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Au-porphyry mineralization in the mantle of the Štiavnica stratovolcano (Western Carpathians)

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Abstract

Au-porphyry occurrences are bound to intrusions of andesite to diorite porphyry in the mantle of the Štiavnica stratovolcano. The most important mineralized body was verified at the locality Beluj. The overall potential of the low grade geological resource, of currently uneconomic ores, reaches 0.5 Moz Au. The rest of localities, in the vicinity of Župkov and Píla, represent mineralogical occurrences of Au porphyry mineralization. Quartz stockwork is the typical indicator of Au-porphyry mineralization. The correlation between quartz stockwork intensity and Au grade in the ore does not exist. Mineralization is related to Na- and K-silicate alteration, commonly overprinted by the intermediate argillic assemblages, especially in the uppermost parts of the zones with quartz stockwork. Magmatic-hydrothermal breccias are rare within the orebodies. The orebody is characteristic by the presence of Fe and Ti-oxides assemblage with minor content of Cu, Zn, Pb sulphides and Bi-Te minerals. Mineralized zones with increased Au grade over 0.1 ppm are accompanied by increased Cu and Zn grades. Au : Cu ratio is very low 1 : 0.08. Extremely low S and As values are probably caused by the lack of lithocap with advanced argillization. Pervasive pyrite rich phyllic alteration rimming the ore bodies and causing geophysical IP anomalies is barren. Au porphyry mineralization is accompanied by economically insignificant manifestations of disseminated Mo mineralization, stockwork-disseminated Pb-Zn mineralization, Bi-Te mineralization and fracture bound zeolite mineralization.

Key words: porphyry intrusions, geochemistry, metallogeny, Neogene volcanics, Beluj, Župkov, Western Carpathians

Introduction

There are several intrusive-hydrothermal centres in the peripheral part of the Štiavnica stratovolcano (Fig. 1). Though some of them were known in the past, they have never been treated by a separate scientific work or studied in detail. This study aims to be the summary of EMED exploration of porphyry style mineralization in this area. At Píla-Mačací vrch site the geochemical works were repeated with similar results as previous exploration (Knésl and Knéslová, 2004). Lithologically similar intrusions are known in Prochot and Šášovské Podhradie areas. Up to date results of stream sediment geochemistry were negative that is why the exploration did not follow up. The most important object with porphyry mineralization was detected at Beluj, therefore there is the highest level of knowledge. Another significant intrusive-hydrothermal centre was discovered in the Župkov area. There the results of preliminary geochemical works were not satisfactory enough for commencing the drilling exploration.

Methodology

Rock samples for mineralogical and geochemical study were collected from natural outcrops, debris, rock floats and drillcore. The drillcore was sampled by 2 meters intervals. Soil samples were collected in the field from the B horizon. Qualitative definition of Au content in selected samples was made by AAS method (fire assay) with detection limit 0.01 ppm in ALS CHEMEX laboratory Rosia Montana, Romania. The rest of elements were defined by ICP MS method (four acid digestion) in ALS CHEMEX Perth, Australia. Detection limits of used analytical method are as follows: Ag – 0.5 ppm, Al – 0.01 %, As – 5 ppm, Ba – 10 ppm, Be – 0.5 ppm, Ca – 0.01 %, Cd – 0.5 ppm, Co – 1 ppm, Cr – 1 ppm, Cu – 1 ppm, Fe – 0.01 %, Ga – 10 ppm, K – 0.01 %, La – 10 ppm, Li – 10 ppm, Mg – 0.01 %, Mn – 5 ppm, Mo – 1 ppm, Na – 0.01 %, Ni – 1 ppm, P – 10 ppm, Pb – 2 ppm, Rb – 10 ppm, S – 0.01 %, Sb – 5 ppm, Sc – 1 ppm, Sr – 1 ppm, Th – 20 ppm, Sr – 1 ppm, Th – 20 ppm, Ti – 0.01 %, Tl – 10 ppm, U – 10 ppm, V – 1 ppm, W –

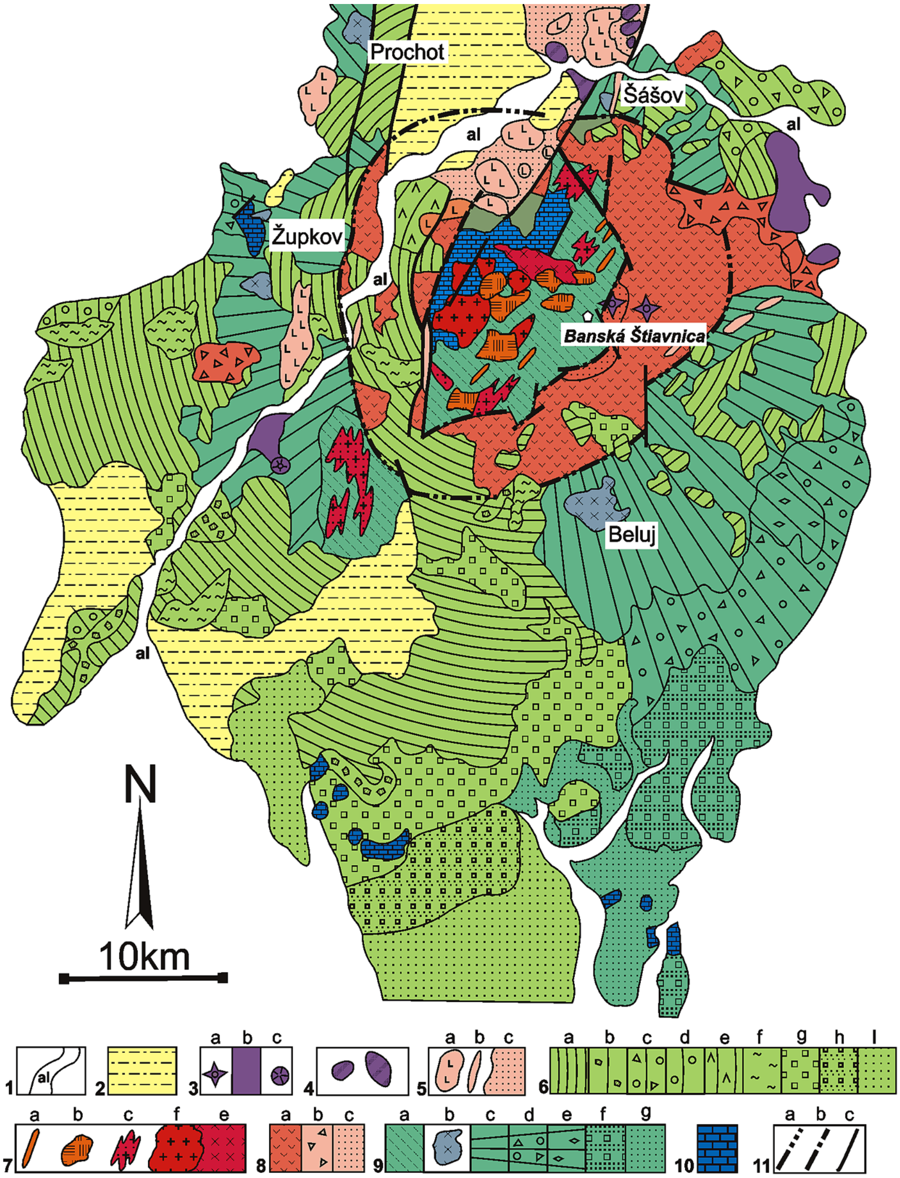
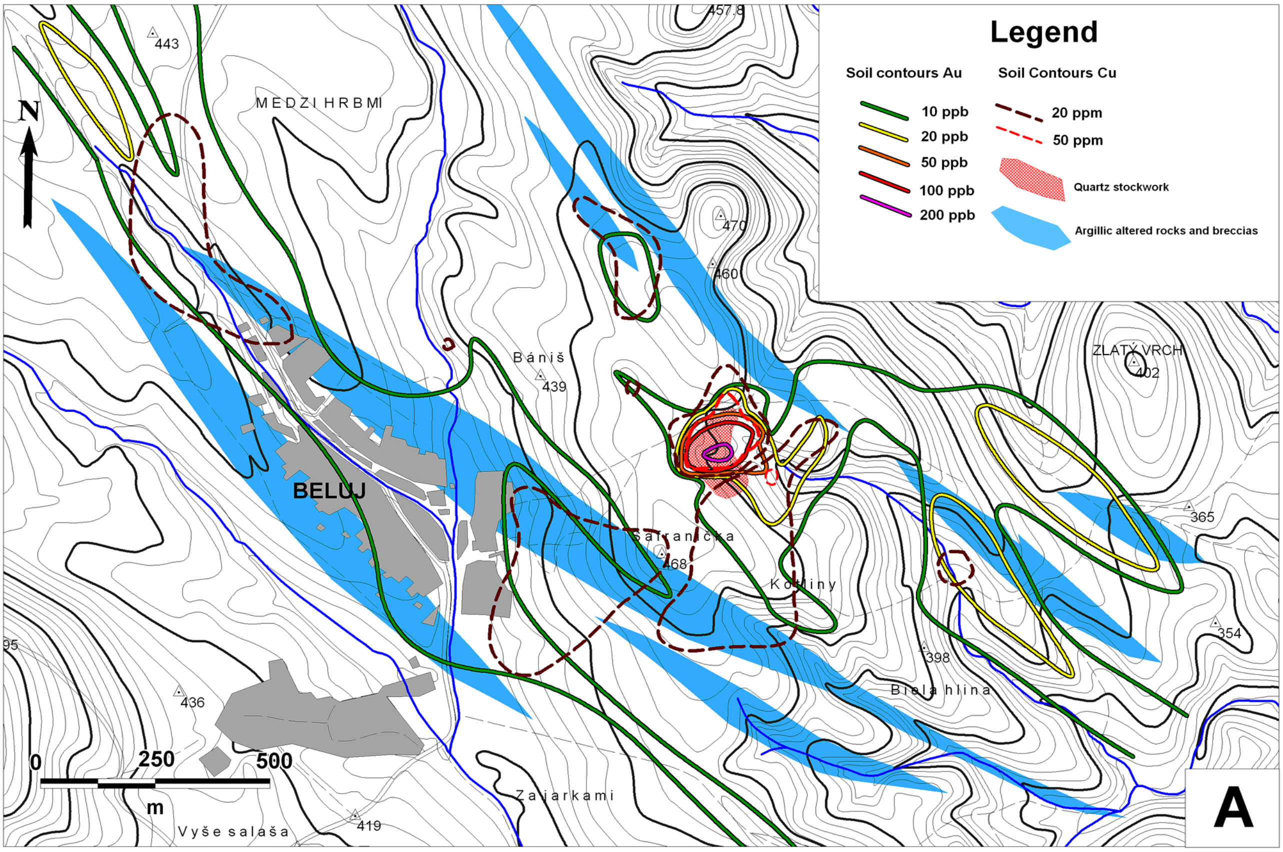


