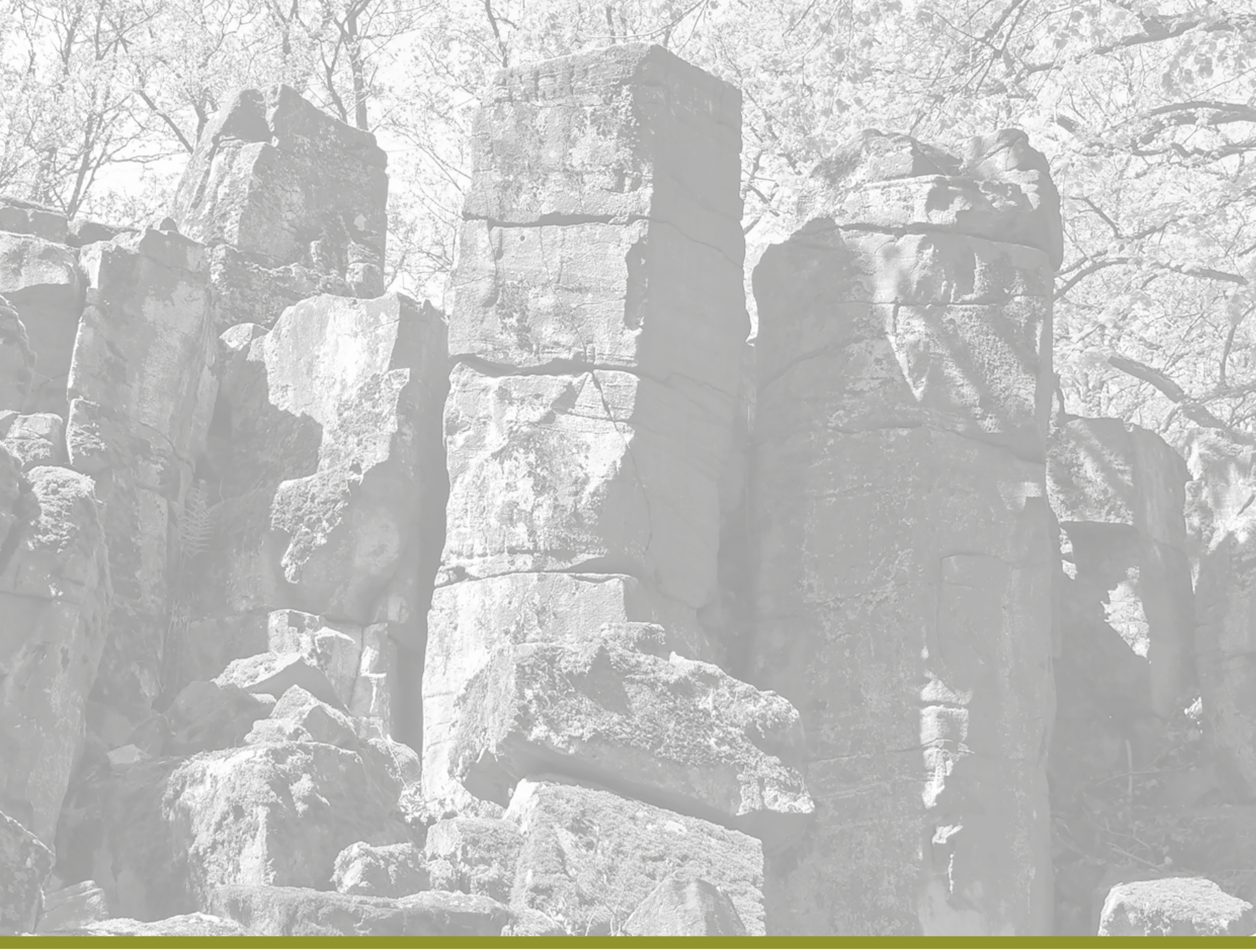

GEOTOPES OF THE BANSKÁ ŠTIAVNICA GEOPARK

VOLCANISM AND STRUCTURE OF THE TERRITORY

RNDr. Vlastimil KONEČNÝ, CSc.
Ing. Patrik PACHINGER

Title: Geotopes of the Banská Štiavnica Geopark – Volcanism and Structure of the Territory

Text authors: RNDr. Vlastimil Konečný, CSc. & Ing. Patrik Pachinger

Reviewers: doc. RNDr. Juraj Bebej, CSc., Javornícka 6180/12, 974 11 Banská Bystrica
Ing. Ján Smolka, CSc., Dolná 24, 969 01 Banská Štiavnica

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Graphic design: Bc. Soňa Laskavá

Translation: Mgr. Marianna Bachledová, Phd., Bc. Mária Bebejová, Bc. Annamária Kapičáková, Bc. Daniela Krnáčová

Proofreading: Mark Wyllie

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Dedication

This publication is dedicated to our families, friends, acquaintances and everyone who supports the idea of establishment and operation of geoparks in Slovakia.

Geoparks as territories are important not only from the viewpoint of geological (the abiotic component of the environment) and biological (the biotic component of the environment) research, but also for archaeology, mining engineering, culture, history, and ethnographic specificity and diversity (the cultural component of the land). They are being established in line with the sustainable development strategy, offer research potential, and help promote the given territory with the focus on environmentalism and education. Geoparks support local development by attracting new economic and cultural activities in the region (nature-friendly and sustainable tourism), and simultaneously help protect the natural and conserve the geo- and biodiversity in Slovakia.

Acknowledgements

We would like to express our sincere gratitude to the Slovak Environment Agency, which supported the creation of this publication and helps raise the environmental awareness of the Štiavnica Stratovolcano – the largest one in Europe – among the broad public.

We would also like to thank our reviewers doc. RNDr. Juraj Bebej, CSc. and Ing. Ján Smolka, CSc. for the attention they paid to the manuscript as well as for their valuable comments and recommendations, which significantly helped us to improve this book.

Moreover, we would like to thank our current as well as former colleagues whose active cooperation and support also allowed for the creation of this unique publication.

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Content

1. Foreword

Dear readers, the book in your hands is difficult to clearly define as specialised or as popular-scientific literature. Its uniqueness lies in the fact that it has been written by a renowned expert whose single goal was to reveal the values, beauty, and stories of the Banská Štiavnica Geopark that would otherwise remain hidden or even invisible to casual visitors. Reading the "hidden" is a gift possessed by few. And only a few of those so inspired can carve such phenomena out of the seemingly invisible reality and what is more, retell their stories for us to make sense as if they were solving a Rubik's cube.

RNDr. Vlastimil Konečný, CSc. (* 25 May 1935 – † 10 March 2018), the author of this publication, was a special person with many talents. In his obituary, his former colleague, RNDr. Jaroslav Lexa, CSc. wrote: "He perfected geological mapping of volcanic complexes in a way that will remain insuperable for a long time. Vlasto was an artist and a great painter. His paintings of the Slovak countryside decorate many of his colleagues' walls. He put this talent to use in his specialised work, too. His drawings of exposures in geological documentation provide not only an aesthetic experience, but they are even more faithful than photographs. Vlasto left us not only the results of his work, but also a series of beautiful paintings." (Geologické práce, News No. 130, pp. 77–82, State Geological Institute of Dionýz Štúr, Bratislava 2017).

The presented publication can be perceived as an effort to repay an imaginary debt to this great man of geological sciences – it showcases many of his exposure illustrations pertaining to the Banská Štiavnica Geopark geological documentation, which he has not only drawn, but also described and turned them into a story. Therefore, the reader has the opportunity to get to know the artistic side of this reputed volcanologist.

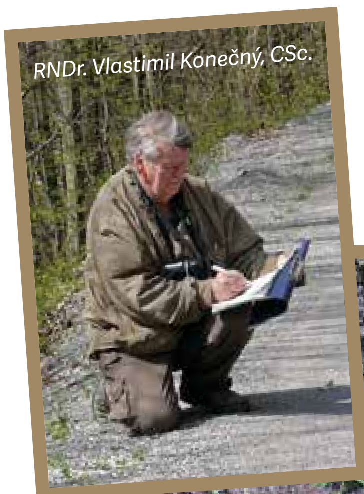
The work on this publication started as early as between 1998 and 2005 when the Banská Štiavnica Geopark was being established and an eponymous geological research task under the auspices of the State Geological Institute of Dionýz Štúr (SGIoDŠ) was completed with the co-investigating organisations: The Slovak Environment Agency in Banská Bystrica (SEA), the Slovak Open-Air Mining Museum in Banská Štiavnica, and the UNESCO Department of the Faculty of Ecology and Environmental Sciences at the Technical University in Zvolen. This broad cooperation among multiple organisations allowed for representative processing of all major objects from the fields of geology, mining engineering, ecology, and biology. This publication is based on an extensive study written by RNDr. Vlastimil Konečný, CSc. 14 years ago, in 2008, which has been edited by Ing. Patrik Pachinger, an employee of the Slovak Environment Agency and currently the President of the Inter-Departmental Commission of the Geoparks Network of the Slovak Republic.

Most of this publication is dedicated to the geotopes of the Banská Štiavnica Geopark – which have been described by RNDr. Vlastimil Konečný, CSc. in a clear and comprehensive way and supplemented by graphic illustrations, and maps. For specialised readers, rock descriptions include brief qualitative and quantitative parameters of the respective rock-forming minerals. Other descriptions include interesting national historical and geographic contexts. This book includes more than 650 figures (schemes, cross-sections, line drawings), photographs, and maps, which make it unique.

A summary of the knowledge about the structure of the exceptional and impressive Štiavnica Stratovolcano can be found at the end of this book. The logical order of chapters allows the reader to understand the complexity of the geological structure of this area not only from the viewpoint of its ancient historical development, but also its current condition. The narrative value of this book will delight both fans of geology and experts in the field.

Dear fans of geology, mining engineering, and ecology, I am convinced that the establishment of the Banská Štiavnica Geopark in the territory of the Štiavnica stratovolcano will significantly contribute to the visibility of the Banská Štiavnica region, and support the efforts to ensure the sustainable development of local tourism. The town in the middle of the largest European stratovolcano deserves all the admiration, respect, and interest, which it is getting around the world. This unique place deserves a geopark to cherish and protect. This publication could contribute to this goal.

Ing. Ján Smolka, CSc.


RNDr. Vlastimil Konečný, CSc.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2. Introduction

The Štiavnica Mountains are part of the volcanic mountain ranges of Neogene andesite volcanism in Central Slovakia – they developed during the later Neogene, specifically Baden and Sarmat.

The systematic research and geological mapping performed by the State Geological Institute of Dionýz Štúr (SGIoDŠ) identified denudation remains of the vast andesite Štiavnica Stratovolcano with the area of more than 2,200 km^2. These remains extend from the Štiavnica Mountains to the Pohronský Inovec mountain range. Towards the north-west, they extend to the eastern and southern parts of the Vtáčnik Mountain, and towards the north-east, they extend to the southern edge of the Kremnica Mountains. Southwards, the products of this stratovolcano lie in the former marine environment of the Krupina Highlands and Ipeľská Pahorkatina Upland (south of Šahy).

The Štiavnica Stratovolcano has a complex structure and is composed of varied rocks – from basalt and basaltic andesite to rhyolitic rocks.

Within this stratovolcano, multiple subvolcanic intrusive complexes as well as a large caldera (18 x 22 km) developed. After the uplift of a vast block in the caldera area, a horst structure formed – the Hodruša-Štiavnica Horst – where the precious metals and polymetallic ores of the Banská Štiavnica-Hodruša Ore Field can be found. The presence of precious metals allowed for the establishment and boom of Banská Štiavnica and Banská Hodruša in the Early Middle Ages. After the establishment of the Mining Academy in (1764), Banská Štiavnica became the centre of geology and mining engineering research with an exceptional contribution to scientific progress during the period.

Natural geological patterns, their interesting volcanic forms, and rock types representing geotopes were researched within the individual tourism territorial units (TTU) of the Banská Štiavnica Geopark. So far, locations in the central part of the Štiavnica Mountains were systematically researched (TTU Štiavnické Bane and TTU Banská Štiavnica) and reported on in the Partial Final Report on the Geological Task No. 04 00 "Establishment of the Banská Štiavnica Geopark" (J. Smolka et al., 2004) and the Final Report on the Geological Task No. 04 00 "Establishment of the Banská Štiavnica Geopark" (J. Smolka et al., 2005). The geological locations researched as geological objects, which are located along the individual educational hiking routes, reflect the structure of the more central parts of the Štiavnica Stratovolcano. However, they only cover a part of the lithological rock types and volcanic forms found in the area. Due to this fact, the systematic research of the representative locations (geotopes) in other TTU covering the slopes of the vast stratovolcano still continues.

In terms of the individual TTU, representative locations which best characterise the geological structure of these areas have been selected and researched. In total, 103 geotope locations have been researched.

These locations have been arranged according to their stratigraphic position in the respective TTU from the oldest to the youngest, allowing the geopark visitor to understand how the Štiavnica Stratovolcano developed over time.

The latest research led to a new synthesis of the geological structure of the Štiavnica Mountains, which resulted in the creation of a geological map of the Štiavnické Vrchy Mountains and the Pohronský Inovec mountain range in the scale 1:50,000 (V. Konečný et al., 1998).

Besides geotopes, this publication briefly summarises the knowledge of the Štiavnica Stratovolcano structure, its metallogeny, and geotectonic position within Neogene volcanism (J. Smolka et al., 2003). It also provides a brief overview of geological surveys and research from early periods until today (J. Smolka et al., 2003).

Geotopes of the Banská Štiavnica Geopark

3. Tourism Territorial Unit Banská Štiavnica

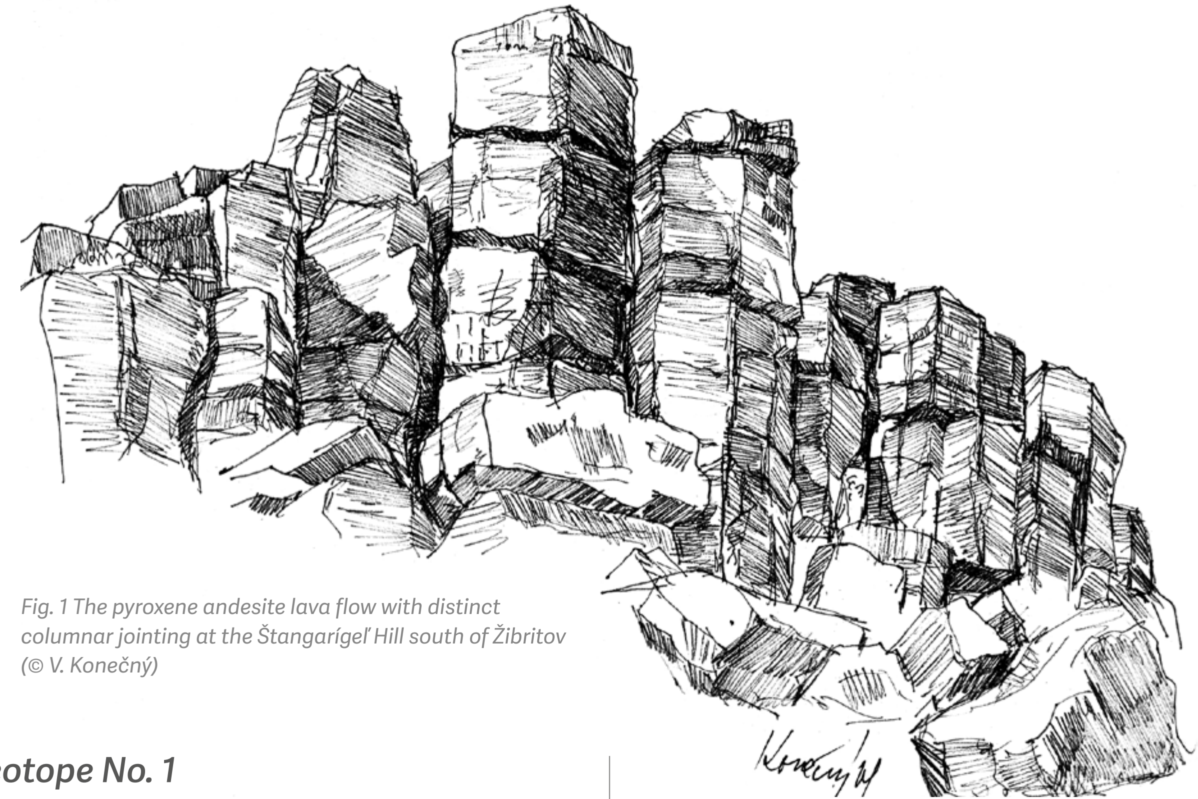


Fig. 1 The pyroxene andesite lava flow with distinct columnar jointing at the Štangarígeľ Hill south of Žibritov (© V. Konečný)

Geotope No. 1

Štangarígeľ

Lava flow with columnar jointing, bottom stratovolcanic structure

At the top of the hill historically named Štangarígeľ (elevation 482m), andesite rocks with distinct columnar jointing can be found (Fig. 1, Photo 1).

Fig. 2 A. Kmeť's bust and commemorative medal (J. Smolka et al., 2005)

In the past, this location was visited and described by Andrej Kmeť, an enthusiastic natural history researcher. Besides dedicating his life to priesthood, he researched nature in this part of the Štiavnica Mountains (Fig 2).

Columnar jointing occurs in lava bodies, mainly lava flows, after they stop moving and start to solidify and crystallise. When the lava body starts shifting to a solid crystalline state, its volume reduces. Due to internal stress, cracks occur and their regular distribution results in regular columnar jointing. This is how contractive jointing is formed (Fig. 3).

Columnar jointing is characteristic and frequent mainly in lava with basalt composition. For example, the "stonefall", a basalt body at the Šomoška castle hill in Southern Slovakia. Columnar jointing also occurs in phonolite lava bodies in Central Bohemia Highlands and the well-known location Teplice – Šenov is often referred to in geology text books.

Less frequently, columnar jointing occurs in basaltic andesite lava bodies. For example, the lava flow opened by the quarry near Šášovské Podhradie (Ladomer).

In the case of the lava flow at the Štangarígeľ Hill, columnar jointing occurred in the andesite of basic composition. The columns are 1 to 1.5 m wide and have five, six, or even more sides (i.e., they are polygonal). Subhorizontal jointing dividing the columns crosswise is visible. This subhorizontal jointing (lamination area-wise) is roughly parallel to the flow base as well as the surface along which the lava flow moved. The orientation of lamination jointing indicates that this lava flow was moving along a flat terrain.

Photo 2 A close-up of the "mysterious signs" (© P. Pachinger).

Columns in its central part resemble vertical "signs" or mysterious "writing". These signs are heavily weathered and their contours are not very clear (Fig. 4, Photo 2). In the local oral tradition, they are considered a written message from an ancient age.

Photo 1 A view of the rocks with columnar jointing at the Štangarígeľ Hill (© P. Pachinger).

However, upon a closer look, it seems that these somewhat regular, tiny shapes follow the tiny vertical cracks and their lateral expansion occurs at the intersections with the horizontal cracks. This pattern is natural and the weathering process contributed to its formation.

On the other hand, every visitor is free to form their own opinion on the origin of these "signs".

The rocks at the Štangarígeľ Hill are composed of basic pyroxene andesite rich with augite. Andesite is dark grey to grey-black, medium porphyric. Phenocrysts are composed of 20–25% of plagioclase $An_{65\text{-}70}$ (6.5–2 mm); 5–6% of augite (0.5–2.5 mm), and 4–5% of hypersthene (0.3–1.5 mm) 4–5%. Augite often prevails over hypersthene, i.e., this andesite is hypersthene-augitic. The base matter is pilotaxic-microlitic to micropoikilitic and fills the spaces between the phenocrysts. It forms tiny needles of plagioclase and pyroxenes.

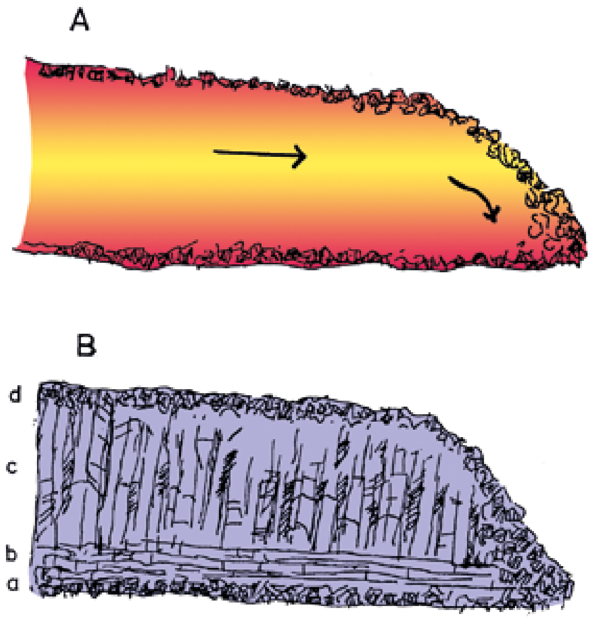
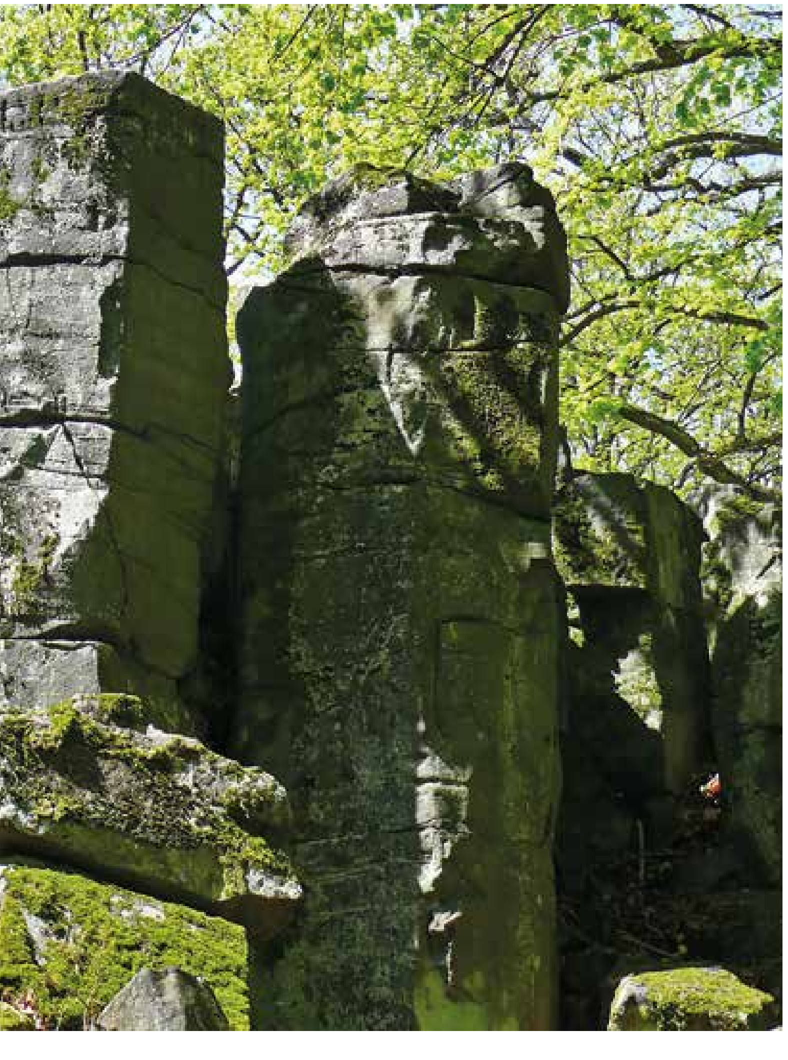


Fig. 3 The formation of contractive columnar jointing (J. Smolka et al., 2005):

A – While the lava flow moves, its cooling surface is turning into a firm crust, which later proceeds to fracture and break, B – when the lava flow stops moving, cooling and crystallisation leads to the formation of columnar jointing (c). It results from the internal stress, which occurs when the lava body reduces is volume during solidification and crystallisation. At the bottom part of the lava flow, mural jointing occurs (b) parallel to the bedrock surface along which the lava flow is moving. At the upper and bottom edges of the lava flow, lava breccia occurs (a, d).



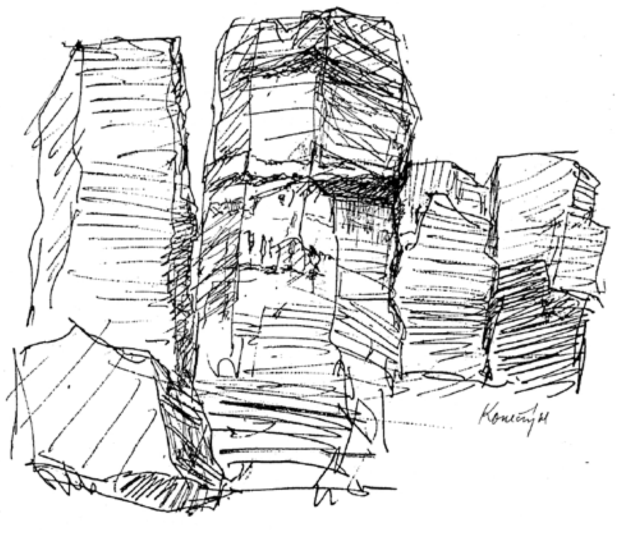


Fig. 4 "Mysterious signs" on the andesite column (© V. Konečný).

Geotope No. 2

Tanád Hill

Bedded intrusion of andesite porphyry, bottom stratovolcanic structure

The upper part of the huge Tanád-type andesite porphyry body is laid bare at the crest of the Tanád Hill. This body takes the form of a bedded intrusion with blocky to columnar jointing (Fig. 1, Photo 1), it lies in the overlying rock of the lava flow complex composed of pyroxene and amphibole-pyroxene andesites, it inclines towards South-East (geological section Fig. 2).

The formation process of the Hodruša-Štiavnica Horst
The horst structure of the central part of the Štiavnica Mountains was formed in the final stage of the stratovolcano formation, i.e., after the formation of the caldera and the following andesite volcanism of the Sarmatian. Today's horst structure (Fig. 2) was formed due to the gradual rise of the large central block in the caldera (approx. 11 to 9 million years ago) between the end of the Sarmatian and the Pannonian. It represents the central part of the Štiavnica Mountains. It was a process of truly grandiose dimensions as the horst block stretches across the area of ca. 11x17 km.

As the horst block was rising, the Žiarska Kotlina Basin was subsiding. Along the fault zone at the western edge of the horst as well as along the tectonic boundary between the rising horst block and the subsiding block of the Žiarska Kotlina Basin, rhyolitic matter rose to the surface.

Photo 1 Andesite porphyry with coarsely-columnar to mural jointing at the top of the Tanád Hill area (© P. Pachinger).

During this period, there was tumultuous volcanic activity in the Žiarska Kotlina Basin area. The formation of extrusive rhyolite domes and effusions of rhyolite lava were accompanied by massive eruptions of ash and pumice, which settled in the subsiding depression. In terms of the hydrothermal processes, hot springs formed, which allowed for the alteration of the rhyolitic

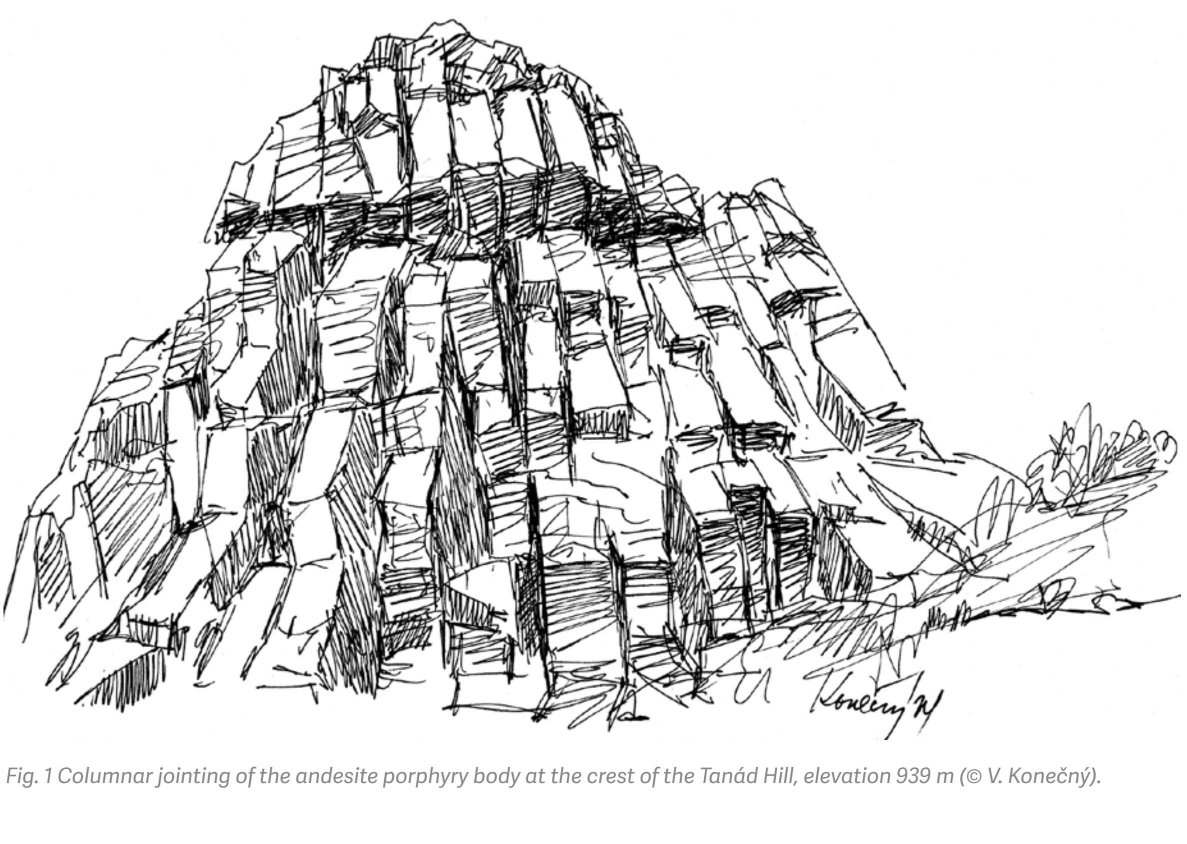
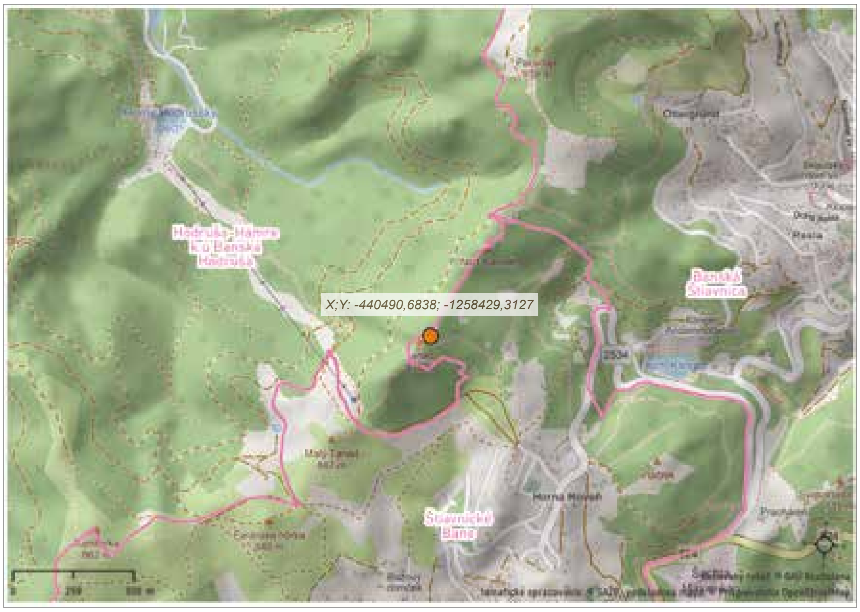


Fig. 1 Columnar jointing of the andesite porphyry body at the crest of the Tanád Hill, elevation 939 m (© V. Konečný).

tuffs and the creation of bentonite with the clay minerals of kaolinite, montmorillonite, illite, etc.

The current bedrock level of the volcanic rocks indicates the magnitude of the vertical movements between the rising horst block and the subsiding block of the Žiarska Kotlina Basin. In the Žiarska Kotlina Basin area, the bedrock subsided 1,600 m below the sea level, while the bedrock of the western part of the horst is currently located 800 m above the sea level. Before the horst rose, the collapsed complexes in the caldera were located ca. 1,500 m below the sea level (bedrock level).



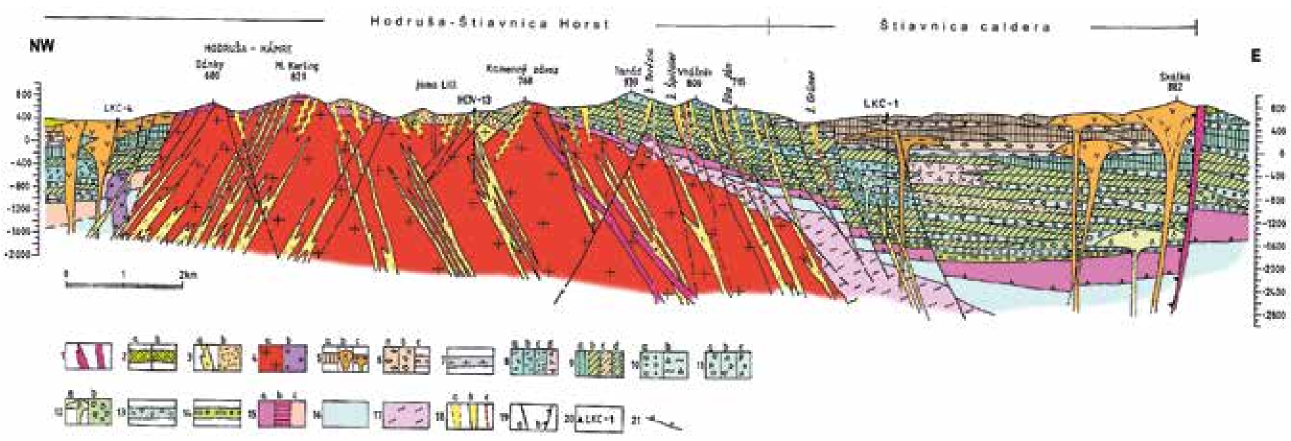


Fig. 2 A geological section through the central volcanic zone at the Hodruša-Štiavnica Horst and caldera (J. Smolka et al., 2005).

1 – rhyolite and rhyolite porphyry dykes (Late Sarmatian).
The upper structure of the Štiavnica Stratovolcano (Sarmatian):
2 – lava flows: a) amphibole-pyroxene andesite with biotite (the Sitno Complex), b) pyroxene andesite ± amphibole (the Jabloňový Vrch Hill effusion complex).
Intrusive complexes:
3 – quartz-diorite porphyry intrusive complex (Banisko complex): a) dykes, b) bedded intrusion, 4 – the Hodruša-Štiavnica Intrusive Complex: a) granodiorite, b) diorite.
The fill of the Štiavnica caldera (Late Baden, Early Sarmatian):
Biotite-amphibole andesite volcanism products (the Studenec Formation):
5 – a) lava flow, b) extrusive dome, c) sill bedded intrusion, 6 – a) pumice tuffs, b) epiclastic volcanic breccias, c) siltstone, claystone, lignite interbeds, 7 – epiclastic volcanic sandstones with siltstone and lignite (the Červená studňa Formation).
Bottom stratovolcanic structure (Baden):
8 – bedded intrusions (sills, laccolites) of andesite porphyry: a) pyroxene-andesite porphyry rich with Tanád-type augite, b) pyroxene andesite ± amphibole, b) pyroxene-andesite porphyry, d) amphibole-pyroxene andesite porphyry ± quartz ± Myšia Hora type garnet, 9 – lava flows: a) basic pyroxene andesite ± olivine, b) pyroxene andesite, b) pyroxene andesite ± amphibole, d) amphibole-pyroxene andesite; 10 – volcanoclastic rocks: a) chaotic breccias of pyroclastic flows, b) tuffaceous breccias, 11 – a) coarse epiclastic volcanic breccias, b) fine epiclastic volcanic breccias, c) epiclastic volcanic breccia conglomerates, 12 – products of extrusive volcanism of hypersthene-amphibolite andesite with garnet: a) extrusion, b) coarse to block epiclastic breccia, 13 – basal group of strata, epiclastic volcanic sandstones, conglomerates.

The geological structure of the Hodruša-Štiavnica Horst
The uplift of the horst block was asymmetrical to the maximum uplift at the north-western edge. As a result, the horst structure inclines 10–120˚ towards SE. The subsequent denudation processes first removed the volcanic rocks (rocks at the bottom of the stratovolcanic structure, caldera fill, and the products of the Sarmatian volcanism) and at the western part of the horst, a large area of pre-volcanic bedrock was uncovered on the surface (geological section, Fig. 2).

The oldest rocks in this area are crystalline schists and a granodiorite intrusion (crushed Vyhne granite) of Veporic crystalline dating back to the Hercynian (ca. 280 million years). In the overlying crystalline rocks, Mesozoic rocks of the Veľký Bok series are located (Triassic, Jurassic, and Cretaceous periods). On the rocks pertaining to Veľký Bok, Hronicum nappe rocks are located in the forwarding position (Šturec Nappe), the sediments on the bottom date back to the Carboniferous and Permian periods, while the upper rocks date back to the Mesozoic, specifically the Triassic Period. Discontinuously deposited sediments of the Paleogene Period have been preserved on the Mesozoic rocks.

Granodiorite pluton
A denudation cut in the central part of the horst exposed a large subvolcanic granodiorite intrusion located in the bedrock (Fig. 3).

In the bedrock of the volcanic complex, granodiorite pluton extends into the area of Banská Štiavnica as it has been confirmed by boring and mining. The total area of this pluton is more than 100 km². Diorite intrusions are located at the northern and western edges of this granodiorite body.

For the following intrusions of granodiorite porphyry (Zlatno type) that penetrate the bottom of the stratovolcanic structure, metallogeny is typical. The later intrusi-

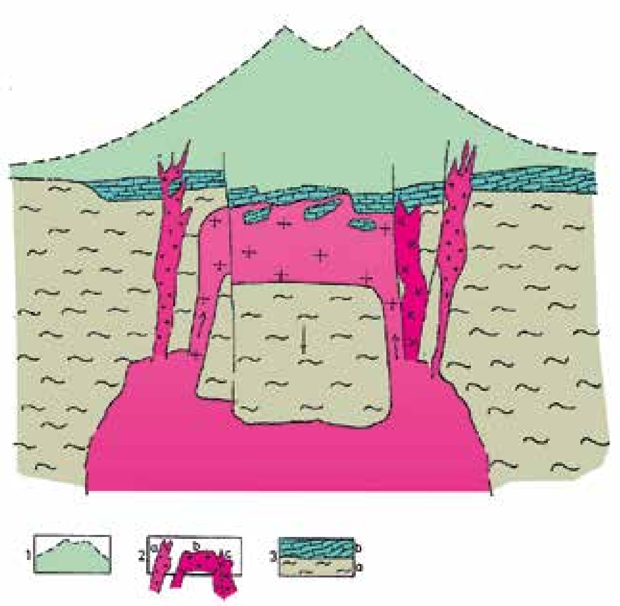


Fig. 3 The formation processes of subvolcanic intrusion, forms of intrusive bodies (J. Smolka et al., 2005).

Magma chamber, subsiding bedrock block, stratovolcano: 1 – stratovolcano, 2 – forms of stratovolcanic intrusions of the Štiavnica Stratovolcano: a) stock-dyke intrusion of granodiorite porphyry (Zlatno complex), b) upside-down bell granodiorite intrusion c) stock diorite intrusion, 3 – pre-volcanic bedrock: a) crystalline complex, b) Mesozoic.

ons of quartz-diorite porphyry dating back to the caldera stage take the form of bedded intrusions and dykes, and penetrate the bottom of the stratovolcanic structure, or even the base of the caldera fill.

Most probably, the granodiorite pluton formed during the final stage of the development of the bottom of the

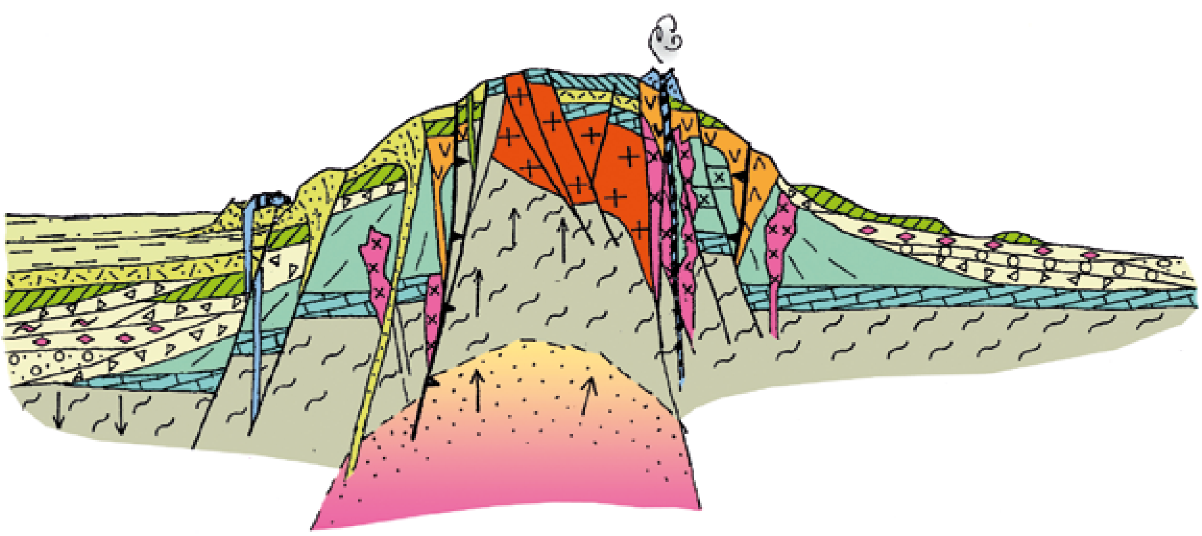


Fig. 4 The scheme of the Hodruša-Štiavnica Horst formation related to the intrusion of granite-rhyolite magma under the volcano (J. Smolka et al., 2005).

stratovolcanic structure at the end of Baden. Radiometric dating supports this idea. Granodiorite magma filled the space in the overlying rock of the bedrock block, which subsided into the magma chamber (Fig. 3).

Reasons for the rise of the horst block

Understandably, this topic can only be addressed in theory. Arcuation of the central part of the caldera during the post-caldera stage has been identified in multiple large calderas around the world (e.g. Creed, Silverton, and Vales calderas in the US). One of the possible explanations is isostasy – less dense and lighter matter (in this case volcanic rocks), which had previously subsided into the space with denser and heavier matter, was pushed upwards in the process of isostatic balance restoration.

Another reason could be a larger volume of acid rhyolitic magma under the arcuation, which was suspected in the case of the large US calderas by R. L. Smith and R. A. Bailey (1968). This concept was applied by V. Konečný (1970, 1971) who tried to explain the formation of the Hodruša-Štiavnica Horst accompanied by rhyolitic volcanism (Fig. 4).

Formation of the horst and metallogenetic processes

The horst did not rise as a monolithic block – as the horst block was rising, it disintegrated into parts (segments) along the fault lines and zones. Some of these faults and fault zones, which divided the subsiding segments (mainly the fault lines and zones with NW-SE to NS directions), allowed for the rise of hydrothermal ore-bearing solutions as well as ore veins of precious metals and polymetallic ore veins in the Banská Štiavnica and Hodruša ore deposits. The magnitude of the tectonic movements accompanied by crushing along these zones ranges from tens of metres to several hundred metres (Fig. 4).

The bottom stratovolcanic structure at the eastern edge of the horst – the Štiavnica part

The denudation cut in the eastern (Štiavnica) part of the horst removed the caldera fill including the later volcanic complexes dating back to the Sarmatian volcanism, middle and lower levels of the stratovolcanic structure were exposed. Therefore, this denudation cut provides a unique opportunity to see the bottom structure of the stratovolcano during the first stage of its formation.

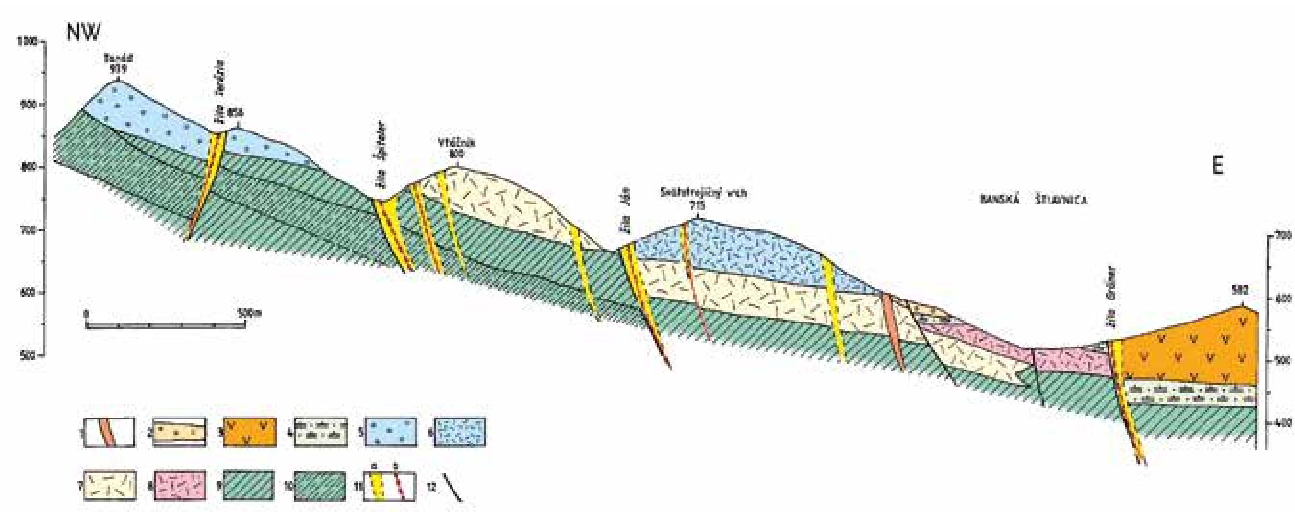


Fig. 4 The scheme of the Hodruša-Štiavnica Horst formation related to the intrusion of granite-rhyolite magma under the volcano (J. Smolka et al., 2005).

Banisko intrusive complex:
1 – dyke of quartz-diorite porphyry, 2 – bedded intrusion of biotite-amphibole andesite porphyry (± pyroxene), Paradajs type.
Fill of the Štiavnica caldera:
3 – products of biotite-amphibole andesite volcanism, lava flows, extrusions, unsegmented volcanoclastic rocks (the Studenec Formation), 4 – epiclastic volcanic sandstones with siltstone and lignite (the Červená Studňa Formation).
Bottom stratovolcanic structure:
5 – pyroxene-andesite porphyry rich with Tanád-type augite, 6 – pyroxene-andesite porphyry, 7 – pyroxene-andesite porphyry (± amphibole) – Vtáčnik type, 8 – amphibole-hypersthene andesite porphyry with biotite (± quartz), 9 – amphibole-pyroxene andesite (lava flow), 10 – pyroxene andesite (lava flow).
Alterations around the veins, metallogeny:
11 – a) argillitisation zone, b) ore vein.
Explanatory notes:
12 – fault.

Photo 3. A view of the northern part of the Štiavnica Mountains, the Hodruša part of the horst structure. The crest composed of the uplifted pre-volcanic bedrock can be seen in the background, the lower Hodruša Lake is located in the valley (© P. Pachinger).

The bottom structure consists mainly of lava flow bodies – pyroxene and amphibole-pyroxene andesites alternating with volcanoclastic rocks (geological section Fig. 2). Towards the end of the first stage, the central zone was penetrated by numerous bedded intrusions (sills and laccoliths) of andesite porphyry. A pyroxene andesite porphyry body (Tanád type) forms the upper part of the Tanád Hill's crest.

Due to the asymmetrical structure of the horst, which inclines towards SE, the lava bodies including bedded intrusions also incline 10–12° towards SE (geological section Fig. 2). The rocks in the bottom structure are propylitised to varying degrees and disturbed by fault tectonics, which makes their demarcation in terms of geological mapping quite difficult. During the final stage of the horst formation, the faults and fault zones allowed hydrothermal fluids and ore-bearing solutions to rise. Today, they take the form of vein structures with ores of precious metals and polymetallic ores.

At the eastern foot of the horst (Fig. 5), the Štiavnica caldera fill has been preserved (originally, it extended to the horst itself).

Andesite porphyry is medium-grained porphyric, grey-green to blue-green (due to propylitisation). Phenocrysts are composed of plagioclase 1–3 mm (ca. 27%), hypersthene 1–2 mm (ca. 10–11%), augite 2–3 mm (ca. 10%). The base matter accounts for 51–52%, it is granular (microlitic-granular to microhypidiomorphically granular) and composed of plagioclase and pyroxene grains.

Due to the alteration (propylitisation), pyroxenes have been partly to completely replaced with a secondary mineral – chlorite. Jointing is coarsely-columnar along the following planes: 340 NW/550, 120 SE/2500 a 80 EN/800.

The crest of the Tanád Hill offers a panoramic view of the northern and southern parts of the Štiavnica Mountains (Photos 3 and 4).

Photo 4. A view of the southern part of the Štiavnica Mountains. Foreground – a broader area of the Štiavnica caldera and Banská Štiavnica, background – the rocky crest of the bottom stratovolcanic structure behind the caldera fault (© P. Pachinger).

Geotope No. 3

Pracháreň

andesite porphyry, bottom structure of the Štiavnica Stratovolcano

Andesite porphyry, exposed by a trench of the state road (Fig. 1) is a part of a more robust body protruding from the broader surroundings of Banská Štiavnica, specifically around the Svätotrojičný Vrch Hill, Tanád Hill slopes, and above the town of Banská Štiavnica – elevation 779.

Bedded intrusions of andesite porphyry penetrated the bottom stratovolcanic structure in the later stages of its formation mainly in the form of sills and laccoliths (Fig. 2).

Fig. 1 The bedded intrusion (sill) of andesite porphyry in the trench of the state road at the slope under the Svätotrojičný Vrch Hill (© V. Konečný).

These bedded intrusions typically cover a relatively large area of several km² and their thickness ranges from several tens of metres to 250 – 300 m. Bedded intrusions formed in favourable lithological interfaces (mainly among volcanoclastic rocks, lava flows or between the bedrock and volcanic structure), which least resisted penetration. Since their location is concordant with their stratification, they are sometimes referred to as "bedded bodies", which distinguishes them from dykes that penetrate the faults discordantly (across) the layered rocks. Bedded intrusions of andesite porphyry show thick-blocky or thick mural jointing. Less frequently, coarse-columnar jointing or its signs can be found, as in this case.

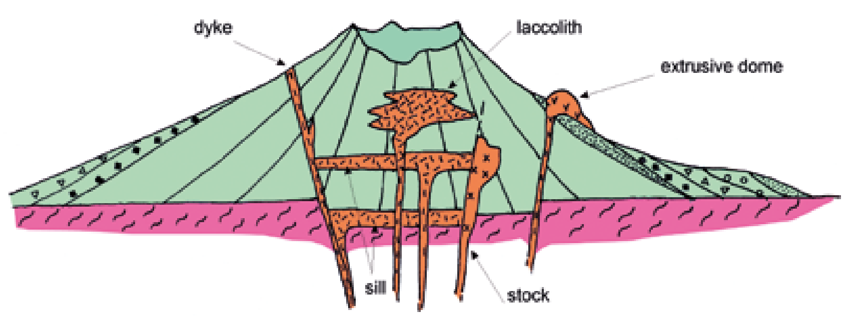


Fig. 2 The position of the intrusive bodies in the bottom structure of the Štiavnica Stratovolcano (J. Smolka et al., 2005).

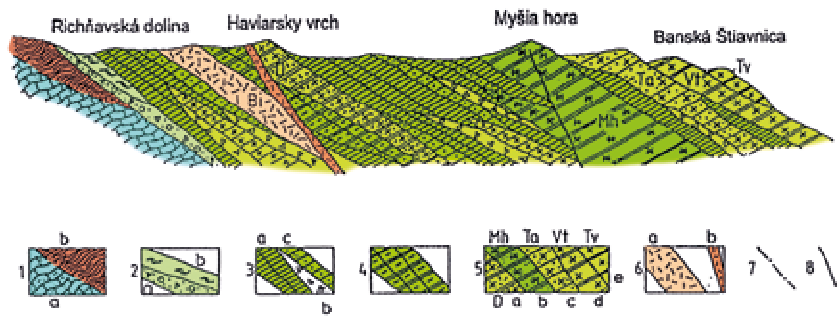


Fig. 3 Geological section through the bottom stratovolcanic structure in the eastern part of the Hodruša-Štiavnica Horst (J. Smolka et al., 2005):

1 – pre-volcanic bedrock: a) Mesozoic, b) Paleozoic (in a forwarding position), 2 – epiclastic volcanic group of strata: a) conglomerates, sandstones, breccias; b) tuffisites, 3 – stratovolcanic structure: a) pyroxene andesite lava flows, b) epiclastic volcanic breccias, c) lava flows of amphibole-pyroxene andesites, 4 – lava flows of biotite-amphibole-pyroxene andesites, 5 – bedded intrusions of andesite porphyry: a) – amphibole-biotite-pyroxene andesite porphyry – Dedinské type (D), b) – amphibole-pyroxene andesite porphyry with quartz and biotite – Myšia hora type (Mh), c) pyroxene-andesite porphyry rich with Tanád-type augite (Ta), d) pyroxene-andesite porphyry ± amphibole – Vtáčnik type (Vt), e) (augite-hypersthene) pyroxene-andesite porphyry – Trojičný vrch type (Tv), 6 – quartz-diorite porphyry intrusive complex (Banisko complex): a) bedded intrusion, b) dyke, 7 – nappe movement line, 8 – fault.

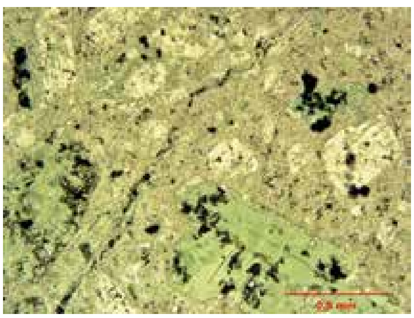


Photo 1 Pyroxene andesite, altered – without crossed nicols (© SGIoDŠ).

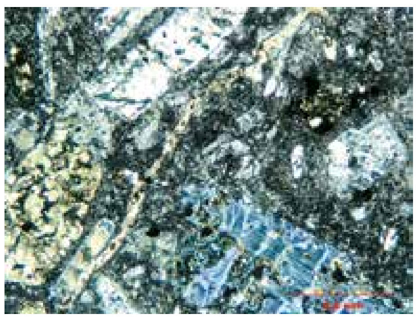


Photo 2 Pyroxene andesite, propylitised – with crossed nicols (© SGIoDŠ).

The typical signs of lava flows such as porosity, lava breccias, and small lamination jointing areas reflecting the texture of the flow are not present in these bedded intrusions. The base matter is mostly of grained, holocrystalline origin, which means it has crystallised in sub-surface conditions. They rise to the surface at the SE edges of the horst in the broader surroundings of Banská Štiavnica (see the geological map).

Individual bodies of bedded intrusions differ in terms of composition and proportion of dark phenocrysts. Based on geological mapping complemented by microscopic petrographic research, individual bodies were identified. The bodies with the largest area include: 1) andesite porphyry rich with Tanád-type augite (a thick body at the crest of the Tanád Hill above Banská Štiavnica, which inclines towards south-east); 2) amphibole pyroxene andesite porphyry – Vtáčnik type; 3) amphibole-hypersthene andesite porphyry with biotite – Myšia hora type, which forms a massive laccolith body in the broader surroundings of the Richňava Pond and in the Banská Štiavnica area, specifically Štefultov-Sitnianska; 4) pyroxene-andesite porphyry –Svätotrojičný Vrch type found in the area of the Svätotrojičný Vrch Hill, which is the subject of this chapter.

A subsequent denudation cut in the area of the horst block, which is in the forwarding position, removed the upper part of the stratovolcanic structure and exposed sub-surface intrusions. Due to the overall inclination of the horst, the bedded intrusions including the remains of the stratovolcanic structure also incline ca. 12–150˚ towards SE (Fig. 3). In the western part of the horst, the volcanic structure has been completely removed, and the pre-volcanic bedrock on the surface has been exposed.

The rock is porphyric, phenocrysts are composed of plagioclase, hypersthene, and augite. The base matter is microlitic and granular. Dark minerals (pyroxenes) are partly to completely chloritised, plagioclase is partly sericitised and replaced by carbonates.

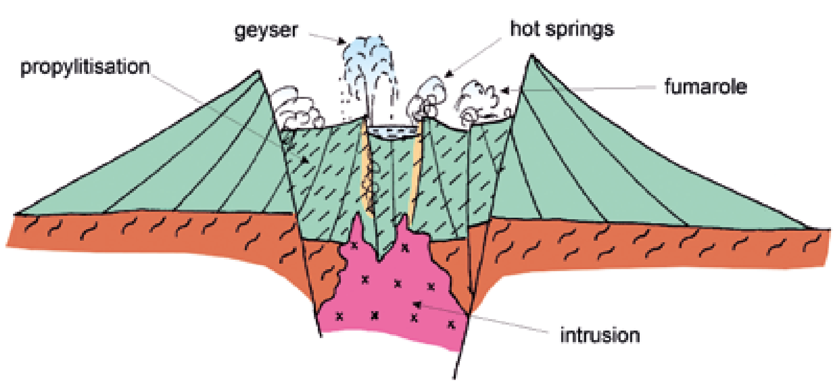


Fig. 4 Scheme of the effect of fluids (gaseous and liquid ones) on the volcanic rocks – propylitisation (J. Smolka et al., 2005).

The overlying rock of the intrusion above the Žigmund Shaft includes remains of the stratovolcanic structure and epiclastic volcanic breccias with lava flow. In the bedrock, there are lava flows and a bedded intrusion of amphibole-pyroxene andesite porphyry.

The rocks at the bottom of the stratovolcanic structure including bedded intrusions of andesite porphyry are propylitised to varying degrees in the horst area. During propylitisation, dark minerals (pyroxene, amphibole, biotite) containing iron (Fe components) disintegrate and generations of new, secondary minerals containing iron are formed. The most common group are chlorites. Due to the crystallisation of chlorites, these rocks gain green to blue-green colour.

Pyroxene andesite porphyry rock is dark, blue-green to black-green, but during more intense alteration or ventilation, it gains lighter green hues. Phenocrysts are composed of plagioclase 1–3 mm, which is partly sericitised and replaced by carbonates.

Dark minerals (hypersthene, augite) are partly to completely chloritised. The base matter je microlitic-granular, partly to completely replaced by secondary mineral aggregates (chlorite, sericite, carbonates, quartz). Compare propylitised pyroxene andesite in passing light (Photo 1) vs. with crossed nicols (Photo 2).

The hydrothermal alteration processes, i.e. propylitisation are related to the formation of the Štiavnica caldera (Fig. 4). Due to the rise of hydrothermal solutions and fluids from the upper parts of the magma chamber related to the collapse of the caldera, the rocks of the bottom stratovolcanic structure have largely undergone alterations, specifically propylitisation.

Geotope No. 4

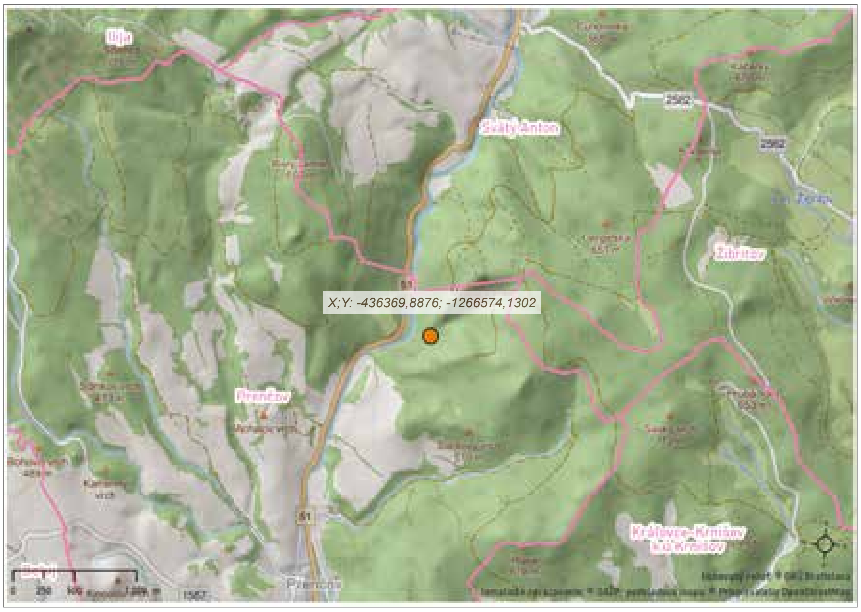
Pod Havranom (slope)

llahar breccia, bottom stratovolcanic structure

The rock cliff at the foot of the slope at the Havran elevation (above the Štiavnica Stream) consists of a breccia with coarse to block andesite material. Its position is distinctively chaotic, which indicates it was formed during a one-time transport of fragments. The fragmented material, which settled under this one-time point of mass transport is referred to as a lahar breccia – the term **lahar** refers to the type of transport (Fig. 1, Photos 1 and 2).

The term "lahar" comes from an Indonesian region with many active volcanoes where locals use it to refer to destructive avalanches of mud and rocks rolling down the steep volcano slopes. These avalanches, which form in relation to the volcanic activity but also without any clear

Fig. 1 Rock cliff – chaotic lahar breccia at the foot of the Pod Havranom slope above the Štiavnica Stream (© V. Konečný).



relation to volcanic eruptions, have always been very dangerous and risky for the locals and their dwellings at the foots of active volcanoes mainly in the tropical zone due to their unpredictability.

Why does this mass of ash, mud, and rocks start moving and kill all the living things in its way?

One of the reasons may be heavy rains, which are frequent in the tropical zone. Water saturates the mass of ash, which subsequently loses its stability on the volcanic slope, the mass starts moving and rips off the coarse and block material from the stratovolcano slope (Fig. 2).

Volcanic eruptions are commonly accompanied by heavy rains because the volcanic ash and gases are spewed into the atmosphere along with huge amounts of water vapour which proceeds to condense into rain. Upon supersaturation with water, the non-cohesive volcanic material turns into mud, which is the main reason why the deposits on the volcanic slopes lose their stability. Their further movement down the slope in the form of an avalanche is simply driven by the gravitational energy. However, lahars can also start moving due to **earthquakes of volcanic origin**.

Crater and caldera lakes are also dangerous, as **their walls can tear during eruptions** (Fig. 2.B) and their contents pour onto the volcanic slope. Another cause can be **an eruption of the burning volcanic material** or effusion of a lava flow onto the **snow-covered slopes** (Fig. 2 C), which melts the snow or ice (e.g. volcanoes in Alaska or Kamchatka). Pyroclastic flow eruptions with burning volcanic material rolling off the volcano slope into a riverbed have also been described; after mixing with water and mud, they have turned into hot lahars (Fig. 2.D). This is how the hot lahar formed during an eruption of the Bezymianny Volcano eruption in Kamchatka.

If a lahar forms directly in relation to an eruption when the burning material spewed from a volcano is partly transported, this formation is referred to as a ***hot lahar***. Lahars formed without a direct relation to eruptions, which carry older cold volcanic material, are called ***cold lahars***.

Lahars can be frequently seen around today's volcanoes. However, lahar deposits have been identified around older volcanoes from the past geological periods as well. In the area of Neogene volcanism in Central Slovakia, lahar deposits and mud flows have been identified among the marine sediments at the southern slopes of the Štiavnica Stratovolcano (V. Konečný, 1966).

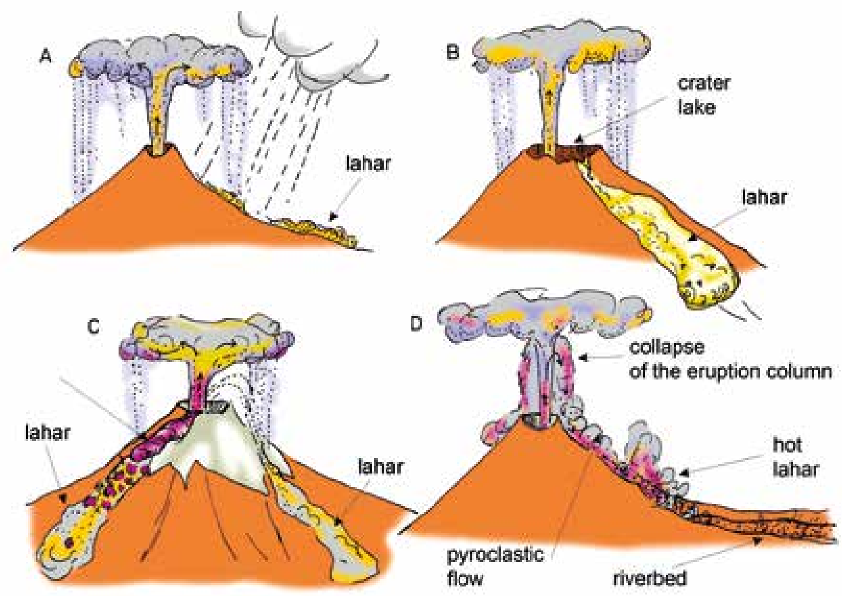


Fig. 2 Causes of lahar (J. Smolka et al., 2005).

A – heavy rains during eruption,
B – tearing of the crater lake wall during eruption,
C – eruption of pyroclastic material or lava flow effusion onto a snow (ice) cover,
D – penetration of a pyroclastic flow into a riverbed.

Since then, lahar breccias have also been commonly identified in other stratovolcano structures in Central and Eastern Slovakia.

The approx. 25 m tall rock cliff on the valley slope (Fig. 1) is composed of chaotically settled coarse fragments and coarse blocks of andesite material (pyroxene and amphibole-pyroxene andesites). These andesite fragments and blocks (5 to 40 cm) are mostly angular to subangular. The large blocks are especially noteworthy, they are subspherical to elliptical with indicated radial jointing and glassier surface.

The base matter (matrix) of the lahar breccia is coarse grained, sandy, with small angular as well as foamy fragments and frequently occurring pumice. The position of the fragmented material is chaotic. Certain concentration of large blocks can be seen near the base as well as in the upper part of the lahar body (Fig. 1).

As for the determination of the lahar's origin, the presence of spheroidal to elliptical blocks with jointing along the radial cracks is of importance. The formation of this block is explained as a result of the contact of a burning lava flow (or extrusion) with the water in the environment. The lava subsequently disintegrated into spheroidal blocks, while they burned, they rotated down the hill and disintegrated along radial cracks.

Based on the stratovolcano's area during the Middle Baden, when it reached its maximum height (before caldera formation), its top is estimated to have been at the level of approx. 3,500 to 4,000 m above the sea level and covered with snow and ice. Based on the presence of blocks with radial jointing, it can be assumed that around the peak area of the stratovolcano, which was covered with snow and ice at the time, lava flows leaked on the snow and ice-covered volcanic slope. As a result, the lava flow disintegrated into spheroidal blocks and smaller fragments. Since the fragmented material on the steep stratovolcanic slope was unstable, it started moving and releasing even more fragmented material from the slope on its way, thus turning into a flow of fragments or lahar, which rolled down the slope towards the foot of the stratovolcano (Fig. 2).

Another explanation could be that an extrusive body was rising from the crater or its slope. When it came into contact with snow and ice, it disintegrated into spheroidal blocks, which rolled down the slope in the form of a lahar (Fig. 2).

When the lahar rolled down from the upper parts of the stratovolcanic slope to its foot, it lost its momentum and settled as a chaotic mass of ash, mud, fragments, and even big blocks. During the following period, which lasted several million years, the volcanic material was undergoing diagenetic processes and solidified into the chaotic breccia that can be seen today. However, another several million years were necessary for the lahar body to be exposed by a cut into the deep valley of the Štiavnica Stream.

Photos 1, 2 A view of the rock cliff made up of chaotic lahar breccia (© P. Pachinger).

Lahars and pyroclastic flows rolling down the slopes of the Štiavnica Stratovolcano often crossed the boundary of the coast located south of Hontianske Nemce, continued moving along the seabed, and turned into mud flows. When they finally stopped moving, the material, which they carried, settled in the form of a chaotic mass of mud and rocks about 5 to 10 km from the coastal zone.

Geotope No. 5

Galgenberg

quarry nearby the open-air museum, bottom stratovolcanic structure

In this part of the bottom stratovolcanic structure, pyroxene andesite lava flows were identified by geological mapping. Occasionally, they alternated with epiclastic-type breccias (see the geological map). The quarry wall in the photo shows an exposed part of the pyroxene andesite lava flow with distinct mural jointing and transitions into irregular large block jointing (Fig. 1).

Mural jointing of lamination origin is characteristic for lava flows, whose course is concordant with the bedrock along which the lava flow moved. This type of jointing occurs in the final stage when the lava flow stops moving and starts solidifying and crystallising into a solid body (Fig. 2.A). Mural jointing probably occurred during the final partial shifts of the jointed parts, while they still were in a semi-solid, very viscous state. Besides mural jointing, the crystallisation of lava flow also results in coarse-columnar jointing (perpendicular to the base or edges of the body, see Fig. 2. B) or even irregular blocky jointing (Fig. 2 C). Contractive columnar or irregular blocky jointing occurs during the later stages of lava body crystallisation.

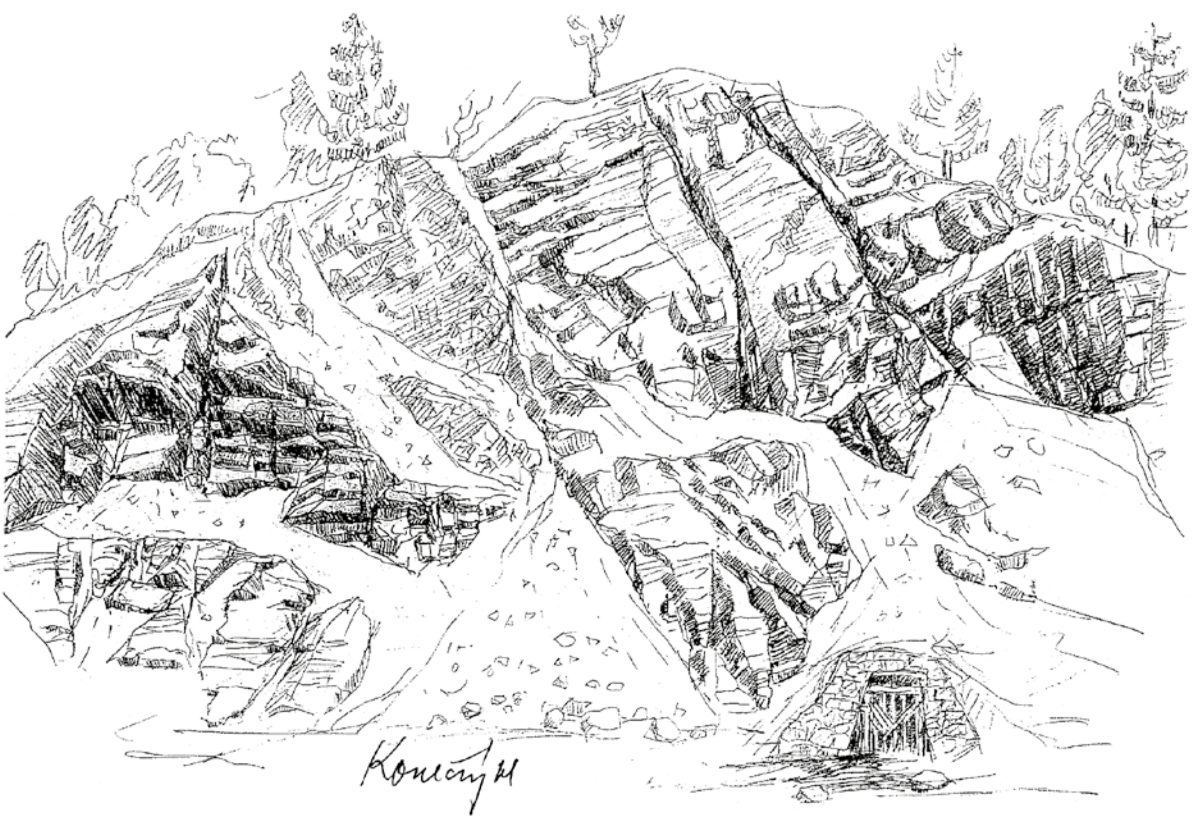


Fig. 1 Propylitised and tectonically disrupted pyroxene andesite, quarry under the Klinger Lake (© V. Konečný).

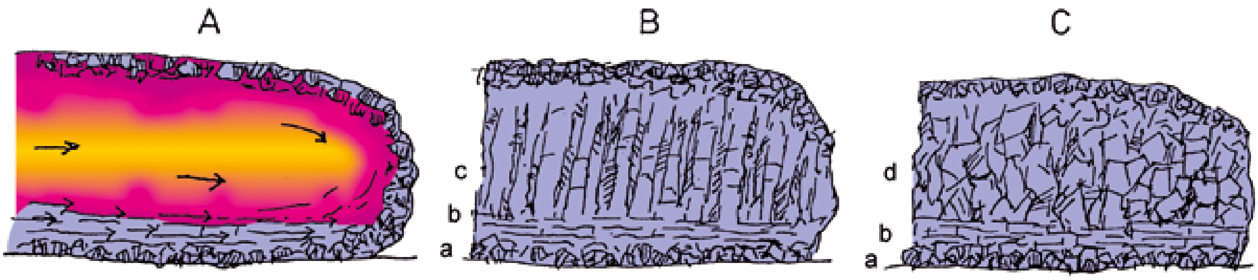


Fig. 2 Different types of jointing formed during cooling and crystallisation of the lava body (J. Smolka et al., 2005):

A – mural jointing of the lamination type occurs in the base part of the body while it remains in a very viscous state and the jointed parts are still slightly moving (shifting). Jointing is parallel to the surface along which the lava flow moved,
B – columnar jointing perpendicular to the lava flow base,
C – irregular blocky jointing in the central part of the lava body: a – lava breccia on the lava flow base, b – mural jointing of lamination origin, c – columnar jointing, d – blocky jointing.

The reduction of the body's volume during crystallisation creates internal stress, which results in the formation of cracks. If the regular network of cracks is perpendicular to the base of edges of the lava body (perpendicular to the cooling edges), columnar jointing occurs (Fig. 2.C). An irregular network of cracks results in the formation of irregular blocky jointing. These types of jointings can be seen in the walls of the andesite quarry (Fig. 1). You can also see that the andesite in the quarry wall shows distinct tectonic disturbance, and it is divided into a system of partial blocks with different shifts.

The origin of tectonic disturbances and formation of the horst structure

The andesite bodies, which are part of the rock complex of the bottom stratovolcanic structure, have been exposed along the eastern edges of the large horst structure – Hodruša-Štiavnica Horst.

However, the Štiavnica Stratovolcano did not stop evolving after the caldera was formed. The renewed volcanic activity in the caldera area and on the stratovolcanic slope during the Sarmatian resulted in the formation of a number of smaller satellite stratovolcanoes (Fig. 3.A).

Dramatic changes in the evolution of the stratovolcano reoccurred during the Late Sarmatian. In the collapsed central part of the caldera, a large rock block arcuated and gradually rose, and a horst structure was formed (Fig. 3.B). Since the block reached its maximum rise at the NW edge, an asymmetrical horst inclined ca. 10–5° towards SW was formed. During the same period, the Žiarska Kotlina Basin subsided and a depression with a lake environment was formed. The massive fault zone at the NW edge of the horst between the rising horst block and the subsiding block of the Žiarska Kotlina Basin allowed the rhyolitic matter to rise to the surface. During this time, there was tumultuous volcanic activity at the southern and eastern edges of the Žiarska Kotlina Basin. There were eruptions of ash-pumice tuffs, effusions, and extrusions of rhyolite lava followed by hydrothermal processes, creation of hot springs as well as solfatara and fumarole activity.

However, the horst did not rise as a monolithic block – as it was rising, it disintegrated into parts (segments) along the forming faults and fault zones. Some of these faults (mainly those with NE-SW to N-S directions) allowed for the rise of ore-bearing solutions and fluids, which turned into veins of precious metals and polymetallic ore veins of the Banská Štiavnica and Hodruša ore deposits (Fig. 3.B).

Movement along the faults, often accompanied by intense rock crushing along the tectonic zones, which can be seen in the quarry wall (Fig. 1), ranged from several metres to several hundred metres. Tectonic movements occurred during and after the formation of ore veins, which is indicated by the breccia nature of the vein fill in some cases.

According to the radiometric dating, the rhyolite bodies are 11.4 to 12.7 million years old while the secondary minerals, which occur when ore veins are formed, are about 12.1 to 12.3 million years old (sericite), which indicates that the rhyolitic volcanism and metallogenetic processes occurred close to each other and are related to the formation of the horst structure.

However, the reason why the horst structure itself formed is still a subject of theoretical consideration. V. Konečný (1970, 1971) assumed that the horst could arcuate and rise due to a larger volume of acidic rhyolite or granite magma under the horst block in accordance with the model designed by Smith & Bailey (1961) who tried to describe the arcuation process undergone by some calderas in the US.

Since the horst block rose asymmetrically, the NW part of the horst (the Hodruša part) was largely denudated, the volcanic structure was completely removed, and the pre-volcanic bedrock was exposed including the subvolcanic intrusive complex of granodiorite and diorite (Fig. 3.C). On the other hand, the denudation cut into the Štiavnica (eastern) part of the horst only removed the caldera fill along with the upper stratovolcanic structure, thus exposing the middle and bottom levels of the bottom stratovolcanic structure. At the same time, it exposed ore vein apexes, which had been already discovered and used by old Celts and Romans. The richness of the precious

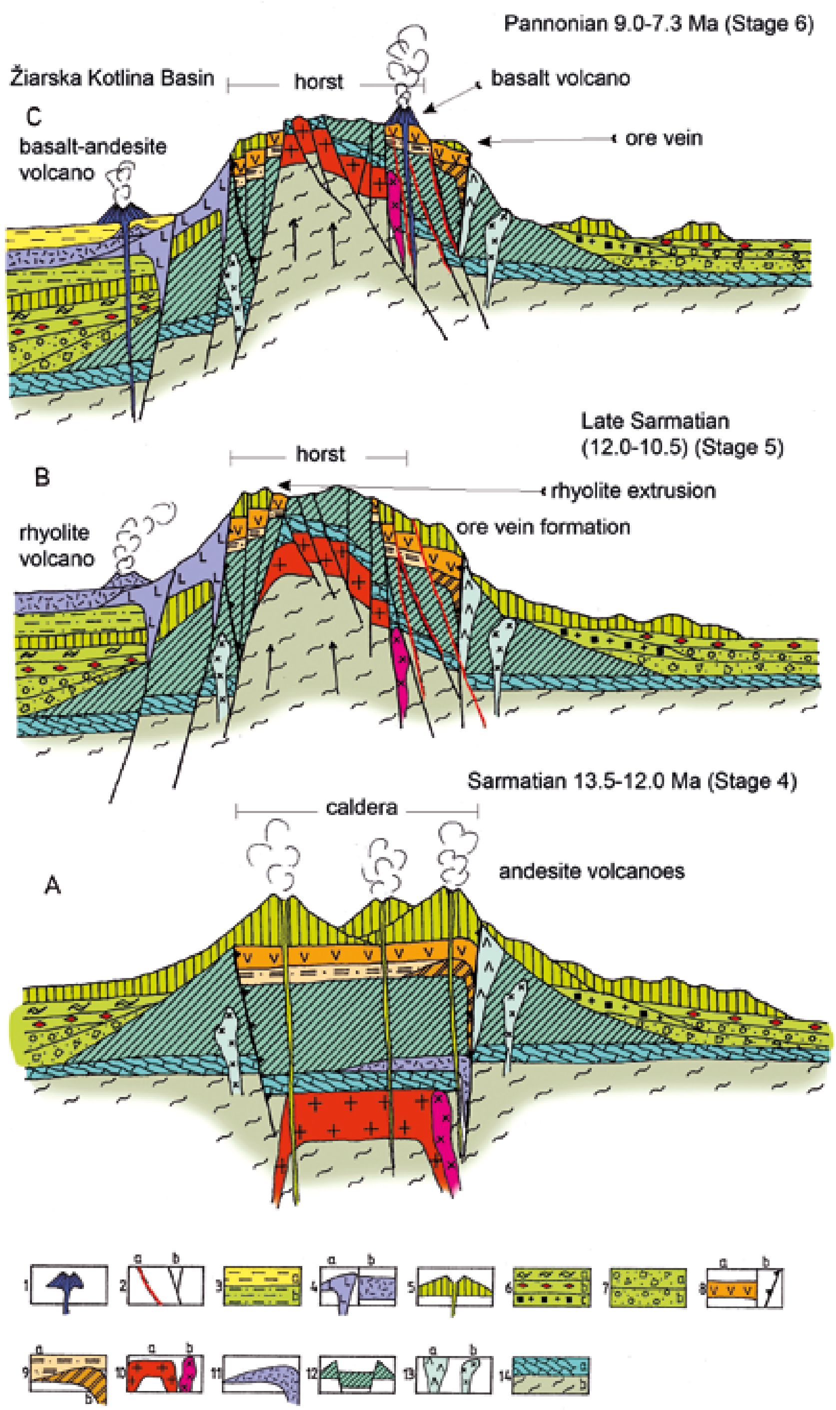


Fig. 3 Evolutionary stages of the Štiavnica Stratovolcano (J. Smolka et al., 2005):

A – during the Sarmatian, a number of smaller volcanoes formed in the caldera area and on the stratovolcanic slope,
B – arcuation and gradual rise of the central block resulted in the horst formation, the Žiarska Kotlina Basin blocks subsided and rhyolitic volcanism occurred, ore veins were created,
C – the final stage of the horst formation was accompanied by the volcanism of basaltic andesite (Žiarska Kotlina Basin) and alkali basalt at the eastern edge of the horst (Kalvária, Kysihýbel).
Explanatory notes:
1 – basalt volcano (Pannonian), 2 – a) ore vein, b) fault, 3 – sediments of the Žiarska Kotlina Basin: a) clays, gravels, sands (Pannonian), b) tuffites, tuffite sandstones and claystones (Sarmatian), rhyolitic volcanism (Late Sarmatian), 4 – a) extrusion, b) rhyolitic tuffs and epiclastics, Štiavnica Stratovolcano:
I. Upper stratovolcanic structure (Sarmatian). 5 – andesite volcanoes, lava flows, 6 – pyroclastic rocks: a) welded pumice tuff ignimbrites, b) pumice tuffs, c) chaotic breccias of pyroclastic flows, 7 – epiclastic volcanic breccias, a) epiclastic volcanic breccias, b) epiclastic volcanic conglomerates and sandstones, II. Fill of the Štiavnica caldera (Late Baden – Early Sarmatian), 8 – a) products of biotite-amphibole andesite volcanism (lava flows, extrusion, pumice tuffs, volcanoclastic rocks), the Studenec Formation, b) caldera fault, 9 – a) sandstones and siltstones with lignites, b) lava flow of biotite-amphibole-pyroxene andesites at the Červená studňa Formation, intrusive complexes,
10 – sub-volcanic intrusive complex, a) granodiorite, b) diorite. 11 – bedded intrusions of quartz-diorite porphyry, III. Bottom stratovolcanic structure (Baden): 12 – the whole (unsegmented) bottom stratovolcanic structure, 13 – a) extrusion, b) sub-surface intrusion, pre-volcanic bedrock, 14 – a) rocks of the Mesosoic age (limestones, dolomites), b) crystalline complex.

metal ore veins gave rise to medieval mining, which contributed to the fame and boom of Banská Štiavnica, the development of mining technology as well as mining engineering, mineralogy, and geological sciences at the Mining Academy founded in 1762.

At the end of the excursion along this educational trail, we would like to invite you to visit the open-air museum where an exposition about the geological evolution of Slovakia showcasing rock displays can be found in a natural environment. The rocks of the bottom stratovolcanic structure, in which the ore veins mined from the Middle Ages until the early Modern Period were born, will also accompany you during your visit of the underground spaces in which you can explore mining technology from previous centuries.

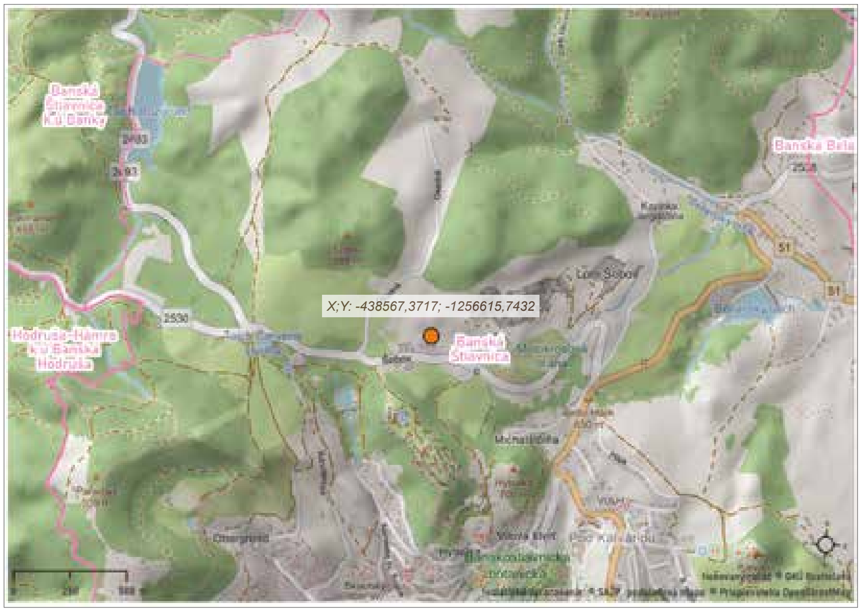
Geotope No. 6

Šobov

Secondary quartzite

The hydrothermal system of Šobov located north of Banská Štiavnica (Fig. 1) is the oldest manifestation of the hydrothermal processes in the central zone of the Štiavnica Stratovolcano.

Its formation was caused by an intrusive diorite body (Fig. 2) and the subsequent release of magmatic gases SO_2, Cl, and CO_2. During condensation in the groundwater of the overlying andesite complex, strong acids and H_2S were created (this system is categorised as the high-sulphidation type since the sulphur was rising in the form of an oxide – Fig. 3). These acids reacted with the andesite and turned it into argillite (ablation of Fe, Mg, Ca, Na, and K and creation of clay rocks, mainly



pyrophyllite – $Al_2(Si_4O_{10})(OH)_2$), and in the centre of the system, even to quartzite (Al ablation and SiO_2 accumulation – Microphoto 14). The reaction of H_2S during which the released Fe turned into pyrite (FeS_2) was the cause of intensive pyritisation around the margins of this hydrothermal system.

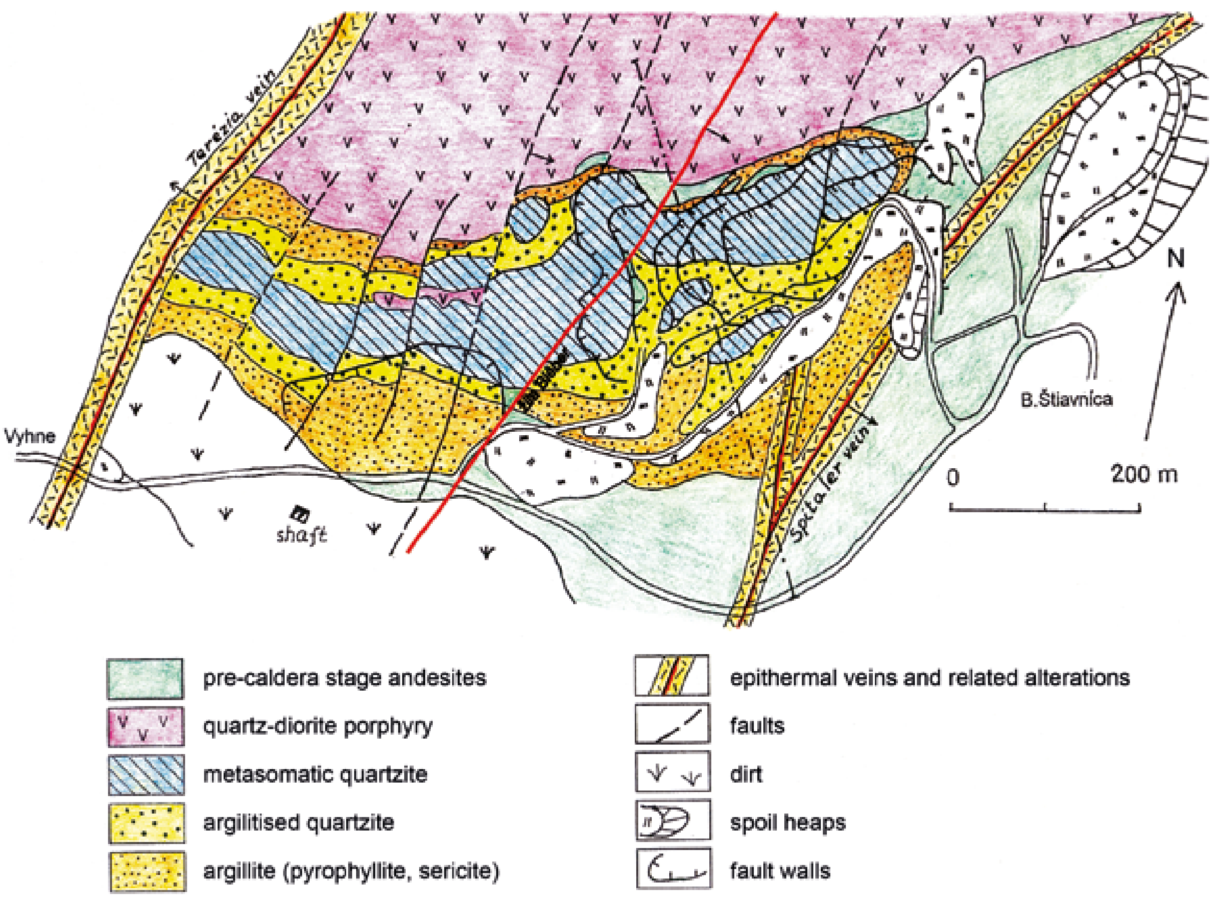


Fig. 1 Scheme of the Šobov high-sulphidation hydrothermal system (J. Štohl et al., 2000).

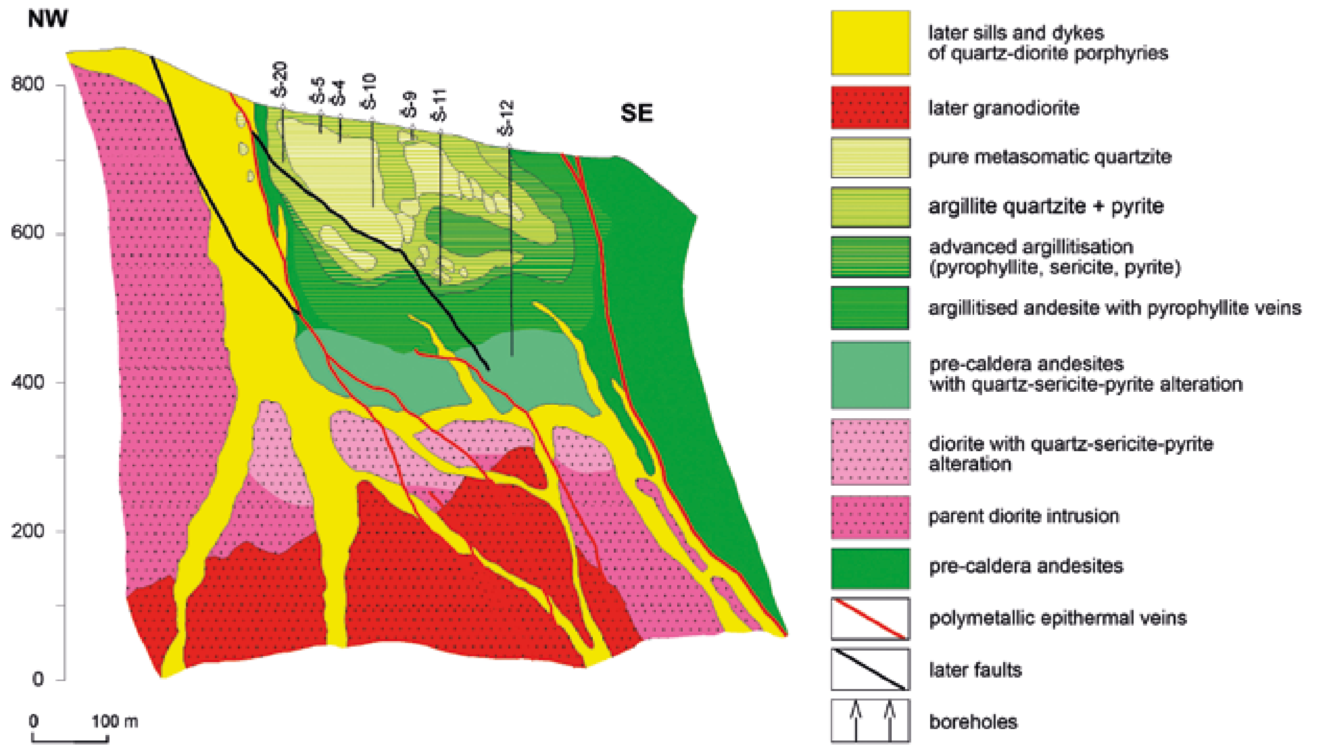


Fig. 2 A section through the Šobov high-sulphidation hydrothermal system (J. Štohl et al., 2000).

The hydrothermal system has been turned into a large quarry (Photo 1) where sceptre-like quartz crystals can still be found (Photo 2). The quartzite found in its central part used to be quarried in Banská Belá as well, where it was used to produce gannister bricks, i.e. fireproof linings for blast furnaces.

Photo 2 A close-up of the smaller sceptre-like quartz crystals (© P. Pachinger).

Photo 1 Šobov Quarry (© V. Konečný).

The pure quality quartzite in the middle of the quarry was quarried in the past. The quartzite with pyrite located at the edge of the quartzite body (rust-coloured due to the effect of limonite) transitions into grey to whitened pyrophylllite argillite with pyrite on the outside (the grey colour is caused by the intruded close-grained pyrite – up to 30% of the content). The whitened zones formed due to the oxidation of pyrite into sulphuric acid during weathering and ablation of iron in the form of sulphate.

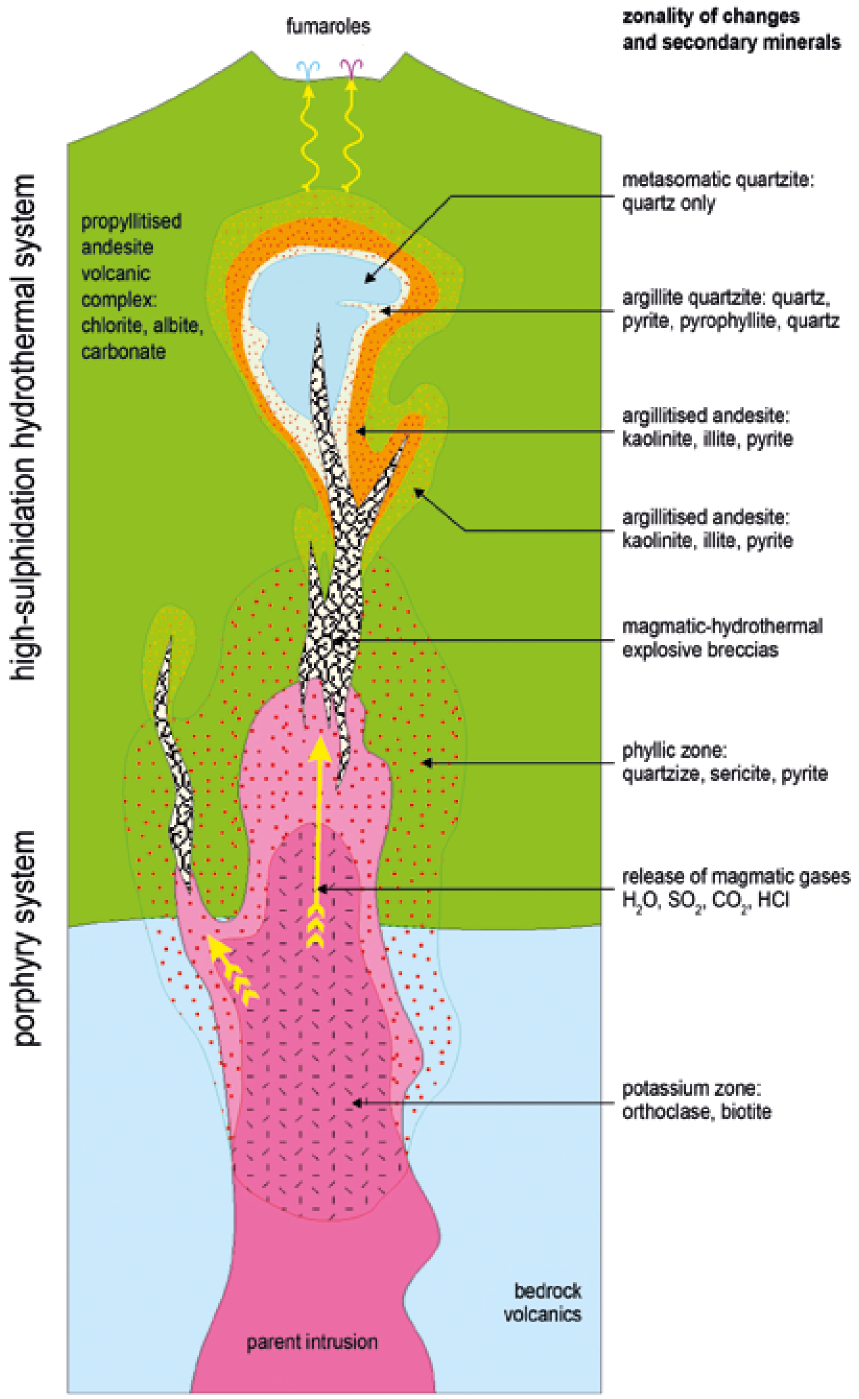


Fig. 3 Scheme of the high-sulphidation hydrothermal system and its relation to the mother intrusion and porphyry system located in a deeper level (J. Lexa, 2005).

Geotope No. 7

Štamberg, Banská Belá

Secondary quartzite

At location No. 10 in the abandoned quarry, a body of secondary quartzite can be found. In the past, secondary quartzite was quarried as a raw material to produce fireproof gannister bricks in the nearby factory.

The body of secondary quartzite rises at the northern slope of the distinct crest called Pod Vartou (elevation 556–548). The geological mapping, application of geophysical methods, and short boreholes identified a body composed mainly of massive quartzite (Fig. 1).

At the northern and southern edges, the body of secondary quartzite extends into the quartzite-argillite zone and continues to the edges of argillite-quartzite zone. The surrounding rock environment consists of biotite-amphibole andesites argillitised to varying degrees.

The 93 m deep A-12 borehole located at the edge of the quartzite body has provided an idea about its vertical dimension (Fig. 2).

In the upper part, the borehole penetrates 9.2 m through the argillite. At 27.5 m, it penetrates the secondary quartzite body composed of fine to crypto-crystalline quartz with occasional breccia-like texture (at 32.0 m). The relicts of dark minerals (amphibole, biotite) are filled with pyrite which forms nests and smudge-like patterns.

From 32.0 m to its end at 93.0 m, the borehole penetrates through argillitised biotite-amphibole andesite. The original phenocrysts of dark minerals are here replaced by pyrite. The plagioclase and base matter are replaced by a mix of kaolinite, quartz, pyrite, and sericite.

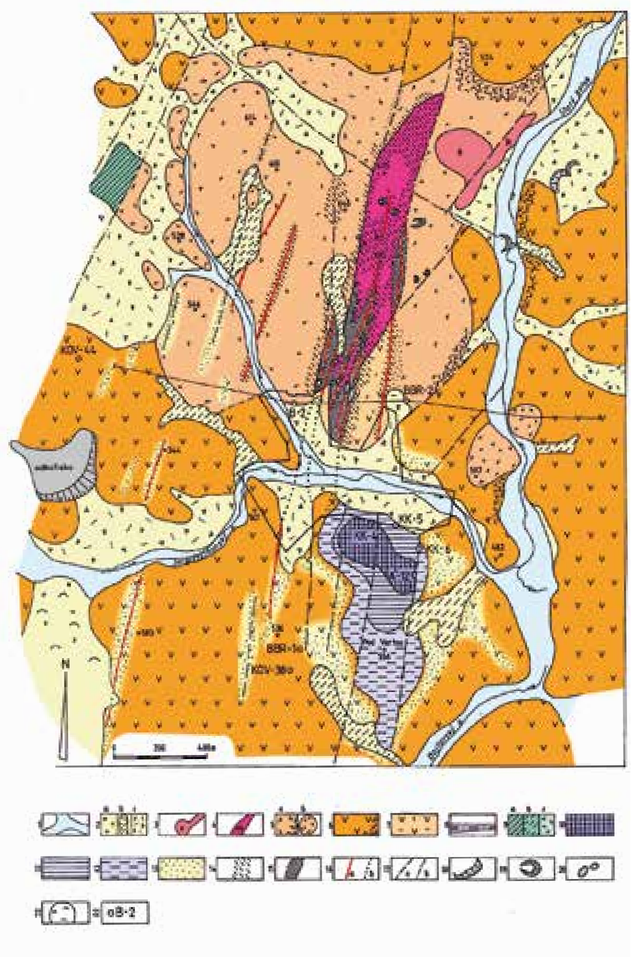


Fig. 1 The geological map of the Banská Belá surroundings (J. Lexa, J. Štohl, A. Brlay, 1989):

The Quaternary:
1 – fluvial (river) sediments, sands, gravels, sandy loam, 2 – deluvial sediments: a) clay slope dirt, deluvial-fluvial wash-down dirt and sandy loam, c) slope dirt, debris composed of rocks or rocks with dirt.
Neogene:
3 – rhyolite (dyke – extrusion), 4 – dacite (rhyodacite).
Caldera fill (the Studenec Formation):
5 – biotite-amphibole andesite porphyry (± quartz): a) bedded intrusion (laccolith), b) protrusion, 6 – biotite-amphibole andesites and volcanoclastic rocks (unsegmented), lava breccias at the edges of the bodies, 7 – intensely hydrothermally altered rocks (of unclear origin), 8 – sediments of the Červená studňa Formation at the base of the caldera fill (epiclastic volcanic sandstones with siltstone and lignite, tuffs, tuffite sediments (in the section only).
Bottom stratovolcanic structure:
9 – a) pyroxene andesite, b) unsegmented bottom structure complex (in the section), c) – amphibole-hypersthene andesite porphyry with biotite (± quartz, ± garnet Myšia Hora type; in the section).
Hydrothermal alteration and ore veins:
10 – secondary quartzite, 11 – secondary quartzite with argillite, 12 – argillite with secondary quartzite, 13 – argillite, argillitised andesite, 14 – manifestations of adularisation (potassium metasomatism), 15 – silicification with an adularia around the ore veins, 16 – a) ore vein, b) the assumed course of the ore vein below the Quaternary.
Explanatory notes:
17 – a) fault, b) assumed course of the fault below the Quaternary, 18 – embankments, dams, 19 – spoil heap, 20 – pingos (hydrolaccoliths), 21 – landslides, 22 – galleries, 23 – shafts, 24 – boreholes.

Secondary quartzite is a product of metasomatic processes during which the original minerals as well as the biotite-amphibole andesite base matter are gradually replaced by secondary minerals. As for clay minerals, kaolinite prevails (30–55%), but mixed-structure illite-type minerals are also present, i.e., smectite and sericite.

The abovementioned alterations indicate that the solutions that caused the metasomatism were acidic. The most distinct disintegration and leaching with the ablation of alkali was identified in the A-12 borehole in the segment between 9.2–27.5 m of depth, which is composed mainly of aggregates of tiny quartz grains.

In comparison with the high-thermal alterations around the veins associated with mixed-structure clay minerals (sericite – pyrophyllite – pyrite a ± kaolinite), the low-thermal mineral association of the quartzite body at Pod Vartou has a higher proportion of kaolinite.

As for the formation of the secondary quartzite body at Pod Vartou and the related hydrothermal-metasomatic alterations, the presence of a deeper diorite intrusion (diorite porphyry), which triggered this alteration, is assumed (Fig. 3).

The secondary quartzite in the quarry wall (Fig. 4) is colourful (yellow, white, and spotted due to the leaks of brown and brown-red limonite).

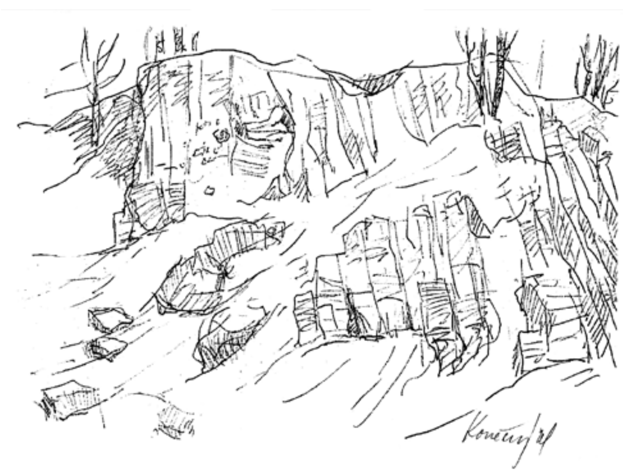


Fig. 4 The abandoned quarry at the NE slope of the Pod Vartou elevation 548 in secondary quartzites (© V. Konečný).

Quartzites are mostly massive, sometimes porous with indicated breccia-like texture. Locally, smaller and bigger cavities partly filled with yellow-brown clay dirt can be found in the rocks. Quartzite shows large-block to coarsely-columnar jointing (with subvertical orientation) or even thick mural jointing along the plane 310 NW/50° (at the right edge of the quarry wall). Beautiful quartz crystal druses have been found in the cavities.

More quarries in the secondary quartzite body are located at the northern and western slopes of the crest under elevation 548 (south of Banská Belá). A marked trail leads there. In the quarry wall, secondary quartzites with breccia-like texture alternating with segments of more massive quartzite with irregular blocky jointing have been exposed.

In the past, secondary quartzites were quarried for the purpose of making gannister bricks in the factory located in Banská Belá. Later, this raw material was obtained from a quarry under Šobov.

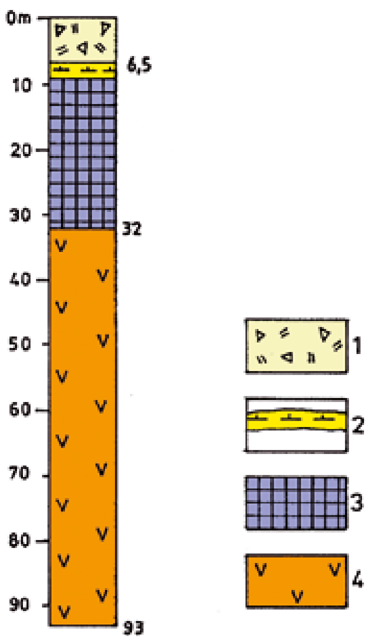


Fig. 2 The geological profile of the A-12 borehole (A. Brlay et al., 1989):

1 – rocky dirt, 2 – argillites (clays), 3 – secondary quartzite, 4 – hydrothermally altered biotite-amphibole andesites.

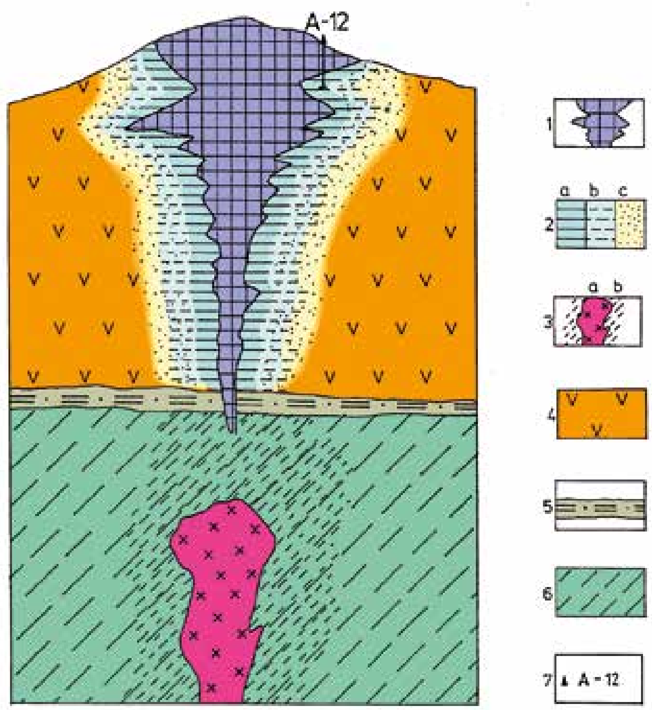


Fig. 3 Schematic section with the assumed source intrusion (J. Smolka et al., 2005):

1 – secondary quartzite,
2 – hydrothermal alteration of the surrounding rocks: a) silicification, b) silicification and argillitisation, c) argillitisation,
3 – a) assumed source intrusion (andesite or diorite porphyry), b) high-thermal alteration zone (biotitisation, actinolitisation),
4 – caldera fill – biotite-amphibole andesites and volcanoclastic rocks (unsegmented),
5 – sediments of the Červená studňa Formation at the base of the caldera fill (epiclastic volcanic sandstones with siltstone and lignite) ,
6 – rocks of the bottom stratovolcanic structure (lava flows and unsegmented volcanoclastic rocks),
7 – A-12 borehole.

Geotope No. 8

Pri Červenej Studni

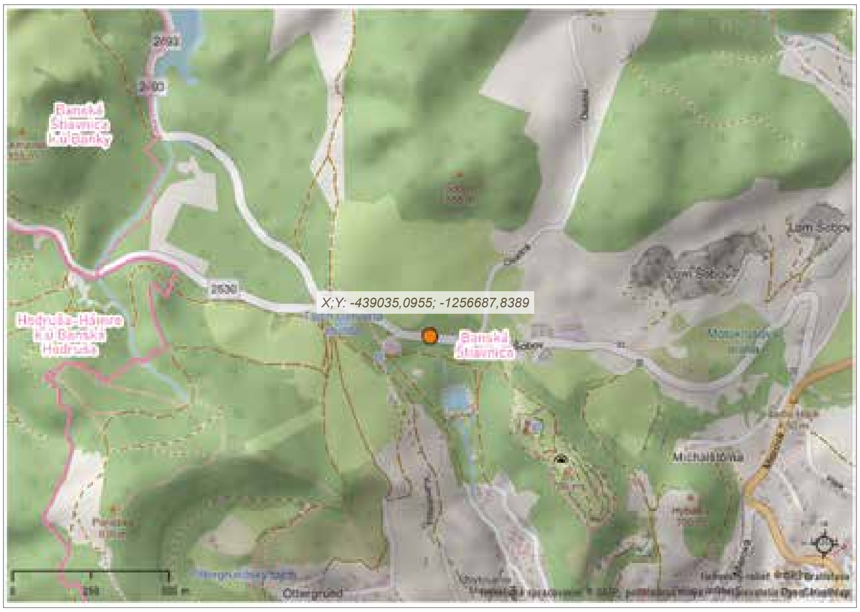
ferriferous breccias

This location includes ferriferous breccias as a result of the hot spring activity during the period when the Štiavnica caldera was subsiding.

The subsidence of the Štiavnica caldera significantly changed the circulation of meteoric waters, magmatic and hydrothermal fluids (Fig. 1).

Cold meteoric waters infiltrated the caldera around its margins, warmed up in the depth, mixed with the magmatic fluids released from the magma chamber, and rose back to the surface as thermal waters. These thermal waters deposited precious metal ores on the sub-surface level (the Hodruša gold deposit) as well as around their surface outlets, thus creating a system of hot springs. Photo 1 shows how these springs probably looked like while they were active.

Mineralisation can be seen in the volcanic-sedimentary rocks of the so called small Štiavnica basin at the caldera base fill, but also in the bedrock andesites from the pre-caldera stage (Fig. 2). The biotite-amphibole andesites at the Šobov elevation cover the mineralisation (because they were formed later). Mineralisation manifests by large-area alteration of rocks into clay minerals and flints, which occur in the broader surroundings of the given location as whitened, yellow, or brown weathered rocks with prevailing kaolinite and flint fragments (irregular blocks and fragments of siliceous rocks).



