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# 6. Relationship of Ore Mineralisations to Regional Geological Structures and Geochemical Anomalies in the Kohút Zone (Southern Veporicum)

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**Abstract:** Systematic research in the western part of the Slovenské rudohorie Mts. (Kohút zone), or the Southern Veporicum tectonic zone (1,200 km$^2$) was focused in geological mapping, geophysical profiling, soil geochemical profiling and metallogenic research. It resulted not only in a more accurate knowledge of the surface geological structure, but also in more detailed identification of the fault and shear zones which are locally accompanied by ore mineralisation. The area under study is covered by quite large amount of exploration works, in order to investigate metal sources.

Methodology of the uniform processing of geological, geophysical, and geochemical data led to the definition of potentially significant metallogenic zones, which have been detached from the zones without potential economic importance.

**Key words:** Veporicum, Kohút zone, Slovenské rudohorie Mts., geological mapping, geophysical profiles, soil geochemistry profiles, ore mineralisation research

## 6.1. Introduction

In the scope of the investigation of western part of the Slovenské rudohorie Mts., within the area approx. 1,200 km$^2$, a complex of geological, geophysical and geochemical methods were carried out, in order to reveal more precisely geological structure from the surface to deeper parts, and to define influence of this structure on the widely present mineralisation, to define potential ore mineralisation zones and their relative importance.

Geological mapping, in spite of a strong Alpine reworking, has revealed fragments of primary Hercynian tectonic relationships. The Alpine shear zones were detected on the surface and in subsurface positions using geophysical methods (gravimetry, magnetics, induced polarisation and resistivity tomography). These methods were performed on regional profiles; partially in granitoids without signs of mineralisation.

In this paper we focus on the relationship of geological structures of regional extension to the soil geochemical anomalies and concomitant mineralisation.

## 6.2. Geological structure of the Kohút zone and its metallogeny

The Kohút zone (as a part of the Slovenské rudohorie Mts.) represents geologically very complicated region lying in the tectonic position beneath the Alpine tectonic slice of the Gemericum superunit. Its geological structure is particularly characterised by the Hercynian metamorphic and granitoid rocks and Late Paleozoic (Slatvina and Rimava Fms.) and Triassic cover sediments (Foederata Fm.), overlain by the Gemericum superunit in the tectonic position.

Geological aspects of this region have been intensively studied for several decades, with focus in Hercynian and Alpine geological history of the rock formations, but many times with controversial results of the P-T conditions of the Alpine metamorphic reworking. This territory was a subject of very intensive exploration in the past, because numerous metal and non-metal occurrences have been revealed here (Au, W, Mo, Cu, Sb, talc, magnesite, graphite, and quartz).

Early Paleozoic metamorphic rock sequences consist of three rock complexes: 1. ortho- and paragneisses with amphibolites, hornblende-rich paragneisses with different, but higher degree of Early Carboniferous granitisation (part of Kráľova hoľa complex), 2. mica schists (Hron complex; sensu Klinec, 1966) and 3. metasandstones to metapelites with lower degree of granitisation or without it (Klenovec complex – "albitic gneisses", sensu Bezák, 1982). The rock sequences presented here underwent metamorphosis of different degree during Hercynian stages and they had a different crustal position during Devonian/Early Carboniferous granitisation period. They belong to different Hercynian tectonic units, and the complex of mica schists (2) belongs to the lowermost tectonic unit (sensu Bezák et al., 1997).

Granitoid rocks of Meso-Hercynian stage are represented by huge masses of tonalitic, trondhjemitic, granodioritic to granitic compositions (mainly representing anatexis of different source – metagreywackes with intercalations of basic metatuffs/orthogneises, granite to granodiorite in composition). Geometry of such intrusions indicates mechanism of laccolithic sheets, with schliered granitoids of tronhjemitic to granodioritic compositions placed at the bottom part and granodioritic to granitic compositions, usually with porphyric facies, at the roof.

SE and E rim of Pre-Carboniferous complexes is represented by the Late Paleozoic complexes designated by Vozárová & Vozár (1982; 1988) as the Revúca Group (Late Carboniferous Slatvina and Permian Rimava formations).

Permian postcollisional granitoids and granite-porphyries – Klenovec type (Hraško et al., 1997) form only small intrusive bodies in the "albitic gneisses" of the Klenovec complex with lower degree of the Hercynian granitisation. The age 266±16 Ma (Finger at al., 2003), magma characteristics and its metallogenic speciation, are similar to Gemericum granites.

A positive magnetic anomaly accompanied by negative gravity in the eastern part of the territory represents the Late Cretaceous (Hraško et al., 1999 – 82±1 Ma; Kohút et al., 2013 – 81,5±0,7 Ma) hidden differentiated granite body of Rochovce type, connected with W-Mo mineralisation (Klinec et al., 1980; Határ et al., 1989).

Alpine shear zones (mostly NE-SW trending sinistral narrow zones) amalgamated different Hercynian crustal bocks (crystalline basement) with/without Late Paleozoic – Triassic cover. This process was accompanied by the Alpine recrystallisation and mylonitisation. The Alpine shear zones are the place of intensive replacement of Hercynian mineral associations by the newer – Alpine ones, usually the lower temperature mineral associations. This recrystallisation was connected with the migrations of ore-forming fluids.

Presence of the Hercynian lithologies with disseminated ore minerals, like mica schists (mostly containing magnetite), with intercalations of black quartzites (with pyrrhotite), metaultramafic rocks, amphibolites, are usually easy-detected by magnetic and aeromagnetic methods. They form linear magnetic anomalies, which are caused by incorporation of the Hercynian mica schists into the Alpine shear zone. The most pronounced Alpine shear zones in the SW part of the Southern Veporicum area, accompanied by Hercynian mica schists (with serpentinites, metabasalts and black quartzites), lying in the depth, are clearly source of the Alpine remobilised metals (mainly Sb, Ag, Cu, Bi and As). It is manifested by the coincidence of metallogenic and geophysical anomalies in the narrow zone, more than 20 km long.

## 6.3. Used Methods

The geological works consisted of geological-geophysical profile measurements and soil geochemical sampling. They were supplemented by geological mapping in profiles, geological mapping among profiles and metallogenic research. The works were carried on about 1,200 km of profiles 5-71, realized perpendicular to the course of geological structures at a distance of approximately 1 km. The works were carried out between Rejdová Village in the east and Podrečany Village in the west of the area (Hraško et al., 2005).

### 6.3.1. Geophysical works

***– methodology of field works***

A complex of geophysical works carried out on the above mentioned profiles consisted of the following methods: the induced polarization (IP) along with resistivity measurements (R) in three depth horizons: 50, 75 and 100 m. A dipole arrangement of electrodes was utilized (time domain) with using devices SYSCAL IP-2 (Syscal, Canada), IPR – 8 (Scintrex, Canada) and GEVY 1 000 (Geofyzika Brno). A spacing of measurements was 50 m. Magnetic measurements were performed by proton magnetometers PM – 2 (Geofyzika Brno) with the same spacings as in the case of resistivity method.

***– methodology of data processing***

A software OASIS Montaj (Canada) was used for handling and processing of obtained data (data base production, filtration, modelling). Whole complex of data is available for potential re-interpretation, or for solution of other geological issues. In addition to these results airborne magnetic measurements and a gravity mapping at the scale 1 : 25,000 were applied.

### 6.3.2. Methodology of sampling of soil horizon and selection for the quantitative analyses

The samples were taken from the profiles 5-71, completed perpendicular to the direction of the geological structures, at a distance of about 1 km. Using soil geochemistry sampling the coverage of the whole area was secured, thereby ensuring an overall picture of the distribution of elements of interest in the soil horizon. There was made a special selection of samples for quantitative analyses of the element content by anomalous geochemical distribution detected by cheaper semiquantitative analysis on the profile. In this way there were geochemically analyzed approximately 3,000 soil samples.

The geochemical soil samples were collected from the B soil horizon after removal of a humus-rich horizon. The samplings were carried out in spacings of 50 m along the profiles, and they were identical with geophysical measurements realized in advance. The collected soil samples were analyzed by semiquantitative SPD determination. Quantitative determinations of elements were made using XRF analysis in the SGIDŠ Geoanalytical Laboratories in Spišská Nová Ves.

### 6.3.3. Methodology of analytical works – soil geochemistry

Quantitative determination of trace elements of Cu, Pb, Zn, Ni, Co, Cr, Sn, Mo, As, Sb, Ag of the compressed tablet by a method XRF spectrometry was carried by spectrometer SPECTRO X-LAB 2000. Statistical evaluation of analytical data is presented in Table No.6.1.

### 6.3.4. Methodology of geochemical research of rocks and manifestations of mineralisation

The aim of the research of mineralisations and geochemical investigation of rocks was, among other issues, to document manifestations of mineralisation in the area and using the lithogeochemistry, to allocate and characterize lithological complexes prospective for the occurrence of accumulations of mineralisation and mineralised structures.

For this purpose, the qualitative and quantitative content of selected elements in the lithotypes and mineralised samples was checked using spectral analysis. In more lithotypes (often with sulphidic impregnations) quantitative content of ore elements (Au, Ag, Bi, Sn, As, Sb, Co, Ni, Cu, Pb, Zn, Mo, W, Hg) in ppm was determined by AAS method.

Tab. 6.1: Statistical evaluation of trace elements in a set of soil samples. The data above the 95-percentile can be considered anomalous. * - in a statistical evaluation, values below the detection limit are replaced by ½ of the limit of detection limit. The detection limits for: Ag, As, Co, Cu, Ni, Pb, Sb, Sn, Bi – 2 ppm, Cr, Mo – 3 ppm, W – 5 ppm.

| | Ag* | As* | Co* | Cu | Mo* | Ni | Pb | Sb* | Sn* | W* | Zn | Bi* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **No** | 3,029 | 2,800 | 1,077 | 2,950 | 3,017 | 3,015 | 2,836 | 2,799 | 2,939 | 2,849 | 2,915 | 3,031 |
| **Av** | <1.01 | 34.17 | 17.44 | 34.05 | 1.63 | 43.60 | 43.29 | 8.01 | 4.77 | 10.57 | 103.93 | 1.19 |
| **Med** | <2.00 | 14.00 | 16.00 | 26.00 | <3.00 | 37.00 | 36.00 | 3.00 | 4.00 | <5.00 | 96.00 | <2.00 |
| **Min** | <2.00 | <2.00 | <2.00 | 2.00 | <3.00 | 2.00 | 6.00 | <2.00 | <2.00 | <5.00 | 15.00 | <2.00 |
| **Max** | 11.0 | 1,379.0 | 114.0 | 6,700.0 | 26.0 | 1,127.0 | 832.0 | 867,0 | 39.0 | 833,0 | 917.0 | 40.0 |
| **Percentile** | | | | | | | | | | | | |
| **10%** | <2.00 | 6.00 | 7.60 | 10.00 | <3.00 | 21.00 | 23.00 | <2.00 | <2.00 | <5.00 | 54,00 | <2.00 |
| **20%** | <2.00 | 8.00 | 11.00 | 15.00 | <3.00 | 26.00 | 27.00 | <2.00 | <2.00 | <5.00 | 66.00 | <2.00 |
| **30%** | <2.00 | 10.00 | 13.00 | 19.00 | <3.00 | 30.00 | 30.00 | <2.00 | 3.00 | <5.00 | 77.00 | <2.00 |
| **40%** | <2.00 | 12.00 | 14.00 | 23,00 | <3.00 | 34.00 | 33.00 | <2.00 | 4.00 | <5.00 | 88.00 | <2.00 |
| **50%** | <2.00 | 14.00 | 16.00 | 26.00 | <3.00 | 37.00 | 36.00 | 3.00 | 4.00 | 5.00 | 96,00 | <2.00 |
| **60%** | <2.00 | 18.00 | 18.00 | 30.00 | <3.00 | 41.00 | 40.00 | 3.00 | 5.00 | 6.00 | 105.00 | <2.00 |
| **70%** | <2.00 | 25.00 | 20.00 | 34.00 | <3.00 | 46.00 | 45.00 | 4.00 | 5.00 | 8.00 | 116.00 | <2.00 |
| **80%** | <2.00 | 37.00 | 23.80 | 41.00 | <3.00 | 53.00 | 50.00 | 5.00 | 6.00 | 10.00 | 130.00 | <2.00 |
| **90%** | <2.00 | 67.10 | 29.00 | 52.00 | <3.00 | 68.00 | 63.00 | 10.00 | 7.00 | 13.00 | 156.00 | <2.00 |
| **95%** | **<2.00** | **111.05** | **34.00** | **64.55** | **<3.00** | **87.00** | **79.00** | **20.00** | **9.00** | **18.00** | **186.30** | **<2.00** |
| **99%** | <2.00 | 384.02 | 48.00 | 150.57 | 6.00 | 148.44 | 183.50 | 103.020 | 14,00 | 150.60 | 286.16 | 5,70 |

### 6.3.5. The methodology of research of mineralised (ore-bearing) samples

The aim of detailed mineralogical and geochemical research of individual occurrences of minerals was to determine, or to specify the knowledge of the mineral content of individual types of mineralisation, the conditions of their formation, clarifying their mutual spatial relationships as well as their ties to the tectonic structures.

For this purpose, samples were collected primarily from the available historical mining works and exposures where the position of sampled material compared to other tectonic or mineralisation structures was clear. At this stage the accessible mining works were levelled. From the data obtained compass sketches were drawn.

The chemical composition of minerals was studied by WDS method in microanalyser CAMECA SX 100, where under BSE mode mutual microstructure relationships of individual mineral phases were investigated. To clarify the genetic conditions the fluid inclusions were studied using cryothermometric methods in an extensive range of samples of transparent minerals (carbonates, quartz). Within the sampled sulphides and carbonates there were investigated stable isotopes ratios S, O and C.

## 6.4. Sources of ore elements in metasediments of the Kohút zone

When evaluating the distribution of sulphide mineralisation in the Kohút zone, it is obvious, that these smaller or larger accumulations of sulphide mineralisation have spatial relations to sedimentary-metamorphic facies, either in the Early Paleozoic or Late Paleozoic metasediments.

The sulphide mineralisation is often linked to the presence of rocks with organic matter and rocks with the presence of basic volcanoclastic material. Such host rocks are present in the following metasedimentary complexes:

1. Late Carboniferous Slatvina Group – the presence of black shales and basic volcanosedimentary material, especially in the SE part of the territory.
2. Early Paleozoic (Hron) complex of mica schists, especially its lower tectonic part, which contains numerous horizons of black shales, metaquartzites rich in organic matter and bodies of metamorphosed mafics, and ultramafic rocks and metavolcanoclastics and rarely metacarbonates.
3. Early Paleozoic complex, so called "albitic gneisses" of the Klenovec complex (Bezák, 1982; quartz – biotite – albite) metapsammites to metapelites, locally with black shales.

The mineralogical research of dispersed quartz-carbonate-sulphidic mineralisation (Ozdín type) in Early Paleozoic metasediments has been done only by Kováčik & Husák (1996) and Ferenc in Hraško et al. (2005) – from rock drilling KH-1 (*Katarínska Huta*). Identical type of mineralisation was studied also at the Ozdín locality (Maťo & Maťová, 1994). Ore mineralisation has been confirmed here along the almost full length of the borehole, and is present mainly in the form of impregnations in rocks, fills in the spaces among foliation planes, inclusions in quartz-carbonate veinlets and also macroscopically visible aggregates and massive accumulations in quartz-carbonate veins and in the rocks.

Based on paragenetic mineral associations and style of appearance, it is possible to distinguish:

1. Older – "syngenetic" mineralisation characterized by magnetite-ilmenite-rutile (± hematite ± pyrite ± pyrrhotite) association,
2. Younger – "epigenetic" pyrrhotite – polymetallic mineralisation of polyphase character.