Fig. 1. Schematic geological map of the Štiavnica stratovolcano with localization of Au-porphyry mineralization occurrences (modified after Konečný et al., 1998). 1 – Quaternary alluvial deposits; 2 – Pannonian to Pliocene postvolcanic sediments; 3. Pannonian to Quaternary alkali basalts (a – beck, b – lava flows, c – cinder cone); 4 – Pannonian basaltic andesite lava flows; 5 – Late Sarmatian rhyolites (a – extrusive domes, b – dykes, c – tuffs and epiclastic volcanic rocks); 6 – Upper structural level – post caldera stage (Sarmatian): a – effusive complex of pyroxenic andesites (± amphibole, ± biotite), b – hyaloclastite breccias, c – epiclastic volcanic breccias – conglomerates, d – epiclastic volcanic conglomerates, e – extrusive domes, f – welded tufs, ignimbrites, g – pumice tufs, h – epiclastic volcanic sandstones and reworked pumice tufs, i – tuffitic sandstones and siltstones; 7 – Subvolcanic intrusions: a – quartz diorite porphyry dykes, b – quartz diorite porphyry sills, c – granodiorite porphyry stocks and dyke clusters, d – granodiorite, e – diorite; 8 – Middle structural level – caldera stage (Late Badenian): a – biotite-amphibole andesite dome/flow complex, b – epiclastic volcanic breccias, c – caldera lake sediments; 9 – Lower structural level – pre-caldera stage (Early to Middle Badenian): a – complex of undivided propylitised andesite lava flows and andesite porphyry sills and laccolites, b – pyroxene and amphibole pyroxene andesite effusive complex, c – stratovolcanic complex, lava flows, block and ash pyroclastic flows and epiclastic volcanic breccias, d – epiclastic volcanic breccias and conglomerates, e – pumice tuffs, f – epiclastic volcanic conglomerates and sandstones, g – epiclastic volcanic sandstones; 10 – Basement outcrops; 11 – a – caldera fault, b – marginal faults of the resurgent horst, c – other faults.

10 ppm, Zn – 2 ppm and Zr – 5 ppm. Chemical composition of minerals was randomly tested by EDX method by CAMECA SX 100 device in the State Geological Institute of Dionýz Štúr in Bratislava. Photodocumentation of minerals was done in backward dispersed electrons (BSE) at the same device.

Regional geological setting

The Štiavnica stratovolcano is the largest stratovolcano in the Carpathian volcanic arc. Evolution of the stratovolcano took place in five stages during the Middle Badenian to Early Pannonian time (Konečný, 1971; Lexa et al., 1999). The 1st stage represents the construction of an extensive andesitic stratovolcano. During this stage, several stock-like intrusive bodies of andesite to diorite porphyry were formed on the slopes of the stratovolcano. Some of them show signs of porphyry mineralization, accompanied by hydrothermal mineralization halo. The 2nd stage is represented by interruption of volcanic activity and massive denudation of the uppermost part of the volcanic structure. During this stage, an extensive granodiorite intrusion was emplaced in the subvolcanic level, being accompanied by diorite stock-like body at the northern side. The younger stage of intrusive activity is represented by granodiorite porphyry stock-like intrusions and dykes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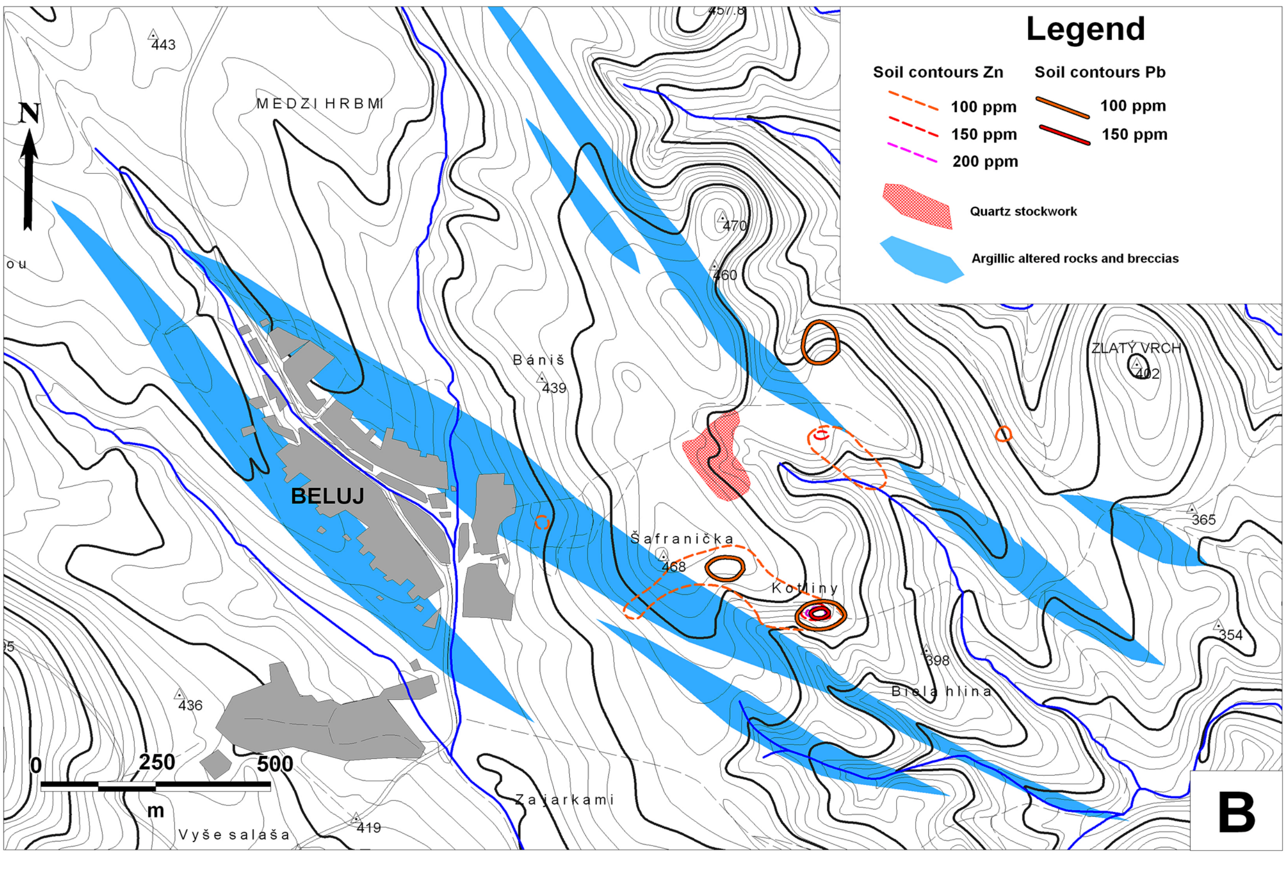
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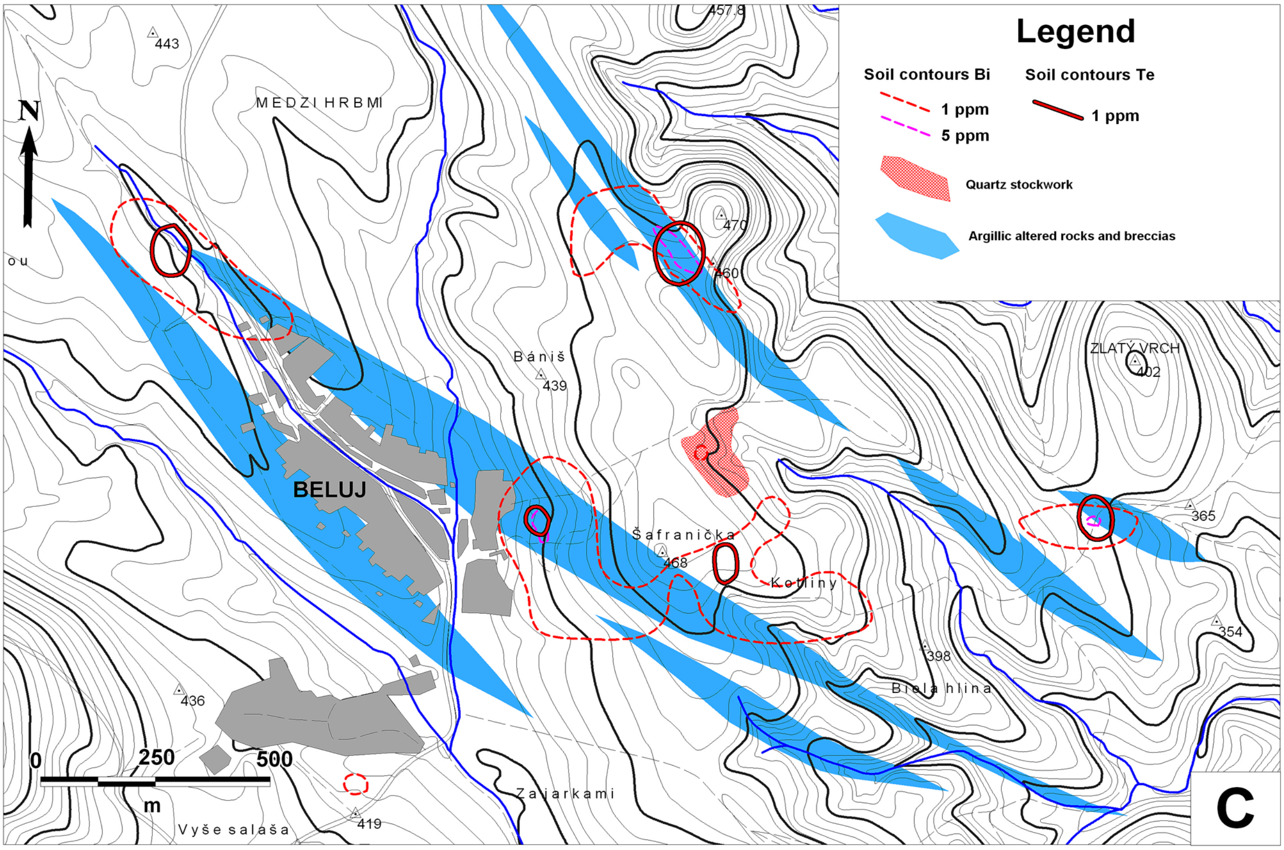