This alteration results from the interaction between the original rocks with hot acidic solutions. Upon contact with the oxygen in the air, H_2S in the thermal waters oxidised into sulphuric acid. Below the oxidation zone, the thermal waters have neutral composition and the typically occurring clay mineral is smectite (montmorillonite). H_2S in thermal waters reacts with the iron contained by the original rocks to form disseminated pyrite (FeS_2; Photo 2.).

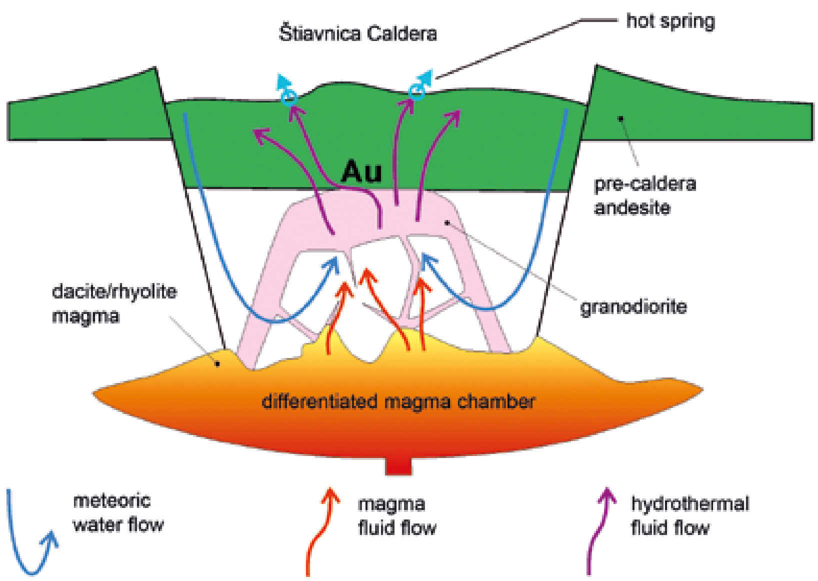


Fig. 1 Scheme of the fluid (water) flow in the Štiavnica Stratovolcano during the period of the caldera's subsidence (P. Koděra et al., 2005).

Limonite ferriferous breccias – gossan
In this location, low-quality iron ore was mined in the past. The iron ore takes the form of limonite or limonite-cemented ferriferous breccias (Photos 3 and 4), which formed due to oxidation and weathering of the intensively pyritised rocks. These limonite accumulations in the oxidation zone of sulphide deposits are called iron hats or gossans. In the past, they belonged among the main sources of easily processable iron ore.

The oxidation of pyrite into limonite and sulphuric acid can be described by a series of three chemical reactions:
1) pyrite reacts with oxygenated meteoric water and forms iron (II) sulphate and sulphuric acid:
$2FeS_2 + 7O_2 + H_2O = 2FeSO_4 + 2H_2SO_4$;

2) iron (II) sulphate reacts with oxygenated meteoric water and forms iron (III) sulphate and insoluble limonite:
$12FeSO_4 + 6H_2O + 3O_2 = 4Fe_2(SO_4)_3 + 4Fe(OH)_3$;

Photo 1 Hot springs and geysers in the Yellowstone Caldera. Yellowstone National Park, USA (© V. Konečný).

3. iron (III) sulphate reacts with water and forms insoluble limonite and sulphuric acid:
$Fe_2(SO_4)_3 + 6H_2O = 2Fe(OH)_3 + 3H_2SO_4$.

The released sulphuric acid soaks the original rock and alters it into quartz and kaolinite. Therefore, the final results of oxidation are flint fragments with kaolinite.

Photo 2 Disseminated pyrite in the altered rock. Microphotograph in reflected light (© SGIoDŠ).

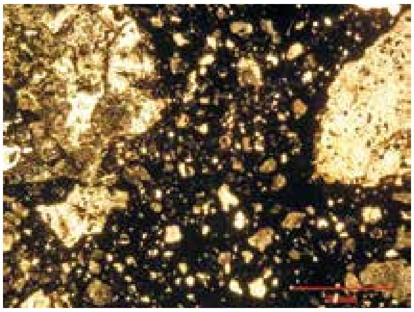


Photo 3 Limonite breccia – dark limonite cements the fragments of silicificated and argillitised rocks. Microphotograph in the passing light (© SGIoDŠ).

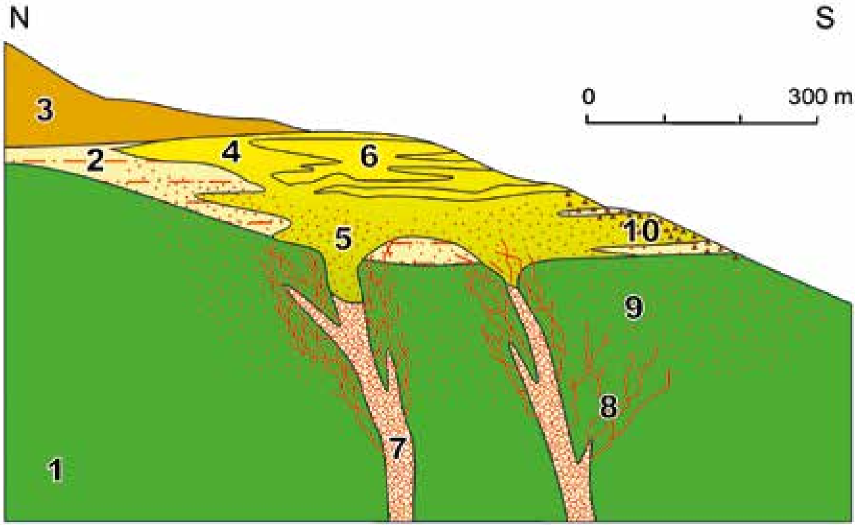


Fig. 2 Scheme of hot spring mineralisation at Červená studňa (J. Lexa, 2005):

1 – propylitised andesites of the pre-caldera stage, 2 – epiclastic volcanic sandstones and claystones, 3 – biotite-amphibole andesite, 4 – argillite with kaolinite, 5 – argillite with montmorillonite and pyrite, 6 – flints and opalites, 7 – hydrothermal-explosive breccias and epithermal veins, 8 – network of irregular veins, 9 – disseminated pyritisation, 10 – limonite breccias of the gossan.

Photo 4 The selected parts of a limonite ferriferous breccia with clear breccia-like texture – the rock is composed of irregular angular fragments (© SGIoDŠ).

Geotope No. 9

Jergištôlňa

dyke of quartz-diorite porphyry

In the abandoned quarry near Jergištôlňa (the Juraj shaft) is an exposed intrusive body of quartz-diorite porphyry, which permeates from the bottom stratovolcanic structure in the form of a dyke (Fig. 1).

The dyke is part of the Banisko intrusive complex (its name refers to the type-location near the village Banisko-Kopanice). Besides dykes, this intrusive complex also includes bedded forms such as sills and laccoliths (Fig. 2).

The denudation cut in the Hodruša-Štiavnica Horst area exposed bedded as well as dyke bodies of quartz-diorite porphyry. In the central part of horst, bedded intrusions in the form of sills and laccoliths prevail. They occur at the boundary between the volcanic complex and the bedrock, but also in the bottom stratovolcanic structure. These bedded intrusions cover an area of several km^2 and can be 100 m thick. The base matter evolved as grained. The deeper the intrusion, the more grained the base matter.

The **dykes** can take the form of individual bodies, but more frequently, they occur in the form of dyke swarms. The width of these dykes ranges from several metres to 100 m, while their length ranges from several tens of metres to 1.5 km. Individual dykes and dyke swarms are mostly oriented in the NNE-SSW direction, less frequently in the N-S to NNW-SSE direction. They mostly incline away from the central block.

In some cases, dykes penetrate bedded intrusions, which indicates that these dykes are younger than the bedded intrusion bodies.

The dykes and bedded intrusions of quartz-diorite porphyry were formed along with the caldera (V. Konečný, 1970), which relates to the subsidence of the jointed sub-surface blocks into the upper levels of the magma chamber. When a block joints and subsides (Fig. 3), a space is created above its upper edge, which is subsequently filled with rising magma. Upon solidification and crystallisation, a bedded body is formed, i.e. **sill** or **laccolith**. A **dyke** is created when the magma that rose along the faults at the edges of the central block solidifies and crystallises.

The dyke of quartz-diorite porphyry in the quarry near Jergištôlňa – composition and textures
The rock is coarse-grained porphyric and dark green (propylitised). The phenocrysts are composed of plagioclase (4–6 mm), amphibole (5–6 mm) and biotite (4–5 mm). Grains of quartz occur sporadically. The base matter consists of irregular (allotriomorphic) tiny grains of quartz and potassium feldspars, which prevail over the grains of plagioclase, amphibole, and biotite. Dark phenocrysts and grains in the base matter are partly chloritised, feldspars are sericitised.

There is large-block to coarsely-columnar jointing (Fig. 1) approximately perpendicular to the course of the dyke body. This type of columnar jointing occurs when the magma body cools and crystallises. During crystallisation, the body reduces its volume and the internal stress creates a network of regular cracks, which demarcate individual columns and **columnar jointing occurs**. Columnar jointing is perpendicular to the edges along which the dyke body was cooling (it is perpendicular to the walls at the dyke's edges).

The dyke is 1.5 km long and its maximum width reaches up to 120 m.

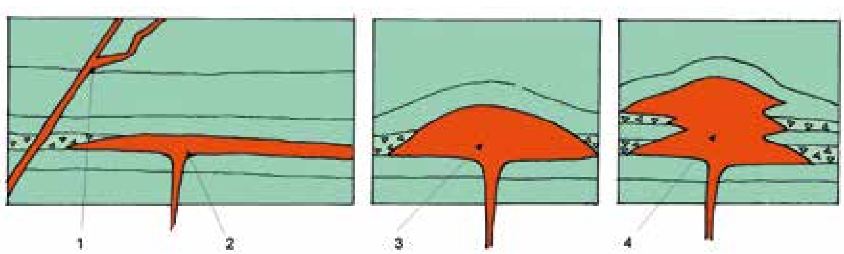


Fig. 2 The forms of intrusive bodies (J. Smolka et al., 2005).

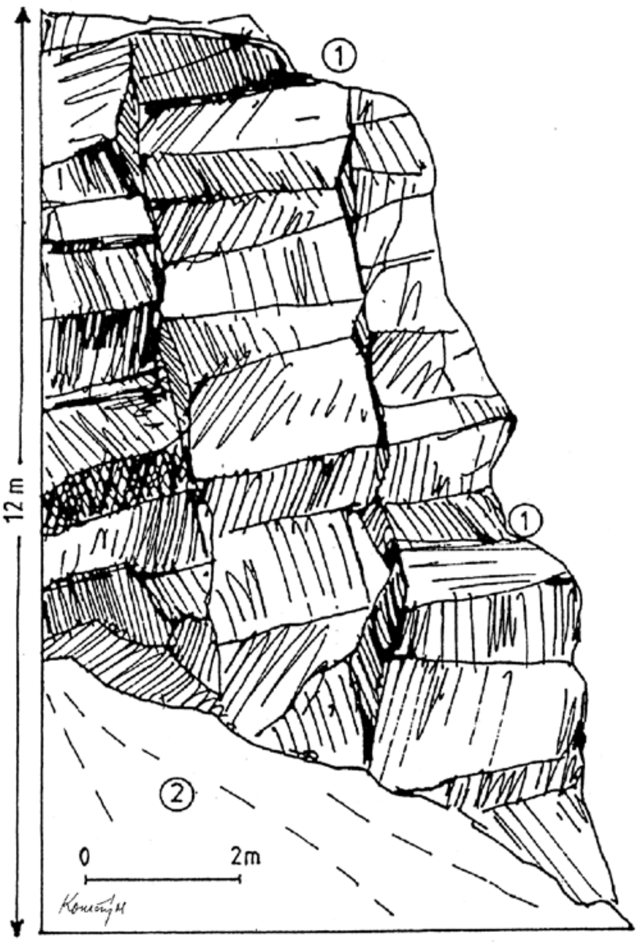
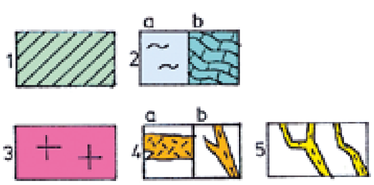


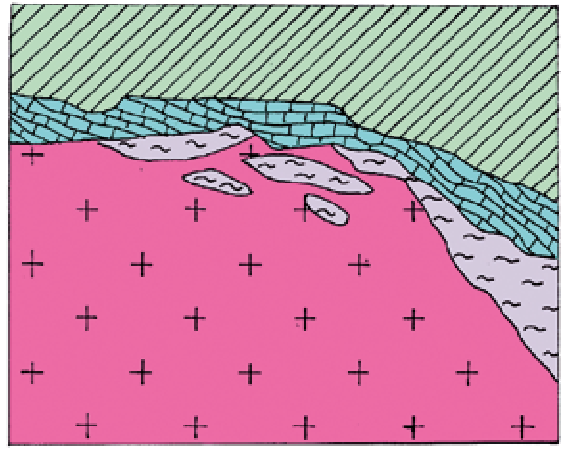
Fig. 1 Abandoned quarry near Jergištôlňa. Dyke of quartz-diorite porphyry (J. Smolka et al., 2005).

1 – quartz-diorite porphyry with coarsely-columnar jointing,
2 – debris.

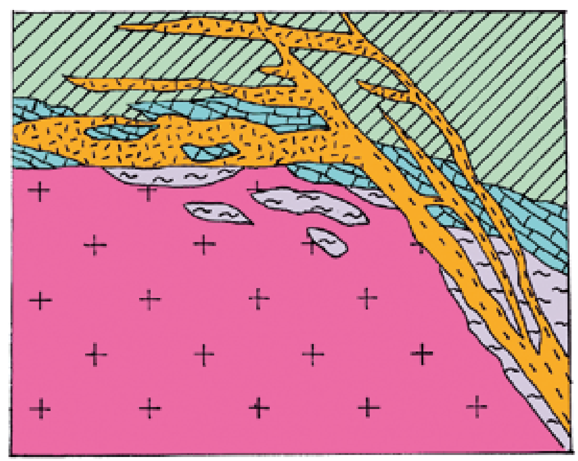
Fig. 3 Scheme of the formation of a quartz-diorite porphyry intrusion complex (J. Smolka et al., 2005):

1 – andesite complex of the bottom structure,
2 – pre-volcanic bedrock:
a) crystalline complex,
b) sediments of the Mesozoic,
3 – granodiorite,
4 – the quartz-diorite porphyry intrusive complex Banisko:
a) bedded intrusion (sill),
b) dyke,
5 – dykes of quartz-diorite porphyry (younger generation).

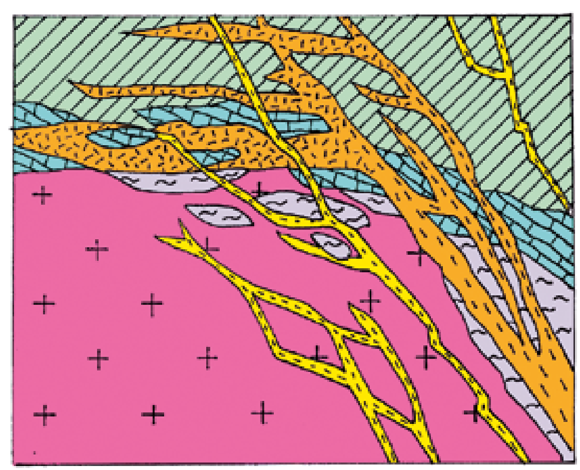




A – The situation before the quartz-diorite porphyry complex was formed. During its formation, the granodiorite intrusion damaged the crystalline complex and the Mesozoic rocks in the overlying rock.



B – While the block subsides, magma rises and fills the space above the subsided block, thus forming quartz-diorite porphyry sills. Along the faults at the edges of subsiding block, dyke bodies are rising.



C – As the block continues to subside, faults are created. Along these faults, the dykes of quartz-diorite porphyry (younger generation) are rising.

Geotope No. 10

Kysihýbeľ

extrusion of biotite andesite amphiboles in the caldera fill

In the past, andesite was quarried in the abandoned quarry on the southern slope under elevation 674 (Fig. 1) for decorative purposes due to its pink-red colour.

At this point, some of the lava body forms in the Štiavnica caldera fill will be discussed in greater detail.

Very viscous lava (with the limited ability to flow) accumulates above the inlet and forms quaquaversal or domatic shapes. These shapes are generally referred to as extrusive domes (Fig. 2.A, B).

These bodies grow as follows: the periods during which viscous lava rises alternate with cooling periods, when semi-solid to solid surface crust is formed.

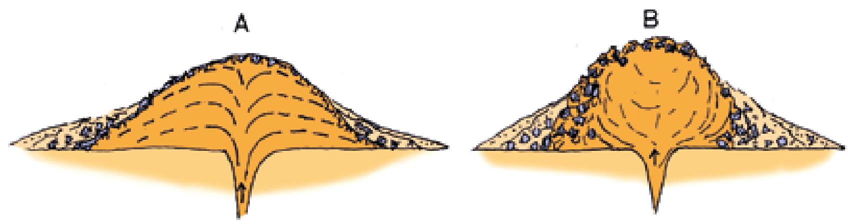


Fig. 2 Extrusive dome shapes (J. Smolka et al., 2005)

A – exogenous extrusive dome, B – endogenous extrusive dome, cumulodome.

Fig. 1 Amphibole-biotite andesite exposed in the quarry under elevation 674 (© V. Konečný).

A) If the body kept growing because lava was rising onto its surface, it belongs to the category of ***exogenous extrusive domes*** (Fig. 2.A). An internal section through these bodies (partly exposed by denudation) shows a fan-shaped system of fluidity planes, which reflects the directions in which the rising lava was moving.

B) If an extrusive body was growing because fresh lava kept flowing into it, i.e., it expanded outwards from the middle, it belongs to the category of ***endogenous domes***. They are usually larger than their exogenous counterparts. The course of fluidity planes is usually steeper at the edges of the body than towards its middle (Fig. 2.B). In literature on volcanology, these shapes are also referred to as ***cumulodomes***.

The detailed field research focused on measuring the direction and inclination of fluidity planes (lava movement directions) performed by V. Konečný and L. Dublan (1969), identified bodies corresponding with cumulodomes in the south-eastern part of the Štiavnica caldera (Fig. 3).

Field research has identified more, often very large bodies of this type. Their diameters reach up to 2,000 or 3,000 metres. Their planes are roughly elliptical to irregular. These bodies often occur in very complicated spatial relationships. They penetrate each other, were gradually accumulated on each other, or overlap chronologically. Therefore, individual bodies are very difficult, sometimes impossible to demarcate. This kind of pattern is referred to as a group of extrusive or polygenous domes (Fig. 4).

During cooling and crystallisation, a semi-solid to solid crust is created on the surface and at the edges of extrusive bodies (both exogenous and endogenous). As more lava flows in and the body's volume expands, it produces stress, which causes the crust to break and disintegrate into fragments. These fragments are cemented together again by fresh lava. This is how autoclastic breccia forms.

Identification of the autoclastic breccias at the edges of the cumulodome-type bodies help geologist define individual bodies during field research.

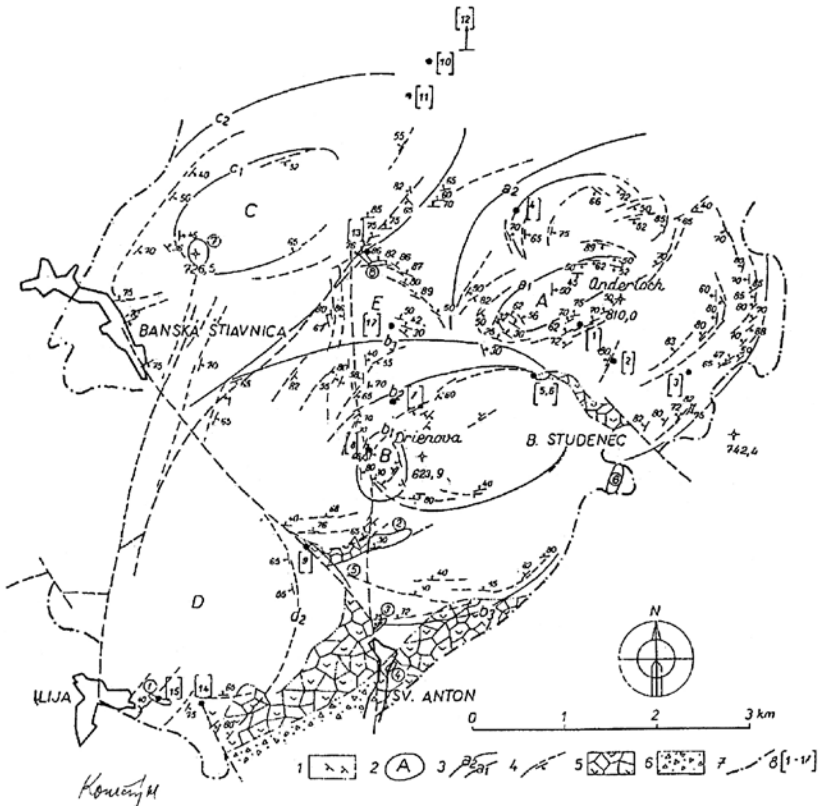


Fig. 3 Interpretation scheme of the structural elements of extrusive domes – cumulodomes (V. Konečný, L. Dublan, 1969):

1 – direction and inclination of fluidity planes, 2 – central parts of the extrusive domes (A, B, C, D), 3 – edges of the extrusive domes, 4 – interpretation of the fluidity plane course, 5 – lava breccias, 6 – epiclastic volcanic breccias, 7 – lava body boundaries, 8 – point of paleomagnetic research sampling.

Andesite in the abandoned double-bench quarry shows mural jointing along the fluidity planes (35 EN/35–40° inclination) and blocky jointing (280 W/70° and 140 SE/90° inclinations).

Andesite is coarse-grained porphyric, phenocrysts are composed of plagioclase (up to 3–4 mm), amphibole (up to 3–4 mm), and less frequently biotite. The base matter is microlitic-pilotaxitic and consists of tiny needles of plagioclase and amphibole as well as volcanic glass.

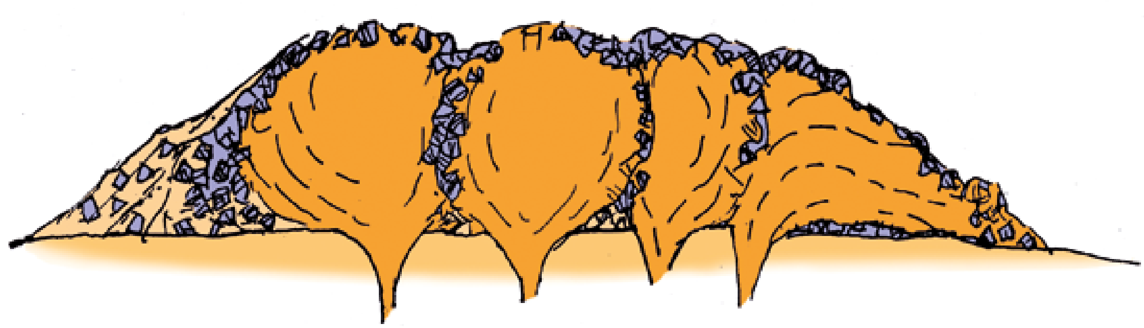


Fig. 4 A group of extrusive domes (J. Smolka et al., 2005).

Geotope No. 11

Kysihýbeľ

basalt neck in the railway trench

During the construction of the railway from Banská Štiavnica to Hronská Dúbrava, a basalt body at the Kysihýbeľ settlement was accidentally exposed. This ***basalt neck*** is a feeder system connected to a surface volcano (Fig. 1).

Besides the basalt body at the Kalvária Hill at the eastern edge of Banská Štiavnica (with a baroque church at the top), this is the second identified feeder system connected to an assumed surface basalt volcano. The surface structure of this volcano has been removed by the denudation processes described below. The erosion furrow subsided below the volcano level, among the rocks of the caldera fill.

The surrounding rock environment, which penetrates the basalt neck, represents one of the many bodies that fill the Štiavnica caldera. It consists of biotite-amphibole andesite of the Studenec formation. The steep course of the fluidal texture (characterised by alternating lighter and darker stripes consisting mainly of plagioclase and amphibole phenocrysts) indicate that very viscous lava (with limited mobility) was rising here. These textures, which can be observed in the walls of the railway trench, indicate that this body is an ***extrusive dome***.

The rock is coarse-grained porphyric, light grey with distinct phenocrysts of plagioclase, amphibole, biotite, and less frequently pyroxene. The base matter is microlitic, it consists of tiny plagioclase bands, dark minerals, and volcanic glass. This rock is weathering and disintegrating quite rapidly.

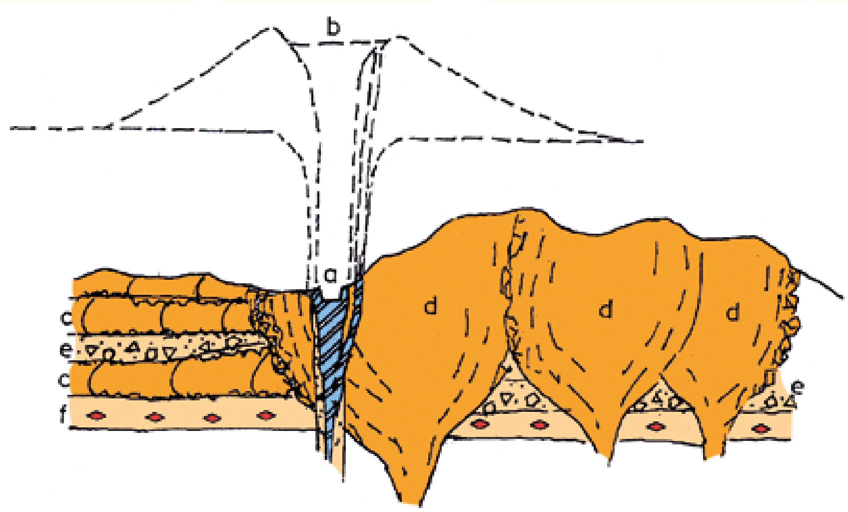


Fig. 1 Basalt neck – the feeder system connected to an assumed surface basalt volcano (J. Smolka et al., 2005).

a) basalt neck, b) assumed surface volcano, rocks of the Štiavnica caldera fill – products of the biotite-amphibole andesite volcanism, c) lava flow, d) extrusion – cumulodome, e) epiclastic volcanic breccia, f) pumice tuffs.

The railway trench allows us to "peek" into the internal structure or the anatomy of the feeder system, i.e., the basalt neck. The grey-black basalt rock visibly contrasts with he surrounding biotite-amphibole andesite, which penetrates the basalt neck.

The basalt neck itself consists of two bodies. The larger body of roughly elliptical cross-section is oriented in the NE-SW direction (Fig. 2.A, B). Another smaller basalt neck, located at its south-eastern edge, has been separated from the main body by a basalt breccia (Fig. 2C).

Distinctive columnar jointing can be seen at the left edge of the main basalt neck. It is perpendicular to the surrounding biotite-amphibole andesite rock of which the original feeder channel walls consisted (Fig. 3).

The jointing in the form of pentagonal and hexagonal columns perpendicular to the walls of the original feeder channel (perpendicular to

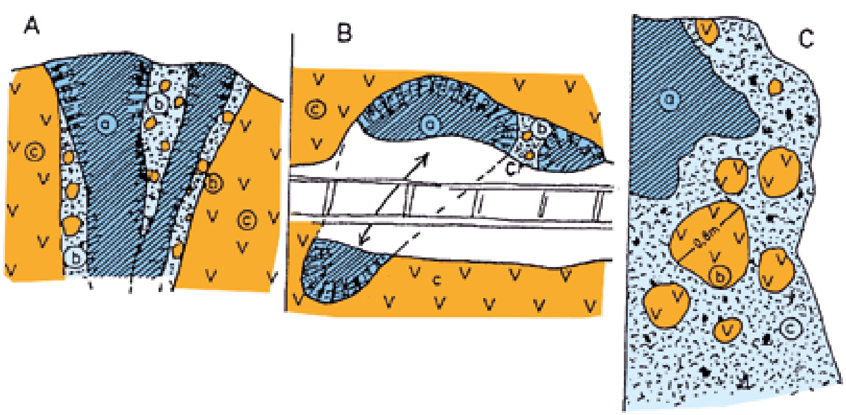


Fig. 2 The basalt neck exposed by the railway trench at Kysihýbeľ (J. Smolka et al., 2005):

A – basalt neck (profile), B – basalt neck (cross-section). a) basalt with columnar jointing, b) breccia in the diatreme fill, c) – pyroxene-biotite-amphibole andesite C – a close-up of the breccia in the diatreme fill: a) basalt, b) rounded blocks of pyroxene-biotite-amphibole andesite that come from the walls of the volcanic feeder, c) breccia in the diatreme fill with the fragments of porous basalt and tuff-grained matrix.

the cooling surface) develops when the magma body solidifies and crystallises into a solid basalt rock. When the lava body crystallises, its volume reduces, which creates internal stress. This stress creates jointing planes and if they take the form of a regular network, columnar jointing occurs. These columns are perpendicular to the surrounding channel walls, which represent the cooling surface of the magma body.

The basalt breccia, which separates the two basalt necks, consists of porous basalt fragments (from tiny 1 cm ones up to 5–10 cm fragments) and granular tuff matter (matrix), which consists of smaller basalt fragments and the fragments of plagioclase, pyroxene, and olivine crystals. This breccia fills the feeder channel connected to the surface volcano, which is referred to as a ***diatreme*** in the volcanological terminology.

Besides basalt, this breccia also contains a lot of fragments or even blocks of biotite-amphibole andesite with

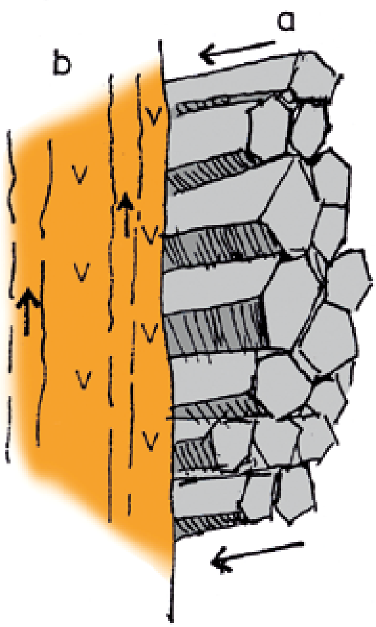


Fig. 3 Scheme of the basalt columns perpendicular to the walls of the feeder channel (J. Smolka et al., 2005):

a) basalt columns, b) biotite-amphibole andesite with steep fluidal texture course.

the size ranging from 0.5 m to an occasional 0.8 m. These blocks are distinctively rounded (Fig. 2.C).

These blocks consist of the rocks permeated by the basalt neck, which definitely indicates that they come from the walls of the feeder channel. But why have they have been rounded so much?

The magma rising from the depths towards the earth surface, rich in magmatic gases, usually follows tectonic disruptions such as faults and fault zones, or even their intersections, i.e. the path of least resistance. After reaching a certain level under the surface, in which the internal stress exceeds the lithostatic pressure generated by the weight of the rocks, gas is suddenly released from the magma column. A stream of high-pressure compressed gases expands rapidly towards the surface, tearing and destroying the rocks in the surrounding walls. These fragments and blocks are transported to the surface, where they explode and create a ***phreatic eruption*** (Fig. 4).

In this eruption phase, the explosive stream of compressed gases broadens the feeder channel and creates a funnel-like depression on the surface. The material consisting mainly of the rock fragments and blocks torn from the channel walls partly layers at the edges of the funnel-like depression and partly falls back into the channel opening.

When magma rises multiple times, the magmatic gases are explosively released on the sub-surface level again and again. These gases also tear off the upper part of magma, which rises through the feeder channel. When these gases suddenly explode, mag-

Fig. 4 Phreatic eruption (J. Smolka et al., 2005).

The stream of compressed gas transports the fragmented material from the feeder channel walls to the surface and erupts into the atmosphere. After landing on the Earth's surface, it accumulates at the edge of the depression and partly falls back into the opening of the feeder channel.

ma is dispersed into fragments and tinier ash-sized particles with crystal fragments. This mix of lava fragments, ash, and gases is rapidly rising towards the surface and erupts into the atmosphere (i.e. ***phreatomagmatic eruption***).

Repeated phreatomagmatic eruptions destroy the feeder channel walls. Fragments and blocks torn off the channel walls are transported towards the surface by a stream of gas and ash. Friction and chipping rounds their shapes on the way, which can be seen in the breccia. However, these blocks have not erupted from the feeder channel opening – when the stream of gas and ash lost its momentum, they have subsided deep back into the feeder system and have been preserved in the diatreme fill together with the tuff-breccia.

The analysis of the internal structure of the neck body allows for a reconstruction of the feeder system's development as well as the formulation of assumptions regarding its surface structure, which has been removed by denudation.

In the ***first stage***, the magmatic gases are suddenly and explosively released from the top of the rising magma column, because the external pressure on it has decreased. The violent expansion of the gases destroys the surrounding rocks, and the gas stream transports fragments, block, and tiny rock particles upwards to the Earth's surface, where this material is spewed out into the atmosphere in the form of a phreatic eruption (Fig. 5.A). During the massive initial eruptions, the diatreme feeder system is created and its surface outlet takes the form of a funnel-like depression. The fragmented material falls back to the ground and accumulates at the edges and on the inner slopes of this funnel-like depression. This is the initial stage of the formation of a surface volcanic pattern referred to as a **maar**.

The ***second stage*** involves phreatomagmatic eruptions (Fig. 5.B) during which mostly volcanic material – tuff, ash, debris, and basalt bombs – is spewed out. Repeated eruptions gradually create a circular tuff wall with dispersed debris and basalt bombs around the edges of the funnel-like central depression. Thus, a maar – a pattern typical for basalt volcanism – is created.

During the **third stage**, a maar lake forms in the central depression and lake sediments are created as can be observed in the areas of basalt volcanism in Southern Slovakia (Fig. 5C). However, in this case, a denudation cut has completely removed the surface maar. However, the basalt neck body and remains of the tuff-breccia diatreme fill with rounded blocks of biotite-amphibole andesite ripped out of the feeder channel walls testify of its past.

In the ***fourth and final stage*** of the diatreme's development, after gases are released, basalt magma solidifies in the feeder channel. In this case, the basalt body of the main basalt neck and its smaller satellite filled the diatreme (Fig. 5.D). The solidification and crystallisation of the basalt neck marked the definitive end of the volcanic activity as the feeder system had been clogged. Over time, denudation has completely destroyed the original surface volcano. Only the basalt neck and tuff-breccia in the diatreme fill testify that it once existed.

The age of the basalt body was determined by radiometric dating using the K/Ar method to be 6.88 ± 0.48 Ma (radiometric age determination was performed in the laboratory of the Hungarian Academy of Sciences in by Dr. K. Balogh). The radiometric age corresponds with the Pannonian (Later Neogene).

The petrographic composition of the basalt body includes nepheline basanite with plagioclase, olivine, and pyroxene phenocrysts. The base matter is microdoleritic, composed of tiny grains of plagioclase, pyroxene, olivine, and magnetite.

Calcite, aragonite and zeolites occur in the fill of cavities left by the escaping gases.

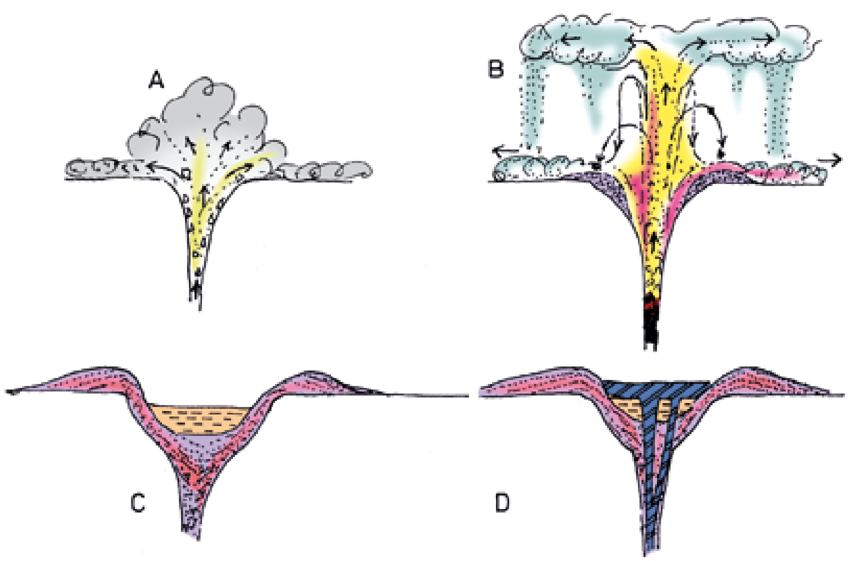


Fig. 5 Developmental stages of a maar volcano (J. Smolka et al., 2005):

A – during the initial phreatic eruptions, the volcanic feeder broadens into a funnel, B – during the following phreatomagmatic eruptions, a tuff ring (wall) forms around the edge of the funnel-like depression – a maar structure is created, C – during the period of volcanic quiescence, sediments (clay, diatomite, alginite) are deposited in the maar lake. D – In some cases, volcanic activity returns and the maar depression fills with basalt lava.

Geotope No. 12

Kalvária Hill

basalt neck

The Kalvária Hill is a distinct morphological landmark east of Banská Štiavnica as it extends about 100m above the surrounding terrain. This hill was part of the town's history since ancient times. Notably, the impressive architectural monument on its top – a baroque church with a Calvary path – is significant.

However, the hill (elevation 659) is also important from the geological viewpoint as it is a result of the latest volcanic activity and takes the form of basalt volcanism.

Its formation was completed when the magmatic source of andesite and rhyolitic volcanism, i.e., the magma chamber under the Štiavnica Stratovolcano was exhausted. The last gifts from the magma chamber offered to human civilisation were precious metals (gold and silver) and polymetallic ore veins. On the other hand, this was not the definitive end of volcanic activity. Later, basalt magma started rising from under the crust and basalt-type volcanic activity was renewed.

Alkali basalt volcanism

After the end of calc-alcaline andesite and rhyolitic volcanism, which formed the andesite stratovolcanoes and monogenetic volcanoes in Central Slovakia, alkali basalt volcanism followed. This volcanism of the later period differs from the previous andesite volcanism in terms of composition. These basalts have higher content of Na_2O and K_2O alkalis and lower content of Si_2O. The volcanic manifestations and volcanic body forms are different as well. Unlike in andesite volcanism, stratovolcanoes are not formed. Basalt volcanism results in scoria and tuff cones, maars, and lava flows. In Central Slovakia, basalt volcanism can be found in the Ostrá Lúka lava complex (south-west of Zvolen), the lava flow remains at Devičie (west of Krupina), the Kalvária Hill basalt neck, the neck at Kysihýbeľ, the Putikov Vŕšok scoria cone with the lava flow at Nová Baňa. A larger area of basalt volcanism is located in Southern Slovakia in the Lučenská Kotlina Basin and Cerová Vrchovina Mountains.

The basalt body of the Kalvária Hill in historical geological research

The basalt body of the Kalvária Hill (elevation 659) used to feed a surface volcano – the ***basalt neck*** (Fig. 1).

The basalt neck of the Kalvária Hill played a key role in historical geological research, specifically in the dispute between the Neptunist and Plutonist schools regarding the origin of these rocks in the 17th and 18th centuries. The Neptunists (named after Neptune, the sea god) led by renowned scientist E. J. Esmark (1798), claimed that all rocks had been created exclusively through sedimentation of solutions, mainly water-based ones. They assumed that basalts had been created by precipitation from solutions (like rock salt). This idea was inspired by the similarity of basalt columnar jointing to salt crystals. On the other hand, the Plutonists (named after Pluto, the fire god) assumed that some rocks had been created by volcanic processes, mainly as the result of lava solidification and crystallisation. The basalt neck of the Kalvária Hill played a role in the Neptunist vs. Plutonist dispute.

In 1818, the French Academy of Sciences sent a special expedition to the Kingdom of Hungary led by F. S. Beudant. Besides geological mapping and research, the expedition was supposed to collect the evidence confirming the Plutonist theory about the origin of volcanic rocks. F. S. Beudant published the results in a four-tome work titled *Voyage mineralogique, geólogique en Hongrie pendant l'année 1818 I–IV* along with a geological map of the Kingdom of Hungary and Transylvania. He used the basalt neck of the Kalvária Hill to explain and confirm the plutonic (volcanic) origin of this formation at the French Academy of Sciences. F. S. Beudant also described the basalt tuffs and bombs on a hill near Nová Baňa (today known as the Putikov Vŕšok Volcano).

The Kalvária Hill basalt body has been referred to in almost every work written by renowned geologists who studied this region since the 19th century (J. Pettko, F. Richthofen, J. W. Judd, J. Szabó, L. Cseh and others). More recent authors who have dealt with the petrographic description and the mineralogical and chemical composition of this rock include F. Fiala (1938), A. Miháliková and M. Šímová (1989), V. Kollárová and P. Ivan (2003).

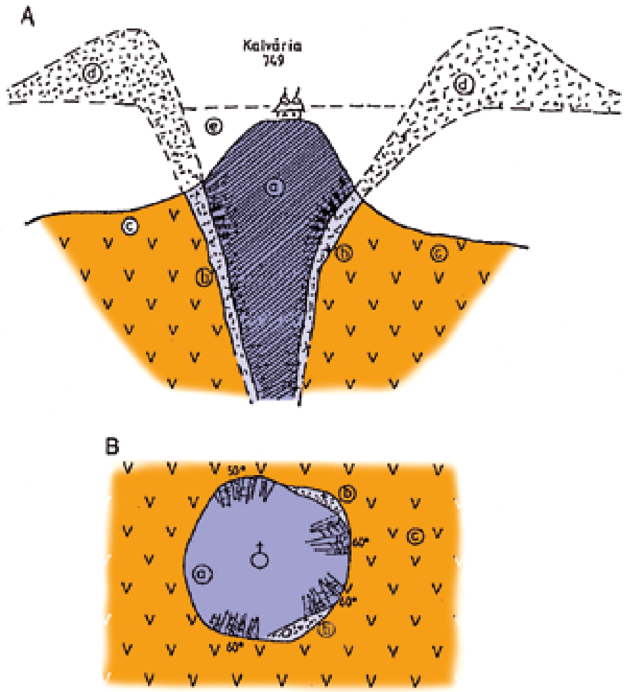


Fig. 1 The Kalvária Hill basalt neck (J. Smolka et al., 2005): A – profile, B – cross-section.

Explanatory notes:
a) basalt with columnar jointing, b) breccia in the diatreme (feeder channel) fill, c) surrounding rock environment – biotite-amphibole andesites (lava flows), d) assumed surface volcano – maar (removed by denudation), e) assumed lava fill of the crater (removed by denudation), f) inclination of the columnar jointing.

Form of the basalt body
The basalt body of the Kalvária Hill has a roughly circular cross-section with the diameter of ca. 90 m (Fig. 1). This basalt body still represents a distinctive morphological formation (landmark) because basalt rocks are more resistant to weathering than the surrounding, less-solid rocks penetrated by this basalt body (Photo 1).

At the edges of this basalt body, distinctive columnar jointing can be observed in multiple places. It consists mainly of pentagonal and hexagonal columns inclining 50–60° away from the body's middle, which resembles an upside-down fan (Photo 2).

Columnar jointing is quite frequent in the lava bodies of basalt composition. It is less frequent in andesite bodies. It occurs at the edges of intrusive bodies such as dykes and bedded intrusions but also in fragment flows. This is the case of this basalt neck as well (Fig. 2).

Columnar jointing develops when the magma body finally solidifies and crystallises. When the body's form turns from liquid into crystalline, its volume reduces, which creates internal stress and in turn, cracks and joint planes. These areas are perpendicular to the body's (cooling)

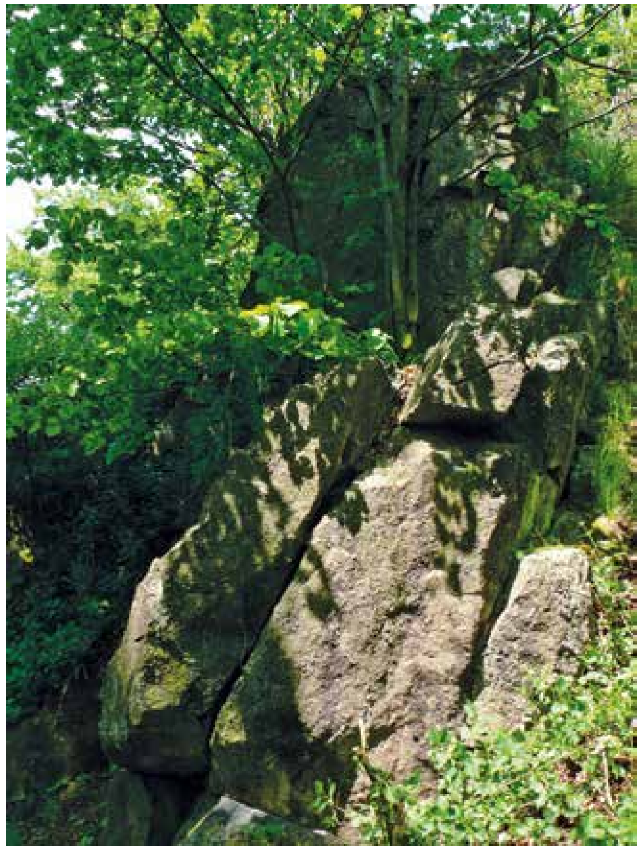


Photo 1 The basalt body located at the southern side of the Kalvária Hill (© P. Pachinger).

Photo 2 A close-up of the columnar jointing at the edges of the basalt body (© P. Pachinger).

surface. When the joint planes form a regular network, columnar jointing occurs. If these planes are not regular, *irregular blocky jointing* occurs.

If the columns are perpendicular to the surface of the cooling body (i.e. the surrounding walls of the feeder channel), and our jointing resembles an upside-down fan, it means that the feeder channel walls in this specific part of the denudation cut must have been broadened. Since the location is below the original surface volcano (which was later removed by denudation), this used to be the transition into a funnel-like crater (Fig. 3).

The columns are perpendicular to the funnel-like crater broadening. In the lower levels of the feeder channel (which have not yet been investigated) the columnar jointing probably becomes perpendicular to the vertical walls. This assumption has been fully confirmed in the basalt neck located at Kysihýbeľ and exposed by a railway trench. The edge of the basalt body with columnar jointing perpendicular to the feeder channel walls can be observed there.

Paleo-volcanological reconstruction
Although erosion has removed the surface volcano at the basalt neck of the Kalvária Hill (including the surrounding rocks, which used to be part of the funnel-like crater), certain assumptions regarding the nature of the surface volcanic pattern can be formulated. Based on the analogy with the familiar surface bodies of basalt volcanism in Southern Slovakia, it can be assumed there used to be a monogenetic volcano – maar (Fig. 1.A), or a combination of a maar with a scoria cone. The initial phreatic explosion (an eruption of magmatic gases and water vapours) creates a funnel-like depression at the surface, narrowing into the feeder channel below. This explosion destroys the rocks in the channel walls and turns them into fragments and close-grained material, which is spewed into the atmosphere, falls back and deposits on the inner slope at the upper part of the funnel-like depression and around its outer edge (Fig. 4.A). The following phreatomagmatic eruptions spew out lava particles from the upper levels of the lava column in the form of volcanic ash and lapilli tuff or debris, and the tuff ring around the funnel-like maar depression grows (Fig. 4.B). Upon the end of this stage of explosive activity, the feeder channel is filled with tuff and a breccia. At this stage, the volcanic feeder with this

Fig. 2 Columnar jointing of the basalt neck at the southern side of the Kalvária Hill (© V. Konečný).

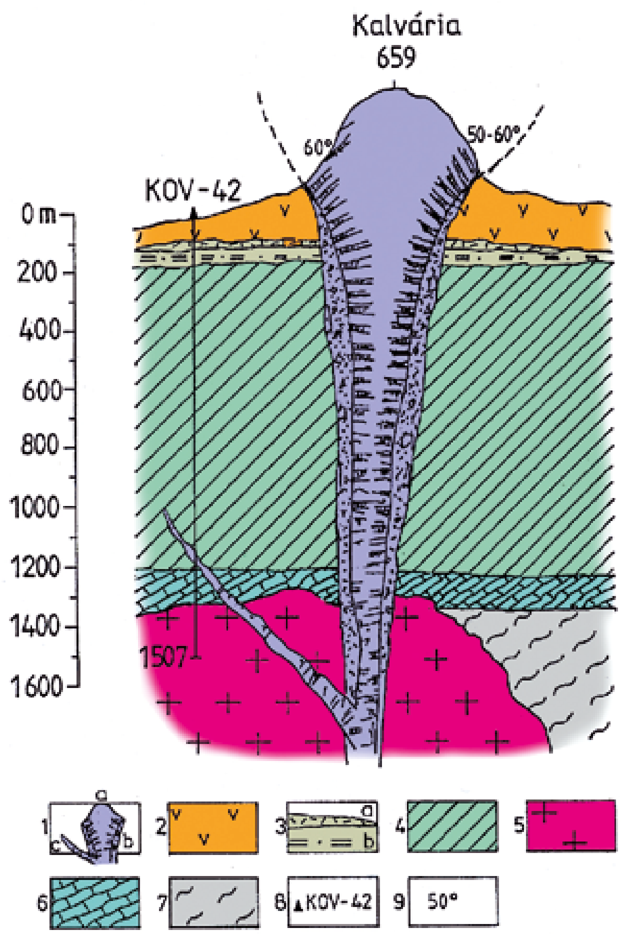


Fig. 3 The basalt neck of the Kalvária Hill – a geological section (J. Smolka et al., 2005):

1 – basalt neck: a) basalt with columnar jointing, b) breccia in the diatreme fill, c) basalt dyke, 2 – lava flows, extrusions, and volcanoclastic biotite-amphibole andesite rocks in the caldera fill, 3 – bottom part of the caldera fill: a) tuffs, b) epiclastic volcanic sandstones, siltstones, lignites (the Červená studňa Formation), 4 – whole bottom structure, 5 – granodiorite, 6 – Paleozoic-Mesozoic sediments, 7 – crystalline complex, 8 – borehole, 9 – inclination of the columnar jointing.

type of fill is referred to as a diatreme. When the volcanic activity ends, lake sedimentation sometimes occurs in the maar depression (Fig. 4.C). In the final stage of this volcano's formation, the lava column has risen to the crater or maar depression level and turned it into a lava lake (Fig. 4.D). In some cases (e.g. Southern Slovakia), the volcanic activity continues even after the maar is created and a tuff-scoria cone forms on the maar's surface (Fig. 4.E). So far, it is not yet known whether this was the case of the volcano that had once been fed by the basalt body of the Kalvária Hill. When lava in the feeder channel solidified and turned into a neck, it clogged the feeder system and the volcanic activity ended. The original diatreme fill is often preserved at the edge of such a neck (e.g., the basalt neck at Kysihýbeľ with the remains of breccias in the diatreme fill).

Another question is whether the assumed *monogenetic volcano – maar* or the scoria cone were accompanied by a lava flow. The distinctive accumulation of basalt blocks at two places, SE and NE of the basalt neck, could come from a disintegrated lava flow.

The KOV-42 borehole (1,197.5 – 2,001.5 m) near the basalt neck of the Kalvária Hill has confirmed a basalt dyke and the two are probably related (Fig. 3).

The age of the basalt body was determined by radiometric dating using the K/Ar method to be 6.89 ± 0.38 Ma (dating was performed in the laboratory of the Hungarian Academy of Sciences in by Dr. K. Balogh).

Basalt is grey-black to black and porous at the edges. The cavities and pores are either empty or filled with calcite, aragonite, and zeolite. Phenocrysts are composed of plagioclase, olivine, and augite. The base matter is granular – microdoleritic and consists of tiny grains of plagioclase, augite, olivine, nepheline microlites, and magnetite. Its composition corresponds with nepheline basanite.

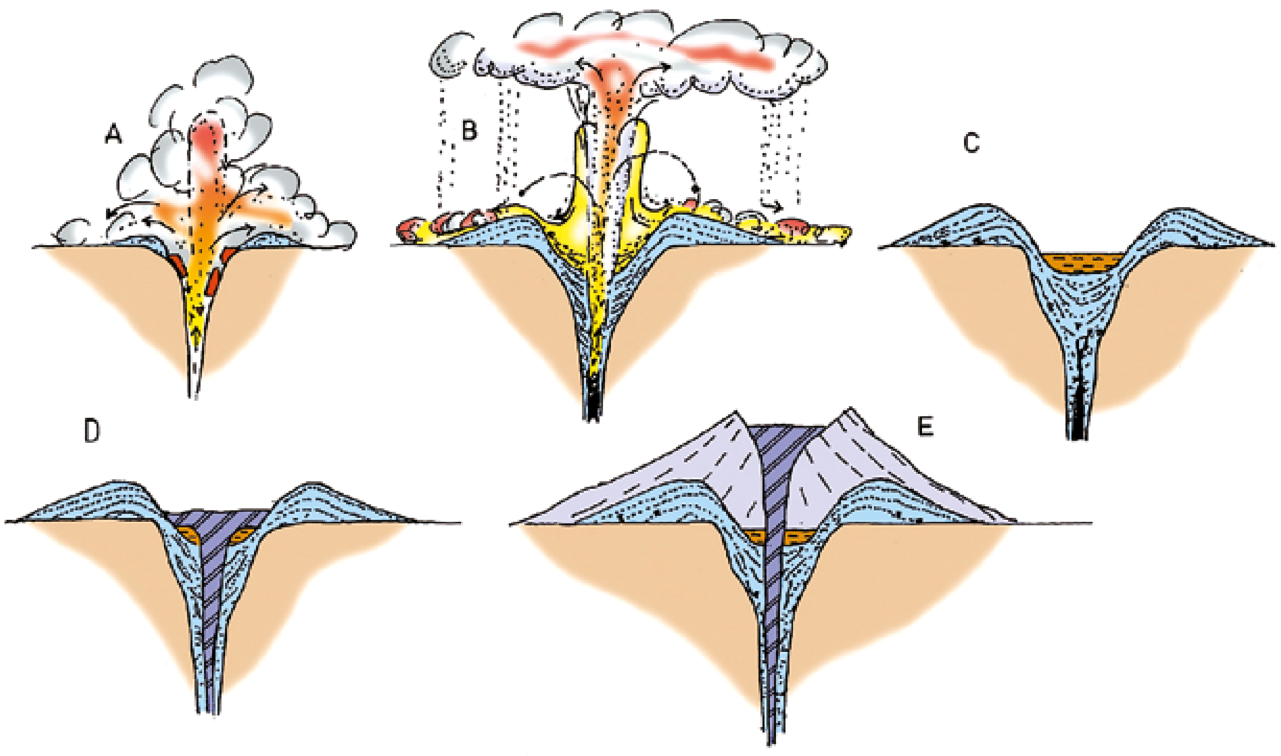


Fig. 4 The stages of basalt volcanism – a paleo-volcanological reconstruction (J. Smolka et al., 2005):

A – phreatic explosions broaden the volcanic feeder and a funnel-like depression is created,
B – phreatomagmatic eruptions continue building the tuff ring around the funnel-like depression – a maar structure is formed,
C – when the volcanic activity ends, the central maar depression turns into lake and sedimentation ensues,
D – the volcanic activity ceases when the basalt magma rises into the crater and maar depression,
E – the continuing explosions create a tuff-scoria cone; finally, basalt magma rises and fills the crater depression.

4. Tourism Territorial Unit Štiavnické Bane

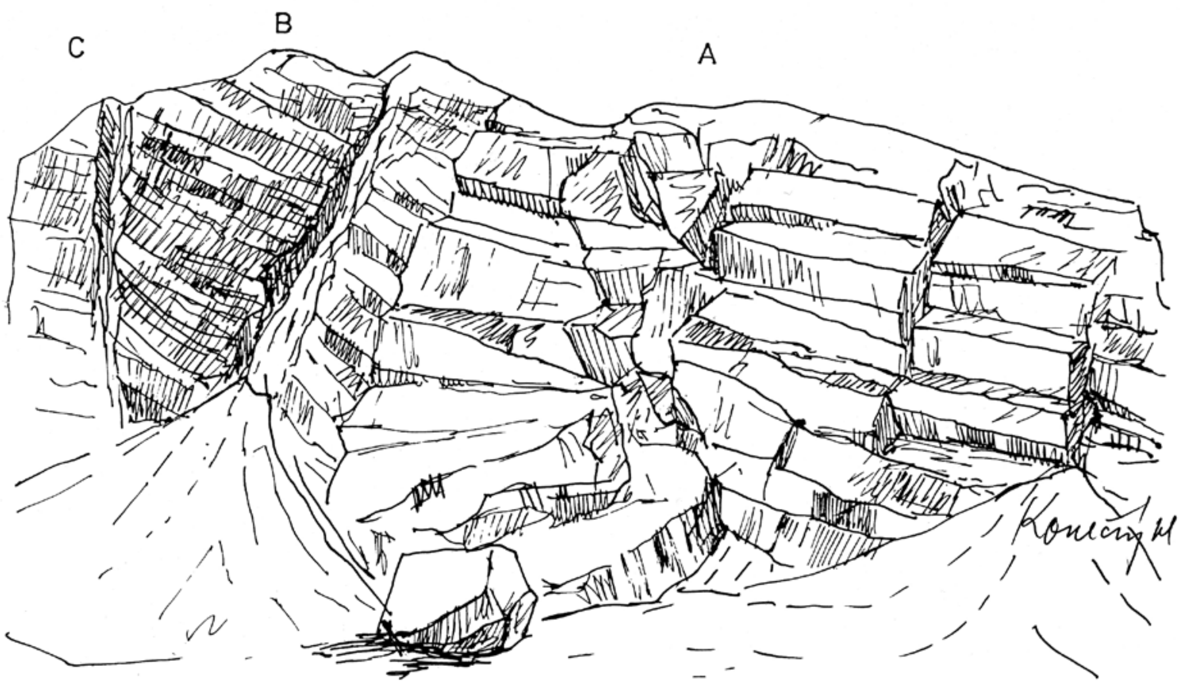


Fig. 1 The bottom structure of the Štiavnica Stratovolcano exposed in an abandoned quarry on the northern slope of Gumanina (© V. Konečný).

Geotope No. 13
Gumanina
bottom stratovolcanic structure

In the wall of an abandoned quarry on the northern slope of Gumanina, by the state road south of the Richňava Lake, rocks of the bottom structure of the Štiavnica Stratovolcano are exposed (Fig. 1, Photo 1).

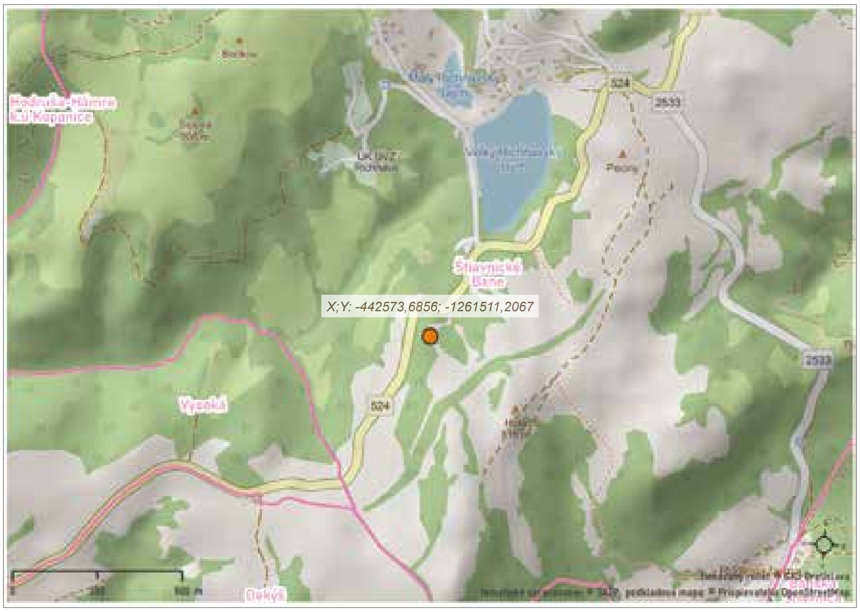
In the right part of the quarry wall is an andesite porphyry with blocky to coarsely-columnar jointing with a subhorizontal course of the joint planes (planes 35 EN/20° prevail). The eastern part of the andesite porphyry body is cut off (truncated) by a fault zone. In the direction of the fault zone, the rock is shattered, intensely propylitised and disintegrated.

Photo 1 The general view of the wall of an abandoned quarry on the slope of Gumanina – the right part (© P. Pachinger).

Behind the fault, andesite with mural jointing (B) inclined towards southwest can be observed. The andesite body (B) corresponding to the lava flow is further penetrated (dislocated) by a fault zone with a steep course from the east. Behind it is the (C) part.

The body in the right part of the quarry wall (A) probably corresponds to the part of the intrusion formed by a rising movement, a dyke body, or a feeder system connected to the bedded intrusion above. The subhorizontal orientation of the coarsely-columnar joint planes indicates a steep course of the surrounding walls between which the magmatic intrusion was deposited. The formation of the coarsely-columnar jointing in the case of intrusive bodies occurs in the process of cooling and crystallisation of magma, and the direction of this jointing is generally perpendicular to the edges of the cooling body (in this case, the surrounding walls).

In the left part of the quarry wall, a fine-grained porphyric pyroxene andesite of a lava flow with lamination-type mural jointing formed during the final lava movements (small-scale movements of lava in a semi-solid state, Photo 2), can be observed. This mural jointing characterizes mainly the lower parts of lava flows and it is parallel to the surface along which the lava flow moves.



The intrusive body of andesite porphyry as well as the andesite stream is located in the overlying rock of a Myšia hora-type laccolith intrusion, which dips beneath it in a southerly direction (Fig. 2).

The tectonic disintegration of the andesite bodies by fault zones took place in a younger period in relation to the formation of the Hodruša-Štiavnica Horst in the Late Sarmatian to the Pannonian.

Andesite porphyry is a fine-grained to medium-grained porphyry, grey-black to blue-black and greenish (propylitised). Phenocrysts consist of plagioclase (up to 2 mm) and augite (up to 15 mm). The base matter is microlithic-granular. Due to hydrothermal alteration, the dark minerals are partly to completely chloritised, the plagioclase is partly sericitised. The pyroxene andesite is dark-green due to propylitisation. Phenocrysts consist of plagioclase (up to 1–.5 mm) and pyroxenes, which are chloritised and often indistinguishable. The base matter is microlithic, microlitic-hyalopilitic, obscured by alternation products, of which the chloritisation of dark minerals is particularly pronounced.

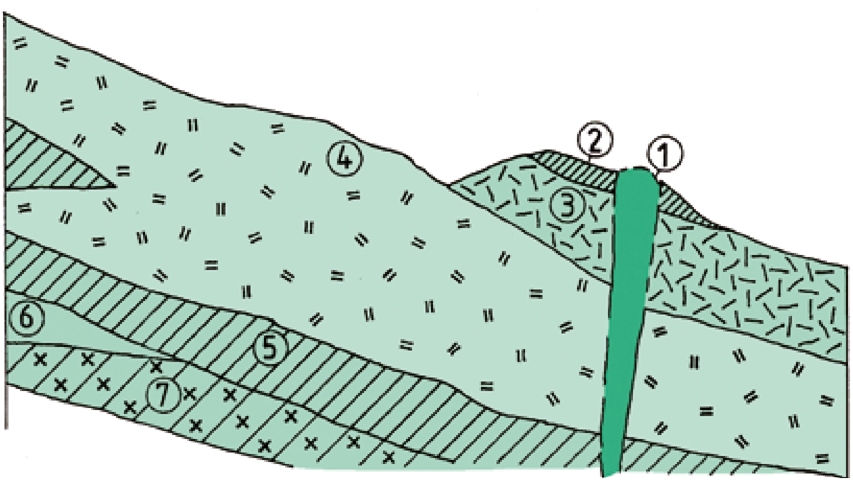


Fig. 2 The position of the intrusion of andesite porphyry in the environment of the bottom stratovolcanic structure (© V. Konečný et al., 2004):

1 - intrusion of pyroxene-andesite porphyry body (dyke), 2 - upper lava flow of pyroxenic andesite, 3 - amphibolic-pyroxenic andesite porphyry (sill), 4 - amphibolic-pyroxenic andesite porphyry with Myšia hora–type biotite (laccolith), 5 - lower lava flow of pyroxenic andesite, 6 - volcanoclastic rocks, 7 - pyroxene-andesite porphyry.

Photo 2 The fine-grained porphyric andesite of lava flow with mural jointing (© P. Pachinger).

Geotope No. 14

Štiavnické Bane

bedded intrusion of andesite porphyry, bottom stratovolcanic structure

The rock cliffs on the southern edge of the ridge below Farárova hôrka, near the northern edge of the Štiavnické Bane village, consist of propylitised andesite porphyry (Fig. 1, Photo 1, 2).

The jointing is coarsely-columnar along the subvertical planes. Planes with orientation 160 SE/70°, 190 SE/80° and 90 E/60° (inclinations) prevail.

The subvertical columnar jointing is characteristic not only for bedded bodies of smaller thickness, but also for higher levels of lava flows. At the base of lava flows, the jointing is mural, subhorizontal (parallel to the surface over which the lava flow is moving). However, in the case of this location, other characteristics typical for lava flows (foaming and brecciation of the upper and lower parts of the flow) are not present. Therefore, it is more of a sill-type body.

The body is a part of a larger body of pyroxene-andesite porphyry extending into the Banská Štiavnica area (Fig. 2). This larger body of pyroxene-andesite porphyry in the broader surroundings of Banská Štiavnica protrudes from the area of the Trojičný Vrch Hill, near the Maximilian Shaft, near Štefultov, from the north-western slopes of the Tanád Hill and above the town of Banská Štiavnica. A body of similar composition is also widespread in the area south of the Richňava Lake. In the area of Štiavnické Bane, a pyroxene-andesite porphyry body separates protrusions of a Myšia Hora-type laccolith body, which are present in its bedrock and overlying rock. A pyroxene-andesite porphyry body rich in augite – Tanád type – is located higher up in the overlying rock of the pyroxene-andesite porphyry, representing the upper part of the Tanád Ridge.

The andesite porphyry is fine-grained to medium porphyric, solid, grey-black to blue-green, propylitised. Phenocrysts consist of plagioclase (up to 0.5–1 mm), pyroxenes are macroscopically almost indistinguishable, chloritised. Microscopically, hypersthene and augite are distinguished. The base matter is microlithic, grained. Due to propylitisation, the pyroxenes are partially to completely chloritised, the plagioclase is partially sericitised. The base matter is replaced by aggregates of secondary minerals such as chlorite, sericite, carbonates and quartz. The Terézia vein in an ore-bearing vein is in the vicinity of the skarn area.

In older mining engineering research works, the term "grünstein" (greenstone) was used for the rocks in the Banská Štiavnica region, originating from the practical mining activity. It referred to the rock in which the gold-silver veins were developed.

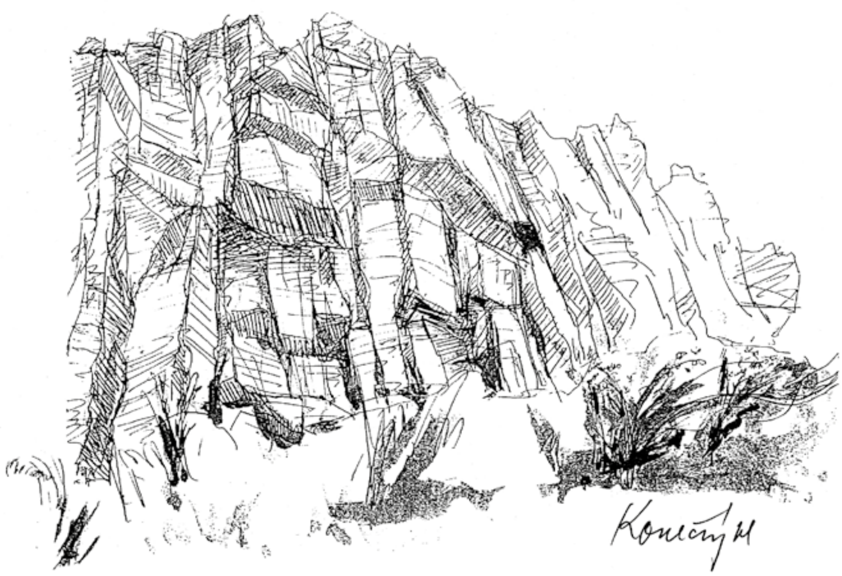


Fig. 1 Rock cliffs of andesite porphyry near the northern edge of Štiavnické Bane - southern slope below Farárova hôrka (© V. Konečný).

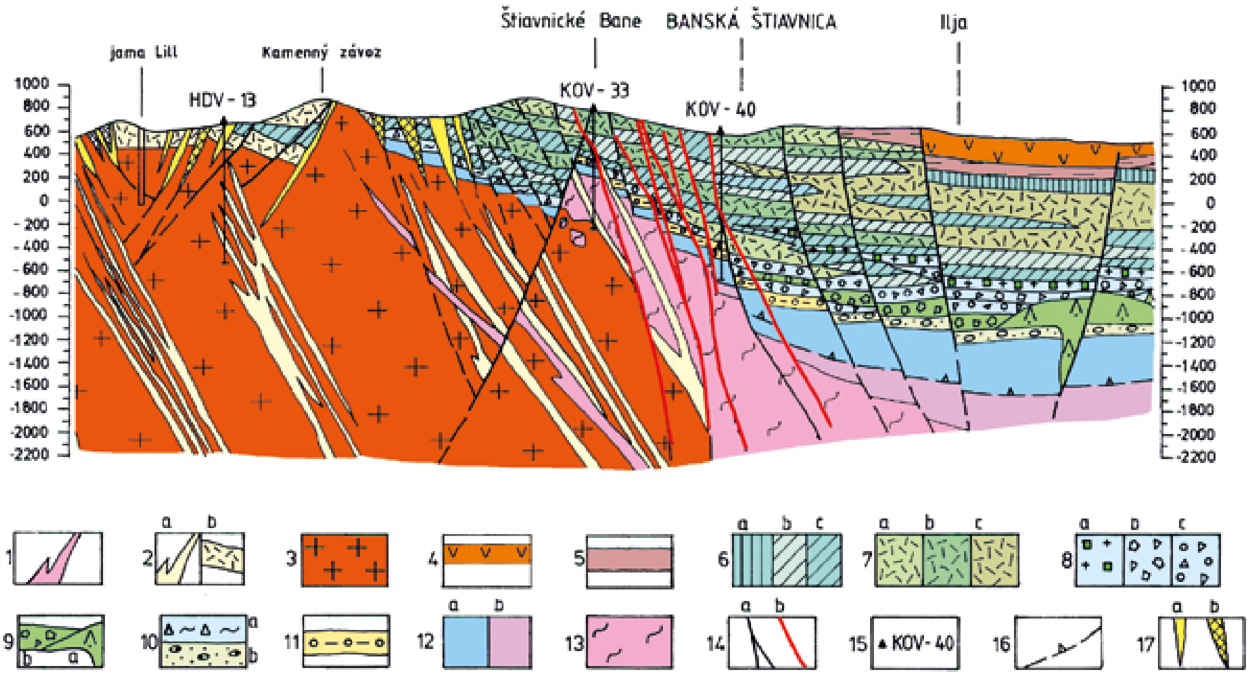


Fig. 2 A geological section in the south-eastern part of the Hodruša-Štiavnica Horst (© V. Konečný et al., 2004):

1 – rhyolite dyke (the Late Sarmatian), 2 – the Banisko intrusive complex: a) sill, b) dyke, 3 – the Hodruša-Štiavnica Intrusive Complex; granodiorite, 4 – the Štiavnica caldera fill, biotite-amphibole andesite (the Studenec Formation), 5 – epiclastic volcanic sandstones with siltstones and lignites, 6 – bottom stratovolcanic structure: lava flows: a) pyroxenic andesites, b) amphibole-pyroxene andesites, 7 – bedded intrusions (sills, laccoliths): a) amphibole-pyroxene andesite porphyry, b) pyroxene-andesite porphyry, c) amphibole-hypersthene andesite porphyry (± quartz ± biotite ± garnet), Myšia hora type, 8 – volcanoclastics: a) chaotic breccias of pyroclastic flows, b) epiclastic volcanic breccias, c) epiclastic volcanic breccias - conglomerates, 9 – products of volcanism of amphibole-hypersthene andesite with garnet: a) extrusion, b) coarse epiclastic volcanic breccias, 10 – a) tuffisite breccias, b) tuffitic sands and conglomerates with non-volcanic material (basal complex), 11 – Paleogene sediments, sandstones, conglomerates, 12 – Mesozoic and Paleozoic rocks: a) sheet unit of the Sillicicum, limestones, dolomites, schists with evaporites (Triassic), b) Mesozoic of the Veľký Bok Series, limestones, dolomites, schists (Triassic, Jurassic, Cretaceous), 13 – Veporicum crystalline complex, crystalline schists, crushed Vyhne granite, 14 – a) fault, b) ore vein, 15 – borehole, 16 – displacement line, 17 – hydrothermal alterations: a) argillites, b) sillicites.

The eminent French researcher F. Beudant (Fig. 3), who visited Banská Štiavnica region as part of an expedition of the French Academy of Sciences to the Austro-Hungarian Empire and Transylvania, described in his four-volume work *Voyage mineralogique, géologique en Hungrie pendent l´année 1818 I – IV*, published in 1822, among other things, the greenish-coloured volcanic rock named "grünstein" (greenstone), which is typical for this region. He added the name "grünstein pyroxenique trachyte" based on its composition.

F. Richthofen (1860) (Fig. 4), who undertook research in the Banská Štiavnica area, introduced the term "propylite" for the altered rocks, previously referred to as "grünstein

Fig. 3 Francois Sulpice Beudant - according to a photograph from an oil painting (J. Smolka et al., 2004).

Fig. 4 F. Richthofen (J. Smolka et al., 2004).

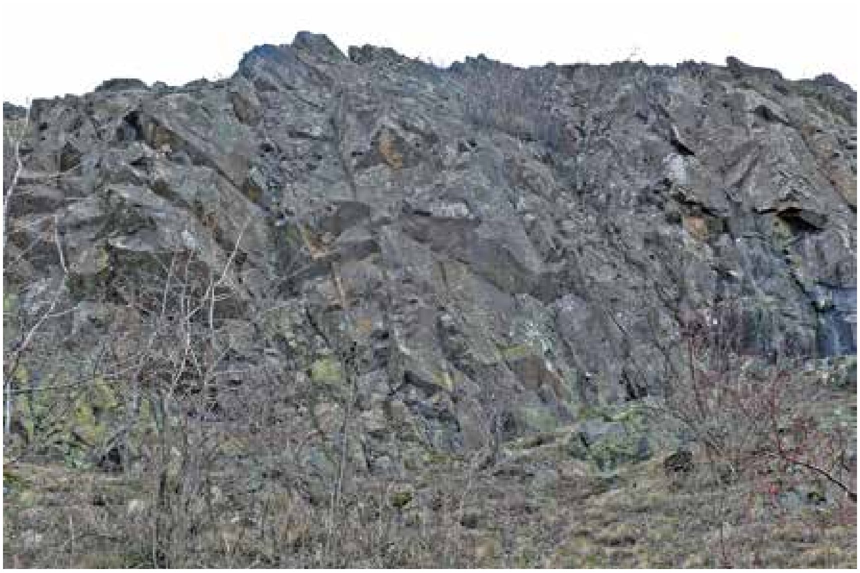


Photo 1 A view of the andesite porphyry rock cliff at the northern edge of Štiavnické Bane (© P. Pachinger).

trachyte". He assumed that they were the result of mass eruptions of magma unusually rich in water. Richthofen's views influenced both current and subsequent generations of geologists, who depicted these large-scale mass eruptions of propylites, often of enormous areal extent, on geological maps in other regions as well. Although subsequent research works have shown that propylites are volcanic rocks affected by later hydrothermal alternations, the terms propylite and propylitisation (originally applied to the rocks of the Banská Štiavnica region) have become terms used worldwide.

Propylitisation is particularly characteristic for the marginal parts of hydrothermal systems. It is the result of the action of slightly acidic CO_2 and H_2S saturated fluids with higher temperature, which permeate through the rock and induce changes in its original mineral composition. These changes are mainly manifested by the transformation of dark minerals (pyroxenes, amphiboles, biotites) into chlorite, i.e. a secondary mineral rich in iron.

Due to this transformation, the rock gains a characteristic green hue (grünstein). Propylitisation is accompanied by other transformations of varying intensity, such as the conversion of plagioclase into the mixture of clay minerals (argillitisation), the formation of epidote, calcite, quartz and pyrite.

The younger transformations affect the rocks around the ore veins. These transformations in the form of adularisation, argillitisation (formation of clay minerals), and silicification (re-sillicification) often show zonal distribution in relation to the ore veins (Forgáč, 1966).

Photo 2 A close-up of the coarsely-columnar jointing of the andesite porphyry rock cliff (© P. Pachinger).

Geotope No. 15

Ilija

ash-pumice tuffs of the Studenec Formation in the caldera fill

In the initial period of the formation of the Štiavnica caldera, a lava flow effusion of biotite-amphibole pyroxene andesite from the southern edge of the caldera took place. The lava flow was directed to the central part of the caldera depression. Subsequent Plinian eruptions produced large volumes of ash-pumice tuffs in the form of ash-pumice flows that filled the space of the subsiding caldera. In the periods between the eruptions, the redeposited pumice tuffs were again redeposited in the lake environment of the caldera in the form of redeposited tuffs and sandstones. Fine-grained material was also carried into the caldera. A lava flow was deposited above.

The lithological structure of the lower levels of the Štiavnica caldera fill is shown in the schematized lithological profile (Fig. 1).

In the wall of a smaller abandoned quarry near the edge of the ridge with the elevation 697 (south of Ilija), a bed of chaotic ash-pumice tuff is exposed (Fig. 2, Photo 1).

The pumice tuff consists of fragments of grey-white pumice, mostly up to 2–3 cm in size, occasionally up to 5–8 cm. The pumice fragments are embedded in a finer-grained ash base-matter (matrix) composed of finer fragments of pumice, plagioclase crystals, amphibole and biotite. Up to 5–10 cm size andesite fragments are also present in smaller quantities. The position of chaotically deposited pumice tuff represents ash-pumice flow deposits.

Pumice represents strongly to extremely foamy lava (in this case andesite), which gains a porous texture and at the same time lighter grey-yellow to grey-white hues. The process of lava frothing occurs as a result of a sudden and massive release of the

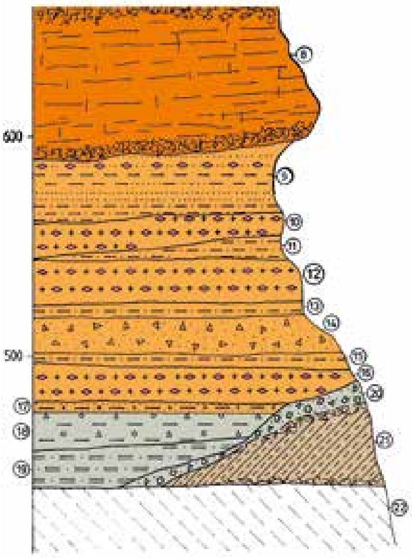


Fig. 1 The lithological profile of the lower part of the Štiavnica caldera fill (© V. Konečný et al., 2004):

The Studenec Formation:
8 – lava flow of amphibole-biotite andesite, brecciated in the upper and lower part, 9 – close-grained to coarse grained epiclastic volcanic sandstones with siltstones and pumice positions (leaf imprints), 10 – ash-pumice flow, 11 – epiclastic volcanic sandstones, siltstones and redeposited pumice tuffs, 12 – ash-pumice flow, 13 – close-grained epiclastic volcanic sandstones, siltstones and redeposited tuffs, 14 – coarse epiclastic volcanic breccias (material of amphibole-biotitie andesites and older amphibole-pyroxene andesites from the bottom of the stratovolcanic structure, 15 – close-grained epiclastic volcanic sandstones, siltstones and redeposited tuffs, 16 – ash-pumice flow, 17 – close-grained epiclastic volcanic sandstones and siltstones with interbedded vitrocrystalline tuffs with amphibole and biotite.
The Červená Studňa Formation:
18 – epiclastic volcanic sandstones and siltstones with positions of minor breccias and conglomerates, 19 – epiclastic volcanic sandstones and siltstones with positions of lignites, 20 – coarse epiclastic volcanic breccias with mixed material of older andesites of bottom structure and lava flow in the bedrock, 21 – lava flow of biotitite-amphibole-pyroxene andesite.
Bottom stratovolcanic structure:
22 – lava flows and volcanoclastic rocks of pyroxene and amphibole-pyroxene andesites unarticulated.

vapour phase. Release of the vapour phase can already occur in the upper part of the magma reservoir (about 5–15 km below the surface, Fig. 3.).

In the magma which is found in a magma chamber, the vapour phase is kept in a soluble state under high pressure induced by the weight of the overlying rock (lithostatic pressue). When cracks open in the roof of the magma reservoir, the vaporous phase ceases to be soluble in the magma and, as a result of the reduced pressure, begins to escape spontaneously to the surface. This leads to the magma frothing in the upper part of the chamber. The frothy magma ascends to the surface through open cracks, reaches the level of reduced pressure and in the last phase of ascent, when it reaches the surface, it explodes violently due to the sudden expansions of the gases – the eruption phase occurs, whereby the frothy magma is torn into particles. These fragments of frothy magma are pumice.

During an explosive eruption, this mixture consists of highly compressed gases, fragments of frothy lava and crystals, ejected from the volcanic orifice into the atmosphere in the form of an eruptive column - a Plinian eruption occurs. The collapse of the eruptive column is followed by the movement of this mass, composed of expanding gases, fragments of frothy lava – pumice – and crystals in the form of turbulent ash-pumice flow, down the volcanic slope.

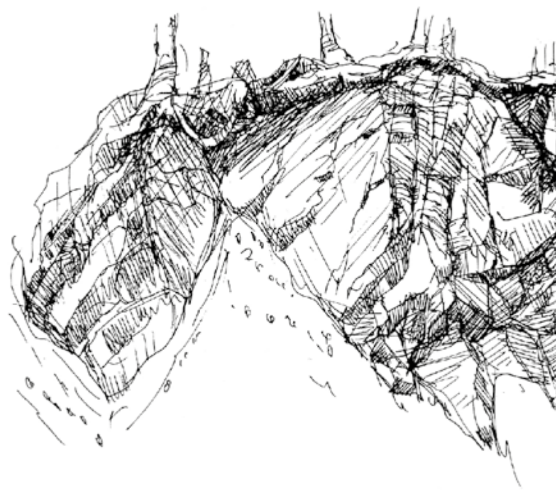


Fig. 2 The ash-pumice flow – the abandoned quarry under e. 697 south of Ilija (© V. Konečný).

Photo 1 The ash-pumice tuff in the wall of an abandoned quarry south of Ilija – right part of the quarry wall (© P. Pachinger).

During this movement, rock fragments from the bedrock over which the flow is moving are often trapped and transported with the flow. If the whole mass retains a sufficiently high temperature after deposition, sintering to welding can occur and ignimbrites are formed.

In the case of the ash-pumice flow in the wall of the abandoned quarry at this site, the transported material was no longer in a hot state and no welding or deformation of the pumice had occurred. In this case it is a cooled ash-pumice flow.

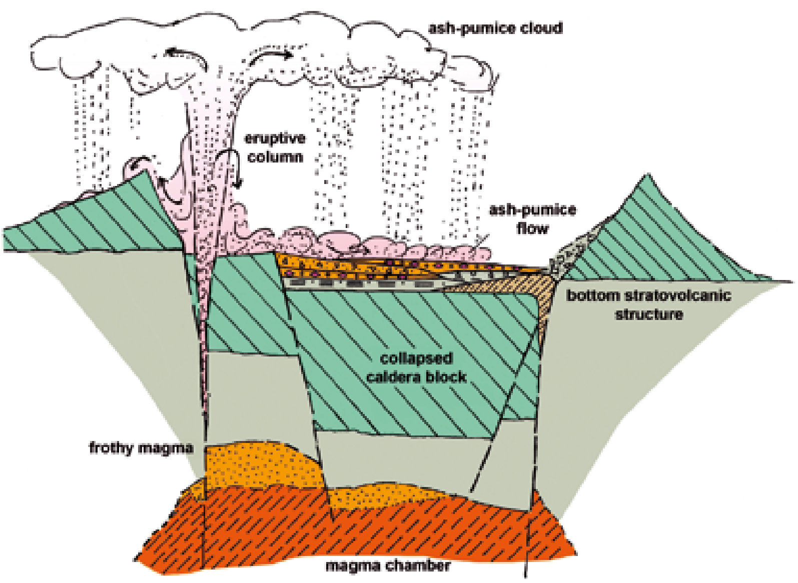


Fig. 3 Scheme of the Plinian eruption in the Štiavnica caldera (© V. Konečný et al., 2004).

Geotope No. 16

Počúvadlo

welded ash-pumice tuffs – ignimbrites – upper structure of the Štiavnica Stratovolcano

In the southern part of the Štiavnica caldera and partly near the edge of the delta fill, the products of explosive activity of Sarmatian volcanism are deposited in the form of welded ash-pumice tuffs – ignimbrites. The source of the ash-pumice tuffs was a Plinian eruption.

The term Plinian eruption was adopted into volcanological terminology in honor of Pliny the Younger. In a letter to Tacitus (the Roman historian), he described the events surrounding the memorable eruption of Vesuvius in 79 AD, in which his uncle Pliny the Elder, a prominent naturalist of that time, died. While investigating this natural phenomenon, Pliny the Elder approached the eruption at a dangerous distance with his slave-driven rowboat, which ultimately proved fatal to him. Pliny the Younger's description of the course of the eruption was so apt and accurate that it has passed into volcanological terminology as one of the types of explosive eruptions.

In a Plinian eruption, a mixture of gases, ash, and pumice is ejected into the atmosphere in the form of an eruptive column (Fig. 1).

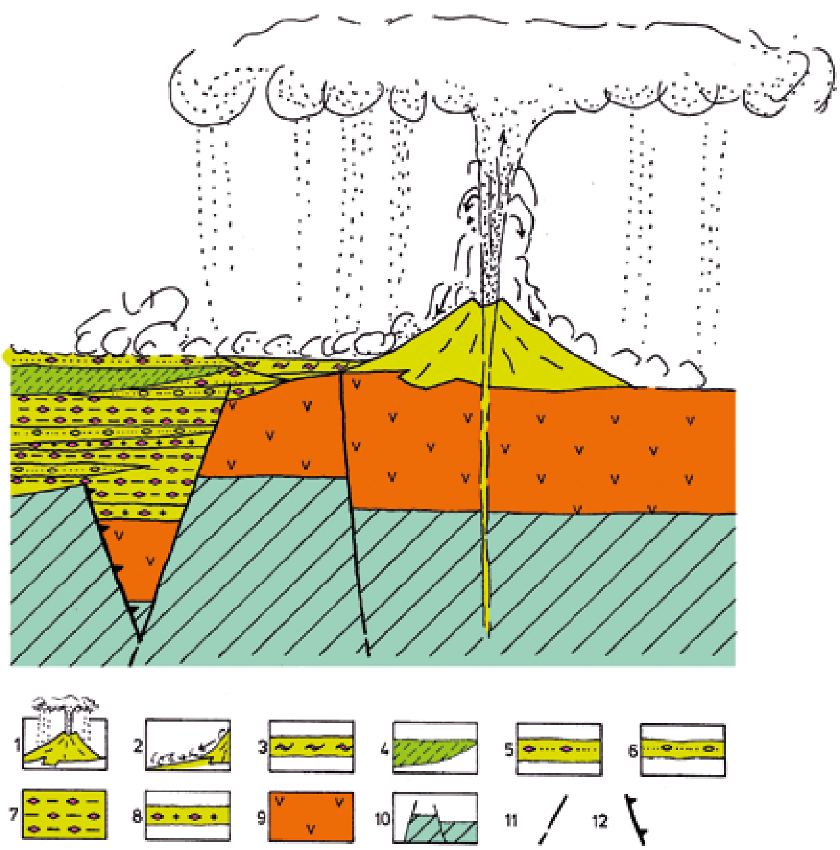


Fig. 1 Palaeovolcanological reconstruction of an Early Sarmatian eruption (© V. Konečný et al., 2004):

1 – Plinian eruption of the presumed Sitno volcano,
2 – ash-pumice flow,
3 – welded tuffs - ignimbrites, products of ash-pumice flows,
4 – lava flow of vitric pyroxene andesite,
5 – redeposited pumice tuffs with positions of epiclastic volcanic sandstones and siltstones (the Biely Kameň Formation),
6 – epiclastic volcanic sandstones with positions of small conglomerates,
7 – pumice tuffs with positions of siltstones and sandstones deposited in an aquatic environment (product of volcanism of pyroxene and amphibole-biotite-pyroxene andesites),
8 – pumice tuffs - deposits of ash-pumice flows,
9 – fill of the Štiavnica caldera, products of biotite-amphibole andesites of the Studenec Formation,
10 – lower stratovolcanic structure,
11 – fault,
12 – caldera fault.

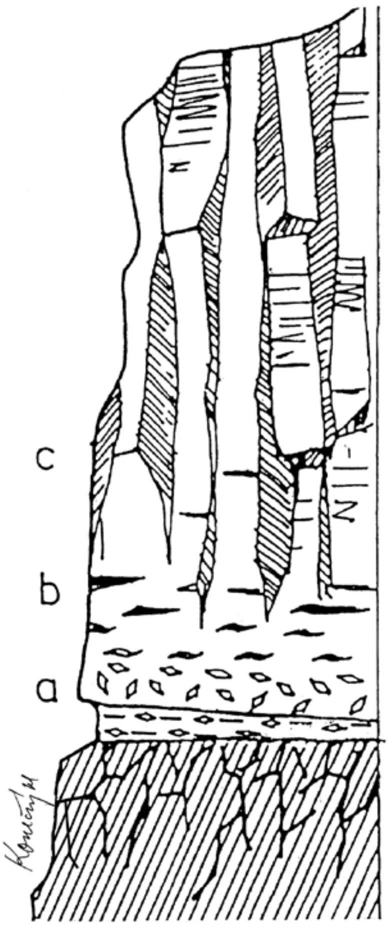


Fig. 2 A typical cross-section of an ignimbrite body (© V. Konečný et al., 2004):

a) – base of ignimbrite with non-welded pumice tuff,
b) – zone with fiamme,
c) – ignimbrite with columnar jointing.

After reaching a critical height, the eruption column begins to sink under its own weight and collapses. After falling to the Earth's surface, the glowing mixture of ash, pumice and gases rolls away from the source of the eruption at high velocity down the sloping hillside in the form of hot, turbulent ash-pumice flow.

After the end of the movement, this glowing mass of ash and pumice undergoes welding due to the high temperature and its own weight. The ash and pumice mass gains the compact character of solid rock and resembles lava (as it was long thought to be). Due to the weight of the ash-pumice mass and the high temperature, the pumice fragments are deformed and

Photo 1 A close-up of ignimbrite (welded tuffs) with columnar jointing, trench of the state road at the northern edge of the village of Počúvadlo (© P. Pachinger).

become vitric, with the pumice fragments forming lenticular formations known as fiamme. A rock with this characteristic is called ignimbrite (Fig. 2).

The lenticular fiamme, only 1-3 cm thick and up to 5-10 cm long, are oriented in a horizontal direction. They are particularly characteristic of the lower parts of the ignimbrite position. At the

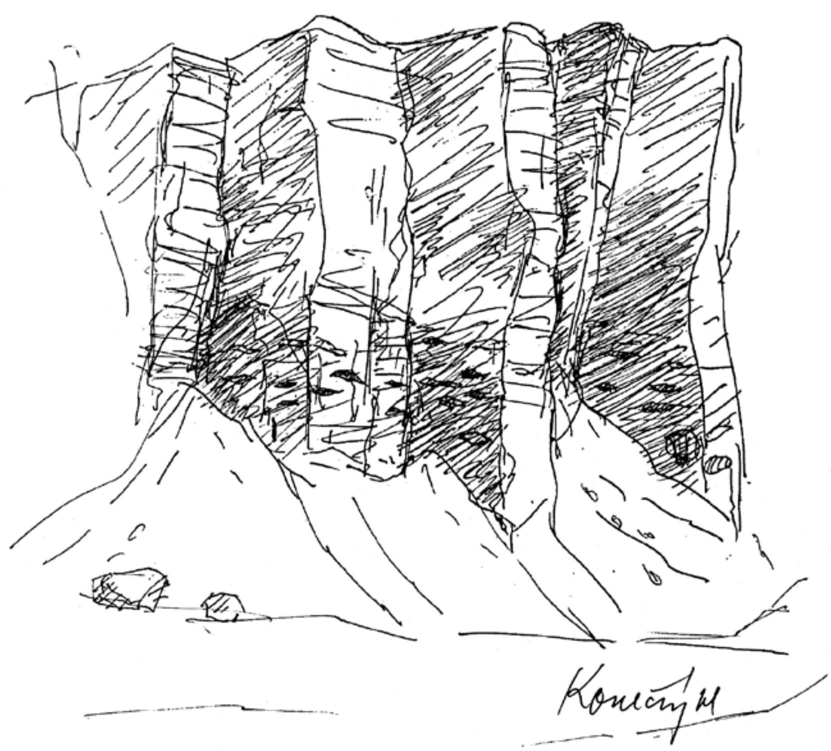


Fig. 3 The coarsely-columnar jointing of ignimbrite – the road trench near the northern edge of the village of Počúvadlo (© V. Konečný).

base of the ignimbrite body, a position of non-welded tuff (a) can be generally found. Above this is a zone of intensively welded type with fiamme (b). Above this zone is a relatively compact rock of welded tuff with coarsely-columnar jointing (c), which was formed during cooling (similar to lava flows). In the upward direction, the compaction and signs of deformation of the pumice gradually diminish and the rock transitions to non-welded tuff.

The welded tuffs – ignimbrites – are characterized by a relatively high compactness in the state road trench, indicative of the relatively high temperature of the ash-pumice flow after its embedding. The jointing is coarsely-columnar along the subvertical planes (Fig. 3). The jointing of this type (contractive jointing) is commonly formed in the case of lava flows in the process of cooling and crystallisation, in which the volume is reduced. Similarly, in the case of ignimbrites, as a result of cooling and continued compaction with deformation of the pumice, the volume decreased and columnar jointing was formed due to internal stresses.

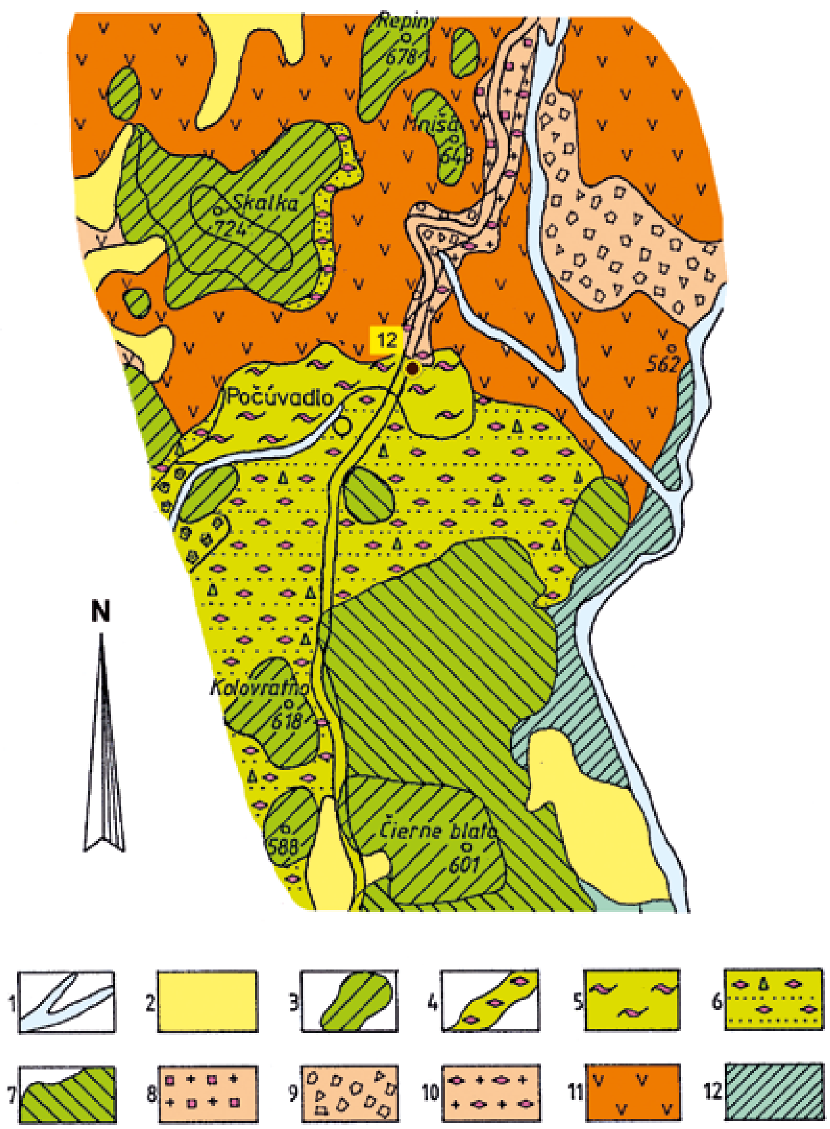


Fig. 4 Scheme of the geological structure near Počúvadlo (© V. Konečný et al., 2004):

1, 2 – Quaternary sediments, 1 –alluvial fluvial sediments, gravels and sands, 2 – stoney-clayey sediments in the valley fill, 3 – amphibole-pyroxene andesite with Sitno-type biotite, 4 – 6 – the Biely Kameň Formation, 4 – epiclastic volcanic sandstones with pumice in the paleodoline fill, 5 – welded ignimbrite pumice tuffs , 6 – redeposited pumice tuffs with insertions of epiclastic volcanic breccias, sandstones and siltstones, 7 – vitric pyroxene andesites of the Baďan Formation, 8 – 11 – products of volcanism of biotite-amphibole andesites of the Studenec Formation, 8 – chaotic breccias of pyroclastic flows, 9 – coarse to blocky epiclastic volcanic breccias, 10 – pumice tuffs, deposits of ash-pumice flows, 11 – lava flows and extrusions of biotite-amphibole andesites, 12 – bottom stratovolcanic structure of the Baden age, unsegmented.

In the lower part of the body, where the compaction is most intense, lenticular fiamme (vitrified pumice) from a few cm to 15-20 cm long are present, oriented subhorizontally (Fig. 3, Photo 1). The matrix is strongly welded to homogenized.

When studying the matrix microscopically, we observe tiny flattened and vitrified fragments of pumice – fiamme. The vitrified matrix is homogenized between the pumice fragments and takes on the structures of airflow around the pumice fragments, amphibole, hypersthene and biotite. The ignimbrites correspond in composition to the welded ash-pumice tuffs of the Biely Kameň Formation. They are the product of explosive Plinian eruptions of amphibole-pyroxene andesites with biotite.

At the bottom part of the ignimbrite body, fragments to blocks of older biotite-amphibole andesites from the bedrock are rarely present, trapped by the ash-pumice flow as it rolled down the volcanic slope. The thickness of ignimbrites near Počúvadlo, verified by boreholes, reaches 25 to 30 m. At the base of ignimbrites is a position of non-welded tuff. The upper part of the ignimbrite body is reduced by erosion, i.e. the original thickness of the ignimbrites was greater. The ignimbrite body ends near the northern edge of the sedimentation basin on the volcanic slope in a terrestrial environment (Fig. 4). Continuing southward, disseminated and redeposited pumice tuffs have been deposited in an aqueous environment.

Geotope No. 17

Sitno

rock cliffs of amphibole-pyroxene andesite ± biotite, upper structure of the Štiavnica Stratovolcano

The peak of the Sitno Hill, shrouded in legends and myths, has been a popular place and a refuge for people since the Neolothic period, it was known to both Celts and Romans and was eventually the site of a medieval castle. The Sitno massif reaches its highest altitude, 1,009 m above the sea level, among the other ridges and peaks of the volcanic mountain range of the Štiavnica Mountains. The top of Sitno is formed by the remains of a lava flow that formed in the area of the Štiavnica caldera during the Sarmatian (roughly 13 million years ago).

The western edge of the Sitno massif is limited by steep rock walls falling to a depth of 40-50 m. The rock walls are subdivided by subvertical to vertical joint planes into a series of rounded blocks, into individual ridges (Fig. 1).

The internal structure of the cliffs is articulated along the mural jointing inclined 10-15° towards the south-east. The mural jointing corresponds to the fluidal planes (creep) formed in the final stage at the termination of the movement of the lava flow (at the

Fig. 1 Rock cliffs on the northwestern edge of the Sitno Hill (© V. Konečný).

time immediately before it stops and solidifies). These planes of mural jointing (also referred to as lamination planes) are oriented parallel to the surface over which the lava flow was moving.

They are an important indication for reconstructing the form of the lava flow and the direction of its movement.

The combination of jointing along steep to vertical planes and perpendicular planes of mural jointing creates remarkable to bizarre forms of rock cliffs. Some resemble the figures or helmets of medieval knights (Fig. 1) who sleep beneath the Sitno Hill, awaiting difficult times when they will be available in full armour (Fig. 2.).

The rock walls of the western edge of the Sitno massif represent the current denudation margin of an originally more extensive lava flow that continued from the northwest in a southeasterly direction (Fig. 3).

Other remnants of this flow form the peaks of Sitience (e. 775) and Biely kameň (e. 657). After crossing the caldera fault, the lava flow continued rolling onto the stratovolcanic slope to a distance of about 10 km away from Sitno. The lava flow followed the paleodoline as it travelled on the outer stratovolcanic slope from the caldera fault southeastward to the foot of the stratovolcano. The lava flow descended from an altitude of about 950 m to 500 m (north of the Devičie village) and reached 17 km.

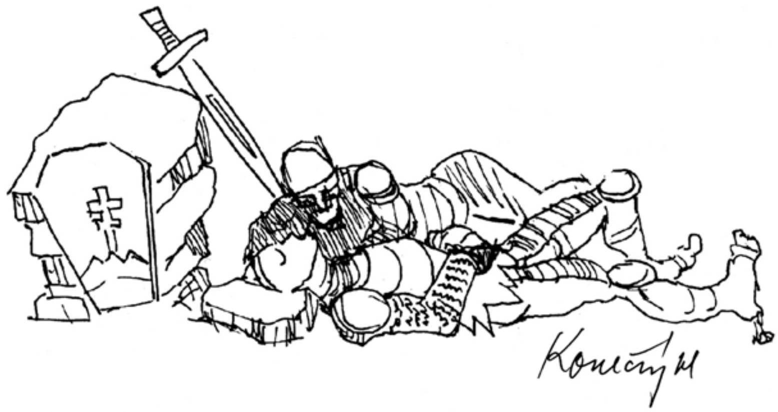


Fig. 2 It is not yet so bad that we awake (© V. Konečný).

The lava plateau of the Sitno massif inlines ca. 10–15° towards SE (its base is near the northwestern edge at the level of approximately 950 m above the sea level, near the southeastern edge it is 750 m above the sea level). Near the western edge, the lava flow of Sitno is deposited on the surface of the amphibole-biotite andesite of the Studenec Formation, towards the southeastern edge, its bedrock is formed by tuffs of the Biely Kameň Formation (Fig. 3). The Biely Kameň Formation is similarly exposed in the bedrock of the relics of the andesite flow of the Sitience

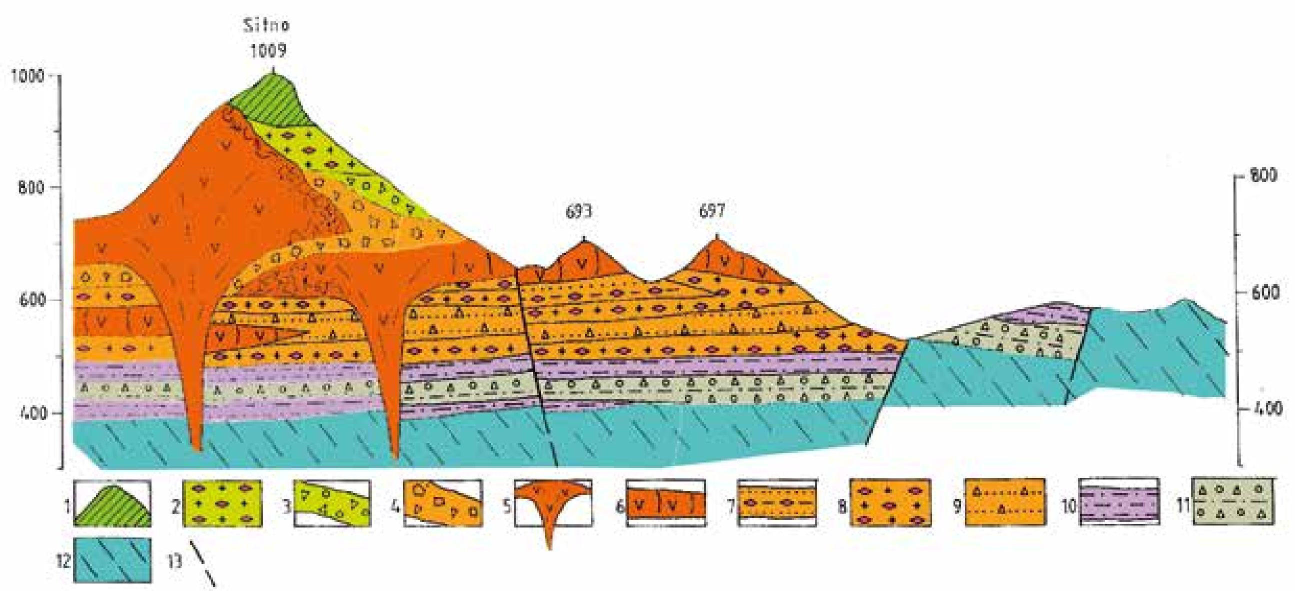


Fig. 3 A geological cross-section on the northeastern slope of the Sitno Hill (© V. Konečný et al., 2004):

1 - the Sitno andesite, 2 - pumice tuffs of the Biely Kameň Formation, 3–9 - rocks of the Studenec Formation in the caldera fill, 3 - epiclastic volcanic breccias, conglomerates, 4 - coarse to blocky epiclastic volcanic breccias, 5 - extrusion, 6 - lava flow of biotite-amphibole andesite, 7 - redeposited pumice tuffs, 8 - ash-pumice flow, 9 – epiclastic volcanic sandstones with minor andesite fragments, 10–11 - the Červená Studňa Formation, 10 - siltstones and sandstones with lignites, 11 - sandstones, siltstones, minor breccias and conglomerates, 12 - bottom stratovolcanic structure, unarticulated, 13 - fault.

and Biely Kameň hills. Based on several isolated lava flow relics in the southern part of the caldera, it can be inferred that the lava flow originally formed a more extensive and continuous lava plateau in the southern part of the caldera, which was bound on the south side by a caldera fault barrier. (Fig. 4).

The lava flow heading southeast from Sitno to the outer stratovolcanic slope was part of the presumed Sitno volcano. Its centre was located in the southern part of the caldera (Fig. 5).

The presumed volcano, from whose slopes lava flows rolled down (Fig. 6 A) and moved further onto the outer stratovolcanic slope, succumbed to denudation and was completely removed (Fig. 6 B). The cause was the enormous uplift of the Hodruša-Štiavnica Horst, in which subvolcanic intrusions and rocks of the pre-volcanic bedrock (the wider aera of Hodruša and Vyhne) were exposed as a result of denudation.

The lava flow in the area of Sitno, with an altitude of 1,009 m, currently represents the highest relic of the lava flow (Photo 1). Originally, the lava flow was deposited at the foot of the presumed Sitno volcano. The top of this volcano was probably 1,500 to 2,000 m higher.

The Sitno massif and other hills covered with the remnants of the Sitno andesite lava flows reach their highest

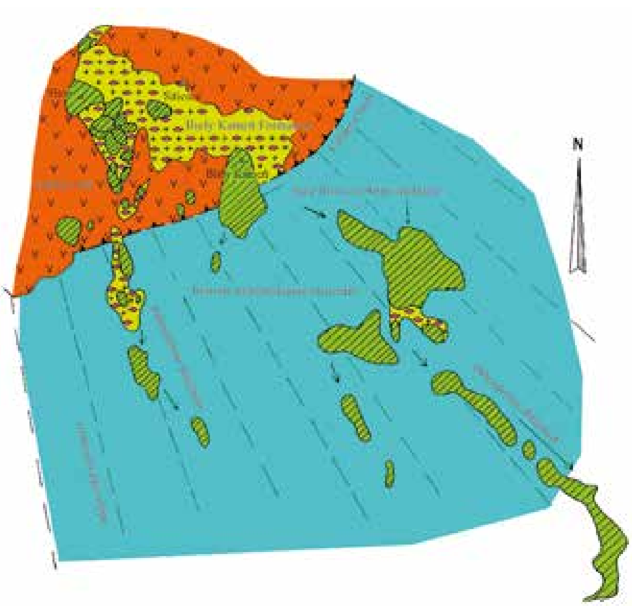


Fig. 4 The distribution of lava flows of the Sitno andesite in the southeastern part of the caldera and on the stratovolcanic slope (© V. Konečný et al., 2004).

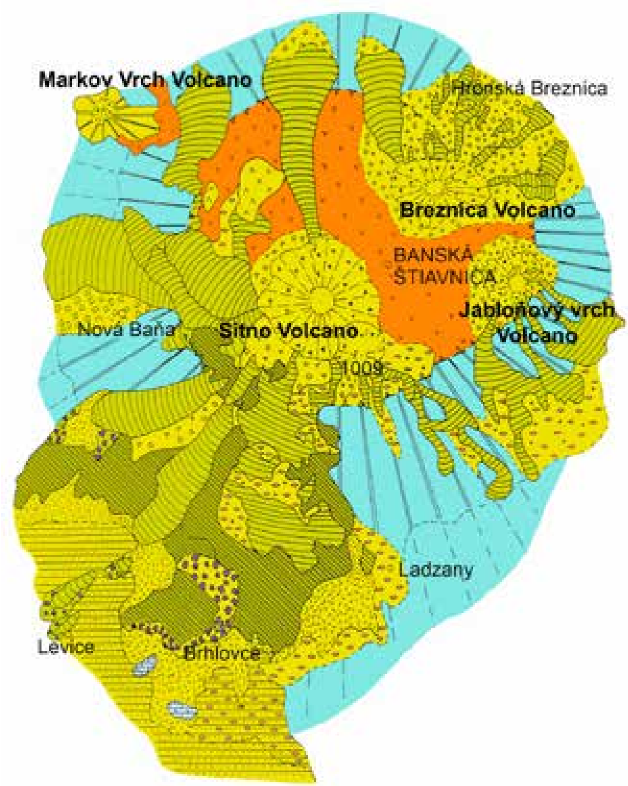


Fig. 5 Reconstruction of Sarmatian volcanoes in the area of the Štiavnica caldera (© V. Konečný et al., 2004).

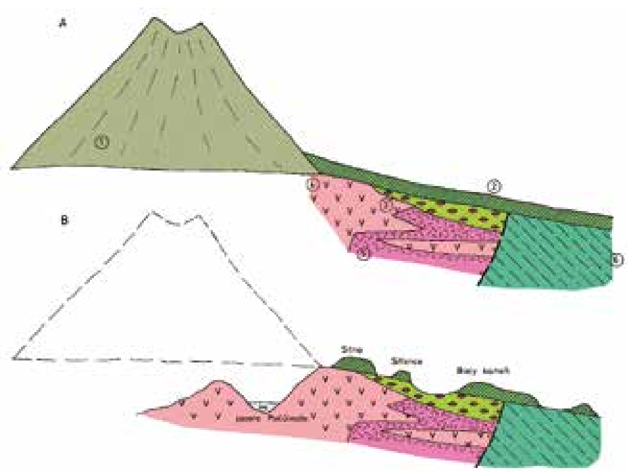


Fig. 6 The evolution of the relief in the area of the Štiavnica caldera (© V. Konečný et al., 2004):

A - formation of the Sitno volcano in the Sarmatian:
1 - presumed cone of the Sitno volcano, 2 - lava flow of Sitno andesite, 3 – pumice tuffs of the Biely Kameň Formation,
4–5 - fill of the Štiavnica caldera, products of volcanism, biotitite-amphibole andesite, the Studenec Formation, 5 - extrusions and lava flows, 5 - pumice tuffs and breccias, 6 - bottom stratovolcanic structure, unarticulated, 7 - caldera fault.
B - the current relief after denudation of Sitno volcano.

