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Neogene volcanics of the Burda mountain range nearby Štúrovo, Slovakia

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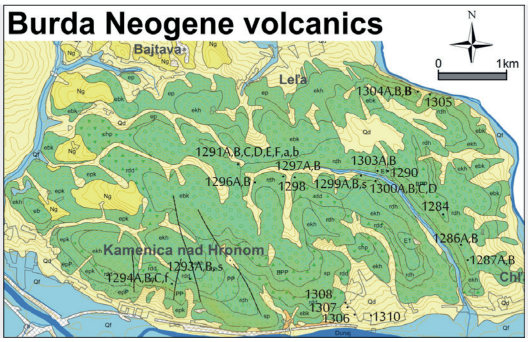
Abstract: The Neogene volcanic products of the Burda mountain range nearby Štúrovo belong to Burda Formation. At the base of the Burda Formation a succession of epiclastic volcanic rocks and pyroclastic rocks of andesites has developed. In the central part of the formation, the volcanic products associated with the activity of submarine volcanism of the Badenian age developed. Submarine extrusive volcanic domes of andesites are typical. In the upper part of the Burda Formation, pyroclastic and epiclastic facies of andesites were formed. Deposits of pyroclastic flows and redeposited pyroclastics are characterized by the presence of relics of petrified tree trunks, indicating transport from emergent forest-covered slopes from the higher levels of the volcanic edifice of the Börzsöny Mountains in today's Hungary. This part of the Burda volcanics represents a transitional volcanic zone with the Börzsöny stratovolcano.

Key words: volcanics, pyroclastic rocks, epiclastic rocks, andesite extrusive dome, Burda Formation

Graphical abstract



Highlights

- Article presents a new map of Neogene volcanic products in Burda volcanic mountain range, neighbouring with Börzsöny and Visegrád volcanic mountains;
- Detail field study has contributed to compiling of new lithostratigraphy of volcanic products included into new lithostratigraphic column;
- Petrified tree trunks in pyroclastic flows indicate transport from higher levels of the volcanic edifice of Börzsöny stratovolcano.

Introduction

The Burda volcanic mountain range (Mts) near Štúrovo is the smallest geomorphological volcanic group in Slovakia. It is located in southwestern Slovakia, at the state border with Hungary. Westward Burda Mts border with the Danube Upland. The southern border is formed by the bed of the Danube river, which in the Vyšehrad (Visegrád) Gate separates Burda Mts from the Hungarian Pilis Mts. The eastern border is formed by the Ipeľ river bed, which separates Burda Mts from Hungarian Börzsöny Mts. The northwestern part of the mountain range is bounded by the Bajtava Gate. The maximum length of the mountain range is 7.5 km and the maximum width is only 3.5 km. Its highest peak is Plešivec 395 m a.s.l. in the central part of the Burda Mts. Volcanic rocks of the Burda Mts are encompassed to Burda Formation (Bezák et al., 2009). The products of the Burda Formation occur within the Burda peat block. The heather block is tilted to the northwest. The flow of the Danube follows the east-west direction of the fault zone at the southern edge of the lowland. The rocks of Burda Formation of Badenian age pass W- to NW-ward to contemporary Bajtava Formation. The assemblage contains a rich marine fauna of the Dagenid zone and the nannoplankton community of the NN-5 zone, corresponding to the Lower Badenian (Nagy et al., 1998). The uranium (Fe) fission track method (Repčok, 1978) revealed 15.7 ± 1.4 Ma age of andesite fragment near Kamenica nad Hronom and K/Ar method 15.2 ± 1.2 Ma age of andesite body (Vass et al., 1979).

Methods

The volcanic rocks of the Burda Mts near Štúrovo were mapped by modern methods of volcanological analysis applying the Garmin GPS map St 62 device, recording the graphic, audio and photographic field documentation diary into the Samsung Galaxy N9 device. The field documentation consisted of more than 150 points, applying the LocusPro program, which enabled us to perform accurate online mapping of volcanic products with digital geolocation. We took 43 samples (Fig. 1) for further detailed research in the ŠGÚDŠ laboratories in Bratislava, encompassing volcanic, lithological, petrographic, mineralogical and geochemical analyses (samples Nos. 1284, 1296A, B, 1287A, B, 1290, 1291A, B, C, D, E, Fa, b, 1293A, B, s, 1294A, B, C, f, 1296A, B, 1297A, B, 1298, 1299A, B, s, 1300A, B, C, D, 1303A, B, 1304B, 1305, 1306,1307, 1308, 1310). Thin sections of the samples were studied by the JENAPOL optical microscope and photographic documentation of the samples was done by the Olympus Camedia C5060 digital camera in the ŠGÚDŠ in Bratislava. Rock-forming minerals were analyzed by CAMECA SX 100 electron-probe microanalyzer (EPMA) in the ŠGÚDŠ laboratory in Bratislava using 15 kV accelerating voltage, 20 nA beam current and predominantly 5 μm beam diameter. Analyzed elements, their measured spectral lines and used standards: Si Kα – wollastonite, orthoclase; Ti Kα – TiO_2; Al Kα – Al_2O_3; Cr Kα – Cr; Fe Kα – fayalite; Mg Kα – rhodonite; Mg Kα – forsterite, MgO; Ca Kα – wollastonite; Ni Kα – Ni; Sr Lα – $SrTiO_3$; Ba Lα– barite; Na Kα – albite; K Kα – orthoclase, F Kα – CaF_2, Cl Kα – NaCl. Whole-rock major and trace element compositions were obtained in the ŠGÚDŠ Geoanalytical laboratories in Spišská Nová Ves (samples 1291A, 1291B, 1293S, 1294F, 1299S, 1304B).

Characteristics of the volcanic rocks of the Burda Mts

Volcanics of the Burda Mts are represented by the Burda Formation (Fig. 2). At the base of formation, a succession of andesite epiclastics and pyroclastics are developed. Rocks in the central part of the formation are products of Badenian submarine volcanism. Submarine andesite extrusive domes are typical, having elliptical to isometric cross-sections with size of up to 220 m. They consist of massive andesite with an irregular blocky separation with a transition to brecciated andesite and up to breccia with a chaotic orientation of fragments. As a result of gradual destruction of these volcanic domes, debris-like material was formed and deposited even outside of its volcanic center further into space by mass breccia flows, debris flows and deposition of coarse to blocky breccias. In upper part of the Burda Fm, facies of pyroclastics and epiclastics of andesites were formed. Deposits of pyroclastic flows and lahars are characterized by the presence of relics of petrified tree trunks, indicating transport from the emergent forest-covered slopes of the higher levels of the Börzsöny volcanic edifice located in nowadays Hungary. These parts of the Burda volcanics represent the transitional volcanic zone of the Börzsöny stratovolcano.

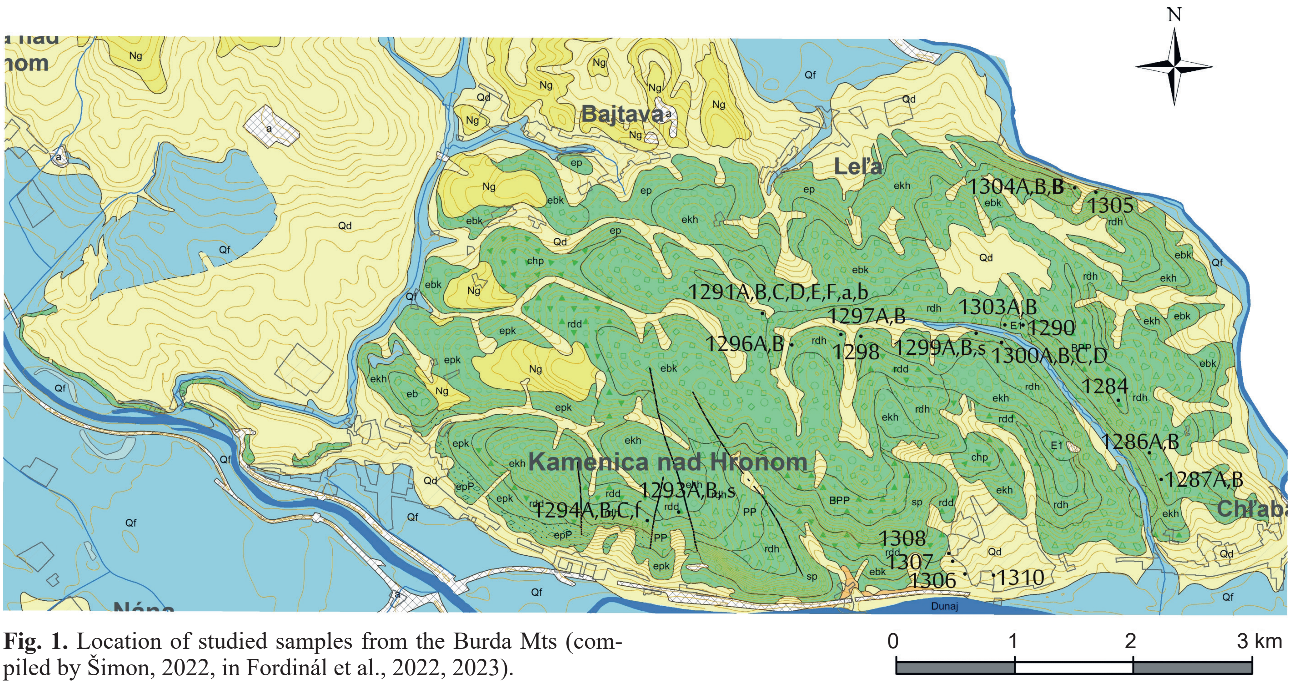


Fig. 1. Location of studied samples from the Burda Mts (compiled by Šimon, 2022, in Fordinál et al., 2022, 2023).

