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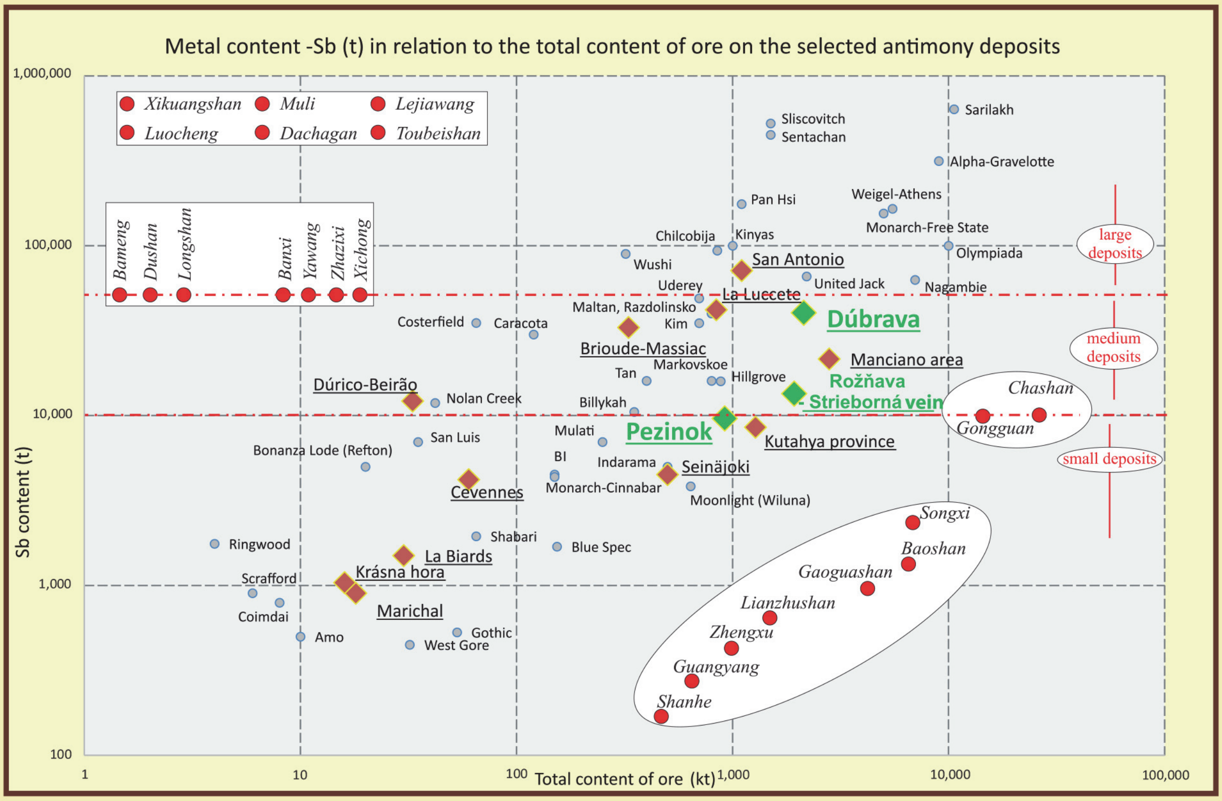
RECENT TRENDS IN THE RAW MINERALS RESEARCH AT SGIDŠ



2/2015

State Geological Institute of Dionýz Štúr, Bratislava

SLOVAK GEOLOGICAL MAGAZINE

Periodical journal of the State Geological Institute of Dionýz Štúr is a biyearly presenting the results of investigation and researches in wide range of topics:

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Preface

The Slovak Republic is a country with a rich mining lasting for several centuries. The impact of this mining activity has been significantly reflected in social and scientific society. Of particular importance was the establishment of the first Mining Academy in the world in 1763 in Banská Štiavnica. Of course minerals were often linked to mining. In the past the mining and quarrying within the current territory of Slovakia accounted for the largest share of production of selected metals worldwide. There was carried out mining and processing of a number of ore metals: Au, Ag, Cu, Fe, Hg, Sb, Pb, Zn, to a lesser extent Ni, Co and U. The local mining often constituted the most important production of the metal (Cu) or a very significant proportion of mining (Au, Ag, Sb) in the European area at that time. From past to present a lot of time passed, there have been found new mineral deposits and mining has shifted to regions outside Europe.

In the last decade the Slovak Republic, similarly to the entire European Union, due to decrease in extraction of ore minerals, has become heavily dependent on imports of raw materials. The import of raw materials, however, is associated with various economic as well as political risks. This led to a study on critical raw materials for EU countries (CRM-EU) in 2010. Since then, several analyses have been elaborated at national and European level and they are constantly updated. The position of the Slovak Republic in this initiative highlights the representation of the Minister of Environment of the Slovak Republic in the High Level Steering Group and of the State Secretary of the Ministry of Environment of the Slovak Republic in the executive branch, so-called Sherpa Group. The above initiative has given a momentum to a significant involvement of the staff of the State Geological Institute of Dionýz Štúr in various projects of European importance, for instance Minerals4EU, MINATURA, ERA-MIN, RawMatters and others. The need for new mineral resources within the European region today is perceived not only by businessmen and industrialists, but also by politicians because of the socio-economic impact on society. The rapidly changing needs of the population, but also new high-tech technology produce a great “hunger” for raw materials. The process of extracting and processing of mineral resources is dependent on clearly defined rules, which affect the whole cycle: geology, mining, metallurgy, recycling, legislation, education, public attitudes as well as environmental protection. The sustainability of the various aforementioned components of this cycle depends on the resources potential, which the Slovak Republic still possesses. Effective utilization of this potential can contribute to the development of innovative technologies, business activities, investment incentives and ultimately increased employment.

The price of metals on world markets compared with the period of extraction attenuation has increased significantly. Large growth can be seen even in metals that have not been previously the subject of exploitation in the Slovak Republic. The issues of mineral resources, and ore resources in particular, should therefore be addressed with a vision of the future development. The period of search, verifying and extraction along with the mineral processing is always a long-term affair. It still needs to perform the area appreciation, focusing on the potential mineral resources. Any complacency with the status quo may lead to embarrassing judgements with great impact for the economy of each country.

Branislav Žec
General Director
SGIDŠ

LIST OF ACRONYMS

AAS	Atomic Absorption Spectrometry
AD	Anno Domini
BC	Before Christ
BSE	Back Scattered Electron (images)
BZVL SR	Register of Reserves of the Mineral Deposits of the Slovak Republic
CED	Certificates on Exclusive Deposit
CRM	Critical Raw Materials
DMO (OBÚ)	District Mining Office
EA	Exploration Area
ERA	European Research Area
EU	European Union
GIS	Geographic Information System
H	Hardness
HREE	Heavy Rare Earth Elements
IOM	Inter Ocean Metal
JTSK	Krovak East North (System of Uniform Trigonometric Cadastral Network)
LREE	Light Rare Earth Elements
MA	Mining Area
MCS	Mineral Commodity Summaries
MIAG	Magnesit Industrie Aktien-Gesellschaft
MoE	Ministry of Environment
NOŠ	New Heritage Gallery (Nová odvodňovacia štôlňa)
NRM	Non-Reserved Minerals
OMW	Old Mining Work
PDA	Protected Deposit Area
PGE	Platinum Group Elements
PGM	Platinum Group Minerals
REE	Rare Earth Elements
SEM	Scanning Electron Microscopy
SG	Specific Gravity
S/GIDŠ	State / Geological Institute of Dionýz Štúr
SGR	Spišsko-gemerské rudohorie Mts.
SGU	Slovak Geological Office (Slovenský geologický úrad)
SNR	Slovak National Council (Slovenská národná rada)
SPD	Spectral Diffraction (Analysis)
SR	Slovak Republic
SQFD	Semi-Quantitative Flame Diffraction
SQL	Structured Query Language
ÚPN VÚC	Spatial Plan of Large Territorial Unit
UPN O	Spatial Plan of Municipality
USD	United States Dollar
USGS	United States Geological Survey
UV	Ultra-Violet
WDS	Wavelength Dispersive Spectrometer
WWI	World War I
WWII	World War II
XRF	X-Ray Fluorescence Analysis

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1. History of Mining at the Territory of Slovakia

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Abstract: The paper is devoted to the history of the mining sector in Slovakia in the timeline from ancient times to the present. The use of stone tools in the Stone Age is discussed, their production for daily necessities up to the beginning of the use of metals. In the Bronze and Iron Ages it documents the origins of the use and improvement of metallurgy and metal ore mining in our territory. The use of precious metal ore resulted in the first coinage in our territory that was introduced by the Celts. In the Middle Ages, at the times when our territory experienced a huge development of mining, which is already documented by written sources, the first bearers of mining were our Slavic ancestors. During the Hungarian state in particular the ore mining continued to develop, the execution of which was for the then society very important. After more than 1000 years in this territory the coins were minted again, based on the production in Banská Štiavnica and later in Kremnica. An important area, however, were also the Central and Eastern Slovakia copper deposits. At the turn of the Middle Ages the Hungary copper ore mining industry was the largest copper producer in the former world. From the beginning the iron-ore mining was purpose-directed as support for precious metals and copper ore mining. The salt mining significantly contributed to the history of mining and later antimony and nickel-cobalt ore exploitation. In the modern history among the non-metallic raw materials a prominent position has occupied magnesite. And we should not forget the extraction of precious opal, which has been historically our only mined precious stone. he paper is devoted to the history and creation of registers of exploration areas, deposits, old mining works and deposits exploration. It describes the Internet applications of deposits registers and their functionality and shows possibilities of development of Internet applications in the future. The assessment of the importance of deposits applications for different user groups is presented.

Key words: Precious metal mining, copper ore mining, iron-ore mining, antimony, magnesite, precious opal

1.1. Introduction

Mining can be characterized as a set of activities related to the acquisition of mineral raw materials (ores, non-metallic and energy) either by surface mining (quarries) or underground method (pits, galleries). Under the term mining we understand a comprehensive summary of the work necessary for search, extraction and treatment of industrial minerals. In a broader sense it comprises extraction of any mining non-renewable resources.

In our territory the exploitation of mineral resources has had a very long and strong tradition. The first direct written mentions of ores from Slovakia are bound to Kievan Nestor‘s Annals, which dates back to the 10th century. Of course mining and quarrying took place much earlier, only there have not been preserved written sources to those activities.

The paper maps the extraction of minerals from prehistoric times to the present with an increased emphasis on mining of ore resources and briefly presents the selected extraction of non-metallic minerals.

1.2 The history of mining in prehistoric times and antiquity

1.2.1. Stone Age

The Slovak territory was inhabited since the Stone Age, in Paleolithic. From this period there are known settlements from our territory (Nové Mesto nad Váhom, Vyšné Ružbachy, Seňa, Poľov), where Homo erectus had lived and produced chopping-tool industry. The best-known tool of that time is hand axe used for hunting. The raw material originated from the vicinity of dwellings.

From the mid-Paleolithic (from 250 ky to 38 ky BC) on our territory much more numerous settlement of Neanderthal man and later the modern human (Homo sapiens) is already documented (most important Gánovce, Hôrka, Beharovce, Radošiná, Bojnice, Banka; Zámora et al., 2003). The Neanderthal man and later modern human had made great skill in stone working. He already produced stone tools which serve him for working hides, meat, antlers, bones and wood.

Of Young and Late Paleolithic (38 ky to 8,000 years BC) a large number of settlements is known in our territory; in eastern Slovakia there are known about 100 settlements (Barca, Seňa, Košice, Veľký Šariš, Tibava and others). In this period there was a great development in the production of stone tools. They were found evidence of the production of stone tools in specialized workshops where some selected specialized professionals in stone processing had worked.

In the Middle Stone Age – Mesolithic (8 ky to 5,000 years BC), and especially in the younger, Neolithic Age (5,000-2,900 years BC) and the Late Stone Age, Eneolithic (2,900-1,900 years BC) great changes occurred in human development. In the Middle Stone Age period the predatory economy started to be replaced by the manufacturing economy. Human began to cultivate the land and raise cattle. These facts required the production of new, specialized instruments (Zámora et al., 2003). The territory of Slovakia provided for the production of stone tools several suitable raw materials. They were mainly SiO_2 materials (quartz, chert, radiolarite, volcanic glass – obsidian, less jasper, agate and chalcedony). Firstly, these raw materials were collected from streams, then from the natural outcrops at the Earth‘s surface, and, finally, the man began to exploit them in excavation pits and tunnels (flint Neolithic site in Zemplínske vrchy Mts., Tóhegy in Hungary).

According to some authors Eneolithic (Chalcolithic) already belongs to the Bronze Age which was a significant

Fig. 1.1 26,5 mm Copper axe blade cross-type Nógrádmarcal (4th millennium BC). The finding from the village of Podkonice 5 km southeast of Špania Dolina, weight: 1049 g, length: 236.5 mm, width of hoe blade 51.2 mm, height of the axe blade: 35.1 mm, hole diameter for shaft: 26.5 mm.

turning point in history, when the mankind began to use metals, mainly copper, silver and less gold for the production of tools of daily use, decorative and cult objects. Metals started to be collected from the outcrops of their deposits on the surface, or from streams and rivers and their sediments, later using panning (gold). The first copper tools were forged from the cold copper. Later the prehistoric man began to crush the ore in the stone mortars and to melt on charcoal. There were produced wedges, hammers (Fig. 1.1), at the beginning similar to stone originals, later, as unique tools which could not be produced from the stone. The copper started to be traded, which is documented by the so-called copper grzywna or "copper cake" found in various places of our territory (Stupava, Handlová, Kočovce; Zámora et al., 2003). In the processing of the ore to metal specialization started to be applied in the Eneolithic, with specific categories of artisans – prospectors, founders, jewellers and traders who provide the distribution of finished products or semi-finished product, in the form of so-called copper cake (Struhár, 2015).

1.2.2. Bronze and Iron Ages

In the Bronze Age (1900-700 BC), around 1600 BC, bronze industry started to prevail in our territory. Bronze is an alloy of copper and tin. Based on the analysis of findings from the Bronze Age tin was added to the alloy at a ratio of 1:10 to 1:20. The copper ore was already treated before smelting. Below the old mining works at the site Piesky – Špania Dolina stone tools (stone crushers) have been found (Fig. 1.2), by which the copper ore was beaten and mulled into flour. It is reported that in the saddle Piesky there were found about 300 stone crushers of different sizes during surveys (Kvietok et al., 2015). At the same site there were also found remains of roasting place for ore. The tools and fireplace are dated back probably in the Early Bronze Age (Zámora et al., 2003). Production of bronze and bronze instruments was not focused only in places of their primary sites, but mainly took place in the major fortified settlements that were at the same time market centres (Veselé near Piešťany, Nitriansky Hrádok near Nové Zámky and Barca near Košice). From these settlements there has been preserved quite a large collection of objects from the Bronze Age, as well as stone and bronze pig moulds used for bronze objects casting. Under the influence of increased production of bronze tools gradually receded into the background the production of stone tools.

Among major metallurgical discoveries occurring roughly in the middle of the second millennium BC belong smelting and production of iron from iron ore. In our area iron smelting began in Hallstatt period (Iron Age) around the 7th to 5th century BC. In our territory we assume oxidized iron ores to be treated as the first ones (limonite, hematite, goethite) from the superficial parts of the iron ore deposits. An important testimony to the processing of iron ore in our territory is Molpír hill-fort near Smolenice, which dates back to the 6th century BC. Here there were found the objects where the ore was processed (forge) with iron slag as well as and semi-products of knives and iron rods. But the massive development of iron production in our territory occurred in the La Tene period. Evidence of extraction of the iron ores are also visible in the Massif of Slepý vrch Hill at Horné Orešany, an important Early La Tene hill-fort (about 5th century BC, Pieta, 2008). The most significant evidence of the extraction and processing of iron ore bind to a written report in the work of Tacitus Tusculi elegia which mentions a Celtic tribe Cotini that pay tribute Quadi and Sarmatians "to their great shame" in iron. The Cotini tribe lived probably in Gemer and Hron area and used local resources and ore. Evidence of the mining and processing of iron ore in particular, are also known from the Upper Váh settlement inhabited by Púchov culture. Especially around Strečno narrows there

Fig. 1.2 Stone crusher and base for ore crushing. Basic tools of prehistoric miners.

is evidenced a mining centre with hematite ore mining and initial metallurgical processing. These are sites Varín and Nezbudská Lúčka with several fields of metallurgical slag heaps (Pieta, 2008).

Celts as first ethnicity in our territory also began minting coins mainly from precious metals gold and silver, less copper. In the beginning these were silver coins tetradrachms and obols dated to the second half of the 3rd century BC (Apolonia types with a lyre, Bátovce type and Ptičie type). Later they began the production of coins in Púchov culture region in northern Slovakia. There were minted coins of the types Veľký Bysterec, Spiš, Hrabušice, Liptovská Mara and Folkušová. In eastern Slovakia again we know the type of small coins of the Zemplín type from Celtic – Dacian environment. These were adjoined by gold coins staters and their parts minted in the Middle Váh valley (staters with ring and blade staters), coins of the types Nimnica, Divinka, Pohanská and Čachtice. The highlights of Celtic coinage in our territory undoubtedly include silver and gold coins from an important centre situated in the territory of present day Bratislava. There were minted coins from gold and silver – stater and tetradrachm of the type Biatec and lower monetary units (Kolníková, 2012). Issues of origin and possible extraction of precious metals from domestic sources by the Celts have not been sufficiently solved yet. It is envisaged, based on metallographic analysis, that the sources of precious metals and thus the extraction were in our territory. The mint from Bratislava oppidum could exploit the gold from the deposits in the Malé Karpaty Mts. or from Danube placers. The coin workshops in the Middle Váh valley were close to the Zlatníky placers in the Považský Inovec Mts. (Fig. 1.3). In the case of silver it is assumed that deposits of silver from

Fig. 1.3 Footprints in the form of mining pits for precious metal ore using panning on site Zlatníky.

the Nízke Tatry valleys, from Štiavnické and Strážovské vrchy Mts. and the Slovenské rudohorie Mts. were utilized (Kolníková, 2012).

1.2.3. Roman period and Migrations

In Roman times it is assumed already quite intensive mining in most well-known mining regions. Our area was settled in that period by Germanic tribes namely Quads. It is important to mention that coinage system in our territory used adjacent Roman Empire currency and the Germans didn't mint their own coins. Based on the finds (Roman coins, terra sigillata and Roman glass) from Banská Štiavnica, site Staré Mesto (Fig. 1.4), which assumes the very

Fig. 1.4 Banská Štiavnica, location Staré Mesto, surface mining on Glanzenberg.

beginning of underground mining in the mining region, we can assume that in Roman times there was operated here quite extensive precious metal ore mining. In terms of German jewellery design and forge it is very important discovery of jewellery making workshop in simple earthing at Stupava (location Urbárske Sedliská). Here they were found several fragments of pots with traces of melting ferrous metals, copper, silver and gold (Varsík, 2011). The Germans were craftsmen in making ostentatious jewellery that symbolized differentiation of power in society, which is evidenced by the relatively numerous findings of several settlements mainly in southwestern Slovakia (Zohor, Stupava, Cífer-Pác, Očkov-Pobedim and others). For the manufacture of agricultural machinery and equipment they used primarily iron, which was supplied as tribute subjugation by Cotini tribe. The Germans were very combative ethnic and neighbouring and they led constant wars with Roman Empire known as Marcomanni wars. In early fifth century our area was attacked by nomadic Huns, which triggered a massive relocation of Germanic tribes, which historians call Migrations.

1.3. The history of mining in the Middle Ages

1.3.1. Early Middle Ages

Expansion of Slavs into our territory took place in the 5th century. Upon arrival in a new homeland the Slavs found at that time already used deposits. The Slavs brought knowledge about the exploitation of metals from their homeland already. After their arrival in our territory they began to improve technologies. This concerned mainly mining and iron ore metallurgy. Like the Germans the Slavs didn't develop their own coinage system. As medium of payment iron grzywnas served them (findings in Pobedim, Hrádok, Nitra, Bošany, and elsewhere). The ores were processed probably near the ore deposits. Particularly high levels reached Slavic blacksmithing. Knives and other tools were quenched in order to become harder. They recognized the hardening of tools using water and heat. In a workshop, various types of iron were processed, made of various ores and deposits (Zámora et al., 2003). We have no direct reports regarding the Slavic extraction and processing of precious metal ores and copper. But given the popularity of these metals by Slavs and proves of processing and manufacturing of jewellery (Bojná, Nitra, Bojnice, Pobedim) we assume that ore deposits were mined in Kremnica, Banská Štiavnica etc.

1.3.2. High Middle Ages

Exploiting of the ore deposits continued even after the demise of the Great Moravian Empire, when Slovakia became part of Early Hungarian state. Demand for iron and particularly for precious metals increased further. It seems that the ore district produced many precious metals which not only were able to cover the domestic consumption, but they were also exported. This is evidenced by the above-mentioned Primary Chronicle of Saint Nestor, which refers to the import of Hungarian silver in Kievan Rus around AD 969. The greatest importance had undoubtedly precious metal ore mining in Banská Štiavnica mining district. It is assumed that 50% of mined silver came from Banská Štiavnica ore district. This silver served as the basis for Hungarian silver coins minting. In the trade, however, not only coins were used for payment, but also so-called chopped silver. During the 10th century in Banská Štiavnica already significant mining of precious metal ore took place. There has been preserved record of AD 963 of the arrival of the Czech miners in Banská Štiavnica (Lichner, 2002). The document from AD 1156 called this territory "terra Banensium" – the land of miners. Later in 1217 it is referred to as "Bana". But the seal at the charter from 1275 already mentioned Štiavnica (Schemnitz). The historians explain that the name Bana refers to the Staré Mesto – Glanzenberg and Štiavnica was a settlement in the valley, which coincides with today's centre of Banská Štiavnica. Production of gold and silver in the 11th century can be considered as very interesting due to the high content of metals in surface part of the deposit and easy accessibility of the ores. Large pits were in rich surface outcrops of the veins Baumgartner and Goldfahrtner in Banská Belá, the Terézia vein (Fig. 1.5), Špitaler, Bieber and Grüner Lode. Reports on rich deposits in the area of Baňa attracted first German settlers, who gradually took over leadership not only of mining, but thanks to extensive privileges over municipalities administration. The Germans improved the work with picker and hammer and introduced a profession of worker. The mines boom brought turn of settlements to city, which in the year 1238 received from King Béla IV. town privileges and mining law. Mining importance is also underlined in the city seal from 1275, where the coat of arms comprises in addition to the city walls also mining tools picker and hammer (Lichner, 2002).

Fig. 1.5 Banská Štiavnica, traces of medieval mining on the vein Terézia.

The first written records proving the existence of Kremnica are from the 14th century. In 1328, King Charles Robert of Anjou granted "guests" – coiners from Kutná Hora in the village of Cremnych Bana special privileges to support its intensive development. The settlement thus obtained privileges of a free royal town and mining and minting rights according to Kutná Hora Law. At that time however, there developed in Kremnica mining business with a total annual output estimated at 130 kg of gold per annum (Beránek, 1977). Shortly after arriving of the coiners started minting of the first coins – Hungarian groschen in the year 1329. Eight years later the Mint increased production by gold florins minting. They later became known as Kremnica ducats. It is assumed that the mining history in Kremnica began much earlier. However, there is no written evidence, attributable to the start of mining at this deposit. The only direct evidence, however, was found in the detailed geological survey at the Šturec site. It was the rest of the wooden pillar of the old workings in Šturec, which was dated to AD 1050 by the method ^{14}C. According to other authors beginnings of mining activity date back to the 8th or 9th century, or to the beginning of the 11th century, when in the years 1004-1008 miners came from the Harz region. Most likely the beginning of the Kremnica mining is the end of the 9th to the beginning of the 10th century. In the charter from 1385 the hereditary gallery is mentioned, for example, which had a length of 4 km. This shows the long-term use of the deposit.

Mining of deposits in the vicinity of Banská Bystrica dates back to Eneolithic. However, the privileges of free royal mining town were granted Banská Bystrica in 1255 during the reign of Béla IV. Mine owners, so-called Waldburgers and their mining rights – to search and mine gold, silver and other metals on the whole territory of Zvolen county – were declared by charter of Béla IV already in 1242. The privileges included also the exemption of all taxes and the only duty was so-called royal compulsory metal delivery (urbura) 01/10 of the mined gold and 01/08 of the mined silver or other metals (derived from Banská Bystrica privileges from 1255).

Oldest codified mining law from Slovakia dates back to the 30s of the 13th century. It was probably Štiavnica mining law, which was in the form of privileges granted by the king Béla IV, but its wording or a charter was probably destroyed during the Tartar invasion in the years 1241-1242. To this day there have been preserved only copies in German from 1466. All mining towns in what is now Slovakia have taken it over either as a whole or at least some parts. Most decisions regarding mining were given to the free mining towns. But already King Stephen I. (997-1038), founder of the Árpád dynasty, introduced a royal mining authority, which was the predecessor of mining chambers.

The second half of the 13th century witnessed a significant development in Slovakia mining. All mined ore deposits in Štiavnické vrchy Mts. Banská Belá, Hodruša, Štiavnické Bane, but also Pukanec and Nová Baňa were exploited. There were mined also occurrences in the Nízke Tatry Mts. Vyšná Boca, Partizánska Ľupča and Hybe. The gold mines from around Rimavská Baňa were also mentioned. In the Spiš region silver was mined mainly in Gelnica, Smolník and Spišská Nová Ves, in the Gemer region in Jasov and Zlatá Idka (Zámora et al., 2003).

1.3.3. Late Middle Ages

Since the 14th century, mining in our territory witnessed a great boom, but with a deepening of mines and tracking of ore lodes in the depth the most mining districts experienced water problems. This resulted in most districts in driving of drainage tunnels and construction of installations for water pumping from mines so-called "gápel". At the same time the deepening of mines the quality of ores reduced and quarrying was more complex and involved the participation of a large number of miners, and thus the costs of ores extraction increased. The mines were developed manually using picker (Fig. 1.6) and hammer, eventually using fire in mining operations, provided good ventilation of a mine was possible.

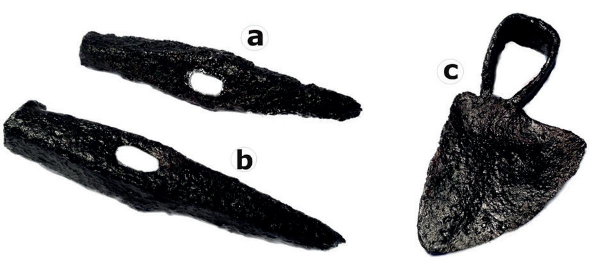

Fig. 1.6 Mining pickers and mining hoe so-called "graca". a – Vyšná Boca, b – Banská Hodruša, c – Vyšná Boca.

In Banská Štiavnica, in the 14th century the great enemy of miners – mining water – occurred. Despite the prosperity of mining the groundwater began to decide on the progress of work. Some mines were flooded and the water could not be withdrawn out of them, so many miners had to close the mine. In each mining town based on the Regulation by King Charles Robert, a royal house was built – Kammerhof – which was a seat of Count of the Chamber. Miners were required to deliver gold and silver in Kammerhof and Count of the Chamber was solely entitled to determine purity of metals. On April 7, 1388, there was held in Banská Štiavnica constitutive meeting of the Association of Central Slovakian mining towns, with the task of joint solving of the mining towns issues.

Fig. 1.7 Contemporary postcard of the mining settlement Piesky at Špania Dolina, 19th century.

15th century brought Banská Štiavnica busy times of fires and power battles for the Hungarian throne, destruction of the old city of Bana (Glanzenberg) completed by the large-scale earthquake in the year 1443. Banská Belá became a separate mining town in the year 1453, but its fame after several floodings of the main mine in the years 1383 and 1474 had never returned despite many efforts and raised funds that were spent on its restoration. Hodruša also sought for the autonomy. The mining was profitable, landscape enabled easy drainage and fast development downwards, therefore in 1494 a new heritage gallery was founded, today the Hodruša heritage gallery. In Banská Štiavnica in the late 15th century the miners began to build water reservoirs to collect surface water that served to drive water wheels.

In the 14th and 15th centuries precious metal ore exploitation in Kremnica reached its maximum and the annual gold production exceeded 400 kg, representing a third of total production in Hungary and tenth in the then world (Beránek et al., 1977). The city's prosperity in the 14th century is documented by its rapid expansion. In Kremnica water aqueducts were built to supply a propulsion for water pumping. The oldest of them, the Turček pipeline, began to be built in the 15th century.

In the 14th and 15th centuries, precious metal ore were exploited in the Malé Karpaty Mts., especially in Pezinok, then around Nitrianske Pravno, Zlaté Moravce and Zlatníky. Precious metal ore production in Smolník in this period had to be at its high when King Charles Robert of

Anjou ordered to establish in Smolník in 1328 one of the two mint chambers in our territory (the other one was in Kremnica). Many precious metals had to be exploited at the deposit in Nová Baňa, where in 1345 24 ore mills were registered.

In the Banská Štiavnica region deposits produced a lot of silver, which was extracted from tetrahedrite ore. Mining in the local mines situated in Špania Dolina, Piesky (Fig. 1.7), Richtárová and Ľubietová was primarily focused on copper ores containing silver (so-called black copper). In the 14th century most of the production of black copper was exported to Venice, where at that time knew how to separate silver. The technology of copper production from the ore with its lower content was introduced at the late 15th century by Cracow burgher Ján Thurzo. Along with the Fugger traders they created in 1494 at then time a grandiose trade and commerce company "Ungarische Handel". During the first half of the 16th century the company dominated all markets with copper. The period of maximum development of copper ore mining with high content of Ag was in the period 1496-1546. In the 16th century Banská Bystrica copper enterprise (Thurzo-Fugger company) was the largest copper producer in the world.

In the Ľubietová settlement, which became in the year 1379 free mining town with confirmed privileges of 1382, the copper ore mining was profitable. Only in the first half of the 15th century, when Ľubietová was looted and burned by the Hussite army, Ľubietová mining declined until the above mentioned Thurzo-Fugger company took control of local mining (Fig. 1.8).

Fig. 1.8 Pottery opened tallow burner from the turn of the 14th to 15th centuries from Ľubietová mining field Svätodušná.

Copper ore mining was also developed in what is now eastern Slovakia. Significant mining factories were in Gelnica, Smolník and Spišská Nová Ves. Notable was mainly production of cementation copper in Smolník.

Iron-ore mining in written reports began to emerge from the 13th century. However, a major iron ore mining development occurred in the 14th century. This was also due to the development of precious metal and copper mining and metallurgy, since they needed iron for the production of manufacturing tooling, for different pumping and conveying equipment. The iron ores were located on the territory of Slovakia in large quantities and in numerous places. In the 14th century iron ore mining was especially prevalent in the Gemer region, but also in Spiš, Abov and Hron regions. In the first half of the 14th century large change occurred in the steel production. There was introduced the water wheel to kilns and trip hammers. Extensive mining of the iron ore was established in the mid-15th century on deposit Železný vrch at Dobšiná. Significant ironworks area was formed around iron ore deposits Železník, Rákoš and Hrádok (Zámora et al., 2003). An important factor in the development of iron ore mining was the fact that royal urbura had not to be paid for the iron ore extracted or produced iron.

Written records from 13th century document salt springs in Prešov. In 1348 there were mentioned three salt springs. Brine of salt springs was exploited by Šoóš family, which owned the land with salt springs.

From the 14th century on deposit in Malachov near Banská Bystrica mercury was exploited. Written reports document also cinnabar mining at sites Dubník in Prešov, Gelnica and Dobšiná. Antimony ores were mined in Čučma.

1.4. The mining in modern history to the present day

1.4.1. Early Modern Period

The beginning of modern history and thus the end of the Middle Ages in our area, according to historians was associated with Battle of Mohács (August 29, 1526) in which the Hungarian troops of Vladislav II. Jagiello were defeated by the Turkish troops led by Sultan Suleiman I. The whole period was marked by struggles against the Turks, who were also linked with Anti-Habsburg uprisings and the struggle for power in Hungary. Early 18th century our territory was befallen by pandemic plague that left significant traces in the mining regions.

The mining in the first half of the 16th century was highly influenced by the bad political situation in Hungary. After entering the Habsburg dynasty to the throne Hungary was chaotic with poor economic, but above all internal political situation. A large part of the Hungarian nobility did not support Ferdinand I as king, but his opponent, national Transylvanian Duke King Ján Zápoľský, which was supported by the Turkish Empire. Hungary collapsed and disintegrated in three separate states. Our territory remained under the influence of the Habsburgs and Bratislava became the capital and coronation city of Hungary for a long period. The flow of low-quality silver money in the country also affected emerging social dissatisfaction of miners and the struggle for their rights. The first riots started around 1525-1526 in the copper ores area with the centre of Banská Bystrica. These riots later spread to Štiavnica areas (especially Hodruša) as well as in Kremnica area. The riots were suppressed by Palatine István Werbőczy. The miners struggle for better social conditions, however, continued and the period of 16th-17th centuries was an epoch of numerous mining uprisings.

At the beginning of the 16th century there were 426 separate mining works around Banská Štiavnica. The work technology was being changed by improving transportation in the mines. Rock was initially transported in bags on backs, then pulled on sledges, then in the boxes on wheels. Finally Tyrol cars were introduced, being adapted to the conditions of Štiavnica mines, so-called Štiavnica pit cars also called Hungarian pit cars. Vertical transport was ensured by using a simple winch, later the treadmill, horse power or water wheel were used. Hydropower was needed and so the miners started to improve artificial water reservoirs. In the period 1500-1638 there were only four water reservoirs /Veľká Vodárenská, Malá Vodárenská, Brenerštôlnianska, Evička/. The water was drawn in tanks on the rope, ventilation was natural, or supported with blowers. Lighting passed from primitive rays and torches to oil burners. The development of mining requested some specialty workers – breakers /disassociating rock/, disposers /disposing rock into transport containers/ and transporters /rock transported to the place of destination/. Special squads provide water pumping. Specialized personnel were engaged in ore treatment and smelting. Individual craftsmen prepared tools, machinery and buildings for operation. Mining foreman and his assistants provided control and operation of mines, smelting and purification plant. The state gradually took over more and more mines from small miners who were unable to keep the mining operation financially.

In the 17th century, an independent mining authority, for state mines, so-called Mining Administration, was established in Vindšachta (Fig. 1.9).

Fig. 1.9 Contemporary postcard of Vindšachta, today Štiavnické Bane, with Leopold shaft building, from the 19th century.

Although in the 17th and early 18th centuries Banská Štiavnica was severely tested – Turkish raids, revolts against Habsburgs, plague epidemic in 1709-1710 to which some 6,000 people fell victim, yet still Banská Štiavnica mining progressed. Cheap labour and state as the largest mining entrepreneur who could invest in mining greater financial resources, contributed to positive development. Year 1690 was the richest year of the Banská Štiavnica mining area when the smelters produced 29,000 kg of silver and 605 kg of gold, the largest production in Banská Štiavnica throughout the life of the mines. Metal mining proceeded deeper, mining work became technically more demanding. Rock disintegration was still manual (using pickers and hammer, exceptionally, a fire). On February 8, 1627, Gaspar Weindl from Tyrol made the first underground mining blasting in the world with black gunpowder in Bieber Upper Gallery. The blasting work quickly extended to other mining districts. The miners also started using a hand drill. Mine water was drawn from the level of heritage galleries to the surface in drainage buckets, leather bags and piston pumps. The first mention of piston pumps is from 1604 in Brenner mine. A horse power was used in 1619 to drive piston pumps. Human and horsepower was not sufficient to accommodate increasing demands for deeper mining in the mines. More emphasis was put on improving the structure of horse-powered pumps and the use of water power.

In early 18th century, in 1700-1701 the propulsion foreman Adam Unger constructed a pumping machine powered by a water wheel. Flooding of galleries became an increasing problem and threatened mines operation. To their recovery contributed mechanical master Matej Kornel Hell. He constructed a water pump in the shaft Magdaléna at Vindšachta and Upper Bieber Gallery. The development required enhanced ore processing. It began to be applied the method of treatment in stamp mills, which was one of the most important finishing processes at Štiavnica ores. The growing need for more driving water led to extension of the network of artificial water reservoirs – reservoirs that provide the energy to drive the mining machinery, water-drawing, hauling and dressing plants and smelters. This sophisticated water management system of artificial water reservoirs, powered and interconnected by collecting, connecting and conducting ditches not only saved Banská Štiavnica mining, but on its energy base there evolved mining pumping equipment, which was a model for other mining districts in the world. To its creation contributed two important figures, mechanical master M.K. Hell and Samuel Mikovíni, who was appointed in 1735 as imperial and royal geometer and the first professor of Mining School based in Štiavnické Bane.

In the nearby Nová Baňa, after a brief flowering era (14th-15th cent.), the city experienced internal turmoil in Hungarian Kingdom and anti-Turkish wars one blow after another – the destruction of the city by the Turks in 1664, Anti-Habsburg Uprising and plague epidemic. In the 17th century the town almost disappeared. Problems of groundwater in the mines hampered further mining development. The flooded workings had to be saved by fire-atmospheric engine, constructed in 1722 by English constructor Isaac Potter (machine model is in Pohronské Museum in Nová Baňa). It was the first steam engine on the European continent.

In Pukanec precious metal ore mining in this period was relatively well developed, but the periods of richer ore mining alternated with periods when the mining was non-economic. In these periods the heritage galleries were maintained thanks to the contribution of the Mining Chamber. The region was also negatively affected by Turkish wars.

In the area of Boca mining business seemed to be very promising in the second half of the 16th century, but in the 17th century, the mines were struggling along.

The Ľubietová mining for silver ore completely ceased and the mine continued to operate only for copper ore.

In the Eastern Slovakia region, the silver ores were exploited in Smolník, Spišská Nová Ves, Švedlár and partly in Rožňava.

The copper ore mining in the 17th century was mainly focused in Ľubietová and Banská Bystrica districts. But it gradually shifted to the Eastern Slovakia mining areas. The rich copper ore mines were in Smolník, Gelnica, Štós Švedlár and Spišská Nová Ves. Thurzo-Fugger Company terminated its activities in 1545 and the mines were taken over by treasury. After Bocskay and Bethlen uprisings the copper company was in a desperate state. The mines were mostly flooded and the miners had gone. The situation was partly improved as treasury signed a contract with leasers W. Paller and L. Henckel, who provided capital for the operation of the mines. Production began to rise slowly. However, the copper businesses began to be challenged by the production in Sweden first, then in Japan. In 1642 the treasury rented the mine Viennese merchant brothers Joanelli. But they rather plundered the mines and exploited the mining staff which led to dissatisfaction. After the George Rákoczi uprising in 1645 came the plague epidemic, famine and miners who did not receive wages on time had gone. In the second half of the 17th century the operation was relaunched, and the treasury introduced measures to streamline the mining and production of copper rose again. The exhaustion of ore reserves was more and more perceptible. The shafts were over 350 m deep, the costs soared, and the production declined. Specific monument of this period are typical "mining signs", tokens, the coins that were minted for the payment of the mining by the working class. They were made of copper and possibly minted initially by miners themselves (mine owners), later by treasury in mining areas of Banská Štiavnica (Fig. 1.10), Špania Dolina (Fig. 1.11) Ľubietová, Smolník and others.

Fig. 1.10 Typical token of Banská Štiavnica in 1696 from the reign of Emperor Leopold I, diameter 22 mm, weight 2 g, probable monetary value – 1 poltura.

Iron-ore mining during this period concentrated in particular in known iron ore deposits in Spiš-Gemer Ore Mountains. However, of great practical importance was the mining in the Hron Valley, around Hronec, Poniky, Ľubietová, Breznica, Vyhne and Horné and Dolné Hámre. Production in this district was primarily streamlined in supplying precious metal copper ore and mining. There were created also new ironworks, e.g. in the late 17th century in Tisovec and Ružomberok. The ores were still largely extracted from surface deposits – gossans. In general, the ores from the Hron Valley had lower metal content than those from Spiš-Gemer district. At the end of the 17th century the first blast furnaces were built; in 1692 in Ľubietová in 1710 in Hnilec.

Fig. 1.11 Typical token from Špania Dolina with inscription Herrn Grund – Špania Dolina from 1739 from the reign of Emperor Charles VI., Diameter 21 mm, weight 2.35 g, probable monetary value – 1 poltura.

The underground salt mining took place from 1572, as the treasury took in their hands the mining from the family Šoóš. Later (in 1586) the plant was leased and during Bocskay uprising completely destroyed. In 1616 the plant was leased to Prešov City. At the end of the 17th century the deposit was accessible by three shafts and developed by several galleries. The production of rock salt was constantly increasing. At the end of the Francis II. Rákoczi Uprising the plant began to decline. In the mid-18th century the salt was still retrieved in two ways; from brine and by extraction of rock salt. However, in 1752 the Solivar mines were flooded by salt water and rock salt mining terminated. The brine extraction continued (Fig. 1.12) in the Leopold shaft (Zámora et al., 2003).

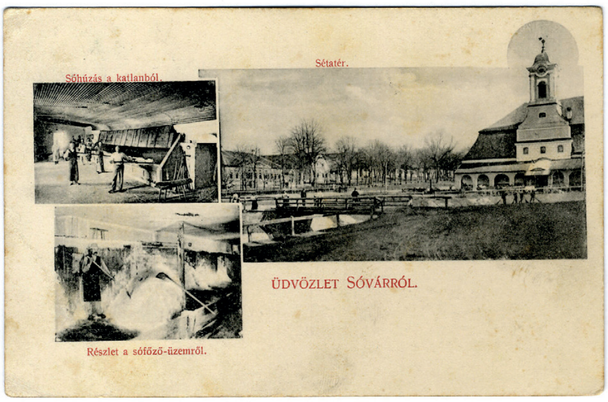

Fig. 1.12 Contemporary postcard of brine processing by cooking in Solivar in the late 19th century.

For other minerals there is mentioned minute extraction of mercury, sulphur and antimony. The first mention about possible extraction of precious opal on Dubník is in the Admissions list for Stephen Kecera by Emperor Rudolf II dated 1603) (Semrád, Kováč, 2003). Upon the arrival of the Habsburgs to the throne the mining legislation big changes arrived. Already Emperor Ferdinand I was trying to impose these changes, but his successor, Emperor Maximilian II managed to enforce amendments. The change is mainly related to decision-making power, which was transferred from the mining towns to newly-formed authorities of the Mining Judge (Bergrichter) and the Royal Office (Mining Court – Berggericht).

1.4.2. Mid Modern Period

In this period the most active mines were in the hands of the feudal state (treasury), which made great efforts to get maximum profit from the extraction. There were implemented new technologies in mining and treatment of metal ores, there were raised the mining experts who implemented new sophisticated mechanisms and thus the ore production of precious metals, copper, iron, salt, and other industrial minerals grew.

In Banská Štiavnica at the late 18th century the construction of additional reservoirs was strongly contributed by Jozef Karol Hell, who in the year 1738 built the first beam pumping machines. J.K. Hell in 1755 put into operation his invention – Hell`s air pump machine which used for drive, besides water, a completely new element – compressed air. The machine was a revolutionary design ahead of its time. Nevertheless, the wide use of atmospheric steam /fire/ pumping equipment continued. In the mining region of Banská Štiavnica the most of them were built. At the end of the 18th century more economical Hell`s water-column machine started to be used (Lichner, 2002).

A major breakthrough in mining of precious metal ores in Banská Štiavnica was the completion of Heritage Gallery of Joseph II. (Voznica), which started to be developed in 1782 and was completed in 1878. This drainage tunnel that drains the deposit to the level of 12th horizon has a length of 16,210 meters and in then time it was unique mining project on a European scale. This adit was very helpful in mining in the region, as it already drew water below mining level and the cost of extraction were no longer so high.

In early 19th century the Hell`s water-column machines were perfected by Jozef Schitko, professor of the Mining Academy in Banská Štiavnica. The mineral processing of ores during the 18th and 19th centuries reached in Banská Štiavnica high technical level. Empress Maria Theresa adopted the proposal of John Thaddaeus Peithner and by Decision of December 13, 1762, ordered to establish a Mining Academy in Banská Štiavnica. It was the first college of affiliate programmes in the world and Banská Štiavnica became the centre of development of mining science and technology in Europe. The first lecture at the Mining Academy was delivered on October 1, 1764. With the names of professors (Jacquin, Poda, Delius, Scopoli) of this school there were associated many European, even world leaderships in science and technology. The Mining Academy later merged with the Forestry Institute to become Mining and Forestry Academy in Banská Štiavnica. The Academy raised number of mining specialists, who participated in the introduction of new methods and procedures for ore extracting virtually worldwide.

In Kremnica in the second half of the 18th century, due to the mine drainage (Deep /Hlboká/ Heritage Adit) and exposure of deeper ore units, the precious metal ore production began to increase. In the years 1748-1800 it yielded an average of 635 grzywnas of gold and 809 grzywnas of silver (Zámora et al., 2003). However, in the early 19th century Kremnica mines already struggled with great difficulty and were unprofitable. The mines got into deeper parts that could not be drained by Deep Heritage Adit and they needed to be drawn, ventilated and transporting of mined ore was also very expensive. In 1841 the work started on the excavation of the Main Drainage Heritage Gallery which was completed in 1899. It reached a length of 15,481 m.

Precious metal ore production from other regions was negligible. The Banská Bystrica area and some Eastern Slovakia locations delivered silver to the mint in the form of so-called black copper, used for the alloying of silver, i.e., the production of alloys suitable for minting coins.

The extraction from the mines in Nová Baňa, Pukanec, Boca, Magurka, Pezinok was minimal, about 200 talents of silver and some gold. The rapid development experienced only the mines near Zlatá Idka that produced at that time about 8,000 talents of silver.

Copper ore mining in Banská Bystrica region /Špania Dolina, Ľubietová/ still survived, but the focus of mining in this period shifted to Spiš-Gemer region. The main mining towns were Gelnica, Smolník and Spišská Nová Ves, but they were gradually joined by other sites of Slovinky, Rejdová, Krompachy, Medzev, Folkmar, Helcmanovce, Poráč, Rožňava, Vondrišel (Nálepkovo), Švedlár. On the Slovak localities it was manufactured in this period about 80% of copper, of the total amount of copper produced in Hungary and 64% throughout the Austro-Hungarian monarchy.

The iron-ore mining experienced a setback in the late 18th century. Mining treasury tried to enforce a change to make the iron minerals the reserved mineral so the State could collect urbura payment. This change, however, was finally implemented by the early 19th century. Treasury at that time was also active in mining of iron ore and owned ironworks in Tisovec, Hronec and partly in Sirk (Železník). But the private miners had still a decisive position within the mining industry. The largest miners of the period include noble families of Andrássy and Coburg. The greatest concentration of iron furnaces and forges were in Spiš and Gemer near abundant deposits. By the late 18th century about 70% of the nationwide production of iron was produced in Gemer (Zámora et al., 2003). Significant deposits of iron ore in Spiš and Gemer at this time were Železník, Rákoš (Fig. 1.13) Hrádok, Dobšiná,

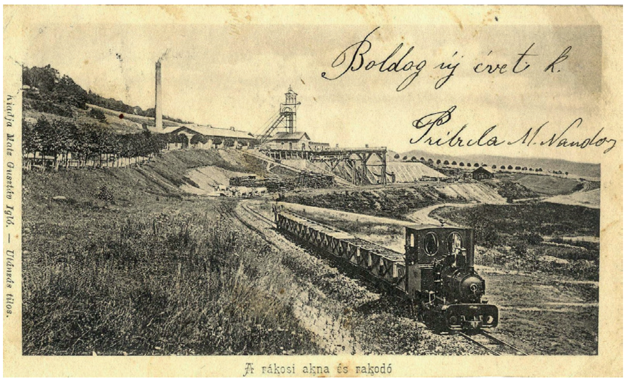

Fig. 1.13 Contemporary postcard with deposit Rákošská Baňa in the late 19th century, at the forefront a mine train transporting mined ore to the treatment plant.

Slovinky, Žakarovce, Gelnica and Medzev. A major drawback of iron ore production was that it focused only on the production of pig iron (lack of manufacturing). Most of the production was exported to western countries of the monarchy, from where different ferrous products were imported (from Austria and Bohemia).

It continued mining of brine by "gápel"' – brine pumping facility driven by horses – in the shaft Leopold in Solivar. At the end of the 18th century there were constructed two cookers with salt settling tanks. The production increased gradually and profits were high enough. About 80% of production was sold on the domestic market, the rest was exported. But the mining couldn't cover market demands and the salt had to be imported from Poland and Transylvania.

Lead ore was extracted mainly in Banská Štiavnica. The lead ores mining in Čavoj, Poniky and Ardovo was of local importance.

Mercury was extracted on a smaller scale on deposits in Nižná Slaná, Zlatá Idka and Gelnica.

The antimony ores began to be exploited in the late 18th century at the deposits Pernek and Pezinok. Around 1840 mining at the deposits Liptovská Dúbrava and Magurka started. In Spiš and Gemer regions the plants Spišská Baňa, Čučma and Poproč were operated.

Cobalt-nickel ores were mined from 1780 in Dobšiná. Initially, the problem was with the usage of the ore (used exclusively in the manufacture of dyes). Early 19th century the ore began to be exported to England, German States and Belgium. Extraction of the cobalt-nickel ore from the deposit Dobšiná accounted for 75% of its mining across the Austro-Hungarian monarchy.

The surface mining of manganese ores in the deposit Kišovce began around the turn of 19th-20th centuries; it supplied the local ironworks. Later, in 1908, Vítkovice ironworks began underground exploitation. But only during the World War I (1916) the mining developed on a large scale, as the import of the manganese ores was interrupted.

The beginnings of mining of magnesite in our territory date back to the end of the 19th century. Its mining was conditioned by the necessity of obtaining fireproof materials for blast furnaces lining. The magnesite deposits were discovered by workers that built the railway line Jesenské – Tisovec in 1871 between the villages Hnúšťa and Hačava. This was followed by a targeted search for the mineral, which resulted in the discovery of deposits of magnesite near Ratkovo, Jelšava, Lubeník, Ochtiná, Bankov near Košice, Ružiná and Cinobaňa. In 1900, the factories of the Company Magnesit Industrie Aktien-Gesellschaft (MIAG) were built in Hačava and Jelšava. So-called Horný Hačavský plant exploited magnesite mined at the deposits Ratkovská Suchá and Burda. The raw material was transported by horse-drawn vehicles and later the cable car was built from Burda to Hačava. In 1909 the Danish company Schmidt installed rotary kiln for sintering of magnesite, which was the first of its kind in the world. The plant Jelšava was supplied from the deposit Dúbrava; the magnesite was burnt only and assorted and dispatched to the brick factory in Kőbánya (Budapest). Later other companies and factories began to mine and process the magnesite and new plants were opened in Hačava, so-called Dolný závod, Chyžná Voda – Lubeník and Bankov near Košice.

The industrial mining of the single Slovak precious stone – precious opal from Dubník is documented in the second half of the 18th century (reign of Empress Maria Theresa). Between 1750-60 Earl Vecsey secretary Szukovicz made trial pits at the site. In 1787 the treasury expressed interest in opal mines, but in the early 19th century the state leased the mines. Gradually during the 19th century it had several leaseholders, the Viennese business family Goldschmiedt operated the opal mines the longest. The most famous opal found at Dubník was so-called Harlequin, or Vienna Imperial Opal, which was found in 1775 and weighs 2,970 carats or 594 g and is now exhibited in the Natural History Museum Vienna (Semrád, Kováč, 2003).

In 1854 so-called General Mining Act came into force in the mining legislation, which replaced the former Maximilian`s Mining Code. It stipulates the procedure for acquiring licenses of deposits and industrial minerals during their extraction. It was the most advanced mining regulation in Europe. The mining administration was also updated. The mining courts were replaced by mining capitanates in Banská Štiavnica and Smolník. After the year 1859 the capitanate of Banská Štiavnica moved to Banská Bystrica and the capitanate in Smolník to Košice and later to Spišská Nová Ves. Mine commissariats located in Kremnica, Nová Baňa, Malužiná and Pezinok were subjected to the capitanate in Banská Bystrica and commissariats in Gelnica, Rožňava and Spišská Nová Ves to the Smolník capitanate.

1.4.3. Contemporary Period

1.4.3.1 Period of 1918 – 1945

The results of the World War I largely marked the mining in our territory. The establishment of Czechoslovakia distorted historical continuity of essential linkages to Vienna and Budapest from the previous period. The government of Czechoslovakia was interested in a weakening of Austro-Hungarian capital, which was established within the territory of Slovakia and in domination, monopolising of industries by own (Czech) concerns. For this purpose, so-called "nostrification laws" were put in force, which obliged the non-resident companies with plants in Czechoslovakia, to translate the residence and management in CSR and to ask the State for accreditation (Zámora et al., 2003). The economic crises of the periods 1921-1923 and 1929-1933 were another factor that affected the mining in our territory. The mining development was impacted also by other circumstances. With the exception of the state blast furnace in Tisovec and in Podbrezová the ironworks disappeared and this fact affected the operation of the iron ore mines. In 1919, the College of Forestry and Mining moved to Hungary and with it most of the teachers had gone. Slovak technical terminology was only just emerging and most of the plants used German or Hungarian language and in the state mines the Czech language. The new management organization and turn in north-south transport to Hungary to the east-west Czechoslovak route brought great difficulties. The last but not least, the beginning of the period was marked by invasion of the Hungarian troops in 1919. At the end of this period, again, the Second World War, the establishment of the Slovak State and the annexation of southern Slovakia to Hungary resulted in losing a lot of mining operations mainly antimony, iron ore and magnesite (Grecula et al., 2002).

Precious metal ore deposits were mined mainly in Kremnica, Banská Štiavnica and Hodruša. Magurka and Zlatá Idka mining deposits were abandoned in 1923 for low precious metal content. Exploratory works on deposits Nová Baňa and Harmanec were unsuccessful. All these operations were in state hands. The operation of Aurea Company in the panning of Danube placers was also terminated.

The plants in Banská Štiavnica and Hodruša were suspended in 1923-1931 due to the reconstruction and rehabilitation of mining and smelting facilities. From the original number of 1,500 miners only 600 of them remained employed. There were launched preparatory works for the opening of the richest veins of ore columns Špitaler and Grüner, and deepened the shafts František, Emil and Mária for ventilation. Later the work began on Maximilán shaft and Svätotrojičná (Saint Trinity) and Pacher galleries (Fig. 1.14). The system of stamp mills and treatment plants was also redesigned. At the František shaft a modern flotation plant was built in the year 1930, which alternately processed the precious metal and polymetallic ores. Around 1930, a full mining operation with extraction was launched on the precious metal ore vein Grüner and polymetallic Špitaler vein. In the observed period there were extracted a total of 405,000 tonnes of ore, of which 187,000 t were precious metals ores and 13,920 t of lead concentrate was produced. The water reservoirs mostly lost their original purpose, ceased to provide energy and water began to serve fishermen and tourists.

Fig. 1.14 Contemporary postcard of Pacher Štôlňa plant in the early 20th century.

The plants in Hodruša implemented an exploration programme focused in Schöpfer vein (Dolný závod – the Lower plant) and Finsterort and Východná veins (Horný závod – Upper plant). The work was carried out also in Vyhne in the veins Pod Šivárňou. As the quality of ores did not reach the expected parameters, in 1939 began the prospection of the Rozália vein for copper ore.

In the year 1922 the plant in Kremnica was taken over by Ing. Aurel Lehotzký, who was a native of Kremnica and a graduate of Mining Academy in Banská Štiavnica. He elaborated a plan of the plant reconstruction, which focused on more promising veins in the mines Ferdinand, Ludovika (Fig. 1.15) and Anna. The ore was treated by amalgamation associated with flotation followed by leaching in the cyanidation facilities. In the period discussed 495,000 t of precious metal ores were extracted, and from the concentrate approximately 2 tons of gold and 4 tons of silver were produced. Thanks to utilizing of the Turček pipeline the mine was self-sufficient in electricity production. The reconstructed hydroelectric system (Ferdinand shaft, Anna shaft and shaft no. IV) allowed to supply electricity even to the public grid.

Fig. 1.15 Contemporary postcard of the Ludovika shaft in Kremnica with the heaps and Šturec undermined area in the early 20th century.

The gold and silver were also produced in the metallurgical process from antimony concentrates and polymetallic ores with factories in Čučma and Medzibrod.

The copper ore mining in this period developed at the deposit in Slovinky. This was originally a plant focused on complex siderite ore with a relatively high copper content of 4 %. Following the liquidation of the Krompachy Ironworks it was decided that the iron component of the deposit will be mined. After installation of the copper smelters in Krompachy the mining was again put into operation in 1938 and it continued only with the extraction of copper ores. In the period 1919-1944 the deposit produced 1,043,000 t of the copper ore which represented 97.7% of the Slovak production.

The iron ore mining experienced problems with finding mined ores markets. For example, in 1929 the mining of iron ores reached 999,000 tonnes, representing 55% of the entire mining in Czechoslovakia, but only 32% of its needs. From 300,000 t of pig iron at the beginning of the reported period, in 1929 the production decreased to one tenth. The abandoned ironworks were replaced by the new steel capacities in Bohemia (Třinec and Vítkovice) and Hungary (Ózd, Diósgyőr). Mining continued at the deposits Koterbachy (Rudňany), Máriahuta, Roztoky, Grétla, Bindt, Mlynky, Dobšiná, Nižná Slaná – Vlachovo, Železník Rákoš, Sirk, Rožňava, Nadabula and Luciabaňa. In the reported period a total of about 20 million t of iron ores were extracted.

Mining of manganese ores decreased compared to war years, the original level was achieved during the WWII and even doubled in 1943. Most of the production was supplied by deposit Kišovce – Švábovce, during the the WWII Michalová and Čučma deposits were mined.

Antimony mining made a significant progress in the period. Exploration and mining activities were conducted on deposits Čučma, Banisko in Bystrý potok stream, Spišská Baňa, Tinnesgrund, Poproč, Zlatá Idka, Pezinok, Magurka, Dúbrava, Medzibrod, Lom, Dve Vody, Chyžné and Zlatá Baňa. Antimony production was rising rapidly, saturated domestic market and exported the surplus. In 1930 the smelter was reconstructed in Vajsková, and it was capable to produce all the required metallurgical products on the market (regulus crudum, oxide) and Au-Ag bullion from concentrates. In the years 1933-1935, Slovakia participated in world 5-7% of antimony production (Zámora et al., 2003). Overall, for the period 428,400 t of the antimony ores at all deposits were extracted (Grecula et al., 2002).

The extraction of mercury ores was carried out in the deposit of complex ores in Koterbachy (Rudňany; Fig. 1.16), where it was a by-product of the extraction of siderite. There were also mined deposits Gelnica-Zenderling and Merník. Of the total production in Rudňany were mined 91.2%, and in Merník 8.4% and in Gelnica-Zenderling 0.4% (Zámora et al., 2003). During the reported period 1,698 t of mercury were extracted on deposits (Grecula et al., 2002).

Fig. 1.16 Contemporary postcard from Rudňany (Koterbachy), mining and processing of mercury ore in the early 20th century.

Magnesite mining was impacted negatively by the recognition of nostrification law, since all the magnesite works were in private hands. At the same time the development of the magnesite industry had an impact on liquidation of the Slovak iron industry in the period after the First World War. Sales to the market represented only 2-3% of total sales. Czech companies were mainly supplied by fireproof materials from Austria. On this market Slovak magnesite works supplied only 7-8% of total sales. The Austrian magnesite industry gained worldwide dominance thanks cartel among the main suppliers of fire-proof materials, which set disadvantaged quotas for the producers from Czechoslovakia. The overseas export of our production had to compete with the magnesite production from Greece and Yugoslavia, thanks to low-cost shipping. In the reported period there were mined deposits Hnúšťa - Dolná magnezitka, Ružiná, Košice – Bankov, Lubeník, Studená, Hačava, Hnúšťa – Horná magnezitka, Ratkovská Suchá, Burda, Ploské, Sirk, Jelšava (Fig. 1.17) and Ochtiná. The products were exported practically to the whole of Europe. Of the total amount 8.5% were sold of the raw magnesite, 76% as clinker and only 15.5% magnesite as a final product. This also reduced the use of such prosperity of this scarce raw material (Zámora et al., 2003). For the reported period there were extracted in all plants around 2.6 million t of raw magnesite.

Fig. 1.17 Contemporary postcard of the magnesite factory in Jelšava the early 20th century.

Brine mining continued in the plant in Solivar that was named in 1925 after President Masaryk. The plant was completely rebuilt and salt was treated on the principle of vacuum cooking. Since the flooding of the mine in 1752 just salt in the form of brine was exploited without direct contact with the deposit, a survey proceeded, which should clarify the structure of the deposit. Four exploration wells completed in 1922 didn`t sufficiently clarified the deposit geometry.

