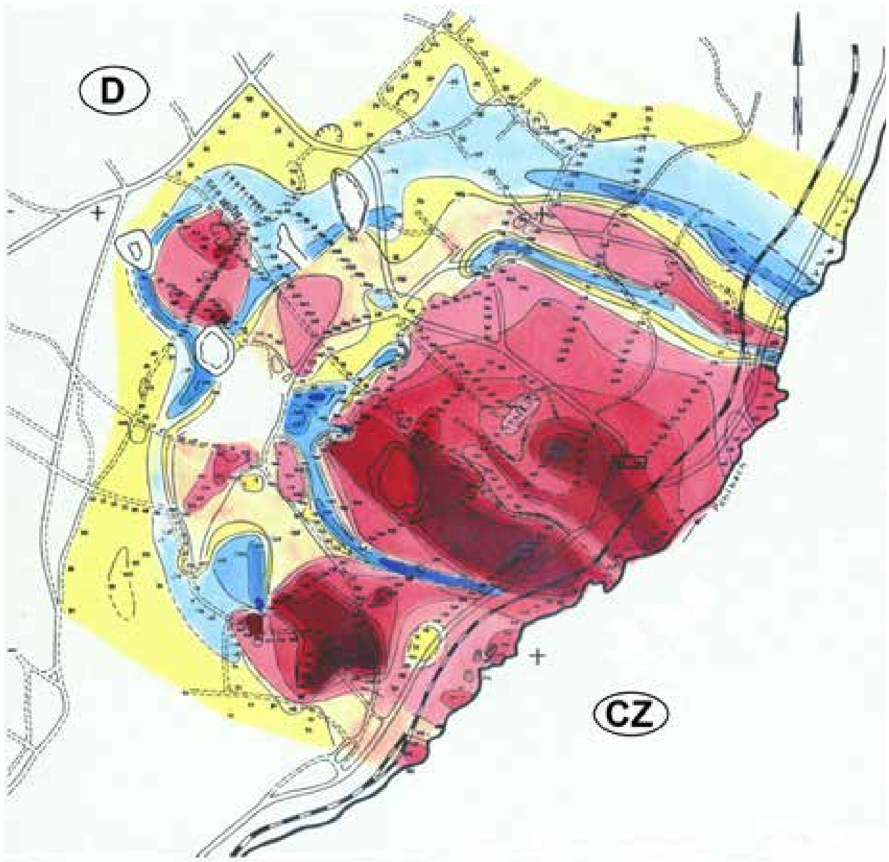


Fig. 14. Map of magnetic anomalies in the area of Hammer-unterwiesenthal (modified after Jäger 1961).

Fig. 15. Peperitic margin of the phonolite; the phonolite intruted into the maar-lake sediments.

Fig. 16. View into the phonolite quarry Richter. The boundary between the phonolite intrusion and the maar-lake sediments is marked by the red line.

Fig. 17. Camptonite dyke in the phonolite.

Locality 2
Mauritius tin-mine at Hřebečná

Horní Blatná granitic body (~12 km^2) belongs to granitic occurrences of the so-called Younger Intrusive Complex which typically have elevated contents of Na, F and incompatible elements while they are somewhat depleted in Ti, Mg, Ca, Fe and K relative to granites of the Older Intrusive Complex, such as the Nejdek–Eibenstock granite massif. Horní Blatná granitic body is likely connected with significantly larger Nejdek–Eibenstock granite massif in greater depths.

Numerous deposits of tin ores have been excavated since at least 15th century in the Ore Mountains (Figs. 18 and 19). These deposits are mostly linked to the occurrences of late Variscan granitic rocks formed from ~330 to ~300 Ma. The most common type of tin ore-rich horizons are the greisen deposits, formed in the post-magmatic realm of granitic intrusions, associated with influx of Sn, W and several other metallic elements. Horní Blatná granite body is known for the largest accumulation of these vein-type Sn–W deposits in the Ore Mountains. The most important mineral mined was cassiterite with crystal size up to 5 mm and the mean Sn concentration of ~0.5% in concentrated ore. Yet, even in 19th Century, some parts of the Sn deposit commonly contained ~2% Sn and in rare parts, Sn contents of up to ~20% were mined. Other ore minerals include pyrite, chalcopyrite, arsenopyrite, löllingite, wolframite, antimonite, and native Bi. Among secondary mineral phases, torbernite, pseudomalachite, beudantite, mixite, mrázekite and libethenite were identified. Quartz is the most common non-ore mineral phase, forming the main part of greisen bodies and sometimes also nearly mono-mineral masses of great extent. Fluorapatite and topaz are quite common in greisen, together with tourmaline, sericite, biotite, fluorite and orthoclase.

