Epithermal Au-Ag mineralisation at the locality Prochot-Lazy in the mantle of the Štiavnica Stratovolcano

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Epitermálna Au-Ag mineralizácia na lokalite Prochot-Lazy v plášti Štiavnického stratovulkánu

Abstract: The Prochot-Lazy area hosts a poorly known historical epithermal precious metal deposit hosted by andesites of the Lower structural unit of the Štiavnica Stratovolcano. According to current exploration, this locality consists of two roughly parallel mineralised zones. The Main zone is probably related to a regional fault and it was followed by old mine workings. The inclined bore hole PT-1 has determined here exploited spaces and remnants of quartz-carbonate veining (with 5.4 ppm Au, 10.5 ppm Ag) and native gold accompanied by tetrahedrite, pyrite, calcite, siderite and rhodochrosite. A zonal arrangement of alteration patterns includes uppermost steam-heated zone (kaolinite, alunite, crystobalite and increased Hg), base of steam-heated alteration (kaolinite, smectite, opal/chalcedony), adularia-rich zone in the hanging-wall of the vein structure and foot-wall alteration (smectite, calcite, kaolinite, adularia, chlorite). Alteration is accompanied by extensive brecciation and pyritisation, with increasing intensity towards the vein. Western continuation of the Main zone and parallel East zone were explored by channel sampling and showed alteration and geochemical features similar to the hanging-wall zone in the PT-1 hole with up to 1.3 ppm Au and 1.7 ppm Ag. The studied mineralisation has an intermediate position between low and intermediate sulfidation types. It evolved during the pre-caldera stage of the stratovolcano with the source of ore-bearing fluids related either to the magma chamber below the central zone of the stratovolcano (similar in source to the Rozália mine Au-deposit) or to a local magma chamber below the Prochot Intrusive Complex.

Keywords: epithermal, exploration, Prochot-Lazy site, alteration, mineralogy, geochemistry, Štiavnica Stratovolcano

1. INTRODUCTION

Prochot belongs to the least known localities with historical exploitation of precious metals in the Central Slovakia Volcanic Field. Old mining works of small extent occur approximately 1 km south of the village of Prochot, near the Lazy homestead. The aim of this paper is to summarise results of earlier and present exploration activities in this area. Based on information from the new exploration at this locality we describe regional and local geological setting of the epithermal precious metal mineralisation, its mineral composition and associated hydrothermal alteration. We also discuss its position in the metallogenetic evolution of the hosting Štiavnica Stratovolcano and implications for future exploration activities in this area.

Based on its mineralogical characteristics, the studied Au-Ag epithermal mineralisation is of low- to intermediate sulfidation type, i.e. it has an intermediate position between these two end-member types of the commonly used classification of epithermal deposits (Hedenquist et al., 2000; Sillitoe & Hedenquist, 2003). Their classification scheme is based on distinct mineralization and alteration styles, sulfide abundance, characteristic metal content and volcano/sedimentary settings.

2. HISTORY OF EXPLORATION

First written records about digging for gold and silver in the vicinity of Prochot village are known only from the beginning of 19th century. However, exploration of precious metals occurred here much earlier, because the adit Anna, which the Mining authority in Štiavnické Bane had started to restore in the year 1808, was driven by hammer and chisel (Jancsy, 1962). Prospection digging of the Mining authority that was based on findings of pieces of opalites, hydrothermal silicites and pyritised rocks with increased amount of Au and Ag, was not successful, despite a relatively high content of precious metals, locally up to 312 ppm Au and 234 ppm Ag.

Next exploration activities started in the second half of the 20th century. In the vicinity of Prochot village, in the southern part of the Vtáčnik mountain range, hydrothermally altered rocks and local geochemical anomaly of molybdenum have been identified and subsequently drill holes VTV-2, 9, 18, and 25 have determined widespread zones of alteration and hydrothermal brecciation. In the VTV-2 drill hole, occurrences of molybdenum-fluorite mineralisation were discovered (Valach & Kúšik, 1974). Following extensive geological mapping and geophysical survey, diorite porphyry intrusion at the hill of Majspiak westward from Prochot village was tested by the MEB-1

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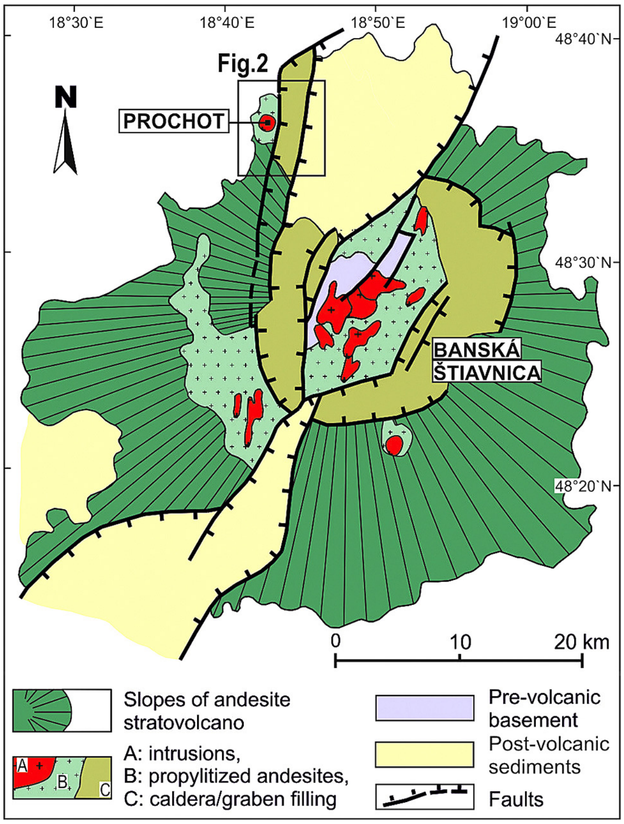

Fig. 1. Schematic structural map of the Štiavnica Stratovolcano with position of the Prochot-Lazy study area (after Lexa et al., 1999).

structural drill hole (Brlay et al., 1980). In this drill hole minor occurrences of base metal and fluorite mineralisation were detected. However, neither drill holes of VTV series nor MEB-1 were assayed for gold.

During implementation of the project "Disseminated Au ores in silicified rocks" (Knésl & Knéslová, 1995) exploration has discovered several other occurrences of epithermal style alteration with locally increased Au content (tenths of ppm) in the vicinity of the village of Prochot. They occur in the surrounding area of Majspiak and Partizánsky vrch hills. Andesitic rock hosts zones of intensive argillic alteration, locally also silicification, variably with limonite.

Since 1990-ties the Prochot-Lazy locality was a target of exploration activities of 3 private companies that contributed to the knowledge of mineralisation and geological setting. During the years 1995–1997 Golden Regent Resources – Slovakia, Ltd. performed exploration drilling focused on testing of the mineralised structure (Knésl & Knéslová, 2000). However, all three drill holes completed (PL-1 to PL-3) were negative. As they have not been localised in a map, only their approximate position is known and thus they are not shown in the maps in Figs. 2 and 3. Gold contents in the drill holes have not exceeded hundreds of ppb.

In the year of 2010 EMED Slovakia, Ltd. collected samples from old mining works and re-analysed drill core from the MEB-1 drill hole (Bakos & Urban, 2013). In samples of quartz-calcite gangue from the locality Lazy contents of 1.58–20.7 ppm Au and up to 9.4 ppm Ag were determined. In samples of propylitised diorite porphyry with pervasive pyritisation in the MEB-1 drill hole in depth of 340–733 m gold contents from 0.01 to 0.1 ppm were assayed. Deeper in the hole, in the depth of 1161 to 1375 m, in a similar rock with quartz-carbonate stockwork, gold contents ranged from 0.03 to 0.09 ppm. Increased Ag content up to 0.9 ppm is limited just to the stockwork zones. The highest Au and Ag values were recorded in hydrothermal breccia cemented by sphalerite and galena in the depth of 1396 to 1398 m (0.31 ppm Au, 4.7 ppm Ag, 0.5 wt.% Zn, 0.36 wt.% Pb).

Since 2013 exploration at Prochot has been performed by the company Green View, Ltd. Eight trenches from 9 to 75 m long (281.5 m in total) were dug, one outcrop in the Jastrabský potok creek was sampled by channels and one inclined PT-1 bore hole, 73 m deep, was drilled at the Lazy homestead, that has crossed exploited spaces on the contact of hydrothermally altered breccia with quartz-calcite stockwork. Furthermore, surface exploration has enabled to discover several other manifestations of epithermal mineralisation and related alteration in a broad area between the Lazy homestead and the village of Prochot.