Older mineralisation is referred to as the original one, sedimentary-metamorphic, Hercynian in age, while younger type of mineralisation is associated with Alpine metamorphic-hydrothermal processes (Kováčik & Husák, 1996). Syngenetic mineral assemblage is arranged on foliation mica surfaces. This mineralisation type has a regional distribution in metamorphic complexes mainly in SW part of the Veporicum area. From the metallogenic point of view it is an important source of gold for the formation of the later, supergene Au mineralisation occurrences (Ferenc et al., 2006a).

Tab. 6. 2 Content of selected trace elements in selected samples of Early Paleozoic micaceous slates and metaquartzites with content of graphitic substance (in ppm).

| Sample | 31/1660 | 37/1155 | 45/1180 | 36/1290 | 36/1355 A | 36/1355 B |
|---|---|---|---|---|---|---|
| Lithotype | Black quartz mica schist | Black metaquartzite | Black metaquartzite | Black metaquartzite | Micaceous metapelite with black intercalations and pink garnet, foliated | Laminated graphitic metaquartzite |
| X (JTSK) | -356,242 | -357,408 | -364,741 | -358,199 | -358,582 | -358,582 |
| Y (JTSK) | -1,238,615 | -1,245,483 | -1,250,546 | -1,244,377 | -1,243,841 | -1,243,841 |
| | ppm | | | | | |
| **Ag** | <0.4 | <0.4 | <0.4 | | | |
| **As** | **33.8** | **104.0** | 5.3 | 5 | 3 | 2 |
| **B** | **39** | **98** | **46** | 8 | **101** | 5 |
| **Co** | 2 | 1 | 2 | 6 | 12 | 2 |
| **Cr** | 70 | 66 | 139 | | | |
| **Cu** | 30 | 18 | 5 | 16 | 18 | 37 |
| **Mo** | 5 | <5 | 6 | <3 | <3 | <3 |
| **Ni** | 4 | 3 | 5 | 18 | 24 | 7 |
| **Pb** | 19 | 8 | 7 | 6 | 25 | 4 |
| **Sb** | **33.1** | 2.0 | 2.7 | <2 | <2 | <2 |
| **Sn** | 4 | 3 | 2 | <2 | 5 | <2 |
| **V** | 199 | **270** | **331** | | | |
| **W** | <5 | <5 | <5 | <5 | <5 | <5 |
| **Zn** | 20 | 16 | 34 | 21 | **106** | 13 |

Tab. 6. 3 Statistical characteristics of the content of selected trace elements in selected samples of metapelites and metapsammites from Slatvina Formation (in ppm).

| | Median | Average | Lower quartile | Upper quartile | Min | Max | No |
|---|---|---|---|---|---|---|---|
| | *Slatvina form. (all lithotypes)* | | | | | | |
| **Ag** | 0.02 | 0.11 | 0.02 | 0.20 | 0.02 | 0,42 | 51 |
| **As** | 4.50 | 12.98 | 1.75 | 10.25 | 0.05 | **198.00** | 76 |
| **B** | 26.00 | 33.96 | 15.00 | 37.00 | <5.00 | **256.00** | 77 |
| **Bi** | 0.30 | 0.69 | 0.05 | 0.40 | 0.05 | 21.90 | 50 |
| **Co** | 10.00 | 10.73 | 6.00 | 14.00 | 0.50 | 36.00 | 77 |
| **Cr** | 93.00 | 118.75 | 80.50 | 110.50 | 14.00 | **749.00** | 51 |
| **Cu** | 17.00 | 25.25 | 9.00 | 34.00 | <2.00 | **232.00** | 77 |
| **Mo** | <3.00 | <3.1 | | | <5.00 | 3.00 | 77 |
| **Ni** | 28.00 | 37.51 | 18.00 | 42.00 | 4.00 | **244.00** | 77 |
| **Pb** | 9.00 | 10.61 | 7.00 | 14.00 | <3.00 | 33.00 | 77 |
| **Sb** | 0.50 | 2.38 | 0.50 | 1.30 | 0.20 | **82.00** | 77 |
| **Sn** | 3.00 | 3.23 | 2.00 | 3.00 | <2.00 | 23.00 | 77 |
| **V** | 124.00 | 118.04 | 99.00 | 138.50 | 11.00 | **231.00** | 51 |
| **W** | <5.00 | | | | <5.00 | 28.00 | 77 |
| **Zn** | 70.00 | 75.44 | 52.00 | 95.00 | 12.00 | **208.00** | 77 |

Although some minerals – molybdenite, arsenopyrite, chalcopyrite, ullmannite, tetrahedrite, sphalerite, galena, stibnite, sulphosalts of Fe-Sb-S, Pb-Sb-S and Bi-Te-S are classified into epigenetic stage, it is very likely that the source of the elements contained in them is their parent rock complex. It also supports presence of a small volume of veins, whose development is linked to the overall Alpine deformation and metamorphism of Paleozoic metasedimentary rocks.

The content of these sulphides is often greater in silicified zones that may represent analogue of silicites, found for example in the Early Paleozoic of Gemericum (Grecula, 1982), where laminae occur, formed by sulphides of Cu-Pb-Zn-Fe, which indicate the alteration of sedimentary component by volcano-exhalation processes in sedimentary basins. Even in Gemericum it was noted that most of stratiform (as well as vein) deposits are located in the roof of black metapelites, lydites and carbonates in conjunction with volcanic horizon.

Slavkay (2005) studied geochemical characteristics of Early Paleozoic mica schists, where the organic material was also analysed. In addition to metamorphic graphite, complex of carbohydrates of bituminous origin is present here (with a maximum of $C_{21-23}$), which are likely to originate during the marine sedimentation in Early Paleozoic sedimentary basins.

Particularly the metaquartzites and metapelites with organic matter in the complex of the Early Paleozoic mica schists and in the Slatvina Formation, contain increased As and Sb concentrations, mainly.

## 6.5. The spatial distribution of anomalies of selected elements in the soil horizon

### *Ag*

In the NE part of the investigated territory dominates Ag anomaly of NW-SE direction, which has an increased content of Ag (>3 SPD). It is located in Príslop ridge – Vysoká hora. Within the extent of this anomaly there are three occurrences of quartz-sulphide mineralisation: *Markuška – Roklinská, Markuška – Mladá hora* and *Slavošovce – Kiar.* The last one is of the utmost importance. The site positionally overlaps with a small but significant Ag anomaly (> 5 SPD), to the south of altitude point Biela skala. Silver is bound to tetrahedrite, as indicated by the increased content in the waste heaps (37 ppm) and, indirectly, to the Hg content – 6.24 wt. % (Gargulák & Rojkovičová, 1993). The mineralisation site *Markuška – Mladá hora* is of a similar nature, but of a lower concentration than at the previous location. The site *Markuška – Roklinská* is characterized by the occurrence of quartz veins with Cu-Ag-Au mineralisation, indicating similarity to the above described locations. Accordingly, the increased Ag contents in anomaly are controlled by the occurrence of quartz veins with Cu mineralisation and especially Hg-tetrahedrite containing silver.

Another significant anomaly (Ag> 3 SPD) is located in the NW part of the territory, in the area between the Dolné Fafáky, Dobroč, saddle Šútova jama, Ozdín and Cinobaňa. Right in there are localized areas with "extreme" Ag contents in the soil (Ag >5 SPD). They usually coincide with the occurrence of siderite and quartz-sulphide mineralisation that were mined previously or they are in close proximity (*Cinobaňa – Jarčanisko, Lovinobaňa – cemetery, Mertlová, Uderiná – Viničky*). This type of mineralisation has significant accumulations right in the SW part of the investigated territory (Ferenc et al., 2006b, 2014). Analysis of the chemical composition of the mineralised waste heap material of siderite occurrences detected average Ag content 112.7 ppm, with the highest content found 625 ppm. The Ag binds mineralogically to tetrahedrite, in particular, in which the average Ag content was 1.04 wt. %. Maximum content found was 3.98 wt. %. Rare silver amalgam similar to eugenite in its composition, was found (*Lovinobaňa – Mertlová*) with Ag content about 75 wt. %.

Of greater importance for the formation of Ag anomalies is epigenetic hydrothermal vein – stockwork quartz-carbonate-sulphide mineralisation of the Ozdín type, with regional distribution and varied mineral association. It was verified by drill-holes in the area of *Ozdín* and *Katarínska Huta*, but in this area there are known also less significant surface occurrences: *Katarínska Huta – Murárka, Cinobaňa – Staré Turíce*. Silver is again bound mainly to tetrahedrite but there were found also other Ag minerals: acanthite, argentite, pure Ag and electrum (Maťo & Maťová, 1994). Increased contents in soil samples are probably caused by Au mineralisation in shear zones (supergene mineralisation, so-called "secondary gold"), which is reflected also by relatively abundant distribution of gold in the river network. Locations of the typical evolution of the mineralisation are *Uderiná – Loviňa* and *Katarínska Huta – cemetery* (Maťo & Maťová,1993; Ferenc et al., 2006a).

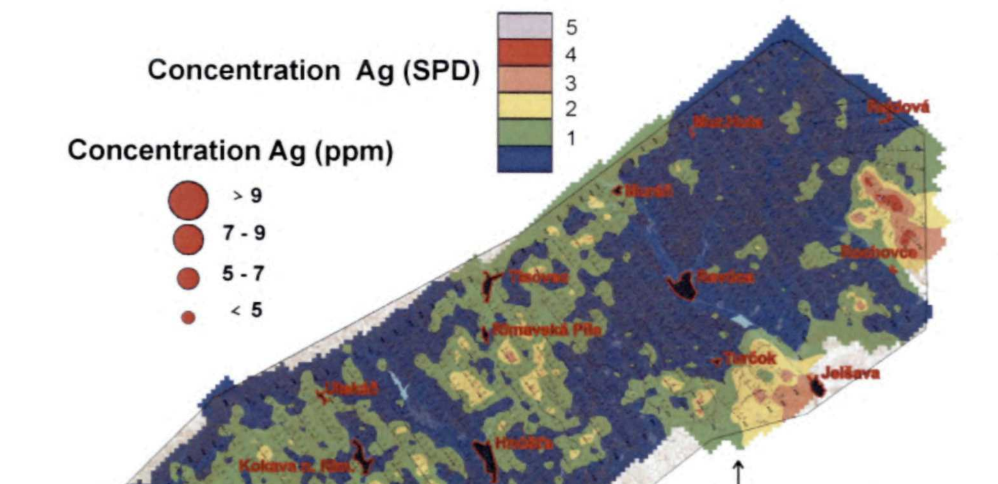


*Fig. 6.1 Distribution of Ag (in SPD scale – isolines, and in quantitative values in ppm – red circles) in soil horizon B. Anomalies in E part of territory are situated in Veporicum Late Paleozoic metasediments (Slatvina ad Rimava Fms.). Anomaly between Jelšava and Tučok belongs to metasediments with metacarbonates of Early Paleozoic and Late Paleozoic metasediments of Gemericum tectonic unit. Most pronounced is the anomaly between Ozdín and Lovinobaňa, which is part of system of wider shear zones in this territory (with incorporation of granitoids, gneisses, mica schists, black metaquartzites, Late Paleozoic Veporicum fragments, even Carboniferous tectonic slices of black metasediments, belonging to the Ochtiná Formation).*

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Silver anomaly in the Podrečany and Ružiná area can be explained either by the existence of supergene Au mineralisation in shear zones and/or the presence of epigenetic hydrothermal vein-stockwork quartz-sulphide mineralisation. In this area, there are a lot of historical surface mining works, focused on gold mining, but the manifestations of primary ore mineralisation at the surface are not known.

Distribution of Ag based on the SPD spectral analysis in semiquantitative scale (isolines), was accompanied by a quantitative assessment (red circles), as shown in Fig. 6.1.

### *As*

In the SE part of the investigated territory there were identified significant As anomalies (>100 ppm) in soils in the area between Rochovce, Kopráš and Čierna Lehota. Significant As anomaly in the area of Dônčová and Hladomorná dolina valley is a result of the occurrence of quartz veins and stockwork-impregnating zones with sulphides. In the centre of the anomaly is the location *Chyžné – Mária*. In the waste heap material there were found up to 14.9 wt. % As, the sole As mineral was arsenopyrite. In the wider area of this site, there are also occurrences of quartz-stibnite mineralisation and quartz veins with pyrite and arsenopyrite (*Chyžné – Malá, Dolinky, Chyžné – Herichová, Kubej*), which results in an As content increase in soil samples (over 10 ppm). In the south direction of the altitude point Homôlka with another As anomaly the occurrences of surface ore mineralisation are not known. Until the beginning of the profile 17 (*Kopráš – Skaličné*), the incidence of vein-stockwork mineralisation of NE-SW direction was detected, of a nature similar to the site *Chyžné – Mária*. The As major mineral is arsenopyrite and the waste heaps material contained up to 2,242 ppm of As. In the very distinctive As anomaly south of the altitude point Homôlka we assume at a depth the occurrence of quartz veins with pyrite, arsenopyrite and pyrrhotite which appear to be the source of As.

In the significant As anomaly between Rochovce and altitude point Dúbrava there are known three occurrences of hydrothermal ore mineralisation, namely: R*ochovce – Ilona, Dubiná – Drábsko* and *Oriešok*. The first two represent impregnated-stockwork mineralisation of the N-S direction, consisting of pyrite, arsenopyrite, galena, sphalerite and others. The rich ore contained 4.2 wt. % As (Slavkay et al., 2004). Virtually the only mineral is arsenopyrite. The *Oriešok* site is characterized by quartz-stibnite vein of NW-SE direction; the arsenopyrite or other As minerals were not found. Increased As content in soil samples can be caused by a vein-metasomatic Pb-Zn mineralisation in crystalline limestones occurring NNW of Ochtiná (*Mária Margita*), in which the arsenopyrite has been also described. In the smaller, but significant anomaly in the beginning part of the profile 16 is the occurrence of magnesite *Ochtiná – Hrádok-Hŕbky* (with accompanying sulphide mineralisation) and also the occurrence of *Jelšava – Delková* with Pb-Zn mineralisation.

The most significant As anomaly (As content is over 50 ppm) with local centres (over 190 ppm As) has a linear character and NE-SW direction. It is located in the central part of the territory and can be traced from the area towards the northwest of Ratkovská Zdychava (NE of Revúca) and to Cinobaňa to the southeast. It is part of a wider shear-deformation zone, referred to as "Zdychava tectonic line".

The occurrence of very significant As anomaly in the area of Rejkovo NW of Tisovec can be explained by the presence of rhyolite bodies with high As content. As is bound to As-monazite and diverse range of REE phosphates and arsenates (Ondrejka et al., 2007).