The Dubník deposit of precious opal was allocated to Soľné Bane Company. The directorate of the company did not manage the Dubník mining and it was the beginning of the end of the opal mines. Then Czechoslovakia rented opal mines for 10 years French enterprise Bittner – Belángenay in 1922. However, the company was unable to continue in mining of opals and so in the same year its activity ceased.

First systematic geological – deposit studies in our territory were carried out by State Geological Survey of Czechoslovakia in the territory between Vrútky and Žiar nad Hronom. The Czechoslovakia government‘s effort was not to create better conditions for the development of geology and mining in Slovakia, creating a geological or mining research organizations or technically oriented university. Prospective students had to study mining engineering at Příbram or Austrian Leoben. In the field of mining science and education in the period reported the first State Mining Museum in Banská Štiavnica was founded in the year 1927. Dr. F. Fiala was commissioned its management and the organization had research character. After his retirement in the year. 1939 the activity of the Museum stagnated. Only after the creation of an independent Slovak state the efforts to establish a professional base for deposit research emerged and paved the way for the emergence of Geological Institute of Slovakia.

1.4.3.2 Period of 1945 – Today

The end of the Second World War was the beginning of division of the European countries in two different socio-economic groupings. On April 5, 1945 the Košice Government Programme ratified the complete subordination of Czechoslovakia to the Union of Soviet Socialist Republics (USSR). It was the beginning of the "popular democracy" and the building of the social set up under the leadership of the Communist Party of Czechoslovakia. Of particular importance for the development of mining was a government decree on the nationalisation of mines and the key industries undersigned by Dr. Eduard Beneš on October 24, 1945. All plants and related properties passed into state property, which commissioned the newly established national management companies. In Slovakia, based on the reported deposits, the following companies incurred in 1946: Železorudné bane (Iron Works), national enterprise (n.p.) Spišská Nová Ves, Rudné bane (Ore Works), n.p., Banská Bystrica and Slovenské magnezitové závody (Slovak Magnesite Works), n.p., Bratislava, later Košice.

In the first years after the WWII there was still in force General Mining Act of 1854, building on the private business. In order to ensure intensive and economical use of mineral deposits the National Assembly of Czechoslovakia adopted on July 5, 1957, Act. 41/1957 Coll. on the exploitation of mineral wealth – the Mining Act. The law defined and introduced new concepts such as reserved and non-reserved minerals, exclusive deposit and mining area and it contained provisions ensuring planned and comprehensive prospecting and exploration. Stewardship over compliance with mining regulations was entrusted with State Mining Authority. The subjected district mining offices (OBÚ) were based in Banská Bystrica and Spišská Nová Ves, later amended on OBÚ in Košice (1945), Bratislava (1954) and Prievidza (1959). The OBÚ were directly subordinated to State Mining Office Inspection in Bratislava (till 1954) and later to Central Mining Office in Prague

Železorudné bane, (n.p.) Spišská Nová Ves comprised several factories. In *Rudňany* mining of siderite ore and mercury was carried out. The total quantity of mined siderite ore during the reported period that covers the years 1945-1990, was 30,615,000 t. Despite a rich tradition and extensive ore field, *Plant Dobšiná* had a problem to ensure more high-quality ores and after the 1958 the Plant was cancelled and production stopped in 1969. For the period 1,363,000 tonnes of iron ore were mined. *Plant Luciabaňa* as a standalone plant ended mining in 1962 and total mining was stopped in 1969. In the reporting period 1,964,000 tonnes of iron ore were extracted. Prior to nationalisation *Plant Železník* was formed by two or even four mining enterprises. The industry nationalisation joined together all of the deposits. In 1946, the plant Rákošská Baňa associated the Železník plant. In 1957, exploration work managed to clarify the geological structure of the hill Železník with deposits Železník in the north and Rákoš in the south. Extensive exploration work didn`t identify such reserves of metallic ores that would ensure the prosperity of the plant. This resulted in the completion of mining of iron ore in 1965. The deposit produced in the period reported 3,450,000 t of iron ore. In the period 1975-1987 there were mined at the deposit Rákoš mercury ores, but the operation was unprofitable. *Plant Rožňava* with the sections Drnava, Malý Vrch, Dolný and Horný Hrádok formed one of the largest iron ore plants in Slovakia. In all known deposits intense mineral exploration took place in post-war times, which ensured workable reserves of iron ores in the veins in Rožňavské Bystré, Rudník, in the central part of the ore field in the deposits Bernard, Sadlovský, Štefan and Mária baňa. In Mária baňa the vein Mária was reviewed and in 1981 vein structure of Strieborná was discovered, with high content of silver in tetrahedrite (150 to 400 g/t). The vein was investigated in detail in the years 1985-1991 and verified a great hopefulness of the mineralisation. The mining works on iron ores were completed in the entire mining district in 1993. In total, in the reported period the production in this mining district equalled to 9,988,340 t of siderite ores and 2,422,700 tonnes of siderite-tetrahedrite ores. *Plant in Nižná Slaná* thanks to intensive geological exploration at the deposit Manó, which resulted in the reserves calculation in the year 1966, ensured the annual extraction of 700,000 t. for 45-50 years. Another geological survey verified the depth continuation of the deposit as well as perspective eastern part Kobeliarovo. The positive results of the survey ranked the district Nižná Slaná as the biggest iron-ore region in Spiš-Gemer Ore Mountains. In the period reported there were mined in this ore district 16,471,800 tonnes of iron ores. The operation was stopped in 2008. *Plant Smolník* extracted pyrite copper ore, which were already the subject of mining in pre-war years. The pyrite ore was processed to a coarse concentrate that was suitable for burning in furnaces for the production of sulfuric acid in all Slovak pulp and paper mills. The granular pyrite rash, containing more than 50% Fe was sold to Vítkovice ironworks, which extracted the copper and silver from it. Mining of these ores ran until 1989. During the period the deposit produced 4,980,700 tonnes of copper pyrite ores. *Plant Slovinky* in the post-war period appeared to be a non-profitable and this plant didn't get any support. Only in 1948, a report evaluating the efficiency of the mining and metallurgical processing of metals (Cu, Au and Ag), was elaborated. This report launched a series of situations that led to the re-establishment of the plant and the start of extensive exploratory programme. From 1950 to 1990, there were extracted in this plant 8,437,000 tonnes of copper ores. *Plant Švábovce* comprised two deposits of manganese ores in Švábovce and Kišovce. The end of mining at these deposits was influenced mainly by cheap ore shipped by USSR – the world's largest producer of manganese ore. For the period reported there were extracted a total of 3,430,000 tonnes manganese ores (Zámora et al., 2004).

Rudné bane, n.p., Banská Bystrica comprised plants in *Banská Štiavnica*, which even in the post-war years exploited precious metal ores, particularly on the vein Grüner and base metal ores were mined on Špitaler vein. Exploration works till 1952 were not systematic, they just met momentary needs. Intensive geological survey started in

1952, but not to a sufficient scale even up to 1965, so irregular development long-term affected the economy of these deposits. After the construction of a Nová (New) shaft in 1973 new conceptual solution of the Štiavnica ore field was developed. It was decided to carry out extensive geological exploration in depth along the entire length of the ore field, including part Piarg in Štiavnické Bane and around the Hodruša ore field. Potential of the ore deposits was estimated to 5 million tonnes of geological reserves. The driving of shaft Roveň in the southern part of the deposit was launched, which should make accessible the ore complexes in the southern part of the ore field. Important event was the New Heritage Gallery excavation (NOS), which should help the Old Voznica Gallery that did not allow draining the entire ore district. Its development started in 1978 and was completed in the year 1989 in a circular profile of 3.4 m. The Plant Banská Štiavnica was the largest factory of Rudné bane, n.p. In the years 1946-1947 there were produced 17,500 tonnes of precious metal ores. After the transition to exploitation of polymetallic ores in the period 1946-1990, 4,078,400 tonnes of ores were exploited equalling to 44,736 t of lead, 5,064 t of copper, 787 kg of gold and 39,460 kg of silver. The zinc concentrate was treated separately from which it was produced 56,470 t of zinc, and 10,871 kg of silver (Zámora et al., 2004). At the high of the plant development 1,500-1,600 workers worked in mining enterprise. After 1989 dissenting voices intensified against the high cost of ore mining and based on the Government Resolution of 1991 on the Concept of exploitation of selected mineral resources in the Slovak Republic, by 1995 the mines in Banská Štiavnica should decrease the extraction and carry out liquidation of redundant mining areas and facilities. In 1992 the mine passed into private hands and Company Hell, s.r.o. continued the extraction till 1993. In 1994, without any detailed analysis the liquidation of the company started, and thus a promising programme for the mine and the town ended and terminated the industry that gave rise to the city and ensured its development (Lichner, 2002). *Plant Hodruša-Hámre* mined the precious metal ore till 1950. In the period 1946-1950 47,000 t of ore were mined. Then the plant switched to the extraction of copper ore at the mine Rozália (Fig. 1.18). For the period reported there were excavated in the plant 1,857,000 tonnes of copper ores. The copper concentrate was supplied to Krompachy metallurgic enterprise. At the beginning of 90s after the end of the exploitation of polymetallic ores there were discovered in the northern part of the deposit precious metals, which have been exploited since 1992. *Plant Kremnica* mined precious metal ores during this period on ore pillars of the Anna shaft. The mining ended here in 1959, in the shaft Ludovika in 1966. The richer veins of the shaft Ferdinand were mined till 1970, when the operation was suspended by the decision of the then Ministry of Mines. Between the years 1959-1965 the precious metal ore was excavated at the deposit Šturec. In early 80-ies the price of gold on the market increased rapidly. This has prompted the interest in exploration activity and the possible resumption of precious metal ores mining by superficial way in Šturec. In the period 1946-1970 there were mined at the deposit a total of 922.300 tonnes of precious metal ores. In the years 1983-1986 there was built a pilot plant line and machinery facility, treatment plant and leaching facility for cyanidation process were reconstructed. The plant developed the proposal to increase the capacity to extract 30,000 tonnes of ore per year, but the implementation didn't occur. On a pilot line in the years 1987-1990 the total of 34,710 tonnes of ore were processed equalled to 46.5 kg of gold and 328 kg of silver. At starting of its operation in 1946 *Plant Poproč* with antimony ores had very little reserves and its closure was proposed in 1948. During the revision of abandoned upper horizons there were found relatively large amounts of ores suitable for flotation treatment. These were mined until 1964, when it was decided to stop mining at the factory and in 1965 the plant was closed. At the closure of the plant residual reserves of 5,200 tonnes of antimony ores were written off. For the period 1946-1958 the plant along with Helcmanovce section mined out about 211,000 t of antimony ores with low Au and Ag components content. *Plant Dúbrava* was almost destroyed after the War and resume operation required the construction of a flotation treatment plant (1946-1948). Exploratory work was carried out intensively in all sections of the known ore district. The survey was able to clarify a complicated system of vein mineralisation impaired by tectonics and the actual status of the ores reserves under steadily increasing mining at the deposit. During the reporting period, the deposit mined a total of 1,268,400 tonnes of antimony ores equalling to 27,869 tonnes of antimony. After 1946 the *Plant Pezinok* was closed due to low reserves and it concentrated solely on geological survey to verify the concentrations of interesting antimony ores. In 1951 ore mining started, which ran until the 90s. In the reported period at the deposit a total of 1,080,000 tonnes of antimony ores was mined out and the amount of antimony in the concentrate was 43,029 tonnes. Since 1946 the *Plant Špania Dolina* developed substantial exploration work and activities. The hereditary adit on Polkanová was developed and it opened up horizons of the blind shaft Ludvika and the Fer-

Fig. 1.18 Portal of the Rozália mine around 2000 operated in 1950-1990 for the extraction of copper ores and since 1992 – to present for the extraction of precious metal ores.

dinand shaft in Špania Dolina. At the same time a survey of old dumps and their metal content in Piesky, Richtárová and Špania Dolina started. Economic reserves of copper – silver ore were detected only in the Piesky deposit. Because of these reserves there was developed a gallery with a length of 1,600 m in order to secure an access to ore complexes in the Piesky deposit. In Špania Dolina a treatment plant was built, which in addition to the ore obtained on plant processed in a certain period ore from slag heaps from Banská Štiavnica, ores from Dúbrava, and particularly 252,000 tonnes of mercury ores from the deposit Malachov in the years 1982-1990 equalling to 293 t of mercury. In total, for the period 730,000 t of copper ores were extracted equalling to 1,844 t of copper production. The last plant was a *Plant Prešov*, which extracted the brine. During the reporting period, the salt of the brine was extracted in two ways. The first was a classic old way of the brines withdrawn in Leopold shaft and evaporated in cookers. This method was functional until 1970, when the building of the shaft and cooking facilities were handed over to the Technical Museum. The second method was the use of leaching from the surface wells that were drilled in the scope of extensive exploration activities since the survey in 1939. Of a total of 15 wells drilled, 11 wells were used for the leaching method. From 1947 to 1990 1,870,000 tonnes of salt were extracted. In 2009, the company Solivary Prešov terminated the brine mining after the centuries long tradition of salt mining in the region. The next deposit, which was discovered in the scope of the oil exploration in 1959, was Zbudza with reserves of 1.5 billion tonnes of salt. At the deposit a 192.6 m deep shaft was excavated along with over 2 km of mining tunnels. The implementation of production by the enterprise Chemko Strážske did not happen, so in 1970 the Zbudza mine objects started to be liquidated (Zámora et al., 2004)..

After the WWII Slovenské magnezitové závody, n.p., Košice (Slovak Magnesite Works, n.e., Košice) started to resume mining in the plant destructed by retreating German troops, mainly the surface objects (generator, furnaces for magnesite burning, electricity sources and others. In previous years geological survey was neglected, the data on possible reserves of magnesite were missing, while magnesite was not among the reserved minerals. SNR Regulation No. 46/1947 of the Slovak Parliament declared magnesite a reserved mineral. In the years 1953-1965 geological exploration was carried out on all deposits of magnesite. Most reserves were confirmed at the deposits Jelšava – Dúbrava, Burda – Poproč, Košice – Bankov, Podrečany and Lubeník – Studená. The magnesite international cartel ceased to function during the war and after the war, in 1947, it was legally dissolved. The new situation enabled the development of the magnesite industry in Slovakia. In 1963, the Government of Czechoslovakia decided on the development of magnesite industry in Slovakia. The plant Jelšava should produce sinters and Lubeník plant should produce bricks. Unfortunately the trends that have been taken to improve the quality and efficiency of the extraction and production, were not maintained, which had a negative impact on the development of the magnesite industry after 1990. In the reporting period, since 1959, the surface mining has been replaced by underground mining of magnesite. The Slovak magnesites are of inferior quality, their processing and post-processing after firing is not easy and the Slovak magnesite industry could hardly withstand the concurrence of natural quality Chinese and North Korean magnesite. Overall, during the period reported, 86.6 million t of raw magnesite were extracted at factories in Hačava, Jelšava, Košice, Lovinobaňa and Lubeník (Zámora et al., 2004).

The function of the geological survey was provided by the State Geological Institute of D. Štúr. The Institute was subordinated to the Chairman of the Central Geological Institute in Prague, but under federal arrangement of Czechoslovakia from 1969 it was subjected to the Slovak Geological Office. The exploration sector of the state geological service component was delegated to Geological Survey, n.p. which was created by merging of several organizations in 1958 with the seat in Turčianske Teplice, later in Žilina, and since 1965 in Spišská Nová Ves.

1.5. Conclusions

As mentioned at the outset, Slovakia has a rich history of mining and quarrying. In prehistoric times human ancestors used different types of suitable raw materials for primitive tools that were improved over time. A major technological breakthrough was the discovery of metals. The large number of stone threshers at the site Piesky evidences prehistoric copper mining on this site. Tacitus documents the mining of iron ore by Cotini tribe who lived in our area. It is very likely that they mined precious metal ore as a commodity for coin production. It is possible that the Slavs were the first miners of precious metal ores in Šturec in Kremnica; this idea is supported by the finding of a wooden pillar in old mine. During the reign of the Árpád dynasty Banská Štiavnica was the source of silver for the coinage of silver coins in Hungarian Kingdom. Several centuries later, under the reign of Anjou dynasty, Kremnica was of the same importance, and thanks to gold mining the city was granted mining rights. In troubled times that followed after the Mohács defeat, Thurzo-Fugger Company, as the largest producer of copper ore deposits extracted near Banská Bystrica, was prosperous. Large mining development and technological advances in mining of metal ores documents the first use in the world of gunpowder for rock disintegration in Banská Štiavnica, but also the use of water from reservoirs and constructing of ingenious machines for pumping water from mines, driving the mining machinery and stamp mills. In the nearby Nová Baňa it was atmospheric fire-engine, which was the first steam engine on the European continent. Based on these important pre-eminences, it is not surprising that the first Mining Academy was established in Banská Štiavnica. Equally important demonstration of technical prowess of mining in our territory was the development of the 16 km long drainage gallery of Joseph II (Voznica Old Heritage Gallery). After the First World War and the establishment of Czechoslovakia, Mining Academy moved to Hungarian territory, and this time the glorious phase of our mining was interrupted. In terms of the common state with Czechs a new generation of mining professionals had to be raised in order to restore the former glory. After World War II unprecedented development of mining occurred due to political changes in Czechoslovakia Totalitarian systems called for increasing mining production and so the government provided for the exploration and mining operations large subsidies. A change occurred with the fall of the totalitarian system and the onset of the democratization period, when most mining operations were halted and the work in them gradually attenuated.

Currently, the only underground mine on precious metal ore in Banská Hodruša is operated reminding the faded glory of the mining region. To conclude we just say goodbye using typical mining greeting "Zdar Boh" "May God give you success!".

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References:

Beránek M., 1977: Rudné bane, národný podnik Banská Bystrica – 30 rokov. (Ore Mines Banská Bystrica, national enterprise – 30 years). Vyd. Osveta, Martin, 235 p. (In Slovak).

Grecula P., Bartalský J., Cambel B., Herčko I., Kaličiak M., Matula M., Melioris L., Polakovič D., Slavkay M., Sombathy L., & Šefara J., 2002: História geológie na Slovensku, zv. 1., vyd. (History of Geology in Slovakia, Volume I). State Geological Institute of Dionýz Štúr, Bratislava, 2002, ISBN 80-967018-8-6, 741 p. (In Slovak).

Kolníková E., 2012: Keltská razba mincí na Slovensku a jej surovinové zdroje. (Celtic Coinage in Slovakia and its Mineral Resources). In. Zborník príspevkov z konferencie Baníctvo a mincovníctvo v dejinách Slovenska, ISBN 978–80–8043–193–8, 154 p. (In Slovak).

Kvietok M., Jeleň S., Šmejkal V., & Sitár A., 2015: Vytĺkaná meď v slovenskom praveku, (Cold Hammered Copper in the Slovak Prehistory). In. Labuda J. (ed.), Argenti Fodina 2014, Zborník prednášok, Banská Štiavnica, 2015, p. 37-42. (In Slovak).

Lichner M., 2002: Banská Štiavnica – svedectvo času. (Banská Štiavnica - Time Testimony). Vyd. Štúdio Harmony, EAN 9788096854783, 256 p. (In Slovak).

Pieta K., 2008: Keltské osídlenie Slovenska, ISBN: 987-80-89315-05-5, 385 p. (In Slovak).

Semrád P., & Kováč J., 2003: Dubnícke opálové bane (Dubník Precious Opal Mines). Vyd. Michal Vaška, Prešov, 151 p., ISBN 80-7165-256-3. (In Slovak).

Struhár V., 2015: Eneolit – doba medená. (Eneolith – Copper Period). http://archeologiask.sk/slovenska-archeologia/chronologia-a-kultury/eneolit.html

Varsík V., 2011: Slovensko na hraniciach Rímskej ríše. (Slovakia at the Borders of the Roman Empire). ISBN 978-80-8082-469-3, 54 p.

Zámora P., Vozár J., Baláž J., Čech F., Ilavský J., Herčko I., & Sombathy L., 2003: Dejiny baníctva na Slovensku, I. diel. (History of Mining in Slovakia, Volume I). Vyd. Ing. Tibor Turčan – Banská agentúra, Košice, ISBN 80-968621-4-6, 327 p. (In Slovak).

Zámora P., Vozár J., Baláž J., Čech F., Kladivík E., Lužina Ľ., Sombathy L., & Širila J., 2004: Dejiny baníctva na Slovensku, II. diel. (History of Mining in Slovakia, Volume II). Vyd vyd. Ing. Tibor Turčan – Banská agentúra, Košice, ISBN 80-968621-5-4, 304 p. (In Slovak).

2. Legislative Conditions for Geological Deposit Exploration in Slovakia

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Abstract: The article deals with legislative conditions of the deposit geological exploration in Slovakia. It provides classi-fication of minerals and their division into reserved (natural wealth of SR) and non-reserved (part of the land). It gives description of the stages of the exclusive deposits exploration as well as deposits of the non-reserved ones and of the procedure at acquiring professional competence in carrying out the geological works and geological authorisation. A process for determining the exploration area for reserved minerals is analysed, along with duties and rights of the holder of the exploration area and the whole process from developing the project of geological works through the solution of conflicts of interests and access to the third party property to permit mining activity, which mainly concerns the special prospecting mining works. The final part of the paper is devoted to the issue of the final report with the estimation of reserves and the conditions for assessing and approving such reports by the competent authorities of the state administration and the entire process is completed by issuance of the certification of the exclusive deposit.

Key words: Deposit geological survey, exclusive deposits, deposits of non-reserved minerals, project of geological works, calculation of mineral reserves, certificate of exclusive deposit

2.1. Introduction

The basic legislation governing the conditions of design, implementation and evaluation of geological works in the Slovak Republic, is the Law no. 569/2007 Coll. on Geological Works (Geological Act), as amended by further legislation. The deposit geological survey is under this regulation a survey, which mainly explores mineral deposits, verifies their reserves and processes geological documents for their exploitation and protection. In addition, under this kind of geological works geological conditions are verified for the establishment and operation of underground gas and liquids reservoirs in natural rock structures and access to the caves, stability of underground spaces is ensured. Security and liquidation of old mine works and the establishment and operation of natural rock structures and underground spaces for the purposes of permanent storage of carbon dioxide in the geological environment are also solved under Geological Act.

The Law no. 44/1988 Coll. on the Protection and Utilisation of Mineral Resources (Mining Act), as amended, outlines the obligations of the organization in the geological exploration of exclusive deposits. It defines the conditions of utilization of the exclusive deposit reserves as a basis for the calculation of reserves and classifies reserves of the exclusive deposit.

The details on both legislations related to the deposit geological survey are laid down by the Regulation of the Ministry of Environment of the Slovak Republic no. 51/2008 Coll., Implementing the Geological Act, as amended, and the Ministry of Environment of the Slovak Republic no. 33/2015 Coll., Implementing certain provisions of Law no. 44/1988 Coll. on the Protection and Use of Mineral Resources (Mining Act), as amended.

2.2. Definition of basic terms in deposit geological exploration

2.2.1. Exclusive deposits and deposits of non-reserved minerals

Exclusive deposits are deposits of reserved minerals, which are radioactive minerals, coal, oil, combus-tible natural gas, bituminous rocks suitable for energy use, minerals, from which there can be industrially produced metals or phosphorus, sulphur, fluorine and its compounds, rare earth elements and elements with the semiconductors properties, further magnesite, rock salt, potassium, boron, bromine and iodine salt, graphite, barite, asbestos, mica, talc, diatomaceous earth, glass and foundry sand, mineral dyes, bentonite, technically useful crystals of minerals, precious stones, halloysite, clay, ceramic and fire-proof clays and claystones, gypsum, anhydrite, feldspar, perlite, zeolite, travertine, also granite, granodiorite, diorite, gabbro, diabase, serpentine, dolomite and calcite (if they are mined in blocks and they are polishable), and the silica, quartzite, limestone, dolomite, marl, basalt, trachyte and phonolite (provided they are appropriate for chemical or melting processing), mineralized water, of which reserved minerals and technically useful natural gases may be obtained industrially. The exclusive deposits represent the mineral wealth of the Slovak Republic.

A natural wealth comprises rock structures and underground spaces, incurred as a result of extraction of oil and flammable natural gas or salt if they are suitable for storage of gases or liquids, and natural rock structures suitable for utilization of geothermal energy.

Non-reserved minerals are minerals and other natural accumulations and backfill in underground mines, dumps, or tailings ponds containing them. These are in particular the deposits of building stone, gravel and sand and brick materials. Since 2002 the non-reserved mineral deposits, of which in 1991 decided the relevant central government authorities that they are suitable for the needs and development of the national economy, or their mining areas were not determined until 2001, have been considered as the exclusive deposits, but only within the determined limits of the mining area. Non-reserved minerals are part of the land.

2.2.2. Stages of the deposit geological exploration of exclusive deposits

In the scope of the deposit geological exploration of exclusive deposits geological conditions and tectonic structure are explored, along with distribution of various minerals by quality, mining-technical conditions that may affect the mining of detected and proven reserves of minerals forming deposits. The issues of possibility of disposal of dumps, heaps and tailing ponds are studied along with expected impact on the environment, the hydrogeological conditions and occurrence and accumulation of groundwater that can affect the deposits mining.

The deposit geological exploration of exclusive deposits is divided into search, detailed and extractive deposit geological survey.

In the scope of the search deposit geological survey an exclusive deposit is verified, its approximate extent is determined, within its parts reserves of category Z-2 are calculated and verified, in the rest parts the reserves of the category Z-3 are verified and calculated or estimates of resource prognosis. The rock structures or underground spaces are identified and verified, their sealing potential and their suitability for storage of gases and liquids.

In the scope of the detailed deposit geological survey reserves of the deposit are verified in the amount and quality of their designed use; they are calculated as reserves of the category Z-1, other reserves of the deposit are calculated as the category Z-2. The range of rock structures or underground space is verified along with the calculation of the volume and the tightness of surroundings, the hydrogeological conditions are determined and the conditions for the establishment and operation of underground reservoirs of gas and liquids.

In the scope of the extractive deposit geological exploration of the exclusive deposit the knowledge on the position of the reserves is specified and their quality and types of pollutants in the raw materials that are needed to regulate the mining of the deposit and Z-1 category reserves are calculated.

The knowledge about geological and mining-technical conditions for the conversion of oil, combustible gas, exploitable gas and salt for the underground storage of gases or liquids, are specified.

2.2.3. Deposit geological exploration of non-reserved minerals

The deposit geological exploration of the deposits of non-reserved minerals has the similar legislative frame as it is in the case of the exclusive deposits. However, only the stage of search exploration is carried out and at a deposit the reserves are verified and calculated, their approximate range, quality and types of resources.

2.3. Chronology of the deposit geological exploration

2.3.1. Award of professional competence for execution of geological works

Professional competence is an essential condition for the implementation of geological works, which in the case of geological exploration must possess a natural person who is an entrepreneur, agent or representative of a legal entity as a contractor of geological works. The professional competence must posses also the principal investigator of the geological task, which manages, coordinates and resolves a geological project.

The professional competence is verified by the Ministry of Environment of the Slovak Republic by an exam upon written request by the applicant or his employer; the request shall contain name, title, date and place of birth, permanent address of the applicant and the definition of geological works, subject to an award of professional qualifications.

The application shall include copies of university education of second or third degree in geology and a copy of the certificate on state, doctoral or PhD examination in the subject, which is identical to deposit geological survey.

The application shall be accompanied by a reference of geological tasks which were addressed by the applicant, including the list of the final reports and other written materials from the archives of the State Geological Institute of Dionýz Štúr, which should document at least five years‘ experience in the deposit geological survey.

A foreign natural person or a representative of a foreign legal entity shall attach to a written request for verification of professional competence a copy of the foreign geological authorisation issued in another state or non-certified or certified translation of such authorisation.

A Certificate of professional competence is not required from the natural person who is resident in a Member State of the European Union and who in Slovakia will temporarily or occasionally carry out geological work of up to six months a year, and will address a maximum of three geological projects, if he proves that he is authorized to carry out geological work under the legislation of a Member State of the European Union.

The application for verification of professional competence shall be accompanied by an electronic stamp with a face value of 33 Euros.

Professional competence is proved by issuing the Certificate of professional competence and is verified every five years.

2.3.2. Award of geological authorisation

The deposit geological survey may carry out an individual who is an entrepreneur and a legal person authorized to carry out geological works. The geological authorisation is issued by the Ministry of Environment of the Slovak Republic on the request for geological authorisation issuance.

The request of the natural person or his representative (if any) for geological authorisation shall contain personal information (name, date of birth and residence), proof of integrity, business name, geological work, to which he has applied geological authorisation, identification number (if it is assigned) and number of the professional competences licences (including principal investigator of the geological task). The integrity means that the individual or his representative should not be condemned for a threat to or damage the environment, which is unjustified waste management, unauthorized discharges of polluting substances, violation of water and air protection, unauthorized manufacture and disposal of ozone depleting substances, violation of plant protection and animals, trees and shrubs, spread of contagious diseases of animals and plants, organisms escape and poaching. The application shall be accompanied by a statement of convictions of a natural person or a representative not older than six months, the original contract between the agent and the applicant for geological authorisation (in case the representative is also a natural person) a certified copy of identification number, provided it has been allocated.

Request of the legal person for geological authorisation contains similar data; change compared with the application of a natural person is in a trade name and registered office, personal data of the member of the statutory body or its representative and the original certificate of Companies Register (or certified copy) not older than three months or contract of company establishment or a certified copy. The application must also be accompanied by the original contract between the agent and the applicant (if a representative is not also a statutory body) and officially verified copy of the identification number of the organization.

In the case of foreign natural or legal person analogous requirements and conditions for issuing geological authorisation are applied. A foreign natural person indicates in the application of geological authorisation also address of the site and the foreign legal person shall sign an undertaking or branch, address, place of business or branch personal data and the head of the company or its branch. A request for issuance geological authorisation shall be submitted in the state language and the application shall be accompanied by non-certified translations of documents into the state language.

The request for issuance geological authorisation shall be accompanied by an electronic stamp with a face value of 50 Euros.

Geological authorisation is issued for an indefinite period.

Without authorisation, the deposit geological survey can be carried out by the contractor of geological works in the mining of exclusive deposits.

2.3.3. Preparation of preliminary documentation and geological intention

The geological task in the scope of the deposit geological survey shall be elaborated by the contractor of the project of geological task that may be preceded by development of preparatory documentation as a general solution or as a preliminary study.

In the general solution geological plan is defined in a wider context, demonstrating the practicality, feasibility and rationality of the geological plan, it provides an overview of the work and an estimate of costs and presents information on the conception and design of long-term forecasts and plans for geological works.

The preparatory study assesses or specifies prognostic resources of minerals and considers the expected economic benefits, claims and justifies the optimum location, analyses the different methodological and technical procedures to address the geological task and evaluates the economic benefits of envisaged solutions including documents for their economic justification.

Geological intention of a geological task includes the name, date of issue, type of geological works, geological exploration stage, the name of the client and the contractor of geological works, signature of the statutory body of the customer and contractor of geological works, the contractor‘s representative of geological works (if appointed) and principal investigator of the geological task. Way of a geological task solving in geological intention includes limits of investigated territory, the name and code number of regions, districts, municipalities and cadastral territories, objective of a geological task, procedure of a solution and its justification and specification, the number and range of the projected works.

Preparatory documentation and geological intention is approved by the customer of geological works.

2.3.4. Determining the exploration area

The deposit geological survey of reserved minerals and natural rock structures and underground spaces on the establishment and operation of underground reservoirs of gas and liquid is among the selected geological works that can be performed only in the exploratory area, which determines the Ministry of Environment of the Slovak Republic on the ordering of geological works.

A proposal to determine the exploration area contains the name or business name and address of the customer of geological works and original extract from the Companies Register, or an officially certified copy. The proposal also includes the name of the exploration area, the name and code of the cadastral territories, municipalities, districts and regions in which the exploration area is located, as well as the relative proportions of municipalities according to the size of the exploration area in the individual cadastral areas. The proposal briefly states the purpose of geological task, designation of the geological works, geological exploration stage and the expected use of the different types of geological works, geological project budget and the date of the geological task completion.

The proposal shall contain definition of exploration area in the exploration area map, coordinates of apex points on the surface of the Uniform trigonometric cadastral network area and exploration area in km^2 rounded to two decimal places, attested by the chief mining meter or authorized surveyor and cartographer.

The extent of the exploration area can be up to 250 km^2. The exploration area proposed for the deposit geological prospecting of reserved minerals may involve only one exclusive deposit with a designated protected deposit area for the same types of minerals and cannot include exclusive deposit with a designated mining area.

The exploration area proposed for deposit geological exploration of natural rock structures and underground spaces for the purposes of the establishment and operation of underground reservoirs of gas and liquid cannot include a protected area for the same purpose.

The exploration areas for the same purpose cannot overlap even partially and for different purposes cannot be fully or partially overlapping provided, this would essentially make it difficult or impossible to carry out geological works or use their results in the case of the survey of developmentally and spatially related deposits of reserved minerals or natural rock structures and underground spaces.

To the application for the determination of exploration area a customer of geological works shall attach geological intention, details of the contractor of geological works (name, location, number and date of issue of the geological authorisation), information on other exploration areas, protected areas, protected deposit areas and mining areas, which cut exploration area or border with it immediately. The application shall also contain a statement of the Department of environmental protection of district office and the opinion of the State Geological Institute of Dionýz Štúr not older than three months.

The application for the determination of exploration area of radioactive minerals shall contain opinions of municipalities falling within the exploration area, and of a self-governing region. They give their statements to the geological intention in terms of objectives and priorities of the programmes of economic and social development of municipalities and counties or binding part of spatial planning documentation.

The deposit geological exploration of oil and combustible gas can be carried out only in areas designated by the Ministry of Environment of the Slovak Republic and which are posted on its website. Upon receipt of the proposal to determine the exploration area to carry out the deposit geological exploration for oil and flammable natural gas the Ministry of Environment of the Slovak Republic shall issue a notice in the Official Journal of the European Union, indicating the time limit within which competing proposal may be submitted, the territory which is the subject of a the proposed duration of determination of exploration area. The proposal must include documents proving financial capacity and technical competence of a customer of geological works. In the case of several proposals for the determination of exploration area for the implementation of deposit geological exploration for oil and flammable natural gas the Ministry of Environment of the Slovak Republic shall make a decision with regard to the technical and financial capacity of the customer, the proposed method of implementation of geological work and the way to obtain the most complete information and better protection of the interests protected by special regulations. The exploration area can be determined also to a group of customers, which jointly fund geological works in a determined area.

The request for a decision on determination of exploration area shall contain electronic stamp with a face value of 35 Euros and on the issue of the decision to change the exploration area requires an electronic stamp with a face value of 30 Euros..

Exploration area is not determined for the deposit geological prospecting of reserved minerals or non-reserved minerals in the mining area and the deposit geological exploration of non-reserved minerals.

2.3.5. Rights of the holder of exploration area

The holder of the exploration area for deposit geological prospecting of reserved minerals is entitled to get determination on the mining area within one year after the review and approval of the final report. In his exploration area the holder has the right to perform selected geological works as stated in the decision on determination on the exploration area alone, if he has a geological authorisation, or he may order them from another person with geological authorisation. In the determined exploration area, the holder may carry out other than selected geological works as stated in geological authorisation. Another person may carry out geological works only with the consent of the holder of the exploration area while respecting conditions and obligations, if it is in accordance with his geological authorisation.

The holder of the exploration area may make a proposal to extend the period of validity of exploration area, but he must allocate at least 70% of the budget of the geological task to carry out selected geological works.

The holder of the exploration area is authorised, upon the approval of the Ministry of Environment of the Slovak Republic to conclude an agreement to transfer exploration area to another person with the condition of allocation at least 10% of the budget of the geological task, in the case of deposit geological exploration for oil and flammable natural gas after spending at least 5% of the budget of the geological task.

The application for approval of legal transfer of exploration area and undertake the necessary changes in the records of exploration areas shall be accompanied by an electronic stamp with a face value of 20 Euros.

2.3.6. Obligations of the holder of the exploration area

The holder of the exploration area shall submit to the Ministry of Environment of the Slovak Republic approved project of geological task with the resolved conflicts of interests protected by special regulations drawn up in accordance with the present geological intention within three months from the entry into force of the law-decision on determining the exploration area. Each change to the project of geological works shall be submitted within 30 days of its approval.

The holder of the exploration area submits to the Ministry of Environment of the Slovak Republic annual report on exploration activities with the results, and evidence of funds allocated for geological exploration within six weeks after the end of the calendar year.

By the end of the second year after the entry into force of the decision extending validity period of the exploration area the holder of the exploration area is obliged to spend on geological works additional 30% of the budget of the geological task.

Payment for exploratory area is, for every year and every km^2 during the first four years, 100 Euros, over the next four years, 200 Euros, over the next two years, 350 Euros and over the next years, 700 Euros. The holder of the exploration area is required to remit the payment to the Ministry of Environment of the Slovak Republic within three months after the start of each calendar year.

2.3.7. Elaboration of the project of geological works

The project of geological works reflects the objective of the geological task, proposes and justifies the selected types of geological works and specifies the logical methodological and technical approach of their professional and safe implementation. It shall be approved by the customer after the prior written consent of contractor of geological works or his representative, if any.

The title page contains the project name of the geological task, date of issue, type of geological works, geological exploration stage and the name of the customer and contractor of geological works. The project shall be signed by the statutory body of the customer and contractor of geological works, the contractor‘s representative (if appointed) and principal investigator. Approval of the project is characterized by the name and surname, signature of the statutory body of the customer, the approval date and stamp of the customer.

The geological part of the project shall contain topographical definition of the investigated territory or object in the appropriate scale, the name and code number of region, district, municipality and cadastral zone. The objective of the geological task should indicate range of issues that need to be addressed with regard to the future, especially economic exploitation of the results of the deposit geological exploration, indicating the expected quantity and quality of entries into deposit reserves divided into the categories (for reserved minerals). When defining the basic facts there must be mentioned geological factors conditioning the solution of geological task, present geological and deposit exploration degree, including data on prognostic resources of minerals and reserves levels by categories, including conditions for reserves utilization. The project set out the relationship of geological works to the creation and protection of the environment.

The main part of the project of geological works is a solution procedure and its justification, specifications, number and extent of the projected kinds of works with their time continuity and qualitative conditions for carrying out geological works. Geological part of the project shall contain graphical attachments that show way of the solution of geological task, documents on dealing with conflicts of interest and a list of references and other sources.

The technical part of the project provides the information how the geological task will be ensured and identifies technological procedures of designed works, conditions for their implementation, technical means, it justifies the place and method of storage of the mineral resource, determines the storage location of the samples, drilling fluid used, the method of handling waste produced in carrying out geological works. The disposal and remediation works are addressed, along with the admissions to the property, measures to safeguard the interests protected by special regulations for preventing damage in carrying out geological works and to ensure the safety of occupational health and safety in operation. Fire prevention measures and social and hygienic facilities shall be documented, too.

The project shall indicate the budget of geological task, which shall include a quantification of the projected costs of geological works by each type of work. The types of works comprise the geological activities (archive excerption, monitoring, control and coordination of work, geological documentation, evaluation of geological data and final processing), technical work, geophysical, geochemical, technological, laboratory, field surveying, special sampling and surveying work and activities. Geological project budget includes the costs of project development, safe-guarding, maintenance and disposal of geological works and geological objects or budgetary provision for costs not possible to predict in the project.

The geological task shall start only after approval of the project of geological works by the customer of geological task. If during the geological project solution a circumstance occurs, asking for a necessity to choose a different methodological or technical approach for the solution, or to perform a greater range of geological works beyond the approved project, the contractor of geological works is obliged to propose an amendment of the project of geological task. Contractor shall also propose amendments to the project in the case, when in the course of the solution it is shown that the objectives of the geological project cannot be achieved for reasons differing from the assumptions set out in the approved project of geological task.

The contractor shall submit an amendment to the geological works if it is possible to carry out geological works without changing the project, but on a different scale of each kind of work without changing the budget of geological works.

The amendment to the project of geological task and amendment to the geological works shall be approved the customer of geological works.

2.3.8. Addressing conflicts of interest

In the project documentation of geological task, it is necessary to define measures to ensure the interests protected by specific regulations. For this purpose it is necessary to seek the statements of interested bodies and organizations, and the project of the geological task should take into account potential conflicts of interest.

The nature protection authority, which is the department of environmental protection in district office at the county, shall give a statement to the project of geological task, to its amendments and to the geological intention from the perspective of ensuring the protection of flora, wildlife and their communities, natural habitats and ecosystems and geological and geomorphological formations.

In the sector of protection of agricultural land and forestry expresses its statement land and forest department of district office at the county.

The competent road authority shall determine the conditions for conducting geological works in protection zones of highways and roads of higher classes (50 to 100 meters from the axis of the adjacent driving belt) as well as lower-class roads and local roads (15 to 25 meters from the axis of the road).

The Railways of the Slovak Republic, state enterprise, Bratislava and railway company Cargo, a.s., Bratislava express their opinions to the project, when the geological works will interfere with the railroad protective zone (60 m from the track) and the prior approval of railway facilities keeper, the relevant regional directorate, is required.

Respective branch of the Slovak Water Management Enterprise, Banská Štiavnica makes its statement to the project of geological works from the viewpoint of the development of water management, technical and operational concerns of the administrator of watercourses and in terms of the requirements of protection against pollution.

The expression of the relevant distribution company is required when the technical works will be implemented in the protected zone of external overhead electrical power of very high, high and low voltage lines and below these lines.

Relevant water supply company shall provide its statements on the existence of utilities networks under the management and operation maintenance of these facilities.

The existence of underground telecommunications facilities shall be formulated by the individual operators of these facilities and the statements to the existence of telecommunication lines and radio equipment as well as general conditions for the protection of networks shall provide telecom operators.

The existence of gas facilities and conditions for carrying out activities within their safety and security zones is expressed by the relevant distribution company Slovak Gas Industry, a.s., Bratislava.

The Memorials Office expresses its statements to the geological work in the field of protection of monuments, archaeological finds and archaeological sites.

If the geological works are performed in a military district, the Ministry of Defence of the Slovak Republic gives conditions of their realization and an opinion for their implementation.

2.3.9. Admission to the foreign property

Geological legislation does not define admission to foreign property as a conflict of interest, and this fact is crucial not only for geological survey, but especially during the subsequent use of research results and permitting mining activities.

According to the Geological Act for the purpose of carrying out geological works in the public interest, the contractor is entitled to execute geological and related works entering on foreign property, in the necessary time and for appropriate compensation with minimum interference with the rights of the owner of the property, including the minimization of potential damages.

However, the question is what is the public interest in carrying out geological works, as clear and unam-biguous definition of public interest is not included in any piece of legislation, including the Geological and Mining Laws. This fact is crucial already at the stage of deposit prospecting, as it blocks the very implementation of opening, preparation and extraction of exclusive deposits.

The contractor shall notify in writing the owner of the property about the method of implementation and duration of geological works at least 15 days in advance. If a property owner disagrees with the scope, method and duration of geological works, based on a proposal from the contractor of geological works the Ministry of Environment of the Slovak Republic shall decide within six months. If this deadline is insufficient for objective reasons, it may be extended for a further six months.

For use of the land belongs to the owner adequate compensation from the contractor of geological works. If the amount thereof is not agreed by the parties, the court shall decide about it.

The rights and obligations of the property owner have also agricultural cooperatives, trustees of state or municipality property, tenant, Slovak Land Fund, land cooperatives with legal personality, legal or natural person who manages forest land and trustee of higher territorial unit property.

2.3.10. Reporting of geological works

The contractor of geological works declares an implementation of the deposit geological exploration to the State Geological Institute of Dionýz Štúr not later than by the date of commencement of geological task (except survey carried out within the designated mining area). The notification shall state the name and address of the contractor and the customer of geological works, the name and number of the geological task, type of geological works and exploration stage, the name and code of the cadastral area and a district, objectives of the geological task, definition, specification and scope of geological works, definition of the territory on the map document on an appropriate scale and the expected date of commencement and completion of geological works. There shall be also declared a change in the extent of area in which geological works are carried out, change in the objective of geological task or range of geological works, or that the announced geological work will not be carried out at all. The electronic announcement shall be done on the website of the State Geological Institute of Dionýz Štúr.

2.3.11. Mining works permission

The deposit geological exploration of the exclusive deposit belongs to mining operations. Authorisation by the competent District Mining Office is required if the survey will be carried by vertical mining works deeper than 40 m, horizontal or inclined mining works longer than 100 m, or even shorter workings when additional workings with a total length of more than 100 m are to be driven.

In this case, the application for authorisation of mining activity shall contain the name and address of the organization, type of mining activity, name and identification number of cadastral area, the name and code of the district, scheduled beginning and completion or interruption of mining activities, the names and addresses of the parties for the authorisation of mining activities (physical and legal persons whose rights and interests protected by law can be influenced, the public concerned and the community, within the territorial jurisdiction of which mining activities shall be carried out). The application shall include documentation of search and exploration of the exclusive deposit by mining works.

2.3.12. Reporting mining activities and activities conducted by mining methods

An organization is obliged to report to the competent District Mining Office about the deposit geological exploration of the exclusive deposit and exploration for non-reserved minerals (which are activities performed by mining method). The reporting obligation shall apply to the realization of wells in the workings and underground wells, laboratory work, monitoring, control and coordination of geological works, geological mapping, compilation of geological maps, conducting geological documentation and special geological works, elaboration of projects of geological works, studies, final reports, calculations of reserves, opinions and research.

The announcement shall contain the name and address of the organization, type, purpose and intended scope of activity, the name of the district, municipality and cadastre, the date of planned start and completion, the nature and type of technical equipment, measures to ensure the safety and health protection, method of remediation of effects of activities and map showing the location and type of activity.

The establishment of boreholes from the surface with a designed depth of more than 500 m, digging pits and shafts and galleries development shall be announced separately.

Commencement, interruption for more than 30 days and discontinued operations are reported eight days in advance.

2.3.13. Procedure in geological exploration of exclusive deposits

In identifying and comprehensive evaluation of all useful minerals of the exclusive deposit and their commercial components, in order to evaluate the possibility of the deployment of individual minerals, the contractor shall provide a sampling work followed by samples testing and provision of special analyzes and tests, including laboratory and modelling research of treatability. It should be reviewed also the possibility of using the examined mineral/s by economic efficiency, which is usually expressed by a factor of economic efficiency and which expresses the ratio of the value of raw materials and production (direct, indirect, capital, investment, reclamation and other) costs recalculated to 1 t/1,000 m^3 of extracted material.

The contractor shall verify the facies and lithological conditions of the exclusive deposit in order to create the conditions for the design of construction of mines and quarries, of opening, preparation and mining of the exclusive deposit according to the principles of mining technology and to ensure the efficient utilization of reserves of the exclusive deposit. The projected geological works by the degree of exploration of the exclusive deposit should check its size, shape, storage and tectonic conditions, physical and mechanical, engineering geological, hydrogeological and other characteristics of the deposit and its surroundings and should solve issue of water-logging of exclusive deposit and disposal of mining water. Last but not least the geological survey should design the optimal method of preparation, development and extraction of exclusive deposits, although this proposal incorporates a plan of opening, preparation and extraction by an organization which possesses a designated mining area.

Geological survey should be carried out so as to avoid impossibility or prevent any use of the exclusive deposit or its part and unjustified loss of its reserves. This means that the geological work should bind minimum geological reserves. They should also examine the negative factors that may affect future mining, for example, the possibility of water in-breaks, auto-ignition in case of coal and gas deposits, or slope deformations at the surface exploited deposits and propose measures to prevent the interconnection of aquifers. Surface structures and equipment should be not situated in places where they block the future use of reserves of the exclusive deposit.

Last but not least, the deposit geological survey assesses the possible effects of the exclusive deposits on other deposits, on the individual components of the environment and other public interests. It examines the possibility of influencing the mined rock structures in particular with sources of natural healing resources and natural mineral waters and defines the conditions to minimize the impact of mining on the environment. At the stage of geological exploration in the final report of the geological task, there are proposed options for disposal of extractive waste so that it does not block future use of deposits and the impact of the muck use on objects and interests protected by special regulations is assessed, for example in relation to the territorial nature protection, the protection and utilization of agricultural land or the already mentioned groundwater resources. Equally important are the provisions regarding the evaluation of the exclusive deposit in relation to land-use planning documentation and cooperation with land-use planning when procuring or updating of land-use planning documentation. The binding nature of spatial planning at the regional level could solve many conflicts of interests between producers‘ organizations and municipalities in the use of the results of deposit geological exploration.

Finally, the measures shall be implemented to secure the geological works and geological objects at the interruption of geological works, so that in the future the deposit geologic exploration and subsequent use by other holders of exploration area or mining area, may continue to be carried out.

2.3.14. Final report elaboration with the estimation of reserves of the exclusive deposit or its part

After completion of the geological task, the contractor is obliged to evaluate geological works in his final report and submit it to the customer of geological works. If the deposit geological survey sought and verified mineral deposits, it must include comprehensive qualitative assessment of the mineral in terms of its potential use and calculation of mineral reserves and accompanying minerals or part thereof. Results of the geological project can be evaluated in interim final reports.

The final report with the calculation of reserves of the exclusive deposit in addition to basic data (name and number of the geological task, type of geological works and stage of the survey, the customer and the contractor of geological works, principal investigator and the investigators and the submission date) contains in the text the topographical definition of territory, objective of geological task and information about the project and its changes. When characterizing the natural conditions the geomorphological, geological, hydrogeological, hydrological and climatic characteristics of the deposit, or areas protected by special regulations, shall be stated. In to date geological exploration the details of the works carried out and their results in relation to addressing the issue shall be discussed. The description of the geological project shall include the method, procedure and temporal link among all realized geological works and activities including waste and extracted materials handling, security measures or liquidation of geological works carried out and measures to eliminate or minimize the impact of technical works on the environment. The spatial characteristics of deposit shall describe comprehensively the deposit and its extent, including the accompanying minerals. The qualitative and technological characteristics shall define the kind of reserved mineral, its technological types, properties of commercial and harmful ingredients, variability in the quality characteristics of deposit, treatment and refining practices, and comprehensive assessment of the mineral in terms of its use in practice. Description of hydrogeological characteristics includes the impact of tectonics on hydrogeological conditions of the deposit, the chemical composition of water, envisaged inflows of water into the deposit during mining and its hydrogeological classification.

The main chapter of the reserves calculation provides calculation methodology and its justification, the basic parameters of the calculation process, principles of the division into blocks, the inclusion of reserves into categories and the basic parameters calculation in tabular form and the overall results of reserves estimation. When tested a non-reserved mineral, its calculation or qualified estimate are indicated, or even an educated guess of prognostic resources. It suggests the optimal utilization of the deposit, its protection and assesses the relationship to the expected mining interests protected by special regulations and relationship to the land-use planning documentation. The text part of the final report concludes comment to economic benefits of the solution of the geological task, data on the geological documentation storage, conclusions and recommendations, and a list of references and other sources.

Part of graphical attachments is situational map of the wider surroundings of deposit, orthophoto of its environs, geological map and basic reconnaissance and mining maps. Graphic annexes include also map of blocks of reserves with their projections on the surface and protection zones and security pillars, vertical and horizontal sections, map of prognostic resources and accompanying minerals (provided their professional estimate was elaborated), targeted and thematic maps, geological documentation of geological works, or other geological documentation and photodocumentation.

Part of the text attachments is the decision on determination of exploration area or a specific exploration area (provided the geological task was financed from the state budget).

Terms of exploitable reserves are the basis for the inclusion of calculated balance between reserves or non-balanced reserves, which are also annexed to the final report with the estimation of reserves of the exclusive deposit, which details the geological, mining-technical and economic indicators. Among the geological indicators we rank, for instance, the minimum amount of balance reserves, or the maximum available quantity of oil, combustible gas, technically usable natural gas from one borehole, minimum/exploitable thickness of the deposit, the maximum thickness of technically unsuitable horizons, the minimum and maximum average content of useful and harmful components (even in the outskirts sample and in the border geological work), the maximum depth of deposit in the deep mining, the maximum stripping ratio, requirements for the raw material properties, the collector characteristics of the productive horizon and requirements resulting from the relevant Slovak technical standards. Geological indicators of conditions of utilization are determined with regard to the type of mineral or the nature of the exclusive deposit. The same goes for mining-technical indicators (mechanical stability of deposit, optimal mining method, treatment and refinement, exploitation ratio, recovery and pollution, measures against unforeseen circumstances, waste mining water and mining waste and the impact of mining activities on the environment) and economic indicators (the price of the mineral resource, operating and investment costs). It should be pointed out that the organization/contractor often defined the conditions of utilization of reserves in conflict with the law. Terms of exploitable reserves are in fact the basis for the classification of reserves between the balanced and the non-balanced reserves and not for the inclusion of reserves in the relevant category, and the inclusion of reserves in free or bound reserves.

The text attachments should contain tables referring to analyses and tests including the verification tests, thickness calculations, density and quantity of reserves in each block, total reserves estimation, geodetical surveying activities (targeting different geological works) or other reports (e.g. geophysical, geochemical, mineralogical, petrological, technological).

Application for approval of reserves includes the name of the deposit, reserved mineral, accompanying materials, exploration area, protected deposit area, mining area, cadastral area, district and region, the geological characteristics, hydrogeological conditions and description of deposits, the use of minerals and accompanying minerals by economic and bound categories, reserves quality, the amount of surface overburden earmarking the amount of agricultural land, or stripping conditions and other parameters listed in terms of utilization of reserves.

If prognostic resources were estimated, the final report shall be accompanied by an inventory sheet containing the name and identification of prognostic area, the name of the mineral and the accompanying minerals, division of prognostic resources (P1 or P2), the estimated amount and geological and hydrogeological characteristics. The index passport deposit is also attached, containing summary information on the deposit and protocols on security and maintenance or disposal of geological works.

2.3.15. Final report elaboration with the estimation of reserves of non-reserved mineral

The content of the final report with the estimation of reserves of non-reserved mineral has a similar structure as in the case of the final report with the estimation of reserves of the exclusive deposit. However, the text part shall contain in simplified form the description of the deposit and its position, as well as hydrogeological characteristics and processing methods and results of the calculation of reserves. The economic benefits of the geological task are not stated. The graphical attachments shall not contain the map of prognostic resources, targeted and thematic maps, geological documentation; sufficient is vertical or horizontal geological cross-section. For purposes of reserves calculating it is not necessary to determine the conditions of utilization of reserves, because reserves of non-reserved mineral are not broken down by categories Z-1, Z-2 and Z-3, neither under the terms of the usability of the balanced and non-balanced reserves nor by accessibility of the free and bound reserves.

2.3.16. Appraisal and approval of the final report with the calculation of mineral reserves

The final report with the calculation of mineral reserves shall be appraised and approved by the Ministry of Environment of the Slovak Republic regardless of the source of funding within six months after its submission; customer shall submit it for approval to the Ministry of Environment of the Slovak Republic within one month after its receipt from the contractor of geological works in written, graphic and digital forms together with the expert‘s opinion elaborated by an authorised person on the deposit geological survey.

For the purpose of issuing the decision on approval of the final report with the estimation of reserves of the exclusive deposit the customer of geological works attaches an electronic stamp with a face value of 35 Euros.

2.3.17. Issue of the exclusive deposit certificate

The Certificate of the exclusive deposit is issued by the Ministry of Environment of the Slovak Republic after appraisal and approval of the final report with the calculation of reserves of the exclusive deposit, based on a proposal for its issuance by the customer of geological works, which includes the name of the exclusive deposit, reserved mineral and accompanying minerals, the name and code of the cadastral area, municipalities, districts and regions, the coordinates of the apex-points of the peripheral blocks of reserves, depth limitation of deposit, division of reserves blocks by categories, economic appreciation and bound reserves proportion, characteristic of reserves, geological and hydrogeological characteristics and estimated effects of exclusive deposit mining on objects and interests protected by special regulations.

The application shall be accompanied by a decision on the approval of the final report and map showing the above data.

For the purpose of issue of the exclusive deposit the customer of geological works attaches an electronic stamp with a face value of 20 Euros.

2.3.18 The rules for submitting final reports with the calculation of reserves of mineral deposits

The final report with the calculation of reserves of mineral deposits shall be transferred to the Ministry of Environment of the Slovak Republic for approval using technology that ensures its durability and reproducibility in addition to the written and graphical forms also in the digital format. The client may specify the conditions under which the final report with calculation of reserves of the deposit shall be disclosed and information provided. Decommissioning of material geological documentation shall be carried out upon the agreement of the client of geological works after proper written and graphical documentation of technical works.

2.3.19 Balance of the raw mineral reserves

Ministry of Environment of the Slovak Republic keeps a balance of reserved and non-reserved minerals. The Balance is issued annually by January 1, and it lists the exclusive deposits arranged by types of exclusive deposits, kind of reserved minerals or non-reserved minerals of exclusive deposits, territorial division and status of utilization of reserved deposits, list of exclusive deposits written off the balance sheet stating the reasons for the exclusion. In addition the Balance provides information on the status of the protection of exclusive deposits with the identification of the protected deposit area and mining area, the name of the holder of the exploration area, an organization that has a designated mining area, or organization that registers or provides the protection of the exclusive deposit, overview of reserves broken down by degree of exploration, utilization of reserves and the conditions of their exploitability, selected chemical, technological or energy properties of reserved minerals. It keeps in an appropriate form records of reserves of non-reserved minerals.

2.4. Conclusions

In accordance with the principle of sustainable development of mineral resource base it will be useful in future to support the deposit geological exploration of mineral resources with particular emphasis on deficient minerals important for ensuring economic needs of the Slovak Republic and in the wider context for the needs of the European Union (e.g. critical raw materials).

Verification of economically important deposits in Slovakia in recent periods points to the merits of further research and exploration activities focused mainly on effective use of deposit potential in the geological conditions of the Western Carpathians.

Acknowledgements:

The authors express their gratitude to peer reviewer for his valuable comments and recommendations.

References

Act no. 569/2007 Coll. on Geological Works (Geological Act) as amended by further legislation

Act no. 44/1988 Coll. on Protection and Exploitation of Raw Mineral Wealth (Mining Act)

Regulation of the Ministry of Environment of the Slovak Republic no. 51/2008 Coll., which regulates some provisions of the Act no. 569/2007 Coll. on Geological Works (Geological Act) as amended by further legislation

Regulation of the Ministry of Environment of the Slovak Republic no. 33/2015 Coll., which regulates some provisions of the Act no. 44/1988 Coll. on Protection and Exploitation of Raw Mineral Wealth (Mining Act) as amended by further legislation

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3. Review of Reserved Deposits of Metals in Slovakia

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Abstract: Distribution of metal deposits and occurrences, related to various geological composition of Slovakia, is very uneven and depends on particular metallogenic conditions. Metal resources relate to particular tectonic and lithostratigraphic units, rock types and stratigraphic stages. At present (2013), 48 reserved deposits with reported metal content (antimony, copper, gold, iron ore, lead-zinc, mercury molybdenum, silver and tungsten) are registered in the territory of Slovakia. Geological reserves reached 335 Mt of ore. Other metal occurrences (manganese, nickel, tin, REE) represent uneconomic accumulations. Exploitation of metal reserves, extensively mined in the past, is limited due to exhaustion of resources, low ore grade and present economic and legal conditions.

Key words: Slovakia, metals, reserved deposit, reserves, mining

3.1. Introduction

Occurrences of mineral deposits are dependent on varied geological composition of Slovak territory. Distribution of mineral deposits is very uneven and depends on geological and metallogenic conditions. Every geological unit has its own characteristic complex of mineral resources, conditional to geological evolution of region.

Metal mining in Slovakia territory has a long history. In the past, mineral wealth provided sources for the development and growth of economy. Copper, mercury, gold and silver were mined extensively during the Middle Age. Famous mining cities have grown up along with advances in mining techniques as mining get deeper underground. Exhaustion of precious metal deposits and decrease of metal prices by the end of 18th century have caused gradual decline of mining activities. The industrial revolution in the 19th and 20th century with its growing demand for raw materials and energy stimulated extensive exploitation of iron, manganese, base metals, coal and varied industrial minerals. After the World War I rising metal demand led to exploitation of deposits in the Slovak territory. Significant increase of mining activities has been brought after the World War II along with intense exploration, as political changes in 1948 resulted in isolation of country from western-world mineral markets. Transition to the market economy in the nineties of the 20th century with a cut of government subsidies resulted in closing of most of metal mines in Slovakia (Grecula et al., 1997).

3.2 Brief characteristics of reserved deposits

At present, reserved deposits with metal content of antimony, copper, gold, iron ore, lead – zinc, mercury, molybdenum, silver, and tungsten (Fig. 3.1) are registered in the territory of Slovakia. Other metal occurrences (manganese, nickel, tin, REE), representing uneconomic accumulations, are not subject of the paper.