3. GEOLOGICAL SETTING

The studied mineralisation south of Prochot village occurs in the southern part of the Vtáčnik mountain range (Figs. 1 and 2). In this area, volcanic rocks are segmented by relatively young faults of a NE–SW to N–S direction into tectonic blocks between the Žiar Basin in the east and uplifted ridge of pre-volcanic basement below the main ridge of the Vtáčnik Mts. in the west (Šimon et al., 1997). In the space between the faults, pre-volcanic basement occurs in the depth of 500 to 800 m and volcanic rocks belong especially to the lower structural unit of the Štiavnica Stratovolcano (the 1st pre-caldera stage of the late early Badenian to early late Badenian age; Chernyshev et al., 2013). Westward from Prochot village these rocks are covered by amphibole andesite of the Plešina Formation (late Badenian) and pyroxene andesite lava flows of the Vtáčnik Formation (early Sarmatian) and southward from Prochot village by amphibole-pyroxene andesite lava flows of the Sitno Effusive Complex (early Sarmatian). In the close vicinity of Prochot village, the lower structural unit represented by effusive complex of pyroxene and amphibole-pyroxene andesites is intruded by rocks of the Prochot Intrusive Complex (Konečný et al., 1998).

Volcanic rocks hosting the mineralization at the Prochot-Lazy site are pyroxene and amphibole-pyroxene andesite lava flows of the Lower structural unit of the Štiavnica Stratovolcano. They are mostly massive with blocky or platy jointing, at margins with transitions into partially oxidised and porous lava breccias. In the broad vicinity of the studied mineralisation they are affected by weak propylitic alteration (chlorite, smectite, and fine pyrite) and locally they are dismembered by steep faults of a NW–SE direction. The drill hole VTV-9 located in the footwall of the mineralised zone (Fig. 3) found moderately altered and argillised andesite until the depth of 92 m. Deeper, propylitised andesite

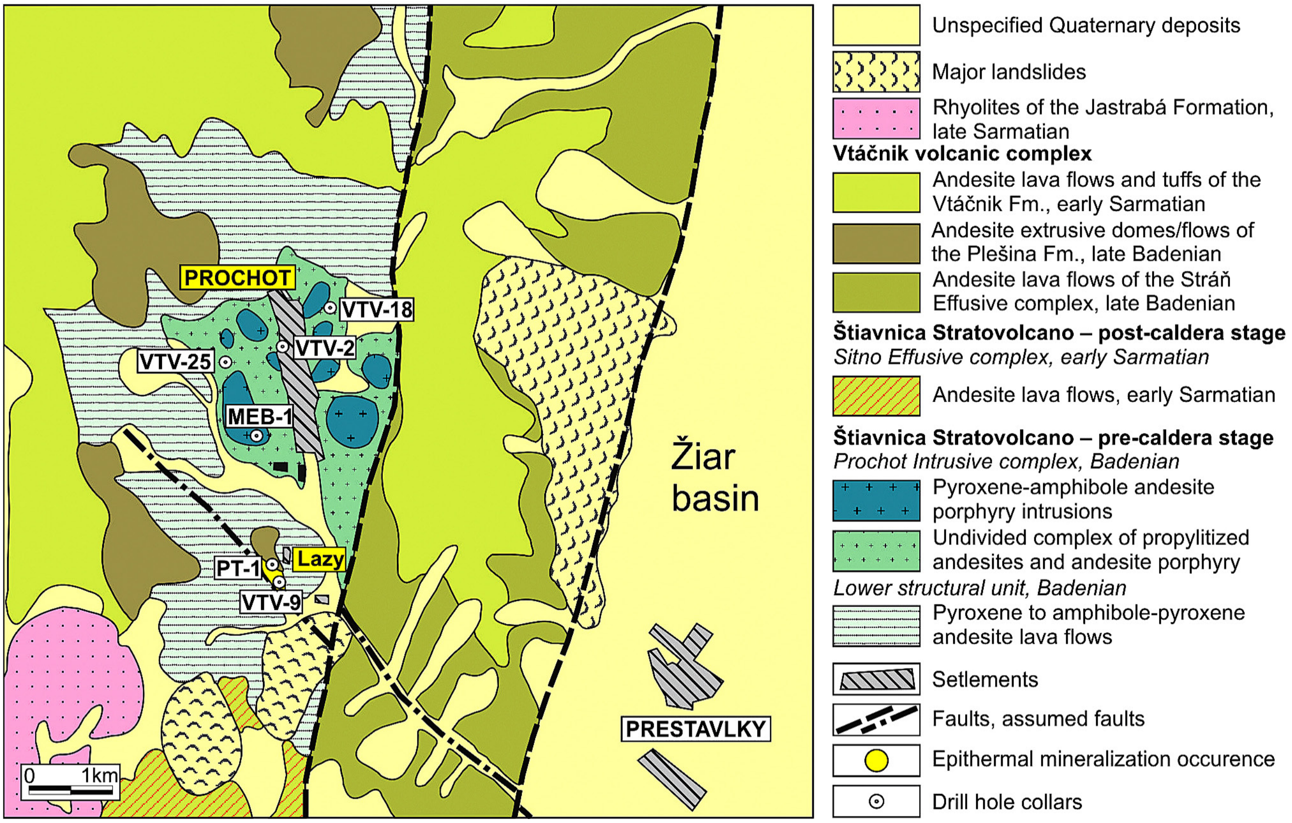

Fig. 2. **Schematic structural-geological map of the area of Prochot village with location of epithermal mineralisation occurrences and major historical and recent drill holes including MEB-1 and PT-1 (after Konečný et al., 1998).**

alternating with lava breccias are present, locally affected by fracturation (Valach et al., 1975). The only distinctive zone of tectonic breccia with hydrothermal alteration occurs in the interval 251.1–268.5 m.

The Prochot Intrusive Complex includes relics of stratovolcanic structure, sills of amphibole-pyroxene andesite porphyry and stock-like intrusions of amphibole-pyroxene diorite porphyry (Konečný et al., 1998). All rocks are affected by propylitisation and pyritisation of variable intensity. In zones of tectonic failure they are also argillised, eventually weakly silicified and variably penetrated by carbonate veinlets (Valach et al., 1975). The upper part of the MEB-1 drill hole located SW from Prochot village (till the depth of 550 m) proved the presence of effusive complex of pyroxene and amphibole-pyroxene andesites with horizons of breccia and tuffs intercalations, in the upper part with two sills of amphibole-pyroxene andesite porphyry (Brlay et al., 1980; Konečný et al., 1998). Deeper in the hole there followed a stock of amphibole-pyroxene diorite porphyry to the final depth of 1400 m. In this drill hole disseminated-stockwork pyrite-pyrhotite mineralisation with small amount of chalcopyrite, vein-type sphalerite-galena mineralisation with pyrite in quartz-carbonate veins and pyrite mineralisation have been identified. The mineralisation is accompanied by an extensive zone of propylitisation in the intrusion neighbourhood, while the intrusion itself is affected by silicification, pyritisation, and sericitisation. The presence of adularia is related to younger veinlets.

4. METHODOLOGY

Old mining works and alteration zones were mapped using GPS with precision below 10 m. The PT-1 drill hole was drilled using a diamond bit with HQ3 diameter and using the wire-line technology and double barrel in order to ensure a maximum core recovery. One meter intervals were used for sampling while half of the core was used for analysis. Channel sampling was performed on outcrops within the Jastrabský potok creek and in eight exploration trenches up to 4 m deep. The length of individual sampling channels was based on lithological contacts and reached 1 to 5 m, while the weight of individual samples was 2 to 3 kg. In total, 13 samples were taken from outcrops in the Jastrabský potok creek from two intervals, 19 m and 5 m long each (Fig. 3). From the exploration trenches 157 samples were taken in total. Logging of drill core and channel samples was documented on a macroscopic scale and included estimation of silicification, argillisation, pyritisation, and chlorite-smectite alteration at the scale from 0 to 5. In addition, 45 lithogeochemical samples were taken from the surface in a broad area between the Lazy homestead and the village of Prochot.

For geochemical analyses, drillcore, channel, and lithogeochemical samples were weighed, dried, and milled so that minimum 70 % of each sample was in fraction < 2 mm. Later, quartered parts of samples with weight of 250 g were milled so that minimum 85 % of each sample has reached the grain size < 0.075 mm. Gold was analysed in the laboratory ALS