The Mauritius mine (Fig. 20) was, in terms of the volume and extent of mining, the largest individual tin mine in the Bohemian part of the Erzgebirge. Although largely flooded nowadays, the accessible parts offer a unique window through ca. 400 years of mining from mid-16th (Fig. 21) to mid-20th Century. The Johannes mine shaft is an exceptionally well-preserved complex of historical mines where the older miners dug enormous underground chambers in an effort to obtain economically important sources of then-used metals. The deepest parts of the mine were ~200 m. Until the inception of modern mining techniques, large mineral deposits that were located sub-horizontally were mined using a technique called 'widening'. With this technique, mine tunnels were used to locate the mineral deposit boundaries and, subsequently, these tunnels were widened to extract all the required minerals. This method was technically quite simple but geotechnically unstable. During spontaneous and unrestrained mining, this method was especially destructive, and often would lead to local cave-ins. This method required the ceiling of the rock bed being mined to be made up of stable material. Around the mid-18th century sub-horizontally located mineral strata began to be mined using a technique that encompassed the use of underhand stoping (horizontal cut) or overhand stoping. This method allowed for better stability of the rock. It is with this technique that the mine chambers in the Johannes mine were created. The steeply inclined mineral veins were mined using the underhand and overhand techniques. The mined ore was transported towards the mine shaft via a stope where, with the assistance of a chute, was poured into the mine carriages and wheeled away.

Unfortunately, no records exist as to how much Sn was mined in the 16th and 17th Century. By mid-18th Century the mine was producing ~400 kg Cu and ~1,700 kg Sn annually. A cumulative estimate of Sn production from the Mauritius mine has been made at ~6,500 tons of tin until 1891.

Fig. 18. Historical illustration of earh-works in the tin-mine.

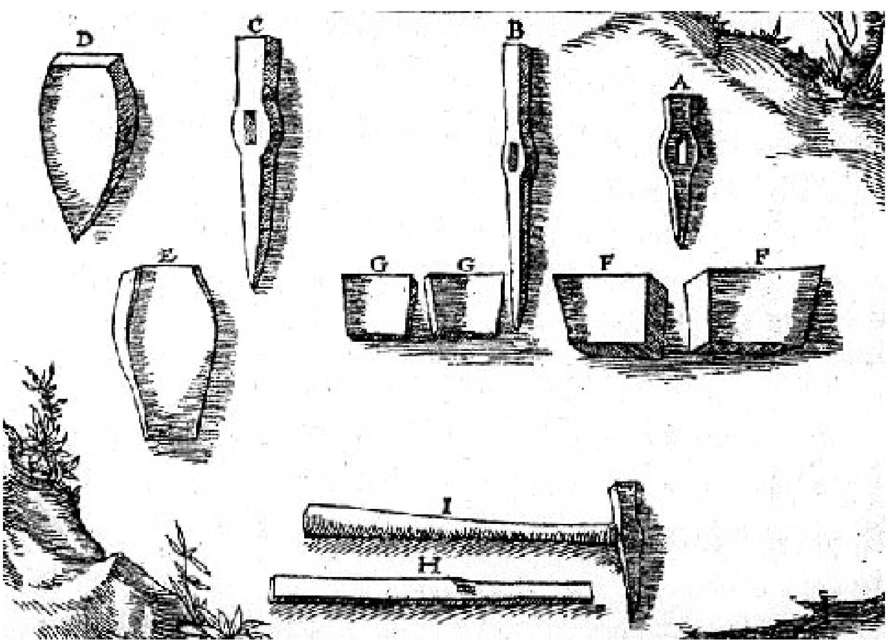


Fig. 19. Mining tools used in tin-mines.