At the base of Burda Fm, a succession of andesite epiclastics and pyroclastics is developed. Upwards there occurs a succession of facies of epiclastics, pyroclastics and products of submarine extrusive domes. The Burda Fm is made up of following facies: epiclastic and pyroclastic horizons, epiclastic volcanic sandstones with pumice, epiclastic volcanic sandstones and conglomerates, epiclastic volcanic sandstones, fine-grained epiclastic volcanic conglomerates, coarse-grained epiclastic volcanic conglomerates, epiclastic volcanic breccias and conglomerates, epiclastic volcanic breccias, fine- and coarse-grained redeposited pyroclastics, block ash pyroclastic flows, subaqueous breccia flows, chaotic breccias of redeposited pyroclastics, extrusive breccias of am-

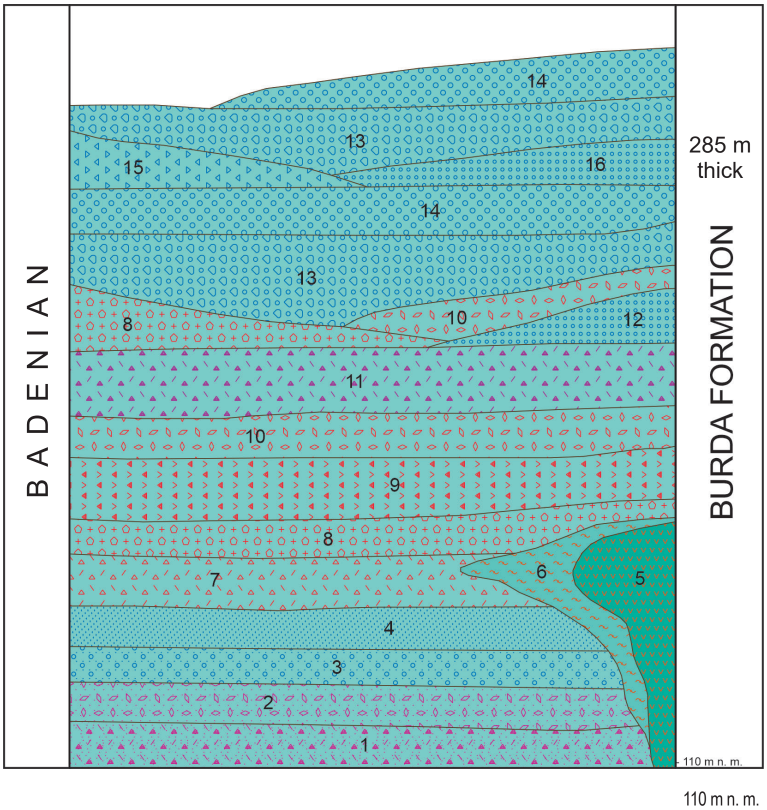


Fig. 2. Lithostratigraphic table of the Burda Formation (compiled by Šimon, 2023): 1 – epiclastic and pyroclastic horizon; 2 – epiclastic volcanic sandstones with pumice; 3 – epiclastic volcanic sandstones and conglomerates; 4 – epiclastic volcanic sandstones; 5 – extrusive domes of amphibole-pyroxene andesites; 6 – extrusive breccias of amphibole-pyroxene andesite domes; 7 – subaquatic breccia flows; 8 – block-ash pyroclastic flows; 9 – chaotic breccias of redeposited pyroclastics; 10 – ash-pumice streams; 11 – redeposited coarse-grained pyroclastics; 12 – redeposited fine-grained pyroclastics; 13 – epiclastic volcanic breccias and conglomerates; 14 – epiclastic coarse-grained volcanic conglomerates; 15 – epiclastic volcanic breccias; 16 – epiclastic fine-grained volcanic conglomerates.

phibole-pyroxene andesite domes and extrusive domes of andesites. The horizon of epiclastics and pyroclastics (Fig. 3A, B, C) represents a succession of volcanoclastic rocks of volcanosedimentary origin with rare positions of autochthonous pyroclastic rocks. This material was accumulated in the intervolcanic period, and partly also in the syneruptive period, when pyroclastic flows and pumice tuffs were formed. Intervolcanic period is represented by positions of epiclastic volcanic breccias, conglomerates, sandstones, but also occasional flows, rapid flushes (hyperconcentrated currents), lahars and mudflows, debris flows and debris avalanches. These epiclastic lithofacies occur in the transitional to marginal volcanic zone. From the petrographic point of view, the volcaniclastic material consists mainly of andesites, but pyroxene andesites are also present, and we have also rarely observed rocks of non-volcanic material and relics of a petrified wood from the original Badenian forest vegetation. Epiclastic volcanic sandstones of andesites are characterized by the presence of autochthonous light porous pumice of angular to spherical shape. Epiclastic volcanic sandstones occur mainly in the lower and marginal parts of the Burda Fm near Kamenica nad Hronom, where epiclastic volcanic conglomerates are deposited in their immediate vicinity. Epiclastic volcanic sandstones are predominantly coarse-grained, fairly well sorted, and occasionally show signs of stratification. There are also small or minor andesite sheets or lenticular positions of fine-grained epiclastic volcanic conglomerates with isolated blocks of andesites. Light porous pumice can be observed, intergrowing into individual beds. The material of epiclastic volcanic sandstones is represented by andesites of dark grey, grey and reddish brown colors, which was proved petrographically. Porous pumice stone, predominantly light grey in colour, has an acidic dacite composition. Epiclastic volcanic sandstones with conglomerates of amphibole-pyroxene andesites occur together with sandstones especially in the marginal parts of the Burda Fm near Kamenica nad Hronom municipality.

Epiclastic volcanic conglomerates consist of small fragments of dark brown, dark or light grey oval or perfectly oval shaped andesites. Epiclastic volcanic sandstones are coarse-grained with fragments of light-coloured andesites that alternate with each other in irregular and occasionally lenticular positions of relatively well sorted conglomerates and sandstones of andesite clasts. Epiclastic volcanic sandstones of andesites occur mainly in the lower and marginal parts of the Burda Fm in the vicinity of Kamenica nad Hronom, Bajtava and Leľa. Epiclastic volcanic sandstones are predominantly coarse-grained, moderately to well sorted and occasionally quite well laminated. Very rarely, andesite sheets and fragments are present, which can form simple thread-like beds of small epiclastic volcanic conglomerates in epiclastic volcanic sandstones. Epiclastic volcanic sandstones consist of dark and light grey, as well as dark brown andesites. Small epiclastic volcanic conglomerates of andesites appear mainly in the upper and marginal parts of the volcaniclastic complex of the Burda Fm in the vicinity of the Chľaba site in Veľká dolina valley. Epiclastic volcanic conglomerates of andesites form positions up to 25 meters thick (Fig. 3D).

Epiclastic volcanic conglomerates (Fig. 3E) contain andesite fragments having up to 35 cm in size, but also andesite sheets up to 50 cm in size are rarely present.

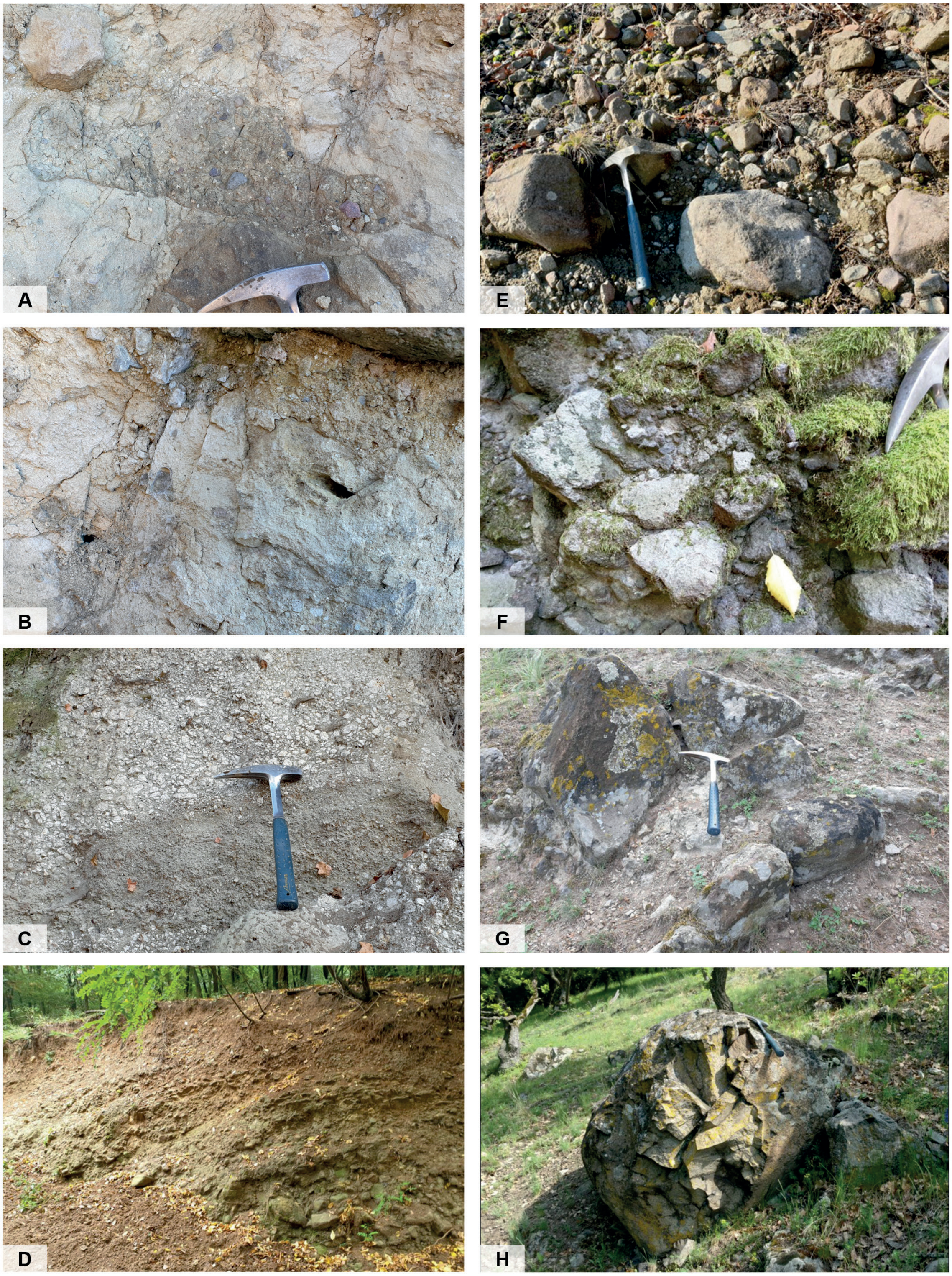


Fig. 3. Morphostructures of volcanogenic rocks in the Burda Mts. A – Submarine debris avalanche. In the rubble avalanche, there is a bounded layer of autochthonous pyroclastics (above the hammer), which was torn down, deformed and transported after a sudden volcanic collapse; B – Submarine debris avalanche. Holes are after petrified wood in the debris avalanche. A–B – Kamenica nad Hronom locality; C – Alternation of submarine pumice and ash flows, Nad Hrdličkou locality; D – Epiclastic volcanic small-boulder conglomerates, Leliansky les locality; E – Epiclastic volcanic boulder-type conglomerates. Čierna hora locality; F – Epiclastic volcanic breccias, Leliansky les locality; G – Breccias of redeposited pyroclastics, Kráľova hora locality; H – Megablock of andesite in breccias of redeposited pyroclastics, Skalka locality.