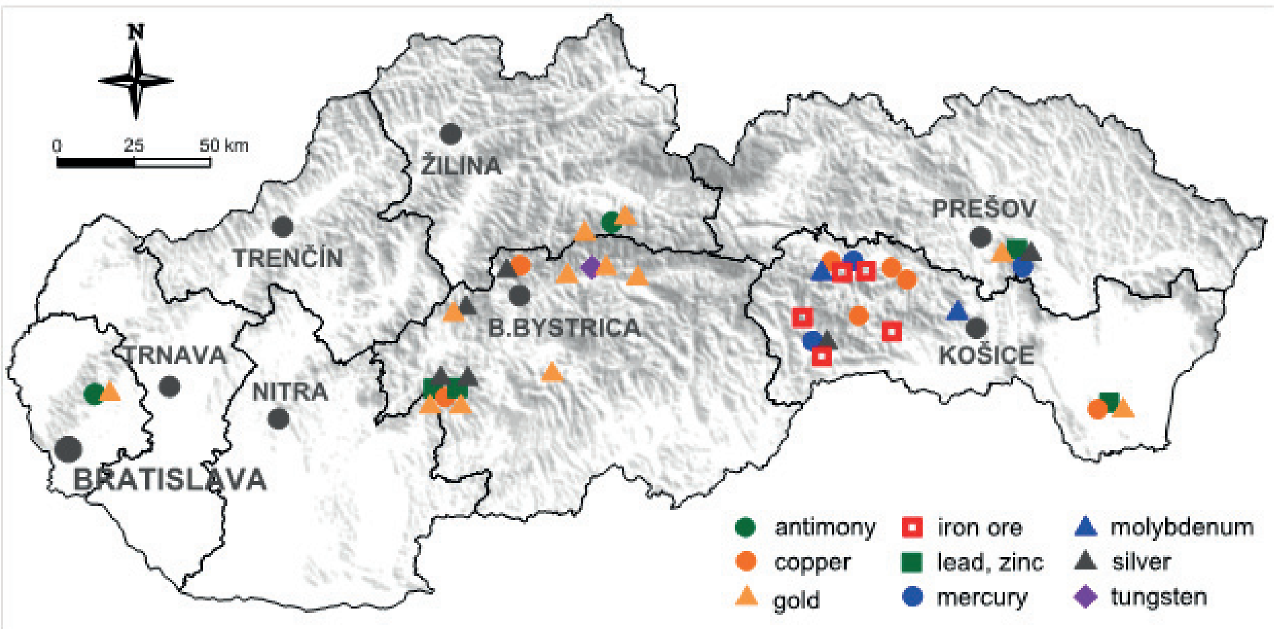

Fig. 3.1 Distribution of reserved deposits of metals (2013). Source: Slovak Minerals Yearbook 2014.

Processes of genesis relate individual mineral deposit types to various tectonic and lithostratigraphic units, rock types and stratigraphic stages. Quaternary formations are hosts for gold accumulations. Numerous metal deposits (antimony, copper, gold, iron ore, lead, silver, mercury, zinc) are hosted by Neogene volcanic formations. Palaeogene and Mesozoic sedimentary rocks host occurrences of gold and molybdenum. Palaeozoic sedimentary and volcanic rock complexes are the source formations of antimony, copper, gold, iron ores, lead, mercury, molybdenum, silver, tungsten and zinc (Fig. 3.2).

Essential classification of deposits reflects their metallogenic association to particular evolutionary stages of the Western Carpathian territory.

Pre-Hercynian and Paleohercynian stage (>380 Ma): reserved deposit of copper (Smolník) is hosted in metamorphosed volcano-sedimentary formations of Gemericum unit.

Neohercynian late-to post-orogenic stage (340–250 Ma): reserved deposits of antimony, gold and tungsten (Pezinok, Dúbrava, Dolná Lehota, Jasenie) are hosted by crystalline basement of the Tatricum and Veporicum units, re-

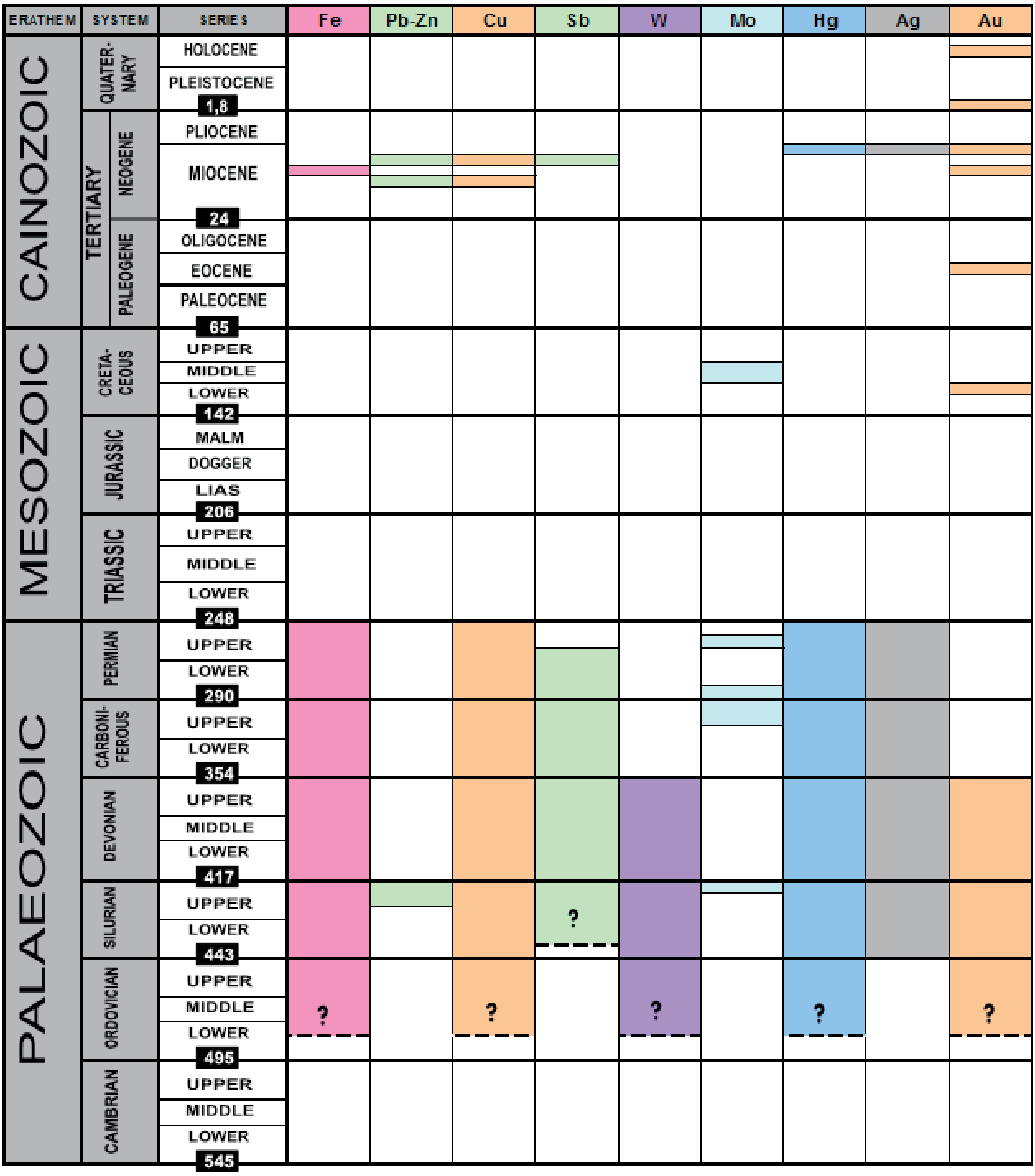

Fig. 3.2 Stratigraphic position of reserved deposits and occurrences (geological age data in million years). Source: Mineral resources of Slovakia (Zuberec at al., 2005), modified.

Tab. 3.1 Reserved deposits of antimony – estimation of Sb metal content in geological reserves

Reserved deposit	Mineralization	Grade [% Sb]	Metal content [tonne]
Dúbrava	Sb-Au, hydrothermal vein and shear-zone	1.9	3,250
Dúbrava – Ľubelská	Sb-Au, hydrothermal vein and shear-zone	1.6	10,140
Dúbrava – Martin štôlňa	Sb-Au, hydrothermal vein and shear-zone	1.7	12,230
Dúbrava – Matošovec	Sb-Au, hydrothermal vein and shear-zone	1.8	9,420
Dúbrava – Predpekelná	Sb-Au, hydrothermal vein and shear-zone	2.3	7,300
Pezinok	Sb-Au, hydrothermal vein and shear-zone	2.9	2,430
Pezinok – Sb	Sb-Au, hydrothermal vein and shear-zone	3.2	480
Pezinok – Vinohrady	Sb-Au, hydrothermal vein and shear-zone	0.4	2,870
Pezinok Sb	Sb-Au, hydrothermal vein and shear-zone	2.2	4,130

served deposits with molybdenum mineralization (Košice, Novoveská Huta) occur in Late Paleozoic formations.

Paleo-Alpine orogenic stage (110-90 Ma): reserved deposits of copper and iron ore (Gelnica, Slovinky, Rudňany, Poráč, Rožňava, Nižná Slaná, Medzev) occur in metasedimentary and metavolcanic rocks of Gemericum unit.

Paleo-Alpine late-orogenic stage (90-70 Ma): reserved deposits of copper and silver mineralization (Špania Dolina, Novoveská Huta) are hosted by Permian formations of the Veporicum and Gemericum units. Mercury mineralization of Rudňany deposit occurs in metasedimentary and metavolcanic rocks of Gemericum unit.

Neo-Alpine orogenic stage (24-10 Ma): reserved deposits with mineralization of copper, gold, silver, base metals and mercury (Banská Hodruša, Banská Štiavnica, Brehov, Vysoká, Detva, Klokoč, Kremnica, Zlatá Baňa) are hosted by Neogene volcanites (Lexa et al., 2007).

Antimony

Nine antimony reserved deposits (Tab. 3.1) concentrated in two deposit areas (Pezinok and Dúbrava) were registered in 2013 (Slovak Minerals Yearbook 2014).

The Pezinok deposit in the Malé Karpaty Mts. is represented by quartz veins and silicified zones. Mineralization (arsenopyrite, stibnite and red antimony) is hosted by complex of Early Paleozoic graphite schists.

Sb-Au mineralization of Dúbrava deposit in the Nízke Tatry Mts. occurs in Hercynian granites and crystalline schists. Mineralization is represented by quartz veins and stockworks with stibnite, pyrite, arsenopyrite, sphalerite, tetrahedrite and rare native gold (Zuberec et al., 2005).

Tab. 3.2 Reserved deposits with copper content – estimation of Cu metal content in geological reserves

Reserved deposit	Mineralization	Grade [% Cu]	Metal content [tonne]
Banská Hodruša	Pb-Zn-Cu-Au-Ag, volcanic hosted low sulphidation epithermal	0.5	27,810
Banská Štiavnica – Pb, Zn, Cu, Au, Ag	Pb-Zn-Cu-Au-Ag, volcanic hosted low sulphidation epithermal	0.3	18,490
Brehov I	Cu-Pb-Zn-Au, intrusion related stockwork/ disseminated	1.0	4,560
Gelnica – Gelnická žila	Cu-Fe, metamorphic-hydrothermal vein	0.8	4,330
Gelnica – Krížová žila	Cu-Fe, metamorphic-hydrothermal vein	1.3	10,830
Gelnica – Nadložná žila	Cu-Fe, metamorphic-hydrothermal vein	0.9	6,860
Gelnica – Nová žila	Cu-Fe, metamorphic-hydrothermal vein	1.0	7,060
Medzev	Cu-Fe, metamorphic-hydrothermal vein	0.4	17,120
Rožňava – Mária žila	Cu-Fe, metamorphic-hydrothermal vein	0.6	14,600
Rožňava – Strieborná žila	Cu-Fe-Ag, metamorphic-hydrothermal vein	1.0	40,740
Rudňany – Matej a Jakub žily	Cu-Fe, metamorphic-hydrothermal vein	0.4	89,350
Slovinky	Cu-Fe, metamorphic-hydrothermal vein	0.7	79,630
Smolník	Cu-S, syngenetic volcanic massive sulphide	0.5	22,040
Spišská Nová Ves – Novoveská Huta	Cu, hydrothermal vein and stockwork/disseminated	1.2	88,010
Špania Dolina – Glezúr – Piesky – Mária šachta	Cu, hydrothermal vein and stockwork/disseminated	0.7	24,630
Vysoká – Zlatno	Cu-Au, intrusion related porphyry-skarn	0.5	67,210

Copper

There were sixteen reserved deposits with reported copper content (Tab. 3. 2) registered in 2013 (Slovak Minerals Yearbook 2014), occurring in the Spišsko-gemerské rudohorie Mts., Nízke Tatry Mts., Central and East Slovakia Neogene volcanites.

Metamorphic-hydrothermal vein deposits occur in the Spišsko-gemerské rudohorie Mts. (Slovinky, Gelnica, Novoveská Huta, Rudňany) and the Nízke Tatry Mts. (Špania Dolina). Ore veins of the Spišsko-gemerské rudohorie Mts. are formed in the Early Paleozoic volcano-sedimentary rocks and the Late Paleozoic sedimentary rocks. The major ore minerals are siderite, Fe-dolomite, chalcopyrite and tetrahedrite. Complex Fe-Cu ores made up by chalcopyrite and tetrahedrite on hydrothermal vein deposits Rudňany and Rožňava occur in the Early and Late Paleozoic in the Spišsko-gemerské rudohorie Mts. Siderite, chalcopyrite, tetrahedrite, cinnabarite and barite are the major economic minerals there. Permian conglomerates, sandstones and shales host copper deposit Špania Dolina in Nízke Tatry Mts. Ore is represented by chalcopyrite, tetrahedrite, pyrite, galena, sphalerite and stibnite.

Massive sulphide copper deposit Smolník, situated in the Spišsko-gemerské rudohorie Mts., is hosted in the Early Paleozoic chlorite/sericite/graphite schists with volcanic rocks. Main ore minerals are chalcopyrite and pyrite.

The skarn-porphyry copper deposits Vysoká is situated in the central zone of the Neogene Štiavnica stratovolcano, formed in the Miocene. Disseminated porphyry type ores are of poor grade. Higher-grade ores are related to exoskarns and endoskarns at diorite/carbonate contacts. Ore mineralization is represented by chalcopyrite, pyrite and native gold.

The epithermal base metal and precious metal vein deposits Banská Hodruša and Banská Štiavnica are situated in the Central Slovakia Neogene volcanites. Ore is made of chalcopyrite, galena, pyrite and sphalerite.

Stockwork copper mineralization of base metal deposit Brehov, situated in the East Slovakia Neogene volcanites, is related to the diorite porphyry intrusion emplaced in Miocene tuffaceous sediments (Zuberec et al., 2005).

Gold

Twenty one metal reserved deposits with reported gold content (Tab. 3.3) were registered in 2013 (Slovak Miner-

Tab. 3.3 Reserved deposits with gold content – estimation of Au metal content in geological reserves

Reserved deposit	Mineralization	Grade [ppm Au]	Metal content [kg]
Banská Hodruša I	Pb-Zn-Cu-Au-Ag, volcanic hosted low sulphidation epithermal	13.9	4,730
Banská Štiavnica – Pb, Zn, Cu, Au, Ag	Pb-Zn-Cu-Au-Ag, volcanic hosted low sulphidation epithermal	0.6	3,730
Brehov I	Cu-Pb-Zn-Au, intrusion related stockwork/ disseminated	2.7	1,410
Detva	Au, high sulphidation epithermal	0.6	48,960
Dolná Lehota	Sb-Au, hydrothermal vein and shear-zone	2.7	3,200
Dúbrava – Ľubelská	Sb-Au, hydrothermal vein and shear-zone	1.6	1,010
Dúbrava – Martin štôlňa	Sb-Au, hydrothermal vein and shear-zone	0.7	460
Dúbrava – Matošovec	Sb-Au, hydrothermal vein and shear-zone	1.1	580
Jasenie – Kyslá	W-Au, hydrothermal vein and shear-zone	0.5	1,400
Klokoč	Au, high sulphidation epithermal	1.7	430
Kremnica	Au-Ag, volcanic hosted low sulphidation epithermal	1.5	39,780
Magurka – št. Adolf – halda	Au in mine waste pile	8.6	2,060
Medzibrod	Sb-Au, hydrothermal vein and shear-zone	2.7	70
Pezinok	Au-As, hydrothermal vein and shear-zone	2.3	190
Pezinok – odkalisko	Au in setting pit	1.2	440
Pezinok – Sb	Sb-Au, hydrothermal vein and shear-zone	2.1	30
Pezinok – Vinohrady	Au-As, hydrothermal vein and shear-zone	2.8	1,830
Pezinok – Zlatá žila	Au-As, hydrothermal vein and shear-zone	3.7	3,600
Pezinok (Pezinok II)	Sb-Au, hydrothermal vein and shear-zone	4.7	2,980
Pezinok I	Sb-Au, hydrothermal vein and shear-zone	1.1	470
Zlatá Baňa	Pb-Zn-Cu-Au-Ag, volcanic hosted low sulphidation epithermal	1.1	2,040

Tab. 3.4 Reserved deposits of iron ore – geological reserves

Reserved deposit	Mineralization	Grade [% Fe]	Ore reserves [thousand tonnes]
Medzev	Cu-Fe, metamorphic-hydrothermal vein	30.1	4,200
Nižná Slaná	Fe, metamorphic-hydrothermal vein, metasomatic	38.1	1,040
Nižná Slaná – Mano – Kobeliarovo	Fe, metamorphic-hydrothermal vein, metasomatic	33.5	17,710
Poráč – Zlatnícka žila	Fe-Cu, metamorphic-hydrothermal vein	33.1	2,740
Poráč – Zlatník	Cu-Fe, metamorphic-hydrothermal vein	30.9	15,160
Rožňava – Mária žila	Cu-Fe-Ag-Sb, metamorphic-hydrothermal vein	36.6	2,320
Rudňany	Cu-Fe, metamorphic-hydrothermal vein	30.1	7,340
Rudňany – Matej and Jakub žila	Cu-Fe, metamorphic-hydrothermal vein	29.3	21,790

als Yearbook 2014), occurring in the Malé Karpaty Mts., Nízke Tatry Mts., Central and East Slovakia Neogene volcanites.

Gold deposits of pre-Tertiary hydrothermal Au-As, Au-W and Au-Sb mineralizations are known from the Malé Karpaty Mts. (Pezinok deposit) and Nízke Tatry Mts. (Dúbrava, Magurka – mine waste pile, Dolná Lehota, Medzibrod, Jasenie) ore districts. Late Hercynian hydrothermal gold deposits occur in Tatricum and Veporicum units of metamorphic complexes and granitic rocks. Pyrite, arsenopyrite, tetrahedrite, stibnite, bertierite, chalcopyrite, galena and sphalerite are the major minerals.

Meaningful precious and base metal epithermal mineralization is related to the Central and East Slovakia Neogene volcanism. The Central Slovakia Neogene volcanic field is represented by Kremnica, Banská Hodruša, Banská Štiavnica, Klokoč and Detva deposits. Kremnica deposit represents Au-Ag mineralization of vein and veinlet type. Pyrite, chalcopyrite, galena, sphalerite, silver sulphosalts and electrum are major minerals. Banská Štiavnica deposit represents base metal and precious metal mineralization with an expressive zonal arrangement, Au-Ag mineralization is concentrated at higher (under surface) levels. The last discovered deposit in Neogene volcanites, representing large porphyry gold ore bodies, is Detva deposit. The only Slovakia´s exploited metal deposit Banská Hodruša represents low sulphidation epithermal gold mineralization. Gold reserves of base metal deposit Brehov, situated in the East-Slovakia Neogene volcanites, are related to the diorite stock emplaced in tuffaceous sediments. The Klokoč deposit, situated in central zone of Javorie stratovolcano, represents high sulphidation epithermal (Zuberec et al., 2005).

Iron ore

Eight reserved deposits with reported iron ore (Tab. 3.4), concentrated in the Spišsko-gemerské rudohorie Mts. deposit area, were registered in 2013 (Slovak Minerals Yearbook 2014, revised).

Economically the most important iron ore deposit Nižná Slaná – Manó – Kobeliarovo is situated in the western part of the Spišsko-gemerské rudohorie Mts. Hydrothermal – metasomatic type deposit occurs in the form of lens, hosted in the Early Paleozoic rock complexes. The major ore mineral is siderite.

Hydrothermal vein deposits (Rudňany, Poráč, Rožňava – Mária žila, Medzev) of the complex Fe-ores occur in the north and south parts of the Spišsko-gemerské rudohorie Mts. hosted by the Early and Late Paleozoic rocks. Siderite, chalcopyrite, tetrahedrite, cinnabarite and baryte are the major ore minerals there (Zuberec et al., 2005).

Lead and zinc

Four base metal reserved deposits (Tab. 3.5a & 5b) were registered in 2013 (Slovak Minerals Yearbook 2014), occurring in the Central and East Slovakia Neogene volcanites.

Epithermal vein deposits Banská Štiavnica and stockwork-disseminated deposit Banská Hodruša in Central Slovakia Neogene volcanites are hosted by a volcanoplutonic complex in the central zone of andesite stratovolcano. Galena, sphalerite, chalcopyrite, pyrite, silver salts and electrum are major minerals there.

Zlatá Baňa and Brehov deposits are situated in the East Slovakia Neogene volcanites. Mineralization of Zlatá Baňa deposit is bound with central zone of andesite stratovolcano. Major minerals are galena, sphalerite, chalco-

Tab. 3.5a Reserved deposits of lead – estimation of Pb metal content in geological reserves

Reserved deposit	Mineralization	Grade [% Pb]	Metal content [tonne]
Banská Hodruša	Pb-Zn-Cu-Au-Ag, volcanic hosted low sulphidation epithermal	0.6	31,230
Banská Štiavnica – Pb, Zn, Cu, Au, Ag	Pb-Zn-Cu-Au-Ag, volcanic hosted low sulphidation epithermal	1.6	105,710
Brehov I	Cu-Pb-Zn-Au, intrusion related stockwork/ disseminated	0.8	77,750
Zlatá Baňa	Pb-Zn-Cu-Au-Ag, volcanic hosted low sulphidation epithermal	1.2	22,560

Tab. 3.5b Reserved deposits of zinc – estimation of Zn metal content in geological reserves

Reserved deposit	Mineralization	Grade [% Zn]	Metal content [tonne]
Banská Hodruša	Pb-Zn-Cu-Au-Ag, volcanic hosted low sulphidation epithermal	0.7	38,010
Banská Štiavnica – Pb, Zn, Cu, Au, Ag	Pb-Zn-Cu-Au-Ag, volcanic hosted low sulphidation epithermal	2.4	161,580
Brehov I	Cu-Pb-Zn-Au, intrusion related stockwork/ disseminated	1.7	164,990
Zlatá Baňa	Pb-Zn-Cu-Au-Ag, volcanic hosted low sulphidation epithermal	2.8	53,600

pyrite, pyrite, silver salts and electrum. Mineralization of Brehov deposit is related to the diorite porphyry intrusion in Miocene tuffaceous sediments. Major minerals are galena, sphalerite, chalcopyrite, pyrite and silver salts (Zuberec et al., 2005).

Mercury

There were two reserved deposits with reported mercury content (Tab. 3.6) registered in 2013 (Slovak Minerals Yearbook 2014, revised), occurring in the Spišsko-gemerské rudohorie Mts. and East Slovakia Neogene volcanites.

Mercury as an admixture in complex Fe-ores occures in Rudňany deposit. Mineralization hosted by the Early and Late Paleozoic rocks is formed by cinnabarite, Hg-tetrahedrite (schwazite) and native mercury (Zuberec et al., 2005).

Molybdenum

Two reserved deposits with reported molybdenum content (Tab. 3.7) were registered in 2013 (Slovak Minerals Yearbook 2014), occurring in the Spišsko-gemerské rudohorie Mts.

Tab. 3.6 Reserved deposits with mercury content – estimation of Hg metal content in geological reserves

Reserved deposit	Mineralization	Grade [% Hg]	Metal content [tonne]
Dubník	Hg, volcanic hosted low sulphidation epithermal	0.16	3,910
Rudňany	Cu-Fe-Hg, metamorphic-hydrothermal vein	0.05	450

The most important economical accumulations of monomineral Hg-ores are situated in the East Slovakia Neogene volcanites (Dubník deposit). Major ore mineral is cinnabarite, locally meta-cinnabarite, accompanied by quartz, chalcedony, calcite, pyrite and marcasite. Mineralization is of veinlet – disseminated type, formed by irregular lens.

U-Mo deposits Spišská Nová Ves and Košice are situated in the north part of the Spišsko-gemerské rudohorie Mts. Stratiform mineralization (U minerals, molybdenite, chalcopyrite, pyrite) is related to Permian volcano-sedimentary horizons of Gemericum unit. Molybdenum is mineralogically bonded with uranium minerals (Zuberec et al., 2005).

Tab. 3.7 Reserved deposits with molybdenum content – estimation of Mo metal content in geological reserves

Reserved deposit	Mineralization	Grade [% Mo]	Metal content [tonne]
Košice I	U-Mo, syngenetic/diagenetic and infiltration	0.05	2,550
Sp. N. Ves – Novoveská Huta	U-Mo, syngenetic/diagenetic and infiltration	0.02	930

Tab. 3.8 Reserved deposits with silver content – estimation of Ag metal content in geological reserves

Reserved deposit	Mineralization	Grade [ppm Ag]	Metal content [kg]
Banská Hodruša	Pb-Zn-Cu-Au-Ag, volcanic hosted low sulphidation epithermal	8.6	45,260
Banská Hodruša I	Pb-Zn-Cu-Au-Ag, volcanic hosted low sulphidation epithermal	15.0	4,980
Banská Štiavnica Pb, Zn, Cu, Au, Ag	Pb-Zn-Cu-Au-Ag, volcanic hosted low sulphidation epithermal	19.4	130,030
Kremnica	Au-Ag, volcanic hosted low sulphidation epithermal	12.0	314,580
Rožňava – Mária	Cu-Fe-Ag-Sb, metamorphic-hydrothermal vein	54.9	127,230
Rožňava – Strieborná	Cu-Fe-Ag-Sb, metamorphic-hydrothermal vein	204.5	866,880
Špania dolina-Glezúr-Piesky-Mária šachta	Cu, hydrothermal vein and stockwork/ disseminated	9.8	37,480
Zlatá Baňa	Pb-Zn-Cu-Au-Ag, volcanic hosted low sulphidation epithermal	32.2	62,160

Silver

Eight reserved deposits with reported silver content (Tab. 3.8) were registered in 2013 (Slovak Minerals Yearbook 2014), occurring in the Spišsko-gemerské rudohorie Mts., Nízke Tatry Mts., Central and East Slovakia Neogene volcanites.

The late volcanic formation is represented by Ag mineralization on precious and base metal deposits Kremnica, Banská Štiavnica, Banská Hodruša (Central Slovakia Neogene volcanites) and Zlatá Baňa (East Slovakia Neogene volcanites). The most productive were upper parts of ore veins in Banská Štiavnica deposit. Downwards Au-Ag mineralization melts into base metal (Pb, Zn, Cu) mineralization of lower Ag content. Majority of silver is bounded in galena, individual Ag minerals (argentite) are rare.

The early silver formation is represented by Ag mineralization related to Ag-tetrahedrites in complex Fe-ore and copper deposits of the Spišsko-gemerské rudohorie Mts. (Rožňava deposit) and Ag-tetrahedrites formed in the Permian rock complexes in Cu deposit Špania Dolina (Nízke Tatry Mts) (Zuberec et al., 2005).

Tungsten

There was one reserved deposit of tungsten (Tab. 3.9) registered in 2013 (Slovak Minerals Yearbook 2014), occurring in the Nízke Tatry Mts.

Gold-scheelite mineralization in Jasenie – Kyslá deposit is related to quartz veins and silicified shear zones in the Paleozoic crystalline schists. Major economic minerals are scheelite and gold here. Tungsten mineralization age is the Late Carboniferous (Zuberec et al., 2005).

3.3 Review on reserves and production

Presented reserves (metal content respectively) are given as geological reserves i.e. in natural state on mineral deposits computed according to the valid efficiency conditions and the classification of reserves (Decree of the SGU no.6/1992 Col.). Present structure of reserves and their exploitation is mostly result of extensive state geological survey realised in the second half of the 20th century.

Following the Register of Reserves of Reserved Mineral Deposits of the Slovak Republic total of 48 reserved deposits with reported metal content (antimony, base metals, copper, gold-silver, iron ore, mercury, molybdenum

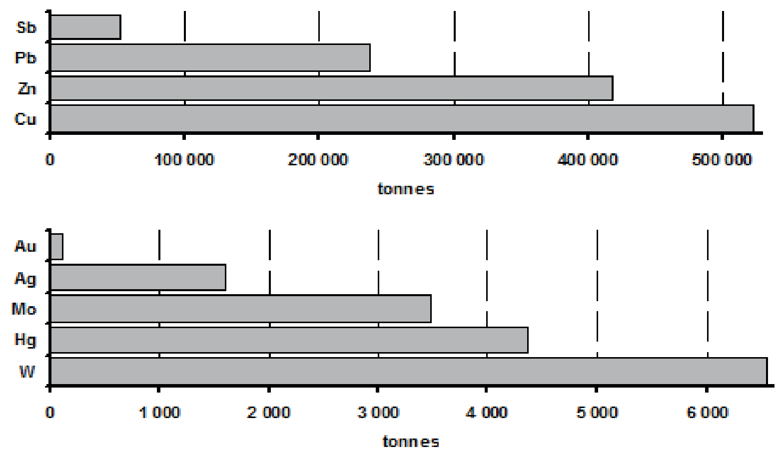

Fig. 3.3 Estimated metal content in geological reserves (in situ) in reserved ore deposits of Slovakia

Tab. 3.9 Reserved deposit of tungsten – estimation of W metal content in geological reserves

Reserved deposit	Mineralization	Grade [% W]	Metal content [tonne]
Jasenie – Kyslá	W-Au, hydrothermal vein and shear-zone	0.2	6,550

Tab. 3.10 Metal content in geological reserves and production of metals (2011-2013). Source: Slovak Minerals Yearbook 2012 – 2014, modified.

Metal	Number of deposits	Metal content in geological reserves	Production 2011*	Production 2012*	Production 2013*
Antimony [t]	9	52,240	-	-	-
Copper [t]	16	523,270	28	31	40
Gold [kg]	21	119,390	398	546	533
Iron ores [kt]	8	72,290 (ore)	-	-	-
Lead [t]	4	237,150	114	166	235
Mercury [t]	2	4,360	-	-	-
Molybdenum [t]	2	3,480	-	-	-
Silver [kg]	8	1,588,590	330	441	508
Tungsten [t]	1	6,550	-	-	-
Zinc [t]	4	418,170	103	134	190

Note: Metal content is calculated for average grade in deposit and geological (in-situ) reserves amount, with regard to grade of economic and uneconomic (potentially economic) reserve categories. Estimated amount of metal is informative figure only.

** Certain amount of silver, zinc, lead and copper occur in concentrate produced by gold ore processing in Banská Hodruša I deposit.*

and tungsten) were registered in 2013 in the territory of Slovakia. Total geological ore reserves reached 335 Mt. Estimation of total metal amount in geological reserves is in Tab. 3.10 and Fig. 3.3.

Exploitation of ores, extensively mined in the past, is limited due to exhaustion of resources, low ore grade and present economic and legal conditions. The only exploited metal deposit is Banská Hodruša I at present, where gold ore is mined since 1993, although history of gold mining is known from 13th century there. Production of metals in 2011-2013 period is figured in Tab. 10.

3.4 Conclusion

Although present metal raw material basis provides relatively wide variety of mineral deposits, real exploitation of metal reserves, extensively mined in the past, is limited due to exhaustion of resources, low ore grade and present economic and legal conditions. The only currently exploited metal deposit is Banská Hodruša I, where gold-silver ores are mined. All production of concentrate is being exported. Because of a large import volume of metals (iron ore, zinc, materials for aluminium, iron and ferroalloys metallurgy) foreign trade metal balance of Slovakia has been permanently passive. Domestic consumption of these metals is covered mainly by import.

Slovak and similarly European production of metals covers only negligible part of the EU economy demands. Ongoing initiatives (Raw Material Initiative, Critical Minerals) point out the necessity of metals and minerals securing, including reevaluation of domestic resources. Slovakia´s potential of EU critical metals includes antimony and tungsten reserves and minerals for metal magnesium and silicon production.

Acknowledgements

The author also expresses his gratitude to peer reviewer for his valuable notes and propositions.

References

Baláž, P. & Kúšik, D., 2014: Slovak Minerals Yearbook 2014. SGIDŠ, Vydavateľstvo D. Štúra, 150 p., ISBN 978-80-8174-004-6

Grecula, P., Lexa, J. & Tozsér, J., 1997: Mineral resources of Slovakia. Bratislava: Ministry of the Environment of Slovak Republic, Geological Survey of Slovak Republic. 53 p. ISBN 80-967018-5-1

Lexa, J., Bačo, P., Hurai, V., Chovan, M., Koděra, P., Petro, M., Rojkovič, I. & Tréger, M., 2007: Explanatory notes to the metallogenetic map of Slovak Republic 1 : 500 000. SGIDŠ. 178 p. ISBN 978-80-89225-11-8

Zuberec, J., Tréger, M., Lexa, J. & Baláž, P., 2005: Nerastné suroviny Slovenska. (Mineral resources of Slovakia). Bratislava, SGIDŠ. 350 p. ISBN 80-88974-77-1

4. Reinterpretation of Panned Concentrates Exploration at the Territory of Slovakia

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Abstract. About 70% of the Slovak Republic territory is explored by panned concentrate survey. Implementation of regional projects of panned concentrate prospection covered almost the 35 year period (years 1962-1992) divided into four separate stages. Only lowlands and the areas with intense and widespread regulation of water flows have remained untouched by sampling. From about 65 thousand samples originally collected a database has been created keeping information on about 51,000 panned concentrates samples. The samples were located in JTSK coordinate system and displayed in the topographic groundwork at scale 1 : 50,000. Part of the panned concentrate samples was mineralogically re-evaluated using newer methods of identification, for example luminescence, dye tracing tests which has resulted in the most uniform processing and assessment of the sample material. The database has allowed to prepare distribution maps of selected types of minerals for the whole territory of Slovakia covered by the sampling. This relates to especially important mineral prospecting species or groups thereof, e.g.: cinnabar, scheelite, gold, barite, cassiterite, tungsten and others. There were also compiled distribution maps of potentially prospecting important accessory minerals such as monazite, xenotime, zircon, ilmenite, rutile, corundum, garnet and others. This way a digital database of panned concentrate samples was created, ideally with more than 60 variables for the sample. This database enables to produce different distribution and interpretive maps according to defined objectives. There is also stored panned concentrate material documentation, which ideally consists of oversize, magnetic, diamagnetic and paramagnetic fractions. An Atlas of Selected Heavy Minerals is published on the website of the State Geological Institute of Dionýz Štúr - Map Portal, Section Atlases.

Key words: heavy minerals, panned concentrate prospecting, localization maps, distribution maps

4.1 Introduction

The modern application of the old prospecting method of panning started in our conditions in the early 60s of the last century. From then until 2000 there were carried out in four stages 12 separate regional projects of the panned concentrate prospecting. All previously realized work covered about 70% of the territory of Slovakia, and there were taken around 65,000 samples. Their evaluation was focused mainly on prospecting minerals and contributed significantly to the knowledge of metallogeny in each regional geological unit. The panned concentrate prospection enabled to discover certain occurrences, or deposits (Ladomírov, Dubník, Jasenie, Sn mineralisation in Gemericum, W and Au mineralisation in Veporicum, etc). During nearly 40 years of the panned concentrate survey some methodologies were changing in assessing the panned concentrate samples and the number of monitored and assessed of minerals rose. Those archived samples which met the localization parameters were included together with passportisation sheets in the database for comprehensive processing and interpretation of mineralogical analyses of the panned concentrate samples. The database contains approximately 51,000 samples with more than 60 variables. On this basis, there were compiled Distribution (1:50,000) and Interpretation (1:800,000) maps for the territory of Slovakia covered by sampling (Bačo et al., 2004b).

4.2 Sampling and processing methodology

The goal of the re-interpretation of the panned concentrate survey in Slovakia was to collect and evaluate the available sample material of individual regional projects (Fig. 4.2) in a comparable manner. The first stage of the regional projects devoted to the panned concentrates survey began with prospecting work in the area of East-Slovakia Neovolcanites (Tab. 4.1, Fig. 4.1). The stage was aimed at a targeted search for prospecting significant minerals or group of such minerals. The initial stage brought a number of new knowledge, which resulted in the subsequent geological prospecting works.

The samples were taken at 250-500 m spacing intervals from recent sediment hydrological pattern. The volume of the sediment to be determined by panning was approximately 10 l after sieving through a sieve of 3 mm mesh. As a rule, the volume corresponded to that of a prospector's pan. This procedure and the volume were kept almost unchanged during solution of all projects within each stage. The evaluation methods in the individual projects were different, according to the objective pursued. From the first stage there has been preserved physically smallest number of samples (about 10,000). The passportisation sheets of individual samples refer to the location data, physical parameters of the sample, the results of mineralogical anal-

Tab. 4.1 Projects of regional panned concentrate prospecting – Ist stage.

No	Project designation	Year of Completion	Coordinator	Number of Samples
	Ist stage			27,339
1.	Vihorlat – Popričný, Prospection	1969	J. Slávik	2,780
2.	East Slovakia – Au	1971	I. Križáni	3,516
3.	Prešov-Tokaj Mts.	1972	J. Tözsér	3,032
4.	Kremnické vrchy Mts.	1972	J. Knésl	4,420
5.	Spiš-Gemer Mts. – South I. II.Prospection – Hg, Cu and other base metals	1973	I. Varga	873
6.	Vranov – Kelča – Hg Ores, Prospection	1977	I. Križáni	2,025
7.	Vysoké Tatry – Prešov, complex mineralogical-geochemical prospection	1979	I. Križáni	8,484
8.	Spiš-Gemer Mts. – High-Thermal Mineralisation, Prospection	1983	P. Malachovský	2,209

ysis and eventual chemical analyses allowed to process and finally include into the database about 27,339 of the samples (Fig. 4.2).

The second stage of the regional panning works (Tab. 4.2) adopted a uniform methodology for panned concentrate sampling, but still different ways of semi-quantitative evaluation of heavy minerals. In parallel with panning works the project 9j (Tab. 4.2) collected also the samples of stream sediments. This project covered a territory of the Tatricum and Veporicum Crystalline (Core Mountains) and partly their Mesozoic unit cover.

Tab. 4.2 Projects of regional panned concentrate prospecting – IInd stage.

No	Project designation	Year of Completion	Coordinator	Number of Samples
	IInd stage			
9.	Regional geochemistry of the W. Carpathians – Ores Prospection	1985	J. Knésl, V. Maťová	22,831
9a.	Malé Karpaty Mts.	1985	S. Polák, P. Hanas	1,413
9b.	Považský Inovec Mts.		S. Polák, P. Hanas	1,273
9c.	Tribeč Mts.		S. Polák, P. Hanas	668
9d.	Suchý – M. Magura Mts.		S. Mikoláš	1,217
9e.	Malá Fatra Mts.		S. Mikoláš	763
9f.	Veľká Fatra Mts.		G. Kravjanský, Z. Hroncová	600
9g.	Nízke Tatry Mts. – West		J. Knésl, V. Maťová	2,554
9h.	Nízke Tatry Mts. – East		J. Knésl, V. Maťová	2,450
9i.	Západné Tatry Mts.		G. Kravjanský, Z. Hroncová	393
9j.	Slovenské rudohorie Mts. – W part		P. Hvožďara, M. Linkešová	11,500

Based on the results of this stage there were implemented several prospecting projects, mainly in the Nízke Tatry Mts. and Veporicum. The sample material has been preserved to about 70%, but quite variably in the different regions. The preserved and well-localised panned concentrate samples and their passportisation sheets allow to process and include into the database about 18,500 of the samples (Fig. 4.2).

The third stage of the regional panning works (Tab. 4.3) was concentrated in the remaining parts of the territory of Slovakia, with the exception of the Danube and the East-Slovakian lowlands (Fig. 4.1). This stage of work is characterized by a uniform method of collection, mineralogical analysis and unified methodology of evaluation and interpretation. In this stage, the undersize fraction (< 0.16 mm) was for the first time chemically analysed and evaluated in the SQFD range (Semi-Quantitative Flame Diffraction). Although most of the work was done outside the potential appearance of ore resources, this stage did find a range of the anomalous regions of the secondary dispersion of significant prospecting minerals and elements. From this stage there has been preserved about 90% of the sample material.

The fourth stage (tab. 4.4) of the panned concentrate survey comprised the projects that were specifically targeted and covered the areas with poorly preserved sample material from the first or second stages of exploration. This was particularly the part of the territory of Gemericum and the Levočské vrchy Mts. area that was previously an area of special protection without the possibility of the panned concentrate sampling. These projects contributed the results of mineralogical analyses of 1,530 samples.

After the archival processing and revision of the panned concentrate samples and passportisation sheets the samples were marked in individual maps at 1:50,000 scale based on the sampling location maps of the respective projects and there were assigned to them topographic coordinates. In new maps there were plotted only unequivocally localised samples with preserved documentation material. Only in exceptional cases the samples were accepted whose location and contents were retrieved from the relevant distribution maps of individual minerals in their original projects. This way into the database there were transferred only localisation and content of those minerals (minerals of groups) that have been the subject of the distribution maps of respective projects, for example, in the case of the Crystalline of Suchý, Malá Magura, Žiar and Veľká Fatra Mts.

The obtained sample material is the primary database that includes original recordings with all the original data. It is archived and accessible, allowing the study of the original records. It has become also an underlying database for about 51,000 samples with more than 60

Fig. 4.1

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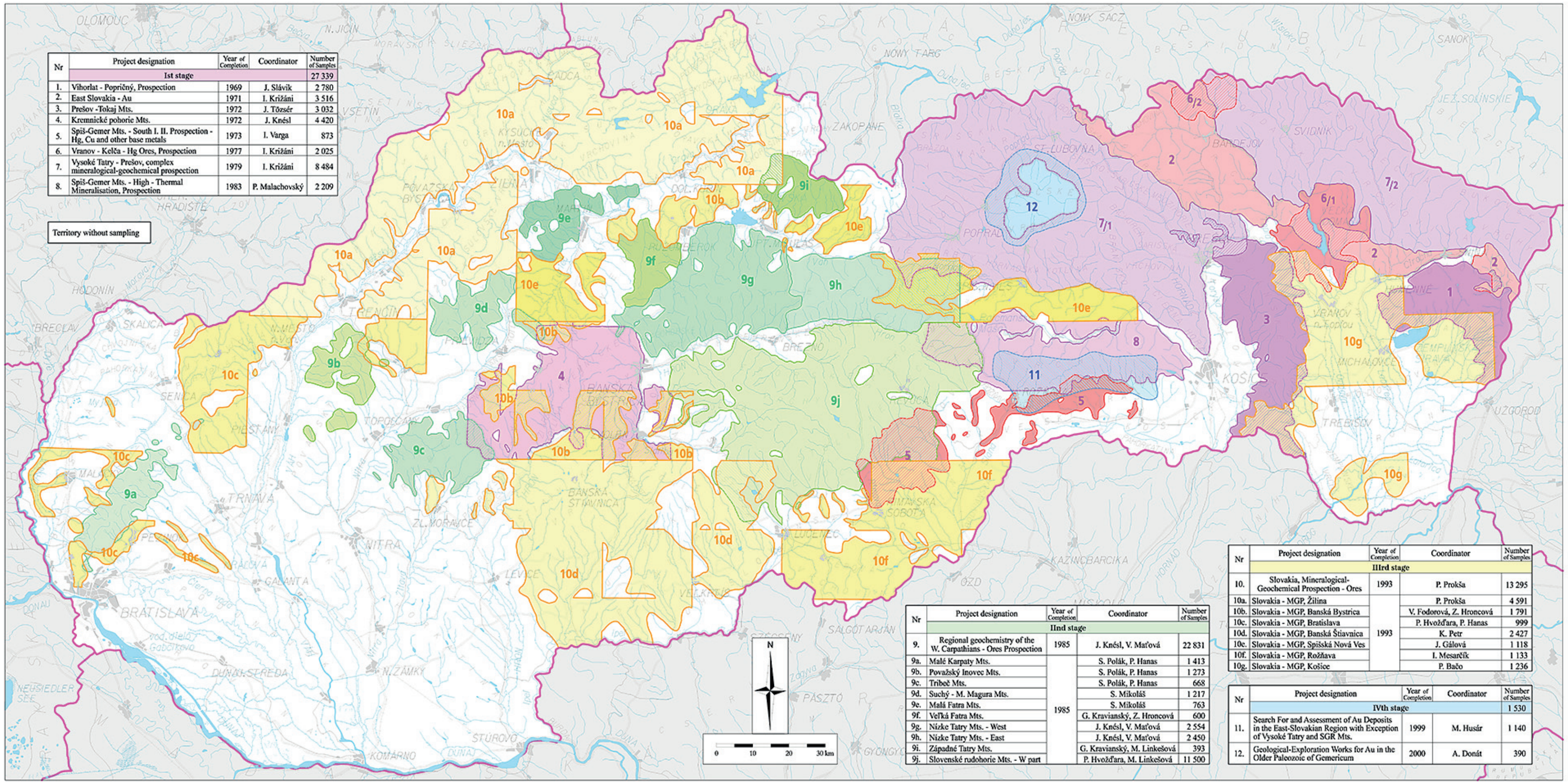
GENERAL MAP OF THE TASKS OF REGIONAL PANNING PROSPECTION

REINTERPRETATION OF THE PANNED CONCENTRATES
SURVEY IN THE TERRITORY OF SLOVAKIA



Nr	Project designation	Year of Completion	Coordinator	Number of Samples
	Ist stage			27 339
1.	Vihorlat - Popričný, Prospection	1969	J. Slávik	2 780
2.	East Slovakia - Au	1971	I. Križáni	3 516
3.	Prešov -Tokaj Mts.	1972	J. Tözsér	3 032
4.	Kremnické pohorie Mts.	1972	J. Knésl	4 420
5.	Spiš-Gemer Mts. - South I. II. Prospection - Hg, Cu and other base metals	1973	I. Varga	873
6.	Vranov - Kelča - Hg Ores, Prospection	1977	I. Križáni	2 025
7.	Vysoké Tatry - Prešov, complex mineralogical-geochemical prospection	1979	I. Križáni	8 484
8.	Spiš-Gemer Mts. - High - Thermal Mineralisation, Prospection	1983	P. Malachovský	2 209

Nr	Project designation	Year of Completion	Coordinator	Number of Samples
	IInd stage			
9.	Regional geochemistry of the W. Carpathians - Ores Prospection	1985	J. Knésl, V. Maťová	22 831
9a.	Malé Karpaty Mts.	1985	S. Polák, P. Hanas	1 413
9b.	Považský Inovec Mts.		S. Polák, P. Hanas	1 273
9c.	Tribeč Mts.		S. Polák, P. Hanas	668
9d.	Suchý - M. Magura Mts.		S. Mikoláš	1 217
9e.	Malá Fatra Mts.		S. Mikoláš	763
9f.	Veľká Fatra Mts.		G. Kraviansky, Z. Hroncová	600
9g.	Nízke Tatry Mts. - West		J. Knésl, V. Maťová	2 554
9h.	Nízke Tatry Mts. - East		J. Knésl, V. Maťová	2 450
9i.	Západné Tatry Mts.		G. Kraviansky, M. Linkešová	393
9j.	Slovenské rudohorie Mts. - W part		P. Hvožďara, M. Linkešová	11 500

Nr	Project designation	Year of Completion	Coordinator	Number of Samples
	IIIrd stage			
10.	Slovakia, Mineralogical-Geochemical Prospection - Ores	1993	P. Prokša	13 295
10a.	Slovakia - MGP, Žilina	1993	P. Prokša	4 591
10b.	Slovakia - MGP, Banská Bystrica		V. Fodorová, Z. Hroncová	1 791
10c.	Slovakia - MGP, Bratislava		P. Hvožďara, P. Hanas	999
10d.	Slovakia - MGP, Banská Štiavnica		K. Petr	2 427
10e.	Slovakia - MGP, Spišská Nová Ves		J. Gálová	1 118
10f.	Slovakia - MGP, Rožňava		I. Mesarčík	1 133
10g.	Slovakia - MGP, Košice		P. Bačo	1 236

Nr	Project designation	Year of Completion	Coordinator	Number of Samples
	IVth stage			1 530
11.	Search For and Assessment of Au Deposits in the East-Slovakian Region with Exception of Vysoké Tatry and SGR Mts.	1999	M. Husár	1 140
12.	Geological-Exploration Works for Au in the Older Paleozoic of Gemericum	2000	A. Donát	390

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Tab. 4.3 Projects of regional panned concentrate prospecting – III[rd] stage.

No	Project designation	Year of Completion	Coordinator	Number of Samples
	III[rd] stage			
10.	Slovakia, Mineralogical-Geochemical Prospection – Ores	1993	P. Prokša	13,295
10a.	Slovakia – MGP, Žilina	1993	P. Prokša	4,591
10b.	Slovakia – MGP, B. Bystrica		V. Fodorová, Z. Hroncová	1,791
10c.	Slovakia – MGP, Bratislava		P. Hvožďara, P. Hanas	999
10d.	Slovakia – MGP, B. Štiavnica		K. Petr	2,427
10e.	Slovakia – MGP, Sp. Nová Ves		J. Gálová	1,118
10f.	Slovakia – MGP, Rožňava		I. Mesarčík	1,133
10g.	Slovakia – MGP, Košice		P. Bačo	1,236

Tab. 4.4 Projects of regional panned concentrate prospecting – IV[th] stage.

No	Project designation	Year of Completion	Coordinator	Number of Samples
	IV[th] stage			1,530
11.	Search For and Assessment of Au Deposits in the East-Slovakian Region with Exception of Vysoké Tatry and SGR Mts.	1999	M. Husár	1,140
12.	Geological-Exploration Works for Au in the Older Paleozoic of Gemericum	2000	A. Donát	390

variables for each sample. The mineralogical analysis of the samples was consolidated into semi-quantitative classes: **a** (up to 10 grains of the panned concentrate or up to 1%), **b** (11 - 100, or up to 5%), **c** (101 – 500, or up to 10%), **I** (up to 25% of the panned concentrate sample), **II** (up to 50%) and **III** (above 50%).

From the database distribution maps were compiled for 37 kinds of minerals on 100 map sheets 1:50,000 covering all the sampled territory of Slovakia. At a scale of 1:750,000 distribution maps were compiled in the form of isoplanes for 37 kinds of minerals presented in 28 pieces of maps.

The database, representing an overview of more than 60 variables (physical quantities – particle size, weight, etc., mineralogical characteristics – types of minerals, and other heavy components), all the samples are presented as a public database (Annex of the final report Bačo et al., 2004b, and at the website www.geology.sk – Map Portal, Section Atlases). On its basis it is also possible to prepare purpose-made distribution maps depending on pursued aspect – geological, metallogenic, environmental and so on.

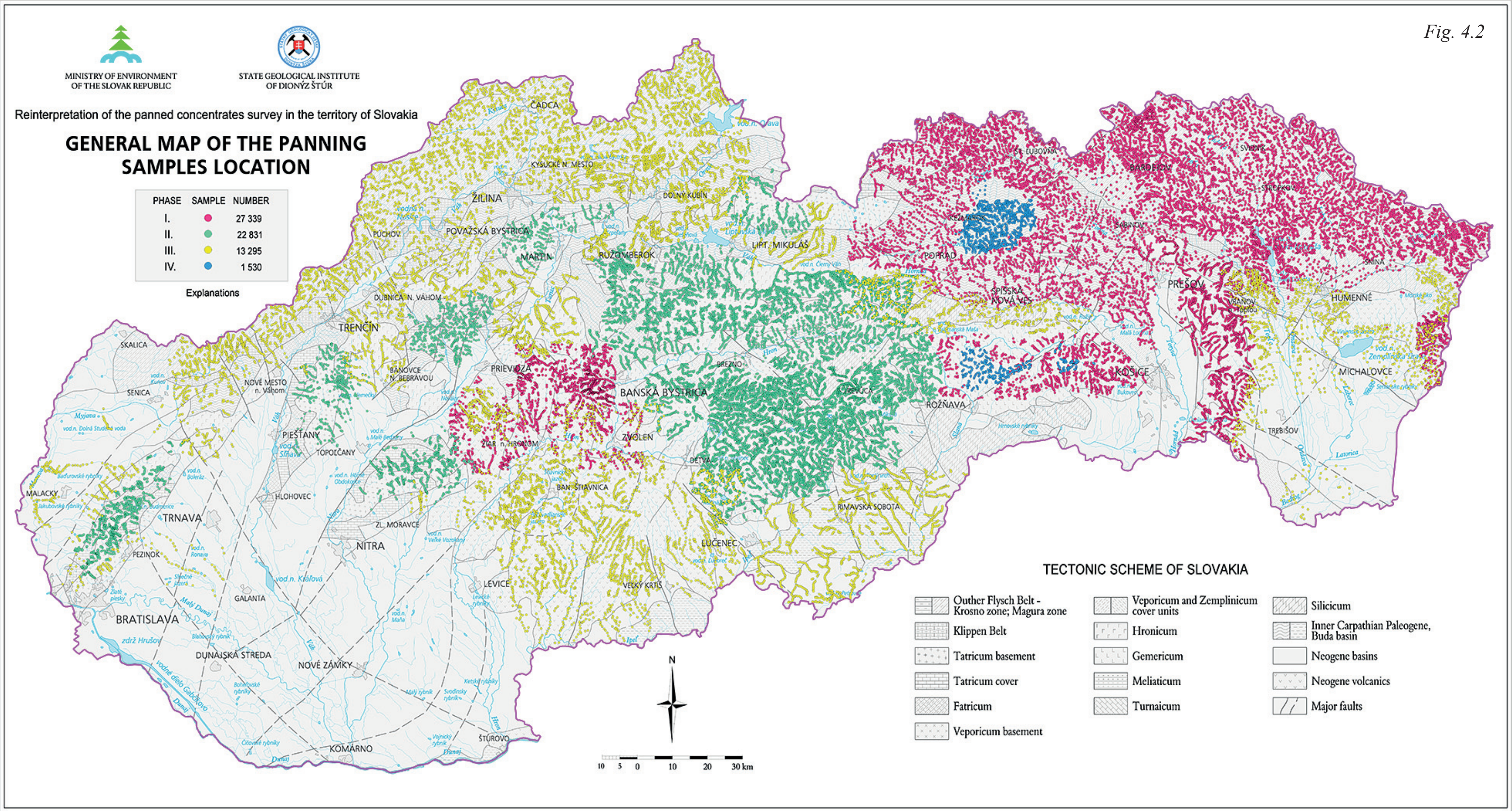
In the period of 1960-1993 there were carried out further local projects aimed at specific prospection or the overall characteristics of area under study. The amount of samples taken ranged from several dozen to several hundred. Among the projects which have a greater range, we can include those whose aim was sampling and evaluation of the eastern part of the Malá Magura Mts. (Böhmer & Hvožďara, 1969), a wider area of the Kremnické vrchy Mts. (Böhmer & Mecháček, 1978), the southern slopes of the central part of the Nízke Tatry Mts. – prospection for scheelite mineralisation (Pulec, 1976, 1977a, b), Javorie and Poľana Mts. (Böhmer & Antal, 1981), Branisko and Čierna Hora Mts. (Fulín, 1987) and the area of the contact zone of Veporicum and Gemericum (Határ et al., 1994). In the aggregate reinterpretation these projects have not been included because of the complete absence of documentation material – panned concentrate samples and very different methodology in their mineralogical evaluation.

The distribution maps for each of the selected minerals and group of minerals at scale 1:750,000 were drawn up based on statistical processing of their contents. In order to show the distribution of the majority of minerals, they were displayed as isoplanes. While creating a set of grid points, kriging method was used with increments of 1 km and 3 km radius of selection, with a lower frequency of positive mineral occurrence there was used point display. A component of the map is the frequency distribution histogram according to the nature of the mineral displayed, either the number of grains or the relative size of semi-quantitative class. The ground layer of the Slovak territory display is the tectonic map (Biely et al., 1996) in the form of hatch patterns. The creation of isoplanes of mineral distribution was carried out in a graphical environment of the product Surfer, Golden Software and the actual map outputs were finalised in the environment MicroStation V7, Bentley Corp.

4.3 Results of the panned concentrates prospecting re-interpretation

The main result is the creation of the database and the distribution maps for selected minerals and mineral groups. Part of the map documents is an essential characteristic of evaluated mineral in panned concentrate specimens and general characteristics of the distribution documented statistically by selected parameters. The mineralogical analyses of samples in the scope of panned concentrate prospecting didn't quantified individual mineral species of certain groups of minerals, for example, group of garnet minerals, apatite, monazite, and tourmaline. Therefore their distribution maps show the potential of any specific mineral species present in certain group. While characterising individual minerals those properties are given that are identified in panned concentrate samples. Their magnetic characterisation applies to separation by isodynamic electromagnet at the following conditions: 1.2 Amp, side slope 15° and tilt of 20°, luminescence properties observed in the short-wave UV spectrum (monochrome, λ = 254 nm).

Fig. 4.2


MINISTRY OF ENVIRONMENT
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STATE GEOLOGICAL INSTITUTE
OF DIONÝZ ŠTÚR
Reinterpretation of the panned concentrates survey in the territory of Slovakia
GENERAL MAP OF THE PANNING SAMPLES LOCATION
PHASE SAMPLE NUMBER
I. 27 339
II. 22 831
III. 13 295
IV. 1 530
Explanations
TECTONIC SCHEME OF SLOVAKIA
Outher Flysch Belt - Krosno zone; Magura zone
Klippen Belt
Tatricum basement
Tatricum cover
Fatricum
Veporicum basement
Veporicum and Zemplinicum cover units
Hronicum
Gemericum
Meliaticum
Turnaicum
Silicicum
Inner Carpathian Paleogene, Buda basin
Neogene basins
Neogene volcanics
Major faults
N
10 5 0 10 20 30 km
ČADCA
KYSUCKÉ N. MESTO
ŽILINA
DOLNÝ KUBÍN
PÚCHOV
POVAŽSKÁ BYSTRICA
MARTIN
RUŽOMBEROK
LIPT. MIKULÁŠ
POPRAD
BARDEJOV
SVIDNÍK
PREŠOV
HUMENNÉ
SPIŠSKÁ NOVÁ VES
KOŠICE
MICHALOVCE
TREBIŠOV
ROŽŇAVA
DUBNICA N. VÁHOM
TRENČÍN
SKALICA
SENICA
NOVÉ MESTO n. Váhom
BÁNOVCE N. BEBRAVOU
PRIEVIDZA
BANSKÁ BYSTRICA
BREZNO
ZVOLEN
DETVA
PIEŠŤANY
TOPOĽČANY
MALACKY
TRNAVA
HLOHOVEC
BAN. ŠTIAVNICA
RIMAVSKÁ SOBOTA
ZL. MORAVCE
NITRA
LUČENEC
PEZINOK
LEVICE
VEĽKÝ KRTÍŠ
GALANTA
BRATISLAVA
DUNAJSKÁ STREDA
NOVÉ ZÁMKY
KOMÁRNO
ŠTÚROVO

Slovak Geol. Mag., 15, 2 (2015), 39 – 86

4.3.1 Anatase TiO_2

H (hardness) = 5.5 – 6.0; **System:** Tetragonal
SG (specific gravity) = 3.8 – 4.0 g.cm^{-3};
Magnetic properties: non-magnetic, and is concentrated in diamagnetic fraction.

Colour in the panned concentrate samples

Colour of anatase in the panned concentrate samples is mostly brown, cinnamon brown to reddish, in different grades and shades (Fig. 4.3a). This type of anatase is typical for the panned concentrates from the Tribeč Mts. Metallic-blue to black colour (Fig. 4.3b) dominates in the panned concentrates of the source areas in Veporicum consisting mainly of granitic rocks. Occasionally, in the panned concentrate samples also small colourless crystals occurred.

Lustre on smooth surfaces of translucent small crystals and small debris is distinct, diamond-like. On the darker coloured crystals of anatase the lustre is metallic. Roughened surfaces have a dull lustre.