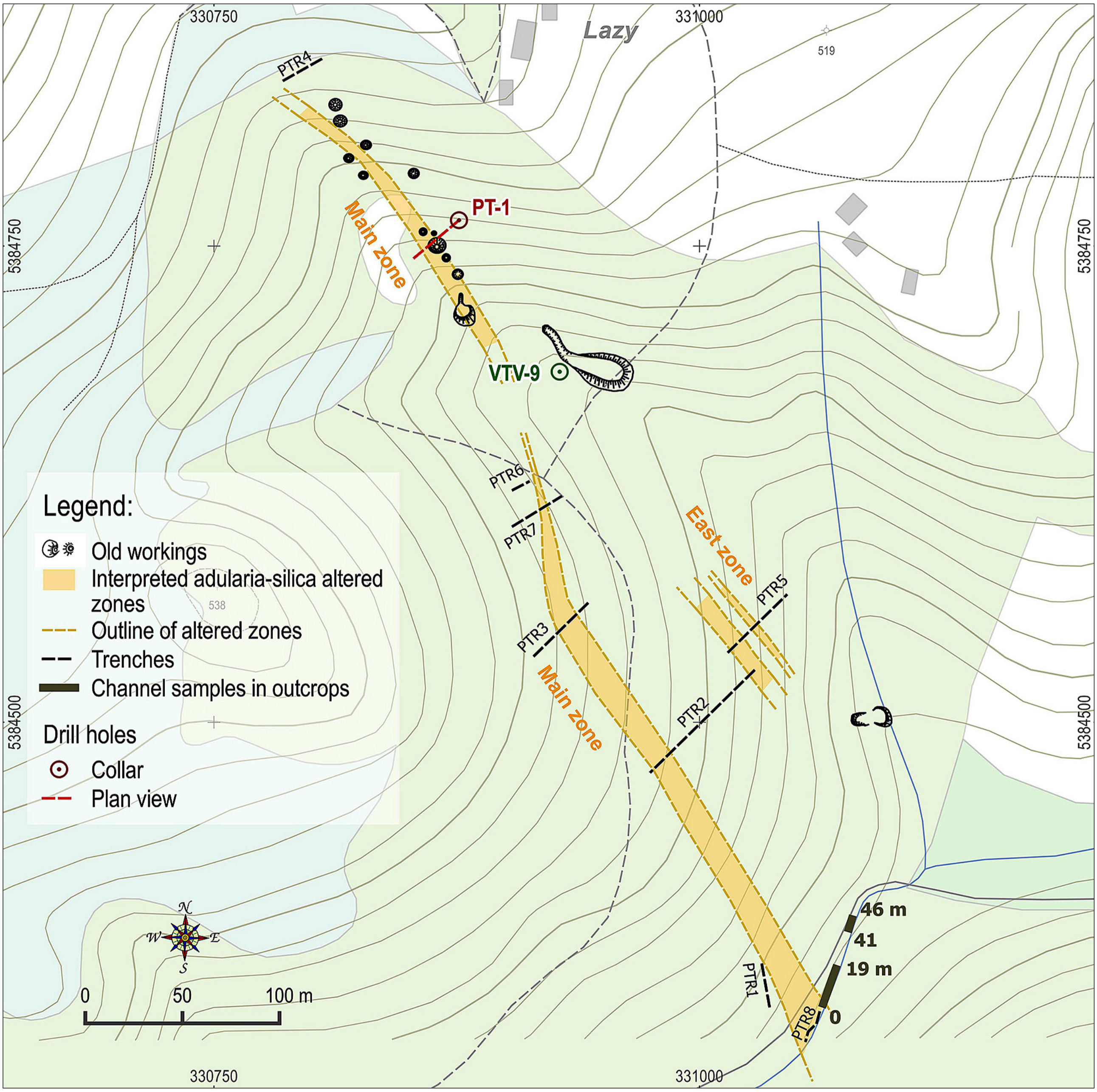

Fig. 3. Mineralized zones, old workings and position of historical and recent drill holes, trenches and channel-sampled outcrop at the Prochot-Lazy site.

CHEMEX Rosia Montana – Romania using fire assay from samples with weight 30 g, followed by Au content determination by AAS (methodology code Au-AA25). The detection limit of this method is 0.01 ppm. One quarter of samples was send to the laboratory ALS Loughrea in Ireland for analysis of other elements using the ICP method (methodology code ME-MS41). Detection limits for this method are following: Ag (0.5–100 ppm), Al (0.01–50 %), As (5–10000 ppm), Ba (10–10000 ppm), Be (0.5–1000 ppm), Ca (0.01–50 %), Cd (0.5–1000 ppm), Co (1–10000 ppm), Cr (1–10000 ppm), Cu (1–10000 ppm), Fe (0.01–50 %), Ga (10–10000 ppm), K (0.01–10 %), La (10–10000 ppm), Li (10–10000 ppm), Mg (0.01–50 %), Mn (5–10000 ppm), Mo (1–10000 ppm), Na (0,01–10 %), Ni (1–10000 ppm), P (10–10000 ppm), Pb (2–10000 ppm), Rb (10–10000 ppm), S (0.01–10 %), Sb (5–10000 ppm), Sc (1–10000 ppm), Sr (1–10000 ppm), Th (20–10000 ppm), Ti (0.01–10 %), Tl (10–10000 ppm), U (10–10000 ppm), V (1–10000 ppm), W (10–10000 ppm), Zn (2–10000 ppm), Zr (5–10000 ppm). This method offers an excellent review on chemical composition of the studied samples with a broad spectrum of elements, but the precision of measurements for some elements is quite limited and it can be used just for semi-quantitative evaluation. They include lithophile elements and elements such as W, Zr, REE that require other methods of chemical decomposition of samples for their precise analyses.

For mineralogical and petrological studies of mineralisation and alteration, standard polished thin sections of representative samples of vein mineralisation and altered rocks from the PT-1 drill hole were prepared. They were studied in an optical microscope in reflected and transmitted polarized light and using electron microprobe. Back-scattered electron images, WDS and EDS analyses were acquired using CAMECA SX 100 (D. Štúr Institute of Geology, Bratislava) and JEOL JXA-8530F (Earth Science Institute of the Slovak Academy of Sciences, Banská Bystrica) electron microprobes. Gold and tetrahedrite was analysed using 25 kV accelerating voltage, 15 nA beam current and 1–3 μm beam diameter. Carbonates and silicate minerals were examined using 15 kV accelerating voltage, 10 nA beam current, and 8 μm beam diameter.

Mineral composition of selected samples of altered rocks was also studied using XRD analyses of bulk rock and clay fraction. For bulk sample XRD analysis, a corundum-spiked sample was milled in methanol using a McCrone Micronizing Mill (Środoń et al., 2001). The clay mineralogy was determined from oriented samples prepared from separated clay fractions (< 2 μm) dried on glass slides and saturated with ethylene-glycol vapour. The XRD analyses were carried out using Philips X-ray PW-1710 diffractometer with Ni-filtered CuKα radiation (Earth Science Institute of the Slovak Academy of Sciences, Bratislava). The scanned range was 4–65°2θ in bulk samples and 2–50°2θ in oriented samples with the scanning speed of 0.8–2 sec per step (0.02°2θ). Quantitative evaluation of XRD records was performed using the RockJock program (Eberl, 2003).

5. MINERALISATION

In the study area, manifestations of epithermal mineralisation occur in products of andesite volcanism of the Lower structural unit of the Štiavnica Stratovolcano and in the Prochot Intrusive Complex in a territory of 4 × 1.5 km. The mineralisation occurs in zones of distinct argillic alteration with local silicification and is variably hosting opal, kaolinite, illite, smectite, alunite, cristobalite, and pyrite. Hydrothermal brecciation and local quartz stockwork are also common. These zones show a NW–SE strike and a relatively shallow dip about 30–50° to SW. In a strongly covered ground with minimum natural outcrops, 8 apparent alteration zones 10 to 50 m thick and 150 to 1000 m long as well as several smaller zones have been identified yet. Argillic alteration with strong pyritisation also occurs on subvertical younger fault structures of a N–S to NE–SW direction. In terms of gold content, the most important part of the ore field is located in the southern part of area at the Prochot-Lazy locality. Until now, two flat SW dipping parallel mineralised alteration zones are known here divided by a distance of about 70 m (Fig. 3) – southern continuation of the Main zone and East zone. Individual alteration zones are probably interconnected while intensive alteration with mineralised breccia zones occur in trenches in the length of about 650 m and in the width of 1 to 11 m.

In the past, the Main zone was followed by several adits, test pits, trenches, and surface excavations (Fig. 3). Manifestations of epithermal mineralisation and accompanying intensive alteration are related to a regional fault structure of a NW–SE direction steeply dipping to NE. The high density of mining works, as well as increased Au content above 3 ppm in samples of rocks on the surface (max. 20.7 ppm Au in a sample of vein rock) are present in the NW part of the Main zone in a length of about 150 m. On the surface, the mineralisation with increased Au content occurs in the form of silicified, adularized, argillised pieces of rock and silica sinter or breccia. The texture of hydrothermal vein rock from the oxidation zone at the surface is porous to skeleton with pseudomorphs of quartz after leached calcite. According to the presence of extracted spaces in the PT-1 hole, the structure was developed down to the depth of at least 40 m from the surface (Fig. 4).