Fig. 2. Map of Beluj intrusive-hydrothermal centre with soil geochemistry anomalies. **A** – Au, Cu; **B** – Pb, Zn (previous page); **C** – Bi, Te.

in the peripheral zone of the granodiorite body. Intrusion activity was accompanied by Fe-skarn mineralizations (Vyhne – Klokoč), Cu-Au skarn-porphyry mineralizations (Zlatno, Šementlov, Sklené Teplice – Vydričná dolina, Pukanec), as well as stockwork-disseminated base metal mineralization. The 3rd stage represents the subsidence of caldera of great dimensions (18 x 24 km), filled by lava flows, extrusive bodies and pyroclastic rocks of total thickness about 350 – 500 m. During the caldera formation the precious metals veins of Rozália style mineralization were formed, followed by sills and dykes of quartz diorite porphyry, emplaced in subvolcanic level and also within the collapsed complex (Koděra et al., 2002). During the 4th stage of renewed explosive and effusive activity of less differentiated andesites, several small stratovolcanoes were formed within the caldera and stratovolcanic slopes (Sitno stratovolcano). The 5th stage represents the uplift of the central block of caldera and formation of resurgent horst structure. Uplifting of the horst was accompanied by rhyolite volcanism and intermediate to low sulphidation epithermal precious to base metal mineralization (Lexa et al., 1999). The latest product of calc-alkaline volcanism took place during the Pliocene and Quaternary and formed small scoria cone Putikov vŕšok with lava flows and two lava necks near Banská Štiavnica (Konečný et al., 1995).

This paper is devoted to porphyry intrusions occurring at a few locations within the stratovolcano slopes, emplaced during the first stage of formation of the Štiavnica stratovolcano (Konečný et al., 1998). The Beluj intrusive centre represents a massive stock-laccolith andesite porphyry body in the S part of the Štiavnica stratovolcano. The Píla – Župkov zone in the proximity of Nová Baňa – Kľak volcano-tectonic zone represents the series of andesite and diorite porphyry intrusions – sills, dykes and small stocks. The Prochot intrusive centre is situated along N – S tectonic zone at the western margin of the Žiarska kotlina depression. Andesite and diorite porphyry intrusion of stock shape was identified here by drillhole MEB-1 (Brlay et al., 1980). Series of andesite to diorite porphyry dykes also occur N of the caldera fault near Šášovské Podhradie. The dykes follow the NNW – SSE fault system.

Beluj intrusive-hydrothermal centre

History of exploration of porphyry targets

Though the Beluj intrusion outcrops very poorly, on the surface it typically forms a rugged topography accompanied by a large area of alteration. In the late Middle Ages, kaolinite clays were locally extracted at several spots in the area for the so-called “Beluj” pottery. Beluj intrusive centre was identified during regional geological mapping of the Štiavnica stratovolcano (Konečný and Lexa, 1977). The Beluj intrusion forms andesite porphyry body of stock

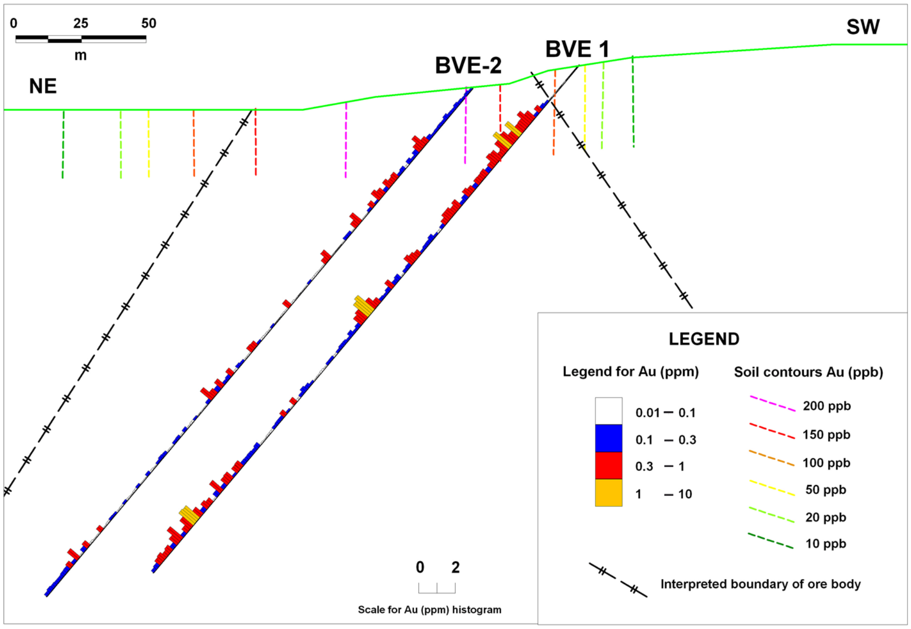

Fig. 3. Section through Beluj Au porphyry orebody with position of scout drillholes and projection of soil geochemistry anomalies to depth.

to laccolith shape. Host rocks represent effusive complex of pyroxene andesites and the complex of extrusions and pyroclastics of hornblende-pyroxene andesites. Both rock types, intrusion itself and overlying unaltered volcano--sedimentary complex of the Sebechleby Formation belong to 1st period of the Štiavnica stratovolcano formation. The concentric aeromagnetic anomaly (Mag high) was traced with diameter 500 to 800 m (Filo et al., 1980). Historical vertical drillhole KB-1/330.3 m was set in the very middle of intrusion and stopped within it. The intrusion is reported to be the stock body of hornblende--hypersthene andesite porphyry with quartz and garnet with quite high level of alteration. The drillhole KB-1 intercepted incipient epithermal mineralization represented by galena impregnations within quartz-carbonate veinlets (Konečný and Lexa, l. c.).

Results of exploration

The Beluj area was tested by the regional stream sediment geochemistry sampling. The series of low grade Au anomalies (around 5 ppb Au, maximum 15 ppb) in the creeks draining the Beluj intrusive centre indicated some metallogenic potential. Altered rock with porphyry style veining was recognized in the road-cut in the central part of the intrusive-hydrothermal centre. The central part was covered by soil geochemistry survey in the grid 100 x 100 m and the outer zone in the 200 x 200 m grid. On the basis of one anomalous soil sample 149 ppb in the central zone, 8 additional infill soil samples were collected in the grid 50 x 50 m to refine the soil anomaly extent. The result was 200 ppb anomaly covering the area of 1 200 m^2 (Fig. 2) with the maximum value 253 ppb. The coverage of 200 ppb anomaly zone corresponds with the extent of porphyry style quartz stockwork and Au positive rock-chips over 0.1 ppm. Maximum grade in rock-chips samples collected from the anomaly reach up to 0.7 ppm Au. 100 ppb anomaly covers the area 100 x 200 m approximately. Two new inclined drillholes BVE-1/253.7 m and BVE-2/254.0 m were drilled in the section oriented SW – NE (Fig. 3).

During the reconnaissance exploration one rock sample of epithermal quartz vein was discovered from the rock pile bordering agricultural fields at Beluj with rich galena impregnations. The sample contained 5.45 ppm Au, 8.9 ppm Ag and 1 % Pb. In a rock sample (argillized silica block) collected W from the intrusive centre Bi anomalous content was detected (356 ppm). Increased Bi values strongly correlating with Te were identified in the soil geochemistry samples of the peripheral zone as well.

K- and Na silicate alteration overprinted by intermediate argillization is typical for the ore body at Beluj. Total biotitization, actinolitization and magnetitization of mafic minerals are dominant. The alteration style is completed by veinlets and nests of K-feldspar. Na-metasomatosis of plagioclase is preserved in relics and the youngest growth zones of inhomogenic plagioclase are enriched in Ba. Plagioclase and the porphyry matrix are usually sericitized, chloritized and smectitized. Intermediate argillic alteration is widespread within the intrusive centre, affecting the intrusion itself and the host rocks. Barren (up to 0.05 ppm Au) post-mineralization advanced argillic altered rocks occur in relics within the elongated NW – SE trending zones. The thickness of zones varies from several meters to several tens of meters. The very centre of these zones is locally formed by argillized and silicified magmatic-hydrothermal breccias with vuggy texture. Blocks of massive silica occur sporadically as floating boulders but never in outcrops. The phyllic alteration occurs in isolated spots only, on the margins of the intrusive centre. The broad surrounding of the intrusive centre is propylitized. The most common accessory minerals in porphyry are monazite, apatite, allanite, thorite, xenotime and zircon.

The marginal zones of the andesite porphyry intrusion are formed by magmatic-hydrothermal breccias. They are probably post-mineralization breccias. In the drillholes BVE-1 and BVE-2 inter-mineralization to post-mineralization breccias occur only locally, in the form of narrow dykes and/or pipes 0.1 to 1 m thick. The brecciation occurred in the initial stage only, or as initial breccia transitions to fully developed breccias with a short transport of the clasts keeping their angular shape. Locally, the post--mineralization breccias of "pebble dykes" type are present (Fig. 4A), with rounded clasts and the rock flour as the matrix.