Morphology in the panned concentrate samples

In the panned concentrate samples anatase is present mostly in the form of tetragonal dipyramids (Fig. 4.3b, 4.4a); the most common are base {111} and steeper {112} dipyramids and combination of them. The steeper one gradually passes into the prism plane (110). Part of small crystals of anatase may evolved secondary pyramid with reduced plane and the resulting shape is ditetragonal dipyramid (Fig. 4.4a). On the anatase of some sites there are developed pinacoidal planes {001} that can turn from the dipyramid shape

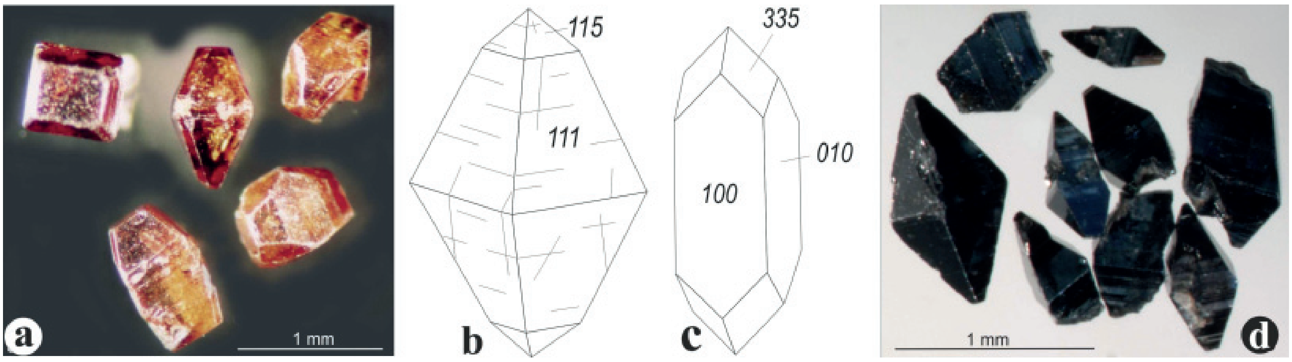


Fig. 4.3a, b, c, d Typical shapes and colour of anatase in the panned concentrate samples. For individual source areas these two features are often characteristic. Site: a – Tribeč, site Zlatno; d – Veporicum – Kocižský potok Brook. Drawings: Rösler, J. H., 1983. Photo: Z. Bačová.

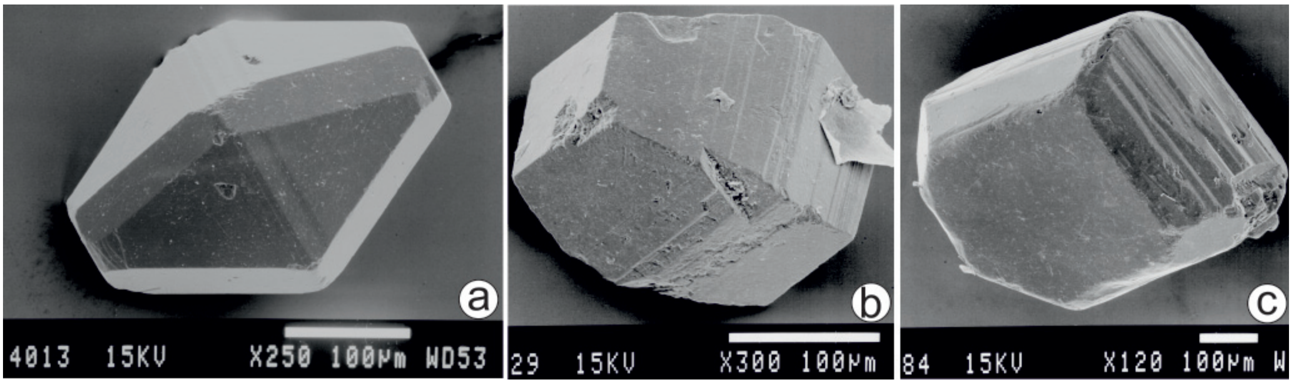


Fig. 4.4a, b, c Typical shapes of accessory anatase from source areas made of prevailingly granitoid rocks. a, c – Tribeč, site Zlatno; b – Tatricum – site Kráľova Lehota. Photo: SEM I. Holický.

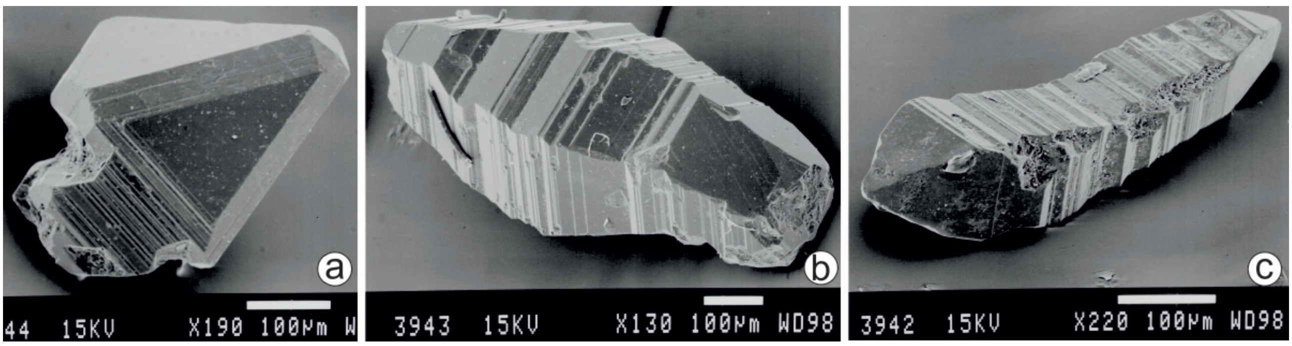


Fig. 4.5a, b, c Typical shapes of accessory anatase from the source areas made of metamorphic rocks of Veporicum, prevailingly. a, c – Veporicum, site Hnúšťa; b – site Pohronská Polhora. Photo: SEM I. Holický.

even into the tabular one (Fig. 4.3a and 4.4c).

Probably of typological importance are the anatases with irregular, hypidiomorphic development (various types of intergrowths even with cyclical pattern (Fig. 4.5a, b, c). Their occurrences are characteristic for the source areas made of metamorphic rocks, often with the presence of Alpine veins paragenesis. Epitaxial coalescence of anatase with other minerals has not been observed in the panned concentrate samples.

During transport due to their hardness and poor cleavability the anatases are very persistent and they become clastogenic component of sediments. Small crystals in the panned concentrate samples have typical dimensions of 0.5 to 1.0 mm, occasionally up to 2 mm.

Tab. 4.5 Presence of anatase in the panned concentrate samples according to content classes.

Database of samples	Negative	Content (semi-quantitative classes)					
	Positive	**a**	**b**	**c**	**I**	**II**	**III**
50,939	30,294	11,057	6,377	2,948	259	3	1
	58	22	13	5.79	0.51	0.006	0.002
	20,645	11,057	6,377	2,948	259	3	1
	41	53.56	30.89	14.28	1.25	0.01	0.00

General distribution characteristics

Anatase was observed in almost half of all evaluated panned concentrate samples (Tab. 4.5; Fig. 4.6a). The concentration of anatase in the panned concentrate samples ranges in the first content classes: a; b; c (Tab. 4.5; Fig. 4.6b, c).

Anatase is a typical accessory mineral and is present in the panned concentrate samples from source areas of almost all regional geological formations (Fig. 4.7). However, it is a typical accessory mineral of some Tatricum and Veporicum granitoids and metamorphic rocks of Veporicum, mainly. It is a component of the paragenesis of the mineralisation type of the Alpine veins.

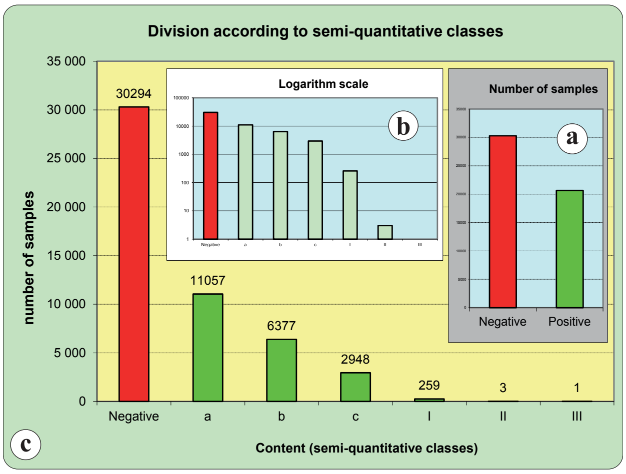
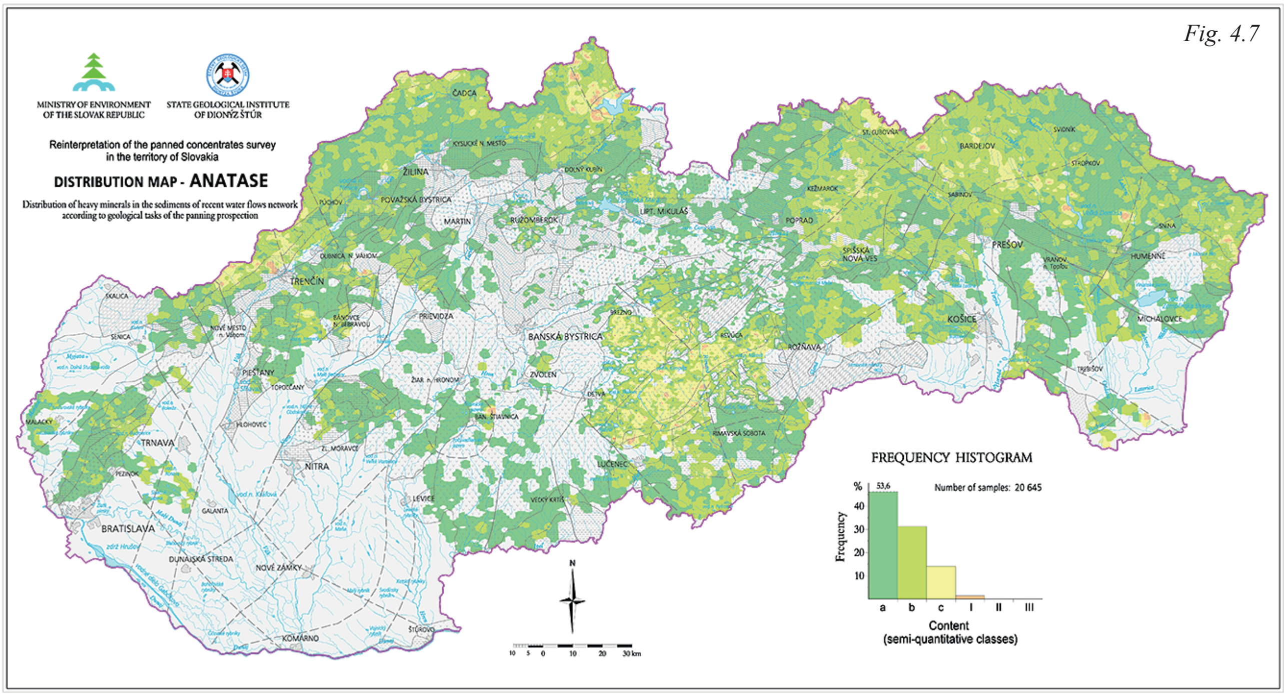


Fig. 4.6a, b, c Distribution of panned concentrate samples according to anatase presence – a. Concentration of anatase is mainly in the first and the second quantitative classes – b, c.



The anatase has entered the Flysch units environment as clastogenic mineral. It is markedly absent in the Neogene volcanic rocks and Mesozoic carbonate environment (Fig. 4.7).

4.3.2 Apatites

Chlorapatite $Ca_5(PO4)_3Cl$; Fluorapatite $Ca_5(PO_4)_3F$; Hydroxylapatite $Ca_5(PO_4)_3(OH)$

H = 4.5 (Cl) – 5.0 (F, Cl); **SG** = 3.16 – 3.22 g.cm^{-3}; **System:** Hexagonal

For the purposes of panned concentrate prospecting for minerals of apatite group (fluorapatite, chlorapatite, hydroxyapatite and other varieties) it was used customary common name apatite.

Magnetic properties: non-magnetic, and is concentrated in diamagnetic fraction.

Luminescence: greenish and orange, in some grains luminescence is indistinguishable.

Colour in the panned concentrate samples

Colour of apatite in the panned concentrate samples is most often white, grey-white, less often orange or brownish in different grades and shades (Fig. 4.8b). Smoke-coloured apatites originate from the environment of Neogene volcanic rocks. In some types of granitic rocks the apatites are translucent. Lustre on flat surfaces is glassy, on fracture planes or on corroded small crystals and grains it is dull.

Fig. 4.8a, b, c Typical shapes and colour of apatite in the panned concentrate samples. On small crystals of apatite prismatic planes dominate with regular and identical habit (a) or irregular (c) one. The crystal termination can be characterised by dominant pinacoid shape (a) or the pyramid (c). Drawings: Rösler, J. H., 1983. Photo (b): P. Bačo.

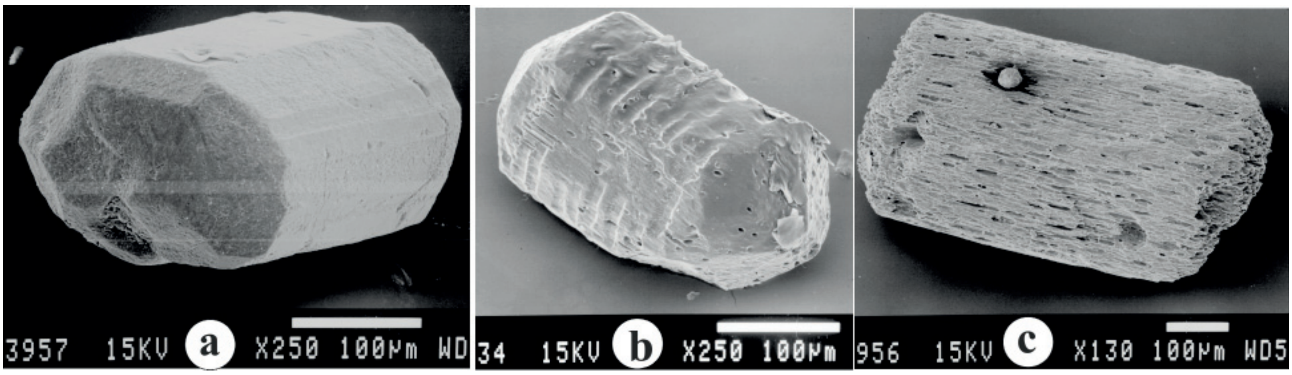


Fig. 4.9a, b, c The most frequent and typical shapes of small crystals of apatite from panned concentrate samples of individual geological environs. Typical and perfect shapes – combination of planes of prisms, pyramid and pinacoid (a). Characteristic are planes` surfaces with different manifestations of disintegration (b, c). Sites: Pukanec (a); Zamutov (b); Hodruša (c). Photo: SEM I. Holický.

Morphology in the panned concentrate samples

In the panned concentrate samples the apatites are present mostly in the form of hexagonal columnar, coarse-prismatic to small isometric crystals, on which dominating are prismatic planes (Fig. 4.9). During transport they are trimmed, rounded up and in the environment of sedimentary rocks (Flysch Zone) the apatites consist of fully rounded grains.

Epitaxial coalescence with other minerals of apatite in the panned concentrate samples doesn't occur, in general (e.g. with monazite). More often, in clear crystals dark cores can be observed. Size of small crystals, their fragments or grains in the panned concentrate samples is up to 0.5 mm, rarely up to 1.0 mm.

General distribution characteristics:

As accessory mineral, the apatite is present mainly in magmatic (Broska et al., 2012) and metamorphic rocks. Quite often it is also associated with various types of hydrothermal mineralisation. Its presence was recorded in

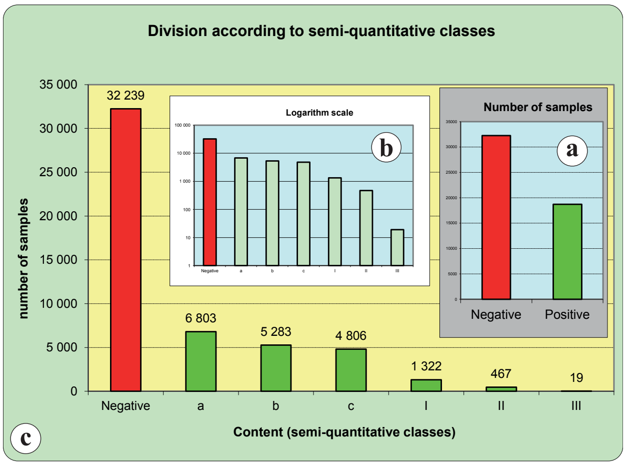


Fig. 4.10a, b, c Distribution of panned concentrate samples according to apatite presence – a. Concentration of apatite is mainly in the first and the second quantitative classes – b, c.

more than one third of the all evaluated panned concentrate samples (Tab. 4.6; Fig. 4.10a). The concentrations of apatite in the panned concentrate samples were observed almost evenly in the first content classes: a; b; c (Tab. 4.6; Fig. 4.10b, c).

Tab. 4.6 Presence of apatite in the panned concentrate samples according to content classes.

Database of samples	Negative	Content (semi-quantitative classes)					
	Positive	**a**	**b**	**c**	**I**	**II**	**III**
50,939	32,239	6,803	5,283	4,806	1,322	467	19
	63	14	10	9.43	2.60	0.92	0.04
	18,700	6,803	5 283	4 806	1 322	467	19
	37	36.38	28.25	25.70	7.07	2.50	0.10

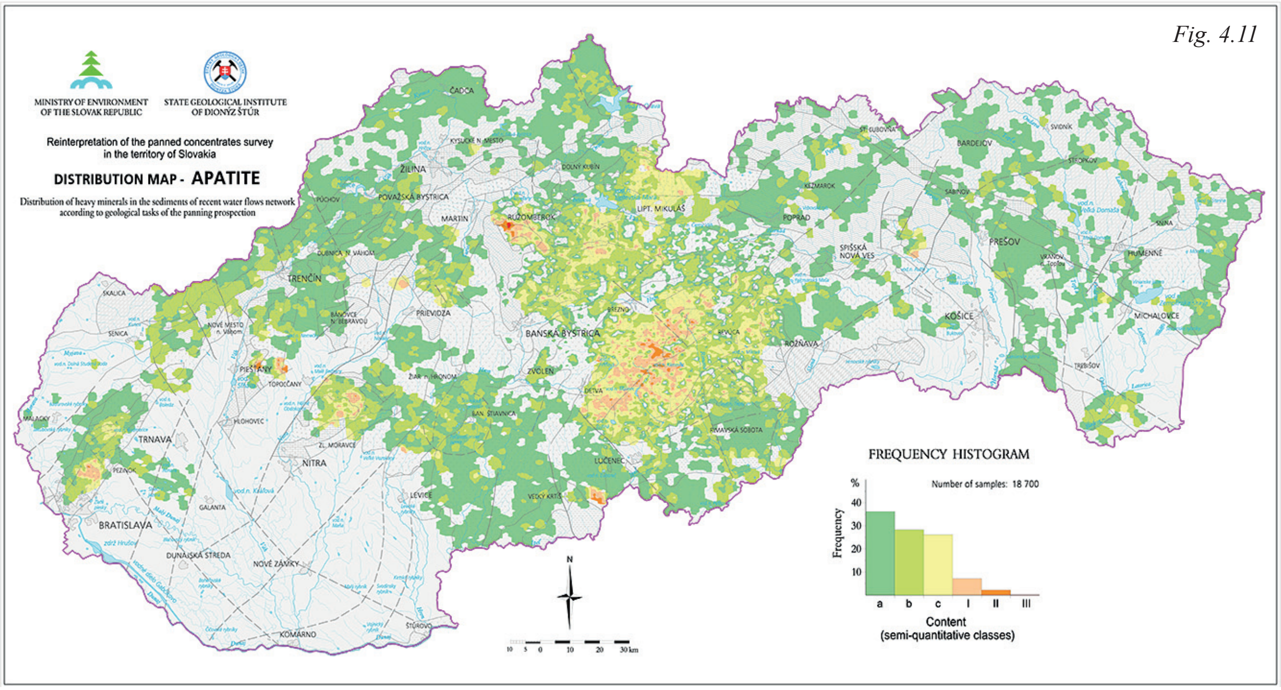


Fig. 4.11

In rare cases, within source area made of granites of the type I, for example, granitoids of the Sihla type (Fig. 4.11) the concentration of apatite in the panned concentrate samples is high and reaches higher content classes (I, II, and exceptionally up to III), i.e., they can create a significant portion of diamagnetic fraction, prevailing in the heavy fraction of panned concentrate samples. Similar concentrations were observed in the case of the source areas made of tonalites of Tribeč and Malé Karpaty Mts. (Fig. 4.11).

Increased incidence is also confirmed in territories made of the neovolcanic rocks. Significantly deficient are the areas made up of Mesozoic complexes and some parts of the Outer Flysch Zone.

4.3.3 Arsenopyrite FeAsS

H = 5.5 – 6.0; **SG** = 5.9 – 6.29 g.cm^{-3}; **System:** Monoclinic

Magnetic properties: concentrated in diamagnetic fraction

Colour in the panned concentrate samples

Colour of arsenopyrite in the panned concentrate samples is the most frequently grey-metallic, often with brown spots, as a manifestation of limonitisation (Fig. 4.12a, e). Near autochthonous occurrences or anthropogenic sources (dumps) small crystals have tin-white colour. Lustre on flat planes is metal, heavily corroded grains are dull.

Morphology in the panned concentrate samples

In the panned concentrate samples the arsenopyrite is often present in the form of pseudobipyramid - planes (101), and thereof fragments, rod-shaped and columnar {230}, and the small crystals and their fragments (Fig. 4.12b, c; Fig. 4.13a) and trimmed isometric grains originating from varied shapes (Fig. 4.12a). Besides the most common grains or grain aggregates the most common are the columnar fragments (Fig. 4.14a, b), in cross-section with strongly flattened rhombs (4.13a) and not uncommon in the tetragonal form and strongly flattened dipyramid (4.13b). On the columnar small crystals it can be observed grooving in the direction of extension (Figs. 4.12e and 4.13). Typical are also star-like intergrowths (Fig. 4.13c; Fig. 4.14c). Epitaxial overgrowth in the panned concentrate samples has not been observed.

Size of small crystals, their fragments or grains in the panned concentrate samples is normally within 0.5 to 1.0 mm. Grainy aggregates occur close to anthropogenic sources, and mainly in the dumps after mining activities, they can reach several mm.

Identification attributes: steel-grey colour, sometimes with brown spots (limonitisation), longitudinal grooving, rhombic cross-section, star-like intergrowths.

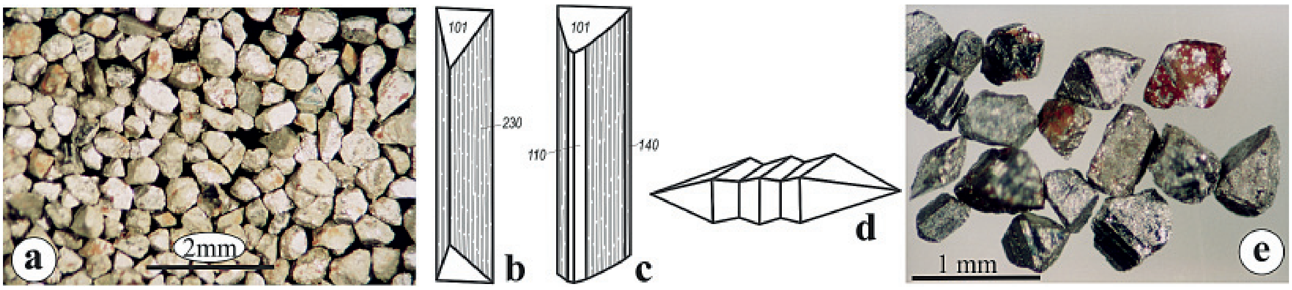


Fig. 4.12a, b, c, d, e Typical shapes and colour of arsenopyrite in the panned concentrate samples. Mostly it is present in the form of irregular sharply-edged fragments (a). Close to the source the crystal shapes are better preserved (b). Site: Nízke Tatry – Jasenie. Drawings: Rösler, J. H., 1983, Photo: P. Bačo.

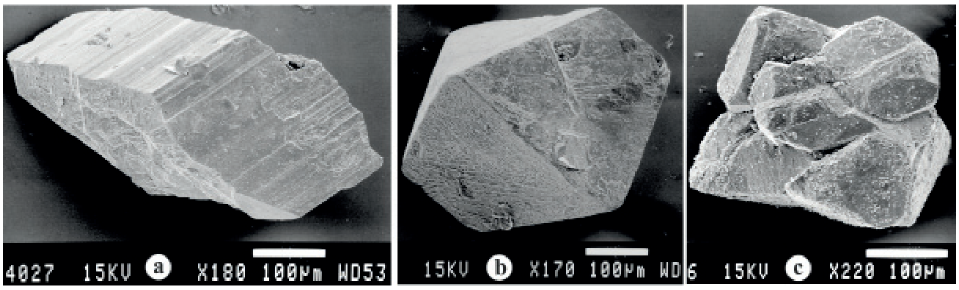


Fig. 4.13a, b, c Small crystals have columnar habit with longitudinal grooving. Characteristic is a rhombic cross-section. Sites: Jasenie-Kyslá (a); Hnúšťa (b); Horné Srnie, (c). Photo: SEM I. Holický.

General distribution characteristics:

Arsenopyrite is relatively common mineral in sulphide deposit occurrences. In the supergene environment arsenopyrite is not stable, and therefore its presence in the panned concentrate samples is often limited. Like the other sulphide minerals the arsenopyrite occurs mainly in the vicinity of anthropogenic sources – heaps and dumps near old workings.

Arsenopyrite was observed in a relatively small number of the assessed panned concentrate samples (Tab. 4.7; Fig. 4.15a). Its content is within the first concentration class: a; b, higher concentrations are very rare (Tab. 4.7; Fig. 4.15b).

Arsenopyrite is characterized by uneven distribution within geological formations, since it clearly reflects the presence of sulphide mineralisation (concentration in classes b and c) and not the rock – the lithological environment within the source areas. Regional extension is recorded in Veporicum, Gemericum and crystalline of the Malé Karpaty Mts., the Ďumbier part of the Nízke Tatry Mts. and the Žiar Mts. (Fig. 4.18).

In the other geological formations its presence is reported sporadically and its concentrations in the positive panned concentrate samples are within first quantitative classes (a, less b). Noteworthy is its distribution in the western parts of the Inner-Carpathian Paleogene and the Orava section of the Klippen Belt (Fig. 4.18).

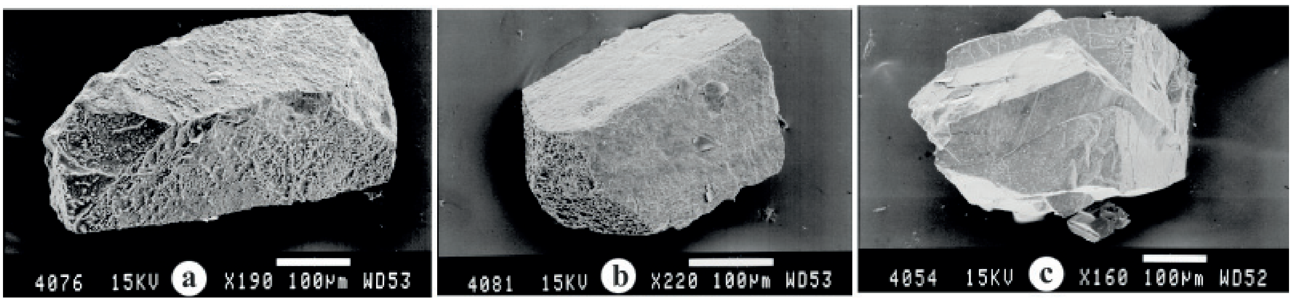


Fig. 4.14a, b, c In the panned concentrate samples besides of most common grains and granular aggregates of arsenopyrite, the fragments of columnar shape are present (a, b). Typical are also star-like intergrowths (c). Sites: Jasenie-Kyslá (a); Pezinok (b); Zlatá Idka (c). Photo: SEM I. Holický.

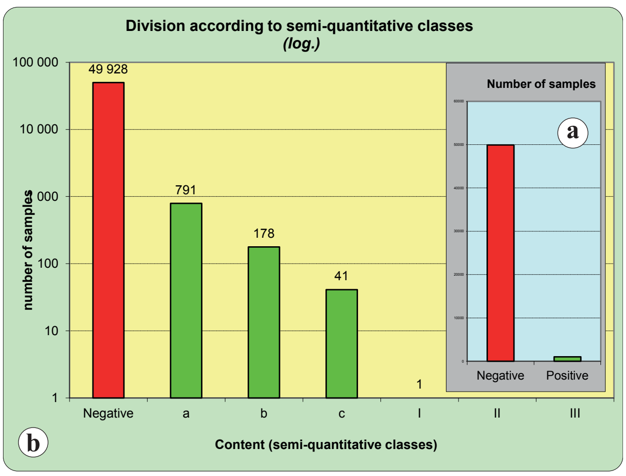


Fig. 4.15a, b Distribution of panned concentrate samples according to arsenopyrite presence – (a). Concentration of arsenopyrite is mainly in the first and the second quantitative classes – a, b (b).

Tab. 4.7 Presence of arsenopyrite in the panned concentrate samples according to content classes.

Database of samples	Negative	Content (semi-quantitative classes)					
	Positive	**a**	**b**	**c**	**I**	**II**	**III**
50,939	49,928	791	178	41	1	0	0
	98	1.553	0.349	0.080	0.002	0	0
	1,011	791	178	41	1	0	0
	2	78.24	17.61	4.06	0.10	0.00	0.00

4.3.4 Stibnite Sb_2S_3

H = 2.0 – 2.50; **SG** = 4.51 – 4.66 g.cm^{-3}; **System:** Rhombic

Magnetic properties: non-magnetic, and is concentrated in diamagnetic fraction

Colour in the panned concentrate samples

Colour of stibnite in panned concentrate samples is metallic grey, often with dark blue colour. Lustre on flat planes is metallic.

Morphology in the panned concentrate samples

In the panned concentrate samples stibnite is present only in the closest vicinity of the primary, but more often in the vicinity of anthropogenic sources. Small crystals are the most often thin-columnar and needle-like and the small crystals are "grooved" in the longitudinal direction (C-axis) (Fig. 4.16a, b, c.).

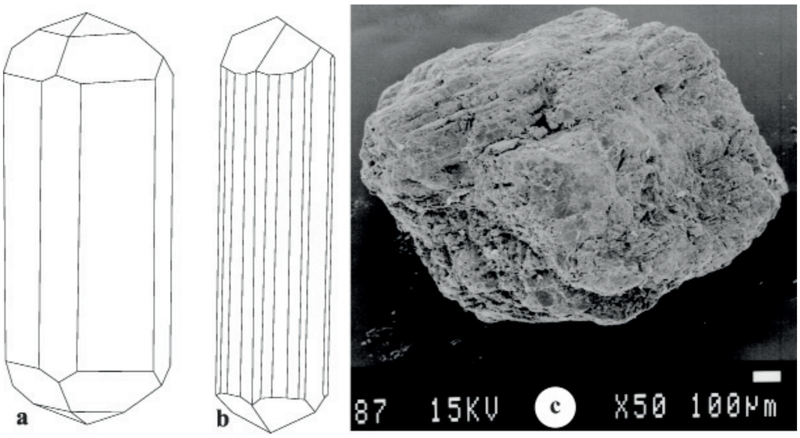


Fig. 4.16a, b, c Typical shapes of stibnite crystals from primary occurrences – a, b. In the panned concentrate samples it is often present in the form of grooved grains – c. Site: Nízke Tatry – below the heaps of the deposit Dúbrava. Drawings: Rösler, J. H., 1983. Photo: SEM I. Holický.

In the sediments fragments of stibnite are mostly present, with dominating cleavability planes (010). Occasionally there occur also fine-grained debris, especially near primary sources, which are mainly dumps of mining work in the area of primary deposits.

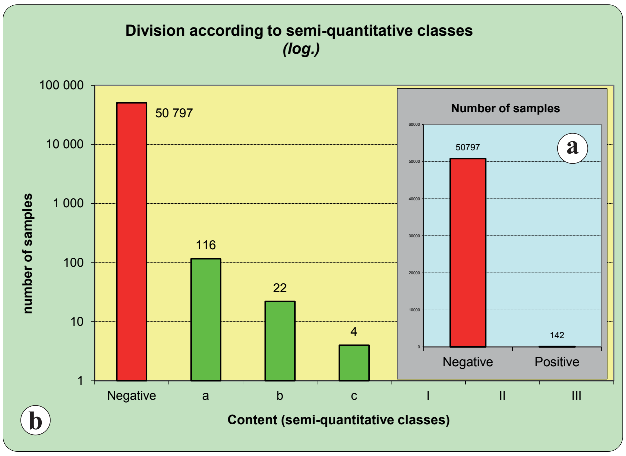


Fig. 4.17a, b Distribution of panned concentrate samples according to stibnite presence (a). Concentration of stibnite is mainly in the first and the second quantitative classes – a, b, (b).

General distribution characteristics:

During transport the stibnite is due to very good cleavability an unstable mineral and very rapidly disappears from the proportion of heavy fraction sediments. Its presence always indicates the proximity of the primary source. In our conditions it is usually the presence of the anthropogenic generated resources - heaps and dumps after mining works.

Only a slight amount of stibnite was observed in the panned concentrate samples (Tab. 4.8). The concentration ranged mainly in the lowest semi-quantitative content class (a) and only rarely is in a greater amount (Fig. 4.17a, b). It was found in the area of Sb deposits in the Nízke Tatry Mts. (Dúbrava, Vyšná Boca), but mainly in the area of the Sb deposits in the Spiš-Gemer rudohorie Mts. (Poproč, Zlatá Idka, wider area of Čučma). It was also identified in the area of the Sb deposits in the Malé Karpaty Mts. (Fig. 4.18).

Tab. 4.8 Presence of stibnite in the panned concentrate samples according to content classes.

Database of samples	Negative	Content (semi-quantitative classes)					
	Positive	**a**	**b**	**c**	**I**	**II**	**III**
50,939	50,797	116	22	4	0	0	0
	100	0.23	0.04	0.01	0	0	0
	142	116	22	4	0	0	0
	0	81.69	15.49	2.82	0.00	0.00	0.00

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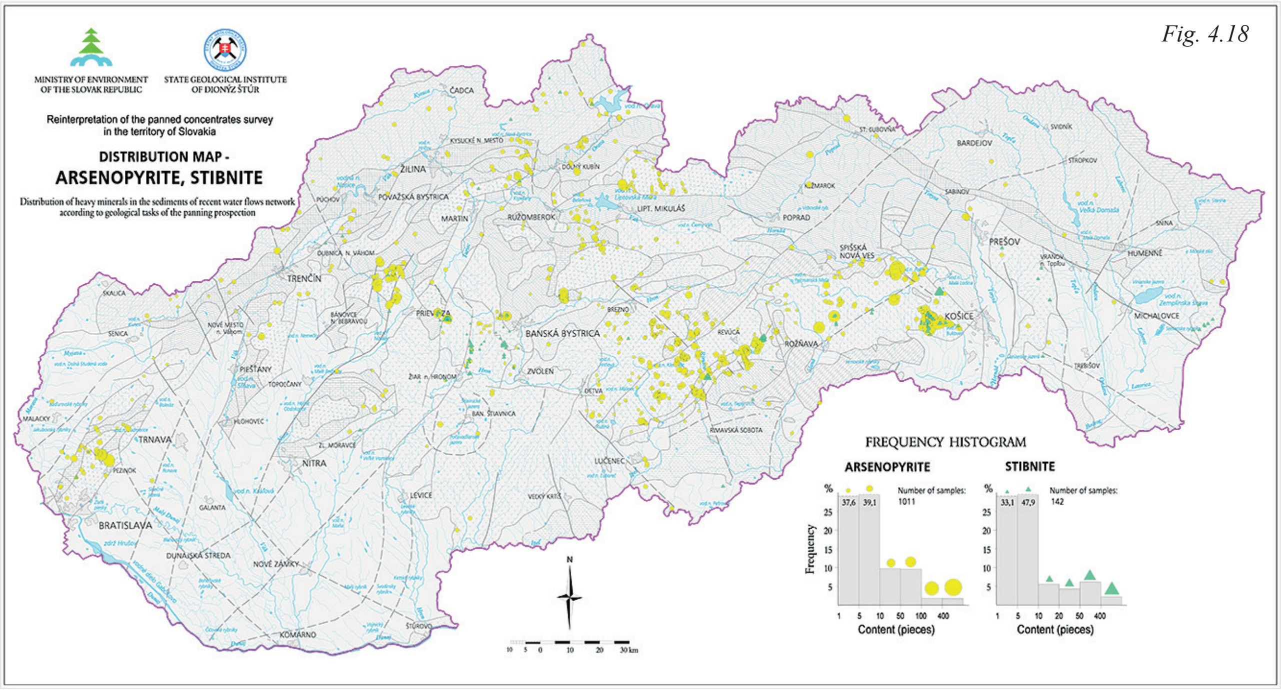


4.3.5 Barite $BaSO_4$

H = 3.5; **SG** = 4.3 – 4.7 g.cm^{-3}; **System:** Rhombic

Magnetic properties: non-magnetic, and is concentrated in diamagnetic fraction

Luminescence: may be bluish and yellowish, but commonly indistinguishable

Colour in the panned concentrate samples

Colour of barite in the panned concentrate samples is usually white, sometimes the fragments are colourless to transparent and clear, or yellowish (due to the presence of Fe oxides). After using dye test the fragments and grains are covered with bright yellow barium chromate coating (Fig. 4.19c). Shine of barite on crystal planes is glassy to pearled, on irregular corroded grains dull.

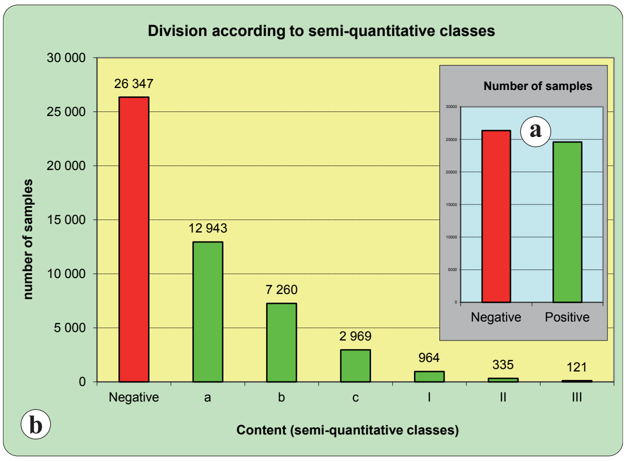


Fig. 4.20a, b Distribution of panned concentrate samples according to barite presence (a). Concentration of barite is mainly in the first and the second quantitative classes – a, b, (b).

Morphology in the panned concentrate samples

In the panned concentrate samples barite is present mostly in the form of irregular fragments, but always with tabular or coarse-prismatic habit, usually with cleavability planes (Fig. 4.19d). Perfect small tabular crystals are present only sporadically; they have not overcome longer transport (Fig. 4.19c). Therefore, they indicate the proximity of primary resources. After longer transport barite gets partly rounded, however, cleavability is well seen in stepwise morphology even on the finest grains (Fig. 4.19d). During transport, due to the hardness of barite and very good cleavability its grain share is significantly increasing without adequate volume changes.

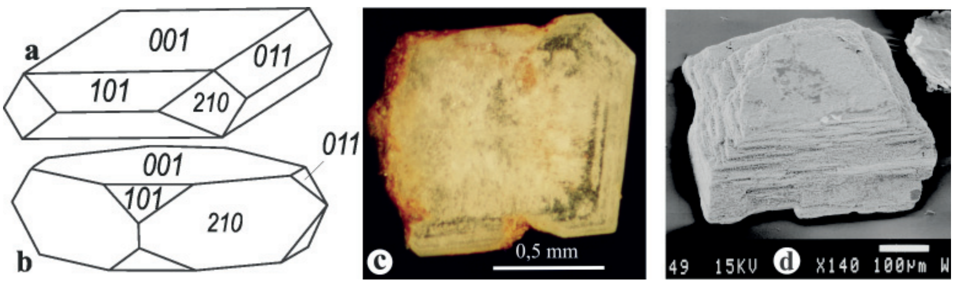


Fig. 4.19a, b, c, d Shapes of crystals, colour and cleavability of barite in the panned concentrate samples. Tabular habit of small crystals (a, b) with dominant shape of basal pinacoid on (001) plane. Very good cleavability predestines the most common morphological modification of barite in the panned concentrate samples. Colour of barite in the panned concentrate samples is white (depicted fragment of crystal with coating of barium chromate, which developed after dye test – c). Split-off fragment of barite with distinct planes of cleavability on (001) plane – d. Sites: Kremnica (c); Malužiná (d). Drawings: Rösler, J. H., 1983, Photo: P. Bačo, SEM I. Holický.

Tab. 4.9 Presence of barite in the panned concentrate samples according to content classes.

Database of samples	Negative	Content (semi-quantitative classes)					
	Positive	**a**	**b**	**c**	**I**	**II**	**III**
50,939	26,347	12,943	7,260	2,969	964	335	121
	52	25	14	5.83	1.89	0.66	0.24
	24,592	12,943	7,260	2,969	964	335	121
	48	52.63	29.52	12.07	3.92	1.36	0.49

Tab. 4.10 Presence of barite in the panned concentrate samples according to content classes. Selected map sheets at scale 1 : 50,000 illustrate areas with deposits and significant occurrences of barite, which is present in all content classes in the panned concentrate samples.

Map	**Database**	**Samples without mineral presence**		**Content (semi-quantitative classes)**											
	Number of samples			**a**		**b**		**c**		**I**		**II**		**III**	
1:50 000		Number	%	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%
Outer Flysch Zone – Magura and Dukla units															
27-14	283	2	1	32	11	78	28	76	27	48	17	37	13	10	4
27-32	828	65	8	323	39	222	27	108	13	71	9	33	4	6	1
28-31	690	172	25	159	23	152	22	97	14	64	9	31	4	15	2
28-32	768	39	5	217	28	246	32	164	21	81	11	17	2	4	1
28-43	819	31	4	219	27	257	31	161	20	110	13	31	4	10	1
Tatricum – Považský Inovec															
35-32	37	3	8	9	24	6	16	8	22	6	16	3	8	2	5
Gemericum – Poráč -Rudňany															
37-11	1529	631	41	476	31	285	19	107	7	23	2	5	0	2	0
37-12	452	55	12	145	32	148	33	63	14	23	5	15	3	3	1
37-21	487	34	7	120	25	113	23	88	18	50	10	52	11	30	6

Epitaxial intergrowths of barite with other minerals were not observed in the panned concentrate samples. Size of small crystals, their fragments or grains in the panned concentrate samples is up to 1.0 mm. In the area of historic barite mining (Rudňany) or mineralisation with barite (a large proportion of deposits in the Spiš-Gemer rudohorie Mts.) there are present in the panned concentrate samples from the close vicinity of such resources (dumps) usually fissile grains and fragments (up to 1 cm, occasionally even more). On the other hand, the size of the fragments from natural sources is very quickly fining up and size of grains is significantly <0.5 mm.

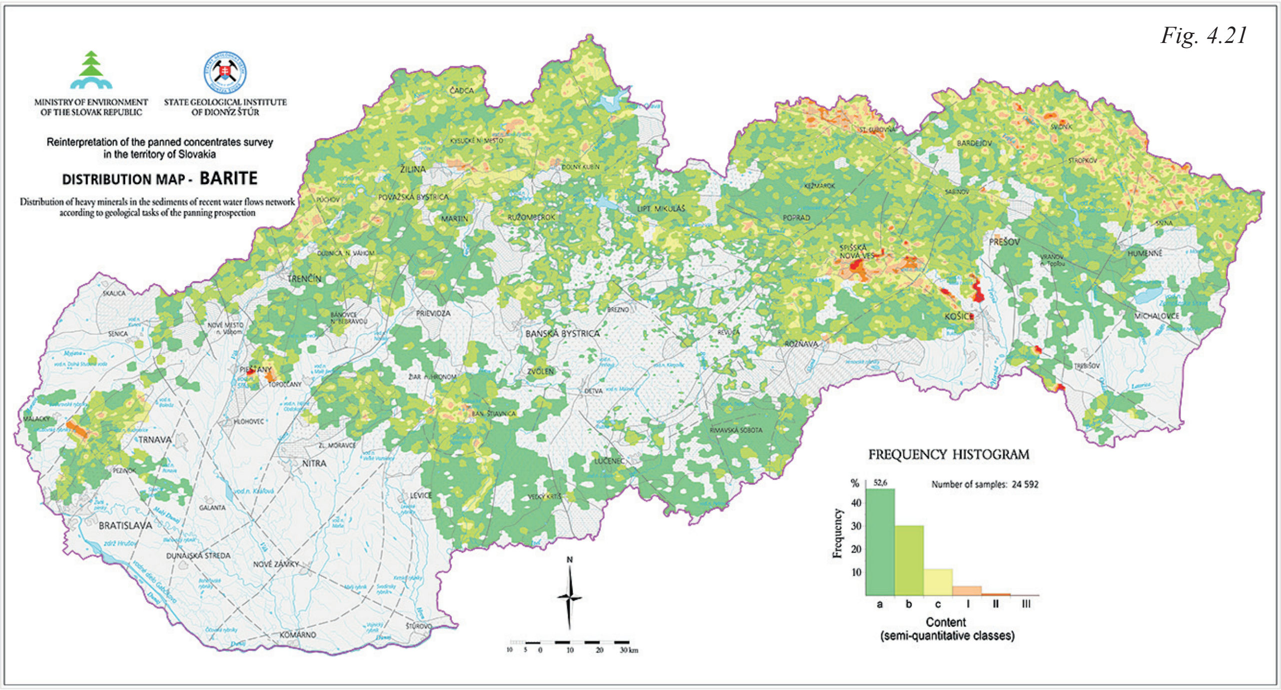


Fig. 4.21

Application of specific methods of identification: dye test, in which barite grains are covered with yellow coating of barium chromate.

General distribution characteristics:

Barite was identified in almost 50% of the collected panned concentrate samples (Tab. 4.9). Its concentration is confirmed in all semi-quantitative classes (Fig. 4.20) with the predominance of classes a – c, which greatly reflects its cleavability. Presence of such samples is even more pronounced outside of primary accumulation. Concentrations I-III are characteristic for barite deposits areas and occurrences, and such samples constitute about 3% of the total panned concentrate samples (Tabs. 4.9, 4.10).

Barite is typical epigenetic mineral associated with metallogenic processes of various types of deposits (barite, but also siderite), especially in Gemericum. Coincidence of maximum levels in samples with deposit areas is evident (Fig. 4.21). The higher content classes are also confirmed in areas of Central and Eastern Slovakia Neovolcanites with deposits of polymetallic and precious-metal low-sulphidation types.

Distribution of barite also points out to another fundamental genetic type of barite – sedimentary origin (Fig. 4.21). This is manifested in higher content classes for certain sedimentary rocks (some sections of Klippen Belt, Rača lithofacies unit of Magura Flysch). Part of these zones also coincides with sedimentary Mn mineralisation.

4.3.6 Cinnabarite HgS

H = 2.0 – 2.5; **SG** = 8.09 g.cm^{-3}; **System:** Trigonal

Magnetic properties: non-magnetic, and is concentrated in diamagnetic fraction

Colour in the panned concentrate samples

Colour of cinnabarite grains is rich-red, in earthy varieties brown-red (Fig. 4.22b, c; 4.23a, b).

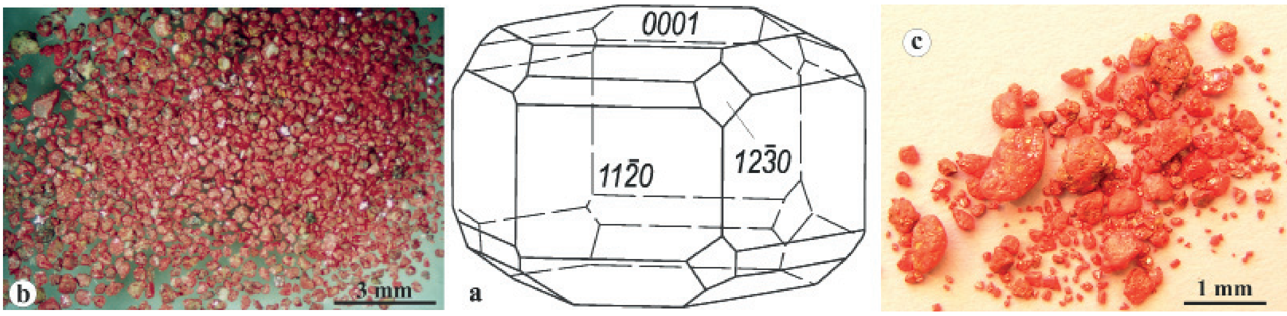


Fig. 4.22a, b, c Crystal shapes and colour of cinnabarite in the panned concentrate samples. Due to its cleavability in the panned concentrate samples it occurs almost exclusively in fissile fragments and well-rounded grains. Sites: Malachov (b); Tribeč – Zlatno (c). Drawing: Rösler, J. H., 1983. Photo: P. Bačo.

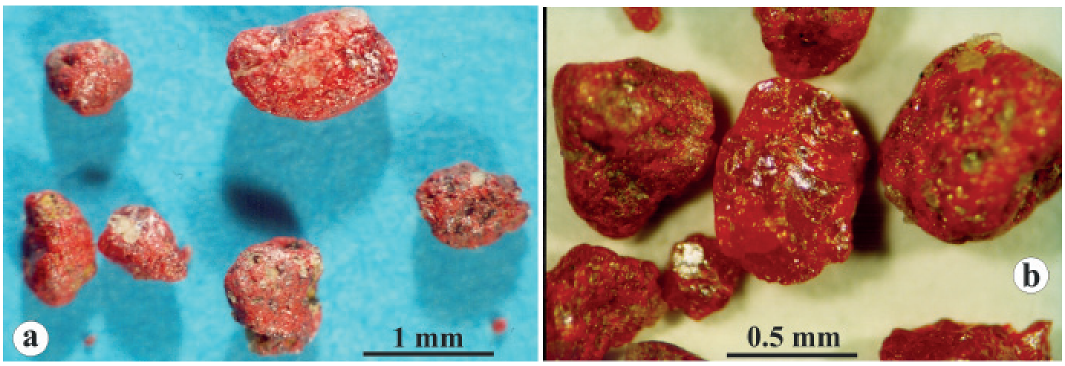


Fig. 4.23a, b Shapes of grains, colour and cleavability of cinnabarite in the panned concentrate samples. Site: Tribeč – Zlatno (a, b). Photo: P. Bačo.

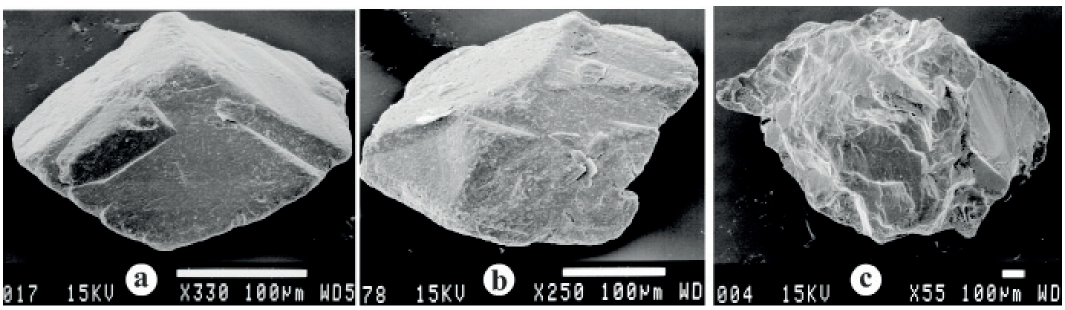


Fig. 4.24a, b, c Typical shapes of cinnabarite – morphology of rhombohedral small crystals and intergrowths. These forms are known mainly from Flysch Zone — its East-Slovakia section. Surface of these small crystals is smooth. Site: Nová Kelča (a, b) Malachov (c). Photo: SEM I. Holický.

Lustre is dull, but on the diamond-like fresh fracture surfaces. Thin leaf-like and flaky forms are translucent.

Morphology in the panned concentrate samples

In the panned concentrate samples the most common are irregular rounded grains with rough, but more often with a smooth surface. On the larger grains good cleavability is sometimes distinct along the (10$\bar{1}$0) plane or irregular fracturing. Near the primary sources there are observed rhombohedral or tabular crystal forms (Fig. 4.24a, b, c). During transport due to the brittleness and good cleavability it disintegrates into very fine particles, and it often concentrates in the lowest granularity classes. It is often gritty and crumbly, easily sliceable (Fig. 4.25a, b, c). Size of small crystals or grains of cinnabarite in the panned concentrate samples is typically up to 0.5 mm. Close to some autochthonous occurrences (e.g. Zlatno in the Tribeč Mts.), the size of grains achieves centimetre magnitude. In source areas of Flysch the size of grains is only 0.X mm.

Identification attributes in the panned concentrate samples: intense red colour, very good cleavability.

General distribution characteristics

Cinnabarite is a typical epigenetic mineral and occurs mainly in the panned concentrate samples in source areas with cinnabarite mineralisation presence. Its content in positive panned concentrate samples is dominantly within the first quantitative class (Tab. 4.11, Fig. 4.26a).

Near the cinnabarite primary sources there are present panned concentrate samples having higher degree of concentration (Fig. 4.26 b, c), and the content can amount to several thousands grains – e.g. Malachov, Dubník (Červenica), Ladomírov. Cinnabarite was the first mineral, whose distribution in selected areas in Slovakia was identified by panned concentrate prospecting (Slávik, 1969; Knésl et al., 1972; Tözsér, 1972). The results that were achieved by this method have shown the appropriateness of its use both in the metallogenetically unpromising areas (Vihorlatské vrchy Mts.) or in the areas of historic mining (Malachov area). Cinnabar concentrations are common in the lower content classes.

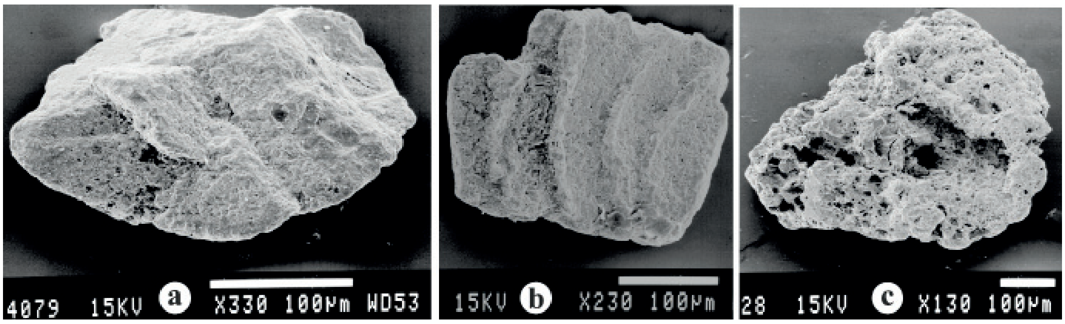


Fig. 4.25a, b, c Typical shapes of granular cinnabarite. Porous, "mushroom-like" form is known from the locality Malachov (b, c). From the locality Zlatno – Tribeč Mts. (a) transitional type of cinnabarite is known. Photo: SEM I. Holický.

In particular, cinnabarite exploitation itself and the creation of deposits and anthropogenic sources – heaps, conditioned the presence of content in II and III concentration classes (Tab. 4.12). This is particularly valid in the historically mined deposits such as Červenica – Dubník, or in the recent past, for example, Malachov, Rudňany, but also in primary occurrences without deposit accumulations, for example, Uderiná (Fig. 4.27).

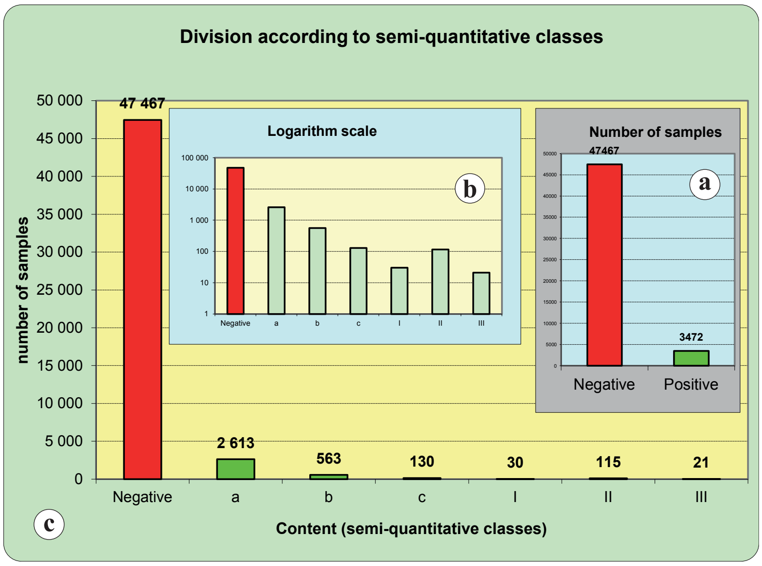


Fig. 4.26a, b, c Distribution of panned concentrate samples according to cinnabarite presence (a). Presence of cinnabarite is dominantly in the first semi-quantitative content class (b, c).

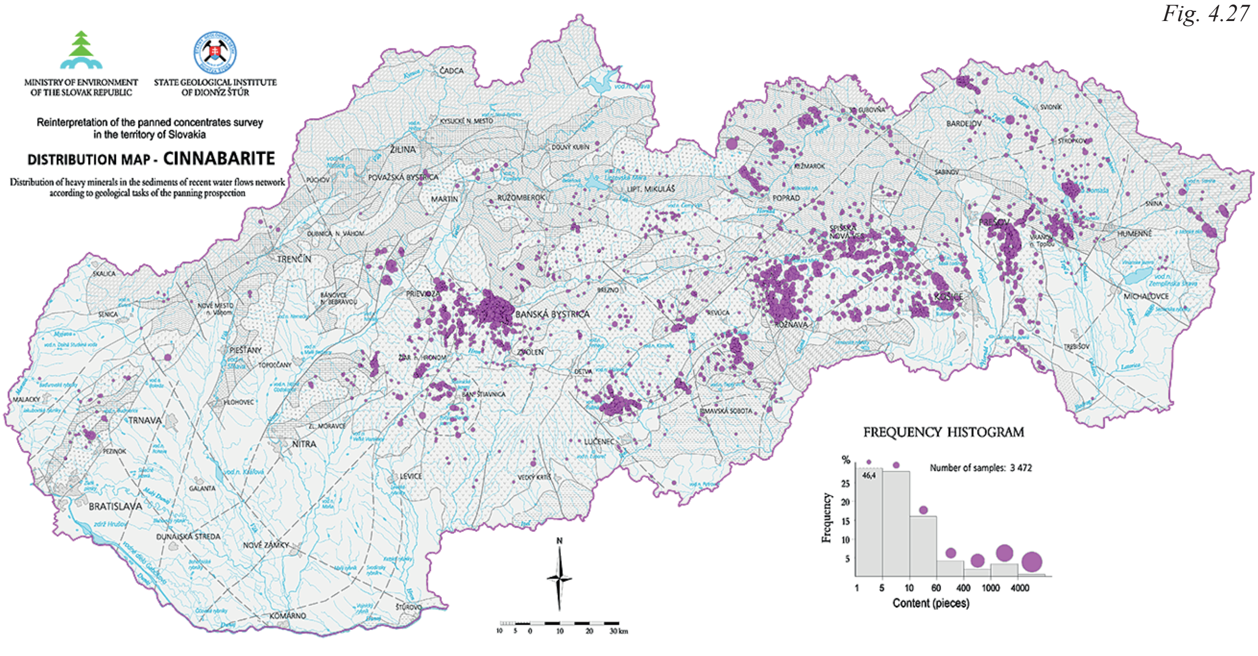
Tab. 4.11 Presence of cinnabarite in the panned concentrate samples according to content classes.

Database of samples	Negative	Content (semi-quantitative classes)					
	Positive	a	b	c	I	II	III
50,939	47,467	2,613	563	130	30	115	21
	94	5.13	1.11	0.26	0.06	0.23	0.04
	3,472	2,613	563	130	30	115	21
	7	75.26	16.22	3.74	0.86	3.31	0.60

Tab. 4.12 Presence of cinnabarite in the panned concentrate samples according to content classes. Selected map sheets at scale 1 : 50,000 illustrate the areas with deposits and significant occurrences of cinnabarite, which is present in the panned concentrate samples in higher content classes.