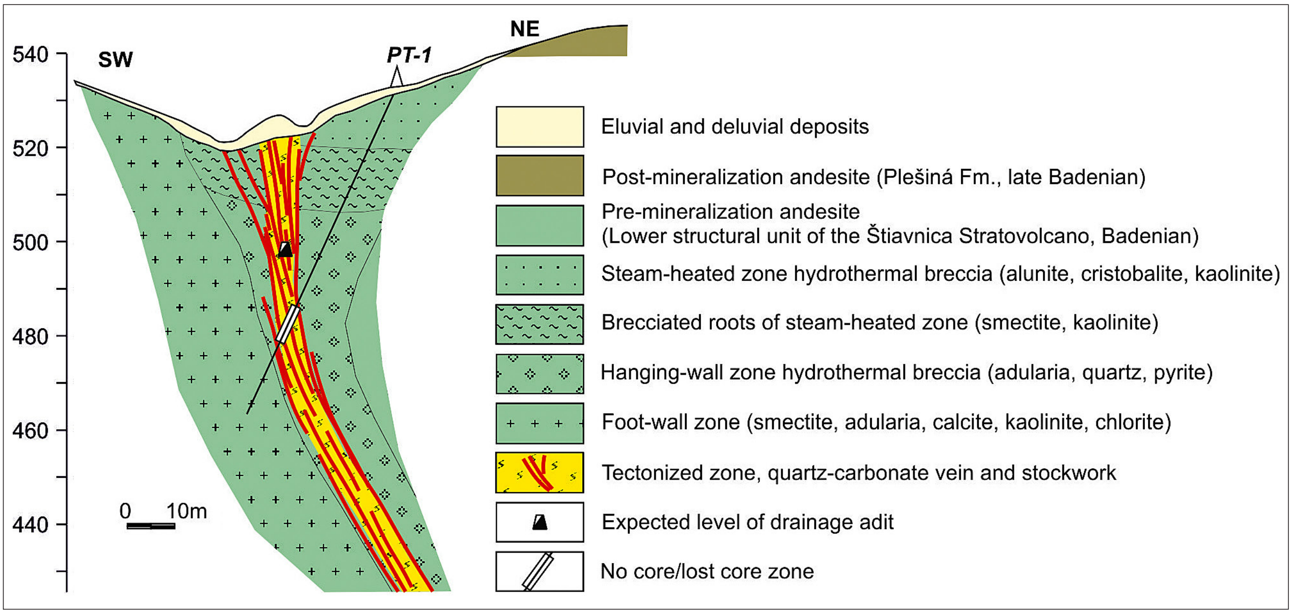

Fig. 4. Schematic cross-section along the PT-1 drill hole at the Prochot-Lazy site with interpreted position of mineralised vein structure and individual alteration zones.

In the PT-1 drill hole the mineralisation is hosted by altered and brecciated andesite (lower structural unit of the Štiavnica Stratovolcano) penetrated by quartz – calcite veins and stockwork (Figs. 4 and 5). Hydrothermal breccia occurs from surface to depth of 46 m, while the real thickness of the breccia zone reaches at least 30 m. Monomict, polymict, initial breccia as well as breccia with well-rounded rock fragments were identified. Transitions among individual types of breccia are gradual. The size of fragments reaches up to 20 cm. Breccia matrix consists of clay minerals, opal – chalcedony, quartz, and pyrite. Pyrite content ranges from 3 to 5 %, locally up to 10 %. Breccia with argillic and opal-chalcedony matrix are barren and increased gold content up to tenths of ppm is typical just for silicified breccia. Vein mineralisation was drilled in depth from 46 to 48 m.

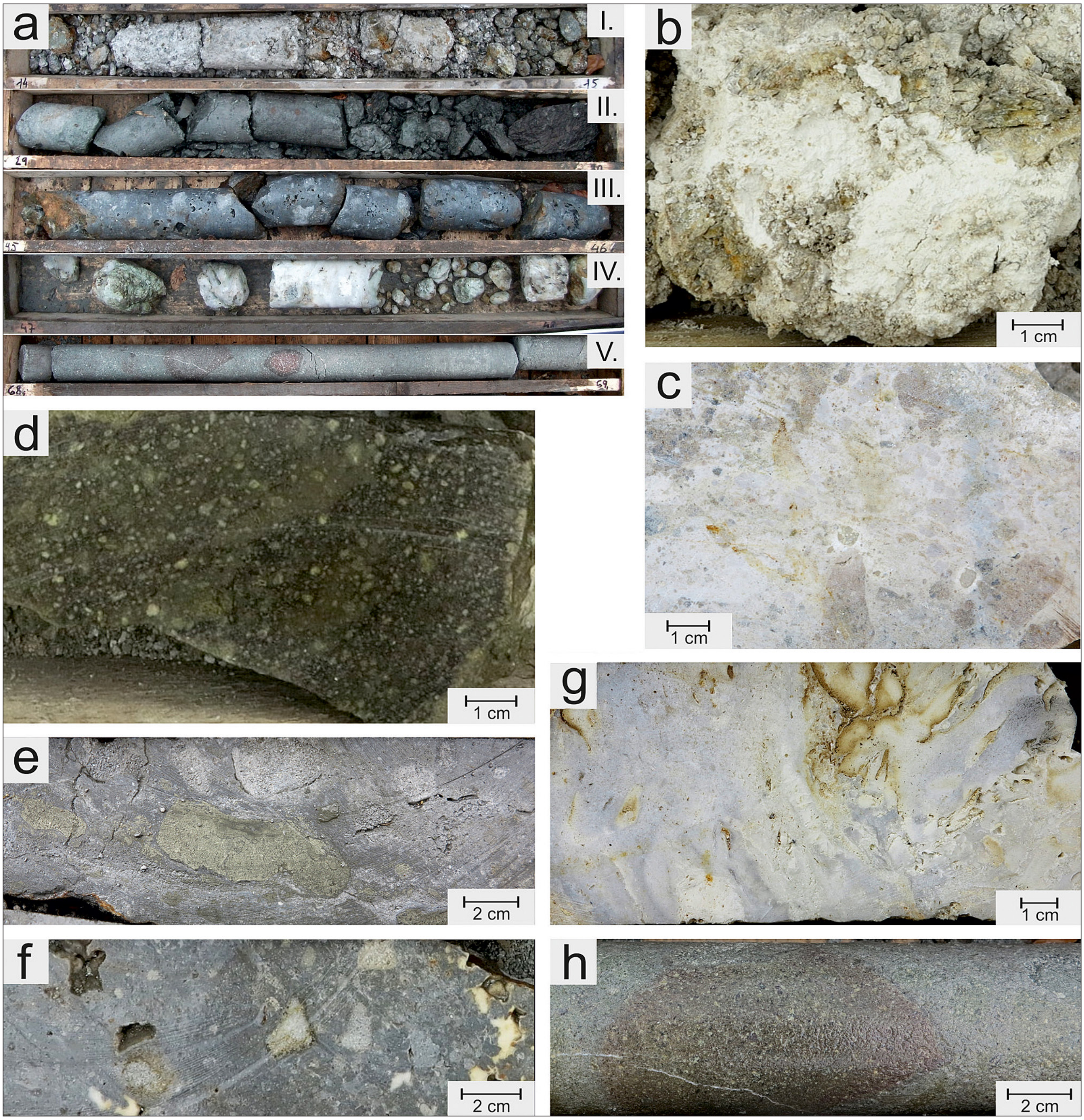

Fig. 5. Textural features of altered rocks and vein mineralisation from the PT-1 drill hole at the Prochot-Lazy site: A – compilation of images of typical sections of core: I. steam-heated zone (14–15 m), II. roots of steam-heated zone (29–30 m), III. hanging-wall zone (45–46 m), IV. vein (47–48 m), V. foot-wall zone (68–69 m); B – alunite-rich rock from the brecciated steam-heated zone (14.6 m); C – opal/chalcedony cementing brecciated andesite at the base of the steam-heated zone (23.8 m); D – smectitised andesite below the steam-heated zone (30.8 m); E – adularia-rich polymict breccia with fragments of variably altered andesite from the hanging-wall zone (43.6 m); F – porous, highly silicified and pyritised polymict breccia, with some cavities filled by late quartz (white) from the hanging-wall zone (45.2 m); G – highly tectonised quartz-carbonate vein filling (47.6 m); H – altered andesite lava breccia (smectite-calcite-chlorite-kaolinite) from the foot-wall zone (68.4 m).