The Au-porphyry mineralization in the Beluj intrusive centre is expressed, besides the typical alteration patterns, by the presence of quartz stockwork (Figs. 4B, C). At least 3 generations of Qtz veinlets can be recognized on the base of drillcore logging. Though the stockwork outcrops on the surface in a small area only, it is quite widespread in the drillholes, sometimes weak (1 – 2 veinlets/meter of core), with transitions (3 – 5 veinlets/meter of core), to rich stockwork (over 10 veinlets/meter of core) to hydrothermal breccias (veinlets reaching over 30 % of rock volume). Locally, spectacular examples of older A-type (hairlike magnetite-quartz) and second generation of B-type (banded quartz) veinlets were recognized. There is no straight relation between the Au grade and the density of quartz stockwork. Quartz stockwork is crosscut by the very common younger calcite and zeolite (chabasite?) veinlets. Typical are the clay and chlorite veinlets (Fig. 4D). Yet undetermined clay minerals of illite-smectite order filling cracks and small structures have sometimes pink or brown--green colour.

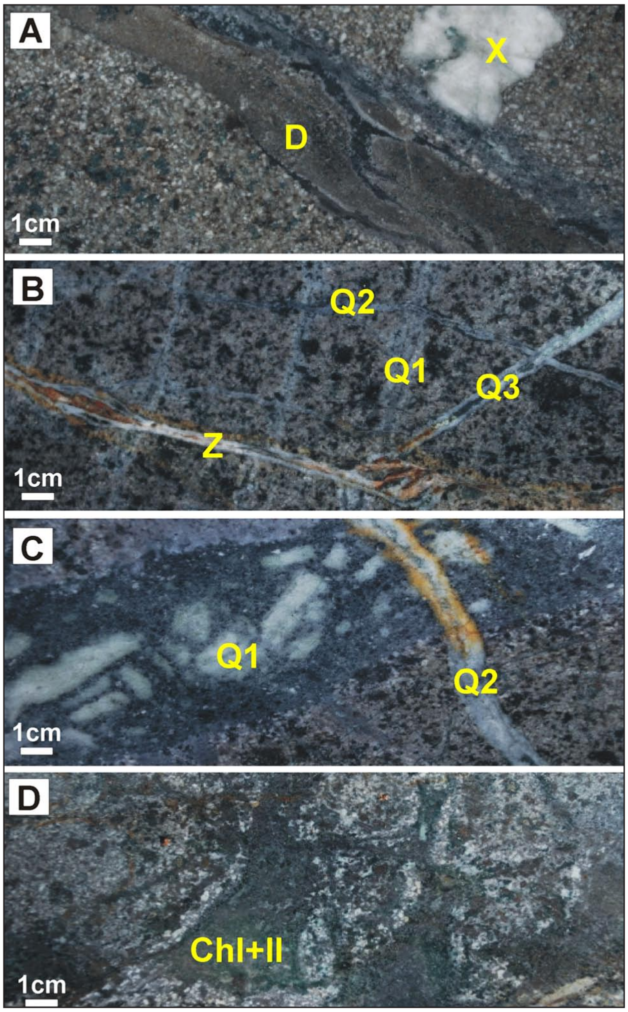

Fig. 4. Typical textures of Au porphyry ore from the BVE-1 drill hole, Beluj. **A** – Chloritized rock with basement xenolith (X), cut by the dyke of fine-grained breccia – pebble dyke (D). **B** – Biotitized and chloritized rock cut by 3 generations of banded quartz veinlets (Q1, Q2, Q3) with magnetite and by the youngest zeolite veinlet (Z). **C** – Inter-mineralization breccia dyke with fragments of earlier quartz veinlets (Q1) in biotitized and chloritized rock cut by later quartz veinlet (Q2). **D** – Chloritization and argillization (Chl + Il) following the crack.

Within the altered rock some sulphides (Figs. 5A, C, E, F, G) occur quite infrequently: chalcopyrite, Cu-S phase (chalcotite, digenite?), Cu-Fe-S phase with different Cu/Fe ratio than chalcopyrite (bornite?), molybdenite, galena, sphalerite and pyrite. The largest grains form pyrite (up to 1 mm), but from the point of frequency chalcopyrite and Cu-S phase are more abundant. Sphalerite is earlier and replaced by chalcopyrite. Sulphides form isolated grains up to 10 μm in size. Molybdenite is very common in the form of micron size impregnations in the altered rock. It locally contains increased Re concentrations. Separate irregular grains of Te-Bi minerals occur locally, sometimes abundantly. Their size reaches maximum 5 μm. Gold forms isometric grains (up to 5 μm) or grains clusters (up to 10 μm) in the altered rock (Fig. 5D). Quartz veinlets contain very often magnetite, rarely chalcopyrite, pyrite and pyrrhotite (Fig. 5H). Relatively common scheelite (up to 10 μm) occurs on the rim of the quartz veinlets. Similarly, monazite forms clusters of isometric rounded grains alined in narrow 0.1 mm thick zones.

An indistinctive geochemical correlation was identified between Au – Cu grades and Au – Zn grades. Cu and Zn contents are constantly increased, reaching 200 ppm Cu and 170 ppm Zn in average (Fig. 10). Mo content is mostly negligible, on the edge of detection limit (1 ppm). Only by the end of the BVE-2 drillhole the Mo content reaches higher values in the range of first tens of ppm. An exception is the sample from the KB-1 drillhole (interval 94.3 – 94.4 m) with 181 ppm Mo. Ag grade is constantly

Tab. 1
Results of scout drilling at Beluj prospect

Drillhole	Interception	Interval	Average Au grade
BVE-1	Entire hole	254 m	0.32 ppm
	20 – 142 m	122 m	0.4 ppm
	26 – 50 m	24 m	0.7 ppm
	26 – 80	54 m	0.51 ppm
	118 – 132 m	14 m	0.67 ppm
	190 – 254 m	64 m	0.4 ppm
	224 – 240 m	16 m	0.67 ppm
BVE-2	Entire hole	254 m	0.17 ppm
	24 – 70 m	46 m	0.3 ppm
	142 – 156 m	14 m	0.38 ppm
	228 – 252 m	24 m	0.26 ppm

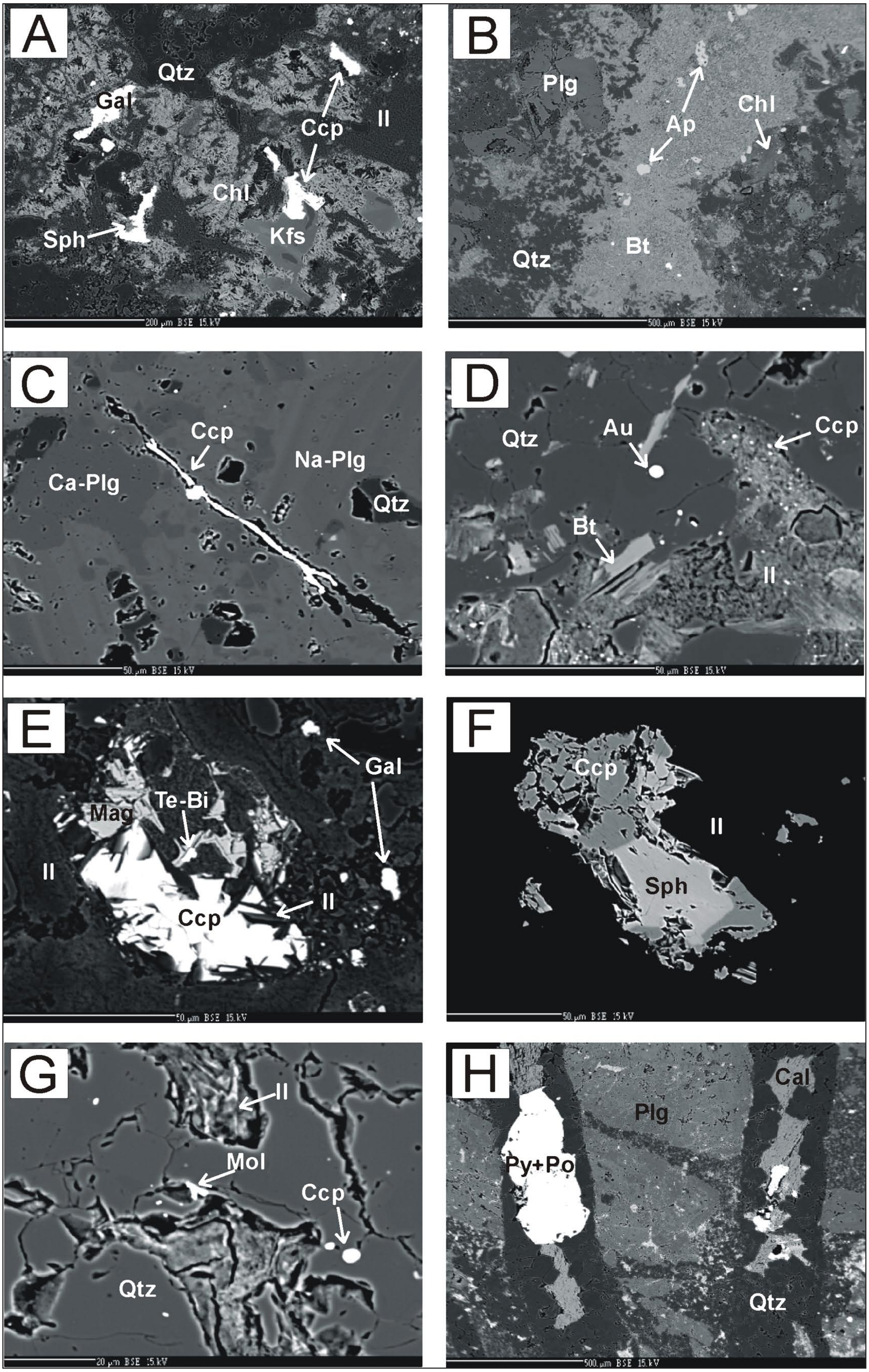

Fig. 5. Alteration mineralogy assemblage from the Beluj Au porphyry ore body. **A** – Typical alteration minerals assemblage: quartz (Qtz), K-feldspar (Kfs), chlorite (Chl) and unspecified clay mineral (Il) accompanied by chalcopyrite (Ccp), galena (Gal) and sphalerite (Sph) impregnations in BVE-1/229.1 m. **B** – Typical alteration minerals assemblage: relics of plagioclase (Plg), quartz (Qtz), biotite (Bt), chlorite (Chl) and apatite (Ap) in BVE-1/226.6 m. **C** – Veinlet of chalcopyrite (Ccp) in inhomogeneous plagioclase (Plg) with quartz (Qtz) in BVE-1/193.3 m. **D** – Gold (Au) on the rim of quartz veinlet accompanied by subtle chalcopyrite (Ccp) impregnations. The veinlet rim is lined by biotite (Bt) crystals and unspecified clay mineral (Il) in BVE-1/226.6 m. **E** – Chalcopyrite (Ccp) and magnetite (Mag) in association with unspecified clay mineral (Il) accompanied by galena (Gal) and Te-Bi mineral (Te-Bi) in a cluster of unspecified clay mineral (Il) in BVE-1/229.1 m. **F** – Sphalerite (Sph) replaced by chalcopyrite (Ccp) in BVE-1/229.1 m. **G** – Impregnations of molybdenite (Mol) and chalcopyrite (Ccp) in the quartz veinlet (Qtz) with unspecified clay mineral (Il) in BVE-1/226.6 m. **H** – Quartz (Qtz) – calcite (Cal) veinlets with pyrite (Py) and pyrrhotite (Po) nests in altered rock with relics of plagioclase (Plg) in BVE-1/193.3 m.