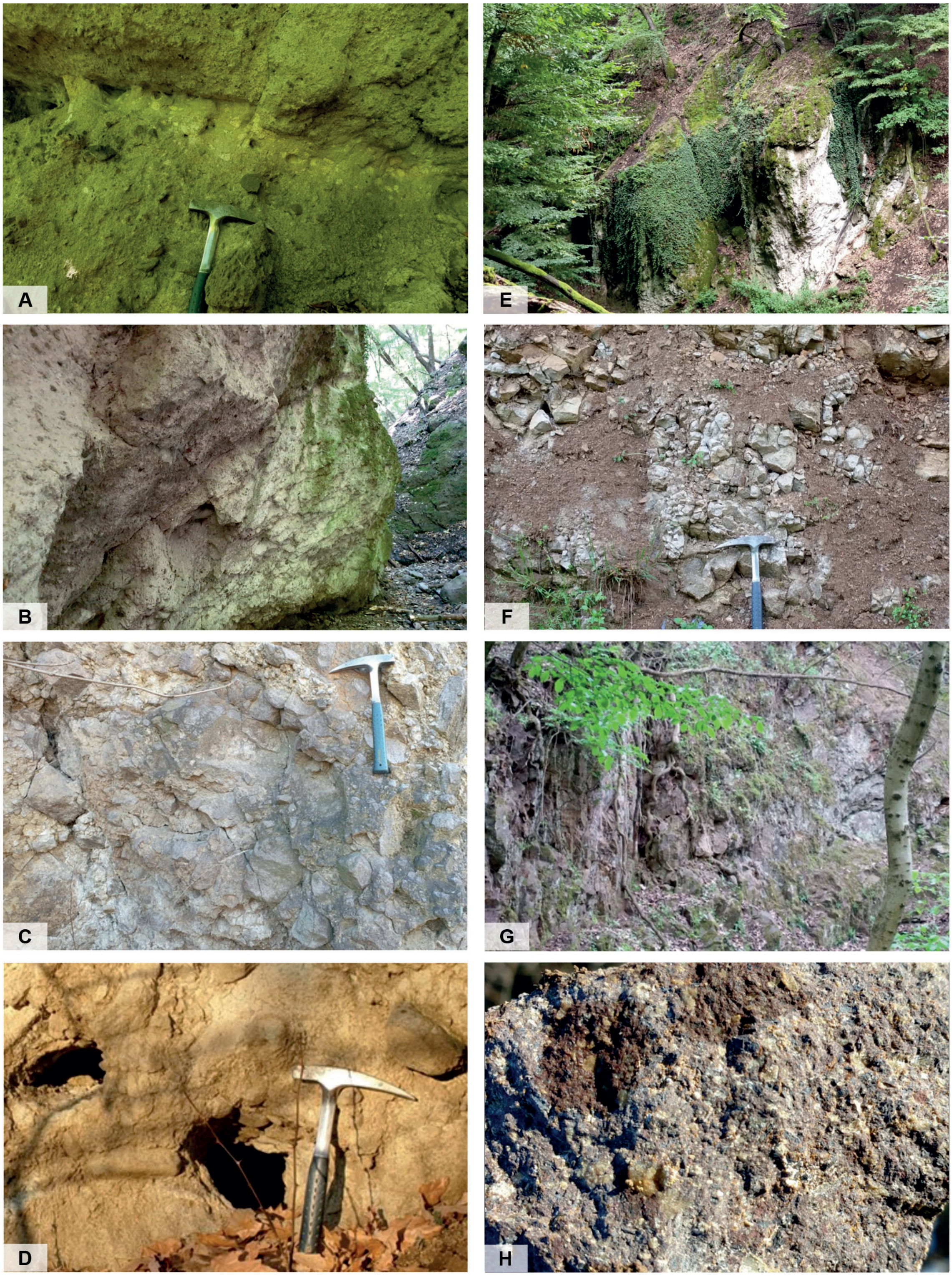


Fig. 4. Morphostructures of volcanogenic rocks in the Burda Mts. A – Block-ash pyroclastic flows, Burdov locality; B – Submarine breccia flows, Kováčov locality; C – Chaotic breccia of deposits of submarine breccia currents, Nosta, Burda locality; D – Holes after petrified trees in volcanic clastics, Višnové locality; E – Pumice pyroclastic flow, Ipeľské prielohy locality; F – Tuff beds, Pod horou locality; G – Andesite of vertical detachment from an extrusive dome, Chľaba locality (near Ipeľ river); H – Fragment of coarse-grained amphibole-pyroxene andesite with brownish-grey garnet affected by weak argillization and silicification, Čierny vrch locality.

The andesites have a suboval to perfectly oval shape. They are dark- and light-grey, grey, dark brown in colour. Beds of epiclastic volcanic conglomerates are poorly or moderately well sorted. Observed was inconspicuous or moderate layering. In some locations, the ungradedness of the andesite beds can be observed within thick bench-like beds, representing the deposits of debris flows. The matrix in epiclastic volcanic conglomerates is medium to coarse-grained sandy, light grey or greenish grey in colour. Epiclastic volcanic conglomerates consist of andesites, but sometimes amphibole-pyroxene andesites with garnet are also present. Coarse-grained to blocky epiclastic volcanic conglomerates of andesites occur mainly in the upper part of the Burda Fm in the vicinity of Kamenica nad Hronom, Bajtava, Leľa and Chľaba localities. Epiclastic volcanic conglomerates form beds up to 20 m thick. They form successions with interbeds of fine-grained epiclastic volcanic conglomerates and epiclastic volcanic sandstones. The size of the andesite fragments is on average up to 55 cm. Positions of conglomerates, containing andesite boulders up to 95 cm in size, also rarely appear. The conglomerate matrix is medium to coarse sandy. In the matrix there are beds of andesites with a solid texture, but sometimes also with a porous texture, dark grey, grey, dark brown or reddish in colour.

Epiclastic volcanic breccias to conglomerates of amphibole-pyroxene andesites (Fig. 3F) occur in the middle and upper part of the Burda Fm in the vicinity of the Leľa, Bajtava and Chľaba localities. They form beds thick up to 15 m. Within the beds, the fragments and sheets of andesites with a diameter of 1 to 25 cm occur. Rarely, there occur also interbeds of coarser or finer epiclastic volcanic breccias and epiclastic volcanic conglomerates, which are poorly sorted and partly layered. Their matrix is unsorted, medium to coarse sandy with small fragments of andesites. Fragments of amphibole-pyroxene andesites have subangular or even oval shape. Andesites have a cohesive and porous texture and are from dark- to light-grey, brown, or reddish-brown in colour. Epiclastic volcanic breccias of amphibole-pyroxene andesites occur in the middle part of the Burda Fm in the vicinity of Kamenica nad Hronom and Leliansky les localities (Fig. 3F).

Epiclastic volcanic breccias form beds up to 20 m thick. Fragments of andesites up to 75 cm in size are present in epiclastic volcanic breccias. Andesites are mostly angular and subangular in shape, but occasionally suboval andesites are also present. Andesites are grey, dark grey, brown or brown-red in colour. Epiclastic volcanic breccias are poorly sorted and poorly bedded. The matrix in them is unsorted, coarsely sandy with small fragments of integral grey andesites. Petrographic study confirms andesite composition of epiclastic volcanic breccias. Small redeposited pyroclastics (Fig. 3G) appear in the complex of volcanic clastics of the Burda Fm in the vicinity of the Chľaba, Bajtava and Kamenica nad Hronom localities.

Redeposited pyroclastics create positions up to 15 m thick, being formed by dark grey or brownish angular and subangular fragments of andesites up to 20 cm in size. The matrix is sandy-tuffitic and unsorted with small fragments of petrographically proved andesites. Coarse-grained redeposited pyroclastics occur in the volcaniclastic complex of the Burda Fm in the vicinity of the Chľaba, Leľa and Kováčov localities, where they form positions up to 20 m thick. They are formed by fragments of andesites up to 60 cm in size, but megablocks up to 200 cm in size are sporadically present, too (Fig. 3H).

Fragments of andesites have an angular and subangular shape and their colour is dark grey or brownish. The matrix is sandy-tuffitic and unsorted with small fragments of petrographically proved andesites. Block-ash pyroclastic flows (Fig. 4A) of andesites emerge in the upper part of the Burda Fm around the Kováčov and Chľaba localities. Block-ash pyroclastic flows create positions up to 20 m thick, consisting of chaotic breccias, which are formed by angular and spherical fragments of andesites of size up to 60 cm in the amount of up to 60 %. Fragments of andesites have a porous texture and some have the character of annealed lighter fragments that were deposited in an unsorted, poorly sintered detrital matrix. The matrix consist of tuff and contains light pumice.

Submarine breccia flows (Fig. 4B, C) of andesites emerge in the middle part of the Burda Fm around the Kováčov locality. Subaqueous breccia currents create positions up to 50 m thick. They are formed by coarse chaotic breccias that associate with the source extrusive bodies.

Chaotic breccias contain fragments of andesites ranging in size from 1 cm to 200 cm. Their colour is dark grey, having an integral texture and angular shape. Brownish colour andesites with porous texture, angular and spherical shape are also present (Fig. 4D). Fragments of andesites are stored in a matrix, representing up to 70 % of rock material. The matrix is ungraded tuff with small clasts of andesites. The occasional redness of the matrix can be observed with a higher degree of homogenization and compaction. From a petrographic point of view, subaqueous breccia flows are formed by porphyritic andesites. Chaotic breccias of redeposited pyroclastics occur in the upper part of the Burda Fm in the vicinity of the Kováčov locality. Chaotic and unsorted breccias of redeposited pyroclastics are up to 25 m thick, they are slightly strengthened by matrix alteration. They are formed of fragments of andesites of dark grey, brown and reddish colours, solid or porous texture. Fragments have an angular and subangular shape. The size of andesite fragments is up to 100 cm, and there are rare fragments up to 150 cm in size. Fragments are stored in a matrix with a content of up to 50 %. The matrix is tuff-sandy with small fragments of grey andesites and light pumice. Holes after petrified trees are occasionally observed (Fig. 4D).

The pumice pyroclastic flow (Fig. 4E) of andesites forms a more continuous horizon of tuffs (Fig. 4F), which are mostly unsorted, chaotic, indistinctly layered in a bench-like form in the lower part of the Burda Fm in the vicinity of the Chľaba and Kováčov localities.