Map	Database	Samples without mineral presence		Content (semi-quantitative classes)											
	Number of samples			a		b		c		I		II		III	
1:50 000		Number	%	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%
Flysch Zone – Stebnícka Huta, Nová Kelča, Ladomírov															
27-24	506	443	88	30	6	22	4	10	2	1	0	0	0	0	0
28-31	690	669	97	18	3	2	0	1	0	0	0	0	0	0	0
28-34	934	830	89	74	8	18	2	7	1	3	0	2	0	0	0
38-22	231	210	91	11	5	6	3	4	2	0	0	0	0	0	0
Central Slovakia Neovolcanic Field, Kremnické vrchy Mts. – Malachov															
36-13	755	581	77	155	21	18	2	1	0	0	0	0	0	0	0
36-14	1,182	706	60	191	16	109	9	33	3	16	1	107	9	20	2
Southern Veporicum – Uderiná, Lovinobaňa, Cinobaňa															
36-43	858	758	88	62	7	27	3	5	1	2	0	4	0	0	0
36-44	797	714	90	62	8	20	3	1	0	0	0	0	0	0	0
Gemericum – Rákoš, Rudňany															
37-14	647	404	62	145	22	76	12	21	3	1	0	0	0	0	0
37-21	487	335	69	106	22	41	8	5	1	0	0	0	0	0	0
East-Slovakia Neovolcanites, Slanské vrchy Mts. – Zlatá Baňa, Dubník-Červenica															
38-11	1,370	1,106	81	186	14	56	4	20	1	2	0	0	0	0	0
38-12	487	410	84	66	14	8	2	3	1	0	0	0	0	0	0

Fig. 4.27



The implemented projects of regional panned concentrate prospecting have found a number of indicia and deposit manifestations. Presence of cinnabarite and its regional distribution has allowed also important tectonic interpretations particularly in the Flysch Zone – the Outer and Inner ones (Križáni 1971; Križáni et al., 1979).

4.3.7 Galena PbS

H = 2.0 – 3.0; **SG** = 7.4 – 7.6 g.cm^{-3}; **System:** Cubic

Magnetic properties: non-magnetic, and is concentrated in diamagnetic fraction

Colour in the panned concentrate samples

Colour of galena in the panned concentrate samples is a lead-grey colour with setting-up hues. Lustre on flat surfaces (nearly always the fission planes) is metallic. It is usually covered with a thin layer of secondary minerals of white, yellowish, grey (anglesite, cerrusite) or to red (cerrusite) colour. Planes on small crystals can have up to metallic lustre.

Morphology in the panned concentrate samples

In the panned concentrate samples galena is very rarely present. On grain surfaces there are developed mainly hexahedron {100}, {111} less octahedron planes (Fig. 4.28a, c). They are mostly fragments; their shape is the result of perfect cleavability along (100) plane and they are therefore the fission fragments of the original crystals (Fig. 4.28b) or fine to coarse aggregates.

occurrence in all content classes almost always means immediate proximity of the primary source. It is almost always dump (heap) of mining works, and in some exceptional circumstances its content may be in the class c (Fig. 4.29b).

Galena is a typical epigenetic mineral and in natural

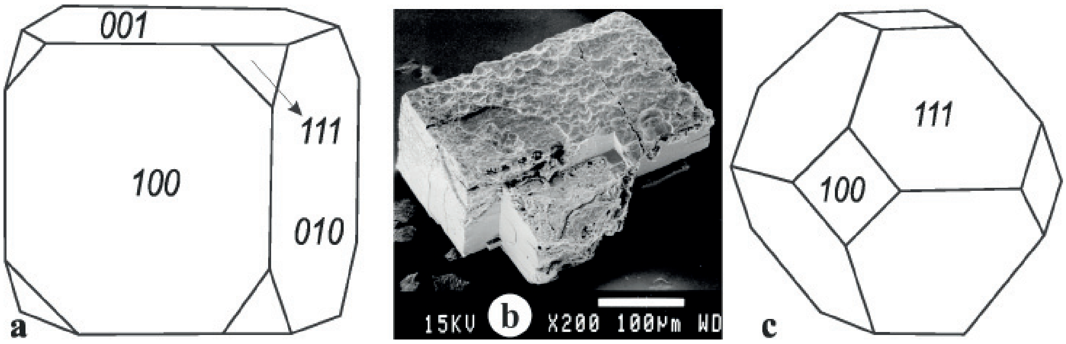


Fig. 4.28a, b, c Basic crystal shapes of galenite (a, c) and their fission fragments (b) in the panned concentrate samples. Thanks to good cleavability galena and sphalerite in the panned concentrate samples occur almost exclusively in fission fragments and well-rounded grains. Site: Slanské vrchy Mts. – Zlatá Baňa (b) – below the heap originating from mining activity. Drawings: Rösler, J. H., 1983, Photo: SEM I. Holický.

During transport and thanks to its excellent cleavability it quickly crumbles and this process facilitates its rapid oxidation and thus the disappearance in the heavy fraction. Size of fission fragments of small crystals in the panned concentrate samples reaches up to 0.5 mm.

General distribution characteristics:

The concentration of galena in positive panned concentrate samples is significantly conditioned by its properties in the supergene environment and it is present only in the first (a) semi-quantitative classes (Tab. 4.13; Fig. 4.29a, b). Its

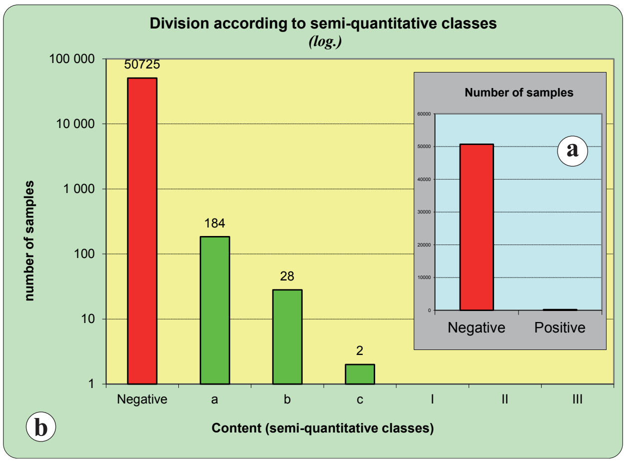


Fig. 4.29a, b Distribution of panned concentrate samples according to galena presence (a). Presence of galenite is dominantly in the first semi-quantitative content class (b).

conditions it occurs along with sphalerite. It appears in polymetallic epithermal hydrothermal mineralisation types, forming important deposits (Fig. 4.33). This is only possible rock environ, from which it gets into the fluvial network and its transport is possible to a very short distance.

4.3.8 Sphalerite ZnS

H = 3.5 – 4.0; **SG** = 3.9 – 4.1 g.cm^{-3}; **System:** Cubic

Magnetic properties: non-magnetic, and is concentrated in diamagnetic fraction, Fe-varieties (marmatite) transit into paramagnetic fraction

Colour in the panned concentrate samples

Colour of sphalerite in the panned concentrate samples is mostly tan, sometimes with very light shades (variety cleiophane) occurring in the panned concentrate samples from Banská Štiavnica region. It is also often brown to brownish-black. Lustre on flat crystal planes or cleavage surfaces is diamond-like, the corroded grains are dull.

Morphology in the panned concentrate samples

In the panned concentrate samples sphalerite is seldom present in the form of small crystals. Most often it is present in the form of irregular angular fragments (Fig. 4.30) and near the primary occurrences they often contain characteristic grooving. On cleavage planes there can be seen grooving that developed due to primary contact among lamellar and penetrating intergrowths. During transport

Tab. 4.13 Presence of galena in the panned concentrate samples according to content classes.

Database of samples	Negative	Content (semi-quantitative classes)					
	Positive	**a**	**b**	**c**	**I**	**II**	**III**
50,939	50,725	184	28	2	0	0	0
	100	0.36	0.05	0.004	0	0	0
	214	184	28	2	0	0	0
	0	85.98	13.08	0.93	0	0	0

sphalerite is quickly (but more slowly than galena) disintegrating due to the good cleavability of the (110) plane and it becomes subject to the oxidation and turns to smithsonite. Size of fragments of small crystals or crystal clusters in the panned concentrate samples is up to 0.5 mm. Only in cases of immediate vicinity of polymetallic mineralisation with heaps the size of grains can be larger.

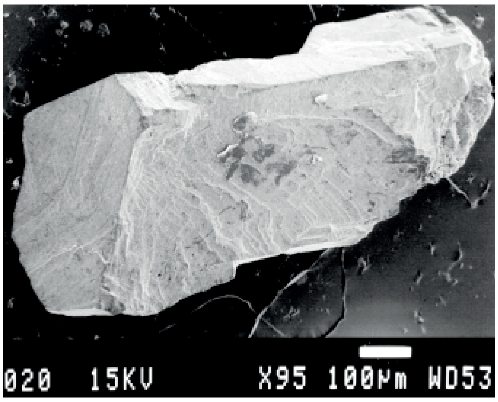


Fig. 4.30 Sphalerite is rare in the panned concentrate samples. Similarly to galena, it occurs in the panned concentrate almost exclusively in the form of fissile fragments and well-rounded grains. It is present close to primary sources, mostly of anthropogenic origin. Site: Pukanec. Photo: SEM I. Holický.

General distribution characteristics:

Sphalerite was observed only in very few samples. Like galena also sphalerite has been found in the panned concentrate samples only in the first semi-quantitative concentration class – a (Tab. 4.14; Fig. 4.31a).

Class b means the immediate proximity of the primary source, which is almost always dump (heap) originating from mining works from which they got to alluvial sediments; however its transport is possible only to a short distance, similarly as galena.

Sphalerite has a wider genetic range compared to galena and therefore its proportion and the presence in the panned concentrate samples is more frequent. More significant deposits with epithermal hydrothermal mineralisation with sphalerite are mainly in Neovolcanites, and to lesser extent the occurrences are known in Tatricum, Veporicum and Gemericum. Thanks to the mining of these deposits is has got to the surface and concentrations of sphalerite reach upper classes (b, c).

Presence of sphalerite in the environment of Outer Flysch Zone (Fig. 4.33) may be associated with cinnabarite mineralisation.

4.3.9 Chalcopyrite $CuFeS_2$

H = 3.5 – 4.0; **SG** = 4.1 – 4.3 g.cm^{-3}; **System:** Tetragonal

Magnetic properties: non-magnetic, and is concentrated in diamagnetic fraction

Colour in the panned concentrate samples

Colour of chalcopyrite in the panned concentrate samples is brass yellow to golden yellow, often impinged with bright colours - blue and purple, of different grades and shades. Lustre is metallic and opaque.

Tab. 4.14 Presence of sphalerite in the panned concentrate samples according to content classes.

Database of samples	Negative	Content (semi-quantitative classes)					
	Positive	a	b	c	I	II	III
50,939	48,814	1,780	286	58	1	0	0
	96	3.49	0.56	0.11	0.002	0	0
	2,125	1,780	286	58	1	0	0
	4	83.76	13.46	2.73	0.05	0.00	0.00

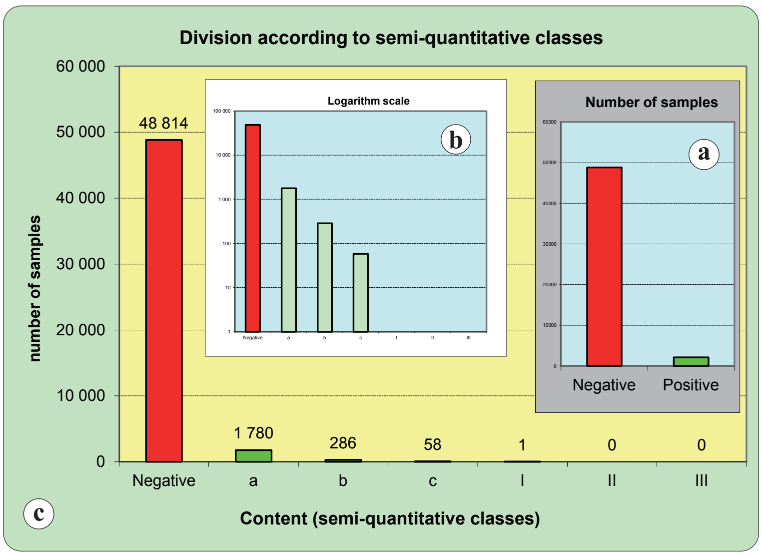


Fig. 4.31a, b Distribution of panned concentrate samples according to sphalerite presence (a). Presence of sphalerite is dominantly in the first semi-quantitative content class (c).

Morphology in the panned concentrate samples

In the panned concentrate samples chalcopyrite is present in the form of regular and sharp-edged grains and only sporadically the original pseudooctahedral or small tetrahedral crystals can be observed, or crystal planes in irregular fragments.

During transport occurs slow diminution as in the case of galena and sphalerite, it is quickly covered with a thin coating of Cu oxides. Size of small crystals, their fragments or grains in the panned concentrate samples is normally within range of 1.0 mm, and in the case of a source proximity there may occur even larger grains.

General distribution characteristics:

The occurrence of chalcopyrite, like most of sulphide minerals in the panned concentrate samples indicates the presence of a close primary source. In the case of chalcopyrite it is often an anthropogenic source – heap after mining operations. Its content in positive panned concentrate samples (Tab. 4.15) is strongly conditioned by its properties in the supergene environment and it is only in the first – **a** (less **b**, and rarely **c**) content classes.

Class c always means the immediate proximity of the primary source. Higher concentrations classes (I – III) are very rare, all-in-all 12 samples from the NW margin of the Suchý Massif, W of Valaská Belá. It is an area without any detailed interpretation.

Chalcopyrite, like other sulphide mineral, is a typical epigenetic minerals, and in natural conditions it occurs along with them. It occurs in base metal epithermal hydrothermal types of mineralisation forming important deposits (Fig. 4.33) as well in individual deposits, often along with siderite mineralisation, especially in Gemericum.

Sporadic occurrences of chalcopyrite were also recorded in the Outer Flysch Zone and Inner-Carpathian Paleogene. They are spatially separated from sphalerite (Fig. 4.33) as well as cinnabarite (Fig. 4.27) and therefore they represent independent type of mineralisation.

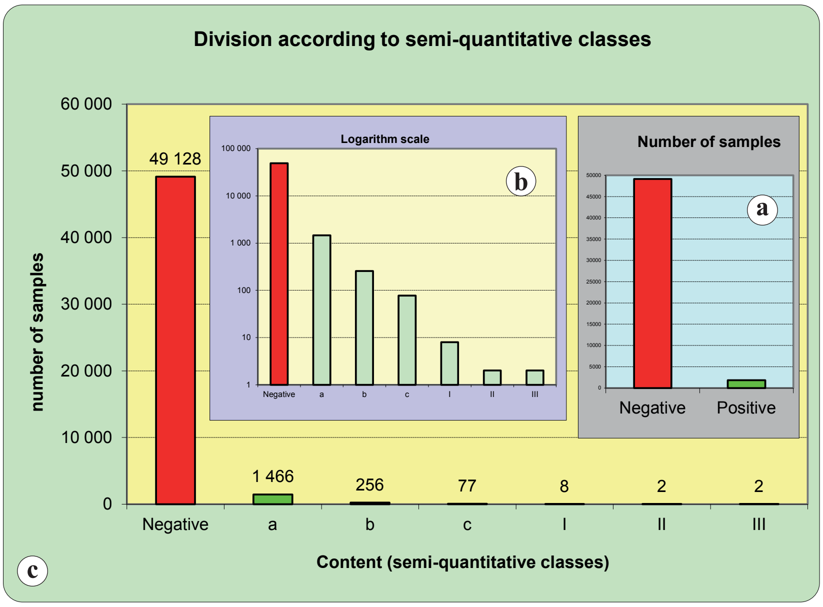


Fig. 4.32a, b, c Distribution of panned concentrate samples according to chalcopyrite presence (a). Presence of chalcopyrite is dominantly in the first semi-quantitative content classes (b, c).

Tab. 4.15 Presence of chalcopyrite in the panned concentrate samples according to content classes.

Database of samples	Negative	Content (semi-quantitative classes)					
	Positive	**a**	**b**	**c**	**I**	**II**	**III**
50,939	49,128	1,466	256	77	8	2	2
	96	2.88	0.50	0.15	0.02	0.004	0.004
	1,811	1,466	256	77	8	2	2
	4	80.95	14.14	4.25	0.44	0.11	0.11

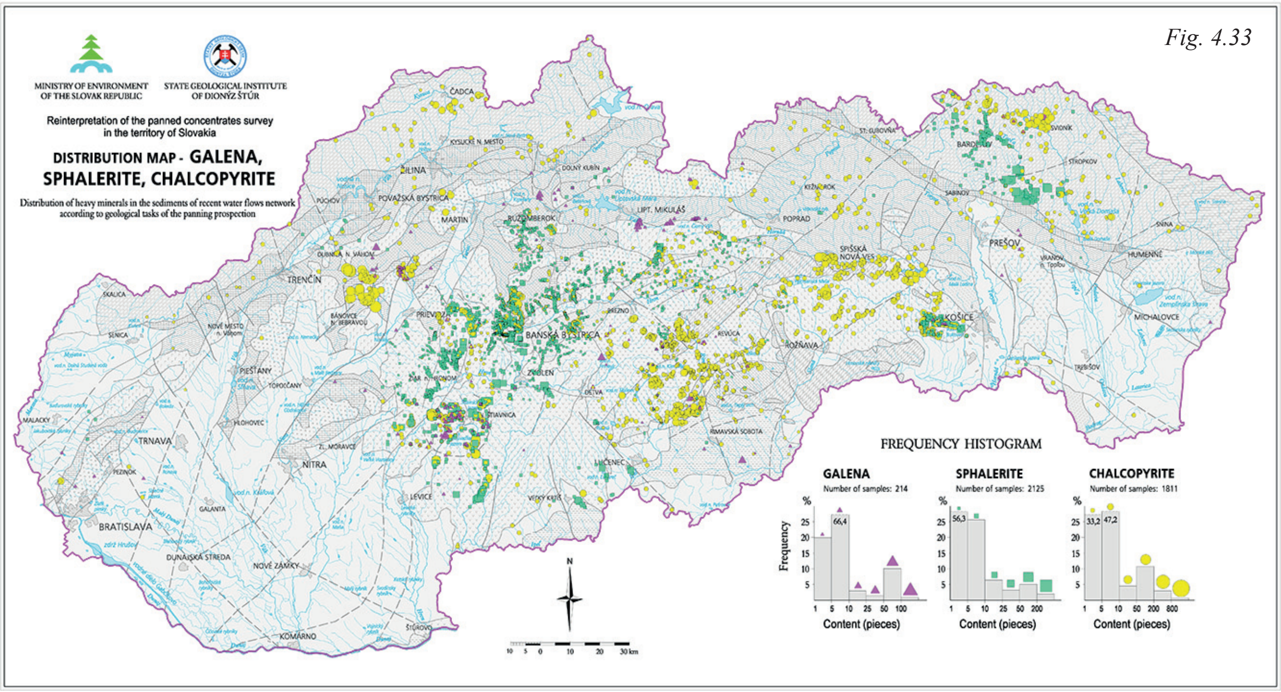


Fig. 4.33

4.3.10 Garnets $(A^{2+}_3)(B^{3+}_2)(C_3)O_{12}$

A = Ca, Mg, Fe^{2+}, Mn^{2+}, Na, Y;
B = Mg, Al, Si, Sc, Ti, V, Cr, Fe^{3+}, Fe^{2+}, Mn^{3+} Cr, Zr, Sn
C = Al, Si, Fe^{3+}

Garnet crystal lattice is capable to take quite a lot of different cations and there are recorded around 20 varieties of silicate garnets (Broska et al., 2012). In practice of panned concentrate prospecting, the maps show the distribution of these minerals as a whole. In the scope of individual projects there were identified the most common varieties of garnets.

"Al garnets"

Pyrope $Mg_3Al_2(SiO_4)_3$ **Almandine $Fe^{2+}_3Al_2(SiO_4)_3$** **Spessartine $Mn^{2+}_3Al_2(SiO_4)_3$**

"Ca garnets"

Andradite $Ca_3Fe^{3+}_2(SiO_4)_3$ **Grossular $Ca_3Al_2(SiO_4)_3$** **Uvarovite $Ca_3Cr^{3+}_2(SiO_4)_3$**

H = 7.0 – 7.5; **SG =** 3.58 (pyrope) – 4.25 (almandine) g.cm^{-3}; **System:** Cubic

Magnetic properties: most commonly concentrated in paramagnetic (pure non-ferric varieties in diamagnetic) fraction

Colour in the panned concentrate samples

Colour of garnets in the panned concentrate samples is very diverse and depends on the predominant species (the proportion of its components) and clarity. The most commonly present almandine garnets are predominant species (Figs. 4.34a, b, c) and in this case the colour is light pink-red in various hues and shades, or brownish. With the growing pyrope species proportion the colour is bright red.

Grossular dominates in greenish garnets. In rare cases there have been also reported colourless and yellow, very small, but perfect rhombic dodecahedron garnets. Lustre on flat surfaces of the crystals is glassy, heavily corroded grains and granular masses are dull.

Morphology in the panned concentrate samples

In the panned concentrate samples the garnets are present mostly in the form of various preserved typical

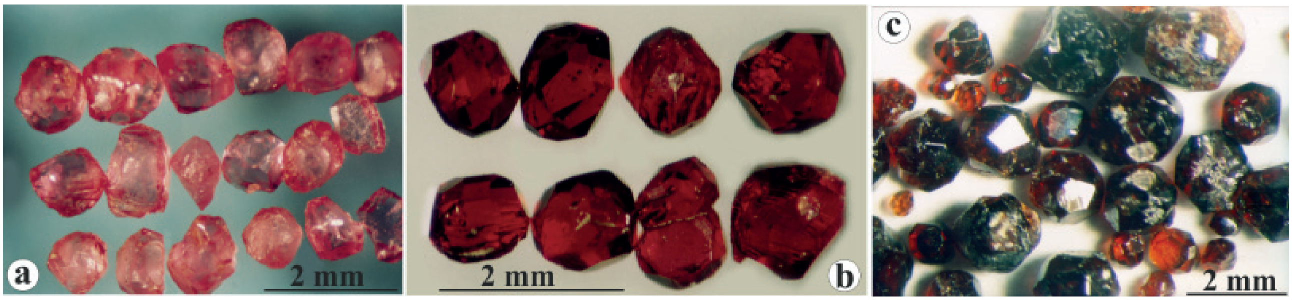


Fig. 4.34a, b, c, d Colour varieties of the most common types of garnets, which are present in the panned concentrate samples. The most frequent are red and pink colours with various hues and shades. Sites: a – Jasenie; b – Ľubietová; c – Juskova Voľa; d – Ruská Bystrá. Photo: P Bačo

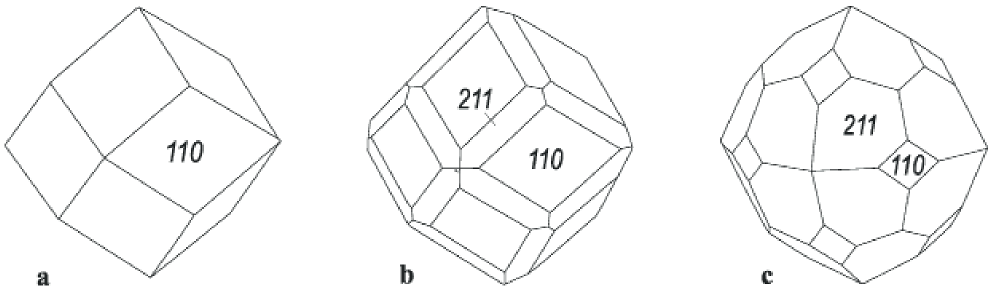


Fig. 4.35a, b, c Crystal shapes of garnets. Basic shape of garnets is rhombic dodecahedron {110}. Other crystal shapes are combinations of further basic habits – hexaoctahedrons of the cubic system. These shapes are typical and commonly present in the panned concentrate samples. Planes are often preserved even on fragments. Drawings: Rösler, J. H., 1983.

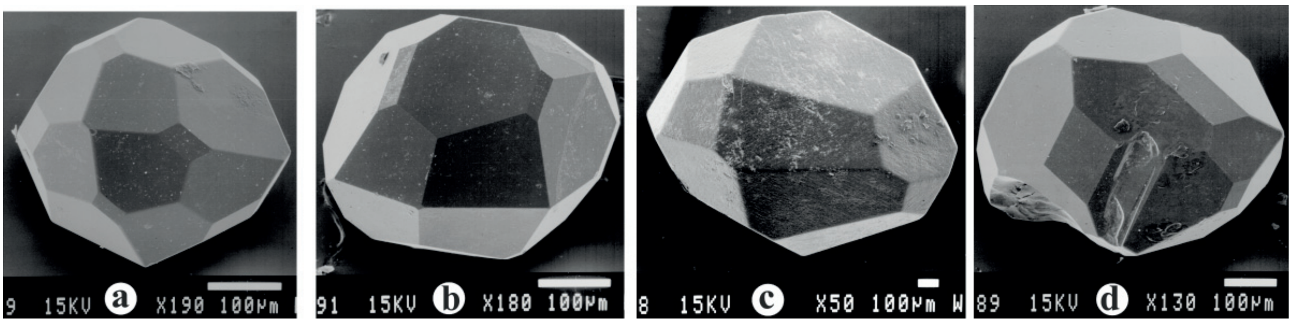


Fig. 4.36a, b, c In the panned concentrate samples the garnets are the most common mineral species with idiomorphic crystals. They are often present in perfect crystals representing basic shapes of hexaoctahedron and their combinations with variously developed planes. Sites: a – Malé Ozorovce, b – Zamutov, c – Juskova Voľa, d – Slanská Huta. Photo: SEM I. Holický.

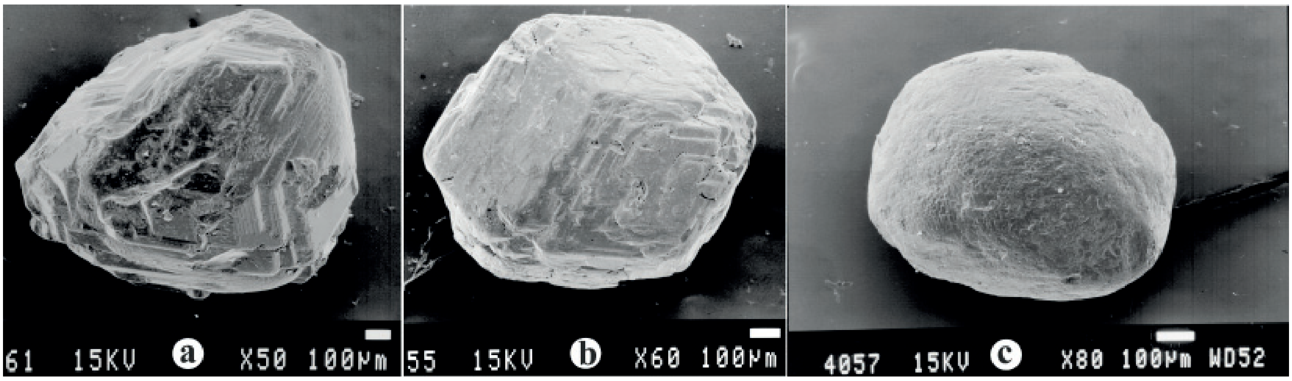


Fig. 4.37a, b, c Thanks to strong resistance in the course of transport the garnets preserve their original crystal shape. During longer transport they become more rounded (b, c) and inherited chemical and physical inhomogeneity is more pronounced (Fig. a, b). Sites: a – Ľubietová, b – Pezinok, c – Kolonica. Photo: SEM I. Holický.

rhombic dodecahedrons {110} with diverse size of individual planes.

The planes of the crystals are very often "grooved" with the skeletal development. Large proportion, particularly large fragments, has character of granular mass with signs of crystal planes. Irregular, often angular fragments of garnets originate from the source areas formed by metamorphic rocks, especially the Crystalline complexes of Tatricum and Veporicum.

During transport they are very stable due to their hardness and poor cleavability and the garnets` habit is retained in small crystals. However, quite common fragments of garnets are present in the vicinity of primary occurrences.

Size of small crystals, their fragments or grains in the panned concentrate samples is very variable and depends on the type of source rocks. Generally, in the Crystalline complexes of Tatricum and Veporicum garnets are present in all grain-size classes and often even reach the size of 1 cm.

In the source areas made of mostly intermediary and above all acidic volcanic rocks, the size of garnets attains typically 0.5 to 1.0 mm, less often up to 5 mm. In the environment of sedimentary rocks their size reaches up to 2 mm, greater grains are rather rare. In the vicinity of the Ruská Bystrá the source rock is Strihovce Member of the Krynica unit and garnets in the panned concentrate samples can reach over 5 mm (Fig. 4.34d).

General distribution characteristics:

Garnets are the most common minerals of heavy fraction of panned concentrate samples. Their concentration in the panned concentrate samples are in all semi-quantitative classes, a – III (Tab. 4.16). The well-preserved original small crystals originate from the neovolcanic areas. Garnets are mainly associated with acidic volcanism and their presence in the panned concentrate samples often points out hidden resources. In the sedimentary environs garnets are also good indicators of the initial presence of volcanic, volcaniclastic rocks.

Garnets are typical accessory minerals and in some cases the rock-forming minerals. For these reasons, they are among the most widespread mineral species in the heavy fraction from almost all regional geological formations (Fig. 4.39).

In the clastogenic sedimentary areas (Flysch Zone, Neogene sedimentary basins) they are the main, dominating minerals of panned concentrate samples (Fig. 4.39). Their predominance is due to their resistance in the supergene environment and ability to round-up during transport.

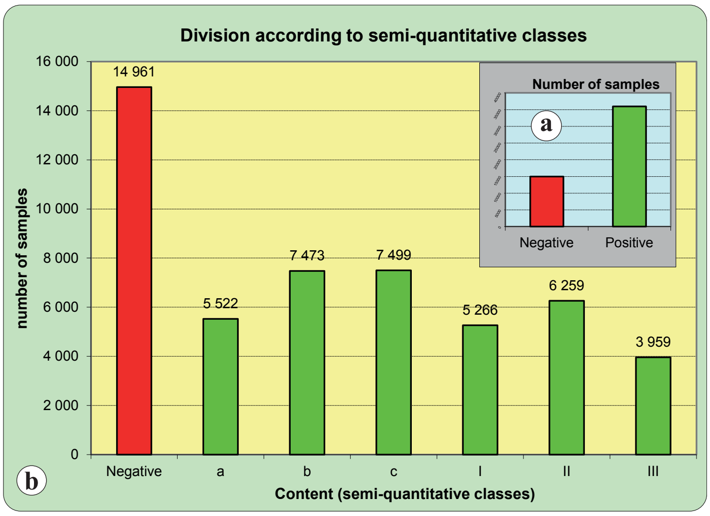
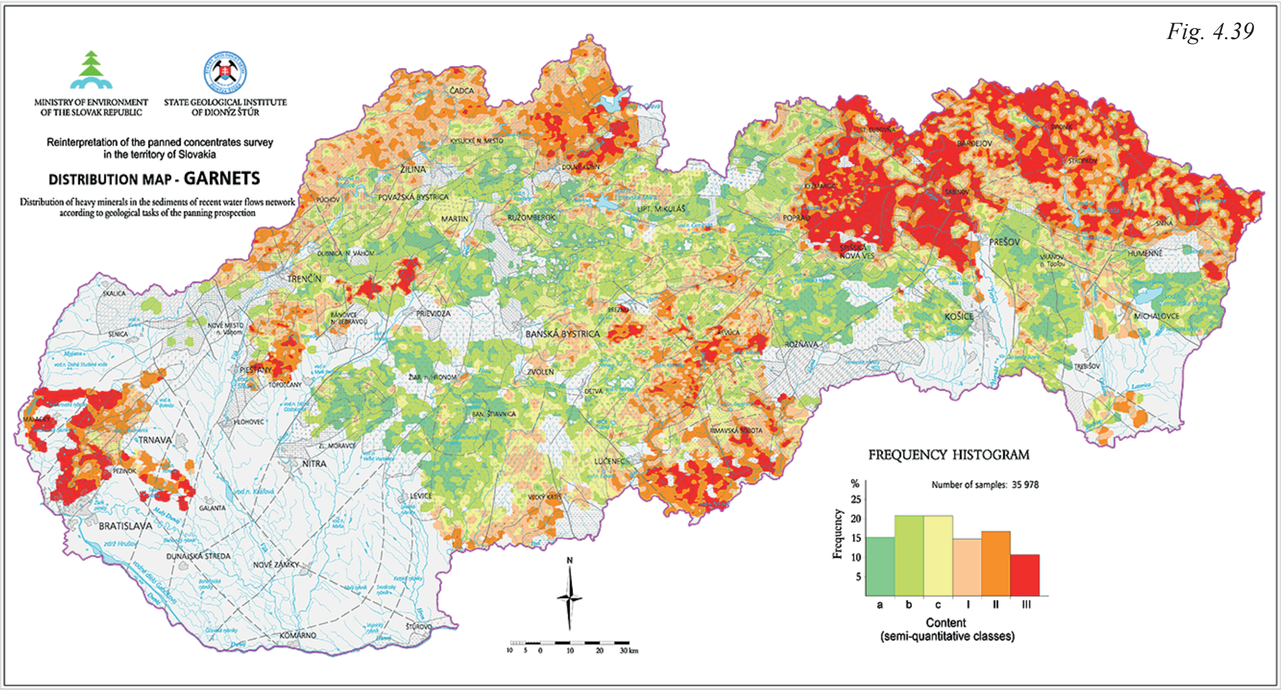


Fig. 4.38a, b Distribution of panned concentrate samples according to garnets presence (a). Garnet is almost proportionally present in all individual semi-quantitative content classes (b).

Tab. 4.16 Presence of garnets in the panned concentrate samples according to content classes.

Database of samples	Negative	Content (semi-quantitative classes)					
	Positive	**a**	**b**	**c**	**I**	**II**	**III**
50,939	14,961	5,522	7,473	7,499	5,266	6,259	3,959
	29	11	15	15	10	12	8
	35,978	5,522	7,473	7,499	5,266	6,259	3,959
	71	15	21	21	15	17	11



4.3.11 Ilmenite $Fe^{2+}TiO_3$

H = 5.0 – 6.0; **SG** = 4.5 – 5.0 g.cm^{-3}; **System:** Trigonal

Magnetic properties: weakly magnetic, and is concentrated in paramagnetic fraction

Colour in the panned concentrate samples

Colour of ilmenite in the panned concentrate samples is mostly black. Lustre on flat planes is semi-metallic and metallic, sometimes dull. On the surface of small crystals and fragments leucoxenisation can be often seen – a greyish white to light-grey fine-grained material (a mixture of rutile, anatase and brookite).

Morphology in the panned concentrate samples

In the panned concentrate samples ilmenite is present in the form of small tabular crystals (Figs. 4.40a, 4.41a, b, d) as a combination of dominant planes {0001} of pinacoid and rhombohedrons {10$\bar{1}$1}, {10$\bar{1}$2} and other surfaces (Fig. 4.40b), but mainly thin plates with prevailing flat pinacoid (0001). In most cases, however, it creates to varying degrees rounded almost isometric grains with tabular habit.

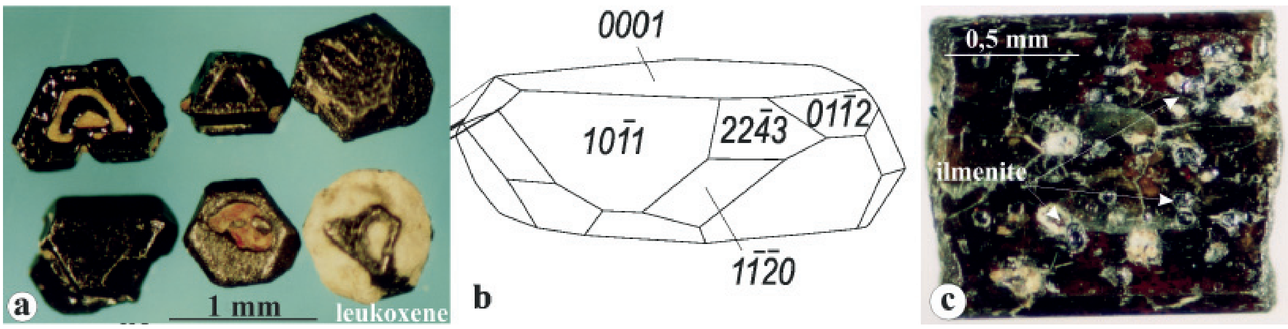


Fig. 4.40a, b, c Colour and lustre of ilmenite from panned concentrate samples. White coatings are made of leucoxene (a). Small crystals of ilmenite in tabular pyroxene (b). Sites: Poruba pod Vihorlatom – a; Ľubietová – c. Drawing: Rösler, J. H., 1983. Photo: P. Bačo.

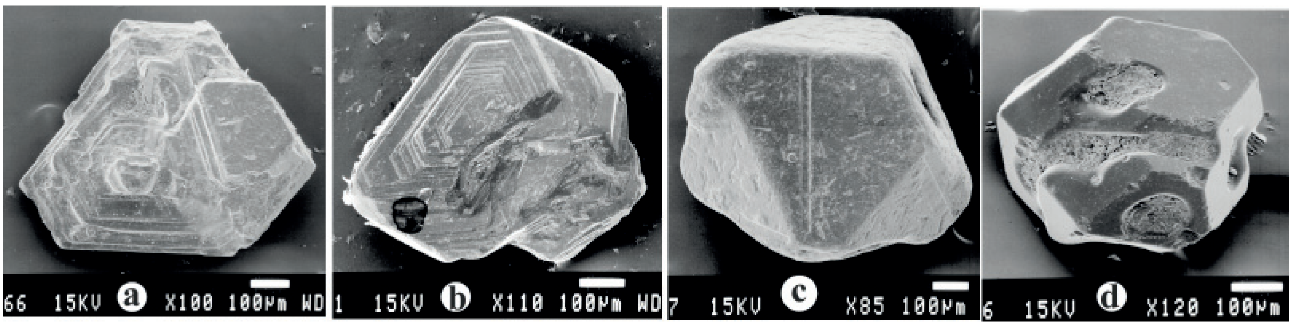


Fig. 4.41a, b, c, d In the panned concentrate samples ilmenite forms small crystals with tabular habit with very extensive range of combinations of individual crystal planes. Sites: a – Skároš, b – Nová Baňa, c – Slanská Huta, d – Banské. Photo: SEM I. Holický.

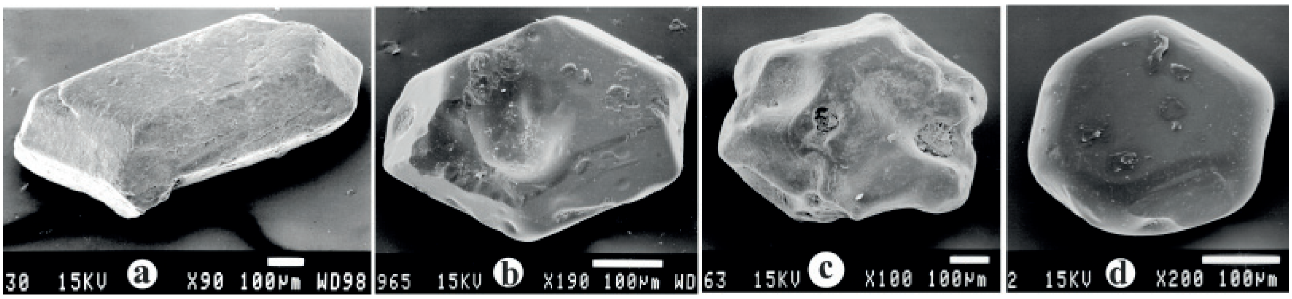


Fig. 4.42a, b, c, d During transport the ilmenite, like other resistant minerals, preserves its original crystal shape. During longer transport it becomes gradually more rounded Cavernous surface evolved due to selective leucoxenisation, whose products were subsequently decomposed within hypergenic environ. Sites: a – Slanská Huta, b – Nový Salaš, c, d – Bacúch. Photo: SEM I. Holický.

On crystals of ilmenite there are often seen a number of planes, and, often stepwise or skeletal habit and generally the dominating, increasingly diminishing pinacoid (0001) plane – Fig. 4.41a, b. Small crystals rich in variegated forms are mainly from the source areas of Neogene volcanic rocks of andesite composition. In other geological environments dominate isometric and small tabular crystals. Locally, in the panned concentrate samples ilmenite can be seen closed in younger minerals. Typical examples are the inclusions in pyroxenes of the Neogene volcanic rocks (Fig. 4.40c).

Very often in the panned concentrate samples the decomposition of ilmenite crystals – leucoxenisation – can be seen, manifested by fine-grained, usually white, sometimes yellowish, earthy mass (mainly composed of anatase, rutile and brookite). This fine-grain material substitutes small crystals of ilmenite up to the stage of full pseudomorphs (Fig. 4.40a). During transport the small crystals of ilmenite and mainly their edges are strongly rounding up (Fig. 4.42).

Size of small crystals or fragments of ilmenite in the panned concentrate samples is 0.5 to 2 mm, in some locations in Central and Eastern Neovolcanites (Poruba pod Vihorlatom) its size reaches up to 0.5 cm. In Flysch source areas the size of small crystals and their fragments attains 1 mm, typically up to 0.5 mm.

General distribution characteristics

Ilmenite is among the most abundant minerals of heavy fraction. It was recorded in almost 60% of evaluated panned concentrate samples (Tab. 4.17, Fig. 4.43a.). It is present from the lowest (a) up to the highest concentration classes (III). Character of distribution of individual concentration levels (Fig. 4.43b) points out that ilmenite is the most common part of almost every rock environment in the panned concentrate samples. It is a typical accessory mineral of the Neogene volcanic rocks of andesite composition and dominates in the panned concentrate samples (content classes I – III) of this environment (Fig. 4.44).

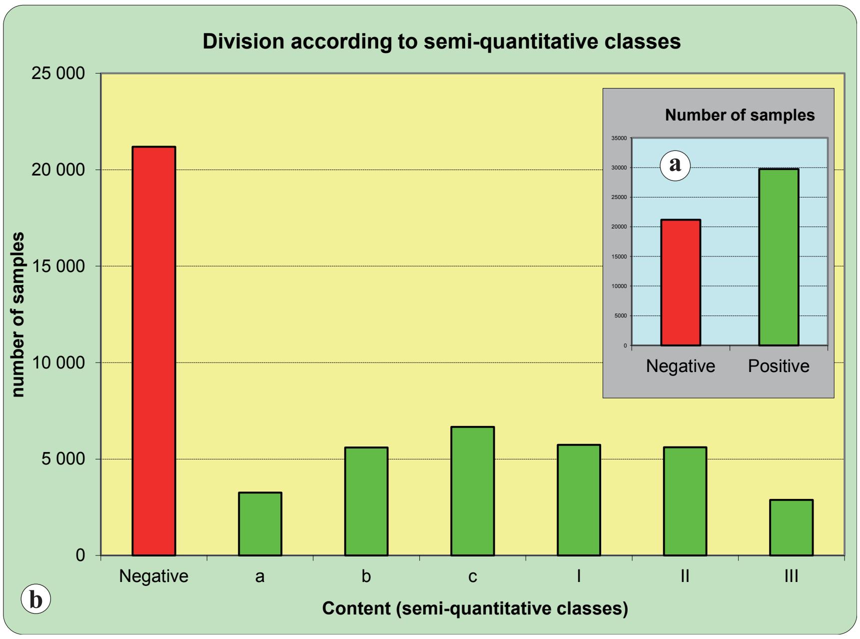


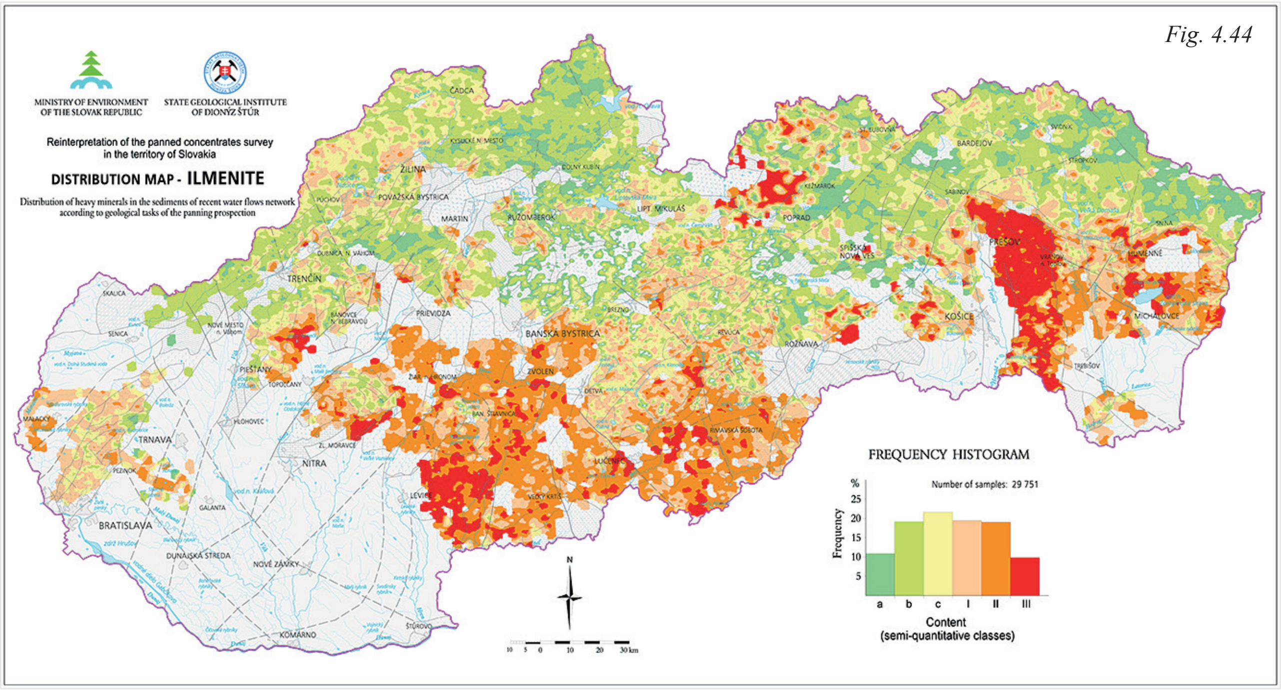
Fig. 4.43a, b Distribution of panned concentrate samples according to ilmenite presence (a) and according to its proportion in individual semi-quantitative content classes (b).

Distribution of ilmenite in the area east of the Vysoké Tatry Mts. may indicate the original extent of fluvioglacial sediments of the Vysoké Tatry Mts. and their redeposition by river network up to Klippen Belt.

Tab. 4.17 Presence of ilmenite in the panned concentrate samples according to content classes.

Database of samples	Negative	Content (semi-quantitative classes)					
	Positive	**a**	**b**	**c**	**I**	**II**	**III**
50,939	21,188	3,256	5,598	6,669	5,738	5,612	2,878
	41.6	6.39	11.0	13.1	11.3	11.0	5.65
	29,751	3,256	5,598	6,669	5,738	5,612	2,878
	58.4	10.9	18.8	22.4	19.3	18.9	9.67

Fig. 4.44



4.3.12 Corundum Al_2O_3

H = 9.0; **SG** = 4.0 – 4.1 g.cm^{-3}; **System:** Trigonal

Magnetic properties: non-magnetic, and is concentrated in diamagnetic fraction

Colour in the panned concentrate samples

Colour of corundum in the panned concentrate samples is mostly blue, of different grades and shades. It can be also blue-grey, dark grey to black, as well as white and in thin tabular forms corundum is colourless and clear (Fig. 4.45a, b, c). Lustre on flat planes is glassy to diamond-like, the heavily corroded grains are dull. Corundum with intense blue colour is assessed as a sapphire (Fig. 4.45b, c).

Morphology in the panned concentrate samples

In the panned concentrate samples corundum is most often present in the form of coarse, but especially thin plates with prevailing (0001) planes highlighted by trigonal prism (Fig. 4.46a). It‘s a characteristic, unmistakable shape of small crystals of accessory corundum in different types of rock environment, but mainly in volcanic rocks. Common are also columnar and spherical shapes (Fig. 4.47b, c) which are couplers of prisms and steep pyramids. These shapes

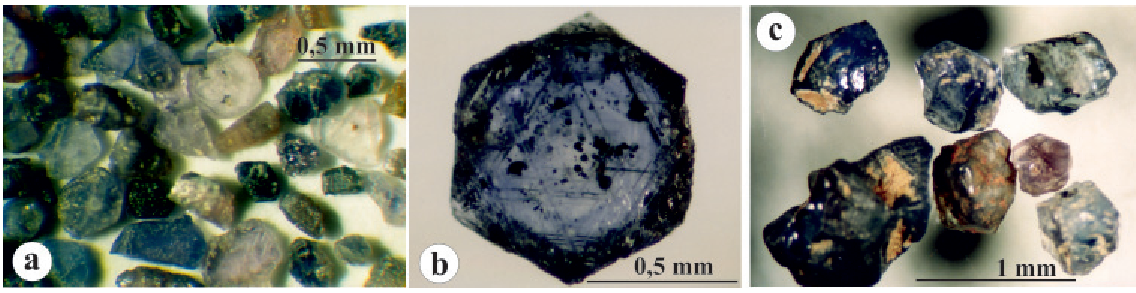


Fig. 4.45a, b, c Coloured varieties and lustre of corundum from panned concentrate samples from various types of source rocks. Sites: a – Remetské Hámre-Kapka, b – Juskova Voľa, c – Hajnáčka. Photo: P. Bačo.

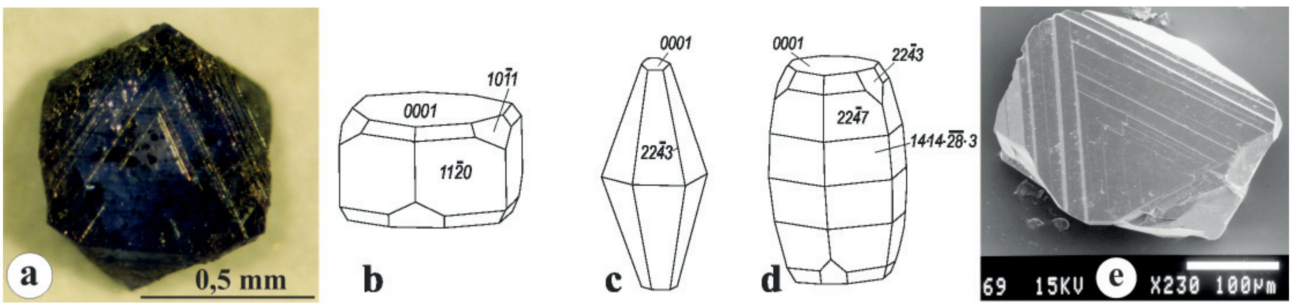


Fig. 4.46a, b, c In the panned concentrate samples corundum is mostly present in the form of a couple of very short trigonal prisms and basal pinacoids (a,b,e). Less frequent are shapes with preferred habit of ditrigonal prism and basal pinacoid – barrel-shaped (c,d). Sites: a – Juskova Voľa, e – Nová Baňa. Drawings: Rösler, J. H., 1983, Photo: P. Bačo, SEM I. Holický.

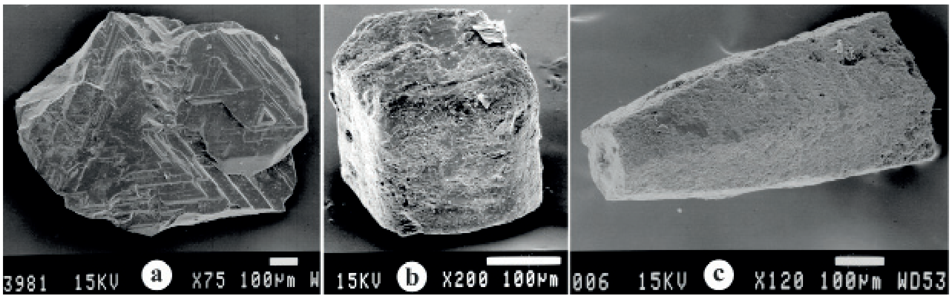


Fig. 4.47a, b, c Typical shapes of accessory corundum (a) and corundum from the environ of hydrothermal alterations. The minerals have preferred habit of ditrigonal prism and basal pinacoid – barrel-shaped habit (b,c). Sites: a – Hrabičov, b, c – Remetské Hámre-Kapka. Photo: SEM I. Holický.

are characteristic of corundum, which originated from high-sulphidation types of alterations in the environment of volcanic rocks (Remetské Hámre-Kapka). Planes of such small crystals are strongly resorbed – roughened.

Irregular, often angular fragments of corundum originate from source areas formed by metamorphic rocks and also basaltic rocks – Hajnáčka (Fig. 4.45c). During transport due to their hardness and very weak to absent cleavability they are very stable and rarely their morphologic change occurs.

Epitaxial intergrowths of corundum were not observed in the panned concentrate samples. In the translucent crystals it is possible to observe the inclusions of opaque minerals (Fig. 4.45b). In the corundum from Remetské Hámre-Kapka area there are often present inclusions of rutile. Size of small crystals, their fragments or grains in the panned concentrate samples is

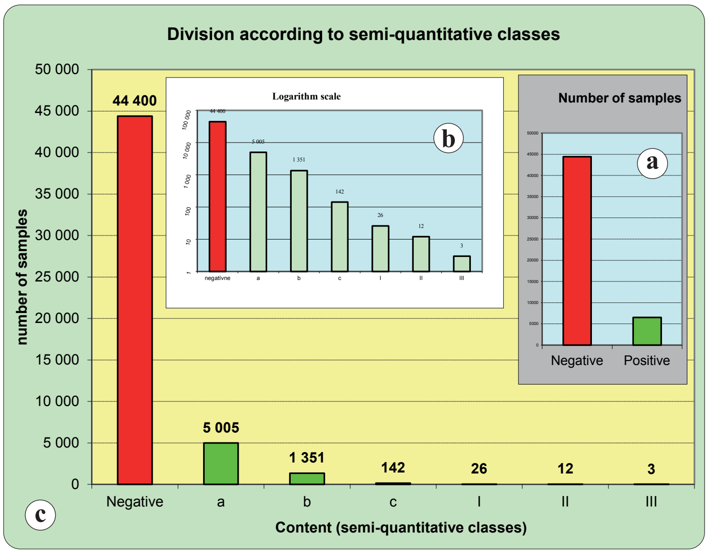


Fig. 4.48a, b, c Distribution of panned concentrate samples according to corundum presence (a) and according to proportion of individual semi-quantitative content classes (b, c).

Tab. 4.18 Presence of corundum in the panned concentrate samples according to content classes.

Database of samples	Negative	Content (semi-quantitative classes)					
	Positive	a	b	c	I	II	III
50,939	44,400	5,005	1,351	142	26	12	3
	87.2	9.8	2.65	0.28	0.05	0.02	0.01
	6,539	5,005	1,351	142	26	12	3
	12.8	76.5	20.7	2.17	0.40	0.18	0.06

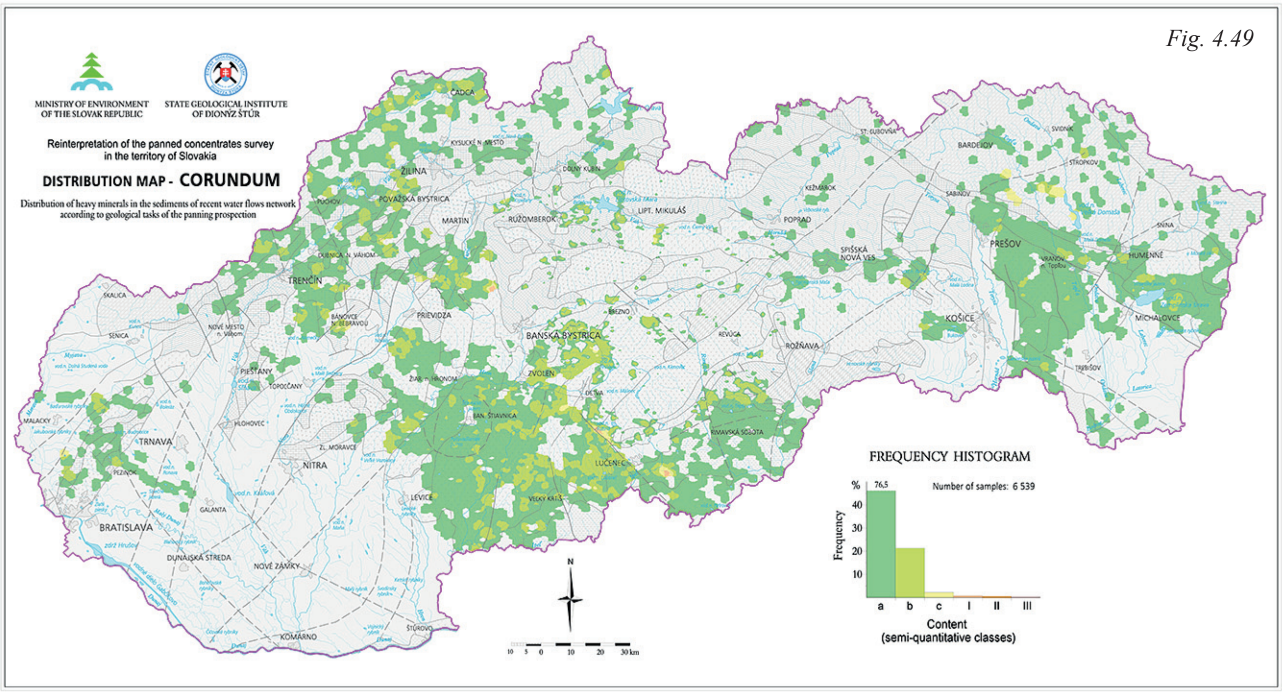


Fig. 4.49

normally within 0.5 to 1.0 mm. In the Hajnáčka area reach corundum of sapphire type several mm.

Identification attributes: Morphology, hardness, in some cases (especially gem varieties), luminescence – reddish colour.

General distribution characteristics

Panned concentrate samples containing corundum, represent a relatively small percentage of evaluated samples (Tab. 4.18). It is mainly present in the lowest concentration classes (a) – Fig. 4.48a.

Near the primary sources of hydrothermal alterations (Remetské Hámre-Kapka) its content may be characteristic in heavy mineral concentrates and it can achieve even semi-quantitative classes I and II.

Corundum is a relatively rare accessory mineral. However, it is characteristic for source areas dominated by Neogene volcanic rocks of andesite composition, less basalts (Fig. 4.49). Corundum, as the residual resistant mineral, can be an indicator of the presence of the original volcanic rocks, which due to denudation processes have been removed. As an example of such an area is the area of the Outer Flysch Zone near the Vihorlat Mts., and wider area of Tisovec and Klenovský Vepor.

4.3.13 Monazite Ce, La, $ThPO_4$

Varieties of monazites: Monazite-Ce $(Ce,La,Nd,Th)PO_4$; Monazite-La $(La,Ce,Nd)PO_4$; Monazite-Nd $(Nd,Ce,La)PO_4$

End members of monazites are as follows (Broska et al., 2012): Monazite $(Ce,La,Th)PO_4$; cheralite $Ca_{0,5}Th_{0,5}PO_4$; huttonite $(Th,U, Pb)SiO_4$.

H = 5.0 – 5.5; **SG** = 4.6 – 5.4 g.cm^{-3}; **System:** Monoclinic

Magnetic properties: concentrated in paramagnetic fraction

Luminescence: in general it is indistinguishable, occasionally orange colour

Colour in the panned concentrate samples

Monazites in the panned concentrate samples are highly variable in colour, but the most common are various shades of tan, and orange honey-yellow colours (Fig. 4.50a, b, c). Rarer colours are emerald green, greenish, reddish, brownish red and grey. Lustre on rarely preserved crystal surfaces is glassy, but on the present roughened surface of grains it is dull, mostly. Sometimes the surface of monazite grains from panned concentrate samples is coated with a layer of white granular masses of rabdofanite(?).

Morphology in the panned concentrate samples

In the panned concentrate samples monazites are present in the form of tabular isometric (Tab. 4.51b), less prismatic shapes which are rounded-up to different levels (Figs. 4.50a, b, c, 4.51a, c; 4.52a, b, c). The tabular shape is characterized by the development of pinacoidal and prismatic planes. On the isometrically developed grains the shapes are determined by almost the same development of pinacoids and prisms.

Elongated, prismatic small crystals are rare, outside the dominant pinacoidal planes there are more strongly represented prismatic planes. Size of the planes ultimately determines the appearance of small crystals (Fig. 4.52b).

In general, in the panned concentrate samples monazite is dominated by small crystals and their fragments, which are rounded-up to varying degrees. In the clastogenic sediments the fragments and small crystals have significantly rounded edges. The surface of small crystals

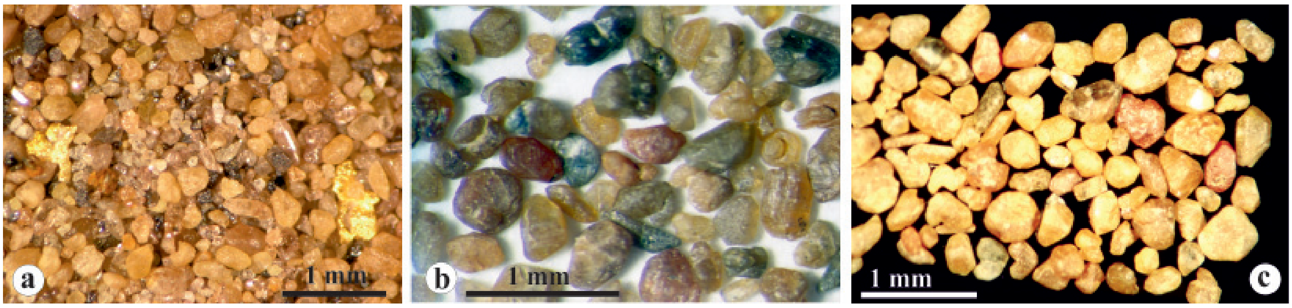


Fig. 4.50a, b, c Coloured varieties and lustre of monazite in the panned concentrate samples; source areas are made of granitic rocks, prevailingly. Sites: a – Kociha, b – Ipeľský Potok, c – Krná. Photo: P. Bačo.