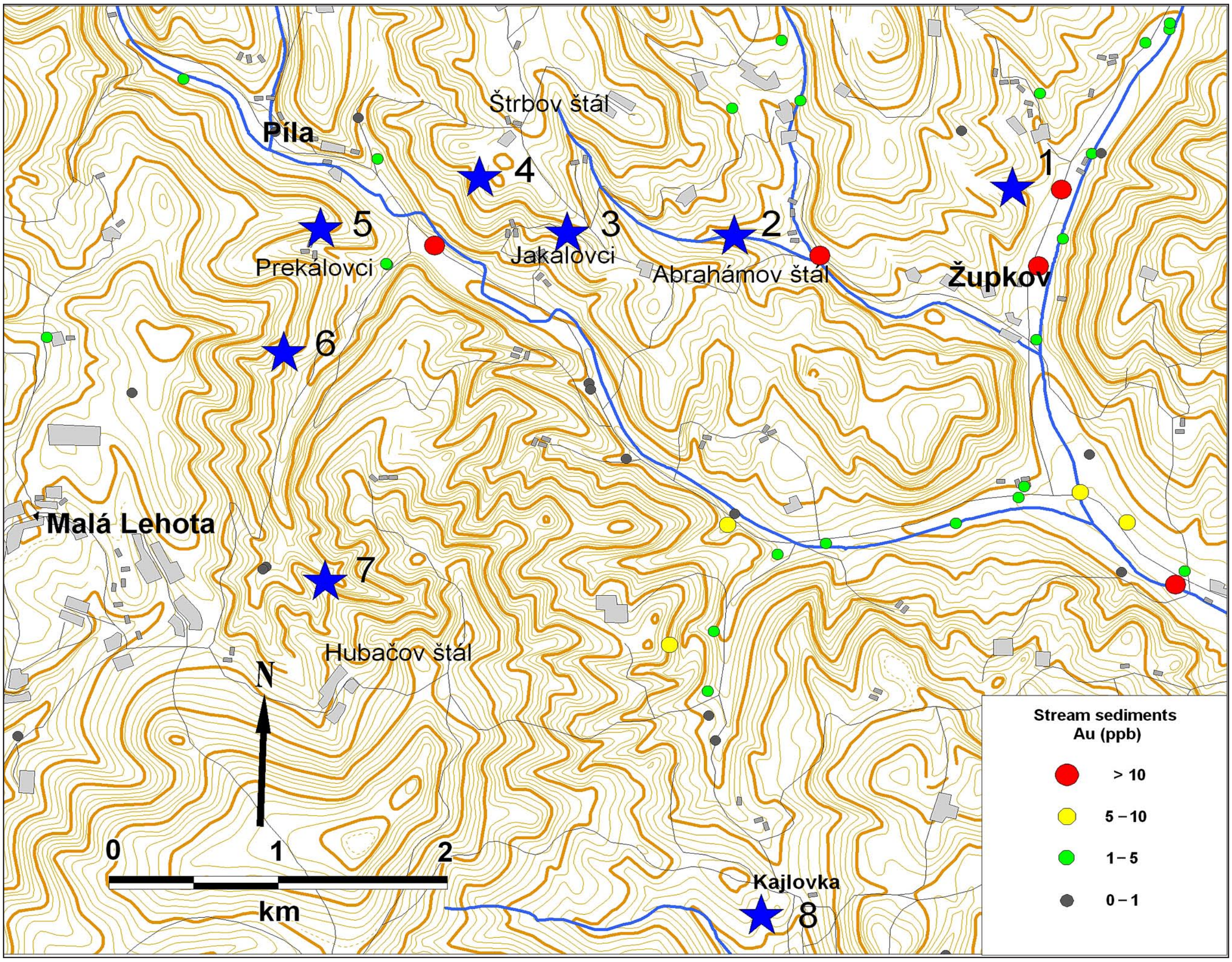

Fig. 6. Map of Žarnovica surroundings with localization of Au-porphyry mineralization occurrences: 1 – Župkov-Bačovci; 2 – Župkov-Hricov štál; 3 – Župkov-Jakalovci; 4 – Župkov-Štrbov štál; 5 – Píla-Mačací vrch; 6 – Píla-Prekálovci; 7 – Malá Lehota-Hubačov štál; 8 – Nová Baňa--Kajlovka.

under detection limit (0.5 ppm) except of an interval 122 to 130 m in BVE-1 where Ag grade is slightly increased in the range 0.6 – 0.9 ppm. Pb grade was constantly low (27 ppm) in average, maximum value was 224 ppm Pb. Average K content is 1.1 %, average Na content 1.2 %.

Mineralization in Beluj drillholes BVE-1 and BVE-2 is of low and irregular grade. Maximum thickness of Au 0.4 ppm interception is 122 m. The average grade of 0.7 ppm Au would result in maximum intercept 24 m (Tab. 1, Fig. 3). The grade varies from 0.01 ppm to 1.19 ppm Au. Au grade from four re-assayed samples of the discarded drillhole KB-1 achieved 0.2 ppm (330.2 – 330.3 m), 0.31 ppm (94.3 – 94.4 m), 0.22 ppm (73.3 – 73.4 m), and 2.55 ppm (57.7 – 57.8 m). Ag and Pb values in this sample are not increased, which indicates that the porphyry was not affected by epithermal overprint. There was identified only minor volume of post-mineralization intrusive activity (young porphyry dykes or breccias which could not act as the Au mineralization depleting or disintegrating factor. The grade irregularity in Au distribution is caused by primary conditions, probably unequal propagation of mineralizing fluids.

A section across the centre of 200 ppb soil anomaly was tested by drilling exploration. 100 ppb anomaly was the outline of the potential deposit presumed on the bases of soil and rock geochemistry and geological mapping. Given mineralization started in 20 m of BVE-1, and BVE-2 did not reach out of the mineralization. We can consider the 50 ppb soil line as more realistic to outline the mineralized body. Four assayed samples from the KB-1 vertical drillhole are all mineralized. As the sample from the interval 330.2 – 330.3 m had still 0.2 ppm Au, we can consider the mineralization opened to the depth (minimum down to 350 m). Given the substantial part of mineralization reach to the depth 350 m from the surface and given the bulk density 2.5 t/m^3, it would represent 58.4 Mt of 0.3 ppm Au ore, which means some 17.5 t of Au as the very rough estimation. Mineralized zones also contain increased but uneconomic Cu and Zn concentrations.

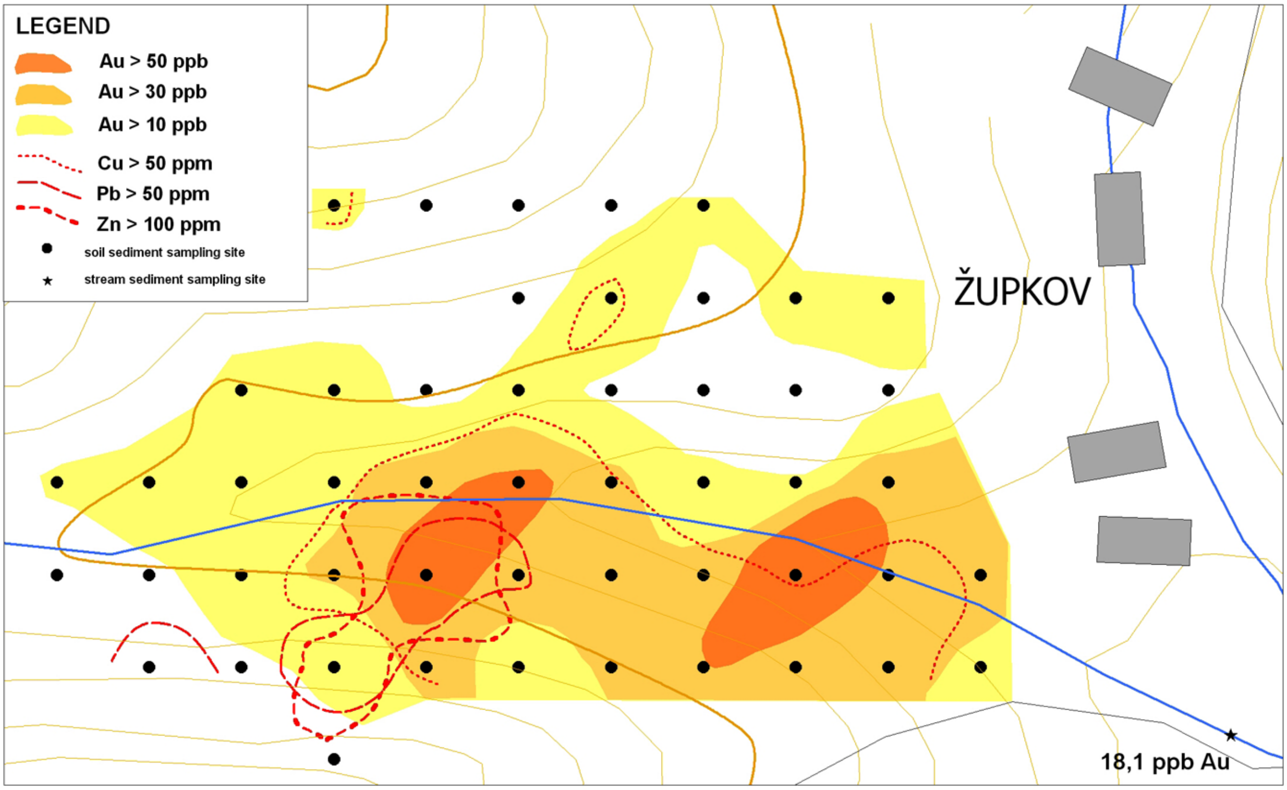

Fig. 7. Soil geochemistry map of the Župkov-Hricov štál intrusive-hydrothermal centre.