In the significant As anomaly area near Hnúšťa, NE of deposit Mútnik and SE of the altitude point Starý chodník, there are two major ore occurrences: *Cerberus I* and *III*. These are stockwork-impregnation mineralisation types represented by pyrite, marcasite and pyrrhotite (+ arsenopy-

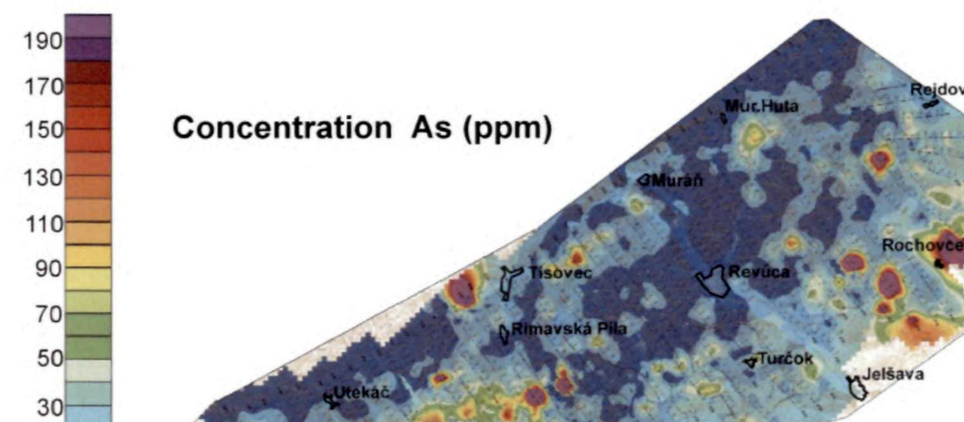

*Fig. 6.2 Concentration of As (in ppm) in soil horizon B revealed continuous As concentration in the Southern Veporicum region. Linear As anomaly of SW-NE direction in the W part of the region is connected with the pronounced Alpine shear zone accompanied by magnetic anomaly.*

rite, bismuthinite, gersdorffite, quartz, dolomite and others) in Ca-Mg-Fe carbonate. In the samples from heaps the As content was found of up to 3,356 ppm, the main mineral was arsenopyrite, gersdorffite was found rarely. Near the SE edge of this anomaly is the small occurrence of *Polom* with talc and magnesite (± indications accompanying sulphide mineralisation). More significant As anomaly is located southwest of Klenovec and is a manifestation of carbonate and quartz – sulphide mineralisation (sites *Klenovec – Medené* and *Nad Medeným*). The SW continuation of this mineralisation is the occurrence *Kokava n. Rimavicou – Chorepa*. It is a carbonate-quartz vein association with a variety of sulphides. The waste heap material of both locations contained 562 ppm As on average, with maximum content 1,477 ppm. The main As mineral was arsenopyrite, increased content of As was found in abundant tetrahedrite (up to 1.75 wt.%), and rare cobaltite was also found.

Arsenic anomalies around altitude point Bodnárka were affected by the presence of quartz-sulphide mineralisation, similar to the site *Klenovec – Medené*. This type of mineralisation on the NW slopes of the Sinec Massif is widely distributed (Ferenc & Bakos, 2006) and apparently causes an increase in As content across the area. Significant occurrences of mineralisation are exposed towards the N and NE of Kokava nad Rimavicou (*Chorepa* and *Brnákovo*).

In the area of significant anomaly between Kokava nad Rimavicou and Krná the surface occurrences of ore mineralisation are not known. The exceptions are sporadic old surface mining works focused in gold (*Zlatno – Kečka*), which are located near surface occurrences of granite of the Klenovec type. The area was recently the subject of intense exploration of the precious metal mineralisation. In samples from boreholes in addition to a diverse range of sulphides the arsenopyrite was identified, too. In general it can be assumed the occurrence of epigenetic stockwork-impregnating quartz-carbonate-sulphide mineralisation (type Ozdín), which is the source of gold in supergene enriched zones (these were the subject of historical surface mining).

Very significant As anomaly in Ozdín area and its wider vicinity is a consequence of the occurrence of epigenetic stockwork-impregnating quartz-sulphide mineralisation, which is considerably present in this part of the Slovenské rudohorie Mts. In the samples from the occurrences *Cinobaňa – Staré Turíce* and *Katarínska Huta – Murárka* the average As content was 153 ppm and the maximum content was 515 ppm. The As anomaly in the NW direction of Cinobaňa is the occurrence *Cinobaňa – Jarčanisko*. In the waste heap material, in addition to siderite veinlets with sulphides, As was found in older quartz veinlets with pyrite and arsenopyrite which were intersected by siderite veins (Ferenc et al., 2006b). This suggests possible expansion of quartz veins with arsenopyrite and pyrite within the wider environment. In the samples from heaps there was found average As content of 2,149 ppm and maximum up to 6,600 ppm. Less and less pronounced As anomaly towards the NE of Maša – Katarínska Huta coincides with the occurrence of mineralisation at the site *Katarínska Huta – cemetery*. This is a supergene Au mineralisation in the shear zone with relics of the Ozdín type mineralisation (Ferenc et al., 2006a). The samples at the site contained up to 314 ppm of As, on average – 111 ppm. The As quantitative content distribution in the soil horizon is in the Fig. 6.2.

### *Bi*

Bismuth anomalies in the examined area are extremely rare. The most significant anomaly is located in the area between Slavošovce and Ochtiná on both sides of the stream Štítnik. In the eastern part of this anomaly there are occurrences of ore mineralisation, namely: *Rochovce – Ilona, Dubiná – Drábska* and *Oriešok* (see arsenic description).

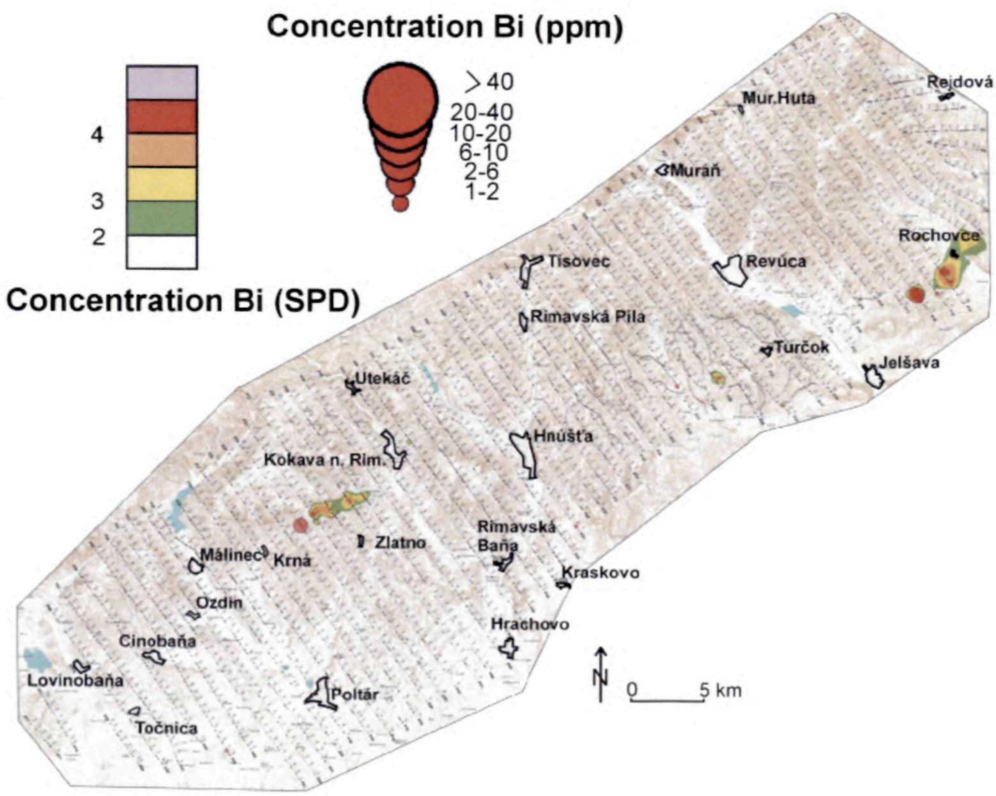


*Fig. 6.3 Concentration of Bi (in ppm) in soil horizon B is strictly connected with the Late Cretaceous Rochovce (W-Mo deposit) granite and with the Permian Klenovec type granite (NW of Zlatno village) here incorporated into the Alpine shear zone.*

Separate bismuth minerals were observed on these sites; in the waste heaps from the site *Dubiná – Drábska* the Bi contents were found equalling to 38 ppm. In the western part of the anomaly (where the Bi content is greater) the mineralisation is known similar to the locations *Ilona* and *Dubiná – Drábska* (location *Rochovce – Lašanka*). Dominant position, however, have quartz veins with pyrite, scheelite, molybdenite and wolframite (sites *Ochtiná – Zlatá Baňa* and *Čížkobaňa*). In the waste heaps material at the site Čížkobaňa the Bi content was just below the limit of detection (or less than 5 ppm) and at the site Zlatá Baňa the Bi content was equal to 17 ppm. The individual Bi minerals were not detected. In the area of the Bi anomaly between Veľká Šteť and Magura there are not known any past mining activities tracking the signs of mineralisation. The Bi minerals – ullmannite with Bi content up to 15.2 wt. % and joseite B with Bi content about 76.5 wt. %, were rarely identified in quartz-calcite veins with fluorite and sulphides in the drillhole RO-9. These locations are situated in Paleozoic overburden of the **Rochovce intrusion**. It can be concluded that the increased Bi content in this area is likely to constitute part of primary geochemical aureole of the Rochovce granitoid intrusion in the basement.

The second significant Bi anomaly is between Vlkovo and Krná. There are not known occurrences of surface ore mineralisation, with the exceptions of the old surface mining works for gold (*Zlatno-Kečka*) in the area of the deformed granite of the type Klenovec. In one sample of quartz veinlets taken from the rubble the Bi content up to 133 ppm was found. The individual Bi minerals were not observed. Based on samples from boreholes that may also be assumed significant hidden incidence of epigenetic stockwork-impregnation quartz-sulphide mineralisation (Ozdín type).

The positions of the two small soil-geochemical Bi anomalies, associated with the presence of the Rochovce granite type of the Late Cretaceous age in the eastern part of the territory and the Middle Permian granite of the type Klenovec, southwest of Kokava nad Rimavicou, are illustrated in Figure 6.3.

### *Co, Ni*

Cobalt anomalies are widespread within the area studied, but the increased Co-content in soil samples is generally caused by lithology of rocks (influence of mafic and ultramafic rocks bodies). Distribution of the anomalies is not decisive in determining mineralised zones.

In the waste heaps material the more pronounced content occurred on those sites with occurrence of quartz-sulphide mineralisation: *Hnúšťa – Mútnik* (295 ppm), *Cerberus I* (3,260 ppm), *Klenovec – Medené* (246 ppm), *Kokava n. Rimavicou – Chorepa* (161 ppm), *Bohaté,* štôlňa *Runina diera* (280 ppm), *Ratkovské Bystré – Bystrianska dolina* (124 ppm) and *Revúca – Dolinský potok* (150 ppm), where ultramafic rocks are usually present.

From the mineralogical point of view, in the mineralised structures the Co-carriers are the minerals: Co-arsenopyrite, cobaltite, gersdorffite, costibite, ullmannite, willyamite (*Hnúšťa–Mútnik, Cerberus I* a *III, Kokava n. Rimavicou–Chorepa, Klenovec-Medené*). The trace Co-content (first tenths of wt.%) was recorded locally in pyrite, pyrrhotite and pentlandite (*Revúca – Dolinský potok stream, Ratkovské Bystré – Bystrianska dolina valley*). In the SW part of the investigated territory the separate Co-Ni minerals within quartz sulphide mineralisation stage are represented by gersdorffite, siegenite and linneite. These minerals were found on sites *Uderiná – Viničky* and *Lovinobaňa – cemetery* (Ferenc et al., 2014), which likely reflects the impact of the amphibolite on the vein filling formation.

In the SW part of the area the increased Co-content at Cinobaňa is probably due to extensive amphibolite bodies. The overall increase in the Co-content could be also due to the presence of epigenetic stockwork-impregnating quartz-sulphide mineralisation (type Ozdín), in which several Co-bearing phases (cobaltite, gersdorffite and Co ullmannite) were identified.

What is true for the distribution of the cobalt anomalies, also applies to Ni anomalies. In general, the increased amount of Ni in the soils is linked to the presence of mica schist complex and metabasic and serpentinite rocks in the geological structure.

The increased Ni-content in waste heaps was observed only at the sites: *Klenovec – Medené* (273 ppm), *Hnúšťa–Cerberus I* (1,682 ppm) and *Revúca-Dolinský potok stream* (273 ppm). The carriers of nickel were ullmannite, gersdorffite and siegenite. In the SW part of the territory overall increase in Ni-content could be due to the presence of epigenetic stockwork-impregnating quartz-sulphide mineralisation (type Ozdín), in which there were identified several Ni-bearing phases (cobaltite, gersdorffite, Co ullmannite). To a lesser extent the anomalies could be partly derived from the occurrences of siderite and quartz sulphide mineralisation (*Uderiná – Viničky*). The average content of Ni in waste heaps on this site is 46.7 ppm, maximum content found was 156 ppm.

### *Mo*

In the area studied, the **Mo** creates rather less plentiful and relatively insignificant anomalies. Towards the east of the area there is strong Mo anomaly between Ochtiná and altitude point Magura. It represents the impact of the late Cretaceous Rochovce ore-bearing intrusion in the basement. In the anomaly quartz veins with pyrite, scheelite, molybdenite and wolframite are present in the overburden of the Paleozoic Rochovce body (sites – *Ochtiná – Zlatá Baňa* and *Čížkobaňa*). In the waste heaps material at the site *Čížkobaňa* the Mo-content was 148 ppm. Maximum content of Mo in soils in the Rochovce area reached 26 ppm. The Mo anomaly around Ozdín and Cinobaňa is probably due to stockwork-impregnation quartz-sulphide mineralisation (type Ozdín) as the molybdenite has been identified in samples from Ozdín and also from Katarínska Huta.

The Mo anomalies presence in the southwest of Muráň with known molybdenite mineralisation (Petro et al., 1998), probably associated with Hercynian leucocratic granitoids, was not detected by the implemented profiles.

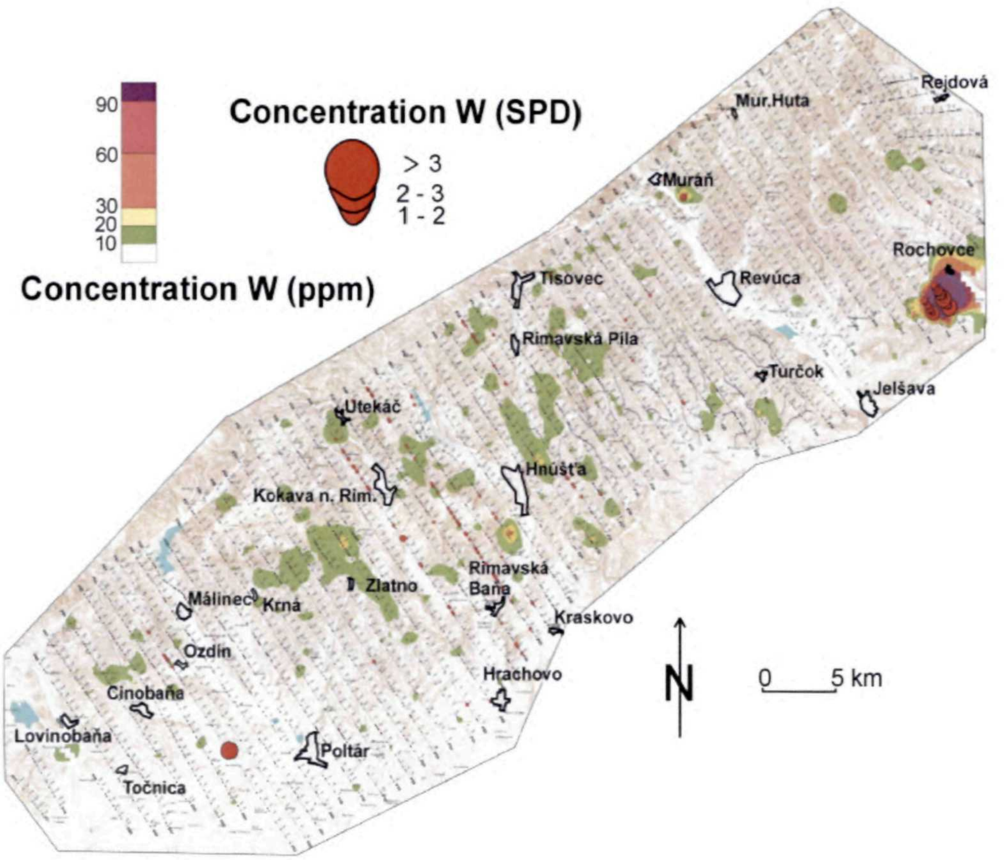


*Fig. 6.4 Concentration of W (in ppm) in soil horizon B is strictly connected with the Late Cretaceous Rochovce (W and Mo bearing) granite.*

Elsewhere in the area studied the scheelite mineralisation is known from the quarry in Klenovec (quarry Ostrá) and at talc-magnesite deposits in Kokava nad Rimavicou. The scheelite is also strongly present in the river network. Fig. 6.4 depicts the excellence of the W anomaly in conjunction with Rochovce granite which is concentrated in the E part of the territory.