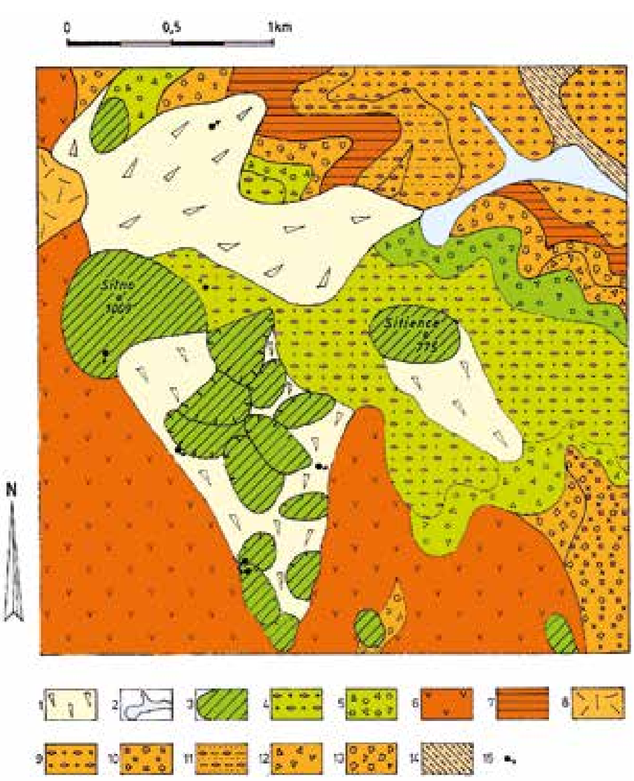


Photo 1 *A view of the Sitno massif with the crumbling of the rock cliffs (© P. Pachinger).*

Fig. 7 Geological map of the Sitno area (© V. Konečný et al., 2004):

1 - rocky slope clays and block slides of the Sitno andesite, 2 - alluvial sediments in the fill of stream bottoms (gravels and sands), 3 - remains of a lava flow of the Sitno andesite, 4 - ash-pumice tuffs of the Biely Kameň Formation, 5 - epiclastic volcanic breccias and conglomerates, 6–13 - fill of the Štiavnica caldera, products of volcanism of biotite-amphibole andesite (the Studenec Formation), 6 - extrusive domes, 7 - lava flows, 8 - laccolith, 9 - ash-pumice flow, 10 - chaotic breccia of pyroclastic flow, 11 - redeposited pumice tuffs, sandstones and siltstones, 12 - tiny epiclastic volcanic breccias, 14 - lava flow of biotite-amphibole-pyroxene andesite, 15 - spring.

elevation in the current relief. However, originally, they were part of a larger lava plateau deposited in a depression in the southeastern part of the caldera on the Biely Kameň Formation. The long-term effect of surface erosive forces (wind, rain, flowing water and gravity) removed less resistant rocks (pumice tuffs, volcanoclastics and bodies of biotite-amphibole andesites). The more weathering-resistant lava flows of the Sitno andesite were progressively exposed until they were finally revealed in the the present summits and crests (Fig. 3). This process, by which a complete reversal in the morphology of the terrain (originally a depression or a valley, eventually a crest) occurred, is called inversion of relief. The Sitno andesite lava flow is a prime example of this process.

The pumice tuffs and redeposited tuffs of the Biely Kameň Formation represent a material relatively poorly resistant to erosive agents. The lava plateau of the Sitno andesite deposited on the Biely Kameň Formation was losing support in its bedrock, becoming gravitationally unstable, breaking up into individual blocks which moved, thus forming a large block field (block slope) on the southern slope of the Sitno Hill (Fig. 7).

Lava flows consist of amphibole-pyroxene andesite ± biotite, medium-grained to coarse-grained porphyric, dark grey. Phenocrysts consist of plagioclase (1-4 mm; (up to 30 %), hypersthene (1-2 mm; 3.3 %), augite (up to 2 mm; 2 %), amphibole (up to 3 mm; 2.3 %) and biotite (1-3 mm, up to 1 %). The base matter (up to 62-70 %) consists of volcanic glass, microlites of plagioclase, amphibole and pyroxenes. The base matter is microlitic-pilotaxitic to microlitic-hyaline (vitric).

5. Tourism Territorial Unit Hodruša Hámre

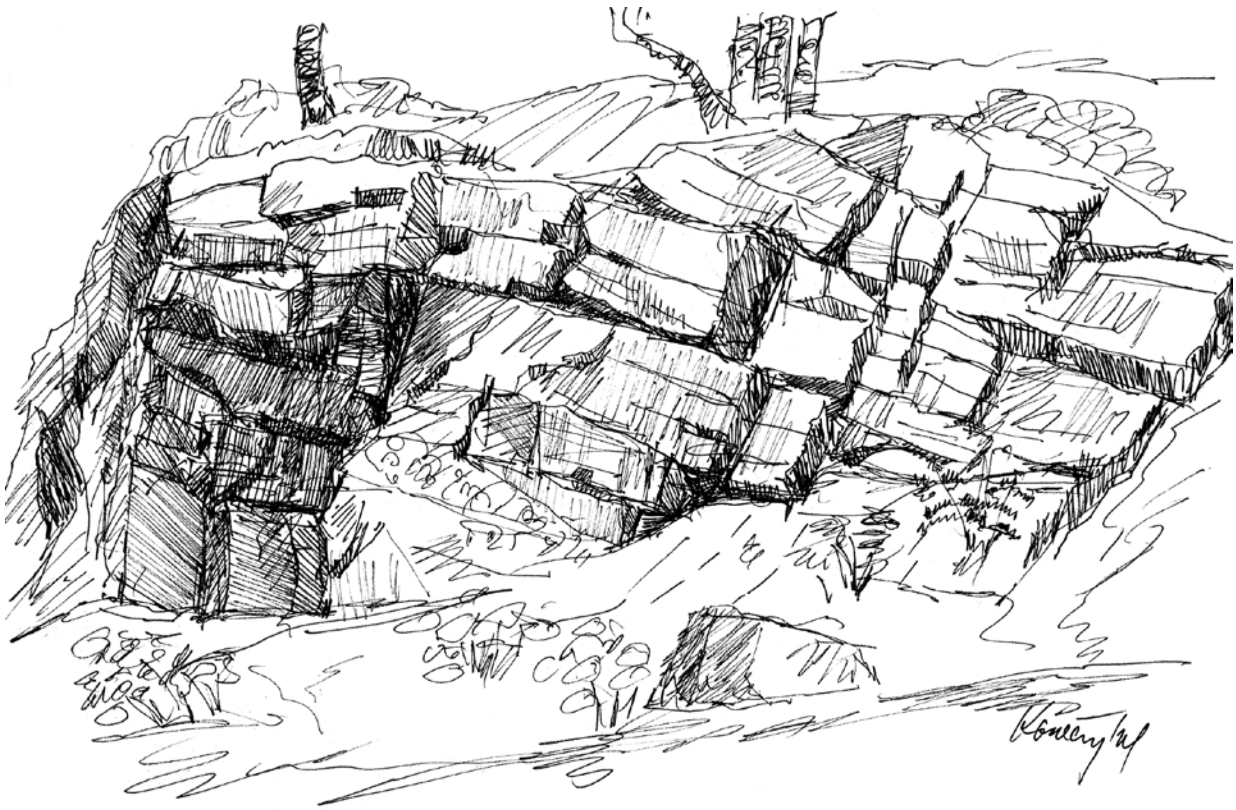


Fig. 1 The Permian sediments exposed by a trench of the forest road in the Suchá Voznica side valley consist of varied sandy schists, alternating with positions of sandstones and siltstones (© V. Konečný).

Geotope No. 18

The Richňavská Dolina Valley

sandstones and schists of the Perm (the Malužiná Formation)

The rocks of the pre-volcanic bedrock rise to the surface in the central to western parts of the Hodruša-Štiavnica Horst. The horst structure was formed at the end of the volcanic activity in the Sarmatian to the Pannonian Period by the uplift of a large block in the central part of the Štiavnica caldera. The denudation cut in the central to western parts of the horst structure, oriented in a northeast-southwest direction, removed volcanic complexes and exposed the geological structure of the pre-volcanic bedrock.

The oldest rocks are crystalline schists and granitoids of the Veporicum of the Hercynian age, mainly represented by the "crushed Vyhne granite", protruding from the northeastern part of the horst. A lower unit represented by *the Veľký Bok mountain series* is deposited in the overlying crystalline rocks. It consists of Mesozoic rocks from the Early Triassic to the Middle Cretaceous Period. The incompletely developed rocks of the Veľký Bok mountain series are tectonically dynamometamorphically affected. They protrude mainly from the north-eastern part of the horst.

In the overlying rock of the Veľký Bok mountain series *the Hronicum sheet unit* is deposited, which, in the horst area, comprises *the Šturec Nappe* (the Choč Nappe in older literature). The Šturec Nappe, superimposed on the lower unit, consists of Carboniferous sediments (the Nižná Boca Formation), Upper Permian sediments (the Malužiná Formation), the Benkovo Formation (quartzites of the Early Triassic), Middle to Late Triassic limestones and dolomites and Lunzian layers of sandy schists and Late Triassic sandstones.

The Permian sediments of the Malužiná Formation consist of varied, cyclically arranged sandstones, fine-grained conglomerates and schists with paleobasalts.

They are characterised by vivid colouring (red, black-grey, light yellow-grey, greenish) and cyclic nature. The 2–5 m thick sedimentary cycle starts with sandstones or small conglomerates, which are replaced by sandstones, siltstones and schists. The sandstones consist of quartz, plagioclase, potassium feldspars and mica grains. Fragments of volcanic rocks (dacites, andesites to basalts) are also present. The volcanic rocks are represented by tuffs, tuffites, andesite-basalt lava bodies within the sedimentary formation, and less frequently by dykes of gabrodiorite porphyrites. According to J. Vozár (1977, 1980), the volcanism corresponded to the tholeiitic-type rift volcanism.

During the Permian Period, sedimentation took place in isolated intermontane depressions in a lake environment in a semiarid to arid climate (hot and dry).

The Permian sediments occur in the Suchá Voznica side valley leading to the main Richňavská Dolina Valley (about 5 km southeast of Voznica), in the 25–30 m long trench exposed by a forest road (Fig. 1, Photo 1).

In the exposure, there are sandy schists of vivid colours (red, purple, green), rhythmically alternating with medium- to close-grained sediments, which are permeated with fine silty sediments in the upper levels. Individual cycles form beds.

Photo 1 A close-up of the Permian sedimentary group of strata with sandy schists alternating with close-grained sandstones and siltstones (© P. Pachinger).

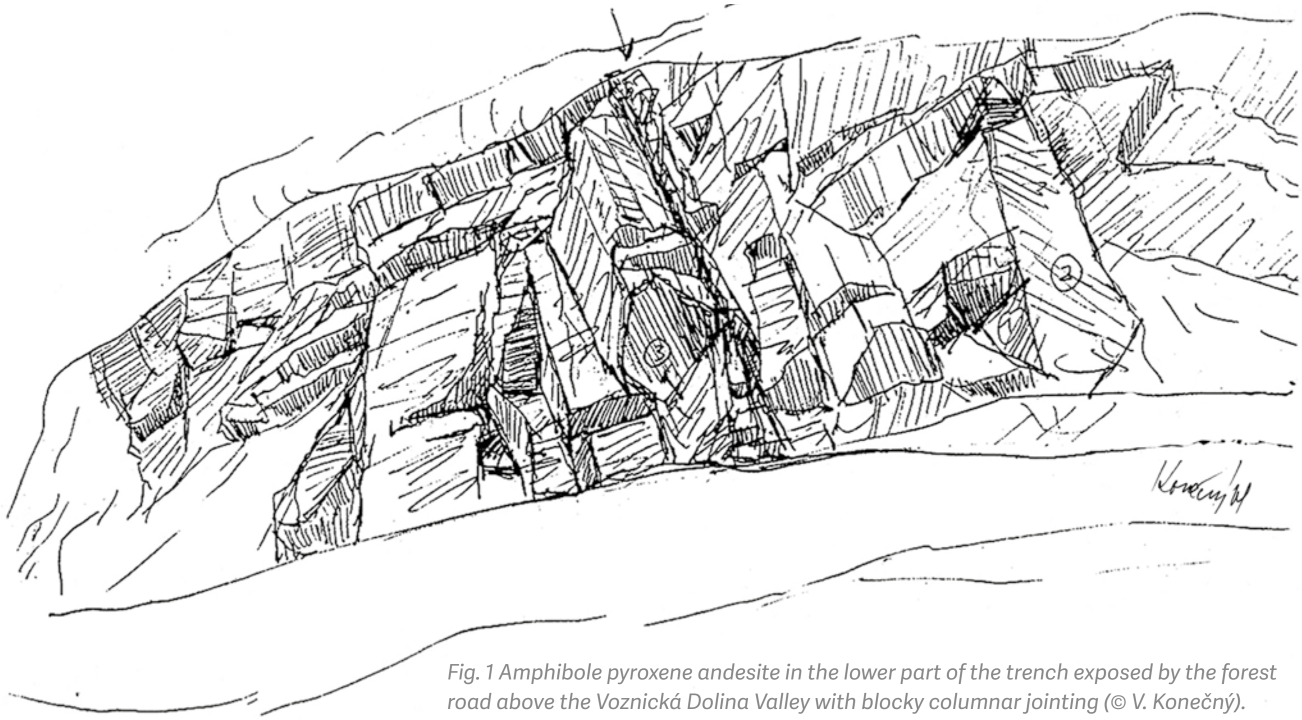


Fig. 1 Amphibole pyroxene andesite in the lower part of the trench exposed by the forest road above the Voznická Dolina Valley with blocky columnar jointing (© V. Konečný).

Geotope No. 19

Suchá Voznica

andesite flow of the bottom stratovolcanic structure

The lowest levels of the stratovolcanic structure have been exposed in the horst area, formed by an uplift of a large block in the central part of the caldera and a subsequent denudation with a removal of rocks of the upper volcanic structure including the caldera fill, and with substantial reduction of rocks of the bottom structure. It is exposed mainly in the lower levels of the slopes of the Richňavská Dolina Valley, in the trenches of the Richňava Stream and the forest road, as well as in the side valleys leading into the Richňavská Dolina Valley. In the exposures, volcanic bodies of diverse lithological composition with predominance of lava flows over volcanoclastic rocks protrude. The bedrock complex is affected by intense hydrothermal alternations (mainly propylitisation), tectonic faults with bands of crushing and is penetrated by multiple dykes of quartz-diorite porphyries.

An exposure of the andesite body in the trench of the forest road turning from the Suchá Voznica Valley in the direction to the northern slope of Sedlo (elevation 683), was selected as an example of the bottom stratovolcanic structure. The andesite with blocky columnar jointing (Fig. 1, Photo 1) to an indicated mural jointing (Fig. 2, Photo 2), has been exposed by a trench of the forest road.

The columnar jointing in Fig. 1 is mainly along the planes 100 SE/90° (1) and 35 EN/60° (2), and the mural jointing is along the planes 240 SW/45° (3). The andesite body corresponds to the middle to upper parts of the lava flow. The 45° inclination of the mural jointing is likely tectonic.

The andesite is medium-grained porphyric, propylitised, dark grey, gree-

Fig. 2 The andesite with mural jointing in the upper part of the trench exposed by the forest road (© V. Konečný).

nish, phenocrysts consist of plagioclase (1–3 mm), amphibole (2–3 mm), pyroxenes (up to 2 mm), dark phenocrysts are chloritised. The andesite body is permeated with crush zones in the 315 NW/80° direction (in the direction indicated by the arrow in Fig. 1).

The pre-volcanic bedrock in the form of Permian sediments protrudes from the bedrock of the andesite body.

Photo 2 A close-up of the andesite with indicated mural jointing (© P. Pachinger).

Photo 1 The exposure of the lava flow of the bottom structure in the trench exposed by the forest road above the Suchá Voznica Valley. In the left part, a columnar jointing corresponding to Fig. 1 can be observed while a mural jointing corresponding to Fig. 2 prevails in the right part (© P. Pachinger).

Geotope č. 20

Banská Hodruša – Sandrik

granodiorite intrusion

A deep denudation cut has exposed a subvolcanic Hodruša-Štiavnica intrusive complex of granodiorite and diorite in the central to western parts of the Hodruša-Štiavnica Horst (the area of maximum uplift), located in a Paleozoic-Mesozoic rock environment. The central part of the complex is dominated by a granodiorite pluton and a diorite intrusion oriented approximately in an east-west direction is located at its northern edge. In the bedrock of the volcanic rocks, the granodiorite pluton extends eastwards into the Banská Štiavnica area as confirmed by boring and mining. The total area of the pluton exceeds 100 km^2.

The Mesozoic sediments and carbonate rocks (limestones and dolomites), which comprise the roof of the intrusion, are hornfelised and skarnised at the contact with the intrusion. Large flat blocks of crystalline complex are embedded in the pluton just below its roof. The granodiorite pluton appears to be a body with a relatively flat top edge and edges that are offset from the centre. It is more than 2 km thick, the B-1 borehole (J. Štohl et al., 1990) did not reach its bedrock. The formation of the granodiorite pluton has been interpreted as the result of subsidence of the central block into a magma chamber with subsequent filling of the space in the overlying block with granodiorite magma in the "ring bell" type form (V. Konečný et al., 1998 a, Fig. 1).

In Banská Hodruša, today the Hodruša-Hámre village in the Sandrik area, across from the Mayer shaft, in a side valley on the slope near the elevation 327.5 in an abandoned quarry, an intrusion of granodiorite has been exposed (Fig. 2, Photo 1, 2).

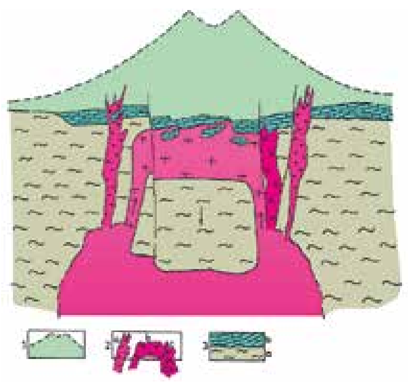


Fig. 1 Scheme of the granodiorite and diorite subvolcanic intrusion in the bedrock of the Štiavnica Stratovolcano (J. Smolka et al., 2005):

Magma chamber, subsiding bedrock block, stratovolcano: 1 – stratovolcano, 2 – forms of stratovolcanic intrusions of the Štiavnica Stratovolcano: a) stock-dyke intrusion of granodiorite porphyry (Zlatno Complex), b) granodiorite intrusion of the upside-down bell type, c) stock diorite intrusion, 3 – pre-volcanic bedrock: a) crystalline complex, b) the Mesozoic.

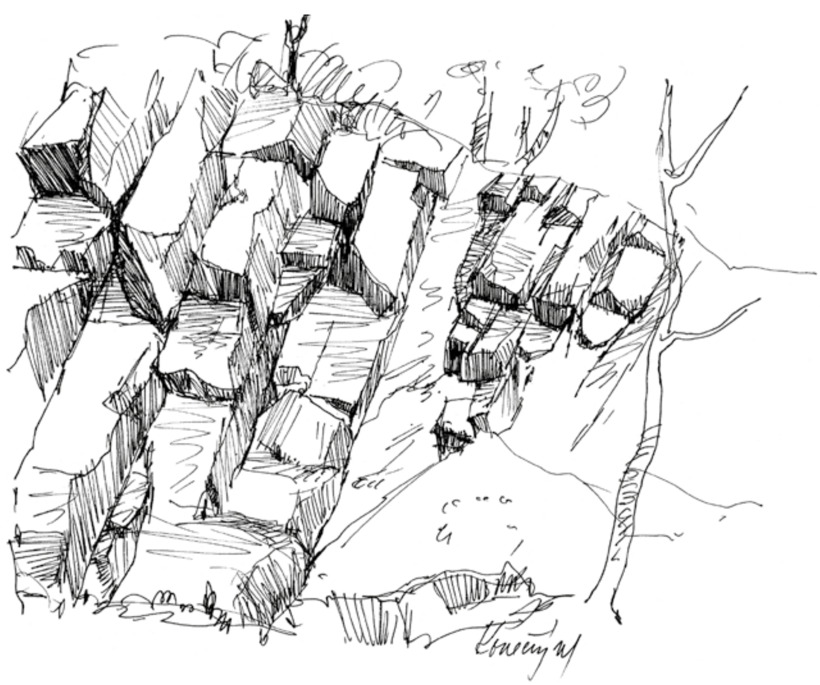


Fig. 2 In the abandoned quarry in Banská Hodruša across from the Mayer shaft, a granodiorite with columnar to blocky jointing is exposed (© V. Konečný).

Photo 1 An abandoned quarry in Banská Hodruša across from the Mayer shaft (© P. Pachinger).

The granodiorite jointing is blocky to coarsely-columnar along the planes: 100 SE/90˚, ON/90˚, 24 OWS/30˚.

The granodiorite is dark grey to light grey, coarse grained with a uniformly granular structure (4–5 mm) composed of plagioclase, amphibole, biotite grains and alotriomorphic grains of quartz and orthoclase. The accessory minerals consist of apatite, titanite, zircon, magnetite, and occasionally tourmaline.

The granodiorite is affected to varying degrees by propylitisation, which is manifested mainly by chloritisation of amphibole, biotite and, with more intense alternation, by albitisation of plagioclase, the presence of sericite, carbonate, pyrite, and secondary quartz.

Photo 2 A close-up of the exposed granodiorite with columnar and blocky jointing (© P. Pachinger).

Geotope No. 21

Kopanice – a trench of the state road

bedded intrusion of quartz-diorite porphyry, intrusion of granodiorite

In a trench exposed by a state road north of Kopanice (the Hodruša-Hámre village), there are exposures of bedded intrusion of quartz-diorite porphyry, and in the continuation of the road leading to Hodruša, there are exposures of porphyric granodiorite.

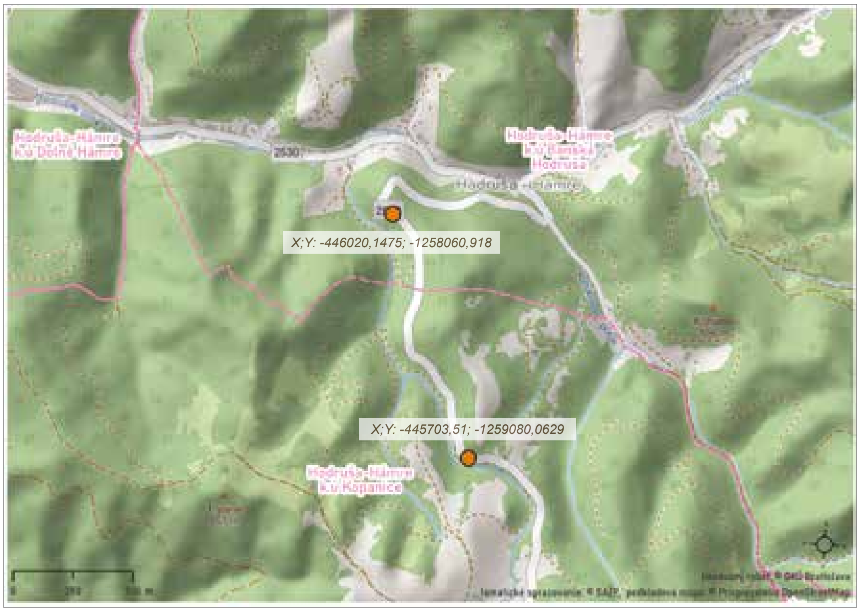
Quartz-diorite porphyry of acid composition without quartz phenocrysts protrudes as a bedded intrusion in the overlying limestones and dolomites of the Middle to Late Triassic Period of the Veľký Bok mountain series and partly in the overlying granodiorite (the Kohútovska Dolina Valley north of Kopanice).

Fig. 1 A bedded intrusion (sill) of quartz-diorite porphyry is exposed in the state road trench north of Kopanice. The jointing is columnar along the subvertical planes (© V. Konečný).

In the exposure of the state road trench about 600 m north of Kopanice, there are about 30-40 m long exposures of quartz-diorite porphyry. The jointing is strongly columnar along vertical to subvertical planes (Fig. 1, Photo 1).

The rock is grey-green (propylitised), coarse-grained porphyric, phenocrysts consist of plagioclase (2–6 mm), amphibole (4–6 mm), biotite (up to 4 mm). The development of the base matter is microhypidiomorphically granular. It differs from the quartz-diorite porphyry of the Hodruša type (Geotope No. 22 The Hodrušská Dolina Valley – road to Adresály) by the absence of quartz phenocrysts.

The body of the quartz-diorite porphyry has been placed in the interface between Paleozoic and Mesozoic rocks in the roof of the intrusion, possibly the interface between the upper part of the intrusion and the overlying volcanic complex.



Porphyric granodiorite can be observed in the lower part of the trench exposed by the state road leading to Hodruša about 1000-1200 m north of Kopanice. The contact with the quartz-diorite porphyry body is tectonic along a northeast-southwest trending line (not exposed in the state road trench).

The body of the porphyric granodiorite is characterised by blocky-columnar jointing along the subvertical planes (Fig. 2, Photo 2).

The porphyric granodiorite represents marginal facies of a coarse-grained omnidirectional granodiorite that protrudes from the central part of the body (Geotope No. 20 Hodruša – Sandrik). The rock is porphyric, large grains of plagioclase, amphibole and biotite are surrounded by grains

Photo 1 The bedded intrusion (sill) of quartz-diorite porphyry with a distinct columnar jointing in the state road trench north of Kopanice (© P. Pachinger).

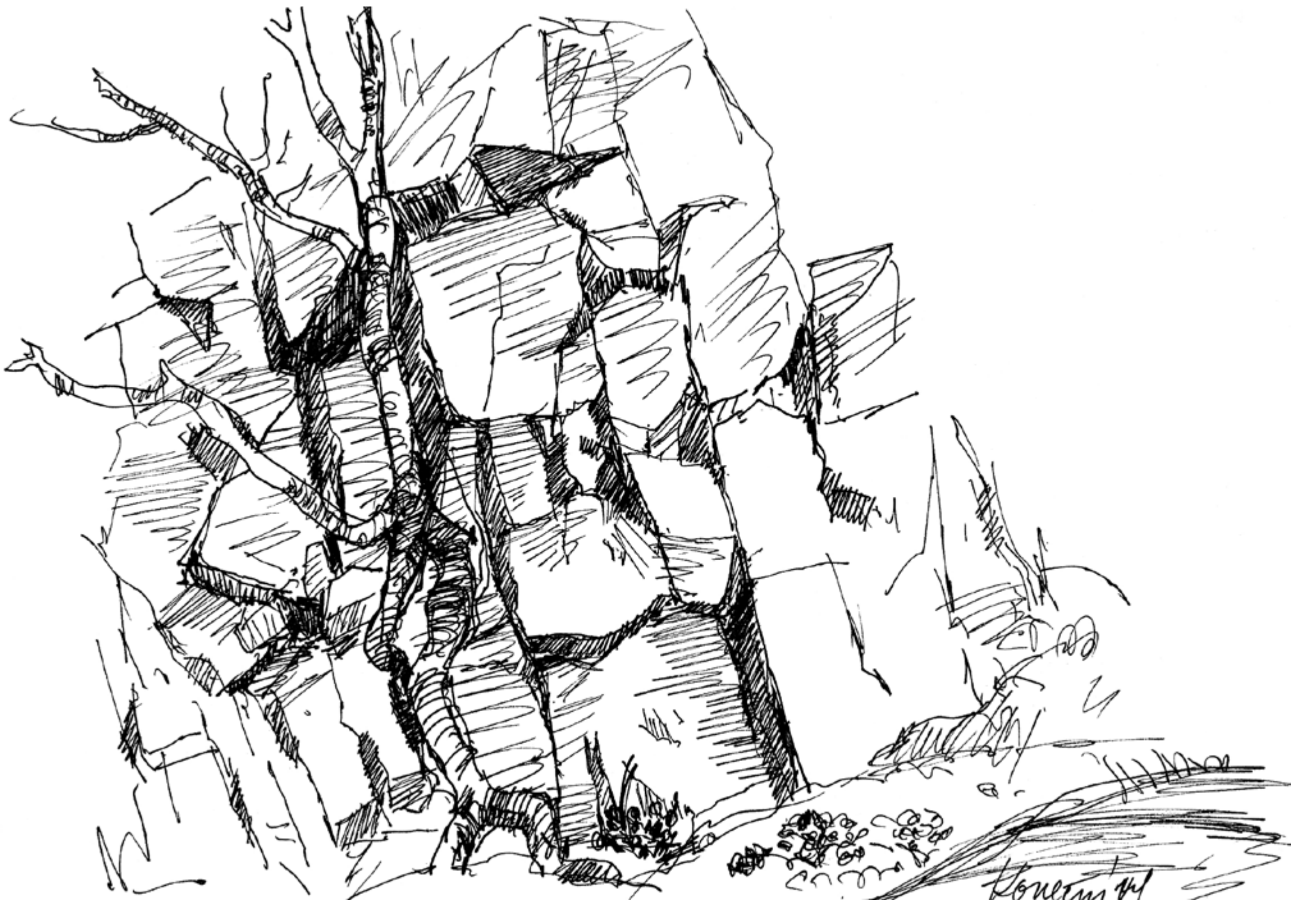


Fig. 2 The porphyric granodiorite exposed in the state road trench north of Kopanice represents the edge of a large granodiorite intrusion, most of which comes to the surface in the Hodruša area. The porphyric granodiorite is characterised by coarsely-columnar jointing with a transition to a large blocky jointing (© V. Konečný).

of orthoclase and quartz of relatively smaller size, which gain the character of a coarse grained microalotriomorphic granular base matter. The accessory minerals are similarly apatite, titanite, zircon and magnetite.

The rock is more severely affected by propylitisation, gaining a greenish hue. Secondary minerals consist of chlorite, sericite, carbonates, pyrite and secondary quartz.

In the area of the Kohútovská Dolina Valley north of Kopanice, a zone of cherts was formed at the contact of porphyric granodiorite and Mesozoic carbonate rocks with the formation of an association of scarn minerals.

The effect of granodiorite on the surrounding rocks, mainly of carbonate composition, created magnetite skarns (locations of Klokoč, Treiboltz, Alžbeta, Rumplovská, Včelín).

Photo 2. The coarsely-columnar to blocky jointing of porphyric granodiorite in the state road trench north of Kopanice (© P. Pachinger).

Geotope No. 22

The Hodrušská Dolina Valley – road to Andresály

sill of quartz-diorite porphyry of the Banisko intrusive complex

Due to intensive denudation, the internal structure of the Štiavnica Stratovolcano – its internal anatomy – was exposed in the area of the Hodruša-Štiavnica Horst. A complex system of intrusive bodies of quartz-diorite porphyries in the form of bedded intrusions (sills) and dyke bodies has penetrated through the bottom stratovolcanic structure.

The formation of bedded intrusions was associated with the formation of the Štiavnica caldera due to subsidence movements of its central block. During these subsidence movements, the central block disintegrated into individual parts and magma has been flowing through the sub-blocks in the form of bedded-bodies – sills. These sills were located at different levels of the bottom stratovolcanic structure, from the lowest level at the interface between the volcanic structure and the bedrock, to the level of lower caldera fill. Bedded intrusions located in the lower levels of the bottom structure are characterised by a coarsely-grained formation of the base matter (higher degree of crystallinity). In the upward direction, the formation of the base matter is finer-grained (lower degree of crystallinity) with a transition to andesite porphyries.

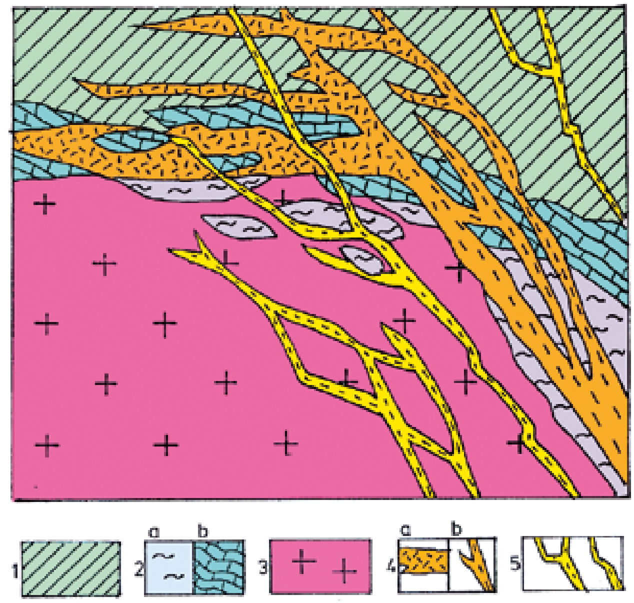


Fig. 1 A scheme of the position of the bedded intrusion (sill) located at the interface between bedrock and volcanic complex (J. Smolka et al., 2005):
1 - andesite complex of the bottom stratovolcanic structure,
2 - pre-volcanic bedrock: a) crystalline complex of the Veporicum, b) Mesozoic sediments of the Veľký Bok mountain series,
3 - granodiorite intrusion, 4 - intrusive complex of the Banisko quartz-diorite porphyry a) bedded intrusion (sill), b) dyke,
5 - dykes of quartz-diorite porphyries of the younger generation.

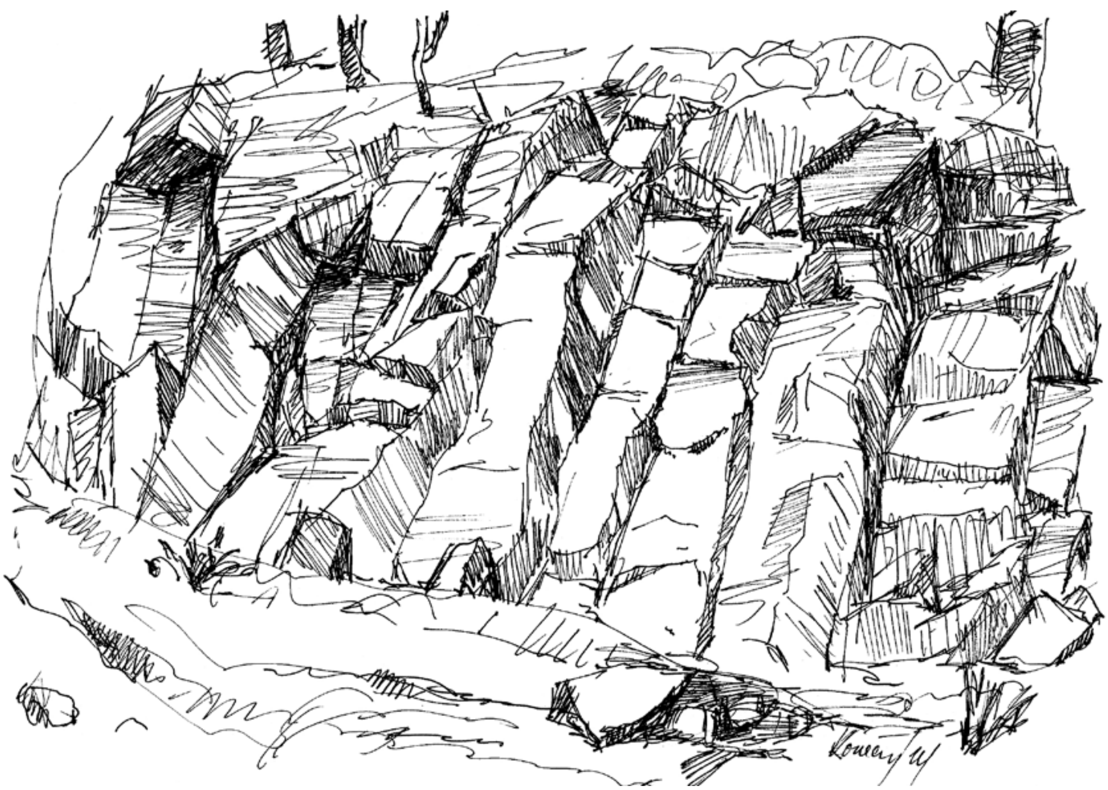


Fig. 2 In the trench exposed by the forest road leading to Andresály, there is a rocky exposure of quartz-diorite porphyry with coarsely-columnar jointing along the subvertical planes (© V. Konečný).

At the lowest level, at the boundary between the pre-volcanic bedrock and the volcanic complex, an intrusion of coarse-grained quartz-diorite porphyry of acid composition with quartz content (2-8 %) was emplaced in the form of a massive sill with a thickness of 150-200 m (Fig. 1).

The intrusion exposed on the surface by a denudation cut near Banská Hodruša plunges in a southeasterly direction beneath the complexes of the bottom volcanic structure, possibly beneath the remains of Mesozoic (Kohútov, Komenská) or crystalline complex (at Andresály), and partly the intrusion is in contact with granodiorite (Fig. 1). The intrusion extends beneath the volcanic rocks to the east into the Štiavnica area, where its presence has been confirmed by boring and mining.

A bedded intrusion of quartz-diorite porphyry (sill) is exposed in a trench exposed by a forest road leading to Andresály, turning from the Hodrušská Dolina Valley to the right up the slope (below from the turn to the lake). Jointing is coarsely-columnar along the subvertical planes, less distinct, and is irregularly blocky along the planes roughly perpendicular to the columnar jointing (Fig. 2, Photo 1).

The rock is coarse-grained porphyric, grey with a greenish hue (propylitised). The phenocrysts consist of plagioclase (2–4 mm, occasionally up to 6 mm), amphibole (4–6 mm), biotite (4–5 mm), pyroxene (1–2 mm), quartz (3–4 mm). The base matter is alotriomorphically granular, with a transition to microalotriomorphically granular at the edges of the body. The dark minerals are partly to completely chloritised, the plagioclase is sericitised and replaced by carbonates or quartz.

Photo 1 A close-up of a coarsely-columnar jointing of quartz-diorite porphyry in the trench exposed by the forest road leading to Andresály (© P. Pachinger).

Geotope No. 23

Červená Studňa

bedded intrusion of quartz-diorite porphyry, the Banisko intrusive complex

In the eastern part of the Hodruša-Štiavnica Horst, inclined to the southeast, denudation cuts led to the removal of the rocks of the caldera fill and partly of the bottom stratovolcanic structure with the exposure of the bodies of the bedded intrusions of *the Banisko intrusive complex*. The Banisko intrusive complex includes a system of bedded intrusions (sills, laccolithes) and dyke bodies of quartz -diorite porphyries that were emplaced in the environment of the rocks of the bottom stratovolcanic structure during collapse movements (subsidence movements) in connection with the formation of the Štiavnica caldera. The subsiding block of rocks within the caldera disintegrated into parts, and rising magma penetrated through the detached blocks and filled the vacated space in the form of powerful bedded intrusions (Fig. 1). The bedded intrusions (sills and laccolithes) were located at different levels of the bottom of the stratovolcanic structure.

At the lowest level, near the interface between the bedrock and the volcanic complex, a 200 m thick intrusion of coarse-grained quartz-diorite porphyry of acid composition covering a large area in the form of a massive sill was located. The intrusion is exposed at the surface near Banská Hodruša (where it is presented as Geotope No. 22. The Hodrušská Dolina Valley – road to Andresály). Other bedded intrusions located in the middle to higher levels of the bottom stratovolcanic structure are characterised by relatively smaller areal extent, smaller thickness and also a lower degree of crystallinity of the base matter, which is finer-grained in comparison with coarse grained base matter of the lower sill. In the upper levels of the volcanic structure, or even at the base of the caldera fill, there are bedded intrusions of andesite porphyries with, relatively, the lowest degree of crystallinity of the base matter. For example, the bedded intrusion of biotite-amphibole andesite porphyry presented as Červená Studňa.

The bedded intrusion is exposed in an abandoned quarry on the northern slope of the Paradajs Hill below the ridge with the elevation of 852 above the state road, about 500 m west of Červená Studňa (Fig. 2, Photo 1). The quarry can be accessed via a dirt road and a trail starting in Červená Studňa.

The bedded intrusion of biotite-amphibole andesite porphyry of the "Paradajs type" is exposed in the quarry wall. The bedded intrusion (sill) is located in the lower level of the Štiavnica caldera fill, between the Červená Studňa Formation and the overlying effusive complex of the Studenec For-

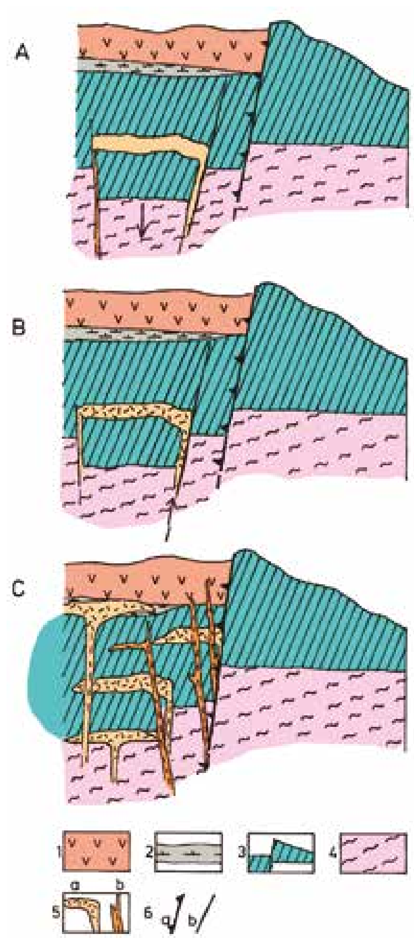


Fig. 1 The mechanism of the bedded intrusion formation (J. Smolka et al., 2005):

A - subsidence of a bedrock block to the top part of a magma chamber opens the space above the block,
B - magma ascends into the vacated space, solidifies and crystallises in the form of a bedded intrusion (sill),
C - position of bedded intrusions in the volcanic structure. Bedded intrusions are located at the interface between the bedrock and the volcanic structure, in the environment of the rocks of the bottom structure, or even at the base of the caldera fill. 1 - caldera fill, 2 - sediments with lignites at the base of the caldera fill, 3 - bottom stratovolcanic structure, 4 - bedrock (unarticulated), 5 - intrusive complex of quartz-diorite porphyries: a) bedded intrusions (sills, laccolithes), b) dykes, 6 - a) caldera fault, b) fault.

mation. The remains of this roughly plate-like body with a thickness of 75-100 m form the upper part of the Paradajs Hill, the area of the Šobovo peak (elevation 888), and its relics protrude in the eastern part of Banská Štiavnica and near the pond of Belianske.

These relics are only remains of an originally larger intrusion (its current area is about 12 km2), the western part of which has been removed by denudation.

The andesite porphyry exposed by the quarry wall is coarse-grained porphyric, grey-green (due to propylitisation). Phenocrysts consist of plagioclase (2-3 mm), dark phenocrysts (amphibole, biotite) are chloritised. The base matter is microlithic-granular to microlithic-poikilitic-granular. Jointing is coarsely-columnar to blocky.

Fig. 2 In an abandoned quarry on the northern slope of Paradajs, a bedded intrusion (sill) of andesite porphyry with coarsely-columnar to blocky jointing is exposed (© V. Konečný).

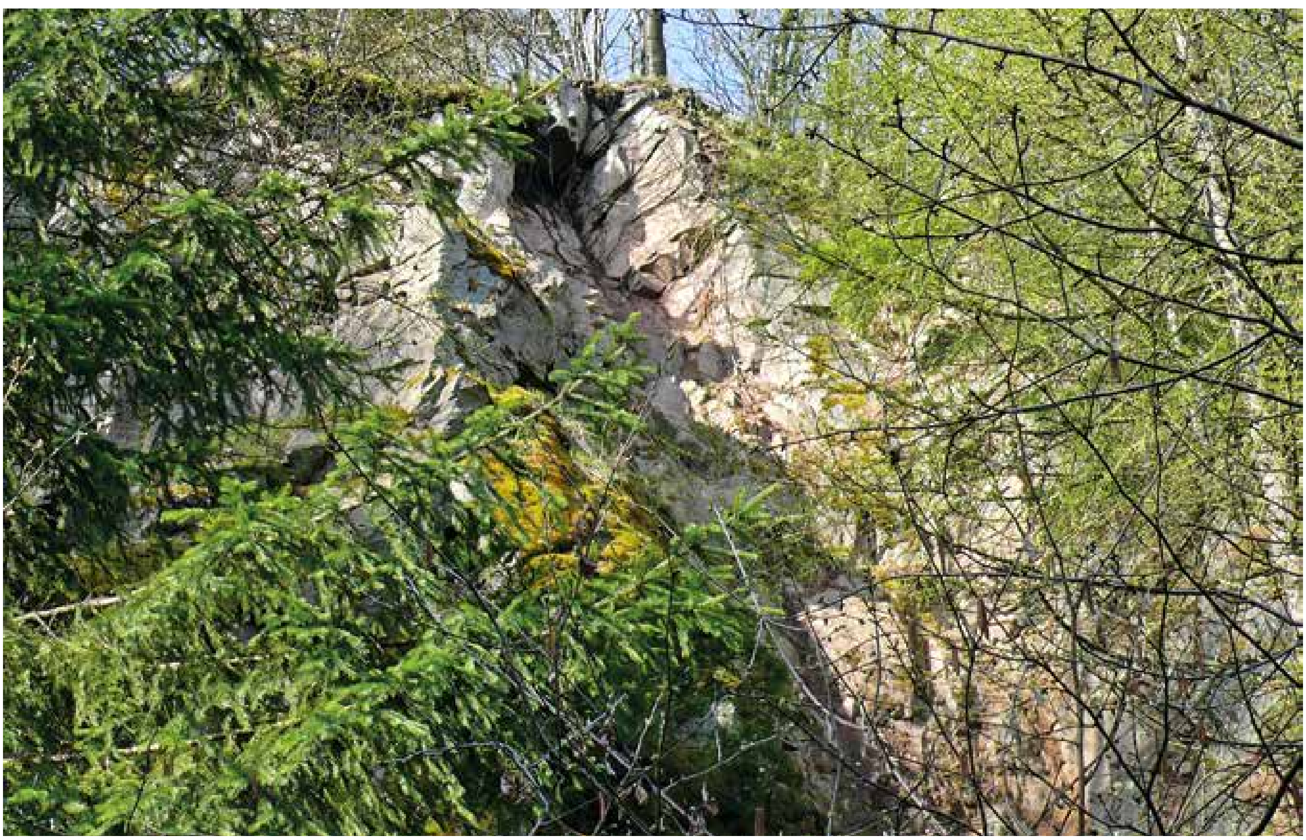


Photo 1 The left part of the abandoned quarry wall on the northern slope of the Paradajs Hill reveals a bedded intrusion of andesite porphyry with coarsely-columnar jointing (© P. Pachinger).

Geotope No. 24

The Richňavská Dolina Valley – forest road trench

dyke of quartz-diorite porphyry, the Banisko intrusive complex

The Banisko intrusive complex includes bodies of quartz-diorite porphyry in the form of bedded intrusions (sills), as well as a dyke-type body. The formation of the intrusive complex is related to the subsidence movements that formed the Štiavnica Caldera. The subsiding caldera block disintegratated into parts and the vacated spaces were filled by the protruding magma in the form of sill- and laccolith-type bedded intrusions (the bedded intrusions are presented by Geotopes No. 23 Červená Studňa and No. 22 The Hodrušská Dolina Valley – road to Andresály).

Dykes and dyke swarms of quartz-diorite porphyry are exposed by a deep denudation cut in the horst area. The dykes penetrate through the rocks of pre-volcanic bedrock and rocks of the bottom stratovolcanic structure and are oriented predominantly in a NNE-SSE to northeast-southwest direc-

Fig. 1 The dyke of quartz-diorite porphyry in the trench exposed by the forest road on the northern slope of the Pod Vtáčnikom Ridge leading to the Richňavská Dolina Valley. The jointing is thick mural to columnar perpendicular to the direction of the dyke (© V. Konečný).

Photo 1 The top edge of the dyke of quartz-diorite porphyry is exposed by a trench of the forest road leading to the Richňavská Dolina Valley (© P. Pachinger).

tion, with a predominantly southeast inclination near the eastern edge of the horst (in the Štiavnica area). In the central part of the horst, especially at its western edge, the dykes usually incline towards west.

Mining has revealed that some dykes which incline away from the central block are inteconnected with bedded intrusions at lower levels. However, there is also evidence of their penetration through older bodies of bedded intrusions, suggesting a younger age of part of the dyke system in relation to the bedded intrusions.

A "ring dyke" mechanism with central caldera block subsidence is assumed in the formation of bedded intrusions and dykes. However, the possibility that part of the dyke system was formed in an overpressure mode – a "cone sheet" dyke mechanism – is not ruled out.

In the trench exposed by a forest road leading to the Richňavská Dolina Valley (below the northern edge of the Vtáčnik Ridge, e. 695) a dyke of quartz-diorite porphyry (Fig. 1, Photo 1) is exposed.

The dyke with a width of about 30-40 m penetrates through the rocks of the bottom stratovolcanic structure. The jointing of the dyke is indicated coarsely-columnar with a perpendicular orientation to its edges. Similarly, a perpendicular orientation of the columnar jointing can be observed at the contact of the dyke with the rocks of the bottom structure and at its lower edge (Fig. 2, Photo 2).

The rock is coarse-grained porphyric, dark grey with a greenish hue (due to propylitisation). The phenocrysts consist of plagioclase (2–4 mm), amphibole (up to 4–6 mm), biotite (up to 2–4 mm), pyroxene and quartz occur sporadically. The base matter is hypidomorphically to microallotriomorphically grained. Tiny grains consist of plagioclase, amphibole, pyroxenes and alotriomorphic grains of quartz and potassium feldspars.

Fig. 2 The bottom edge of the dyke with coarsely-columnar jointing perpendicular to the course of the dyke (on the left part). Below, near the right edge, the andesite of the bottom structure is partially crushed and intensely propylitised. The contact is covered by a debris cone (© V. Konečný).

The bottom structure at the lower contact of the dyke consists of medium to fine-grained porphyric pyroxene andesite – propylitised and partly crushed (Fig. 2).

Photo 2 A close-up of the coarsely-columnar jointing at the lower edge of the dyke (© P. Pachinger).

Geotope No. 25

Pod Vysokým Bokom

andesite flows of the Sitno Complex

Explosive eruptions of ash-pumice tuffs were followed by massive lava effusions of the Sitno effusive complex in the Early Sarmatian Period. Lava flows of amphibole-pyroxene andesites (± biotite) filled the western, southwestern, and southern caldera area, where they formed a powerful lava plateau in the overlying rock of the caldera fill. After crossing the caldera fault, lava flows continued onto the stratovolcanic slope in many places, following the

Fig. 1 The lava flow of andesite of the Sitno Complex in a trench exposed by a forest road below the Vysoký Bok with indicated columnar jointing and jointing along the lamination planes inclined towards NW (© V. Konečný).

course of the paleodolines towards the foot of the stratovolcano. On the southeast stratovolcanic slope, this is exemplified by the Sitno Peak lava flow, which continued from the caldera area to the southeast slope of the stratovolcano within a southeast-trending paleodoline, reaching a distance of about 17 km.

Other lava flows directed south, southwest to northwest reached the area at the foot of the stratovolcanic slope (Vojšín, elevation 819 at the western edge of the stratovolcano).

The centre of the lava effusions was the supposed Sitno volcano, which was located in the southeastern part of the Štiavnica caldera. The lava effusions were preceded by massive eruptions of ash-pumice tuffs deposited in the southern part of the caldera (the Biely Kameň Formation) and at the base of the paleodolines in the area of the stratovolcanic slope, where they are located in the bedrock of the lava flows of the Sitno Complex. The textures of the lava

Photo 1 The coarsely-columnar jointing of the Sitno-type andesite. The indicated jointing, along the lamination planes inclined towards northwest, shows the inclination of the underlying relief in the same direction, along which the lava flow was moving (© P. Pachinger).

Photo 2 The changes of the inclination of the mural jointing, from subhorizontal to steeper, indicate the filling of the local paleodoline by a lava flow (© P. Pachinger).

Fig. 2 The inclination of the mural jointing of the Sitno andesite varies from subhorizontal to steeper, documenting the internal structure of the lava flow (© V. Konečný).

flows and the internal structure of the lava flows of the Sitno Complex can be observed in the trenches exposed by the forest road below the Vysoký Bok, north of Dolné Hámre (Fig. 1, 2, Photo 1, 2).

The powerful effusion complex in the western part of the caldera, deposited on the caldera fill, consists of a greater number of lava flows, often brecciated and porous, separated by tuff interbeds to beds. In the overlying rock of the effusion complex is deposited a thick plateau of welded tuffs – ignimbrites of the Drastvica Formation (the area of the Drastvica peaks, elevation 834, the Veľký Žiar – elevation 852, Kojatín – elevation 509 and others).

Geotope No. 26
Kojatín
welded tuffs (ignimbrites)

After the Štiavnica caldera formation and the effusions of lavas of amphibole-pyroxene andesites (± biotite) of the Sitno Complex, massive eruptions of ash-pumice tuffs of the Drastvica Formation followed. During the Plinian eruptions, large volumes of ash-pumice tuffs were ejected in the form of eruptive columns rising to high levels of the atmosphere, where they extended into volcanic ash clouds and were the sources of the air-fall tuffs covering the slopes of the stratovolcano (Fig. 1).

Due to the recurring collapses of eruption columns, hot ash-pumice pyroclastic flows were formed, they filled the western caldera area and, after crossing the caldera fault, rolled onto the stratovolcanic slope and moved further within the paleodolines to the foot of the stratovolcano, where they were deposited as masses of chaotic ash-pumice material. Due to the residual magmatic tempe-

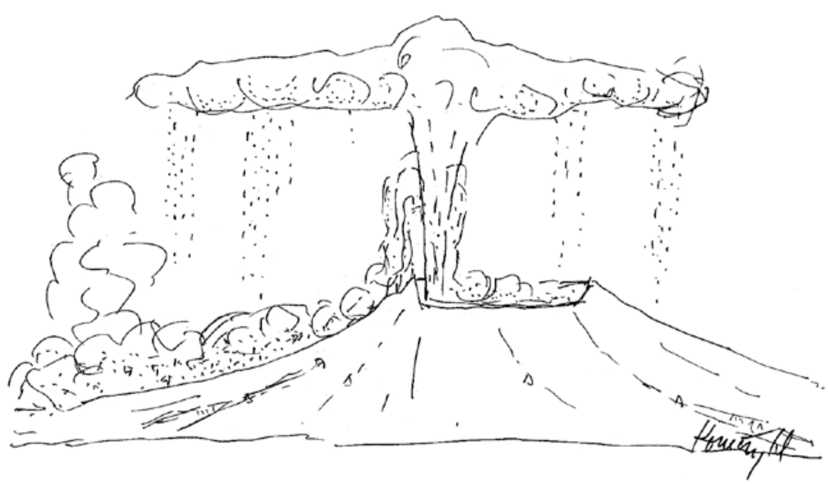


Fig. 1 A scheme of the Plinian eruption in the form of an eruption column transforming in the upper levels of the atmosphere into a volcanic ash cloud, which is the source of the air-fall tuffs. The collapse of the eruption column produces pyroclastic ash-pumice flows (© V. Konečný).

Fig. 2 Ignimbrite rock cliffs on the top of elevation 637 – Kojatín. The jointing is coarsely-columnar to blocky (© V. Konečný).

rature, sintering to welding of the ash-pumice material, and the formation of welded tuffs – ignimbrites occurred. The ash-pumice flows, which moved in the paleodoline direction to the western slope of the stratovolcano, formed ignimbrite plateaus in the broader area of Veľká Lehota and at the western foot of the stratovolcano near the Obyc-Hostie area (Geotope No. 50 Obyce). In contrast, ash-pumice flows, moving through the paleodoline to the southeast to south-southeast slope of the stratovolcano, encountered the marine environment in the coastal zone, where they were deposited as non-welded ash-pumice flows (Geotope No. 100 Čajkov).

After the deposition of large masses of the ash-pumice tuffs in the western part of the caldera and their subsequent welding, a powerful ignimbrite complex with a thickness of 250-300 m was formed. Its remains cover, in the present period, the peaks of Drastvica (elevation 852), Veľký Žiar (elevation 852) (Geotope No. 44 Veľký Žiar), Sedlo (elevation 685), Vavrišová (elevation 583) and more northerly the area of Kojatín (elevation 509) and elevation 637 east of Kojatín.

Due to the rapid succession of ash-pumice flows that deposited the hot ash-pumice material, it was welded into a uniform to nearly homogenous mass. The top area of crest with the elevation 637 – Kojatín, consists of ignimbrite rock cliffs with a height of about 8–10 m (Fig. 2, Photo 1). The ignimbrite jointing is coarsely-columnar to blocky. The rock is dark grey to grey-black, gains brown hues with weathering. Due to the high degree of welding, the original texture is almost indistinguishable. Only signs of a subparallel oriented texture can be observed in the form of darker vitric formations (fiamme), which were formed by the collapse (flattening) of the original pumice fragments due to the weight of the overlying hot ash-pumice mass. The original matrix – ash-pumice is strongly homogenised, there are distinguishable crystals of plagioclase, amphibole and tiny flakes of biotite. Occasionally, fragments of older andesites, which are stripped from the surface over which the ash-pumice flow was moving, are present.

Lower down on the western slope of the Kojatín Hill is a block slope, which was formed by the disintegration of rock cliffs (Photo 2). Below the block slope there, are again ignimbrite rock exposures with coarsely-columnar jointing (Fig. 3, Photo 3).

The ash-pumice material, welded in the form of ignimbrites, corresponds in petrographic composition to biotite-amphibole-pyroxene andesite.

Photo 1 Ignimbrite rock cliffs in the summit area of the ridge with the elevation 637 – Kojatín. The jointing is coarsely-columnar along the steep planes and large blocky along the subhorizontal planes (© P. Pachinger).

Photo 2 The block slope with ignimbrite material, formed by the disintegration of the original rock cliffs in the Glacial Period (© P. Pachinger).

The massive ignimbrite plateau in the western part of the caldera is deposited on lava flows of the Sitno Complex. Ash-pumice tuffs with no signs of welding (due to the cooling of the ash-pumice pyroclastic flow at its contact with bedrock) are deposited at the base of the ignimbrites. Ignimbrite plateau is deposited on lava flows of the Sitno Effusive Complex. Immediately at the base of the ignimbrite plateau, positions of redeposited tuffs, consisting of worked pumice fragments deposited in a tuff-sand to sandstone-claystone matrix with signs of sorting and layering, are locally preserved. They represent the products of initial eruptions deposited by washing at the base of the paleodolines, which were later infilled by ash-pumice flows of the Drastvica Formation.

Photo 3 The rock exposure of ignimbrite with columnar jointing on the western slope of the Kojatín elevation (© P. Pachinger).

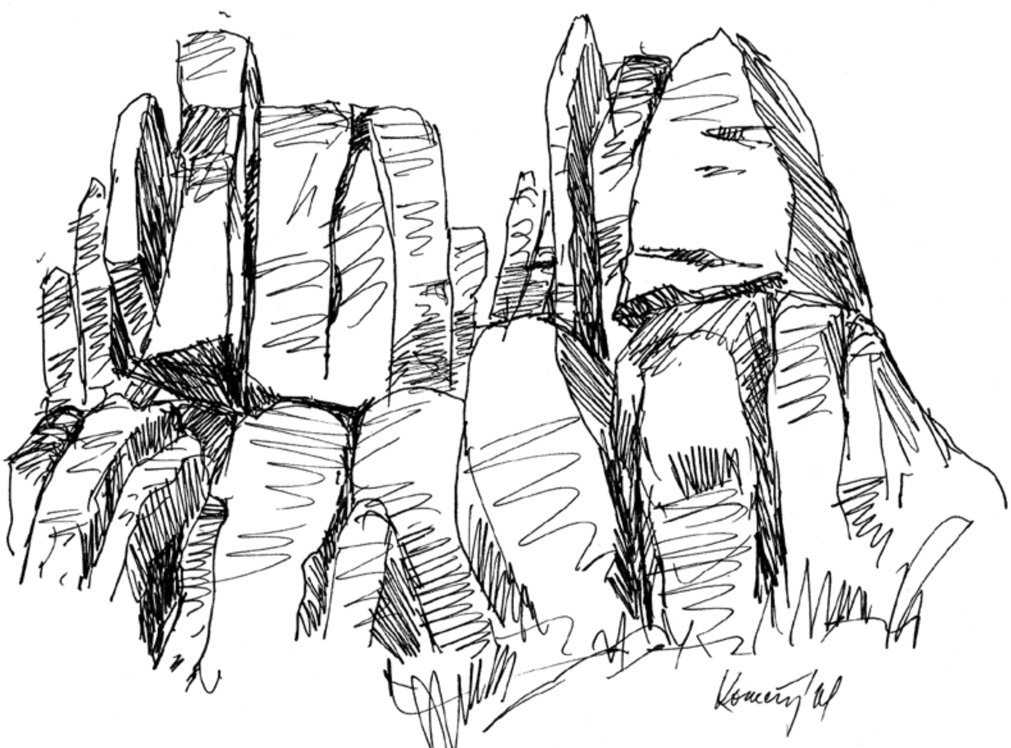


Fig. 3 The ignimbrite rock cliff in the lower level of the slope below the Kojatín elevation. The jointing is coarsely-columnar to blocky (© V. Konečný).

Geotope No. 27

Havránková Lúka – Kojatín (eastern ridge)

extrusion of rhyolite

The uplift of a large block in the central part of the Štiavnica caldera and its development into the Hodruša-Štiavnica Horst in the Late Sarmatian Period was accompanied by massive explosive-extrusive rift volcanism. The rhyolitic magmas used the fault system near the western edge of the horst as an outlet pathway, along which the maximum uplift movement occurred. The fault zone (comprising the fault system) traced by the exposure of rhyolitic magmas continues northeastward at the interface between the horst and the southern edge of the Žiarska Kotlina Basin (which was intensively subsiding at this time). The fault zone expands near the eastern edge of the Žiarska Kotlina Basin in the northward direction into the Kremnica Mountains. The fault zone is referred to as *the Vyhne-Ihráč volcano-tectonic zone*. During the Late Sarmatian Period, explosive volcanism followed by massive extrusions of rhyolite lavas took place along this zone near the south-eastern to eastern edge of the Žiarska Kotlina Basin.

Fig. 1 The thick mural jointing of the rhyolite porphyry along the steep planes (© V. Konečný).

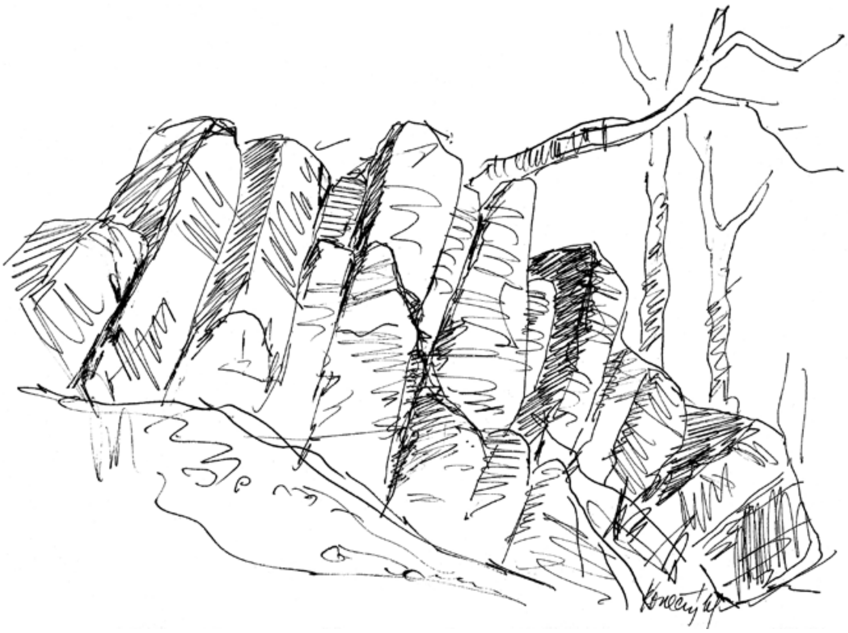


Fig. 2 The coarsely-columnar to thick mural jointing of rhyolite porphyry in the lower level of the slope below Kojatín (© V. Konečný).

A series of rhyolitic dykes, extrusions and intrusions of rhyolitic porphyries oriented in the NNE-SSW to N-S direction are exposed near the western edge of the horst. One of these bodies is an extrusion of rhyolite of smaller dimensions east of the elevation 509 – Kojatín-Havránková Lúka, about 1.5 km east of Voznica on the northern slope of the Richňava Valley.

The rock cliff on the eastern slope of elevation 640 (about 500 m east of Kojatín), in the area of the ridge, consists of a rhyolite with thick mural jointing along the planes 300 NW/70°, inclined towards southwest (Fig. 1).

In the lower level, the inclination of the mural jointing changes to 340 NE/35° (Fig. 2, Photo 1).

The thick mural jointing corresponds to fluidity planes in the direction of outward movement of rhyolitic lava accentuated by weathering.

The fan-shaped arrangement of the fluidity planes suggests an extrusive–type form (extrusive dome).

The rhyolite is light grey to off-white. Distinct phenocrysts consist of plagioclase (3–4 mm), biotite forms tiny flakes (up to 2 mm).

Photo 1 A close-up of the coarsely-columnar jointing of the rhyolite porphyry in the lower level of the slope below Kojatín (© P. Pachinger).

Geotope No. 28

Pod Veľký Žiar – Rusková

dyke of rhyolite porphyry

During the Late Sarmatian Period i.e., the final period of the development of the Štiavnica Stratovolcano, dramatic changes to its morphology occurred. Due to the gradual uplifts of the central block of the caldera, the structure of the Hodruša-Štiavnica Horst was formed. The maximum uplift of the horst block took place along the fault zone at the western edge of the horst. Along this fault, running roughly north-south, rock complexes of pre-volcanic bedrock, exposed by a denudation cut in the horst area, intersect with the neovolcanic rocks west of the fault. The mentioned fault zone allowed the rhyolitic magmas to rise to the surface roughly synchronously with the uplift movements of the horst block during the Late Sarmatian Period. This is confirmed by the presence of a series of rhyolitic bodies oriented in a roughly NNE-SSW to north-south direction. One of these bodies is the rhyolite porphyry dyke on the eastern slope of the elevation 767 – Drieňov and elevation 852 – Veľký Žiar.

The fault zone referred to as *the Vyhne-Ihráč volcano-tectonic zone* ran further along the northeast boundary of the Hodruša-Štiavnica Horst and the Žiarska Kotlina Basin (which subsided during this period) and, continuing northwards near the eastern edge of the Žiarska Kotlina Basin, allowed the rhyolite masses to rise to the surface and was the scene of tumultuous volcanic activity during the Sarmatian Period.

Photo 1 A close-up of mural jointing of rhyolite porphyry with a steep course (© P. Pachinger).

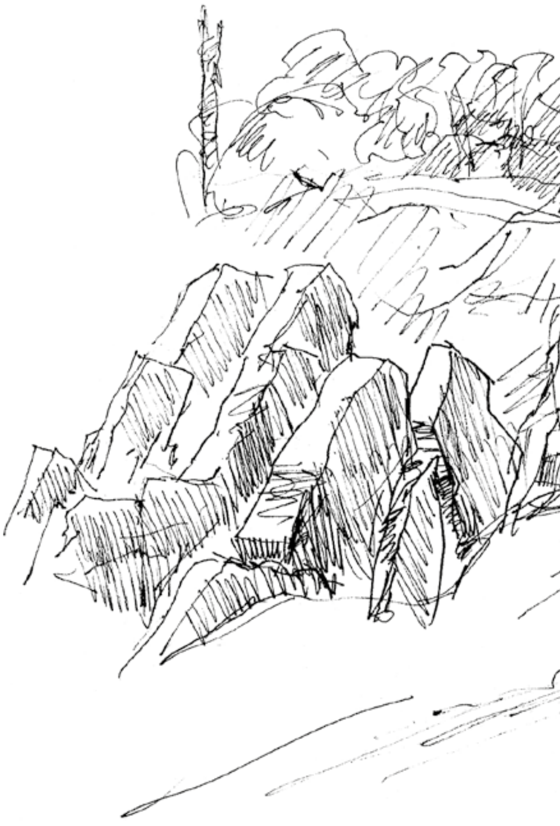


Fig. 1 The distinct mural jointing of the rhyolite porphyry dyke on the southeast slope below the elevation of Veľký Žiar (© V. Konečný).

The rhyolite porphyry dyke protrudes in a series of exposures near the forest road of the southeastern slope below Veľký Žiar (elevation 852) above the Suchá Voznica Valley. The rhyolite porphyry dykes are characterised by mural jointing along the subvertical planes 160 SE/85–90° (Fig. 1, Photo 1).

The mural jointing corresponds to fluidal planes with alternating darker and lighter bands.

The rhyolite porphyry is light to off-white, the phenocrysts consist of plagioclase (3–5 mm), quartz (1–2 mm), biotite, amphibole (up to 1–3 mm). The rock is slightly porous.

6. Tourism Territorial Unit Vyhne

Geotope No. 29

The Vyhnianska Dolina Valley – Handel

crushed Vyhne granite (porphyric granodiorite)

Schists and the crushed Vyhne granite (porphyric granodiorite) are the oldest rocks in the Hodruša-Štiavnica Horst, which was formed at the end of the Štiavnica Stratovolcano's formation by an uplift of a large block in the central part of the caldera).

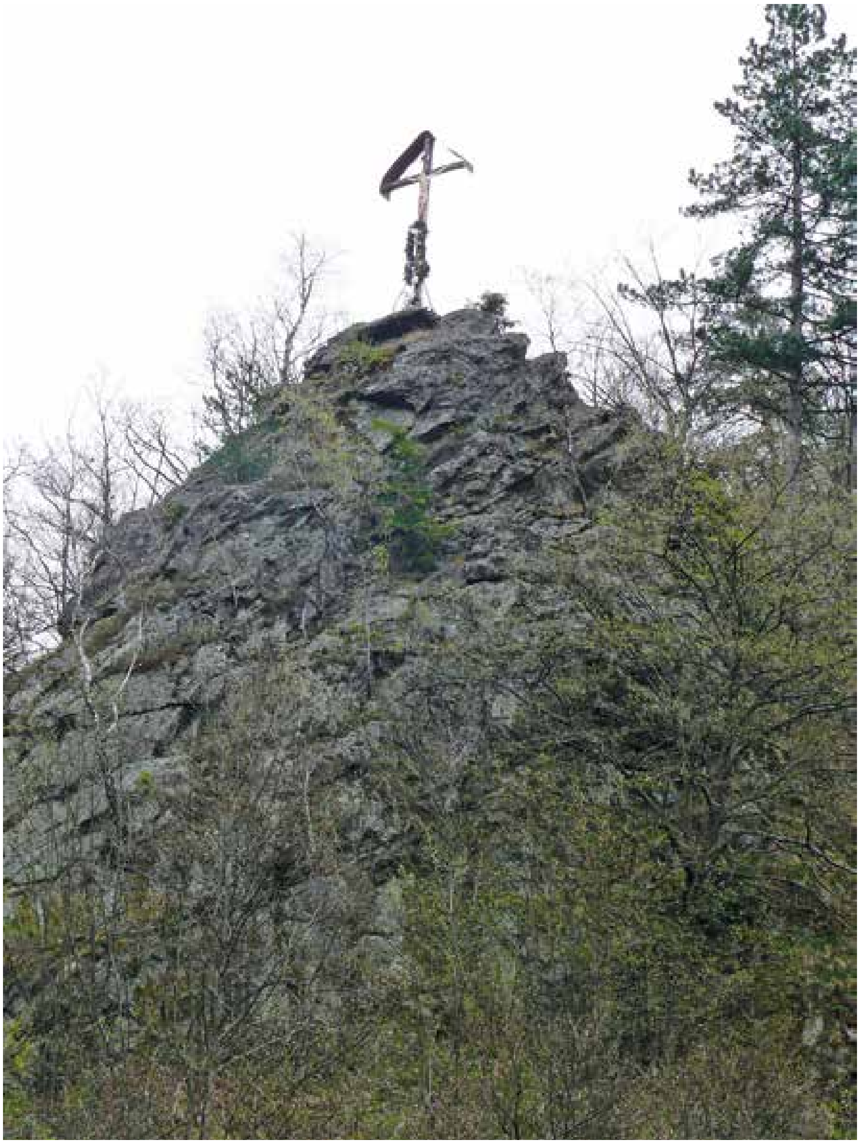


Photo 1 The rock cliff consisting of "crushed Vyhne granite" with irregular blocky jointing to heavy-bedded jointing (© P. Pachinger).

The rocks of the Hercynian crystalline complex exposed by a deep denudation cut rose to the surface in the northern part of the Hodruša-Štiavnica Horst, thus creating several elevations between Sklené Teplice and Banská Hodruša.

The most extensive exposures are in the Kamenná Dolina Valley, south of Sklené Teplice, on the slopes of the Vyhnianska Dolina Valley (under the Ostružka and Banský Vrch hills, in the area of the Klokoč Hill and the Hodruška Valley).

The rocks of the crystalline complex consist of porphyric biotite granodiorite (referred to as "crushed Vyhne granite" as recommended by Prof. J. Šalát), sericite-chlorite schists, sillimanite-biotite orthogneiss, and tectonic breccia.

The most visible rock is porphyric granodiorite, or "crushed Vyhne granite". The rock cliff on the outskirts of Vyhne consists of the crushed Vyhne granite (Fig. 1, Photo 1).

There is a cross on the top of the rock cliff. The cliff itself can be accessed from the state road across a bridge, which crosses the stream and subsequent ca. 180 m long ascent from its spring to the rock wall.

The rock is coarse grained, brown-grey to greenish. The grains ranging from 0.6 cm to 1 cm consist of plagioclase, potassium feldspar, rare biotite, and muscovite. Chlorite, sericite and accessory minerals represented by apatite, zircon, and titanite represent the secondary minerals. Quartz is always undulose (with irregular extinction under the microscope with crossed polars). Plagioclase (represented by oligoclase) slightly outnumbers potassium feldspars in which it is embedded along with biotite and quartz.

Potassium feldspars and plagioclases have been altered (pertitised) by sericitisation and saussuritisation. Biotite is chloritised and baueritised (it is colourless due to the removal of the Fe component).

Fig. 1 The rock cliff consisting of "crushed Vyhne granite" in Vyhne. (© V. Konečný).

Fig. 2 The rock wall formed of "crushed Vyhne granite" with bedded jointing (© V. Konečný).

Photo 1 The contact zone of diorite with crystalline schists at the bend in the state road, across from the turn leading to Banky. The rock is characterised by distinct large block or coarsely-columnar jointing (© P. Pachinger).

As a result of the Alpine tectonic processes related to the displacement of rock blocks and formation of the Carpathian Nappe, the rock is oriented and cleaved to almost mylonitic stage (crushed into fine material). The rock's structure is variable, from cataclastic (debris) and mortar to dynamo-fluidal or porphyroclastic.

Crushed Vyhne granite with bedded jointing can be found in the lower part of the cliff's exposures (Fig. 2). Due to weathering, the grain orientation with secondary "airflow" around grains (dynamo-fluidal structure) is accentuated. Schistosity is accentuated by chlorite streaks. Jointing along the planes 110 SE/20° can be seen. The rock is disturbed along the planes 76 EN/35–40°..

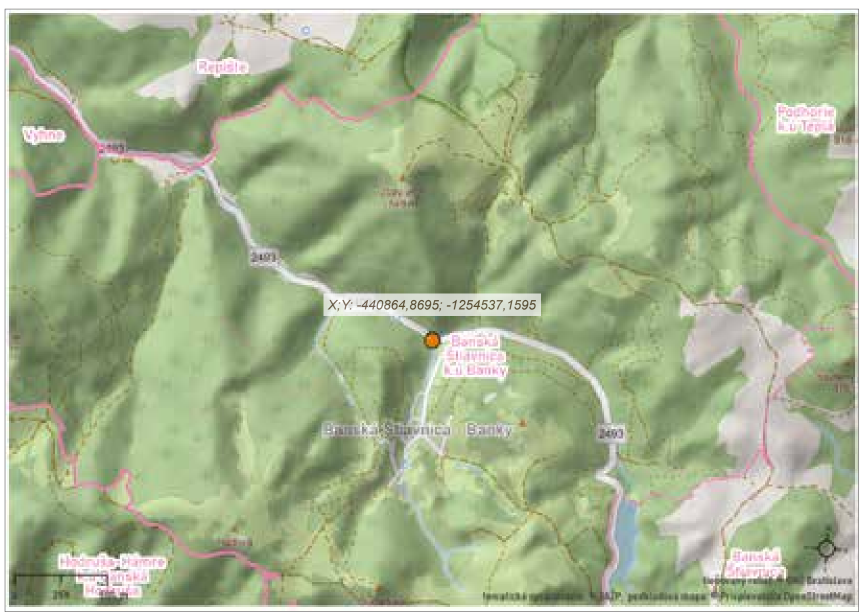
Geotope No. 30

The Vyhnianska Dolina Valley

hybrid rocks at the intersection of diorite and crystalline schists

Silimanite-biotite orthogneisses, the lowest part of the profile, protrude from the southern slope of the Zlatý Vrch Hill (above the Vyhnianska Dolina Valley and across from the turn leading to Banky).

The overlying rock on the slope of the Zlatý Vrch Hill consists of tectonic breccias, sericite-chlorite schists and crushed Vyhne granite (porphyric granodiorite). Mesosoic rocks in the form of Lower Triassic quartzite of the Veľký Bok mountain series sedimentary



cover are part of the overlying rock of the crystalline complex below the peak of the Zlatý Vrch Hill (elevation 849). In the overlying rock of quartzites, denudation remnants of Middle and Late Triassic limestones and dolomites belonging to the Šturec Nappe are in a tectonic position.

The lowest part of the profile – sillimanite-biotite orthogneisses – are in direct contact with a diorite intrusion. A belt of hybrid rocks, which have almost aplitic character, occurs at the point where diorite comes into contact with the crystalline complex.

The belt has been exposed in an abandoned quarry near a bend in the road, across from a turn leading to Banky (Fig. 1, Photo 1).

Jointing is coarsely-columnar or large block along the following planes: 115 SE/45°, 30 EN/75°, 180 S/80°.

In the exposure at the bend in the road and in the quarry wall (Fig. 2, Photo 2), belts of grained, grey-black, greenish rock corresponding to diorite are interspersed with belts of fine-grained, almost aplitic light grey or off-white hybrid rocks (Fig. 3, Photo 3).

Fig. 1 The rock exposure at the bend in the state road, across from the turn leading to Banky, exposes the contact of the diorite intrusion with the Paleozoic crystalline schists. Large blocky jointing can be observed here (© V. Konečný).

Photo 2 The abandoned quarry above the state road. Diorite intrusions in crystalline schists and a light-coloured aplitic rock have been exposed in the quarry wall (© P. Pachinger).

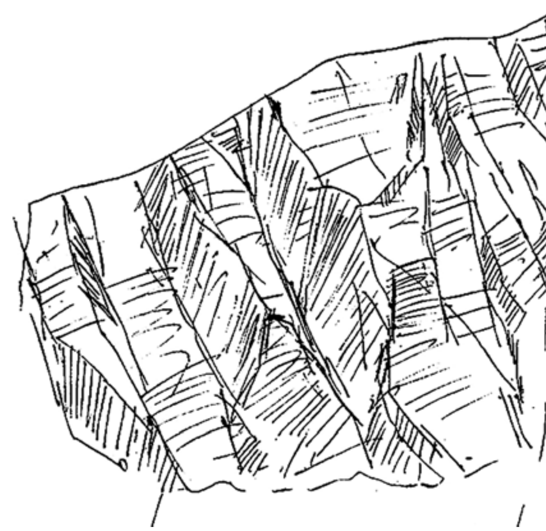


Fig. 2 The abandoned quarry on the slope over the state road. Diorite intrusions in crystalline schists have been exposed in the quarry wall, as shown in Fig. 3 (© V. Konečný).

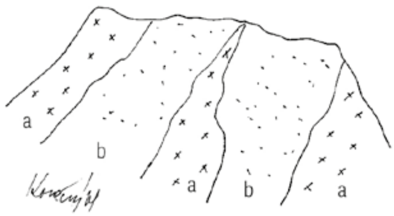
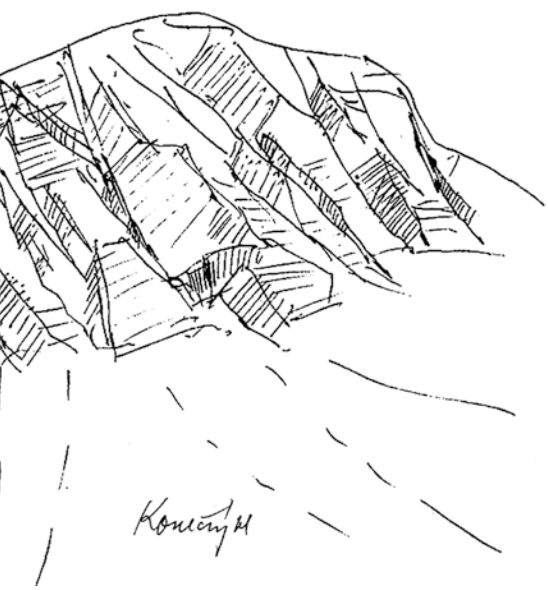


Fig. 3 Scheme of diorite intrusions in the crystalline schists. Due to the contact action of diorite, an aplitic rock has been formed: a) diorite, b) aplite (© V. Konečný).

Photo 3 A close-up of a diorite intrusion – dark-coloured rock – in crystalline schists, forming aplite – light-coloured rock (© P. Pachinger).



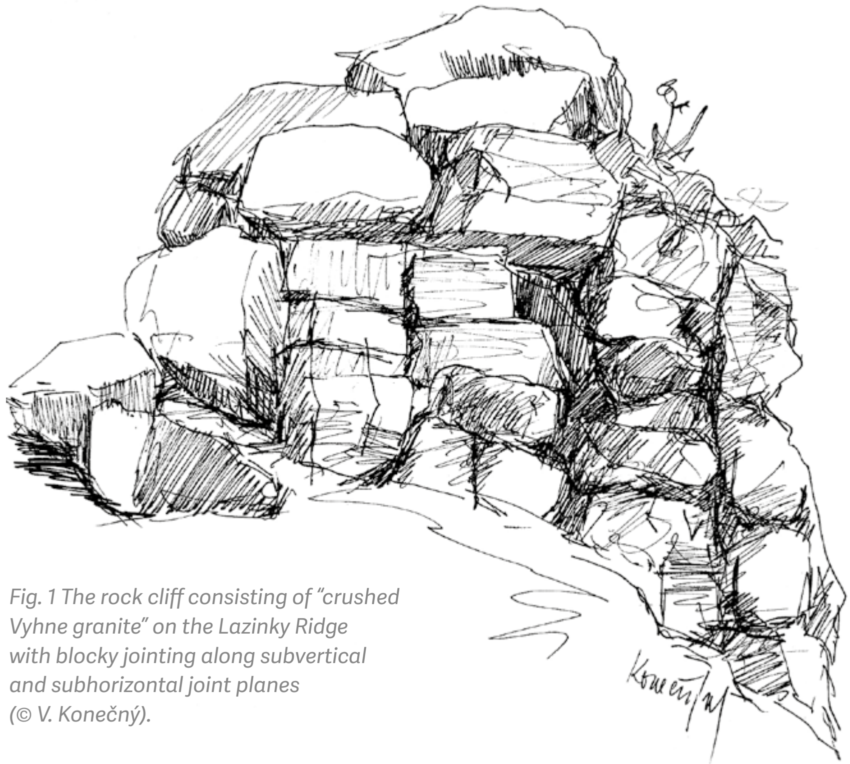


Fig. 1 The rock cliff consisting of "crushed Vyhne granite" on the Lazinky Ridge with blocky jointing along subvertical and subhorizontal joint planes (© V. Konečný).

Geotope No. 31

The Zlatý Vrch Hill — The Lazinky Ridge

crushed Vyhne granite

The northern slope of the Zlatý Vrch Hill (elevation 849), south of Sklené Teplice, offers a chance to get acquainted with the rocks of the crystalline complex (crushed Vyhne granite), Mesozoic rocks (Lower Triassic quartzites), and Paleogenic rocks (basal group of strata).

The crystalline complex consists of the Hercynian (early Paleozoic or Proterozoic) "crushed Vyhne granite" (porphyric granodiorite).

Smaller rock cliffs protrude from the Lazinky Ridge (Photo 1), which starts at the elevation of 849 and runs northwards. The 4–5 m tall cliffs with large blocky jointing along vertical (subvertical) and subhorizontal planes have broken down into rectangular blocks (Fig. 1, Photo 2, 3).

The rock is coarse grained, the plagioclase and quartz grains are 1–2 cm large. Due to dynamometamorphosis, the rock is clearly oriented in a specific direction.

Grains are lenticular and follow a subparallel course (photo 3). The orientation is accentuated by green streaks (secondary chlorites).

Dynamometamorphic alterations of the rock are the result of Alpine tectonic processes. The Crystalline complex rocks deposited in a duplex–scaly position with shifts from northeast to southwest (or NEE to SWW) correspond with the crystalline complex of northern Veporicum, which is close to the root zones of the Krížna Nappe (V. Konečný, J. Lexa, J. Hók, 1993).

Photo 2 The rock cliff consisting of "crushed Vyhne granite" on the Lazinky Ridge with strong orientation (cleavage foliation) caused by dynamometamorphic processes – on the right side, next to the hammer (© P. Pachinger).

Photo 3 A close-up of the texture of "crushed Vyhne granite" with clearly visible light-coloured plagioclase phenocrysts, potassium feldspars, and quartz (© P. Pachinger).

Photo 1 A view from the Lazinky Ridge overlooking Vyhne (© P. Pachinger).

Geotope No. 32

The Zlatý Vrch Hill – west of the Bartkov Majer area

early Triassic quartzites

Rock cliffs consisting of Lower Triassic quartzites are located on a mountain ridge west of the Bartkov Majer area (Fig. 1, Photo 1, 2). The quartzites deposited on the crystalline complex rocks (their contact with the subjacent crystalline complex is obstructed by debris) are considered to be part of the Veľký Bok mountain series of the Veporicum sedimentary cover (A. Biely, O. Fusán, 1967).

Quartzites and quartzite schists comprise basal sediments deposited during the sea's transgression. The clastic material washed off the shore sedimented in the shallow sea. The subsequent diagenetic processes caused its solidification and homogenisation, which resulted in the formation of the quartzites seen today.

Quartzites are fine or coarse grained, grey, grey-yellow or pinkish, with jointing that can be mural to heavy-bedded based on the bedding planes. Bed

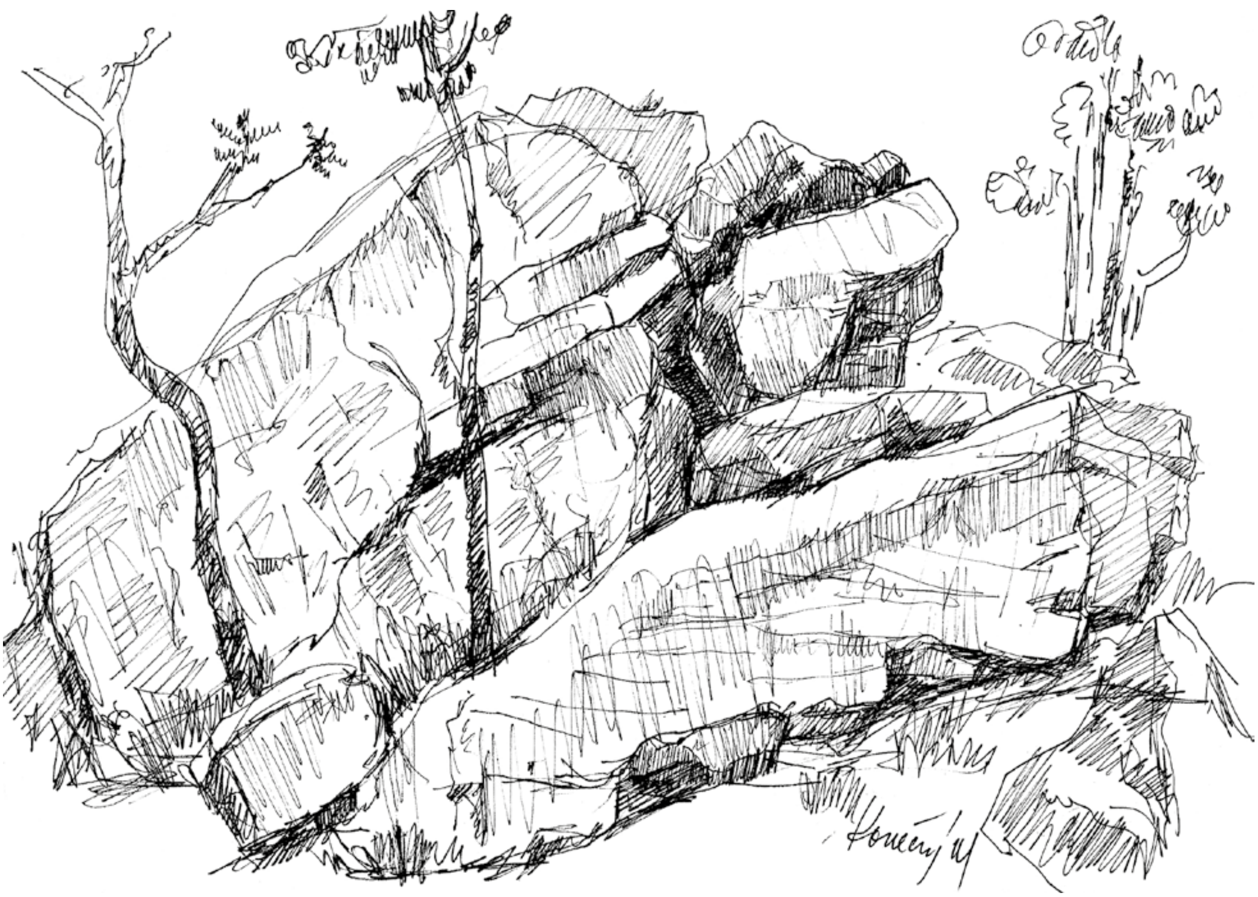


Fig. 1 Lower Triassic quartzites west of the Bartkov Majer area with heavy-bedded jointing (© V. Konečný).

Photo 1 The rock cliff consisting of Lower Triassic quartzites with bedded jointing west of the Bartkov Majer area (© P. Pachinger).

thickness varies from 10 to 30 cm, occasionally from 1 to 2 m (at the upper part of the cliff). Bedding joints are filled with silicified sericite schists. Local cleavage foliation, which is the result of dynamometamorphic processes, is mostly visible in the lower parts of the complex, near the area of contact with the subjacent crystalline complex.

The crystalline complex – the crushed Vyhne granite in the bedrock of Lower Triassic quartzites rises in the trench exposed by a forest road leading north to the Lazinky Ridge (Geotope no. 31. The Zlatý Vrch Hill – The Lazinky Ridge).

Middle Triassic to Late Triassic limestones and dolomites rise in the overlying rock of Lower Triassic quartzites near the Bartkov Majer area. The limestones are off-white or dark grey, partially cleaved and marbled. The dolomites are light grey, their texture is granular, almost sugary. Further northwards, in the trench exposed by the forest road under elevation 747, Paleogene conglomerates of the Eocene have been exposed (Geotope no. 34 The Zlatý Vrch Hill – west of the Bartkov Majer area).

Photo 2 View of the Bartkov Majer area (© P. Pachinger).

Geotope No. 33

Sklené Teplice – the Bukovec Hill

contact of Early Triassic quartzites with the Veporic crystalline complex

The broader area of Sklené Teplice represents the north-eastern border of the Hodruša-Štiavnica Horst. A deep denudation cut has caused the removal of the surface volcanic structure and an extensive exposure of the pre-volcanic bedrock. South of Sklené Teplice, in the valley of the Teplá Stream, rock cliffs consisting of Early Triassic quartzites of the Veľký Bok mountain series protrude from the lower part of the Bukovec Hill's western slope. The series is considered to be a sedimentary unit of the Veporic crystalline complex, which is located in the sub-autochthonous position and represents a sedimentary complex deposited on the rocks of the Veporic crystalline complex. The crystalline complex in this area consists of crushed Vyhne granite (biotite granodiorite).

Fig. 1 The bottom part of the rock cliff on the slope of the Teplá Dolina Valley is part of the "crushed Vyhne granite" crystalline complex (Kr). Early Triassic quartzites of the Veľký Bok mountain series in the tectonic position form the upper part of the cliff (Me). The arrow indicates the tectonic contact. A view of the rock cliff from the north to the south (© V. Konečný).

The crystalline complex rocks, as well as the Paleozoic-Mesozoic rocks of the Veľký Bok mountain series, have cleaved due to the Alpine tectonic processes. Rocks of this series have been heavily tectonically deformed, which is the reason for their lenticular nature and past metamorphosis.

Based on the results of the deformation analysis, the rocks of the Veľký Bok mountain series and the crystalline complex have undergone deformation at the same time. There is evidence of rock complexes being moved from the northeast to the southwest (V. Konečný, J. Lexa, J. Hók, 1993).

Rocks of the Hronicum sheet unit, which correspond with the rocks found in the Šturec Nappe, have been deposited in the upper part of the overlying rock. Rocks of the Šturec Nappe protruding from the upper parts of the Bukovec Hill's western slope are altered only slightly or not at all, and they have been discordantly deposited on the subjacent series of the Veľký Bok mountain. Consequently, the deformation and metamorphosis of the Mesozoic Veľký Bok Mountain series, together with the subsequent denudation of a considerably thick mass, occurred before the Šturec Nappe's thrust.

The rock cliffs consisting of Early Triassic quartzites in a raised tectonic position protrude from the western slope of the Bukovec Hill above a state road, ca. 1.5 km south of Sklené Teplice (Fig. 1).

Photo 2 A close-up of the Early Triassic quartzites' thrust on the heavily cleaved crystalline complex (next to the hammer). It shows a flake of the crystalline complex stuck between Triassic quartzites in the overlying rock as well as bedrock. The crystalline complex – crushed Vyhne granite – is located in the lower part (© P. Pachinger).

Photo 1 The rock cliff shows the thrust of Early Triassic quartzites onto the crystalline complex bedrock (© P. Pachinger).

The basal complex consists of quartzites corresponding to the Lúžna Formation. They are fine to coarse-grained, off-white to pinkish and heavy-bedded, with beds that are mostly 30–40 cm, maximum one metre thick. The bedding joints are filled with silicified sericite schists. Dynamic metamorphosis which resulted in cleavage foliation and formation of secondary minerals – chlorite, sericite, muscovite – is typical. Beds are tectonically disrupted and penetrated by quartz veinlets.

Fig. 2 The upper part of the rock cliff on the slope of the Teplá Dolina Valley is formed by Early Triassic quartzites (Me). The heavily cleaved crystalline complex (Kr) consisting of "crushed Vyhne granite" forms the lower part. The arrow indicates the contact area. The crystalline complex flake is stuck between Early Triassic quartzites (upper arrow). View of the rock cliff from the south to the north (© V. Konečný).

The rocks of the Hercynian crystalline complex represented by "crushed Vyhne granite" (biotite granodiorite) emerge in the bedrock of bedded quartzites. These rocks are coarse to medium-grained, grey-brown to grey-green. The grains are composed of quartz, potassium feldspar, plagioclase, biotite, muscovite, and secondary minerals of chlorite a sericite. Apatite, zircon, and titanite represent the accessory minerals. Due to tectonic impacts, quartz is always undulose (with irregular extinction). The rocks are visibly oriented. The crystalline complex is heavily cleaved with thin-bedded jointing to almost mylonitised near the tectonic contact with the overlying quartzites. The tectonic contact is along the plane 330/50° (Fig. 2, Photo 1, 2).

The earlier tectonic disturbances with crosswise orientation moved the separated blocks (Fig. 3, Photo 3).

Photo 3 A close-up of the tectonic movement along the older fault – on the right side, next to the hammer (© P. Pachinger).

Fig. 3 The block shift along an older fault 330/50° has separated two blocks. The fault along which the blocks moved is indicated by the arrow (© V. Konečný).

Geotope No. 34

The Zlatý Vrch Hill – north of the Bartkov Majer area

Paleogene basal group of strata

The sediments of the Central Carpathian Paleogene found in the surface exposures of the Hodruša-Štiavnica Horst are not part of a continuous group of strata. They take the form of relatively thin remnants. The Paleogene sediments represent an Eocene basal group of strata deposited during sea transgression.

The Eocene basal group of strata consists mainly of fine-grained and less frequently coarse-grained polymict conglomerates (composed of multiple rocks). The proportion of the individual rock types in the pebbles depends mainly on the immediate bedrock structure from which the material originated. The conglomerates in the Teplá Valley consist mainly of Permian pebbles, while those near the Bartkov Majer area are composed of limestone and dolomite pebbles derived from the bedrock. In general, the conglomerate matrix is sandy to sandy-clayey. Beds with nummulite fauna are present near Vyhne. Limestone interbeds and beds are oftentimes present in these conglomerates.

Eocene conglomerates have been exposed by a trench of the dirt road north of the Bartkov Majer area at the southern edge of the ridge with the elevation of 747 (Fig. 1, Photo 1).

The material found in the conglomerates (with well to perfectly rounded

Fig. 1 The paleogene basal group of strata comprised of pebbles as well as dolomite and limestone breccias are exposed by a trench of the dirt road north of the Bartkov Majer area (© V. Konečný).

Photo 1 A close-up of the Paleogene basal group of strata with light dolomite and dark grey limestone pebbles (© P. Pachinger).

pebbles) and breccias (with angular debris) is comprised of light grey to off-white dolomites and dark grey limestones originating from the immediate bedrock (Middle to Late Triassic limestones and dolomites of the Veľký Bok mountain series). The matrix is brown and sandy-clayey.

The breccias and conglomerate have been deposited in the tidal zone of the transgressing sea.

Besides the basal Eocene sediments, sediments of the Late Lutetian facies deposited in the relatively deeper marine environment were confirmed by the HDŠ-1 borehole in the Repište area (west of Sklené Teplice).

Geotope No. 35

Sklené Teplice – the Teplá Valley

Middle to Late Triassic limestones and dolomites

Middle to Late Triassic limestones and dolomites of the Veľký Bok mountain series are exposed in an abandoned quarry on the western slope of the Bukovec Hill in the Teplá Valley, ca. 1.2 km south of Sklené Teplice. Limestones and dolomites have been deposited in the immediate overlying rock of Early Triassic quartzites (Geotope No. 33 Sklené Teplice – the Bukovec Hill, ca. 300 m to the south). Limestones are off-white, dark grey to grey-black, bedded, frequently cleaved and marbled. Ochre facies with porous, sponge-like strucutre are also referred to as rauhwackes.

The original sedimentary structures have been altered and sporadically preserved in the form of fine lamination. The fact that they date to the Early Triassic Period has been confirmed by the presence of gastropods (I. Vitalis, 1916) and algae (A. Biely, J. Bystrický, 1964).

Photo 1 Middle to Late Triassic limestones and dolomites of the Veľký Bok mountain series exposed in the upper part of an abandoned quarry south of Sklené Teplice (© P. Pachinger).

Geotope No. 36

The Vyhnianska Dolina Valley

diorite intrusion

At the end of the Baden Period, an intrusive granodiorite and diorite complex, the Hodruša-Štiavnica intrusive complex, formed in the bedrock of the Štiavnica Stratovolcano. The intrusive complex exposed by a deep denudation cut surfaces in the central and western parts of the Hodruša-Štiavnica Horst. The central part consists of an extensive, almost 80 km^2 large granodiorite intrusion. In the bedrock of the volcanic complex, it extends eastwards into the Štiavnica part of the horst, as it has been confirmed by boring and mining.

Photo 1 The diorite rock cliff with irregular large blocky jointing (© P. Pachinger).

Fig. 1 The rock cliff in the ridge above the Pivná Dolina Valley leading into the main valley, the Vyhnianska Dolina Valley. Diorite shows irregular large blocky jointing (© V. Konečný).

A 2.5 km long (Spálený Vrch – Vyhnianska Dolina – Banky – Šobov) diorite intrusion with NWW-EES orientation surfaces near the northern edge of the grandiorite intrusion.

As assumed by V. Konečný and J. Lexa (2001), the granodiorite and diorite intrusive complex was formed by a bedrock block that subsided into the upper levels of a magma reservoir. Subsequently, the space in the overlying rock was filled with granodiorite magma. The fault line near the granodiorite intrusion's northern edge allowed the diorite intrusion to form from the east to the west.

Small diorite bodies occasionally protrude from the roof of the grandiorite intrusion (the Pivovarský Vrch Hill, south of Hodruša), near its western edge (Horná Kostolná) and near its southern edge (the Richňavská Dolina Valley). These bodies indicate there had originally been a larger number of diorite bodies, which were destroyed by the formation of the main diorite intrusion.

The diorite rock forms a ridge above the Pivná Dolina Valley, which turns to the Vyhnianska Dolina Valley below a road leading to Banky (Fig. 1).

The rock cliff consists of diorite with irregular blocky jointing (Photo 1, 2). Diorite is dark, grey-black, and uniformly granular (it gains a blue-green hue due to propylitisation). It includes plagioclase of basic composition (An55-72), augite, amphibole, and biotite. The space between the grains is filled with quartz. The structure is omnidirectionally grained, ophitic.

At the edges, the diorite intrusion has altered into porphyric diorite and its base matter has hypidiomorphic to allotriomorphic texture.

Hydrothermal alterations mainly include chloritisation, pyroxene actinolitisation, and actinolitisation of biotite and amphibole.

Photo 2 The diorite rock cliff with irregular blocky jointing (© P. Pachinger).

Geotope No. 37

Vyhne

stone field

During the Late Sarmatian, approximately 11 million years ago, there was active rhyolite volcanism in the Central Slovakia Neogene Field. It followed andesite volcanism, during which a number of andesite stratovolcanoes had been formed. The largest one was the Štiavnica Stratovolcano whose volcanic products cover an area of more than 2,200 km^2.

Explosive-extrusive type ryolite volcanism took place at the northern edge of the stratovolcano and at the southern to eastern edge of the Žiarska Kotlina Basin. The rise of rhyolite magmas frequently coincided with the rise of a large block in the central part of the Štiavnica caldera, resulting in the formation of the Hodru-

Fig. 2 Stone field (block slope) on the southwestern slope of the Kamenná elevation near Vyhne was formed due to disintegration of a rhyolite body (© V. Konečný).

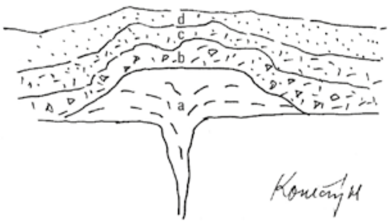


Fig. 1 Scheme of the laccolith intrusion in the rhyolite tuffs (© V. Konečný):

a) laccolith intrusion, b) rhyolite tuff-breccias, c) ash-pumice tuffs, d) close-grained rhyolite tuffs.
The sediments in the overlying rock of the laccolith intrusion have been deformed due to its location.

ša-Štiavnica Horst and the subsidence of the Žiarska Kotlina Basin. Rhyolite magmas surfaced through a fault zone at the western edge of the Hodruša-Štiavnica Horst, at the south-east edge of the Žiarska Kotlina Basin (where it represented a boundary between the rising horst block and the subsiding block of the Žiarska Kotlina Basin), and at the eastern edge of the Žiarska Kotlina Basin, which leads northwards into the Kremnica Mountains. This fault system, active during the Late Sarmatian, is referred to as the Vyhne-Ihráč volcano-tectonic zone.

After the initial explosive eruptions of ash-pumice tuffs came the extrusions of viscous rhyolite lavas, which transformed into mostly dome-shaped extrusive domes and short, thick lava flows. Bedded bodies, sills and laccoliths occurred in the rhyolite tuff areas.

Photo 1 Stone field on the SW slope of the Kamenná elevation consists of angular fragments to rhyolite blocks (© P. Pachinger).

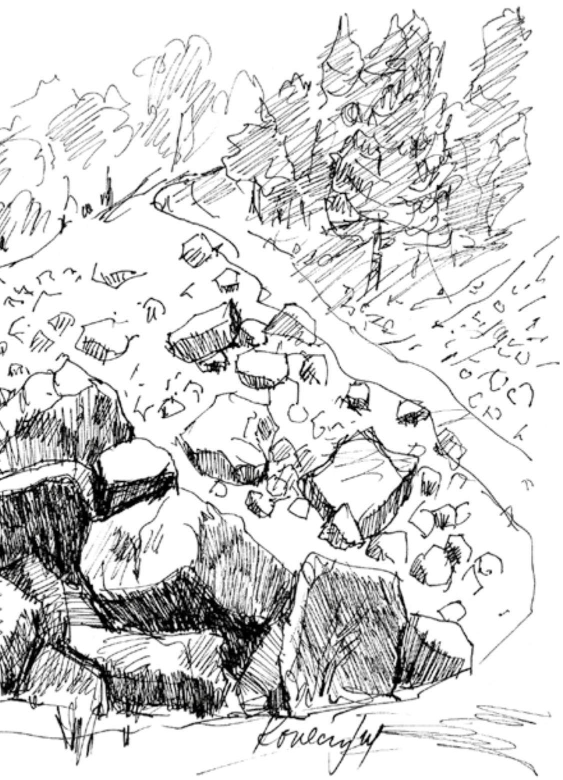


Photo 2 Chaotic accumulation of angular rhyolite blocks caused by gravitational energy (© P. Pachinger).

A bedded body of a rhyolite laccolith (Fig. 1) protrudes from the southern to eastern slope of Kamenná (elevation 495). The body is composed of rhyolite that has undergone hydrothermal-metasomatic processes which resulted in the formation of adularia (potassium feldspar). The base matter is recrystallised, alotriomorphically granular.

Sanidine-plagioclase rhyolite prevails at the top part of the Kamenná elevation and on its western slope. Sanidine phenocrysts (potassium feldspar) prevail over plagioclase. The presence of biotite and quartz is rare.

Due to physical disintegration of the rhyolite body and its subsequent gravitational movement, a block slope consisting of large coarse blocks to smaller angular rhyolite fragments, poetically referred to as the "Vyhne Stone Field", was formed on the south-eastern slope under the Kamenná elevation (Fig. 2, Photo 1, 2, 3). A periglacial block slope formed mainly during the last glaciation, when physical disintegration of rocks was the most intensive. The block slope was formed after the disintegration of rocks, mainly due to gravitational movements of individual blocks and fragments.

Photo 3 A close-up of large coarse rhyolite blocks (© P. Pachinger).

Geotope No. 38

Hliník nad Hronom – the Štátna Hora Hill

rhyolite laccolith

In the Late Sarmatian Period, when andesite volcanism was coming to an end, rhyolite volcanism started. Explosive eruptions producing large volumes of volcanic ash and pumice were dominant at first. These were later followed by extrusions of rhyolite lavas, which accumulated in the area of their ascend due to their low viscosity, creating dome-shaped bodies – extrusive domes or bread-form laccolith bodies in the tuffs. Short and thick lava flows and protrusions (or tholoids) are less frequent.

The products of rhyolite volcanism (tuffs, breccias, lava bodies) present mainly in the Žiarska Kotlina Basin are part of the Jastrabá Formation. The Jastrabá Formation volcanic rocks are concentrated mostly at the southern, eastern to north-eastern edge of the Žiarska Kotlina Basin. Rhyolite masses rose to the surface along huge fault lines along the Žiarska Kotlina Basin. The basin subsided intensely during the Late Sarmatian and its area was filled with a system of lakes and swamps, with rivers flowing into them from the north and the east.

Fig. 1 The internal structure of the rhyolite-laccolith body with distinct columnar jointing is exposed in an abandoned quarry in the eastern slope of the Štátna Hora Mountain (elevation 451) (© V. Konečný).

Photo 1 The abandoned quarry under the Štátna Hora elevation with coarsely-columnar rhyolite jointing (© P. Pachinger).

Rhyolite jointing is coarsely-columnar in the whole area exposed by individual benches of the quarry. The jointing is irregularly blocky in some places. The columnar jointing inclines away from the vertical orientation on the left side of the central bench.

The rhyolite is off-white, pinkish or ochre-yellow, and heavily porous (Photo 3).

The locally observed darker (glassier) stripes alternating with brighter stripes represent fluidal textures (lava flows). These textures are subhorizontal to strongly inclined, locally wavy to irregular.

Quarries in the northern slope of the Štátna Hora Hill (elevation 451) expose one of the many rhyolite bodies. In the past, rhyolite was massively quarried here, leaving behind vast quarries and heaps of waste material.

The quarry walls expose the internal structure of the rhyolite body in several benches (Fig. 1, Photo 1, 2).

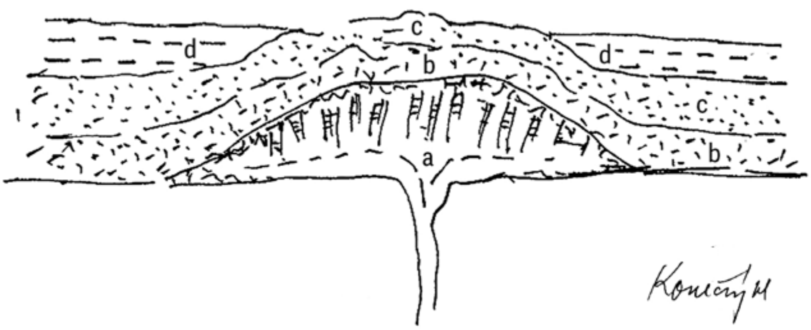
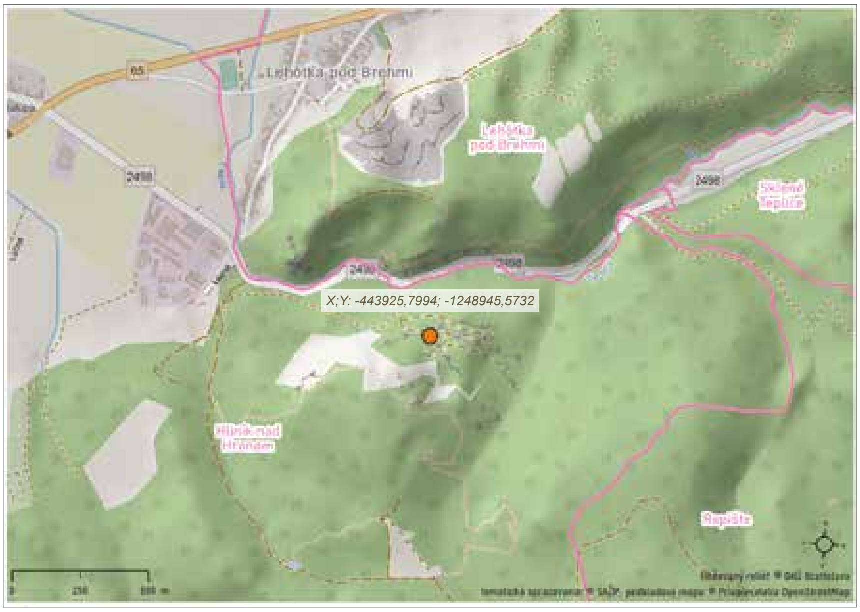


Fig. 2 Scheme of the laccolith intrusion in the Žiarska Kotlina Basin area located in rhyolite tuffs (© V. Konečný):

a) laccolith intrusion with columnar jointing, b) ash-pumice rhyolite tuffs, c) redeposited tuffs (cases of a) and b) are deformed in the overlying rock of the intrusion), d) later sediments of the Žiarska Kotlina Basin.

Photo 2 The lower bench of the quarry under the Štátna Hora elevation (© P. Pachinger).



Rhyolite has a variable composition of plagioclase, biotite, and rarely amphibole. Accessory minerals include apatite, zircon, and magnetite. The Štátna Hora rhyolite body was affected by potassium metasomatism, which resulted in the formation of potassium feldspar (adularia). The original (felsitic) base matter is metasomatically recrystallised and has gained a secondary microgranite or microallotriomorphically granular structure.