Župkov intrusive-hydrothermal centre

History of exploration of porphyry targets

Sills, laccoliths and dykes of pyroxene andesite porphyry were reported from the proximity of Nová Baňa – Kľak tectonic line, for example Nová Baňa-Kajlovka, Malá Lehota and Píla (Konečný et al., 1998). The geological prospection works carried out by Geotechnic Consulting in 2002 confirmed the presence of Au mineralization bound to the andesite porphyry intrusion at Mačací vrch hill (Knésl et al., 2006). 100 ppb 100 x 50 m anomaly with maximum around 400 ppb was identified and verified by 19 shallow drillholes. The mineralization, which appeared to be related to the weak quartz stockwork, started from the surface and quickly died out with depth. The best intercepts from the drillholes include: PLV-1B 31.4 m @ 0.58 ppm Au, 11 m @ 1.29 ppm Au; PLV-1C 20.6 m @ 0.7 ppm Au, 10.6 @ 1 ppm Au. On the basis of J. Lexa information, the andesite porphyry bodies discovered during geological mapping in the Hubačov štál and Prekálovci area S from Píla were verified in the field. Any traces of Au porphyry mineralization were noticed.

Results of exploration

In 2008, the whole Veľké Pole exploration area was tested by the stream sediments geochemistry. Up to 50 ppb Au anomaly was identified near Píla and three 10 – 20 ppb Au anomalies in the Župkov area. During the reconnaissance exploration, several Au-porphyry mineralization occurrences were discovered in this zone (Fig. 6).

In the area delimited by the triangle Nová Baňa – Župkov – Píla, a few intrusive centres were identified. The most important intrusive – hydrothermal centre with signs of Au-porphyry mineralization is located in the Župkov vicinity (Hricov štál). Two types of intrusive rocks were macroscopically recognized at the locality. Fine grained andesite to diorite porphyry forms the E part of the mineralized area with the most intense quartz stockwork. Porphyric diorite forms W part of the locality. It contains weak quartz stockwork and is characteristic by the weak alteration. The intrusive centre is traceable in the area of about 400 x 200 m (Fig. 7). Intrusive breccias are developed on the margins of the intrusion. Host rock is represented by the contact metamorphosed andesites set on Permian to Lower Triassic sediments. Strong contact metamorphism is distinctive as far as 200 to 500 m from the intrusion. Garnet, amphibole and carbonate veinlets, locally pyrite impregnations are very common in the affected rocks. Quartz stockwork (Fig. 8), the typical feature of Au porphyry mineralization, is identified on the surface of entire intrusive centre. It extends locally to surrounding rocks, mainly to andesite. Quartz veinlets have never been identified within the diorite intrusive body.

K- and Na-silicate alteration is typical for Župkov-Hricov štál intrusive–hydrothermal centre. Typical alterations are

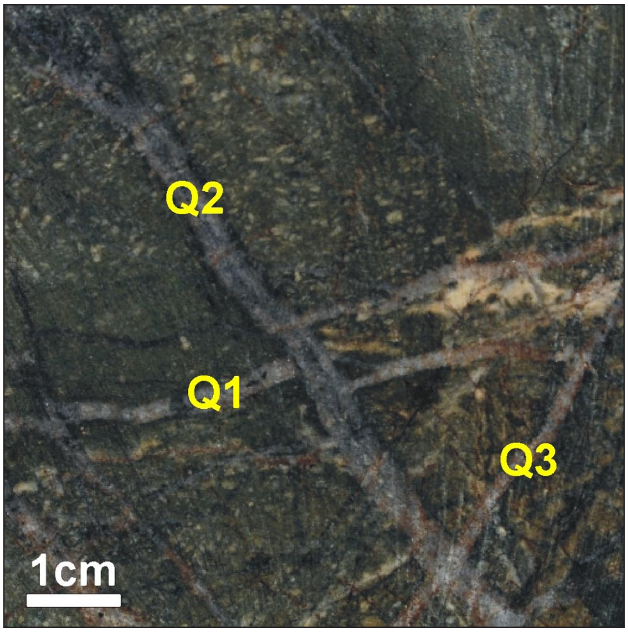

Fig. 8. Typical sample of strongly altered rock with quartz stockwork (3 generations of quartz – Q1, Q2, Q3) from the locality Župkov--Hricov štál locality.

represented by the dominant biotitization, actinolitization and magnetitization, less by K-feldspar nests and veinlets (Figs. 9A, C, F). Chloritization, scarce sericitization and intermediate argillic alteration represent younger overprint (Fig. 9E). Monazite and thorite were detected as common accessory minerals, scheelite is more rare (Fig. 9B). Sulphides, such as chalcopyrite, galena and pyrite, occur rarely within the altered rocks, forming isolated grains up to 10 μm in diameter (Figs. 9C, F). Gold was not identified in the studied samples. Magnetite and ilmenite are common within quartz veinlets, chalcopyrite and pyrite are rare. Fluorite occurs locally in the form of clusters up to 0.5 mm big in quartz veinlets (Fig. 9D). The mineralization typically shows increased Au, Cu and Zn grades. Au grade in rock chips samples from Župkov-Hricov štál locality is very low, while only some 15 % of the samples had Au grade higher than 0.1 ppm. Average Au grade in 42 samples reach 0.05 ppm Au, max. 0.4 ppm. Cu grade varies in the range from a few ppm up to 807 ppm, 140 ppm in average. Zn grade ranges between a few ppm and 577 ppm, 105 ppm in average. Pb is typically low, mostly tens of ppm, max. 571 ppm. Maximum Mo grade reaches 13 ppm, Bi 3 ppm, and Ag 0.6 ppm. K average concentration reaches 1.19 %, max. 4.4 %, Na average concentration reaches 1.65 %. Other elements do not reach increased concentrations.

If we would estimate the potential of Au resource taking as a base 200 x 400 m 50 ppb Au anomaly up to the depth of 200 m and specific weight set 2.5 t/m^3 and considering 15 % of the volume having grade 0.1 ppm Au we would come to conclusion of 6 Mt of 0.1 ppm ore, which means 0.6 t Au. These numbers are far from being economic and thus the locality Župkov-Hricov štál represents a small mineralogical occurrence only and its potential is none.

Two other smaller intrusive centres occur in the surroundings of the Hricov štál locality, between Abrahámov štál and Jakalovci settlements and near Štrbov štál. Host rocks and the character of alteration are similar to Hricov štál occurrence. The size of both objects reach max. 100 x 100 m. Au grade reaches only 0.0X ppm and from the point of view of geological prospecting these objects represent only mineralogical occurrences of Au-porphyry mineralization.

The Au-porphyry mineralization manifestations and characteristic alterations were detected at the locality Nová Baňa-Kajlovka as well. On the surface of almost 1 km^2, intermediate argillic alteration, magnetitization and pyritization are developed in the environment of andesite. Scarce quartz stockwork was identified in the rock floats. Strong argillization, character of topography and scarcity of the floats disable a more detailed description of the locality. Au grade in lithogeochemical samples reached only 0.0X ppm.

Erosive remnants of upper parts of the porphyry system were identified in the material of Pleistocene gravels from the small basin between Hrabičov and Župkov. Gravels represent paleoplacer with clasts of argillites, vuggy silica and intermediate argillic altered rocks with quartz stockwork. Au grade in channel samples in gravel outcrops reached 0.0X ppm Au, max. 0.1 ppm Au in selected clasts.

Discussion

Though the Beluj intrusive centre was verified only by one line of drillholes, it runs across the centre of the highest soil anomaly. There are evident signs of the ore body continuation to depth. Though a further drilling might enlarge the extent of Au porphyry mineralized body, verified grades are too low from being economic. One sample of 2.55 ppm Au from KB-1/57.7 – 57.8 m indicates the possibility of higher grade zones within the mineralized body. One float rock sample at Beluj was the sample of epithermal quartz vein with visible galena impregnations. It raises the question of possible unknown epithermal mineralization occurrence in Beluj intrusive centre and its surroundings.

Signs of geochemical zonation can be traced in the Beluj intrusive centre. Whilst Au and Cu anomalies form the central zone, Mo anomaly forms the proximal and Zn and Pb anomalies form the distal zone. This is in coincidence with the geochemical model of Au-porphyry deposits (Sillitoe, 2000). One of the typical geochemical features of the Beluj intrusive centre is Bi-Te mineralization occurrence, which is located in the distal zone. Its presence is confirmed by correlation of BiTe contents in soil samples, Bi anomalous value in the argillized vuggy silica rock sample as well as by the presence of common Bi-Te minerals in the drillcore.