Within the beds, the matrix is predominant, which is tuff, it also contains grey-white pumice, and various fragments of petrographically proved andesites of angular and spherical shape, porous and glassy texture and dark grey to black-grey colors are also present. Sometimes we also record fragments of non-volcanic material in the tuffs. Intrusive-extrusive breccias of amphibole-pyroxene andesites occur in the lower part of the Burda Fm in the vicinity of the Kováčov and Chľaba localities. Breccias represent marginal parts of intrusive-extrusive bodies. On the one hand, they are connected by a transition to their own body, on the other hand, they eventually pass into the breccias of subaqueous breccia flows. The brecciation zones are up to tens of meters thick. Extrusive breccias appear in facies with massive solid texture andesites of a light grey colour with facies built of angular fragments of grey non-porous andesite in a crushed lava matrix. Extrusive breccias are unsorted, chaotic, with a maximum fragment size of up to 100 cm. Fragments of andesites in extrusive breccias are present in amounts up to 80 %. Occasionally there occur weakly oxidized red-brown andesite and spherical fragments of brown andesite both with porous texture. The matrix is formed by crushed andesites of light grey colour and porous texture, being petrographically proved. Extrusive domes of andesites in the lower part of the Burda Fm occur in the vicinity of the Kováčov and Chľaba localities (near Ipli) (Fig. 4G, H). Extrusive domes are isometric shape, occasionally slightly elliptical bodies with dimensions up to 200 m, formed of massive andesite with vertical, blocky and roughly blocky separation. Indistinct fluid textures were observed in the bodies. The textures have a typical vertical to fan-like course. Zones of extrusive breccias developed at the edges of extrusive domes. The bodies are made of light grey to greenish porphyritic andesite with phenocrysts of plagioclase, hypersthene, augite and amphibole in the ground mass, which is microlithic in the middle part of the bodies and microlithic to microlithic-hyalopilitic at the edges of the bodies.

Geochemistry of volcanic rocks of the Burda Formation

These rocks were analysed for whole-rock major and trace element contents: 1291A, B – amphibolic andesite with biotite and orthopyroxene, 1293S – biotitic-amphibolic andesite with orthopyroxene, 1294F – biotitic-amphibolic andesite with orthopyroxene, 1299S – biotitic-amphibolic andesite with orthopyroxene, 1304B – amphibolic andesite with biotite and orthopyroxene. According to the classification TAS diagram (Le Bas et al., 1986; Fig. 5), the analysed samples represent andesite and the sample 1291A corresponds to dacite. Samples 1291B, 1293S, 1299S and 1304B have a relatively similar composition. Sample 1294F can be considered as acid andesite. All andesites correspond to high-potassium andesite and belong to the high-potassium calc-alkaline series (high-K CA) according to the diagram of SiO_2 vs. K_2O (Peccerrillo & Taylor, 1976; Fig. 6). The trace element contents of the studied rocks can be presented

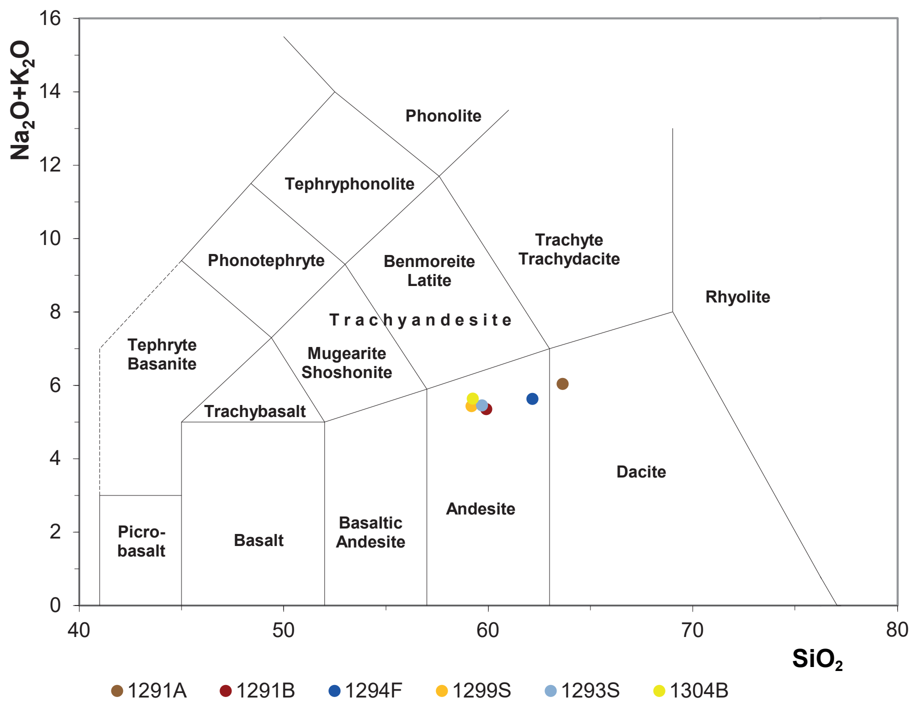


Fig. 5. Position of studied samples in classification TAS (total alkali – silica) diagram (sensu Le Bas et al., 1986).

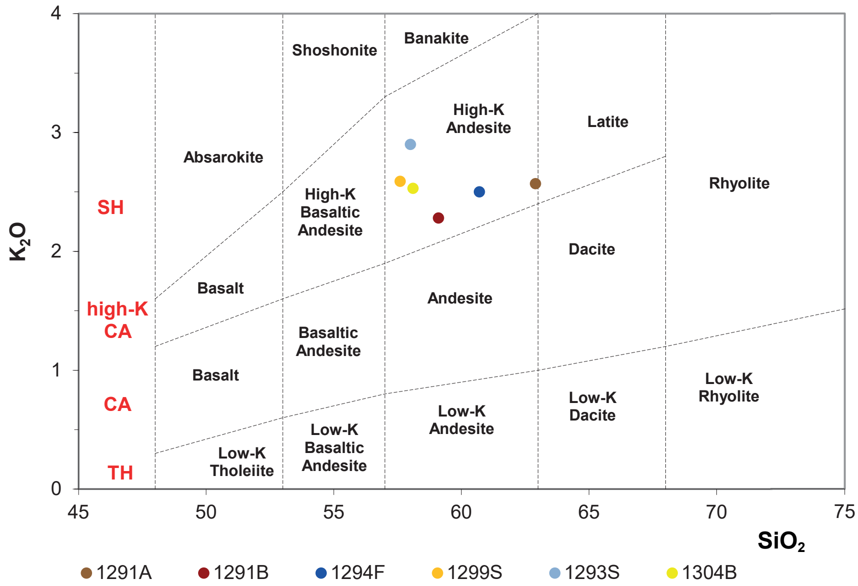


Fig. 6. Position of studied samples in classification diagram of SiO_2 vs. K_2O (sensu Pecerrillo & Taylor, 1976). Petrogenetic series: TH – tholeiitic, CA – calc-alkaline, high-K CA – high-potassium calc-alkaline, SH – shoshonitic.

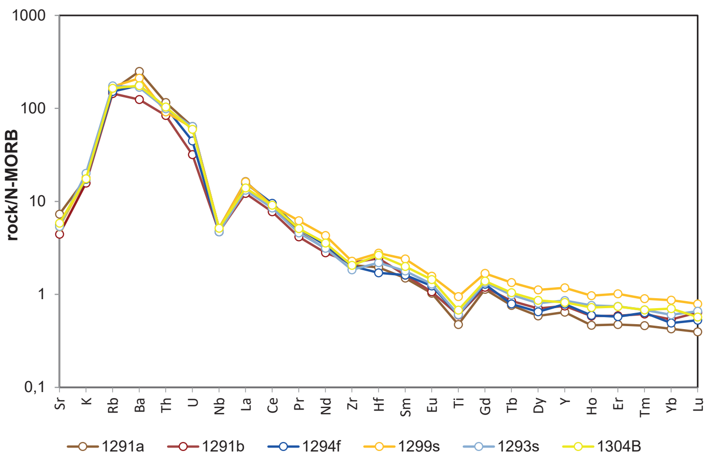


Fig. 7. Multi-element diagram (spiderogram; sensu Sun & McDonough, 1989). Contents of elements are normalized to N-MORB.

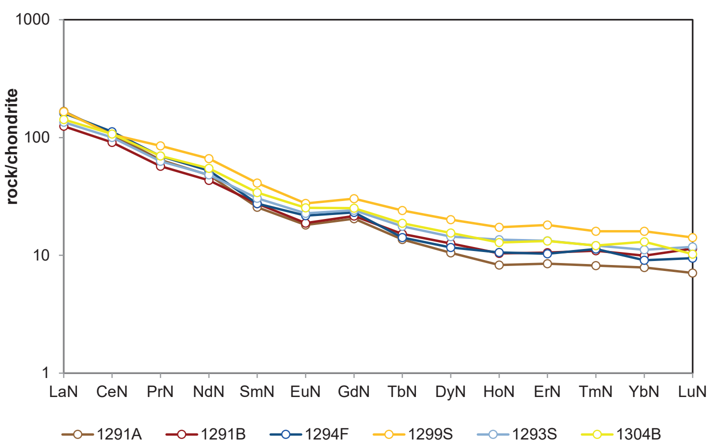


Fig. 8. Normalized REE patterns (normalization according to Evensen et al., 1978).

using multi-element diagrams (spiderograms, Fig. 7). On the diagram, we can see features typical for rocks of island arcs and active continental margins: the LILE enrichment (large-ion lithophile elements; K, Sr, Ba, Rb) and depletion in HFSE (high-field strength elements; Nb, Ti). The normalized REE patterns (REE = rare earth elements; Fig. 8) have a slight slope in the studied samples of andesites. The weak europium anomaly indicates that extensive fractionation of plagioclase did not take place in the genesis of andesite magmas.

Mineralogical and petrographic characteristics of volcanics of the Burda Formation

The studied samples are represented by fragments of andesites from volcanoclastic rocks, by andesites of intrusive bodies and by volcanoclastic rocks themselves. Andesites form two petrographic types: biotitic-amphibolic andesites with orthopyroxene and amphibolic andesites with biotite and pyroxene (Fig. 9).

Biotitic-amphibolic andesites with orthopyroxene have a porphyritic texture with a hyalopilitic (Fig. 9A, B) or microcrystalline (Fig. 9C, D, E) groundmass. There is one sample which can be identified as an andesite porphyry due to the more coarse-grained groundmass (sample 1310, Fig. 9F). The proportion of phenocrysts compared to the groundmass is 20–30 %. Plagioclase, amphibole and biotite are the main rock-forming minerals. This type of andesite occurs in the samples the most frequently.