The Štátna Hora body located in the rhyolite tuffs is likely an extensive and shallow, laccolith-type intrusion (Fig. 2). Rhyolite quarries are situated near the southern edge of the laccolith intrusion.

In the past, rhyolite was quarried here mainly for the purpose of construction, it was used to make road kerbs, cladding stone, etc. Rhyolites were also used as a material for the construction of millstones as indicated by the unfinished or disintegrated millstones.

Photo 3 Various types of rhyolite textures (© P. Pachinger).

Geotope No. 39

Hliník – the Szabóova Skala Cliff

rhyolite extrusion

The products of Late Sarmatian rhyolite volcanism are also part of the Jastrabá Formation (named after the village of Jastrabá located on the southern slope of the Kremnica Mountains). Rhyolite volcanism occurred at the end of the Sarmatian Period, when enormous tectonic movements caused the uplift of the Hodruša-Štiavnica Horst as well as the subsidence of the Žiarska Kotlina Basin. Rhyolite masses surfaced along a fault zone referred to as the Vyhne-Ihráč volcano-tectonic zone, which borders with the Hodruša-Štiavnica Horst from the west. This zone extends into the area in question along the south-eastern edge of the Žiarska Kotlina Basin (thus creating a border between the rising horst block and the subsiding block of the

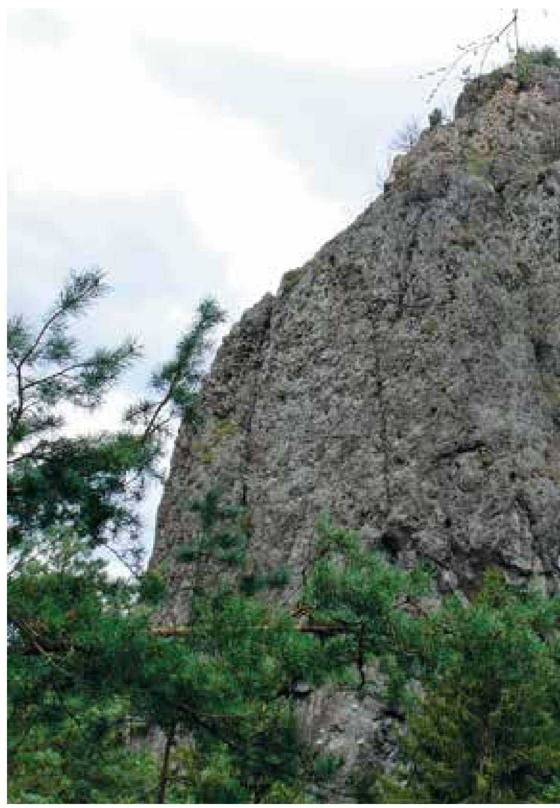


Photo 1 A view of the Szabóova Skala rock cliff from the road leading to the Štátna Hora Mountain (© P. Pachinger).

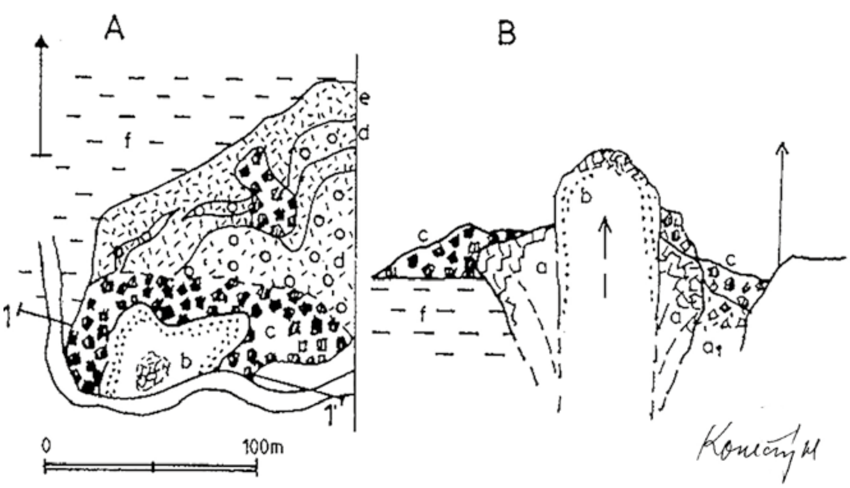


Fig. 1 The Szabóova Skala rhyolite extrusion (V. Konečný, J. Lexa, 2001):

A – horizontal scheme, B – geological section
1 – 1' a) – an earlier, destructed rhyolite extrusion, a1) – extrusive breccias,
b) – later extrusion – the Szabóova Skala Cliff with a perlite edge, c) – hyaloclastite breccias, d) – epiclastic volcanic conglomerates, sandstone and redeposited tuffs,
e) – pumice tuff and tuff, f) – sediments of the Žiarska Kotlina Basin.

Žiarska Kotlina Basin). It continues northwards along the eastern edge of the Kremnica Mountains basin.

At the end of the Sarmatian Period, the Žiarska Kotlina Basin was full of lakes and swamps fed by rivers flowing from the north and the east.

Rhyolite volcanism in the Žiarska Kotlina Basin is characterised by a wide range of volcanic forms and a rich lithological composition of the volcanoclastic rocks.

The lava bodies take the form of dykes, extrusive domes, protrusions (tholoids), lava flows, sills, laccolith-type bedded intrusions, and phreatomagmatic cones. The volcanoclastic rocks include ash-pumice tuffs, breccias, redeposited tuffs, and epiclastic volcanic sandstones and conglomerates. The volcanoclastic material washed off from the western, more rapidly subsiding Žiarska Kotlina Basin, was deposited in the form of sedimentary formations.

The edges of the rhyolite bodies such as extrusive domes, heavy lava flows, and tholoids, which came into contact with water from the lakes in the Žiarska Kotlina Basin, turned into hyaloclastite breccias and vitrified, which caused the formation of rhyolite glass – obsidian. At the edges of the extrusive domes, two kinds of material accumulated. Firstly, the fragmented material from the hyaloclastite breccias and secondly, the material from the cooling and disintegrating top layer of the extrusive domes. The latter was released during the formation of these extrusive domes as well as during their explosive destruction. The primary deposits of coarse material were further destructed and relocated, which caused the formation of epiclastic conglomerates, sandstones, and redeposited tuffs. Tuffs and pumice tuffs were deposited further away and overlapped with the sediments of the Žiarska Kotlina Basin.

Photo 2 Steep fluidality textures and vertical hollows created by escaping gases (litophysas) were casued by the rising viscous rhyolite lava – in the direction indicated by the arrow (© P. Pachinger).

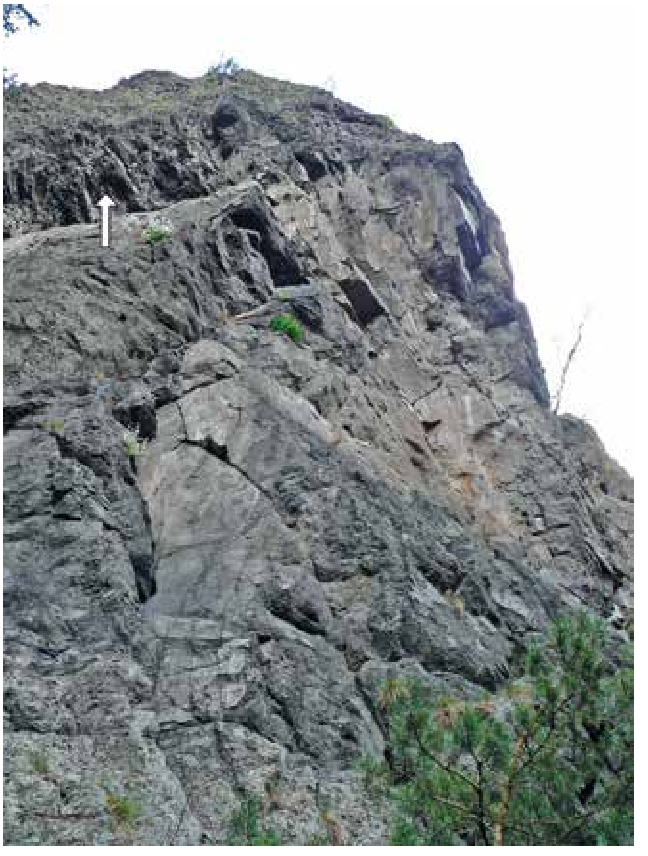


Photo 3 The breccia on the top of the Szabóova Skala Cliff is a remnant of the original brecciated crust, which was uplifted by the rising protrusion (© P. Pachinger).

The Szabóova Skala Cliff is a distinct rock cliff at the southeastern border of the Žiarska Kotlina Basin at the entrance into the Sklené Teplice Valley where the Teplá Stream is located (Photo 1).

The rhyolite body of the Szabóova Skala Cliff represents the final protrusion of heavily viscous lava that penetrated an older, destructed extrusive dome (Fig. 1).

A line of hyaloclastite breccias formed at the outer edge of the old extrusive dome. Blocks of these breccias surfaced in a nearby forest, approximately 150 m north of the Szabóova Skala Cliff.

A line of glassy perlite rhyolite or obsidian (rhyolite glass) can be found at the edge of the Szabóova Skala rhyolite body. The presence of hyaloclastite breccias of the older extrusive dome as well as the glassy edge of the Szabóova Skala body show that these bodies came into contact with water from an assumed lake or stream in the southern part of the Žiarska Kotlina Basin at the time of their formation.

The vertical hollows created by escaping gases (litophysas) and the fluidal texture in the form of lighter stripes alternating with darker stripes are signs that the protruding body was formed by vertically rising lava (Photo 2).

On the top of the cliff, a remnant of an autoclastic breccia, which is a remnant of the brecciated crust of the original body, has been formed by rising viscous lava and preserved (Photo 3).

Photo 4 Perlite rhyolite – obsidian (rhyolite glass) on the right, hyaloclastite-type rhyolite breccia on the left (© P. Pachinger).

Photo 6 A chaotic tuff breccia with a mass pyroclastic flow has been deposited at the bottom of the tuff cone. In the upper level of the exposure, tuffs with the texture of a base surge alternate with pyroclastic surges (© P. Pachinger).

Photo 5 An inscription on the cliff (© P. Pachinger).

Photo 7 A close-up of the chaotic breccia deposited by a pyroclastic flow (© P. Pachinger).

The Szabóova Skala body, similarly to the Štátna Hora laccolith body (Geotope No. 38 Hliník nad Hronom – the Štátna Hora Hill), consists of plagioclase rhyolite and contains plagioclase phenocrysts, biotite, and occasionally amphibole.

In many places, the vitric base matter has frequently recrystallised into spherolites with a radial (spherolitic) structure. Rhyolite glass – obsidian can be seen in Photo 4 on the right, while the texture of the hyaloclastite-type rhyolite breccia is shown on the left.

The Szabóova Skala Cliff is a natural monument named in honor of a great scientist and petrographer J. Szabó, a professor at one of the universities in Budapest. He worked in the Banská Štiavnica area and authored one of the first geological maps of the Banská Štiavnica ore district. He made exceptional contributions for the progress in geology and petrography of volcanic rocks. The cliff bears his name (Photo 5).

East of the Szabóova Skala Cliff, at the edge of Lehôtka pod Brehmi, a part of the phreatopyroclastic cone consisting of rhyolite tuffs alternating with ash-pumice tuffs has been exposed (Photo 6, 7).

Geotope No. 40

The Pustý Hrad Hill

rhyolite extrusion with vitric edges

The Pustý Hrad Hill with the elevation of 692.2, west of Sklené Teplice, is a tholoid-type rhyolite extrusion rock cliff. The area can be accessed via a 1.7 km long footpath starting in the village of Repište, leading northwards up the slight eastern slope of the Vrcháje ridge and ending at the Pustý Hrad hill (elevation 629).

The rhyolite rock cliff is located at the southern edge of the slope (under elevation 629). The rhyolite at the edges of the cliff is vitric and locally permeated with grey-black to black rhyolite glass – obsidians which have disintegrated into angular fragments (Fig. 1, Photo 1).

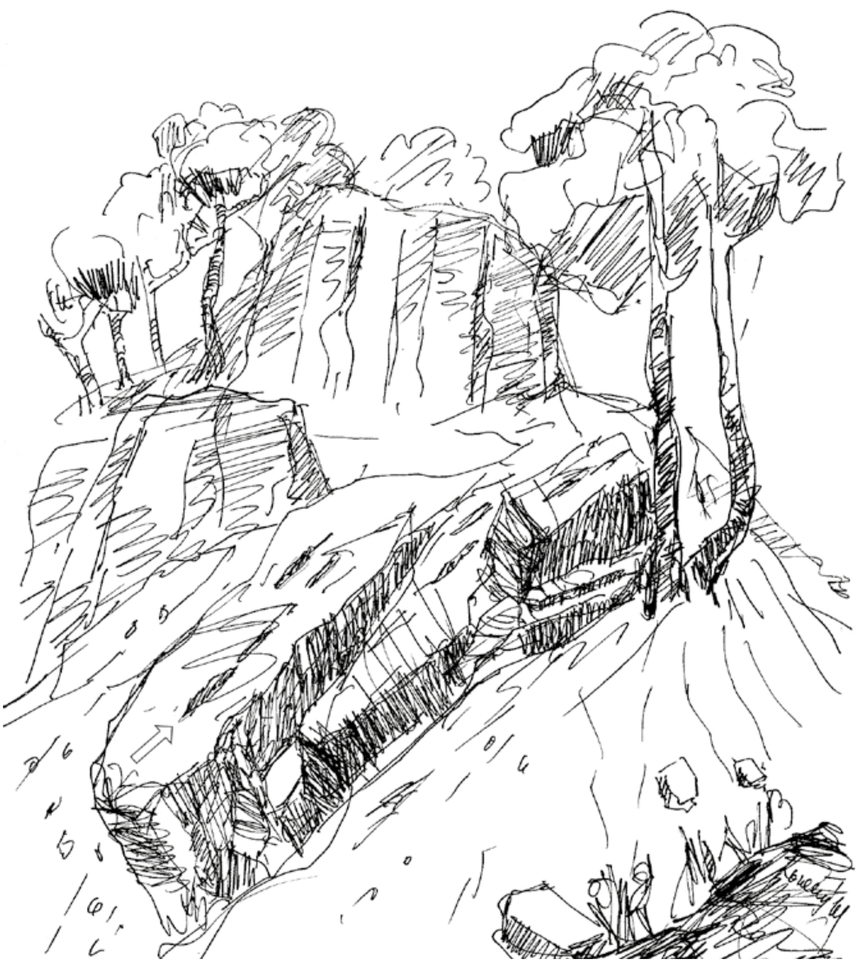


Fig. 1 The Pustý Hrad rock cliff is a protrusion-type (tholoid) rhyolite body. The rhyolite at the edges of the cliff is vitric and locally permeated with rhyolite glass – obsidians. Vertical litophysas (hollows left after the escaping gases; their orientation is indicated by the arrow) show that rhyolite lava rose to the surface steeply, almost vertically (© V. Konečný).

The rhyolite is very foamy, the pores and hollows at the edge of the cliff are filled with secondary minerals. The fluidality planes accentuated by stripes show the directions of lava flow. They are relatively steep, along planes 35 EN/70° towards the north. The hollows created by escaping gases (litophysas) follow the direction of fluidality. Columnar jointing occurs in the top part of the rhyolite body along steep planes (Photo 2).

Off-white rhyolite inclined along the planes 50 EN/75–80° can be found in the central parts of the body. The fluidal planes in the central part of the body are relatively steep and a fan-shaped structure at the edges is indicated, which shows that this pattern is a transitional form between a tholoid and an extrusive dome (Fig. 2). The upper part of the rhyolite body as well as the area around sediments have been removed by denudation.

Rock exposures and blocks of the off-white porous rhyolite can be seen at the top of the body.

Remnants of walls and foundations of the original watchtower can be found at the southern edge of the hill (Fig. 3).

Photo 1 The rock cliffs at the southern border of the rhyolite body. The cliff in the foreground consists of vitric rhyolite permeated with obsidian with texture of steep fluidity (© P. Pachinger).

Photo 2 Columnar jointing in the upper part of the rhyolite body along steep planes (© P. Pachinger).

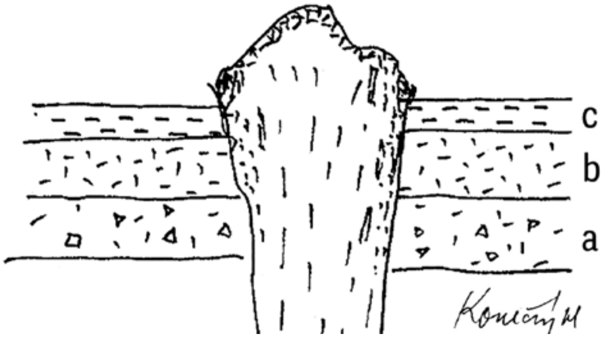


Fig. 2 The Pustý Hrad tholoid-type rhyolite body penetrates volcanoclastic rocks, pumice tuffs (protrusions) and sediments of the Žiarska Kotlina Basin (© V. Konečný):

a) rhyolite volcanoclastic rocks,
b) pumice tuffs,
c) sediments of the Žiarska Kotlina Basin.

Fig. 3 The foundations of the watchtower at the top of the Pustý Hrad elevation (© V. Konečný).

Geotope No. 41

Sklené Teplice – thermal spa

travertine mounds

The Sklené Teplice area represents the best known hydrothermal structure with a natural spring in the Štiavnica Mountains. The temperature of the Ca-Mg-So_4 thermal water is 51–57°C with a mineralisation of 2.5 $g.l^{-1}$. Triassic carbonate rocks (Middle to Late Triassic limestones and dolomites) are the source of thermal springs, which is indicated by their chemical composition as well as the ST-4 and ST-5 hydrogeological boreholes. Thermal water rises to the surface at the intersection between the Sklené Teplice fault (NNE-SSW direction; it delimits the western edge of the Hodruša-Štiavnica Horst) and the cross fault, which delimits the uplifted block of Mesozoic rocks from the west. From the structural point of view, it is an open hydrothermal structure, i.e., firstly, it is a structure with an infiltration area (continuously refilled by infiltration). At the same time, it is a structure with an accumulative-transit area, which determines the basic chemical composition of water, and thirdly, there is a seepage area. This area is drained by natural springs located directly in the town of Sklené Teplice (A. Remšík et al., 2001).

In the vicinity of the springs near the local stream, travertine mounds can be seen. They have been deposited by older, now inactive springs (Photo 1).

The geothermal waters in the central part of the Štiavnica Mountains and their relation to the geological structure of the bedrock.

The thermal water springs located in the middle of the Štiavnica Mountains have been well known for a very long time. Some of them are still used for balneological purposes (Vyhne, Sklené Teplice) Photo 2.

Photo 2 A thermal spring in front of the Park hotel, Sklené Teplice spa (© P. Pachinger).

Photo 1 A travertine mound in the bed of the Teplá stream in Sklené Teplice (© P. Pachinger).

It has been confirmed that geothermal water sources are mainly associated with Mesozoic carbonate rocks, which form the bedrock of the volcanic rocks of the Štiavnica Stratovolcano. In the central part of the Štiavnica Mountains, there are two such units in particular.

The lower unit is represented by the Veľký Bok mountain series, which has been deposited in the bedrock of the Veporic crystalline complex and covers it today. The Veľký Bok mountain series even extends into the whole northeastern part of the Hodruša-Štiavnica Horst (broader surroundings of Sklené Teplice). However, its presence in the middle of the horst is discontinuous and fragmentary, i.e. only some of its parts can be identified.

From the bottom up, the Veľký Bok mountain series looks as follows: a) Early Triassic quartzites; b) Werfenian schists (Early Triassic Period);

c) limestones and dolomites (Middle and Late Triassic Period); d) schists, sandstones, dolomites, evaporites – the Carpathian Keuper (Late Triassic Period); e) pink limestones, radiolarites, quartz and radiolarian limestones (Middle to Late Jurassic Period); d) marly limestones and marls (Late Jurassic – Early Cretaceous Period); g) dark schists, sandy schists, sandstones – Albian (Middle Cretaceous).

The mesozoic rocks of the Veľký Bok mountain series are intensely tectonically deformed (boudinaged), some components were heavily reduced, they gained lenticular nature, and altered to varying degrees. A considerably thick layer of Mesozoic sediments has undergone the processes of tectonic deformation, metamorphosis, and denudation. This had happened before the thrust of the higher tectonic Hronicum unit represented by the Šturec Nappe took place.

The higher unit – the Šturec Nappe – rises to the surface between Hodruša and the middle part of the Richňava Valley, but also in the area of Suchá Voznica and the Zlatno Valley. Its bedrock consists of rocks of the Veľký Bok Mountan series.

The rock complex consists of (bottom up):

a) the Nižná Boca Formation of the Late Carboniferous Period in the form of dark schists, sandstones, and conglomerates;
b) the Malužiná Formation of the Permian Period in the form of variegated sandstones, schists, and conglomerates with paleobasalt;
c) the Benkovo Formation of the Early Triassic Period in the form of quartzites with interbeds of sandy schists;
d) limestones and dolomites of the Middle to Late Triassic Period;
e) Lunzian beds in the form of sandy schists and sandstones (Late Triassic period)

Geothermal water sources are mainly associated with carbonate rocks. Thick layers of carbonate rocks can mostly be found at the edges of the Hodruša-Štiavnica Horst, especially in its northern or north-eastern parts.

The faults and fault zones through which thermal waters rise to the surface are another important factor. The most significant structure is the fault system at the western edge of the Hodruša-Štiavnica Horst. Along this edge, the most intense uplifts occurred during the formation of the horst itself. During the Sarmatian Period, rhyolite magmas rose to the surface through the fault system referred to as the Vyhne-Ihráč volcano-tectonic zone (V. Konečný et al., 1998 a). The local thermal springs are related to both this fault system and the subparallel faults. From south to north, these include:

a) the Lukavica area, where the Ca-Mg-HCO_3-SO_4 thermal water with a temperature of 35°C has been confirmed by the LKC-4 borehole;
b) the Zlatno Valley, where the Ca-Mg-HCO_3-SO_4 thermal water with a temperature of 35°C has been confirmed by the R-3 borehole;
c) in the adit in the Vyhne area, Ca-Mg-HCO_3-SO_4 thermal water with a temperature of 33-36°C has been confirmed by a borehole;
d) in the area of Sklené Teplice, thermal water rises to the surface and has been confirmed by boreholes with a temperature of 51-57°C.

Geotope No. 42

Vyhne – water paradise

travertine mound

The local thermal water (Ca-Mg-HCO_3-SO_4) with a surface temperature of 33-36°C collects in an adit and a borehole. Its mineralisation is about 1.1g.l-1. It comes from the carbonate rocks pertaining to the Hronicum (the Šturec Nappe, which is a higher tectonic unit) or to put it simply, the overlying rock of the Veľký Bok mountain series (A. Remšík et al., 2001). The genetic link to this Mesozoic unit lies in its chemical composition, specifically, the significantly lower sulphate content (the absence of anhydrite and gypsum is typical of the Šturec Nappe).

The rise of this geothermal water is linked to the Vyhne-Ihráč zone fault system, which separates the Hodruša-Štiavnica Horst from the west (also referred to as the Považie fault in this part of the area). This fault system has a large uplift amplitude, which represents the boundary between a Paleozoic-Mesozoic rock block and neovolcanic rocks (which rise west of the fault). The fault system continues southwards to Uhliská.

Further southwards, the presence of geothermal water in the fault zone and accompanying faults has been confirmed by boreholes in Lukavica and Zlatno.

Photo 1 The travertine mound left after an extinct thermal spring (© P. Pachinger).

In the Vyhne area, it currently takes the form of a hydrothermal structure with an infiltration and a transit-accumulation area, but without springs (A. Remšík et al., 2001). No natural geothermal springs have been found in this area, but they probably existed in the past, as indicated by the travertine mound at the entrance to the Klokočský Potok Valley at the southern edge of Vyhne (Photo 1, 2).

The local source of geothermal water was discovered when the adit was dug, later a borehole helped bring it to the surface and an outdoor swimming pool was built. The medical spa built here was destroyed in a fire at the end of WW2.

Photo 2 The travertine mound is also referred to as the "elephant head" (© P. Pachinger).

7. Tourism Territorial Unit Pukanec

Photo 1 The state road trench between Pukanec and Brehy exposes the Tatiar intrusive complex, i.e., quartz-diorite porphyries and rhyolitic porphyries which penetrate rocks of the bottom stratovolcanic structure in the form of dykes (© P. Pachinger).

Geotope No. 43

Tatiar – the Obecný Potok Stream

dykes of quartz-diorite porphyry of the Tatiar intrusive complex

The Tatiar intrusive complex (named after the feature at elevation 734 – Tatiar) consists of a diorite dyke swarm and quartz-diorite to granodiorite porphyries in the Pukanec Horst area (west of the Štiavnica caldera). The dyke swarm is about 2–3 km wide and 7 km long, oriented in the north-south direction. It penetrates through the complexes of the bottom stratovolcanic structure in the area between Rudno nad Hronom and Pukanec. The northern part of the dyke system has been cut off by a caldera fault.

In the denudation cut, the intrusive complex takes the form of a dyke swarm. At lower levels, it transitions into massive stock bodies (as confirmed by boreholes). At the border between the bottom of the stratovolcanic structure and the bedrock, fragments to blocks of hornfelised and skarnised bedrock sediments embedded in intrusive bodies are frequently present.

The dykes transition into a massive granodiorite porphyry to porphyric granodiorite at the bottom levels. The intrusive complex is linked to the Cu-porphyry-type mineralisation.

The northern part of the Tatiar intrusive complex is exposed by a road trench north of Tatiar (elevation 734), south of Brehy (Photo 1).

The intrusive complex in this area includes dykes *of coarse-grained porphyric quartz-monzodioritic porphyries* with phenocrysts of plagioclase (1–4 mm), amphibole (up to 4–6 mm), and occasionally biotite and quartz. The base matter is microhypidiomorphically granular and consists of plagioclase, potassium feldspar, and quartz grains.

Photo 2 The contact zone of rocks pertaining to the bottom stratovolcanic structure – to the left of the hammer; with coarse-grained porphyric quartz-diorite porphyry – to the right of the hammer (© P. Pachinger).

Photo 3 A close-up of the contact zone between the bottom of the stratovolcanic structure and the quartz-diorite porphyry. The bottom structure is intensely crushed, the contact zone is smoothed – to the right of the hammer (© P. Pachinger).

Dykes of *quartz-diorite porphyry* with more close-grained base matter are also present.

The dykes oriented in the north–south direction penetrate through the bottom stratovolcanic structure, which consists of pyroxenic and amphibole-pyroxene andesites in the form of lava flows (Photo 2, 3).

Photo 4 On the right side of the state road trench, a dyke intrusion of coarse-grained porphyric quartz-diorite porphyry (upper left), which penetrates through the bottom stratovolcanic structure (lower right) has been exposed. Their contact zone has been penetrated by a rhyolite porphyry dyke – see the direction indicated by the arrow (© P. Pachinger).

Rocks of the bottom structure are intensively propylitised (hydrothermally altered), with a dark green colour, which they gained from a secondary mineral – chlorite. The bottom structure in this area is heavily tectonically disrupted, penetrated by numerous zones of tectonic crushing. Andesite gains a light green hue due to weathering. Andesites are mostly fine-grained porphyric.

Dyke bodies consisting of dark green coarse-grained porphyric quartz-diorite porphyries with distinct plagioclase (not exceeding 6 mm) and amphibole (not exceeding 5 mm) phenocrysts penetrate the bottom structure (Photo 4.). Besides these bodies, close-grained quartz-diorite porphyry is also present. Zones of crushing penetrate the bottom structure in the direction 160 SE, inclined 60° towards the SE.

Later intrusions take the form of rhyolite to rhyodacite porphyry dykes, which also occur in zones of tectonic faulting oriented in the N-S direction. Rhyolite porphyries are light grey to greenish, the phenocrysts are composed of plagioclase, fine-grained biotite and amphibole, and less frequently quartz.

Another apex of a rhyodacite porphyry dyke is located in the upper part of the trench of the state road leading to Pukanec. The dyke penetrates through the contact zone between the bottom structure and the quartz-diorite porphyry (Photo 5).

Photo 5 Rhyodacite porphyry dyke (indicated by the arrow) penetrates through the contact zone between the quartz-diorite porphyry dyke – on the left – and the bottom of the stratovolcanic structure – to the right of the rhyodacite porphyry dyke (© P. Pachinger).

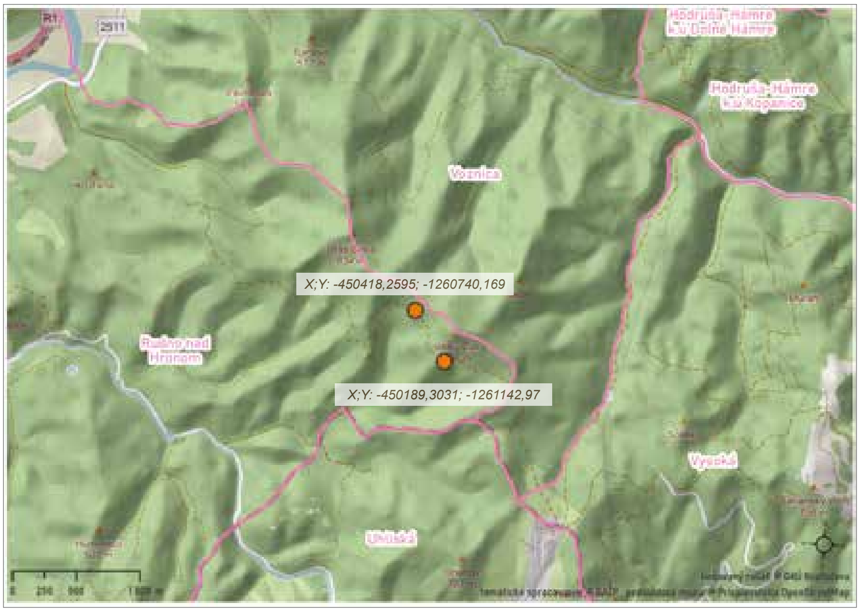
Geotope No. 44

Veľký Žiar

welded ash-pumice tuffs – ignimbrites of the Drastvica Formation

In the Sarmatian period, massive eruptions of ash, pumice, and volcanic gases immediately followed the lava effusions from the Sitno volcano, which filled the western and southern parts of the caldera and rolled further down through the paleodolines on the stratovolcanic slope. During repeated Plinian eruptions, huge masses of ash-pumice material were spewed out in the form of eruption columns rising to the upper levels of the atmosphere, where they spread laterally into volcanic ash clouds. Subsequently, countless collapses of the eruption columns formed hot, turbulent pyroclastic flows, which rolled down the volcanic slope and transported a hot ash-pumice mixture of disintegrated magma through the rapidly expanding volcanic gases (Fig. 1).

The western part of the caldera (subsiding again) was filled up with pyroclastic flows, and in rapid succession, ash-pumice flows. After reaching the caldera fault, these flows continued to roll along the western and southwestern slopes of the stratovolcano through deep trenches of the paleodolines all the way to the stratovolcano's foot.



The ash-pumice flows in the west-facing paleodoline reached a distance of more than 25 km (the Obyce area, see Geotope No. 50 Obyce). The ash-pumice flows moving through the SW to SSW-oriented paleodolines are indicated by ignimbrite remnants in the area of elevation 437, south of Brehy – on the western slope of the Priesil Hill – on the slopes under Stará Hora (elevation 471). Another paleodoline, filled with ignimbrites and pumice flows, extended into the Čajkov area. These ash-pumice tuffs stopped at the coastline of the Sarmatian sea, where the material was deposited. Due to rapid cooling, welding of the pyroclastic material

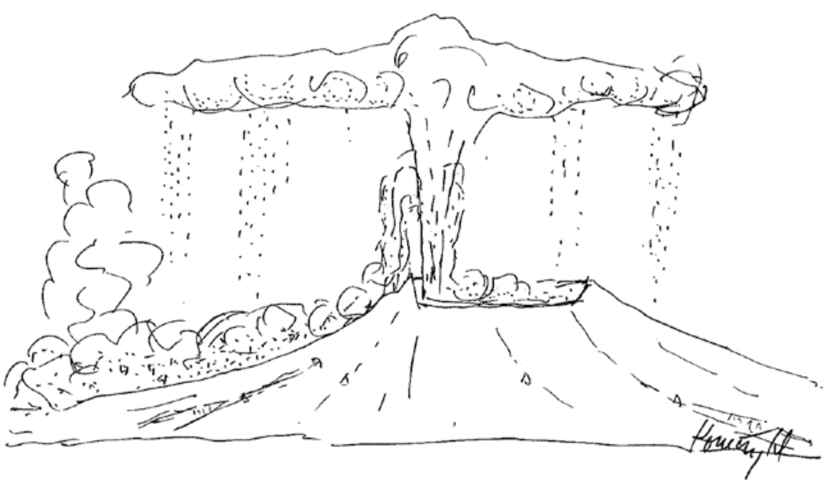


Fig. 1 The scheme of the ash-pumice flow formation caused by the collapsing Plinian eruption column. A volcanic ash cloud was the source of airfall tuffs (© V. Konečný).

Fig. 3 The mural to coarsely-columnar jointing of ignimbrite on the southern slope of the Žiar elevation (© V. Konečný).

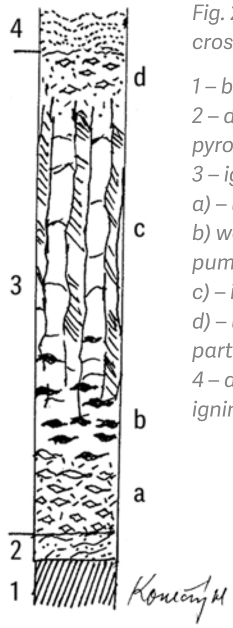


Fig. 2 The scheme of the ignimbrite body's cross-section (© V. Konečný):

1 – bedrock of the ignimbrite body,
2 – dust and ash material deposited by the pyroclastic surge (base surge),
3 – ignimbrite body:
a) – unwelded ash-pumice tuff,
b) welded tuff with fiamme textures (vitrified pumices),
c) – ignimbrite with columnar jointing,
d) – unwelded ash-pumice tuff in the upper part of the ignimbrite body,
4 – airfall tuffs in the overlying rock of the ignimbrite body.

did not occur (see the unwelded ash-pumice tuffs of the Geotope No. 100 Čajkov). The ash-pumice material carried by the pyroclastic flows, still hot after being deposited, underwent welding due to the residual magmatic temperature, which resulted in the formation of welded tuffs – ignimbrites.

During the welding of the ash-pumice material, deformation and vitrification of pumice fragments occurred (due to the weight of the overlying mass). The fragments gained lenticular structure with a subparallel orientation and are referred to as "fiamme" (Italian for small flames). Similarly to the cooling and crystallisation of lava flows, when the pyroclastic mass cools down and releases gases in the form of fumaroles, its volume reduces and coarsely-columnar jointing occurs.

The unit of ash-pumice material transported and deposited by a single pyroclastic flow (several metres to a few tens of metres thick) is called *a flow unit*. The vertical cross-section shows distinctive changes to the lithological composition (Fig. 2).

In the immediate bedrock (1) of the ash-pumice flow, there is a thin layer of dust and ash material (2) with wavy texture, deposited by a base surge that was moving very quickly in front of a pyroclastic flow and carrying the dust and ash material (this layer is not always present).

Photo 1 The coarsely-columnar to mural jointing of ignimbrites in the rock cliffs on the southern slope of the Žiar elevation (© P. Pachinger).

In the bottom part of the unit deposited by the ash-pumice flow, there is unwelded ash and pumice (3a), which is the result of cooling upon the contact with the bedrock. Above that is a gradual transition into welded ash-pumice tuff–ignimbrite with distinctive lenticular fiamme (3b) with a subhorizontal orientation. In the middle to upper parts, coarsely-columnar to columnar jointing with vertical orientation has formed (3c). The upper part of the ignimbrite body consists of mildly welded to unwelded ash-pumice tuff (3d). Airfall tuffs were deposited on the surface of the ignimbrite body's overlying rock. The layers follow the bedrock's topographic relief (4).

Fig. 4 Ignimbrite rock cliffs on the southern slope of the Žiar elevation with coarsely-columnar jointing (© V. Konečný).

If numerous hot pyroclastic flows (flow units) follow in a rapid succession, the welding process affects the whole mass of the deposited pyroclastic material. The differences between the lithological compositions become less distinct with each consecutive flow and this mass of welded tuff is referred to as the cooling unit.

During the Plinian eruptions, which created the ash-pumice flows, a major ignimbrite complex was deposited in the western part of the caldera. The ignimbrite remnants deposited in the overlying rock of the lava flows pertaining to the Sitno Complex in the Drastavica area (e. 834) – Veľký Žiar (e. 852) – Sedlo (e. 685) – Vavrišová (e. 583) and further southwards, in the area of Kojatina (e. 509), can be 250 to 300 m thick. Behind the caldera fault, the massive ignimbrite complex west of the Hron River (bounded by the rising Nová Baňa rhyolite body from the west) has been partially deposited on the rocks of the bottom stratovolcanic structure (southern part) as well as on the Sitno Complex.

Ignimbrite rock cliffs with a distinct coarsely-columnar to mural jointing along subvertical joint planes protrude from the southern slope of elevation 834 – Žiar (Fig. 3, 4).

The indicated coarsely-mural jointing transverse to the columnar jointing accentuated by weathering is less pronounced (Fig. 4, Photo 1).

A small number of exposed unwelded ash-pumice tuffs in the bedrock of ignimbrites can be seen in the forest road trench on the southern slope of the Žiar elevation (Photo 2, 3).

The welded ash-pumice tuffs called ignimbrites are dark grey to grey-black with brown hues caused by weathering. The vitric lenticular formations called "fiamme" with a subparallel orientation can be observed in the break. The ash–crystalline matrix is heavily welded, the crystals of plagioclase, amphibole and biotite are distinguishable. Fragments of older andesites occur rarely.

Microscopic examination indicates that before vitrification occurred, the molten matrix flowed around the crystal and andesite fragments. The fragments of pumice were deformed into a lenticular shape.

Petrographically, the rock corresponds with the biotite-amphibole-pyroxene andesite.

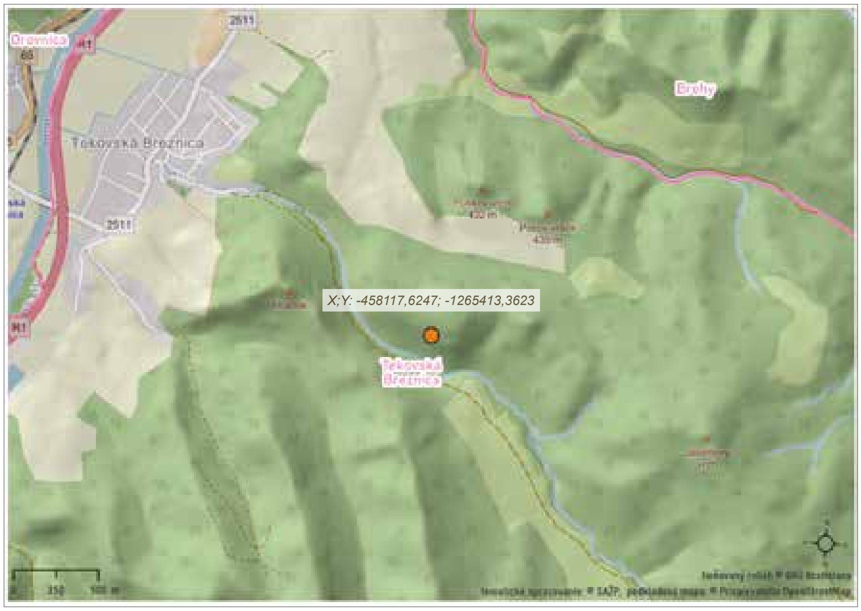
Photo 2 The unwelded ash-pumice tuffs in the bedrock of the ignimbrites on the southern slope of the Žiar elevation (© P. Pachinger).

Photo 3 A close-up of the unwelded ash-pumice tuffs. The light-coloured pumice fragments have been deposited in a more fine-grained ash-pumice matrix (© P. Pachinger).

Geotope No. 45

The Pútikov Vŕšok Volcano

basalt scoria cone



The calc-alkaline andesite volcanism was followed by volcanism of alkali basalts in the area of Central Slovakian neovolcanic rocks. The relicts of this volcanism, which was active from the Pannonian to the Pontian Periods (6–8 million years ago) include the Dobrá Niva – Ostrá Lúka basalt nappe (SSW of Zvolen), a lava flow relict near Devičie (SE of Krupina), and the Kalvária lava neck near Banská Štiavnica as well as the railway trench near Kysihýbeľ (east of Banská Štiavnica).

During the Quaternary, after a long time gap, the Pútikov Vŕšok scoria cone formed south of Nová Baňa. The scoria cone is located south-east of Tekovská Breznica, in the area of a ridge (elevation 477) above the Chválenská Dolina Valley, south of a local hill (elevation 432). The rather small volcano was formed during the Strombolian and Himalayan activity as a result of the eruptions of basalt debris, bombs, and lapilli tuffs. During the later stages of the volcanic activity, a basalt flow formed, moving from the scoria cone southwards and obstructing the Starý Hron River (Fig. 1).

The cone's structure and the lithological nature of the volcanic ejecta can be observed in the exposures on the western slope of the scoria cone.

Photo 1 The rock cliff on the western slope of the Pútikov Vŕšok scoria cone consists of sintered basalt debris – agglutinates with basalt bombs – to the right from the hammer (© P. Pachinger).

The cone consists of basalt debris and bombs alternating with the interbeds to beds of lapilli tuffs (2–3

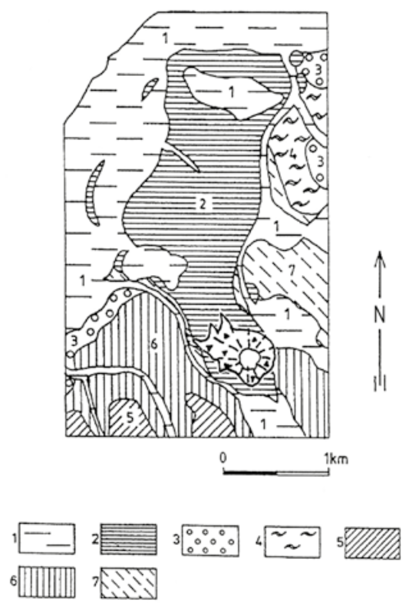


Fig. 1 The scheme of the geological structure of the area around the Putikov Vŕšok Volcano (L. Šimon, 2000):

1 – unsegmented Quaternary sediments, 2 – the Pútikov Vŕšok Volcano: a) scoria cone, b) lava flows, 3 – Pannonian to Pontian sediments, 4 – pyroclastic rocks of the Drastvica Formation, 5 – lava flows of the Sitno Complex, 6 – lava flows and epiclastic rocks of the bottom structure of the Štiavnica stratovolcano, 7 – unsegmented lava flows of the bottom structure of the Štiavnica stratovolcano.

Photo 2 A close-up of the internal structure of a basalt bomb (above the hammer). Radial jointing is indicated at the edges (© P. Pachinger).

Photo 4 A close-up of the scoria cone's structure. The debris-lapilli material inclined in the same direction as the primary slope has partially sintered. The basalt bombs accumulated at the bottom level of the cone (© P. Pachinger).

cm large fragments of basalt lava), deposited at the inclinations of 25–30° in the direction away from the crater (periclinal position) Photo 1, 2, 4.

The basalt debris, spewed out as fragments of burning lava, often sintered in the form of agglutinates after falling onto the volcanic slope. Ľ. Šimon and R. Halouzka

Photo 3 In the upper part of the scoria cone, there is a cave (tunnel) in the sintered agglomerative pyroclastic rocks. There is a light-coloured film of sublimates of fumarolic activity on the walls of the tunnel (© P. Pachinger).

(1996) suggest calling these fragments of fluidal lava, which have solidified into irregular forms, “spatters”.

On the volcanic slope, basalt bombs of various dimensions (from several cm to 0.5 m) and forms (spherical, cylindrical, spindle, pear-shaped, unipolar and bipolar bombs) can be observed. The basalt lava fragments, which were still fluidal enough to deform into the characteristic cow dung-like formations upon falling onto the ground, are also common. They are referred to as the cow dung-type forms.

Photo 5 The interior of this “tunnel” consists of sintered pyroclastic products (© P. Pachinger).

Large basalt blocks (up to 1.2 m in size) are often present within the deposits of debris, bombs, and lapilli tuffs sintered into agglutinates. They are parts of the feeder system bodies that were destroyed and spewed out during eruptions.

The volcanic bombs of spherical to irregularly elliptical shapes consisting of heavily foamy basalt lava have disintegrated along radial cracks (Photo 2). At the higher level of the cone slope, a cave (tunnel) has formed in the pyroclastic products (Photo 3, 5).

The Pútikov Vŕšok scoria cone is the youngest volcano in Slovakia. Its age is estimated at 140–130 thousand years. A considerably larger area of basalt volcanism can be found in Southern Slovakia (around Fiľakovo and the Cerová Vrchovina Highlands).

Geotope No. 46

Brehy

basalt flows of the Pútikov Vŕšok Volcano

During the later stages of the Pútikov Vŕšok scoria cone’s formation, the effusions of lava flows moved northwards from the edge of the volcano into the valley of the Starý Hron river and dammed its flow. The thickness and length of these lava flows is variable. The lava flows (up to several tens of metres long) on the cone’s slope and foot are strongly brecciated. With increasing distance from the cone in the direction of the original slope, their thickness increases to up to 15 m, reaching the maximum length of 3.2 km.

In the walls of an occasionally used quarry, on a slope above the Hron River (west of Brehy), a succession of several lava flows have been exposed (Fig. 1).

At the bottom level of the left (northern) part of the quarry wall (A, Photo 1), there is a lava flow with subvertical columnar jointing (a). In its

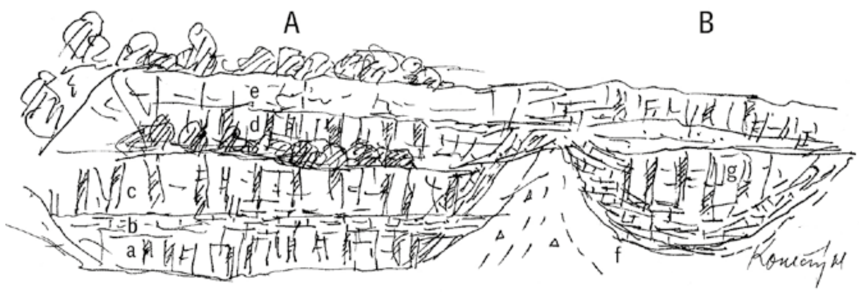


Fig. 1 The scheme of the left part of the basalt quarry near Brehy (© V. Konečný):

A – the left part of the quarry: a) the bottom lava flow with columnar jointing, b) mural jointing of the central lava flow, c) coarsely-columnar jointing of the central lava flow, d) coarsely-columnar jointing of the upper lava flow, e) irregular blocky jointing of the top lava flow.

Mural jointing at the right edge of the lava flow is inclined in the same direction as the bedrock relief:

B – the lava flow in the right part of the quarry wall fills the local valley: f) the mural jointing in the bottom part follows the morphology of the valley, g) in the central and upper part, there is a transition into coarsely-columnar jointing with subvertical orientation.

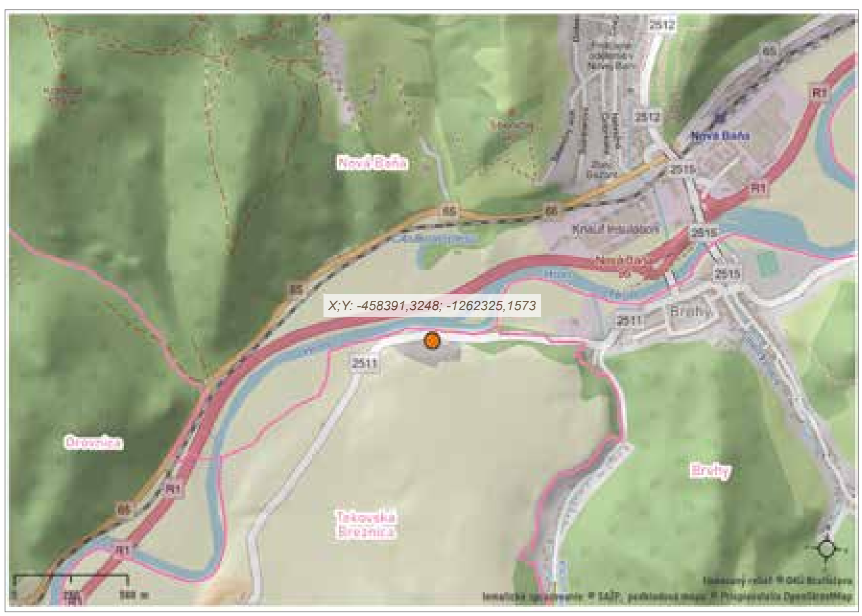


Photo 1 An overview of the left part of the basalt quarry (© P. Pachinger).

Photo 2 The central part of the quarry wall. The lava flow fills the trough-shaped depression (© P. Pachinger).

overlying rock, a lava flow with subhorizontal mural jointing along the lamination surfaces can be observed (b). Above, it is replaced by coarsely-columnar jointing (c), which is followed by a lava flow with columnar jointing at the upper level (d), and irregularly blocky jointing in the top part (the upper bench) of the quarry wall (e). At the right edge, the lava flow was obstructed by a local elevation consis-

Photo 3 A close-up of the edge of the central lava flow that fills the local depression. The mural jointing at the left edge follows the inclination of the local depression. At the upper level of the central part, a transition into columnar jointing with subvertical orientation occurred (© P. Pachinger).

ting of breccias that separate it from the lava flow in the central part.

In the central part of the quarry wall (B, Photo 2, 3), the lava flow has been deposited in a trough-shaped depression. The morphology of this depression is accentuated by mural jointing in the bottom part of the lava flow, which is subhorizontal in its central part (f), and gets gradually steeper to subvertical at the edges. Above the mural jointing, a transition into coarsely-columnar jointing can be observed (g, Photo 4).

There are several lava flows with irregular blocky jointing in the right (southern) part of the quarry. In the top part of the lava flows, a transition into a zone with foamy structure and brecciation with irregular or scoria surface of "Aa-type lavas" can be observed. The lava flow has been deposited on the terrace gravel of the Hron River (the 3rd middle terrace), which correspond with the Late Riss Period. In the overlying rock, a loess loam corresponding to the Würm Period has been deposited. The position of the lava flow indicates that the volcanic activity in the Pútikov Vŕšok area dates back to the end of the glacial period – from the Late Riss Period until the Riss/Würm interglacial period, which corresponds with the geological estimation of 140 to 130 thousand years (L. Šimon, R. Halouzka, 1996).

Photo 4 A close-up of the lava flow jointing transition from mural to coarsely-columnar (© P. Pachinger).

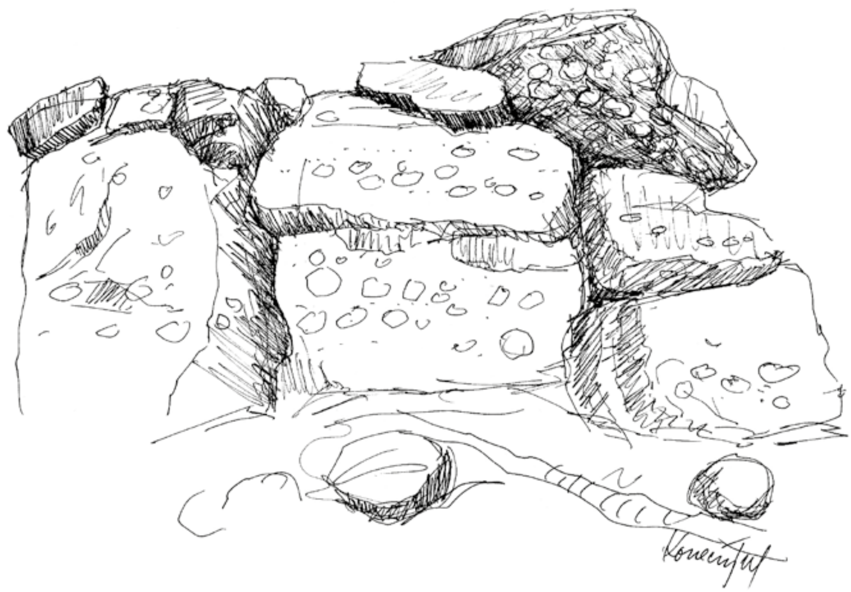


Fig. 1 Coarse conglomerates with ferruginous putty at the top of Krahulčie (elevation 437) south of Nová Baňa (© V. Konečný).

Geotope No. 47

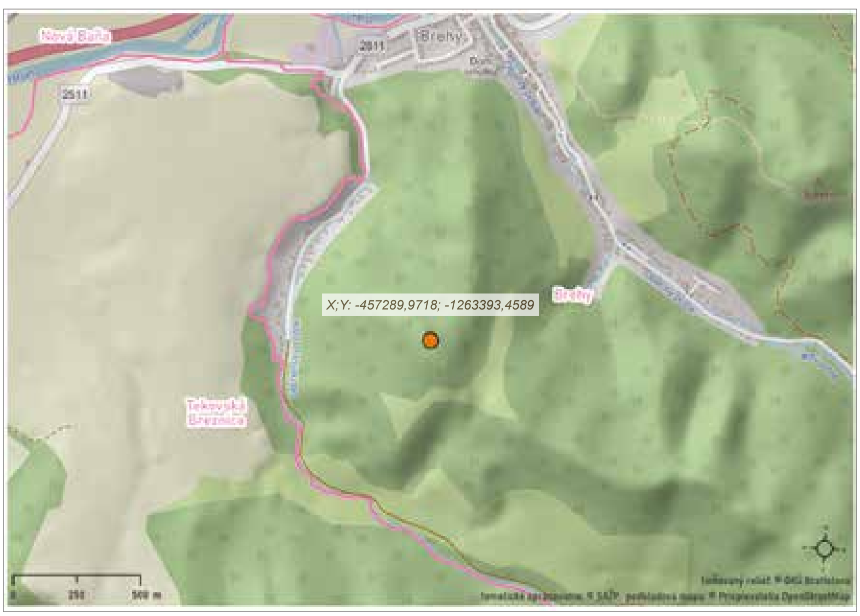
Brehy – Krahulčie

conglomerates with ferruginous cement

South of Nová Baňa, near Brehy (south of the Hron River), rock cliffs consisting of conglomerates with ferruginous cement occur in the area of the Krahulčie Hill (elevation 437) (Fig. 1).

The well to perfectly rounded pebbles, boulders (5–35 cm) or blocks (up to 0.5 m) consist of rhyolites, which are to varying degrees argillitised and silicified. Ignimbrite boulders of the Drastvica Formation and andesite pebbles occur less frequently.

The matrix consists of unsorted, less rounded, coarsely-sandy to finely-fragmented material strongly rein-



forced with ferruginous (limonite) cement (which is why this conglomerate has not been affected by denudation). Locally, the material is coarsely sorted with an indicated subhorizontal position (Photo 1, 2, 3).

The rhyolitic material of conglomerates, affected by hydrothermal alterations, indicates that it originated from the Nová Baňa rhyolite body, an area affected by hydrothermal alterations around the apex of ore veins of the Nová Baňa Ore Field.

A block slope consisting of these altered rocks is located on a crest west of Kohútovo, near a forest path leading to the Štamproch area.

Photo 1 A rock exposure of coarse conglomerates with ferruginous cement in the Krahulčie Hill area (© P. Pachinger).

Photo 2 The close-up shows light-coloured rhyolite pebbles, often with foamy structure (to the left of the hammer). The less frequently occurring dark fragments consist of andesite (© P. Pachinger).

Photo 3 The bottom part of another close-up shows a coarse to blocky conglomerate with dominant rhyolite blocks, occasionally with andesite pebbles (dark fragments at the left edge). The upper part shows a finer, sorted conglomerate – a gravel terrace. The dark hollows are remnants of pebbles that have fallen out can be seen at the tip of the hammer (© P. Pachinger).

The conglomerates deposited on the Krahulčie Hill, 437 m above the sea level, consist of river sediments from the Starý Hron terrace. These sediments most likely formed during the Pannonian Period (8–9 mil. years ago), when the Hron River was making its way through the barrier represented by the Nová Baňa rhyolite body, and deposited boulders and blocks onto its bed. The ferriferous cement indicates the presence of thermal water springs with high Fe hydroxide content in the surrounding area, which likely indicates subsiding hydrothermal activity linked to the formation of ore veins.

The block conglomerates on the slope east of the Hron River, on a crest 400 m above the sea level (south of Tekovská Breznica), are in a similar position. Similarly, on the slope on the opposite side of the Hron River, in the Klíč Hill area (e. 430) near Hronský Beňadik, 3–4 m large rhyolite blocks and coarsely-blocky conglomerates with well to perfectly rounded rhyolite and andesite material can be found.

Coarse to blocky conglomerates deposited in the hills near the Hron River,

Photo 4 One of the many meanders of the River Hron near Nová Baňa. The Krahulčie Hill with the deposits of coarse conglomerates containing ferruginous cement, representing the original level of the terrace sediments of the Hron River, can be seen in the background (© P. Pachinger).

400–430 m above the sea level, are the earliest river deposits, which was still very young during the period when it was making its way southwards through the volcanic masses, carrying massive rock blocks. Today, the Hron River is a calm, mature river that does not rush through the sinuous valley, but rather carves countless meanders into its alluvium, as if it wanted to slow down before meeting the sea, which will inevitably swallow its waters forever (Photo 4).

8. Tourism Territorial Unit Nová Baňa

Fig. 1 The Stará Huta waterfall was formed by the stream trench in the pyroxene andesite lava flow at the bottom stratovolcanic structure. The andesite is characterised by mural jointing alongside subhorizontal lamination planes (© V. Konečný).

Geotope No. 48

The Stará Huta Waterfall

paleodoline fill in Nová Baňa – Stará Huta area-wise, pyroxene andesite of the bottom structure

In Nová Baňa – Stará Huta area, a deep erosion furrow of the Stará Huta Stream Valley penetrated the rocks of the bottom stratovolcanic structure of the Štiavnica Stratovolcano. In the overlying rock, the furrow exposed the lithological structure of the paleodoline fill, which consisted of the products of biotite-amphibole-andesite volcanism of the Studenec Formation (from the caldera formation period) at the bottom. In the form of redeposited pumice tuffs and sandstones deposited at the fill base immediately on the rocks of the bottom structure. Above in the paleodoline fill, there ensue coarse up to block epiclastic volcanic breccias. Near Stará Huta, coarse up to block conglomerates and lahar breccias with biotite-amphibole-andesite material are deposited at the paleodoline base. In this period, the fill used to extend to about 500 m in thickness (southwards below elevation 779 Sedlová Skala).

In the following period (Early Sarmatian), the erosion furrow was refilled. At the bottom, it was filled with lava flows of the Sitno Complex. In the overlying rock of the Sitno Complex lava flows (in the westward course of the paleodoline), the products of the explosive activity in the form of ash-pumice welded tuffs – ignimbrites of the Drastvica Formation are located, followed by lava flows and the volcanoclastic rocks of *the Priesil Formation* above, and by lava flows of the Inovec Formation at the top, which completed the fill of the paleodoline.

From Stará Huta to the Stará Huta Waterfall, there is an ascent of about 150 m up the slope along the forest trail into the side valley. The waterfall with a height of 6 to 8 m (Fig. 1, Photo 1) was formed by a stream trench in the pyroxene andesite lava flow.

Andesite is grey-black, fine-grained porphyric, the phenocrysts consist of plagioclase up to 1–2 mm, pyroxenes (augite, hypersthene up to 1–2 mm). The mural jointing of the lamination type with the subhorizontal course indicates a relatively flat relief of the bedrock, along which the lava flow moved.

Photo 1 The Stará Huta Waterfall is a pleasant place to relax in a romantic setting (© P. Pachinger).

Geotope No. 49

The Vojšín Hill

amphibole-pyroxene-andesite (± biotite) lava flow of the Sitno Complex

The caldera formation in the top-level area of a large andesite stratovolcano of the Baden period did not mark the end the volcanic activity, it only completed one volcanic-magmatic cycle. In the Sarmatian, the conditions for the initiation of the volcanic activity were fulfilled as magma from the depths re-ascended into the subsurface magma chamber.

During the explosive-effusive activity, a series of smaller satellite volcanoes emerged in the caldera area and on the stratovolcanic slope. One of them was *the Sitno Volcano* situated in the south-eastern part of the caldera.

The explosive eruptions of ash-pumice tuffs, deposited in the southern area of the caldera and on the stratovolcanic slope (the Biely Kameň Formation), were followed by lava effusions. In southern to western area, the sediments of ash-pumice tuffs covered the lava flows of amphibole-pyroxene andesites. After crossing the caldera fault, the lava flows continued moving along the stratovolcanic slope down to its foot, along the trenches of deep paleodolines. The lava flows headed towards the south-eastern stratovolcanic slope (lava flow Sitno – Sitience – Biely Kameň – Hlava) and reached distances of up to 17 km.

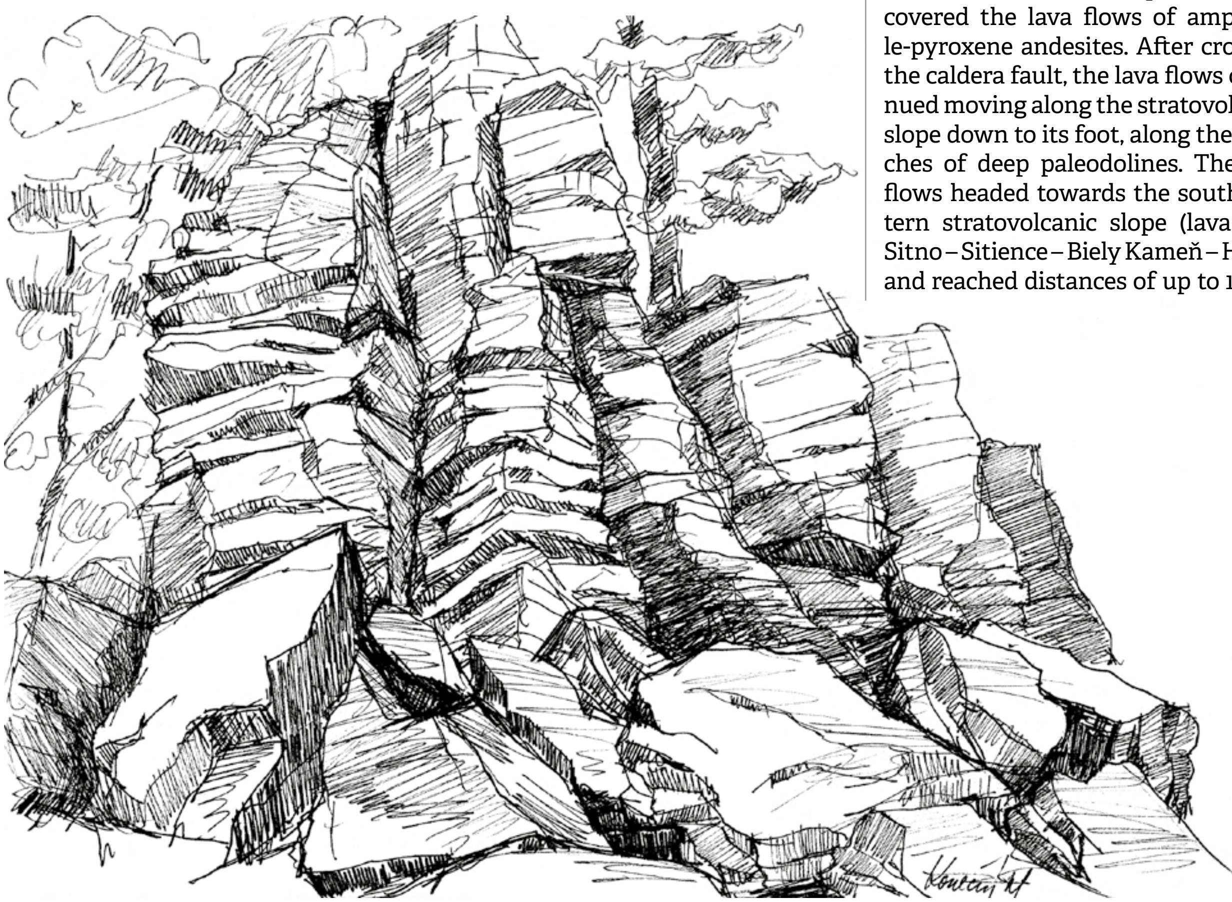


Fig. 1 The andesite rock cliff of the Sitno Complex at the southern slope (elevation 819 the Vojšín Hill). Andesite is characterised by a distinctive mural jointing alongside lamination planes inclined northwards. The coarsely-columnar disintegration is indicated alongside subvertical planes (© V. Konečný).

Photo 1 The mural jointing of the andesite rock cliff (under elevation 819 the Vojšín Hill, © P. Pachinger).

A particularly large complex of brecciated and heavy-porous lava flows was deposited in the western part of the caldera. After crossing the caldera fault within the wide paleodoline, the lava flows continued moving towards west to north-west (Kostivrch area) until they reached the foot of the stratovolcano (north-east of Veľká Lehota). In this area, they created a huge complex of lava flows inclined to the north-west (elevations 754, the Bujakov Hill and 819, the Vojšin Hill). On the north-western side, the lava complex is tectonically limited. In relation to the rocks of the pre-volcanic bedrock, the volcanic complex is subsided alongside the fault stretching from NE to SW. In the bedrock of some lava flows within the fill of the paleodolines on the south-western slope of the stratovolcano, the positions of ash-pumice tuffs, which were deposited there during the explosive eruptions immediately followed by the effusions of lava flows (northern edges of the lava complex north of Kostivrch), were preserved.

The products of the following eruptions of ash-pumice flows of the Drastvica Formation were deposited in the overlying rock of the lava flows around Veľká Lehota, and they were subsequently welded into the form of ignimbrites.

The andesite rock cliffs of the Sitno Complex protude from the southern slope (under elevation 819 the Vojšín Hill, Fig. 1, Photo 1).

The subvertical planes indicate coarsely-columnar disintegration of andesite. Mural jointing alongside lamination planes (parallel to the surface, along which the lava flow moved), inclining 20–25° northwards, is more distinctive.

Andesite is medium to coarse-grained porphyric, light grey, phenocrysts consist of plagioclase (1–4 mm), pyroxenes (augite, hypersthene 1–2 mm), amphibole (1–3 mm), and partly to completely resorbed biotite (1–3 mm) occurs sporadically. The base matter is microlitic-pilotaxitic and consists of tiny needles of microlite, plagioclase, pyroxene, amphibole, and volcanic glass. In isolated cases, olivine and quartz have been found.

Geotope No. 50

Obyce

welded ash-pumice tuffs – ignimbrites of the Drastvica Formation

During the Sarmatian, after the formation of the Sitno Volcano in the south-western part of the caldera, massive eruptions of ash-pumice tuffs of amphibole-pyroxene andesites (± biotite) took place. During the Plinian eruptions in the form of eruption columns, the ash-pumice material was carried high into the atmosphere, where it spread laterally, forming an ash cloud, and subsequently was the source of air-fall tuffs, which covered the area of the caldera of the stratovolcanic slope and wide surroundings (Fig. 1).

As a result of recurring collapses of eruption columns, the ash-pumice flows were formed at the Earth's surface. These filled the caldera area, and after crossing the caldera fault, they continued moving along the stratovolcanic slope, following mainly the morphology of erosive paleodolines. Following a rapid succession of eruptions with subsequent transport of hot mass of gases, ash, and pumice, sintering to welding of pyroclastic material and the formation **of welded tuffs – ignimbrites occurred**. In the western part of the caldera, a massive plateau of ignimbrites was formed, of 250–300 m in thickness (ignimbrites in the caldera area are discussed under Geotope no. 26. Kojatín in TTU Hodruša – Hámre and Geotope no. 44. Veľký Žiar in TTU Pukanec).

Welded ash-pumice tuffs – ignimbrites filled several paleodolines within the stratovolcanic slope. It is possible to reconstruct the course of these paleodolines out of preserved ignimbrite remains.

The paleodoline on the western stratovolcanic slope, stretching from the east to the west, is the most distinctive. It began near the western edge of the caldera fault (Nová Baňa area) and continued westwards as far as to the area of Obyce – Hostie, where it widened to ca. 4 km in width. The ash-pumice flows moving through this paleodoline reached the length of more than 25 km. The welded tuffs – ignimbrites around Nová Lehota extend to about 150 m in thickness (GK-5 borehole verifies the thickness of about 750 m south of Veľká Lehota).

Another paleodoline, bound towards south-west, is indicated by ignimbrite and pumice tuff remains on the slopes south of the Hron River (a hill with elevation 437, south of Brehy – western slope below Priesil – western slope below Stará Hora, elevation 471).

The third paleodoline was oriented more towards south-west, as indicated by pumice tuff and ignimbrite relicts on the south-eastern slopes of Stará Hora in the Bukovinská valley, north-west of Čajkov. The ash-pumice tuffs in this area reached the edge of a marine shoreline, therefore after their contact with the water and subsequent cooling, no welding occurred. The ash-pumice tuffs in this area are discussed under Geotope no. 100. Čajkov in TTU Levice.

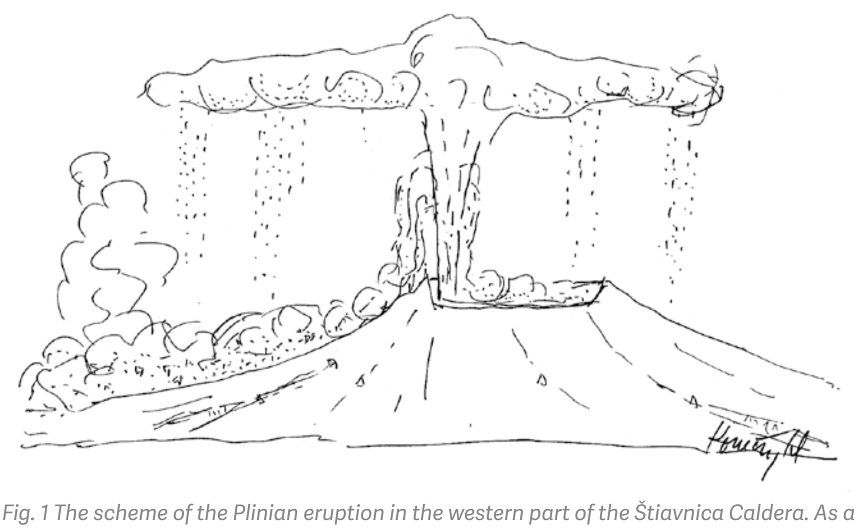


Fig. 1 The scheme of the Plinian eruption in the western part of the Štiavnica Caldera. As a result of recurring collapses of the eruption column, ash-pumice flows are formed, transporting a hot ash-pumice material towards the stratovolcanic slope. The ash-pumice material is subsequently welded into ignimbrites. The ash cloud is a source of air-fall tuffs (© V. Konečný).

The ignimbrite remains at the southern slope (elevation 616 Varta) and in the valley of the Podlužianska Stream north-northeast of Čajkov indicate the fourth paleodoline, oriented more to the south-west.

Due to welding within hot and slowly cooling tuff-pumice matter, pumice fragments become deformed and vitrified, obtaining lenticular or flamelike shapes called "fiamme". Due to fumaroles emerging from the bottom parts of the hot complex, secondary minerals are formed, resulting in a strong alteration and homogenisation of the pyroclastic material, which in turn becomes a massive and solid rock.

Near the western edge of the neovolcanic area, the welded tuffs – ignimbrites are exposed in an abandoned quarry near the western edge of Obyce (Fig. 2, Photo 1, 2). The abandoned quarry can be accessed along the 60 to 80-metre-long dirt road from Obyce.

The walls of the abandoned quarry consist of welded ash-pumice tuffs of light grey-green to yellow-green hues with traces of inhomogeneous structure. The ignimbrites have irregular blocky to coarsely-columnar jointing.

Fig. 2 In the abandoned quarry near the north-western edge of Obyce, welded tuffs – ignimbrites with irregular blocky jointing have been exposed. (© V. Konečný).

Due to fumarole activity, the welded rocks are highly homogenised. The textures of the fiamme type are faint to indistinct.

The original amphibole and biotite phenocrysts of up to 3–4 mm are partially to wholly altered (chloritised and limonitised). Occasionally, fragments of older andesites are present, torn off the bedrock, along which the ash-pumice flow moved. The original pyroclastic nature of the material (pumice and crystal fragments) can only be identified with the use of a microscope.

Photo 2 A close-up of the left side of the quarry wall. The rock is massive, compact, with irregular blocky jointing (© P. Pachinger).

Photo 1 An overall view of the walls of the abandoned ignimbrite quarry near Obyce (© P. Pachinger).

The western edge of ignimbrites, stretching into the Hostie area, is denudational. It can be presumed that the initial area of ash-pumice flows – ignimbrites moving towards west was significantly larger.

Photo 1 A view of andesite rocks cliffs of the Inovec Formation at the southern slope (under elevation 981 Veľký Inovec, © P. Pachinger).

Geotope no. 51

Veľký Inovec

pyroxene andesite lava flow of the Inovec Formation

As a result of recurring lava effusions of pyroxene andesites during the later Sarmatian volcanism (4th stage of the Štiavnica Stratovolcano formation), a lava complex was formed on the western slope and the foot of the stratovolcano. It covered a large area of the volcanic rocks of the later Sarmatian volcanism. The massive and extensive lava complex (lava plateau), fills the paleodoline, which has widened significantly in lower levels of the slope, transforming itself into a flat relief at the foot of the stratovolcano.

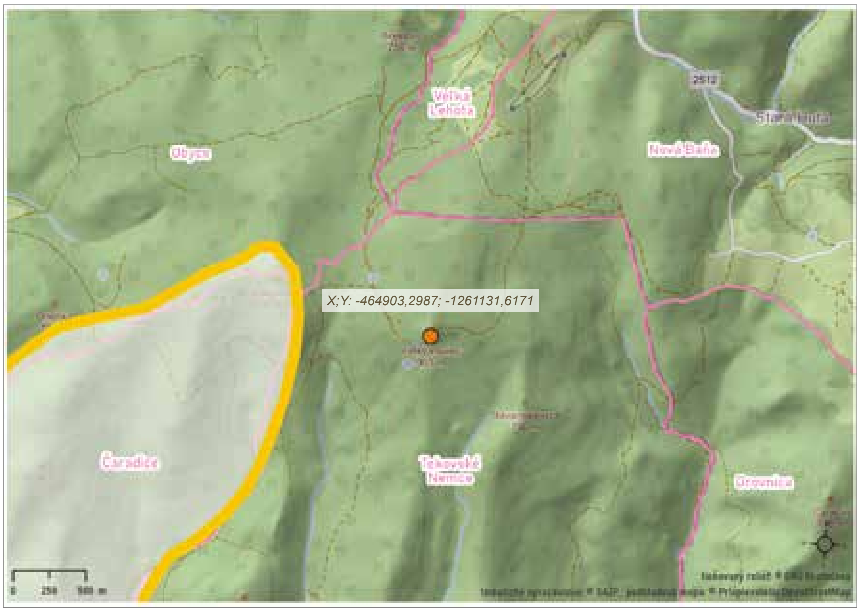


Fig. 1 A pyroxene andesite rock cliff of the Inovec Formation (under elevation 981 Veľký Inovec). Andesite has mural jointing alongside north-western lamination planes (© V. Konečný).

In the central to northern part, the lava plateau is deposited in the overlying rock of welded tuffs – ignimbrites of the Drastvica Formation, or on the older lava flows of the Sitno Complex (north-west of Veľká Lehota). At the southern edge, the complex of lava flows is deposited on the volcanoclastic rocks and on the amphibole-pyroxene andesite lava flows of the Priesil Formation.

The lava flows at the southern edge of the lava complex form flat plate bodies inclining 10 to 20° (or even more) towards north-west into the inner part of the complex, thus indicating the southern slopes of the original paleodoline, along which the lava flow moved and gradually solidified.

The present-day edges of the extended lava plateau are denudational. Due to denudation, the plateau was completely removed from higher stratovolcanic slopes. Its presence is assumed to have reached the caldera edges, defined by the caldera fault (wider area of Rudno nad Hronom). At the south-eastern to eastern denudational edge, the lava plateau base is located at the altitude of about 750 to 775 m above the sea level, and it subsides under 350 m above sea level at the western edge.

In the lower levels of the stratovolcanic slope and at its foot, the lava flows were undergoing hyaloclastite brecciation while entering the water (Geotope no. 52 Machulince).

The lava complex is formed in the area of Veľký Inovec at a lower level by leucocratic vitric pyroxene andesite lava flows (low-pyroxene up to 0.5–1%). In the overlying rock of the leucocratic andesite (elevation 901), pyroxene andesite lava flow is deposited.

At the southern edge of the peak, the lava flow forms rock walls of 18–20 m in height (Fig. 1, Photo 1, 2). A distinctive mural jointing alongside lamination planes inclined 10–15° towards north-west (congruent to the bedrock) points to the southern edge of the slope of the original paleodoline, which inclines towards north to north-west into its middle.

Due to denudation with the complete elimination of softer rocks, which used to form the slopes of the original paleodoline, more resistant andesite flows gradually reached peak positions. The abovementioned process is called the inversion of relief.

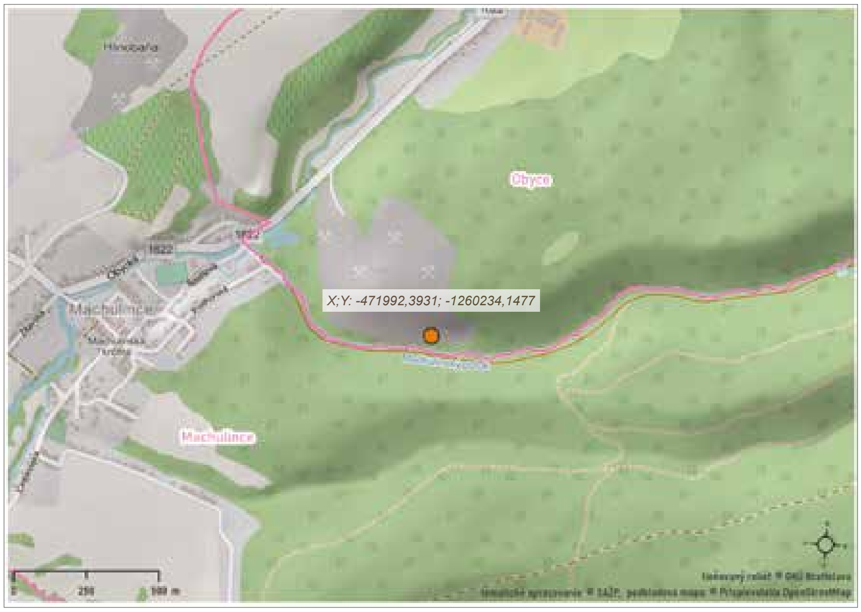
Andesite is dark grey to grey-black, phenocrysts consist of plagioclase (2–3 mm), pyroxenes (augite, hypersthene up to 1–2 mm) of 4 to 6%. The base matter is microlitic, grey-black from dispersed magnetite, or microlitic-hyaline with a fluidal texture.

Photo 2 The disintegration of the andesite lava flow of the Inovec Formation to partial blocks in the peak area (elevation 981 Veľký Inovec, © P. Pachinger).

Geotope no. 52

Machulince

lava flows and hyaloclastite breccias of pyroxene andesites of the Inovec Formation



During the Sarmatian, massive lava effusions of pyroxene andesites of the Inovec Formation took place at the western slope of the Štiavnica Stratovolcano. At the foot of the stratovolcanic slope, they formed an extensive lava plateau. The lava flows moving from the stratovolcanic slope followed a broadening paleodoline, which was transformed into a proluvial plain at the foot of the stratovolcano. In this area, the lava plateau broadened significantly, and occupied the area from Machulince (at the southern edge) to the Šibeničný Hill area (elevation 627) northwest of Nová Lehota. The origin of the paleodoline, along which the lava flows moved, can be most likely placed in the area of Nová Baňa. Massive lava effusions, probably originating from cracks at the western stratovolcanic slope and bending towards the western stratovolcanic foot, used the former paleodoline, in which welded ash-pumice tuffs – ignimbrites of the Drastvica Formation had been located.

The lava flows followed and gradually filled deep erosion furrows at the surface of softer ignimbrites, while the airflow of isolated, uncovered "isles" occurred within the lava plateau. Deep erosion furrows into the underlying softer ignimbrites can be traced at the slopes of the Žitava River valley, north of Obyce.

The lava flows, having reached the foot of the stratovolcano, encountered the water environment and underwent brecciation, which resulted in the formation of hyaloclastite breccias. The processes of hyaloclastite brecciation can be observed within the walls of an abandoned quarry south of Machulince. The alternation of lava flows with hyaloclastite breccias can be seen in the quarry wall. In its central part, a debris cone divides the quarry wall into a western and an eastern part. (Fig. 1).

At the lowest level of the western part (A), an upper part of the lava flow (a) is exposed, transforming itself into a hyaloclastite breccia (a1) at the overlying level. The breccia consists of angular fragments to andesite blocks, and of multicoloured grained matrix.

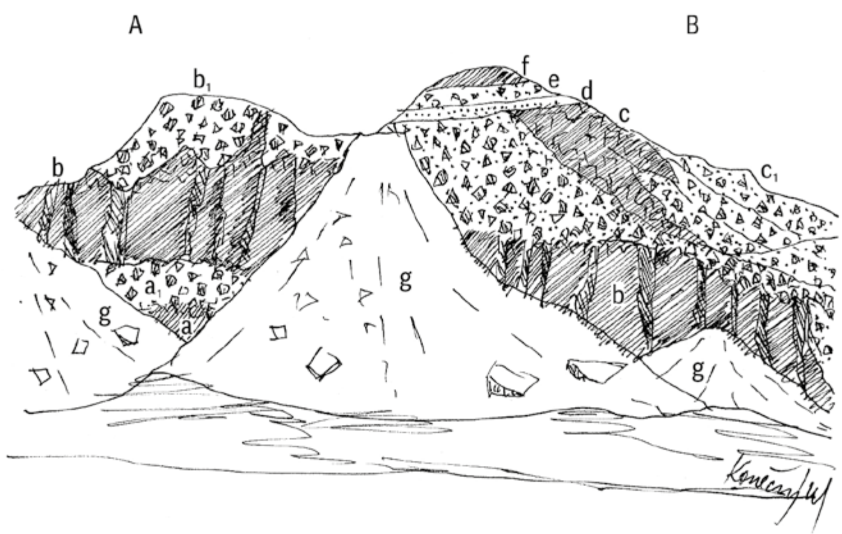


Fig. 1 In the abandoned andesite quarry in the side valley at the southern edge of Machulince, the alternation of lava flows and hyaloclastite breccias can be observed. In its central part, the debris cone divides the quarry wall into the western (A) and the eastern part (B) (© V. Konečný):

a) – bottom lava flow, a1) – hyaloclastite breccia in the overlying rock of the bottom lava flow, b) – middle lava flow, b1) – hyaloclastite breccia in the overlying rock of the middle lava flow, c) – upper lava flow, c1) – hyaloclastite breccia of the upper lava flow, d) – sediments in the bedrock of the hyaloclastite breccia, reddened due to the thermic effect, e) – hyaloclastite breccia – brecciated lava flow, f) – lava flow in the upper part of the quarry wall, g) – debris cone.

Photo 1 The eastern part of the quarry wall illustrates the situation in Fig. 1. B. There is a lava flow in the bottom part of the wall, a hyaloclastite breccia in its overlying rock, a brecciated lava flow and a hyaloclastite breccia in the upper part of the quarry wall. On the left side, there is a reddened sediment, and a hyaloclastite breccia – a brecciated flow in its overlying rock (© P. Pachinger).

A lava flow (b) with a broken, uneven surface is layered steeply on the underlying breccia, gradually transforming itself into a hyaloclastite breccia in its overlying rock (b1). "Apophyses", short lava offshoots, project out of the lava flow up into the breccia. The central part of the crack in the breccia is filled with a lava dyke.

The observed phenomena in the western part of the quarry wall illustrate the process of hyaloclastite brecciation. The hyaloclastite brecciation (disintegration into fragments and grained matrix) due to rapid cooling after the contact with water affects mainly the upper part of the lava flow. The hyaloclastite breccia carried by the lava flow acts as a protection layer preventing a complete brecciation of the lava flow. Short lava injections (apophyses) penetrate from the lava flow upwards into emerging cracks.

The eastern wall of the quarry (B) illustrates a gradual formation of the hyaloclastite complex and the brecciation of the lava flow (Fig. 1, Photo 1, 2). After the bottom lava flow (b) penetrated the water environment, the hyaloclastite brecciation occurred in its upper part and on its surface (b1). Subsequently, an erosion of the hyaloclastite breccia occurred and an erosion furrow (channel) was formed. Another upper lava flow (c) penetrates the erosion furrow and undergoes a complete brecciation, being thus transformed into ahyaloclastite breccia (c1) which fills the erosion furrow (channel).

Moreover, an erosion in the upper part of the wall occurred, resulting in the formation of an inclined slope. This surface bears a sediment – redeposited hyaloclastite breccia (d), which turned brick red (e) due to the thermic effect (oxidation of Fe component) of a brecciated lava flow in its overlying rock. The uppermost part of the exposure consists of andesite with blocky jointing (f).

Andesite is black, vitric, with distinctive plagioclase phenocrysts (2–4 mm). Pyroxenes are macroscopically invisible; low levels (up to 0.5%) of hypersthene and augite up to 0.5–1 mm are detected with a microscope. The base matter is microlitic-hyaline (vitric) with distinctive fluidal structures, frequently with brown or grey-black hues due to dispersed magnetite.

Photo 2 A close-up of the upper left part of the quarry wall. A hyaloclastite breccia – a brecciated flow lies in the overlying rock of the reddened layer. Reddening is the result of a thermic effect of the lava flow onto its basement (© P. Pachinger).

Geotope no. 53

Benát – Kamenné vráta

pyroxene andesite lava flows of the Inovec Formation, lava flow structures

The pyroxene andesite lava flows of the Inovec Formation at the western slope of the Štiavnica Stratovolcano and its foot form an extensive lava plateau, lying on the older products of the Sarmatian volcanism. They fill the original paleodoline which gradually spread towards the foot of the stratovolcano, where lava flows extend into a maximum thickness of 30–50 m. At the stratovolcanic foot, the lava flows encountered the water of the receding Sarmatian sea and underwent hyaloclastite brecciation. The processes of the hyaloclastite brecciation can be observed in the walls of an abandoned quarry (not in use back then) at the southern edge of Machulince (Geotope no. 52).

Photo 1 A rock cliff at the top of the Benát crest consists of andesite with subhorizontal mural jointing, moderately inclined towards north-west (© P. Pachinger).

These lava flows of the bottom effusion complex consist predominantly of leucocratic pyroxene andesites, frequently of vitric base matter and considerably low-pyroxenic (up to 0.5%).

In contrast, the lava flows of the upper effusion complex consist of high-pyroxene andesites (augite, hypersthene up to 6.5%). The absence of the hyaloclastite brecciation indicates no contact between the lava flows and the water.

The lava flows of the upper effusion complex form flat platy bodies, generally inclined towards south-west, south, and north-west. Some lava flows bear a brecciated layer of varying thickness (from several decimetres to 1–2 m) with a strongly foamy (porous) structure, which disintegrates into irregular scoria fragments. Due to oxidation, the lava breccia gained brown-red and purple-red hues.

At the bottom part of the lava flow (above a base lava breccia), an andesite body has usually mural jointing (parallel to the surface, along which the lava flow moved). Above, it transforms itself into andesite either of massive nature or with irregular blocky jointing (disintegration into angular blocks alongside smooth jointing planes). Occasionally, andesite lava flows have columnar jointing alongside the polygonal planes. The columns are usually subvertical to vertical. This jointing is formed during the solidification and crystallisation phases as the reduction of the body's volume creates internal stress. In the upper part of lava flows, a transformation through the porous layer and brecciation layers into the lava breccia can frequently be observed.

Photo 2 Andesite with coarsely-columnar jointing can be seen in the quarry wall of an abandoned quarry under the Benát Hill (© P. Pachinger).

Photo 3 A close-up of irregular columnar jointing in the right part of the quarry wall. The jointing is formed alongside subvertical (often concave) jointing planes (© P. Pachinger).

Fig. 1 The wall at the entrance to the abandoned quarry. Due to physical weathering, secondary spherical jointing was formed on the original columnar jointing (© V. Konečný).

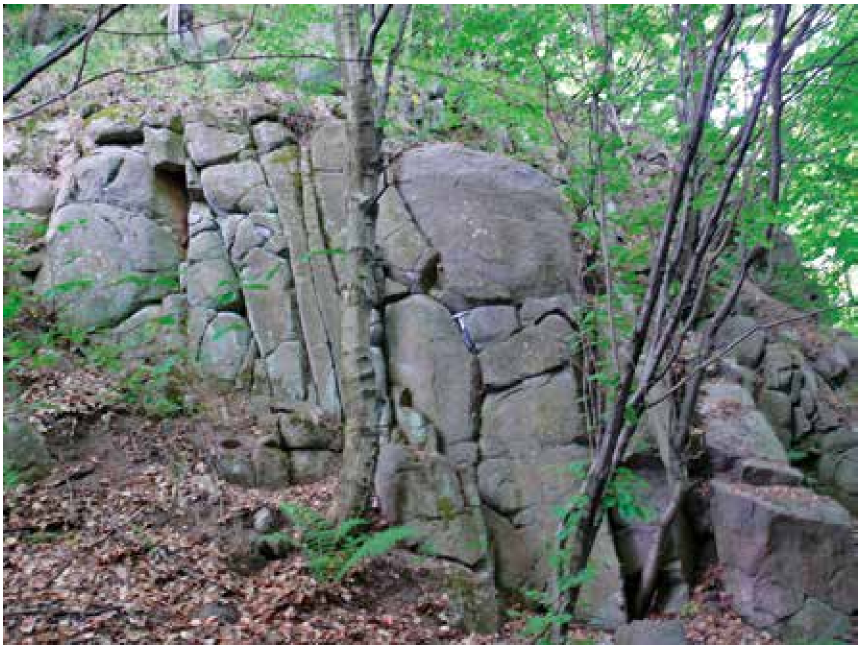


Photo 4 The formation of spherical jointing due to the weathering of andesite with original columnar jointing (© P. Pachinger).

The Benát – Kamenné vráta crest area, east of Machulince, consists of pyroxene andesite lava flows of the Inovec Formation, deposited high in the effusion complex. On the western slope (under elevation 712 Krivá), there is a rock cliff of pyroxene andesite with distinctive mural jointing alongside the planes 240 SW/5–10° (inclination), moderately inclined towards south-west (Photo 1). Subhorizontal mural jointing indicates a relatively flat relief, along which the lava flow moved.

Below on the slope in the abandoned quarry (Photo 2), an inner structure of the lower lava flow with subvertical to vertical columnar jointing is exposed (Photo 3). In the right bottom part of the quarry wall, traces of subhorizontal mural jointing can be observed. It indicates a flat bedrock of the lava flow.

During the process of weathering, spherical jointing was formed alongside the vertical and horizontal cracks. This secondary jointing can be observed in the rock wall at the entrance to the quarry (Fig. 1, Photo 4).

Geotope no. 54
Štamproch
the edge of a rhyolite extrusion

During the Late Sarmatian, the explosive-extrusive rhyolitic volcanism of the Jastrabá Formation took place. The products of the explosive activity in the form of ash-pumice tuffs and extrusive bodies (represented by extrusive domes) lie predominantly at the south-eastern up to northern edge of the Žiarska Kotlina Basin, stretching to the Kremnica Mountains. During their rise toward the surface, the rhyolitic bodies used faults and fault zones as paths of the least resistance. It is mainly the case of the fault zone at the western edge of the the Hodruša-Štiavnica Horst, which stretches from the southern to eastern edge of the Žiarska Kotlina Basin northwards to the Kremnica Mountains and is called *the Vyhne-Ihráč volcano-tectonic zone*. During the rhyolitic volcanism, the central block of the Štiavnica caldera was rising, and the horst structure was being formed. At the same time, the block of the Žiarska Kotlina Basin was subsiding, and the fault zone between the rising and subsiding blocks allowed the rhyolitic matter to rise to the surface, followed there by a turbulent volcanic activity.

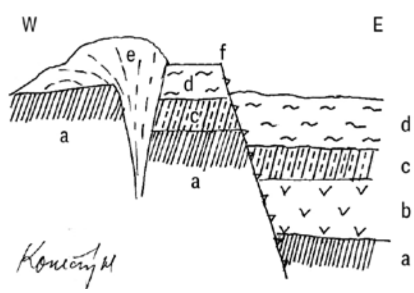


Fig. 1 The scheme of the position of the Nová Baňa rhyolite body (J. Smolka et al., 2005):

a) – bottom stratovolcanic structure,
b) – the Štiavnica caldera fill,
c) – Sitno effusion complex,
d) – ignimbrites of the Drastvica Formation,
e) – Nová Baňa rhyolite body,
f) – caldera fault.

Fig. 2 The walls of the abandoned quarry Štamproch are composed of rhyolite with irregular blocky to coarsely-columnar jointing. An unfinished millstone is found in the left upper part of the quarry wall – marked by the arrow (© V. Konečný).

The fault zone west of Žiarska Kotlina Basin – the Nová Baňa-Kľak volcano-tectonic zone, stretching from the north to the south, also allowed the rhyolitic magma to rise to the surface. It formed a massive rhyolitic body (a linear extrusion due to rising rhyolitic lava) with a north-south direction.

A vertical direction of the rising rhyolitic lava is indicated by a fluidal texture at the eastern edge of the body. In contrast, the fluidal texture at the western edge of the body gains a subhorizontal direction, as it transforms itself into a short, massive lava flow (Fig. 1).

As the Nová Baňa rhyolite body was rising alongside the tectonic zone, it penetrated the rocks of the bottom stratovolcanic structure (exposed at the western edge of the body) as well as the rocks of the later Sarmatian volcanism, lava flows of the Sitno andesite and welded tuffs – ignimbrites of the Drastvica Formation (at the eastern edge of the body). The Nová Baňa rhyolite body is exposed in an abandoned quarry at the north-western slope of the crest (elevation 511 Štamproch near Nová Baňa). The abandoned quarry can be accessed from the eastern edge of the town along the forest trail through the valley near Kohútov, and then along the crest northwards to the abandoned quarry at the north-western slope (elevation 511 Štamproch).

A rhyolitic block slope is located at the western crest near the forest trail north of Kohútov. In this area, the ore veins of the Nová Baňa ore district wedge down and terminate. The original rhyolite rocks in this area are found around the ore veins. They are affected by intensive adularisation (potassium metasomatism related to the formation of potassium feldspars – adularias) and strong silicification. This alteration is accompanied by the formation of tiny veinlets of chalcedony, jasper and opal. Within the rhyolite blocks, breccia textures can be found sporadically. It indicates a hydrothermal-explosive activity of the boiling hydrothermal system (J. Lexa, 2005).

A pale to pink rhyolite rock with sporadic rubiginous to brown or grey shades is exposed in the quarry wall of the abandoned quarry (Fig. 2, Photo 1). Rhyolite is porous, penetrated by jasper veinlets. Brecciation zones with irregular to subvertical course can be observed sporadically. Small debris material is cemented with silicite – jasper. Rhyolite rocks have irregular blocky to coarsely-columnar jointing.

The fluidal textures are not very distinctive. They consist of alternating darker (brown) and lighter stripes, and porosity alternation. The fluidal textures within the quarry wall change from steeper south-eastern to moderate north-western inclination. These changes indicate the overturn of the edge of the body towards north-west, most likely being transformed into a short lava flow (Fig. 1).

In the past, rhyolite was used for building purposes, mainly road constructions. More recently, it was used in the construction of a motorway feeder road in Nová Baňa.

In the past, rhyolite was used to make millstones, as indicated by a rock block preserved in the upper part of the quarry wall (left upper part, Fig. 2, Photo 1), which is worked almost to the final shape of the millstone.

Photo 1 An overall view of the wall of the abandoned rhyolitic quarry Štamproch. Rhyolite with irregular blocky jointing and traces of columnar jointing alongside the subvertical planes. An unfinished millstone in the left upper part (© P. Pachinger).

Geotope no. 55

Nová Baňa

rhyolite quarry Na Háj, the Červená Skala rhyolite cliff

At the southern edge of the main crest (Na Háj location), large rhyolitic quarries can be found, together with heaps of waste material in their vicinity.

Rhyolite rocks of predominantly light hues (pale pink, yellow-white, pale grey) with irregular blocky jointing (Fig. 1, Photo 1) are exposed in the walls of the abandoned quarry.

Rhyolite is porous, sporadically bubbled. The fluidal textures are not very weathered and are characterised by alternating lighter and darker stripes with predominantly subvertical direction. The fluidal textures indicate that an extrusive body was formed by rising semisolid lava. In comparison to Štamproch, Na Háj is located more to the central part of the rhyolitic body.

The Červená Skala rock cliff (Photo 2) can be reached after descending the crest towards SSW.

The rock cliff offers an impressive view of the Hron River Valley and of mountain crests and peaks of the Štiavnica Mountains. The mountain massif of Chlm (elevation 726) is visible south-east of the Hron River; the Tatiar Hill (elevation 734) and the Agraš Hill (elevation 734, Photo 3) can be seen further in the background.

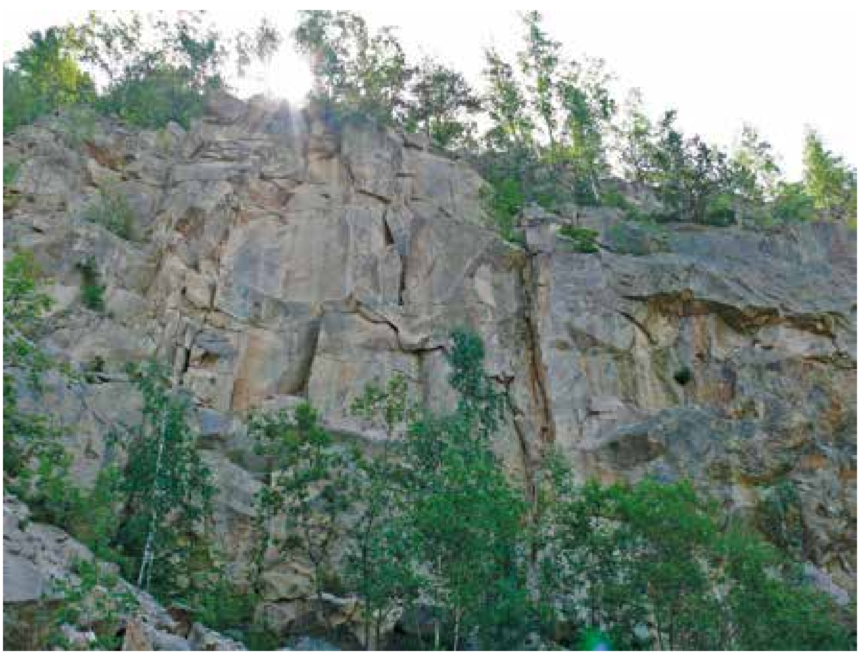


Photo 1 An overall view of the rhyolitic quarry wall with large-blocky to irregular blocky jointing of the rhyolitic body (© P. Pachinger).

Photo 3 A view of the Hron River Valley and northern slopes of the Štiavnica Mountains as seen from the Červená Skala Hill. The mountain massif of Chlm in the foreground, the mountain crest together with the Agraš Hill and the Tatiar Hill in the background (© P. Pachinger).

Photo 2 A view of the Červená Skala rhyolite cliff near Nová Baňa as seen from the Hron River (© P. Pachinger).

Geotope no. 56

Kopanica

stone field (block slope)

When the volcanic activity ended, weathering and denudation processes occurred on the surface of the Štiavnica Stratovolcano due to exogenous factors (wind, rain, water flows), which caused the disintegration of volcanic bodies. A fragmental to blocky material accumulated at the foot of the rock cliffs and it was

Fig. 1 The "stone field" in the Žitava River Valley, south of Malá Lehota (© V. Konečný).

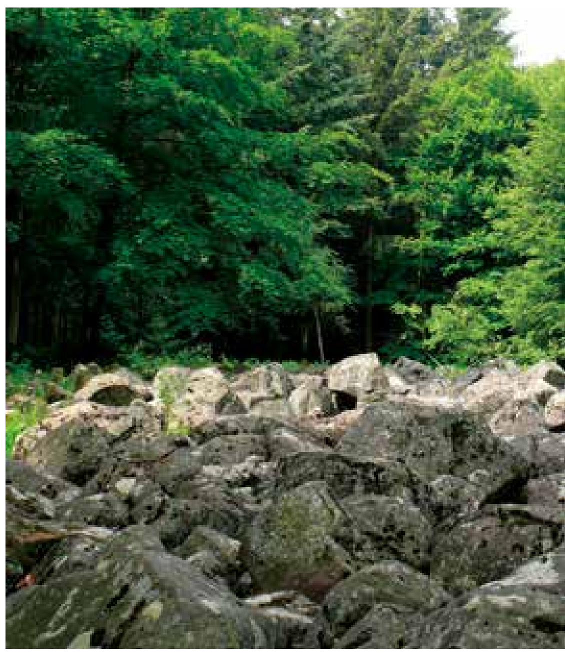


Photo 1 A view of the "stone field" in the Žitava River Valley, south of Malá Lehota (© P. Pachinger).

transported further downwards at the stratovolcanic slope due to gravitation. Particularly intense processes of physical disintegration of volcanic bodies (including lava flows) occurred during the final glacial period, mainly at its closing stages, when heavy frosts alternated with ice and snow melting. These temperature alternations efficiently allowed for the disintegration of lava bodies and the formation of block slopes at the foot of the rock cliffs.

The destruction of lava bodies at the western edge of the Štiavnica Stratovolcano and a subsequent accumulation of the blocky material resulted in the formation of a "stone field" (block slope) in Kopanica in the Žitava River Valley, south of Malá Lehota (Fig. 1, Photo 1).

The blocky material from the destruction of the nearby pyroxene andesite lava flows was transported downwards to the valley, mainly due to the gravitational energy accelerated by temporary water flows, which emerged as a result of massive snow and ice melting. The creation of temporary water flows is indicated by a relatively low-worked shape of the blocky material and its chaotic accumulation.

Photo 1 A pyroxene andesite rock cliff with mural jointing and echelon disintegration alongside subvertical jointing planes. There is an outline of the Tureň Castle tower ruin in the background (© P. Pachinger).

Geotope no. 57

The Žitava River Valley

pyroxene andesite rock cliff under Tureň Castle ruins

During the Sarmatian, in the later stages of the formation of the upper structure of the Štiavnica Stratovolcano, massive lava effusions of pyroxene andesites of the Inovec Formation occurred at the western slope of the Štiavnica Stratovolcano. Eruptive centres of this volcanic activity have not yet been discovered. However, it is assumed that the lava effusions rose from the cracks near the caldera fault. Explosive products (pumice tuffs, pyroclastic breccias) of this volcanism have not yet been identified.

The lava flows which moved from the volcanic slope towards west, followed the paleodoline emerging most likely from around Nová Baňa. The paleodoline broadened westwards, and after the lava flows left its area, they formed an extensive lava plateau at the western foot of the stratovolcano. Its current (denudation-reduced) western edge stretches from the area south of Machulince to the area north-west of Veľká Lehota (elevation 627 the Šibeničný Vrch Hill).

The lava flows form flat plate bodies, generally inclined south-west to west (along the stratovolcanic slope). The lava flows, which encountered the water environment at the stratovolcanic foot, underwent hyaloclastite brecciation (Geotope no. 52 Machulince). The bedrock under the lava flows within broader surroundings of Obyce and west of Veľká Lehota consists of ignimbrites (welded tuffs) of the Drastvica Formation (Geotope no. 50 Obyce). The surface of the ignimbrite plateau

Fig. 1 A pyroxene andesite rock cliff with distinctive mural jointing. There is a Tureň Castle tower ruin in the background (© V. Konečný).

was divided by multiple deep erosion furrows and valleys, which were followed and filled by lava flows of the Inovec Formation as they moved towards west. The fact that the lava flows filled the deep erosion valleys is best illustrated at the slopes of the Žitava River Valley, in the area between Machulince, Obyce, and the Osná Dolina Valley.

A complex of lava flows, which is located at the north-western edge, is tectonically limited by the fault zone of NE – SW direction (north of elevation 490 Hradište under elevation 616 Háj). This fault zone is bordered by a volcanic complex, which is in a subsided position in relation to the pre-volcanic bedrock.

At the northern slope of the Žitava River Valley, within the crest area above the valley, under the tower of Tureň Castle ruins, a pyroxene andesite rock cliff protrudes (Fig. 1, Photo 1).

Andesite is grey-black to black, vitric, with distinctive phenocrysts composed of plagioclase 2–4 mm, pyroxenes (augite, hypersthene) up to 1,2 mm. The base matter is microlitic to microlitic-hyaline (vitric), grey-black from dispersed magnetite. It has distinctive mural jointing alongside lamination planes (Fig. 1).

9. Tourism Territorial Unit Žarnovica

Fig. 5 Coarse to block epiclastic volcanic breccia north of the edge of the extrusive dome (© V. Konečný).

Geotope no. 58

Hrabičov

extrusive dome with an extrusive breccia zone at the edge

At the north-western slope of the Štiavnica Stratovolcano, in the area between Župkov, Ostrý Grúň, and Kľak, a group of extrusive bodies of hypersthene-amphibole andesites of *the Plešina Formation* (named after Plešina Hill) protrudes. Extrusive bodies (predominantly extrusive domes) are characterised by an isometric, elliptical to irregular cross-section, and a varying size (Fig. 1).

The size of the bodies ranges roughly from 200 to 1,000 m, except for the largest one of 4,000x6,000 m in diameter around the Plešina Hill (elevation 1,061 m above the sea level). The extrusive domatic bodies formed by an outward movement of viscous lava (with low mobility), which

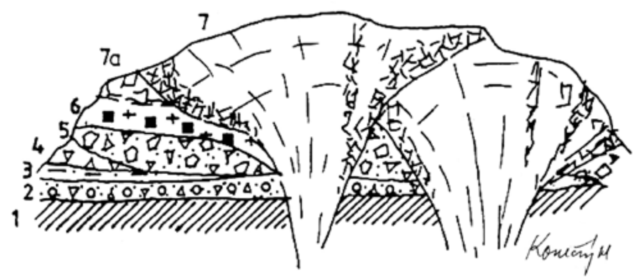


Fig. 1 Schematic section of the Plešina Formation at the western edge of the extrusive body (elevation Plešina) (J. Smolka et al., 2005):

1 – lava flow of the bottom structure of the Štiavnica Stratovolcano, 2 – epiclastic volcanic breccias – conglomerates, 3 – sandstones, siltstones and redeposited tuffs, 4 – fine epiclastic volcanic breccias, 5 – coarse epiclastic volcanic breccias, 6 – chaotic breccia of pyroclastic flow, 7 – extrusive domatic body of hypersthene-amphibole andesite, 7a – extrusive breccia.

accumulated above the feeder channel, are characterised by steep vertical to fan-shaped fluidity planes, which indicate an outward movement of lava immediately before its solidification. The fan-shaped course of the fluidity planes is characteristic of the extrusive domes. The bodies, which were formed by a vertical rise of semisolid lava, consist of protrusions or tholoids characterised by a vertical course of fluidity planes.

During the formation of extrusive domes, a rapidly cooling semisolid to solid crust is formed on their surface. As the extrusive dome grows and broadens, it produces stress over the crust, which therefore proceeds to fracturing and brecciation. The superficial, rapidly solidified crust keeps a dome-shaped form of the body and prevents it from lateral expansion (Fig. 2).

When internal stress critically increases (due to magmatic gases) and breaks through the firm crust surface, the crust is explosively destroyed and the extrusive dome collapses (Fig. 3.A). The collapse process also occurs when an extrusive dome grows on an inclined slope because of loss of gravitational stability (Fig. 3.B).

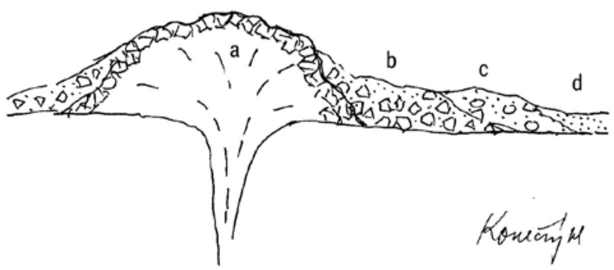


Fig. 2 Scheme of the extrusive dome with brecciated surface crust (Ján Smolka et al., 2005):

At the edge of the extrusive dome (a) lie coarse to block epiclastic volcanic breccias (b), epiclastic volcanic conglomerates (c), and epiclastic volcanic sandstones (d) further away.

Photo 1 Steep fluidity course within the extrusive dome, accentuated by weathering (© P. Pachinger)

Collapses of extrusive domes are accompanied by the formation of block-and-ash pyroclastic flows ("glowing avalanches" type), which move downwards alongside the volcanic slope at high speed due to gravitational energy. They are particularly destructive to human settlements at the foot of the volcanoes, as in several well-known cases from Indonesia (volcanoes Merapi, Kelud, and others).

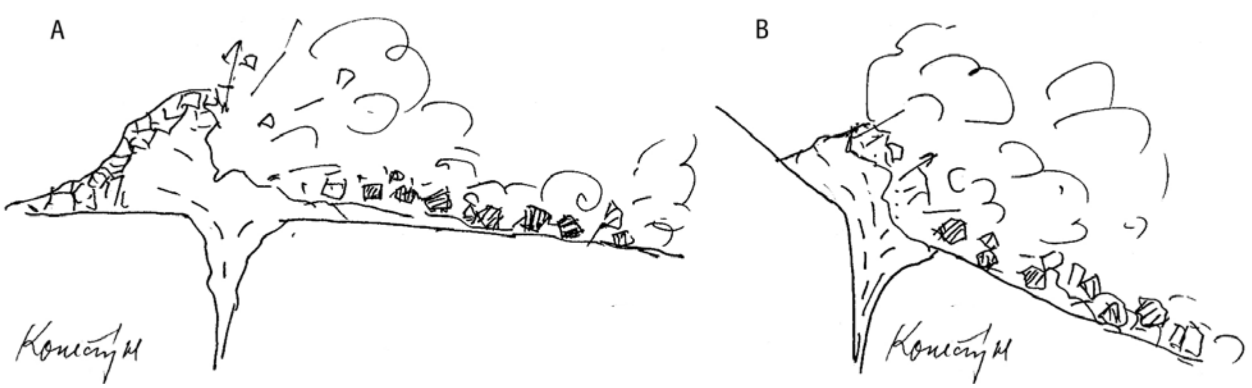


Fig. 3 A – explosive destruction and collapse of extrusive dome accompanied by the formation of a block-and-ash pyroclastic flow. B – collapse of extrusive dome on an inclined slope due to loss of gravitational stability (J. Smolka et al., 2005).

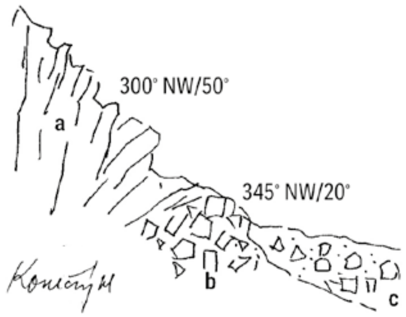


Fig. 4 Scheme of the edge of the extrusive dome north of Hrabičov (J. Smolka et al., 2005):

a) – hypersthene-amphibole andesite with mural jointing alongside fluidity planes,
b) – extrusive breccia at the edge of the extrusive dome,
c) – coarse to block epiclastic volcanic breccias.

In the final stage, when the extrusive dome is almost solidified (in the transition to a solid state), an overall rising movement is divided into movements of individual parts (segments). This process results in the formation of steep crushing and brecciation zones between particular segments.

A typical cross-section through an extrusive complex around the Plešina Hill (Fig. 1) shows mutually overturning extrusive domes with a fan-shaped structure of fluidity planes. The outer domes at the edge are transformed into a zone of extrusive breccias. At the outer edges of the extrusive domes lie coarse to block breccias and chaotic breccias of block-and-ash flows. At the edges, the extrusive domes are pervaded by steep brecciation zones, which accentuate the movements of their individual parts (segments).