All interpreted regional faults in the Beluj intrusive centre are oriented NW – SE to NNW – SSE. Field observations, such as magmatic – hydrothermal brecciation and zones of argillic alteration along these structures, are supported by the soil geochemistry showing increased Au grade (up to 32 ppb). NW – SE orientation of local

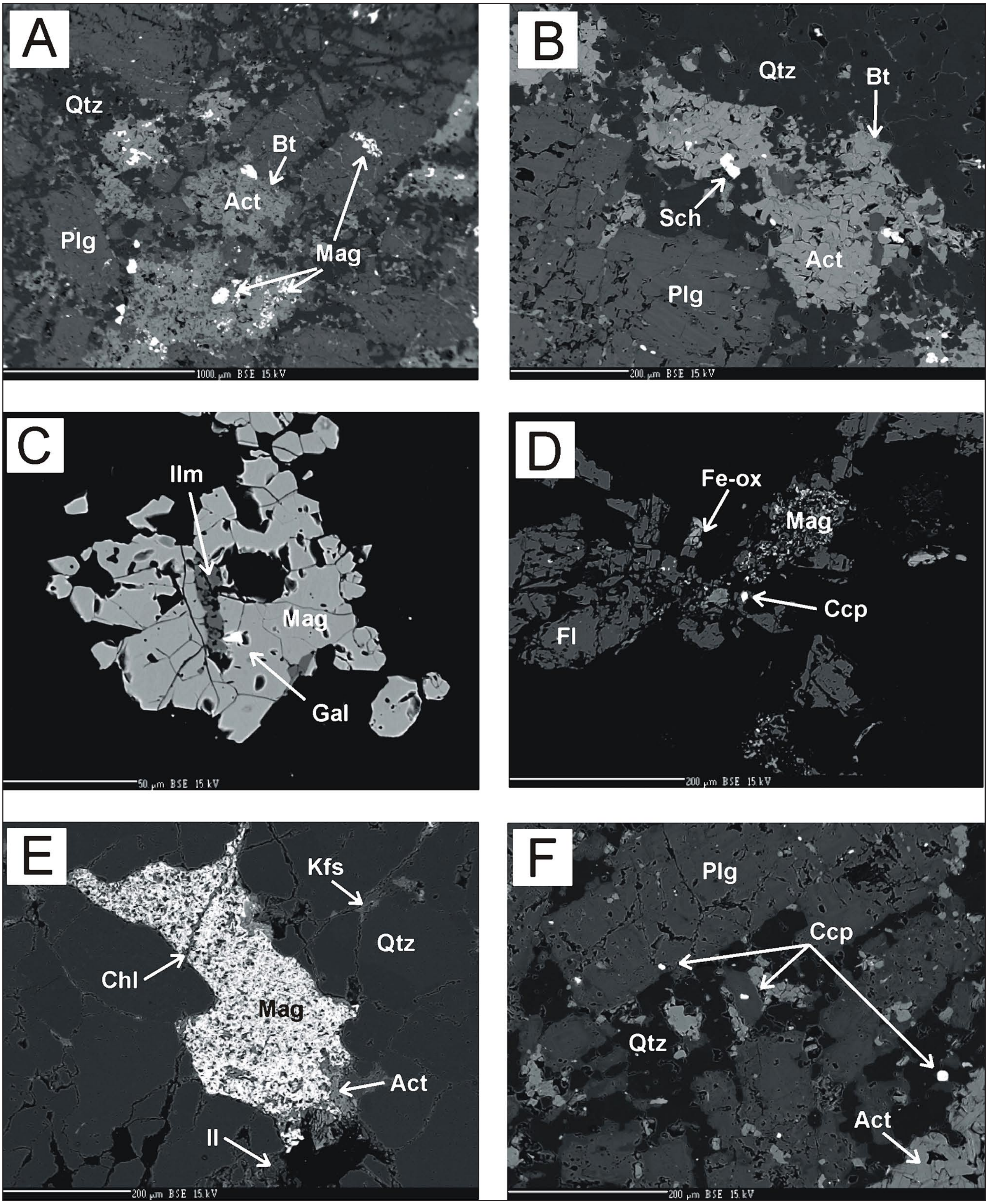

Fig. 9. Typical alteration minerals assemblages from the locality Župkov-Hricov štál locality: **A** – Quartz (Qtz), plagioclase (Plg), actinolite (Act), biotite (Bt), accompanied by magnetite (Mag) impregnations. **B** – Scheelite (Sch), actinolite (Act) and biotite (Bt) on the rim of quartz veinlet (Qtz) in altered rock with plagioclase phenocrysts (Plg). **C** – Galena (Gal) in magnetite (Mag) and ilmenite (Ilm) cluster. **D** – Nest of fluorite (Fl), magnetite (Mag), Fe-oxide/hydroxide and rare chalcopyrite (Ccp) in the quartz veinlet (black). **E** – Centre of quartz veinlet with nest of magnetite (Mag), actinolite (Act) and unspecified clay mineral (Il) crosscut by veinlets of chlorite (Chl) and K-feldspar (Kfs) in the cluster. **F** – Impregnations of chalcopyrite (Ccp) in altered rock composed mainly of quartz (Qtz), plagioclase (Plg) and actinolite (Act).

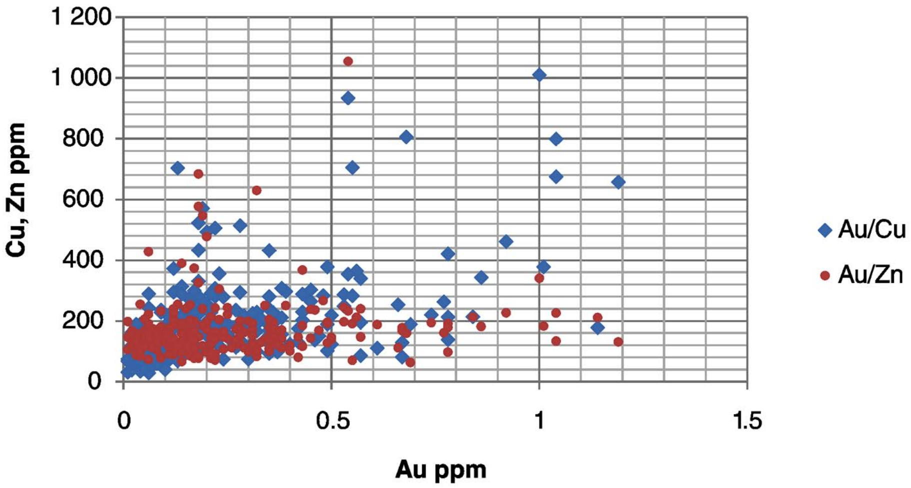

Fig. 10. Relationships between Au vs. Cu and Au vs. Zn in the drillcore assays from the Beluj intrusive-hydrothermal centre.

tectonics corresponds to pre-Tertiary tectonics trend of the basement. This fault system was juvenilized by radial fault tectonics, perpendicular to the central zone of the Štiavnica stratovolcano (Konečný et al., 1998).

Considering the facts that the only remnants of advanced argillic alteration zone are preserved, the erosion level at Beluj intrusive centre could be estimated as deeper than the erosion level in the central zone of the Javorie stratovolcano, but shallower than in the Župkov intrusive centre. Within the Píla – Župkov zone the erosion level can be considered as very deep. This theory is supported by the fact of very low volume percentage of the rocks affected by advanced argillization in paleoplacers between Župkov and Hrabičov. Another option is a possibility that intrusions did not preserved communication with their magmatic chamber. The hydrothermal systems were small and short living, which corresponds to the minor extent of alterations. This theory is supported by several times lower volume of magmatic-hydrothermal breccias on studied ore bodies in the mantle of Štiavnica stratovolcano in respect to Au porphyry mineralization occurrences in the Javorie stratovolcano.

Geochemical works at Píla-Mačací vrch prospect provided similar results as presented by Knésl et al. (l. c.). If comparing logging and Au grades, it becomes clear, that the mineralization does not correlate with the degree of porphyry style alteration. Mineralized body at Píla locality is characteristic by 5 times lower average Cu grade (22 ppm) than the rest of occurrences of porphyry mineralization in the Central Slovakian Volcanic Field (>100 ppm). That is why we came to conclusion, that the Píla-Mačací vrch prospect probably does not represent a typical Au-porphyry mineralization.

Increased Au grades over 0.1 ppm within Beluj and Župkov porphyry ore bodies in the Štiavnica stratovolcano are always accompanied by increased Cu and Zn grades. This fact corresponds with the results of porphyry mineralization lithogeochemistry in the Javorie stratovolcano (Hanes et al., 2010). There is no correlation between Au vs. Cu or Au vs. Zn grades. Au/Cu ratio is very low (1 : 0.08). Increased Zn grade correlates with Cd grade. Ag, Bi, Sb, Ni, Co, Cr, W, REE grades are typically low, mostly below their detection limits.

Au porphyry ore bodies at Beluj and Župkov are typical by very low sulphides content (average S 0.06 %, As 7 ppm), and the lowest Ba, P and V contents compared to porphyry mineralization occurrences in the Javorie stratovolcano (Hanes et al., l. c.). Low sulphide content within the orebody in the South American Au porphyry deposits is in relation with the lithocap absence, which distal parts are usually pervasively pyritized (Vila et al., 1991; Sillitoe, 2000). Increased Na content in comparison with depletion in K indicates slight dominance of Na-silicate alteration over K-silicate alteration, especially at Župkov intrusive-hydrothermal centre.

Correlation of Bi and Te values in soil geochemistry at Beluj witnesses the presence of Bi-Te mineralization within the distal zone of the intrusion. Mineralization is related to the zones of argillization and magmatic-hydrothermal brecciation in the distance 0.1 – 1.5 km from the intrusion. Bi-Te minerals, not studied in detail, were detected in the orebody itself. Bi-Te mineralization at the Župkov-Angletovci locality (Sejkora et al., 2004) was described in argillized zone within the andesites about 1 km from the Župkov-Hricov štál intrusive centre. On the basis of an analogy with Beluj locality we consider Bi-Te mineralization in Župkov genetically related to Au-porphyry mineralization.

Comparing the geochemical features of porphyry mineralization occurrences of the Štiavnica stratovolcano, porphyry mineralization within the stratovolcanic mantle is bound to andesite to diorite porphyry intrusions yielding typical Au-porphyry type with Au/Cu ratio about 1 : 0.08, while mineralizations bound to more acid granodiorite porphyry intrusions in the central zone of the stratovolcano represent transitional Au-Cu (Mo) porphyry type of mineralization with Au/Cu ratio between 1 : 0.4 and 1 : 1

in the sense of Sillitoe (1979). Typical alteration zonation within Au-porphyry bodies is from inner Na- and K-silicate zone through retrocedent intermediate argillic altered zone to outer propylitic zone with local phyllic altered spots. Au-Cu porphyry zonation starts as Na-Ca and K-silicate alteration zone in the depth overprinted by albite and epidote alteration. Outer well pronounced phyllic zone transits to external propylitic zone (Marsina et al., 1995).