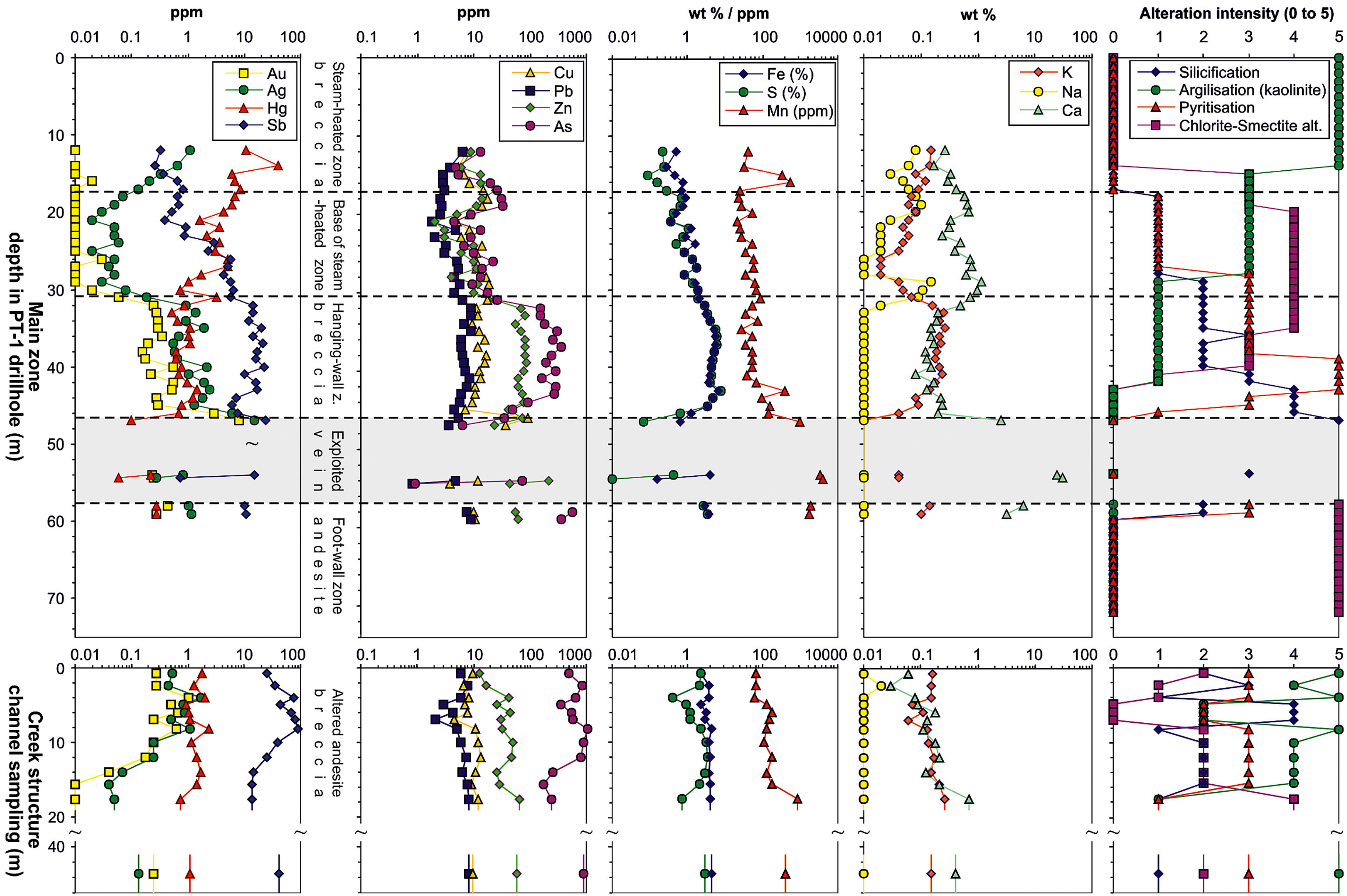

Fig. 6. Geochemical and logging profiles of selected elements and alteration pattern intensity along the PT-1 drill hole in the Main zone and along channel sampling in Creek structure at the Prochot-Lazy site with interpreted position of vein structure and individual alteration zones.

The vein rock has a massive texture, composed of fine-grained quartz and coarse-grained calcite. The average Au content in 46–48 m section of hole reaches 5.4 ppm Au (max. 7.88 ppm Au) and 10.5 ppm Ag (Fig. 6). Below, in depth 48 to 58 m exploited spaces were drilled and the core was also lost due to strong disintegration of rock. From the 10 m thick zone, only a disintegrating rock of sugar-like texture could be recovered in the depth of 54–55 m, composed of quartz and calcite. From 58 to 60 m quartz-carbonate stockwork with tenths of ppm of Au is present in argillised rock. The thickness of veinlets reaches just a few centimetres, max. 10 cm. From 60 to 73 m strongly altered rock without mineralisation was found.

The Au:Ag ratio in vein rock varies from 1:1 to 1:6. In the PT-1 drill hole gradual increase in Au:Ag ratio up to the value 1:100 was determined in the hanging-wall of the vein structure in the depth of 19 m in a direction to surface (Fig. 6). The Ag content in the hole ranges from 0.02 to 14.9 ppm (1.2 ppm on average). The highest Ag content occurs in vein mineralisation, while in breccia the maximum Ag content of 2.4 ppm was determined. Concentrations of Cu, Bi, Mo, Pb, and other metals are nearly below limits of detection. Elevated values reach just Sb (81 ppm on average, max. 148 ppm), As (71 ppm, but in the vicinity of vein up to 201 ppm in average, max. 555 ppm) and very slightly Zn (max. 52 ppm).

The southern continuation of the Main zone was explored by trenches and it is represented by a multi-generation breccia hosting quartz and carbonate gangue as well as altered rock cemented by clay. The zone is penetrated by a weak stockwork of dark-grey quartz with pyrite and at margins it passes into a strongly argillised andesite with a dense pyrite dissemination. Breccia as well as argillised andesite is disturbed by two generations of faults that are also accompanied by argillisation. The older system of faults has a NNE–SSE direction and subvertical dip. The younger fault system has a NE–SW direction and 60–80° dip. Breccia and quartz stockwork explored by channel sampling and trenches contain 0.02 to 3.25 ppm Au (Fig. 6), on average 0.53 ppm Au and 1.14 ppm Ag within 8.3 m of average thickness of mineralised structures. Argillised andesite with pyrite contains up to 0.24 ppm Au. The Ag contents roughly correlate with Au contents, ranging from 0.04 to 4.43 ppm Ag. Thus, the Au:Ag ratio is very similar to that in the hanging wall of vein in the PT-1 drill hole (mostly close to 1:1–1:2). Zn, Sb, As contents are also very similar to this part of the hole; however, as content is slightly higher, 436 ppm on average, reaching up to 3130 ppm in one of the pyrite-rich samples.

The East zone was found just in the PTR-5 trench (Fig. 3), forming a subhorizontal layer of breccia about 5 m thick with average grade of 0.26 ppm Au and 0.12 ppm Ag. Compared to the Main zone it has a lower Au:Ag ratio (1:0.5) and two times higher concentration of phosphorus (up to 2220 ppm, 1400 ppm on average), but the concentration of other elements is similar. Continuation of the zone could not be further explored due to a difficult terrain.

Tab. 1. Representative WDS analyses (wt.%) of gold from vein in the PT-1 drill hole at the Prochot-Lazy site (PT-1/47.6).

	1	2	3	4	5
Ag	22.76	22.82	18.01	17.07	18.61
Fe	n.a.	n.a.	0.03	0.05	0.04
Ni	n.a.	n.a.	0.01	0.00	0.00
Au	77.80	77.31	80.90	80.55	79.94
Te	0.00	0.00	0.20	0.18	0.04
Bi	n.a.	n.a.	0.00	0.18	0.00
S	0.00	0.00	0.01	0.03	0.02
Σ	100.57	100.13	99.17	98.04	98.65
formula calculated on the basis of 1 atom					
Ag	0.35	0.35	0.29	0.28	0.30
Fe	n.a.	n.a.	0.00	0.00	0.00
Ni	n.a.	n.a.	0.00	0.00	0.00
Au	0.65	0.65	0.71	0.72	0.70
Te	0.00	0.00	0.00	0.00	0.00
Bi	n.a.	n.a.	0.00	0.00	0.00
S	0.00	0.00	0.00	0.00	0.00
Σ	1.00	1.00	1.00	1.00	1.00

n.a. – not analysed

6. MINERALOGY OF VEIN MINERALIZATION IN PT-1 DRILL HOLE

Samples with hydrothermal vein mineralization in the depth interval 47–48 m from the PT-1 drill hole contained the following minerals:

Gold typically forms isolated allotriomorphic grains in quartz with tetrahedrite and pyrite (Fig. 7C–D). Grains are irregularly distributed and their size does not exceed 20 μm. Gold contains significant amount of Ag (17.07 to 22.82 wt.%; Tab. 1). Trace concentrations of Te (up to 0.20 wt.%) and Bi (up to 0.18 wt.%) were also detected.

Tetrahedrite occurs in the form of isolated allotriomorphic grains in quartz up to 30 μm in diameter (Fig. 7C). WDS analyses (Tab. 2) show that tetrahedrite contains significant concentrations of Ag (up to 10.36 wt.%), Zn (up to 7.28 wt.%) and As (up to 1.89 wt.%). Trace amounts of Pb (up to 0.15 wt.%) and Cd (up to 0.13 wt.%) were also detected.

Pyrite was determined by EDS analyses and is very rare in vein filling. It forms separate idiomorphic grains in quartz up to 12 μm in diameter (Fig. 7C).

Quartz is the dominant gangue mineral of the studied mineralization, accompanied by less frequent carbonate minerals. Quartz has white or grey colour and massive texture (Fig. 5G). Local vugs in quartz often contain Ca-Fe-Mn carbonates (Fig. 7E).