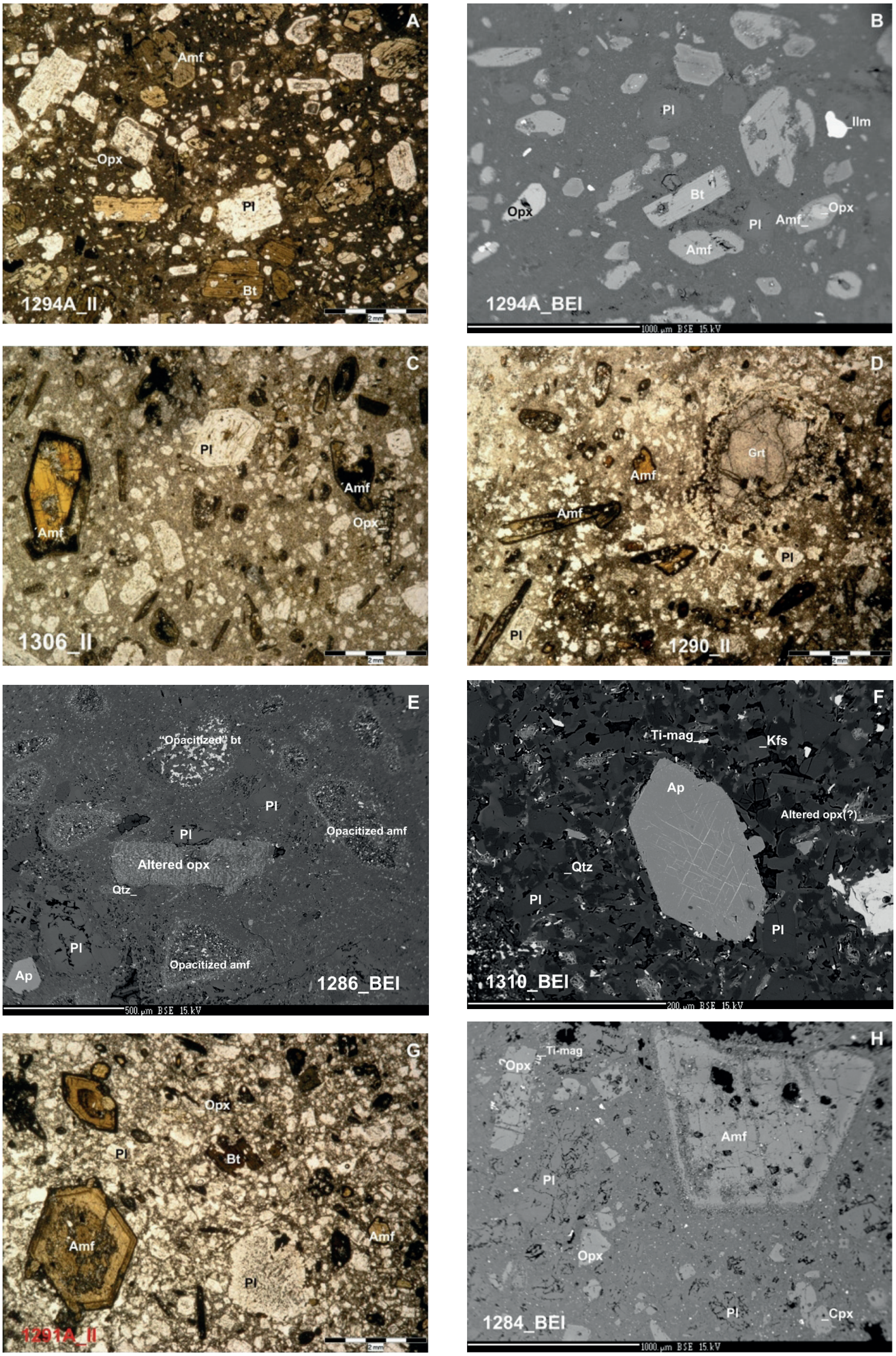


Fig. 9. A – photo of the sample 1294A, parallel polars, B – BEI of the same sample, C – photo of the sample 1306, parallel polars, D – photo of the sample 1290, parallel polars, E – BEI of sample 1286, F – BEI of the groundmass material, sample 1310, G – photo of the sample 1291A, parallel polars, H – BEI of the sample 1284.
Pl – plagioclase, Amf – amphibole, Bt – biotite, Opx – orthopyroxene, Cpx – clinopyroxene, Ilm – ilmenite, Ti-mag – Ti-magnetite, Kfs – potassium feldspar, Qtz – quartz, Ap – apatite, Grt – garnet, BEI –backscattered electron image.

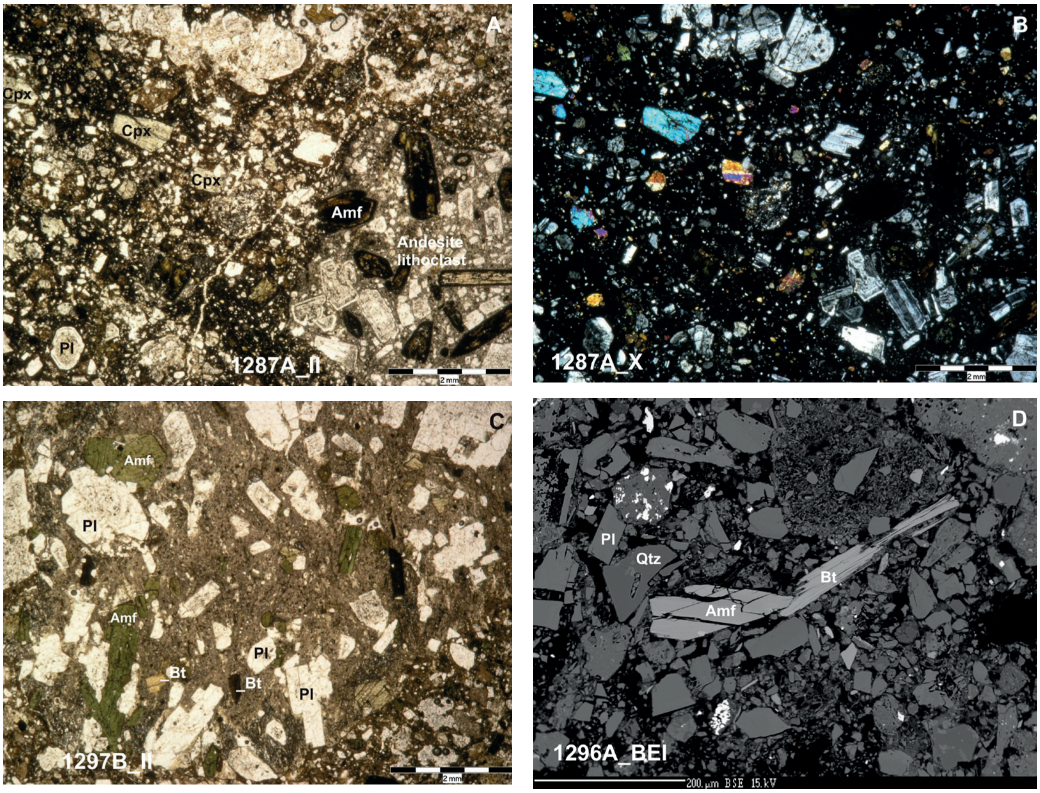


Fig. 10. Photo of the sample 1287A with parallel (A) and crossed (B) polars, C – lithoclast of biotitic-amphibolic andesite in the sample 1297B, parallel polars, D – crystalloclasts in the tuff sample 1296A, BEI. Pl – plagioclase, Amf – amphibole, Bt – biotite, Cpx – clinopyroxene, Qtz – quartz, BEI – backscattered electron image.

Amphibolic andesites with biotite and pyroxene (Fig. 9G, H) have a porphyritic texture with a microcrystalline groundmass. These rocks are characterized by a high proportion of phenocrysts compared to the groundmass (up to 50 %). Plagioclase and amphibole are the main rock-forming minerals. Sample 1297A has a special position in this group with plagioclase as the highly prevalent mineral, with mafic minerals rarer and smaller than in other samples and with the proportion of the phenocrysts compared to the groundmass about 30 %.

Plagioclase is the most abundant rock-forming mineral in both types of andesites. It forms phenocrysts and glomeroporphyric aggregates of tabular and lath shape and needles in the groundmass. Plagioclase is zoned and characteristically twinned. Amphibole forms idiomorphic to hypidiomorphic phenocrysts and aggregates which may enclose plagioclase. Preserved amphiboles are pleochroic, some of them are zoned. They are opacitized to the variable degree – from weakly opacitized crystal rims to complete opacitization. Biotite forms pleochroic tables and laths. It can enclose plagioclase. Biotites are preserved, or they show a phenomenon similar to the opacitization of amphibole: Fe-Ti oxides and potassium feldspar are formed at the expense of biotite (potassium feldspar instead of orthopyroxene in amphibole). Orthopyroxene forms idiomorphic to hypidiomorphic phenocrysts or is a part of glomeroporphyric aggregates. It also forms needles in the groundmass. It can be partially or completely altered. Very rare clinopyroxene is found in the sample 1284. Apatite is present as small phenocrysts or groundmass grains in some samples with crystallized groundmass. In three samples (1304B, 1290, 1310) there is garnet of almadine composition with a reaction rim. The crystallized groundmass consists of plagioclase, sanidine, quartz, orthopyroxene, Ti-magnetite, ilmenite, ± apatite.

Volcaniclastic material was studied in the samples 1287A and B, 1297B, and tuff in the samples 1296A and 1298.

The samples 1287A (Fig. 10A, B) and 1287B contain plagioclase, amphibole, orthopyroxene, and clinopyroxene crystalloclasts. There is no biotite in the samples. The presence of clinopyroxene may indicate their origin from pyroxenic andesites. Sample A contains orthopyroxene-amphibolic andesite lithoclast. Sample 1297B (Fig. 10C) contains rock lithoclasts and crystalloclasts of plagioclase, amphibole, and biotite. The lithoclasts are composed of biotitic-amphibolic andesite with plagioclase, green amphibole and hyalopilitic groundmass, of andesitic porphyry and of amphibolic(?)-pyroxenic andesite.

Sample 1296A (Fig. 10D) represents tuff. It contains amphibolic-pyroxenic andesite lithoclast (also with clinopyroxenes). Crystalloclasts are represented by plagioclase, amphibole, biotite, Fe-oxide, quartz and pyroxenes(?). In the tuff sample 1298, crystalloclasts are strongly predominant: plagioclase, green and brown amphiboles, biotite, clinopyroxene and orthopyroxene.