Conclusion

Results of systematic exploration of porphyry mineralization in the mantle of the Štiavnica stratovolcano can be summarized as follows:

• Au-porphyry mineralization occurs in the mantle of the stratovolcano bound to intrusions of andesite to diorite porphyry. Central stratovolcanic zone contains Au-Cu skarn-porphyry deposits and occurrences bound to intrusions of granodiorite porphyry.

• There were not identified any economic and currently exploitable ore bodies. The locality Beluj can be classified in the category of subeconomic deposit occurrences. The rest of the localities represents only mineralogical occurrences of Au porphyry mineralization.

• Au-porphyry mineralizations are expressed in stream sediments by weak anomalies in the range of 5 – 20 ppb.

• Porphyry objects are present in various levels of erosion cut. Barren lithocap with advanced argillization is preserved only at Prochot locality. Advanced argillic root zones are present at Beluj locality, while at Župkov locality it is only present in form of clasts in paleoplacers.

• Mineralization is associated with Na- and K-silicate alteration overprinted by intermediate argillic assemblages, especially in the uppermost parts of quartz stockwork zones.

• Qtz stockwork is the typical indicator of Au-porphyry mineralization. There is no correlation between Qtz stockwork intensity and Au grade in the ore.

• Magmatic-hydrothermal breccias are rare within the orebodies and small in size, forming maximum 1 vol. % of rock.

• Mineralization in the orebodies is characteristic by the presence of Fe, Ti-oxide assemblage (5 – 10 vol. %) with minor content of Fe, Cu, Zn, Pb sulphides (totally up to 0.05 vol. %).

• Increased Au grade over 0.1 ppm within the mineralized zones is always accompanied by increased Cu and Zn grades. There is no correlation between Au vs. Cu or Au vs. Zn. Au/Cu ratio is very low (1 : 0.08). Ag grade is typically low, mostly under the detection limit.

• Pervasive pyrite-rich phyllic alteration rims on the side of the ore bodies are barren, causing geophysical IP anomalies.

• Au porphyry mineralization is accompanied by economically insignificant manifestations of disseminated Mo mineralization, stockwork – disseminated Pb-Zn mineralization, Bi-Te mineralization and crack-filling zeolite mineralization.

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References

Brlay, A., Forgáč, J., Mihaliková, A. & Dovina, V., 1980: Structural drillhole MEB-1 (Prochot) – partial final report. *Manuscript. Bratislava, archive ŠGÚDŠ (In Slovak).*

Filo, M., Bárta, R., Kollár, Ľ., Kováčiková, M. & Pospíšil, Ľ., 1980: Geophysical survey of “Beluj” intrusive complex, Central Slovakian volcanics. *Final report for 1978 – 1980 period. Manuscript. Bratislava, archive of ŠGÚDŠ, 13 p. (In Slovak).*

Koděra, P., Lexa, J., Rankin, A. H. & Fallick, A. E., 2005: Epithermal gold veins in a caldera setting: Banská Hodruša, Slovakia. *In: Mineralium Deposita, 39, 921 – 943.*

Knésl, A., Koděra, P., Lexa, J. & Michňová, J., 2006: Results of exploration for gold at the locality Píla, Rázdiel part of the Tribeč mountain range. *In: Miner. Slov. (Bratislava), 38, 202 – 214 (In Slovak).*

Knésl, J. & Knéslová, A., 2004: Final report from geological Tribeč-Rázdiel (Au mineralization), situation by 31. 5. 2004. *Manuscript. Bratislava, archive ŠGÚDŠ (In Slovak).*

Konečný, V., 1971: Evolutionary stages of Banská Štiavnica caldera and its post-volcanic structures. *In: Bull. Volc. Tome (Napoly), 35, 1, 95 – 116.*

Konečný, V. & Lexa, J., 1977: Basic geological exploration and mapping at a scale 1 : 25 000, sheet Prenčov. *Manuscript. Bratislava, archive ŠGÚDŠ (In Slovak).*

Konečný, V., Lexa, J. & Hojstričová, V., 1995: The central Slovakian Neogene Volcanic Field: A review. *In: Downes, H. & Vaselli, O. (eds.): Neogene and related magmatism in the Carpatho--Pannonian region. Acta Volcanol., 7, 63 – 78.*

Konečný, V., Lexa, J., Halouzka, J., Hók, J., Vozár, J., Dublan, L., Nagy, A., Šimon, L., Havrila, M., Ivanička, J., Hojstričová, V., Mihaliková, A., Vozárová, A., Konečný, P., Kováčiková, M., Filo, M., Marcin, D., Klukanová, A., Liščák, P. & Žáková, E., 1998: Explanations to the geological map of the Štiavnické vrchy and Pohronský Inovec Mountains (Štiavnica stratovolcano). I. and II. part. *Bratislava, GS SR, Publish. D. Štúr, 473 p. (In Slovak).*

Lexa, J., Štohl, J. & Konečný, V., 1999: Banská Štiavnica ore district: Relationship among metallogenetic processes and geological evolution of the central volcanic zone. *In: Mineralium Deposita, 34, 639 – 654.*

Marsina, K., Hojstričová, V., Konečný, V., Konečný, P., Lexa, J., Rojkovičová, Ľ. & Žáková, E., 1995: Comparison of skarn – Cu-porphyry objects in the central zone of the Štiavnica stratovolcano and their evaluation. *Manuscript. Bratislava, archive ŠGÚDŠ, 124 p. (In Slovak).*

Sejkora, J., Litochleb, J., Černý, P. & Ozdín, D., 2004: Bi-Te mineral association from Župkov (Vtáčnik Mts., Slovak Republic). *In: Miner. Slov. (Bratislava), 36, 303 – 315 (In Slovak).*

Sillitoe, R., 1979: Some thoughts on gold-rich porphyry copper deposits. *In: Mineralium Deposita, 14, 161 – 174.*

Sillitoe, R., 1993: Gold-rich porphyry copper deposits: Geological model and exploration implications. *In: Kirkham, R. V., Sinclair, W. D., Thorpe, R. I. & Duke, J. M. (eds.): Mineral deposit modelling. Geol. Assoc. Canada, Spec. Pap., 40, 465 – 478.*

Sillitoe, R., 2000: Gold-rich porphyry deposits: Descriptive and genetic models and their role in exploration and discovery. *In: SEG reviews, 13/2000, 315 – 345.*

Vila, T., Sillitoe, R., Betzhold, J. & Viteri, E., 1991: The porphyry gold deposit at Marte, Northern Chile. *In: Econ. Geol. (New Haven), 86, 1 271 – 1 286.*

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Au porfýrová mineralizácia v plášti štiavnického stratovulkánu

Oblasť štiavnického stratovulkánu bola v rokoch 2006 – 2009 predmetom systematického geologického prieskumu spoločnosti EMED. Pomocou geochémie aluviálnych sedimentov sa zistili doteraz neznáme anomálie Au (5 – 20 ppb). Pri terénnej rekognoskácii sa overilo, že tieto anomálie sú spôsobené výskytmi Au porfýrovej mineralizácie. Au porfýrová mineralizácia v študovanej oblasti bola známa len na lokalite Píla-Mačací vrch (Knésl et al., 2006). Nové výskyty sa zistili v Beluji, na viacerých lokalitách v okolí Župkova (Hricov štál, Štrbov štál, Jakalovci atď.) a mineralogické indície v Prochote a Šášovskom Podhradí (obr. 1, 6). Predmetom podrobnejšieho prieskumu boli lokality Beluj a Župkov-Hricov štál, kde sa v litogeochemických vzorkách potvrdil systematicky zvýšený obsah Au vyšší ako 0,1 ppm. Na obidvoch výskytoch sa urobila pôdna metalometria. Pozitívne výsledky na lokalite Beluj umožnili aj realizáciu 2 vrtov.

Mineralizácia sa viaže na štokové intrúzie andezitových až dioritových porfýrov v plášti stratovulkánu. Typickým indikátorom je kremenný žilník (obr. 2A), porfýrové alterácie (Na metasomatóza, K metasomatóza, stredná argilitizácia a v malej miere vyvinutá pokročilá argilitizácia). Ďalšou črtou mineralizácie je multištadiálna brekciácia. Asociáciu primárnych vysokoteplotných alteračných minerálov tvoria aktinolit, biotit, K živec, kremeň a Fe-Ti oxidy. Hornina je často postihnutá retrográdnou strednou argilitizáciou reprezentovanou chloritom, kremeňom a ílovými minerálmi. Rudnú mineralizáciu tvoria mikroskopické impregnácie, zriedkavo aj hniezda chalkopyritu, bližšie neurčeného Cu-S minerálu, molybdenitu, sfaleritu, galenitu, pyritu, pyrotitu, zlata a ojedinele aj bližšie neurčených Bi-Te minerálov. Zóny pokročilej argilitizácie, ktorej relikty lemujú rudné teleso na lokalite Beluj, sprevádzala intenzívna brekciácia. Lokalita Župkov sa nachádza v hlbšom erozívnom zreze. Úlomky hornín s pokročilou argilitizáciou vystupujú v materiáli pleistocénnych štrkov v lokálnej panvičke medzi Župkovom a Hrabičovom.

Au porfýrová mineralizácia v pôdach sa geochemicky prejavuje zvýšenou Cu, Zn a Pb anomáliou (obr. 2B, 7). Zvýšený obsah Bi a Te viazaný na zóny argilitizácie je typický pre okrajové časti porfýrových systémov (obr. 2C). Charakteristickým znakom je veľmi nízky pomer Au : Cu (1 : 0,08). Obsah Au v rudných telesách na dvoch najvýznamnejších lokalitách (Beluj a Župkov-Hricov štál) dosahuje priemerne spodné desatiny ppm. Obsah Au na ostatných lokalitách len ojedinele dosahuje 0,1 ppm. Najväčší potenciál má lokalita Beluj. Je tam možné do hĺbky 350 m odhadnúť približne 58,4 Mt prognóznych zdrojov Au porfýrovej rudy s priemerným obsahom 0,3 ppm Au, čo predstavuje 17,5 t Au.