Carbonate minerals are minor part of the vein mineralisation. Calcite dominates in the form of macroscopic low-crystalline aggregates, forming veinlets or bladed crystals in vuggy quartz (Fig. 7E). Chemical composition of calcite was confirmed by EDS analyses. Rhodochrosite and siderite are less common and of microscopic size, typically occurring as zoned aggregates in

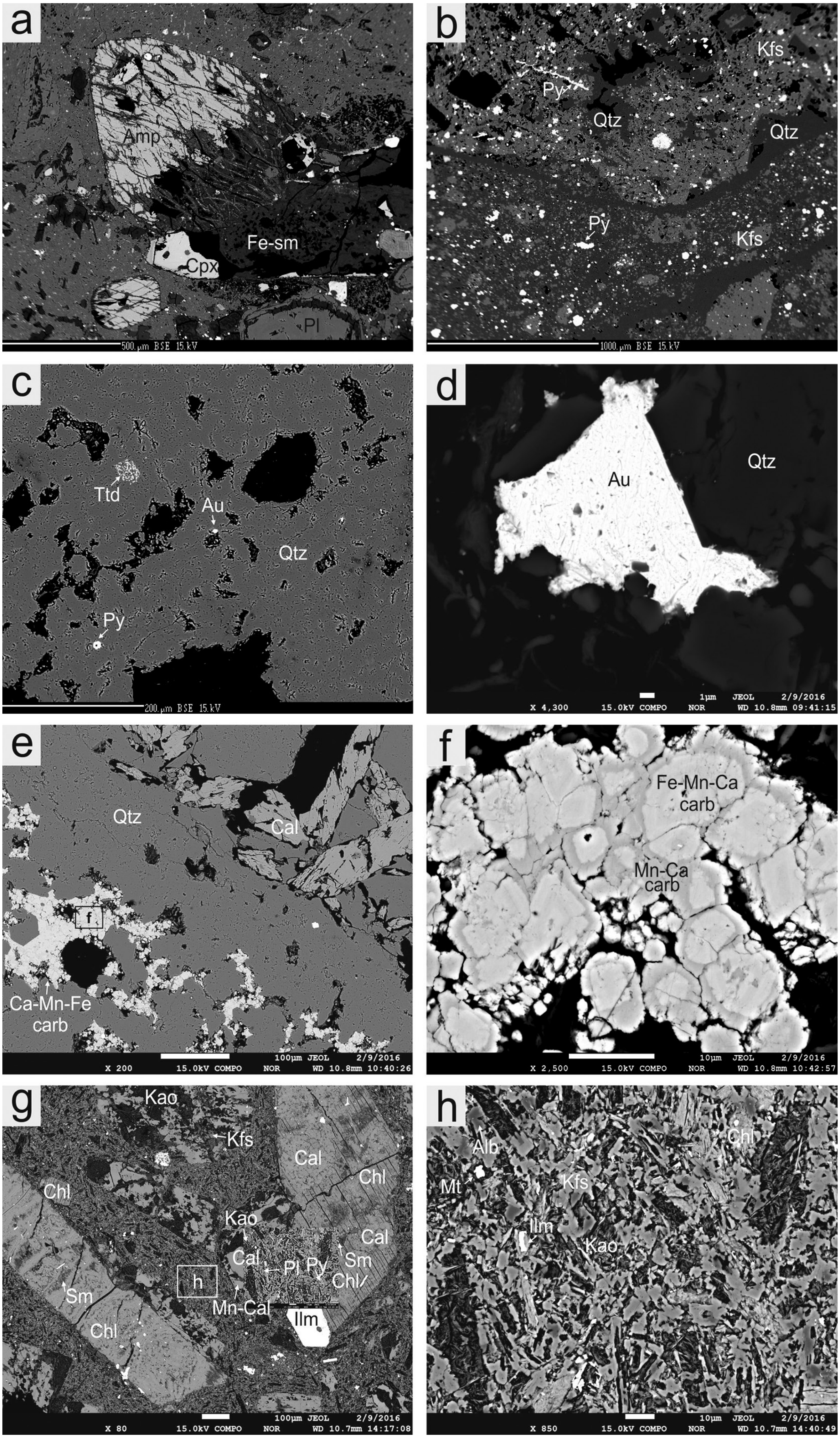

Fig. 7. Backscattered electron images of alteration and mineralisation from the PT-1 drill hole at the Prochot-Lazy site: **A** – andesite below the steam-heated zone with smectite replacing mafic minerals and selected zones in plagioclase (30.8 m); **B** – breccia from the hanging-wall zone with fragment of andesite replaced by adularia, pyrite, and quartz, cemented by fine-grained quartz with pyrite (45.4 m); **C** – tiny grains of gold, pyrite, and tetrahedrite disseminated in vein quartz (47.6 m); **D** – detail of gold grain in a cavity of vein quartz (47.6 m); **E** – quartz-carbonate vein with bladed calcite grains overgrown by quartz, while cavities in quartz are filled by Ca-Mn-Fe carbonates (48.0 m); **F** – detail of carbonates from Fig. E with Mn-Ca carbonate overgrowing Fe-Mn-Ca carbonate; **G** – andesite from the foot-wall zone with mafic minerals replaced by chlorite, smectite, and calcite and plagioclases replaced by adularia and kaolinite (68.4 m); **H** – detail of groundmass from Fig. G, composed mostly of K-feldspar, albite, kaolinite, and chlorite Amp = amphibole, Cpx = clinopyroxene, Pl = plagioclase, Fe-sm = Fe-smectite, Qtz = quartz, Py = pyrite, Kfs = K-feldspar, Ttd = tetrahedrite, Au = gold, Cal = calcite, carb = carbonate, Chl = chlorite, Kao = kaolinite, Alb = albite, Ilm = ilmenite, Mt = magnetite.

Tab. 2. **Representative WDS analyses (wt.%) of tetrahedrite from vein in the PT-1 drill hole at the Prochot-Lazy site (PT-1/47.6).**

	1	2	3	4	5
S	23.61	23.45	23.77	24.14	23.94
Pb	0.13	0.15	0.10	0.11	0.04
Ag	9.32	10.36	10.10	9.46	9.34
Cu	31.44	30.65	30.02	31.05	31.59
Sb	26.05	25.51	24.97	25.83	24.87
Fe	0.00	0.67	0.43	0.15	0.59
Bi	0.05	0.00	0.00	0.04	0.02
Cd	0.00	0.11	0.08	0.11	0.13
Zn	7.28	6.84	6.91	7.12	6.81
As	1.38	1.47	1.89	1.28	1.93
Se	0.00	0.05	0.06	0.00	0.07
Σ	99.26	99.24	98.32	99.35	99.36
formula calculated on the basis of 29 atoms					
Cu	4.49	4.32	4.36	4.48	4.50
Ag	1.51	1.68	1.64	1.52	1.50
Σ A	6.00	6.00	6.00	6.00	6.00
Cu	4.14	4.12	3.93	4.00	4.09
Fe	0.00	0.21	0.13	0.05	0.18
Zn	1.94	1.83	1.85	1.89	1.80
Cd	0.00	0.02	0.01	0.02	0.02
Pb	0.01	0.01	0.01	0.01	0.00
Σ B+C	6.09	6.19	5.94	5.96	6.09
Sb	3.73	3.66	3.60	3.68	3.53
As	0.32	0.34	0.44	0.30	0.45
Bi	0.00	0.00	0.00	0.00	0.00
Σ X	4.06	4.01	4.04	3.98	3.98
S	12.85	12.80	13.01	13.06	12.91
Se	0.00	0.01	0.01	0.00	0.02
Σ Y+Z	12.85	12.81	13.02	13.06	12.93

vuggy quartz (Fig. 7F). Back-scattered electron images show that siderite is partially replaced by rhodochrosite. According to WDS analyses (Tab. 3, Fig. 8) rhodochrosite contains up to 11.8 wt.% of CaO and up to 3.39 wt.% of FeO. Siderite analyses shows significantly increased amount of MnO (up to 23.36 wt.%) and CaO (up to 6.8 wt.%).

7. HYDROTHERMAL ALTERATION

In the upper part of the PT-1 drill hole in oxidation zone down to depth of about 20 m, alteration occurs in the form of variably argillised hydrothermal breccia with common presence of Fe-oxides (Fig. 5B). Typical is a fine-grained disintegrating material of grey, grey-green and white colour, characteristic for kaolinite. XRD analyse of clay fraction from depth of 14.6 m determined the presence of predominant natroalunite, accompanied by less frequent alunite, cristobalite, and minor smectite (Tab. 4). Geochemical data are available just from the depth of 12 m and revealed increased content of Hg and depletion in S and Sb (Fig. 6).

From the depth of 20 to 32 m the alteration pattern gradually changes, the intensity of argillisation decreases and the rock is less disintegrated. At the beginning of this section breccia with opal/chalcedony cement is quite common (Fig. 5C), but gradually the amount of siliceous mater decreases and colour changes from white to green-grey (Fig. 5D). The rock flour that is cementing monomict breccia contains some pyrite. According to the whole-rock XRD analysis of section of core unaffected by brecciation from the depth of 30.8 m, the main alteration mineral is smectite accompanied by rarer kaolinite (Tab. 4). Quartz is nearly absent, while K-feldspar content reaches 2.4 % and pyrite content is 1.6 %. Primary magmatic minerals, especially plagioclase (14 %) and amphibole remain partially unaltered. XRD analyse of clay fraction confirmed the prevalence of smectite over kaolinite, while the presence of mixed-layered silicates was not determined (Tab. 4). Microscopic study has shown that smectite replaces especially mafic minerals and partially plagioclase, but smectite is also the dominant secondary mineral in altered groundmass (Fig. 7A). Based on its chemical composition smectite is close to Fe-montmorillonite. Geochemically, this alteration zone shows only a minor increase in S, Sb, and Cu, especially if compared to the oxidation zone (Fig. 6).