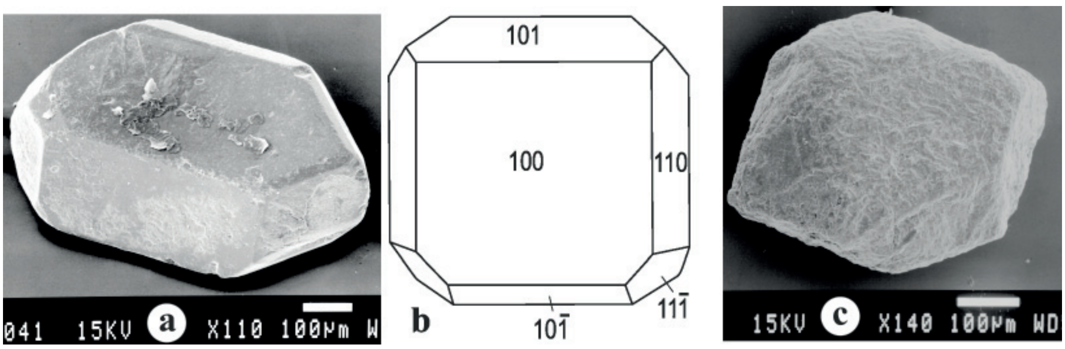


Fig. 4.51a, b, c In the panned concentrate samples monazite is present in the form of tabular (a) and isometric small crystals (b). Frequently, the smooth surface of planes (a) has not been preserved. Sites: a – Pohronská Polhora, c – Krná. Drawing: J. H. Rösler, 1983, SEM I. Holický.

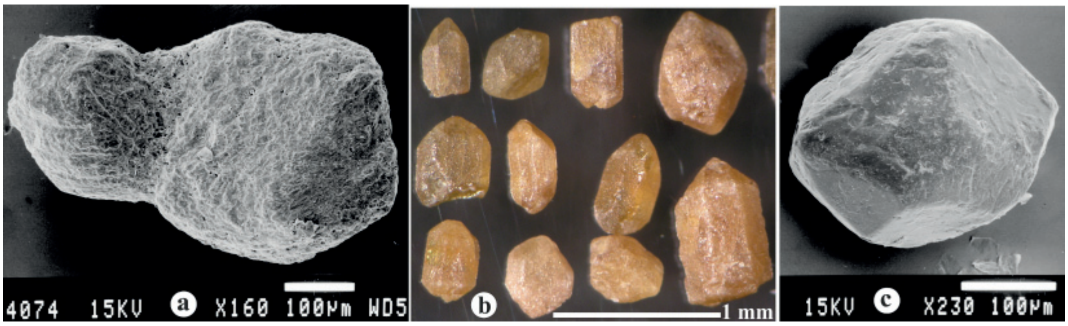


Fig. 4.52a, b, c Monazite in the panned concentrate samples mostly creates small crystals with tabular habit with very wide scale of couples of individual crystal planes, which ultimately determine resulting habit. Sites: a, c – Krná, b – Kociha – Kocižský potok Brook. Photo: P. Bačo (b), SEM I. Holický.

and fragments is often rough and dull. Perfectly limited morphological shapes in the panned concentrate samples are curiosities – for example, Fig. 4.51a and Fig. 4.52b.

In the panned concentrate samples from different geological environments there can be observed intergrowths of two, as well as several single crystals of monazite. Random intergrowths with other types of minerals have been reported mainly from the South Veporicum – wider area of Krná, Kociha and Podrečany. The most common are intergrowths with zircon – with prismatic habit with different coefficient of elongation. Most of them are variously oriented intergrowths, on which the preferential orientation was not observed, or any coupling parallel to the plane – which could mean epitaxy (Fig. 4.53c, d).

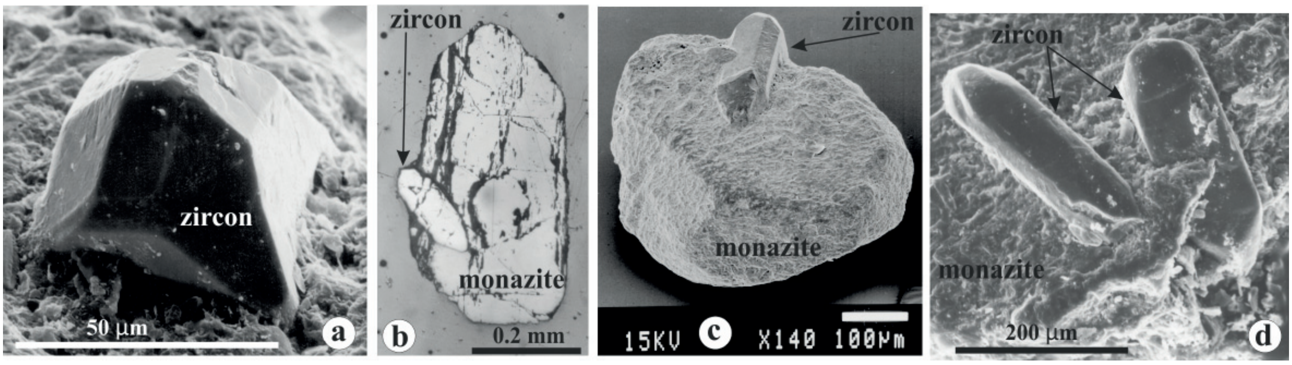


Fig. 4.53a, b, c, d Intergrowths of monazite with zircon. Site: a – d – Krná. Photo: SEM I. Holický.

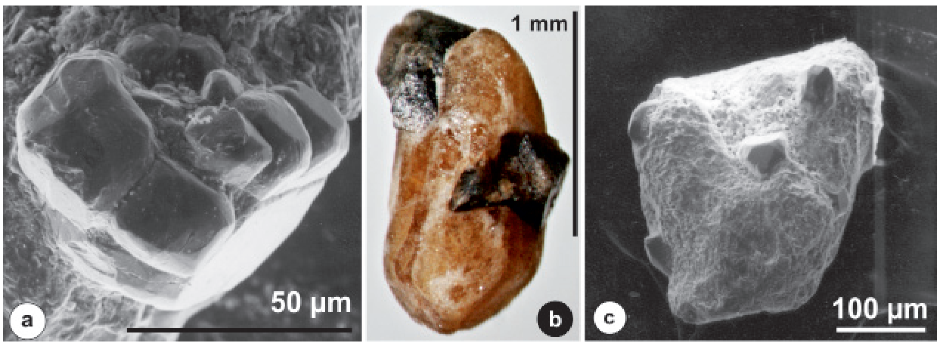


Fig. 4.54a, b, c Integrowths of monazite with zircon (a, c) and xenotime (b) . Site: a, c – Krná, b – Kociha. Photo: P. Bačo, SEM I. Holický

The amount of individuals zircon overgrown with monazite is variable. They occur either alone (Fig. 4.54c) or in large clusters (Fig. 4.54a). Rarely there were also recorded separate intergrowths of zircons (Fig. 4.54b).

Size of small crystals or fragments, and to varying degrees rounded grains is 0.5 to 1 mm. Near-occurrence of some autochthonous source rocks (e.g. localities Krná, Podrečany, Pezinok) size of different crystals or their mutual intergrowths may achieve up to several mm. In source areas of the Flysch Zone the size of grains reaches only 0.X mm.

General distribution characteristics:

Monazite was observed in approximately one third of the panned concentrate samples (Tab. 4.19, Fig. 4.55a). It is present in the lowest (a) up to the highest concentration classes (III). Its content in the panned concentrate samples is quite variable and is strongly conditioned by the type of source rocks in source areas (Fig. 4.56). In positive samples it is typically present in the first quantitative classes (Fig. 4.55b, c).

Monazite is a typical accessory mineral and is present in the panned concentrate samples from source areas of almost all regional geological units. Exceptions are areas made of Neogene volcanism products, and some Tertiary sedimentary areas.

Tab. 4.19 Presence of monazite in the panned concentrate samples according to content classes.

Database of samples	Negative	Content (semi-quantitative classes)					
	Positive	**a**	**b**	**c**	**I**	**II**	**III**
50,939	34,107	11,355	4,220	726	411	108	12
	68	22	8.28	1.43	0.81	0.21	0.02
	16,832	11,355	4,220	726	411	108	12
	33	67.46	25.07	4.31	2.44	0.64	0.11

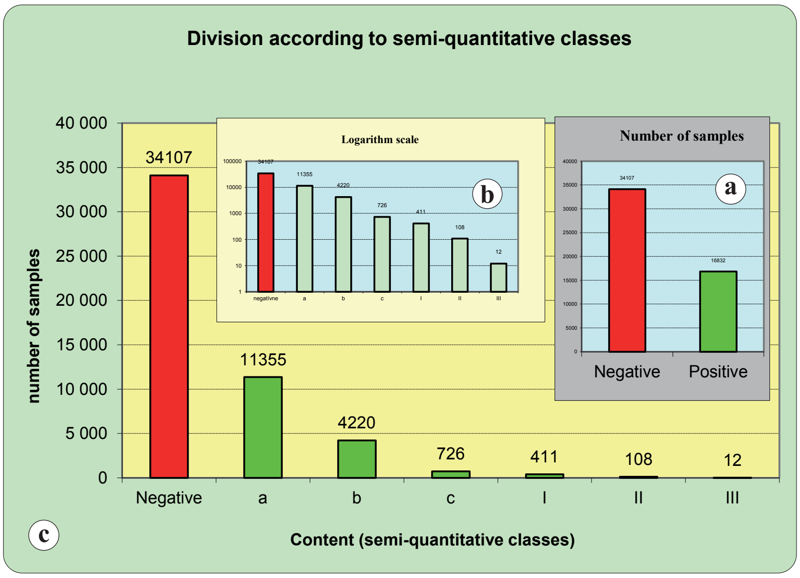


Fig. 4.55a, b, c Distribution of panned concentrate samples according to monazite presence (a) and according to proportion of individual semi-quantitative content classes (b, c).

Because of its relatively good resistant properties it enters sedimentary basins as part of clastogenic sediments. In such an environment it can often create more significant accumulations (Bačo et al., 2004a). In recent aluvial sediments of the river network, however, it is the most widely present in the source areas, which are formed by granitic rocks of type S (Broska, et al., 2012) – e.g. Bratislava Massif, SW part of the Tribeč Mts., etc.). From the source areas made of some types of granitic rocks there are known contents of the class II – Ipeľský Potok, Kociha, Pezinok. Elevated concentrations are also from the areas with the occurrence of paleoplacers – e.g. Poltár Formation in the Southern Slovakia Basin – Podrečany (Zuberec et al., 2004). It is fairly widely represented in source areas formed of metamorphic rock types such as Krná area.

4.3.14 Pyrite FeS_2

H = 6.0 – 6.5; **SG** = 4.9 – 5.2 g.cm^{-3}; **System:** Cubic

Magnetic properties: non-magnetic, and is concentrated in diamagnetic fraction, the intense limonitised one transits into paramagnetic fraction

Colour in the panned concentrate samples

Colour of pyrite in the panned concentrate samples depends on the genetic type and the way it has entered into the supergene environment. The original brass-yellow colour is kept close to the autochthonous occurrence - natural

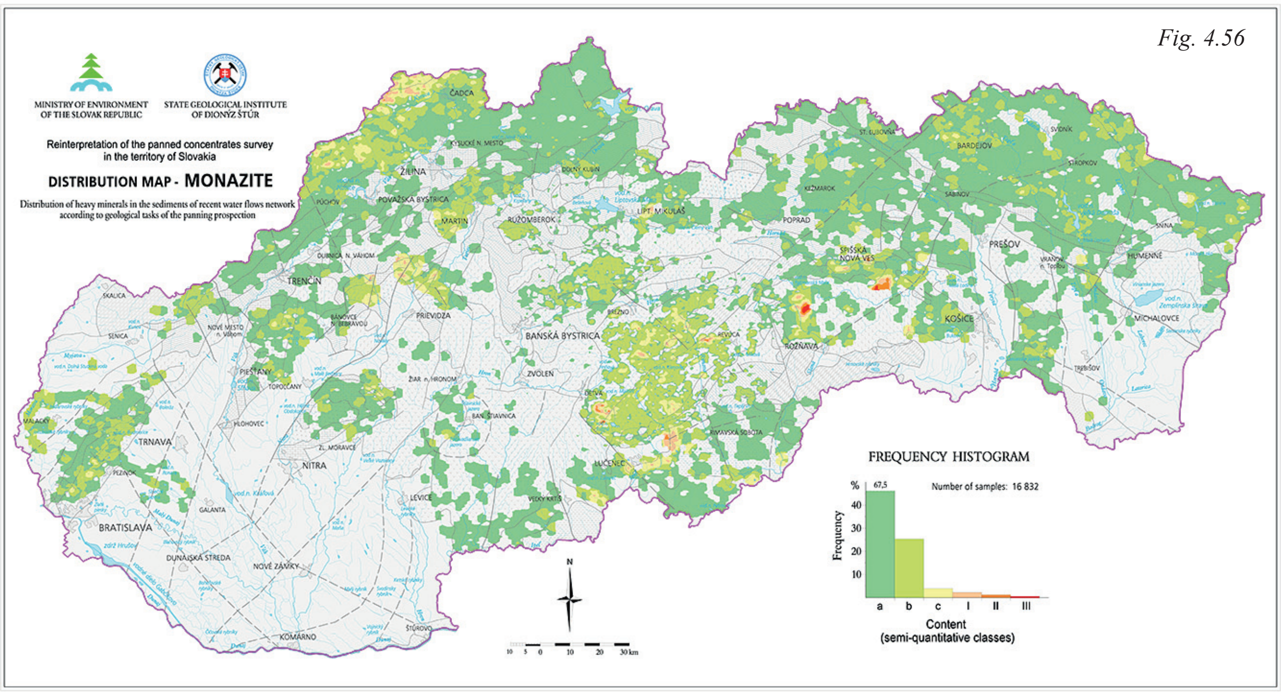


Fig. 4.56

or anthropogenic. Common are yellow-brown or so-called brownish coating colours. Lustre on the planes of fresh crystals is metal, or dull on limonitised parts and limonite pseudomorphs after pyrite.

Morphology in the panned concentrate samples

In the panned concentrate samples pyrite is present in the most diverse forms (Fig. 4.57a, b, c, d). Morphology of these shapes is characteristic and unique to the pyrite. There are often present perfect hexahedron {100} small crystals characteristic for accessory type, but also for epithermal mineralisation. Octahedron {111} small crystals (Fig. 4.58a, b, c, d) are present in the samples from the Flysch areas, mainly. Pentagonal dodecahedron {210} crystal shapes are mainly from the areas of epigenetic sulphide mineralisation. More common in the panned concentrate samples are different couplings and mutual intergrowths of basic shapes (Fig. 4.59a, b, c, d).

Besides cyclic and different contact intergrowths and aggregates there are present completely restricted intergrowths of pentagonal dodecahedrons (Fig. 4.60a, b, c), or shapes according to the Spinel Law (Fig. 4.59c). Characteristic is also grooving of hexahedron planes of small crystals, which is not generally applicable to the spatial distribution of this mineral. Quite common is its presence in the form of irregular fragments and grains, or isometric grains.

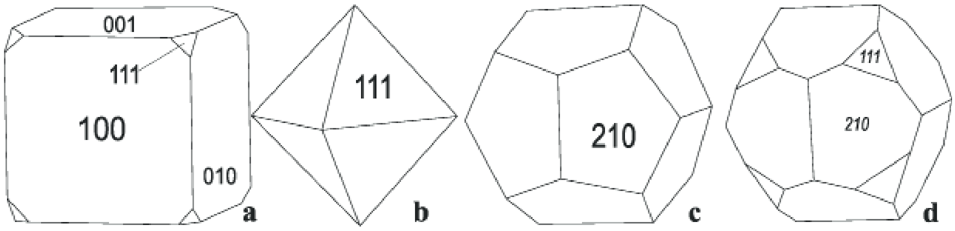


Fig. 4.57a, b, c, d Basic crystal shapes and couples of pyrite, which are mostly present in the panned concentrate samples. Drawings: J. H. Rösler, 1983.

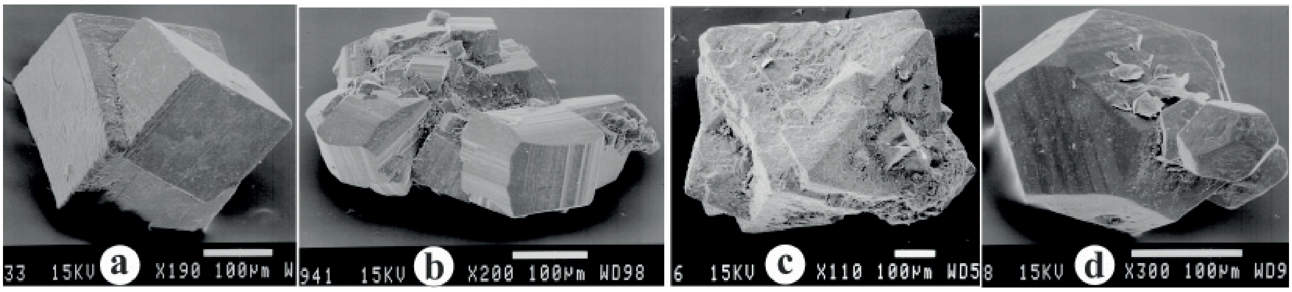


Fig. 4.58a, b, c, d In the panned concentrate samples pyrite is present in all basic shapes. Some shapes are characteristic for certain rock – source environ. Sites: a – Vernár, b – Livov, c – Hodruša Hámre, d – Kremnica. Photo: SEM I. Holický.

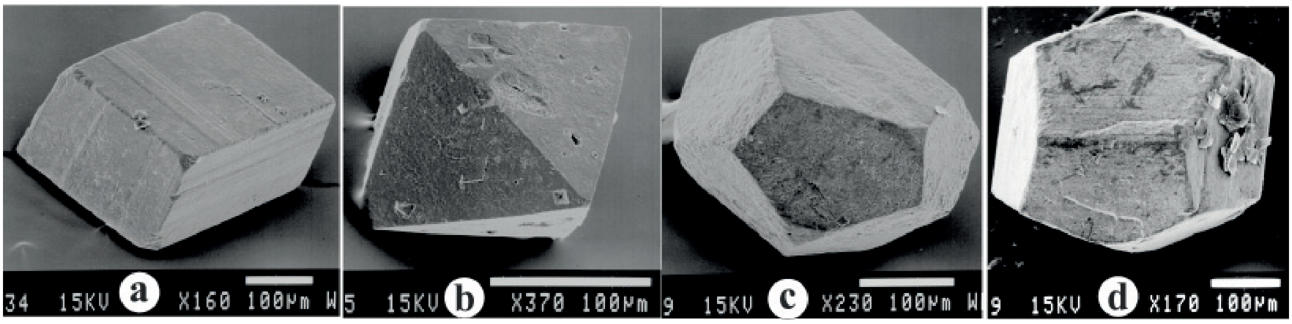


Fig. 4.59a, b, c, d Sites: a – Vernár, b – Kremnica, c – Kysucká vrchovina – Ráztoky, d – Vyšná Boca. Photo: SEM I. Holický.

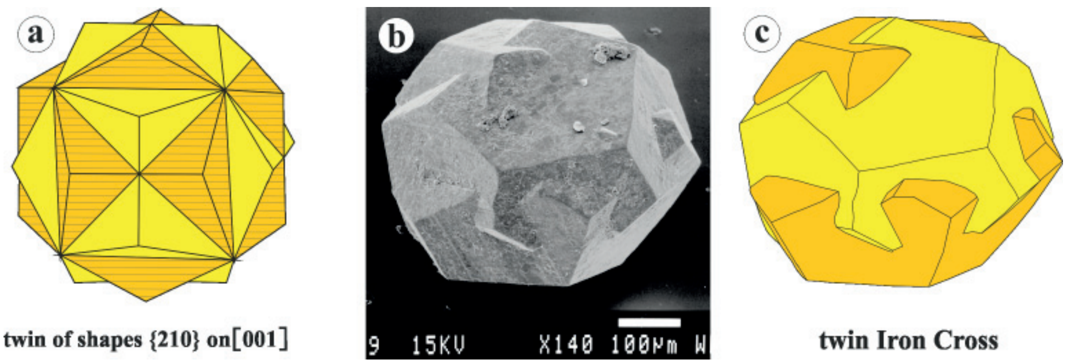


Fig. 4.60a, b, c Intergrowth of two crystals – twin of pentagonal dodecahedron {210}, twinning axis is [001]. Site: a – Nízke Tatry – Dúbrava. Drawings: a – Klein, 2006, c – Repčiak in Bačo et al., 2004. Photo SEM I. Holický.

Types of pyrites may also have some local typological relevance to the specific geological environment. Size of small crystals, their fragments, grains or aggregates in the panned concentrate samples is typically up to 2.0 mm. However, in the Flysch Zone their size rarely exceeds 2 mm.

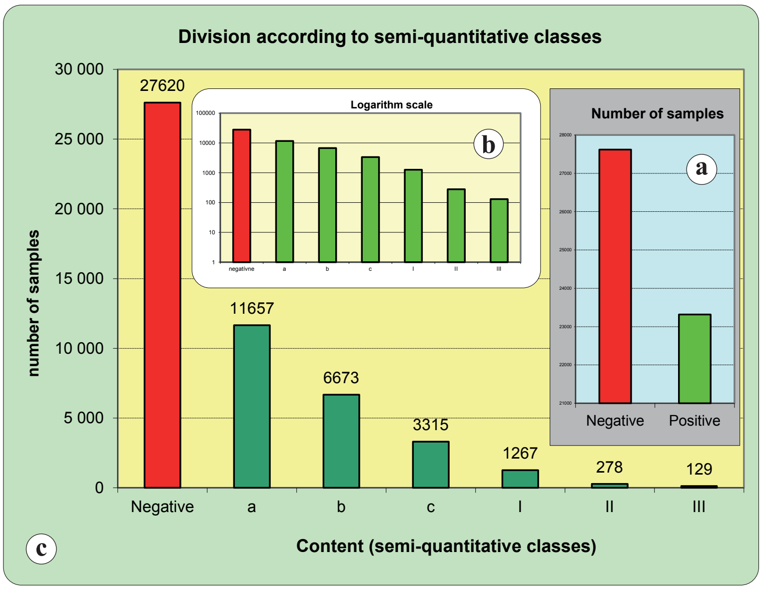


Fig. 4.61a, b, c Distribution of panned concentrate samples according to pyrite presence (a) and according to proportion of individual semi-quantitative content classes (b, c).

General distribution characteristics:

Pyrite is the fixed component of the heavy fraction (Tab. 4.20) and is one of the most stable sulphides in the panned concentrate samples. A significant proportion is observed primarily in the areas of epigenetic sulphide mineralisation, in which it is a stable accompanying mineral of almost all genetic types of ore mineralisations of deposit significance or their manifestations. In such areas the concentrations are within the highest classes.

Pyrite is present in almost all types of rocks and it is accompanying mineral of all the epigenetic and syngenetic ore mineralisations. Its occurrence in the panned concentrate samples, particularly those in the highest content classes (Fig. 4.61c) is partially limited by relatively weak resistance in supergene conditions. It is characteristic for all regional geological units (Fig. 4.62). Preferential binding at higher content classes is to the areas with the occurrence of ore mineralisation in the Central Slovakia Neovolcanic Field or Gemericum.

In the panned concentrate samples from sedimentary environment there are present pyritised tests of primarily foraminifera, molluscs and shellfish, various concretions and aggregates. In these types of source areas this form of pyrite appearance is often the dominant one.

Tab. 4.20 Presence of pyrite in the panned concentrate samples according to content classes.

Database of samples	Negative	Content (semi-quantitative classes)					
	Positive	a	b	c	I	II	III
50,939	27,620	11,657	6673	3315	1267	278	129
	54	23	13	6.51	2.49	0.55	0.25
	23,319	11,657	6673	3315	1267	278	129
	46	49.99	28.62	14.22	5.43	1,19	1.11

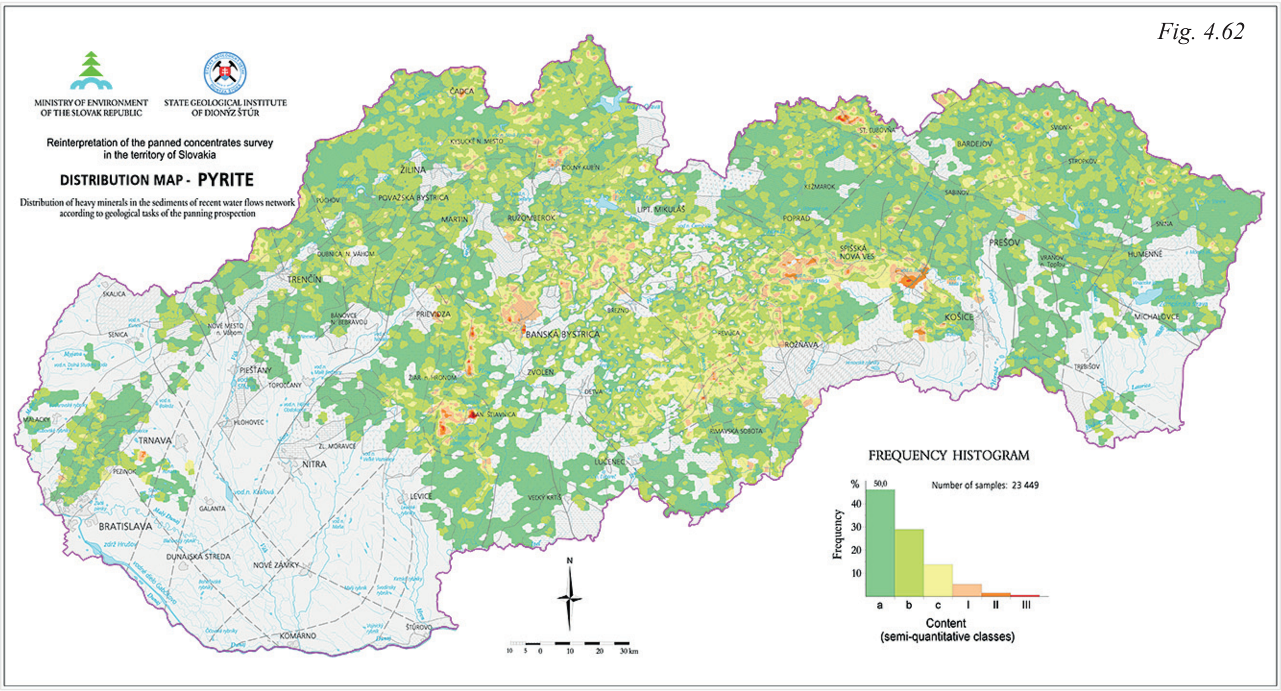


Fig. 4.62

4.3.15 Pyroxenes

In evaluating the panned concentrate samples there were determined individual mineral species, for example, Mg-Fe (e.g. enstatite), Ca-Na-Mg (e.g. augite), Ca-Mg (e.g. diopside) as subgroups of pyroxene uniformly - without distinction of mineral species. The reason, among others, is the possibility of macroscopic identifying and view of the distribution as well as effectiveness of panned concentrate prospecting.

H = from 5.5 to 6.0 (according to the type); **SG** = from 3.18 to 3.33 g.cm^{-3} (according to the type)

System: Monoclinic (augite, diopside); Rhombic (enstatite, Fe-enstatite – "hypersthene")

Magnetic properties: they are concentrated in paramagnetic fraction, rare non-ferric varieties can pass into the diamagnetic fraction.

Colour in the panned concentrate samples

Diopside in the panned concentrate samples is mostly green in different grades and shades. Colour of augite is mostly black, brownish black; Fe-enstatite (hypersthene) in various shades of green (Fig. 4.63a, d). Lustre of smooth planes is glassy or dull on the corroded grains.

Identification attributes: coarse-prismatic, prismatic, but also tabular shape of small crystals, greenish colour.

Application of specific methods of identification: To determine the species it is necessary the optical study, X-ray or electron microanalysis.

Morphology in the panned concentrate samples

Pyroxenes in the panned concentrate samples often retain the characteristic small crystals of tabular and columnar habit (Fig. 4.64a, b, c).

Diopside in the panned concentrate samples is present most often in the form of small short-columnar crystals and debris. Typical is its square cross-section (Fig. 4.63b). Augite in the panned concentrate samples is present mostly in the form of short columnar to small isometric crystals and their fragments. Typical for them are square and octagonal cross-sections. Fe-enstatite – "hypersthene" in the panned concentrate samples is present mostly in the form of short-columnar and tabular small crystals and their fragments. Typical are the rectangular and square cross-sections.

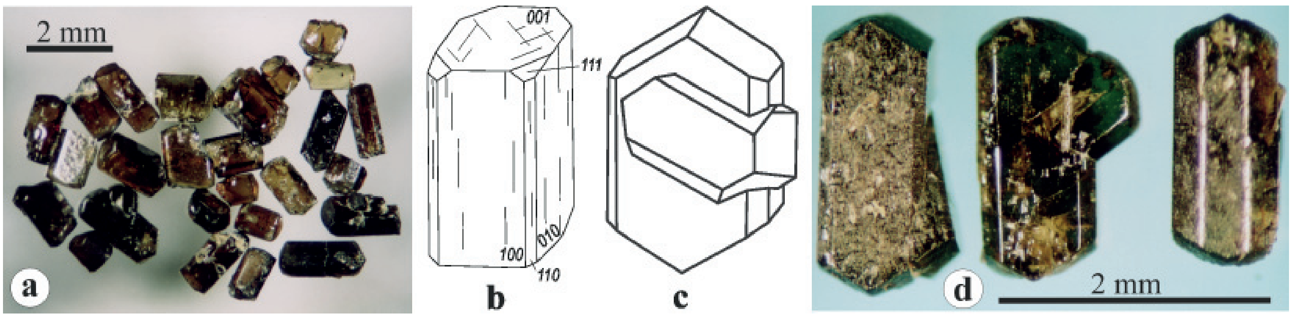


Fig. 4.63a, b, c, d Crystal shapes of the group of monoclinic and rhombic pyroxenes (b, c). Characteristic colour of small crystals and fragments is green in various shades and saturation. Dark colouration occurs often due to numerous inclusions of opaque minerals (Fig. 4.40c). Site: a, c – Ľubietová. Drawings: b, c – Rösler, J. H., 1983. Photo: P. Bačo.

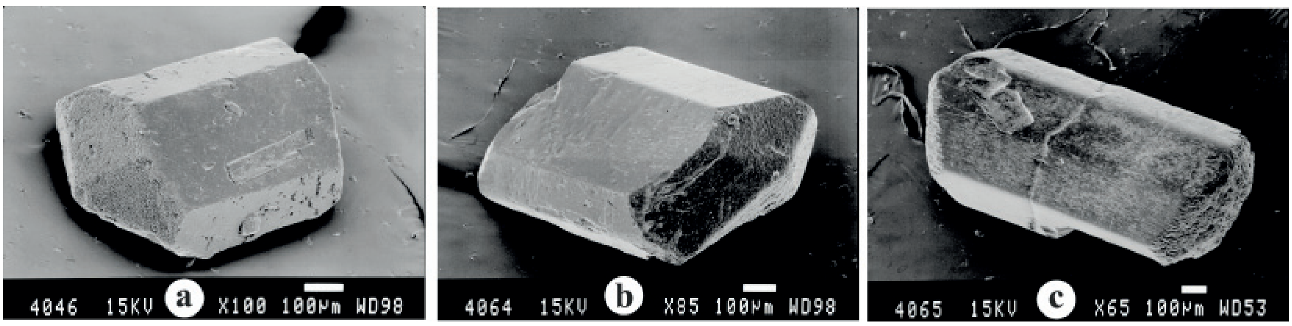


Fig. 4.64a, b, c Typical columnar habit of pyroxenes in the panned concentrate samples. Small crystals often terminate with dipyramid planes (a, b) or with magmatic-corroded planes of these pyramids (c). They are idiomorphic and typical in volcanic source areas. During transport the edges are quickly reworked, but their habit remains unchanged. Sites: a – Slanské vrchy Mts. – Slanská Huta, b, c – Slanské vrchy Mts. – Banské. Photo: SEM I. Holický.

Tab. 4.21 Presence of pyroxene in the panned concentrate samples according to content classes.

Database of samples	Negative	Content (semi-quantitative classes)					
	Positive	**a**	**b**	**c**	**I**	**II**	**III**
50,939	30,099	5,425	5,209	2,572	2,074	3,263	2,297
	59	11	10	5.0	4.1	6.4	4.5
	20,840	5,425	5,209	2,572	2,074	3,263	2,297
	41	26.03	25.00	12.34	9.95	15.66	42.34

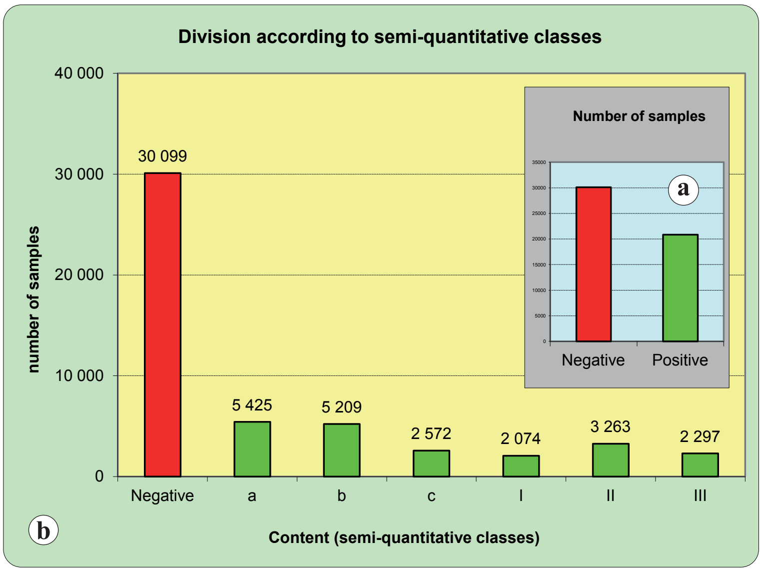


Fig. 4.65a, b Distribution of panned concentrate samples according to pyroxenes presence (a) and according to proportion of individual semi-quantitative content classes (b).

During transport pyroxenes are quite intensively processed and disintegrated due to good cleavability. Irregular grains, however, maintain the original habit, or the habit along the cleavability planes. Quite common are intergrowths of two or several small crystals often with a distinct crystal shape typical for pyroxenes (Fig. 4.63d). Epitaxial intergrowths of ilmenite (differently oriented, often magmatic-corroded) are quite commonly observed mainly from volcanic regions. The occurrence of the inclusions of ilmenite in the plane of the dominant prism is typical (Fig. 4.40c).

Size of small crystals in the panned concentrate samples from the environment of Neovolcanic rocks of andesite composition is typically up to 2.0 mm, or even above this size. Their average size from the other source areas is smaller.

General distribution characteristics:

Pyroxenes were recorded in more than one third of all evaluated panned concentrate samples (Tab. 4.21; Fig. 4.65a). Their concentration in positive panned concentrate samples is from the lowest (a) to the highest content classes (III) with a slight predominance of the first ones (a – c) – Fig. 4.65b. The concentration of pyroxenes is strongly dependent on the prevailing rock environment source areas. They are mostly the intermediary volcanic rocks and their contents are stable above 50% of heavy minerals (Fig. 4.66). In other areas the contents are in the first concentration classes (a – c).

Pyroxenes can be included to the discriminatory minerals that uniquely identify the type of geological environment in source areas. These are Neogene volcanic rocks of andesite composition. They are deposited by hydrological network present in the environment. The deficient source areas are those made of mostly carbonatic rocks and older clastogenic sedimentary rocks.

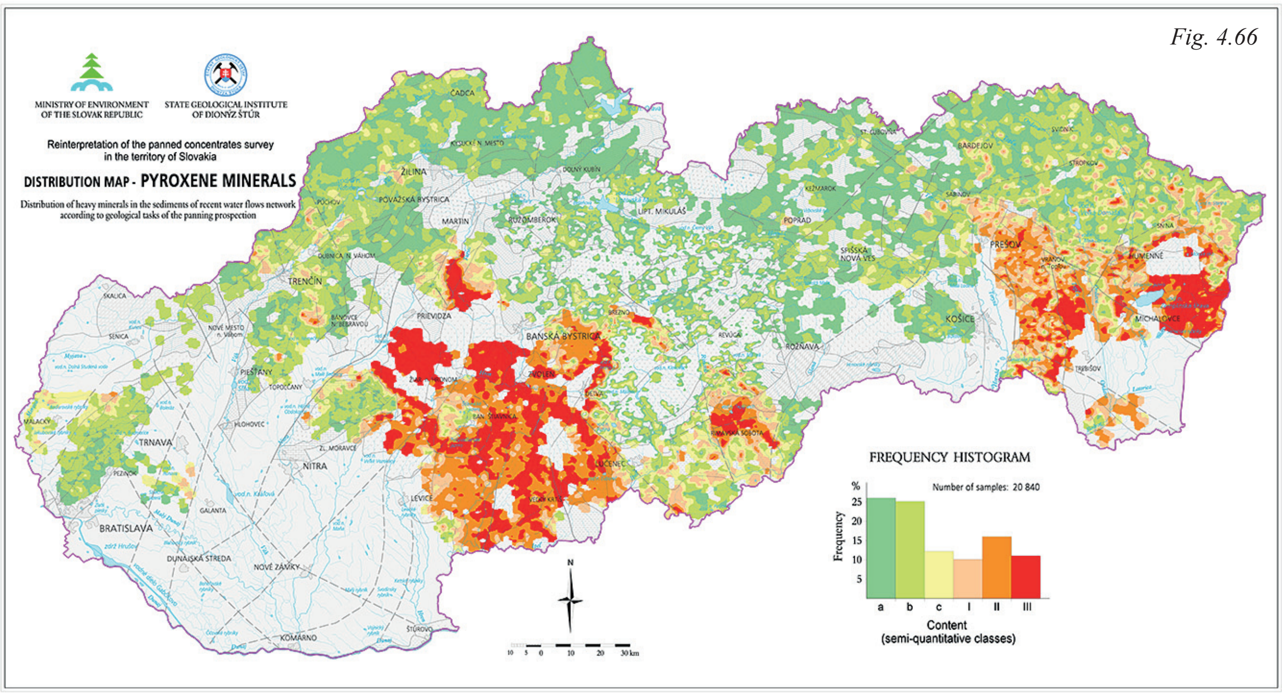


Fig. 4.66

4.3.16 Rutile TiO_2

H = 6.0 – 6.5; **SG** = 4.18 – 4.25 g.cm^{-3}; **System:** Tetragonal

Magnetic properties: concentrated in diamagnetic and partially in paramagnetic (variety nigrine) fraction

Colour in the panned concentrate samples

Colour of small crystals is deep reddish brown and brown (Fig. 4.67b) with a metallic to diamond-like lustre. It is also often dark brown to black in colour – nigrine

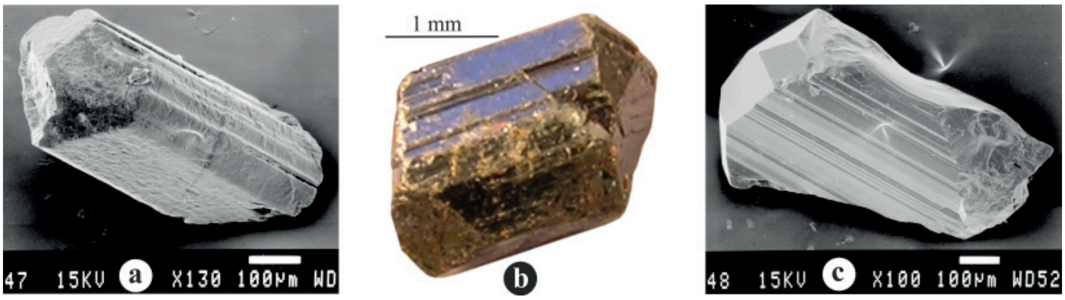


Fig. 4.67a, b, c Characteristic colour and shine of small crystals of rutile (b) with preserved columnar habit. On crystal planes of tetragonal prisms characteristic "grooving" is visible. Site: Sinec Massif – Kokava nad Rimavicou, Photo: P. Bačo. Photo: SEM I. Holický.

(variety containing Fe^{3+}, Fe^{2+}) and rare yellow to tan (sagenite). On the fresh and fracture or cleavage surfaces it has the metal to diamond-like shine.

Morphology in the panned concentrate samples

In the panned concentrate samples from areas of granitic and metamorphic rocks rutile is present in the form of small crystals of columnar habit with strong longitudinal "grooving".

In most cases, fragments of small crystals are present, rarely terminated with the pyramid planes. Characteristic are twin intergrowths on (101) plane in which the c-axis angle is 114° – "knee-shaped" intergrowth or on (301) – c-axis angle of 54° – "heart-shaped" intergrowth (Fig. 4.68a, b, c, d). Due to destruction during transport the small crystals are reshaped in varying degrees (Fig. 4.69a, c), preferably along cleavability (110) planes. In the source areas formed by sediments the fragments are reworked and well-rounded (Fig. 4.69b), but the original habit is often maintained as a result of high mechanical and chemical resistance.

Size of small crystals or fragments of rutile in the panned concentrate samples is from 0.5 to 2 mm, in some sites of the western part of the Slovenské rudohorie Mts. (mainly in the wider area of the Sinec Massif) the size can reach over 1 cm. In the Flysch source areas the fragments reach the size of 1 mm, exceptionally 5 mm.

Rutile is present in the form of inclusions in corundum and topaz. Fragments of quartz with rutile (sagenite) have not been recorded in the panned concentrate samples. Submicroscopic rutile is also a component of "leucoxene" – breakdown product of ilmenite.

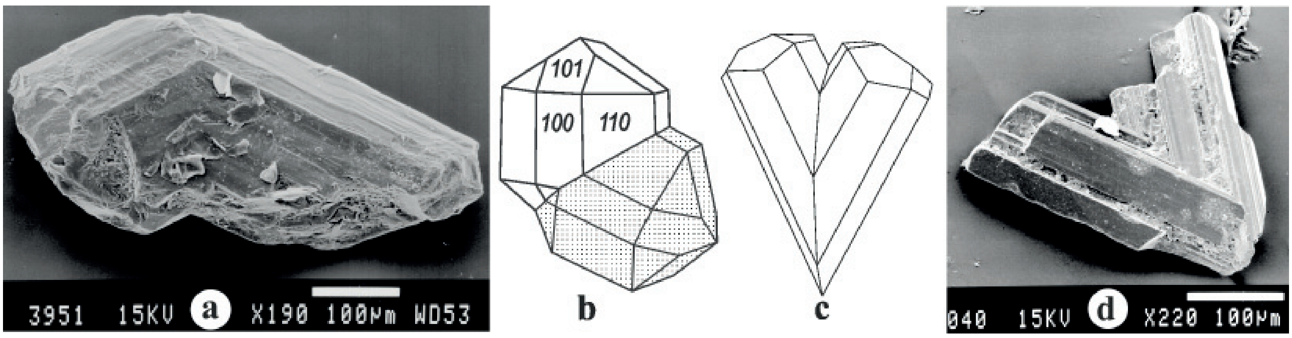


Fig. 4.68a, b, c, d Crystal of rutile with basal crystal planes, ditetragonal prism and ditetragonal dipyramid (b). These planes and shapes are present on very frequent, typical and characteristic intergrowths of rutile. Characteristic morphological sign of rutile in the panned concentrate samples are intergrowths on (101) plane, "knee-shaped" intergrowth (a, b) and on (301) plane, "heart-like" intergrowth (c, d). Sites: a – Sinec Massif – Kokava nad Rimavicou, d – Pohronská Polhora. Drawings: b, c – Rösler, J. H., 1983. Photo: SEM I. Holický.

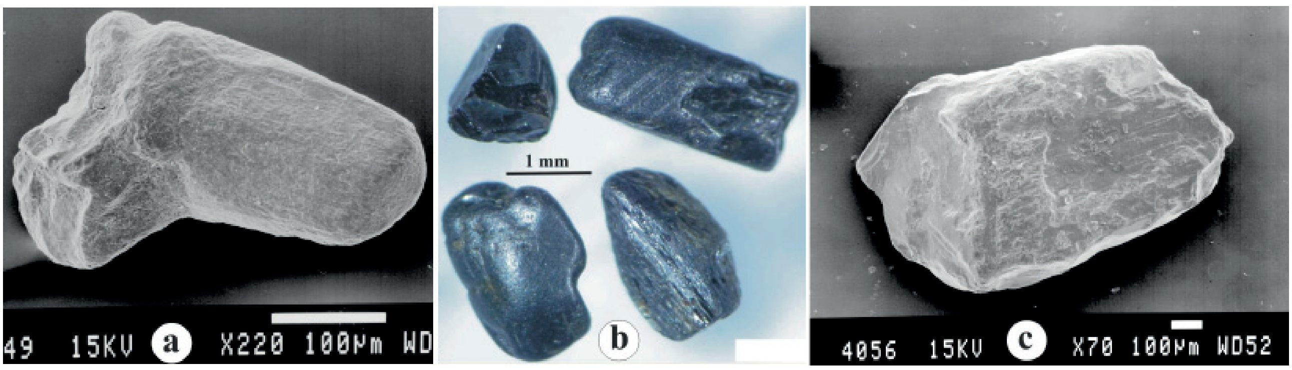


Fig. 4.69a, b, c Morphology of fragments and small crystals of rutile from various types of source areas. Fragments of rutile crystals preserve columnar habit. It is a frequent and typical shape of clastogenic type. Sites: a – Inner-Carpathian Paleogene – Nižné Repaše; Outer Flysch Zone: b — Ruská Bystrá, c – Kolonica. Photo: P. Bačo – b. SEM I. Holický – a, b.

General distribution characteristics:

Rutile was detected in more than half of assessed panned concentrate samples (Tab. 4.22). Its content is common within the first quantitative classes (a – c) (Fig. 4.70b). In these classes it is present in almost all regional geological formations (Fig. 4.71). In the Crystalline areas its contents can locally reach the highest class, for example, wider area of the Sinec Massif.

Rutile is significantly present in the heavy fraction of sedimentary complexes of the Outer Flysch Zone, its eastern and western parts, and Inner-Carpathian Paleogene. Together with garnet they form the bulk of heavy fraction. Compared to the original association in other geological conditions a selective enrichment is typical (Fig. 4.71). From this point of view interesting significant enrichment is known from the source area formed by the Dukla unit in the vicinity of Smilno.

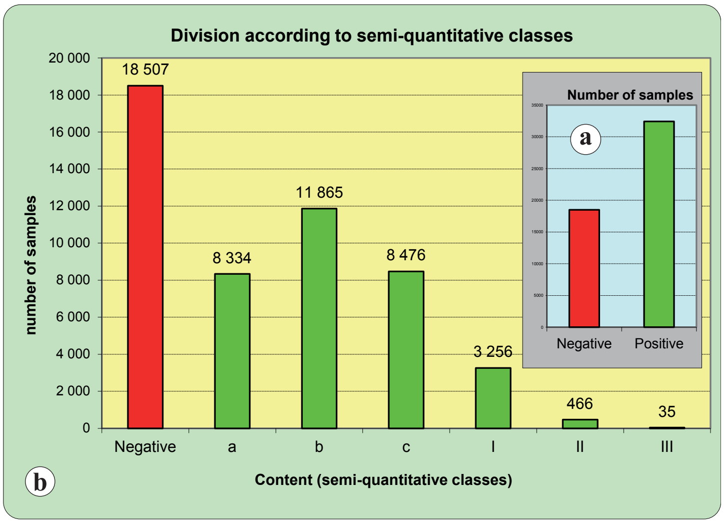


Fig. 4.70a, b Distribution of panned concentrate samples according to rutile presence (a) and according to proportion of individual semi-quantitative content classes (b).

4.3.17 Scheelite $CaWO_4$

H = 4.5 – 5.0; **SG** = 6.10 – 5.5 g.cm^{-3}; **System:** Tetragonal

Magnetic properties: concentrated in diamagnetic fraction, the intergrowths with wolframite (ferberite) can pass into paramagnetic fraction

Luminescence (shortwave spectrum of ultraviolet radiation, monochromatic, λ = 254 nm): pure blue-white colour (Fig. 4.72b, c), white – at the content 0.5 % Mo, yellow – at > 0.5 % Mo

Colour in the panned concentrate samples

The most common colours are various shades of white – grey white, yellowish or colourless (Fig. 4.73a, b). In the panned concentrate samples there were rarely identified other colours of scheelite. It has a greasy to glassy lustre, small grains are translucent.

Tab. 4.22 Presence of rutile in the panned concentrate samples according to content classes.

Database of samples	Negative	Content (semi-quantitative classes)					
	Positive	**a**	**b**	**c**	**I**	**II**	**III**
50,939	18,507	8,334	11,865	8,476	3,256	466	35
	36.3	16.4	23.3	16.6	6.4	0.91	0.07
	32,432	8,334	11,865	8,476	3,256	466	35
	63.7	25.7	36.6	26.1	10.0	1.4	0.11

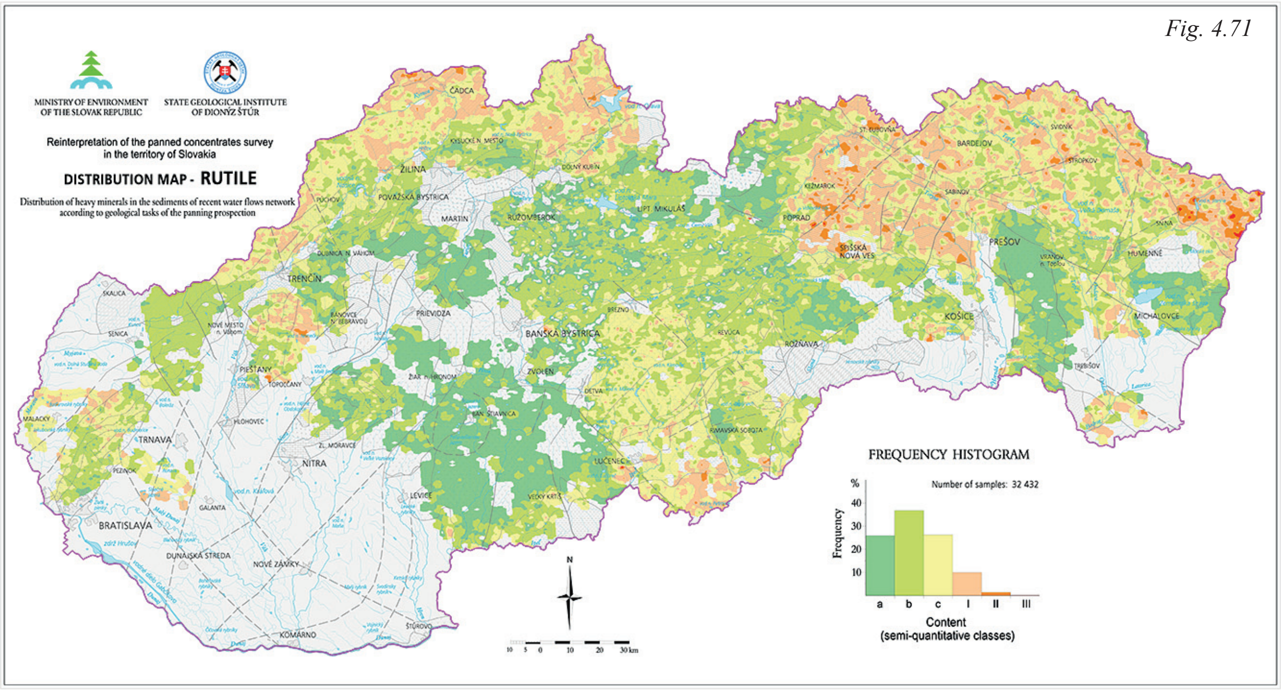


Fig. 4.71

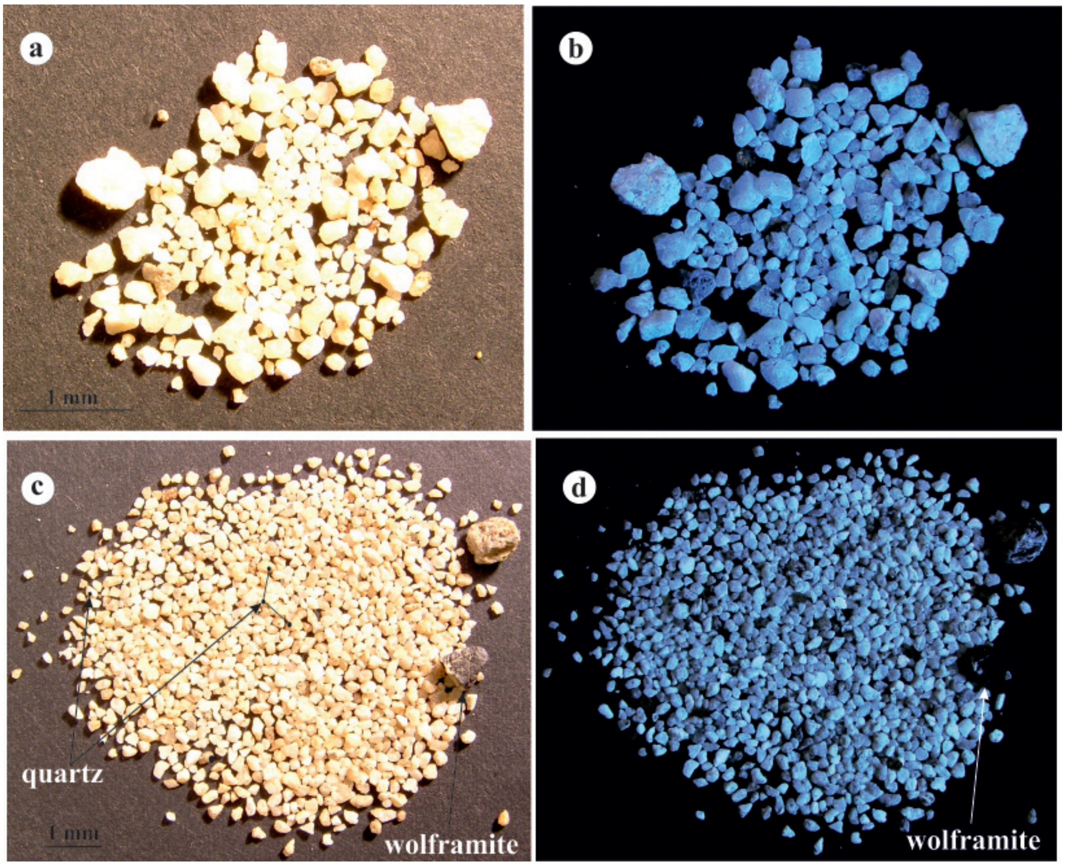


Fig. 4.72a, b, c, d For its colour and visual similarity to quartz in the panned concentrate samples it was disregarded in the first stages of regional prospecting. In Figs. a-b and c-d are examples of scheelite colours under daylight (a and c) and under ultraviolet light (b and d). In the sample (c) a larger wolframite grain is present intergrown with scheelite with very distinct luminescence effect. Under UV light quite distinguishable are tiny grains of quartz. Sites: a – Sopotnická dolina, c – Kokava nad Rimavicou – Bohaté. Photo: P. Bačo.

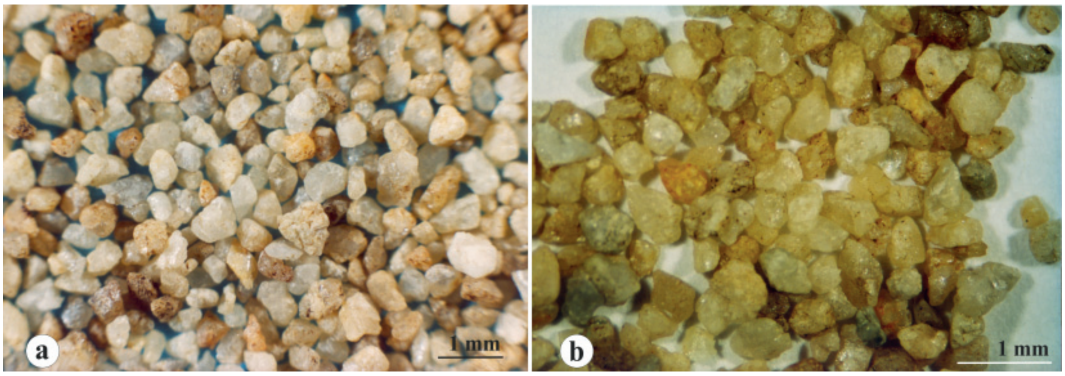


Fig. 4.73a, b Scheelite from panned concentrate samples intergrown with quartz. The grains are irregular with sharp edges. Characteristic colour is white with brownish parts. Sites: a – Jasenie – Kyslá, b – Kokava nad Rimavicou – Bohaté. Photo: P. Bačo.

Morphology in the panned concentrate samples.

In the panned concentrate samples scheelite is only rarely present in the form of crystals or their fragments. Mostly they consist of irregular grains with an uneven rough surface (Fig. 4.74a, d). Under destruction and during transport the fragments of small crystals are reworked to varying degree and they create isomorphic grains without any dominant shape. Surface of fragments of irregularly sharp-edged small crystals and isometric grains is glossy, but often rough and dull.

Epitaxial coalescence is rare, with the exception of mutual intergrowth with wolframite (Fig. 4.72c). Size of fragments of small crystals, but mostly of well-rounded grains, is up to 0.5 mm. In the areas with greater epigenetic accumulation (Core mountains - Tatricum with a variety of occurrences mainly in the Nízke Tatry Mts. and the Malé Karpaty Mts., further in Veporicum and Gemericum) or deposit occurrences (locality of the Nízke Tatry Mts. – Jasenie, Sopotnica Valley, Gemericum – Rochovce, Gemerská Poloma) the size of grains reaches several mm in mutual intergrowths with quartz.

General distribution characteristics

Scheelite has been identified in approximately 20% of the panned concentrate samples collected from all over Slovakia (Tab. 4.23, Fig. 4.75a). Scheelite content is mainly in the first semi-quantitative classes (a – c), this is valid

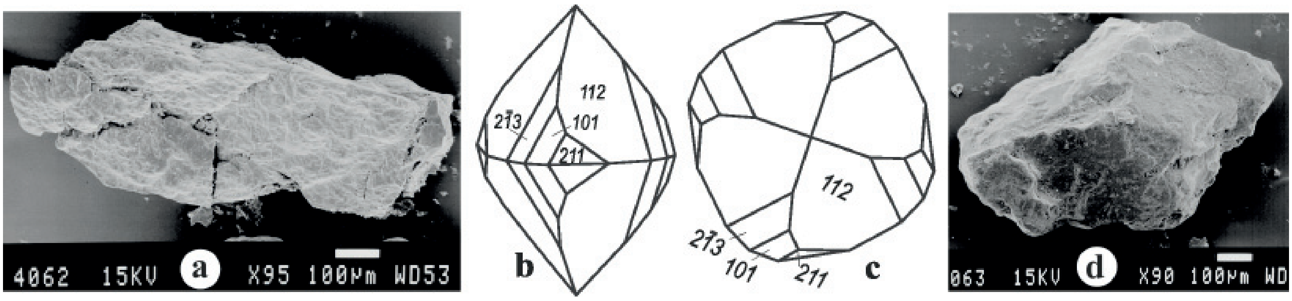


Fig. 4.74a, b, c, d Characteristic shape of scheelite crystals is a combination of tetragonal (proto)dipyramid and rudimentary planes of other pyramids (b, c). In the panned concentrate samples scheelite small crystals are rare and almost exclusively irregular fragments are present (a, d). Sites: a, d – Nízke Tatry – Jasenie – Kyslá. Drawings: b, c – J. H. Rösler, 1983. Photo: SEM I. Holický.

for up to 90% of positive samples (Fig. 4.75b, c). These concentrations characterise the geological environment of Tatricum and Veporicum Crystalline complexes. The stable presence is also in Gemericum. In other areas there have been recorded only sporadic occurrences (Fig. 4.76).