### *W*

The most striking **W** anomaly in the area is located in the area between Ochtiná and altitude point Magura (locally over 90 ppm to 833 ppm in soils). It represents the impact of the Rochovce intrusion in the basement. In the area of the W anomaly quartz veins with pyrite, scheelite, molybdenite, wolframite are present in the Paleozoic overburden of the Rochovce body (sites *Ochtiná – Zlatá Baňa* and *Čížkobaňa*). In the waste heaps material at the site *Čížkobaňa* the content of W was 424 ppm. The W anomalies around Ozdín and Cinobaňa could be theoretically caused by stockwork-impregnating quartz-sulphide mineralisation (type Ozdín) as scheelite has been identified in samples from Ozdín and also from Katarínska Huta.

### *Sn*

The most striking **Sn** anomaly in the area studied is located between Ochtiná and altitude point Magura. It represents the impact of the Rochovce intrusion in the basement. In the area of the anomaly quartz veins with pyrite, scheelite, molybdenite and wolframite are present in the overburden of the Late Paleozoic of the Rochovce body (sites *Ochtiná – Zlatá Baňa* and *Čížkobaňa*). In the waste heaps material at the site

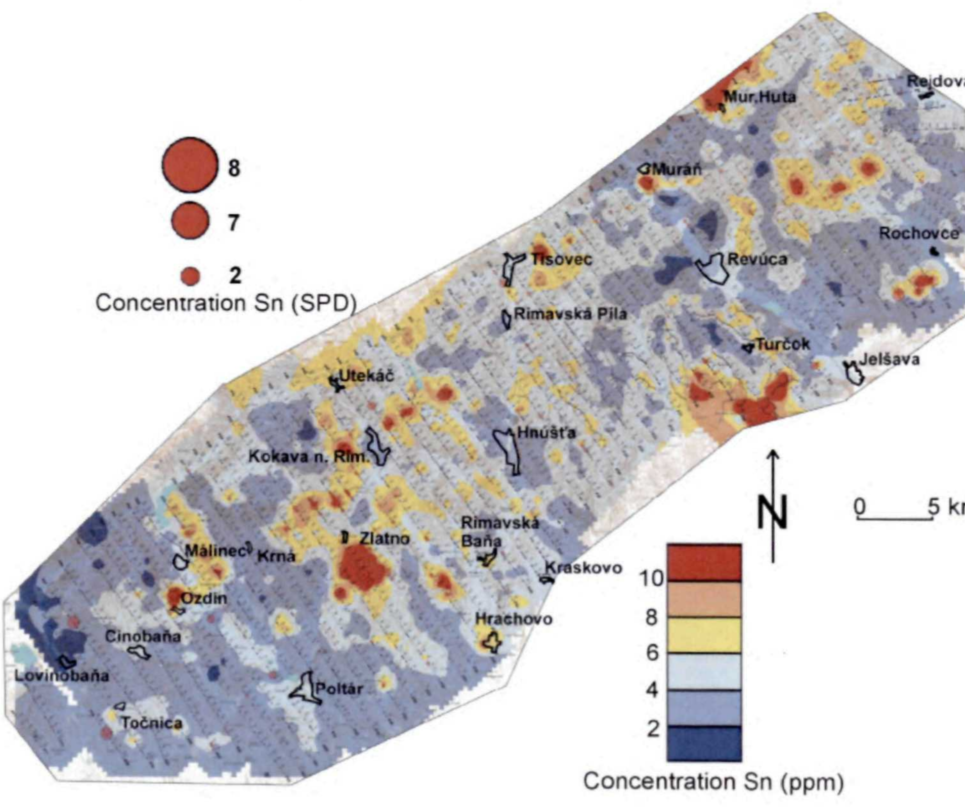


*Fig.6.5 Concentration of Sn in soil horizon B (isolines in ppm and red circles in SPD scale)*

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*Čížkobaňa* the content of Sn was 3 ppm and in Zlatá Baňa, the content of Sn was in the range of 0-8 ppm (Garguľák & Rojkovičová, 1993). Individual Sn minerals in veinlets were not observed. The Sn anomaly around Ozdín may be caused by the stockwork-impregnating quartz-sulphide mineralisation. The presence of separate mineral phases of Sn, however, was not observed.

Part of the soil-geochemical anomalies is bound to leucocrate granitoids type (most extensive anomaly is linked to the Hercynian two-mica granite S of Zlatno, and to the micaceous lithology in the mica schist complex (Fig. 6.5).

### *Sb*

Significant **Sb** anomaly is located in Dônčová and Hladomorná dolina Valley (spatially coincides with the As anomaly). Quartz veins and stockwork-impregnating zones with sulphides (pyrite, pyrrhotite, arsenopyrite, galena, sphalerite, chalcopyrite and others) are present here. Right in the centre of this anomaly is the site *Chyžné – Mária*, with mining activities in the past. In the sample of waste heap material the Sb content was 309 ppm, and among the Sb minerals there were found here Ag-tetrahedrite, bournonite, boulangerite, jamesonite. In the wider area of this site there are occurrences of similar nature (*Chyžné – Malá, Dolinky*), causing increased content of Sb in soil samples.

The known quartz-stibnite mineralisation at locations *Chyžné – Herichová* and *Kubej*, which are also in close proximity of this anomaly, does not occur in soil samples, even though the profile no. 18 passes at a distance of about 250 m from one of them (*Herichová*). Minor Sb anomaly is at the beginning of the profile 17 and is caused by vein-stockwork mineralisation of a similar nature of the site *Chyžné – Mária*. Here, the Sb minerals lillianite, stibnite and unspecified Pb-Sb sulphosalts were found.

In Sb anomaly NE of Rochovce is the Oriešok location where it developed quartz-stibnite vein of NW-SE direction with ore content quality = 2.19 wt. % Sb. Up to 1.15 wt. % of Sb was found in the rich ore from the site *Dubiná – Drábska* (Slavkay et al., 2004), which represents impregnation-stockwork mineralisation with pyrite, arsenopyrite, galena, sphalerite, stibnite.

Distinct Sb anomaly southwest of Klenovec is bound to the occurrence *Klenovec – Medené* (see As description). Average Sb-content in the samples of waste heaps was 1,476.2 ppm; the maximum content was 5,913 ppm. From the mineralogical point of view, the Sb is bound mainly to tetrahedrite, less to the Bi-jamesonite, and minerals berthierite – garavellite (Ferenc & Dzúrová, 2015).

Significant Sb anomaly of linear nature with local "extreme centres" (Fig. 6.6) is roughly equal to the linear As anomaly and can be followed in the direction NE of Zlatno till Uderiná to the SE. The southeast part of this anomaly (vicinity of Cinobaňa and Uderiná) is due to the occurrence of siderite and quartz-sulphide mineralisation (*Cinobaňa – Jarčanisko, Lovinobaňa – cemetery, Mertlová, Uderiná – Viničky*). While investigating the chemical composition of mineralised waste heaps from siderite occurrences there was detected average content of Sb 10,932 ppm, and the highest content found was 82,490 ppm.

From the mineralogical point of view the Sb is bound in particular to tetrahedrite, to a lesser extent to jamesonite. The remaining part of the linear anomaly could be caused by regionally widespread epigenetic stockwork-impregnation quartz-sulphide mineralisation (type Ozdín) with relatively abundant Pb-Sb sulphosalts. In the samples taken from the waste heaps of sites *Cinobaňa – Staré Turice* and *Katarínska Huta – cemetery* the average Sb content is 1,105 ppm, the maximum content recorded was 2,909 ppm. From the mineralogical point of

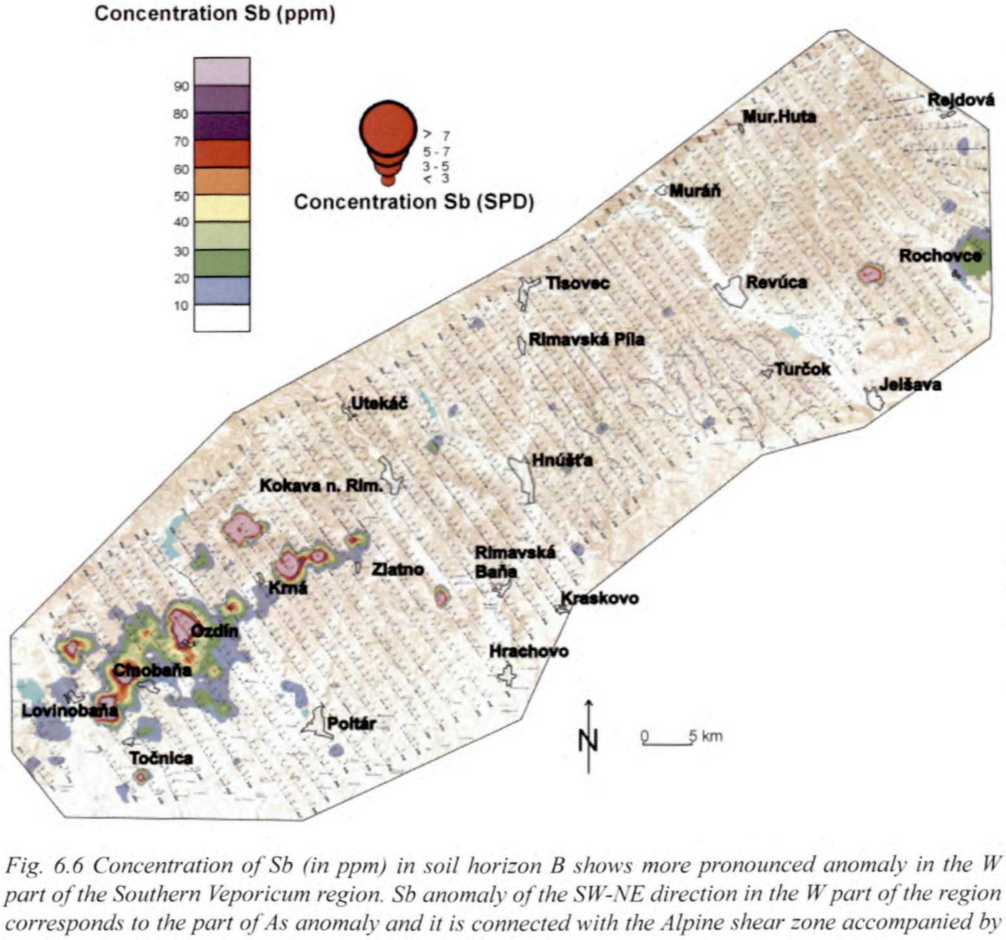


*Fig. 6.6 Concentration of Sb (in ppm) in soil horizon B shows more pronounced anomaly in the W part of the Southern Veporicum region. Sb anomaly of the SW-NE direction in the W part of the region corresponds to the part of As anomaly and it is connected with the Alpine shear zone accompanied by magnetic anomaly.*

view the Sb is bound to tetrahedrite, gudmundite, stibnite and various sulphosalts (meneghinite, boulangerite, etc.). There were identified pure Sb and gold containing Sb-Ni (Ozdín).

Less pronounced Sb anomaly is identified N of Málinec in the space between settlements *Štefančíkovci* and *Bansko*. This is a pyrrhotite mineralisation with minor content of other sulphides (pyrite, sphalerite). In the samples taken from mining works (*Štefančíkovci*), the Sb content reached only 13 ppm.

### *Cu*

The **Cu** anomalies are relatively widespread in Veporicum. Since copper minerals are widespread and dominant in almost any type of ore mineralisation, there is no need to comment on any relationship to the particular anomaly of Cu deposit/occurrence.

In the SW part of the study area there is an increased background (over 10 SPD) caused by occurrences/indications of epigenetic stockwork-impregnation quartz-sulphide mineralisation (*Ozdín, Katarínska Huta*) and siderite and quartz-sulphide mineralisation (*Lovinobaňa – Mertlová, Cinobaňa – Jarčanisko*). In the central part (*Klenovec – Hnúšťa*) the most significant Cu anomalies are caused by occurrences of carbonate and quartz-sulphide mineralisation (*Klenovec – Medené, Hnúšťa – Mútnik, Kokava nad Rimavicou – Chorepa*). In the eastern part these are mainly quartz veins with pyrite, pyrrhotite and chalcopyrite (*Slavošovce – Ostrý vrch, Za Hvarkou, Trebejová*), then the quartz veins with pyrite, arsenopyrite, galena, sphalerite, and stibnite, etc. (e.g. *Rochovce – Ilona, Dubiná – Drábska, Ochtiná – Lašanka*) and hydrothermal – metasomatic Pb-Zn mineralisation (*Mária Margita*). In the SE part, near the border of the study area the Cu anomalies are derived from the vein and metasomatic siderite (+ sulphide) bodies in Gemericum.

The most abundant Cu minerals in the area studied are chalcopyrite, tetrahedrite, to a lesser extent, low Cu-content is bound to some local sulphosalts. In the supergene conditions particularly widespread is malachite, less covellite, azurite, cuprite, and tenorite.

### *Pb*

The **Pb** anomalies are less extended within the territory. This is due to the relative rarity of Pb mineralisation in this area. Significant Pb anomaly east of Slavošovce is probably due to manifestations of vein-metasomatic Pb-Zn mineralisation (sites *Ochtiná – Mária Margita*) in the crystalline limestones. The mineralisation contains up to 2.18 wt. % Pb. To a lesser extent the anomaly can be caused by impregnation-stockwork mineralisation represented by pyrite, arsenopyrite, galena, sphalerite, etc. (*Rochovce – Dubiná-Drábska, Ilona*). The mineralisation contained an average of 1.28 wt.% Pb (Slavkay et al., 2004).

The Pb anomaly north of Rákošská Baňa correlates with stockwork-impregnation Hg mineralisation (Hg deposit *Rákoš*) developed along the tectonic line between the Early Triassic and Late Carboniferous rocks.

In the SW part of the territory near Cinobaňa, the Pb anomaly is present, caused by the old deposit *Cinobaňa – Jarčanisko*. It is the siderite-sulphide mineralisation. The average Pb content of waste heaps was 2.7 wt. %, the maximum content found was 12.8 wt. %. The Pb presence is linked in particular to jamesonite, to a lesser extent to galena and Pb-tetrahedrite (where there were detected maximum Pb-contents up to 11.2 wt.%).

Extensive and significant Pb anomaly north of Ozdín is caused probably due to the occurrence of epigenetic stockwork-impregnation mineralisation. There were identified a series of Pb-bearing mineral phases, namely: galena, jamesonite and boulangerite.

### *Zn*

Significant **Zn** anomaly east of Slavošovce is probably due to manifestations of vein-metasomatic Pb-Zn mineralisation (sites *Ochtiná – Mária Margita*) in the crystalline carbonates. The mineralisation contained up to 13.8 wt. % Zn. To a lesser extent the anomaly can be caused by impregnation-stockwork mineralisation, represented by pyrite, arsenopyrite, galena, sphalerite, etc. (*Rochovce – Dubiná-Drábska, Ilona*). The ore contained an average of 1.12 wt. % of Zn (Slavkay et al., 2004).