At a location north of Hrabičov, at the slopes in the trench of a road and a side valley up to the peak of the crest, there are exposures of an outer part of the extrusive dome which is transformed into the zone of extrusive breccias, and further out to coarse epiclastic volcanic breccia sediments (Fig. 4).

Weathering accentuates thick mural jointing alongside fluidity planes 300° NW (direction) inclined 50° towards NW on the higher level, and 345° NW inclined 20° towards NW on the lower level. At the summit area of the crest, the course of fluidity planes is steep to subvertical, inclined 70 to 85° towards west (inner parts of the extrusive dome) Photo 1.

The zone of extrusive breccias in the trench of the side valley and the slope shows a gradual transition from a compact andesite (Fig. 4.a) through the fracturing zone into the brecciation zone with isolated fragments to blocks enclosed within porous, foamy lava (Fig. 4.b). Disintegration of porous lava results in the formation of grained detrital matrix. The fragments within porous lava matrix do not usually have clearly visible edges (Photo 2).

Photo 2 Close-up of the extrusive breccia at the edge of the extrusive dome. Fragments to blocks are cemented by light high-foamy lava – lava matrix (© P. Pachinger).

Photo 3 The trench of the road north of the edge of the extrusive dome and Hrabičov (© P. Pachinger).

On the outer side, further away from the edge of the extrusive dome, in the trench of the road, a coarse to block breccia with chaotic positioning of fragmented material and grained detrital matrix is exposed (Fig. 4.c, 5, Photo 3, 4).

Andesite is light grey, porous, medium to coarse-grained porphyric, phenocrysts are composed of plagioclase (up to 3–4 mm), amphibole (up to 6–10 mm), pyroxene/hypersthene (up to 2–3 mm). The base matter is hyalopilitic to microlitic, composed of tiny microlites of plagioclase, amphibole, hypersthene, and volcanic glass. Andesite and extrusive breccias are auto-metamorphically altered (slightly chloritised).

The extrusive bodies of the Plešina Formation rose during the period between Baden and Sarmatian, roughly 13 million years ago.

Photo 4 Coarse to block epiclastic breccia with grained to grain-sand matrix further away from the extrusive dome (© P. Pachinger).

Geotope no. 59

Markov Vrch Hill

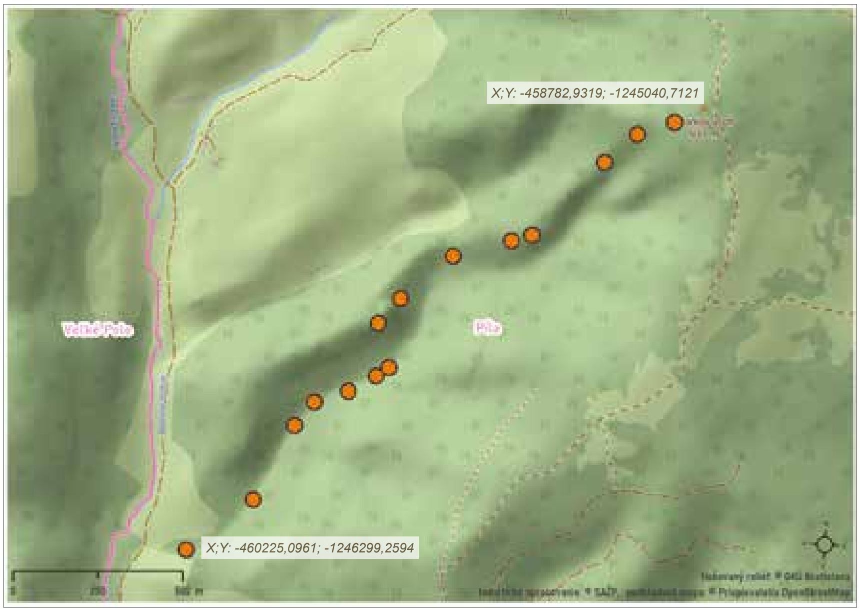
side view of an andesite volcano

At the north-western edge of the neo-volcanic area lie the remains of the andesite volcano – Markov Vrch Hill (a smaller stratovolcano), which is located at the north-western slope of the Štiavnica Stratovolcano, south of the andesite Vtáčnik Stratovolcano. Only the eastern part of the original volcano is preserved, the western one was eroded by denudation. A deep erosion furrow exposed the remains of a pyroclastic cone, and a complex of lava flows higher above, inclined towards the east, north-east, and south-east. The lava flows are inclined alongside a periclinal position in the direction away from the original crater (Fig. 1).

A pyroclastic cone exposed by a denudation cut in the lower levels is formed by autochthonous pyroclastic breccias alternated with positions of thin, heavily brecciated

Photo 1 Dark grey-black shales of Carboniferous age (© P. Pachinger).

Photo 2 Interbeds of quartz shales within the sediments of Carboniferous age (© P. Pachinger).



lava flows. Higher above, there are lava flows separated by discontinuous tuff interbeds, which form a more continuous lava complex in the upper level, covering eastern and south-eastern volcanic slopes. Within the central zone, there are partially exposed bodies of feeder systems in the form of dykes and intrusions.

The stratovolcanic structure of the Markov Vrch Hill lies in the south-western part on the rocks of the bottom structure of the Štiavnica Stratovolcano. In south-eastern, eastern, and north-eastern parts, it is transformed into the overlying rock of the earlier Plešina Formation, formed predominantly by extrusive bodies of hypersthene-amphibole andesites.

The internal stratovolcanic structure is represented by a profile stretching from the trench of the Čierny Potok Stream valley near the exposure of the pre-volcanic bedrock. The bedrock, consisting of black shales of the Carboniferous era, bears basal volcanic tuffs and breccias. The profile continues higher onto the eastern crest above the Čierny Potok Stream valley, and in the direction of an ascent below the Markov Vrch Hill, it gradually crosses the volcanic bodies (agglomerates, breccias, lava flows, dykes), which form the internal volcanic structure.

Photo 3 Epiclastic volcanic sandstones with pumice and crystalline fragments, and fragments of quartz bedrock shales on the base of the volcanic structure of Markov Vrch Hill (© P. Pachinger).

This is how the profile forms individual sections of this structure (see the photos). In the Čierny Potok Stream valley, when the diminishing stream reaches the slope, black shales of Carboniferous age with platelet subhorizontal jointing (Photo 1) protrude within the exposure, and quartz shales are exposed higher above on the stream bed (Photo 2).

Inside the side of the stream and the slope, there is an exposure of ca. 15 m lengthwise, consisting of epiclastic sandstones and tuffs with pumice fragments (0.5–3 cm) and with frequently worked fragments of crystalline and quartz shales of pre-volcanic bedrock (Photo 3). Sandstones and tuffs form the base of the volcanic structure.

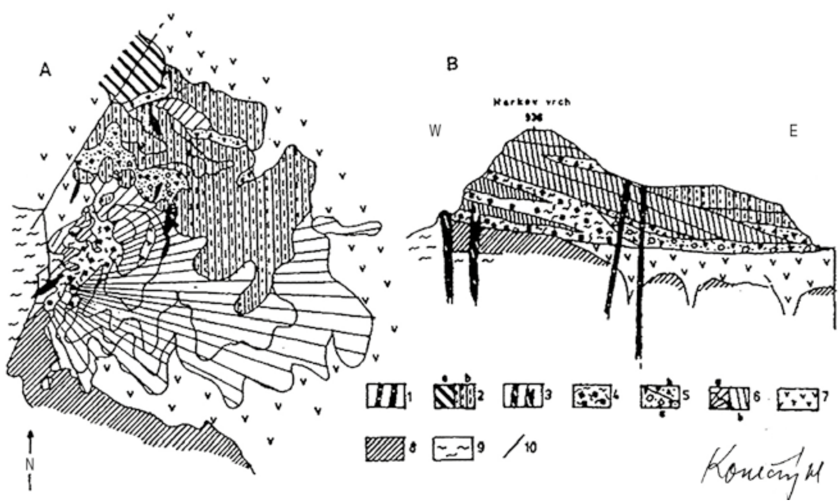


Fig. 1 The Markov Vrch Hill volcano
A – surface scheme, B – geological section (J. Smolka et al., 2005):

1 – dykes of basaltic-pyroxene andesites in the Šibeničný Vrch Hill complex, 2 – lava flows of the Vtáčnik Formation (a), of the Žiarska Kotlina Basin complex (b), 3 – brecciated andesite dykes, 4 – coarse to block pyroclastic breccias of a volcanic cone, 5a – epiclastic volcanic breccias, 5b – redeposited pyroclastic breccias, 6 – lava flows of pyroxene andesites in the surface scheme (A) and the section (B), 7 – extrusions of the Plešina Formation, 8 – bottom stratovolcanic structure of the Štiavnica Stratovolcano, 9 – unsegmented rocks of pre-volcanic bedrock, 10 – faults.

Photo 4 Autochthonous pyroclastic breccia in the stream valley cut (© P. Pachinger).

At this level, on both sides of the stream cut, there are rock exposures of chaotic pyroclastic breccias, composed of fragments to blocks of andesites with a porous structure and a vitreous edge of varying size (5–30 cm), and occasionally, even blocks up to 0.8 m can be found. The matrix is reddish with tiny porous fragments – autochthonous pyroclastic breccia (Photo 4).

Higher on the stream bed and inside the slope, there is a dyke of base andesite exposed (15–25 m in width), penetrating a chaotic pyroclastic breccia. Andesite has steep jointing alongside fluidity planes (inclined 175 SW/85–90° SOW). A zone of brecciation and crushing is found at the edges of the dyke. Andesite is grey-black, porous, fine-grained porphyric (Photo 5).

Photo 6. Lava flow of base pyroxene andesite with mural jointing (© P. Pachinger).

Higher on the side of the stream, a strongly-frothy (porous) basaltic andesite with plated subhorizontal jointing is exposed (Photo 6).

Higher in the side of the stream, an exposure of ca. 6 m lengthwise consists of a pyroclastic breccia with tiny fragments of fine-grained porphyric andesite with a porous structure and highly sintered tuff matrix, with porous fragments (Photo 7.). Jointing is plated alongside steep planes. Higher (ca. 50 m further) in the direction of the stream, a chaotic breccia with fragments to blocks up to 20–35 cm and highly sintered red tuff matrix is exposed.

Photo 5. Andesite dyke penetrates autochthonous pyroclastic rocks (© P. Pachinger).

Disintegration of blocks into angular fragments (crater breccia) is observed. An andesite dyke protrudes higher at the slope (Photo 8).

An ascent alongside a steep slope to the crest. At the southern edge of the crest, there are rock cliffs of brecciated andesite with jointing alongside steep planes. The autoclastic breccia consists of porous, foamy fragments and grained matrix with a prevailing orientation alongside steep planes. Higher above, it is transformed into an andesite dyke with a brecciated edge (Photo 9).

In the upward direction alongside the crest ensue rock cliffs consisting of a chaotic breccia with fragments to blocks up to 0.5–1 m and grey-white grained matrix. The fragments

Photo 7. Chaotic pyroclastic breccia with highly sintered tuff matrix with andesite fragments (© P. Pachinger).

Photo 8. Andesite dyke with blocky jointing (© P. Pachinger).

Photo 9. Andesite dyke with a brecciated edge (© P. Pachinger).

within the matrix do not usually have clearly visible edges. Higher above, it is transformed into a dyke (Photo 10).

Rock cliffs of 30–40 m in height continue along the crest. There is an andesite dyke in the foreground, penetrating through coarsely-layered pyroclastic rocks (Photo 11). The dyke has irregular block disintegration (Photo 12). Coarse to blocky breccias with visible to thick gradation are inclined ca. 10° westwards (Photo 13).

Higher in the direction of the crest, there are rock cliffs of ca. 8 m in height, consisting of agglomerate pyroclastic rocks with visible gradation of fragments to blocks of up to 0.8 m, and inclined 20–25 ° westwards (Photo 14). The blocks are predominantly spherical to subspherical. Some of them show disintegration alongside radial cracks near

Photo 10. Chaotic pyroclastic breccia at the peak of the crest in the upward direction below Markov Vrch Hill (© P. Pachinger).

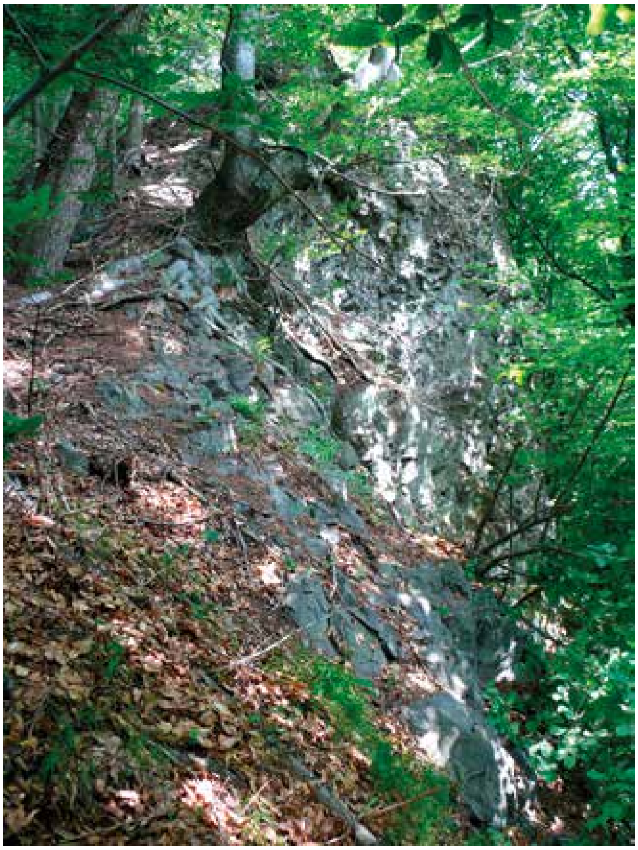


Photo 11. The andesite dyke in the foreground penetrating through pyroclastic breccias in the background (© P. Pachinger).

Photo 12. Irregular large-block disintegration of the andesite dyke penetrating through pyroclastic breccias (© P. Pachinger).

Photo 14. Agglomerate pyroclastic rocks with visible gradation inclined westwards. Matrix is tuffaceous and highly sintered with tiny foamy fragments (© P. Pachinger).

"chilled margins". Higher on the crest, andesite with blocky jointing alongside subvertical planes (dyke) is exposed (Photo 15.A, B).

Rock exposures at this level consist of large-block agglomerate with blocks of up to 2.5 m. The matrix is tuffaceous, with traces of sintering with tiny porous fragments (Photo 16).

A blocky agglomerate with chaotic blocks of up to 1.5 m and with a sintered tuff matrix continues at this level. Their position is chaotic (Photo 17).

Above the blocky agglomerate, there are smaller rock cliffs of base andesite with distinctive phenocrysts composed of pyroxenes (augite) of up to 0.5–1 cm, which form a lava flow. There is large-block to thick mural subhorizontal jointing (Photo 18).

A coarse to blocky breccia is exposed in the rock cliff immediately under the Markov Vrch Hill. Blocks of up to 30–50 cm (occasionally to 1 m) are distinctively angular. Their position is chaotic. A fragmental to blocky material comes from the destruction of the bodies of the feeder system (Photo 19).

Photo 15.A. Rock exposure of andesite with blocky jointing along subvertical planes (© P. Pachinger).

Photo 15.B. Andesite dyke penetrating through agglomerate pyroclastic rocks (© P. Pachinger).

Photo 13. Autochthonous pyroclastic breccias with visible gradation inclined towards north-west. Matrix is tuffaceous and highly sintered with tiny fragments. There is a contact with the andesite dyke on the left side (© P. Pachinger).

Photo 16. Large-block agglomerate with traces of matrix sintering with tiny fragments. Large blocks are visibly inclined westwards in the direction of the original volcanic slope (© P. Pachinger).

Photo 17. A chaotic blocky agglomerate at the higher crest level towards Markov Vrch Hill (© P. Pachinger).

Photo 18. The rock cliff of base pyroxene andesite with large-block to thick mural jointing (© P. Pachinger).

Photo 19. The rock cliff with coarse to blocky breccia under the Markov Vrch Hill (© P. Pachinger).

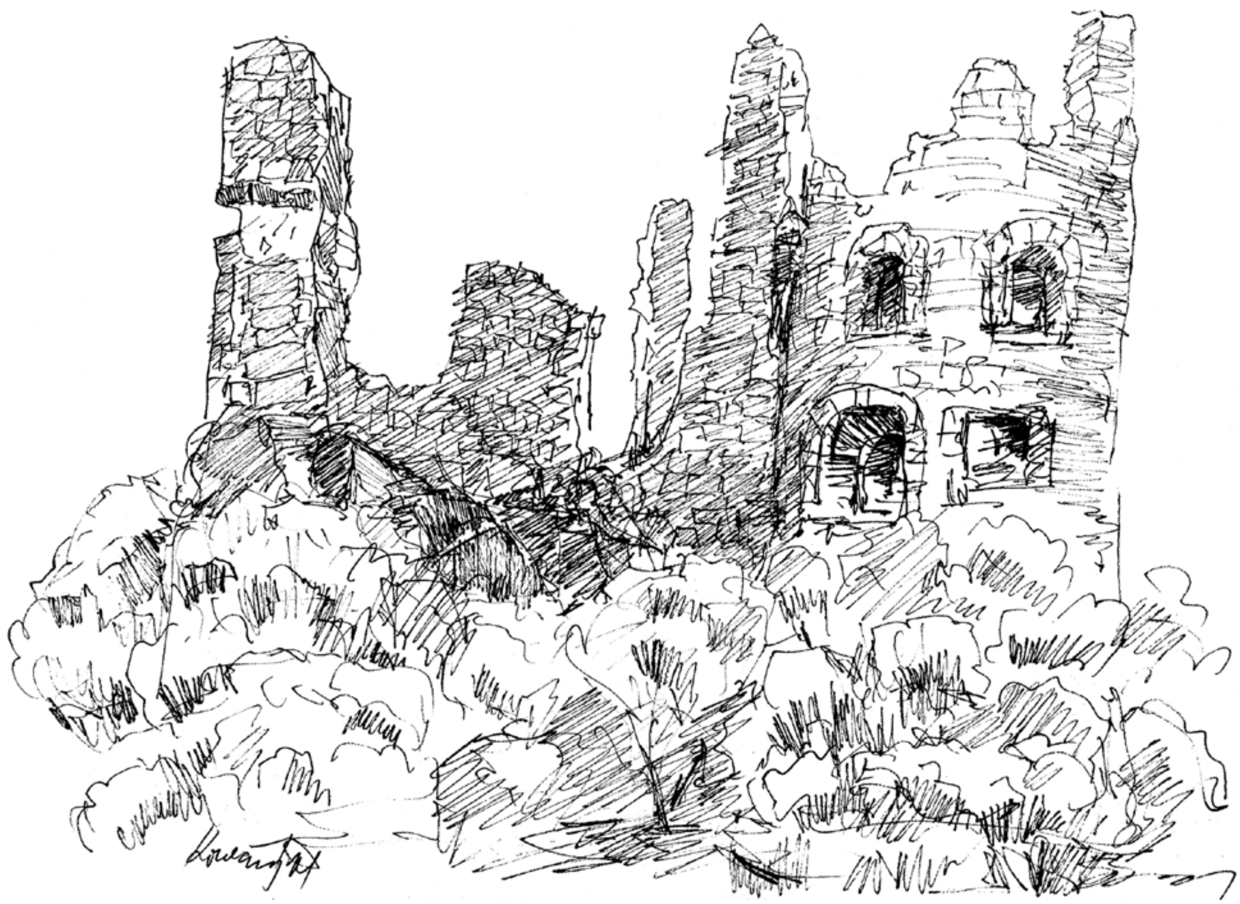


Fig. 1 Revištie Castle ruins stand on the Sitno-type andesite rock cliff (© V. Konečný).

Geotope no. 60

Revišťské Podzámčie

Sitno-type andesite rock cliffs on the top of the castle hill

A steep rocky slope above the Hron River at the northern edge of Revišťské Podzámčie is dominated by the Revištie Castle ruins. The castle was built on a rock cliff, which consists of a Sitno-type andesite lava flow relict, deposited on the rocks of the caldera fill.

The fill in the north-western part of the caldera consists predominantly of the products of extrusive-effusive volcanism of biotite-amphibole andesites of the Studenec Formation. Biotite-amphibole andesite protrudes at the bottom level of the rock slope at the southern edge.

Andesite is coarse-grained porphyric with irregular blocky jointing. Phenocrysts consist of plagioclase (1–4 mm), amphibole (up to 4–6 mm), occasionally biotite (up to 2–4 mm). Dark minerals are partly to wholly altered (chloritised). Andesite near the caldera fault is hydrothermally altered and partially crushed.

In the western to north-western part of the caldera (west of the Hron River), lava flow remains of the Sitno Complex (west of Žarnovica) lie in the overlying rock of the caldera fill.

The caldera fill is penetrated by extrusive bodies of amphibole-hypersthene andesites (± biotite, ± quartz) in the broader surroundings of the Peťov Vrch Hill (east of Michalovci). A later rhyolite body penetrates the caldera fill north of Žarnovica. Near the caldera fault north of Žarnovická Huta, a group of sandstones and conglomerates lies in the upper part of the caldera fill.

Relicts of Sitno-type andesite lava flows continue along the north-western stratovolcanic slope to the edge of neovolcanic rocks (north of Veľká Lehota), where the complex ends in a fault, along which it subsidies together with its bedrock.

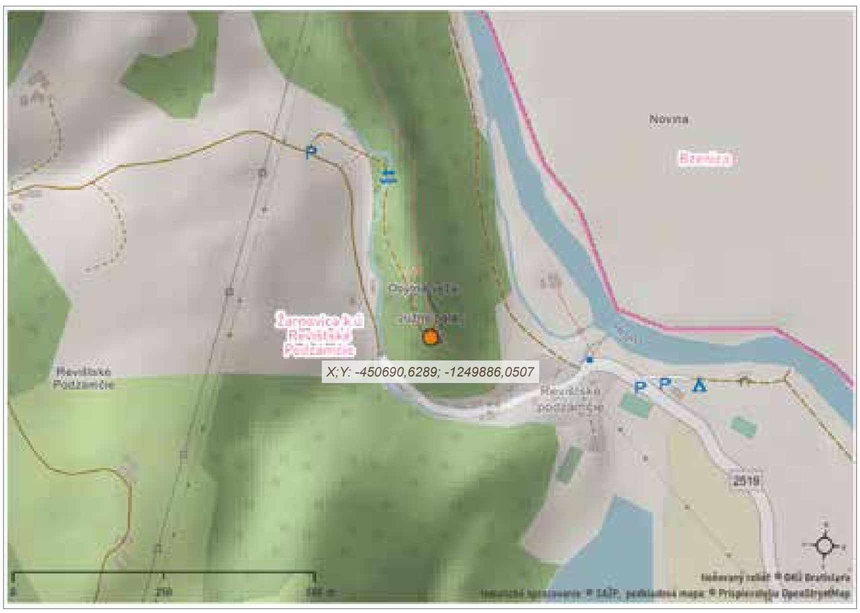
The lava flows were associated with the formation of the Sitno Volcano with an assumed centre in the south-western to western part of the caldera (the area of the assumed centre is currently located within an uplifted and denuded horst block). After the lava flows filled the southern, southwestern to western parts of the caldera depression, they continued onto the outer stratovolcanic slopes, following the morphology of deep paleodolines bound towards the foot of the stratovolcano. A distinctive westward-directed paleodoline is illustrated by lava flows west of Žarnovica, where they are interrupted by a rising rhyolite extrusion within the area of Drienčie (elevation 711). After being interrupted by the uplifted block of the bottom structure (the broader surroundings of Štále – Štepnica), the lava flows continue towards west to northwest to the Vojšín area (elevation 819).

Lava flows which crossed the paleodoline in the north-west direction created a lava complex in the overlying rocks of the bottom stratovolcanic structure (north of Horné Hámre). In the area of the Čierny Vrch Hill (elevation 758) and Poľana Hill (elevation 754), in the overlying rock of the Sitno Complex, lava flows of later pyroxene andesites settled.

Within the caldera area, the lava flows of the Sitno Complex consist of flat, platy bodies inclined towards the caldera edges. In the western part of the caldera, they form a massive effusive complex of up to 200 m in thickness. It is composed predominantly of heavily foamy and brecciated lava flows. In the area of the stratovolcanic slope, the lava flows form tongue-like bodies inclined towards west to north-west.

Photo 1 An angular bastion of the Revištie Castle (© P. Pachinger).

The base of some lava flows bears a zone of lava breccias, higher up mural jointing is formed parallel to the surface along which the flow moved, a middle to higher part of the flows consists of andesite with coarsely-columnar to irregular blocky jointing. The lava flows are transformed into the zone of foamy structures and brecciation in the upper part.



A rock cliff of Sitno-type andesite is found at the top of the castle hill, under the castle ruins (Fig. 1).

Andesite is medium-grained porphyric, grey-black, with thick mural to blocky jointing. Phenocrysts are composed of plagioclase (1–3 mm, occasionally up to 5 mm), amphibole (up to 2–4 mm), and pyroxenes (up to 1–2 mm).

The top of the rock cliff bears ruins of the medieval Revištie Castle which has been entangled with several legends. The castle ruins and their surroundings are a renowned tourist destination.

The castle was built in the second half of the 13th century, probably around 1253, together with Šášov Castle situated 15 km to NE on the opposite side of the Hron River. Both castles used to guard a passage through the narrow Hron Valley – an access route to the Central Slovakia mining region. The first written reference to Revištie Castle dates back to 1265 (and later 1331). Initially, the castle belonged to the archbishop of Esztergom. At the beginning of the 14th century, it was conquered by Matthew Csák. After his death, the castle was managed by the castellans appointed by the king. After the death of Louis I of Hungary, Sigismund of Luxembourg became the castle owner. In 1424, he eventually gave it as a wedding gift with its former mining towns to Queen Barbara. The castle continued to be a part of the royal property. In 1447, it was seized by John Jiskra who later made a bargain with a royal successor, Matthias Corvinus, who bought it for his spouse, Queen Beatrice. In 1490, the queen gave it with Šášov Castle to the Dóczy family as a reward for their loyal service. As with many other castles in Central Slovakia, it remained in their possession until 1647. After the last member of the Dóczy family was executed, the castle came under the administration of the main Chamber County in Banská Štiavnica. The castle was thus left at the mercy of Thököly's anti-Habsburg insurgents. The castle was seriously damaged during their defeat at the Battle of Svätý Kríž. After a partial reconstruction, it later served to accommodate the mining chamber officers in 1790–1792. The castle gradually fell into ruin, which it eventually became in the 19th century (Photo 1, 2).

Photo 2 Upper part of the castle as viewed from the tower (© P. Pachinger).

Geotope no. 61

The Vígľaš Hill

rock cliffs of amphibole-pyroxene andesites of the Žiarska Kotlina effusive complex

The Žiarska Kotlina effusive complex, which is located at the north-western slope of the Štiavnica Stratovolcano (west of Ostrý Grúň), consists of the products of effusive activity during the Sarmatian. The effusive complex consisting of several lava flows is inclined towards the north-east. The base of the effusive complex at its eastern edge below Víglaš (elevation 911 m) is at a level of ca. 850 m above sea level, and in a direction facing north-west below Klenový Vrch Hill, it subsides to the level of ca. 700 m above the sea level. It seems that the lava flows followed the paleodoline inclined towards the north-west.

The bedrock at the northern edge of the lava complex consists of extrusive bodies of hypersthene-amphibole andesite of the earlier Plešina Formation, in the southern part, the lava flows deposited in the overlying rock of the lava flows of pyroxene andesites of the Markov Vrch Hill stratovolcano. Looking at the pre-volcanic bedrock, the western edges of the complex are tectonic alongside the fault stretching from NNE towards SSW.

The lava complex is composed of individual lava flows of up to 50–100 m in thickness. Some flows form a base for a brecciation zone with distinctive foamy lava structures oxidised to at least 1 m in thickness. At a higher level, it is transformed into andesite with mural (lamination) jointing, which is roughly parallel to the bedrock, along which the lava flow mo-

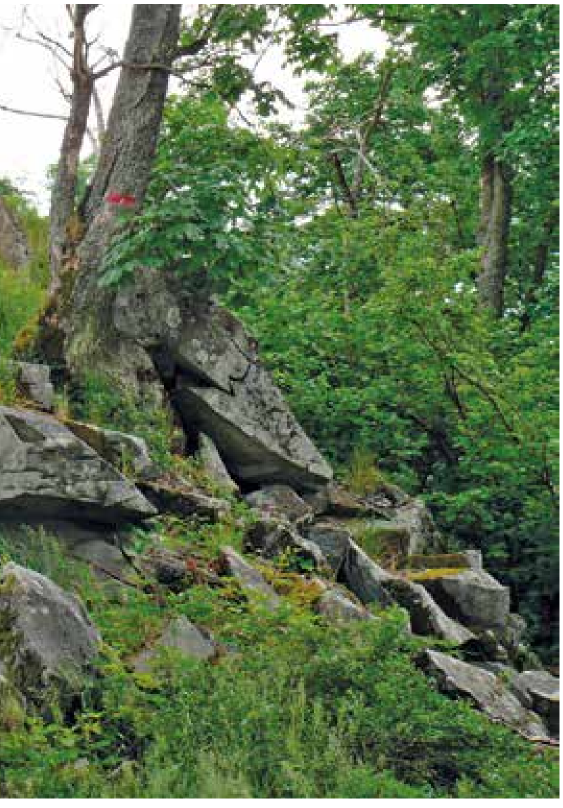


Photo 1 Block disintegration of the rock cliff of amphibole-pyroxene andesite at the top of the Vígľaš Hill (© P. Pachinger).

ved. The middle and the upper part of the lava flow consists of andesite with coarsely-columnar to irregular blocky jointing. It retransformed into a zone of light porous lava breccias in the upper part.

An andesite rock cliff with mural jointing alongside lamination planes, inclined ca. 10° southwards and with traces of coarsely-columnar jointing alongside subvertical planes (Fig. 1, Photo 1) protrudes at a sharp-edged crest of Vígľaš Hill (elevation 911 Víglaš).

Andesite is dark grey, coarse-grained porphyric, phenocrysts consist of plagioclase (4–6 mm), abundant amphibole up to 2–4 mm (occasionally up to 6 mm), and hypersthene (1–2 mm). Olivine was found in isolated cases. The base matter is microlitic-pilotaxitic.

Vígľaš Hill offers a panoramic view of the area of Kľak and of the southern slopes of Vtáčnik Mountain (Photo 2).

Photo 2 View from Vígľaš Hill towards north, at the southern slopes of Vtáčnik Mountain, Kľak valley, and the Kremnica Mountains to the right (© P. Pachinger).

Fig. 1 The rock cliff of amphibole-pyroxene andesite of the Žiarska Kotlina complex (elevation 911 Vígľaš). Andesite is characterised by mural jointing inclined southwards, and less distinctive jointing alongside subvertical planes (© V. Konečný).

Geotope no. 62

The Rakytie Hill

lava flow of amphibole-pyroxene andesite in the crest area of the Rakytie Hill (elevation 679) – the Žiarska Kotlina effusive complex

After the formation of the Štiavnica caldera (Sarmatian), volcanic activity was renewed from several eruption centres situated within the caldera area as well as on the stratovolcanic slope. The renewed explosive-effusive activity resulted in the formation of numerous smaller satellite volcanoes. The massive lava effusions formed extensive lava plateaux, mainly at the south-western and western stratovolcanic foot.

After denudation of these volcanoes, only their remains were preserved in the form of volcanoclastic rocks and lava flows, which cover the products of earlier stages of volcanic activity at the north-western slope of the Štiavnica Stratovolcano. One of these remains of denudation is a lava flow in the crest area of the Rakytie Hill (elevation 679).

The Žiarska Kotlina effusive complex consists of denudation remains of lava flows of amphibole-pyroxene andesites, situated at the north-western stratovolcanic slope (east of the Žiarska Kotlina Basin), Fig. 1.

Volcanoclastic rocks were removed by denudation. The eruptive centre of the original volcano has not been identified. However, based on the spatial arrangement of the remains of the lava flows, it is assumed that it was located in the north-western part of the Štiavnica caldera (at present, this area is located in a subsided position within the Žiarska Kotlina Basin – graben depression), covered by later sediments.

Due to their higher resistance to weathering, denudation remains of the lava flows cover contemporary hills and crests (less resistant surrounding rocks, mainly the volcanoclastic ones, were removed by denudation). It is mainly the Žiar Hill (elevation 845), Kološiar Hill (elevation 606), Rakytie Hill (elevation 679), and Ležisko Hill (elevation 759). The lava flows initially filled the paleodolines at the north-western stratovolcanic slope.

The lava flows of the first group (closer to the edge of the Žiarska Kotlina Basin) within a subsided block lie directly on the rocks of the bottom structure of the Štiavnica Stratovolcano (Kološiar Hill), and on the rocks of the fill of Kremnica Graben (Rakytie Hill) more to the north.

West of the subsided block, the remains of the lava flows lie on the products of extrusive volcanism of the Plešina Formation (lava flows of Žiar Hill and Ležisko Hill). They are located ca. 150–200 m higher in relation to the subsided block at the western edge of the Žiarska Kotlina Basin.

The western group of the lava flows (Vígľaš Hill, Klenový Vrch Hill) also lie on the products of extrusive volcanism of the Plešina Formation, and

Fig. 1 The rock cliffs of amphibole-pyroxene andesite at the top of the crest of Rakytie Hill. Andesite has thick mural subhorizontal jointing inclined towards north-west (© V. Konečný).

at the same time in the overlying rock of the lava flows of the Markov Vrch Hill volcano.

The spatial arrangement of the lava flows indicates that they initially filled two distinctive paleodolines: a) the eastern one stretching from NNE to SSW, with lava flows relicts of Koložiar Hill and Žiar Hill; b) the western one stretching from NW to SE, with lava flows of Vígľaš Hill and Klenový Vrch Hill).

The lava bodies are predominantly inclined 5–10° westwards. They were following the original relief of the bottom of wide paleodolines. After their surrounding softer rocks were denuded, they found themselves in the peak positions. The abovementioned process is called the inversion of relief.

Lava flows are relatively massive, reaching a thickness of 50–100 m. The base of the lava flows bears a zone of brecciation of up to 1 m, with distinctive foamy structures and oxidation of brecciated lava. Above this base lava breccia, distinctive lamination jointing was formed, which is subparallel to the bedrock surface, along which the lava flow moved. Higher above in the central part of the flows, there is irregular blocky jointing, occasionally being transformed into coarsely-columnar. The upper part of the lava flows consists of a relatively thick zone of light porous lava breccias.

Andesite is dark grey, coarse-grained porphyric, phenocrysts consist of plagioclase (4–6 mm, or even 8 mm), amphibole (2–4 mm), occasionally hypersthene (up to 1–2 mm) and olivine. The base matter is microlitic-pilotaxitic. Andesite has plated to irregular blocky jointing alongside lamination planes.

The crest area of the Rakytie Hill offers an impressive panoramic view of the Žiarska Kotlina Basin between volcanic mountains (Fig. 2, Photo 1).

The basin was formed during the Sarmatian to Pannonian by massive subsidences alongside the subparallel faults stretching from NNE towards SSW within (the southern part of) the Kremnica Graben. In its upper part, the basin is filled with the Pannonian to Pliocene sediments. During the Late Sarmatian, rhyolite volcanism was active at the eastern and southern basin edges. Its products consist of lava bodies in the form of extrusive domes and bedded intrusions (sills, laccolites) protruding within the zone of tuffs and breccias. A close-grained tuff material had been washed away into the central or even western part of the basin, where it has become a part of sediment formations.

Fig. 2 Rock cliffs in the southern crest part of Rakytie Hill. The rock cliffs offer an impressive view of the Žiarska Kotlina Basin area to the east (© V. Konečný).

During the Pannonian, basaltic andesite volcanism was taking place at the south-eastern and eastern edges. Denudation remains of this volcanism form basaltic andesite bodies in the form of dykes, necks, intrusions, bedded intrusions, and lava flows, and the products of explosive activity in the form of tuff cone remains at the eastern edge of Žiar nad Hronom (Geotope no. 70 Šibeničný Vrch Hill).

Photo 1 A view of the southern part of the Žiarska Kotlina Basin and of northern slopes of the Štiavnica Mountains, as seen from the crest area of the Rakytie Hill (© P. Pachinger).

10. Tourism Territorial Unit Žiar nad Hronom

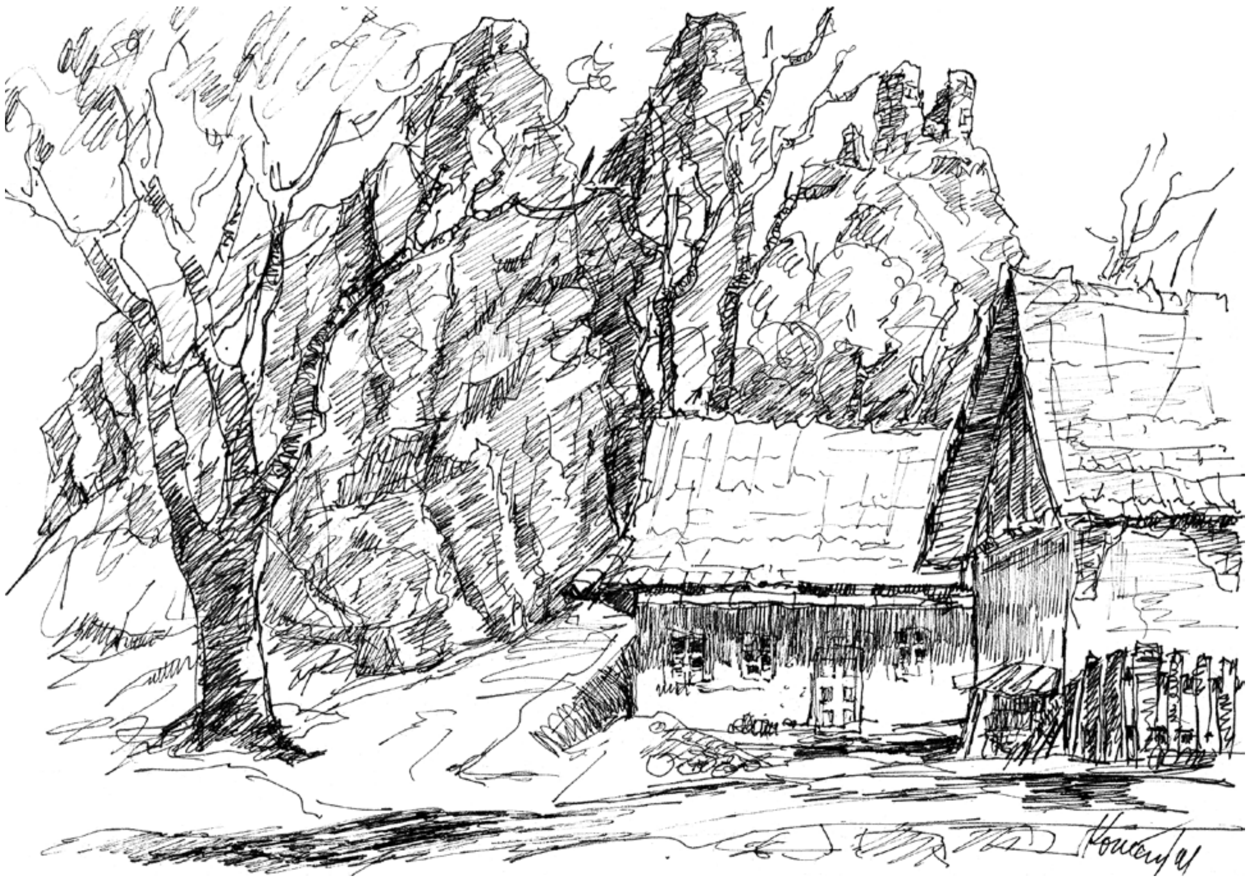


Fig. 1 The rock cliff at Šášovské Podhradie consists of vitreous leucocratic pyroxene andesite of the Turček Formation. This andesite shows irregular blocky jointing and is partly brecciated. The Šášov Castle ruins can be found on its top (© V. Konečný).

Geotope No. 63
Šášovské Podhradie
andesite rock cliff, the Turček Formation

From the north, the massive Kremnica Graben (a depression, which was formed by subsiding along the sub-parallel faults) extends to the northern edges of the Štiavnica Mountains. The eastern edge of this depression, which marks the fault zone, runs from the southwestern edge of Šášovské Podhradie towards the southwest, and divides the subsided western block with the products of rhyolitic volcanism from a relatively uplifted block of the Farská Hora Hill on the eastern side of the fault zone. The fault zone continues north of the Hron River, east of Pitelová and Jastrabá and into the northern part of the Kremnica Mountains.

A rock cliff consisting of vitreous leucocratic andesite protrudes at the northern edge of Šášovské Podhradie (Fig. 1, Photos 1 and 2).

Based on its analogous petrographic composition, this andesite has been determined to be part of *the Turček Formation* (J. Lexa, 1998).

The Turček Formation, which dates back to the Baden, consists of a lithographically varied series of lava flows, hyaloclastite and pyroclastic breccias, epiclastic basaltic andesite, pyroxene andesite, and leucocratic andesite, which fill the bottom part of the Kremnica Graben and are about 500 m thick. The Turček Formation rises to the surface north of the Hron River in the area of the Kremnica Mountains. The rocks with an analogous composition and geological position, which rise west of the edge of the

Žiarska Kotlina Basin, known as *the Kľak Formation*, are considered to be roughly the same age as the Turček Formation located in the Kremnica Mountains.

The rock cliff at Šášovské Podhradie consists of grey-black vitreous and leucocratic andesite, which is identical with the castle rock on which the Šášov Castle ruins can be found.

The andesite is sparsely porphyric, mildly porous, with irregular blocky to brecciated jointing. The lava flow has not been preserved in its original position – it has been erected due to a subsidence at the fault located at the edge of the Kremnica Graben.

The rock cliff faces a trench in the road, which exposes a tectonically disrupted zone. It runs along the fault at the edge of the Kremnica Graben, from NE to SW. The tectonically disrupted zone shows tectonic breccias and tectonically crushed andesite porphyry rocks as well as mild argillitisation.

Ruins of the medieval Šášov Castle can be found on the top of the rock cliff (Photo 3). This castle was mentioned for the first time in 1253 as a property of the de Vancha brothers. One of them, Štefan, was the archbishop of Esztergom. Šášov Castle and Revište Castle, which is located further to the south on the other side of the Hron River, used to protect the passage and ro-

Photo 1 The pyroxene andesite rock cliff of the Turček Formation. The Šášov Castle ruins can be seen in the background (© P. Pachinger).

Photo 2 A close-up of the rock face consisting of massively brecciated andesite with a transition into a hyaloclastite breccia (© P. Pachinger).

ads to the mining site, mainly Banská Štiavnica. Maybe that was the reason why Šášov Castle was acquired by an important Štiavnica Count in 1320. It became the centre of the Šášov Estate. During the Gothic and Renaissance periods, its owners frequently changed. In 1424, King Sigismund gifted it to Queen Barbara of Cilli, but by 1447, it already belonged to John Jiskra of Brandýs. In 1490, Queen Beatrice of Naples, the wife of King Matthias Corvinus, gifted it to the Dóczy family who owned it until their family died out in 1647. In 1650, Gáspár Lippay bought the castle estate. During the Thököly Uprising in 1677, insurgents took over the castle and plundered it. Since then, it was managed by the country administration, but when it lost its protective function in the 18th century, it became dilapidated.

Photo 3 The Šášov Castle ruins – a close-up of the interior (© V. Konečný).

Geotope No. 64
Močiar
siltstone, claystone, diatomites – sediments of the intra-caldera basin

During the early Sarmatian, after the Štiavnica caldera was formed, local lakes and swamps formed in different parts of the caldera in which close-grained siltstone and claystone with diatomites sedimented. Leaf prints in the lake sediments indicate that these lakes and swamps were surrounded by vegetation, deciduous and coniferous forests.

The diatomic clay and phreatopyroclastic tuff found north of Močiar (the village is called literally a "swamp" in Slovak) in the north-eastern part of the caldera fill confirm the existence of one of these lakes. The dirt-covered slope of the abandoned quarry pit shows partly exposed lake sediments (Photo 1).

Photo 1 A general view of the diatomic clay quarry pit north-west of Močiar (© P. Pachinger).

At the bottom levels of the sedimentary complex, positions of claystones alternate with volcanic sandstones and tiny andesite fragments (Fig. 1). The overlying tuff-sandstone rock contains diatomic clay and light grey to grey-white diatomites.

Slightly higher above the diatomites (quarried in the past) lay ash-pumice tuffs containing amphibole. The overlying rock contains a thin layer of grey-blue to blue-green siltstones often with leaf prints (Fig. 2 and 3, Photo 1).

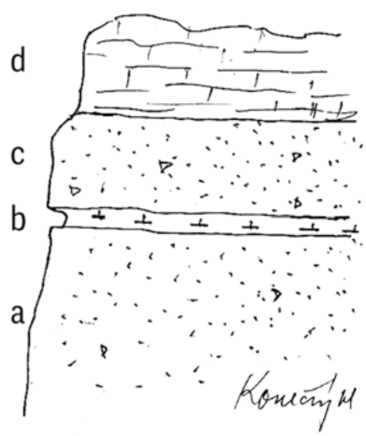


Fig. 1 Sediments at the bottom of the abandoned quarry pit (Ján Smolka et al., 2005):

a) unsorted sandstones with andesite fragments up to 5–8 cm,
b) light yellow claystones,
c) unsorted sandstones with occasional andesite fragments,
d) diatomic clays, diatomites.

Fig. 2 Ash-pumice tuff above the diatomites (Ján Smolka et al., 2005).

a) dark ash tuff,
b) grey-blue to blue-green siltstone with leaf prints,
c) ash-pumice tuff.

The overlying rock above the siltstone layer contains ash-pumice tuffs with a high content of amphibole, which are products of phreatopyroclastic eruptions. The phreatopyroclastic activity has deposited ash-pumice tuff. The light grey to ochre pumice fragments (up to 1–3 cm) are dispersed in the more close-grained ash-pumice matrix. Tiny, mostly angular andesite fragments occur frequently. Layering is indistinct or not present at all. Phreatopyroclastic rocks often alternate with tiny siltstone interbeds (Fig. 4).

The overall thickness of the phreatopyroclastic deposits in the overlying rock above the diatomites is 8–10 mm. The tuffaceous clay with diatomites is max. 5 m thick. This volcanic-sedimentary complex located in a lake environment allows for the following reconstruction: During

Fig. 3 Leaf prints in the siltstone (© V. Konečný).

Foto 2. Zachované listy v polohe siltovca (© P. Pachinger).

the temporary volcanic quiescence, sedimentation took place in the isolated swamp-lake environment, which is favourable for the development of organisms with a cretaceous shell, i.e., Diatomacea and lake flora. The peaceful sedimentation in the swamp-lake environment was interrupted by a sudden landing of the ash-pumice material (which fell from a volcanic cloud) as the explosive activity of the amphibole-pyroxene andesites started. Afterwards, the sedimentation continued for a short time as a layer of grey-blue siltstones indicates. Phreatopyroclastic eruptions caused by a rising magma, which came into contact with water, followed. The ash-pumice material was transported into the lake sedimentation area via pyroclastic flows, specifically base surges. During the break in the volcanic activity, the sedimentation of lake clays continued in the renewed lake environment. New phreatomagmatic eruptions definitively stopped sedimentation and in turn, life in the lake environment. The volcanic ash and pumices were deposited, thus creating the upper part of the fill of the local sedimentary basin.

In the broader surroundings, specifically in the northern part of the caldera, the remains of ash-pumice tuffs – the Biely Kameň Formation – were covered with lava flows of amphibole-pyroxene andesites of the *Sitno effusion complex.*

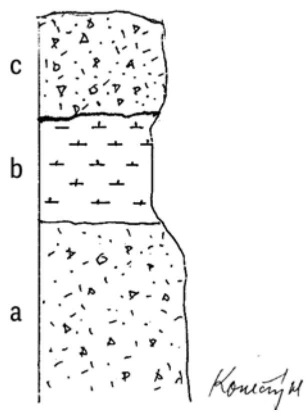


Fig. 4 Phreatopyroclastic tuff in the overlying rock above the diatomites, alternating with siltstone interbeds (J. Smolka et al., 2005):

a) ash-pumice tuff with tiny andesite fragments,
b) light grey claystone,
c) ash-pumice tuff with andesite fragments.

When V. Sitár (1970) evaluated the leaf prints and macrofauna remains in the sediments of the swamp basin, he concluded the basin was formed during the Early Sarmatian period.

Geotope No. 65

The Suť Hill

amphibole-pyroxene andesite protrusion

Besides the denudation remains of the Sarmatian volcano products, i.e. the lava flows and volcanoclastic rocks deposited on the surface of the earlier Baden stratovolcano on the stratovolcanic slope and in the caldera, geological mapping identified bodies of volcanic feeder systems such as dykes, necks, and protrusions. The position of these feeder systems indicates that parasitic (satellite) volcanoes probably existed on the stratovolcanic slope and in the caldera. However, they were completely removed from the stratovolcano's surface due to denudation.

The Suť Hill (elevation 718) located in the northern stratovolcanic slope represents a dominant hill, and its steep slopes tower high above the surrounding hills and crests (Photo 1).

Photo 1 The land north of Močiar with the top of the Suť elevation in the background (718) (© P. Pachinger).

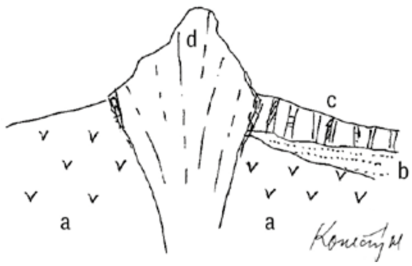


Fig. 1 Scheme of the andesite intrusion (protrusion) on the Suť hilltop (J. Smolka et al., 2005):

a) – amphibole-biotite andesite,
b) – redeposited tuffs and epiclastic rocks of the Biely Kameň Formation,
c) – a lava flow of amphibole-pyroxene andesite,
d) – intrusion (protrusion) of amphibole-pyroxene andesite on the Suť hilltop.

The hilltop of the Suť elevation is actually a massive intrusion of medium to coarse-grained porphyric amphibole-pyroxene andesite with an elliptical cross-section and dimensions of 500x200 m oriented from NNW to SSE. The intrusion (protrusion) penetrates a thick lava flow of similar composition. A horizon of epiclastic rocks and redeposited tuffs of the Biely Kameň Formation have been deposited in the bedrock of the lava flow (Photo 1).

This is the reason for the massive landslides, which continue northwards into the valley of the Hron River.

The andesite on the Suť hilltop is dark grey to grey-black, distinctive phenocrysts are composed of plagioclase (3–4 mm), amphibole (4–6 mm), and pyroxenes (2–3 mm). Jointing is irregular blocky (Fig. 2, Photo 2).

On the southern crest below the hilltop, coarsely-columnar jointing with a subhorizontal course (column disintegration) indicates that the body transformed into a dyke further in the south.

Fig. 2 Andesite with irregular blocky jointing – a view from the Suť hilltop (© V. Konečný).

Fig. 3 The block slope on the western slope under Suť elevation (© V. Konečný).

On the western side of the Suť elevation, there is a large block slope of periglacial origin, which was probably formed during the last glacial age (Fig. 3, Photo 2).

From the hilltop of the Suť elevation, there is a southwards panoramic view of Banská Štiavnica, the caldera fill around Močiar (Photo 3), course of the caldera's edge, dyke swarm near Močiar, and mountains covered with the remains of lava flows from the period of Sarmatian volcanism (4 stages of the Štiavnica Stratovolcano formation). Further in the distance, the Hodruša-Štiavnica Horst (elevated structure) can be seen.

Photo 2. The block slope on the western slope under Suť elevation (© P. Pachinger).

Photo 3 A view of the mountains around Močiar. The mountains around Banská Štiavnica can be seen on the right (© P. Pachinger).

Geotope No. 66

Hronská Breznica

debris flows, lahar breccias, epiclastic volcanic breccias and sandstones

Due to renewed volcanic activity with a larger number of eruption centres within the caldera area and on the stratovolcanic slope during the Sarmatian period, multiple smaller volcanoes known as *satellite volcanoes* were formed (in the older volcanological terminology, they were referred to as parasitic volcanoes). The denudation remains of these volcanoes, which take the form of lava flows and volcanoclastics (e.g. the Sitno lava flow) can be found in the caldera area, but they are especially common on the stratovolcano slope. One of these volcanoes, the Breznica Volcano, was located in the northern part of the caldera near the caldera fault (Fig. 1).

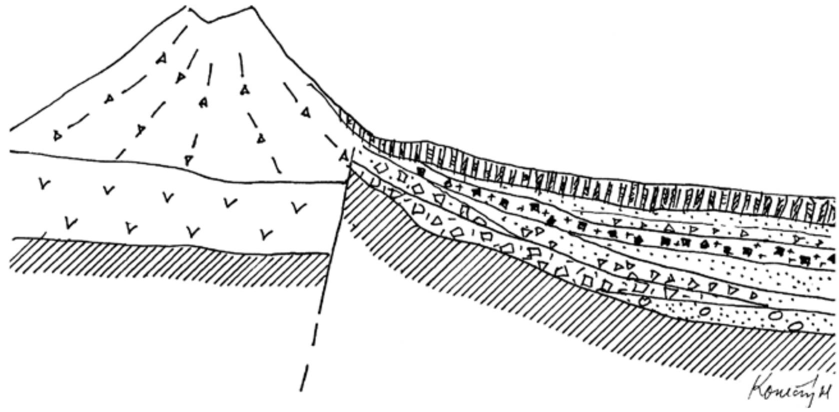
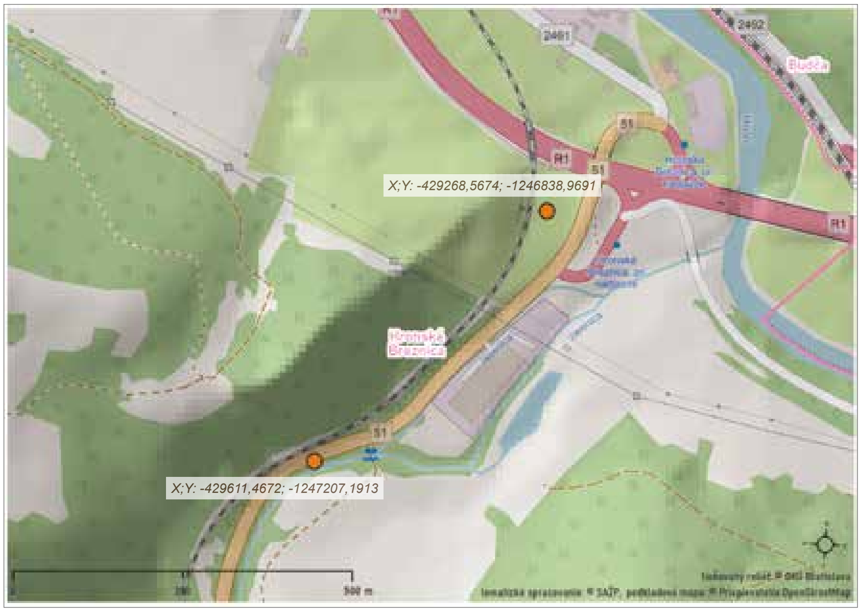


Fig. 1 Scheme of the Breznica Volcano's structure in the northern part of the Štiavnica caldera and its volcanic products deposited in the paleodoline, which extends towards the Kremnica Mountains in the north (J. Smolka et al., 2005).

Fig. 2 A chaotic lahar breccia in the trench of the state road near Hronská Breznica (© V. Konečný):

a) in the bottom part of the exposure, an epiclastic volcanic breccia with tuff-sand matrix was deposited,
b) in the overlying rock, there is a discontinuous layer of tuff-sand sediment,
c) a chaotic coarse to large-block lahar breccia in the upper part of the exposure.
The upper right part contains andesite blocks with radial jointing. A piece of a large-block chaotic breccia slipped from a higher position to the right bottom area.

This is evidenced by the remains of lava flows and volcanoclastic rocks deposited in the overlying rock within the caldera fill, which cover numerous hilltops. The products of this volcano can found be often on the northern stratovolcanic slope filling deep paleodolines, which are cut into the surface of an earlier Baden volcano. According to the JF-1 borehole (south of Jalná), these paleodolines, which are filled with the products of the Later Sarmatian volcanism, can reach a depth of 500 m. This indicates that *the Breznica Volcano* used to have a very high relief, which is in line with the amount of gravitational energy that transported the fragment flows and lahars. The products of the Breznica Volcano can also be found northwards, i.e., at the southern edge of the Kremnica Mountains (north of Hron), where it grew thicker and broader, and formed alluvial fans (Fig. 1).



A mixed volcanoclastic material can be found in the lower levels of the paleodoline fill. Besides the products of a new stage of the volcanic activity (pyroxene and amphibole-pyroxene andesites), older fragments of biotite-amphibole andesites, which come from the destructed and denudated bodies in the caldera fill, are present here.

In the middle and higher levels of the paleodoline fill on the northern and north-eastern slopes, breccias of block-and-ash flows (Hronská Breznica – flyover) can be found besides the epiclastic volcanic material. The upper level of the fill contains lava flows, which are part of the hilltop of the Boky Crest (north of the Hron River).

Photo 1. *The chaotic large-block lahar breccia lies discordantly on another close-grained breccia. There is a discontinuous layer of sandy sediment on the lahar's base. In the lower right part, there is a piece of a large-block lahar breccia, which slipped there. A block with radial jointing can be seen in the upper right part of the lahar breccia (© P. Pachinger).*

The bottom level of the paleodoline fill, into which the Jasenica Stream valley cuts, has been exposed by trenches of the state road near Hronská Breznica (in front of the bridge across the Hron River under the railway) Fig. 2, Photos 1 and 2.

At the bottom, there is a protruding epiclastic volcanic breccia with andesite fragments (5–30 cm) and tuff-sand matrix containing disseminated pumice (Fig. 2.a). There is a thin, discontinuous layer of a tuff-sand sediment on the surface of the bottom epiclastic volcanic breccia (Fig. 2.b).

The overlying rock contains a chaotic lahar breccia whose base is in sharp, discordant contact with the underlying sediment (Fig. 2.c). The lahar breccia consists of fragments to blocks and their size varies from 5 to 40 cm. Sporadically, there are blocks of up to 2 m with typical radial jointing and glassier edges. They are isometric to elliptical. The fragmented material is mostly angular to subangular. The sand-tuff matrix contains tiny angular andesite fragments with up to 3–5 cm and variable amounts of pumice

Photo 2. A close-up of the large-block chaotic lahar breccia deposited on a layer of an epiclastic volcanic close-grained breccia. There is a discontinuous layer of sandy sediment on the lahar's base (© P. Pachinger).

(Photo 2). Besides the fragments of amphibole-pyroxene andesite, the variable part (5–15%) contains fragments to blocks of biotite-amphibole andesite, which come from the destructed rocks within the caldera fill. Their positions are chaotic and correspond with a one-time mass transport of the fragmented material due to gravitation, i.e., it is a lahar. The right part of the exposure shows a block of chaotic lahar breccia, which slipped into place.

The blocks with radial jointing and edges that turned vitreous upon cooling were produced by disintegration of an extrusive body (extrusive dome) or a lava flow that came into contact with water (snow or ice) around the top of the volcano. The disintegration of the lava body probably destabilised the material on the volcano slope, which started moving and turned into a mass flow, i.e., a lahar. The chaotic mix of fragments, ash, and water-saturated sand was steered by the gravitational energy and this mass moved through the paleodoline northwards toward the foot of the stratovolcano.

Fig. 3. The trench above the railway exposes the paleodoline fill – a formation of epiclastic volcanic rocks. In its central part, there is an erosion furrow on the surface of layered, sorted epiclastic rocks, lahar breccias, and epiclastic sandstones filled with a chaotic lahar breccia. In the upper part of the exposure, the epiclastic volcanic sandstones alternate with lahar breccias and epiclastic volcanic breccias (© V. Konečný).

Photo 3. In the trench above the railway closer to the Hron River, there is a large exposure, which shows the fill consisting of epiclastic volcanic rocks (© P. Pachinger).

Photo 4. In its central part, there is an erosion furrow filled with a chaotic lahar breccia. The edge of the erosion furrow is outlined by the black line. In the upper left part, layered epiclastic volcanic sandstones with tiny epiclastic volcanic breccias can be seen (© P. Pachinger).

In the trench above the railway closer to the Hron River, there is a large exposure, which shows the fill of the paleodoline running northwards (Fig. 3, Photos 3 and 4).

In the upper central part (Fig. 3, Photo 4), there is a distinct channel filled with a chaotic coarse-fragment breccia. The overlying rock contains close-grained to coarse-fragment breccias with chaotic positions, which used to be fragmented flows. The tiny breccias with signs of sorting and layering alternate with tiny interbeds to layers of epiclastic volcanic sandstones. These deposits were created by temporary, hyperconcentrated flows on the northern slopes of the Štiavnica Stratovolcano, which transported the fragmented and sandy material towards the foot of the stratovolcano, where they were deposited as alluvial fans and a prolluvial plane.

In the bottom part, chaotic breccias (debris flows, lahars) alternate with epiclastic volcanic breccias with indicated sorting and layering. They are divided by thin, irregular interbeds to layers of sandstones (Photo 5).

Photo 5. Close-up of a chaotic large-block lahar breccia in the bottom part of the exposure above the railway deposited in the fill of the erosion furrow in epiclastic volcanic sandstone – the bottom part (© P. Pachinger).

Geotope No. 67

Hronská Breznica – flyover

chaotic breccia of a pyroclastic flow

In the fill of the paleodoline, which extends northwards of the northern slope of the Štiavnica Stratovolcano, there are not only epiclastic volcanic breccias, lahar breccias, fragment flows, and sandstones, but also chaotic breccias of block-and-ash flows deposited in the central levels.

The chaotic breccia of a block-and-ash flow formed the rock cliff on the southern slope under the Čertova Skala Hill (under the flyover near the Hron River), see Fig. 1, Photo 1.

This breccia consists mainly of angular andesite fragments sized 5–30 cm (ca. 30%) and blocks sized 0.6 – 1.5 m (ca. 20 %). Blocks with jointing along

Fig. 1. The chaotic large-block breccia of the block-and-ash pyroclastic flow in the rock cliff near the state road flyover leading to Hronská Breznica (© V. Konečný).

the radial cracks are common (a manifestation of autoexplosivity), fragments to blocks pertaining to an older volcanic structure can be found in isolated cases. Smaller fragmented material is partly subspherical and has a porous structure. The tuff matrix is highly consolidated to sintered, dark grey to reddish. Its position is chaotic.

The petrographic composition of the fragmented material corresponds with amphibole-pyroxene andesite (± biotite).

The pyroclastic block-and-ash flow starts on the outer side of the crest south of Hronská Breznica and continues northwards under the Čertova Skala Hill (north of the Hron River). In accordance with the paleodoline's morphology, it has broadened significantly (to ca. 3 km) and continues towards the south-eastern edges of the Kremnica Mountains. Here it was covered by later lithofacial units of the Breznica Complex. The course of the pyroclastic flow's base copies the cauldron-like relief of the paleodoline (Fig. 2).

The presence of the deposited block-and-ash pyroclastic flows in the central and upper levels of the paleodoline fill indicates an increased explosive volcanic activity during which the volcanic structure expanded. In the later to final stages of this volcanic activity, lava flow effusions prevailed. They flowed from the crater towards the stratovolcano's foot and their course was directed by the broadening paleodoline. Finally, they covered the volcanoclastic rocks. Today, the denudation remains of the lava flows cover the hilltops of the crests known as Črangalov grúň – Bučan – the Čertova Skala Hill – Boky.

Photo 1. The chaotic large-block breccia of a pyroclastic flow mostly consists of angular fragments to blocks. The tuff-ash matrix shows the signs of high consolidation to sintering with tiny fragments (© P. Pachinger).

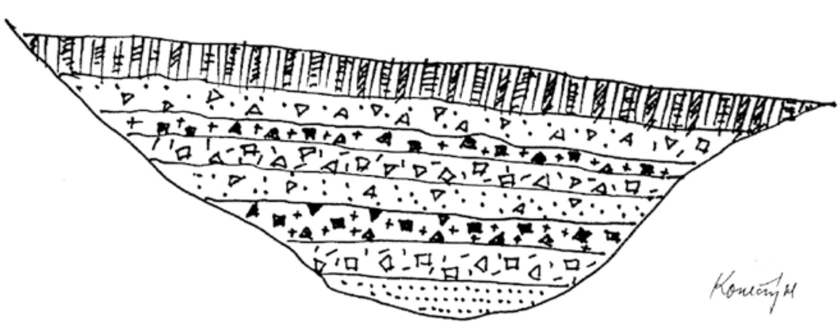


Fig. 2. Scheme of the paleodoline fill on the northern slope of the Štiavnica Stratovolcano. The bottom part of the fill consists mostly of an epiclastic volcanic material with chaotic breccias of pyroclastic flows on the top, which alternate with lahar breccias. The paleodoline fill is covered by a lava flow (J. Smolka et al., 2005).

Photo 2. Close-up of the large-block breccia of a pyroclastic flow, which consists mostly of angular fragments to blocks (© P. Pachinger).

The chaotic block-and-ash flows are the result of volcanic eruptions and are associated with the formation of an eruption column. A burning mixture of gases, ash, and semi-solid to solid lava fragments to blocks including the fragments and blocks of the older volcanic structure is ejected into the atmosphere. When the eruption column collapses and lands, it turns into a turbulent, high-temperature flow rolling down the slope from the crater. However, pyroclastic flows can also be formed during an explosive destruction of the lava dome protruding from the crater or a crack in the volcanic slope.

The mixture of expanding, highly compressed burning gases, ash, solid and semi-solid to plastic parts of lava (from the internal part of the extrusive dome), which rolls down the slope, is often referred to as a glowing avalanche. The abovementioned formation process is evidenced by blocks with radial jointing and glassier, cooled edges found in the pyroclastic flow found in this location (Photo 2).

Geotop č. 68

Stará Kremnička

rhyolite extrusive dome

During the final stage of andesite volcanism, there was an active rhyolitic volcanism in the Central Slovak neo-volcanic area. The explosive volcanism in the form of ash-pumice tuff, lava extrusion (extrusive dome), and lava flow eruptions of the Late Sarmatian concentrated mainly around the southern, eastern, and north-eastern edges of the Žiarska Kotlina Basin (Graben-type depressions), which was intensively subsiding during this period. The extrusions and effusions of the rhyolite lava took place mainly along the massive fault zone along the eastern edge of the Žiarska Kotlina Basin, which continues northwards into the Kremnica Mountains. The products of this volcanic activity, mainly ash-pumice tuffs and breccias, were washed down and transported by watercourses, and deposited in the central to eastern part of the Žiarska Kotlina Basin in the form of thick sedimentary formations.

When the rhyolite lava rose to the surface, it accumulated around the feeders due to its high viscosity (reduced ability to flow) and formed cumulous shapes referred to as extrusive domes.

There are two main types of extrusive domes:

a – *exogenous extrusive domes* – formed by the rhyolite lava flowing out and sideways,

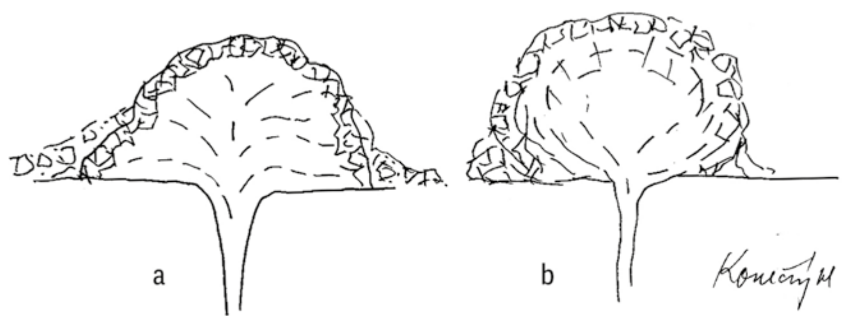


Fig. 1. Scheme of the two types of extrusive domes (J. Smolka et al., 2005):

a) exogenous extrusive dome, b) endogenous extrusive dome.

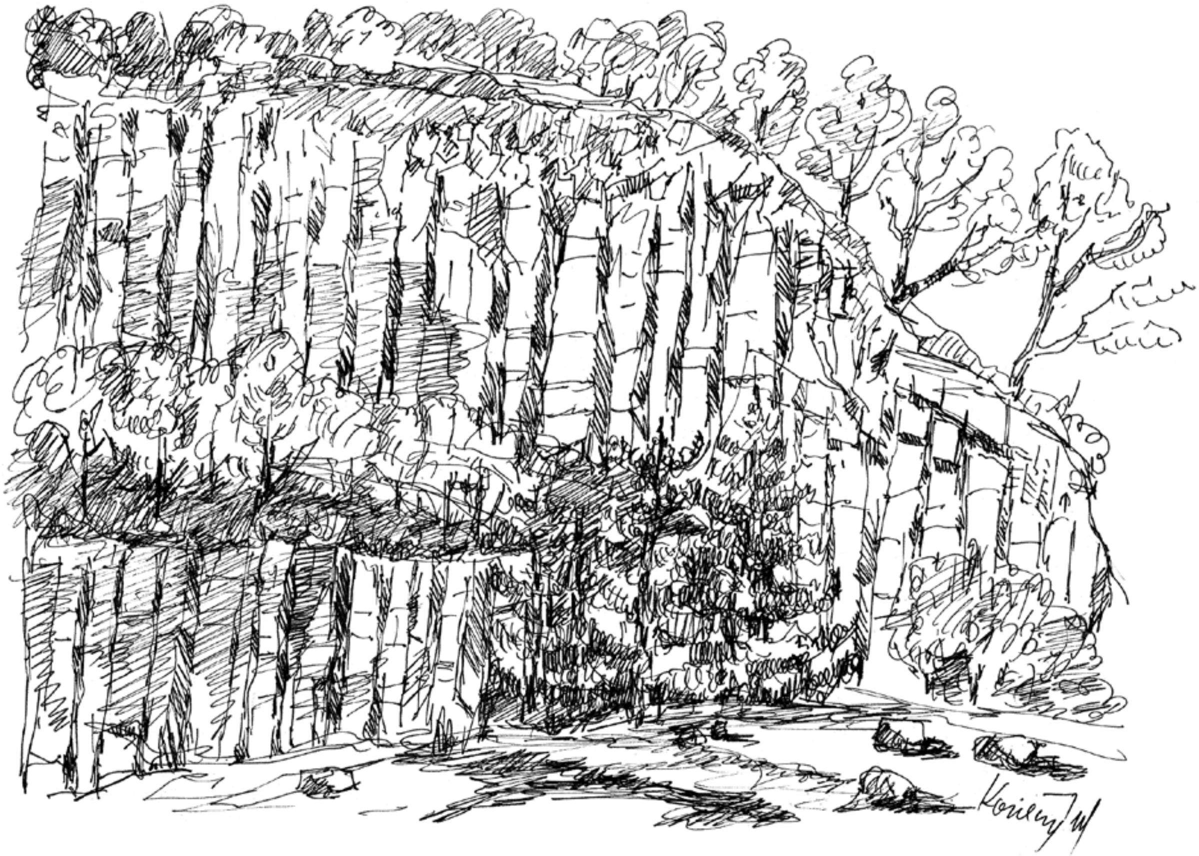


Fig. 4. The abandoned rhyolite quarry in the southern slope of the Skalka elevation (south of Stará Kremnička). Distinctive subvertical columnar jointing of the rhyolite can be seen (© V. Konečný).

Fig. 2. An extrusive dome having been transformed into a lava flow (J. Smolka et al., 2005).

b – *endogenous extrusive domes* – formed by internal expansion caused by the influx of more lava from the inside (Fig. 1),

On steep slopes, lava often turns into a short but powerful flow. This is referred to as a dome flow, see Fig. 2.

The body near the Skalka Crest (elevation 412) located south of Stará Kremnička represents an example of an extrusive dome (type 2). This extrusive dome with an irregularly elliptical cross-section covers an area of 1,000 m x 500 m. Its longer side is oriented from NE to SW. It is interrupted by the valley of the Kremnica Stream, but the railway trench shows that it continues to the northeast. This extrusive body penetrates surrounding epiclastic rhyolite sandstones, conglomerates, breccias, and tuffs. The course of mural jointing at its edges copies its distinctive fluidality and indicates a vertical contact with the surrounding volcanoclastic rocks (Fig. 3).

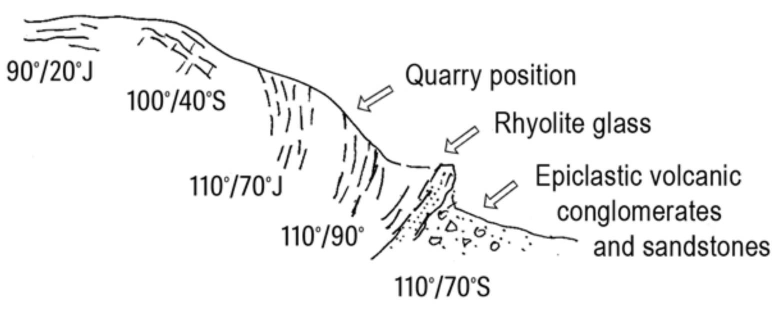


Fig. 3. The course of the fluidality planes (lava movement direction) found on the extrusive dome in the Skalka area (J. Lexa, 2005).

The edges of this extrusive body consist of vitreous rhyolite to rhyolite glass (obsidian) with the thickness of 5–8 m. Further inwards, this vitreous rhyolite turns into spherulitic rhyolite (rhyolite with spherulitic base matter) or even grey-white rhyolite (with felsite base matter consisting of feldspar needles).

Photo 1. An overview of the rhyolite quarry wall. Subvertical columnar jointing of the rhyolite with the transition into a rhyolite breccia in the upper part (© P. Pachinger).

In the abandoned quarry in the eastern slope under the Skalka Crest (elevation 412), the edge of this extrusive dome has been exposed. It consists of light to white rhyolite with coarsely-columnar subvertical jointing (Fig. 4, Photo 1). Cavities left by escaping gases – lithophyses are irregular to steeply oriented (Photo 2).

Rhyolite is a sparsely porphyric sanidine quartz with sanidine phenocrysts (potassium feldspar), quartz, biotite, and sometimes plagioclase in the felsite base matter. The fluidal texture often takes the form of alternating dark and light stripes. The pores and cavities left by the escaping gases are indistinctive.

In the southern part of the quarry – near the contact with the epiclastic volcanic conglomerates exposed by the access road to the quarry – a transition into vitreous rhyolite can be seen. This vitreous rhyolite is partly argillitised and has turned into a secondary clay rock, i.e., smectite.

Based on the overall evaluation of the jointing and fluidity courses, it can be presumed that there is a transition between fan-shaped and onion-shaped fluidity plane structures. Fan-shaped structures prevail on the edges while the onion-shaped structures can be found in the central part of the body.

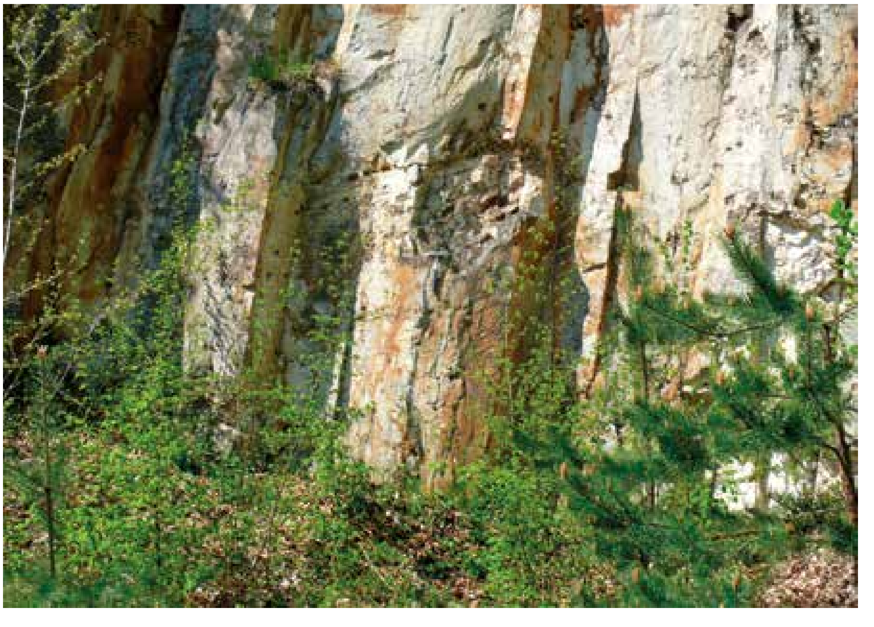


Photo 2. The cavity left by escaping gases – lithophyse in the middle (© P. Pachinger).

Geotope No. 69

Ladomer

basaltic andesite lava flow and phreatopyroclastic deposits

In the Pannonian Period, the rhyolitic volcanism was immediately followed by a basaltic andesite volcanism. It concentrated at the eastern edge of the Žiarska Kotlina Basin (phreatopyroclastic rocks, lava intrusions, dykes, bedded intrusions, and lava flows). The volcanic bodies in this area are part of the *Šibeničný Vrch Hill* complex (named after the location at the eastern edge of Žiar nad Hronom). This volcanism occurred in a river-lake environment, which caused the phreatopyroclastic eruptions when the rising lava came into contact with the water-saturated sediments or the lake water itself.

North-west of Šášovské Podhradie, there is another abandoned quarry with an exposed lava flow of basalt-pyroxene andesite of the leucocratic type (low in pyroxene), see Fig. 1, Photos 1 and 2.

The andesite is dark grey, close-grained porphyric, phenocrysts are composed of plagioclase (2–3 mm); rare pyroxene phenocrysts consist of hypersthene and augite. The base matter is hyalopilitic-pilotaxitic consisting of tiny plagioclase needles as well as occasional pyroxenes and volcanic glass.

The andesite jointing is coarsely-columnar, subvertical, with a transition into debris-and-block lava breccias in the upper part. In the northern part

Photo 1. In the wall of the abandoned Ladomer quarry near Šášovské Podhradie, a basaltic andesite lava flow has been exposed. It shows irregular blocky jointing, mainly along the subvertical planes in the upper part (© P. Pachinger).

Fig. 1. The abandoned Ladomer quarry near Šášovské Podhradie (© V. Konečný):

a) light pumice tuffs,
b) dark tuffs with transitions into debris breccias,
c) a lava flow with blocky-columnar jointing in the upper part and a transition into a lava breccia.

Fig. 2. On the right side of the quarry wall, columnar jointing along polygonal planes with a subvertical course can be seen; locally, it develops a radial orientation as can be seen in the upper left part (© V. Konečný).

of the quarry wall, columnar polygonal jointing with subvertical orientation can be seen (Photos 3 and 4). The local orientation of columnar jointing gains fan-shaped to radial nature (Fig. 2).

Columnar jointing occurs in the phases of solidification a crystallisation of the lava body. Due to volume reduction, internal stress is generated inside the body and jointing along the planes perpendicular to the cooling surface occurs. If the lava moves along a flat relief, subvertical to vertical columnar jointing occurs. Radial jointing results from the local thermal anomalies inside the lava body. This lava flow has been deposited on rhyolitic tuffs with rhyolite fragments, which indicates it is younger than the rhyolitic volcanism.

The overlying rock above the lava flow contains the products of phreatic and phreatomagmatic activity, which consist of porous to debris andesite (the fragments are greenish, palagonitised). A considerable volume of foreign fragments has been transported by the phreatic eruptions from the bedrock of the lava flow to the surface. This fragmented material comes mainly from rhyolitic tuffs but andesite pebbles are common as well. In the upper level, where phreatic eruptions deposited the matter, the amount of pumice tuff increases. Its composition is similar to that of the lava flow, which indicates the presence of phreatic (i.e., water vapour) to phreatomagmatic eruptions, during which particles of the exploded lava erupted.

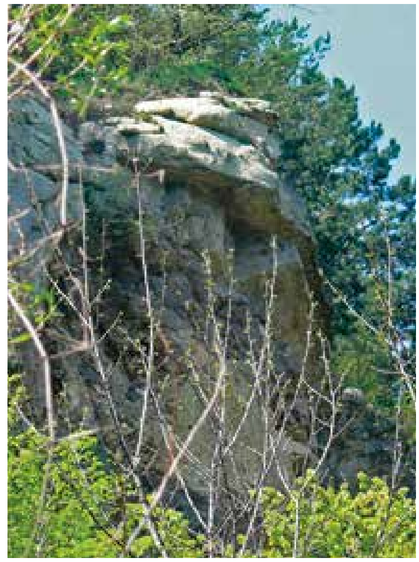


Photo 2. A debris breccia has been deposited in the left upper edge of the overlying rock of the lava flow. Light pumice tuffs can be seen slightly higher in the right upper edge (© P. Pachinger).

Photo 3. Columnar jointing on the right side of the quarry wall (nearer to the Hron River). The polygonal columns show a subvertical orientation (© P. Pachinger).

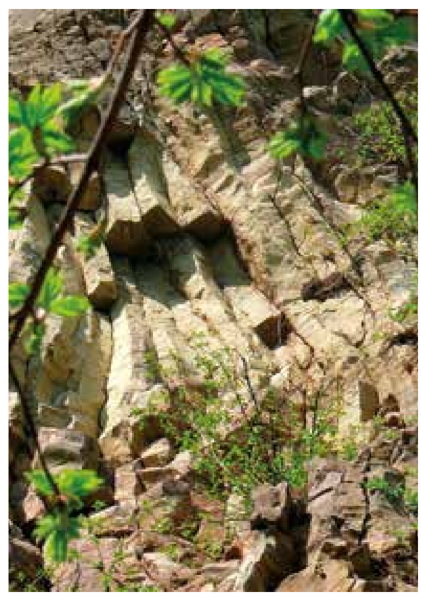


Photo 4. Close-up of columnar jointing along pentagonal and hexagonal planes. The columns are slightly bent and their surface is rough and wavy (© P. Pachinger).

Geotope No. 70

The Šibeničný Vrch Hill

phreatic cone and an intrusion of basaltic andesite

In the Pannonian Period (approximately 9 million years ago), the rhyolitic volcanism was followed by the basaltic andesite volcanism. The denudation remains of this volcanism accumulated at the eastern edge of the Žiarska Kotlina Basin include dykes, intrusions, necks, bedded intrusions, lava flows, but also remains of a phreatopyroclastic cone and phreatopyroclastic rocks. These bodies are either rising above the older rhyolitic tuffs and rhyolite rocks of the Jastrabá Formation, or cover them. The relicts of the basaltic andesite bodies are considered part of the Šibeničný Vrch Hill complex.

A part of the tuff cone, which was formed during the phreatic and phreatomagmatic eruptions, has been exposed at the eastern edge of Žiar nad Hronom (Fig. 1, Photos 1 and 2).

The bodies consisting of the pyroclastic material incline towards south and southwest. They were created by recurring phreatomagmatic eruptions (caused by a rising magma, which came into contact with water or water-saturated sediments). The volcanic ash-lapilli material has been transported to the cone's slopes by base surges as well as by falling back from the atmosphere. Larger fragments, tiny volcanic bombs, and scorias were expelled from the crater followed ballistic trajectories and landed on the slopes of the tuff cone.

Photo 1. The bottom part of the tuff cone consists of alternating coarse-grained and close-grained palagonitised tuffs with rhyolite and andesite pebbles, which were transported from the bedrock to the surface by the eruptions (© P. Pachinger).

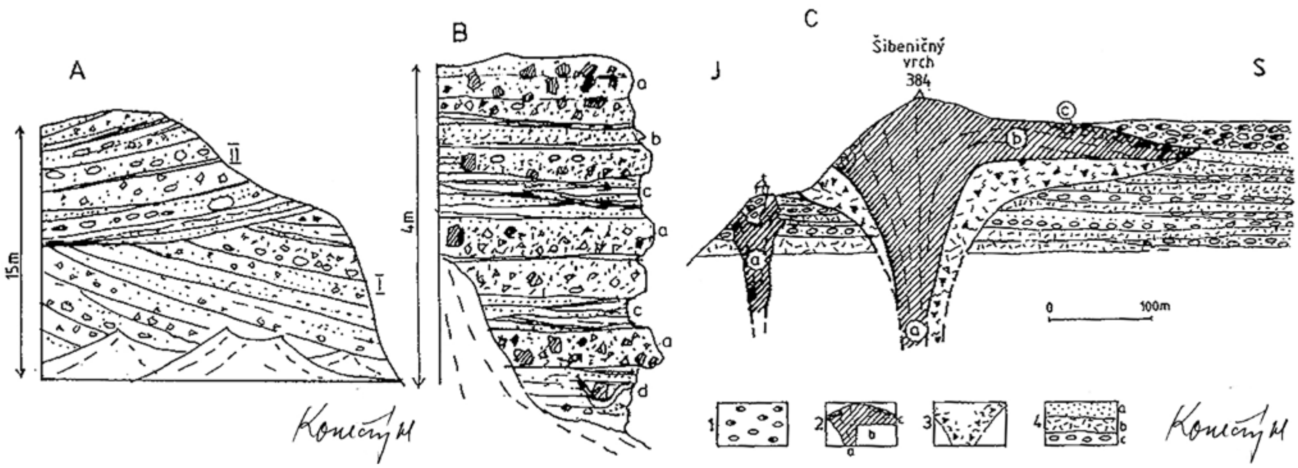


Fig. 1. The products of the basaltic andesite volcanism pertaining to the Šibeničný Vrch Hill formation located at the eastern edge of the Žiarska Kotlina Basin (Ján Smolka et al., 2005):

A – the phreatopyroclastic cone on the south-western slope under the Šibeničný Vrch Hill (elevation 384) east of Žiar nad Hronom. I – the older pyroclastic cone inclined 25–30° southwards consists of alternating close-grained to coarse-grained palagonitised tuffs with basalt fragments, and rhyolite and andesite pebbles that come from the bedrock, II – the younger phreatopyroclastic cone whose layers incline 15–20° towards the north-west also consists of alternating close-grained to coarse-grained palagonitised tuffs with frequently occurring andesite and rhyolite pebbles;
B – a close-up of the pyroclastic cone's structure: a) close-grained breccias with fragments of basaltic andesite and bedrock pebbles (rhyolite, andesite, quartzites, crystalline complex), b) palagonitised medium-grained to coarse-grained tuff, c) close-grained tuff with the base surge (pyroclastic surge) texture, d) impact structures that were created by the landing fragments of basaltic andesite and bedrock fragments; the bedrock layer has been deformed;
C – the intrusion of basaltic andesite, which penetrates the Jastrabá Formation east of Žiar nad Hronom: a) basaltic andesite with blocky jointing, b) epiclastic volcanic sandstones, tuffs, and conglomerates of the Jastrabá Formation, c) debris. 1. terrace gravels consisting of rhyolite and andesite pebbles, 2. the intrusion of basaltic andesite with a transition into a lava flow, 3. breccias and tuffs in the diatreme fill (volcanic feeder), 4. rhyolite gravels, coarse-grained and close-grained tuffs pertaining to the Jastrabá Formation.

Photo 2. Close-up of the layered tuffs in the upper cone, which contain rhyolite, andesite, and quartzite pebbles (© P. Pachinger).

Photo 3. The bottom part contains sedimented close-grained tuff with base surge textures. The higher parts contain coarse-grained tuffs with basalt fragments and bedrock pebbles, which alternate with close-grained tuffs (© P. Pachinger).

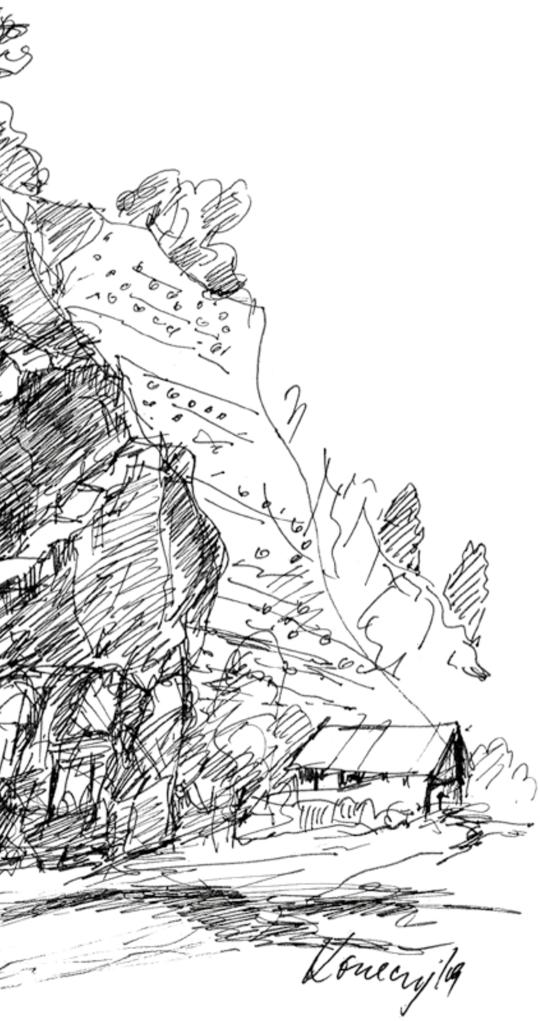
The layered pyroclastic material with the textures typical for base surges consists of light-green palagonitised basalt fragments, pumice, and the material which comes from the terrace sediments in the bedrock (i.e., andesite and rhyolite pebbles). This material erupted to the surface during phreatic explosions of gases and water vapour (Fig. 1.A, Photo 3).

Sporadically occurring fragments and bombs of basaltic andesite created distinctive impact structures as they landed on the tuff sediments (Fig. 1.B).

Northwards, the body of basaltic andesite, which penetrates the phreatomagmatic cone, turns into a short, thick lava flow (Fig. 1.C).

At the south-eastern edge of the Šibeničný Vrch Hill, the body of basaltic andesite penetrates conglomerates and sandstones containing rhyolite, i.e., the terrace sediments created by the River Starý Hron (Fig. 2, Photo 4).

Fig. 2. The basaltic andesite intrusion permeating the gravel-sand terrace sediments. The intrusion lifted and deformed the sediments (© V. Konečný).



The terrace sediments were lifted, deformed, and fragmented by the rising intrusion (Photo 5).

On the right side, the sediments are steeply inclined in the opposite direction (© P. Pachinger). In the central part of the quarry wall, the intrusion penetrates the sediments. The intrusive body was connected to one of the lava flow feeder systems, which covers the phreatopyroclastic rocks pertaining to the tuff cone on the surface.

The basaltic andesite is dark, grey-black, and its phenocrysts are composed of plagioclase, pyroxenes (augite, hypersthene), and rarely olivine. The base matter is doleritic-trachytic, composed of tiny plagioclase, pyroxene, olivine, and magnetite grains.

According to the radiometric dating (K/Ar method), the basaltic andesite bodies in the broader surroundings are 11.0–8.2±0.5 million years old, which corresponds with the volcanic activity of the Pannonian Period (K. Balogh, V. Konečný, J. Lexa, 1998).

Photo 5. A close-up of the upper part of the quarry – the exposed terrace sediments inclined according to the rising intrusion (© P. Pachinger).

Photo 4. An overview of the basaltic andesite intrusion permeating the gravel-sand terrace sediments (© P. Pachinger).

11. Tourism Territorial Unit Zvolen

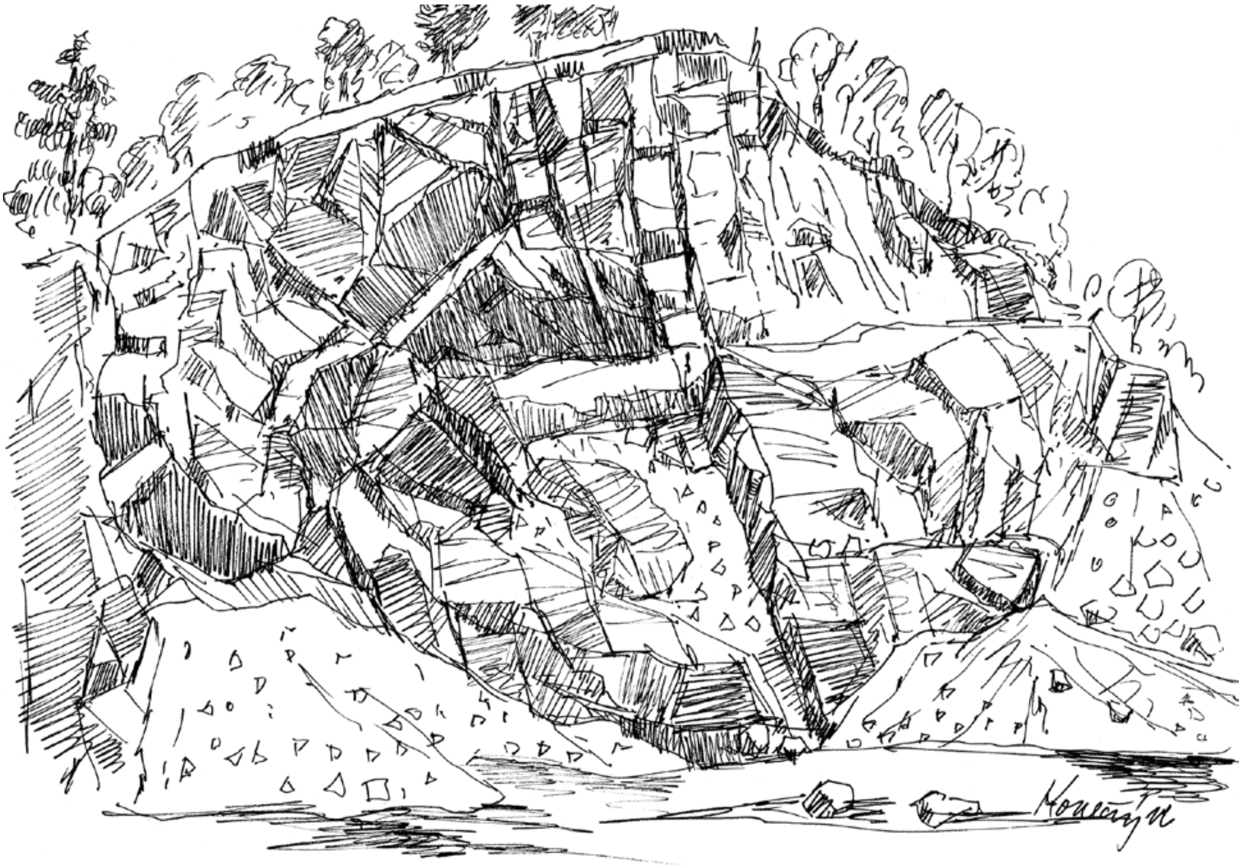


Fig. 2 The andesite quarry on the southern slope (elevation 502.6 Homolka) in the Neresnica River Valley near Breziny. Andesite with large block jointing with indications of coarsely-columnar jointing along subvertical planes – central part of the quarry wall (© V. Konečný).

Geotope No. 71

Breziny – Široká Homolka

andesite extrusive dome with garnet

The activity of andesite volcanism within Central Slovakia began in the Early Baden Period as extrusive bodies of hypersthene-amphibole andesite with garnet started to rise. The rising of these bodies was associated with the disintegration of the territory into a system of horsts and depressions (grabens) due to extensional processes that prevailed on the inner side of the Carpathian Arc during the Late Neogene. The extrusive bodies were rising mainly along faults and fault zones that bounded the emerging graben depressions and horsts (rising blocks). In the southern part of the territory, the graben depressions were flooded by the sea, which penetrated northwards into the graben depressions of Central Slovakia (depression of Zvolen, Žiar, and Handlová). These were later transformed into lakes as a result of their isolation due to volcanic activity.

Due to their viscosity (which reduced flow capacity), the extrusive andesite bodies with garnet did not form typical lava flows, but instead lava masses rising along fault lines accumulated around rising paths and formed quaquaversal forms designated as *extrusive domes* (Fig. 1).

The surface, faster solidifying parts underwent brecciation and explosive destruction as the domes were growing and expanding. A fragmental to block material either accumulated in their immediate vicinity, or was transported to greater distances by pyroclastic flows, fragment flows, and lahars.

Extrusive andesite bodies with garnet and their volcanoclastic rocks, rising to the surface in different parts of Central Slovak neo-volcanic area (the Kremnica Mountains, the Vtáčnik Mountain), but included in the Neresnica Formation due to their typical occurrence on the slope of the *Neresnica River Valley*.

On the southern slope of Široká Homolka (elevation 502.6) near Breziny (in the Neresnica River Valley south of Zvolen), an extrusive andesite body with garnet is exposed in the quarry (Fig. 2, Photo 1).

Andesite is characterised by large block jointing (left part of the quarry), in the central part of the quarry along steep subvertical planes. In some places, it is possible to observe alternating lighter and darker (more vitreous) stripes with a steep course, which were formed during the rising lava movement (flow). They form fluidal textures. Longer amphibole columns are often oriented in their direction.

Andesite is coarse-grained porphyric, grey to grey-green; phenocrysts are composed of plagioclase (3–5 mm), amphibole (5–6 mm to 1 cm), pyroxenes, hypersthene, augite, sporadically quartz and garnet (almandine) up to 0.5–1 cm. At the edges of the body, the base matter is microlithic-crystalline, passing to microalotriomorphic-grained in its central part. The andesite is affected by auto-metamorphic alterations, mainly by chloritisation.

Fragments of older, especially crystalline rocks (granitoids and schists) are often sealed within the andesite.

At the edges, the extrusive body is bordered by zones of extrusive breccias, and coarse to block breccias are deposited further from the edges.

The age of the andesite body was determined by radiometric dating using the K/Ar method to be 15.9 ± 1.2 Ma. (V. Konečný, G. P. Bagdasarjan, D. Vaas, 1969). The radiometric age corresponds with the Early Baden.

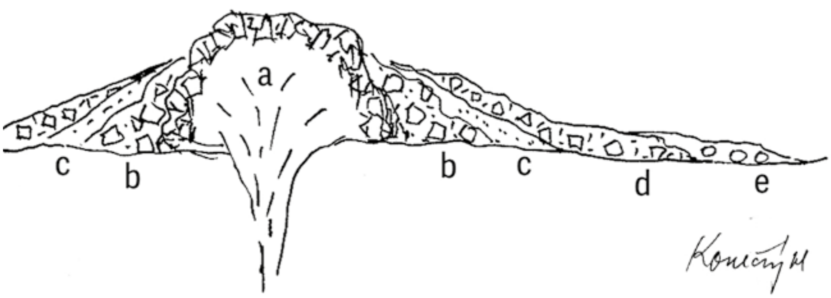


Fig. 1 Scheme of extrusive dome and coarse material deposited in its surroundings (J. Smolka et al., 2005):

a – extrusive dome with brecciated surface crust,
b – coarse block breccias deposited at the foot of the extrusive dome,
c – epiclastic volcanic sandstones,
d – chaotic lahar breccia,
e – coarse to block epiclastic volcanic conglomerate.

Photo 1 Overall view of the quarry wall in an extrusive dome of hypersthene-amphibole andesite with garnet (© P. Pachinger).

Geotope No. 72

Breziny – Podzámčok

coarse to block breccias, conglomerates, lahar breccias

On steep slopes, west of the Neresnica River (in the area between Breziny and Podzámčok), there are exposures of coarse to block breccias, conglomerates, lahar breccias and epiclastic volcanic breccias falling under the Neresnica Formation.

The rising lahar breccias exposed in the rock exposures are composed of coarse to block andesite material of variable dimensions, ranging from fragments of a few cm to blocks of 0.5–2.5 m, occasionally of up to 5 m (Fig. 1, Photo 1).

Blocks are mostly angular to subangular, sporadically suboval. Their position is chaotic. The matrix which forms the fill between the blocks is grained, sandy with small angular fragments. Occasional pumice fragments are present. The base contacts with the bedrock sharply, discordantly.

Breccias are formed by deposits of mass gravitational flows which transported the debris material down the steep slope to the lower levels of the volcanic slope.

Coarse to block conglomerates form irregular positions, separating bodies of chaotic breccias. They are thoroughly worked and sorted. Matrix is sandy, grained with mildly worked fragments (Fig. 2, Photo 2).

Photo 1 Chaotic lahar breccia, composed of mildly worked fragmental to block andesite material (© P. Pachinger).

Fig. 1 The lahar breccia in the rock exposure on the slope of the Neresnica River Valley consists of coarse to block andesite material with chaotic deposition (© V. Konečný).

Unlike lahar breccias, the positions of epiclastic volcanic breccias, which are composed of finely to coarsely-fragmented andesite material, are characterised by sorting of the fragmented material and its layering and a thoroughly worked shape. The matrix is sandy with a clay component.

Fig. 2 Large block epiclastic volcanic conglomerate with partly to thoroughly-worked andesite blocks of up to 0.6–1 m (© V. Konečný).

Epiclastic volcanic breccias alternate with positions of lahar breccias, conglomerates and sandstones. At a greater distance from the extrusive bodies, at the slopes below Vŕšok (elevation 387.1 near Mlyn, west of Podzámčok), positions of chaotic breccias composed of coarse to block material alternate with positions of fine-grained material, separated by positions of sandstones (Fig. 3, Photo 3).

Volcanoclastic rocks of variable lithological composition, protruding in the exposures on the slope

Photo 2 A close-up of a large-block epiclastic volcanic conglomerate shows the thoroughly worked shape of the block material, deposited with distinctive sorting. The matrix is sandy, light grey (© P. Pachinger).

between Breziny and Podzámčok, represent the products of the destruction of andesite bodies, and the subsequent gravitational transport of mass debris flows (lahars), fluvial flows and washes.

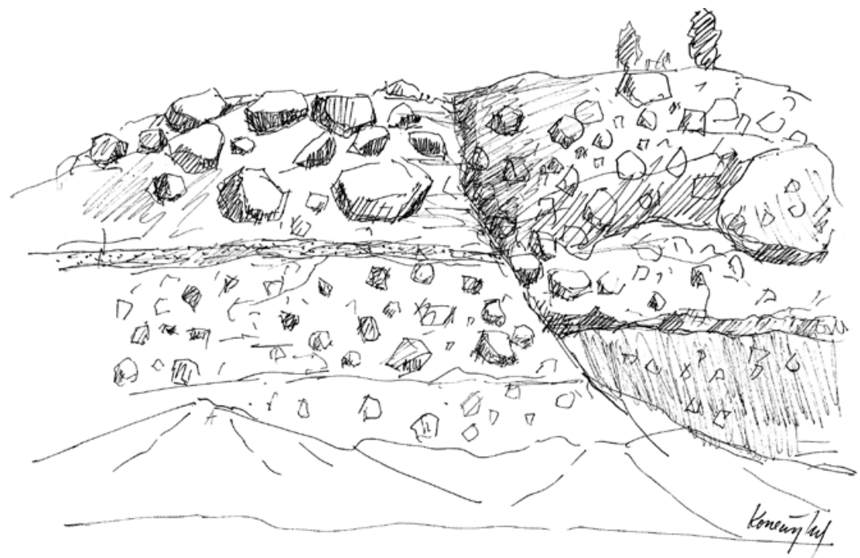


Fig. 3 In the rock exposure, at the foot of the Neresnica River Valley (elevation 387.1 Vŕšok, near Mlyn, west of Podzámčok), positions of fine-grained breccias (deposits of debris flows) alternate with positions of coarse to block lahar breccias (in the upper part of the rock exposure). The positions of breccias are separated by interbeds to thin positions of epiclastic volcanic sandstones (© V. Konečný)..

Photo 3 documents the right part of Fig. 3. In the bottom part, there is a fine-grained breccia of the debris flow, and a coarse to lahar breccia is located in the upper part (© P. Pachinger).

Geotope No. 73

Dobrá Niva – Žigovci

pyroxene-amphibole andesite extrusion

The extrusive body of pyroxene-amphibole andesite, exposed by a quarry on the slope west of the reservoir near Žigovci (north-west of Dobrá Niva), represents one of the series of bodies within the Neresnica Formation in its southern continuation (Fig. 1, Photo 1).

Andesite of the extrusive body is dark grey, medium-grained to coarse-grained porphyric, phenocrysts are composed of plagioclase (2–3 mm), pyroxenes (1–2 mm), amphibole (3–4 mm, sporadically 8 mm–1 cm). Andesite has irregular blocky jointing with predominant planes with subvertical jointing in 115 SE/70° direction (Photo 2).

In the right part of the quarry wall, distinctive banding with alternation of light and darker stripes oriented in 118 SW/43–45° direction can be observed.

Inclusions of bedrock rocks, predominantly crystalline schists, are common.

Based on the abovementioned features, the andesite body corresponds to the extrusive type (extrusive dome), formed by an outward movement of viscous lava.

Fig. 1 The abandoned quarry near Žigovci reveals the internal structure of the extrusive body. Andesite is characterised by irregular large block jointing, in the upper part of the rock wall, jointing along subvertical planes prevails (© V. Konečný).

Photo 1 An overall view of the abandoned quarry wall near Žigovci (© P. Pachinger).

Photo 2 In the quarry walls, there is andesite with blocky jointing mainly along subvertical planes (© P. Pachinger).

Geotope No. 74

The Tri Kamene Mountain

transition of an extrusion into a lava flow

An abandoned quarry in the area of the Tri Kamene Mountain (elevation 834), west of Dobrá Niva, exposes an internal structure of an extrusive body (extrusive dome) showing signs of a transition into a lava flow.

The body of biotite-amphibole andesite is a part of the Štiavnica caldera fill and of its eastern part.

Andesite if partly frothy, and it gains brownish-red hues due to oxidation of Fe component. In places, it is strongly porous and vitreous. Phenocrysts are composed of plagioclase (2–4 mm), amphibole (up to 4–6 mm), biotite (up to 2–4 mm). The base matter is microlitic-hyaline. Cavities (litophyses) due to escaping gases occur frequently.

The quarry has two tiers. In the bottom tier, there is andesite with jointing mostly along steep planes (Fig. 1, Photo 1).

In the upper tier, there is andesite with block to roughly columnar join-

Fig. 2 In the upper tier, andesite with block to roughly columnar jointing is exposed. Fluidity planes range from 35–40° to subhorizontal inclination (© V. Konečný).

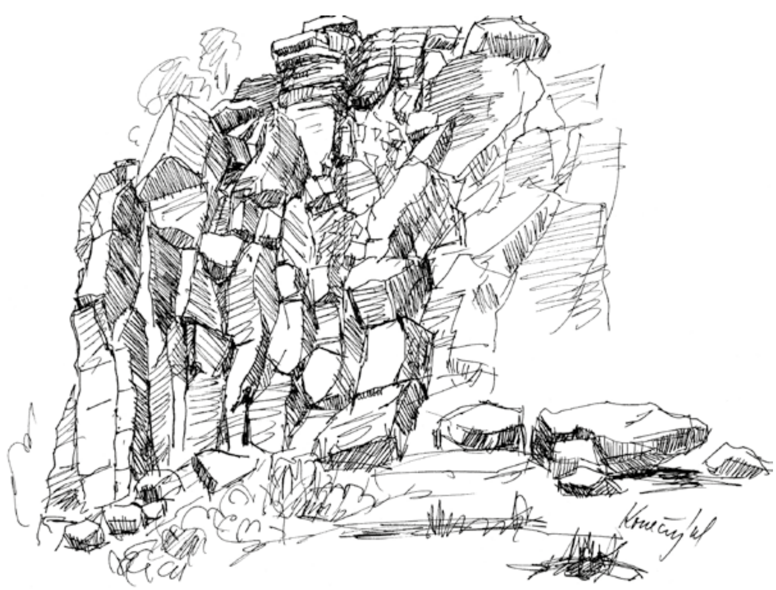


Fig. 1 In the bottom tier of the abandoned quarry at the Tri Kamene Mountain location, andesite with jointing mostly along steep, subvertical planes is exposed (© V. Konečný).

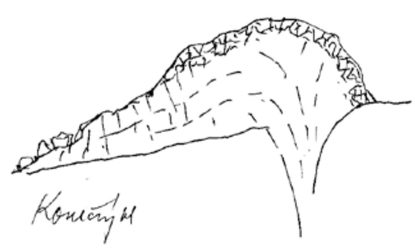


Fig. 3 Scheme of the extrusive dome with a transition into the lava flow (© V. Konečný).

Photo 1 Bottom-tier andesite with coarsely-columnar jointing, in the right part a crushing zone with vertical orientation and disintegration into tiny angular fragments (© P. Pachinger).

ting. The course of the fluidity planes ranges from 35–40° to subhorizontal inclination (Fig. 2, Photo 2, 3, 4).

This fact indicates a body with fan-shaped distribution of fluidity planes (extrusive dome) with a transition into a lava flow (Fig. 3).

In the past, andesite was quarried in the Tri Kamene Mountain for the needs of the construction industry (road maintenance, foundation and chiselled stone).

Photo 3 A close-up of irregular large blocky jointing in the left part of the quarry wall in the upper tier (© P. Pachinger).

Photo 4 A close-up of the right part of the quarry wall of the upper tier, andesite with indicated subvertical coarsely-columnar jointing (© P. Pachinger).

Photo 2 Overall view of the upper-tier quarry wall. Andesite with large block jointing – left part with indicated coarsely-columnar jointing – right part (© P. Pachinger).

Geotope No. 75

The Čertova Skala Mountain

lahar breccia

After the formation of the Štiavnica caldera (between the Baden and the Sarmatian), volcanic activity was renewed from several eruptive centres during the Sarmatian, and parasitic (or satellite) volcanoes were formed within the caldera area and on the stratovolcanic slope. One of these volcanoes was the smaller *Breznica volcano* in the northern area. Relics of volcanic products in the form of lava flows and volcanoclastic rocks are found in the northern part of the caldera, but mostly on the northern stratovolcanic slope, where they fill the paleodoline, which extends from the northern slope of the Štiavnica Stratovolcano to the southern part of the Kremnica Mountains. The volcanoclastic rocks of this fill are exposed in a series of rock exposures on the southern slope of Boky-Čertova Skala Mountain (elevation 567). The rock exposures are accessible by a nature trail which runs from the eastern edge of the crest, at the entrance to the side valley from the main road, about 1.5 km west of Budča.

This site is represented by rock exposures of lahar breccia below elevation 567 at Čertova Skala Mountain and a cliff with a boulder, called logan (rocking stone).

The chaotic lahar breccia is deposited in the overlying rock of the position of epiclastic volcanic breccia – conglomerate, characterised by a higher degree of working and sorting of the fragmented material

Photo 1 The rock cliff is formed by a chaotic lahar breccia deposited on another breccia conglomerate and on epiclastic volcanic sandstone (immediate bedrock of the lahar breccia). An andesite block with jointing along the radial cracks can be seen higher up (© P. Pachinger).

Fig. 1 The rock cliff on the slope of the Čertova Skala Mountain consists of chaotic coarse to block lahar breccia, deposited on the position of a sorted breccia – conglomerate and epiclastic volcanic sandstones (bottom part). Within the breccia, there is a block with jointing along the radial cracks – see arrow (© V. Konečný).

Photo 2 A close-up of a block with radial jointing at the edges caused by rapid cooling of a burning block (the structure type is called chilled margin). The structure is formed as a result of the contact of the burning lava with water, and subsequent disintegration of the lava flow or extrusion into blocks (© P. Pachinger).

Photo 3 The rock cliff consists of tiny fragments of a chaotic breccia (debris flow) deposited on the position of coarse to block breccia (at the bottom edge). In the upper part, there is an interbed of epiclastic volcanic sandstone, and higher in the overlying rock, there is a large block chaotic breccia of the lahar flow – upper part (© P. Pachinger).