From the depth of 32 m down to vein structure in the depth of 47 m a polymict grey and grey-green breccia is present, cemented by silicified rock flower, rich in disseminated pyrite (Fig. 5E–F). Fragments of grey and green colour are affected by various types of alteration. The whole-rock XRD analysis from the depth of 43.6 m has determined dominant presence of adularia (52 %), quartz (32 %) and less frequent pyrite and

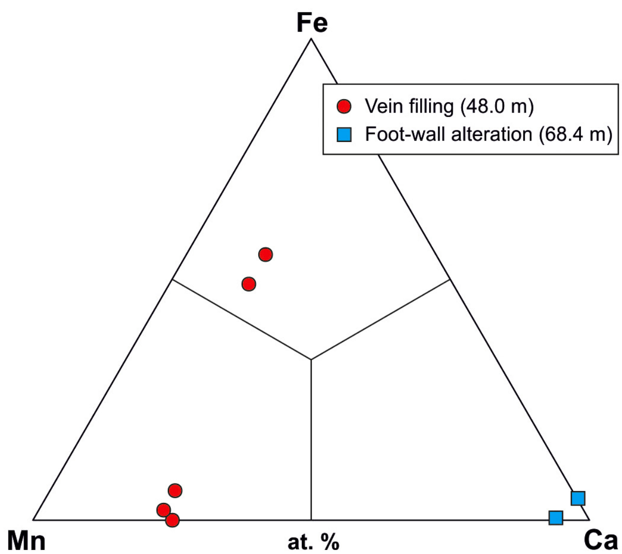

Fig. 8. **Chemical composition of carbonates from the PT-1 drill hole at the Prochot-Lazy site based on electron microprobe analyses.**

marcasite (13 %; Tab. 4). The presence of clay minerals is very minor, represented especially by illite (1.2 %). Based on microscopic study, the composition of fragments is variable, as several generations of breccia are probably present here. In some of them hydrothermal quartz dominates, cemented and overprinted by marcasite that locally has a typical collomorph texture. Other fragments are represented by heavily altered andesite, locally with partially preserved porphyritic texture. Phenocrysts as well as groundmass are altered especially by K-feldspar (adularia) and younger quartz, rarely by sericite (Fig. 7B). In zones of intensive silicification fragments are cemented by fine-grained quartz with concentric texture. Disseminated pyrite is also common and sometimes it forms short veinlets. Geochemically, this section is manifested by increased amount of S, Fe, As, Cu, and several other metals (Fig. 6). Potassium, accompanied by obvious depletion in Ca, Na, Mg and Al, which is related to total replacement of plagioclases and mafic minerals, is also increased.

In the section below the vein structure, i.e. below the depth of 58 m, there is present propylitised andesite of green colour, locally with indications of a breccia texture (Fig. 5H). According to whole-rock XRD analyse of a sample from the depth of 68.4 m the main alteration mineral is again smectite (30 %), but calcite (13 %), kaolinite (11 %), K-feldspar (11 %), quartz (11 %), chlorite (10 %), and illite (5 %) are also present (Tab. 4). Pyrite content is just small (2.5 %). Magmatic plagioclase and pyroxene are preserved just in accessory amounts. The XRD analyse of clay fraction confirmed the prevalence of smectite over chlorite and kaolinite, while the presence of mixed-layered silicates was not determined (Tab. 4). According to microscopic study this sample represents altered andesite with preserved porphyritic texture, but most of the phenocrysts are totally altered. Plagioclase is replaced especially by calcite, but sporadic older K-feldspar and rarer sericite are also preserved (Fig. 7G). Locally, calcite is enriched in manganese (Fig. 7G, Tab. 3). Mafic minerals are variably replaced by smectite and chlorite (composition between clinochlore and chamosite). The groundmass is fine-grained, composed mostly of K-feldspar, albite, kaolinite, and chlorite (Fig. 7H). The rock also host tiny calcite veinlets. Rare quartz locally fills pores in the rock. Geochemical data are available just to the depth of 60 m, while in accordance with the mineral composition of the rock they show increased content of Ca (Fig. 6). Increased concentrations also show most of metals, but their concentrations are lower than in altered rocks above the vein structure, except of manganese.

The southern continuation of the Main zone explored by channel sampling showed alteration pattern similar to the hanging wall breccia zone in the PT-1 drill hole (Tab. 4). According to whole-rock XRD analyses of the outcrop in the Jastrabský potok creek, nearly the entire section of the channel sampling here has very high content of adularia (60 to 76 %), accompanied by quartz (13 to 27 %), pyrite (6 to 8 %), and variably illite

Tab. 3. Representative WDS analyses (wt.%) of carbonates from vein and altered rocks in the PT-1 drill hole at the Prochot-Lazy site.

	1 (rds)	2 (rds)	3 (rds)	4 (sid)	5 (sid)	6 (sid)	7 (cal)	8 (cal)
Sample	PT-1/48.0	PT-1/48.0	PT-1/48.0	PT-1/48.0	PT-1/48.0	PT-1/48.0	PT-1/68.4	PT-1/68.4
SiO_2	0.06	0.25	0.52	0.19	0.11	0.23	0.06	0.06
CaO	11.80	10.63	10.03	6.40	6.82	6.49	52.62	52.28
FeO	0.54	1.58	3.39	31.13	34.16	31.00	2.47	0.24
MnO	47.37	47.18	45.56	23.36	19.36	22.24	0.25	4.55
MgO	0.31	0.16	0.16	0.29	0.21	0.31	0.32	0.15
Al_2O_3	0.02	0.10	0.16	0.05	0.04	0.10	0.01	0.04
SrO	0.00	0.04	0.01	0.04	0.05	0.00	0.11	0.01
BaO	0.00	0.02	0.06	0.00	0.00	0.00	0.05	0.00
*CO_2	39.42	39.28	39.39	39.31	38.75	38.70	43.48	44.30
Σ	99.51	99.26	99.29	100.83	99.50	99.10	99.37	101.62
formula calculated on the basis of 1 atom								
Si	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
Ca	0.24	0.21	0.20	0.13	0.14	0.13	0.95	0.93
Fe	0.01	0.02	0.05	0.49	0.54	0.49	0.03	0.00
Mn	0.75	0.80	0.73	0.37	0.31	0.36	0.00	0.06
Mg	0.01	0.00	0.00	0.01	0.01	0.01	0.01	0.00
Al	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sr	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ba	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Σ	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

*calculated

Tab. 4. Mineral composition of altered rocks (wt.%) from the PT-1 drill hole and from the channel-sampled outcrop in the Main zone at the Prochot-Lazy site based on quantitative XRD whole-rock analyses and semiquantitative XRD analyse of clay fraction. Note, that concentration values below 0.5 wt.% might represent a background signal and the presence of such phases is uncertain.

Whole-rock									Clay fraction		
	PT-1/30.8	PT-1/43.6	PT-1/68.4	0 to 1.3 (GV-108)	3.4 to 4.4 (GV-110)	6.4 to 7.4 (GV-113)	11 to 13 (GV-116)	16 to 19 (GV-119)	PT-1/14.6	PT-1/30.8	PT-1/68.4
Quartz		32.4	10.9	21.3	12.5	27.4	21.0	6.8			
K-feldspar	2.4	52.4	11.5	67.0	75.6	64.3	60.0	29.7			*
Plagioclase	14.0		1.5					38.2		**	*
Calcite	1.6		13.3		0.2		0.2	4.2			
Dolomite	0.4	0.3			1.0	0.2	0.3				
Ankerite	0.4					0.4	0.3				
Siderite					0.5			0.1			
Amphibole	3.3										
Pyroxene	0.4	0.1	1.6								
Pyrite	1.6	13.4	2.5	5.9	8.0	6.2	6.2	0.3			
Galena				0.1				0.1			
Anhydrite			0.4								
Hematite			0.1					0.2			
Goethite	0.9							0.4			
Apatite	1.0	0.1	0.2					0.1			
Anatase				0.5	0.4	0.3	0.3				
Ilmenite	0.6							0.5			
Kaolinite	12.6		11.5	0.7			0.5	1.6		**	**
Illite (Muscovite)	0.5	1.2	5.1	4.5	1.8	1.1	10.0				*?
Montmorillonite	59.1		30.4					7.3	*	***	***
Biotite			0.6				1.6	0.8			
Chlorite	1.3		10.4		0.2		0.1	9.8			**
Alunite									**		
Natroalunite									***		
Cristobalite									**		

*** >30 %; ** 5–30 %; * <5 %

(1 to 10 %). According to thin section observations, adularia and minor illite are mostly hosted by altered fragments of andesite in breccias where they replace former plagioclase phenocrysts, but adularia is also largely included in groundmass of the fragments. Locally, multiple brecciation can be recognised, including rock-flour and strong pyrite alteration. Geochemical data also show a similar geochemical pattern as it was observed in the hanging wall zone in the PT-1 hole, i.e. high K/Na ratio, high Mn content, and increased Fe and S values related to strong pyrite alteration. Interestingly, there is an apparent increase in K, Ca, Mn, and Zn towards the northern end of the continuous channel sampling, accompanied by depletion of most metals, which probably indicates transition to less altered rocks more distant from the source structure. Whole-rock XRD analyse and thin section petrography of a sample from this part of the section confirmed the presence of mostly unaltered plagioclase phenocrysts (38 %), accompanied by K-feldspar (30 %) and minor chlorite (10 %), quartz (7 %), smectite (7 %) and calcite (4 %), mostly replacing former mafic minerals (Tab. 4, GV-119). Pyrite and quartz veining is nearly absent.