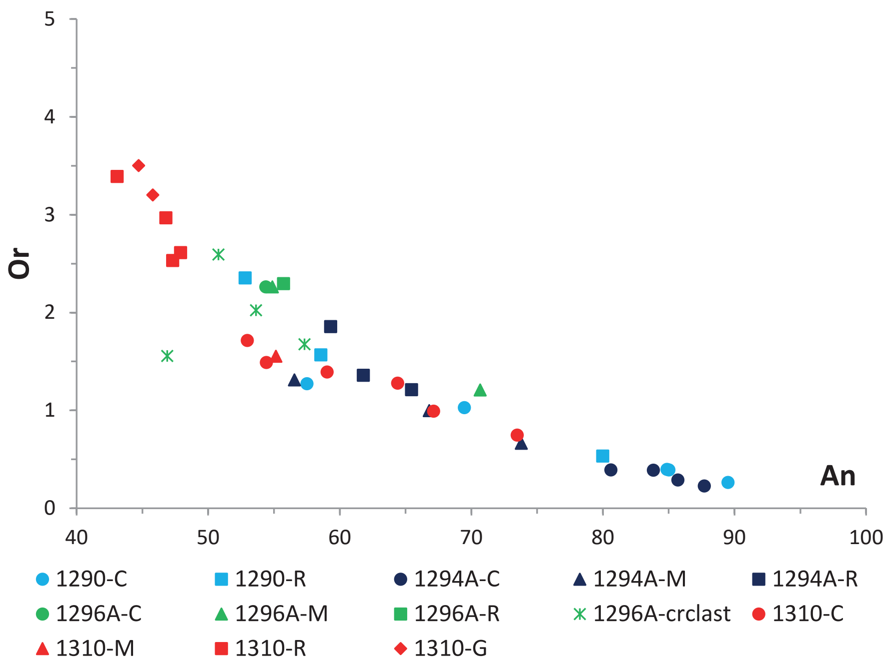


Fig. 11. Variability of plagioclase composition in the samples 1290, 1294A, 1296A and 1310. C – core, M – mantle, R – rim of plagioclase, G – groundmass plagioclase, crclast – plagioclase crystalloclast, An – anorthite, Or - orthoclase.

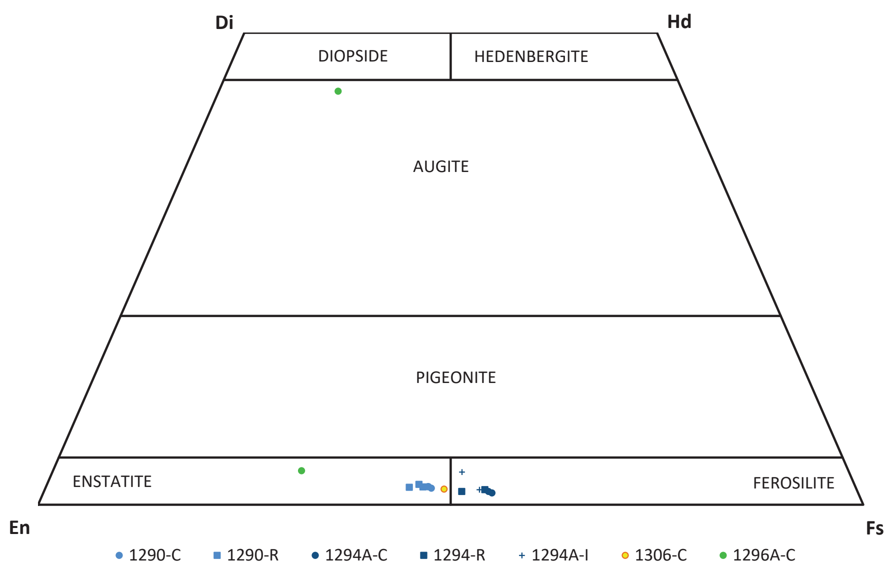


Fig. 12. Classification diagram for pyroxenes (Morimoto et al., 1988). C – core, M – mantle, R – rim of pyroxene, I – inclusion of orthopyroxene in another mineral, Di – diopside, Hd – hedenbergite, En – enstatite, Fs – ferosilite.

Characteristics of the chemical composition of andesite and tuff minerals

The analysed plagioclases in andesite samples 1290 and 1294A have the composition An52–An90. The composition trend of plagioclase in both samples is approximately the same. Diagram An vs. Or (Fig. 11) shows the normal plagioclase zonation: the cores are the most basic and the rims are the most acidic. Plagioclases of andesite porphyry sample 1310 are more acidic. Their composition varies from An43 to An74 and also indicates normal zonation. The composition of the groundmass plagioclase is similar to the composition of the plagioclase phenocryst rims. In addition, there is "gap" in the range of about 5 % of the An component between the composition of the inner part (core and mantle) of plagioclase (An53–74) and the plagioclase rims + groundmass plagioclase (An43–48). This gap may be caused by a change in chemical composition, or simply by an insufficient number of analyses. In the tuff sample 1296A, phenocrysts in the amphibolic-pyroxenic andesite clast and mineral crystalloclasts were analysed. The composition of the plagioclase phenocryst in the andesite clast is around An55, with a relatively significant zone with An70 in the phenocryst. The composition of plagioclase crystalloclast is variable, perhaps also related to which part of the crystal was analysed – whether it was the interior or the rim – it can be difficult to detect in crystalloclasts.

Only orthopyroxenes were analysed in the andesites of samples 1290, 1294A and 1306. There are no clinopyroxenes in these samples. The composition of analysed orthopyroxenes varies around the enstatite-ferrosilite boundary (Fig. 12), which reflects crystallization from a relatively differentiated magma. The analysed orthopyroxene in the amphibolic-pyroxenic andesite clast (tuff sample 1296A) has an enstatitic composition (Fig. 12), while En component is significantly higher than in other analysed orthopyroxenes. Clinopyroxene from the same andesite clast corresponds to augite and is found near the diopside field (Fig. 12). The composition of orthopyroxene and the presence of clinopyroxene indicates that they originated from a more basic magma than the other analysed orthopyroxenes.

Two classification diagrams (Hawthorne et al., 2012) were compiled for analysed amphiboles: diagram for amphiboles in andesites (Fig. 13A) and for amphiboles in volcaniclastics (Fig. 13B). Fe^{3+}min content (recalculated by Schumacher, in Hawthorne et al., 2012) was used for simplicity in both diagrams. According to the diagram on Fig. 13A, all amphiboles from andesites correspond to pargasite. Since there is no calcium in position A (y-axis), an increasing value on the y-axis indicates an increase in the alkali content of the amphibole. Amphibole from sample 1306 (analysed core, mantle and rim) has the highest alkali content. At the same time, this amphibole has the lowest Fe content of all analysed amphiboles. According to the diagram on Fig. 13B, all analysed amphiboles in the volcaniclastics also correspond to pargasite. The points on the diagram corresponding to the analysed phenocrysts in lithoclasts are less scattered than the points of the analysed crystalloclasts.

Paleogeography and paleovolcanic reconstruction of the Burda Mts

Paleogeography of the Burda Mts is demonstrated in Fig. 14 where the maximum range of Danube volcanics in the Da nube basin is indicated, while the

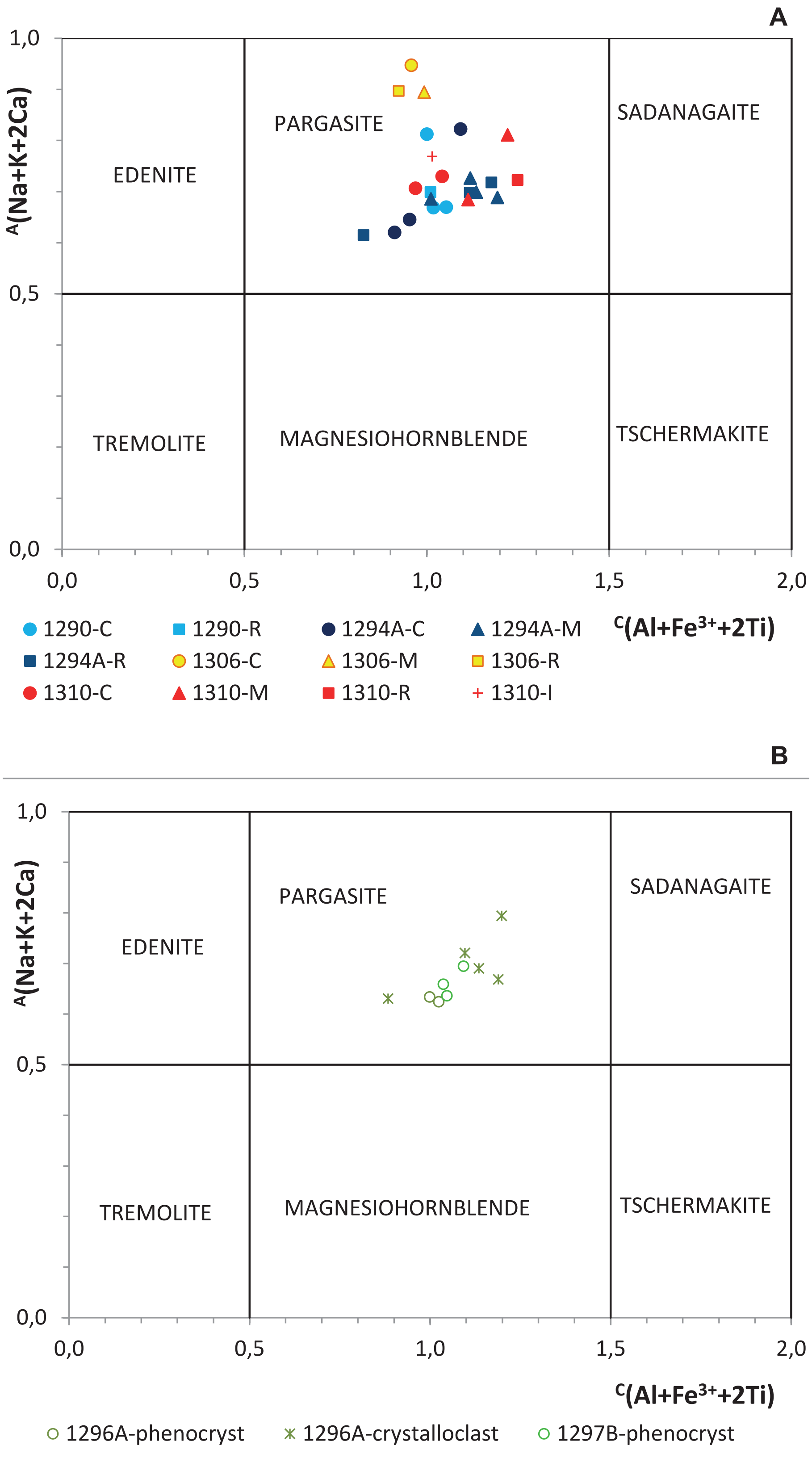


Fig. 13. Classification diagram for amphiboles (Hawthorne et al., 2012) for Fe^{3+}min. Diagram A is for amphiboles in andesites, diagram B for amphiboles in tuff. C – core, M – mantle, R – rim of pyroxene, I – inclusion of amphibole in another mineral.