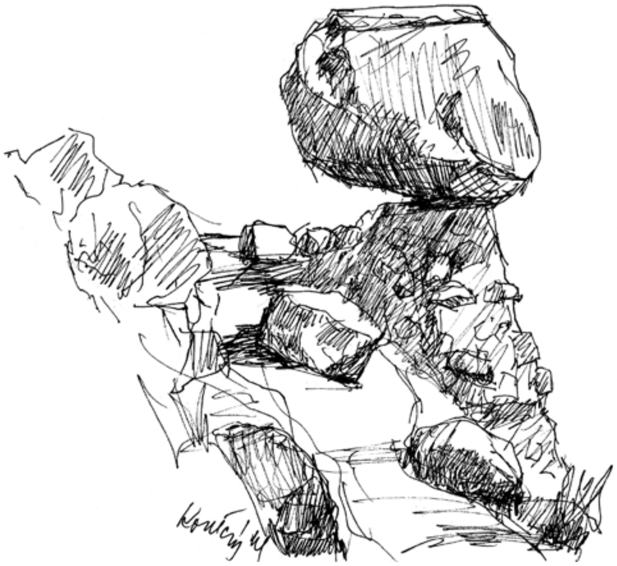


Fig. 2 An almost isolated block, on the position of a chaotic breccia, resembles a devil's head looking down into the Hron River Valley (© V. Konečný).

deposited in a tuff-sand matrix. The position of the breccia – conglomerate bears the chaotic lahar breccia with a sharp and discordant base-bedrock contact, with signs of bedrock erosion (Fig. 1, Photos 1 and 2).

The chaotic lahar breccia consists of fragments to blocks of andesite of variable size, mostly 5–35 cm and subordinately up to blocks of up to 2.5 m. The fragments and blocks are characterised by predominantly angular shapes, blocks with a higher degree of working are less frequent. The matrix is grained, sandy with a minor clay component. Blocks with radial jointing are sporadically present, probably originating from disintegration of extrusive bodies or lava flows due to sudden cooling (Fig. 1 above arrow).

In the vicinity of the lahar breccia cliff, there are exposures with lahar breccias, fragment flows, and conglomerates alternating with interbeds to positions of epiclastic volcanic sandstones on the slope (Photo 3).

A remarkable natural formation can be found in an almost isolated andesite block called the "Devil's head", which is only partially supported by its bedrock. The block was formed by weathering and erosive removal of a surrounding rock (Fig. 2).

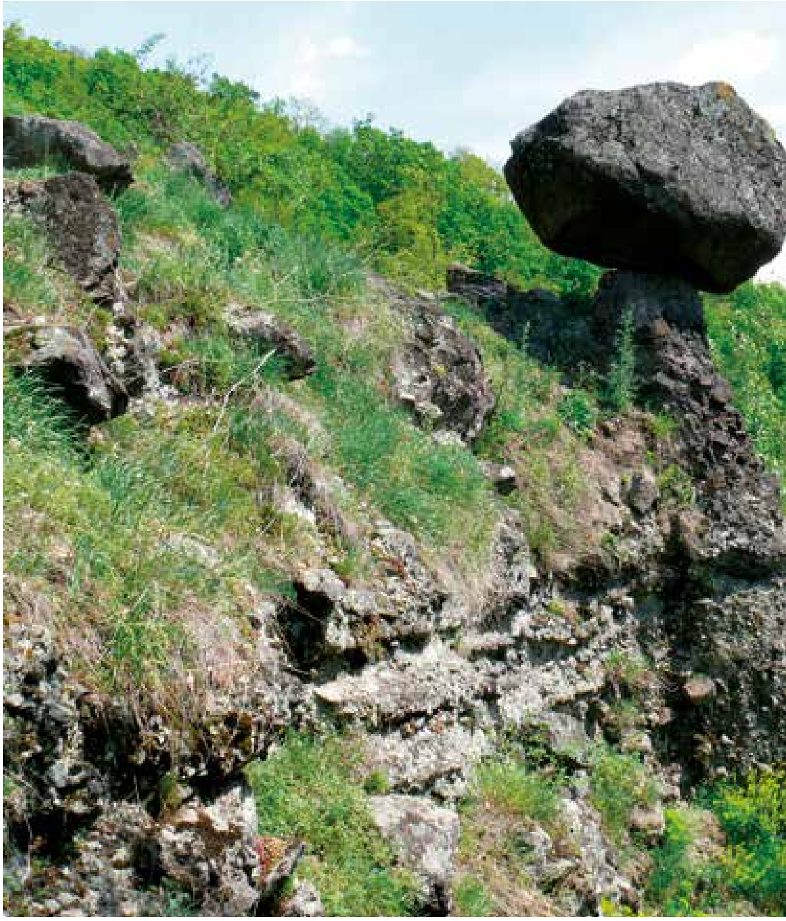


Photo 4 The rock cliff in the bedrock of the "Devil's head" is documented in Fig. 3 (© P. Pachinger).

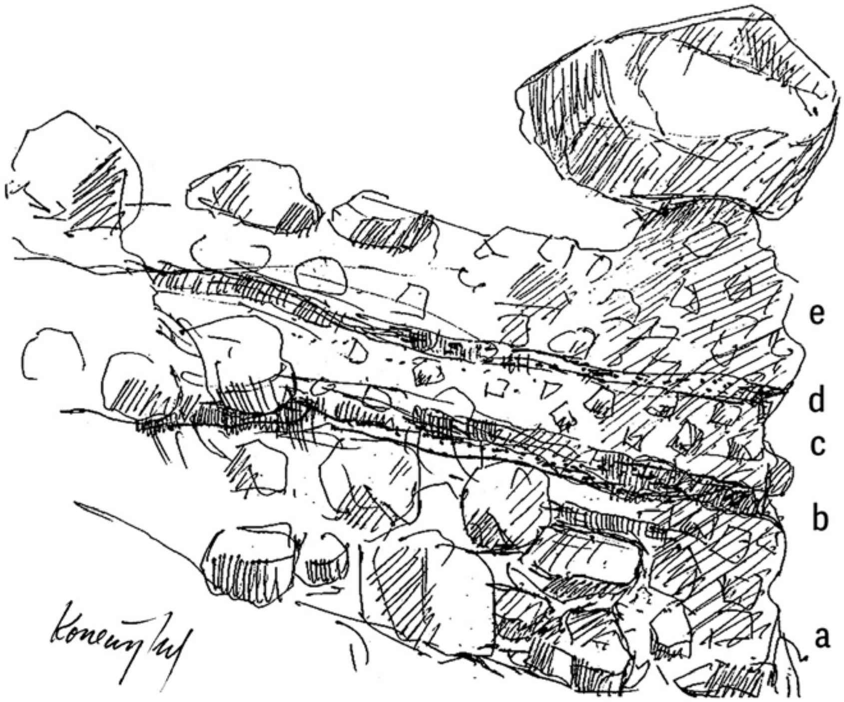


Fig. 3 The rock cliff in the bedrock of the "Devil's head" is formed from the bottom upwards by large block lahar breccia (a), followed above by a position of epiclastic volcanic sandstone (b), tiny fragments of a chaotic breccia (c), an irregular position of epiclastic volcanic sandstone (d), and a chaotic coarse to block lahar breccia (e) (© V. Konečný).

In the bedrock of the "Devil's head", a rock cliff was formed by alternating large blocks and tiny fragments of chaotic breccias, separated by interbeds of epiclastic volcanic sandstones (Fig. 3, Photo 4).

The volcanoclastic material which fills a wide paleodoline was washed by the gravitational energy by mass and fluvial flows. At the upper level, the paleodoline fill is overlain by a lava flow.

Geotope No. 76

The Pustý Hrad Castle

chaotic breccias of pyroclastic flow

On the north-western slope of the Pustý Hrad Castle crest (elevation 571), in the overlying rock of the volcanoclastic rocks of the older Neresnica Formation (epiclastic volcanic breccias of pyroxene-amphibole andesite with garnet), chaotic breccias of pyroclastic block-and-ash flow of the Javorie Formation are deposited.

The chaotic breccia rises on the slope near the trail which leads to castle ruins in the area of the hilltop crest, and takes the form of a rock cliff with a height of ca. 6–8 m (Fig. 1, Photo 1).

In the bedrock of the chaotic breccia, there is strongly to extremely frothy

Photo 1 Large block breccia of pyroclastic flow on the hiking trail leading to the ruins of Pustý Hrad Castle. Fragmental to blocky andesite material is strongly sintered with tuff matrix (© P. Pachinger).

scoria tuff-breccia with signs of sintering of porous fragments with matrix into homogeneous matter. This breccia corresponds to a pyroclastic flow with an extremely high degree of foaming (vesiculation) – see photos 2 and 3.

The chaotic breccia in the overlying rock, formed by a rock cliff, consists of andesite fragments with angular and spherical to subspherical borders (fragments with frothy structure), mainly sized 5–25 mm (sporadically there are blocks of up to 30–60 cm). The matrix is tuffaceous, dark grey and grey-brown, locally reddish with abundant tiny frothy fragments, strongly consolidated to sintered (Photo 1).

Andesite fragments of the chaotic breccia of the pyroclastic flow consist of fine-grained porphyric, pyroxene andesite with a distinctly porous structure and a higher degree of oxidation of the Fe component. The characteristic features correspond to the breccia of pyroclastic block-and-ash flow. Block-and-ash flows are formed by a hot mixture of gases, ash, pumice, and fragments of solid to semi-solid burning lava, which moves down a steep slope as a turbulent flow. After the movement ceased due to declining magmatic temperature, sintering to welding of the pyroclastic material occurred.

The formation of pyroclastic flows occurred during volcanic eruptions, as a result of collapses of the eruption column or else during the explosive destruction of extrusive domes (Fig. 2).

The ascending nature trail leads to the top of the crest, where the ruins of the medieval castle are located (Photo 4).

The Pustý Hrad Castle was built on the site of an older castle settlement. The first written record of the castle is found in the chronicle of the so-called Anonymus from the turn of the 13th century, it states that the Zvolen Castle was founded by chief Borš at the turn of the 10th century. The castle was a military and administrative centre, probably already before its incorporation into the Kingdom of Hungary, and later the administrative, milita-

Fig. 1 Chaotic large block breccia of pyroclastic flow on the northern slope below Pustý Hrad Castle (elevation 571) (© V. Konečný).

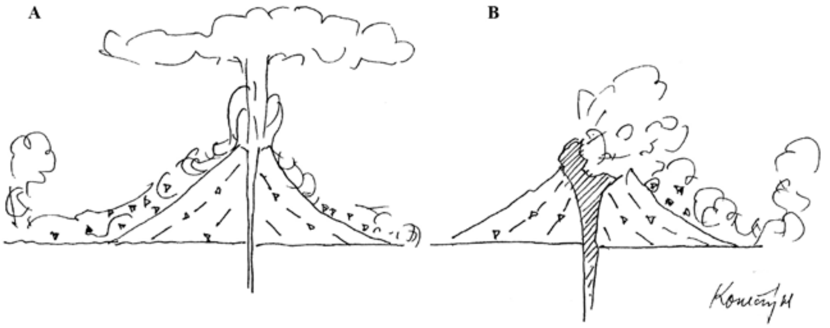


Fig. 2 Scheme of the formation of two types of pyroclastic flows (J. Smolka et al., 2005):

A – pyroclastic flow occurs during the collapse of the eruption column during volcanic eruptions.
B – formation of block-ash pyroclastic flow is associated with an explosive destruction and collapse of the extrusive dome.

Photo 2 Pyroclastic flow with an extremely high degree of foaming – vesiculation (© P. Pachinger).

Photo 3 A close-up of the base of the pyroclastic flow. In the bedrock, there is a strongly to extremely frothy breccia of an older pyroclastic flow (© P. Pachinger).

Photo 4 Remains of the medieval castle wall (© P. Pachinger).

ry and, economic centre of the royal Zvolen Estate, a vast territory from Hont to Liptov and Orava, which was transformed into the Zvolen County in the first half of the 13th century. Its area originally covered such a large part of Central Slovakia that three more counties were created there in the 14th century – the Liptó, Árva, and Turóc County. At the same time, it was a seat of Hungarian kings during their hunts in the Zvolen Forest. Over time, the castle fell out of the accessible territories on the routes of long-distance roads, and thus ceased to fulfil its original function as an administrative, military, and economic centre. The extreme location thus became one of the main reasons for the relocation of its original functions to the new castle, and its gradual disappearance. Graphic sheets from the beginning of the 17th century, depicting the city of Zvolen, describe the castle as a ruin. In 1992, archaeological research began, which continues to this day. Alongside this, the above-ground parts of the castle walls are being uncovered and preserved, giving the castle a new appearance.

Fig. 1 An overall view of the rock cliff formed by breccia in the fill of the explosive volcanic neck. The right part of the neck is dominated by a large-block breccia with predominant angular andesite blocks (© V. Konečný).

Geotope No. 77

Turová

explosive neck

Near Turová (about 200 m north of the church), an explosive neck rises in the environment of tuffs, pumice tuffs, and agglomerates. Due to its higher resistance to weathering, it forms a rock cliff in the present relief.

The fill of the neck consists of an explosive breccia with sintering features in the form of a chaotic breccia with angular fragments to blocks of solid andesite, sized up to 60–90 cm (ca. 60%), and spherical fragments of porous andesite up to 40–60 cm (ca. 20%) Fig. 1, Photo 1.

The matrix is tuff-detrital, sintered with fine, disseminated pumice. Fragments to blocks show varying degrees of disintegration and explosive fracturing. A higher degree of sintering and oxidation of the matrix is observed in the central part of the neck, near the left edge (Fig. 1). The matrix is reddish and strongly consolidated (Fig. 2).

Near the edge of the explosive neck, the degree of matrix sintering is lower, and larger andesite blocks are present (Photo 2).

At the eastern edge of the neck, there are exposures of grey-blue tuffs with tiny fragments of frothy andesite of up to 2–3 cm (occasionally up to 5–10 cm, Photo 3).

Dispersed pumice of up to 2–3 cm are abundant in the tuffs (Photo 4).

The volcanic neck is considered to be a volcanic centre for eruptions of pyroclastic flows of the Turová Formation of the Sarmatian. The relics of these flows protrude in the vicinity.

Photo 1 Overall view of the explosive neck with the large-block breccia on the right (© P. Pachinger).

Fig. 2 In the central part of the neck (in the left part of Fig. 1 and Photo 1), there is a breccia with finer fragments of higher porosity and with more intense sintering of tuff-detrital matrix – intense reddening (© V. Konečný).

Photo 2 Large-block chaotic breccia near the right edge of the explosive neck with lower degree of matrix sintering (© P. Pachinger).

Photo 3 Pumice tuff exposures at the right edge of the explosive neck through which the neck body penetrates (© P. Pachinger).

Photo 4 A close-up of the tuff with dispersed fragments of light pumice (© P. Pachinger).

12. Tourism Territorial Unit Krupina

Geotope No. 78

Horné Túrovce

elevation of Mesozoic-Paleozoic rocks

In the southern part of the marine sedimentary environment, an elevational structure of pre-volcanic bedrock, built up by rocks from the Veporic crystalline complex of the Permian and the Mesozoic, was rising in the Early to Middle Baden. It is referred to as *the Santovka-Turovce Elevation*. This elevational structure limited the transport of coarse volcanoclastic material into the space with marine sedimentation, south of the elevation. It presented an insurmountable obstacle to debris material mass flows, which ended at the northern foot of the elevation (Fig. 1).

The rocks of the Veporic crystalline complex, in the form of muscovite-chlorite schist with amphibole interbeds, rise to the surface in the Olvárský and Berinčenský stream valleys. The phyllites with positions of amphibolite were identified by the ŠV-8 borehole near Horné Semerovce in the bedrock of the Triassic and Permian rocks from a depth of 1,203.6 m to the bottom of the borehole.

Permian rocks in the form of altered siliceous conglomerates are exposed on the surface north of Horné Túrovce and have also been confirmed in the overlying crystalline complex rocks in borehole ŠV-8.

The Permian rocks rise as cliffs north of Horné Túrovce on the eastern slope below Gomboš, near the Krupinica River. The rock cliffs are formed by colourful (reddish-purple, grey-green) altered siliceous conglomerates with rolled out quartz pebbles (Fig. 2, Photo 1, 2).

Fig. 2 The rock cliffs on the slope of the Krupinica watercourse, north of Horné Túrovce, consist of altered siliceous Permian conglomerates (© V. Konečný).

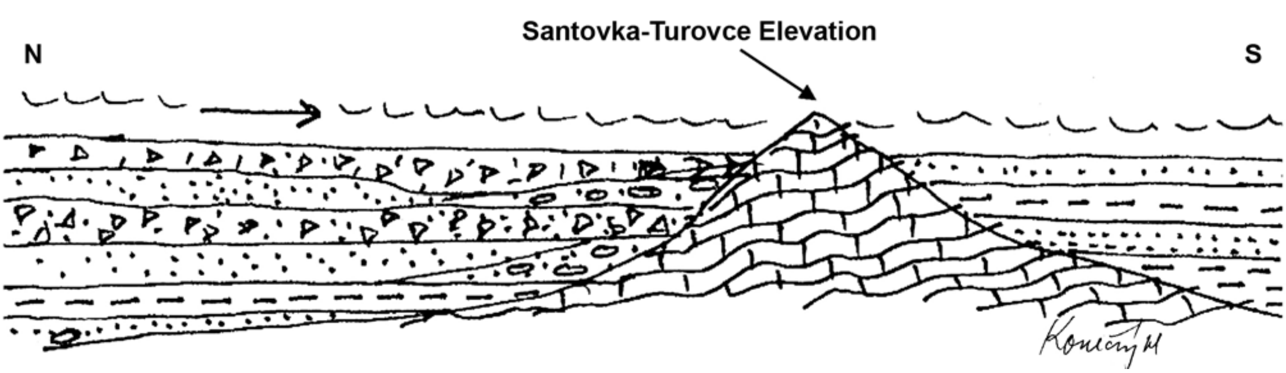


Fig. 1 A scheme showing the transport of volcanoclastic material of the Štiavnica Stratovolcano and its deposit in the sedimentation basin in the sublittoral zone. In the southern part of the sedimentation basin, the elevation of the pre-volcanic coast is exposed (© V. Konečný).

A morphological elevation in the southern part of the sedimentation zone, represented by a rising crest of Paleozoic-Mesozoic rocks oriented in a NWW-SEE direction, presented a distinct seabed barrier that prevented the accumulation of coarse material into the space south of this elevation (Fig. 1).

Triassic rocks that rise to the surface south of Horné Túrovce are deposited in the Permian overlying rock, where they are exposed by an active quarry. The Triassic rocks are represented by light grey quartzites with positions of quartzite schists (Photo 3, 4).

Photo 1 The rock cliff on the slope of the Krupinica watercourse valley consists of altered siliceous Permian conglomerates (© P. Pachinger).

Photo 2 A close-up of altered siliceous Permian conglomerates showing the "rolling out" of the conglomerates in a subhorizontal direction by the effect of tectono-metamorphic processes (© P. Pachinger).

Photos 3, 4 Light grey to ochre-yellow quartzites and quartzite sericite schists are exposed in the quarry south of Horné Túrovce (© P. Pachinger).

Geotope No. 79

Hontianské Nemce – Dianiš

debris flows and lahars of the Štiavnica Stratovolcano bottom structure

The southern slopes of the bottom stratovolcanic structure of the Štiavnica Stratovolcano are formed in the area of transition to the coastal zone – littoral – mostly by epiclastic volcanic rocks, represented by breccias, conglomerates and sandstones, lahar breccias and debris flows, which are part of the transitional volcanic zone. In the higher levels of the stratovolcano slope, chaotic breccias of pyroclastic flows and lava flows of amphibole-pyroxene and pyroxene andesites are deposited in the overlying rock of the epiclastic formations.

A complex of epiclastic volcanic rocks is exposed in the state road trench about 1 km north of Hontianske Nemce (Fig. 1, Photos 1, 2, 3).

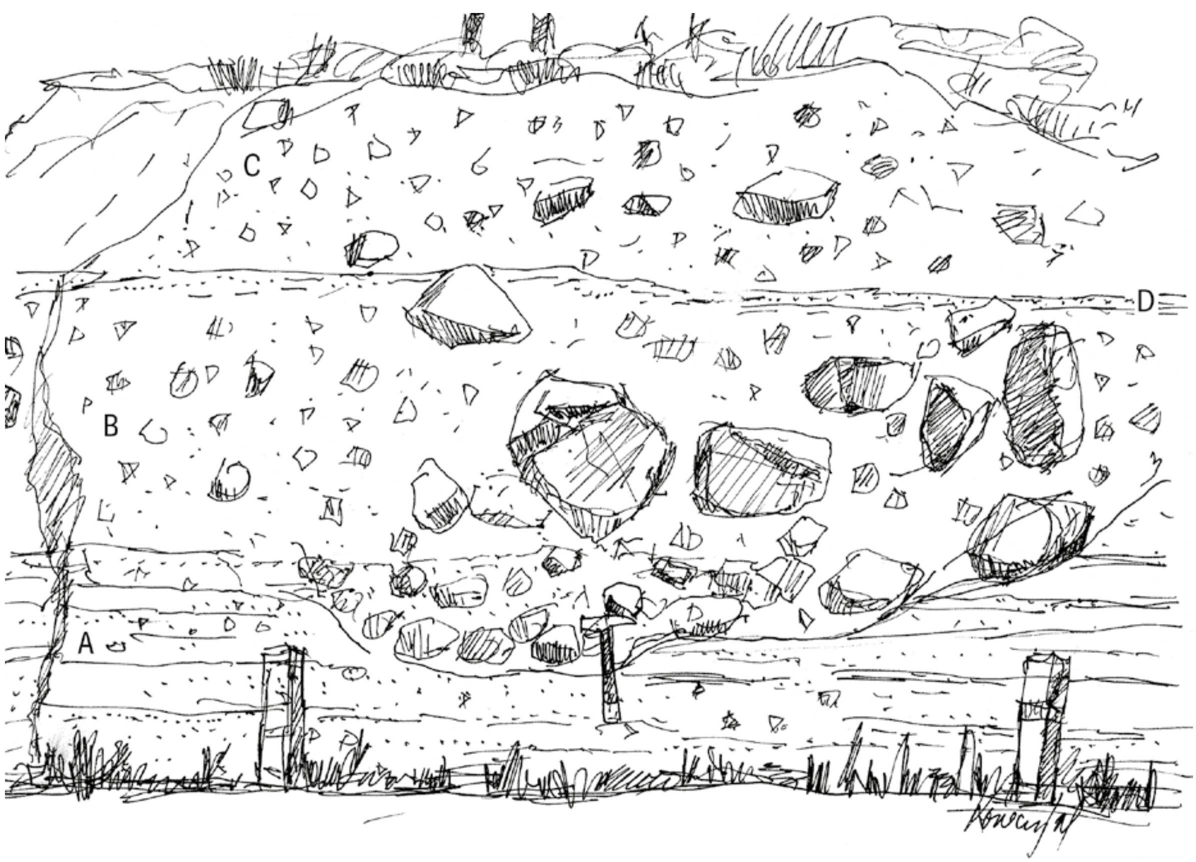


Fig. 1 An exposure of epiclastic formations in the state road trench north of Hontianske Nemce at the western foot of the Dianiš Hill elevation. It was deposited on the southern slope of the Štiavnica Stratovolcano in the area of transition to the coastal zone. An erosion furrow in the epiclastic sandstones (erosive channel) is filled with chaotic large block lahar breccia. A body of a higher lahar with tiny material fragments was deposited in the overlying rock of the thin sandstone (© V. Konečný).

Photo 1 General view of the epiclastic complex in the state road trench north of Hontianske Nemce. In the lower left part, epiclastic volcanic sandstones with tiny fragments of andesite material are eroded by an erosion furrow, which is filled with a tiny conglomerate in the bottom part and, in its overlying rock, large block chaotic lahar breccia is deposited. In the upper part of the exposure, a chaotic lahar breccia with tiny fragments of andesite material is deposited in the overlying rock of a thin sandstone (© P. Pachinger).

A – At the lower level of the exposure in Fig. 1, epiclastic volcanic sandstones with signs of layering and the presence of tiny clasts are exposed in the state road trench. Locally, tree cavities are present. On the surface of the area of medium grained sandstones, there is an erosion furrow filled with tiny conglomerate.

B – The chaotic lahar breccia is deposited higher up, with a predominance of angular to subangular fragments in the 5-30 cm fraction, and occasionally with blocks up to 40-80 cm. Matrix is tuff, reddish with signs of increased compaction. Fragmented material constitutes ca. 30%, matrix ca. 70%. Its position is chaotic. The position of chaotic breccia corresponds to a hot lahar. It may have originally been a pyroclastic flow that was transformed into a hot lahar by mobilisation of older material and saturation with water in the river channel. In the bottom part, a tiny conglomerate is deposited in an erosion furrow.

Photo 2 A close-up of the bottom part of the erosion furrow in the epiclastic volcanic sandstone that is filled with conglomerates. A large block lahar breccia is deposited above (© P. Pachinger).

Photo 3 A close-up of the upper lahar breccia base with tiny fragments of material, deposited on the epiclastic volcanic sandstone interbed and on the lower large block lahar breccia (© P. Pachinger).

C – Higher in the overlying rock, a less coarse chaotic breccia follows, with a predominance of tiny fragments up to 5-8 cm (occasionally larger blocks) and sandy matrix (fragments make up ca. 60% and matrix ca. 40%). The breccia corresponds to a debris flow.

D – The breccia is separated from the underlying lahar by a discontinuous interbed of sandstone-claystone sediment.

The sequence illustrates the processes of transport and deposit of fragmented material at the foot of the stratovolcano slope in the area of transition to the proluvial plain. The transport of fragmented material was via mass gravity currents (debris flows, lahars) and washes. The presence of tree cavities indicates that the slopes were covered with forest vegetation during this period.

Geotope No. 80

Domaníky – road trench

epiclastic volcanic sandstones and conglomerates of the coastal zone

On the southern slope of the Štiavnica Stratovolcano, formations of epiclastic volcanic rocks were deposited in the coastal (litoral) zone of the Baden sea. During the Middle Baden, the products of volcanic activity and fragmented material transported from the stratovolcano slope in the shallow-water environment of the litoral zone, were deposited in this coastal zone (running roughly south of Krupina – Sebechleby – Ladzany line).

The disruption and destruction of lava flows and the effect of surge waves produced fragmented to block material. As a result of its processing and deposition, a facies of coarse to block coastal conglomerates is exposed in the exposures in Hontianske Nemce and south of Domaníky in

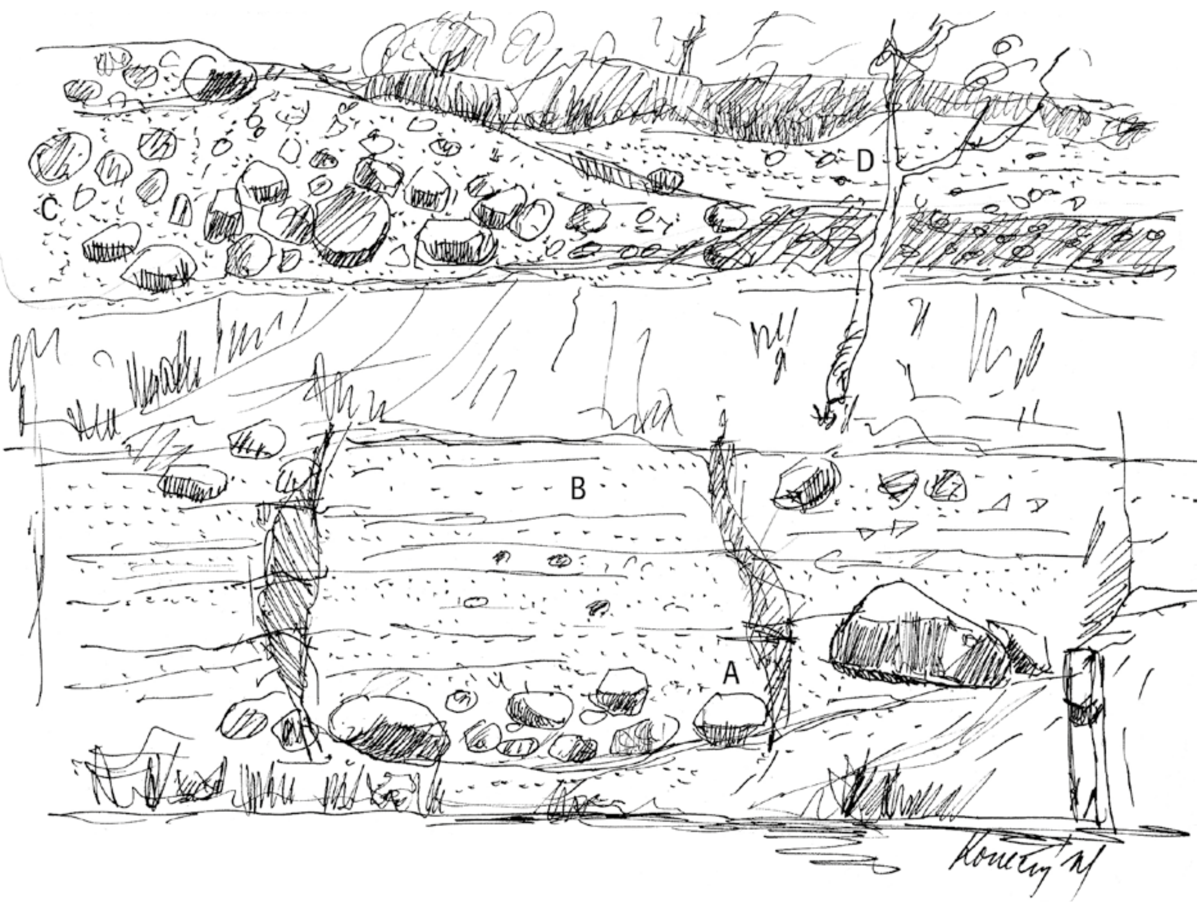


Fig. 1 A state road trench south of Domaníky reveals a complex of epiclastic volcanic rocks deposited in the coastal zone (© V. Konečný).

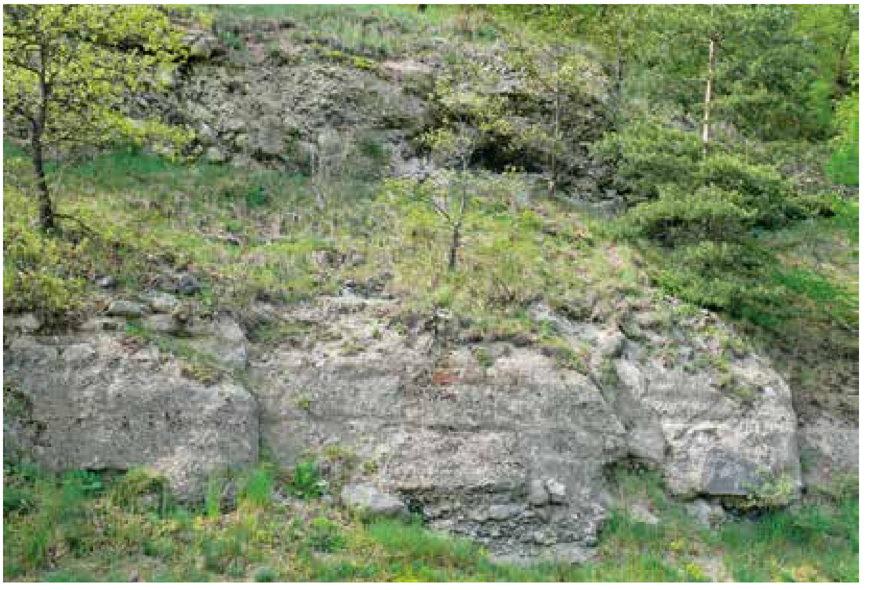


Photo 1 Epiclastic volcanic sandstones and conglomerates in the state road trench south of Domaníky. In the bottom part of the exposure are worked andesite blocks transported from the littoral to the sedimentation zone by the gravity density current. In the upper part of the exposure, there is a position of conglomerates with coarse graded bedding and in its overlying rock a position of epiclastic volcanic sandstone (© P. Pachinger).

the state road trenches. South of the coastal zone, the size of conglomerate material gradually decreases in parallel with the increase in the volume of the sandstone formations (Domaníky area), which are the prevailing facies in the southern part of the sedimentation zone (area south of Rykynčice). The sedimentation zone was occasionally penetrated by pyroclastic flows moving from higher levels of the stratovolcano slope, which were transformed into lahars when in contact with seawater. After the end of the transport motion, they were deposited in the form of bodies of chaotic lahar breccias (Medovarce-Horné Rykynčice area).

A complex of epiclastic volcanic sandstones is exposed in the state road trench south of Domaníky (Fig. 1, Photo 1, 2, 3).

In the bottom part of the exposure, the position of massive unconsolidated sandstones was deposited by a mass density current (A). Within this position, dispersed worked andesite blocks are more concentrated in the bottom part (Photo 2). The emplacement of this position probably occurred as a result of a slip process that occurred in the coastal zone, and the worked andesite blocks were also sheared off by the movement of the sandy mass.

Higher up, there are medium to coarse-grained sandstones with indistinctly outlined layering and occasional dispersed andesite pebbles (B).

In the upper part of the exposure, a position of medium to coarse andesite conglomerates is deposited on the sandstone formation, which locally fills erosion furrows in the sandstones (C) photo 3. In their overlying rock, they are followed by sandstones with textures of layering and interbeds of small conglomerates (D).

The exposures in the state road trenches from Hontianske Nemce to Domaníky illustrate the lithological structure of the Baden sea coastal zone with the deposition of coarse to block conglomerates and sandstones formations.

Photo 2 A close-up of a large-block conglomerate in the bottom part of the exposure, transported by mass gravity flow from the coastal zone to a deeper part of the sedimentation zone (© P. Pachinger).

Photo 3 A close-up of the base of the upper position of the conglomerate that forms the erosion furrow fill in the epiclastic volcanic sandstone bedrock (lower right part). In the overlying rock of the conglomerates, there is a position of epiclastic volcanic sandstone – top right (© P. Pachinger).

Geotope No. 81

Medovarce

lithological profile of the sublittoral zone facies

South of the coastal zone (Hontianske Nemce-Domaníky area), in the shallow sublittoral zone, a varied sequence of facies with epiclastic volcanic sandstones, conglomerates, breccias, debris flows and lahars was deposited during the Middle Baden.

The debris and tuff-sand material covering the southern Štiavnica stratovolcano slopes was mobilised from time to time and moved down the volcanic slope in the form of mass debris flow, or lahar, by gravity, due to the disruption of its stability (as a result of heavy rains or seismic shocks). After crossing the coastal zone, the mass debris flows continued further out on the seabed and, after some distance, deposited their contents in the form of chaotic coarse breccias. The chaotic breccias bodies deposited in the Medovace-Rykynčice area have been identified and labelled as submarine mud flows in the past (V. Konečný, M. Marková, D. Vass, 1965) and correspond to

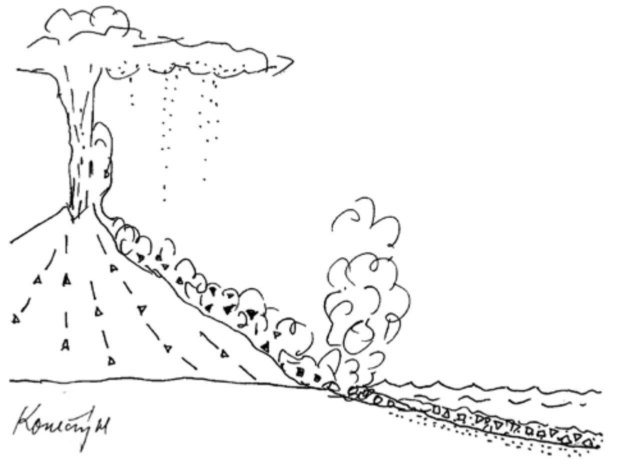


Fig. 1 A scheme of hot lahar formation. In the volcanic-type eruption, a pyroclastic block-and-ash flow was formed as a result of the eruption column collapse, which moved down the volcanic slope and, after crossing the coastal zone, continued further on to the seabed. Due to the cooling, it transforms into a hot lahar on the contact with sea water and mobilised coastal sediments (© V. Konečný).

Photo 1 Chaotic lahar breccia at the foot of the slope of Domanické. The breccia consists partly of worked andesite blocks and smaller subangular fragments and tuff-sand matrix (© P. Pachinger).

a specific-type of lahars. Chaotic breccias bodies with a higher degree of tuff-sand matrix compaction (indicating higher temperature at the time of their deposit) probably represented pyroclastic flows moving down the stratovolcano slope, which transformed into *"hot lahars"* (Fig. 1) in the course of further movement along the seabed, and also due to the loss of temperature, increase of water content and mobilisation of seabed sediments.

The lithological structure of the sublittoral zone facies is exposed on the valley slopes of the Krupinica river (elevation 304, Domanické), west of Medovarce (Fig. 2).

At the foot of the slope, above the state road, a chaotic coarse to block lahar breccia is deposited (blocks up to 0.5-1 m). The matrix is tuff-sand with a clay component (cold lahar), Photos 1, 2. Tree cavities that were transpor-

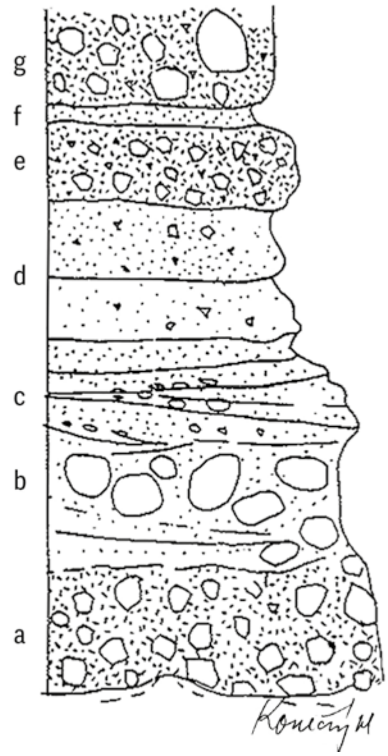


Fig. 2 Schematic lithological profile of the slope below the elevation 304 Domanické, west of Medovarce (© V. Konečný).

Photo 2 A close-up (© P. Pachinger).

Photo 3 Coarse to block conglomerate deposited in the coastal zone of the Baden sea. Boulders to blocks with a high degree of reworking are deposited in positions of coarse grained epiclastic volcanic sandstones (© P. Pachinger).

ted by a lahar (a) are present. A coarse to block conglomerate with well to perfectly worked andesite blocks up to 0.5-1.5 m (b) is deposited in the overlying rock, Photo 3. Higher up, positions of medium to coarse grained epiclastic volcanic sandstones, containing tiny, mostly angular fragments, follow and represent deposits of hyperconcentrated flows (c). Sandstone positions alternate with positions of tiny-fragment breccias with sandy matrix and chaotic deposition, corresponding to debris flows deposits (d). At a higher slope level, a chaotic breccia with fragments to blocks of 20-30 cm to 0.5 m and tuff-sand matrix with increased compaction is deposited below the elevation 304 Domanické (e). The breccia corresponds to the hot lahar, Photo 4. In the overlying rock of lahar breccia, there is a position of variable thickness (up to 0.8 to 1 m) of close-grained tuff with scattered pumice (f). The presence of pumice is indicative of ongoing explosive activity in the upper stratovolcano area. Lithologically, the sequence ends with the position of chaotic lahar breccia 12–15 m thick, with andesite blocks up to 1.5–3 m and a tuff matrix with increased compaction, containing tiny porous andesite fragments. The breccia corresponds to the hot lahar (g) Photos 5, 6. The lithological profile with elevation 304 Domanické is a typical example of the facies complex structure in the coastal zone.

Photo 4 Chaotic lahar breccia of the lower lahar in the upper part of the Domanické slope. Tiny-fragment to medium-fragment andesite material, with occasional larger blocks with radial jointing at the edges (below the hammerstone), is deposited chaotically. The matrix is tuff-sand, showing a high degree of consolidation - hot lahar (© P. Pachinger).

The lithological sequence on the Domanické slope with the elevation 304, illustrates the dynamic sedimentation conditions in the coastal zone, punctuated by mass input of debris material by lahars and debris flows.

Photo 5 Chaotic lahar breccia of the upper lahar with blocks up to 1 m or more in size, deposited in the upper level of the Domanické slope. The matrix is tuff-sand, strongly consolidated, the breccia corresponds to the hot lahar (© P. Pachinger).

Photo 6 A close-up of a lahar breccia with large andesite blocks (© P. Pachinger).

Geotope No. 82

Rykynčice

siltstones, sandstones, conglomerates, sediments of the deeper sublittoral zone

The site is located in the north-south profile of the sedimentary sea basin in the area of a deeper sublittoral zone at a distance of about 14 km south of the shoreline (Hontianske Nemce).

The deeper littoral zone is dominated by close-grained sedimentation in the form of sorted epiclastic volcanic sandstones alternated with interbeds to more continuous positions of siltstones (very fine clayey sediments) with occasional interbeds to positions of tiny to medium epiclastic volcanic conglomerates.

In an abandoned quarry, at the edge of the state road about 0.35 km south of Dolné Rykynčice, the following sequence has been exposed (Fig. 1, Photo 1):

A – in the bottom part of the abandoned quarry wall, light grey to ochre-yellow siltstones, finely-bedded with platy to irregularly dice disintegration, are rising. There are limonite coatings and, sporadically, leaf prints on the joint plane.

Photo 1 Abandoned quarry at the edge of the state road leading south from Dolné Rykynčice (© P. Pachinger).

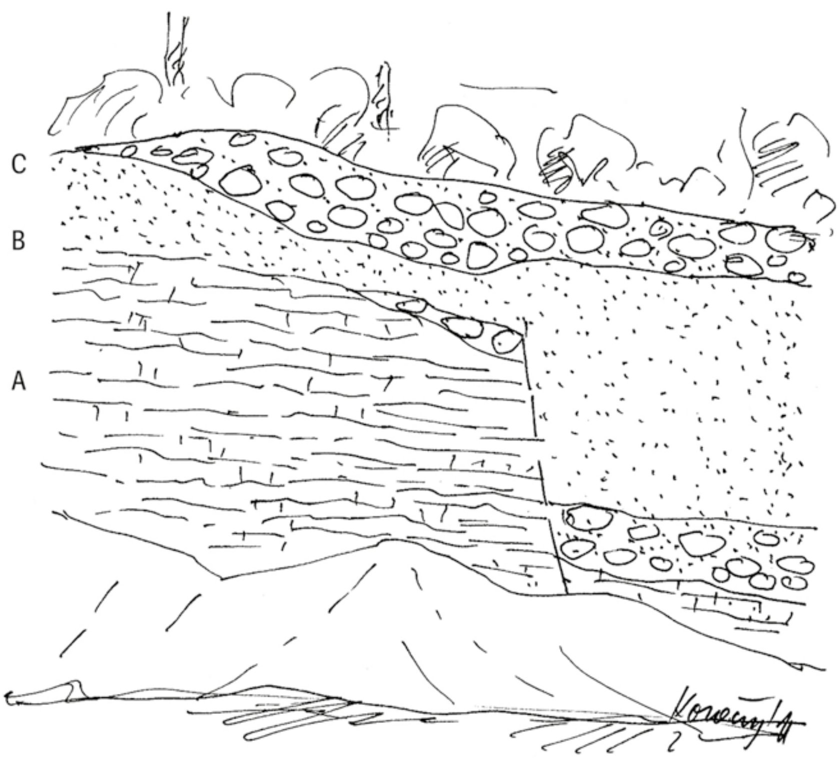


Fig. 1 An exposure in the abandoned quarry wall by the state road south of Dolné Rykynčice (© V. Konečný).

B – in the overlying rock of the siltstones, unconsolidated sandstones with lenticular interbeds of small conglomerates follow at the higher level.

C – in the upper part of the quarry wall, the position of andesite conglomerates and coarse-grained sandstones emerges. The base of the position is uneven with signs of base erosion. The conglomerate position is thought to be a product of the slip process and subsequent mass transport and deposition in the deeper level of the sublittoral zone.

In the right part of the exposure, subsidence along a synsedimentary fault (a fault active during sedimentation) is offset by the deposit of a thicker position of volcanic epiclastic sandstones (Photo 2).

Photo 2 In the abandoned quarry wall, there are light, ochre siltstones in the lower part, and higher in their overlying rock are epiclastic volcanic sandstones with tiny andesite pebbles (© P. Pachinger).

The lithological profile in the abandoned quarry wall documents quiet sedimentation of the deeper part of the sublittoral zone. Sedimentation is disrupted by the formation of a synsedimentary fault with a subsidence in the direction of the central part of the basin, indicating seismic unrest during sedimentation in the sublittoral zone. Sedimentation is interrupted in the upper part by a sudden mass accumulation of sand-conglomerate material, originating from the shallower level of the sublittoral to littoral zone, transported via mass flow (Photo 3).

Geotope No. 83

Kňazova Hora

lava flow of the bottom stratovolcanic structure on the eastern stratovolcano slope

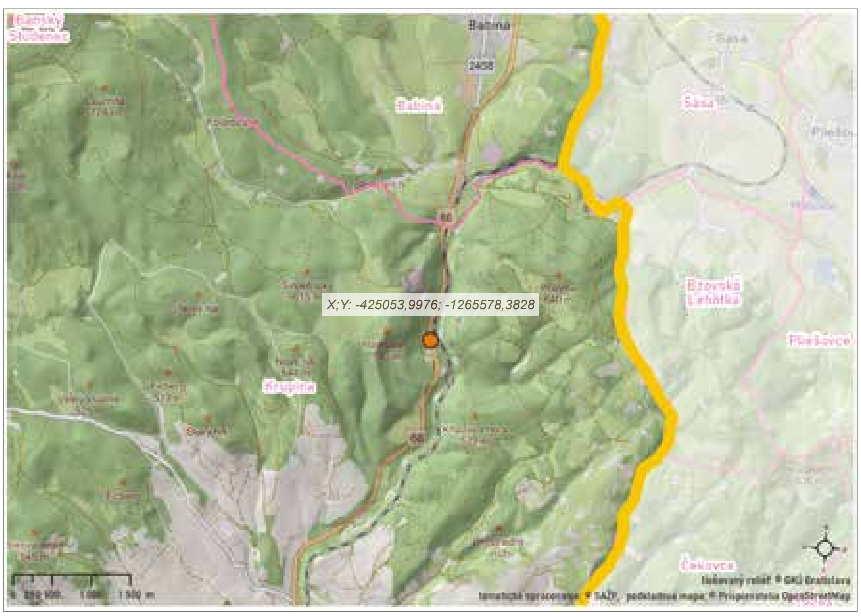
Lava flows directed to the eastern stratovolcano slope have expanded in the area of the lower slopes and at the stratovolcano foot to form a more continuous complex. The remains of this complex, exposed by a deep trench of the Krupinica river valley, rise on the slope with elevation 521.9 Kňazova Hora (about 4 km north of Krupina) in a series of impressive rock cliffs (Fig. 1, Photo 1).

Rock cliff andesite is fine to medium-grained porphyric, dark grey to light grey with phenocrysts of plagioclase (1–3 mm), pyroxenes (augite, hypersthene) and microlithic base matter. The mural jointing of the lamination type (parallel to the lava flow base) is subhorizontal with a slight dook to the south-east to east ca. 5–20° (in the direction of the stratovolcano slope). The lava flow is deposited on volcanoclastic rocks of the bottom stratovolcanic structure, represented by epiclastic volcanic breccias and conglomerates.

Photo 1 Pyroxene andesite rock cliffs on the western slope of Kňazova Hora (© P. Pachinger).

Higher up the slope, after being interrupted by the position of volcanoclastics, is another complex of lava flows of similar composition. Radiometric K/Ar dating by the lava flow method on the slope below Kňazova Hora yielded a date of 13.4 ± 0.6 million years, corresponding to the Late Baden period.

Photo 3 In the upper part of the abandoned quarry wall, the position of medium to coarse epiclastic volcanic conglomerates is emplaced, representing mass flow sediments (© P. Pachinger).



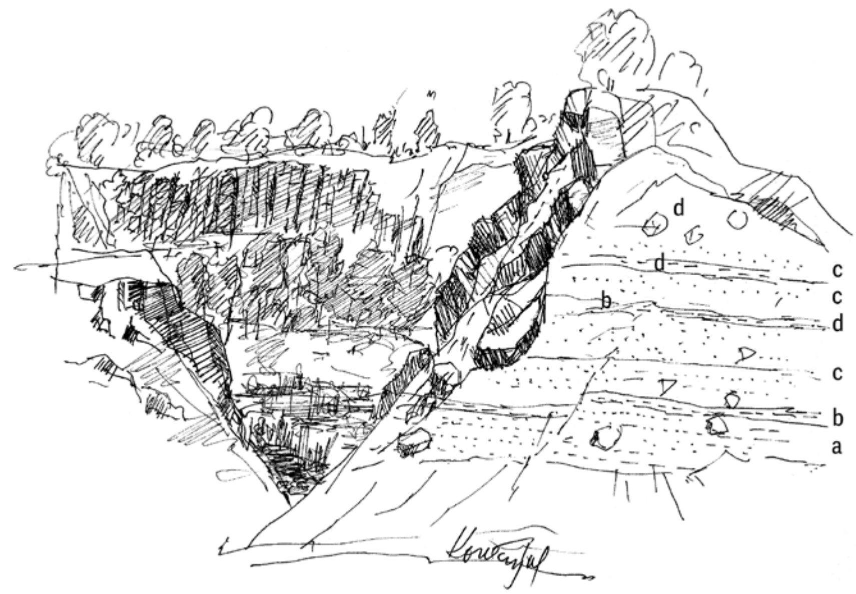


Fig. 1 General view of the Ficberg quarry, located north-west of Krupina. At the entrance to the quarry, there are sediments exposed on the right part of the slope, in which a paleodoline erosion furrow has been excavated. The furrow is filled by a pyroxene-andesite lava flow. On the slope near the right edge, there is an indication of columnar andesite jointing perpendicular to the paleodoline slope. A quarry wall with subvertical orientation of the columnar jointing rises in the background, with andesite with block jointing in the left part (© V. Konečný).

In the hilltop area of the crest (elevation 640), in the overlying rock of the complex of lava flows and volcanoclastics of the bottom stratovolcanic structure, volcanoclastic rocks (breccias, conglomerates) and lava flows of amphibole-pyroxene andesites (± biotite) are deposited. They belong to the upper stratovolcanic structure of the Štiavnica Stratovolcano, formed in the Sarmatian Period.

Fig. 1 A rock cliff of pyroxene andesite on the slope below the Kňazova Hora Hill (© V. Konečný).

Geotope No. 84

Ficberg

pyroxene-andesite lava flow in the paleodoline fill (erosion furrow) on the SE slope of the Štiavnica Stratovolcano

On the south-eastern stratovolcano slope, ca. 1.8 km north-west of Krupina, a lava flow of pyroxene-andesite is exposed in an abandoned quarry, which forms the fill of a local paleodoline – an erosion furrow excavated in an older complex of sediments (Fig. 1).

The sedimentary complex exposed at the right edge of the quarry entrance (Fig 1, Photo 1), consists in the direction from bottom to top of: a) epiclastic volcanic breccias with tuff-clay matrix, b) pumice tuffs alternating with positions of epiclastic volcanic sandstones, c) siltstones with sandier interbeds and occasional leaf prints arising in the upper part of the exposure, d) sediments deposited in the lake-type environment.

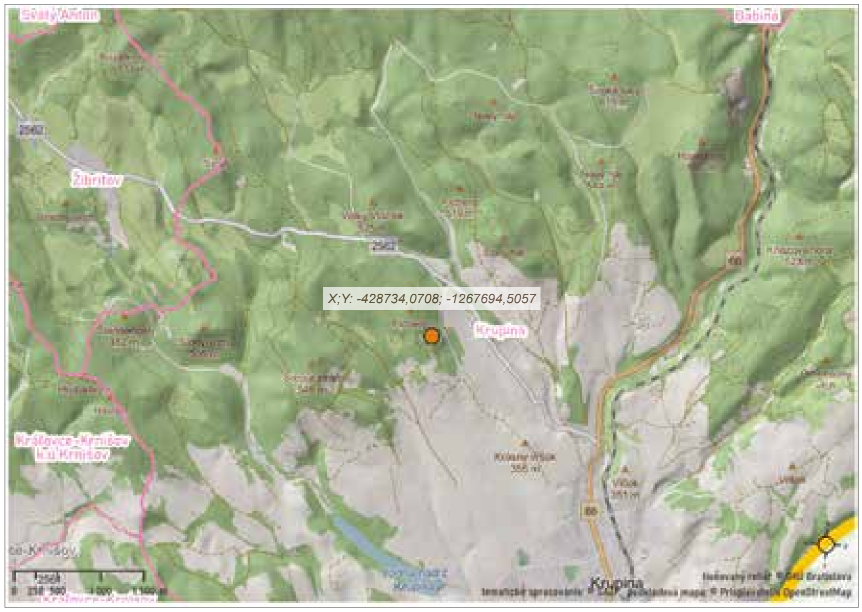
The lava flow body in the erosion furrow fill has a characteristic jointing. At the right edge of the body, a columnar jointing perpendicular to the inclined slope is indicated at the contact with the sediment slope (Fig. 1). In the central to the western part of the quarry, an uplift of the columnar jointing is observed, which gains a subvertical to vertical orientation (Photo 2, 3), suggesting that the lava flow was moving westward over flat terrain (possibly over an extended paleodoline with a flat bottom).

Near the left edge of the partially excavated quarry, the jointing of the andesite body is large-block, transitioning to columnar with subvertical to vertical orientation in the upper part (Fig. 2, Photo 4).

In the bottom part of the quarry, blocks of sediments enclosed in an andesite body rise, partly rotated. Locally, penetration of the lava body into the sediments is observed, which are reddish at the contact and hardened by the thermic effect of the burning lava flow.

Andesite is dark grey to grey-black, fine to medium-grained porphyric. Phenocrysts are composed of plagioclase (1–3 mm) and pyroxenes (augite, hypersthene). The base matter is microlitic-hyaline.

Lava bodies show columnar jointing as a result of cooling and crystallisation. As its volume decreases (solidified and crystallised lava has a smaller volume after the loss of the gas phase), internal stresses arise, which are compensated by the formation of cracks. In the case of slow solidification and crystallisation, a columnar jointing perpendicular to the cooling surface (area of contact with the surrounding environment) develops. In contrast, with rapid cooling, a block jointing with an irregular orientation of the joining planes develops.



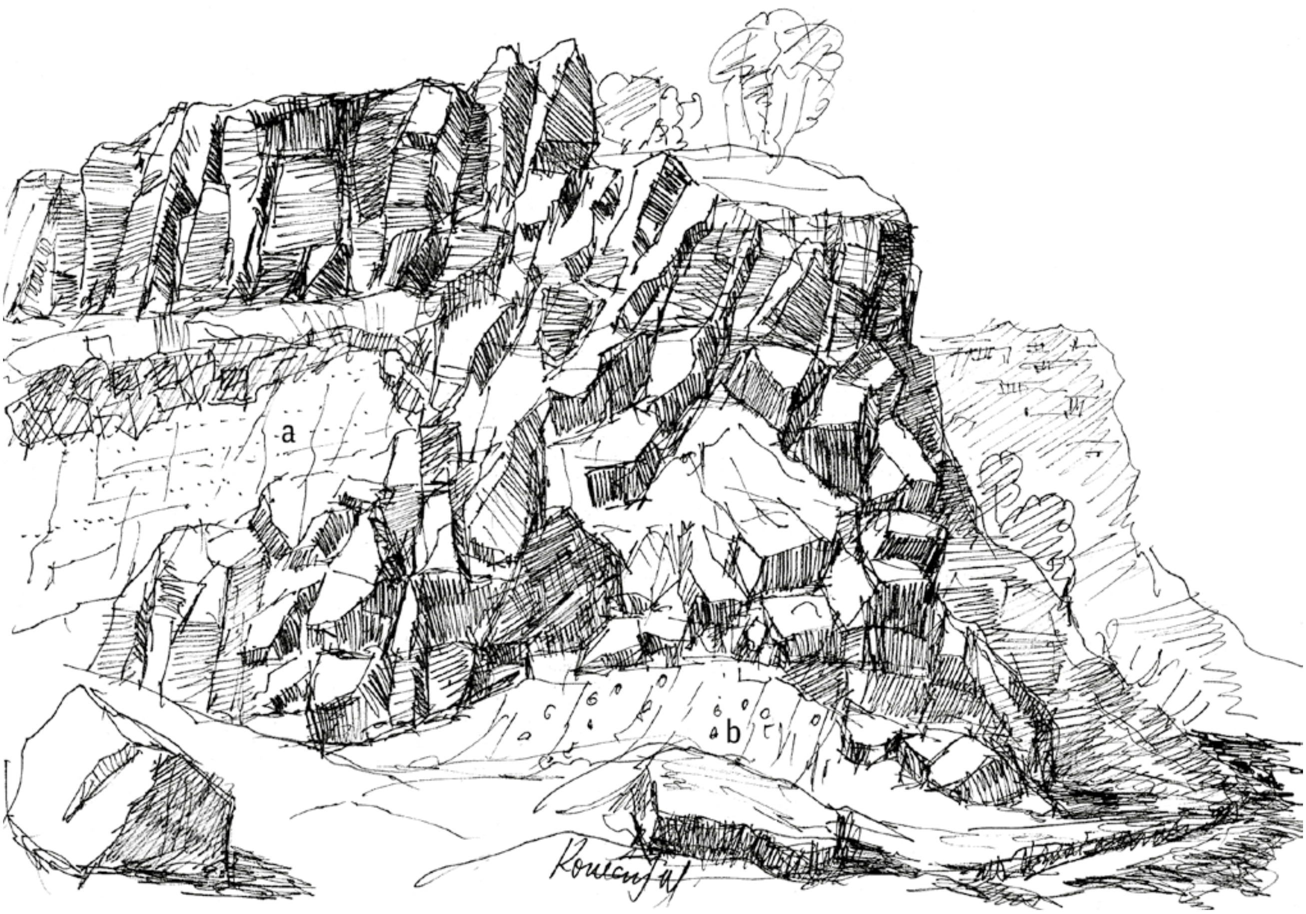


Fig. 2 Coarsely-columnar jointing of andesite in the upper part of the quarry wall. Below is the transition to the large-block irregular jointing. A block of sediments is enclosed in the left side of the quarry wall a). In the bottom part of the exposure b), a block of sediments is in an upright position (© V. Konečný).

Photo 1 At the entrance to the quarry, on the left side, the original sediments are exposed, in which an erosion furrow was excavated prior to the intrusion of the lava flow. In the upper part, positions of sandstones alternate with positions of pumice tuffs. In the upper part, the position of light-ochre siltstones is more distinctive. To the left on the slope are remains of unexcavated andesite (© P. Pachinger).

Older results of radiometric dating of the lava flow by the K/Ar method determined its age at 11.4 ± 0.3 million years (G. P. Bagdasarjan, V. Konečný, D. Vass, 1970), and therefore pointed to its formation in the Sarmatian Period. In contrast, the results of the new dating by the K/Ar method put the age at 13.5 ± 0.3 million years, and thus correspond to the Late Baden in the sense of the new subdivision (Černyšev et al., 2008).

Photo 2 Gradual uplift of the columnar jointing into the subvertical direction is observed in the back side of the quarry wall (© P. Pachinger).

Photo 3 Vertical columnar jointing in the lower and middle part of the quarry, with wetland in the foreground (© P. Pachinger).

Photo 4 Coarsely-columnar andesite jointing on the left side of the quarry. Below is the transition to the block jointing. Near the lower edge is a block of light brown sediments (© P. Pachinger).

Geotope No. 85

Drieňovo – Gašparov vŕšok

chaotic breccias of a pyroclastic flow of the Čelovce pyroclastic volcano

The wider area of Drieňovo-Čabradský Vrbovok represented an area of marine sedimentation in a shallow sublittoral to littoral coastal zone during the Baden Period. Into this area, debris material was washed down from the eastern slope of the Štiavnica Stratovolcano and simultaneously from the north-western slope of the Čelovce volcano and transported by debris and pyroclastic flows, which gradually filled the area of the subsiding Bzovík depression.

The processes of this sediment filling and fragmented volcanic material are documented by lithological profiles on the slopes of the deep trench of the Litava river valley (Fig. 1, 2).

At the bottom levels of the slopes of the deep trench of the Litava valley, a powerful group of strata of epiclastic volcanic sandstones with frequent textures of cross bedding (a) rises. Higher up in their overlying rock, there is a position of tiny to medium-size conglomerates and epiclastic volcanic sandstones with cross bedding (b). This is followed in the overlying rock by a powerful position of tiny epiclastic volcanic breccias with signs of sorting and layering (c). Higher in the overlying rock, there is a formation of epiclastic volcanic sandstones with distinct textures of cross bedding (d). Coarse to block

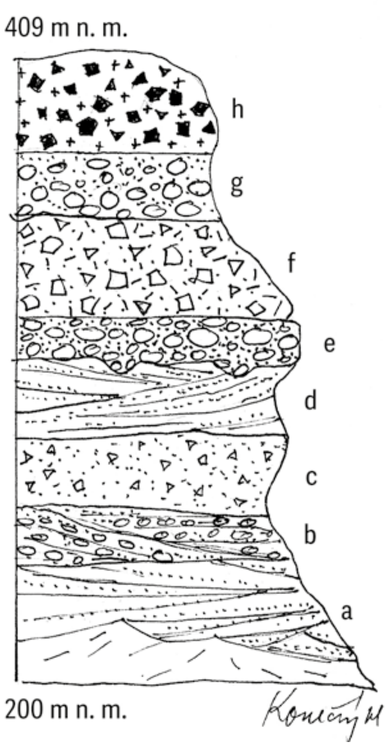


Fig. 1 The schematic profile of the slope of the Litava valley below Antalov laz documents the gradual filling of the sedimentary space with volcanic material (© V. Konečný):

a - epiclastic volcanic sandstones with oblique layreing,
b - epiclastic volcanic sandstones with positions of tiny to medium-size conglomerates,
c - tiny sorted epiclastic volcanic breccias,
d - epiclastic volcanic sandstones with oblique layering,
e - medium to coarse epiclastic volcanic conglomerate,
f - large to block lahar breccia,
g - large to block epiclastic conglomerate,
h - chaotic breccia pyroclastic block-and-ash flow.

Photo 1 The rock cliff of the block-and-ash flow below Gašparov vŕšok is on the edge of the steep slope above the Litava valley. The rock cliff consists of fragments to blocks of andesite, strongly sintered with an ash matrix. The position of the fragmented to block material is chaotic (© P. Pachinger).

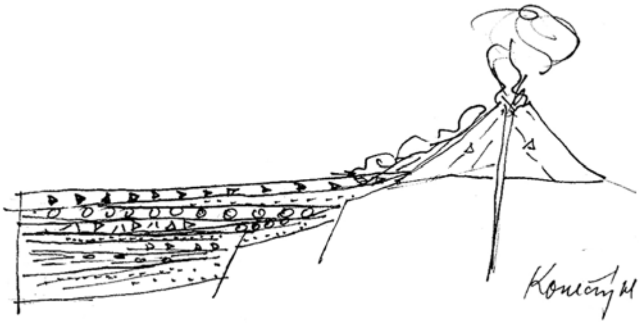


Fig. 3 Schematic cross-section of the Čelovce pyroclastic volcano and the Bzovík depression, into which volcanic material was transported (© V. Konečný).

epiclastic volcanic conglomerates are deposited on top of the epiclastic volcanic sandstones. Conglomerate material fills erosion furrows on the surface of the underlying epiclastic volcanic sandstones (e). Chaotic coarse to block lahar breccia (f) and overlying coarse to block epiclastic volcanic conglomerates (g) are deposited at a higher level. The lithological sequence ends with the position of chaotic pyroclastic breccia, which represent the deposits of the block-and-ash flow (h).

The deposition of conglomerates and breccias indicates that it was flattened by sedimentation.

The Čelovce pyroclastic volcano at the southern edges of the Krupinská planina plateau formed in the coastal zone of the Baden sea (roughly about 13.5 million years ago). The eruptive centers of this volcano, exposed by erosion furrow (necks and dykes), rise in the wider area of Čelovce. The products of the volcanic eruptions (ash-pumice tuffs) and debris pyroclastic material (block-pumice flows) were transported mainly to the north and north-west into the area of the subsiding Bzovík depression.

At the Gašparov vŕšok (elevation 415.9), at the edge of the steep slope above the Litava valley, rock cliffs formed by chaotic breccias of the block-and-ash pyroclastic flow transported from the eruptive centres of the Čelovce volcano rise to the surface (Fig. 3, Photo 1).

The breccia consists of andesite fragments mostly 5–25 cm in size. Blocks up to 40 cm and occasionally up to 0.6 to 0.8 m in size are less abundant. Fragments to blocks are angular to subangular and to a lesser extent subspherical (blocks and fragments with porous structure). Occasionally, worked blocks are present (they have been sheared by flow movement from the underlying conglomerates). The matrix is tuff, strongly consolidated, reddish to sintered in places, containing tiny angular but also spherical frothy fragments (Photo 2). Based on the petrographic

Photo 2 A close-up of the breccia of block-and-ash pyroclastic flow. The block disintegration by radial cracks into angular fragments (indicated by vertical arrow). Most blocks of porous andesite have subspherical constraint (horizontal arrow). Photo documents high degree of consolidation and sintering of tuff matrix with andesite fragments (© P. Pachinger).

Fig. 2 The rock cliff below Gašparov vŕšok is on the edge of the upper slope of Litava valley (© V. Konečný).

composition of the fragmented material and the spatial situation, the chaotic breccia is considered to be the product of the Čelovce pyroclastic volcano.

The movement of the burning mass of pyroclastic material, consisting of a mixture of magmatic gases, ash, pyroclastic fragments to blocks after the collapse of an eruption column on volcanic slope, took the form of a turbulent flow with a high temperature. Once the transport energy was exhausted, sintering to welding of the pyroclastic material occurred.

The origin of block-and-ash flows is associated with volcanic-type eruptions due to collapse of eruptive columns (Fig. 4 a) or explosive destruction of extrusive domes (Fig. 4 b).

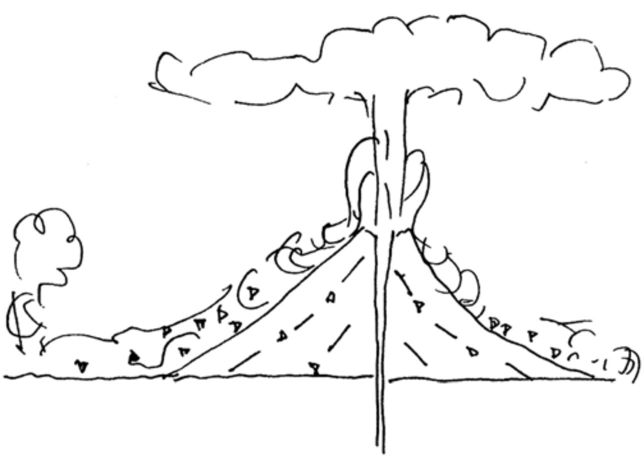


Fig. 4 a This shows a volcanic eruption with the formation of an eruption column and after its collapse a pyroclastic flow moving down the volcanic slope (© V. Konečný).

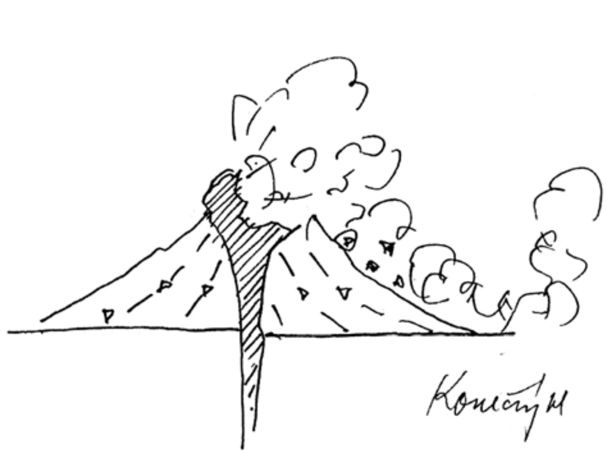


Fig. 4 b During the explosive destruction and collapse of an extrusive dome, a block-and-ash flow "glowing avalanche" is formed, which moves down the volcanic slope (© V. Konečný).

Geotope No. 86

Litava Valley

sediments of the sublittoral zone

The bottom levels of the Litava valley expose lower levels of the Čelovce formation composed of sedimentary rocks, mostly epiclastic volcanic sandstones, conglomerates and breccia positions with volcanic material of the Čelovce pyroclastic volcano. The deep trench of the Litava valley exposes the north-western segment of the Čelovce volcano in the peripheral volcanic zone (or distant volcanic zone), where the deposit of volcanic material took place in the shallow sublittoral zone of the Baden sea.

In the forest road trench, on the left slope, in the direction of flow of the Litava river, a formation of epiclastic volcanic sandstones with interbeds to positions of small conglomerates is exposed (Fig. 1).

Close-grained to medium-grained sandstones are characterised by graded bedding (coarser-grained material is deposited at the bottom, which gradually transitions into closer-grained material upwards). This type of grain size corresponds to sediments deposited by hyperconcentrated flows. Less common are textures of reverse graded bedding, where a weakening current caused the accumulation of coarser material.

Sedimentation is interrupted by mass accumulation of tiny clastic material via debris flows (in the lower to middle part, Fig. 1).

The massive, unbedded body of sandstones in the upper part of the exposure represents deposits of mass gravity flow “turbidite” or “tangle”.

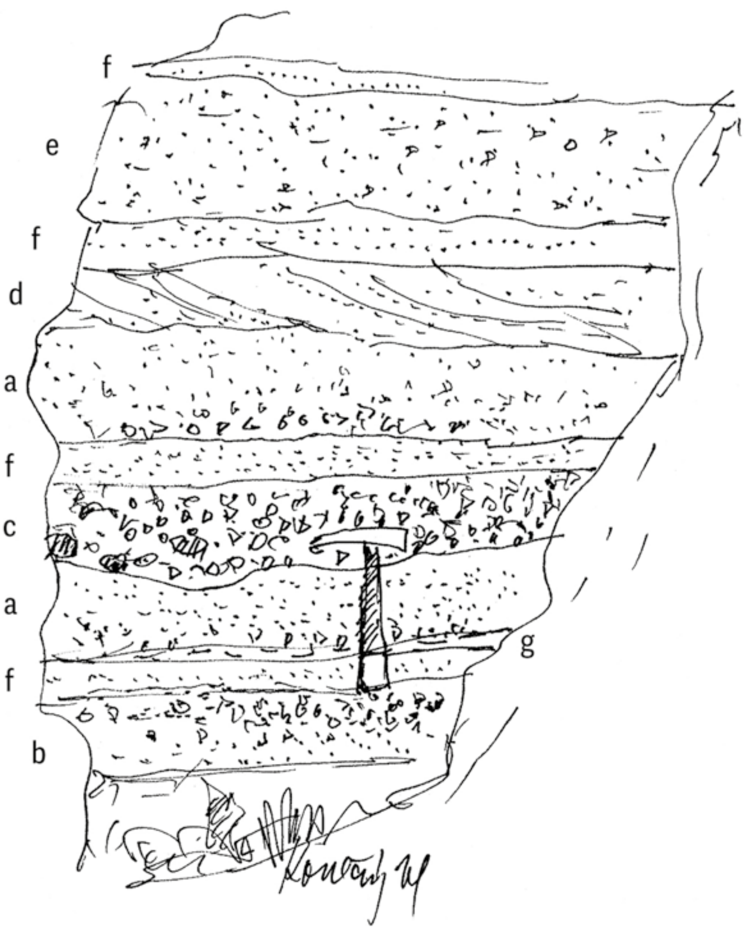


Fig. 1 Lithology of sediments of the sublittoral zone in the forest road trench on the slope of the Litava valley (© V. Konečný):

a - normal graded bedded epiclastic volcanic sandstones,
b - reverse bedded epiclastic volcanic sandstones,
c - debris flow,
d - cross bedded epiclastic volcanic sandstones,
e - unbedded massive sandstones deposited by turbidite,
f - positions of close-grained sandstones,
g - siltstone interbed.

The textures of the cross bedding (the higher part of the exposure) are the results of the tidal current's action. Locally, the cross bedding is accentuated by the deposition of small andesite conglomerates.

Locally, erosion furrows filled with epiclastic volcanic sandstones with interbeds of small epiclastic volcanic conglomerates are observed (Fig. 2, Photo 1, 2).

In the upper part of the exposure, worked andesite blocks are stripped from the coastal zone and transported by mass flow into the deeper part of the sedimentary zone (Photo 3).

Exposures in the lower levels of the Litava river slopes document processes of sedimentation in the shallow littoral zone. The accumulation of sandy material was mediated by hyperconcentrated flows, debris flows, tangles and turbidites. The effects of tidal flow were evident in the flattened environment.

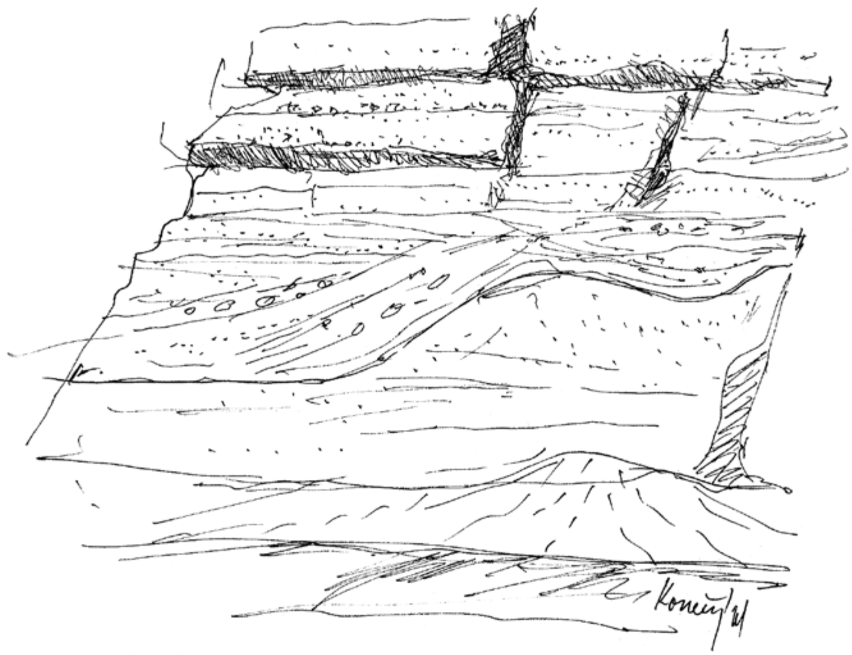


Fig. 2 The erosion furrow on the surface of the epiclastic volcanic sandstones filled and aligned by the deposit of cross bedded sandstones with interbeds of conglomerates. In the upper part there are positions of graded bedded epiclastic volcanic sandstones (© V. Konečný).

Photo 2 A close-up of the filling of the erosion furrow by coarse-grained sandstone with tiny clasts. At the bottom, there is a position of unbedded sandstone with scattered fragments of small pumice which represents a position deposited by a mass flow – turbidite (© P. Pachinger).

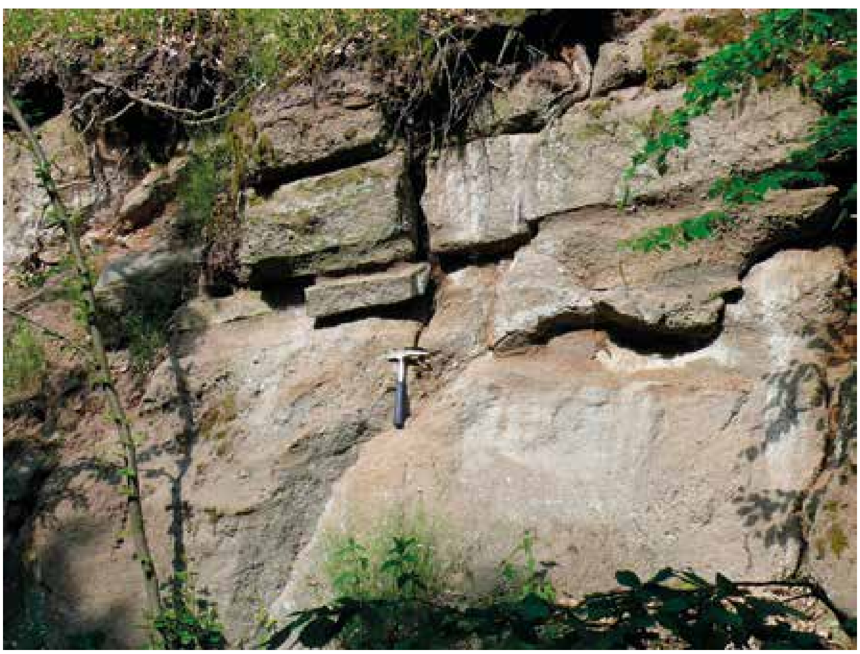


Photo 1 An erosion furrow disrupts the position of unbedded epiclastic volcanic sandstone (turbidite) and is filled by a deposit of coarse grained sandstone with fragments of small clasts. Higher up are deposited positions of epiclastic volcanic sandstones with graded bedding (© P. Pachinger).

Geotope No. 87

Čabraď

castle hill, coastal zone sandstones and conglomerates of the Baden sea

The volcanic rocks of the Štiavnica Stratovolcano meet and partly cover the rocks of the Čelovce pyroclastic volcano at its south-eastern edge.

The Čelovce pyroclastic volcano evolved during the Middle Baden period (roughly 13.5 million years ago) on the sea coast. In the course of explosive eruptions of ash-pumice tuffs and eruptions of pyroclastic flows, the pyroclastic volcano structure was formed on the sea coast.

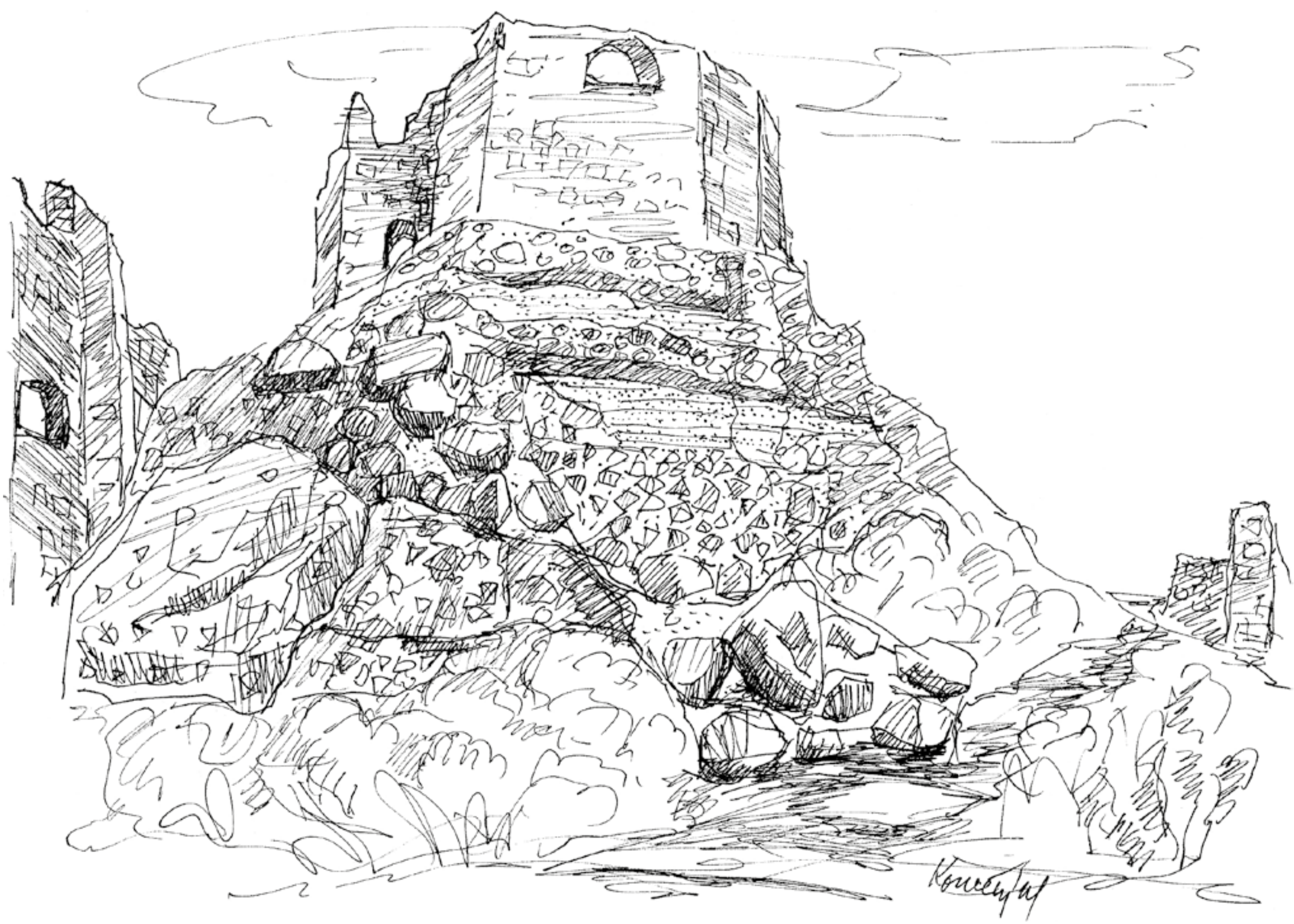


Fig. 1 The rock cliff of the Čabraď castle formed by deposits of coarse to block epiclastic volcanic conglomerates, chaotic lahar breccias and epiclastic volcanic sandstones (© V. Konečný).

Photo 1 The trench of the castle moat reveals a coarse to block chaotic lahar breccia (lower right part). The position of the lahar breccia is interrupted by an erosion furrow, which was subsequently filled with fine-fragment material transported by a debris flow (© P. Pachinger).

Photo 2 A close-up of the contact between the lahar breccia and the erosion furrow fill (© P. Pachinger).

The eruptive centres of this volcano (explosive necks and dykes), exposed by erosion, are seen rising in the wider surroundings of Čelovce. The volcanic products of the explosive eruptions (tuffs and breccias) were transported from the eruptive centres mainly to the north and north-west into the area of the Bzovík depression, which was intensively subsiding during this period. In addition to the volcanic material of the Čelovce pyroclastic volcano, the products of the volcanic activity of the Štiavnica Stratovolcano were transported into this area at the same time. Together they were deposited in the shallow-water environment of the coastal zone, mainly in the form of epiclastic volcanic sandstones, conglomerates and breccias. Pyroclastic flows, directed into this area from the exposed volcano slopes, met the marine environment at their foot and were transformed into lahars, debris flows and mud flows.

Photo 3 A view of the ruins of the Čabraď castle from the Litava Valley (© P. Pachinger).

On the slopes of the steep crest, formed by the meander of the Litava river, rise the rock exposures, which, especially in the upper area below the ruins of the castle, are formed by alternation of coarse to block epiclastic volcanic conglomerates, sandstones and breccias (Fig. 1).

Beneath the ruins of the castle tower, in the centre of the lower part, a chaotic lahar breccia, consisting mainly of lightly worked to unworked fragments to blocks of andesite, where it forms the fill of the local erosion furrow. A coarse to block conglomerate with a predominance of worked blocks is deposited to the left.

Layered epiclastic volcanic sandstones and higher positions of conglomerates alternating with those of sandstones follow in the overlying rock of the lahar breccia, in the erosion furrow fill.

In the trench of the castle moat, in the rock wall, a chaotic lahar breccia is exposed (lower right part of Photo 1). The position of the lahar breccia is interrupted by an erosion furrow filled with finer debris material, with a predominance of angular fragments, transported by a debris flow (Photo 2, a close up from Photo 1).

Photo 5 South bastion of the castle (© P. Pachinger).

The rocks exposures illustrate the dynamic conditions that prevailed in the coastal zone during the evolution of both volcanoes. They are characterised by the deposition of sandy material, the working of coarse material in the offshore zone and its deposition in the form of block epiclastic volcanic conglomerates. The sedimentation process was episodically interrupted by sudden mass accumulation of coarse material, through lahars and debris flows.

Photo 4 Entrance gate to the castle (© P. Pachinger).

The ruins of the medieval castle of Čabraď tower on the rock cliff. The castle, also known as the Litava Castle, was built in the 13th century and is documented in 1276. It was supposed to protect the roads to the mining towns of Central Slovakia. In the 13th and 14th centuries, it belonged to the Hunt family and the Čabraď manor. In the 15th century, it was a royal castle and its core consisted of a fortified tower; later a palace and a chapel were added to the courtyard. In the 15th century, it was occupied by Jiskra's troops, who stayed there for a long time. In the late Gothic period it was well fortified, it had four bastions. Tomas Bakocz had the castle rebuilt after 1513, but after his death it fell into such disrepair that its demolition was proposed in 1584. However, the threat from the Turks forced its restoration, enlargement and the construction of new massive fortifications. This work was probably led by the well-known Italian fortification builder Giulio Ferrari. Thanks to these modifications, the Turks never conquered the castle. In the 16th century, it was owned by the Pálffy family, in the 17th century by the Koháry family. Later, in the 17th and 18th centuries, it was seized by the armies of the Estate's rebels. In the 18th century, the castle lost its importance, the Koháry family moved to a more comfortable, newly built manor house in Antol and had the castle burnt down in 1812 (Photos 3, 4, 5).

13. Tourism Territorial Unit Levice

Geotope No. 88

Plášťovce

sediments of the sublittoral zone

During the Early to Middle Baden, the marine environment at the southern foot of the Štiavnica Stratovolcano was bounded by a coastal zone from the north (approx. along the line Krupina – Hontianske Nemce – Ladzany), which consisted of coarse to block conglomerates. South of the coast, mostly coarse to close-grained sandy material was deposited in the deepening sea basin, alternating with areas of conglomerates. Debris flows and lahars episodically penetrated the coastal zone and deposited chaotic breccia bodies (the Medovarce – Horné Rykynčice area). Southwards, the extent of sandstone groups of strata with interbeds of fine to medium-sized conglomerates and siltstones gradually increases. In the broader surroundings of Plášťovce, the close-grained siltstone sediments are thicker and more continuously deposited. The position of siltstone sediments indicates a peaceful sedimentation in a marine environment, further away from centres of active volcanism.

The peaceful siltstone sedimentation has been disrupted by a sudden mass flow of fine to coarse conglomerate material in an abandoned quarry south-west of Plášťovce. Several bodies deposited above each other and partly separated by siltstones and sandstones consist of this material (Fig. 1).

Siltstones are fine, light grey or light pink to ochre sediments, which often alternate with thin layers of close-grained sandstones. They are characterised by weathering and platelet to cubical disintegration. Pumice interbeds and beds are often present (2–3 cm large pumice

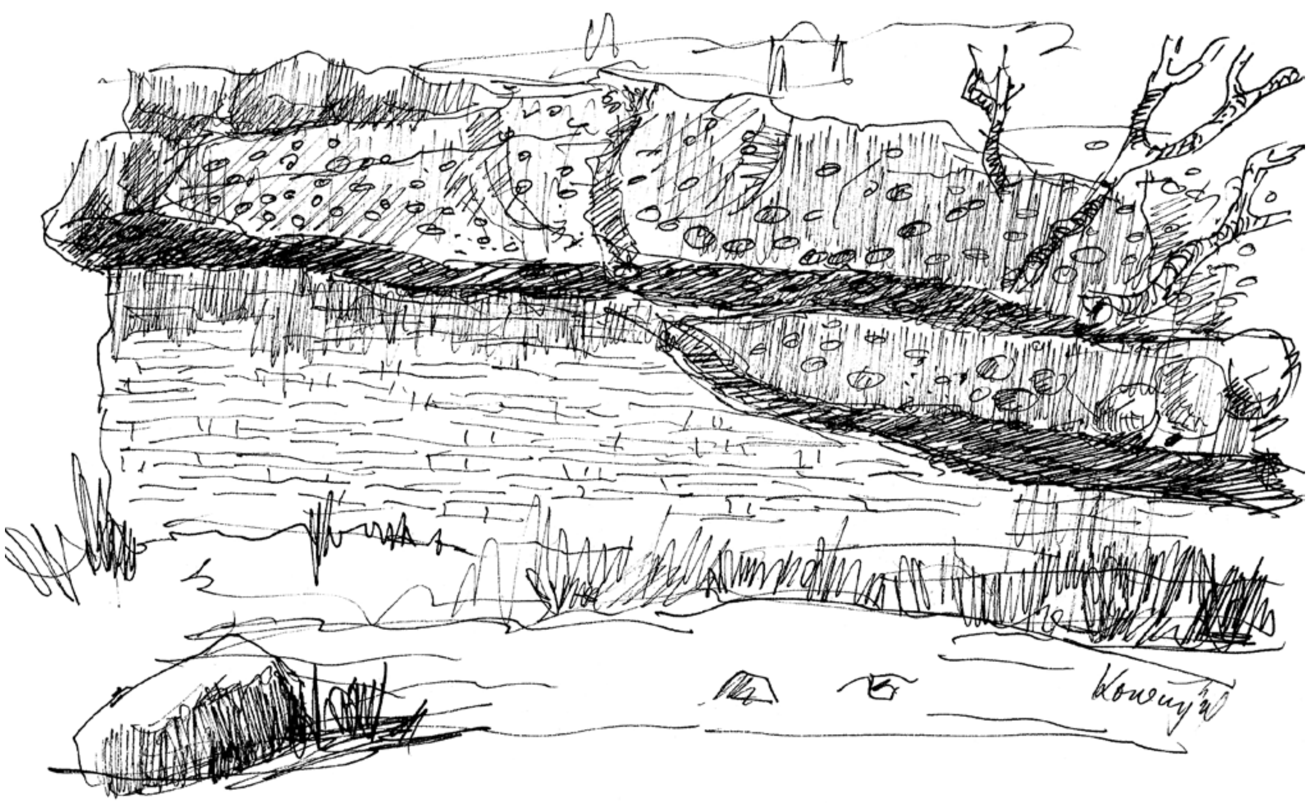
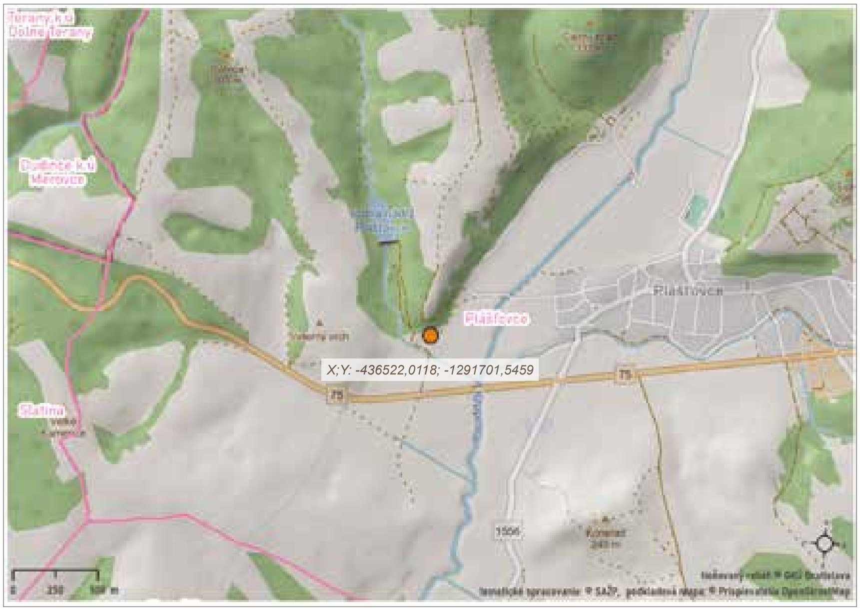


Fig. 1 In the abandoned quarry south-west of Plášťovce, bodies of fine to coarse conglomerates are deposited in the overlying rock of siltstones (© V. Konečný).



which caused the sudden relocation of the conglomerate material originally deposited near the coastal zone (Photo 3).

The conglomerate material moved in the direction towards the deeper parts of the sedimentation area, likely because of seismic shocks associated with volcanic activity, or because the volcanic matter was deposited suddenly and the bedrock sediments subsequently lost their stability. The movement of mass flows transporting conglomerate and sandy material in the direction towards the south has been limited by the rising elevation of the pre-volcanic bedrock (the Santovka-Túrovce Horst), which was an insurmountable barrier.

fragments). They are the products of ash-pumice, which fell from volcanic ash clouds and subsequently sedimented at the seabed as well as of ash material which was washed off the volcanic slope. The volcanic ash is a substantial component of siltstone sediments. Prints of leaves, flora and woody parts washed off higher volcanic slopes into the sedimentation zone occur frequently (Photo 1.).

Conglomerate bodies deposited in the overlying rock of siltstones (Photo 2) are the products of mass flows,

Photo 1 In the bottom part of the exposure, fine siltstone sediments with irregular to cubical disintegration has been deposited. Limonite leaked into the cracks (© P. Pachinger).

Photo 2 The conglomerate body has been deposited on siltstones with a sharp, discordant contact – without a gradual transition (© P. Pachinger).

Photo 3 A close-up of the conglomerate material originally deposited near the coastal zone (© P. Pachinger).

Geotope No. 89

Sudince

shallow water marine sediments

During the formation of the bottom stratovolcanic structure of the Štiavnica Stratovolcano, in the Early to Middle Baden (the first development stage), the volcanoclastic material was transported from the southern slopes of the stratovolcano towards the south, where it was deposited in a coastal (littoral) zone, and in a sublittoral zone even further south. While the coastal zone deposits usually consist of coarse to block material (coarse to block conglomerates along the line Hontianske Nemce – Ladzany), in the gradually deepening littoral and shallow sub-littoral zone south and south-west of the coast, sandy sediments have been deposited as coarse to close-grained sandstones with interbeds of tiny conglomerates and siltstones.

At the south-eastern edge of Sudince (ca. 5 km north-west of Hontianske Tesáre), a complex of shallow coastal zone sediments is exposed in an abandoned quarry (Fig. 1, Photo 1).

In the bottom part of the quarry wall, close-grained to medium-grained epiclastic volcanic sandstones alternate with more continuous siltstone layers (Fig. 2.).

Above, there are more interbeds of tiny conglomerates, which are more continuous in the upper part of the wall (Photo 2). Graded bedding, normal as well as reverse, occurs frequently. The cross bedding is more pronounced in the upper part of the quarry wall (Photo 3).

The bedding textures of sediments in the upper part of the wall indicate the sedimentation area has shallowed. The cross bedding has been caused by sea waves in a shallow littoral to sublittoral zone.

Photo 1 General view of the abandoned quarry walls south-east of Sudince (© P. Pachinger).

Fig. 1 General view of the abandoned quarry wall south-east of Sudince. In the upper part of the quarry wall, epiclastic volcanic sandstones alternating with siltstone and tiny conglomerate interbeds have been exposed (© V. Konečný).

Photo 2 A layer of tiny conglomerates in the upper part of the sandstone group of strata (© P. Pachinger).

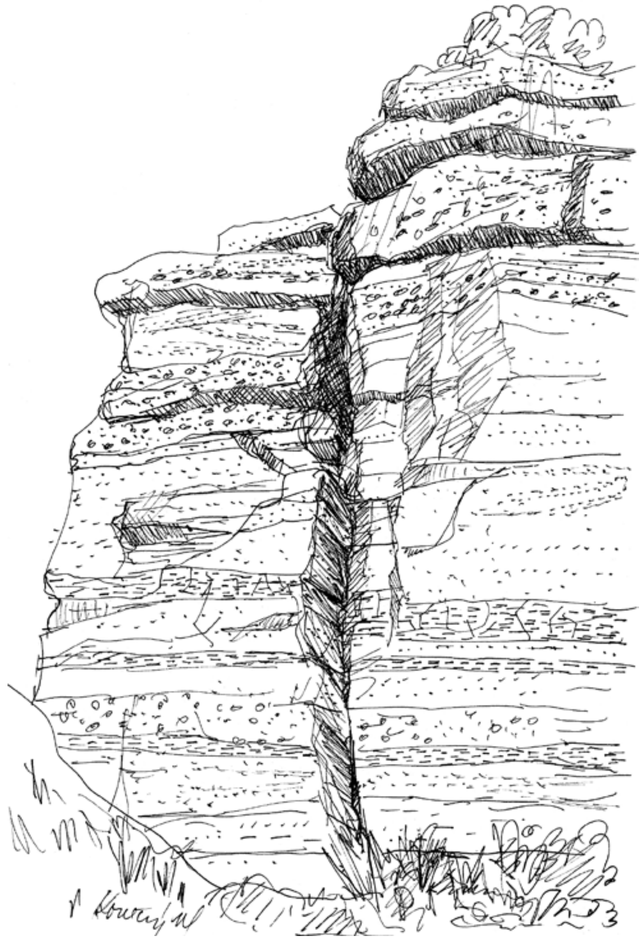


Fig. 2. In the bottom part of the quarry wall, close-grained sandstones alternate with siltstone layers. The number of interbeds to beds of tiny conglomerates gradually rises in the upper parts of the quarry. There are cross bedding textures in the sandstone layers, caused by tidal currents (© V. Konečný).

Photo 3 The cross bedding textures in the sandstone group of strata – in the bottom part and at the left edge (© P. Pachinger).

Geotope No. 90

Ladzany – the Husárka Hill

lava flow textures

During the massive effusions of pyroxene andesite lava flows pertaining to *the Baďan Formation* (the 4th stage of the Štiavnica Stratovolcano's formation), in the Sarmatian period, a large lava plateau formed at the southwestern foot of the stratovolcano and partly in the coastal zone. Today, its denudation remains can be found in an 80 km2 large area. The lava plateau consists of a large number of lava flows, some of which upon contact with water disintegrated and brecciated, thus forming hyaloclastite breccias.

In an abandoned quarry near the Ladzany – Levice state road, in the southern slope of Husárka Hill (e. 562, ca. 4.5 km west of Ladzany), the internal structure of the lava flow pertaining to *the Baďan Formation* is exposed (Fig. 1).

The lava flow consists of grey-black to black andesite with distinct plagioclase phenocrysts (1–3 mm) and smaller pyroxene phenocryst (1–2 mm). The base matter is vitreous. The andesite disintegration is platelet along the lamination surfaces, or irregular with angular fragments.

The andesite jointing is roughly mural along the fluidity planes, and subhorizontal (parallel to the surface on which the flow was moving) in the right part of the quarry wall (Photo 1). The mural jointing in the left part of the quarry wall has been gradually raised into a steep subvertical inclination (Photo 2).

Photo 2 In the left part of the abandoned quarry, a gradual rise of the mural jointing into a subvertical inclination can be observed (© P. Pachinger).

Fig. 1 In the abandoned quarry wall west of Ladzany, the internal structure of the pyroxene andesite lava flow is exposed (© V. Konečný).

Photo 1 In the right part of the abandoned quarry wall west of Ladzany, an andesite with indicated subhorizontal mural jointing and coarsely-columnar to irregular jointing along the subvertical planes can be observed (© P. Pachinger).

Such mural jointing along the fluidity planes (also referred to as lamination jointing), occurs in the final stage of the lava flow movement, when the lava flow stops and starts to solidify. In this stage, parts of the semi-solid lava body in a very viscous state start moving along tiny joint planes – lamination surfaces. The presence of such planes allows for the formation of mural jointing. This jointing is roughly parallel to the relief surface, along which the lava flow is moving. If the bedrock relief is flat, the mural jointing has a subhorizontal course. If the relief inclines at the edge of the flow (e.g., the lava flow is moving through a valley), the course of the mural jointing follows this inclination.

This is likely the reason for the formation of the mural jointing, which transitions into a steep, subvertically inclined jointing at the left edge of the quarry wall (Fig. 1).

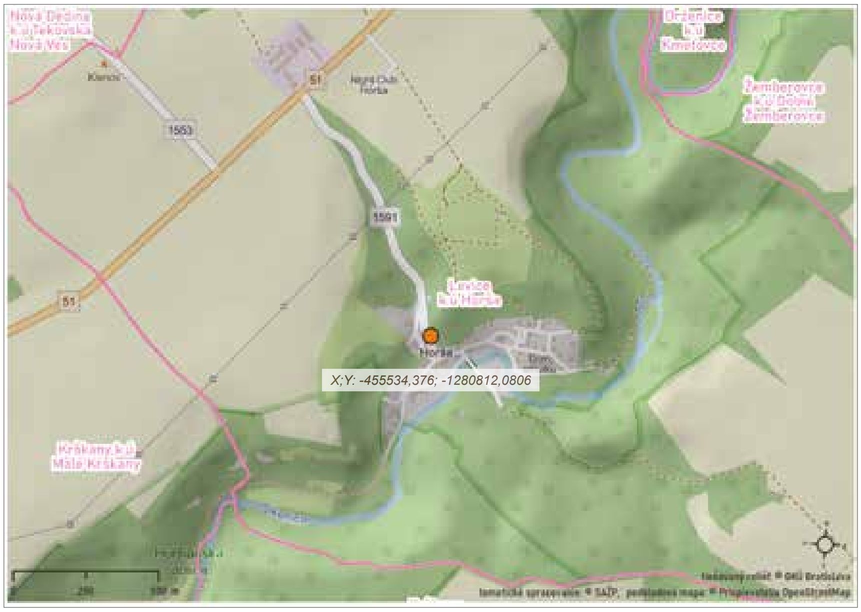
In the central to right part of the quarry, a coarse-columnar jointing along the subvertical planes is indicated, which have formed as the lava flow solidified and crystallised. Due to volume reduction, internal stress is generated and jointing along the planes perpendicular to the cooling surface occurs. The orientation is subvertical to vertical (the central and right parts of the quarry wall).

Geotope No. 91

Horša

vitreous pyroxenic andesite lava flow

At the upper end of the Horša municipality (ca. 6.0 km north-east of Levice), a lava flow of vitreous pyroxenic andesite pertaining to *the Baďan Formation* (the 4th stage of the Štiavnica Stratovolcano's formation) is exposed in an abandoned quarry. The quarry can be accessed via an 80 m long dirt road starting at the state road (Fig. 1).



The lava flow represents the southern edge of a large lava plateau, which has formed at the southern foot of the stratovolcano during the multiple pyroxene andesite lava effusions. Today, the denudation remains of this plateau can be found in an 80 km2 large area. The lava flows came into contact with the marine environment after rolling down the stratovolcanic slope towards the south, they solidified due to rapid cooling, became vitreous and were subject to hyaloclastite brecciation (hyaloclastite breccias are the subject of another, more northern locality, situated in a valley above the Vozárov Mlyn area).

The massive lava effusions occurred after the ash-pumice tuff eruptions, which were deposited on the southern stratovolcanic slope and in the coastal zone in the form of massive groups of strata (Brhlovce and Žemberovce). The lava then formed an extensive lava plateau in the overlying rock.

Fig. 1 The pyroxenic andesite lava flow exposed by a quarry at the northern edge of Horša. Andesite disintegration along vertical subvertical planes forms a curtain-like structure. The indicated mural jointing has a subhorizontal course (© V. Konečný).

Photo 1 The curtain-like andesite disintegration along the subvertical planes (© P. Pachinger).

Photo 2 A close-up of mural jointing along the lamination surfaces (© P. Pachinger).

The andesite in Horša is grey-black to black with distinct, up to 2–3 mm large plagioclase phenocrysts. The lava flow has disintegrated along the steep jointing into a curtain-like series of blocks (Photo 1). The jointing is mural along the subhorizontal to horizontal planes (lamination surfaces), which indicate the flat surface along which the lava flow moved and subsequently solidified (Photo 2).

The age of the andesite in Horša was determined by radiometric dating using the K/Ar method to be 12.9 ± 0.5 million years old, which corresponds with the Early Sarmatian.

Geotope No. 92

Vozárov mlyn

hyaloclastite breccias

The renewed volcanic activity during the Sarmatian, after the initial ash-pumice tuff eruptions, resulted in massive effusions of pyroxene andesite lava flows pertaining to the Baďan Formation. These effusions formed an extensive lava plateau at the southern foot of the Štiavnica Stratovolcano. The remains of this plateau are distributed in the area south of Baďan, between the Tlmače and Gondovo municipalities, and further to the south between Krškany and Ladzany. The lava plateau in the southern part of the area was deposited on a massive group of strata of epiclastic volcanic sandstones with pumice layers (Geotope No. 95 – Brhlovce). The lava flows at the southern edge of the stratovolcano came into contact with the marine environment upon reaching the coastal zone and were subject to a heavy hyaloclastite brecciation (Fig. 1).

Fig. 1 Scheme of hyaloclastite brecciation of a lava flow upon its contact with the marine environment (© V. Konečný).

The hyaloclastite brecciation occurs when the burning lava comes into contact with water. This lava starts to rapidly cool down and subsequently becomes solid. Due to the internal stress and additional movements, the semi-solid to solid lava starts to disintegrate and brecciate into mainly angular fragments and blocks. As the lava brecciated and disintegrated into fragments, an important role was played by the violent expansion of water vapour, which occurs upon contact of the burning lava flow (with the temperature of 900–1,000 °C) with sea water. This mass of fragments then moves further down the steep slope of the sea bed. After it deposits and solidifies, a chaotic hyaloclastite breccia forms. These processes took place at the southern edges of the Štiavnica Stratovolcano, in the coastal zone, roughly 12.5 to 13 million years ago.

In the Vozárov Mlyn area north of Horša, on the slope of the side valley leading into the main valley through which the Sikenica River meanders, vast exposures of hyaloclastite breccias can be observed (Fig. 2, Photo 1, 2).

Tiny, from 5 to 30 cm large fragments, and sporadically up to 1.5 m large blocks with a vitreous base matter, which are often heavily porous, usually angular or subangular.

The matrix between fragments is granular, grey, brownish or reddish with a higher content of tiny angular fragments (2–3 or up to 5 cm large). Their position is strongly chaotic.

The hyaloclastite breccias form a line at the southern edge of the lava plateau, which varies in thickness from a few metres to tens or hundreds of metres. Further to the south, the deposits of the chaotic breccias gradually transition into redeposited hyaloclastites, which consist of fragmented material alternating with sandstone layers.

Fig. 2 The rock exposure of a hyaloclastite breccia in the slope of the side valley leading into the main valley with the Sikenica River (© V. Konečný).

Photo 1 General view of the chaotic hyaloclastite breccia in the slope of the side valley leading into the main valley with the Sikenica River (© P. Pachinger).

Photo 2 A close-up of the chaotic hyaloclastite breccia consisting of mostly angular fragments of vitreous pyroxenic andesite. The subspherical fragments are heavily porous – to the left of the hammer (© P. Pachinger).

Geotope No. 93

Kamenec

sediments of the Sarmatian littoral zone

During the Sarmatian, the sea moved from the eastern part of the neo-volcanic region to the west due to the relocation of subsidence centres into the Danube Lowland. During this period, the marine environment extended into the area at the southwestern foot of the Štiavnica Stratovolcano (west of Ladzany).

During the Sarmatian, ca. 12–13 million year ago, there was tumultous volcanic activity on the southwestern stratovolcanic slope. After the massive ash-pumice tuff eruptions took place, vast effusions of pyroxene andesite lavas pertaining to *the Baďan Formation* (the 4th stage of the Štiavnica Stratovolcano's formation) created an extensive lava plateau in the coastal area at the southwestern foot of the stratovolcano. Lava flows which came to contact with the marine environment, disintegrated and brecciated. As

a result, hyaloclastite breccia masses accumulated at the southern edges of the lava plateau.

The fragmented material of hyaloclastite breccias was further transported by the sea currents and deposited in the coastal zone. In the tidal zone, the breaking waves disrupted the lava flows and caused the formation of coarse to block conglomerates.

In an abandoned sand quarry near Kamenec (ca. 9.5 km north-east of Levice), epiclastic volcanic conglomerates of a dark grey to grey-green colour with layers of andesite gravels are exposed. At the bottom of the quarry, rounded andesite blocks

Photo 1 The rounded andesite blocks buried in sandstones at the bottom of an abandoned sand quarry (© P. Pachinger).

Photo 2 The well to perfectly rounded blocks are more than 1 m large (© P. Pachinger).

of various sizes (up to 1 m) are partly exposed, dispersed, and buried in sorted volcanic sandstones (Photos 1, 2, 3).

The rounded blocks come from the vitreous pyroxene andesite lava flows pertaining to the Baďan Formation, which have been eroded and disrupted in the tidal zone.

At the upper level of the overlying rock, poorly hardened, sorted sandstones have been exposed. They contain volcanic material in the form of andesite grains and frag-

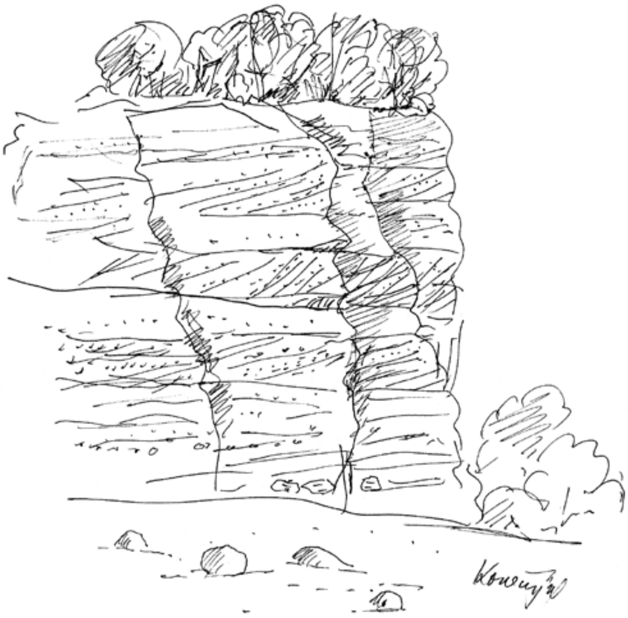


Fig. 1 In the walls of the abandoned sand quarry, sandstones with distinct textures of cross bedding have been exposed (© V. Konečný).

Photo 4 The cross bedding sedimentary textures of sandstones in the wall of the abandoned sand quarry (© P. Pachinger).

Photo 3 The rounded block on the left side consists of pyroxene andesite with a vitreous base matter and porous structure, pertaining to the edge of a destructed lava flow (© P. Pachinger).

ments, rounded pumice (up to 3 to 8 cm), as well as quartzite grains and pebbles (Fig. 1).

The sedimentary textures, especially the *"herringbone-type"* cross bedding, have formed in the shallow marine environment due to tidal currents (Photo 4, 5).

From the bottom up, the number of layers with cross bedding caused by tidal currents rises.

The sedimentary complex consisting of sandstones, conglomerates and gravel is a delta sedimentation in a shallow marine environment. Northwards, a varied series of volcanic rocks including hyaloclastite breccias, pumice tuffs, epiclastic breccias and lava flows has been deposited in a delta fill.

Photo 5 A close-up of the "herringbone-type" cross bedding of sandstones (© P. Pachinger).

Geotope No. 94

Žemberovce

epiclastic volcanic sandstones with layers of pumice tuffs

At the south-eastern edge of Žemberovce, in an abandoned quarry, a group of strata of volcanic sandstones and pumice tuffs deposited in the coastal zone at the southern slope of the Štiavnica Stratovolcano have been exposed (Photo 1).

The group of strata from the 4th stage of the Štiavnica Stratovolcano's formation during the Early Sarmatian pertain to *the Baďan Formation*. During this period, pyroxene andesite volcanism was active. It had started with massive ash-pumice tuff eruptions, which were followed by effusions of lava flows. The repeated effusions allowed an extensive lava plateau to form in the overlying rock of a sandstone-tuff group of strata at the southern foot of the stratovolcano.

Medium to coarse-grained sandstones alternating with interbeds to beds of pumice tuffs have been deposited in the walls of the abandoned quarry (Photo 2).

The graded bedding textures (the coarse-grained material deposited at the bottom layer becomes finer at the upper layers) and cross bedding textures indicate that the sandy material from hyper-concentrated flows gradually deposited in a shallow marine environment. Besides the layers with signs of layering and sorting, sandstone layers without the signs of graded and cross bedding, containing dispersed andesite pebbles, are also present in the sandstone groups of strata (Photo 3).

The non-layered sandstone bodies are the deposits of density currents (turbidites). They occasionally formed further to the north, on the slope of the seabed. The loose sandy material was transported by these density currents further south, into deeper parts of the sedimentation area, where it was deposited.

The occurrence of density currents – turbidites, which transported the non-consolidated (loose) sandy material, was likely caused by seismic shocks (related to the volcanic activity) or by the sudden placing of huge masses of pumice-tuffs and sandy material on the inclined seabed, which affected its stability.

Layers of epiclastic volcanic sandstones alternate with non-layered ash-pumice tuffs. The ash-pumice tuffs come from the explosive Plinian eruptions. During these eruptions, the repeated collapses of eruption columns allowed the formation of hot ash-pumice flows, which rolled down the volcanic slope and penetrated the marine environment.

The events that happened on the seabed south of the coastal zone can be observed in the exposed walls of the abandoned quarry. The sedimentation on the inclined seabed, represented by the layering of sandy tuffs (layers with graded and cross bedding), has been episodically interrupted by mass flows of sandy material, which were transported by density currents – turbidites, as well as by ash-pumice flows from the Plinian eruptions, which fell from the ash-pumice volcanic clouds.