The Zn anomaly southwest of Slavošovce is probably due to the presence of the stockwork ore mineralisation represented by galena, sphalerite, pyrite, stibnite, arsenopyrite and boulangerite. This reasoning is based on the occurrence of mineralisation at the site *Slavošovce za Hvarkou* (Zn content in the ore was up to 8.85 wt. %) located on the north side of the anomaly and also on the findings of this type of mineralisation on the heap of the Kopráš Tunnel.

The Zn anomaly northwest of the Čierna Lehota coincides very well with the occurrence of quartz veins with chalcopyrite, tetrahedrite and pyrite (*Slavošovce – Kiar, Markuška – Mladá Hora*). The Zn-contents in waste heap material were 237 ppm (*Kiar*) and 46.6 ppm (*Mladá Hora*).

The Zn anomaly N of Rákošská Baňa correlates with stockwork-impregnation Hg mineralisation (deposit Rákoš) developed along the tectonic line between the Early Triassic and Late Carboniferous rocks.

The pronounced Zn anomaly N of Ratkovská Zdychava correlates with the occurrence of siderite-sulphide mineralisation at the site *Ratkovská Zdychava – Rovienka*. The mineral association at this site is represented by siderite, boulangerite, pyrite, arsenopyrite, sphalerite, galena. The zinc content in the ore mineralisation was 0.86 wt. % (Slavkay et al., 2004).

The Zn anomaly around the altitude point Ohrablo in Hnúšťa very roughly coincides with the occurrence of metasomatic Pb-Zn mineralisation Ostrá II. The zinc content in the ore was 4.2 wt. % (Garguľák et al., 1995).

The double Zn anomaly NE of Kokava nad Rimavicou very well coincides with the occurrences *Chorepa* and *Brnákovo*. These are minor manifestations of carbonate and quartz-sulphide mineralisation (type *Klenovec – Medené*). Nevertheless, in the waste heaps material there was found Zn content of just 37 ppm (*Chorepa*). The Zn anomaly towards N of Ozdín is probably due to the occurrence of epigenetic stockwork-impregnation mineralisation.

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## 6.6. Geophysical anomalies connected with ore anomalous zones.

Substantial geophysical works were carried out in the past in the scale of 1 : 25,000 mainly. The main methods were areal gravimetry and magnetometry. Later these measurements were supplemented by airborne magnetic and gamma spectrometry methods. Some complex geophysical researches in the neighbouring areas – Spišsko-gemerské rudohorie Mts. and Lučenec – Rimava basins were performed during 60-ties and 70-ties.

Other works dealing with problems of regional extension were: Maps of geophysical indication and anomalies in the area Lubeník – Hnúšťa and Slovenské rudohorie Mts. – West.

A more detailed research which contributed into solution of metallogenic and deposit problems was made in the contact zone of Veporicum with Gemericum unit near Rochovce, surroundings of Muránska Zdychava and within the Muráň – Tisovec area. Other works were devoted to the prospection of graphite and gold.

Most of the geophysical works in this area were summarised by Kucharič et al. (2005).

**Map of the total vector of the earth magnetic field**

A magnetic field in the area is rather variegated. A dominant extensive magnetic anomaly situated in the NE part of the area is a result of a superposition of magnetic effects caused by several sources in various depths. Bearers of the magnetization are Alpine granites with notable content of magnetite (e.g. Határ et al., 1989) with the average depth around the sea level (Fig. 6.14), and locally magnetite and pyrrhotite in the hydrothermal zones near granite. Next expressive magnetic object is a continuous belt of mostly negative anomalies which is situated to the SE of the previous structure. The direction of this 2D anomaly is parallel to the Lubeník line. This form of the magnetic field is evolved by presence of metamorphosed rocks in the Rimava Fm. (a formation of Alpine metamorphic magnetite was found in the scope of field research), as well as in neighbouring mafic and ultramafic rocks of the Ochtiná Fm.

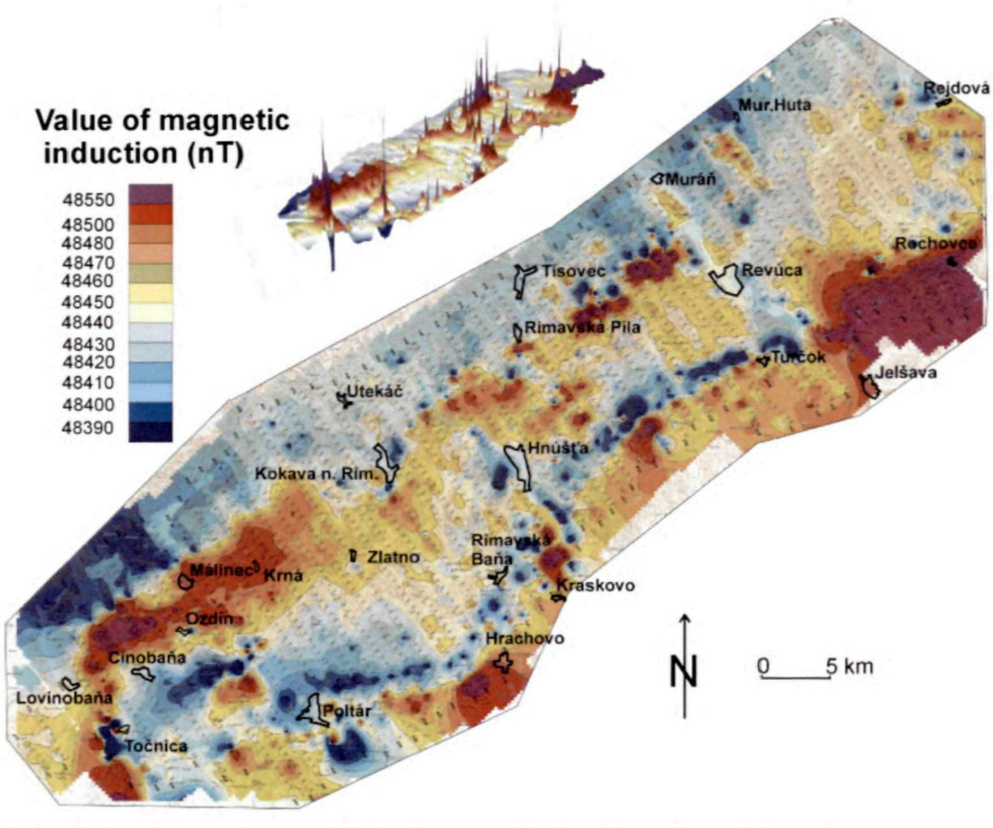


*Fig. 6.7 Map of the total vector of the earth magnetic field. Magnetic anomalous zones are represented by anomaly caused by granite enriched in magnetite in the depth in the Rochovce area; magnetic masses as a part of the Ochtiná Fm. (serpentinites, metasediments with pyrrhotite) in the SE belt of anomalies; and small, less significant anomalies in the Late Paleozoic envelope of the Veporicum unit. The expressive linear magnetic anomaly situated almost in the centre of the area (NE-SW direction in the area between Lovinobaňa – Muránska Zdychava – NE of Revúca Town) in the length ca 50 km is a part of so-called "Zdychava tectonic line".*

A relatively large area to the SW of Lubeník line is characterized by the presence of Tertiary volcanics products. Its manifestation is typical of sudden alteration of polarity of the magnetic field. The character of these anomalies is superficial – they form more expressive morphological elevations with the thickness of about 100 m. The anomalies are caused by volcanoclastics of the Tertiary Pokoradza Fm. These rocks influence the magnetic field in the vicinity of the villages Polom and Ratkovská Zdychava. Special magnetic effects to the south of Lovinobaňa belong to the Late Tertiary basalt volcanism.

An important and expressive magnetic zone of linear shape has been detected between Lovinobaňa and Muránska Zdychava villages (NE of Revúca Town). This zone is a reflex of superficial, or shallow magnetic masses of the mica schist complex with metamorphosed ores and magnetite. These complexes are a part of complicated Zdychava shear zone (Fig.6.7) which is simultaneously anomalous.

**Map of induced polarization**

An arrangement of geoelectric measurements enabled to assess a distribution of apparent polarizability in the depths of 50-100 m below surface. The most important advantage of this method is its sensibility with regard to graphite content, or scattered, disseminated sulphidic mineralisation that is connected with the graphitic zones. Due to the fact that the investigated area possesses the quantity of debris, often with the thickness more than 10 m, this method was useful for detection of such covered, or hidden graphitic zones.

The most expressive geophysical echo is obtained from the black metasediments of the Ochtiná Fm. These were observed also in the western part of the area where they create detached masses of an overthrust sheet. Their amplitude is the highest in the area and this anomalous field is the largest as well. This field flanks the whole southern part of the area from Ochtiná to Kalinovo villages. The dark mostly psammitic complexes of the Slatvina Fm., situated to the north of the previous anomalous zone, are less expressive. Local highs of the field of apparent polarizability are bound to the occurrences of mica schists and black quartzites in the frame of mica schist complex which is a component of the Zdychava tectonic zone. It is possible to expect in this field a local enrichment by graphite, even in the crystalline form (Hraško et al., 2005). However, such investigation requests more detailed prospecting scale.

A spatial analysis of the magnetic field and the induced polarization proved that both elements are quite close to each other. It is caused by proximity of black shales, or mica schists and metamorphosed rocks of the Early and Late Paleozoic. In the majority of cases these zones are connected with effects of mineralisation, what was confirmed by the results of soil geochemistry.

## 6.7. Metallogenic development of the western part of the Slovenské rudohorie Mts. region

Distribution, type variety and the character of the ore occurrences/deposits and some non-metallic minerals in the western part of the Slovenské rudohorie Mts. reflect a complex geological evolution of the area. To the metallogenic specialization of the region contributed Hercynian, but mainly Alpine orogenic cycles, during which the current status was created. In the period of tectonic relaxation after major tectonic phases of the Alpine orogeny (Paleogene, Neogene and Quaternary) the formation and accumulation of certain types of mineral raw materials continued (placer deposits, non-metallic deposits).

A summary of knowledge on the metallogenic evolution of the western part of the Slovenské rudohorie Mts. (or Southern Veporicum tectonic zone), is discussed in Slavkay et al. (2004). The mineralisation in this area is the result of a number of remobilisation processes at each locality, often within one mineralized structure. The determination and classification of mineralisation older than the Alpine metamorphosis of Veporicum is problematic and questionable, because the character of metamorphosis is often completely obscured. In the following, we will stick to the division in Hercynian and Alpine orogeny metallogenic epoch sensu Lexa et al. (2007).

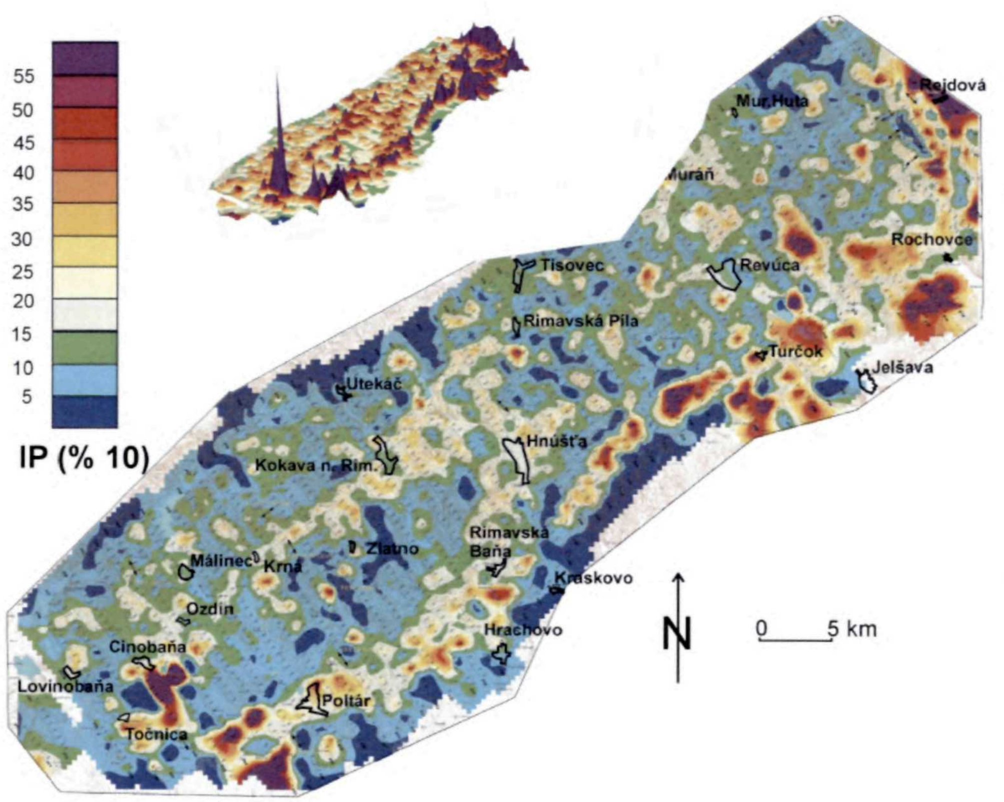


*Fig. 6.8 Black and dark pelite-psammite rock complexes are reflected in the map of the induced polarization.*

### 6.7.1. Pre-Hercynian (?) and Hercynian metallogenic stage

For mineralisation manifestation of this epoch stratiform sulphide mineralisation can be considered (pyrite, pyrrhotite, chalcopyrite), which is present at sites *Revúca – Dolinský potok* and *Ratkovské Bystré – Filier*. Most likely it originally represented Pre-Hercynian exhalation-sedimentary sulphide ores incurred in the deeper parts of the sedimentary pool in an anoxic mode. During the next orogenic cycles these were partly metamorphosed and remobilized into younger structures. Of a similar genesis is probably the occurrence *Hradište-Štefančíkovci.*

The origin of the mineralisation suggests the analysis of isotopes of pyrrhotite. The value of $\delta\,^{34}S$ ranges from -10.3 to -15.9‰. The pyrrhotite is enriched in light isotope

$^{32}S$, indicative of potential bacterial reduction of sulphates (Kantor and Petro, 1976; Kantor and Ďurkovičová, 1977). Such δ $^{34}S$ values are very different from those of δ $^{34}S$ found in sulphide minerals from some other types of mineralisation in Veporicum. δ $^{34}S$ is between 3.24 and 6.09‰, with the largest number of measurements in the interval of 1.56 to 1.93‰.

An equivalent type of mineralisation falling within Pre-Hercynian (?) to Paleo-Hercynian stage represent pyrite-arsenopyrite impregnated mineralisation in dark phyllites at the site *Ratkovská Zdychava – Zlatá Baňa.* The position of mineralized dark slates in close contact with granite of Rimavica type suggests the possibility that the mobilization of metals and subsequent precipitation of minerals, were primarily due to thermal effects of leucocratic granitoids on the dark phyllites.

Relics of the manifestations of Pre-Hercynian magmatic mineralisation are retained in the listvenite body (magnesite-dolomite-quartz-Cr-Ni-muscovite) at Muránska Zdychava at the site Rýpalová (Ferenc et al., 2011; Uher et al., 2013). The body is situated in the muscovite-biotite paragneiss, in the structure of phyllonitized rocks. The geological position indicates that listvenite represents the original Early-Paleozoic (?) body of peridotite, forming part of volcano-sedimentary package that was intruded by granitoids in the Carboniferous. Early magmatic crystallization stage of utramafic magma indicate relics of chromite in listvenite. Late magmatic stages of the ultramafic rocks forming may indicate a rare pyrrhotite with lamellae of pentlandite and pyrite with accompanying chalcopyrite and a relatively low content of Co and Ni.