designation of the volcanic centers of covered volcanics are numbers in the direction from west to east as follows: 1. Rusovce, 2. Gabčíkovo, 3. Tešedíkovo, 4. Palárikovo, 5. Kolárovo, 6. Šurany, 7. Bešeňov, 8. Dubník, 9. Bíňa and in the western part of the territory the volcanics of the Burda Mts near Štúrovo, the Börzsöny stratovolcano and the Visegrad volcanics are exposed (the central Slovakia volcanic field is located northeast of the territory; Šimon & Lacika, 2022). The volcanics of the Burda Mts nearby Štúrovo are included into the Burda Fm. At the base of the Burda Fm a succession of epiclastic volcanic rocks and pyroclastic rocks of amphibole-pyroxene andesites has developed. This horizon represents a succession of volcanoclastic rocks of volcanosedimentary origin with rare positions of autochthonous pyroclastic rocks. Their material has accumulated in the intervolcanic period, and partly also in the syneruptive period, when pyroclastic flows and pumice tuffs have formed. In the intervolcanic period, epiclastic material has formed, being represented by the positions of epiclastic volcanic breccias, conglomerates, sandstones formed at occasional flows, rapid flushes, lahars and mudflows, debris flows and debris avalanches. These epiclastic lithofacies occur in the transitional to marginal volcanic zone. From a petrographic point of view, the volcaniclastic material consists mainly of andesites, but we have rarely observed rocks of non-volcanic material and relics of a petrified wood from the original Badenian forest vegetation. Epiclastic volcanic sandstones of amphibole-pyroxene andesites are characterized by the presence of autochthonous light porous pumice fragments of angular to spherical shape. Epiclastic volcanic sandstones are predominantly coarse-grained, fairly well sorted, and occasionally show signs of stratification. There are also small or minor andesite sheets or lenticular positions of fine-grained epiclastic volcanic conglomerates with isolated blocks of andesites. In the beds, you can observe light porous pumice, which intergrows into individual beds. The material of epiclastic volcanic sandstones is represented by andesites of dark grey, grey and reddish brown colour. Porous pumice stone, predominantly light grey in colour, has an acidic dacite composition. Epiclastic volcanic sandstones with conglomerates of andesites crop out together with sandstones.

In the central part of the formation, volcanic products associated with the activity of submarine volcanism of the Badenian age developed. Submarine andesitic extrusive

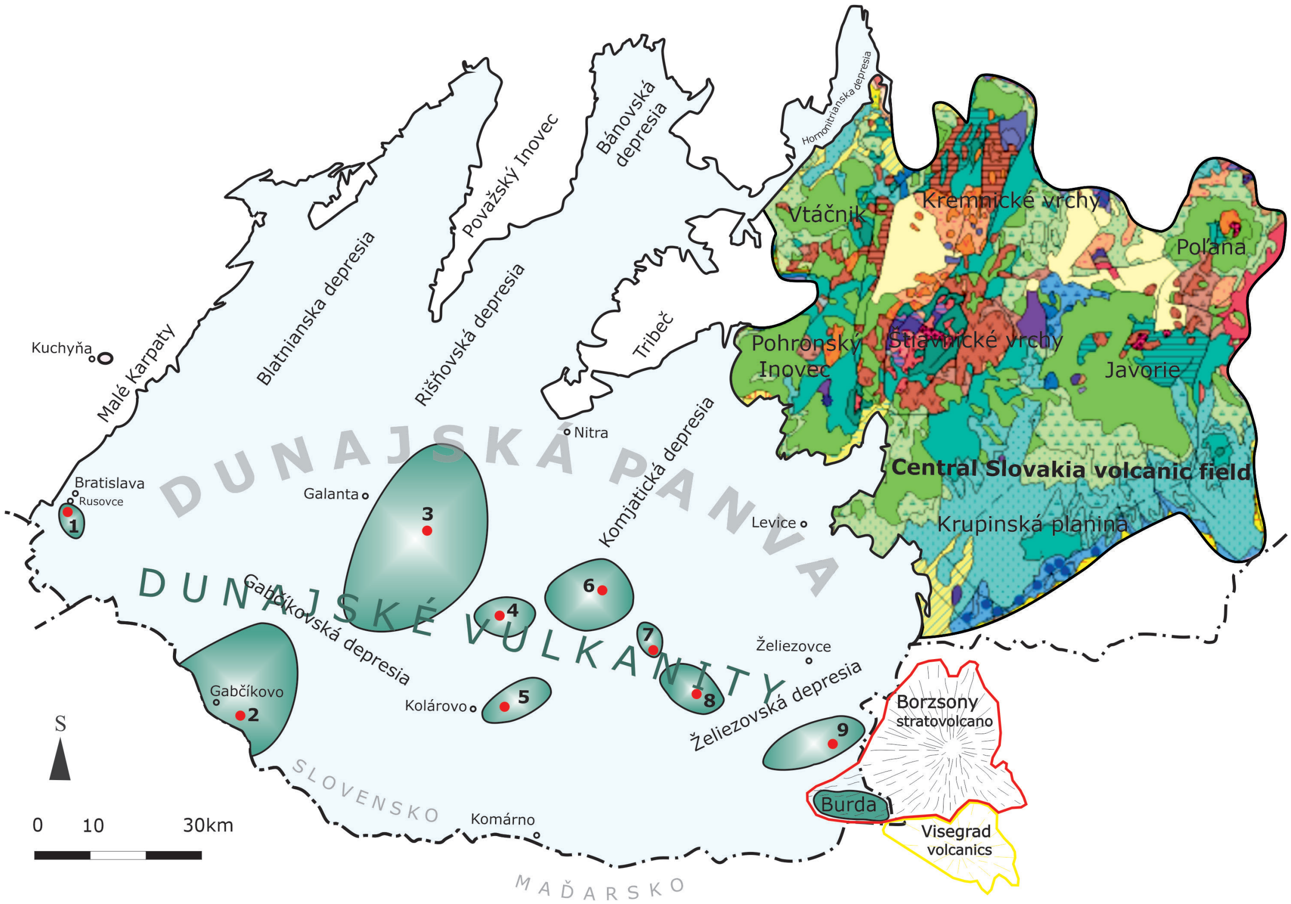


Fig. 14. Paleogeography of the Burda Mts near Štúrovo, the Börzsöny stratovolcano, the Visegrad volcanics and covered Danube volcanic centers: 1 – Rusovce, 2 – Gabčíkovo 3 – Tešedíkovo, 4 – Palárikovo, 5 – Kolárovo, 6 – Šurany, 7 – Bešeňov, 8 – Dubník, 9 – Bíňa.

volcanic domes of andesites are typical. They are formed of massive andesite with irregular blocky disintegration with a transition to brecciated andesite and up to breccia with a chaotic orientation of fragments. Extrusive domes of massive amphibole-pyroxene andesites have isometric shape, but occasionally also slightly elliptical bodies with dimensions of up to 200 m and vertical, blocky and roughly blocky disintegration. The indistinct fluid textures in the bodies were observed. The textures have a typical vertical to fan-like course. Zones of extrusive breccias developed at the edges of extrusive domes. The bodies are composed of light grey to greenish porphyritic andesite with phenocrysts of plagioclase, hypersthene, augite, amphibole and occasionally garnet in the ground mass, which is microlithic-grained in the middle part of the bodies and microlithic to microlithic-hyalopilitic at the edges of the bodies. As a result of the gradual destruction of these volcanic domes, debris-like material was formed and deposited even outside its volcanic center further into space applying the mass breccia flows, debris flows and deposits of coarse to blocky breccias. Intrusive-extrusive breccias of andesites represent marginal parts of intrusive-extrusive bodies. On the one hand, they are connected by a transition to their own body, on the other hand, they eventually pass into the breccias of subaqueous breccia flows. The brecciation zones are up to tens of meters thick. Extrusive breccias appear in facies with massive andesites of a light grey colour with solid texture and facies with angular fragments of grey non-porous andesite in a crushed lava matrix. Extrusive breccias are unsorted, chaotic, with a maximum fragment size of up to 100 cm. Fragments of andesites in extrusive breccias are present in amounts up to 80 %. Occasionally there was observed the presence of weakly oxidized red-brown andesite with a porous texture and spherical fragments of brown andesite with a porous texture. The matrix is formed by crushed andesites of light grey colour and porous texture. In the upper part of the Burda Formation, pyroclastic and epiclastic facies of pyroxene-amphibolic andesites were formed. Deposits of pyroclastic flows and redeposited pyroclastics are characterized with the presence of relics of petrified tree trunks, indicating transport from emergent forest-covered slopes in higher levels of the volcanic edifice of the Börzsöny Mts in present-day Hungary. This part of the Burda volcanics represents the transitional volcanic zone of the Börzsöny stratovolcano.

Acknowledgment

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Charakteristika neogénnych vulkanitov pohoria Burda pri Štúrove, Slovenská republika