Photo 1 General view of the abandoned quarry at the southeastern edge of Žemberovce (© P. Pachinger).

Photo 2 In the abandoned quarry wall, layered as well as non-layered tuff-sandstones alternate with pumice tuffs – the off-white layers (© P. Pachinger).

Photo 3 The non-layered sandstone in the wall of the abandoned quarry. In the bedrock and overlying rock of sandstone bodies, pumice tuffs have been deposited. The non-layered sandstones are the products of density currents – turbidites. On the surface of the lower sandstone body, pumice tuffs have been deposited. Pumice fragments have been dispersed in a sandstone mass. The upper sandstone body – turbidite (above the hammer) has been deposited in a sharp contact with the pumice tuff. On the left side, above the hammer, the pumice layer with dispersed pumice fragments in a sandy mass has been swirled (© P. Pachinger).

Geotope No. 95

Brhlovce

pumice tuffs and rock dwellings

Brhlovce is located at the southern slopes of the Štiavnica Stratovolcano, ca. 9 km east of Levice. In the surroundings of Brhlovce, layers of pumice tuff formed by the Sarmatian explosive eruptions (ca. 12.8–13.0 million years ago) can be observed. The renewed pyroxene andesite volcanic activity, which was part of the 4th stage of the Štiavnica Stratovolcano's formation, started as abrupt Plinian eruptions (Fig. 1), which produced a large volume of volcanic ash and pumice. The location of the eruption centres, which were the source of ash and pumice, is assumed to be in the southern part of the caldera, or on the SW and S slope of the Štiavnica Stratovolcano, where a line of smaller parasitic (satellite) volcanoes has formed.

In the course of repeated explosive eruptions, during which eruption columns collapsed, the ash-pumice material was transported in the form of ash-pumice pyroclastic flows. These flows were moving from the upper levels of the stratovolcanic slope to the south, where they halted in the shallow marine environment. The ash-pumice material, in the form of volcanic eruption columns saturated with volcanic gases, rose to the upper levels of the atmosphere where it was spread sideways by wind currents and transformed into volcanic ash clouds. The volcanic ash and pumice from the ash cloud formed tuff plateaus on the stratovolcanic slope and was deposited in the shallow marine environment in thin or thick layers alternating with epiclastic volcanic sandstones and tiny conglomerates.

The layers with interesting textures of ash-pumice tuffs deposited in the shallow marine environment can be observed in the walls of a nearby abandoned quarry, west of Brhlovce (Photo 1).

The non-layered pumice tuffs (thick several tens of cm to 1 m) represent the ash-pumice flows deposits, which were transported from the stratovolcanic slope and deposited in water. The chaotic position of pumice fragments and the absence of any signs of sorting and layering indicate that they have been mass transported due to gravitation and deposited after the mass flow stopped.

The pumice tuff layers, which testify that the eruptions took place, alternate with layers of dark grey tuff-sandstones and more close-grained siltstones. The sandy material that has been washed off the stratovolcanic slopes and deposited in the littoral zone has often slid and moved, in the form of granular flows, into the deeper parts of the sea basin, where it was deposited as non-layered sandstones.

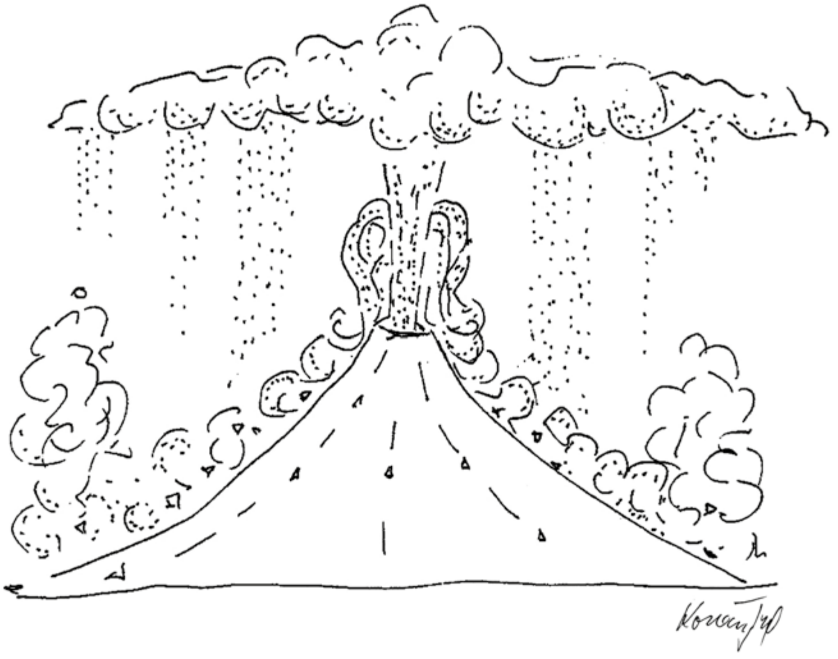


Fig. 1 Scheme of a Plinian eruption (© V. Konečný).

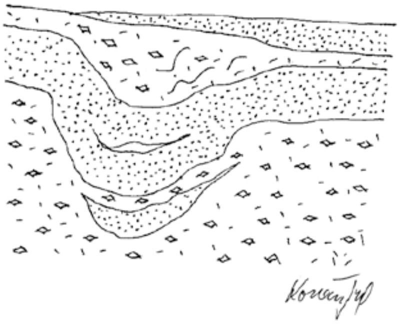


Fig. 2 The deformation texture in the sandstone layer caused by the weight of the pumice tuff deposited above (© V. Konečný).

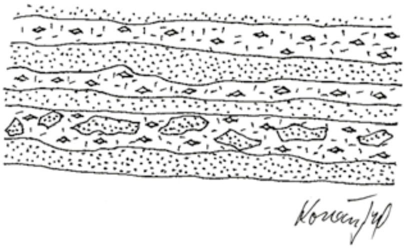


Fig. 3 The sandstone layer divided due to the sideway sliding movement (© V. Konečný).

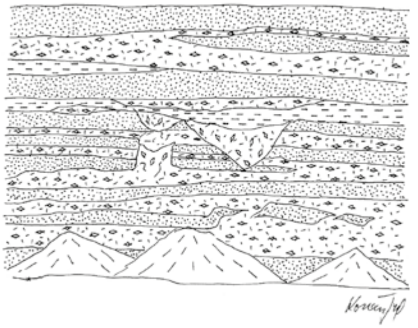


Fig. 4 The erosion furrow in the sandstone layer filled with pumice tuff – on the right, and the texture of the pumice tuff pushed upwards – on the left (© V. Konečný).

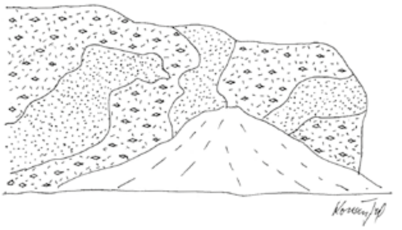


Fig. 5 The deformed sandstone fragments are embedded in pumice tuff (© V. Konečný).

Photo 1 General view of the abandoned quarry west of Brhlovce (© P. Pachinger).

Fig. 6 The rock dwelling and cellar cut into tuff-sandstones (© V. Konečný).

New layers of pumice tuffs and sandstones represented an additional weight on the lower layers, which caused them to bend and deform (Fig. 2). The sliding movement of the sandstones caused their division into individual parts, which were further deformed and dispersed in the pumice tuff (Fig. 3).

The erosion of sandstone layers and the subsequent filling of the erosion furrow with pumice tuff can be observed in Fig. 4 (on the right). On the left, the pumice tuff has been pushed upwards, which caused disruptions of the sandstone layers. The deformed parts of the sandstone layer are dispersed and embedded in pumice tuff (Fig. 5).

These textures document the conditions of the marine sedimentation area during the volcanic eruptions. On the other, the layers with signs of layering indicate that the sandy material has been sorted and settled gradually.

The age of the lava flow north of Brhlovce was determined by radiometric dating using the K/Ar method to be 19.9 ± 0.3 mil. years (G. P. Bagdasarjan, D. Vass, V. Konečný, 1968). The leaf prints in the tuff group of strata near Brhlovce, which were evaluated by F. Němejc (1967), indicate it originated in Late Baden to Early Sarmatian. The Early Sarmatian is considered to be the real age of the group of strata near Brhlovce.

In the past, rock dwellings, stables for livestock or cellars for storing crops were built into the sandstone-tuffs due to their malleability (Fig. 6, Photo 2).

Visitors can experience the conditions of living in such rock dwellings in the open-air museum.

Photo 2 A view of a farmyard – a dwelling and farm spaces cut into tuff-sandstones can be seen in the background (© P. Pachinger).

Geotope No. 96

Hontianska Vrbica

delta sediments

During the Early Sarmatian, the shallow epicontinental sea was gradually receding to the west, into the area of the Danube Lowland. The volcanic material washed off from the southern slopes of the Štiavnica Stratovolcano through rivers was deposited in the coastal zone in the form of an alluvial cone – delta. This delta, extending from Baďan and Počúvadlo on the north to the broader surroundings of Levice on the south, consists of conglomerates, siltstones, and sandy sediments in the form of epiclastic volcanic sandstones.

During the Early Sarmatian, the volcanic activity of explosive-effusive volcanism of pyroxene andesites pertaining to the Baďan Formation was renewed. In the initial stage of this activity, eruptions of ash-pumice tuffs prevailed. The ash-pumice material covered the stratovolcanic slopes after it fell from the eruption cloud. Subsequently, it was washed off by rain and rivers into the coastal zone and deposited as a part of the delta sediments, where it forms interbeds to beds of redeposited ash-pumice tuffs. Further to the south, in the calm transition zone between delta and sea sediments, more close-grained sediments have deposited in the form of siltstones and claystones with interbeds of diatomic clays to diatomites, or bryozoan limestones rich in marine fossils (SE of Kukučínov).

North of Hontianska Vrbica, in an abandoned quarry pit near the state road, a group of strata of loose tuffite sands to sandstones has been exposed (Fig. 1, Photo 1).

Fig. 1 In the wall of the quarry pit north of Hontianska Vrbica, tuffite sands to sandstones pertaining to the Baďan Formation have been exposed (© V. Konečný).

Photo 1 An overview of the wall of the quarry pit. In the center of the shot, a trough-like furrow in the bottom group of strata of tuffite sandstones can be observed (© P. Pachinger).

The layered tuffite sandstones have been exposed in the bottom part of the quarry wall and disturbed by an erosion furrow in its upper part. The trough-like erosion furrow has been filled with chaotically deposited sandstones containing siltstone fragments. The bottom part of the erosion furrow has a higher concentration of coarse fragments. (Fig. 2, Photo 2).

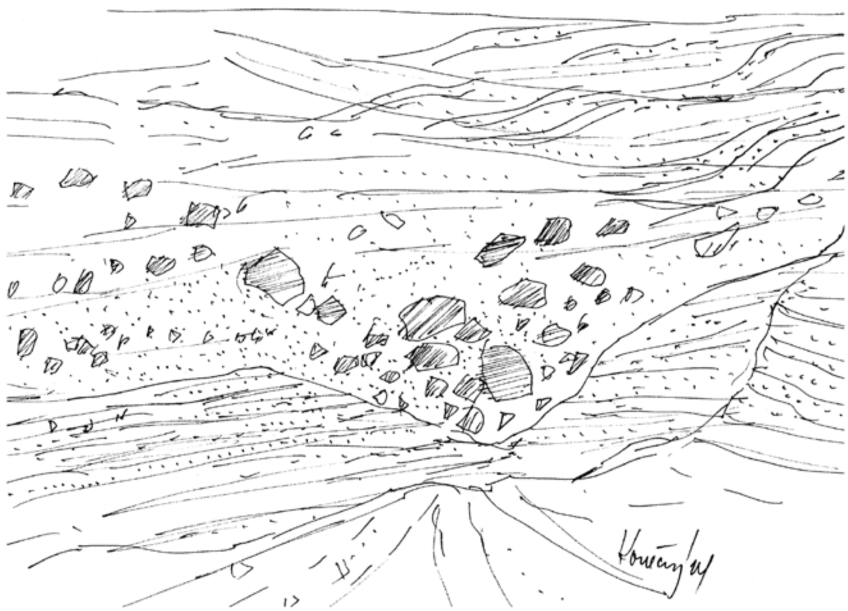


Fig. 2 A close-up of the fill of the trough-like furrow with a higher concentration of siltstone fragments and blocks in the tuffite sandstone, deposited by a turbidite (© V. Konečný).

The body of a chaotically deposited sandstone, which fills the erosion furrow, consists of deposits of a dense turbidite, which has disrupted the siltstone layer as it moved and transported fragmented material into deeper levels of the sedimentation area, where it has been deposited. The turbidite flows have likely formed due to the sudden accumulation of sandy material, which became unstable on the steep seabed. The reason for its movement in the form of a mass turbidite flow could have been a seismic shock related to the volcanic activity.

Layered tuffite sands with cross bedding have been deposited in the upper part of the quarry wall. The sigmoidal bend of the sand strata results in sigmoidal layering, which is typical for an environment significantly affected by tides (Photo 3).

The texture in the walls of the abandoned quarry show the conditions of sedimentation in the shallow marine environment of a delta. In the overlying rock, delta sediments covered by lava flows of pyroxenic andesite pertaining to the Baďan Formation, which formed an extensive lava plateau at the southern foot of the stratovolcano and partly in the coastal zone, can be observed (Geotope No. 91 – Horša).

Photo 2 A close-up of the bottom group of strata disrupted by a trough-like furrow filled with siltstone fragments (© P. Pachinger).

Photo 3 The cross bedding textures and sigmoidal bend of strata indicate the effects the tides had in the shallow marine environment (© P. Pachinger).

Geotope No. 97

Pečenice

forms of andesite weathering

On the southwestern slope of the Štiavnica Stratovolcano, at the northern edge of Pečenice, strangely-shaped blocks, which are the result of lava flow weathering, are dispersed in the area of a moderately inclined crest. Pyroxene andesite lava flows, which often have a vitreous base, pertaining to *the Baďan Formation* of the Sarmatian Stage (the 4th stage of the Štiavnica Stratovolcano's formation), form a continuous lava plateau at the southwestern foot of the stratovolcano. The lava plateau consisting of a large number of lava flows has been deposited on the products of explosive activity (mostly pumice tuffs), which occured after the lava effusions. The northern edge of the pyroxene andesite lava flows have been partly covered by younger lava flows of amphibole-pyroxene andesites ± biotite, pertaining to the Sitno Complex.

In the process of physical disintegration – weathering of vitreous pyroxe-

Photo 1 The spherical jointing of vitreous pyroxene andesites (© P. Pachinger).

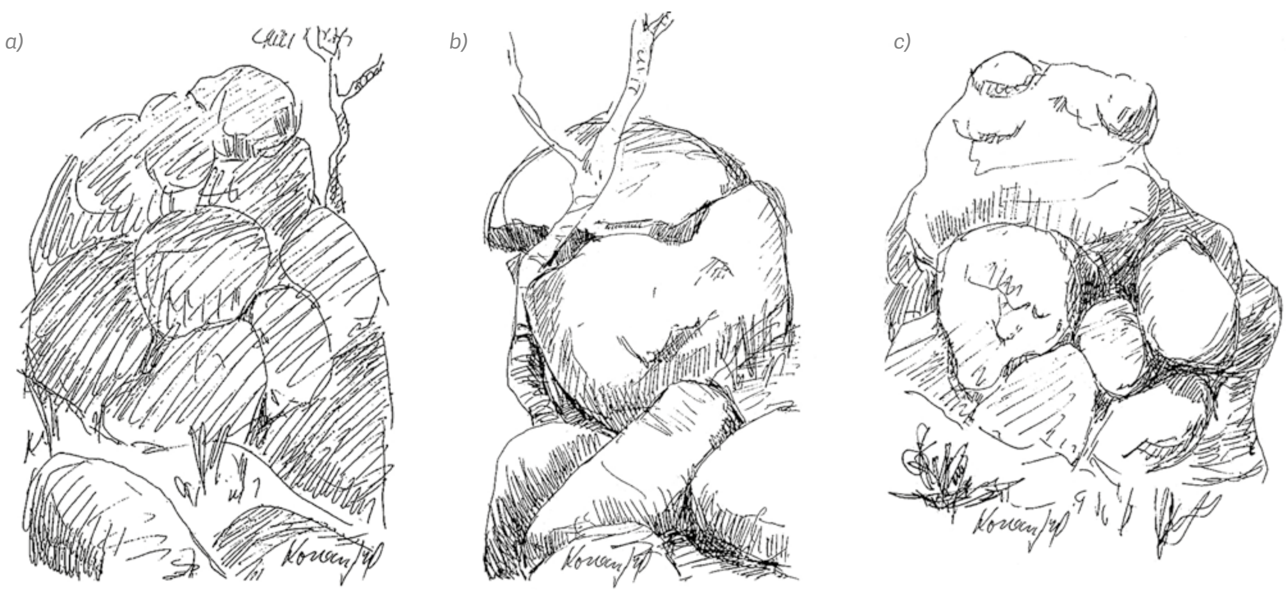


Fig. 1 The strange and bizarre shapes of andesite caused by physical disintegration – weathering (© V. Konečný).

ne andesite, spherical jointing occurs, which causes the formation of strange and often bizarre shapes (Fig 1, Photo 1), which resemble figurative compositions of the brilliant sculptor Henry Moore (a – Family Group, b – Helmet Head, c – Motherhood, d – Head of a Woman, e – Siblings, f – Stone Throne), even though they are nature's own masterpieces.

The blocks of interesting shapes create secluded spaces, which inspire reflection as well as relaxation in the heart of nature.

d)

e)

f)

Geotope No. 98

Kubáňovo

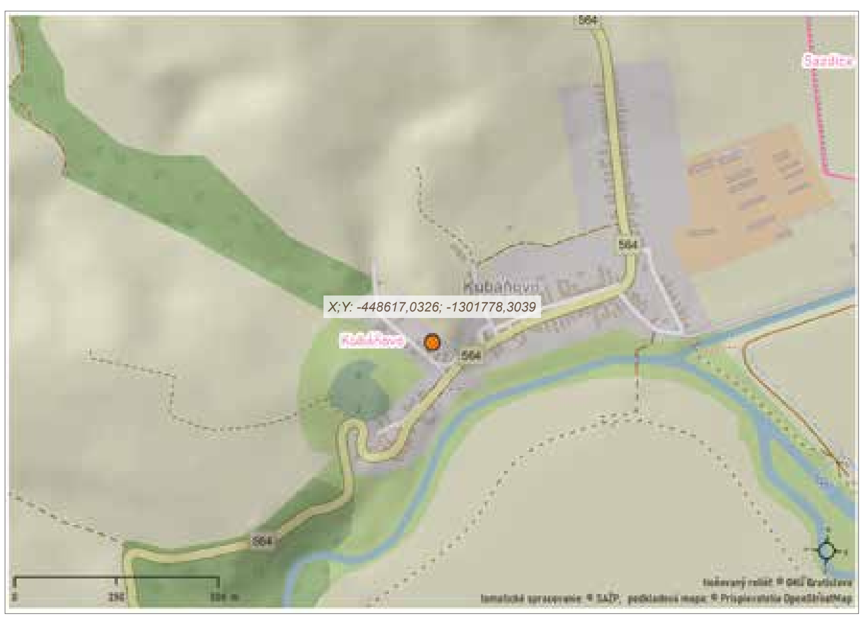
delta sedimentation

Near Kubáňovo, in the southernmost zone of marine sediments pertaining to the Štiavnica Stratovolcano, a complex of tuffite sandstones and claystones can be observed in natural as well as artificial exposures (Fig. 1).

In the lower part of Fig. 1, from 3 to 4 meters thick, light green, close-grained sandstones with pumice pebbles, which are locally coloured light to dark brown by Fe oxides (limonite), can be observed. Sandstones have graded and cross bedding (Photos 1, 2). Above, the light green close-grained sandstones are followed by colourful, hardened sandstones with distinct textures of cross bedding (Photos 3, 4, 5).

The 5 to 6 m thick sandstones have been deposited above them, with 10 to 20 cm thick layers of bent sandstones, distinctively coloured rust-brown by

Fig. 1 The exposure of close-grained sandy sediments and claystones at the edge of Kubáňovo (© V. Konečný).



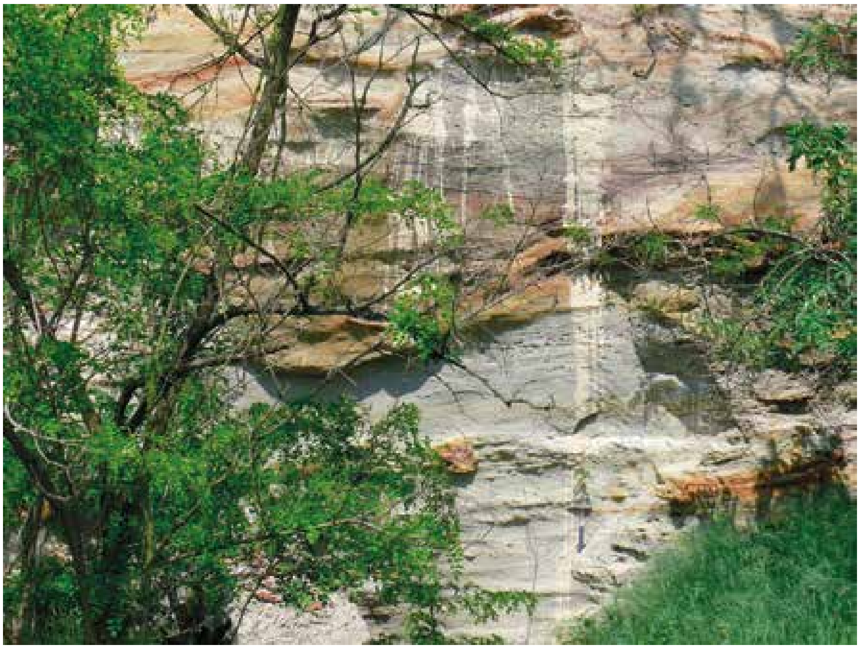


Photo 1 The exposure of close-grained sandy sediments at the edge of Kubáňovo. The sediments at the lower level have distinct graded and cross bedding (© P. Pachinger).

Photo 2 A close-up of the cross bedding of sandstones. Sporadically, sandstones contain tiny fragments of rounded pumice – to the left of the hammer (© P. Pachinger).

Fe oxides. At the same time, these deformed layers have been hardened by Fe oxides and they protrude among the surrounding sediments due to the weathering (Photo 6, 7).

In the overlying rock of sediments with deformed textures, up to 10 m thick grey-green tuffite clays have been deposited (Photo 8, 9).

The abovementioned sediments have been interpreted by A. Nagy at al. (2001) as terminal (the final part of the inverted valley). As the sea level locally decreased, a river cut into beach

Photo 3 In the overlying rock of the lower sandy sediments, close-grained, yellow-green, hardened sandstones have been deposited. Above them are rust-brown, limonitised and deformed sediments. The upper part of the exposure consists of yellow-white to off-white claystones (© P. Pachinger).

sediments and brought its alluvial deposits (the middle layer). Due to the subsequent rise of water levels, the sedimentation of clays occurred. There have been many prints of leaves, silicificated branches and tree trunks found in the clays. The weight of overlying clays has likely caused hydroplastic deformation of the upper layers of bedrock sandstones. The clay sedimentation resembles estuary sediments.

In the clays, fauna represented by foraminifera of *Ammonia beccarii* (L.), *Elphidium flexuosum flexuosum* (Orb.), *Elphidium macellum* (F.-M.) and *Protelphidium bogdanowiczi* (Volosh.) has been observed. Ostracods are represented mainly by *Cytheridea hungarica* (Zal) and *Hemicyprideis dacicg* (Hejjas). Leaf prints are represented by *Carpinus*

Photo 4 The yellow-green, hardened sandstones with distinct textures of cross bedding in the bedrock of deformed layers (© P. Pachinger).

Photo 5 A close-up of yellow-green, hardened sandstones with distinct textures of cross bedding (© P. Pachinger).

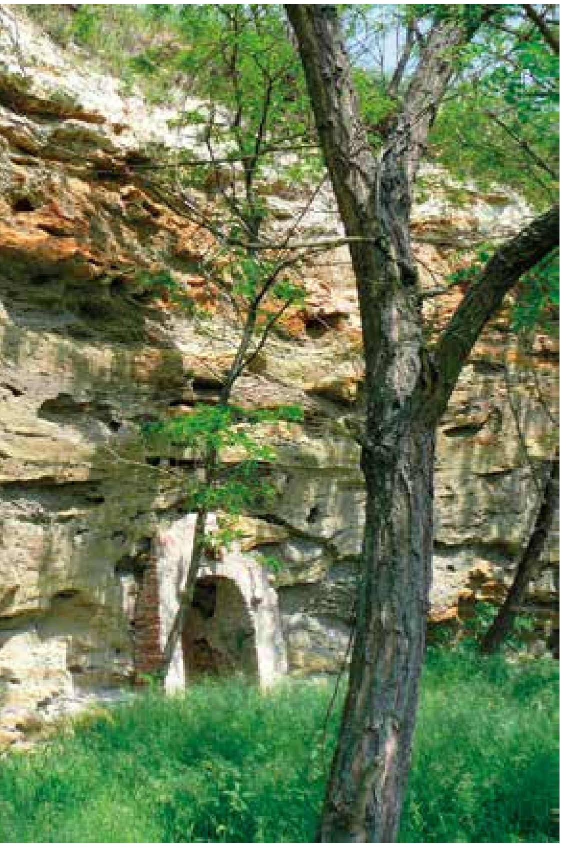


Photo 6 The deformations in sandy layers accentuated by limonite (© P. Pachinger).

Photo 7 A close-up of the deformed texture (© P. Pachinger).

grandis Ung., *Betula makrophylla* Heer, *Betula prissa* Ett., *Alnus cecroprafolia* (Ett.) Berger, *Pteris palacoarita, Salix varians, Betula prisce, Bűttneria tiliaefolis, Juglans acuminata, Ulmus longifolia*, and many others. All of these species thrive in cold environments, which are typical for the Sarmatian.

Sediments of the so-called delta sedimentation pertain to *the Baďan Formation*. Newer sediments are referred to as *the Kubáňovo Beds* (A. Nagy et. al, 2001). Based on the abovementioned paleontological evidence, the sediments were deposited in the Early to Middle Sarmatian, ca. 12 to 13 million year ago.

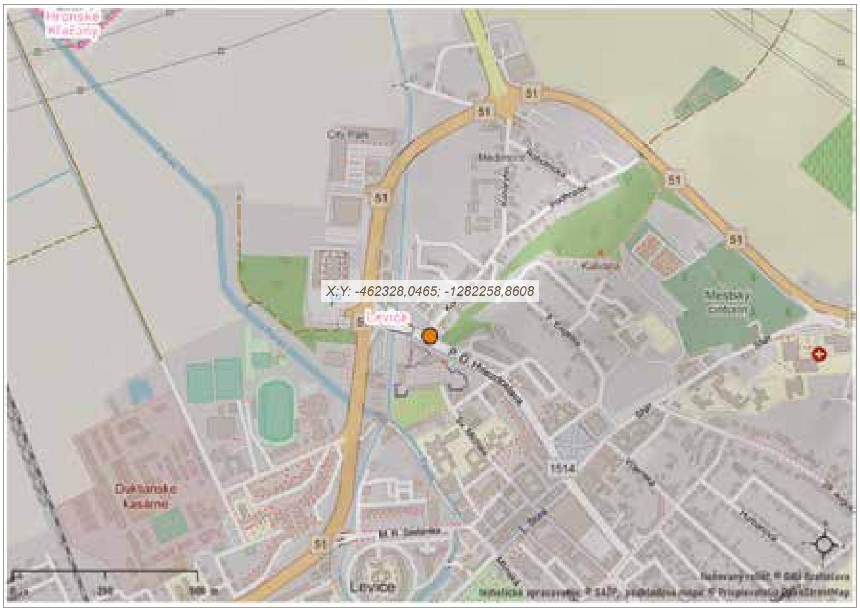
Photo 8 The tuffite clays in the overlying rock of the deformed layers. (© P. Pachinger).

Photo 9 A close-up of the tuffite clay base deposited on the bedrock of sandy sediments. Tiny cavities have been created by insects (© P. Pachinger).

Geotope No. 99

Levice – the castle hill

hyaloclastite breccias



During the Sarmatian, after the formation of the Štiavnica Caldera, the intensive volcanic activity continued in the caldera and on the stratovolcanic slope (the 4th stage of the Štiavnica Stratovolcano's development). Products of the explosive-effusive volcanism of amphibole-pyroxene andesites pertaining to *the Priesil Formation* consist of volcanoclastic rocks (fragmented rocks) and lava flows. These products have filled a large paleodoline extending from Nová Baňa to the Kozmálovské Kopce Hills on the south-west. The lower levels of this fill consist mainly of volcanoclastic rocks (pyroclastic flow breccias, epiclastic volcanic breccias, hyaloclastite breccias, sandstones, and conglomerates), while the upper part of the paleodoline fill consists mainly of lava flows. The remains of the paleodoline fill can be found at the hilltop of the Priesil massif (elevation 748), north of Čajkov, on the southern slopes of the Veľký Inovec and Malý Inovec Hills, in the surroundings of Kozárovce, and in the area of the Kozmálovské Kopce Hills (west of Tlmače). Relicts of this fill in the form of hyaloclastite breccias can be found at the northern edge of Levice – the castle hill (Fig. 1) and the rock cliffs opposite.

Remains of lava flows can be found in the surroundings of Podlužany, north of Levice.

The lava flows, moving within the abovementioned paleodoline towards the south-west, came into contact with the marine environment in the coastal zone at the foot of the stratovolcano and were converted into hyaloclastite breccias. Coarsely-fragmented to block hyaloclastite breccias were formed.

The brecciation of a lava flow can be observed on the slope of a rock cliff across from the castle hill (Fig. 2).

Fig. 1 General view of the rock exposure of the rock cliff under the Levice Castle (© V. Konečný).

Photo 2 An overview of the rock cliff under the Levice Castle (© P. Pachinger).

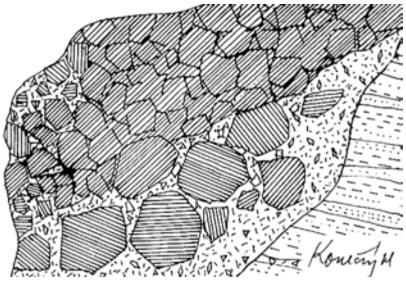


Fig. 2 The rock cliff across from the Levice Castle shows the process of brecciation of a lava flow upon contact with the marine environment. The original sediments in the form of sandstones and siltstones are in the bottom right part. Above them are sediments disrupted by a furrow, which has been filled with pumice-tuff material. In the upper part of the furrow, a brecciated lava flow with a transition into a hyaloclastite breccia (the left edge) can be observed (© V. Konečný).

Photo 1 The rock cliff across from the castle hill. A close-up of disintegration and brecciation of the lava flow into angular fragments (© P. Pachinger).

The lava flow was moving through an erosion furrow carved into the surface of close-grained sandstones and siltstones. The bottom part of the furrow was initially filled with pumice tuffs. Upon contact with water, the lava flow disintegrates into fragments and blocks due to the rapid cooling and subsequent solidification (due to internal stress), and turns into a chaotic hyaloclastite breccia (Photo 1). The chaotic breccia, moving further as a hyaloclastite flow, causes the erosion of sediments in its bedrock.

The rock exposure in the northern edge of the castle hill shows a coarse to block hyaloclastite breccia, which consists of deposits of a hyaloclastite flow (Fig. 3).

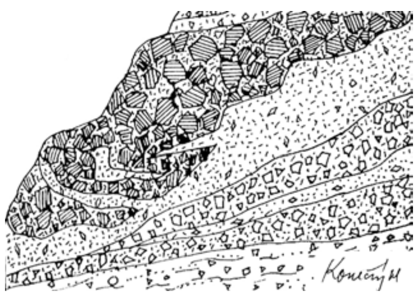


Fig. 3 The bottom part of the rock cliff under Levice Castle consists of sorted and layered epiclastic breccias. Layers of chaotic breccia of fragment flows are deposited above and alternated with pumie tuff layers with andesite fragments, which are products of the a mass transport in a water environment. In the top part a chaotic breccia – hyaloclastite flow consisting of vitreous andesite fragments to blocks can be observed (© V. Konečný).

The mostly angular fragments and blocks (up to 0.5 m in size) consist of porphyric amphibole-pyroxene andesite. Their matrix is granular and relatively compact. The material of the hyaloclastite flow is chaotic, without any signs of sorting or layering. In the breccia bedrock, a layer of pumice tuff with andesite fragments has been deposited. Below them are breccias of fragment flows and sorted, coarsely-layered epiclastic volcanic breccias (Photo 2, 3).

The rock exposures at the edge of Levice document the processes of the coast of the Sarmatian sea, into which the lava flows moving from the slopes of the Štiavnica Stratovolcano penetrated, which then disintegrated and brecciated.

Photo 3 Detail of the chaotic breccia of pyroclastic flow (© P. Pachinger).

Geotope No. 100

Čajkov

ash-pumice tuffs

On the southwestern slope of the Štiavnica Stratovolcano, north of Čajkov, pumice tuffs pertaining to the Drastvica Formation (the 4th stage of the Štiavnica Stratovolcano's development) have been exposed in the walls of an abandoned quarry.

In bottom part of the quarry wall, at the left edge of the semicircular quarry, close-grained tuff layers alternate with pumice-dense layers (Fig. 1, Photo 1).

The textures indicate that the close-grained material deposited after falling from the ash cloud have been sorted, as well as locally transported (washed away). The layer of close-grained ash-tuff with tiny pumice fragments in the bottom part of the quarry wall is in Photo 2.

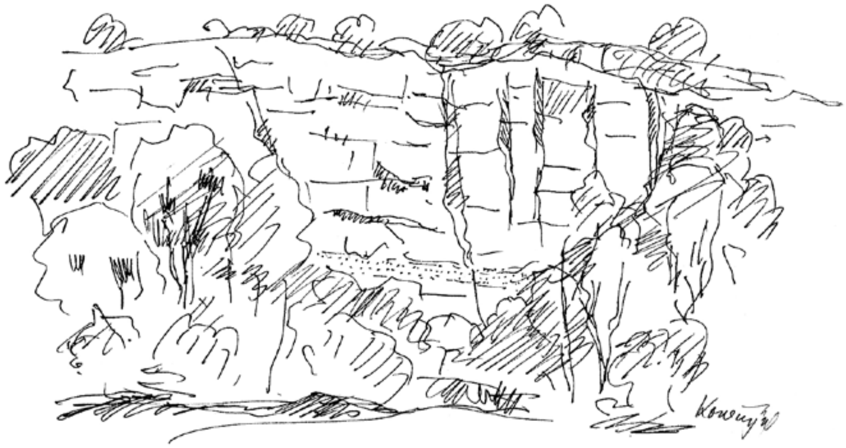


Fig. 1 Ash-pumice tuffs exposed by the quarry north of Čajkov. A layer of close-grained tuff can be be observed in the bottom part. Ash-pumice tuffs of pyroclastic flows have been chaotically deposited above them (© V. Konečný).

At the upper levels of the quarry wall, layers of light grey to ochre and locally reddish pumice tuffs without signs of sorting or layering have been deposited (Photo 3). Colourful pumice fragments (ochre, off-white, yellow, brown), ranging from 0.5 to 5 cm and occasionally 10 cm, have been dispersed in a close-grained ash-pumice matrix (Photos 4, 5). The presence of 3–5 cm large andesite fragments is rare.

Photo 1 General view of the ash-pumice tuff quarry wall north of Čajkov (© P. Pachinger).

The 3–5 m thick pumice tuff layers with chaotically deposited material are divided by a thin layer of sorted close-grained tuffs, often containing layers of fine conglomerates.

The pumice tuff layers consist of sediments of ash-pumice flows, which formed during Plinian eruptions due to the repeated collapses of an eruption column full of hot volcanic gases, ash and pumice. After this mixture falls on an inclined volcanic slope, it creates a fast and turbulent flow, which starts rolling down the slope and destroying every living thing that gets in its way. The high magmatic temperature of the moving ash-pumice flow gradually dropped (Fig. 2).

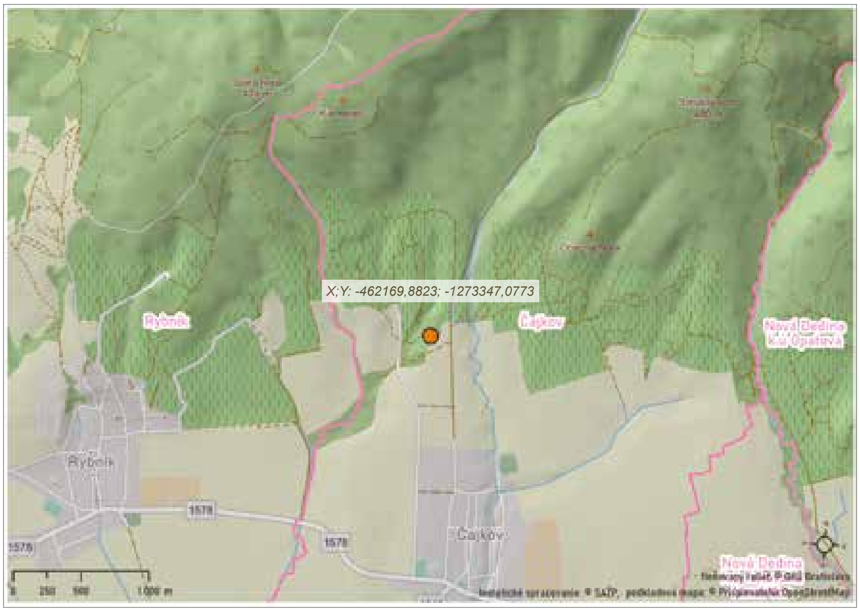


Photo 2 The layer of close-grained ash-tuff with pumice (© P. Pachinger).

The ash-pumice flows, moving from the caldera area onto the southern stratovolcanic slopes, reached the marine environment at the foot of the stratovolcano. Consequently, their temperature rapidly dropped. Due to the temperature drop, the pyroclastic material of these flows has not been sintered or welded (Fig. 2).

By contrast, the ash-pumice material of hot pyroclastic flows deposited at the upper levels of the stratovolcanic slope and on the western slope, out of reach of the water, have been welded with consequent formation of welded tuffs – ignimbrites (Geotope No. 26 – Kojatín, Geotope No. 44 – Veľký Žiar, Geotope No. 50 – Obyce).

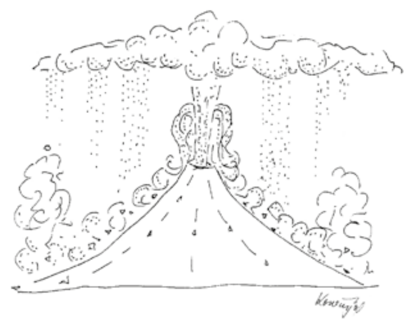


Fig. 2 Scheme of a Plinian eruption. After the eruption column collapsed onto the stratovolcanic slope, a hot turbulent flow occurred, transporting the ash-pumice material from the crater down the steep slope before coming into contact with the water at the coast. (© V. Konečný).

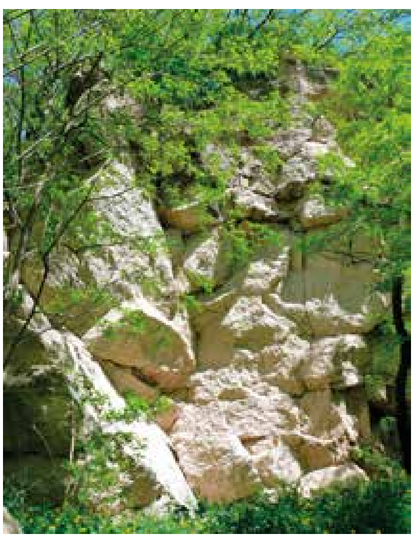


Photo 3 In the overlying rock of the close-grained ash-tuff, ash-pumice tuffs of a pyroclastic flow have been chaotically deposited – on the right (© P. Pachinger).

Photos 4, 5 In the close-up, the chaotically distributed pumice fragments (light grey to white), ranging from 0.5 to 10 cm, can be observed in a close-grained, light pink matrix. (© P. Pachinger).

Geotope No. 101

Kozárovce

lava flow, hyaloclastite breccias

At the eastern edge of the Kozárovce municipality (near the railway track), on the southwestern rocky slope of the Štiavnica Stratovolcano, two lava flow bodies have been exposed by a quarry, along with hyaloclastite breccias and sandy tuffs pertaining to *the Priesil Formation* of the Sarmatian – the 4th stage of the Štiavnica Stratovolcano's formation (Fig. 1).

The lava flows pertaining to *the Priesil Formation*, after moving from the upper levels of the stratovolcanic slope towards the southwestern foot of the stratovolcano, came into contact with water in the coastal zone of the Sarmatian sea and were turned into hyaloclastite breccias.

In the abandoned quarry east of Kozárovce, pyroxenic andesite lava flows have been exposed. In the right part of the quarry wall, the process of hyaloclastite brecciation caused by the contact with water can be observed (Fig. 1, Photo 1).

In the left bottom part of the quarry, the bottom lava flow with indicated columnar jointing along the inclined subvertical planes can be observed (Photo 2). The andesite is dark grey with a greenish hue, phenocrysts (up to 2–5 mm) consist of plagioclase. Dark phenocrysts (pyroxenes, amphibole) are partly to strongly altered (chloritised and limonitised). In the overlying rock, the upper lava flow with a similar composition has been deposited. It has columnar jointing along the irregular subvertical planes and partly indicated subhorizontal jointing along the lamination (fluidity) surfaces (Photo 3).

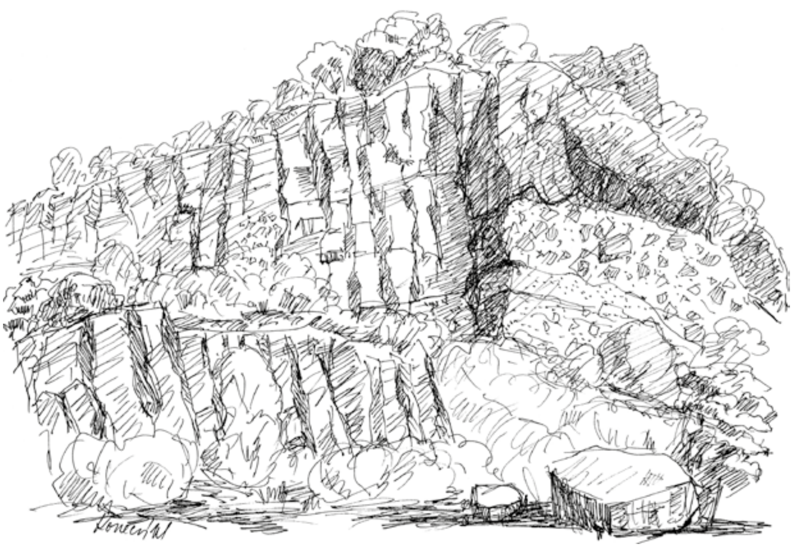


Fig. 1 The abandoned andesite quarry east of Kozárovce. In the left bottom part, the bottom lava flow with subvertical, coarsely-columnar jointing can be observed. Above that is the overlying upper lava flow, also with columnar jointing. In the right bottom part, the exposed layered epiclastic sandstones and overlying redeposited hyaloclastite breccias can be seen. Above them, in the overlying rock of the hyaloclastite breccia, the upper lava flow transitioning into the brecciation zone and hyaloclastite breccia has been deposited (© V. Konečný).

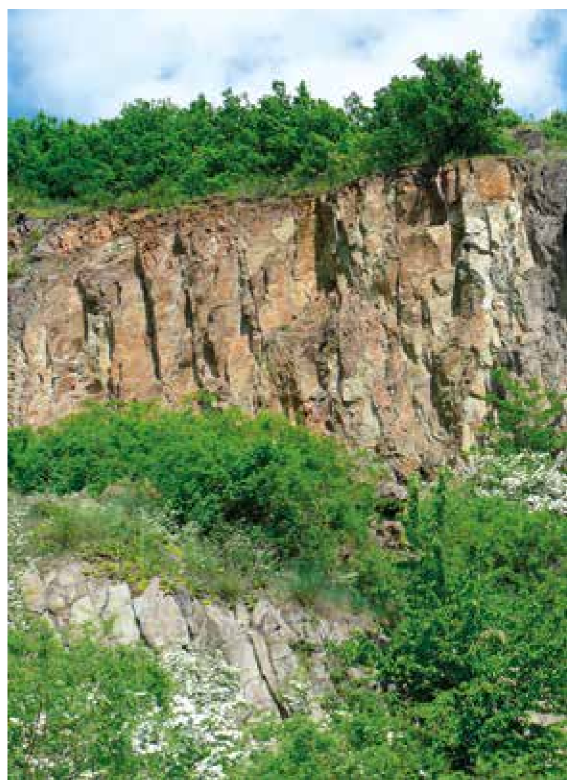


Photo 1 General view of the abandoned quarry walls east of Kozárovce (© P. Pachinger).

Photo 2 A close-up of the coarsely-columnar jointing of the bottom lava flow (© P. Pachinger).

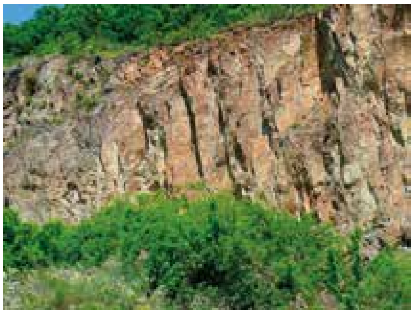


Photo 3 A close-up of the coarsely-columnar jointing of the upper lava flow (© P. Pachinger).

In the right part, the upper lava flow transitions into the overlying rock of a complex of redeposited hyaloclastite breccias, deposited on sandy tuffs containing tiny andesite fragments (Photo 4).

The complex of breccias and sandy tuffs inclines towards the south (Photo 5). The right part of the upper lava flow is gradually brecciated and transitions into a hyaloclastite breccia (Photo 6).

This subhorizontal jointing, which is parallel to the surface along which the lava flow moves, occurs when the lava flow stops moving and lava starts solidifying. By contrast, the columnar jointing (perpendicular to the lamination surfaces) occurs during the solidification and crystallisation of the lava flow, due to the volume reduction caused by the transition to a solid state.

Photo 4 General view of the right part of the quarry wall, where the upper lava flow has been deposited on a layer of hyaloclastite breccias (© P. Pachinger).

Photo 5 A close-up of the right part of the quarry wall. There are epiclastic volcanic sandstones with indicated layering and andesite fragments at the bottom. At the upper level, they transition into a hyaloclastite breccia consisting of angular andesite fragments and sandy-granular matrix. The breccia has signs of a short transport (© P. Pachinger).

Photo 6 A close-up of the brecciation of the upper lava flow, which transitions into a hyaloclastite breccia at the right edge (© P. Pachinger).

The hyaloclastite brecciation is a process occurring due to the rapid cooling of a moving lava flow upon its contact with water (or snow/ice). In this case, it was the marine environment of the Sarmatian coastal zone. The lava flow starts to solidify due to the rapid temperature drop and release of gases. As it is moves further, it brecciates and disintegrates into fragments due to the internal stress.

At the same time, the hyaloclastite brecciation of the upper lava flow indicates that it is a zone of transit from the stratovolcanic slope into the Sarmatian coastal zone, where lava flows came into contact with water (Photo 7, 8).

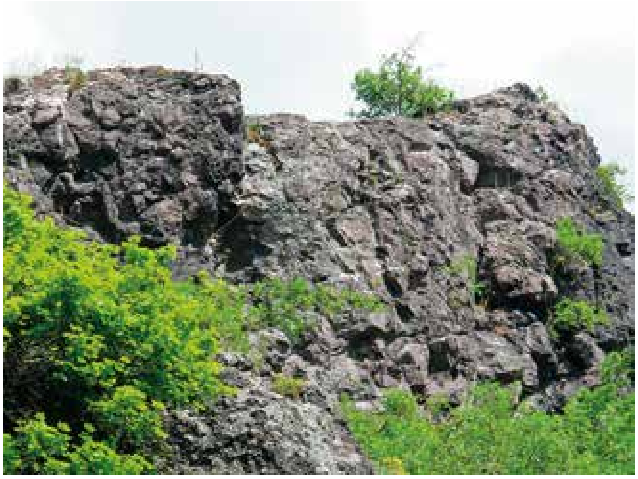


Photo 7 A close-up of brecciation of the upper lava flow, which disintegrates into angular fragments to blocks and granular matrix. It is the initial stage of lava flow disintegration (© P. Pachinger).

Photo 8 The bedrock of the bottom part of the upper lava flow contains a hyaloclastite breccia with granular matrix (© P. Pachinger).

Geotope No. 102

Dudince

freshwater limestones – travertines

The partially exposed travertine mound is located near the road between Dudince and Hontianske Moravce, ca. 1,200 m to the west. The artificial exposure was caused by quarrying in the first half of the twentieth century (Fig. 1, Photo 1).

The main rock mass consists of hard, strongly layered and partly porous, light yellow, white-yellow or cream yellow travertines. Weathered and disintegrated travertine parts are also present.

Locally, remains of reddish fossil soil called "terra rossa" can be found on the surface of the travertine.

The travertine mound, like other travertine mounds in the spa resort in Dudince, in the Vápnik (Šiklóš) area near Levice and in Santovka, are the products of abovementioned hot thermal springs.

The travertines are heavily layered. Besides the soft travertine deposits, layers of a more resistant aragonite are also present. Due to the presence of aragonite, the few mm to 5–7 cm thick layers have a compact, crystalline and transparent appearance. The milk-coloured layers alternate with light to honey-yellow layers in a rainbow-like manner. Big, transparent calcite crystals are present locally (Photo 3).

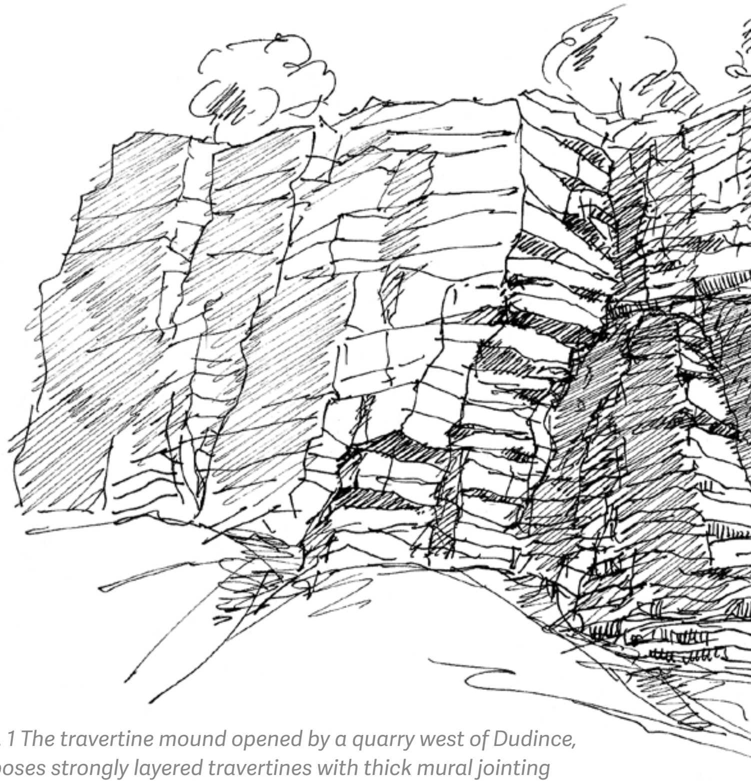


Fig. 1 The travertine mound opened by a quarry west of Dudince, exposes strongly layered travertines with thick mural jointing (© V. Konečný).

Photo 1 General view of the travertine quarry west of Dudince. The light yellow travertine layers alternate with ochre to brown layers. In the upper part of the quarry, there is a distinct weathering crust with a transition into terra rossa. The travertines in this part have been disrupted by an ice wedge and filled with debris material (© P. Pachinger).

Photo 2 Strongly layered travertines with platelet breakdown. The disintegration of the travertine into fragments in the bottom part occurred during the formation of the travertine mound, likely due to a tremor or other another type of movement of the mass (© P. Pachinger).

Photo 3 A close-up of the aragonite layer with calcite crystals inside the cavities (© P. Pachinger).

As opposed to the Levice travertine found in the Vápnik area, which has been called "golden onyx", the travertines in this area are much more weathered, which is why they are not mined anymore.

Since the bedrock of the travertine mound consists of older clay rocks, the travertine mound has been sliding down due to its weight, and gradually expanding cracks have occurred as a consequence of weathering. These cracks are represented mainly by visible ice wedges, which form during winters as a result of water freezing inside the cracks that are oftentimes filled by debris from the weathered travertine.

The travertine mounds in the surroundings of Dudince and Santovka are the oldest. They were formed in the latest stages of the Tertiary, during the Pontian and Pliocene, which corresponds with an age of 2–4 million years.

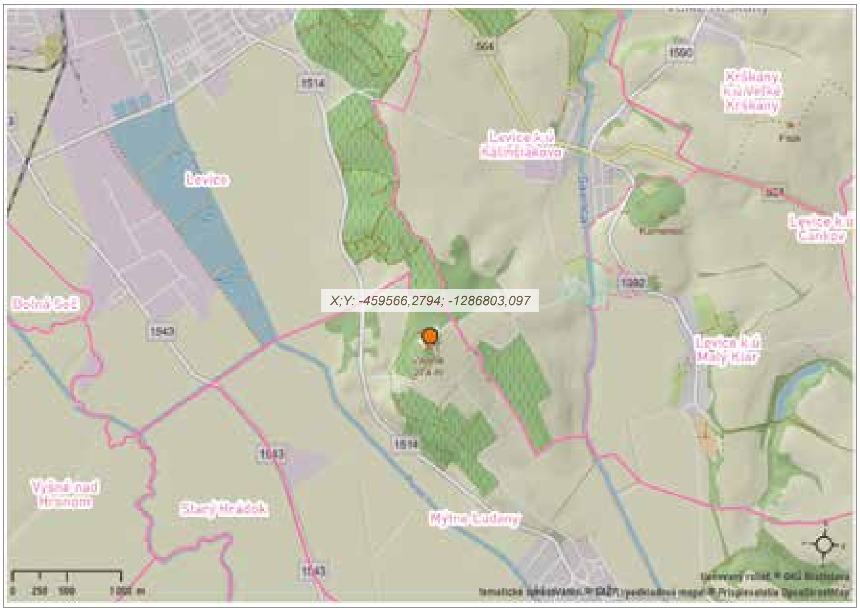
Geotope No. 103

Levice – Vápnik (Šiklóš)

travertine quarry

The abandoned travertine quarry is located ca. 5 km south of Levice, in the Vápnik (Šiklóš) Hill area, under the elevation 274 with a World War II memorial in the form of an observation tower.

The travertine mound is the largest in the Danube Lowland. The main rock mass consisting of strongly layered and partly porous yellow, light yellow or cream yellow travertines has been exposed in the right part of the quarry wall (Photos 1, 2).



Continuous travertine crusts typically form in the topmost travertine layers. Residual layers of the *"terra rossa"* fossil soil and loess with loess loams are present on the surface of the travertine.

In the bottom parts of the travertine quarry, blocks of quality onyx marble are surrounded by red dirt (Photo 3). Onyx marble is a product of hot thermal water, which formed

Photo 1 In the abandoned quarry in the slope of the Vápnik (Šiklóš) Hill, layered travertines have been exposed (© P. Pachinger).

Photo 2 A close-up of the grey-yellow, yellow-white layered travertine. The joint planes are coloured by limonite (© P. Pachinger).

Based on the presence of a turtle shell of *the Emis orbicularis* (L.), the age of travertines in the Vápnik area was determined to be in the Pliocene (2–4 million years).

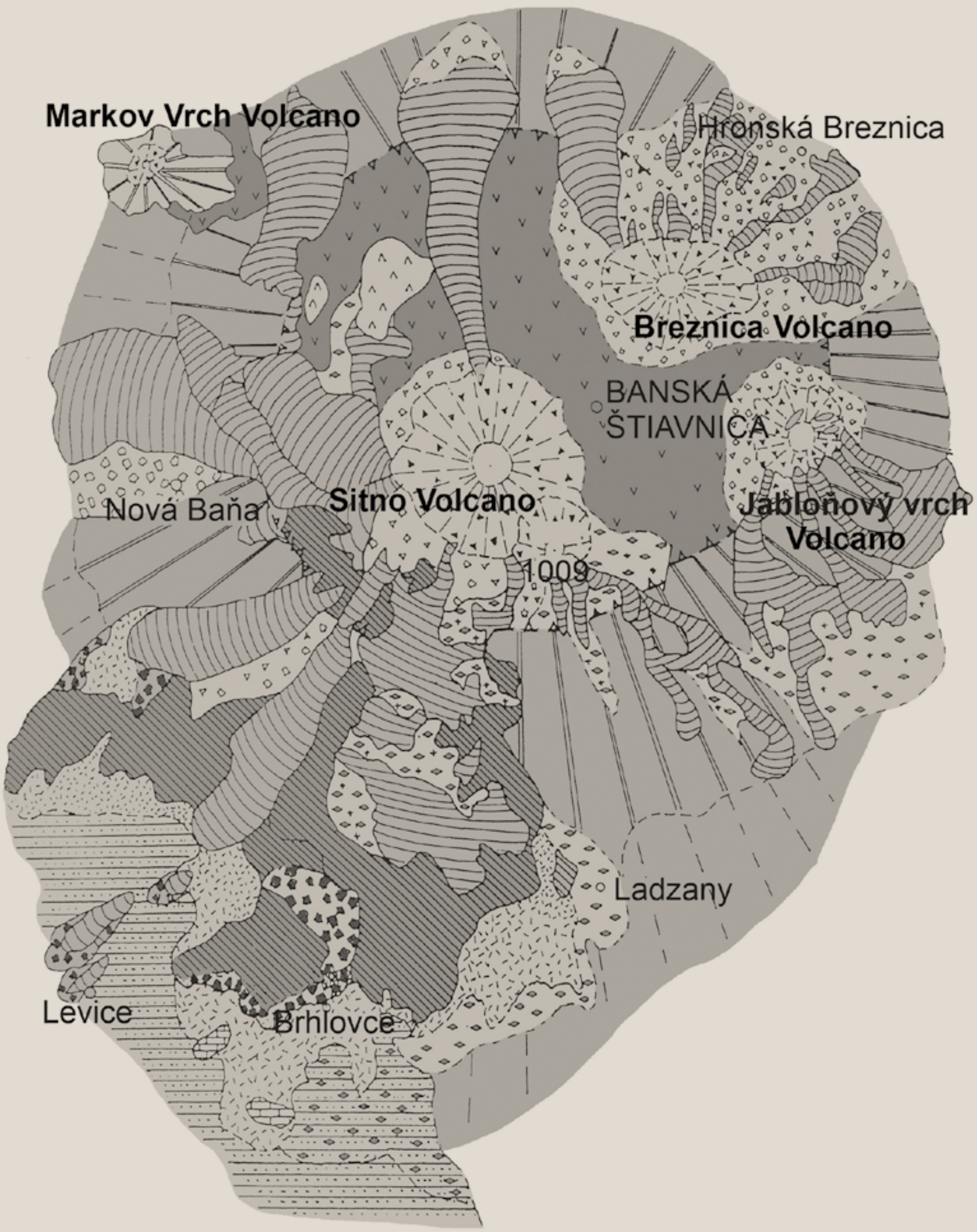
In recent years, the crystalline parts of the travertines – the so-called golden onyx – were used for making memorabilia (ashtrays, paperweights, etc.). Today, the mining of the highly-valued onyx has ceased.

Photo 3 A block of high quality onyx marble (© P. Pachinger).

a resistant aragonite instead of softer travertine deposits. Relicts of original travertines with various degrees of secondary recrystallisation indicate that thermal water has also likely affected the older travertines. Aragonite causes the travertines to have a compact, coarsely-crystalline and partly transparent appearance in the form of a few mm to 5–7 cm thick, milk-coloured to light yellow layers which alternate in a rainbow-like manner (Photo 4).

Photo 4 The aragonite layers with light yellow to honey-yellow hues in a travertine block (© P. Pachinger).

Volcanism and structure of the Banská Štiavnica Geopark



14. Geotectonic position of the Neogene volcanism

During the Neogene Period, the Carpathian Mountains had the form of an island arc with a microcontinent of the Western Carpathians (the area of Slovakia), which migrated towards the N, NE, and even E. As a result of the subduction of the oceanic (or suboceanic) flysch basin crust, the arc gradually collided with the massive edge of the European platform. The abovementioned arc's movement was compensated by a backarc extension including a diapiric ascent of the asthenosphere, and a lateral shrinkage of the lithosphere from the Alpine collisional zone (L. H. Royden, P. Dövenýi, 1988, Csontos et al., 1992, J. Lexa, V. Konečný, 1998).

The extensional processes resulted in a disintegration of the territory on the inner side of the Carpathian arc to a horst-and-graben system. A neogenic volcanic activity on the inner side of the Carpathian arc was caused by the previous subduction (Fig. 1).

The subduction of the oceanic flysch basin crust (located at the foothills of the Carpathian arc) under the Carpathian arc, which was moving towards the NE, E, and even SE, resulted in processes within the Earth's mantle which led to the formation of magmas. The origin of magma has been deduced from the partial melting of mantle matter (occurring after the previous subduction of the Magura-Pieniny flysch basin crust), and the subsequent diapiric ascent through the Earth's crust along with the backarc extension.

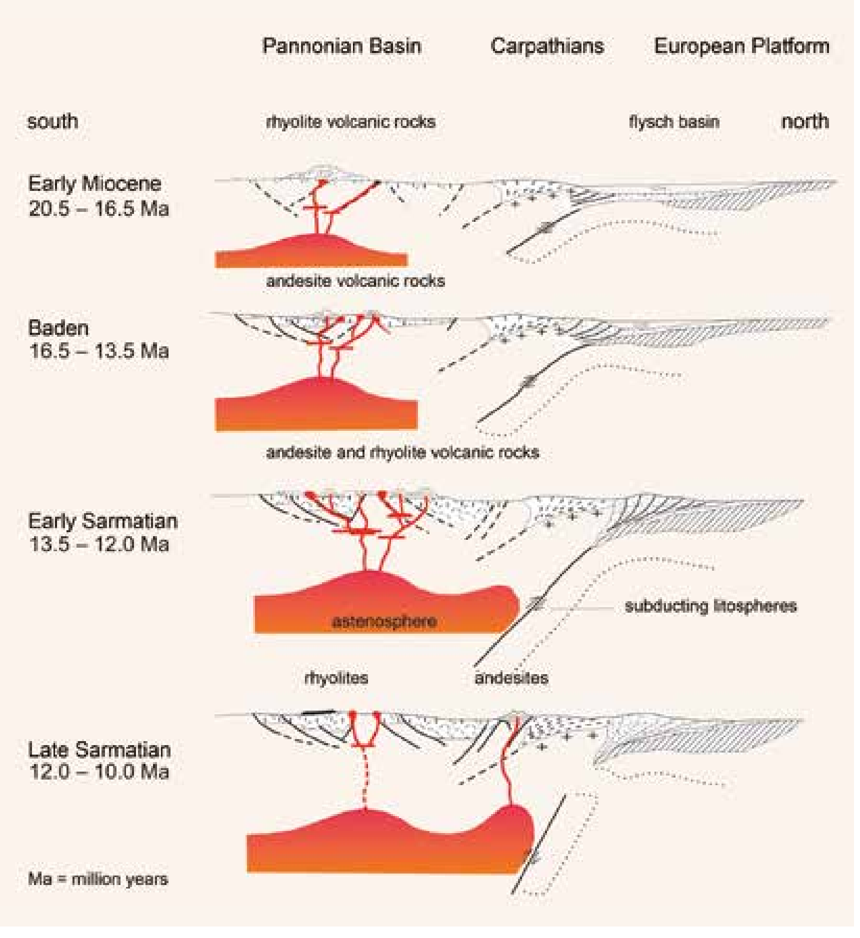


Fig. 1 Model of the oceanic flysch basin crust subduction (J. Smolka et al., 2003).

Primary basaltic magma, which was caused by partial melting inside the Earth's mantle within the asthenosphere, rose towards the Earth's surface thanks to its lower density. Its composition was progressively changing due to the processes of fractional crystallisation (separation of crystals from the melt), during the stagnation in magma chambers, as well as due to the crust material assimilation (magmatic melting of crust rocks), and other mixing processes inside sub-surface magma chambers. The original basaltic magma gradually became andesite magma, and in extreme cases crust matter was melted even into rhyolite magma (Fig. 2).

During the final stage of its rising to the Earth's surface, the magmas used faults and fault zones at the edges of horsts and grabens, which were being formed during extensional processes and were subsequently a source of a tumultuous volcanic activity at the Earth's surface.

During the volcanic activity of andesite and rhyolitic volcanism on the inner side of the Carpathian arc, a discontinuous zone of volcanic mountains was formed, including the area of Northern Hungary – apart from Middle Slovakia and Eastern Austria (Börzsöny, Visegrád, Czerhát, Mátra). Further away, the volcanic zone within Eastern Slovakia (the Slanské Vrchy Mountains, the Vihorlat Mountain) and Hungary (the Zemplén Mountains, the Tokaj

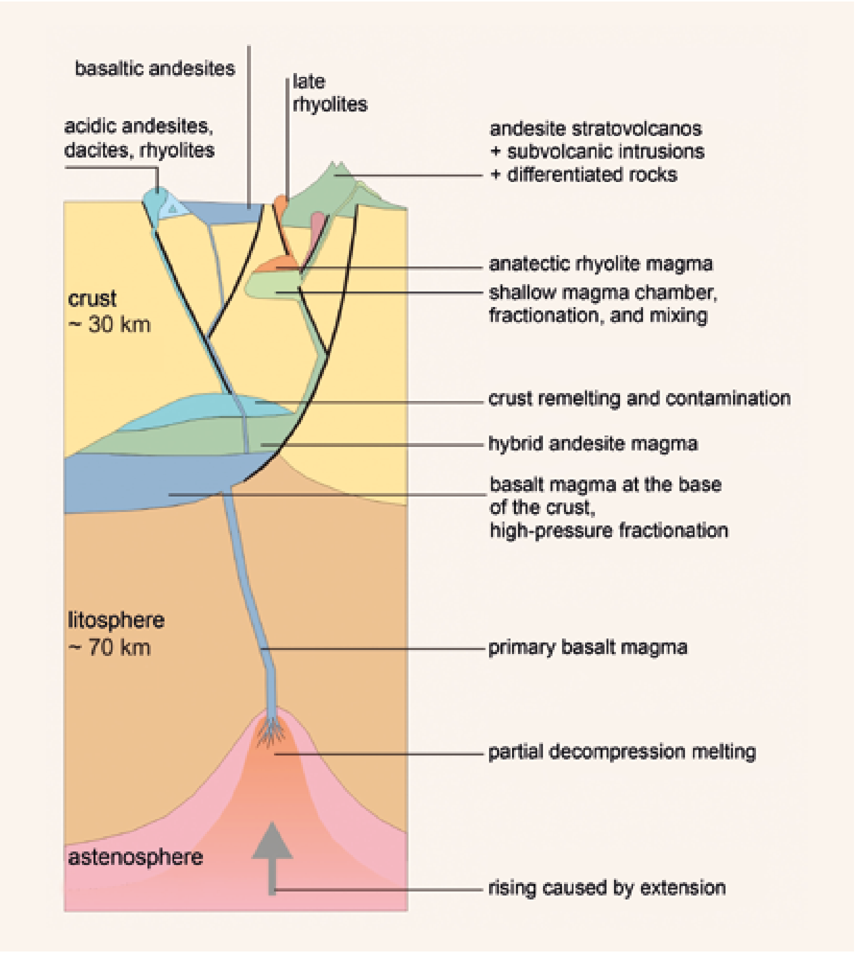


Fig. 2 Scheme of development of the magma chamber under the volcano, and of differentiation processes of magmas (J. Smolka et al., 2003).

Mountains) continued onto Western Ukraine, winding south-eastwards towards Romania, where the volcanic chain ends (Fig. 3).

The volcanic activity began roughly 20.5 Ma ago, during the Early Miocene, on the territory of the Pannonian basin in the form of rhyolite magma eruptions. During the Baden and the Sarmatian, it continued as andesite and rhyolitic volcanism in the area of Central and Eastern Slovakia roughly until 9 Ma ago (the Pannonian). Depending on the gradual shift of subduction processes towards E to SW, the eastern branch of andesite volcanism continued until later periods within Ukraine and Romania, where it ended several hundred thousand years ago.

The andesite and rhyolitic volcanism of calc-alkalic type was superseded by the basaltic volcanism of alkalic type, which continued within Central and Southern Slovakia, Northern Hungary (the area around Salgótarján) and around Lake Balaton.

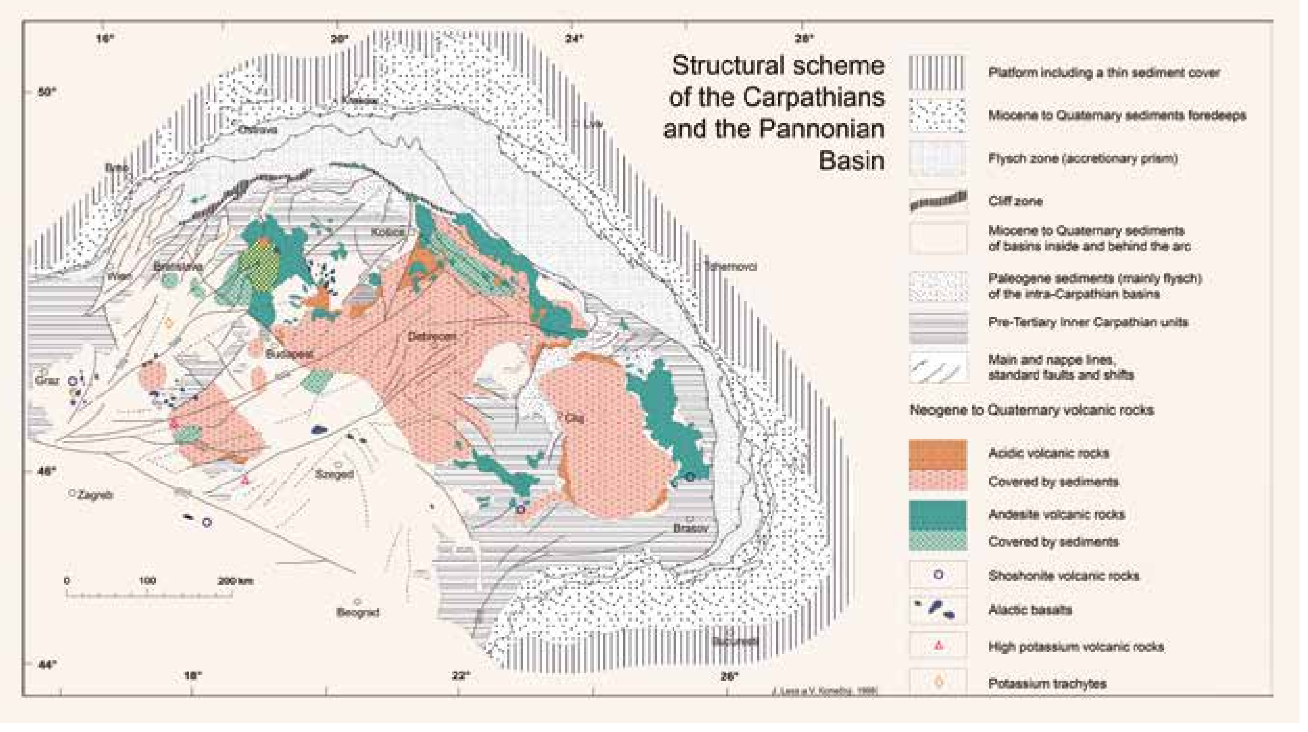


Fig. 3 Scheme of the structure of the Tertiary and Quaternary volcanic rocks within the Carpathian-Pannonian area (J. Smolka et al., 2003).

15. Neogenic volcanism in the area of Central Slovakia

During the Neogene Period, the andesite and rhyolitic volcanism of areal type was active in the area of Central Slovakia. It was caused by subduction processes with subsequent diapiric ascent along with the extension, which dominated the inner side of the Carpathian arc at that time.

The andesite volcanic activity in Central Slovakia lasted from 16.5 Ma ago (the Early Baden) until 9 Ma ago (the Pannonian). During the Early Miocene, the andesite volcanism was preceded by rhyodacite-rhyolitic volcanism of areal type with assumed centres in Northern Hungary. In Southern Slovakia, this volcanism has been manifested through rhyodacite to rhyolite tuffs in the Eggenburgian sediments, and to a lesser extent in the Carpathian sediments.

During the Baden to Sarmatian, a volcanic area of ca. 5,000 km² was formed in Central Slovakia (Fig. 4).

In the southern part of the territory, which was flooded by a shallow epicontinental sea during the Early Baden, rising of a considerable number of extrusive bodies of amphibole-pyroxene andesites of the Vinica Formation occurred at the southern edge of the Krupinská Planina Plateau. In the marine environment, the domatic-type andesite bodies underwent disintegration and explosive destruction, accompanied by accumulation of debris material in their immediate vicinity. Coarse to blocky material underwent additional redeposition there, and a group of epiclastic volcanic breccias, conglomerates, and sandstones, further deposited from extrusive bodies, was formed. The rising of the extrusive bodies depended on the course of the NE-SW fault zone – the *Šahy-Lysec volcano-tectonic belt*.

In the central to northern part of the Central Slovakia neo-volcanic area, rising of extrusive bodies of hypersthene-amphibole andesite with garnet of *the Neresnica Formation* occurred alongside regional fault lines, or fault zones, at the edges of horsts and gra-

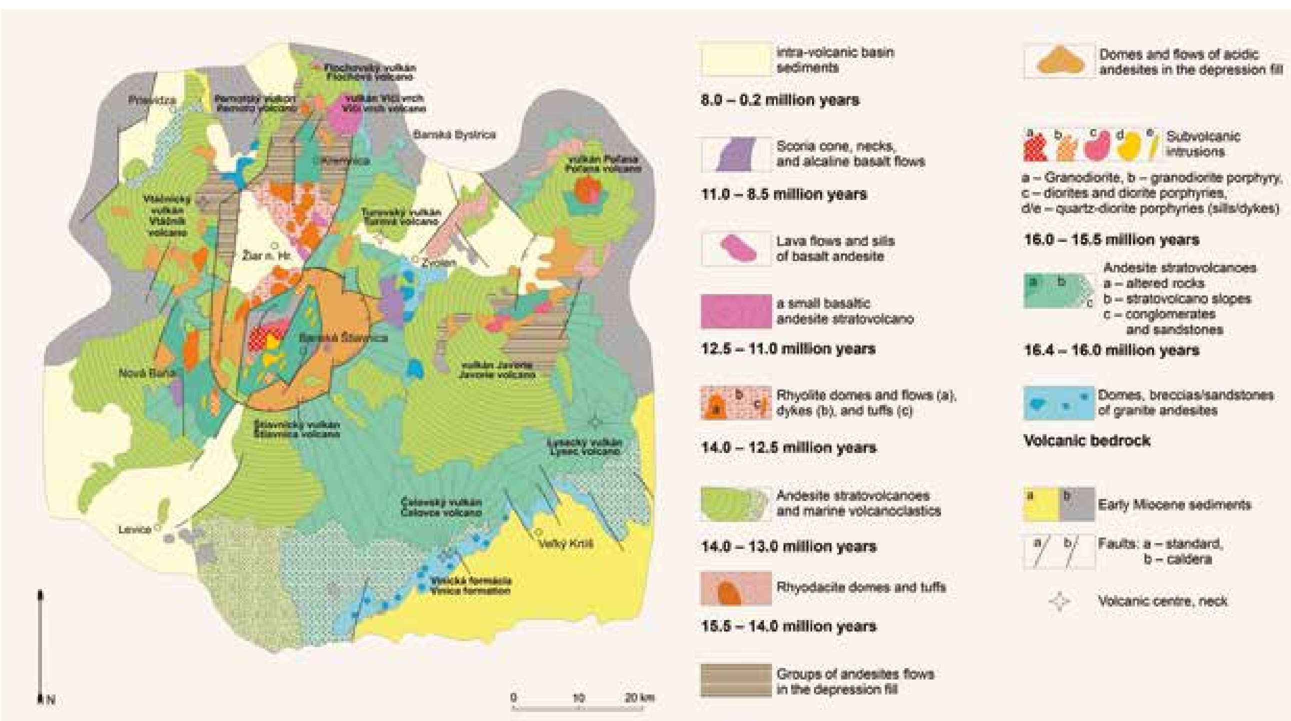


Fig. 4 Scheme of the structure of neovolcanic rocks in Central Slovakia (J. Smolka et al., 2003).

bens in the continental environment. Generally, the extrusive bodies (extrusive domes) and volcanoclastic rocks have been exposed by a denudation cut south-east of Zvolen, on the slopes of the Neresnica River Valley. Other bodies rise to the surface on the southern and western slopes of the Kremnica Mountains, and on the northern edge of the Vtáčnik Mountain.

During the Middle Baden, *the pyroclastic Čelovce Volcano* was formed in the coastal zone at the southern edge of the Krupina Highlands. The products of the explosive activity (tuffs and breccias of the pyroclastic flows) were transported towards NW and N into the area of the Krupina and Bzovík depression, which underwent an intense subsidence during this period.

During the Middle and Late Baden, another smaller volcano was formed in the north-eastern part of the Šahy-Lysec volcano-tectonic belt – *the pyroclastic Lysec Volcano*. The volcano was formed in the continental terrestrial environment, and during the course of explosive eruptions, a cone consisting predominantly of pyroclastic material was formed. The products of volcanic eruptions (tuffs, breccias) were transported from the volcanic slope towards the south to the Strháre-Trenč Depression, which was subsiding at that time, and thus they were deposited in the lake environment in the form of epiclastic volcanic groups (sandstones, conglomerates, breccias). During the final period, amphibole-andesite bodies in the form of protrusions (tholoids) were penetrating the volcanic structure in the area of the central volcanic zone.

During the Baden and the Sarmatian, a relatively extensive andesite stratovolcano was being formed in the north-eastern part of the neo-volcanic region – *the Javorie Stratovolcano*. Its Badenian development was accompanied by the formation of volcano-tectonic depressions – grabens, which were being filled by lava effusions of basaltic to intermediary andesites at first, followed by the formation of hyaloclastite breccias, which indicate the presence of water within the graben. Lava extrusions of amphibole-pyroxene andesites to rhyodacites ensued, constituting the upper part of the graben fill. During the Sarmatian, in the course of the explosive-effusive activity, an upper volcanic structure was formed. Its remains form the upper parts of the Javorie Mountains. In the central volcanic zone, the denudation cut has exposed stock intrusions of diorite to monzodiorite porphyries, which indicate porphyry-type polymetallic (Pb-Zn-Cu) and Au mineralisation.

In the north-eastern part of the region (north of the Javorie Stratovolcano), a medium-sized *andesite stratovolcano is located – the Poľana Hill*. During the Late Baden, the bottom stratovolcanic structure was formed in the course of the explosive-effusive activity of the pyroxene-andesite volcanism. During the Early Sarmatian, massive eruptions of ash-pumice tuffs were followed by hilltop subsidence of the stratovolcano, and the caldera was formed. The caldera subsidence was compensated for by rhyodacite lava extrusions and effusions. During the Middle to Late Sarmatian, an upper stratovolcanic structure with predominant pyroxene-andesite lava flows was formed in the overlying rock of the caldera fill and the older volcano. In the central volcanic zone, an intrusive complex in the form of stock bodies of andesite to diorite porphyries was formed.

The gigantic *Štiavnica Stratovolcano* in the western part of the neo-volcanic region is characterised by the caldera formation, differentiated subvolcanic and intravolcanic intrusive complexes, and the formation of the horst structure. The characteristics of this stratovolcano, which is also part of the proposed establishment of the Banská Štiavnica Geopark, is dealt with in more detail in a separate chapter.

During the Baden and Sarmatian, a complex volcanic structure in the form of several vertically layered bodies was formed in the northern part of the neovolcanic region. The bottom structural layer in the area of the Kremnica Mountains consists of the remains of a Baden stratovolcano – *the Turček Volcano* (Formation). In its central volcanic zone (which has been turned into a present-day horst), bedded intrusions of andesite porphyries protrude, and at the lower level, there are diorite to gabrodiorite intrusions. During the Early to Middle Baden, a massive, ca. 200 m thick group of conglomerates and sandstones settled in the lake-river environment at the western stratovolcanic foot. During the Late Baden, further subsidence in this area induced the lake-swamp sedimentation together with the formation of coal seams in the deposit of Nováky and Handlová, and the formation of overlying clay rocks of ca. 300 m in thickness.

The period of Late Baden represents an important change in the morphological structure of the territory. Along the fault lines which run roughly in a north-southward direction, subsidence occurs, and *the Kremnica Graben* is formed in the same direction. In the initial stage, the graben formation was accompanied by explosive-effusive volcanism of hypersthene-amphibole andesites, followed by lava effusions of basaltic-pyroxene andesites with the formation of hyaloclastite breccias and phreatopyroclastic rocks, which indicate the presence of water inside the graben during this period. The higher part of the graben fill consists of a massive complex of lava flows of amphibole-pyroxene andesites (± biotite). The overall thickness of the volcanic rocks within the Kremnica Graben fill (middle structural layer) exceeds 1,000 m.

The upper structural layer consists of several smaller stratovolcanoes situated near the peripheral fault lines of the Kremnica Graben, which was formed during the Early to Late Sarmatian. At the western to north-western edge of the Kremnica Graben, the abovementioned stratovolcanoes are: *the Markov Vrch Volcano, the Vtáčnik Volcano, the Remata Volcano*, and *the Flochová Volcano*. During the Sarmatian period, *the Sielnica Volcano* was formed on the south-western slopes of the Kremnica Mountains, with *the Turová Volcano* being formed in its overlying rock.

16. Geological units under the Central Slovakia neovolcanic rocks

In the Central Slovakia neo-volcanic area, the pre-Neogene rocks form the fundament – bedrock for groups of volcanic rocks. The pre-volcanic bedrock protruding at the eastern edge of the neovolcanic rocks dives under volcanic groups and continues further westwards.

There are only sporadic data on the geological structure of these older units deposited under the neo-volcanic rocks. The data shows that the bedrock occasionally rose to the surface in the form of elevational structures, or horsts. Their hilltops have been exposed by a denudation cut. In the eastern part of the neo-volcanic region, it is seen mainly as a deep trench of the Madačka Stream Valley (near Ábelová), the Lieskovec Horst (east of Zvolen), and the Pliešovce Horst (south of Zvolen). In the southern part of the territory, it is mainly the Santovka-Turovce Horst north of Šahy. However, most information about the structure of the bedrock in the western part of the neovolcanic rock comes from an extensive bedrock exposure in the area of the Hodruša-Štiavnica Horst. The rocks pertaining to this horst will be described in more detail. Structural boreholes also provide valuable information about the structure of the pre-volcanic bedrock, which they have reached after having penetrated the volcanic complex.

The main structural-tectonic units in the neo-volcanic bedrock are: Tatricum, Veporicum, Gemericum, Hronicum, and Silicicum. Sediments of the Paleogene Age and of the Early Miocene can be found in the neovolcanic bedrock as well.

The Tatricum represents the oldest tectonic unit, which protrudes from the surface exposures at the north-western edges of the neovolcanic rocks. It consists of granitoids and Hercynian crystalline schists at the bottom, followed by Mesozoic carbonate rocks of the Ráztočno Succession, which date back to the Triassic, Jurassic, and Cretaceous periods. Except for the northern edges, its further expansion has not been assumed.

The Veporicum forms a higher tectonic unit deposited onto the Tatricum. Rocks of this tectonic unit protrude in the form of a wide zone along the eastern edge of the neovolcanic rocks, dive under them, and then continue as lines roughly in the NE-SW direction, and towards SW in the neovolcanic bedrock. At the bottom, the Veporicum units consist of granitoids and Hercynian crystalline schists, and of the coat remains in the form of Paleozoic and Mesozoic rock in the overlying layer. The Hercynian granitoid rocks rise to the surface in the trench of the Madačka Stream Valley (south of Ábelová), then in the area of the Lieskovec Horst, and in the extensive exposure around the Hodruša-Štiavnica Horst. The crystalline schists have been exposed at the hilltop of the bedrock elevation north-east of Šahy (the Breinčenský Stream Valley).

The rocks of the coat unit consisting of the Mesozoic sediments protrude to the surface around the Lieskovec Horst and the Pliešovce Horst, but mainly around the Hodruša-Štiavnica Horst, where the formation has been more complete. More detailed characteristics of the Veporicum rocks in this area are described in the following part.

The Gemericum is a tectonic unit, which stretches under the neovolcanic rocks only partly at the SE edge of the neovolcanic region. In this area, this unit consists of Early-Carboniferous metasediments.

The Hronicum is a higher tectonic unit deposited onto Veporicum units. This unit usually occurs in the western part of the neovolcanic bedrock, where it has been confirmed by boreholes and surface exposures. It protrudes in the Hodruša-Štiavnica Horst area and will thus be discussed in more detail in that part. In the bottom part, this sheet unit consists of Carboniferous sediments (dark schists with sandstone and conglomerate interbeds) and Permian sediments (multicoloured schists, sandstones, and conglomerates). Higher up, the sediments are followed by a series of Mesozoic rocks represented by quartzites, schists, and Early-Triassic quartzites, and by limestones and Middle to Late Triassic dolomites in the overlying rock.

The Silicicum, or rather the Silica Nappe, is placed onto the Veporicum and Hronicum units at the northern edge of the neo-volcanic rocks. The Silica Nappe consists of multicoloured Early Triassic schists with evaporite, sandstones, and quartzites with the products of rhyolitic volcanism, and higher of limestones and dolomites of the Middle Triassic Period. Silicicum rocks have been identified by boreholes around Banská Štiavnica.

Paleogene in the volcanic bedrock. During the Eocene, sandstone, conglomerate, and limestone sediments deposited on the denudational surface of Mesozoic rock groups in the course of sea transgression.

In the Krupina Depression area, the GK-4 borehole has identified a thick (ca. 500 m) group of multicoloured (brown-red, purple-red, green-grey) sandstones with layers of Mesozoic conglomerates, alternating with limestone components. Based on the floral pollen evaluation, the group is considered to date back to the Late Cretaceous until the Early Paleogene Period (V. Konečný, J. Lexa, E. Planderová, 1983), corresponding to the Cretaceous Period of Gossau (M. Polák, 1978). The overlying rock consists of grey, brown, and spotted claystones and marlstones with pollen biocoenosis corresponding to the Eocene.

As the depression-like structure stretches further northwards towards an area south-west of Zvolen, the GK-8 borehole near Ostrá Lúka has identified a group of calcareous sandstones with layers of conglomerates, fine-grained breccias and nummulitic limestones as dating back to the Eocene (The Lutetian). The group is around ca. 100 m max. thick.

In the northern part of the Central Slovakia region, Paleogene sediments of several hundred metres in thickness protrude in the neovolcanic bedrock. They reach the surface around Kordíky (north-eastern edges of the Kremnica Mountains) and near Handlová. These sediments form a part of a zone running in the east-west direction, with occurrences of Paleogene sediments. The zone stretches from Brezno to the Bánovská Kotlina Basin. During the Neogene Period, the Paleogene sediments in this zone were protected against erosion thanks to their former subsidence. The Paleogene sediments in this zone are represented by the basal **Borové Formation** in the form of conglomerates with Mesozoic and older rocks, breccias, and calcareous sandstones. **The Huty Formation** and **the Zuberec Formation** of claystones and sandstones with breccia interbeds overlie the Borové Formation, with their age ranging from the Eocene to the Oligocene.

In the overlying rock of the Central Carpathian Paleogene in this area, the Egerian sandstone formation protrudes as a result of a later separate sedimentation cycle.

17. Morphological-tectonic structure of the neo-volcanic bedrock in Central Slovakia

The neo-volcanic bedrock in Central Slovakia is divided by fault lines into horsts and grabens (either raised or lowered blocks of the Earth's crust). The formation of this horst/graben system is depicted in the morphological-structural scheme of the neo-volcanic bedrock (Fig. 5). It took place predominantly during the Late Tertiary (the Miocene) concurrently with the volcanic activity. The formation of horsts and grabens was caused by the extension of the Earth's crust on the inner side of the Carpathian arc due to subduction processes ongoing on its outer side.

Subsiding grabens were filled with fragmental volcanic material, which compensated for their descent. In the southern part of the region, some grabens were flooded by sea water and close-grained sediments deposited there, or they became isolated depressions of lake-swamp types with abundant vegetation, and later developed into coal basins.

Volcano-tectonic depressions are a special type of depressions formed by blocks of the Earth's crust subsiding into upper vacant parts of a magma chamber. An example of this type of depression is represented by the Štiavnica Caldera with a roughly elliptical shape with a protruding horst, which was elevated in the final stage of the volcanic activity. Other examples include the Javorie Graben and the Vígľaš Graben, which have been filled with lava flows, and penetrated by intrusive bodies. The Poľana Graben with a central caldera is a similar case. The massive Kremnica Graben, stretching into northern parts of the Štiavnica Stratovolcano, underlays the Žiarska Kotlina Basin in its southern part. During the Pliocene, the basin was subsiding until recent historical periods. The pre-volcanic bedrock of this basin has subsided more than 2,200 m below sea level. The majority of these depressions in the western part of the region show deeper subsidence at their western edges, which explains their asymmetrical nature. The examples include the

Žiarska Kotlina Basin, the Hornonitrianska Kotlina Basin, and the Bátovce Depression.

The depressions at south-western edges of the Štiavnica Stratovolcano were characterised by a marine environment until the Middle to Late Sarmatian, when the sea gradually freshened, and became brackish or even of a lake-swamp type. The remaining vegetation there was the source for brown coal seams (the Pukanec Basin within the Bátovce Depression).

Elevational structures, which were being formed in the course of the volcanic activity in the paleo-relief, often acted as barriers towards expanding sea transgressions. They had an impact on the formation of sedimentation basins, as well as on transport of volcanic products (the Šahy Elevation, the Santovka-Turovce Elevation).

The most distinctive horst/graben system in the N–S direction in the western part of the neo-volcanic region, which was formed during the Baden to Sarmatian, includes the Turiec Depression (graben), the Kremnica Graben with a central horst, the Žiarska Kotlina Depression (graben), the Hodruša-Štiavnica Horst, and the Pukanec-Bátovce Depression (graben). Horst and graben blocks west of the axis of symmetry of this system show westward inclinations (the Handlová Crest, the Hornonitrianska Kotlina Basin), while blocks east of this axis are inclined eastwards (the Zvolen Basin). The resurgent Hodruša-Štiavnica Horst, which was formed within the Štiavnica Caldera towards the end of the volcanic activity, and the subsidence of the Žiarska Kotlina Depression, are linked chronologically as well as genetically with the rhyolitic volcanic activity. The horst/graben nature of the bedrock structure of the neo-volcanic rocks in Central Slovakia has been defined on the basis of boreholes and geo-physical data, notably gravimetry (V. Konečný, J. Lexa, J. Šefara, 1978).

The formation of the horst/graben system was affected by the changing orientation and intensity of the stress field. During the Early Baden, compression of the NW–SE direction led to the formation of horsts and grabens in the very same direction. During the Late Baden, the axis of maximum stress was rotating in the NE–SW direction, hence horsts and grabens oriented in the N–S and NE–SW direction were formed (M. Nemčok, J. Lexa, 1990, M. Nemčok et al, 1993).

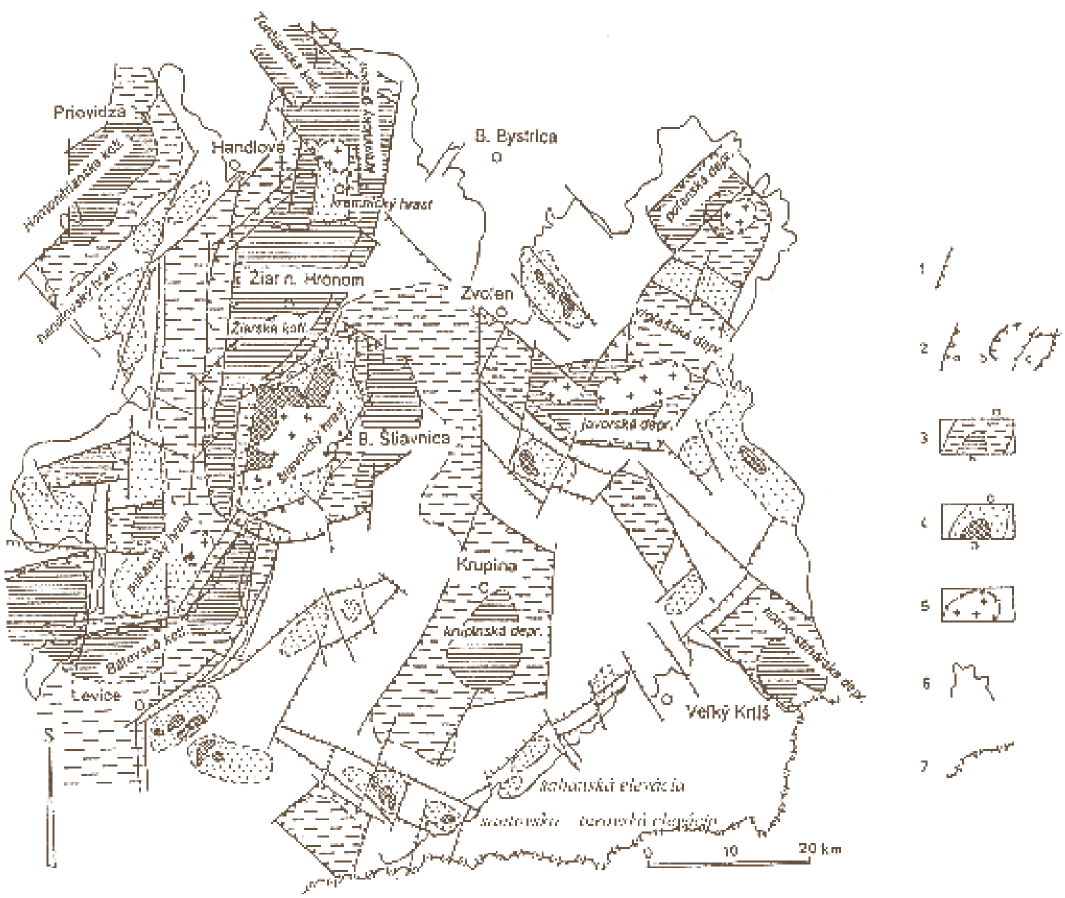


Fig. 5 The morphological-tectonic structure of the pre-volcanic bedrock of the neo-volcanic rocks in Central Slovakia as reconstructed from geo-physical data and structural boreholes (V. Konečný, J. Lexa, 1995, V. Konečný, J. Lexa, 2001):

1 – fault lines in the neo-volcanic bedrock, 2 – fault lines delineating: a) grabens, b) calderas, c) volcano-tectonic horsts, 3 – depressions: a) shallow part, b) deep part, 4 – elevations: a) elevational slopes, b) surface protrusion of the bedrock, 5 – subvolcanic intrusive complex delineated on the basis of geo-physical data, 6 – borderline of the neo-volcanic rocks, 7 – state border.

18. An outline of the geological structure of the Štiavnica Stratovolcano bedrock

Rocks of the pre-volcanic bedrock rising to the surface have been exposed by a denudation cut in the western part of the Hodruša-Štiavnica Horst, which was formed by an uplift of an extensive block within the caldera area during the final stage of the volcanic activity (Late Sarmatian to the Pannonian). As the rocks of the upper structure of the Štiavnica Stratovolcano, including the caldera fill and the bottom of the stratovolcanic structure were removed, the pre-volcanic bedrock including sub-volcanic intrusive complexes of the Štiavnica Stratovolcano were exposed to a large degree.

18.1. The Veporicum crystalline complex

The oldest pre-volcanic bedrock within the Hodruša-Štiavnica Horst consists of Hercynian rocks represented by the Veporicum crystalline complex. Rocks of the Veporicum crystalline complex rise to the surface in the area between Sklené Teplice and Hodruša. Exposures in the Kamenná Dolina Valley east of Sklené Teplice are the widest ones. Other exposures are located on the slopes of the Vyhnianska Dolina Valley (under Ostružka), in the area of Klokoč, Rumplovská, in the Hodruška Valley, and on the southern slope of the Zlatý Vrch Mountain north of Banky.

Crystalline schists, as a part of the crystalline complex, consist of *sillimanite-biotite orthogneisses placed* at the very bottom. They protrude at the southern slopes of the Zlatý Vrch Mountain (Goldberg), north of Banky. In their overlying rock, there are sericite-chlorite schists and porphyric granodiorite rocks (the crushed Vyhne granite) with a Mesozoic envelope.

These rocks were subject to dynamic processes, mainly high pressure, which resulted in the formation of stripes, partial recrystallization, and a new arrangement of minerals. Significant components are feldspars, quartz (grains sized up to 1 cm), biotite flakes, and sillimanite (a mineral formed during metamorphosis), and other meta-minerals such as andalusite, sericite, and chlorite. Tourmaline and zircon occur sporadically as accessories.

In the upper part of the orthogneisses where they meet the Vyhne granite, there is a zone of heavily to extremely crushed mylonitised rocks.

Porphyric granodiorite – the Vyhne granite – is a coarse-grained to medium-grained rock of brown-grey to green-grey colour. Its main components are potassium feldspar, plagioclase, biotite, chlorite, and sericite. Other components include apatite, zircon, and titanite. The rock was formed during Hercynian orogenetic processes, and is thus directed, crushed, and sporadically gains porphyroblastic texture as a result of Alpine tectonic processes. In some heavily affected areas, the texture is cataclastic (debris-like) or even dynamo-fluidal.

Near the crushed Vyhne granite deposit, in the area of Klokoč, *sericite-chlorite schists occur*. The schists are grey-green to green, with tiny stripes or leaves. Significant components are chlorite, sericite (feldspars are heavily sericitised), quartz grains, muscovite flakes, and sporadic biotite. The rocks have been identified as diaphtorite (rocks affected by alteration to a lesser degree in comparison to the first stage of alteration).

Rocks of the crystalline complex in the horst area have been deformed multiple times. They are deposited in a duplex-scaly position shifted from NE to SW. Their nature is similar to that of the northern Veporicum crystalline complex within the area near the root zones of the Krížna Nappe (V. Konečný, J. Lexa, J. Hók, 1993).

18.2. The Mesozoic Veporicum in the volcanic bedrock

In the Hodruša-Štiavnica Horst area, the Veporicum crystalline rocks, represented mainly by the Vyhne crushed granite, bear a series of Mesozoic rocks referred to as the **Veľký Bok series**. This group is frequent in the north-eastern part of the horst around Sklené Teplice, where it has been completely formed. In the central part of the horst, this group is discontinuously represented mainly by some of its bottom components (see the lithostratigraphic table of the bedrock in the Hodruša-Štiavnica Horst area, Tab. 1).

The bottommost component of the Veľký Bok series is the *Lúžna Formation dating back* to the Early Triassic. Its main components are fine-grained to coarse-grained quartzite rocks of either pale to dark grey or pinkish colour, which are often layered and bedded (beds are 40 to 100 cm thick), while these beds are separated by silicified sericite schists. Typical signs are those of pressure metamorphosis, manifested in the form of cleavage foliation, clastic textures, and formation of new minerals: chlorite, sericite, and muscovite. Quartzite layers are broken, and the cracks are penetrated by new quartz veinlets. The quartzite rocks were formed by solidification of original sorted siliceous beach sands deposited in a shallow-water coastal zone. The quartzites are the basal component of the group.

Another type of the Early Triassic sediments is the **Werfen Formation** represented by multicoloured (red-purple, ochre, yellow-green, grey) sediments. Schists are micaceous and clayish with sandstone interbeds. They are often silicified. Alteration caused the formation of new sericite and chlorite.

Quartzites and sandy Werfenian schists are only sporadically present in the central and southern parts of the horst, or not present at all.

Limestones and dolomites of the Middle to Late Triassic are deposited higher in the stratigraphic succession. Limestones are white to dark-grey or even black-grey, layered, and often cleaved and marbled due to metamorphic processes (pertaining mainly to light-coloured types). The original sedimentary textures have seldom been preserved. Ochre limestones with porous structure are referred to as rauhwackes. Dolomites are pale-grey, have grained to sugary texture, and are layered (the layers are max. 50 cm thick). Limestones and dolomites are frequently karstified.

When the limestones come into contact with granodiorite, its thermic and metasomatic effect results in their alteration into calcic skarns, while dolomites are altered into magnesian skarns. The limestones and dolomites are subsequently recrystallised.

Higher in this stratification, above limestones and dolomites, there are multicoloured schists, sandstones, dolomites and evaporites of the Late

The Hodruša-Štiavnica Horst area

STRATIGRAPHY				VEPORICUM – VEĽKÝ BOK SERIES			HRONICUM – ŠTUREC NAPPE			SILICICUM		
				m	LITHOLOGY	ROCK CHARACTERISTICS	m	LITHOLOGY	ROCK CHARACTERISTICS	m	LITHOLOGY	ROCK CHARACTERISTICS
MESOZOIC	CRETACEOUS		CENOMANIAN									
			ALBIAN	[illegible]		dark slates, sandy slates						
			APTIAN									
			BARREMIAN									
			HAUTERIVIAN									
			VALANGINIAN	[illegible]		altered slickenside limestones and slickensides						
			BERRIASIAN									
	JURASSIC	MALM	TITHONIAN									
			KIMMERIDGIAN									
			OXFORDIAN	[illegible]		pink limestones, radiolarites, radiolarite limestones (altered)						
		DOGER	CALLOVIAN									
			BATHONIAN									
			BAJOCIAN									
			AALENIAN									
		LIAS	TOARCIAN									
			DOMERIAN									
			CARIXIAN									
			LOTHARINGIAN									
			SINEMURIAN									
			HETTANGIAN									
	TRIAS		RHAETIAN									
			NORIAN	[illegible]		variegated slates, sandstones, dolomites, evaporites (altered)						
			CARNIAN				[illegible]		LUNZ FORMATION			
			LADINIAN	[illegible]		dolomites limestones rauvaks	[illegible]		dolomites limestones	> 870		dolomitic limestones, varied slickenside- calcareous shales, sandy-clayey shales, evaporites
			ANISIAN									
			SCYTHIAN	[illegible]		altered sandy slates LÚŽNA FORMATION (altered)	[illegible]		BENKOV FORMATION quartz sandstones, slates			
PALEOZOIC	PERM						[illegible]		MALUŽINÁ FORMATION sandstones, slates, conglomerates with basalt and porphyry bodies			
	CARBONIFEROUS						[illegible]		NIŽNÁ BOCA FORMATION sandstones with conglomerates and slates			
				< 300		porphyritic granodiorite (Vyhne crushed granite) sillimanitic-biolitic orthogneiss sericitic-chloritic schists						

Tab. 1 Lithostratigraphic table of the Štiavnica Stratovolcano bedrock in the Hodruša-Štiavnica Horst area (V. Konečný et al., 1998 a).

Triassic, referred to as **the Carpathian Keuper**. Multicoloured schists, as is clear from their name, are characterised by variegated colouring (yellow-grey, grey-green, purple, or purple-red). Clay schists often alternate with sandy ones. Sediments are evidence of a shallowed nature of the marine environment, and of denudation of material from a nearby continent.

The Jurassic sediments (the Middle to Late Jurassic) are represented by *pink limestones*, *radiolarites* (siliceous sediments consisting of shells of tiny organisms – *radiolarian limestones*. These sediments were being deposited in a deep marine environment. During the Late Jurassic to Early Cretaceous Period, limestone and marlstone layers were being deposited. Ensuing tectonic processes resulted in cleavage foliation of the sediments, and limestones were partly recrystallised – marbled.

The uppermost part of the stratification of the Veľký Bok series consists of *dark clay schists alternated with sandy schists to sandstone layers*, which were being deposited during the Late Cretaceous Period. In the bottom part of this group, there are coarse-grained sandstones to conglomerates consisting of quartz, limestone, coral limestone, and crystalline schist fragments. Clay schists are partly altered and are thus forming black-grey phyllites.

The rocks of the Veľký Bok series are generally affected by dynamo-metamorphic processes in connection with Alpine orogenetic processes which were taking place during the Late Cretaceous Period, resulting in cleavage foliation and mild metamorphosis of these rocks. The Veľký Bok series in the Hodruša-Štiavnica Horst area is characterised by tectonically reduced stratification, i.e., lack of some lithological components. In the overlying granodiorite rock further to the south, this rock group protrudes only fragmentarily. Granodiorite contact-metasomatic effects caused recrystallisation of limestones and dolomites, which resulted in the formation of marbles and skarns.

18.3. The Paleozoic and Mesozoic Hronicum in the volcanic bedrock

The Hronicum forms a higher tectonic sheet unit in the Hodruša-Štiavnica Horst area. This unit consists of sediments dating back to the Late Paleozoic (the Carboniferous, the Permian) and the Mesozoic eras. The Hronicum rocks protrude to the surface in the western and the northern part of the horst, and there are sporadic smaller surface protrusions of the bedrock in the form of isles, e.g., the one near Levice. The Hronicum rocks of the sheet unit either lie directly on the Veporicum crystalline complex (the Goldberg area) or on diverse components of the Veľký Bok series, or else within the overlying granodiorite and diorite rocks. In this case, the intrusions have had thermic and contact-metasomatic effects on the rocks, which have thus been altered, recrystallised (marbled), and skarnised. The sheet unit consists of Carboniferous and Permian sediments in the southern part of the horst, Early Triassic quartzites and schists in its central part, and Middle to Late Triassic limestones and dolomites in its northern part.

The bottommost component of the sheet unit is the **Nižná Boca Formation** of Carboniferous age (vestfál-stefan). It is composed of multiple alternations of **sandstones and tiny conglomerates with interbeds of dark schists**. The sediments are thoroughly sorted and consist predominantly of rounded quartz fragments, which are a result of disintegration of crystalline schists and granitoid rock, or acidic volcanic rocks. The base matter (cement) is lightly recrystallised, siliceous, with clay minerals. Mildly disseminated organic matter makes for the dark colour of the rocks. As the sediments were being altered (metamorphosed), new clay rocks (illite, kaolinite) as well as chlorite, calcite, and quartz were being formed at the same time.

After the Hercynian orogenetic processes stopped, Carboniferous sediments were deposited in the emerging sedimentation basins on the continental crust in delta-lake to lake environment. During this period, the climate was humid and warm, favourable to the emergence of swamp-lake vegetation, which was a condition for the formation of coal deposits.

In the overlying rock of the Nižná Boca Formation, the **Malužiná Formation** of the Permian age can be found. It consists of multiple alternations of sandstones (often with tiny conglomerate interbeds to layers) with sandy and clay schists. It is characterised by variegated colouring (purple, pale grey, grey-green or even purple-red). The main components of the sediments are quartz and feldspar grains, which are a result of disintegration and weathering of crystalline rocks. They are often mixed with volcanic material in the form of volcanic minerals and tiny basalt-andesite fragments. The original clayish cement was subsequently transformed into chlorite and illite, and calcite, or even siliceous cement. The sediments comprise lava bodies of basaltic andesites in the form of lava flows, or bedded bodies (sills), as well as intrusive bodies of diorite porphyries in the form of dykes and intrusions. The volcanic material is also present in the form of interbeds to layers of ash tuffs. The original volcanic minerals have been transformed into a mixture of secondary minerals (chlorite, calcite, sericite, zoisite, epidote, and others).

The Permian sediments were formed in the area of intermontane depressions of the new Hercynian mountain ranges in an arid (dry and hot) climate, when sandy and fine material was being carried from denudated mountains down into the lake environment. The formation of sedimentation basins and drying salt lakes was accompanied by intensive volcanic activity.

The Malužiná Formation is followed by the overlying **Benkovo Formation** dating back to the Early Triassic Period. It comprises bedded siliceous sandstones with interbeds of sandy schists. The sandstones are pale grey, evenly grained, bedded (the beds are 10–30 m thick), alternated with interbeds of close-grained schists. There are also tiny fragments of basic to acid volcanic material.

During the Early Triassic, sedimentation was taking place first on the continent, and later as transgression was progressing, it proceeded to the marine environment. The main component of sandstones and schists is a clastic material washed off the continent. Later (still during the Early Triassic), marlstones emerged.

In the overlying rock of the Benkovo Formation lie **limestones** and **dolomites** dating back to the Middle Triassic Period. Limestones are pale grey to white, massive, close-grained, often recrystallised, and more frequently occurring in comparison to dolomites. They comprise the remains of dasycladaceous algae, thanks to which it is possible to locate their age to the Middle Triassic Period (the Anisian and the Ladinian). In the area of Bukovec and Windischleunten adit, they are penetrated by quartz veinlets, while cavernous silicites are formed at the same time. Reef-building organisms have been discovered inside the limestones, hence they are considered to be reef facies of the Wetterstein limestone.

The Middle to Late Triassic Period is characterised by sedimentation taking place on extensive platforms within shallow seawater. Sporadically, they were penetrated by sediments originating in continental environment, or were lagoon deposits.

In the overlying rock of limestones and dolomites ensue layers of **the Lunz Formation** consisting of alternating middle to coarse-grained sandstones with schist layers. The sandstones are grey-green or gain reddish hues due to their contact with the air. Clay schists are dark grey to pale grey. The material which constitutes sandstones comes from the continent, where it resulted from weathering and disintegration of rocks. This is where the stratification of the Mesozoic Hronicum rocks ends.

18.4. The Mesozoic Silicicum in the Hodruša-Štiavnica Horst area

Rocks of the Silicicum sheet unit have been verified by structural boreholes around Štiavnické Bane (KOV-39 borehole) and Podsitnianska (KOV-40 borehole). The boreholes have identified **multicoloured schists with evaporite and sandstone-claystone schists with layers of sandstones, dolomite-like breccias, anhydrites, and gypsums** in the bottom part of the rock group. These represent sediments which originated in the lagoon area. In the overlying rock lie limestones and dolomites identified as dating to the Middle Triassic Period. The abovementioned Silicicum group is intensively altered around Štiavnické Bane, and is even altered into phyllites with talc, sericite, epidote, and calcite. The group is also hydrothermally altered and impregnated by dispersed polymetallic sulphide mineralisation. It is penetrated by numerous dykes or bedded intrusions of quartz-diorite porphyries. In the bottom part, i.e., a contact area with a granodiorite intrusion, it has been intensively altered.

18.5. The formation of the Mesozoic sedimentation zones

The Mesozoic sediments were being deposited in the Tatricum, Veporicum, Hronicum, and Silicicum sedimentation zones from north to south respectively. The closest zone within the reach of the European platform (once a continent), was the Tatricum sedimentation zone. Here the continental impact was the strongest, resulting in the formation of continental facies (mainly during the Triassic as multicoloured Keuper facies were formed). On the contrary, the Hronicum sedimentation area was closer to the open ocean, and therefore the continental impact was the weakest there. In the course of the following orogenetic processes (collision stage), the sedimentary rocks emerging in the sedimentation basins of several hundred kilometres in width, were thrusted into a mountain range of only several dozen kilometres in width, wherefore the sediments were folded, thrust faults were formed, and nappes (sheets) were moved tens of km away.

The period of orogenetic processes (during the Middle to Late Cretaceous) brought folding processes with the formation of the Central Carpathian nappes and was characterised by the absence of sedimentary components (surfacing stage).

After the orogenetic processes stopped during the late Cretaceous to the Paleogene, sediments of varied composition were deposited in local depressions; conglomerates, sandstones, limestones, sandy limestones etc.

18.6. The Paleogene sediments

The Paleogene sediments in the area of the Hodruša-Štiavnica Horst do not form compact nappes, they only protrude in the form of denudation remains with relatively little thickness. The sediments represent a basal complex of the Eocene age. The sediments are composed mostly of tiny to coarse-grained conglomerates with sandstone interbeds. The conglomerates consist predominantly of Permian pebbles. Cement is sandy to sandy-clayish. Limey layers with nummulite fauna are located near Vyhne. The HDŠ-1 borehole near Repište has identified claystone sediments with marine fauna of the Eocene age (the Late Lutetian).