Presence of scheelite in the higher content classes (I and II) points to epigenetic mineralisation (Tab. 4.24). In the panned concentrate prospecting very significant presence of a large number of occurrences has been confirmed in Ďumbier part of the Nízke Tatry Mts. (from Vajsková Valley to the east to the conclusion of Sopotnica Valley to the west – Pulec, 1977a, b). These occurrences or deposit accumulations were indicated by the panned concentrate prospecting.

Concentrations of similar but smaller scale anomalies in the Veporicum, are bound mainly to the metamorphic complexes with a number of occurrences (wider area of Čierny Balog, Kokava nad Rimavicou, Hnúšťa, Muráň in the SE of Veporids – Hvožďara et al., 1985). In other Core mountains (Tatricum) there were reported similar occurrences especially in the Suchý, Malá Magura and Žiar Mts. (Mikoláš, 1985). Quite extensive is anomaly in the Západné Tatry Mts., which secondarily enriched the environment of the Inner-Carpathian Paleogene of the Liptov Basin (Linkešová, 1985). A similar effect of scattered accumulation is seen in Branisko and Čierna hora Mts. (Fulín, 1987).

In terms of the overall distribution it is in many places a clear coincidence with the main tectonic lines (Fig. 4.76). Significantly coincide anomalies in the Spiš-Gemer rudohorie Mts. with the Margecany-Lubeník failure. The deposit of the W-Mo ores near Rochovce shows significant scheelite anomaly.

Areas with absenting scheelite are Mesozoic carbonate complexes source areas and neo-volcanic rocks.

Tab. 4.23 Presence of scheelite in the panned concentrate samples according to content classes.

Database of samples	Negative	Content (semi-quantitative classes)					
	Positive	**a**	**b**	**c**	**I**	**II**	**III**
50,939	42,328	6,064	2,112	389	28	17	1
	83	12	4.15	0.76	0.05	0.033	0.002
	8,611	6,064	2,112	389	28	17	1
	17	25.70	37	26	10	1.44	0.11

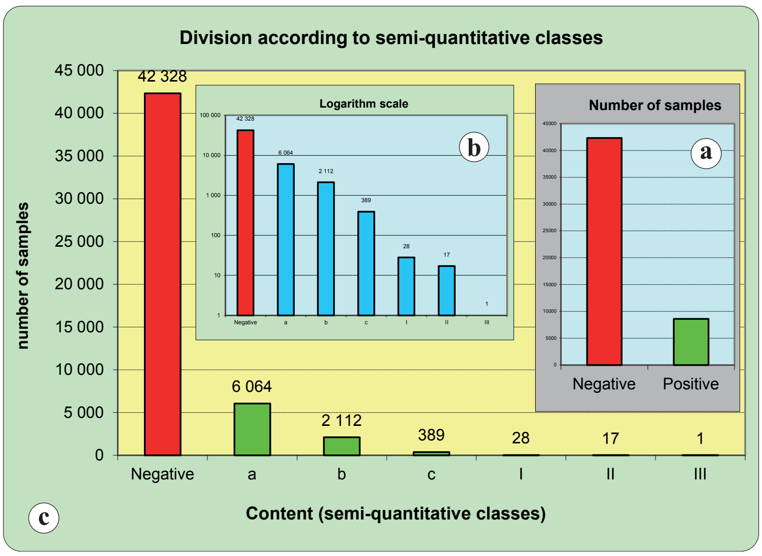


Fig. 4.75a, b, c Distribution of panned concentrate samples according to scheelite presence (a) and according to proportion of individual semi-quantitative content classes (b, c).

Deficient areas or only sporadical occurrences with very low levels are also the territories of the Inner-Carpathian Paleogene and Outer Flysch Zone

Slightly higher amounts (up to class b are recorded in NE part of the Dukla unit and in Spišská Magura (Klippen Belt on the border with Poland). In general we can say that scheelite is stably present in Tatricum and Veporicum complexes and is deficient in other regional geological units.

Part of the found anomalies of the secondary scattering of scheelite was subject to the later stages of deposit exploration. Currently wider area of Ochtiná and Rochovce is being verified. Prospective are some areas in Gemericum (e.g. Gemerská Poloma), in Veporicum and Malá Magura Mts. Tungsten was ranked among the critical metals for the countries of the European Union.

Tab. 4.24 Presence of scheelite in the panned concentrate samples according to content classes. Selected map sheets at scale 1 : 50,000 illustrate areas with deposit accumulations and significant occurrences of scheelite, which is present in the panned concentrate samples in higher content classes.

Map	Database	Samples without mineral presence		Content (semi-quantitative classes)											
	Number			a		b		c		I		II		III	
1:50 000	of samples	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%
Malá Fatra Mts.															
26-33	282	138	49	103	37	38	13	3	1	0	0	0	0	0	0
Západné Tatry Mts.															
26-44	496	310	63	123	25	31	6	31	6	1	0	0	0	0	0
Malé Karpaty Mts. – Pezinok area															
34-44	591	340	58	180	30	67	11	4	1	0	0	0	0	0	0
44-22	447	177	40	170	38	79	18	21	5	0	0	0	0	0	0
Suchý, Malá Magura Mts.															
35-22	530	277	52	156	29	89	17	8	2	0	0	0	0	0	0
35-24	286	155	54	66	23	52	18	12	4	0	0	0	0	1	0
Nízke Tatry Mts. – Jasenie, Sopotnica Valley															
36-21	1113	679	61	274	25	102	9	37	3	14	1	7	1	0	0
Veporicum – Čierny Balog, Pohronská Polhora, Kokava nad Rimavicou															
36-23	1155	615	53	293	25	198	17	42	4	3	0	4	0	0	0
36-24	1438	877	61	428	30	113	8	16	1	3	0	1	0	0	0
36-42	2143	902	42	780	36	394	18	63	3	3	0	1	0	0	0
36-43	858	384	45	260	30	175	20	36	4	1	0	2	0	0	0
36-44	797	277	35	244	31	222	28	50	6	2	0	2	0	0	0
Contact zone of Veporicum and Gemericum															
37-13	1394	887	64	375	27	110	8	21	2	1	0	0	0	0	0
37-31	999	566	57	330	33	95	10	8	1	0	0	0	0	0	0

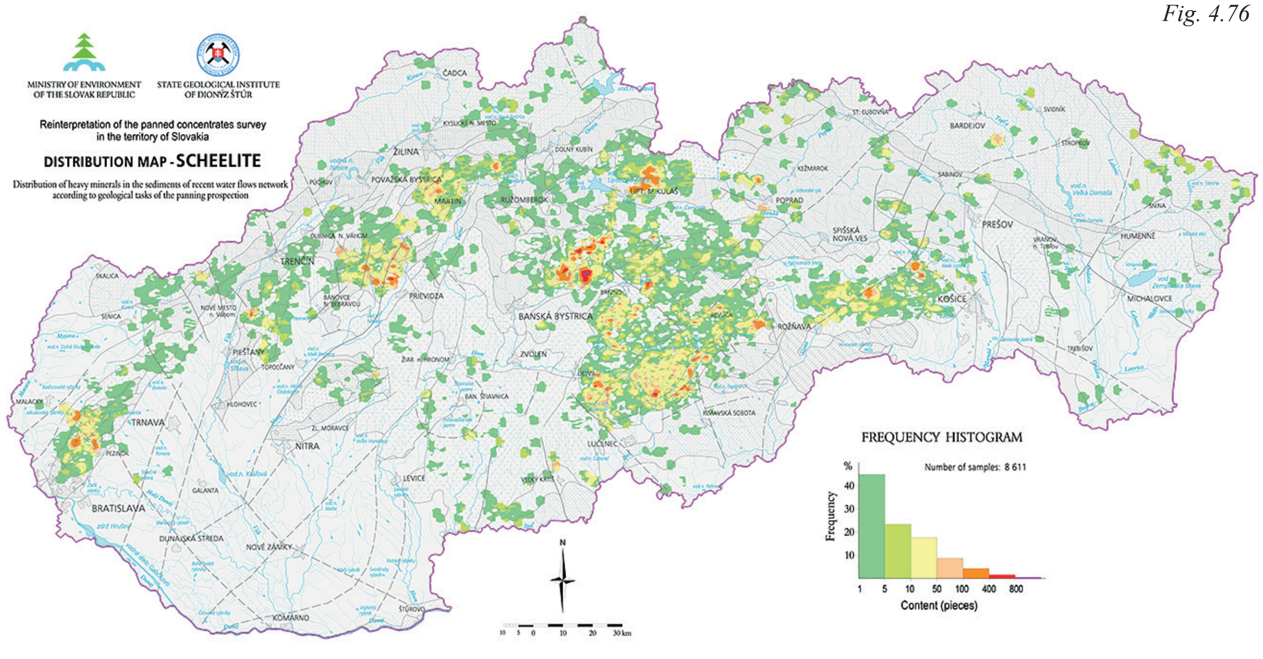


Fig. 4.76

4.3.18 Spinel $MgAl_2O_4$

Variety Cr spinel with content of Cr_2O_3 35% – 58%

H = 7.5 – 8.0; **SG** = 3.58 g.cm^{-3}; **System:** Cubic

Magnetic properties: non-magnetic, and is concentrated in diamagnetic fraction, Fe^{2+} variety – picotite passes into paramagnetic fraction

Colour in the panned concentrate samples

Colour of spinel in the panned concentrate samples is usually black (Fig. 4.77a, c). Spinels of another colour in the panned concentrate prospecting were not disclosed. Lustre on flat surfaces is glassy, sometimes dull.

Morphology in the panned concentrate samples

In the panned concentrate samples spinel is present most frequently and almost exclusively in the form of octahedrons {111}. Frequent are intergrowths along the (111) planes, or cyclic intergrowths according to the Spinel Law

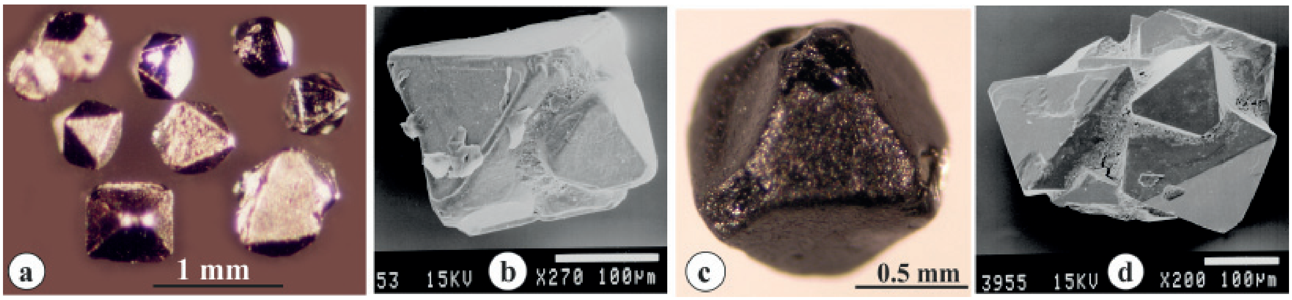


Fig. 4.77a, b, c, d Colour, lustre and crystal shapes of spinel in the panned concentrate samples. Characteristic colour of spinels is black-brown to black. Sites: a – Haligovce, b – Dubovica, c – Ruská Bystrá, d – Vyhne. Drawings: b, c – Rösler, J. H., 1983. Photo: P. Bačo, SEM I. Holický.

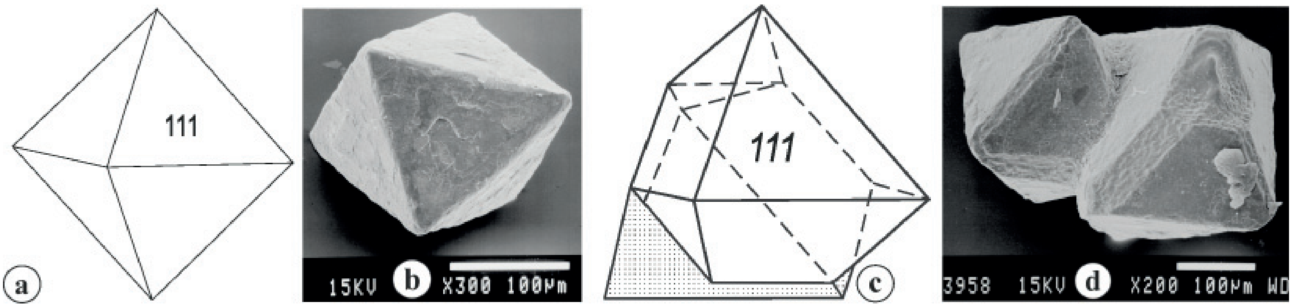


Fig. 4.78a, b, c, d Basic crystal shapes and couples of spinel, which are mostly present in the panned concentrate samples. The base shape of spinel crystals is octahedron {111} (a,). These shapes are typical for Cr-spinels in the panned concentrate samples and other crystal shapes have not been recorded. Frequent are intergrowths on (111) plane – Spinel Law (c, d and also Fig. 4.77a, b, d). Sites: b – Tvarožná, d – Fiľakovo. Drawings: J. H. Rösler, 1983. Photo: SEM I. Holický.

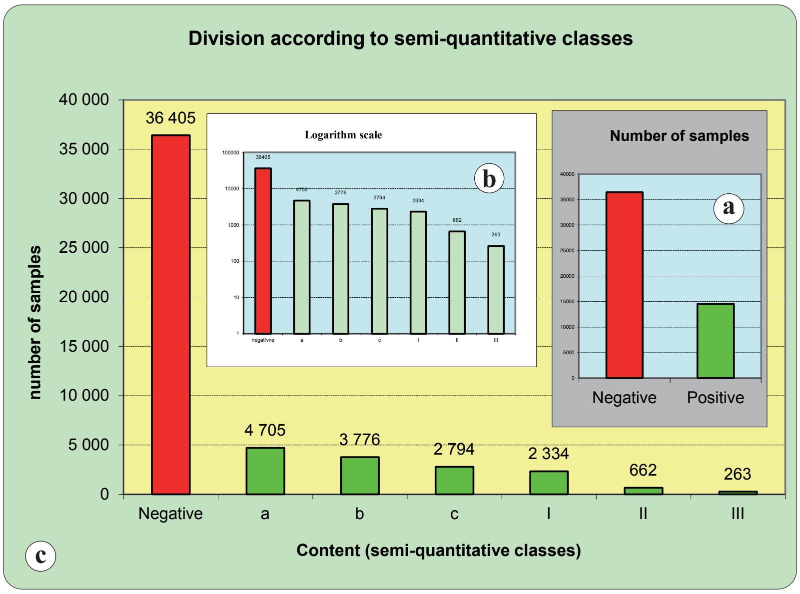


Fig. 4.79a, b Distribution of panned concentrate samples according to spinel presence (a) and according to proportion of individual semi-quantitative content classes (b, c).

(Fig. 4.77b; Fig. 4.78c, d). Although spinels are known primarily from flysch strata of clastogenic origin, they retain distinct octahedron habit. Only occasionally fragments of small crystals are found.

During transport due to their hardness and lack of cleavability they are very stable and only rarely morphologically changed.

Epitaxial intergrowths in the panned concentrate samples have not been observed. Microscopically, however, inclusions were found (pyrite) and non-uniformity (chrommagnetite rim) of Cr spinel (Spišiak et al., 2001). Size of small crystals of Cr-spinels, their fragments or grains in the panned concentrate samples is up to 0.5 and only occasionally up to 1.0 mm – usually of the cyclic intergrowths.

Identification attributes: octahedron habit and intergrowths according to the Spinel Law, black colour and glassy lustre, high hardness, non-magnetic behaviour.

General distribution characteristics

Panned concentrate samples containing spinel (Cr spinel) make up only about 30%

Tab. 4.25 Presence of spinel in the panned concentrate samples according to content classes.

Database of samples	Negative	Content (semi-quantitative classes)					
	Positive	**a**	**b**	**c**	**I**	**II**	**III**
50,939	36,405	4,705	3,776	2,794	2,334	662	263
	72	9	7	5	5.00	1.00	1.00
	14,534	4,705	3,776	2,794	2,334	662	263
	29	32.37	25.98	19.22	16.06	4.55	1.81

Tab. 4.26 Presence of spinel (chromspinel) in the panned concentrate samples according to content classes. Selected map sheets at scale 1 : 50,000 illustrate areas of the Eastern sector of the Outer Flysch Zone with spinel present in the panned concentrate samples in higher content classes.

Map	Database	Samples without mineral presence		Content (semi-quantitative classes)											
	Number			a		b		c		I		II		III	
1:50 000	of samples	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%
Eastern Sector of the Outer Flysch Zone															
27-24	506	400	79	7	1	16	3	16	3	35	7	28	6	4	1
27-32	828	56	7	121	15	166	20	141	17	143	17	94	11	107	13
27-41	667	165	25	31	5	103	15	129	19	96	14	68	10	75	11
27-43	906	13	1	30	3	168	19	305	34	342	38	34	4	14	2
28-31	690	135	20	55	8	93	13	95	14	123	18	163	24	26	4
Inner Carpathian Paleogene															
37-21	487	178	37	67	14	70	14	70	14	57	12	32	7	13	3
37-22	373	50	13	67	18	85	23	103	28	63	17	3	1	2	1

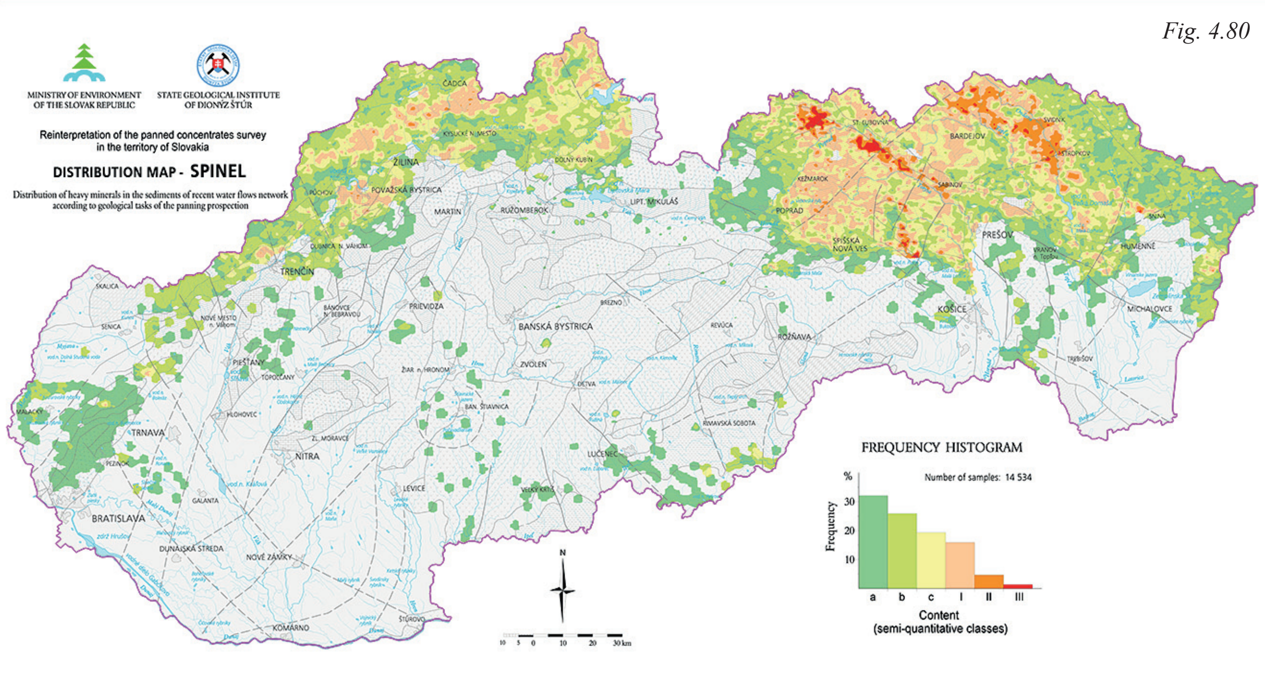


Fig. 4.80

of the total number of samples collected (Tab. 4.25). Its concentration in positive panned concentrate samples, however, is within all semi-quantitative classes (Tab. 4.25, Fig. 4.79b, c). It suggests a typology bound to the extend of the original source rocks.

Spatial distribution of positive panned concentrate samples is concentrated to the eastern part of the Outer Flysch Zone and Inner-Carpathian Paleogene (Fig. 4.80) with a hint of continuing in the Kysuce sector of the Flysch Zone (Bačo et al., 2004a). With a relatively small number of panned concentrate samples high frequency content of the highest grade – III is remarkable. Almost one third of the panned concentrate samples from a wider area of Cígeľka – Stropkov and Šambron to Sabinov has the dominant mineral spinel (Tab. 4.26 – map sheets 27-32, 27-41, 28-31).

The distribution and concentration of spinels is one of the most contrasting ones in the Slovak part of the Western Carpathians (Fig. 4.80). Cr spinels are present in the Inner-Carpathian Paleogene and Outer Flysch Zone. In other regional geological units the Cr spinels frequency in the panned concentrate samples is minimal.

High contrast in the distribution of Cr spinels is visible within the units of the Outer Flysch Zone and Inner-Carpathian Paleogene, where it is possible to identify several distinct zones and areas. Within the Inner-Carpathian Paleogene particularly evident is a significant connection to Šambron Zone (the interface between Inner-Carpathian Paleogene and Klippen Belt – Huty Formation). Presence of this formation around Branisko clearly shows the distribution of spinels (Fig. 4.80). A series of small local anomalies along the Klippen Belt and further to the SE in the Outer Flysch Zone is a significant anomaly in space of greywacke and arkosic sandstones. Sensitivity of the methodology is clearly reflected in the area of Smilno tectonic outlier. This confirms the high discriminatory level of this mineral. It can be used for very detailed interpretive procedures (Jablonský et al., 2001, Spišiak et al., 2001).

4.3.19 Titanite $CaTiSiO_5$

H = 5.0 – 5.5; **SG** = 3.45 – 3.55 g.cm^{-3}; **System:** Monoclinic

Magnetic properties: concentrated in paramagnetic and partially also in diamagnetic fraction

Colour in the panned concentrate samples

Colour of titanite is variable, most often are various shades of yellow, light brown to brown (Fig. 4.81b, 4.82c), it occur also green, grey and in exceptionally clear varieties. In the panned concentrate samples mainly from resedimented environment – Outer Flysch Zone – titanite hass dull surface, its colour and lustre losing saturation and intensity.

Fig. 4.81a, b, c Colour and lustre of small crystals of titanite (b) with preserved tabular habit. Sites: a, b – Veporicum – Sihla, c – Tribeč – Topolčianky. Photo: P. Bačo. Photo: SEM I. Holický.

Morphology in the panned concentrate samples

In the panned concentrate samples titanite is present in the typical form of small crystals in the form of a highly flattened envelope with the wedge-like termination (Fig. 4.82a, b, c) and the dominant (111), (100) and (001) planes. More often, however, it is present in the form of fragments of small crystals with a characteristic strongly flattened rhombic cross-section and fragments on which it is dominating cleat plane (Fig. 4.81a, c) mainly according to twin lamellae (221). Only very rarely it has different crystal shape and this is decisive and unmistakable titanite form in the panned concentrate samples. In the course of destruction during transport small crystals are reworked to varying degree, with the original shapes and shape with a flat cleat (110) being preserved.

In source areas made of sediments the fragments are heavily reworked and rounded, oval with losing the original habit. The surface of small crystals and fragments is shiny, but often rough and dull.

General distribution characteristics:

Titanite was identified in approximately 1/5 of the assessed panned concentrate samples (Tab. 4.27). Titanite has content in the classes a – c (Fig. 4.83b, c) and normal distribution, indicating a relatively equitable distribution of the occurrence region. Samples containing titanite within higher concentration classes already define its own resources within the source area.

At the regional scale panned concentrate prospection has very clearly defined (Fig. 4.84) position of the granitic rocks of the I type that are most important concentrators of titanite within the Slovak part of the Western Carpathians (Broska et al., 2004). These titanite source rocks are present mainly in the Veporicum, Malá Magura and Malé Karpaty Mts. The highest concentration levels are known from the Tribeč Mts.,

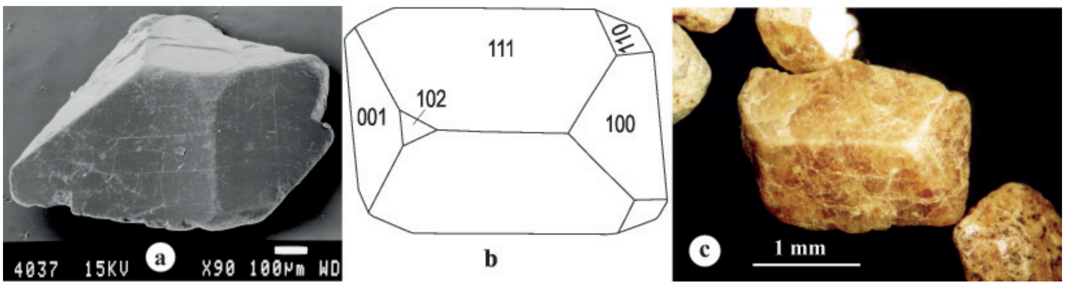


Fig. 4.82a, b, c "Envelope-shaped" small crystals with characteristic planes (111), (100) and wedge-shaped termination. Original shape is preserved on fissile fragments. Site: a – Veporicum – Sihla. Drawing: (b) J. H. Rösler, 1983, Photo: (c) P. Bačo, SEM I. Holický (a).

Tab. 4.27 Presence of titanite in the panned concentrate samples according to content classes.

Database of samples	Negative	Content (semi-quantitative classes)					
	Positive	**a**	**b**	**c**	**I**	**II**	**III**
50,939	41,735	2,157	3,088	2,600	762	497	100
	83	4	6	5	1.00	1.00	0.00
	9,204	2,157	3,088	2,600	762	497	100
	18	23.44	33.55	28.25	8.28	5.40	1.09

where it occurs in the highest concentration class (Fig. 4.83b, c) in the panned concentrate samples and creates the most intense anomalies within the territory of Slovakia (Fig. 4.84).

Distribution of titanite in other regional units of the Slovak part of the Western Carpathians is linked to specific local source environments. In general, these are mostly granitoid rocks of individual Core Mountains and Gemericum. Appearance in other areas is conditional on the deposition from the above areas.

In general, titanite poor areas are those of Neogene volcanism (in which significant Ti-bearer is ilmenite) and regional units made of Mesozoic carbonate rocks. Flysch Zone is characterized by deficiency of titanite in the concentrates, or its low contents. Only in the area of the Vysoké Tatry Mts. it is present in the source area of glacial-fluvial sediments or in the residues after these sediments. Slightly elevated concentrations are in the SE part of the Dukla unit, but without specific knowledge of the origin of titanite.

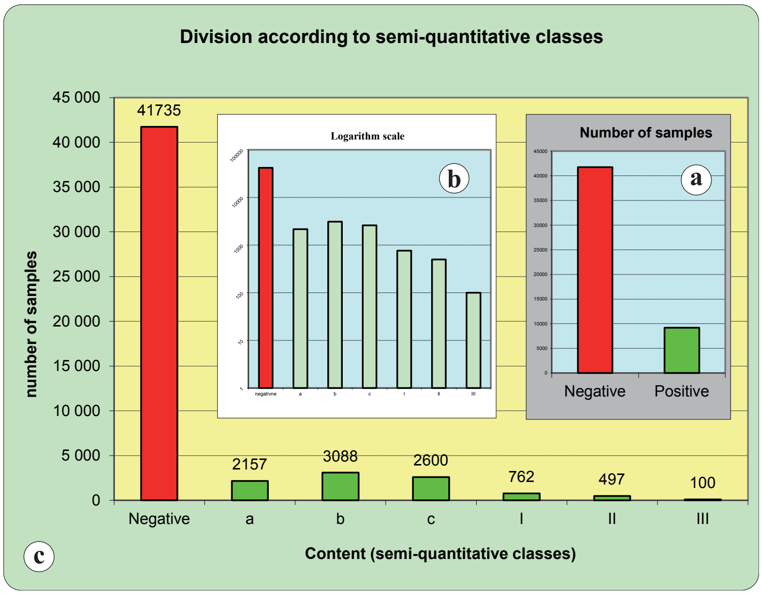
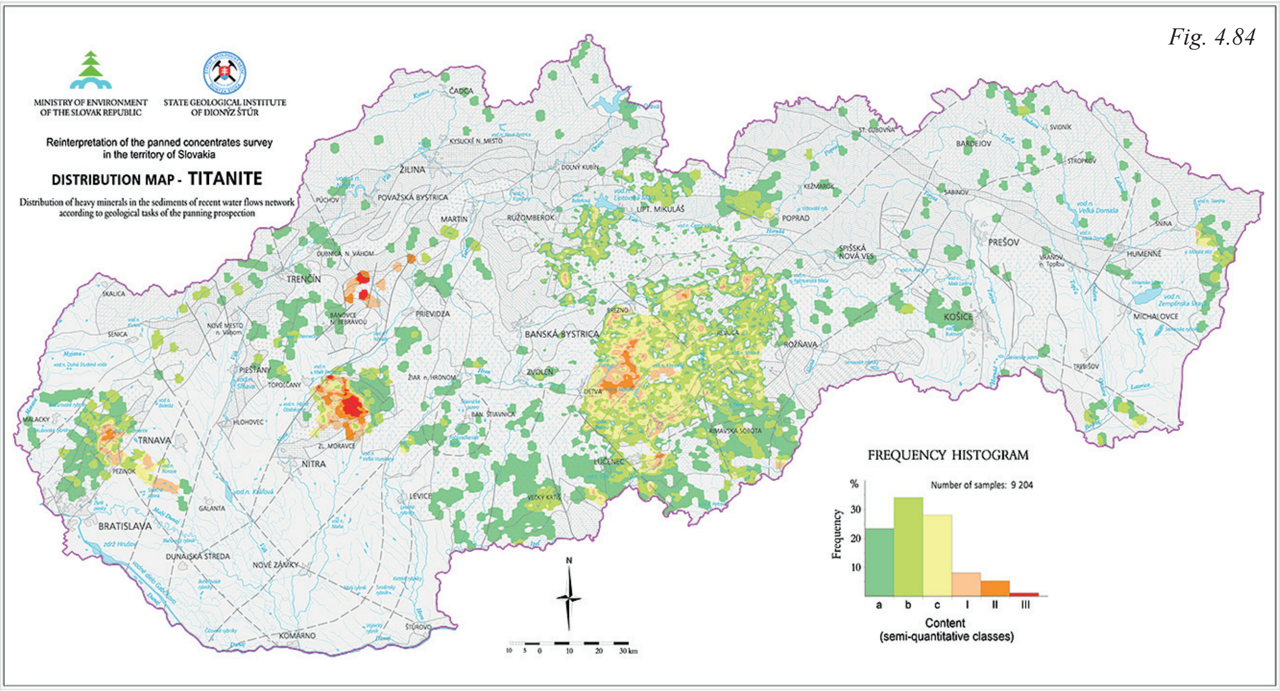


Fig. 4.83a, b, c Distribution of panned concentrate samples according to titanite presence (a) and according proportion of individual semi-quantitative content classes (b, c).



4.3.20 Zircon $ZrSiO_4$

H = 7.5; **SG** = 4.6 – 4.7 (metamict varieties 3.6 – 4.0) g.cm^{-3}; **System:** Tetragonal

Magnetic properties: non-magnetic, and is concentrated in diamagnetic fraction

Luminescence: majority of zircons have orange and yellowish luminescence colour

Colour in the panned concentrate samples

Zircon in the panned concentrate samples is most often colourless, clear, with a gentle hue of yellowish or pink in colour (Fig. 4.85a, c). However, it has often variegated coloures in association (secondary) with colourless and clear crystals. Other most common colour is orange reddish (hyacinth) in different grades and shades. Less frequently it is present a dark brown to black zircon (cyrtolite).

Morphology in the panned concentrate samples

In the panned concentrate samples zircon is present in the form of crystals of columnar habit (Fig. 4.86a, b, c, d) with dominating prisms and dipyramid termination.

Typology of zircon (mainly autochthonous occurrence) is used for the genetic classification of granitic rocks as well as for temperature indices of host rocks (Western Carpathian granitoid rocks, Broska & Uher, 1991; Broska et al., 2012).

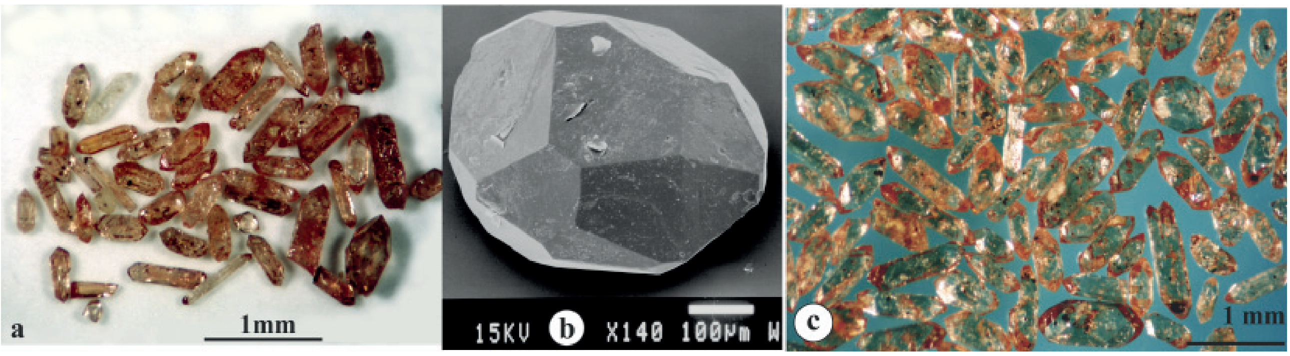


Fig. 4.85a, b, c Colour, lustre and crystal shapes of zircon in the panned concentrate samples. Zircons with colour and shapes typical for neovolcanic areas. Sites: a – Pukanec, b – Horné Plachtince, c – Juskova Voľa. Photo: a, c – P. Bačo, SEM b – I. Holický.

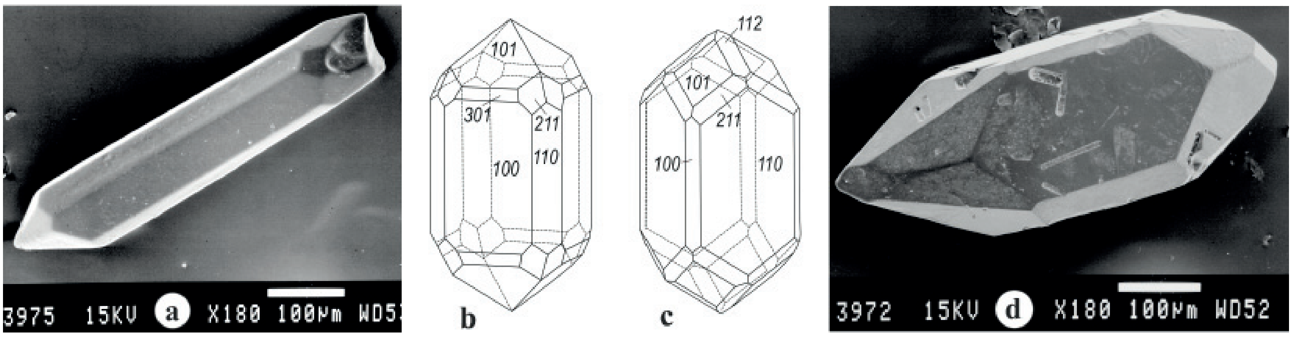


Fig. 4.86a, b, c, d Crystal shapes of zircon in the panned concentrate samples. Sites: a – Žemberovce, d – Vyhne. Drawings: b, c – Rösler, J. H., 1983, Photo: SEM I. Holický.

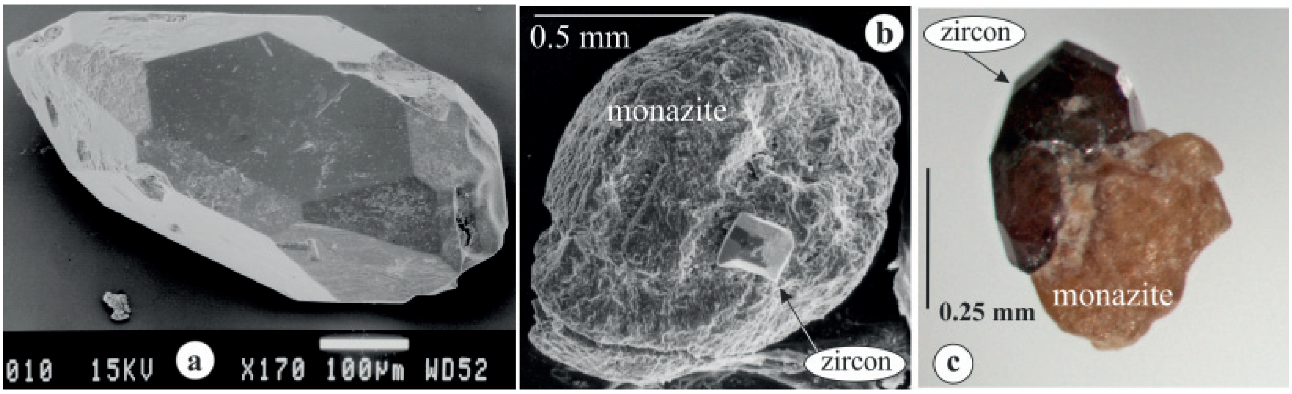


Fig. 4.87a, b, c Crystal shapes of zircon and intergrowths with monazite in the panned concentrate samples. Sites: a – Haligovce, Veporicum: b – Krná, c – Kociha, Photo: c – P. Bačo, SEM a, b – I. Holický.

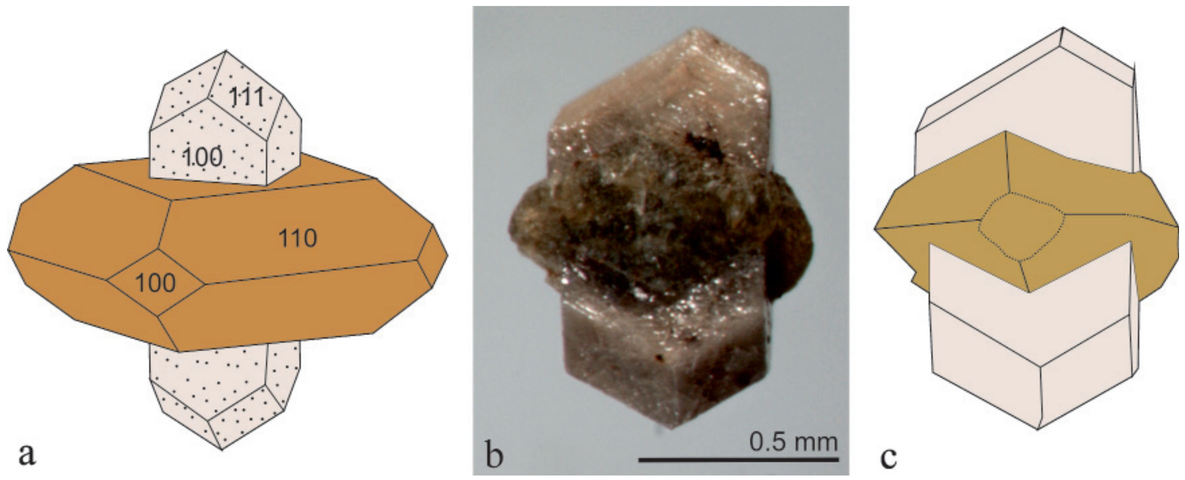


Fig. 4.88a, b, c Oriented interpenetration of xenotime with zircon. Site: b – Veporicum – Kociha. Drawings: a – Lukáč, 1968, c – Z. Bačová, Photo: b – Z. Bačová,

During the transport zircons remained stable due to their physical and chemical resistance. In the sedimentary areas in which zircon is clastogenic component, we can observe rounding of edges, the original habit, however, maintains. Size of small crystals in pannings is normally within 0.5 and 1.0 mm, larger grains are rare.

Intergrowths of zircons are very rare and were observed only on zircon coupled with monazite (Fig. 4.53 – 4; 4.87b, c).

Interesting is epitaxial intergrowth with the isostructure xenotime (4.88a, b, c). It is interpenetration twin in the direction of plane [001] (Lukáč, 1968).

General distribution characteristics

Zircon is among the most common minerals in the panned concentrate samples (Tab. 4.28; 4.89a). Its concentration is in all semi-quantitative classes with the most substantial share of the classes b and c (Fig. 4.89b).

Zircon is a typical accessory mineral and occurs in the panned concentrate samples from source areas of all regional geological units. To-date, more significant deposit accumulations of zircon are not known. However, it is present in the Danube garnet sands, where its presence may be of some prognostic significance.

Its physical and chemical stability makes it suitable as a dominant mineral in the heavy fraction for all types of sedimentary rocks (Fig. 4.89a, b). Peak concentrations are in the areas of primary occurrences, i.e. where source areas are formed by granitoid rocks. Elevated contents are known from samples of the sedimentary source areas.

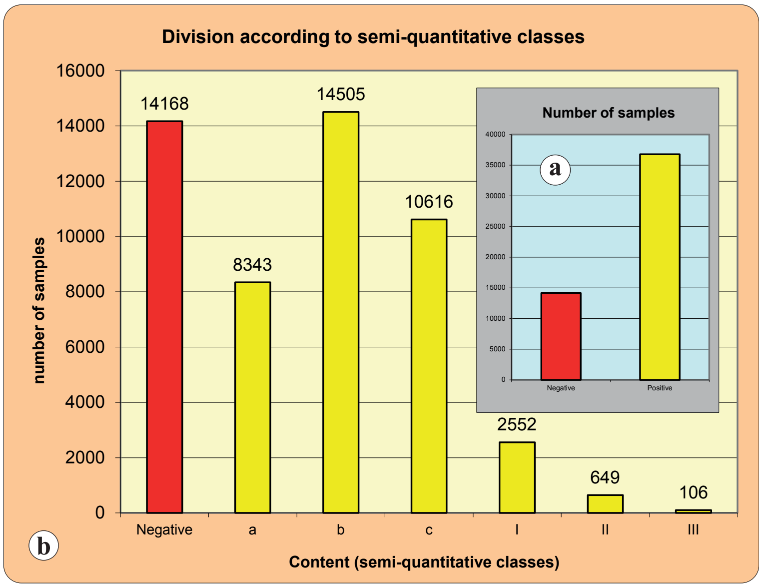


Fig. 4.89a, b Distribution of panned concentrate samples according to presence of zircon (a) and according to proportion of individual semi-quantitative content classes (b).

Tab. 4.28 Presence of zircon in the panned concentrate samples according to content classes.

Database of samples	Negative / Positive	Content (semi-quantitative classes)					
		a	**b**	**c**	**I**	**II**	**III**
50,939	14,168	8,343	14,505	10,616	2,552	649	106
	29	16	28	21	5.00	1.00	0.00
	36,771	8,343	14,505	10,616	2,552	649	106
	72	22.7	39.4	28.9	6.94	1.76	0.29

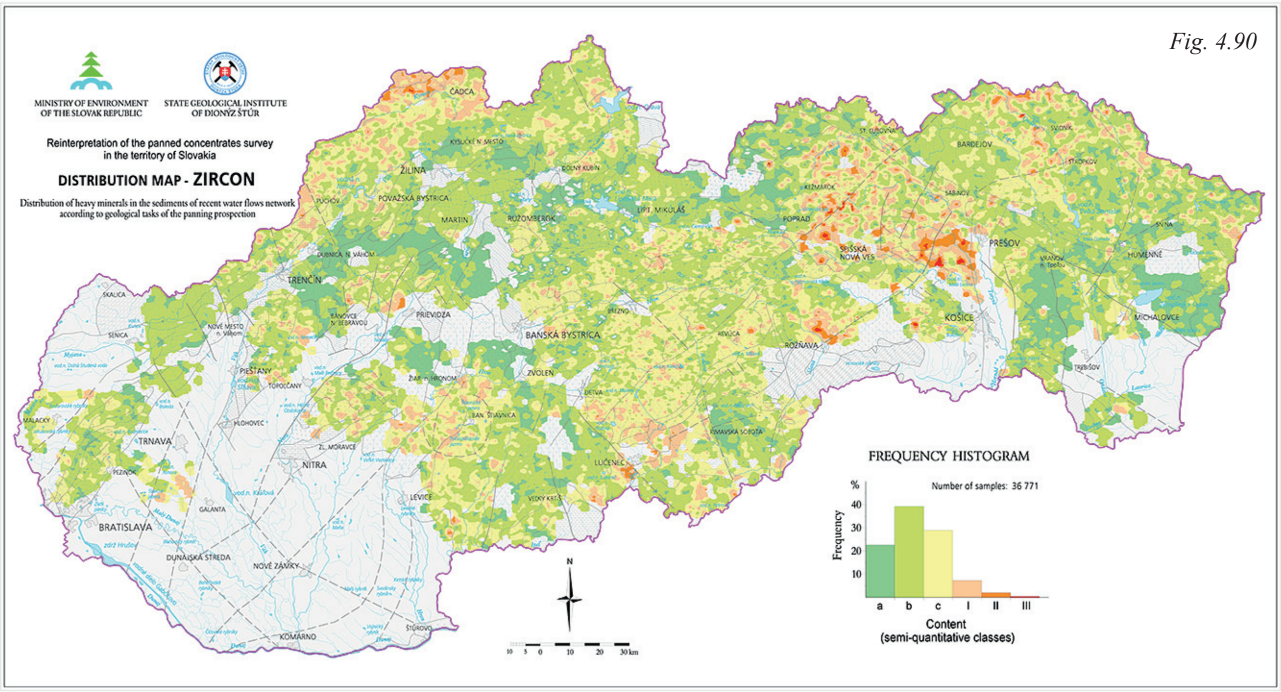


Fig. 4.90

4.3.21 Gold Au

H = 2.5 – 3.0; **SG** = 15.5 – 19.3 g.cm^{-3} (depending on impurities, mainly Ag); **System:** Cubic

Magnetic properties: gold is non-magnetic, and is concentrated in diamagnetic fraction

Colour in the panned concentrate samples

Colour of gold in the panned concentrate samples is clear golden yellow (Fig. 4.91a, b, c). It depends upon the genetic type of primary source according to which it can contain impurities of other metals (mainly Ag). These original colours preserves gold only in closest proximity of a primary occurrence.

Transport of gold flakes causes in hypergenic conditions a genuine rim, which has a bright yellow colour. Lustre of gold flakes is metallic.

Morphology in the panned concentrate samples

In the panned concentrate samples the gold flakes are present in the most diverse forms. Near the source original crystals (Fig. 4.92a, b, c, d) are preserved in dendritic forms (Fig. 4.93b) with partial rounding and softening of the edges. Gradually the original habit is diminishing, only locally the initial wire-like, or tinfoil habit is preserved (Fig. 4.93a, c; 4.94a, b, c; 4.95a, c).

In the panned concentrate samples from old mining areas there are present gold flakes, which have the features of mechanical working in ore crushers (Fig. 4.95c).

Thanks to transport, the gold flakes attain typical alluvial trimmed and flaky nature. Sometimes the gold flakes contain tiny penetrated grains of other minerals, usually quartz (Fig. 4.91c).

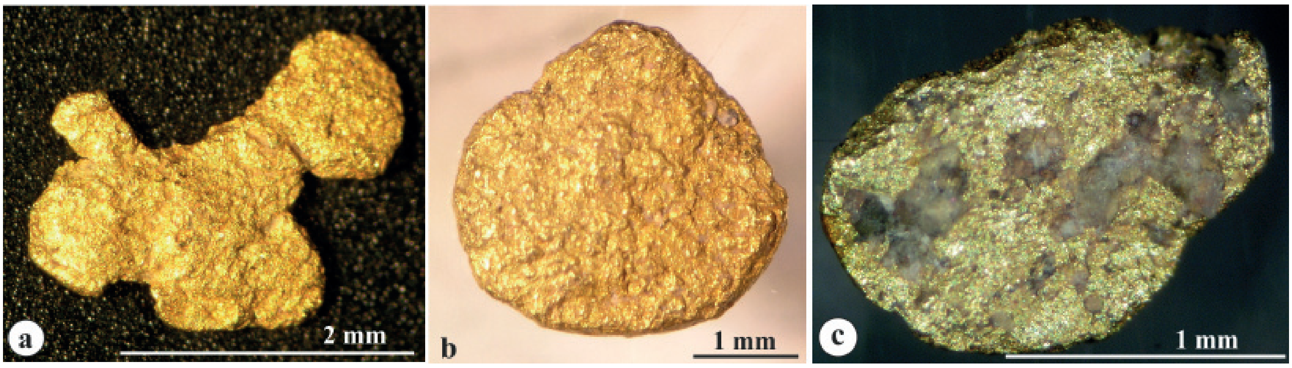


Fig. 4.91a, b, c Colour and lustre of gold in the panned concentrate samples. Colour and shades are dependent on impurities, mainly Ag. At its high content it has dark-yellow colour, at Cu-content it turns to reddish-yellow hue. Part of gold flakes can be coated by Mn- and Fe- oxides. Site: a – c Ruská Bystrá. Photo: P. Bačo.

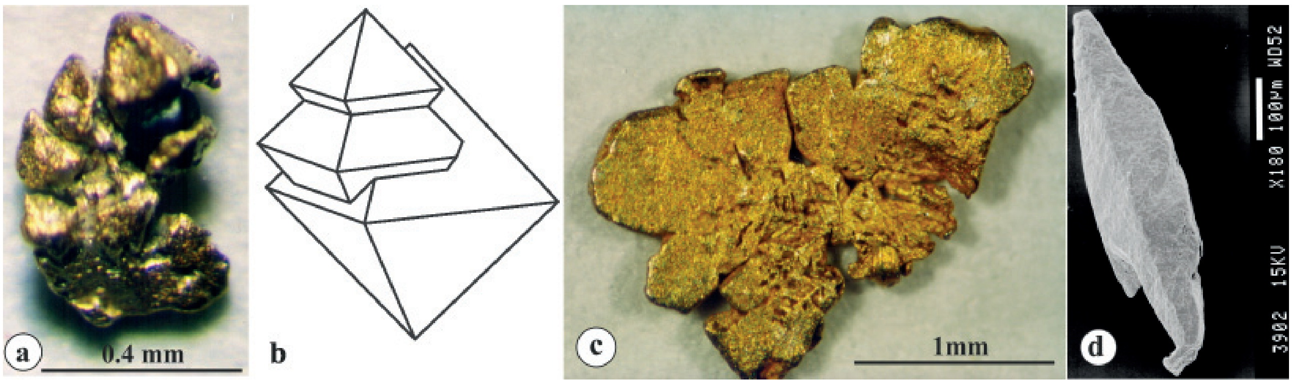


Fig. 4.92a, b, c, d Crystal shapes of gold in the panned concentrate samples. Rare octahedron and hexahedron shapes create by mutual combinations simple and complex couples. The gold in the panned concentrate samples occurs typically in the form of gold flakes, without preserved crystal planes. Site: a, c, d – Pukanec. Drawing: b – J. H. Rösler, 1983, Photo: a, c – P. Bačo: SEM d – I. Holický.

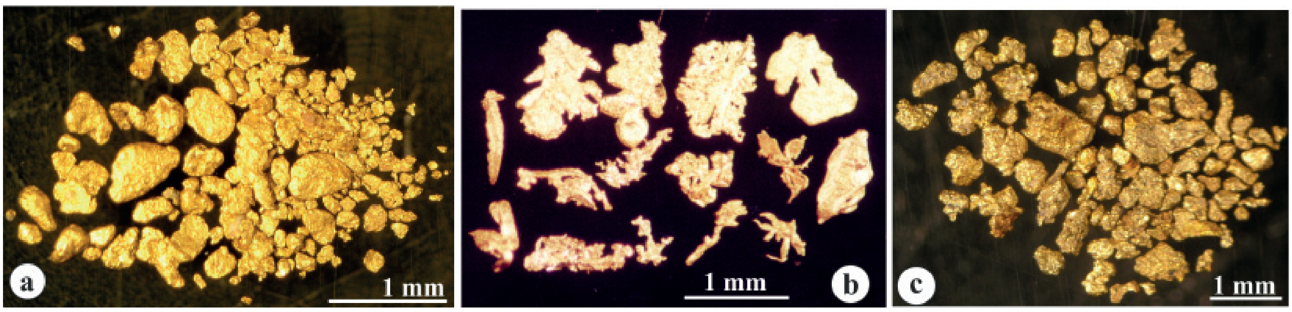


Fig. 4.93a, b, c Crystal shapes of gold close to the source (b); after short transport (a, c) in the panned concentrate samples. Alluvial gold flakes, examples of morphology from various geological environs. Sites: a – Ruská Bystrá, b – Pukanec, c – Selce. Photo: P. Bačo.

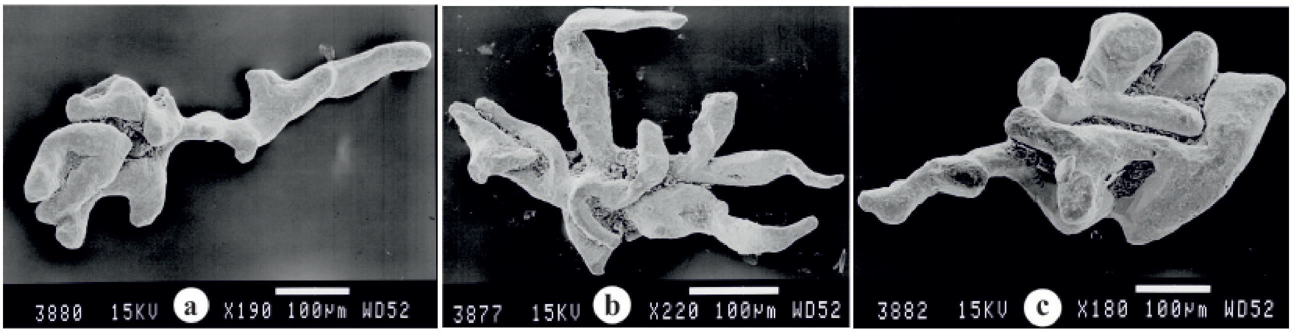


Fig. 4.94a, b, c Crystal shapes of alluvial gold which underwent short transport. Site: a-c Pukanec. Photo: SEM I. Holický.

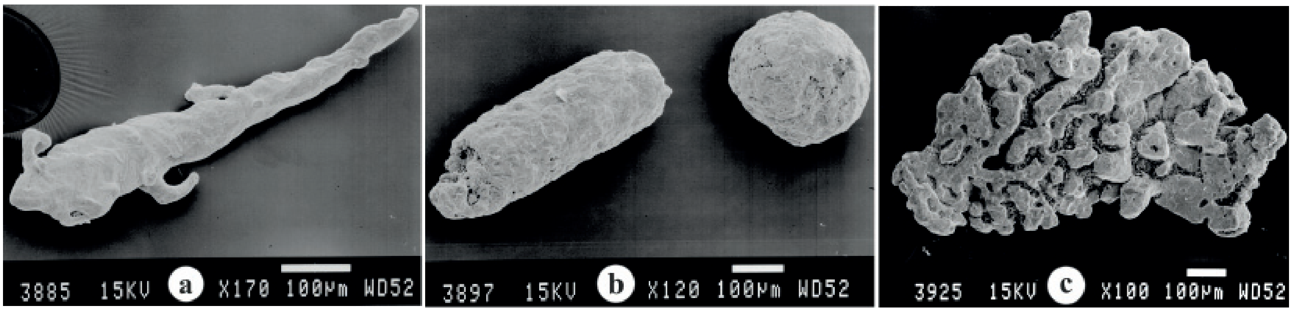


Fig. 4.95a, b, c Shapes of gold in the panned concentrate samples. Site: a-c Pukanec. Photo: SEM I. Holický.

Tab. 4.29 Presence of gold in the panned concentrate samples according to content classes.

Database of samples	Negative	Content (semi-quantitative classes)					
	Positive	**a**	**b**	**c**	**I**	**II**	**III**
50,939	47,590	3,271	75	3	0	0	0
	93.4	6	0	0	0.00	0.00	0.00
	3,349	3.71	75	3	0	0	0
	6.6	97.7	2.24	0.09	0.00	0.00	0.00

General distribution characteristics:

Gold (in the form of gold flakes) is quite rare mineral within the whole sampled territory (Tab. 4.29). Its presence was noted within the relatively small number of the panned concentrate samples. By contrast, they were captured virtually all of the primary gold mineralisations, which may pass into the alluvial deposits – placers (Tab. 4.30). Exceptions are impregnation types (Carlin), high-sulphidation and porphyry type of Au-mineralisations, which for obvious reasons (the form of gold in the ore – usually μm-grains of Au in quartz) didn't create secondary aureoles of gold in the form of gold flakes.

Gold was recorded mainly in the first and only exceptionally in the higher content classes (Fig. 4.95b, c). Due to the characteristics of gold, each occurrence creates a secondary aureoles, which have been recognized in the Slovak part of the Western Carpathians (Fig. 4.97, Tab. 4.30) – Bakos, Chovan et al., 2004.

In addition to well-known occurrences (with gold mining in the past) the panned concentrate prospecting detected gold appearance mainly in the Outer Flysch Zone, its Eastern section. There is a clear spatial coincidence with coarse-detrital facies of the Strihovce Member of the Krynica unit of the Magura Nappe.

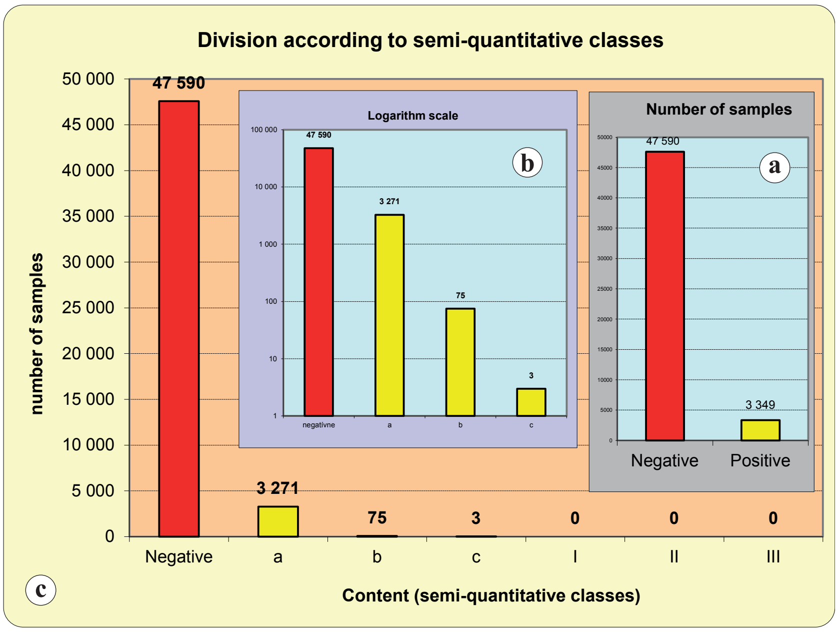
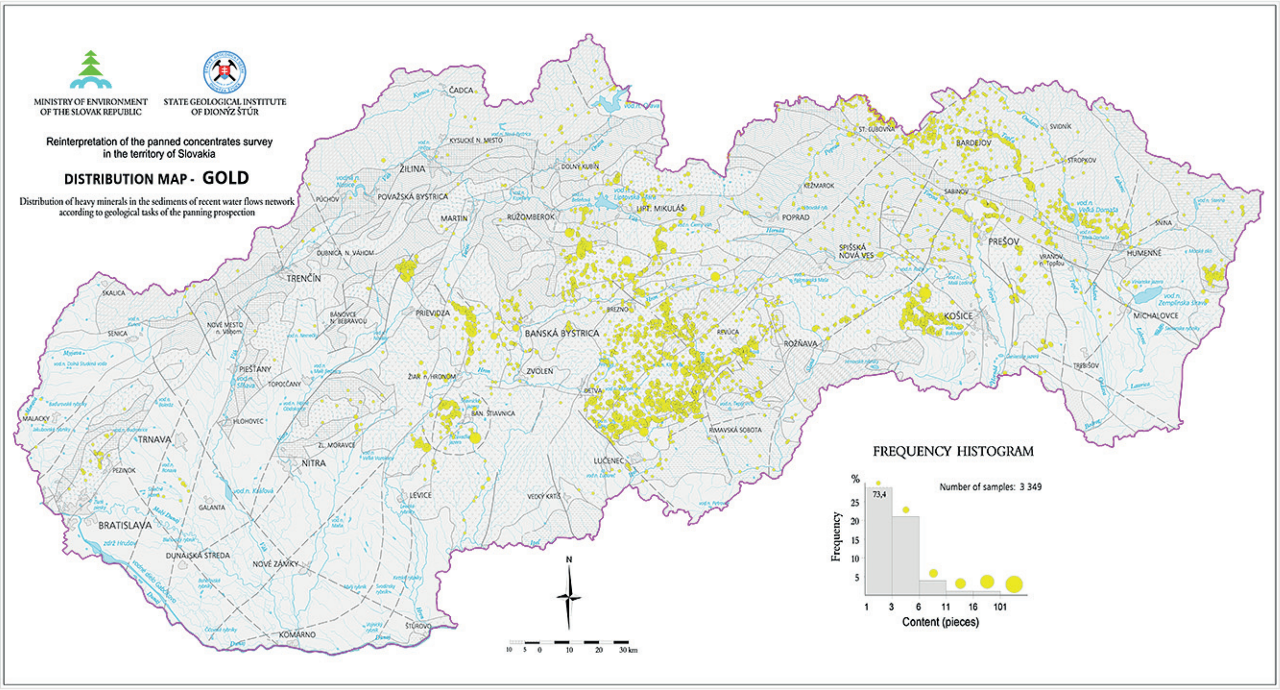


Fig. 4.96a, b, c Distribution of panned concentrate samples according to gold presence (a) and according to proportion of individual semi-quantitative content classes (b, c).