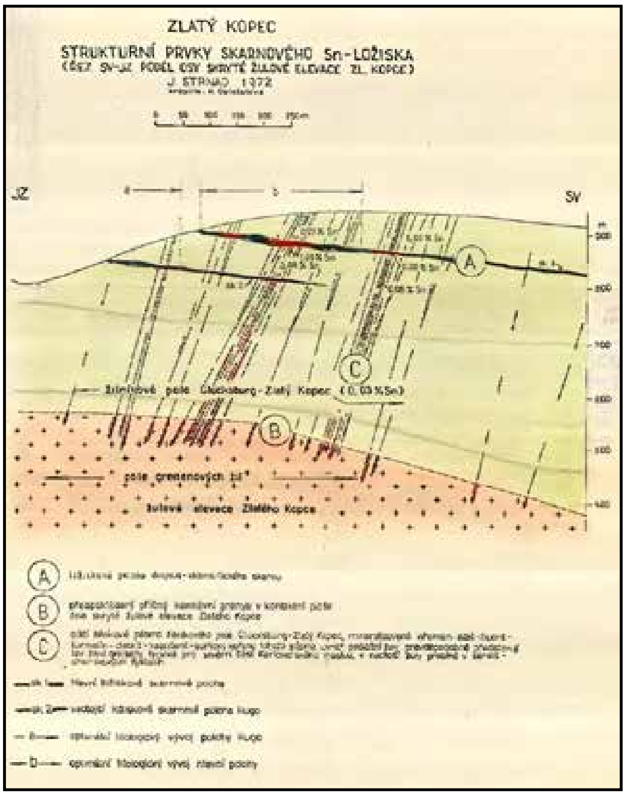


Fig. 20. Geological cross-section of the Mauritius tin-deposit.

Fig. 21. Historical scheme of the Mauritius mine.

Locality 3
Hřebečná abandoned quarry, basaltic lava from the Božídarský Špičák volcano

The abandoned quarry of Hřebečná (at present Natural Reservation Site) at the edge of the Krušné hory / Erzgebirge Mts. fault scarp exposes a well-preserved columnar jointing of trachybasalt. About 270 m long cliff represents a lava flow but its path does not follow recent morphology of the Krušné hory / Erzgebirge Mts. fault. This lava most likely erupted from the nearby Božídarský Špičák volcano (Fig. 22). According to geological mapping and available geochemical data, this volcano erupted two distinct lava flows. The earlier lava of Hřebečná (Fig. 23) of trachybasaltic composition differs in higher contents of silica, aluminium and alkalis and lower magnesium and iron compared to the younger (overlaying) lava of Rýžovna exposed in a small quarry some 400 m to the NE. We explain this reverse geochemical trend of lavas erupted from a single conduit in terms of the presence of a zoned magma chamber below. The upper part of the chamber was depleted in phenocrysts of olivine and clinopyroxene, and therefore during the exhaustive phase of the magma chamber, the more evolved lava was emitted before the less evolved lava.

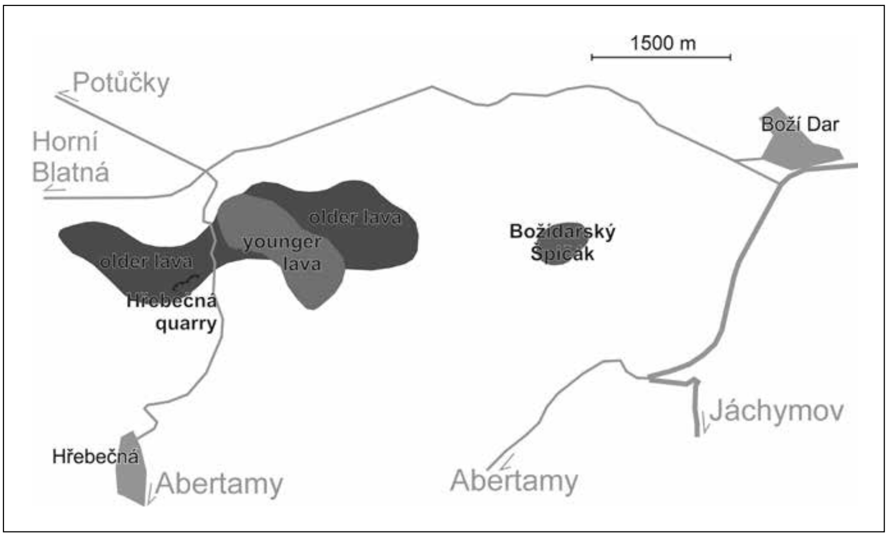


Fig. 22. Sketch map of Božídarský Špičák lava remnants.