During the later period, towards the end of the Paleogene and at the beginning of the Miocene (rupel-eger), new sea transgression penetrated from the south into the area of the Krupina Depression, where in this partly isolated space, lagoon-like hypersaline sediments (gypsums, anhydrites) of **the Krupina Formation** were formed (the GK-4 borehole in Bzovík).

19. Formation of the Štiavnica Stratovolcano

Thanks to its size of more than 2,000 km^2, the Štiavnica Stratovolcano ranks among the biggest volcanoes on the inner side of the Carpathian arc. It is characterised by a complex structure, differentiated volcanic products, multistage formation of intrusive complexes, caldera formation, and finally horst structure formation with uplift of an extensive block within its area. The stratovolcanic formation was accompanied by metallogenetic processes causing polymetallic mineralisation and mineralisation of precious metals, which established a rich tradition of mining, and enabled the birth of the mining towns of Banská Štiavnica and Banská Hodruša (present-day Hodruša-Hámre).

The formation of the extensive and complex Štiavnica Stratovolcano during the Early Miocene (roughly between 16 to 11 Ma) took place over a period of explosive and effusive eruptions, alternated with periods of temporary volcanic quiescence and denudation. Within the formation of this impressive stratovolcano, characterised by the formation of an upper caldera and an intrusive subvolcanic complex, six developmental stages have been determined (Fig. 6).

19.1. Developmental stages of the Štiavnica Stratovolcano

Developmental **stage 1** of the Štiavnica Stratovolcano (16–15 Ma). During the Early to Middle Baden, in the course of explosive-effusive eruptions, a vast stratovolcano was progressively formed. It consisted of fragmental volcanoclastic material alternating with lava flows of pyroxene and amphibole-pyroxene andesites. In the southern part, the stratovolcano reached a shallow subtropical sea. Since its products expanded to the area of more than 2,200 km^2 it is assumed that the stratovolcano reached the height of 3,500–4,000 m, and its hilltop was covered with snow and ice. Towards the end of its development, numerous bedded intrusions of andesites and andesite porphyries in the form of sills and laccoliths were deposited in the central volcanic zone. In the area of the stratovolcanic slopes, domatic extrusions rose and penetrated numerous stock and dyke intrusions (schematic section). The relatively smaller Kremnica Stratovolcano was emerging north of the Štiavnica Stratovolcano. Volcanic products of the abovementioned stratovolcanoes overlaid extrusive bodies and coarse breccias of older garnet andesites.

Developmental **stage 2** was a period of volcanic quiescence, accompanied by denudation of the stratovolcanic structure. During this period, magma differentiation was taking place in the magma chamber (reservoir). Subsequently, as the central block subsided into the magma chamber, the magmas started to rise and deposit in the form of subvolcanic intrusions of granodiorite and diorite. On the NW stratovolcanic slope, in a partially isolated swamp-like environment, the development of vegetation began. It would later become the basis for lignite deposits of the Handlová–Nováky coal district. North of the stratovolcano, the Kremnica Graben was being formed due to a block subsidence accompanied by lava effusions. It reached the northern slopes of the Štiavnica Stratovolcano. Towards the end of this stage, the initial subsiding movements occur in the stratovolcanic hilltop area, resulting in the formation of a lava flow and a swamp-lake environment. The subsiding movements gradually proceed into the caldera stage.

Developmental **stage 3** during the Late Baden to the Early Sarmatian represents the formation of the Štiavnica caldera, linked with an explosive-effusive activity of biotite-amphibole andesites. Products of the explosive activity in the form of pumice tuffs and pyroclastic flows, followed by lava

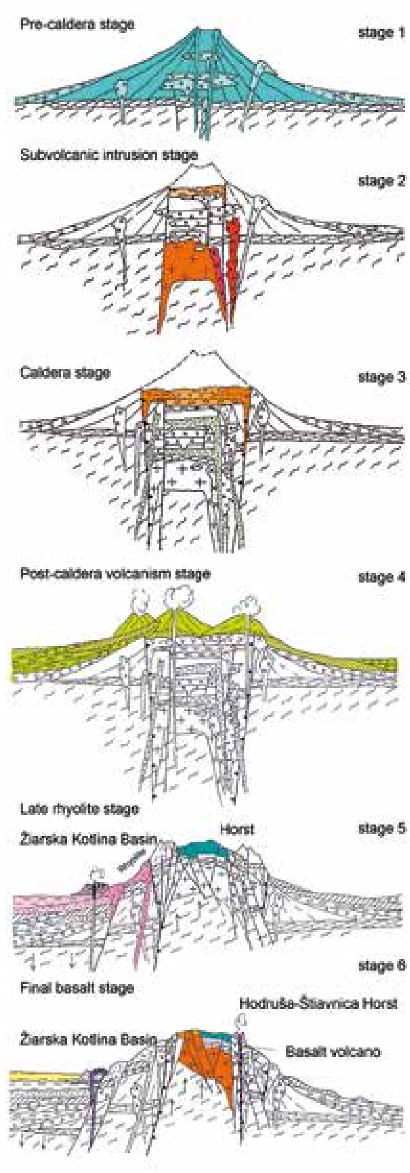


Fig. 6 The main developmental stages of the Štiavnica Stratovolcano (J. Smolka et al., 2005).

effusions and extrusions, would fill the caldera, and after crossing the caldera fault would continue towards the stratovolcanic slope into radially oriented paleodolines. During this period, as the central block continued to subside into the magma chamber, bedded intrusions (sills) and dykes of quartz-diorite porphyries were deposited at subsurface (subvolcanic) level. At the edges of the Kremnica Graben, a series of smaller phreatopyroclastic cones and stratovolcanoes emerged.

Developmental **stage 4** (the Early to Middle Sarmatian) represents a renewed explosive-effusive activity of pyroxene and amphibole-pyroxene andesites (frequently containing biotite), which led to the formation of smaller stratovolcanoes and stratovolcanic complexes within the caldera and on the stratovolcanic slope. Products of this activity filled the edges of the caldera and the paleodoline on the stratovolcanic slope. Lava flows, which reached the coastal zone at the SE volcanic foot, were undergoing brecciation. Further to the south from the coastal zone, there were deposits of tuffs, epiclastic volcanic sandstones, conglomerates, and finer sediments.

Developmental **stage 5** (the Late Sarmatian – the Pannonian) represents a dramatic turn in the formation of the stratovolcano. During the long-lasting uplift of the central block within the caldera, a resurgent horst was formed, and Žiarska Kotlina Basin subsided at the same time. The relative movement between the abovementioned blocks reached as much as 3,000 m. A fault zone between the uplifted and the subsided block channelled the ascent of rhyolite magma, and the commencement of explosive-effusive and extrusive volcanic activity. Products of this activity border the southern and eastern edges of the Žiarska Kotlina Basin. The fault zones within the horst block formed ore veins.

Developmental **stage 6** (the Pannonian – the Pliocene) includes the uplift of the central block together with deforming of the horst structure, and denudation of volcanic complexes in its hilltop area. Volcanism of basaltic andesites has continued sporadically (at the eastern edge of the Žiarska Kotlina Basin) It was later replaced by volcanism of alkali basalts, while one of its most recent results is the Putikov Vŕšok Volcano near Nová Baňa. Its age has been estimated to be 120,000–150,000 Ma.

20. Structure of the Štiavnica Stratovolcano

During the Early Baden, new sea transgression coming from the south reached the Krupina Depression, and from there it continued further to the north into the Zvolen and the Žiarska Kotlina Depression, and as far as into the area around Handlová. The transgression was immediately followed by the activity of a larger number of eruption centres of amphibole-pyroxene andesites and hypersthene-amphibole andesites with garnet in the form of extrusive bodies, protruding in the southern part of the region in the marine environment, and in the northern part in the continental/terrestrial environment. This was already a period just before the beginning of explosive-effusive andesite volcanism, which led to the formation of the Štiavnica Stratovolcano.

After the end of the volcanic activity of andesites with garnet in the form of dispersed extrusive domes surrounded by coarse material, an eruptive centre of the Štiavnica Stratovolcano in the western part of the neo-volcanic region was activated.

In the course of the explosive-effusive activity during the Baden to the Sarmatian, the large Štiavnica Stratovolcano was formed. The stratovolcano is divided into **the bottom stratovolcanic structure** (formed during the Early to Middle Baden), **the caldera fill** (the Late Baden, the Early Sarmatian), **intrusive complexes, the upper stratovolcanic structure** (the Early to Middle Sarmatian), and **rhyolite volcanism** (the Late Sarmatian).

20.1. The bottom stratovolcanic structure

During the first developmental stage, **the bottom stratovolcanic structure** – the Štiavnica Stratovolcano of impressive dimensions was formed in the course of explosive eruptions alternated with lava effusions of pyroxene and amphibole-pyroxene andesites. At the beginning, a shallow subtropical sea reached from the south as far as to the stratovolcanic edges, which is reflected in the vitreous nature of lava, and in the presence of hyaloclastite breccias, which were emerging as lava flows came into contact with the marine environment. Pyroclastic flows, which formed during the Plinian eruptions, were moving from the stratovolcanic slope towards its foot in the form of a chaotic mass of burning fragmental material. After they reached the seacoast and cooled, they continued further along the seabed as submarine mudflows or lahars.

Due to the expanding stratovolcanic structure, the coastline progressively moved southwards, where it eventually settled at the stratovolcanic foot. In the coastal zone, coarse to block (blocks sized min. 1–3 m) conglomerates were formed. Further to the south from the coastline (south of Hontianske Nemce), the coarse material was deposited together with finer sediments in the form of sandstones to siltstones, which have gradually dominated the southern sedimentation basin. At the southern edge of the marine basin, a crest composed of the pre-volcanic bedrock was surfacing (the Santovka-Turovce Crest). It represented a significant barrier for submarine debris flow, mass flows with finer material, and mudflows, all of which were stopped by it. Volcanic products were being deposited at the northern and north-eastern stratovolcanic slopes on dry ground, or in the river-lake environment (sandstones and conglomerates near Kamenec pod Vtáčnikom).

Towards the end of the stratovolcanic development, numerous bedded intrusions of andesite porphyries in the form of sills and laccoliths were deposited in its central part. In the area of the stratovolcanic slope, numerous domatic extrusions rose and penetrated stock intrusions of diorite porphyries.

The stratovolcano, which was formed towards the end of the first developmental stage, was characterised by unusual massiveness, its products were being disintegrated within an area of more than 2,000 km^2. The height of the stratovolcano, which was formed on the coast of a subtropical Baden Sea, can be deduced from its area. It possibly reached a height of 3,500–4,000 m, and its hilltops were covered with snow and ice.

The bottom structure of the central volcanic zone has been exposed by a denudation cut in the eastern part of the Hodruša-Štiavnica Horst (in the western part, even the pre-volcanic bedrock has been exposed). Except for the horst, the central volcanic zone is covered with the caldera fill.

The remains of the stratovolcanic complex dating to the initial developmental stages of its formation also constitute the structure of the central volcanic zone. They consist of lava flows, and occasionally of volcanoclastic rocks. The remains of the stratovolcanic complex are penetrated by numerous bodies of andesite porphyry in the form of sills and laccoliths. Bodies of these bedded intrusions are characterised by grained crystallised base matter, which indicates their solidification and crystallisation under the surface of the volcanic structure. The sills and laccoliths are further characterised by a massive and compact nature, and blocky jointing (unlike often porous and brecciated lava flows). The bodies of andesite porphyry in the form of sills and laccoliths were deposited at the bottom levels of the central stratovolcanic part as late as during the final stages of its formation (the first developmental stage), i.e., when the magma was already rising, but did not reach the stratovolcanic hilltop yet. The most massive bedded intrusion is the one of amphibole-pyroxene porphyry with biotite and quartz (of the Myšia hora type), which penetrates the upper levels of the bottom structure in the form of complex laccolith.

At the bottom levels of the stratovolcanic structure near the bedrock borderline, tuffisite breccias penetrate the interlayer areas. These are the results of abrupt gas expansion within the rising lava, which was transformed into fragments, and these together with fragments of surrounding rocks penetrated the interlayer areas in the form of tuffisite breccias just like the bedded intrusions.

The bottom structure in the horst area, including bedded intrusions, is penetrated by later intrusive bodies, sills, and dykes of quartz-diorite porphyry of the caldera stage. The bodies of the bottom structure within the central zone are inclined ca. 10–150 towards the SE due to the overall inclination of the horst block in the same direction.

The rocks of the bottom structure are broadly hydrothermally altered – propylitised (proved by their greenish colour), and often silicified and argillitised around ore veins. Due to hydrothermal alterations, rocks of variable lithological and petrographic composition have become almost homogenous, and borderlines between individual bodies blend, which considerably complicates detection and deciphering of their original composition and the overall structure of the central volcanic zone.

Propylitised volcanic rocks around Štiavnica used to be referred to as grünstein, or grünstein-trachyte due to their green colour. The term propylite denoting the rocks in the Banská Štiavnica region was introduced by F. Richthofen (1860), who supposed that the rocks are products of mass eruptions of water-rich magma. In spite of the fact that later research proved the rocks to be results of later hydrothermal alterations, which affected already solidified rocks, the words propylite and propylitisation, which were used for the first time in the Banská Štiavnica region, spread and became world-wide used terms denoting hydrothermal alterations of such type.

20.2. Subvolcanic intrusions

During the temporary volcanic quiescence in the Late Baden, intense denudation and stratovolcanic destruction were taking place (2nd Developmental stage). During this period, the original stratovolcanic height was significantly reduced. Destruction of its hilltop during the immensely powerful explosions towards the end the first developmental stage might have possibly occurred as well. Volcanic hilltop denudation and destruction reached as far as the depositional levels of shallow intravolcanic intrusions of the first developmental stage.

Differentiated magmas which did not reach the surface after their rise from the magma reservoir, were being deposited at the sub-surface, subvolcanic levels, where they solidified and crystallised into the form of stratovolcanic intrusions.

The bottommost level is represented by **the Hodruša-Štiavnica Intrusive**

Complex of granodiorite and diorite, exposed by a cut in the central part of the horst block. A granodiorite pluton, which occupies the inner part of the intrusive complex, seems like a body with a relatively flat cap and steeper edges. It is supposed that the granodiorite intrusion was formed as the bedrock subsided into the upper parts of the magma chamber. Granodiorite magma was rising along the fault lines which separated the subsiding bedrock block, and therefore the granodiorite magma settled in this new area over it. The shape of the intrusive body corresponds with the shape of an upside-down bell jar (Fig. 7).

The total area of this intrusion is more than 100 km². The remains of the Mesozoic sediments in the overlying rock of the intrusion, which represent the original cup, are hornfelised and skarnised. A diorite intrusion at the northern edge of the main granodiorite intrusion, oriented in the E-W direction, is steeply inclined northwards.

The second stage of the intrusive activity is represented by the formation of a larger number of stock-dyke bodies of granodiorite to quartz-diorite porphyry – **the Zlatno Intrusive Complex**, situated mostly outside the main granodiorite intrusion. The Zlatno Complex intrusions penetrated as high as to the bottom of the stratovolcanic structure (unlike the granodiorite intrusion which settled within the pre-volcanic bedrock). The depositing of these stock-dyke intrusions is linked to intense hydrothermal alterations of neighbouring volcanic mountain ranges, and manifestations of skarn-porphyry ore mineralisation.

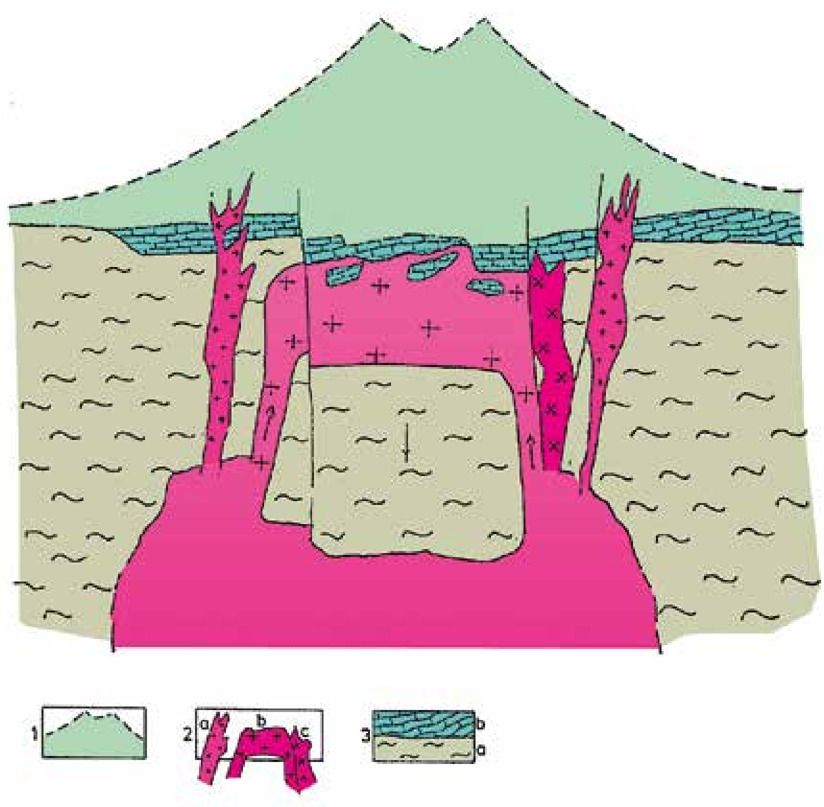


Fig. 7 The formation processes of stratovolcanic intrusions, shapes of intrusive bodies (J. Smolka et al., 2005).

Magma chamber, subsiding bedrock block, stratovolcano:
1 – stratovolcano,
2 – shapes of stratovolcanic intrusions of the Štiavnica Stratovolcano: a) stock-dyke intrusion of granodiorite porphyry (Zlatno complex), b) upside-down bell jar shape of granodiorite intrusion c) stock diorite intrusion,
3 – pre-volcanic bedrock: a) crystalline complex, b) the Mesozoic.

Towards the end of the second developmental stage in the Late Baden, the initial subsiding movements occurred at the top of the stratovolcano, leading to the formation of a depression with lake-swamp sedimentation, and to lignite formation – **the Červená Studňa Formation**. The sediments (sandstones, siltstones with lignite) are up to 60–80 m thick. A fault zone at the southern edge of the depression enabled the rise of the magma to the surface, and the formation of a lava flow of biotite-amphibole-pyroxene andesite at the SE edge of the emerging caldera. The lava flow was moving towards the central part of the subsiding depression.

20.3. Fill of the Štiavnica caldera

The caldera subsided after a prolonged, but temporary period of volcanic quiescence (2nd stage), during which differentiation processes were taking place in the magma chamber. They created more acidic andesite to andesite-dacite magma. The first massive explosive eruptions of ash-pumice tuffs (the Studenec formation) disrupted the peaceful swamp-lake sedimentation in the depression at the top of the volcano. They were related to the initial subsidence movements along the opening caldera fault. The continuous Plinian eruptions produced ash-pumice pyroclastic flows. Together with the airfall tuffs from the volcanic clouds, they began filling the subsiding caldera and partly deposited on the stratovolcano slope. In the later stage of caldera formation, biotite-amphibole andesite lavas erupted. They took the form of lava flows and more viscous, degassed extrusive domes in the upper levels of the caldera fill (Figs. 8, 9).

During this period, lava eruptions alternated with the eruptions of coarse to block pyroclastic flows and

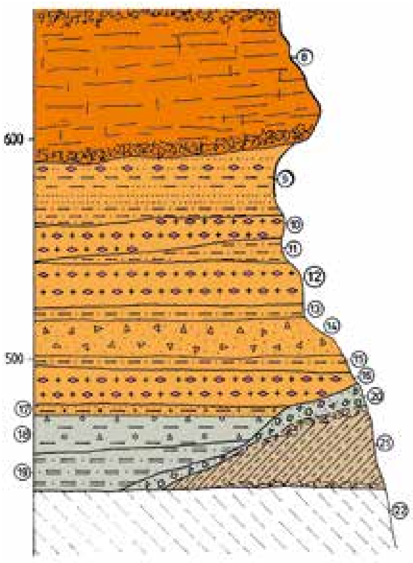


Fig. 8. The lithological profile of the bottom part of the Štiavnica caldera fill (J. Smolka et al., 2005):

The Studenec Formation):
8 – amphibole-biotite andesite lava flow, brecciated in the upper and lower parts, 9 – close-grained to coarse-grained epiclastic volcanic sandstones with siltstones and pumice (leaf prints), 10 – ash-pumice flow, 11 – epiclastic volcanic sandstones, siltstones, and redeposited pumice tuffs, 12 – ash-pumice flow, 13 – close-grained epiclastic volcanic sandstones, siltstones, and redeposited pumice tuffs, 14 – epiclastic volcanic breccias (amphibole-biotite andesite and older amphibole-pyroxene andesite coming from the bottom stratovolcanic structure), 15 – close-grained epiclastic volcanic sandstones, siltstones, and redeposited tuffs, 16 – ash-pumice flow, 17 – close-grained epiclastic volcanic sandstones and siltstones with the interbeds of vitreocrystalline tuffs with amphibole and biotite.
The Červená Studňa Formation:
18 – epiclastic volcanic sandstones and siltstones with fine breccias and conglomerates, 19 – epiclastic volcanic sandstones and siltstones with lignites, 20 – coarse epiclastic volcanic breccias with mixed material containing older andesite pertaining to the bottom structure and lava flow in the bedrock, 21 – lava flow of biotite-amphibole-pyroxene andesite.
The bottom stratovolcanic structure:
22 – lava flows and volcanoclastic rocks containing pyroxene and amphibole-pyroxene andesite (unsegmented).

pumice tuffs. Ash-pumice, coarse pyroclastic material, and lava flows were transported onto the stratovolcano slope in places where the caldera fault was disrupted. These masses moved along deep paleodolines, which took the form of radially oriented canyons. In the final stage of caldera formation along a roughly elliptical caldera fault (18x22 km), the subsiding caldera block was filled with a 300 to 500 m thick layer of explosive and effusive-extrusive activity products. After the caldera formed, local lake environments with diatomites and flints formed inside the caldera depression (near to Močiar and Podhorie). Hydrothermal centres with hot springs allowed for the formation of argillites, alunites, and flints near Dekýš (Fig. 10).

At the subvolcanic level, in relation to the disintegration of the subsiding caldera block, bedded intrusions in the form of quartz-diorite porphyry sills and dykes of **the Banisko intrusive complex** were formed.

The sills are located mainly in the central part of the horst block at the boundary between the bedrock and the overlying volcanic structure. Less frequently, they are located in the bottom stratovolcanic structure.

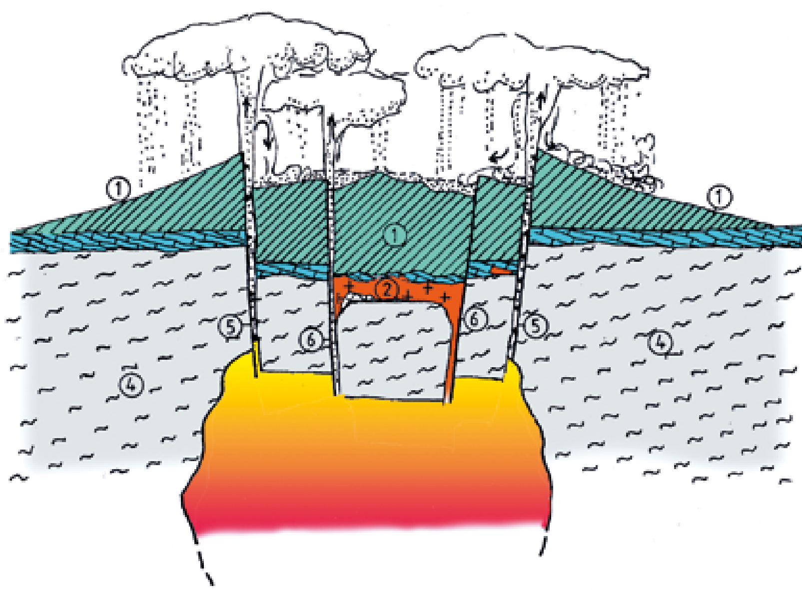


Fig. 9. The collapse of the Štiavnica caldera 13 million years ago was accompanied by massive eruptions of ash-pumice tuffs (J. Smolka et al., 2005):

1 – bottom stratovolcanic structure, unsegmented – the Baden stratovolcano, 2 – a granodiorite pluton located in the overlying rock of a block that subsided into the magma chamber, 3 – Mesozoic-Paleozoic bedrock, 4 – crystalline rocks, granitoids, crystalline schists, 5 – caldera fault, 6 – fault.

The dykes formed dyke swarms with a mostly NE-SW orientation tilted away from the central block. They often penetrate the bedded intrusions – sills. The formation of the youngest intrusive complex was related to the subsidence of the caldera block through the "ring-dyke" mechanism (Fig. 11).

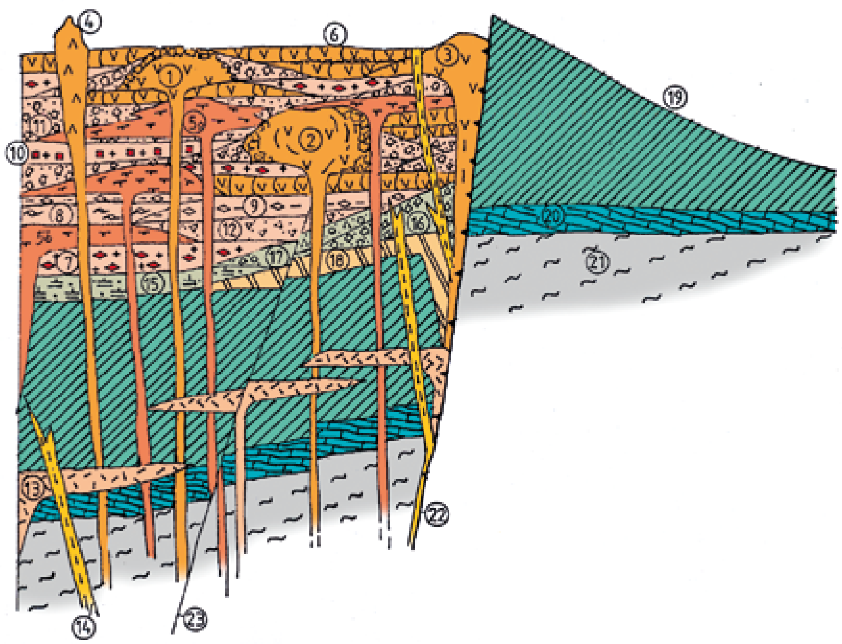
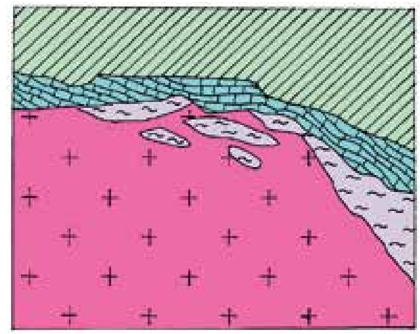
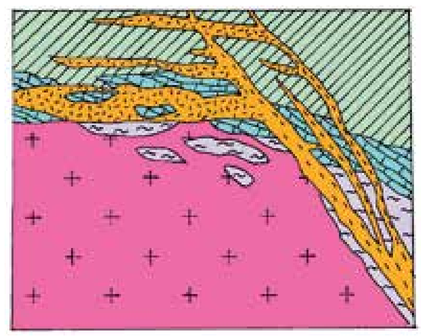


Fig. 10. Scheme of the Štiavnica caldera fill (J. Smolka et al., 2005):

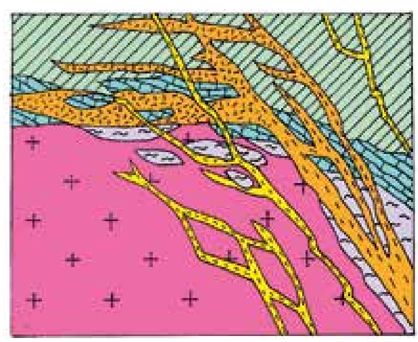
Caldera fill (Late Baden – Early Sarmatian).
The Studenec Formation – biotite-amphibole andesite volcanism:
1 – extrusive dome, 2 – cumulodome, 3 – extrusive dome with a transition into a flow, dome flow, 4 – protrusion, 5 – bedded intrusion, a) laccolith, b) sill, 6 – lava flows, 7 – ash-pumice flows, 8 – welded tuffs – ignimbrites, 9 – redeposited pumice tuffs, sandstones, siltstones, 10 – chaotic breccias of pyroclastic flows, 11 – coarse to block epiclastic volcanic breccias, 12 – fine epiclastic volcanic breccias, Banisko intrusive complex – quartz-diorite porphyries: 13 – sill, 14 – dyke.
The Červená Studňa Formation:
15 – epiclastic volcanic sandstones with siltstone and lignite interbeds, 16 – coarse to block epiclastic volcanic breccias, 17 – fine epiclastic volcanic breccias – conglomerates, 18 – lava flow of biotite-amphibole-pyroxene andesite, 19 – the bottom stratovolcanic structure, unsegmented.
Pre-volcanic bedrock:
20 – Paleozoic and Mesozoic sediments, 21 – crystalline complex, 22 – caldera fault, 23 – fault.



A – The situation before the quartz-diorite porphyry complex was formed. During its formation, the granodiorite intrusion damaged the crystalline complex and the Mesozoic rocks in the overlying rock.



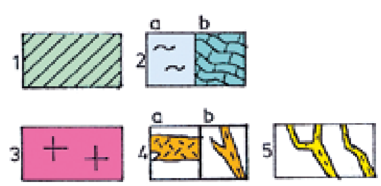
B – While the block subsides, magma rises and fills the space above the subsided block, thus forming quartz-diorite porphyry sills. Along the faults at the edges of subsiding block, dyke bodies are rising.



C – As the block continues to subside, faults are created. Along these faults, the dykes of quartz-diorite porphyry (younger generation) are rising.

Fig. 11. Scheme of the formation of the quartz-diorite porphyry intrusion complex (Ján Smolka et al., 2005):

1 – the andesite complex of the bottom structure, 2 – pre-volcanic bedrock: a) crystalline complex, b) Mesozoic sediments, 3 – granodiorite, 4 – the quartz-diorite porphyry of the Banisko intrusive complex: a) bedded intrusion (sill), b) dyke, 5 – younger generations of quartz-diorite porphyry dykes.



20.4. The upper structure of the Štiavnica Stratovolcano

During the Sarmatian Period after the caldera subsided, the pyroxene and amphibole-pyroxene andesite volcanism with biotite was renewed at multiple points within the caldera as well as on the stratovolcano slope. During the explosive-effusive eruptions, a series of smaller stratovolcanoes and stratovolcanic complexes referred as the upper stratovolcanic structure was formed (Fig. 12).

The products of this renewed activity were deposited within the caldera and filled its upper part; however, they mostly cover the stratovolcano slope, fill the paleodolines and continuous lava plateaus mainly at the southwestern and western parts of the stratovolcano foot.

The Sarmatian volcanism started with explosive eruptions of amphibole-pyroxene andesite with biotite. The ash-pumice material transported mainly in the form of pyroclastic flows and partly by air flows was deposited on the SW stratovolcano slope within the paleodoline. It started south of Počúvadlo and continued into a delta, which opened into the marine environment of the littoral zone. The ash-pumice tuff deposits around Ladzany – Hontianske Moravce are referred to as **the Ladzany Formation**. The following pyroxene andesite lava flows pertaining to **the Baďan Formation filled** this paleodoline. At the SE foot of the stratovolcano, they formed a large lava plateau with the area of 80-100 km2. The lava flows were in contact with water, which caused brecciation. Vitric hyaloclastite breccias were formed. At the southern edge of the lava plateau in the shallow coast area, formations of coarse epiclastic breccia conglomerates alternated with sandstones were deposited. Southwards, formations of ash-pumice tuffs and finer tuff sediments were deposited in the shallow water.

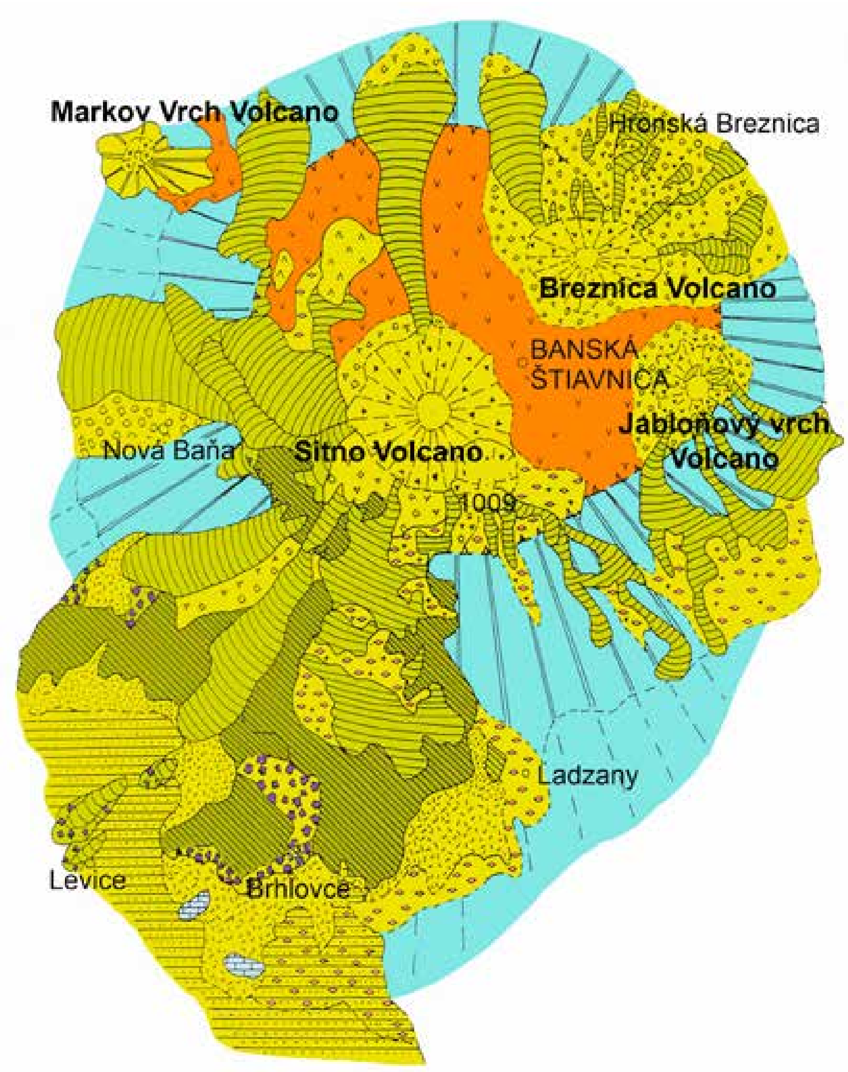


Fig. 12. A reconstruction of the Sarmatian volcanoes in the Štiavnica caldera (Ján Smolka et al., 2004).

The following Plinian eruptions produced masses of ash-pumice tuffs, which were deposited in the southern part of the caldera and partly on the stratovolcano slope in the form of paleodoline fills referred to as **the Biely Kameň Formation**. Explosive eruptions were followed by effusions of **the Sitno Complex** lavas (amphibole-pyroxene andesites with biotite) from the assumed Sitno volcano in the southern part of the caldera. After filling the southern and south-western parts of the caldera, the lava flows ran down the stratovolcano slope along the paleodolines and filled their upper parts.

The subsequent eruptions of ash-pumice tuffs and amphibole-pyroxene andesite with biotite of **the Drastvica Formation** were directed towards the western slope of the stratovolcano and followed the paleodoline relief towards the area of Obyce for more than 25 km. The ash-pumice tuffs covered the local coal basin north of Obyce. After the hot ash-pumice material was deposited, it welded into **ignimbrites**. Further eruptions directed to the SW slopes of the stratovolcano deposited ash-pumice tuffs in the coastal zone (north of Rybník and Čajkov).

The products of the following explosive and effusive eruptions of amphibole-pyroxene andesites pertaining to **the Priesil Formation** gradually filled the paleodoline running SW from Nová Baňa into the area of the Kozmálovské Kopce hills. They covered the tuffaceous claystone sediments with coal seams, which formed at the edge of the bay near to Hronský Beňadik and Orovnica during the Early Sarmatian. Upon contact with water, lava flows brecciated – coarse to block hyaloclastite breccias were formed. Due to the expansion of the volcanic structure, the coastal area of the Sarmatian sea was gradually moved to the western edges of the Kozmálovské Kopce hills. The fact that a coast used to be in this area is indicated by the presence of coarse to block conglomerates, which were formed by the destruction of lava flows caused by the waves in the surf zone.

During the Late Sarmatian, massive effusions of vitric and leucocratic pyroxene andesite of the **Inovec Formation** occurred. Major lava effusions probably came from the cracks occurring on the western stratovolcano slope. During the Sarmatian period, an eruptive centre at the eastern edge of the caldera fault was activated and a smaller pyroxene andesite volcano referred to as **Jabloňový Vrch** was formed.

At the north-eastern edge of the caldera, another smaller volcano of pyroxene and amphibole-pyroxene andesites was formed referred to as **the Breznica Formation**. At the NE slopes of the stratovolcano slope towards its foot, two smaller volcanoes, **Sielnica** and **Turová** (with the centres near Turová) were formed during the Sarmatian period. At the SW slopes of the stratovolcano slope, the smaller **Markov Vrch** stratovolcano was formed.

During the Middle to Upper Sarmatian, the Žiarska Kotlina Basin started subsiding, which was compensated by the depositing of fine sediments. Similarly, at the SW edges of the Štiavnica Stratovolcano, a series of subsidence depressions referred to as grabens were formed. They were filled with marine sediments pertaining to the Middle to Late Sarmatian.

20.5. Rhyolite volcanism and horst structure formation

The rhyolite volcanism took place at the end of the Sarmatian period approximately 12.5 to 10.5 million years ago along with the uplift of the Štiavnica caldera and subsidence of the Žiarska Kotlina Basin (Fig. 13). Along the extensional faults at the western edge of the horst as well as along the tectonic boundary between the uplifting horst block and the subsiding block of the Žiarska Kotlina Basin, rhyolitic matter rose to the surface. The amplitude of the vertical movement between these blocks is about 3,000 m. This fault system, which continues along the eastern edge of the Žiarska Kotlina Basin northwards to the Kremnica Mountains is referred to as the Vyhne-Ihráč volcano-tectonic zone. Similarly, the faults caused by the horst's uplift caused the formation of rhyolite dykes around the ore veins. West of the Žiarska Kotlina Basin's edge, another fault system was active, i.e., the Nová Baňa-Kľak volcano-tectonic zone. It led from North to South and the extrusive domes along this line transi-

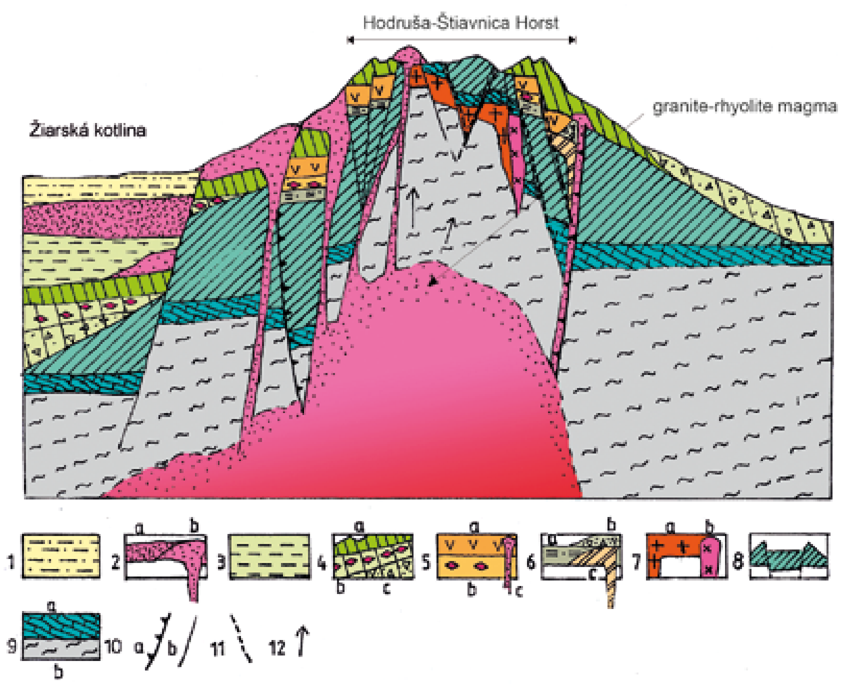


Fig. 13. The position of the rhyolitic volcanism during the uplift of the Hodruša-Štiavnica Horst – Stage 5 (J. Smolka et al., 2005).

1 – Pliocene sediments, 2 – rhyolite volcanism during the Late Sarmatian – the Jastrabá Formation: a) rhyolitic tuffs, b) extrusion, 3 – Sarmatian sediments in the fill of the Žiarska Kotlina Basin, 4 – andesite volcanism during the Sarmatian: a) stratovolcanic complex (lava flows, volcanoclastic rocks), b) pumice tuffs, c) volcanoclastic rocks, 5 – the fill of the Štiavnica caldera – the Studenec Formation (Late Baden, Early Sarmatian): a) lava flows, extrusions, and volcanoclastic biotite-amphibole andesite rocks, b) pumice tuffs, c) rhyolite a rhyodacite dykes (extrusions) in the eastern part of the caldera at the caldera fault, 6 – the Červená Studňa Formation (bottom part of the caldera fill): (epiclastic volcanic sandstones with siltstones and lignites, b) coarse epiclastic volcanic breccias at the edge of the caldera fault, c) a lava flow of amphibole-pyroxene andesite, 7 – the Hodruša-Štiavnica intrusive complex: a) granodiorite, b) diorite, 8 – bottom stratovolcanic structure (Baden), lava flows and volcanoclastic rocks, unsegmented, 9 – pre-volcanic bedrock: Paleozoic-Mesozoic sediments, b) crystalline complex, 10 – a) caldera fault, b) fault, 11 – ore vein, 12 – maximum uplift direction.

tioned into lava flows (the northern part of the Nová Baňa rhyolite body).

In the northern part of this volcano-tectonic zone, the fault system with a NS orientation caused the formation of the Tisové Bralo extrusive rhyolite body, lined with extrusive breccia zones along its edges. The products of the surface volcanic activity are concentrated mainly at the southern, south-eastern, and eastern edges of the Žiarska Kotlina Basin. They take the form of extrusive rhyolite domes often transitioning into lava flows. The rise of the rhyolite magma was accompanied by violent phreatic and phreatomagmatic eruptions caused by the contact of the rhyolite lava with the water in the lake environment, which was expanding within the subsiding Žiarska Kotlina Basin at the time. The products of the phreatic, phreatomagmatic, and Plinian eruptions accumulating around the eruptive centre formed tuff rings and cones. The tuff material was transported and deposited on the slopes of the tuff rings and cones during rhythmically recurring eruptions, which took the form of pyroclastic surges, flows, but also airfall.

The rising viscous rhyolite lava had limited movability and caused the formation of numerous extrusion domes, which often transitioned into short and thick flows at the volcanic slope. During their formation, the edges of the extrusive domes were solidifying more rapidly, which caused brecciation and fragmented material was accumulated around them. Upon contact with the water in the lake environment, hyaloclastite breccias were formed. The extrusive domes forming in the central parts of the tuff rings and cones were often suddenly damaged by explosions caused by the internal overpressure of the magmatic gases), and some of them may have been destroyed. These sudden destructive explosions created mass flows partly consisting of burning fragmented material referred to as glowing avalanches.

In the final stage, the degassed, highly viscous lava rose in the form of needles, protrusions, and tholoids because it moved vertically (apart from extrusive domes and lava flows). At the edges of these bodies, vitreous rhyolite to rhyolite glass (obsidian) zones were formed due to rapid cooling (Szabova skala, Photo 1., Pustý hrad at Sklené Teplice). The lava bodies that never reached the surface stayed among tuff formations and breccias in the form of bedded bodies (sills and laccoliths). The formation of these shallow intrusions was accompanied by hydrothermal alteration of the surrounding tuff complexes, i.e., argillites and zeolitised tuffs were created. The pumice tuffs produced during the Plinian eruptions deposited in the lake-river environment and formed massive tuff horizons. The river and other occasionally occurring water flows transported the fragments and tuff mainly into the western part of the Žiar Depression, which was intensively subsiding. During this process, epiclastic volcanic breccias, conglomerates, sandstones, redeposited tuffs, and tuffaceous-siltstones were accumulated.

The activity of hot springs containing SiO_2 caused the formation of flints referred to as **limnoquartzites**. The activity of these hydrothermal solutions also caused argillitisation of tuff formations during which argillites consisting of clay minerals (illite, kaolinite, montmorillonite) also known as bentonites were created. Argillite, argillitised rocks, limnoquartzite, zeolitised tuff, and perlites (vitric rhyolites) are important raw materials. Rhyolites are used in construction as well as a decorative stone.

The gradual uplift of the central block within the caldera synchronous with the rhyolitic volcanism caused the formation of the Hodruša-Štiavnica Horst during the Late Sarmatian to Pannonian. It is of an asymmetrical type with the maximum uplift at the western edge. The horst structure is inclined approx. 10–15° towards SE. During the uplifts, the horst structure disintegrated into blocks mostly along the faults with the NNE–SSW to N–S directions. The faults occurring mainly at the eastern edge of the horst and in its middle allowed for the rise of hydrothermal solutions, which, in turn, allowed for the formation of epithermal polymetallic precious metal ore veins of the Hodruša-Štiavnica ore zone. V. Konečný (1970, 1971) assumed that the horst was uplifted due to the rising and depositing of granite-rhyolite magma in the upper part of the magma chamber, which is in line with the concept proposed by R. L. Smith and R. A. Bailey (1968) who investigated the arcuation of the Creed and Silverton calderas in the US.

Photo 1. Perlitic rhyolite – obsidian (rhyolite glass) from Szabova skala (© P. Pachinger).

21. Basaltic andesite volcanism

The final stage of the calc-alkaline andesite volcanism – in the area where the Central Slovak neovolcanic rocks were formed – included basaltic andesite to basalt volcanism during the Early Pannonian (10.5–9.0 million years ago). The denudation remains of this volcanism represented by lava bodies such as intrusions, dykes, lava flows, shallow bedded intrusions, and volcanoclastics can be found at the eastern and south-eastern edges of the Žiarska Kotlina Basin. Based on their location, they are referred to as the **Šibeničný Vrch Hill complex**. (Šibeničný Vrch Hill east of Žiar nad Hronom, Photo 2).

Photo 2. The products of the basaltic andesite volcanism pertaining to the Šibeničný Vrch Hill formation pertain to the period of Early Pannonian, i.e., 10.5–9.0 million years ago. (© P. Pachinger).

At the eastern edge of Žiar nad Hronom around Šibeničný Vrch Hill, a pyroclastic cone was formed during the period of phreatic and phreatomagmatic eruptions. The phreatic and phreatomagmatic eruptions were caused by the contact of the rising magma with the aquiferous horizon.

During the recurring explosions, the erupted pyroclastic material was deposited around the eruptive centre and formed a tuff ring. It consists mostly of the lake and river sediments (sands and gravels) transported to the surface during explosive eruptions, which fills the eastern part of the Žiarska Kotlina Basin. Throughout the course of these eruptions, the position of the eruptive centre was changing, which is why the deposited material shows a variety of inclinations. During the rhythmical phreatic and phreatomagmatic eruptions, the fine dust-ash to sandy material was transported by base surges and deposited. However, the eruptions also expelled coarser material, which was originally part of the river terrace gravels. Occasionally, basalt lava fragments and tiny basalt bombs were expelled as well.

After the tuff ring or cone was formed, explosive eruptions were replaced by the rising andesite-basalt magma around the eruptive centres. It is evidenced by the basalt body, which penetrates the sandstone-conglomerate formation with rhyolite material pertaining to the Jastrabá Formation at the eastern edge of Šibeničný Vrch Hill. The subsequent lava effusions filled the central depression of the tuff cone – maar. The denudation remains of this lava fill cover the top of the Šibeničný Vrch Hill crest (elevation 384).

Besides this location, there is also a group of intrusions, dykes, and bedded intrusions (sills and laccoliths) at the eastern edge of the Žiarska Kotlina Basin. They can be found in around the rhyolite tuffs pertaining to the Jastrabá Formation, which proves there was intensive volcanic activity in this part of the basin. Smaller volcanoes such as small stratovolcanoes and scoria cones were formed here.

Near Šášovské Podhradie, a basaltic andesite lava flow was deposited on a layer of rhyolite volcanoclastics pertaining to the Jastrabá Formation. Remains of palagonitised basalt tuffs and pyroclastics can be found in the overlying rock, which documents the phreatomagmatic eruptions that followed the lava flow effusion. Phreatomagmatic eruptions and the palagonitisation processes prove there was a lake-river environment in the Žiarska Kotlina Basin during this stage of its formation.

The products of basaltic andesite volcanism can also be found in the western part of the neo-volcanic region around the Vtáčnik Mountain, e.g., the Ostrovica neck (elevation 855) (west of Kľak) or the dyke swarm near it. They prove that scoria cones or even smaller stratovolcanoes had formed in this area but were later removed through denudation. The existence of similar volcanic forms can also be assumed west of Sklené Teplice (neck and dykes around the Farkaška crest) and north-west of Nová Baňa (the neck near the Struhárka crest).

22. Alkali basalt volcanism

During the later Neogene (Pannonian to Pontian) and Pliocene, there was active alkali basalt volcanism, which formed a larger volcanic zone in Southern Slovakia (Lučenská Kotlina Basin and Cerová Vrchovina Mountains), which continued into the territory of northern Hungary, particularly Salgótarján.

The products of this volcanism can be found in the Central Slovak neo-volcanic region, although they are much less numerous. The relicts of this volcanism are lava flows, projecting lava necks, and a scoria cone with lava flows near Nová Baňa.

The SE slope of the Štiavnica Stratovolcano near Devičie (SW of Krupina) is a denudation remnant of a lava flow that filled the paleodoline running in the SWW-NEE direction. However, the assumed scoria cone was not preserved. According to the radiometric dating, the lava flow originated during the Pannonian (8.5±0.5 million years).

Between the Pannonian and Pontian, a lava plateau was formed at the eastern slope of the Štiavnica Stratovolcano due to the effusive activity. Lava flows filled the broad paleodoline, which runs north (Bacúrov – Dobrá Niva – Ostrá Lúka). The scoria cone at the SW edge of the lava plateau i.e., the assumed source of the lava flow was not preserved due to denudation. The paleodoline was dammed south of the lava plateau (south of Dobrá Niva) and a smaller lake formed. The lake sediments are several tens of metres thick. According to the radiometric dating, the lava plateau is 6.59±0.28 million years old (K. Balogh, A. Miháliková, D. Vass, 1981) which corresponds with the period between the Pannonian and Pontian. The analysis of the pollen extracted from the lake sediments indicated a slightly younger age, which corresponds with the fact that the local basin and its lake environment were formed only after the effusive activity had ended.

Another projecting basalt neck can be found near Banská Štiavnica – the Kalvária Hill (elevation 749) is a landmark towering over the town. There is a calvary on its western slope and an important historical monument, a baroque church, on its top. The basalt neck is a lava body that solidified in the feeder channel of a surface volcanic form that itself was later removed by denudation. It is assumed that this body was originally a maar. At the edges of the basalt neck, preserved breccias can occasionally be seen. They were part of the older fill of the diatreme (Fig. 14).

Columnar jointing of this basalt body (caused by cooling and crystallisation) takes the form of an upside-down fan. It indicates that the upper part of the lava body kept expanding and probably transitioned into a lava lake, which used to fill the internal depression of the original maar. This fill as well as the assumed surface maar were removed by denudation, which uncovered the feeder channel under the surface, i.e., the basalt neck.

The petrographic composition of this neck corresponds with basanite with plagioclase, olivine, and augite phenocrysts with microdoleritic base matter including nepheline. According to the radiometric dating using the K/Ar method, the age of Kalvária Hill is 7.1±0.42 million years (K. Balogh, A. Miháliková, D. Vass, 1981).

The Kalvária Hill basalt played a role in the history of European geology thanks to F. S. Beudant who described it in 1822 and proceeded to successfully defend its Plutonist (volcanic) origin in the French Royal Academy of Sciences against the Neptunist theory advocated by E. J. Esmark (1798), who assumed these rocks formed through sedimentation from a water environment.

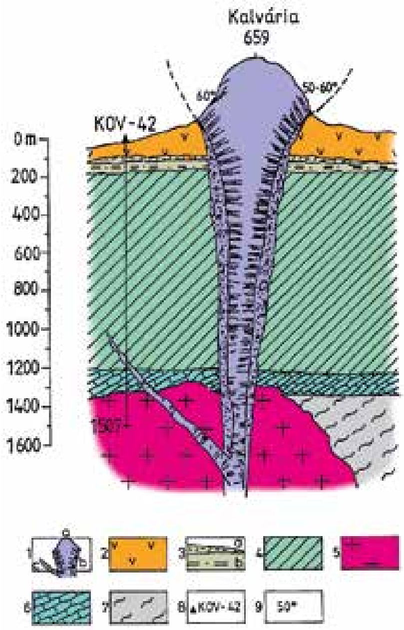


Fig. 14. The basalt neck of the Kalvária Hill – a geological section (Ján Smolka et al., 2005):

1 – basalt neck: a) basalt with columnar jointing, b) breccia in the diatreme fill, c) basalt dyke 2 – lava flows, extrusions, and volcanoclastic biotite-amphibole andesite rocks in the caldera fill, 3 – bottom part of the caldera fill: a) tuffs, b) epiclastic volcanic sandstones and siltstones with lignites (the Červená Studňa Formation), 4 – whole bottom structure, 5 – granodiorite, 6 – Paleozoic-Mesozoic sediments, 7 – crystalline complex, 8 – borehole, 9) inclination of the columnar jointing.

Another basalt neck was accidentally uncovered during the construction of the railway near Kysihýbel east of Banská Štiavnica (Fig. 15). This basalt neck penetrates biotite-amphibole andesite in the caldera fill and has an elliptical cross-section, and a longer axis in the NW-SE direction. A smaller satellite neck located at its southern edge has been separated from the main body by a basalt breccia. Contractive columnar jointing perpendicular to the walls of the feeder channel can be seen at the edges of this neck. Similarly to the Kalvária Hill neck, jointing occurred when the basalt body was cooling and crystallising.

The breccia, which divides the basalt necks, used to be the fill of an older diatreme. During the final stage, this fill was penetrated by the basalt neck. The breccia consists of fragments of porous basalt and a grained tuff matrix. The material was mixed with the fragments to blocks of biotite-amphibole andesite torn out of the feeder channel walls. The blocks were distinctively rounded when they were moving towards the surface during the eruption of high-pressure gas-ash mass. After the explosive eruptions ended and a maar or a pyroclastic cone was formed on the surface, the basalt lava rose through the feeder channel and effused to the surface. When the basalt lava solidified in the feeder channel, it plugged the feeder system and ended the volcanic activity.

The petrographic composition of the basalt at Kysihýbel is similar to that of the Kalvária Hill neck, i.e., it consists of nepheline basanite. The basalt contains numerous cavities left by the escaping gases. Rocks such as aragonite, calcite, and zeolites can be found in these cavities. According to the radiometric dating using the K/Ar method, the age of this neck is 6.88±0.48 million years.

The eruptive centres taking the form of basalt necks are located in the fault zones along the eastern edges of the Hodruša-Štiavnica Horst.

After a very long break, the basalt volcanism centre at the western slope of the Štiavnica Stratovolcano was activated in the Quaternary. It created the youngest **basalt volcano** known as **Pútikov Vŕšok** near Nová Baňa (Fig. 16). This volcanic centre is located in the southern part of the Nová Baňa-Kľak volcano-tectonic zone (during the Late Sarmatian, the rhyolite masses rose to the surface in this zone).

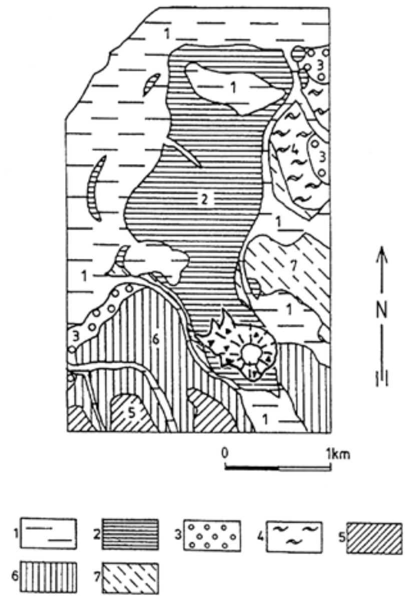


Fig. 16. Scheme of the geological structure around the Putikov Vŕšok Volcano (L. Šimon, 2000):

1 – unsegmented Quaternary sediments,
2 – Pútikov Vŕšok Volcano: a) scoria cone, b) lava flows,
3 – Pannonian-Pontian sediments,
4 – pyroclastics of the Drastvica Formation,
5 – lava flows the Sitno Complex,
6 – lava flows and epiclastics of the bottom structure the Štiavnica Stratovolcano,
7 – unsegmented lava flows of the bottom structure of the Štiavnica Stratovolcano.

During the explosive eruptions, a smaller scoria cone today known as the Putikov Vŕšok Volcano was formed. Later, lava flow effusions moving northwards into the paleo-Hron valley followed.

The initial phreatomagmatic explosions deposited the palagonitised tuffs on the cone's base (L. Šimon, 2000). The following Stromboli and Hawaii-type eruptions created a volcanic cone consisting of lapilli tuffs, basalt scoria, agglutinates, and basalt bomb deposited in a 30˚ angle.

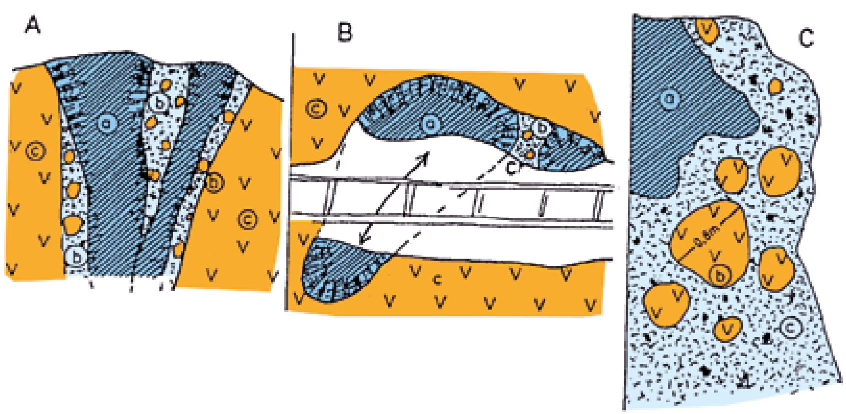


Fig. 15. The basalt neck exposed by the railway trench at Kysihýbeľ (J. Smolka et al., 2005):

A – basalt neck (profile),
B – basalt neck (cross-section), a) basalt with columnar jointing, b) breccia in the diatreme fill, c) pyroxene-biotite-amphibole andesite,
C – a close-up of the breccia in the diatreme fill: a) basalt, b) rounded blocks of pyroxene-biotite-amphibole andesite that come from the walls of the volcanic feeder, c) breccia in the diatreme fill with the fragments of porous basalt and tuff-grained matrix.

In the later stage of this volcanic activity, effusions of basalt flows from the scoria cone moved northwards into the paleo-Hron valley, where it covered the river terrace. Its contact with the water caused hydrovolcanic explosions and as a result, smaller scoria cones on the surface of the lava flows as well as hyaloclastite breccias were formed. Most probably, these lava flows dammed the flow of paleo-Hron for some time.

Based on the location of the lava flows in the rock overlying the river terrace pertaining to the Riss period, these lava flows are assumed to be 130–140 thousand years old (L. Šimon, R. Halouzka, 1996). According to the radiometric dating (K/Ar method), their age is 0.25±0.12 million years. (K. Balogh, A. Miháliková, D. Vass, 1981).

After the volcanic activity ceased in the Štiavnica Stratovolcano area, intensive denudation processes gradually removed the volcanic rocks from the upper part of the horst structure. The pre-volcanic bedrock including the subvolcanic intrusive complex of granodiorite and diorite were uncovered in the western part of the horst (Figs. 17, 18).

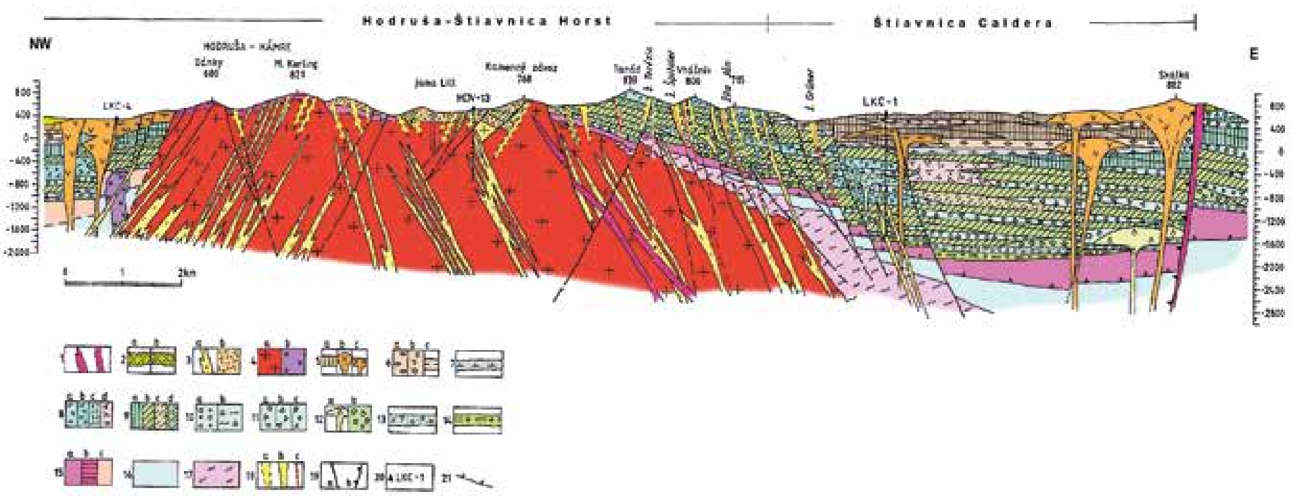


Fig. 17. The geological section through the volcanic zone of the Hodruša-Štiavnica Horst and caldera (Ján Smolka et al., 2005):

1 – rhyolite and rhyolite porphyry dykes (Late Sarmatian). The upper structure of the Štiavnica Stratovolcano (Sarmatian):
2 – lava flows: a) amphibole-pyroxene andesite with biotite (the Sitno Complex), b) pyroxene andesite ± amphibole (the Jabloňový Vrch effusion complex). Intrusive complexes:
3 – quartz-diorite porphyry intrusive complex (Banisko complex): a) dykes, b) bedded intrusion,
4 – the Hodruša-Štiavnica Intrusive Complex: a) granodiorite, b) diorite.

The fill of the Štiavnica caldera (Late Baden, Early Sarmatian): Biotite-amphibole andesite volcanism products (the Studenec Formation):
5 – a) lava flow, b) extrusive dome, c) sill, a bedded intrusion,
6 – a) pumice tuffs, b) epiclastic volcanic breccias, c) siltstone, claystone, lignite interbeds,
7 – epiclastic volcanic sandstones with siltstones and lignites (the Červená Studňa Formation).
Bottom stratovolcanic structure (Baden):
8 – bedded intrusions (sills, laccolites) of andesite porphyry: a) pyroxene-andesite porphyry rich with Tanád-type augite, b) pyroxene andesite ± amphibole, b) pyroxene-andesite porphyry, d) amphibole-pyroxene andesite porphyry ± quartz ± Myšia Hora type garnet,
9 – lava flows: a) basic pyroxene andesite ± olivine, b) pyroxene andesite, b) pyroxene andesite ± amphibole, d) amphibole-pyroxene andesite,
10 – volcanoclastic rocks: a) chaotic breccias of pyroclastic flows, b) tuffaceous breccias,
11 – a) coarse epiclastic volcanic breccias, b) fine epiclastic volcanic breccias, c) epiclastic volcanic breccia conglomerates,
12 – products of extrusive volcanism of hypersthene-amphibolite andesite with garnet: a) extrusion, b) coarse to block epiclastic breccia,
13 – basal group of strata, epiclastic volcanic sandstones, conglomerates.

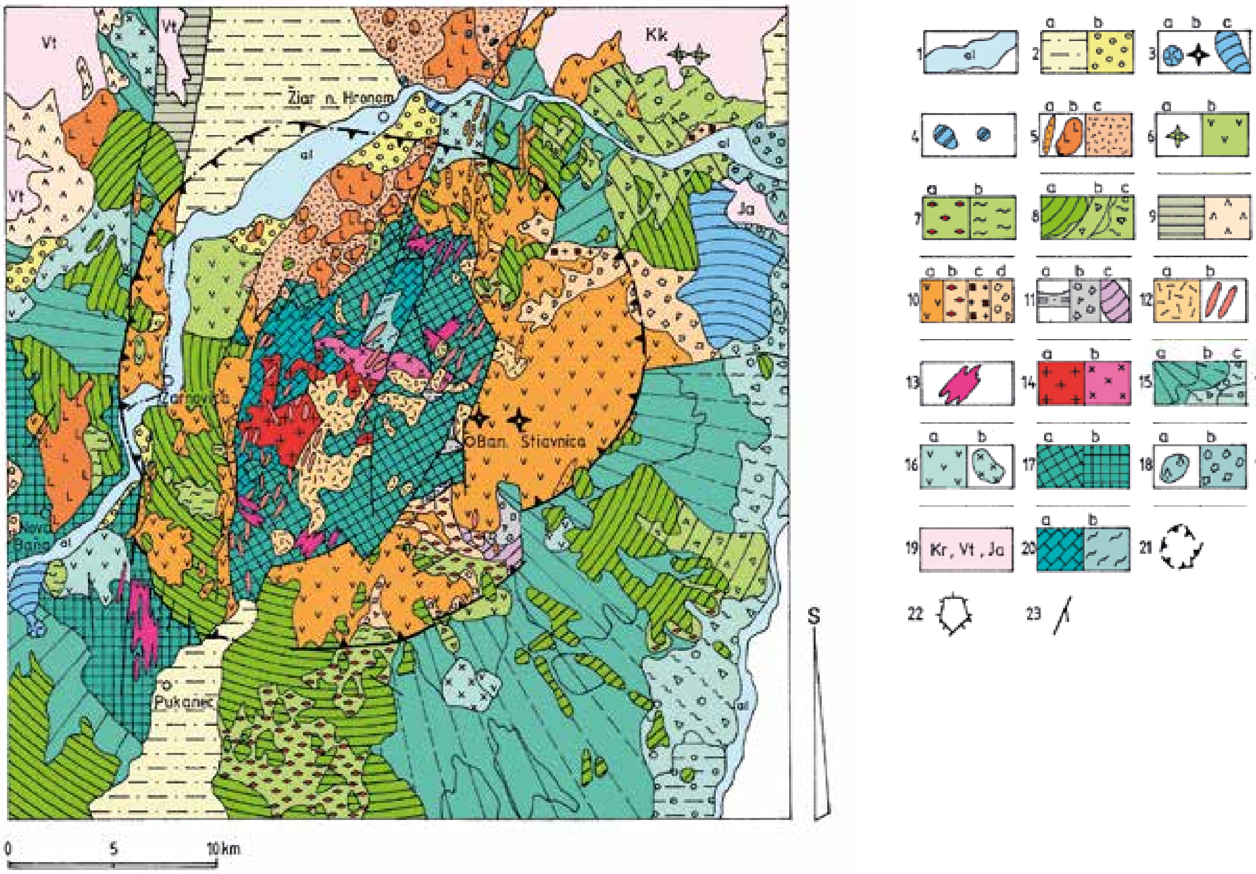


Fig. 18. Scheme of the Štiavnica Stratovolcano (J. Smolka et al., 2005).

The Quaternary:
1 – river (alluvial) sediments, gravel, lag gravel, sands – the Quaternary:
2 – a) sediments in the Žiarska Kotlina Basin and Pukanec Depression, clays, gravels, sands, b) fluvial gravels and sands of the Hron terrace, alkali basalt volcanism (Pannonian, Quaternary):
3 – a) Putikov Vŕšok scoria cone, b) lava neck, c) lava flow, basalt-andesite volcanism at the eastern edge of the Žiarska Kotlina Basin (Pannonian):
4 – lava flows, necks, dykes, bedded intrusions, pyroclastics, rhyolite volcanism (Late Sarmatian):
5 – a) dyke, b) extrusion and lava flow, c) pyroclastics,
the Štiavnica Stratovolcano:
I. Upper stratovolcanic structure
6 – a) andesite neck, b) extrusion, 7 – a) pumice tuffs, b) welded pumice tuffs – ignimbrites, 8 – stratovolcanic complex: a) lava flows, b) pyroclastic breccias and tuffs, c) epiclastic volcanic breccia conglomerates and sandstones, 9 – a) fill of the Kremnica Graben (lava flows and volcanoclastic rocks), b) extrusions of hypersthene-amphibole andesites,
II. Fill of the Štiavnica caldera
10 – products of biotite-amphibole andesite volcanism pertaining to the Studenec formation: a) lava flows, extrusions, b) pumice tuffs, c) pyroclastic flows, d) epiclastic breccias, 11 – the Červená Studňa Formation: a) sandstones and siltstones with lignite interbeds, b) coarse epiclastic breccias, c) a lava flow of biotite-amphibole-pyroxene andesite, intrusive rocks: 12 – quartz-diorite porphyry: a) bedded intrusions, b) dykes (Banisko intrusive complex), 13 – granodiorite porphyry (Zlatno intrusive complex), 14 – a) granodiorite, b) diorite (Hodruša- Štiavnica intrusive complex),
III. Bottom stratovolcanic structure
15 – stratovolcanic complex: a) mostly lava flows, b) lava flows a pyroclastics, c) epiclastic volcanic breccias and conglomerates, d) conglomerates and sandstones, 16 – stratovolcano slope area: a) andesite extrusions b) andesite to diorite porphyry intrusions, 17 – propylitised complexes (lava flows and bedded intrusions): a) the central volcanic zone in the Hodruša-Štiavnica Horst area, b) Nová Baňa – Pukanec area, 18 – products of extrusive volcanism of hypersthene-amphibolite andesite with garnet: a) extrusions, b) coarse epiclastic breccias, 19 – volcanic complexes: Kr – Kremnica Mountains, Vt – Vtáčnik Mountain, Ja – Javorie,
pre-volcanic bedrock:
20 – a) rocks of the Mesosoic age, b) crystalline complex, 21 – caldera fault, 22 – faults lining the Hodruša-Štiavnica Horst, 23 – fault.

23. Metallogenetic processes and metal deposits in the Štiavnica Stratovolcano structure

The rocks containing precious metals mined mainly during the Middle Ages supported the boom and development of Banská Štiavnica and Banská Hodruša. The current state of knowledge of the metallogenetic processes in the central zone of the Štiavnica Stratovolcano (Banská Štiavnica-Hodruša Ore Field) has been expanded by several generations of geologists. Today's knowledge of metallogeny builds mainly on the research and surveys of 1950–1995, in particular the complex research of the State Geological Institute of Dionýz Štúr (J. Štohl et al., 1990; D. Onačila et al., 1995; J. Lexa, 2000; J. Lexa, P. Konečný, 2001; P. Koděra, A. H. Rankin, A. E. Fallick, 2001; M. Háber et al., 2001) whose employees created the current metallogenic model of the Štiavnica Stratovolcano.

The vast Štiavnica Stratovolcano gave rise to major deposits of precious metals and polymetallic ores as well as different types of mineralisation. Their formation is closely related to the stratovolcano's development, mainly the formation of the subvolcanic intrusive complex and the shallow magma chamber. The andesite volcanism of the pre-caldera stage showed no mineralisation. However, the formation of the diorite intrusions is related to the creation of the Šobov hydrothermal system with minor Au deposits and polymetallic mineralisation. There are deposits and occurrences of magnetite skarns (Vyhne – Klokoč, Hodruška, Hodruša – Včelín) around the granodiorite intrusion as well as a deposit of veinlet-disseminated polymetallic ores at the Rozália Mine in Hodruša. The location of dyke swarms and stocks of granodiorite porphyry caused the formation of skarn-porphyry Cu ± Mo, Au mineralisation (Zlatno, Šementlov, Sklené Teplice – Vydričná Dolina). During the initial stage of the caldera's subsidence, hydrothermal systems, i.e., hot springs (Dekýš, Červená studňa) were formed. The Varta hydrothermal system near Banská Belá and the atypical epithermal vein gold deposit of the Rozália Mine in Hodruša also come from this period. Andesite volcanic rocks of the post-caldera stage show no mineralisation. The vast systems of polymetallic and precious metal epithermal veins (Banská Štiavnica, Banská Belá, Banky, Hodruša, Pukanec, Rudno nad Hronom, Nová Baňa) were formed in relation to the uplift of the resurgent Hodruša-Štiavnica Horst (and other horst structures) as well as the rhyolite magmatism of the post-caldera stage.

23.1. Mineralisation of the pre-caldera and caldera stages

1 – The Šobov hydrothermal system

The hydrothermal system of Šobov located north of Banská Štiavnica is the oldest manifestation of the hydrothermal processes in the central zone of the Štiavnica Stratovolcano. Its formation was caused by an intrusive diorite body and the subsequent release of magmatic gases SO_2, Cl, and CO_2, which condensed in the groundwater of the overlying andesite complex and created strong acids and H_2S. These acids reacted with the andesites and turned them into argillites (they caused ablation of Fe, Mg, Ca, Na, and K and creation of clay rocks). In the centre of this system, quartzites were formed (due to Al ablation and SiO_2 accumulation). The reaction of H_2S during which the released Fe turned into pyrite was the cause of intensive pyritisation around the margins of this hydrothermal system.

The hydrothermal system has been turned into a large quarry. The quartzite found in its central part used to be quarried in Banská Belá as well, where it was used to produce gannister bricks, i.e., fireproof linings for blast furnaces.

2 – Magnetite skarns

In the 14th to 19th centuries, magnetite skarns provided a source of ore for the important ironworks in Vyhne. Mainly the Klokoč deposit south of Vyhne was mined.

The formation of skarns was related to the large diorite intrusion. In places where magma projected into the limestone environment and dolomites of the Veľký Bok mountain series, thermal recrystallisation turned them into marble. The following interactions caused the release of magmatic solutions and the formation of skarns. The presence of Ca-Fe garnet, Ca-Fe pyroxene, wollastonite, and in the environment with dolomites also forsterite and phlogopite is typical. As the temperature decreased and the solutions mixed with the meteoric waters, magnetite, epidote, actinolite, tremolite, chlorite, and serpentinite were created. Sporadically disseminated sulphides (mainly pyrite) were created in the final stage of hydrothermal mineralisation.

3 – Skarn-porphyry Cu(Au) mineralisation – Zlatno type

The deposits and manifestations of this mineralisation are related to the dyke swarms and stocks of granodiorite porphyry pertaining to the Zlatno intrusive complex in places where intrusions penetrated limestones and dolomites. On the surface, mineralisation manifests via intensive alteration of andesites (quartz, sericite, pyrite) as well as an increased content of copper. The productive zone consists of exo- and endoskarns associated with the following minerals: garnet, diopside, wollastonite, forsterite, phlogopite, serpentinite, actinolite, tremolite, and epidote. As for the ore-bearing minerals, mainly pyrite, pyrrhotite, and chalcopyrite are present. Mineralisation consisted of two stages.

4 – Veinlet-disseminated polymetallic mineralisation

This mineralisation between the Rozália and Bakali veins was discovered during the survey in the 1970s. Its richest parts were depleted in 1990–1991.

Galenite, sphalerite, chalcopyrite, epidote, and chlorite can be found in the dense network of cracks in the granodiorite intrusion's ceiling. Less frequently, they take the form of massive ores in the remnants of the Mesozoic limestones. In the rocks overlying the mineralisation layer, there is a vast area of alteration through acid leaching (quartzites, argillites) separated by a younger sill of quartz-diorite porphyry.

This hydrothermal system formed due to the formation of the granodiorite intrusion. It released vapour and gases containing SO_2, which altered the overlying andesites that show signs of pyritisation. Subsequently, when the intrusion was cooling, a network of cracks was formed, which allowed for the circulation of meteoric waters. When they mixed with the magmatic fluids released from the crystallising granodiorite deep down, it caused the crystallisation of sulphides.

5 – Manifestations of hot spring mineralisation

These can only be found around Dekýš and Červená Studňa. Since they rose within the caldera fill, they date back to the caldera stage of the stratovolcano. The surface occurrence of opal-chalcedony flints and intensely kaolinised and pyritised rocks (sometimes with alunite) is characteristic. These transformations are the result of acid leaching due to the oxidation of H2S to sulphuric acid in the subsurface of the hot spring vents.

6 – Hydrothermal Au mineralisation

It was unexpectedly discovered on the Hodruša gold deposit in Rozália Mine during the survey of the northern continuation of the Bakali vein in 1988. Before the mine was temporarily closed in 2003, about 4 tons of gold were extracted. However, mining was later resumed and it was active as recently as 2020. Mineralisation rises within the environment of strongly disrupted and altered andesites right above the granodiorite layer. The mineralised zones are separated by younger faults and sills of quartz-diorite porphyry. Mineralisation consisted of two stages. The first stage involved silicification, sericitisation, and pyritisation of andesites. Subhorizontal barren quartz veins sometimes containing higher purity gold were created. In the second stage, striped quartz-carbonate veins with Cu, Pb and Zn sulphides and abundant lower purity gold were created. The development of mineralisation is related to the subsidence of the caldera in the centre of the Štiavnica Stratovolcano initiated by the formation of the hydrothermal system. The precipitation of gold was caused by the boiling of solutions in the lower pressure zone.

23.2. Mineralisation of the post caldera stage

Ore veins of precious metals and polymetallic epithermal ore veins

The source of thermal energy and metals was a shallow-seated intrusion or magma chamber of andesite or rhyolite magma. Escaping magmatic fluids with a temperature of 400–500 °C with increased chloride and metal contents (carried in the form of complexes with chlorine and sulphur) initially moved upwards through a network of contractive cracks, then through the ex-

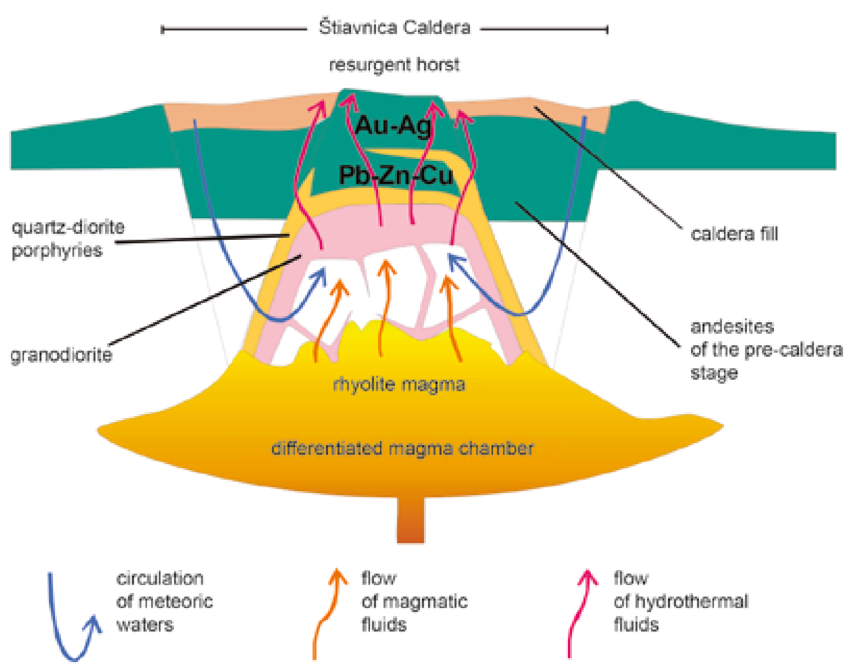


Fig. 19. Scheme of fluid flow in the central zone of the Štiavnica Stratovolcano during the period when the epithermal veins were formed (P. Koděra et al., 2005).

tensional fault structures at the upper levels. In the extensional structures, the fluids were gradually diluted by mixing with meteoric waters and their temperature dropped to 300–350 °C.

As a result of mixing and cooling, quartz, carbonates and polymetallic sulphides eventually precipitated out of the fluids, gradually forming ore veins. These take the form of **the Štiavnica type polymetallic veins** (Fig. 19).

Fluids start boiling at a depth of several hundred metres below the surface as a result of decreasing pressure as they approach the surface. Boiling is a condition for intensive precipitation of quartz, calcite, sulphides, and gold. This is how the **Hodruša type silver veins and the typical Kremnica type precious metal ores were** created. The fluid boiling zone in the hydrothermal system extends to the surface, where hot springs and geysers accompanied by intense precipitation of siliceous sinters can be found. However, they were not preserved in this case. The current erosion furrow of these hydrothermal systems is located 100–300 m below the original surface.

Based on the composition of the ore fill, ore veins are divided into polymetallic (lead, zinc, copper) and precious metal ore veins (gold, silver). The representation of economic minerals tends to be common, although in varying proportions depending on the processes of formation and the depth of deposition. Veins are deposit bodies into which mineralisation has concentrated due to the intrusion of hydrothermal solutions and

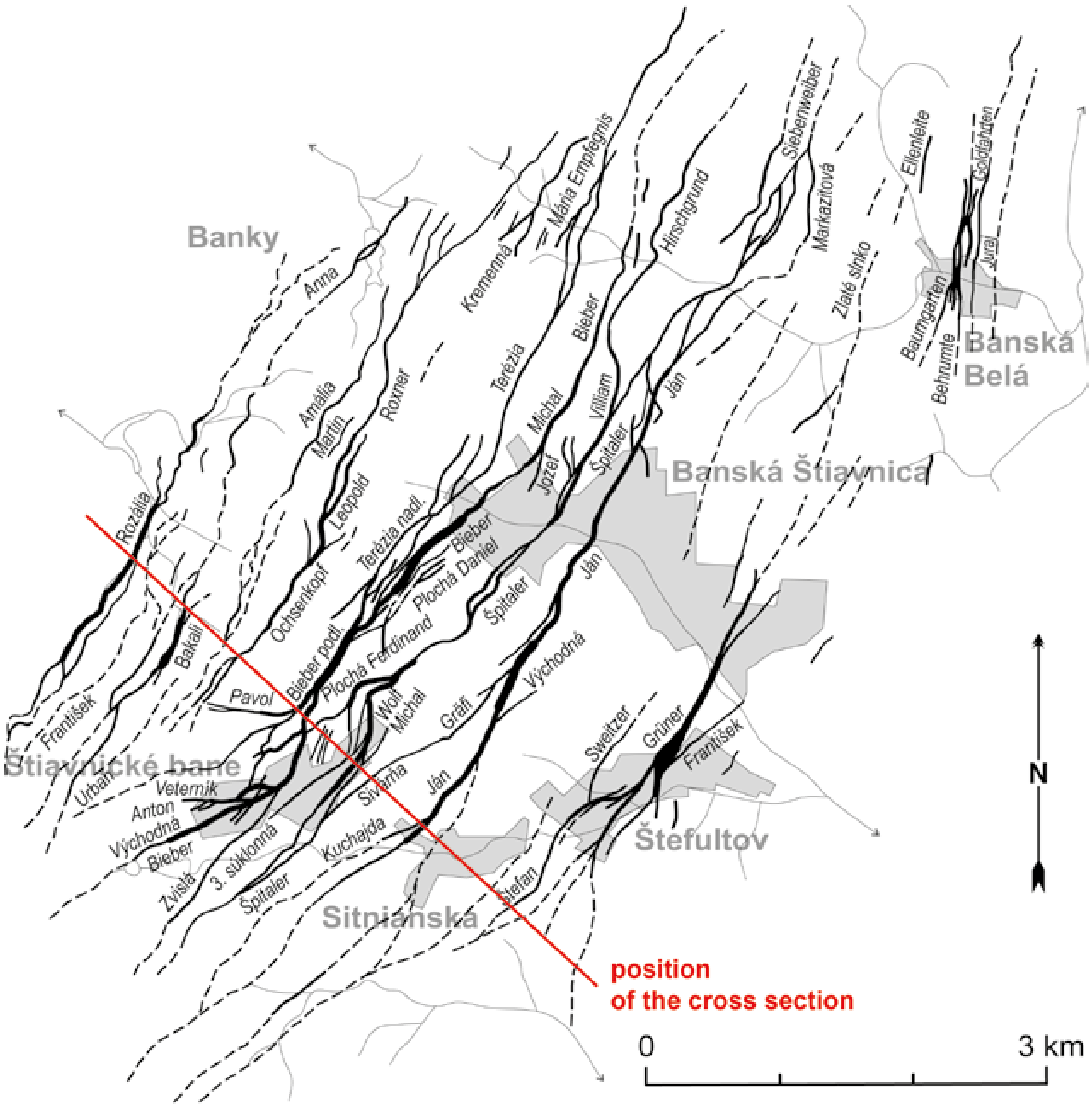


Fig. 20. Scheme of the Štiavnica type epithermal polymetallic vein system (J. Smolka, J. Lexa, 2002).

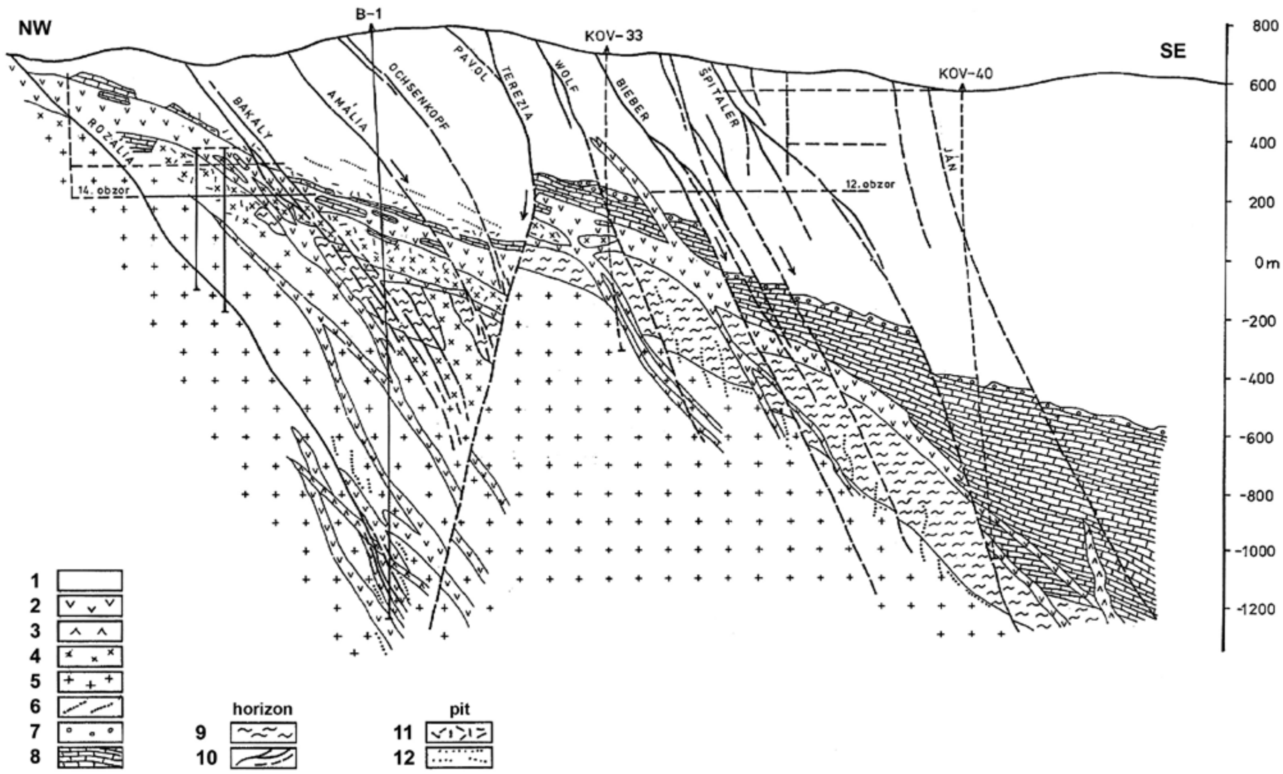


Fig. 21. Cross-section of the Štiavnica type epithermal polymetallic vein system in the area of Štiavnické Bane (J. Štohl et al.., 1990):

1 – andesites of the pre-caldera stage (stage I), 2 – quartz-diorite porphyry, 3 – granite (rhyolite) porphyry, 4 – porphyric granodiorite, 5 – even-grained granodiorite, 6 – thin aplite veins, 7 – Paleogene conglomerates, 8 – sedimentary Triassic rocks, 9 – crystalline schists, 10 – epithermal polymetallic veins, 11 – veinlet-disseminated, polymetallic mineralisation, 12 – subhorizontal polymetallic veins and veinlets.

gases from which ore (galenite, sphalerite, chalcopyrite, etc.) and non-ore minerals (quartz, calcite, etc.) may have crystallised. Veins were formed as a result of intense tectonic movements of rocks and subsequent hydrothermal and tectonic activity. Massive, but also small cracks were formed in the rocks, in which mineralisation was trapped. The composition of ore fills is very variable, depending on the variety and quantity of economic mineral components, but it varies most depending on the depth of deposition.

Most often, the veins were formed on subsidence faults and are usually inclined the east, less frequently to the west. Their inclinations vary within the interval of 30°–70°. The course of their direction reflects the north-east to south-west orientation of the Western Carpathians tectonic plane. The thickness of these veins varies from several centimetres to tens of metres. A characteristic feature of the veins are "ore columns", a vein tends to have several of them. These are the richest places with abundant ore reserves.

In the western part of the Banská Štiavnica-Hodruša Ore Field, mainly the **Hodruša type silver epithermal veins** provide ore mining potential. These include the majority of veins in this part of the ore field, the common feature of which is uniform mineralisation during the alteration of the surrounding rocks. The veins are predominantly silver while the gold to silver proportion is 1:100. Due to secondary mineralisation in the near-surface parts of the veins, extremely high contents of gold and silver have been found locally. These veins formed around the faults in the western part of the Hodruša-Štiavnica horst system, their direction is mostly north-east to south-west, and their inclination is 40°–50° to the east. In some parts of the ore field, they are combined with strike-slip veins that incline 70°–80° to the west. Due to complex tectonic movements rock, ore columns were formed. The veins are filled with compact, brecciated, and drusy quartz-carbonate ores containing pure gold and noble silver-bearing (silver sulpho-salts), but also other minerals (polybasite, pearceite, pyrargyrite, pyrostilpnite, acanthite, stephanite, wurtzite, pyrite, sphalerite, galenite, chalcopyrite). To a lesser extent, Kremnica type epithermal precious metal veins (Móderštôlňanská, Zlatá, and Trojkráľová), Štiavnica type epithermal polymetallic veins (Amália, Bakali, Rozália, and Medená) as well as other low-temperature gold-silver mineralisation of mineralogical significance, which does not form vein structures, can be found in the ore field.

In the eastern part of the Banská Štiavnica-Hodruša Ore Field, mainly the **Štiavnica type epithermal**

polymetallic veins provide ore mining potential (Figs. 20, 21).

These include the majority of veins in this part of the ore field that have undergone the same mineralisation periods, alteration of the surrounding rocks. They are predominantly polymetallic and the main minerals (chalcopyrite, galenite, sphalerite, silver sulpho-salts, and pure gold) can be found in the quartz-carbonate gangue. The zonality of this epithermal system reflects in the fact that the contents of gold and silver decrease with depth, while the content of copper increases. On the contrary, the contents of gold and silver increase in the sub-surface and marginal parts of the vein system. These veins formed around the faults in the eastern part of the Hodruša-Štiavnica horst system, their direction is mostly north-east to south-west, and their inclination is 40°–80° to the east. An exception is the Terézia strike-slip vein (and some diagonal stringers). The veins branch into stringers and branches in the bedrock and overlying rock, but ore columns and "horse-tail" type structures formed at their northern and southern ends. They occur in the environment of hydrothermally altered (propylitised) andesites, andesite and quartz-diorite porphyries, and penetrate the sedimentary bedrock at the deeper level. The research has shown that these veins have undergone 6 stages of gradual mineralisation. Although their nature varied, as a result, mostly brecciated and often cavernous fill of pre- and inter-mineralisation structures can be found. The veins are filled with compact brecciated-cavernous and drusy quartz-carbonate ores containing pure gold and noble silver-bearing ore (silver sulpho-salts), but also other ore-bearing (argentite, stephanite, polybasite, pearceite, Ag-tetrahedrite, pyrargyrite, acanthite, scheelite, haematite, matildite, pyrite, pyrrhotite, marcasite, bornite, covellite, sphalerite, galenite, chalcopyrite, and bismuth sulpho-salts) and non-ore bearing minerals (quartz, quartz with haematite needles – „sinople", quartz-amethyst, rhodonite, rhodochrosite, calcite, ankerite, dolomite, sideroplesite). This mineralisation is much deeper in comparison with the Hodruša type epithermal silver veins in the western part of this ore field. The research has shown that some veins start thinning below 100 m above the sea level. To a lesser extent, Kremnica type epithermal precious metal veins (veins Goldfahrten, Baumgarten, and Juraj in Banská Belá); metasomatic ores (galenite, sphalerite, chalcopyrite, pyrite) formed around the veins Bieber and Špitalér, and their stringers Viliam and Michal in an environment of sedimentary rocks altered by contact metamorphism under the volcanic rock. The vein structures around Pukanec, Brehy, and Rudno nad Hronom represent the eastern part of the **Pukanec-Nová Baňa Ore Field**. These are part of multiple structural zones (Agraš, Biela baňa, Zlatá studňa, Chlm, etc., Photo 3) or systems of cracks, which were formed around the Pukanec deposit along with the "parasitic" volcanic-intrusive centre in the external zone of the Štiavnica Stratovolcano. Major metallogenic activity in this area is also evidenced by other types of ore-bearing mineralisation (polymetallic, copper-porphyry). Most veins in this part of the ore field are inclined 40°–70° to the east and have numerous branches in the bedrock and overlying rock of the structural zones. They consists of quartz-carbonate, often brecciated gangue containing pure gold and silver sulpho-salts (less frequently argentite, galenite, and sphalerite).

Photo 3. Surface mining in the Chlm structural zone (© P. Pachinger).

Photo 4. The portal of the Granner-Neufang heritage adit (© P. Pachinger).

Vein structures of the Nová Baňa deposit represent the western part of the Pukanec-Nová Baňa Ore Field. Besides a number of smaller veins, the deposit consists of two main vein zones with a north-south direction, which are part of veins Jakub and Laurenz. The veins in this part of the ore field show a combined inclination of 40°–70° to the east and north, and were formed mainly in rhyolites and their tuffs, less frequently in andesites and quartz-diorite porphyries.

They consist of quartz, less frequently quartz-carbonate gangue containing pure gold bound to pyrite and arsenopyrite. Silver was bound to sulphides and sulpho-salts (argentite, polybasite, proustite, pyrargyrite, and stephanite). Secondary mineralisation zones were also part of this deposit. The veins in the deposit extend over a length of 2–2.5 km. They were traced to a depth of 240 m below the surface and 50 m below the level of the Granner-Neufang heritage adit (Photo 4).

24. History of the geological research and surveys in the Banská Štiavnica region

Thanks to the presence of precious metals, **Banská Štiavnica** assumed a leading position among European towns and cities with a mining tradition. The numerous unique inventions as well as mining and ore processing procedures invented here attracted the attention and interest of scholars across Europe. In the course of long-term and systematic research into the geological structure and composition of volcanic rocks, the foundations for the knowledge of the structure and formation of the unique Štiavnica Stratovolcano were laid here.

First stage of research

Technological advances in mining methods necessitated more rigorous investigation of the rock environment, mining-engineering, and mineralogical studies, which were summarised in monographs including sketches of the first geological maps. An important role in this process was played by the establishment of the Mining Academy in Banská Štiavnica in 1762, at which major European scientific authorities lectured at the time. Banská Štiavnica became an important research centre. The local research of igneous rocks, their origin, petrographic composition, and terminology provided answers to many questions regarding volcanological processes, thus contributing to global progress.

The knowledge of mineralogical-geological and mining engineering conditions of Banská Štiavnica and its surroundings was summarised in the works by Ch. Tr. Deliuss (1770) and the monograph by G. A. Scopoli (1776). Major researcher E. J. Esmark (1798), a leading advocate of the sedimentary origin of rocks (and member of the Neptunist school named after Neptune, the ruler of the seas), described the Hodruša-Štiavnica granodiorite as syenite-porphyry. He considered other volcanic rocks surrounding Banská Štiavnica its modifications.

In 1818, the French Academy of Sciences sent a special expedition to the Kingdom of Hungary led by F. S. Beudant. The goal was to map the local volcanic mountain ranges. The expedition was supposed to gather evidence to justify the volcanic origin of rocks advocated by the Plutonist school (named after the Greek god of fire, Pluto). In 1822, F. S. Beudant published his findings in a four-tome work titled Voyage mineralogique, geólogique en Hongrie pendant l'année 1818 I–IV along with a geological map of the Kingdom of Hungary and Transylvania at a scale of 1:1 million. He has successfully advocated the Plutonist (volcanic) origin of the Kalvária Hill basalt body near Banská Štiavnica. F. S. Beudant also described the basalt tuffs and bombs near Nová Baňa (today known as the Putikov Vŕšok Volcano). In more detail, he investigated the geological structure of the surroundings of Banská Štiavnica, which he depicted on a geological map at a scale of 1:100,000. He introduced the term "trachyte" for the volcanic rocks and also used the term "grünstein pyroxénique" for the present-day propylitised pyroxene andesite.

Establishment of the Department of Geology, Palaeontology and Mineralogy at the Mining Academy in 1840, where lectures were given by prominent scholars of the time such as S. Winkler, H. Böck, I. Vitalis and others, contributed to significant progress in the research into rocks and the geological structure of the Štiavnica Mountains.

A remarkable work on the geological conditions in the area of Banská Štiavnica, covering petrographic types of rocks, and their order of formation was created by A. David in 1829 (although his work remained unpublished).

J. Pettko described the rock types in the vicinity of Banská Štiavnica and compiled a geological map of its surroundings, which was published in 1853. Based on the placement of the volcanic rocks over Paleogene sediments containing shells of Tertiary numulites, he dated their origin to the Tertiary. He also formulated the opinion that the area of Banská Štiavnica and Kremnica once consisted of large craters surrounded by a ring of trachytes. In his extensive monograph of 1860, F. Richthofen described the volcanic rocks based on their mineralogical composition. He introduced the term "propylite" for the rocks previously referred to as "grünstein trachyte" (they were green due to hydrothermal alteration). He assumed that these rocks were formed due to mass effusion of water-rich magma. As we already know, this theory was later corrected, but the terms "propylite" and "propylitisation" invented for the rocks pertaining to the Banská Štiavnica region are now used around the world. Today, these terms are generally used to refer to rocks that have undergone hydrothermal alterations.

The second half of the 18th century was unusually fruitful in the history of geological research, when almost the entire territory of the Austro-Hungarian Empire was geologically mapped at a scale of 1:75,000. The western part of Central Slovak neovolcanic rocks (western part of the Štiavnica Mountains, Pohronský Inovec mountain range, Vtáčnik Mountain) was mapped by F. Andrian (1866). The eastern part of these neovolcanic rocks (including the eastern part of Štiavnica Mountains, Javorie, and Poľana) were mapped by K. M. Paul (1866). The southern part of these neovolcanic rocks up to Lučenec and Karanč were mapped by F. Fötterle (1866), M. Raczkiewicz (1866), and O. Hinterhuber (1866).

Further information about the geological structure in the area of Banská Hodruša and Banská Štiavnica, including a geological map was published by M. V. Lipold (1867). The work is supplemented by two geological sections compiled based on underground work.

After visiting the Banská Štiavnica region, the eminent English explorer N. J. Judd concluded that the granodiorite and diorite intrusions belonged together with the surface volcanic structure. He published his findings in the work entitled On the Ancient volcano of the district of Schemnitz of 1876.

J. Szabó, professor at the University of Budapest, and his collaborators E. Hussak, L. Czech, and S. Gezell collected and processed about 7,000 rock samples, and used microscopic analysis and microchemical staining tests to identify feldspars in their petrographic research. Their findings were published in an extensive monograph of 1885 and supplemented with a geological map of the broader Banská Štiavnica surroundings at a scale of 1:14,400. This geological map was awarded the first prize at an international congress in Bologna.

The research work was continued by Hugo von Böck, who was a full professor at the Department of Geology at the Mining Academy from 1899. He built on his predecessors' findings, made the terminology of volcanic rocks more precise, performed further chemical analysis of the rock types, and determined their order of formation. This stage of research ended when the Mining Academy was dissolved in 1918.

Second stage of research

The next stage of research began after WW1. It was organised by the experts from the joint Czecho-Slovak state who founded the Dionýz Štúr Mining Museum in Banská Štiavnica. Czech geologist F. Fiala, who was in charge of the museum, continued the petrographic investigation of volcanic rocks using modern analytical methods. He has described numerous volcanic forms, mainly those related to basalt volcanism, and presented new information about the composition of intrusive rocks identified during underground works. However, the promising geological research was interrupted by the events of WW2.

Third stage of research

After WW2, the research focused mainly on exploring the geological structure of Central Slovak neovolcanic rocks. They provided raw material and were mainly available in the Banská Štiavnica region. A research team from the Faculty of Natural Sciences at Comenius University in Bratislava led by prof. R. Lukáč (E. Krist, M. Harman, M. Šímová) carried out geological mapping in the broader area of Banská Štiavnica. Another research team from the Mining Faculty at the Technical University in Košice led by prof. J. Šalát (L. Rozložnik, F. Zábranský, 1971) researched the geological structure surrounding Nová Baňa and Hodruša while focusing on the granodiorite and diorite intrusions and their contact effect on the surrounding rocks (J. Šalát, 1955, L. Rozložník, J. Šalát et al., 1956).

The Department of Neovolcanics at SGIoDŠ in Bratislava led by prof. M. Kuthan (K. Karolus, E. Karolusová, A. Miháliková, J. Forgáč) was entrusted with the task to map the neovolcanic mountain ranges and create a geological map at the scale of 1:200,000 including explanatory notes (M. Kuthan et al., 1963). Neogene volcanism was divided into volcanism stages (3 andesite stages, 3 rhyolite stages, and the final stage of basalt volcanism) and the stratovolcanic type of the mountain range structure was determined.

The geological map at the scale of 1:200,000 provided a unified view of the geological structure of these volcanic mountain ranges. It integrated the knowledge acquired by a broad collective of researchers from universities and academies, geological surveys and research, as well as the findings of researchers pertaining to the older generation of researchers.

Fourth stage of research

The subsequent research involved mapping at more detailed scales (1:25,000 to 1:10,000) with the help of deep boreholes and geophysical works. Geological mapping at the scale of 1:25,000 was performed south of Sitno (J. Burian, 1964), in the western part Štiavnica Mountains (K. Karolus et al., 1967) and around Hodruša (L. Rozložnik, 1966).

There was a project focused on researching the structure of the deep bedrock of the neovolcanic rocks in order to identify potential raw materials (M. Kuthan, 1962). It involved geophysical works and drilling deep boreholes in the area of Central Slovak neovolcanic rocks including the Banská Štiavnica region.

In this stage, the **Geological Institute of Dionýz Štúr** assumed the leading role in the research of the Banská Štiavnica region and cooperated with experts from Comenius University in Bratislava and the Technical University in Košice. This deposit-geological research performed in the central part of the Štiavnica Mountains focused on lithology and broadening of the sedimentary basin (M. Koděra, J. Kováčik, 1968). The boreholes helped explore the structure of the pre-volcanic bedrock and bottom levels of the volcanic complex. The metallogenetic structures were evaluated as well (J. Burian et al., 1968). The research outputs included a new concept of the structure and formation of the Štiavnica Stratovolcano presented by V. Konečný (1970, 1971). The formation of the stratovolcano was divided into five stages, the caldera was defined, and the formation of the horst structure was explained. This concept represents a ground-breaking view of the formation and structure of the Štiavnica Mountains.

Petrographic and petrological evaluation of the boreholes helped identify individual types of intrusive rocks and provided more information about their relation to the volcanic structure and metallogenetic processes (A. Miháliková, V. Konečný, 1977). Hydrothermal alteration of rocks, i.e. propylitisation and alteration surrounding the veins, accompanies and indicates ore-bearing mineralisation (J. Forgáč, 1966). Some types of alterations found around shallow intrusions indicate the presence of raw materials such as argillites, alunites, and zeolitised tuffs (E. Žáková, V. Hojstričová, J. Lexa, 1995, V. Hojstričová, D. Vass, E. Žáková, 1995).

During his research in the Hodruša area, L. Rozložník used boreholes, specifically the HDŠ-3 borehole in the Zlatno location, to identify the presence of polymetallic mineralisation (L. Rozložník et al., 1970). The findings provided by this borehole initiated intensive deposit-geological research and surveys using more structural and exploration drilling. Polymetallic skarn-porphyry type mineralisation was confirmed in Zlatno (J. Burian, J. Smolka, 1982) and Šementlov locations (J. Daubner et al., 1992).

The relation between mineralisation in the Banská Štiavnica and Kremnica ore districts extending towards the Central-Carpathian lineament (horst/graben system in the western part of the neovolcanic rocks) was researched by J. Štohl (1976). He pointed out that the ore-forming processes were related to subvolcanic intrusions, specified several stages of ore-forming mineralisation, and contributed to the exploration of epithermal ore vein zonality (J. Štohl, 1960, 1962).

Systematic mapping of the surface structure at the scale of 1:25,000 allowed for the creation of geological maps of Uhliská, Banská Štiavnica, and Prenčov (V. Konečný, J. Šefara, L. Zbořil, 1973, V. Konečný, 1977). They were used to create a geological map of the Central Slovak neovolcanic rocks at the scale of 1:100,000 (V. Konečný, J. Lexa, 1979, V. Konečný, J. Lexa, E. Planderová, 1983). Instead of volcanic stages, volcanic rocks were divided into formations and complexes, and their positions were evidenced by biostratigraphic data and radiometric dating.

The following deposit-geological research of the Štiavnica Stratovolcano's central part (J. Štohl, 1955) allowed for the creation of a geochemical model of the skarn-porphyry mineralisation and its prognostic evaluation (K. Marsina et al., 1993, 1995). The central part of the Štiavnica Mountains were geologically mapped at the scale of 1:10,000 (V. Konečný, J. Lexa, J. Hók, 1993), which included the area of the Hodruša-Štiavnica Horst and the adjacent caldera parts. This map allowed for the creation of a metallogenetic model and prognostic evaluation of the raw materials in the central part of the Štiavnica Stratovolcano. (J. Štohl et al., 1990, D. Onačila et al., 1994, 1995, J. Lexa et al., 1997).

After systematic mapping of the whole Štiavnica Mountains including the southern slopes and Pohronský Inovec mountain range at the scale of 1:25,000 was completed, a regional geological map of the Štiavnica Mountains at the scale of 1:50,000 including explanatory notes was created (V. Konečný et al., 1998 a) It was supplemented by geological sections, which summarise the knowledge of the geological structure, lithology, stratigraphy, tectonics, and raw materials. This work represents the most recent synthesis of the knowledge about the Štiavnica Stratovolcano, which confirmed the caldera structure as well as the resurgent horst.

Geologický prieskum Spišská Nová Ves (national enterprise) began its activity in the Banská Štiavnica region with a prospecting survey focused on the vein structures (S. Polák, 1955) and the Klokoč magnetite deposit (S. Gavora, 1961 to 1969). Metasomatic ores (J. Klubert et al., 1970) and the northern part of the Banská Štiavnica ore field were surveyed (P. Moško, 1983) using deep boreholes aimed at finding raw materials (J. Klubert et al., 1976) At the same time, polymetallic ore veins were investigated in the broader surroundings of Hodruša, i.e., the veins Bakali and Rozália (J. Klubert et al., 1973, S. Gavora et al., 1983), and Ján Benedikti (J. Slovák et al., 1992). A hydrogeological survey of the central part of the Štiavnica Stratovolcano was performed as well (M. Lukaj et al., 1983).

In the 1980s, the Banská Štiavnica deposit was investigated for in-depth continuation of the ore veins (J. Smolka, J Daubner, 1992, K. Petr et al., 1992) as well as the direction of their course (M. Schmidt et al., 1994).

Au-Ag ores were searched for around Banky (J. Šály et al., 1993), at the sub-surface levels of the Terézia vein (J. Smolka et al., 1993), and in the newly discovered vein named Svätozár, and in the mining area of Rozália vein in Hodruša (J. Šály, M. Kámen, 1992, J. Šály et al., 1993). The prognostic evaluation of the raw material sources was performed by J. Smolka et al. (1993), while the geological evaluation of the new drainage gallery was performed by P. Moško et al. (1990) and J. Smolka et al. (1994).

In 1960 to 1970, the **Faculty of Mining, Ecology, Management, and Geotechnology at the Technical University in Košice** participated in the basic research of raw material deposits organised by SGIoDŠ. It addressed specific problems related to the geological structure, metallogeny, and alteration processes in the Hodruša-Vyhne-Zlatno area (L. Rozložník, 1966, 1968, 1969, L. Rozložník, F. Zábranský, 1971, L. Rozložník et al., 1970, 1991, K. Jakabská, G. M. Tirnčák, 1987, K. Jakabská, 1992). Their research findings contributed to the discovery of the skarn-porphyry mineralisation in the Zlatno area as well as to the knowledge of contact metasomatism between intrusions and the surrounding rocks.

The Faculty of Geology and Geography at Comenius University in Bratislava contributed to the exploration of metallogeny processes mainly thanks to the works by prof. M. Koděra (M. Koděra, 1963, 1965, M. Koděra, J. Michalenko, J. Pastor, 1966, M. Koděra, J. Kováčik, 1968, M. Koděra, F. Mrákava, 1968). Petrographic knowledge was also acquired (E. Krist, 1969, E. Krist, J. Burian, 1971) along with the information about post-volcanic mineralisation (J. Miškovic, V. Miškovicová, 1977), and non-traditional sources of Au mineralisation (V. Oružinský, L. Sombathy, 1986).

Geofyzika Brno, branch Bratislava (national enterprise) also significantly contributed to the knowledge of the geological structure of the bedrock below the neovolcanic rocks and volcanic complexes. This research included areal gravimetric mapping (J. Šefara, 1986), aeromagnetic measuring (K. Šalanský, 1970), and later more detailed aeromagnetic and aerogammaspectrometric measuring (T. Gnojek, F. Janák, 1986). The hydrothermal alteration zones were identified as the last. In the 1980s, a more-detail and complex geophysical research was performed in the broader surroundings of the Banská Štiavnica-Hodruša Ore Field. Geoelectric and magnetic profile survey using probes followed (M. Filo et al., 1990, 1997, A. Panáček et al., 1991).

Rudné bane Banská Bystrica, branch Banská Štiavnica (national enterprise) focused mainly on the reserves in the mined deposits. They performed basic reserve calculations for the Banská Štiavnica (J. Michalenko, J. Pástor, 1965, R. Gazdík et al., 1986), and Hodruša deposits (S. Harazím, 1955, J. Štohl, 1955, F. Mrákava, 1967, L. Sombathy et al., 1986, J. Michalenko, J. Mitáček, 1987).

Slovenská banská spoločnosť, s. r. o., Hodruša-Hámre (private company) carried out an extensive survey (1994–2000) in the newly discovered deposit of Au-Ag ores in the Svätozár veins, which were already being mined. This work significantly contributed to the knowledge about the new type of mineralisation (J. Šály, 1994, J. Šály, M. Veselý, 1997, J. Prcúch, 1997).

The Institute of Geology, Slovak Academy of Sciences, branch Banská Bystrica addressed specific problems related to Au-Ag and polymetallic mineralisation in the Banská Štiavnica and Hodruša deposits from 1985. It cooperated with foreign experts and used specialised instrumentation. In 1987, the Terézia vein was processed and in 1991, the physical-chemical model of the formation of the local Au-Ag and polymetallic mineralisation was presented. It covered the whole Banská Štiavnica deposit (V. A. Kovalenker et al., 1991). Similar important mineralogical research was carried out in the Hodruša area on the veins Svätozár and Rozália (Ľ. Maťo et al., 1996).

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