8. DISCUSSION

Exploration at the Prochot-Lazy locality has discovered widespread alteration zones with continuous low-grade breccia and a high grade mineralised vein – veinlet structure in the depth of 46 to 59 m of the PT-1 drill hole. However, only the first and last meter of this interval had some core recovery. The remaining part with zero recovery represents worked-out spaces and/or a soft disintegrated rock that was washed out during drilling.

In this interval the probable nature of the rock is indicated by scattered pieces of crushed material from the depth of 54 to 55 m, composed of quartz and calcite with sugary texture. Because the hanging-wall of the exploited space is made by hard fine-grained quartz with 8 ppm of Au, we assume that the target of mining was a tectonically crushed vein filling or a quartz-carbonate stockwork with gold grades possibly even significantly higher than 8 ppm of Au.

The studied mineralisation has typical features of both intermediate and low sulfidation epithermal deposit types. The features include silicification and the presence of sericite and adularia, which are typical for both types of deposits. However, the studied mineralisation also contains Mn-carbonates and tetrahedrite, which are more common for intermediate sulfidation type, but the low amount of sulfides and high Au-Ag ratio are more in favour of the low sulfidation type of epithermal deposits (Hedenquist et al., 2000; Sillitoe & Hedenquist, 2003). Thus, the mineralisation seems to have an intermediate position between the both styles of epithermal deposits.

The PT-1 drill hole has confirmed a distinct zonal arrangement of alteration zones. In the hanging wall of the vein, the uppermost zone with kaolinite, alunite, and cristobalite is indicative of a steam-heated environment, probably occupying a former vadose zone. The near-paleosurface environment is also indicated by increased mercury content and low concentration of most other metals, which is the result of high mobility of mercury in vapour at low temperature in contrast to low mobility of precious and base metals (Barnes & Seward, 1997). In steam-heated environments, the presence of alunite and microcrystalline quartz/chalcedony occur in low temperature (< 120°C) and low pH conditions (pH = 2–3; Sillitoe, 2015). The alternative origin of alunite due to active pyrite oxidation in supergene processes is unlikely due to its massive proportion in the rock and the white colour with the absence of limonite/jarosite products of weathering. The steam-heated zone gradually transfers into smectite-kaolinite alteration assemblage, which indicates continuous change towards less acidic conditions in roots of the steam-heated zone, probably below the palaeo-groundwater table. Opal/chalcedony cementing brecciated andesite just at the base of the steam-heated zone is likely to represent palaeo-groundwater table silicification. Deeper occurring adularia-rich zone is a typical proximal wall-rock type of alteration in low- to intermediate sulfidation type of epithermal systems. Remarkable there is an obvious increase in silicification and pyritisation towards the vein structure in the depth (Fig. 6).

Interestingly, the steam-heated zone occurs relatively close to mineralised quartz-carbonate vein (just ~30 m); however, this paleo-surface feature is commonly separated from epithermal precious metal deposits by several hundred vertical meters (Sillitoe, 2015). The observed telescoping of shallower over deeper alteration patterns might be related to descent of paleo-groundwater table due to fault-related uplift, valley incision or sector collapse of the host volcano. The persisting presence of kaolinite in deeper parts of the hole, including footwall of the vein, is probably related to a late-stage descent of the steam-heated waters as the epithermal system waned (Sillitoe, 2015).

The widespread brecciation, which occurs predominantly in the hanging wall of the vein, can be attributed to sealing of the impermeable silicified horizon and eventual build-up of pressures and rupturing, which have probably also caused brecciation of the overlying steam-heated blanket (Mongillo & Allis, 1988).

The foot-wall rocks in the PT-1 drill hole are apparently less altered with only a limited brecciation. The alteration with chlorite, calcite, albite, and various clays is typical for regional propylitisation (cf. Taylor, 2009), probably related to the Prochot Intrusive Complex. However, the presence of adularia, illite, and relatively large amount of calcite (including Mn-calcite) is also indicative of wall rock alteration next to the epithermal vein.

The contrasting difference in intensity of alteration and brecciation between the footwall and hanging wall of the vein suggest that the host structure is inclined. Extensive alteration in the hanging walls usually results from escaping vapours from boiling fluids ascending in a permeable tectonic structure. Decompression-induced boiling is considered as a major trigger for precipitation of gold and adularia in the vicinity of low- and intermediate sulfidation type epithermal systems (e.g., Seward, 1989; Hedenquist & Arribas, 1999). The host structure is inclined either to northeast, as interpreted in the cross-section in Fig. 4, or to southwest. Relative steep inclination to northeast is slightly more favoured based on the position of historical exploration workings at the surface just above the mineralised zone in the PT-1 drill hole, expected level of the drainage adit and course of the mineralised Main zone at the surface which respects topography only if assuming NW dip of the zone.

The alteration pattern and mineralisation in the southern continuation of the Main zone shares several geochemical and mineralogical properties with the hanging-wall breccia zone in the PT-1 drill hole, including strong adularia alteration, brecciation, pyritisation, high K/Na ratio, and Au, Ag and Mn contents. However, the southern continuation of the Main zone was not a target of ancient exploration and mining probably due to the absence of high-grade vein type ores.

The obtained new data on geological setting and properties of the mineralisation at Prochot enable us to affiliate it to the metallogenetic evolution of the hosting Štiavnica Stratovolcano. The studied mineralisation occurs on a fault structure of NW–SE direction in the environment of altered pyroxene andesite of the Lower structural unit (the 1st pre-caldera stage) effusive complex of the stratovolcano. On the NE side in the hanging-wall of the vein structure there occurs a relict of a lava flow of amphibole andesite of the Plešina Formation that is not affected by alteration. This implies that the mineralisation is relatively older compared to most other epithermal systems of the Central Slovakia Neogene Volcanic Field, probably of the Badenian age. This is in agreement with the orientation of the mineralised fault structure, which indicates NE–SW oriented extension. Extensional structures of this orientation are typical for the Badenian stage (Nemčok et al., 1993; Pulišová & Hók, 2015).

There are no other similar epithermal systems of this age known in other parts of the Štiavnica Stratovolcano. However, in the central zone of the stratovolcano the same host rock (pre-caldera stage andesites) host the Au-Ag-Pb-Zn-Cu epithermal deposit at the Rozália mine that is also of the intermediate sulfidation type and shows some mineralogical attributes similar to the vein mineralisation at the Prochot-Lazy site, like a similar Au:Ag ratio of ores (2:1 to 1:1), the presence of Mn-carbonates in vein filling, and adularia-sericite alteration in wall-rocks (Koděra et al., 2005, 2014). In spite of this, the deposit at the Rozália mine is younger, showing different structural control, related to the early caldera stage of the stratovolcano. We can speculate that the magmatic source of fluids for the epithermal mineralisation at Prochot could be related to the evolving large magma chamber below the central zone of the stratovolcano (i.e. similar source to the Rozália mine deposit), but equally probable might be a relationship to late-stage evolution of the local magma chamber below the Prochot Intrusive Complex, which is supported by extensive hydrothermal activity clearly related to this complex.

9. CONCLUSIONS

Though the epithermal vein mineralisation at Prochot was the target of underground mining already several centuries ago, a very little information existed about it till now. In this study, we have discovered and characterised epithermal Au-Ag mineralisation that was the target of mining in this area. Despite the fact that the exploration PT-1 drill hole has found mostly exploited spaces, the remaining vein material at the surface indicates gold grades at least in tens of ppm. Mineralogical, alteration, geochemical, and geological data along the PT-1 drill hole suggest that the vein mineralisation of the low- to intermediate sulphidation type evolved during the pre-caldera stage in evolution of the hosting Štiavnica Stratovolcano (Badenian). This mineralisation shares several features with the epithermal Au-Ag-Pb-Zn-Cu deposit at the Rozália mine which can indicate a similar source of magmatic component in the ore-bearing fluids, derived from the magma chamber below the central zone of the stratovolcano. However, a relationship to the Prochot Intrusive Complex and its magmatic source can not be excluded. The Au-Ag mineralisation at the Prochot-Lazy site is the first occurrence of this style of mineralisation outside of the central zone of the stratovolcano and further exploration for this type of mineralisation in the mantle of the stratovolcano is strongly encouraged.

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