Fig. 23. Thick-columnar jointing of trachybasalt in the Hřebečná quarry.

Locality 4
Krásný vrch abandoned quarry, sectioned Miocene basaltic tuff-cone in the Sokolov Basin

Surprisingly well-preserved remnant of a phreatomagmatic tuff-cone can be found in the Sokolov Basin near Hroznětín. The internal structure of the tuff-cone was exposed in a 500 m long profile (Fig. 24) exposed during exploitation of basalt, bentonite, kaoline and uranium ore. In the profile, we can observe inner parts of the volcano as well as periclinally bedded pyroclastic facies of the wall facies of a monogenetic volcano. The pyroclastic deposits are dominated by alternation of clast-supported lapilli-stones (Fig. 25) and tuffs. The basal unit of the pyroclastic deposits contains frequent petrified fragments of fossil wood (Fig. 26). Unfortunately, the petrified wood fragments were completely re-crystalized and do not allow any paleontological classification. The pyroclastic deposits of the upper part contain frequent xenoliths of basement granite (Fig. 27). The central part of the volcano is penetrated by several dykes feeding lava flows covering the top of the hill. Variable orientations of the lava flows dip may suggest shifts in eruptive centre, but this theoretical assumption requires further targeted research.

The age of this spectacular volcano has been recently determined by the K/Ar method at 17.21 ± 0.99 Ma. This age is in good agreement with geological position of the volcano overlaying Miocene sediments of the Sokolov Basin. From the pyroclastic sequence, the eruptive evolution of the volcano can be reconstructed as follows (Fig. 28): a-b) the marshy landscape saturated with water caused phreatomagmatic style of the eruption. The early pyroclastic deposits buried dense flora of the marsh. c) in the water-saturated environment, the focus of the phreatomagmatic explosions was shifting downwards into the granitic basement.d) when the pyroclastic deposits started to insulate ascending magma from surrounding water, the eruptions were no more influenced by phreatomagmatic reactions and basanitic lava flows were emitted.

Fig. 24. A 3D image of the Krásný vrch quarry.

Fig. 25. Close up on clast-supported phreatomagmatic lapilli-stone of the Krásný vrch volcano.

Fig. 26. Basal layer with petrified trees.

Fig. 27. Upper layer with frequent granite xenoliths (upper part of the photo).