The granitoid magmatism of the Hercynian period is linked with minor magnetite mineralisation (skarn?) at the occurrence *Slavošovce – Kozí chrbát* (Gargulák et al., 1995).

In a shallower parts of (Late Precambrian to Early Paleozoic?) sedimentary basins, with oxygen sufficiency (and also carbon dioxide, chloride, phosphate, etc.), sedimentary Fe-ores were created (chamosite, hematite), which were metamorphosed during later geological events (Hercynian orogeny), resulting in formation of magnetite deposits (*Kokava nad Rimavicou – Hrabina*). This issue was studied in more detail by Radvanec (2000) and Kováčik (2000).

To the end of the Hercynian orogenic cycle U-Th mineralisation in the Permian metasediments of the Revúca Group (*Rejdová-Gandžalova dolina*) can be included.

To the final stage of the Hercynian metallogenic era belongs the genesis of magnesites, so-called Northern magnesite belt. This is characteristic by coeval occurrence Németh et al. (2004) of talc and magnesite deposits (*Kokava nad Rimavicou – Sinec, Borovana, Hnúšťa – Mútnik, Samo...*). According to Németh et al. (l.c.) the magnesites originated by metasomatic replacement of carbonates of Carboniferous age by Permian-Scythian Mg-rich solutions during post-collision Hercynian development.

During the Permian (Finger et al., 2003 – 266 ± 16 Ma) specialized granites of Klenovec type (Hraško et al., 1997) intruded in the western area, with the age and geochemical characteristics similar to granitoids of Gemericum. Differentiated phases of this type represent a potential source of elements linked to the development of acid granite magma.

The problem is the inclusion of vein quartz with arsenopyrite and pyrite (locally with increased Au content) from waste heaps at the site *Cinobaňa-Jarčanisko*. The mineralisation is older than vein siderite and primary fluid inclusions in quartz are not present. Secondary inclusions, however, by their nature, correspond to younger metamorphic fluids closely linked to the Alpine metamorphic quartz mineralisation and quartz-sulphide (Cu) mineralisation. The veins probably originated in Neo-Hercynian late-orogenic stage. The age of the mineralisation is apparent only from the mineralogical-paragenetic relations against a younger type of mineralisation and analogy to similar types of mineralisation in Tatricum. In Veporicum this mineralisation can be compared to quartz veins (containing arsenopyrite, pyrite, cobaltite), preceding the formation of a major amount of calcite at the site *Klenovec-Medené* (Ferenc et al., 2004). By analogy with pyrite-arsenopyrite mineralisation of Tatricum we suggest that the mineralisation originated from chloride aqueous solution rich in $CO_2$, of low to moderate salinity (up to 15 wt.% NaCl equiv.). Homogenization temperatures of inclusions in quartz (Tatricum) are between 280 to 380 °C (Ozdín, 2008) and they are close to temperatures, obtained by independent arsenopyrite thermometer 320 to 445 °C (Ferenc, 2008). The pressure ranged from 1.5 to 3.5 kbar. The origin of ore-bearing fluids was metamorphic or magmatic (Chovan et al., 2006; Hurai et al., 2002). In this case, the effect of Permian granites of the Klenovec type can not be excluded, whose relics were found west of the Hradište settlement, but are heavily affected by Alpine deformation.

Hardly classifiable are also relics of quartz veins (without mineralisation) that have been observed in the area of siderite locality *Lovinobaňa – Mertlová*. Based on the study of fluid inclusions in quartz we can say that it originated from highly saline fluids containing $CO_2$ and $N_2$ (Ferenc et al., 2014). Such inclusions are not frequent in the area of the Western Carpathians. In Alpine hydrothermal systems of the Western Carpathians (Gemericum) $CO_2$ inclusions are known with a small content of $CH_4$ and $N_2$ in quartz with tourmaline on stibnite veins in the Čučma settlement (Urban et al., 2006).

Inclusions composed predominant nitrogen ($CO_2$ content to 16.4 mol.%) were identified in the barite-siderite mineralisation at the top of Droždiak vein in Rudňany (Hurai et al. 2008a). In the Veporicum itself, the nitrogen has been detected in the fluid inclusions only sporadically (max. 8 mol.%) (Hurai & Horn, 1992). Since quartz with $N_2$-rich inclusions creates only relics in carbonate filler vein structures, it is clearly older than Fe carbonate and quartz-sulphide mineralisation.

Disseminated mineralisation represented by magnetite, pyrite, pyrrhotite, rutile and hematite detected at localities *Katarínska Huta* (borehole KH-1), *Ozdín – Cerina, Lovinobaňa – Mertlová* and *Uderiná – Viničky* (in the latter two only relics in quartz and ankerite) can be considered as Hercynian metamorphosed, previously sedimentary mineralisation (Grecula et al., 1995).

### 6.7.2. Alpine metallogenic stage

Alpine orogenic cycle significantly affected geological configuration of Veporicum and gave rise to the most distinctive (and most typical) accumulations of ore and non-metallic minerals in this area. In the first approximation the Alpine hydrothermal ore mineralisation in the area can be divided into two main genetic types:

#### I. Mineralisation genetically linked to the development of shear zones

Types of mineralisation located in the metamorphic rocks of green schists to amphibolite facies that are genetically linked to the development of local shear zones, or systems of shear zones (Sinec zone, Zdychava zone ...) in Veporicum (Fig. 6.9). When asking about their formation we consider the predominant influence of metamorphic (or metamorphic-mobilized) ore-bearing fluids, whereas some mineralogical aspects are indicative of mixing with magmatic fluids (to-date only hypothetical intrusions). In the case of Au mineralisation of supergene type impact of meteoric superheated fluid circulating in near-surface parts of the shear zones is assumed.

The most significant accumulations of ore vein mineralisation (carbonate-siderite and quartz-sulphide) are present in shear zones, generally with sinistral sense of movement, of NE-SW strike, which originated in transpression mode. Mineralisation in this case matches with the metamorphic or mylonite foliation.

Ore occurrences are less likely bound to the steeply sloping and vertical transverse NW-SE or WNW-ESE or N-S structures of extension character. The ore veins with typical Alpine NE-SW course were formed during the most intense stage of the formation of the shear zones (representing the central part of the so-called C-structure sensu Platt, 1984). The transverse veins of the extension character represent either so-called early-extension veins occurring in the initial stages of formation of a shear zone (*Kokava nad Rimavicou-Bohaté-Východ*), which are intersected/shifted by the above structure in the C position, or some veins of this strike (*Cinobaňa-Jarčanisko*) may represent extension veins of the final stages in the development of the shear zone formation; the end of the vein mineralisation on the shear-controlled deposits (Hodgson, 1989; De Ronde et al., 2000).

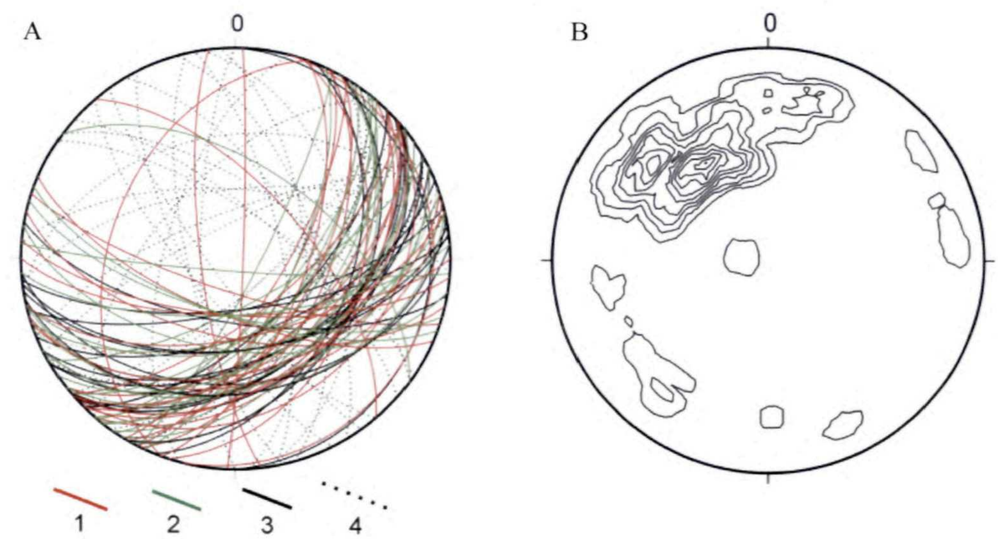


*Fig. 6.9 A) Summary tectonogram of the Alpine deformation structures of the studied sites in the south-western Veporicum. B) Contour diagram of pole structures (Ferenc, 2008).*

*Data are from sites: Ratkovské Bystré-Podlaz, Klenovec-Medené, Kokava n. Rimavicou-Bohaté-východ, Brnákovo, Bodnárka, Hnúšťa-Samo, Lovinobaňa-Mertlová, Murárka, Katarínska Huta-cemetery.*

*Explanation: 1 – structures (faults, shear zones, cracks) of significant carbonate and quartz-sulphide mineralisation. 2 – structures (faults, shear zones, cracks) without significant ore mineralisation (barren metamorphic quartz veins, and carbonate veins, rarely manifestations of sulphide mineralisation). 3 – metamorphic (mylonite) foliation., 4 – small, local tectonic faults, usually without mineralisation.*

#### II. Mineralisation genetically linked to granite intrusions

In the territory of SE Veporicum (and within the whole Western Carpathians) it is known only one detected intrusion of the Late Cretaceous age – Rochovce intrusion, which significantly formed metallogenic character of the E part of this territory. In the formation of this mineralisation played role largely magmatic ore-bearing fluids, which is reflected in their specific mineralogical character. A specific characteristic is the absence of metasomatic siderite-sulphide mineralisation, which is widespread in Gemericum. However, in the case of polymetallic and W and Mo mineralisation, the Rochovce granite intrusion affected both Veporicum and Gemericum rock complexes.

Local metallogenic significance can be assumed due to the presence of Permian Klenovec type granite.

#### *I. Mineralisation genetically linked to the development of local shear zones, or systems of shear zones*

Probably the oldest genetic type of hydrothermal vein mineralisation of Paleo-Alpine age is Au (Bi, Te) mineralisation – occurrence *Kokava nad Rimavicou – Bohaté – východ* (Ferenc & Bakos, 2006). Quartz veins with ore mineralisation fill short subvertical tension cracks of NW-SE strike in chlorite-muscovite schists of the Sinec shear zone. Their orientation is 75°-90° to the direction of the shear zone (typically having the NE-SW Alpine direction), and originated probably in the initial stages of its formation (AD 2, Cretaceous age, sensu Németh et al., 2004), prior to the peak of the Alpine metamorphosis in Veporicum. The identified gold-bearing vein mineral assemblage (tourmaline, pyrite, tetradymite, telurobismuthite, gold), typomorphism of gold and structural-tectonic indicators indicate a possible (hypothetical) igneous source of the fluids, or their mixing with meteoric water. The frequent presence of tourmaline indicates that hydrothermal solutions were enriched in volatiles, while the very low proportion of pyrite in veins suggests little content of thiocomplexes.

The igneous origin of Au mineralisation is supported by the occurrence of dikes of leucocratic granitoids and pegmatite in the immediate vicinity of the site and in the wider context of the Sinec shear zone. It should be noted that we do not know precisely the ages of these small igneous bodies. The mineralisation in this case is markedly different from other types of mineralisation in Veporicum and is clearly older than the Alpine siderite (carbonate) – quartz-sulphide mineralisation. A mineralisation of similar type was observed even at Krokava at locations *Háj* and *Lazy* (Bakos et al., 2006). Even in this case, in the vicinity larger bodies of aplitic leucogranite of unknown age are present, (Permian?) penetrating in the form of finger-like intrusions into the older crystalline complexes.

With the development of mineralisation (and the whole Sinec shear zone) occurrences and deposits of talc are closely related, together with magnesite in the so-called Magnesite northern belt (*Kokava nad Rimavicou – Sinec, Borovana, Hnúšťa – Mútnik, Samo...*). The Alpine deformation and Alpine migration of Si into magnesite and Mg-rich fluids into surrounding rocks was documented by Hraško in Molák et al. (1990) and Kováčik (1996a). According to Németh et al. (2004) the talc was formed by penetration of Mg and $SiO_2$-rich fluids into the structures with Mg metasomatites in the initial stage of the Sinec shear zone development. This occurred only after the formation of structures with Au (Bi, Te) mineralisation. This suggests a dissection into blocks and strike slips in gold-bearing veins and also the destruction of primary fluid inclusions in gold-bearing quartz. This period is characterized by the formation of tectonic structures of NE-SW strike.

Lenticular **quartz veins** (syndeformation) with so-called Alpine paragenesis have a regional extension throughout the entire Veporicum. These veins were formed due to escape of large amounts of fluids strongly enriched in $SiO_2$ during the peak Alpine metamorphism of the Southern Veporicum. Quartz crystallized from low-saline $CO_2$-rich solutions at a temperature of about 300-400 °C and at a pressure of maximum 100-200 MPa. Microthermometric data are consistent with published results of Hurai et al. (1997) for Alpine metamorphic fluids in Veporicum.

**Scheelite mineralisation** is present at some deposits and occurrences of talc and Magnesite of the magnesite northern belt (e.g. *Kokava nad Rimavicou – Sinec*). It is likely consistent with the formation of lenticular quartz veins. The metamorphic fluids had the largest share in its formation. Problematic is the genesis of stockwork and impregnation scheelite mineralisation present on the occurrence *Klenovec - Quarry Ostrá*. According Hvožďara (1979) the mineralisation belongs to the high-thermal ore formation of intraplutonic to periplutonic type in flyschoid and volcaniclastic strata. Based on the study of fluid inclusions (Hurai, 1983) the assumption about the metamorphic origin of mineralisation fluids can be confirmed. The Alpine (Late Cretaceous) age was also defined by Slavkay et al. (2004).

**Siderite (Fe-carbonate) mineralisation** in the Slovenské rudohorie Mts. is considerably widely distributed. It reaches the greatest concentration and the best development at the southwest of the studied area (*Cinobaňa – Jarčanisko, Lovinobaňa – Mertlová, Lovinobaňa – cemetery, Uderiná – Viničky*), to a lesser extent it is present in the central and north-eastern parts of the territory (*Ratkovské Bystré – Podlaz, Ratkovská Zdychava – Rovienka, Mokrá lúka – Trešková, Muránska Huta – Tarčová*). Within the Veporicum it is completely absent in eastern and south-eastern parts. Its precise age classification within the Veporicum metallogenic plan is currently not possible and there are not known (or only partially) exact age relationships among the structures with the presence of siderite mineralisation.