Vulkanické pohorie Burda pri Štúrove je plošne najmenší geomorfologický celok na Slovensku. Nachádza sa na jz. Slovensku, na hraniciach s Maďarskom. Na západe hraničí s Podunajskou pahorkatinou. Južnú hranicu tvorí koryto Dunaja, ktorý sa prerezáva cez Vyšehradskú bránu a oddeľuje Burdu od maďarského pohoria Pilis. Východnú hranicu tvorí koryto rieky Ipeľ, ktorá oddeľuje Burdu od maďarského pohoria Börzsöny. Severozápadnú časť pohoria ohraničuje Bajtavská brána. Maximálna dĺžka pohoria je 7,5 km a maximálna šírka len 3,5 km. Najvyšším vrchom je Plešivec (395 m n. m.) v centrálnej časti pohoria. Vulkanity v pohorí Burda reprezentuje formácia Burda. Produkty formácie Burda vystupujú v rámci hrasťového bloku Burdy. Hrasťový blok je uklonený na SZ. Zlomovú zónu pri južnom okraji hrasti smeru V – Z sleduje tok Dunaja. Formácia Burda je bádenského veku. Horniny tejto formácie v smere na Z a SZ prechádzajú do bajtavského súvrstvia, ktoré vznikalo súčasne s formáciou. Súvrstvie obsahuje bohatú morskú faunu lagenidovej zóny a nanoplanktón spoločenstva zóny NN-5 zodpovedajúce spodnému bádenu. Na báze formácie sa vyvinula sukcesia epiklastík a pyroklastík amfibolicko-pyroxénických andezitov. V strednej časti formácie sa vyvinuli vulkanické produkty späté s aktivitou submarinného vulkanizmu bádenského veku. Typické sú podmorské andezitové extruzívne dómy amfibolicko-pyroxénických andezitov. Submarinné extruzívne dómy andezitov majú eliptický až izometrický prierez s dĺžkou do 220 m. Tvorí ich masívny andezit s nepravidelnou blokovitou odlučnosťou s prechodom do zbrekciovateného andezitu až do brekcie s chaotickou orientáciou úlomkov. Vplyvom postupnej deštrukcie týchto vulkanických dómov sa tvoril úlomkovitý materiál a ukladal sa aj mimo svojho vulkanického centra ďalej do priestoru prostredníctvom masových brekciovitých prúdov, úlomkových prúdov a uložením hrubých až blokových brekcií. Vo vrchnej časti formácie Burda sa vytvorili fácie pyroklastík a epiklastík pyroxénicko-amfibolických andezitov. Uloženiny pyroklastických prúdov a laharov sú charakteristické prítomnosťou reliktov petrifikovaných kmeňov stromov. Formáciu Burda reprezentuje sukcesia fácií epiklastík, pyroklastík a produktov submarinných extruzívnych dómov. Je budovaná týmito fáciami: horizont epiklastík a pyroklastík, epiklastické vulkanické pieskovce s pemzami, epiklastické vulkanické pieskovce a konglomeráty, epiklastické vulkanické pieskovce, drobné epiklastické vulkanické konglomeráty, hrubé epiklastické vulkanické konglomeráty, epiklastické vulkanické brekcie a konglomeráty, epiklastické vulkanické brekcie, drobné redeponované pyroklastiká, hrubé redeponované pyroklastiká, blokovo-popolové pyroklastické prúdy, subakvatické brekciovité prúdy, chaotické brekcie redeponovaných pyroklastík, extruzívne brekcie dómov amfibolicko-pyroxénických andezitov a extruzívne dómy amfibolicko-pyroxénických andezitov.

Vzorky, z ktorých boli urobené celohorninové chemické analýzy, podľa klasifikačného TAS diagramu (obr. 5) zodpovedajú andezitu a vzorka 1291A dacitu. Pomerne blízke zloženie majú vzorky andezitu 1291B, 1293S, 1299S a 1304B. Vzorku 1294F možno považovať za acidný andezit. Podľa diagramu SiO_2 vs. K_2O (obr. 6) všetky vzorky zodpovedajú vysoko draselnému andezitu a patria do vysoko draselnej vápenato-alkalickej série. Obsah stopových prvkov v študovaných horninách možno znázorniť pomocou multiprvkových diagramov (tzv. spiderogramy, obr. 7). Na diagrame vidieť vlastnosti typické pre horniny ostrovných oblúkov a aktívnych okrajov kontinentov: obohatenie oproti N-MORB o tzv. LILE (K, Sr, Ba, Rb) a ochudobnenie o tzv. HFSE (Nb, Ti). Krivky normalizovaného obsahu vzácnych zemín (obr. 8) majú v prípade študovaných vzoriek andezitov mierny sklon. Nevýrazná európiová anomália poukazuje na to, že v genéze ich magiem neprebiehala rozsiahla frakcionácia plagioklasu. Študované vzorky predstavujú fragmenty andezitov z vulkanoklastík, andezity intruzívnych telies a samotné vulkanoklastiká. Andezity tvoria dva petrografické typy: biotiticko-amfibolické andezity s ortopyroxénom a amfibolické andezity s biotitom a pyroxénom (obr. 9). Biotiticko-amfibolické andezity s ortopyroxénom majú porfýrickú štruktúru so základnou hmotou hyalopilitickou (obr. 9A, B) alebo mikrokryštalickou (obr. 9C, D, E). V jednom prípade možno vzorku vďaka hrubšej zrnitosti základnej hmoty označiť ako andezitový porfýr (vzorka 1310, obr. 1F). Podiel výrastlíc oproti základnej hmote je 20 – 30 %. Hlavné horninotvorné minerály sú plagioklas, amfibol a biotit. Tento typ andezitu sa vo vzorkách vyskytuje najčastejšie. Amfibolické andezity s biotitom a pyroxénom (obr. 9G, H) majú porfýrickú štruktúru s mikrokryštalickou základnou hmotou. Pre tieto horniny je charakteristický vysoký podiel výrastlíc oproti základnej hmote (až do 50 %). Hlavné horninotvorné minerály sú plagioklas a amfibol. Osobitné postavenie v skupine má vzorka 1297A, v ktorej je dominantným minerálom plagioklas, pričom mafické minerály sú zriedkavejšie a menšie ako v iných vzorkách. Podiel výrastlíc oproti základnej hmote je zhruba 30 %. Najpočetnejší horninotvorný minerál v oboch typoch andezitov je plagioklas, ktorý tvorí výrastlice a glomeroporfýrické agregáty tabuľkového a lištového tvaru a ihličky v základnej hmote. Plagioklasy sú zonálne a charakteristicky zdvojčatené. Variabilitu ich chemického zloženia znázorňuje diagram An vs. Or (obr. 11). Amfibol tvorí idiomorfné až hypidiomorfné výrastlice a agregáty. Môže uzatvárať plagioklas. Zachované amfiboly sú pleochroické, niektoré sú zonálne. Sú do rôzneho stupňa opacitizované – od nevýrazných opacitových lemov až po úplnú opacitizáciu. Analyzované amfiboly zodpovedajú pargasitu (obr. 13A). Biotit tvorí pleochroické tabuľky a lišty, môže uzatvárať plagioklas. Biotity sú zachované alebo sa pri nich prejavuje obdoba opacitizácie amfibolu. Na úkor biotitu vznikajú Fe-Ti oxidy a draselný živec (namiesto ortopyroxénu v amfibole). Ortopyroxén tvorí idiomorfné až hypidiomorfné výrastlice alebo je súčasťou glomeroporfýrických agregátov. Tvorí aj ihličky v základnej hmote. Môže byť čiastočne až úplne alterovaný. Zloženie analyzovaných ortopyroxénov je na rozhraní enstatit-ferosilit (obr. 12). Vo vzorke 1284 sa nachádza veľmi zriedkavý klinopyroxén. V niektorých vzorkách s vykryštalizovanou základnou hmotou je vo forme malých výrastlíc alebo v základnej hmote prítomný apatit. V troch vzorkách (1304B, 1290, 1310) sa nachádza granát s almadínovým zložením s reakčným lemom. Vykryštalizovanú základnú hmotu tvorí plagioklas, sanidín, kremeň, ortopyroxén, titanomagnetit, ilmenit ± apatit. Vulkanoklastický materiál bol študovaný vo vzorkách 1287A, B a 1297B a tuf vo vzorkách 1296A a 1298. Vzorky 1287A (obr. 10A, B) a 1287B obsahujú kryštaloklasty plagioklasu, amfibolu, ortopyroxénu a klinopyroxénu. Biotit vo vzorkách nie je. Prítomnosť klinopyroxénov môže poukazovať na ich pôvod z pyroxénických andezitov. Vzorka A obsahuje litoklast amfibolického andezitu s ortopyroxénom. Vzorka 1297B (obr. 10C) obsahuje litoklasty hornín a kryštaloklasty plagioklasu, amfibolu a biotitu. Litoklasty tvorí biotiticko-amfibolický andezit s čistými plagioklasmi, zelenými amfibolmi a hyalopilitickou základnou hmotou, andezitový porfýr a amfibolicko(?)-pyroxénický andezit. Vzorka 1296A (obr. 10D) je tuf. Obsahuje litoklast amfibolicko-pyroxénického andezitu (aj s klinopyroxénmi). Kryštaloklasty predstavuje plagioklas, amfibol, biotit, oxid Fe, kremeň a pyroxény(?). Vo vzorke tufu 1298 silne prevažujú kryštaloklasty: plagioklas, zelené a hnedé amfiboly, biotit, klinopyroxén a ortopyroxén. Variabilitu chemického zloženia minerálov vulkanoklastík odrážajú diagramy na obr. 11, 12 a 13B.

Paleogeografia pohoria Burda je znázornená na obr. 14, kde je vyznačený maximálny rozsah dunajských vulkanitov. Vulkanické centrá zakrytých vulkanitov sú označené číslami v smere zo západu na východ: 1 – Rusovce, 2 – Gabčíkovo, 3 – Tešedíkovo, 4 – Palárikovo, 5 – Kolárovo, 6 – Šurany, 7 – Bešeňov, 8 – Dubník, 9 – Bíňa. Na obrázku sú znázornené aj vulkanity pohoria Burda pri Štúrove, odkrytý stratovulkán Börzsöny a vyšehradské vulkanity (vulkanické pole stredného Slovenska sa nachádza na severovýchode územia; Šimon a Lacika, 2022). Na báze súvrstvia Burda sa vyvinula postupnosť epiklastických vulkanických hornín a pyroklastických hornín amfibolicko-pyroxénických andezitov. Horizont epiklastík a pyroklastík predstavuje postupnosť vulkanoklastických hornín vulkanosedimentárneho pôvodu so vzácnymi polohami autochtónnych pyroklastických hornín. Tento materiál sa nahromadil v medzivulkanickom období a čiastočne aj v období synerupcie, keď sa vytvárali pyroklastické prúdy a pemzové tufy. V medzivulkanickom období sa vytvoril epiklastický materiál, ktorý predstavuje polohy epiklastických vulkanických brekcií, zlepencov a pieskovcov vznikajúcich v občasných tokoch, rýchlych splachoch, laharoch a bahnotokoch, sutinových prúdoch a sutinových lavínach. Tieto epiklastické litofácie sa vyskytujú v prechodnej až okrajovej vulkanickej zóne. Z petrografického hľadiska vulkanoklastický materiál tvoria prevažne andezity. Ojedinele sme zaznamenali aj horniny nevulkanického materiálu a relikty skameneného dreva z pôvodnej vegetácie bádenského lesa. Epiklastické vulkanické pieskovce andezitov sú charakteristické prítomnosťou autochtónnej ľahkej poréznej pemzy hranatého až guľovitého tvaru. Sú prevažne hrubozrnné, pomerne dobre vytriedené a občas vykazujú známky stratifikácie. Vyskytujú sa tu aj malé andezitové pláty alebo šošovkovité polohy jemných epiklastických vulkanických konglomerátov s izolovanými blokmi andezitov. Vo vrstvách možno pozorovať svetlú pórovitú pemzu, ktorá sa prelína s jednotlivými vrstvami. Materiál epiklastických vulkanických pieskovcov predstavujú andezity tmavosivej, sivej a červenohnedej farby. Porézna pemza prevažne svetlosivej farby má kyslé dacitové zloženie. Spolu s pieskovcami vystupujú epiklastické vulkanické pieskovce so zlepencami andezitov.

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