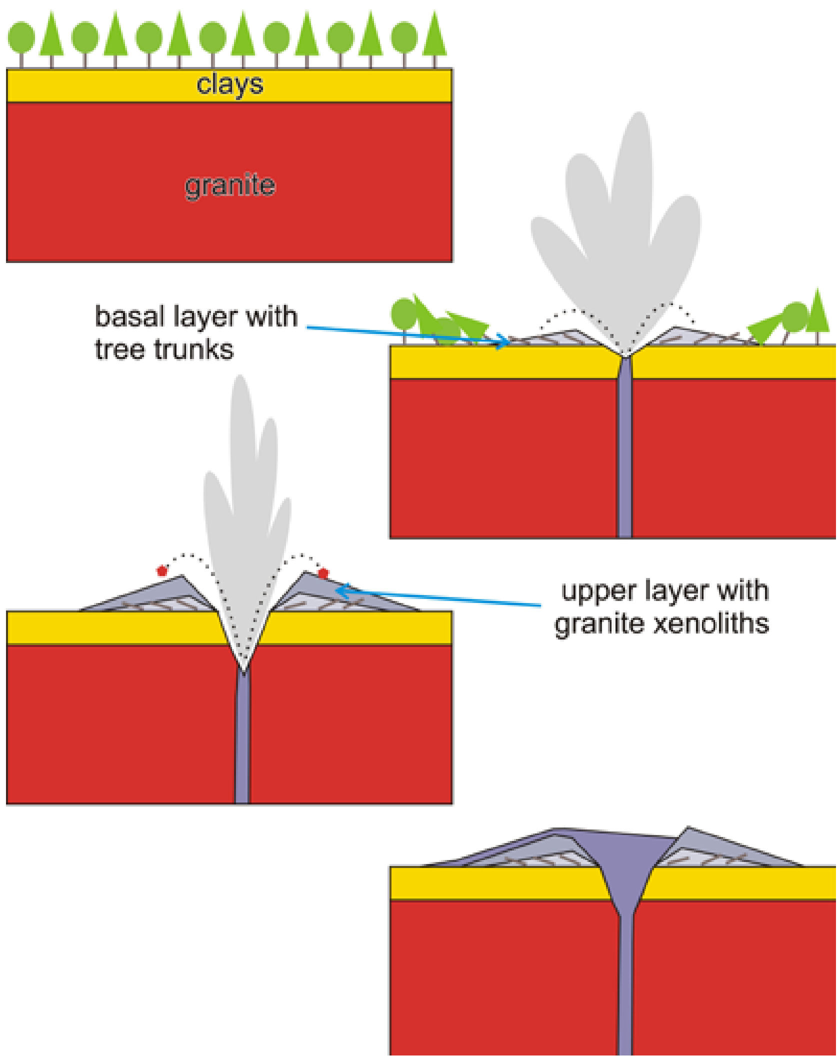


Fig. 28. Schematic evolution of the Krásný vrch volcano.

Locality 5
Sedlečko abandoned quarry, tephriphonolite lava associated with Šemnice phonolite

The Doupovské hory Volcanic Complex (DHVC) is dominated by basaltic lava sequences with only scarce phonolitic and trachytic dykes and lavas being exposed (Skácelová et al., 2009). Two phonolitic bodies (lava dome and spine) then occur on the very western margin of the DHVC. Šemnice lava spine erupted at 25.8 Ma (Ulrych et al., 2003) through granitic rocks of the Nejdek–Eibenstock pluton (Fig. 29). This lava spine was thought to be isolated and not associated with any other volcanic rocks. During the field work in 2017, a tephriphonolitic lava was recognized in close proximity of the Šemnice phonolite. This tephriphonolite lava (formerly mapped as basalt), exposed in several smaller abandoned quarries at Sedlečko (Fig. 30) covers lahar deposits of the DHVC. The thickness of the lava was determined in 1960´s by drilling survey to reach 40 m. The recent morphology, as well as the geometry of the lava base suggest that this lava flew from the Šemnická skála down the rift-fault scarp, over the lahar deposits towards the north, where the valley of present-day Eger / Ohře River started to develop on a tectonic zone probably since Late Oligocene. The petrography suggests that the Sedlečko lava represents slightly more primitive magma before the highly fractionated Šemnice phonolite erupted in the form of volcanic spine.

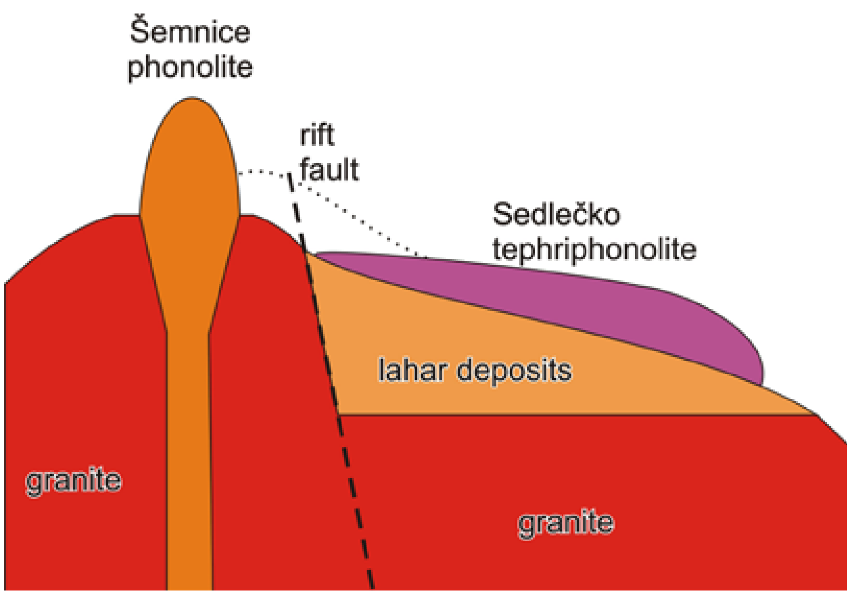


Fig. 29. Scheme of Šemnice-Sedlečko geological situation.

Fig. 30. Combination of columnar and platy jointing of tephriphonolite in the Sedlečko quarry.

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