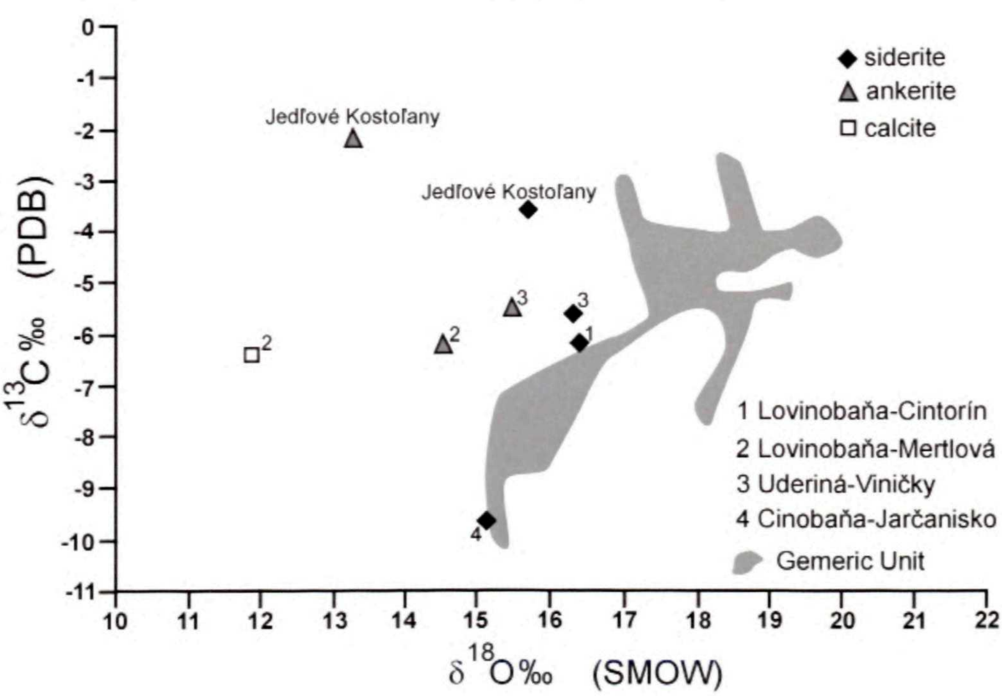


*Fig. 6.10 O/C isotope ratios in carbonates veins of the area Lovinobaňa-Uderiná-Cinobaňa, compared to the occurrences in northern Veporicum (Ozdín, 2008) and Gemericum (Hurai et al., 2008a, b). According to (Ferenc et al., 2014)*

The isotope ratios of C and O in siderite from the neighbourhood of Lovinobaňa, Uderiná and Cinobaňa (Fig. 6.10), resemble rather Southern Gemericum siderite (Rožňava, Krásnohorské Podhradie, Jedľovec; Hurai et al., 2008b) and siderite from northern Veporicum (Ozdín, 2008), which may indicate similarity of mineralisation processes. Location of sites in close proximity of the Lubeník thrust line, allows to consider the circulation of "Gemeric" fluids (sensu Hurai et al., 2008 a, b). These were mobilized from the overburden of the Gemericum fundament (green schist facies) during the Late Cretaceous, after the thrust of Gemericum over Veporicum, after the collision of Veporicum with Gemericum, at the end of the Middle and Late Cretaceous (sensu Lexa et al., 2007).

**Barite mineralisation** in the area is represented by a small occurrence in Hrlica, where it formed in the form of isolated vein without other minerals. On the basis of parallels with Gemericum, Middle to Late Cretaceous age of the mineralisation is assumed.

Genetic status of the occurrence of **Fe mineralisation** *Turičky – Etelka* within garnet mica schists of the Ostrá complex is unclear (Slavkay et al., 2004). Ankerite mineralisation of metasomatic type is not known in Veporicum. The occurrence is rather close to ankerite metasomatic mineralisation in Gemericum (*Jelšava – Ždiar* and *Ochtiná – Horný Hrádok – Aragonite Cave*). The Etelka occurrence is situated almost within the Lubeník line. The Gemericum overthrust above Veporicum in this area is characterized by the tectonic outliers of the Ochtiná Fm. Therefore it can be deduced the possibility that the deposit Etelka (in the current erosion level) represents one of these Gemericum tectonic outliers.

**Carbonate-quartz-sulphide mineralisation** within Veporicum has a regional extension and in the structures it often interferes with older mineralisation structures (e.g. metamorphic quartz mineralisation, siderite mineralisation). It dominates the western half of the territory, roughly from the Ratkovské Bystré settlement on NW, to Lovinobaňa village to the SW. It is characterized by its shape and mineralogical diversity due to topomineral influence of the surrounding rocks. This type of mineralisation has metasomatic, stockwork to impregnation character in carbonate (calcite) lenses on the deposits *Ostrá I* and *II* near Hnúšťa, or in magnesite and dolomite on magnesite-talc occurrences on the Magnesite northern beld (*Hnúšťa – Mútnik, Hnúšťa - Samo, Hačava – Bystrý potok, Kokava n. Rimavicou – Sinec*). Metasomatism in carbonate (calcite) lenses is also reflected on the occurrence *Klenovec – Medené* and *Kokava nad Rimavicou – Chorepa*. In this case, it coincides with the position of the carbonates, which were deformed in the tectonic structure of NE-SW direction and then replaced by carbonate-quartz-sulphide mineralisation. From the morphological point of view, the mineralisation has vein character, but metasomatism of the carbonate lenses indicates the same isotopes of C and O in the basic "vein" carbonates of these sites as well as in the occurrences *Ostrá I* and *II*.

In the Sinec Massif, this type of mineralisation overprints the structures with Au (Bi, Te) mineralisation (*Kokava nad Rimavicou – Bohaté-východ*) and the lenticular quartz veins (*Kokava nad Rimavicou – Bohaté, Gallery Runina diera, Kokava nad Rimavicou – Bodnárka*). Stockwork-veined (to impregnation) character has the epigenetic carbonate-quartz-sulphide mineralisation on the occurrence *Ozdín-Cerina* (Maťo & Maťová, 1994; Ferenc & Maťo, 2003), *Katarínska Huta (borehole KH-1)*, to a lesser extent at the occurrence *Zlatno – Kečka* (mineralisation of the Ozdín type). This type of mineralisation can be also assigned to minor occurrences *Cinobaňa – Staré Turíce* and *Katarínska Huta – Murárka*. The study of fluid inclusions in quartz and carbonates of this type of mineralisation demonstrate the effect of the Alpine metamorphic fluids. Source of metals are most likely black schists, as evidenced by the fact that the composition of the most colourful veins/stockworks is just close to the black metasediments.

Within the penetration of hydrothermal fluids through volcanosedimentary Permian rocks with elevated U-content, it was probably remobilised to a lesser extent and subsequently uraninite crystallised in tiny veins at several occurrences (*Hnúšťa-Mútnik*).

The **quartz-sulphide mineralisation** is characterized by a number of development stages:

a) quartz – arsenopyrite – pyrite (± cobaltite, polydidymite, siegenite, ullmannite)
b) quartz – Cu sulphide (calcite, dolomite, pyrite, pyrrhotite, tetrahedrite, tennantite, chalcopyrite, galena, sphalerite, gold I?...)
c) quartz – dolomite – sulphosalts (stibnite, boulangerite, jamesonite, pilsenite, tsumoite, bismuth, gold II?...)
d) cinnabarite.

The development of this type of mineralisation closely follows the above-described metamorphic quartz mineralisation. The fluids which originated from different types of metamorphic quartz are typical of the content of $CO_2$ and less (only locally) $N_2$ and $CH_4$. To the contrary, the fluid inclusions in quartz and dolomite that associate with Cu sulphides (chalcopyrite, tetrahedrite ...) contain only trace amounts of $CO_2$. The mentioned inclusions have a wide range of salinity (6-25 wt.% NaCl equiv.), whereas the maximum of the inclusions range from 13 to 25 wt. % NaCl equiv. Compared to the inclusions in metamorphic quartz (approximately 315 to 339 °C) they have a slightly reduced temperature of total homogenization (averaging 289 °C), indicating a trend of metamorphic fluids cooling, the depletion of $CO_2$ and increasing salinity from the earliest generations of quartz metamorphic mineralisation till the youngest quartz/dolomite quartz – sulphide mineralisation (Fig. 6. 11).

Generally speaking, the nature of the secondary inclusions in quartz of older metamorphic mineralisation corresponds to the nature of the primary inclusions in younger quartz, which is the bearer of sulphide mineralisation (Ferenc, 2008).

The solutions responsible for formation of the youngest generation of carbonates (dolomite), and Pb-Sb mineralisation (the quartz-dolomite-sulphosalts stage) reached the lowest thermality, which is indicated by a temperature homogenization of the inclusions in the range 133-200 °C (163

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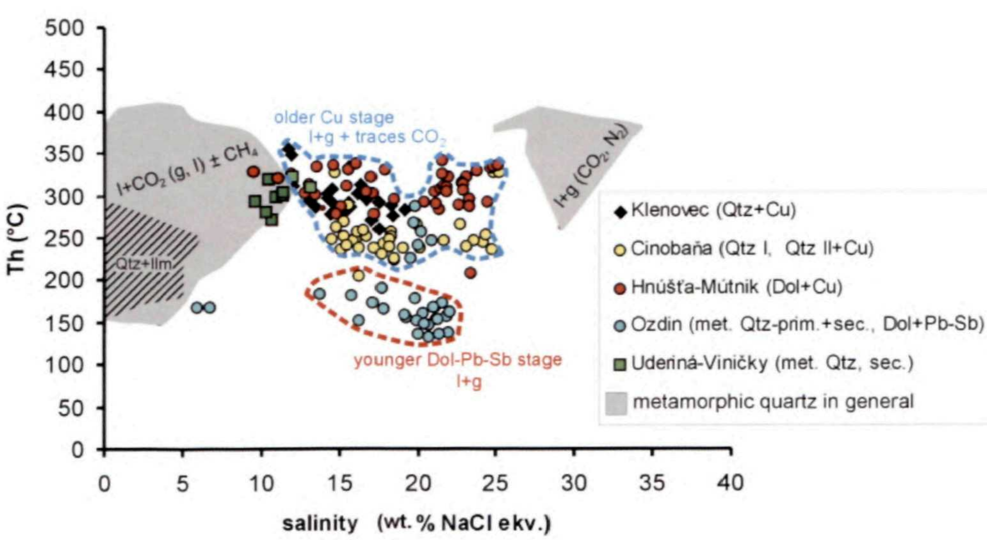


*Fig. 6.11 The dependence of total homogenization temperatures and salinity of fluid inclusions in quartz and dolomite that carry ore mineralisation, compared with metamorphic quartz mineralisation (grey area) in the Southern Veporicum (Kohút zone), studied by Ferenc and Bakos.*

°C on average). They are characterized by high salinity in the range of 14-22 wt. % NaCl equiv. (Fig. 6. 11). The inclusions consist of the aqueous brine only, and the bubbles of the water vapour; within the gas phase there were not found any traces of $CO_2$. Based on analogies from other deposits worldwide, in this case we may consider "cooling" effect of water descending to the existing hydrothermal system. Mineralisation had formed after the Alpine metamorphism maximum of SW part of Veporicum and after the formation of lenticular quartz veins with Alpine paragenesis.

**Geological and metallogenic significance of SW part of Zdychava tectonic zone**

From metallogenic, geophysical, geochemical and geological point of view, the most important element in the area of the Kohút zone (Southern Veporicum) represents Zdychava tectonic zone, a wider tectonic zone of SW-NE direction, which is the result of Hercynian configuration of rock complexes (Bezák et al., 1997) and Alpine thrust-overthrust and shear deformation.

In the SW part of the territory, from the underlier of granitised complexes through multiple (imbricated) thrust and shear systems, the complex of geophysically and geochemically anomalous rocks was exhumed (mainly black schists, metaquartzites with intercalations of sulphide mineralisation), which belong to the complex of garnetiferous mica schists of the Hron complex (Fig. 6.12).

Creation of Alpine shear zones is more intense in areas with a minimum thickness of the rigid lithology (granitoids), accompanied by formation of a schistose lithologies, of mostly diaphtoritic origin.

In the SW end of surface occurrences of Veporicum complexes, there can be observed shallow dipping structures and direct overthrusts of black metasediments of the Ochtiná Fm. In several parts, thrusts of the Ochtiná Fm. metasediments were found over the Early Triassic Veporicum envelope, but also directly over the Veporic Early Paleozoic basement. Due to strong weathering processes and Quaternary cover, the local presence of this higher tectonic unit over Veporicum in the area between Ozdín and Lovinobaňa is not always clear in details. Several ge-

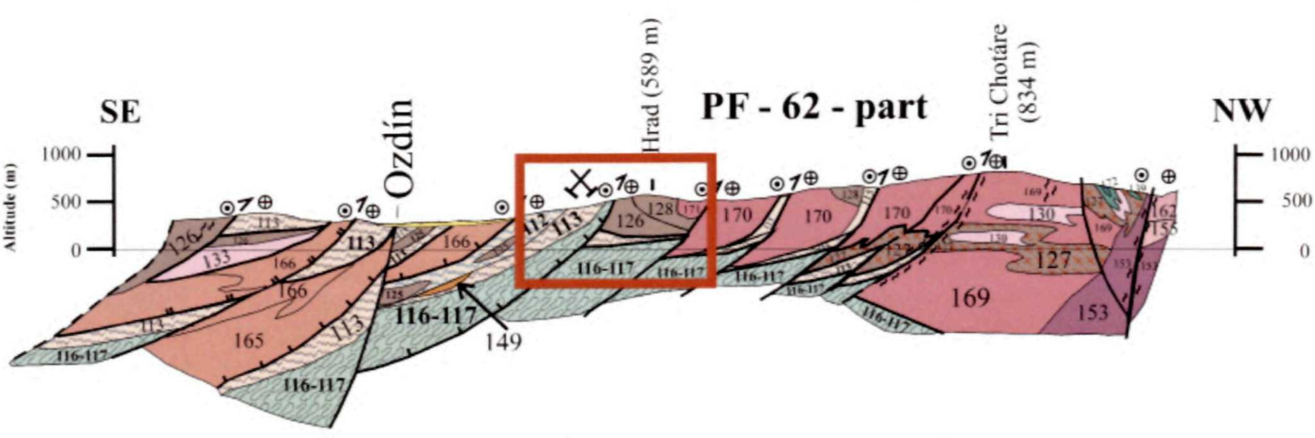


*Fig. 6.12 Geological cross-section along a part of the profile no. 62 in the area south of Ozdín village toward Tri Chotáre Hill.*

*Profile captures the position of the mineralisation near Hrad hill (589 m). An essential condition for the formation of ore accumulations can be considered the thin rigid lithology of the crust formed by higher metamorphosed and granitised rocks (gneisses, migmatites – brown colour – 125, 126, 127, 128; orthogneisses – pink colour – 130, 133, and different types of Early Carboniferous granitoids (red colour) (Kráľova hoľa complex) in tectonic position over easily deformable mica schists of Hron complex (116-117 – green colour). Contact of different Pre-Alpine lithologies is mediated by wide mylonitic to utramylonitic zones (112, 113) with fragments of mylonitised Permian Klenovec type granite (149), incorporated into the Alpine shear zone. Red box represents maximum of magnetic anomaly and metallogenetically (crossed hammers) anomalous zone – Ozdín-Cerina (Fe-carbonate–sulphide mineralisation) (adapted from Hraško et al., 2005).*

ophysical indications, however, suggest shallow dipping synforms formed by the Ochtiná Fm. metasediments. The fact that after the overthrust very narrow and steep shear zones with metasediments of the Ochtiná Fm. were developed, with magnesite bodies, was testified by exploration work near Uderiná (Galko et al., 2002).

The formation of magnetic geophysical elevation of mica schists of the Ostrá complex (or Hron complex sensu Klinec, 1966; Fig. 6.12) occurred during the formation of the Alpine thrusts and overthrusts. The subsequent strike slip displacements caused linear character of Zdychava shear (tectonic) zone with manifestations of mineralisation.

Concentration of major soil-geochemical and ore mineralogy anomalies associated with lower thermal ore-bearing solutions (mainly Ag, Sb) in the south-western part of the Zdychava shear zone, the presence of shallow dipping tectonic fragments of the black metasediments of the Ochtiná Fm. with carbonate bodies suggest shallower tectonic position and lower thermality of this part of the shear zone during deformation within the Zdychava shear zone.

**Relationship of the ore mineralisation in the shear zones to the geological environment**

In several places in the shear zones there have been observed close links between the ore quality and the lithological composition of surrounding rocks. Shale complexes containing sulphophile elements (see Tabs. 6.2, 6.3) through-migrating fluids during deformation and metamorphic processes provided ore elements for the formation of hydrothermal veins.

Unless identical shear system continued into „barren“ lithologies (mainly Hercynian granitoid masses), the sterile zones of quartz vein developed (Fig. 6.13) and surroundings of vein structures were accompanied by intense mylonitisation of rocks to form micaceous mylonites to ultramylonites.

***II. Mineralisation genetically linked to Alpine granite intrusion***

In Veporicum, these types of mineralisation are extended only in the E part of the territory, where their formation was conditioned by metallogenic influence of Late Cretaceous granite intrusion of the Rochovce type. Their position, accounting for the distance from the Rochovce intrusion, is zonal, while in general, with increasing distance we may observe their reduced thermality (Slavkay & Petro, 1993; Garguláк et al., 1995; Slavkay et al., 2004).

Based on observations of the tectonic position of individual sites as well as their detailed mineralogical studies and studies of interactions between different types of mineralisation, in the vicinity of Rochovce intrusion the following types of mineralisation are distinguished: A. pyrite mineralisation, B. Mo-W mineralisation, C. fluorite mineralisation, D. Pb-Zn mineralisation, E. Sb mineralisation, F. Bi-Te mineralisation (?), G. zeolite mineralisation.

The pyrite mineralisation in this area is greatly extended and is present at many locations. The mineralisation is represented by quartz, pyrite, or by marcasite and it originated from the fluids with a wide range of salinity (0-20 wt.% NaCl equiv.), the solution temperature ranged roughly 200 to 400 °C. (Fig. 6.11). To this mineralisation there can be assigned zones of intense pyritisation in the overlying rocks near Rochovce granite body.

**The vein – stockwork and impregnation W and Mo mineralisation** (Ochtiná- Rochovce) is present in the Late Paleozoic metasediments in the roof of granitic intrusions. The Mo mineralisation is concentrated in endocontact and exocontact of the Rochovce intrusion with Late Paleozoic Slatvina Fm. metasediments and Rimava Fm. (Határ et al., 1989). In larger distances (of the order of hundreds of meters) from the intrusion, vein and stockwork zone of W and Mo mineralisation is localized. It is bound to the basal part of the tectonically overlying Carboniferous Ochtiná Fm., to significantly pyritised black schists, at places

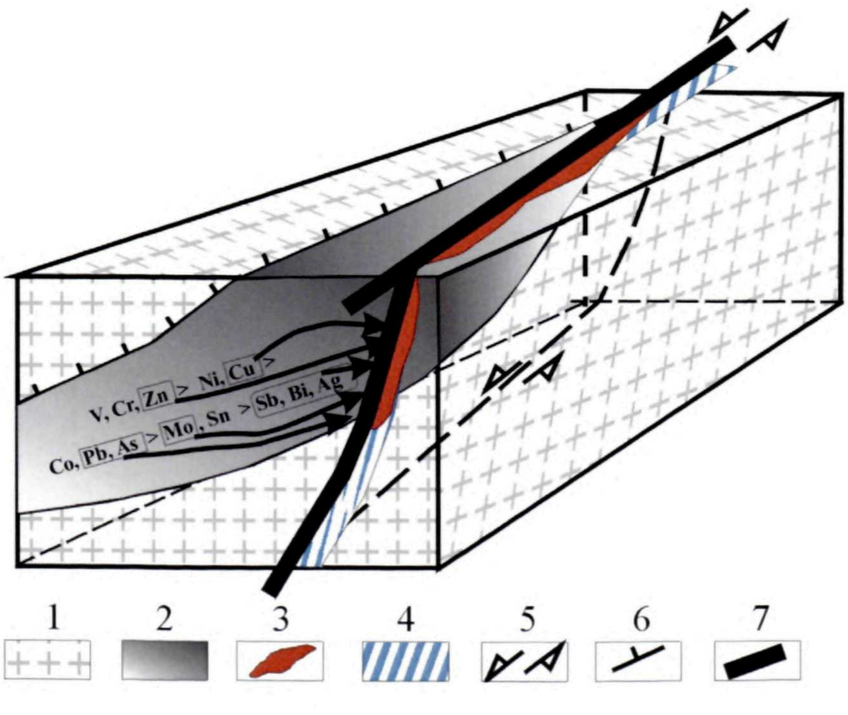


*Fig. 6.13 Schematic expression of linkage of sulphide mineralisation on meta-sediments/ Hercynian granitoids within the Alpine shear zone. Metal elements under the influence of fluids migration and deformation are concentrated within a shear zone in lithotype with appropriate content of sulphophile metallic elements. Other elements remain as part of the metamorphic rock associations in the form of separate minerals (mainly oxides) and as part of the rock-forming minerals (mainly micas). Passing through shear zone with low metal elements there were formed mainly barren quartz veins, or quartz veins with low content of sulphide in high salinity fluid environment.*

*Explanations:*

*1 – granitoids, 2 – metasandstones, phyllites, 3 – veins with a higher content of sulphides, 4 – pure quartz veins with low sulphide content, 5 – sense of movement within the shear zone, 6 – older surface of older compression stage, 7 – course of shear zone*

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with the positions of massive pyrite accumulations of the strata-bound type. Surface occurrences were found in the form of quartz-pyrite veins with molybdenite, scheelite, ferberite and huanzalaite (*Ochtiná – Zlatá Baňa, Ochtiná – Čížkobaňa*). In recent years, during field research several major vein structures of NNE-SSW direction have been discovered, while also thinner vein structures of W-E direction are present. This ore mineralisation is of vein – stockwork and impregnation character.

**Fluorite mineralisation** is present in the granite body itself and creates separate veins (fluorite, calcite, quartz, feldspar) in the overlying Paleozoic rocks (boreholes RO-9, RO-15).

The **quartz-sulphide mineralisation** is widely extended in the vicinity of granitic intrusion and has a number of occurrences. It is characterized by quartz veins and stockworks with pyrite and arsenopyrite (*Chyžné – Skalica, Starý háj, Chyžné, Herichová II, Slavošovce Trebová*) or with chalcopyrite and pyrrhotite (*Kopráš – Slnná, Mníšany – Trebušková*).

This type of mineralisation is overprinted by **polymetallic mineralisation** (chalcopyrite, galena, sphalerite, tetrahedrite, bismuthite, etc.), which is reflected for example, on the occurrences *Ochtiná – Lašanka, Rochovce – Dubina, Slavošovce – Za hôrkou, Chyžné – Mária-Margita*. On the occurrences *Ochtiná – Mária-Margita, Jelšava – Delková* and *Jelšava – Galmajka* the polymetallic mineralisation is of stockwork to metasomatic character, which is affected by the surrounding rocks (Mesozoic carbonates and Late Paleozoic metasediments).

The **stibnite mineralisation** is not widespread. It occurs on sites *Chyžné – Kubej, Chyžné – Herichová* and *Rochovce – Oriešok*. Structures with stibnite mineralisation intersect older sulphide mineralisation (which is represented by quartz, pyrite and arsenopyrite).

Insufficiently clarified is the position of **W mineralisation** represented by hübnerite (Kantor, 1955) at the occurrence *Chyžné-Herichová*. Based on the hübnerite findings in separate quartz veins and also based on the consideration of different thermality of stibnite and hübnerite it can be postulated that W mineralisation is older than that of stibnite.

Locally there was reported the mineralisation association of with pyrite, joseite B, bismuth, bismuthinite and Bi-ullmannite in quartz veins. On the basis of this association of ore minerals compared to other mineral paragenesis ore occurrences in the aureole around the Rochovce intrusion, it can be postulated that this is a separate type of hydrothermal vein mineralisation.

Perhaps the youngest type of hydrothermal mineralisation, which is linked to the effects of the Rochovce intrusion, is the **calcite-zeolite mineralisation**, represented by calcite and laumontite. These minerals form crystals on the cracks in tectonically disrupted Paleozoic rocks.

### *Neo-Alpine stage*

The termination of the metallogenic development (Neo-Alpine postorogenic stage) is documented by **supergene Au mineralisation**, described at the locations Uderiná-Loviňa (Maťo & Maťová, 1993), *Katarínska Huta-cemetery* (Ferenc et al., 2006a) and *Divín – Divínsky Háj*. The emergence of mineralisation can be caused by acid and overheated meteoric solutions with high salinity, circulating relatively shallowly through the shear zones. This caused the hydrothermal alteration of the surrounding rocks (formation of clay minerals) and the decomposition

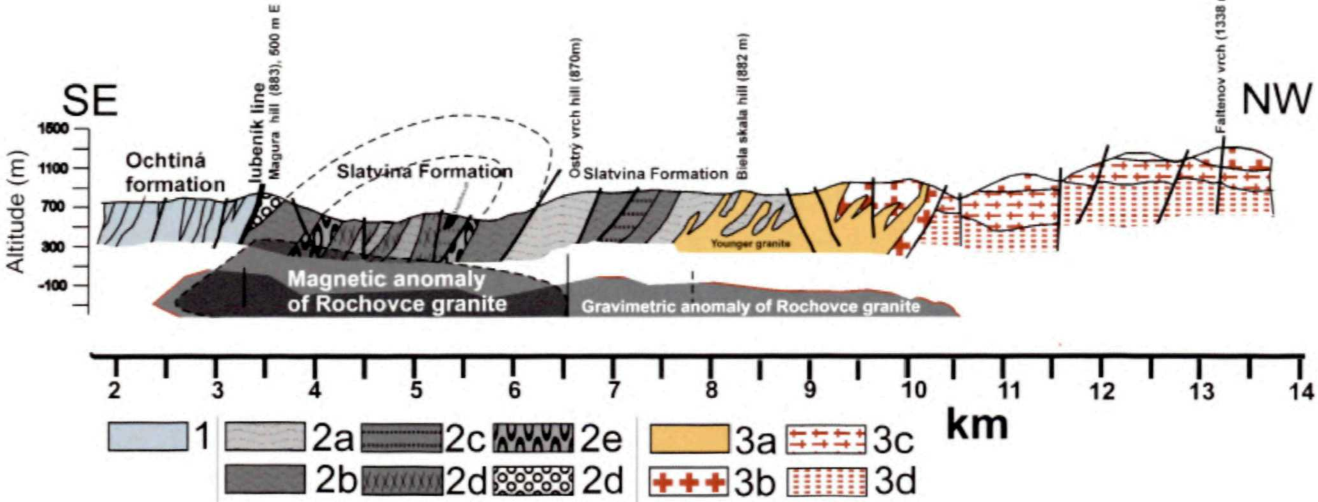


*Fig. 6.14 Geological cross-section in the eastern part of the Southern Veporicum zone at the contact zone with Late Cretaceous Rochovce granite (part of profile No 16). Source of metals in the contact zone has combined origin – in metasediments of Slatvina/Ochtiná Formations and in the granite itself.*

*Explanations: 1 – Ochtiná Fm., undivided; 2 – Revúca Group: 2a-2e – Slatvina Fm., 2a – pale-grey metasandstones with contact biotite, 2b – dark schistose metasandstones, 2c – dark metapelites, 2d – metapelites with contact cordierite and garnet, 2e – strongly metamorphosed metaconglomerates and metaquartzites, 2d – Rimava Fm.: metaconglomerates and sericite meta-arkose. 3 – granitoids: 3a – younger aplitic to coarse-grained feldspar rich leucogranites of unknown age; 3b-3d – Hercynian granitoids: 3b – coarse-grained to porphyric biotite granite, 3c – deformed and schliered porphyric granitoids, 3d – schliered granodiorites, with gneissic xenoliths (adapted from Hraško et al., 2005)* of sulphide minerals. It can be assumed that on the surface simultaneous kaoline weathering took place (Sarmatian – Pannonian), which was responsible for the emergence of significant accumulations of kaoline in south-western Veporicum.

The presence of illite, illite-smectite and smectite in the present weathered crust indicates a change of the physicochemical conditions (e.g. temperature, pH). This could be due to a possible climate change from warm wetlands to a drier and cooler climate, hence the change from acidic environ to neutral to slightly alkaline. Geological factors and high gold content also indicate that the transport of Au occurred, possibly due to the chloride complexes in an acid environment. Geochemical barriers could be oxides and hydroxides of Fe arising from the conversion of pyrite (or pyrrhotite). The primary source of gold supergene mineralisation was probably vein, stockwork and quartz-sulphide to impregnation mineralisation of the Ozdín type (of scattered, but regional character).

To the Neo-Alpine period falls the formation of gossans and supergene products on metasomatic and vein-type deposits of carbonates containing Fe and sulphides.

The youngest phase of the Alpine metallogenic epoch represents the formation of **gold-bearing placer deposits**, which are widely distributed in the area. The issues of gold placer deposits are discussed in the work by Hvožďara (1999). These are deluvial-eluvial placer deposits located in the area northwest of Podrečany, between Lovinobaňa and Ozdín and in the broader area of Kokava nad Rimavicou, Hačava and at Krokava and alluvial placer deposits: Rimavica, Bystrý potok creek and Bystrický potok creek). The source of the gold placers was hydrothermal Au (Bi-Te) mineralisation (in the case of gold placers at the locality. *Kokava nad Rimavicou – Bohaté*), or supergene Au mineralisation (Au enrichment zone in eroded shear zones).

## Conclusions

The complex geological, geophysical, geochemical and metallogenic research in the western (Veporicum) part of the Slovenské rudohorie Mts. revealed two substantial forms of sulphidic mineralisations.

The first one is represented by accumulations of ore occurrences in the Alpine (Zdychava) shear zone (NE-SW direction), which represents quasi linear subparallel systems of Alpine shear zones. It is developed on the Hercynian shallow dipping tectonic contacts between different Early Paleozoic tectonic blocks (mica schists of the Hron complex and paragneisses and granitoids of the Kráľova hoľa complex). Lower tectonic unit – mica schists of the Hron complex, with the intercalation of black schists and black metaquartzites, with disseminated ore mineralisation in micaschists, metaquartzites, shales, amphibolites, metaultramafics and its tectonic overburden formed by paragneisses, granites and orthogneisses, amphibolites. This originally Hercynian structure was later affected by Alpine thrusts and strike slip systems of SW-NE direction, which caused the tectonic exhumation of underliers of the mica schists complex.

As a source of mineralisation is considered here a disseminated sulphidic mineralisation in metamorphic rocks of Early and Late Paleozoic. A mobilization of ore bearing mineralisation solutions took place along shear zones by presence of fluid phase. This type of mineralisation is more significantly developed in the western part of the area and it is fixed into area with manifestations of the Zdychava shear zone.

Zoning of ore mineralisation and geochemical anomalies along the Zdychava shear zone indicates the presence of lower thermal fluids in the SW part. This is consistent with the geological characteristics of the area where metasediments of the Ochtiná Formation create shallow synforms, which were later transformed into steeply dipping shear systems of SW-NE direction. This also roughly coincides with the lowest temperature isotherms of the Alpine metamorphism indicated by Kováčik (1996b) in the SW part of the Veporicum unit.

The second important type of mineralisation is connected with a Late Cretaceous granite in the vicinity of Rochovce village (the eastern part of the area). This is principally a source of W and Mo mineralisation. A part of sulphidic mineralisation in this area is equally connected with a lithological filling of Late Paleozoic metasediments in combination with shear deformation and following intrusion of granite.

Other manifestations of mineralisation in this area are connected with local sedimentary and volcano-sedimentary processes of the Pre-Hercynian (Early Paleozoic) stage. Meso- and Neo-Hercynian processes of granite formation are of lower economic importance.

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