Tab. 4.30 Presence of gold (flakes) in the panned concentrate samples according to content classes. Selected map sheets at scale 1:50,000 illustrate areas with deposits and significant occurrences of gold, which is present in higher content classes in the panned concentrate samples.

Map	Database	Samples without mineral presence		Content (semi-quantitative classes)					
	Number of samples			a		b		c	
1:50 000		Number	%	Number	%	Number	%	Number	%
Area of Vysoké Tatry Mts. – Kriváň									
26-43	523	472	90	49	9	2	0	0	0
Suchý – Malá Magura									
35-22	530	472	89	53	10	5	1	0	0
Nízke Tatry Mts. – Magurka, Dúbrava, Nižná and Vyšná Boca									
36-21	1113	981	88	120	11	12	1	0	0
36-22	1050	981	93	67	6	2	0	0	0
Malé Karpaty Mts. – Pezinok, Limbach									
44-22	447	424	95	23	5	0	0	0	0
Veporicum – Kokava nad Rimavicou, Kociha, Hnúšta, Divín, České Brezovo									
36-42	2143	1829	85	310	14	4	0	0	0
36-43	858	714	83	139	16	5	1	0	0
36-44	797	588	74	199	25	10	1	0	0
Gemericum – Čučma, Poproč, Zlatá Idka, Henclová, Stará Voda									
37-23	811	704	87	99	12	6	1	2	0
37-24	380	289	76	90	24	1	0	0	0
Kremnické vrchy Mts.									
36-13	755	690	91	57	8	8	1	0	0
Štiavnické vrchy Mts. – Pukanec, Brehy, Banská Štiavnica, Hodruša									
36-33	530	444	84	80	15	5	1	1	0
Slanské vrchy Mts. S part – Byšta, Banské									
38-31	537	524	98	13	2	0	0	0	0
Outer Flysch Zone									
27-23	95	72	76	23	24	0	0	0	0
38-23	564	551	98	12	2	1	0	0	0

4.4 Conclusion

Panned concentrate prospection is a wide-spread search method of ore mineralisation types, dominantly. This highly effective method is used mainly in poorly-explored areas. However, its use has been justified even in regions with rich mining activities, which experienced some parts of the territory of Slovakia.

Within the "Re-interpretation Project" a large part of the panned concentrate samples were again mineralogically assessed using current methods (identification under UV light, dye tracing tests), and approximately 70% of the sample material uniformly processed and evaluated. The major part of the more than 50,000 records database has over 60 variables. The database has been created with sample documentation localised in the coordinate system and displayed in the topographic documents at scale 1:50,000. This has enabled to compile the distribution maps of selected types of minerals for the whole sampled territory of Slovakia. The database allows to construct similar maps from mineral species which have not been depicted in the last map works. The map outputs can be compiled not only for the whole territory of Slovakia, but also for the arbitrarily selected area. The database is publicly available.

The assembled distribution and interpretive maps of various types of minerals characterise various regional geological units throughout the Slovak part of the Western Carpathians. These minerals are Cr-spinel, corundum, pyroxenes, garnets and many other minerals. Some mineral types have a discriminatory character up to lithological level (monazites) and across regional geological units. Their applicability in the context of cross-correlation of the lithological types is a value added.

The results are crucial for raw materials appreciation of Slovakia. Secondary dispersion aureoles have contributed to characterisation of almost all deposits of ore resources. Based on their characteristics the regional units as well as local areas can be evaluated from their potential point of view. The database allows very detailed view into the arbitrarily selected area within the sampled territory. This is obvious in the scales 1:50,000 and possibly the greater scales for those types of materials, which are represented by e.g. cinnabarite, cassiterite, gold, scheelite or accompanying base metal deposits, for example, barite, cerrusite and wulfenite. Even a singular registered presence of certain rare minerals, for example, topaz, corundum, andalusite points to the presence of specific alteration processes associated with specific types of mineralisation. The presence of sulphide minerals, e.g. galena, sphalerite, stibnite almost always refers to the closeness of anthropogenic sources – heaps, which ultimately are also indication of mineralisation.

The panned concentrate prospection in the Slovak part of the Western Carpathians has become the basis for prognostic evaluation of gold. A large number of anomalies in various regional geological units has previously been subjected to a higher stage of geological research and exploration, but some of the secondary anomalies were still unverified and their sources have not been identified. The distribution map, prepared in the framework of the "Re-interpretation Project" provided also the basis for map supplement of the representative publication Gold in Slovakia (Bakos and Chovan et al., 2004).

To date, the panned concentrate prospecting shall find its particular importance in the environmental field. In fact, a panned concentrate sample contains a large portion of various anthropogenic substances, often with polluting action. Its distribution is recorded and studies of possible impacts on biotic aquatic environment may follow up.

Acknowledgements:

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References

Bačo P., Dzurenda Š., Hvožďara P., Potfaj M., Repčiak M., Abarham M., Žáček M. & Veleba B., 2004b: Vonkajšie flyšové pásmo ZK – zhodnotenie z pohľadu šlichovej prospekcie, Reinterpretácia šlichového prieskumu na území SR. (Outer Flysch Zone of the W. Carpathians – from the Viewpoint of Panned Concentrate Prospection, Re-Interpretation of Panned Concentrate Prospection at the Territory of Slovakia). Interim report, Manuscript, Geofond Archive, Bratislava, 127 p. (In Slovak).

Bačo P., Bačová N., Bakoš F., Bóna J., Fodorová V., Dzurenda Š., Holický I., Hvožďara P., Karabínová V., Knésl J., Kovaničová Ľ., Križáni I., Kyseľová M., Mihaľ I., Ondíková H., Polubňáková E., Repková E., Repčiak M., Smolka J. & Šofranec F., 2004b. Reinterpretácia šlichového prieskumu na území Slovenska. (Re-Interpretation of Panned Concentrate Prospection at the Territory of Slovakia). Final report, Manuscript, Geofond Archive Bratislava, 127 p.

Bakos F., Chovan M., Bačo P., Bahna B., Ferenc Š., Hvožďara P., Jeleň S., Kamhalová M., Kaňa R., Knésl J., Krasmec Ľ., Križáni I., Maťo Ľ., Mikuš T., Pauditš P., Sombathy L. & Šály J., 2004: Zlato na Slovensku. (Gold in Slovakia).Slovenský skauting, Bratislava, 298 p. (In Slovak).

Böhmer M. & Hvožďara P., 1969: Výsledky šlichového výskumu z východnej časti Malej Magury (Horná Nitra). (Results of Panned Concentrate Prospection from the Eastern Part of the Malá Magura Mts.). Manuscript, Geofond Archive, Bratislava, 42 p. (In Slovak).

Böhmer M. & Mecháček E., 1978: Výsledky regionálneho geochemického vyhľadávania v Kremnických vrchoch. (Results of Regional Geochemical Prospection in the Kremnické vrchy Mts.). Minerál. Slov.10, 6, p. 551-556. (In Slovak).

Böhmer M. & Antal B., 1981: Šlichový a metalometrický výskum Javoria a Poľany. (Panned Concentrate and Metallogenic Research of the Javorie and Poľana Mts.). Manuscript, Geofond Archive, Bratislava. (In Slovak).

Biely A. et al., 1996: Vysvetlivky ku geologickej mape Slovenska 1 : 500,000. (Explanations to the Geological Map of Slovakia 1 : 500,000). Dionýz Štúr Publishers, Bratislava. (In Slovak with English Summary).

Broska I., Vdovcová K., Konečný P., Siman P. & Lipka J., 2004: Titanit v granitoidoch Západných Karpát – distribúcia a zloženie. (Titanite in the granitoids of the Western Carpathians: Distribution and composition). Mineralia Slovaca, 36, p. 237-246. (In Slovak).

Broska I., Petrík I. & Uher P., 2012: Akcesorické minerály granitických hornín Západných Karpát. (Accessory Minerals of Granitic Rocks of the Western Carpathians). VEDA, SAV, Bratislava. 235 p. ISBN 978-80-224-1255-1

Donát A., Miháľ F. & Novotný L., 2000: Geologickoprieskumné práce na Au v staršom paleozoiku SGR (Geological-Prospection Works for Au in the Older Paleozoic in SGR Mts.). Final report. Manuscript, Geofond Archive, Bratislava. (In Slovak).

Fulín, 1987: Šlichová prospekcia Braniska a Čiernej hory. (Panned Concentrate Prospection in Branisko and Čierna hora Mts.). Manuscript, Archive of MF TU Berg Košice, 93 p. (In Slovak).

Határ J., Gargulák M. & Snopko L., 1994: Zhodnotenie šlichovej prospekcie v styčnej zóne veporika a gemerika, oblasť medzi Ochtinou a Dobšinou. (Assessment of Panned Concentrate Prospection in the Contact Zone of Veporicum and Gemericum, Area between Ochtiná and Dobšiná). Final report. Manuscript, Geofond Archive, Bratislava, 35 p. (In Slovak).

Hvožďara P., Hurai V., Linkešová M. & Kravjanský G., 1985: Regionálna geochémia Západných Karpát. Slovenské rudohorie – západná časť – VP, rudy. (Regional Geochemistry of the W. Carpathians, Slovenské rudohorie Mts. – Western Part – Prospection, ores). Interim report. Manuscript, Geofond Archive, Bratislava, 259 p. (In Slovak).

Husár M. & Stašík L., 2000: Vyhľadanie a zhodnotenie ložísk zlata vo východoslovenskom regióne s výnimkou Vysokých Tatier a SGR. (Prospection and Assessment of Gold Deposits in the Eastern Slovakia Region except of the Vysoké Tatry and SGR Mts.). Final report. Manuscript, Geofond Archive, Bratislava, 70 p.

Jablonský J., Sýkora M. & Aubrecht R., 2001: Detritické Cr spinely v sedimentárnych horninách mezozoika Západných Karpát (prehľad nových poznatkov). (Detritic Cr-Spinels in Mesozoic Sedimentary Rocks of the Western Carpathians (overview of the latest knowledge). Mineralia Slovaca, 33, p. 487-498. (In Slovak, with extended English Summary).

Klein C., The Manual of Mineral Science, Preklad – Majzlan, J., 2006: Mineralógia, OIKOS-LUMON, Bratislava, 666 p. ISBN 80-968535-5-4

Knésl J., Lukaj M. & Linkešová M., 1972: Kremnické pohorie – Hg rudy – VP. (Kremnické vrchy Mts. – Hg Ores – Prospection). Final report. Manuscript, Geofond Archive, Bratislava, 216 p. (In Slovak).

Knésl J. & Maťová V., 1986a: ZS úlohy Regionálna geochémia Západných Karpát VP. (Final report of the project Regional Geochemistry of the W. Carpathians). Manuscript, Geofond Archive, Bratislava, 109 p. (In Slovak).

Knésl J. & Maťová V., 1986b: Čiastková správa úlohy Regionálna geochémia Západných Karpát – časť Nízke Tatry. (Interim report of the project Regional Geochemistry of the W. Carpathians – Part Nízke Tatry Mts.). Manuscript, Geofond Archive, Bratislava, 64 p. (In Slovak).

Kravjanský G. & Hroncová Z., 1985: Regionálna geochémia Západných Karpát. Veľká Fatra – VP, rudy. (Regional Geochemistry of the W. Carpathians – Veľká Fatra Mts., Prospection, Ores). Interim report. Manuscript, Geofond Archive, Bratislava, 27 p. (In Slovak).

Kravjanský G. & Linkešová M., 1985: Regionálna geochémia Západných Karpát. Západné Tatry – VP, rudy. (Regional Geochemistry of the W. Carpathians – Západné Tatry Mts., Prospection, Ores). Interim report. Manuscript ,Geofond Archive, Bratislava, 27 p. (In Slovak).

Križáni I., 1971: Magurský flyš východného Slovenska. Správa o šlichovej prospekcii. (Magura Flysch of Eastern Slovakia. Report on panned concentrate prospection). Manuscript, Geofond Archive, Bratislava, 110 p. (In Slovak).

Križáni I., Ďuďa R. & Bacsó Z., 1979: ZS Vysoké Tatry – Prešov. Komplexná mineralogicko-geochemická prospekcia. (Final report Vysoké Tatry – Prešov. Complex Mineralogical-Geochemical Prospection). Manuscript, Geofond Archive, Bratislava, 222 p. (In Slovak).

Lukáč R., 1968: Všeobecná mineralógia I., Kryštalografia, (Mineralogy I, Crystallography). SPN, Bratislava. p. 319. (In Slovak).

Malachovský P., Grecula P., Dianiška I. & Matula I., 1983: SGR – vysokotermálna mineralizácia, VP. (SGR – High-Thermal Mineralisation. Prospection). Final report, Manuscript, Geofond Archive, Bratislava. (In Slovak).

Mikoláš P., Kováčik I. & Cuninga R., 1985a: Regionálna geochémia Západných Karpát. Malá Fatra – VP, rudy. (Regional Geochemistry of the Western Carpathians – Malá Fatra – Prospection, Ores). Interim report. Manuscript, Geofond Archive, Bratislava, 63 p. (In Slovak).

Mikoláš P., Kováčik I. & Cuninga R., 1985b: Regionálna geochémia Západných Karpát. Malá Magura, Suchý, Žiar – VP, rudy. (Regional Geochemistry of the Western Carpathians - Malá Magura, Suchý, Žiar – Prospection, Ores). Interim report. Manuscript, Geofond Archive, Bratislava, 73 p. (In Slovak).

Polák P., Rak D. & Hanas P., 1985a: Regionálna geochémia Západných Karpát. Malé Karpaty – VP, rudy. (Regional Geochemistry of the Western Carpathians – Malé Karpaty – Prospection, Ores). Interim report. Manuscript, Geofond Archive, Bratislava, 76 p. (In Slovak).

Polák P., Rak D. & Hanas P., 1985b: Regionálna geochémia Západných Karpát. Považský Inovec – VP, rudy. Interim report. Manuscript, Geofond Archive, Bratislava, 91 p. (In Slovak).

Polák P., Rak D. & Hanas P., 1985c Regionálna geochémia Západných Karpát. Tríbeč – VP, rudy. (Regional Geochemistry of the Western Carpathians – Tribeč – Prospection, Ores). Interim report. Manuscript – Geofond Archive, Bratislava, 84 p. (In Slovak).

Prokša P., Matula I., Petr K., Bačo P., Mesarčík I., Galová M. & Fodorová V., 1992: Slovensko, mineralogicko – geochemická prospekcia. VP. (Slovakia, Mineralogical-Geochemical Prospection). Final report. Manuscript, Geofond Archive, Bratislava, 58 p. (In Slovak).

Pulec M., 1976: Šlichovanie na liste Mýto pod Ďumbierom. (Panning on the Map Sheet Mýto pod Ďumbierom). Interim report. Manuscript, Geofond Archive, Bratislava. (In Slovak).

Pulec M., 1977a: Čiastková záverečná správa – Šlichovanie na liste Korytnica (1 : 25,000). (Panning on the Map Sheet Korytnica). Manuscript – Geofond Archive, Bratislava. (In Slovak).

Pulec M., 1977b: Čiastková záverečná správa – Šlichovanie na liste Jasenie (1 : 25,000). (Panning on the Map Sheet Jasenie). Manuscript, Geofond Archive, Bratislava, 84 p. (In Slovak).

Rösler J. H., 1983: Lehrbuch der Mineralogie, VEB Deutscher Verlag für Grundstoffindustrie, L.eipzig, 833 p. (In German).

Slávik J. & Valko P., 1969: ZS Vihorlat – Popričný, VP. (Final Report Vihorlat – Popričný Prospection). Manuscript, Geofond Archive, Bratislava, 255 p. (In Slovak).

Spišiak J., Soták J., Biroň A. & Mikuš T., 2001: Cr spinely zo serpentinických pieskovcov šambronskej zóny. (Cr-spinels from serpentinic sandstones of the Šambron Zone). Mineralia Slovaca, 33, p. 499-504. (In Slovak).

Tözsér J., 1972: Prešovsko – tokajské pohorie – Hg – VP. ZS z etapy vyhľadávacieho prieskumu. (Prešov – Tokaj Mountains – Hg-Prospection). Final Report. Manuscript, Geofond Archive, Bratislava, 239 p. (In Slovak).

Varga I., 1973: ZS SGR – juh I. VP – Hg, Cu a ostatné farebné kovy. (Final report SGR – South, I Prospection, Hg, Cu and Other Base Metals). Manuscript, Geofond Archive, Bratislava, 149 p. (In Slovak).

5. Potential Occurrence of Selected, Mainly Critical Raw Materials at the Territory of the Slovak Republic in Respect to EU Countries Needs

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Abstract. The most promising metal mineral resources in Slovakia are those that were previously subject to exploitation – ores of **Sb**, Fe, Cu, Pb, Zn, Au, Ag. The further prospective minerals appear even those which were the subject of ore reserves estimation – ores of **W**, Ni, Co and Sn.

Antimony ores are still the most promising object either for the recently exploited mining reserves or for further exploration. We can state the presence of resources comparable to many countries of the world (outside China) and persistently prominent place among the EU countries, despite their long-term exploitation.

For economic and other reasons we can positively evaluate and reconsider the attitude to the resources of Co and W. The most promising for cobalt (with Ni) are the sources in weathering crusts of ultrabasic rocks. The prospective for tungsten seems mainly porphyry type mineralisation type Ochtiná I.

The source materials for metal magnesium in geological conditions of the Western Carpathians are dolomites and magnesites. The supplies of these raw materials in Slovakia are immense in comparison to European countries. However, the raw material potential is necessary to verify from the technological point of view.

Graphite – only areas with higher metamorphic grade are of interest from the viewpoint of quantitative parameters. However, we can expect only objects with very small resources.

Selected polymetallic and copper mineralisation of deposits with reserves of ore were tested for the presence of metals such as In, Ga, Ge. Results to date have not demonstrated their unequivocal presence. However, we still consider polymetallic and copper mineralisation as a potential source, seeing that general genetic model and the specific deposit define them as one of the most important sources.

A comparison of raw material sources for REE + Sc and Y-Nb-Ta in the world and within the geological conditions of Slovakia shows on one hand, the absence of the host rock, on the other hand, the presence of another, very promising type of geological environment – alkaline granitic rocks.

Fluorite is a mineral, known for multiple mineralogical occurrences, however not from the Western Carpathians.

Issues of Be-mineral resources of bertrandite type and chemical elements of the platinum group is investigated within basic research.

The created and continuously updated relevant base of data enables permanent comparison of identified resources (Sb, W, Co, graphite) with qualitative and quantitative parameters of resources in other EU countries or with global deposits of various genetic types.

Key words: Critical Raw Materials for EU, CRM – prices development, Slovakia – CRM reserves and reserves potential

5.1 Introduction

Recently, the issue of availability of certain metals or mineral resources in the world is a hot spot. Their current extraction is concentrated in very few deposits and often even in a few countries. This fact makes these metals and materials "critical raw materials" (CRM). For these reasons, the European institutions have adopted in recent years several important documents that respond to this situation in the field of mineral resources. One of the most important was the document in which there are defined critical raw materials for EU countries in terms of their economic importance and availability of these raw materials on world markets (Fig. 5.1).

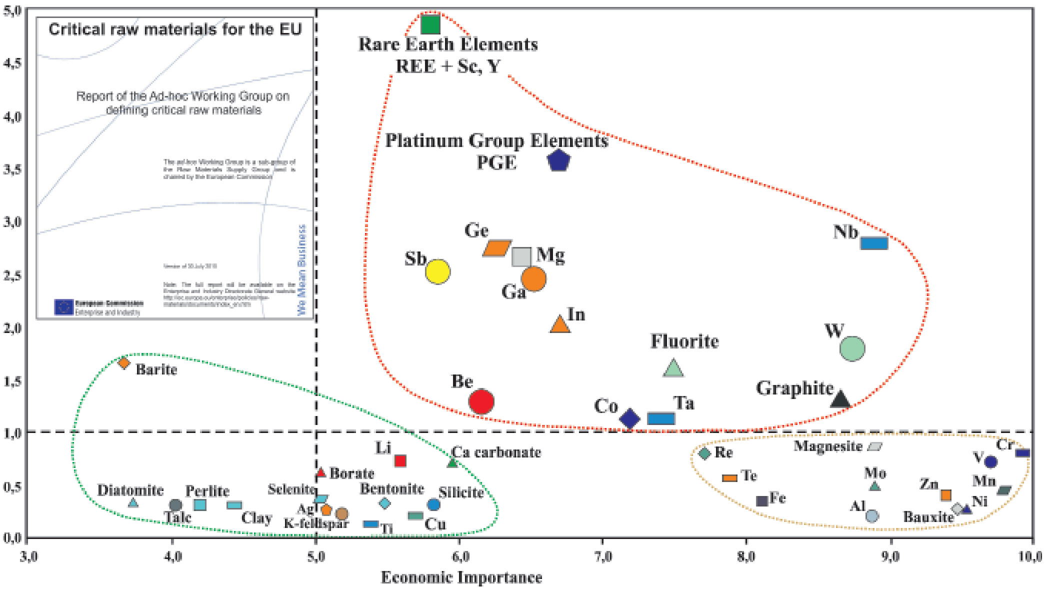


Fig. 5.1 The critical raw materials for the EU countries as being determined by the Ad-Hoc Working Group chaired by EC (modified after: http://ec.europa.eu/enterprise/policies/raw-materials/files/docs/communication_sk.pdf).

Tab. 5.1 Concentration of production of critical raw materials and recycling rate. Source: KOM (2011) 25 as of 2.2.2011; modified.

Raw material	Main producing countries	%	Main EU import sources	%	Import dependence	Recycling rate (%)
REE	China	97	China	90	100%	1
	India	2	Russia	9		
	Brazil	1	Kazakhstan	1		
Niobium	Brazil	92	Brazil	84	100%	11
	Canada	7	Canada	16		
Antimony	China	91	Bolivia	77	100%	11
	Bolivia	2	China	15		
	Russia	2	Peru	6		
	South Africa	2				
Beryllium	USA	85	USA, Canada, China, Brazil		100%	
	China	14				
	Mozambique	1				
PGE only Pt	South Africa	79	South Africa	60	100%	35
	Russia	11	Russia	32		
	Zimbabwe	3	Norway	4		
Germanium	China	72	China	72	100%	0
	Russia	4	Hong Kong	7		
	USA	3	USA	3		
Indium	China	58	China	81	100%	0.3
	Japan	11	Hong Kong	4		
	Korea	9	USA	4		
	Canada	9	Singapore	4		
Magnesium	China	56	China	82	100%	14
	Turkey	12	Israel	9		
	Russia	7	Norway	3		
			Russia	3		
Tantalum	Australia	48	China	46	100%	4
	Rwanda	9	Japan	40		
	Dem. Rep. Congo	9	Kazakhstan	14		
Cobalt	Dem. Rep. Congo	41	Dem. Rep. Congo	74	100%	16
	Canada	11	Russia	19		
	Zambia	9	Tanzania	5		
Graphite	China	72	China	75	95%	0
	India	13	Brazil	8		
	Brazil	7	Madagascar	3		
			Canada	3		
Tungsten	China	78	Rwanda	13	73%	37
	Russia	5	Bolivia	7		
	Canada	4	Russia	5		
Fluorspar	China	59	China	27	69%	0
	Mexico	18	South Africa	25		
	Mongolia	6	Mexico	24		
Gallium	N.A.		USA, Russia			0

Many countries of the world have become a major importer of metals and minerals which are necessary for technology and products and the sustainment of economic growth and development. The share of production, or certified, as well as anticipated sources of these raw materials in the EU countries is very small, possibly to none. For this reason, the European Union countries are dependent on their import (Tab. 5.1).

The analysis shows a dominance of certain countries in production and often in registered reserves within their territories. Since 2010, this view of the raw materials is constantly changing (Fig. 5.2) depending on the demand for individual metals, which reflects the needs of the economy and its changes, as well as verification and start of producing some CRM in some EU countries or the so-called “import reliable” countries.

Among the many suggestions and recommendations proposed in the area of mineral policy resonates need of knowledge of local resources and their subsequent protection against all possible blockades of their use. Therefore, large group of the states (or groupings, e.g. EU) is conducting various studies, in order to review and assess whether they have an access to the defined mineral resources.

In Slovakia no deposit is currently exploited that would produce some of the metals from the Critical Raw Materials (CRM) group. Closed and to varying degrees conserved are deposits of Sb ores as well as deposits on which part of the metals could act as an accompanying raw material.

5.2 Present knowledge of deposits of accumulated critical mineral resources in Slovakia.

Most critical mineral raw materials, as referred to Fig. 5.1., do not create separate deposits in the Slovak part of the Western Carpathians (Fig. 5.3). The metal, which was exploited in the past on several deposits (in the Malé Karpaty, Nízke Tatry Mts. and Gemericum) is **Sb**. According to Balance of Reserves of Exclusive Deposits of the Slovak Republic as of 01/01/2014 a summary of residual state of individual deposits in SR is about 3,200 kt of ore containing around 55 358 t of Sb (Baláž & Kúšik, 2014). According to the metal content (amount of metal – Tab. 5.2), in the Slovak part of the Western Carpathians there are registered 24 deposits and 71 deposits and mineralogical occurrences of the Sb-ore (Tab. 5.3), Lexa et al. (2007).

In the past there were exploited the Ni-**Co** deposits in the vicinity of Dobšiná (Grecula et al., 1995). At present, the remaining reserves at the deposits in Dobšiná equal to around 100 kt of Ni-Co ores. On the residual type deposit at Hodkovce there are reported around 16,000 kt, but with a much lower content of Co (Zlocha et al., 1986). Registered are two deposits and two deposit and mineralogical occurrences

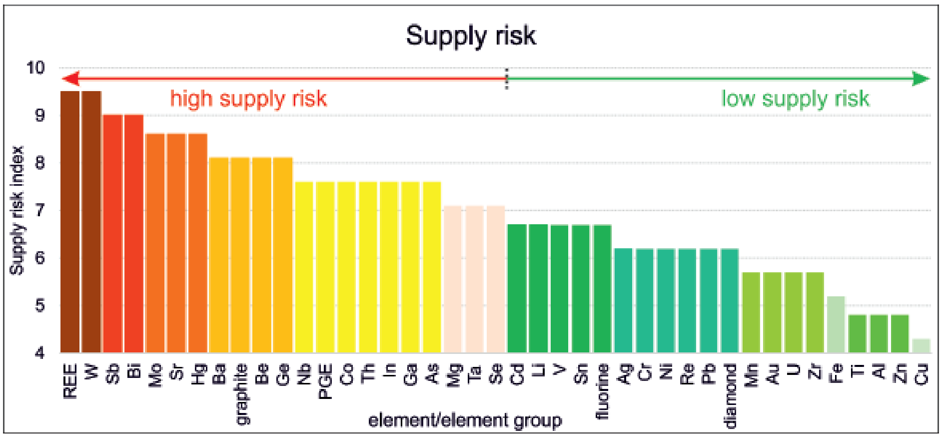


Fig.5.2 Distribution of monitored metals and minerals from the perspective of the final analyses. Source: NERC, 2012, BGS 2012; modified.

(Lexa et al., 2007) with the Co presence as useful component (Tab. 5.3).

A third metal from the group of critical metals is **tungsten**. It was not exploited, but the reserves are recorded, about 2,800 kt of the scheelite (scheelite-wolframite) type ore with around 6,500 tonnes of metal (Bláha et al., 1993; Lörinc et al., 1993; Baláž & Kúšik, 2014).

The mined deposits, and especially smaller independent ore occurrences of these metals (Sb, Co, W) are quite numerous, particularly in Tatricum, Veporicum and Gemericum (Lexa et al. 2007).

These ores were studied in the scope of extensive deposit surveys financed from the state budget until the end of the 90s of the last century (Grecula et al., 1995; Zuberec et al., 2005; Lexa et al., 2007). The deposits of Sb, Co and W ores are not bound to other accompanying "critical" metals (theoretically perhaps PGE elements of residual-type mineralisation at the ultramafic "Komárovsky" body), which are listed on Fig. 5.1. – red dotted polygon – at a rate at which it could be considered as the accompanying raw material.

From earmarked critical metals in Fig. 5.1. the search survey for **graphite** was conducted including estimation of prognostic resources. Its accumulations are bound to graphitic slates of the Early Paleozoic and Carboniferous rock complexes. From a technological point of view, these are the two basic types (Očenáš, 1992): 1. Occurrences in which carbon has a low degree of graphitization – microcrystalline and amorphous graphite, for example, deposit occurrence Kadlub (Sombathy, 1949); 2. Occurrences where the environment has been affected by medium to high metamorphic grade. Carbon has a good crystallinity – flake graphite – deposit Kokava nad Rimavicou (Petro et al., 1998).

Tab. 5.2: Classification of deposits, deposits occurrences and mineralogical occurrences, according to the amount of metal; Tréger in Lexa et al. (2002)

Metal	Unit of measure	Mineralogical occurrence	Deposit occurrence	Deposit		
				small	medium	large
Sb	**kt**	**< 0.1**	**0.1 – 1**	**1 – 10**	**10 – 100**	**> 100**
W	**kt**	**< 0.1**	**0.1 – 1**	**1 – 10**	**10 – 100**	**> 100**
REE	**t**		**< 1 000**	**1,000 – 20,000**	**20,000 – 100,000**	**> 100,000**
Cu	**kt**	**< 1**	**1 – 10**	**10 – 100**	**100 – 1,000**	**> 1,000**
Pb	**kt**	**< 1**	**1 – 10**	**10 – 100**	**100 – 1,000**	**> 1,000**
Zn	**kt**	**< 1**	**1 – 10**	**10 – 100**	**100 – 1,000**	**> 1,000**
Sn	**kt**	**< 0.1**	**0.1 – 1**	**1 – 10**	**10 – 100**	**> 100**
Ni	**kt**	**< 0.5**	**0.5 – 5**	**5 – 50**	**50 – 500**	**> 500**
U	**kt**	**< 0.1**	**0.1 – 1**	**1 – 10**	**10 – 100**	**> 100**
Ag	t	< 5	5 – 50	50 – 500	500 – 5,000	> 5,000

Explanations:

- (yellow) deposits of metal possibly containing **In, Ge,** and **Ga** as accompanying metal
- (green) deposits of metal possibly containing **Nb** and **Ta**, rarely also **REE** as accompanying metal
- (blue) deposits of metal, where in conditions of the W. Carpathians **Co** is present as a main, or accompanying metal
- (blue) deposit of metals with eventual presence of **PGE** as accompanying metals
- (red) deposit of metals with eventual presence of **REE** as accompanying metals
- (pink) deposit of metals (tetrahedrite type) with eventual presence of **PGE** as accompanying metal

Note:

REE – light REE (LREE): La, Ce, Pr, Nd, Pm, Sm, Eu, Gd + Sc
– heavy REE (HREE): Tb, Dy, Ho, Er, Tm, Yb, Lu + Y

PGE – light PGE (LPGE): Pd, Rh, Ru
– heavy PGE (HPGE): Pt, Ir, Os

Tab. 5.3 Critical metals (minerals) in the view of the presence of deposits and occurrences in the Slovak Republic, modified after Lexa et al. (2002), note: REE; PGE – explanations Tab. 5.2

metal/mineral	Mineralogical occurrence	Deposit occurrence	Deposit		
			small	medium	large
Antimony	51	20	18	6	
Tungsten	7	3	2	1	
Cobalt	1	1	1	1	
Graphite	12	1			
Rare earth elements – REE + Y, Sc	2	3			
Niobium	11	2			
Tantalum	11	2			
Fluorite	X0	unregistered deposits neither deposit occurrences			
Beryllium	3	unregistered deposits neither deposit occurrences			
Magnesium	not been studied of view of production of magnesium metal				
Platinum group elements – PGE	unregistered deposits neither deposit occurrences				
Gallium	solo unregistered, but present on Pb, Zn deposits				
Germanium	solo unregistered, but present on Pb, Zn deposits				
Indium	solo unregistered, but present on Pb, Zn deposits				
Zinc	*38*	*11*	*10*	*2*	*1*

Group of three metals – **Ga**, **In** and **Ge** has no tradition in our mining history and no systematic research and prognostic evaluation. In the world these metals are obtained mostly as a by-product of mining of polymetallic epithermal ores (In, Ge and Ga, and also Te and Tl) or copper ores (In), or bauxite (Ga – in the past it was obtained during the processing of bauxite). Deposits or occurrences, for which there would be stated their presence as utility metals are not recorded in Slovakia, but there are recorded potential deposits (13) and occurrences (49) (deposits of polymetallic ores; Lexa et al., 2007), in which they might occur as accompanying raw minerals.

Precious metals **Nb** and **Ta** (or their carriers – minerals) and their accompanying minerals (REE, Li, Rb, Cs, Sn, etc., and partly it is also true vice versa) were identified at several locations in Slovakia. Their presence is linked to the occurrences of several genetic types:

1. For the time being their occurrences in granites and pegmatites in the form of accessory minerals (in summary in Uher in Broska et al., 2012), are registered in the mountain ranges of Považský Inovec, Žiar, Nízke Tatry and Malé Karpaty – here also in secondary positions in the concentrate of heavy minerals in sediments of the Limbach stream.
2. Occurrences in greisenised parts of the Permian Gemericum granites in the wider area of Hnilec and Gemerská Poloma (Drnzík et al., 1982, Malachovský et al., 1992).
3. Occurrences of Nb and Ta were found in albititic metasomatites of some Gemericum granites (Li-F) in the wider area of Podsúľová – Čučma (Malachovský et al., 1992b).
4. The presence of Nb-Ta along with REE, Y, Zr mineralisation in a variegated volcanic complex of Gemericum. The occurrences are linked to the Th-U anomaly of the wider area of Rejdová, Rakovec and Hnilčík-Ráztoky (Malachovský et al., 1987; Repčiak et al., 1997).

All the above types of mineralisation with the presence of Nb and Ta are rated as mineralogical, or deposit occurrences – a total of 13 sites (Lexa et al., 2007).

At the Gemerská Poloma-Dlhá dolina site there were estimated prognostic resources of these metals (Malachovský et al., 1992).

Rare earth elements – **REE** (including **Y** and **Sc**) are among the most risky commodities imported into the EU and they are of crucial importance for technological and manufacturing processes in the European Union countries. In Slovakia there are known relatively large number of occurrences of minerals, which are their bearers and which were the subject of geological deposit survey (Hvožďara et al., 1994; Repčiak et al., 1997; Zuberec et al., 2004; Ďuďa & Ozdín, 2012).

In the Slovak part of the Western Carpathians the only area with calculated reserves of rare earths is Čučma. The mineralisation is bound to the quartz veins in the rock environment of porphyroids. After the last survey (Donát, 1998), there were estimated reserves in the amount of 7.8 kt of rare earth ores containing 0.2% LREE and HREE.

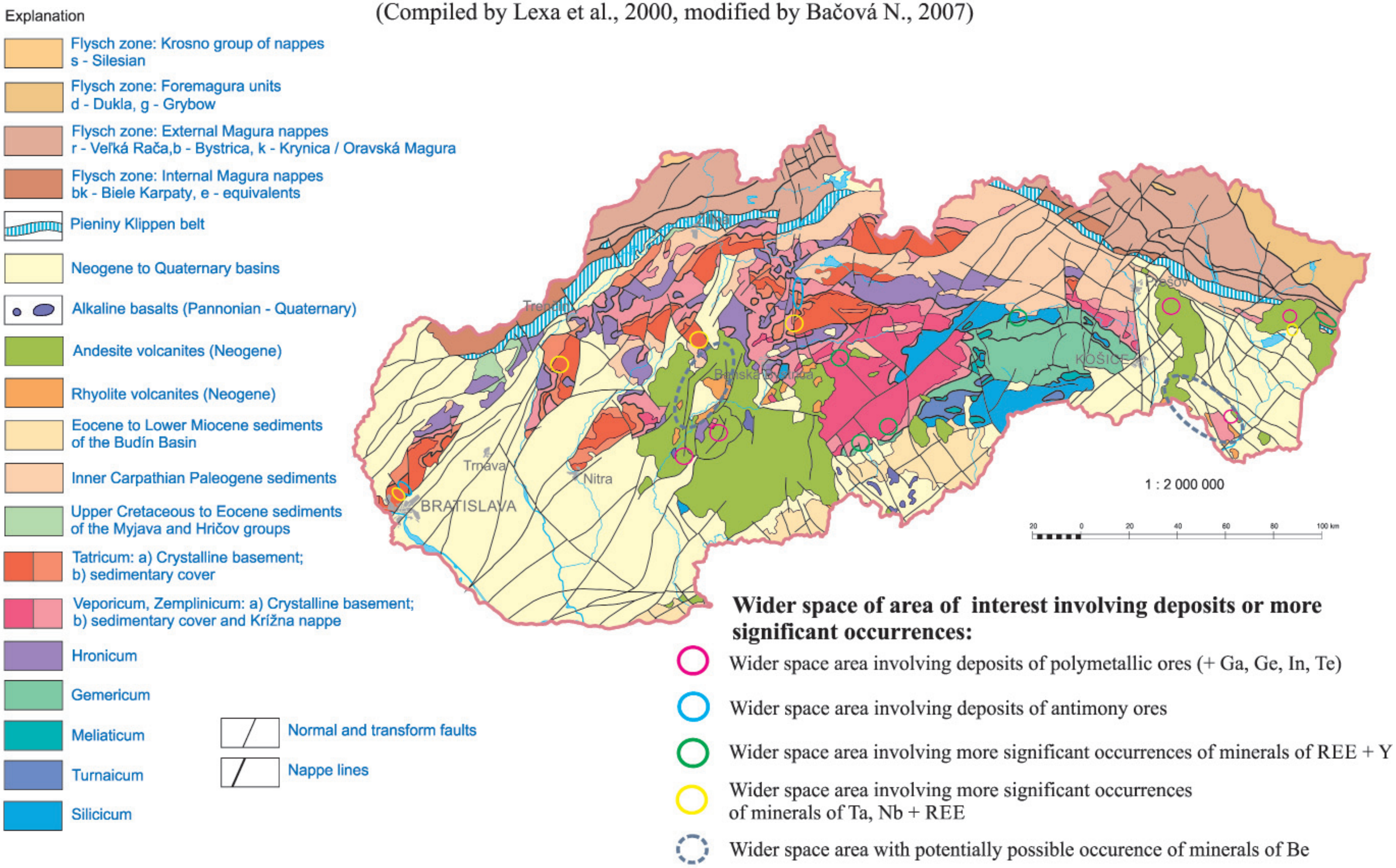
In the Slovak part of the Western Carpathians conditions could exist theoretically for further unconventional mineralisation type. It is **Be**-carrier, bertrandite, volcanogenic epithermal mineralisation. In 1992 it was completed the first study dealing with the possibility of the presence of this type of Be mineralisation (Knéslová et al., 1992) in Slovakia. There were recorded elevated levels of Be, however, the bertrandite mineralisation in acidic volcaniclastics could not be identified.

Fluorite is not a frequent accompanying vein mineral, but it is described in some deposits in the Western Carpathians (Koděra et al., 1989; Ďuďa & Ozdín, 2012). Abundant occurrence was recorded in deposits and occurrences of Sn mineralisation (Drnzík et al., 1982; Grecula et al., 1995) and in connection with the occurrence of boron-containing rocks in tourmalinite deposits – Zlatá Idka (Kobulský et al., 2000) in Gemericum.

The special status of the mentioned 14 elements and minerals – "critical raw materials for the EU" in Fig. 5.1 has a **magnesium metal**. The Slovak Republic has great reserves of raw minerals – magnesite and dolomite, which are the initial source for the production of this metal. However, so far these material resources have not been broader evaluated from this perspective. There are known only experimental works on its production from raw magnesite

Fig. 5.3 **Structural scheme of the Western Carpathians in territory of the Slovak Republic**

(Compiled by Lexa et al., 2000, modified by Bačová N., 2007)



(Tomášek et al., 1995). There were even deliberations on running its production in the Slovak Magnesite Works in Jelšava (Immer, 1998).

Information on the presence of **platinum** group metals (PGE) in Slovakia are still very limited. Ambiguous is the published information on the presence of Pt minerals in gold ore deposit Banská Hodruša (Križáni et al., 2003; Andráš et al., 2006). There is anticipated occurrence of Pt mineralisation on the Strieborná Vein at the deposit Mária in Rožňava (Sasvári et al., 2003). Ultrabasic bodies in terms of occurrence of these metals were not studied in more detail, or they gave a negative result (Radvanec in Lexa et al., 2002). Recent analyses of this issue provided the first unbiased information within the study of the mineral composition of the ultramafic rocks and metagabbros with olivine for the need of artificial carbonation and disposal of CO_2 – this was first discovery of the presence of PGE and PGM in Slovakia. The rocks contain small inclusions of metals and their alloys (Radvanec in Bačo et al., 2013).

5.3 Critical raw materials in Slovakia, the situation and the possibility of verifying the industrial accumulations of these raw materials

5.3.1 Sb – deposits and occurrences at the territory of Slovakia

Slovakia was a major producer of this metal in the 19th century. Currently, there are registered (Tab. 5.4) about 70 mineralogical and deposit occurrences and about 20 deposit accumulations, including depleted ones, with various remaining reserves. The most significant deposits with calculated reserves have been from the Tatricum crystalline (Fig. 5.4; Table 5.4) in the western part of the Nízke Tatry Mts. (Dúbrava, Magurka, Dolná Lehota – Lom and others) and the Malé Karpaty Mts. (Pezinok). Major Sb mineral is antimony. Historically, there were significant deposits in Gemericum. They are present in the anticlinal axis of the Gemericum structure in Early Paleozoic epizonal metamorphic rocks (Betliar, Čučma, Poproč, Zlatá Idka). Here, too, the main Sb mineral was stibnite. From the metallogenic point of view these deposits belong among the hypo- to epizonal ones (Fig. 5.5), developed in an environment of crystalline granitoid rocks and orogenic to postorogenic development stage of ore field space.

In all Sb deposits in Spiš-Gemer Ore Mountains the mining was discontinued due to depletion of reserves. However, an important role in the production of Sb in the future can play a deposit of tetrahedrite in Rožňava – Strieborná Lode; Sb is supposed to become a by-product of Ag-mining.

Small accumulations of antimony are known from the occurrences in Veporicum (Chyžné-Kubejka) and the neo-volcanic areas (their location is shown in Fig. 5.6), which were partly exploited in the past (Kremnica, Zlatá Baňa).

Accompanying metal of the antimony deposits in the Western Carpathians is gold. In the case of Au-bond on Sb-mineralisation, in the ore processing the gold passed into the Sb concentrate and became a by-product (deposits in Spiš-Gemer Ore Mountains, Tatricum of the Nízke Tatry Mts.). A significant amount of gold, especially from the Malé Karpaty deposits, is bound to other sulphide miner-

Tab. 5.4 Sb – occurrences and deposits in the Slovak Republic, source: Lexa et al. (2007) and Tréger in Lexa et al. (2002); compiled and modified

Metal	Unit of measure	Mineralogical occurrence	Deposit occurrence	Deposit		
				small	medium	large
Sb	kt	< 0.1	0.1 – 1	1 – 10	10 – 100	> 100
	number	51	20	**18**	**6**	

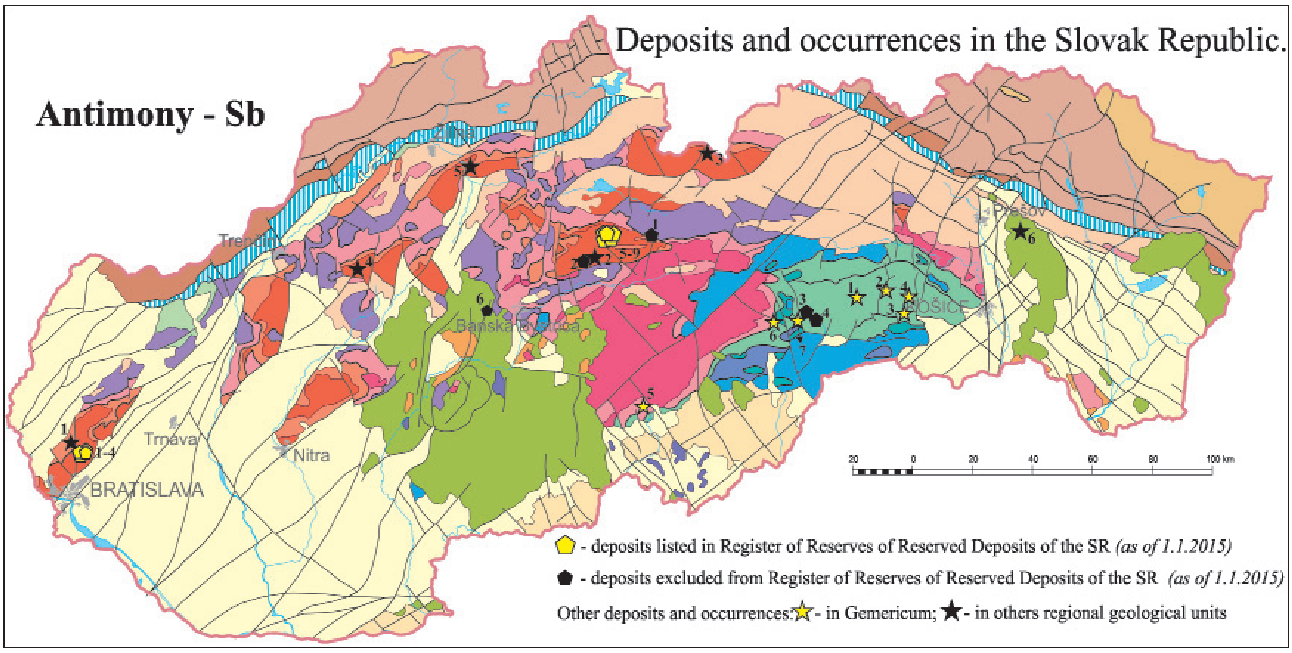


Fig. 5.4 Deposits and significant occurrences within individual geological units.

NEOHERCYNIAN LATE- TO POST-OROGENIC PHASE (340 - 250 Ma)			
Crystalline basement of the Tatricum unit			
Transtension to extension and late-orogenic granitic magmatism of the I, S and A type			
Hydrothermal vein and shear-zone type mineralizations			
Quartz-stibnite-Au deposits and occurrences	**Pezinok-Sb (Pezinok II)**	1	⬠ (yellow)
	Pezinok-Sb (Pezinok I)	2	⬠ (yellow)
	Pezinok-Vinohrad	3	⬠ (yellow)
	Pezinok	4	⬠ (yellow)
	Pernek-Jahodnisko	1	★
	Dúbrava-Ľubeľská	5	⬠ (yellow)
	Dúbrava-Martin štôlňa	6	⬠ (yellow)
	Dúbrava-Matošovec	7	⬠ (yellow)
	Dúbrava-Predpekelná	8	⬠ (yellow)
	Dúbrava	9	⬠ (yellow)
	Dolná Lehota-Lom	1	⬟
	Lomnistá - Husárka	2	⬟
	Nižná Boca	2	★
	Kriváň-Krivánske bane	3	★
	Chvojnica	4	★
	Bystrička	5	★

Explanations:
⬠ (yellow) - deposits listed in Register of Reserves of Reserved Deposits in the SR
⬟ - deposits excluded from Register of Reserves of Reserved Deposits in the SR
Other deposits and occurrences: ☆ - in Gemericum unit;
★ - in others regional geological units

PALEO-ALPINE LATE-OROGENIC PHASE (90 - 70 Ma)				
Crystalline basement of the Tatricum and Veporicum units, metasedimentary and metavolcanic rocks of the Gemericum unit				
Thermal reactivation in the transtension and extension regime, sporadic granitic magmatism				
Metamorphic-hydrothermal vein and stockwork/disseminated mineralizations of shear zones				
Stibnite-gold deposits and occurrences	Gemericum	***Betliar-Straková***	3	⬟
		Čučma-Matej	4	⬟
		Spišská Baňa	1	☆
		Helcmanovce	2	☆
		Poproč	3	☆
		Zlatá Idka	4	☆
	Veporicum cover	Ozdín	5	☆
		Chyžná	6	☆
		Rochovce-Oriešok	7	☆

NEO-ALPINE OROGENIC PHASE (24-10 Ma)			
Neogene volcanites			
Andesite and rhyolite volcanism accompanied by subvolcanic intrusive complexes and the evolution of volcanotectonic			
Volcanic hosted low sulphidation epithermal mineralizations			
Sb-Au occurrences	Kremnica	6	⬟
	Zlatá Baňa	6	★

edited by Lexa et al. (2007) and Register of Reserves of Reserved Deposits in the SR (as of 1.1.2015)

Fig. 5.5 The list of deposits and major occurrences (including the depleted ones) regarding their metallogenic attributes. Yellow highlighted pentagons indicate deposit objects with calculated reserves.

als (mainly arsenopyrite, less pyrite). When processing Sb ores by flotation the arsenopyrite was extruded from the concentrate and then deposited on the pond together with gold, which has therefore become a potential source of gold.

There have not been observed other elements that could represent a by-product on the Sb deposits (probably As).

Reserves of Sb ores and potential amount of metal in the deposits of SR – according to the inventory of

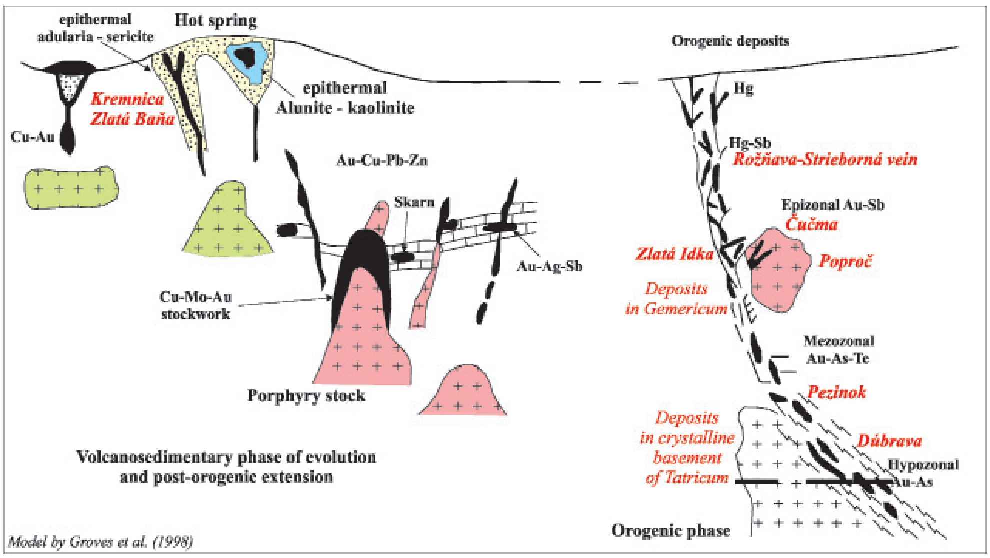


Fig. 5.6 Genetic model of Sb type mineralisation with specific assignment of individual deposits from the Slovak part of the Western Carpathians, modified and supplemented by Groves et al. (1998).

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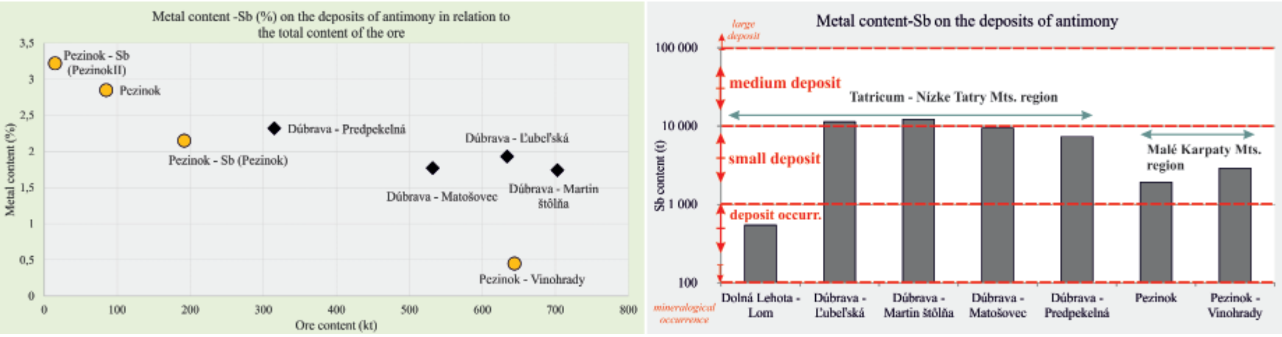

Fig. 5.7a, b Reserves of Sb ores on individual deposits in the Slovak part of the Western Carpathians, classified by size criteria. Data source: Tréger in Lexa et al.; 2002, Baláž & Kúšik, 2014

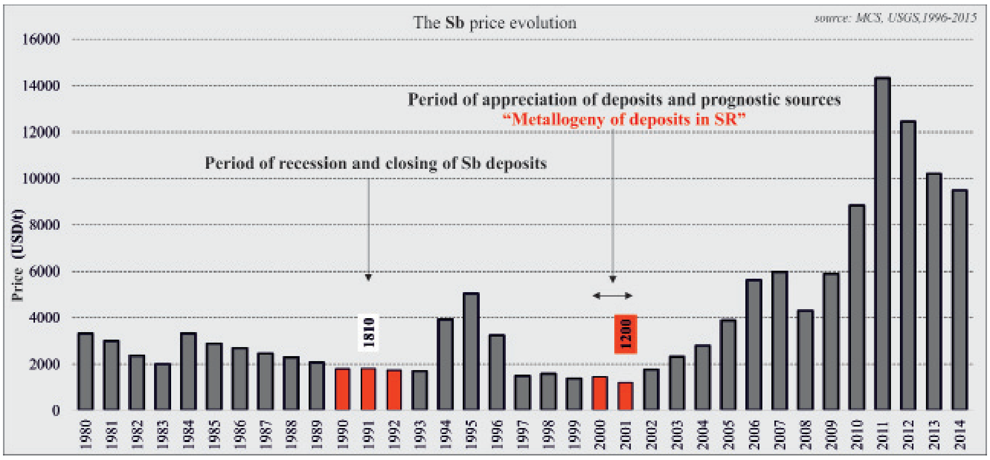

Fig. 5.8 Sb price developments in world markets with consequences in different time frames. Data source: © Kitco USGS and Mineral Commodity Summaries 1996-2015; supplemented, modified

the exclusive deposits of this metal there are registered 2,884,000 tonnes of ore with capacity of 55,358 tonnes Sb so far within the individual deposit bodies (Fig. 5.7a, b) (Baláž & Kúšik, 2014).

Within the EU the Slovak Republic has relatively large reserves of the antimony ores. Damping programmes in the 90s of the last century have caused the closure and a not fully controlled disposal of mining operations in Dúbrava and Pezinok.

The analysis of these developments on the timeline pointed out some interesting information. At the time of deposits closing, the price of 1 t Sb was around 1,800 USD (Fig. 5.8). Development of prices during the downturn of our Sb deposits was at historic lows. After the closure of the deposits (which were state subsidized) there was a slight increase in prices and subsequent record fall. That resulted in the closing of a number of deposits across the world. At this time in our country there was re-evaluated economic value of the closed (damped) deposits.

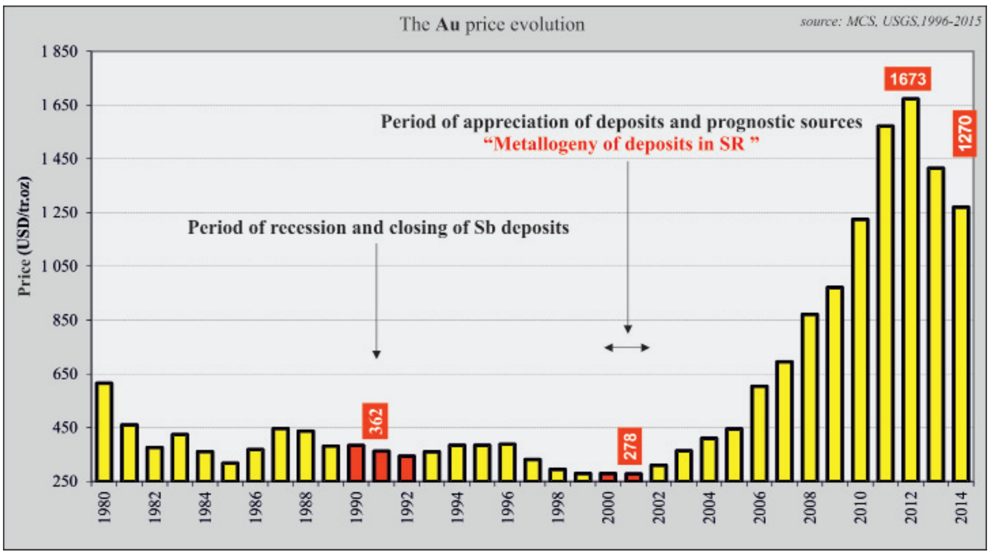

Fig. 5.9 Development of prices on world markets in relation to the various important social and geological activities since deposits closure in Slovakia until the present. Data source: © Kitco USGS and Mineral Commodity Summaries 1996-2015; supplemented, modified

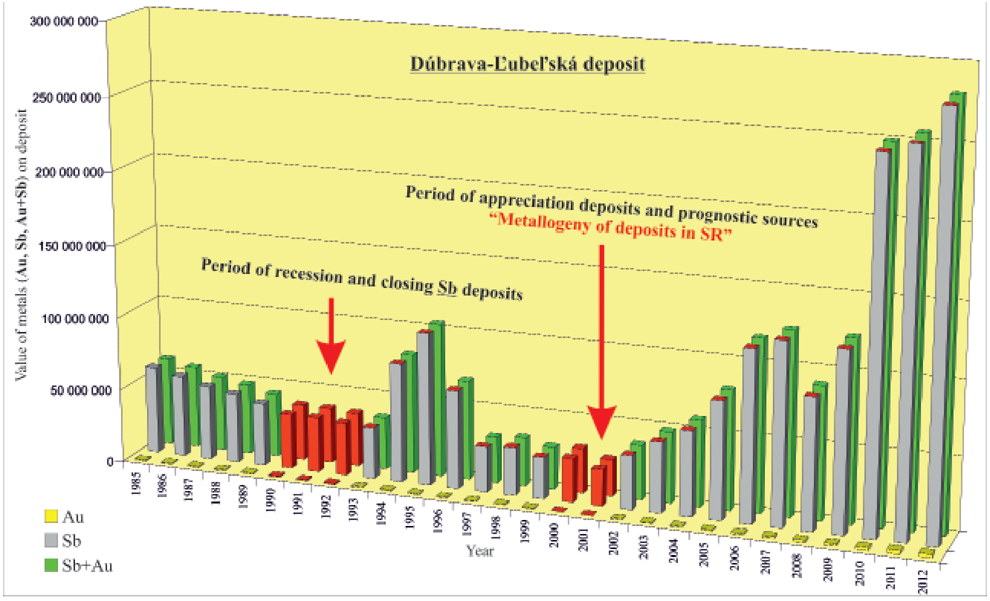

Fig. 5.10 Indicative calculated evolution of net asset value of residual metals – Sb and Au at the deposit Dúbrava – Ľubeľa after damping in the 90s of the last century. We point out that this is the value of the measure of the balance of the metal therein, without accounting for the cost of any physical extraction from the deposit. Source: Inventories and USGS © Kitco and Mineral Commodity Summaries 1996-2012, supplemented, modified

For obvious reasons (provided the price was the main factor) many deposits were evaluated as uneconomic. Of course, the adverse price developments affected the accompanying metal at our Sb deposits, namely the gold (Fig. 5.9). Gold price development is equivalent, which ultimately may result in a significant reassessment of the value of the metals (Fig. 5.10) within the individual deposits in Slovakia.

Comparison of the amount of ore and Sb metal reserves on SR deposits and in selected deposits throughout the world

From the comparison of the amount of metal reserves on the Slovak and foreign deposits (Fig. 5.11 b; Fig. 5.12) follows:

1. Based on the data available the Sb metal reserves in the deposits of Slovakia are among the largest within the EU. It confirms our continued dominance as in the past.
2. Among the European deposits there are (were) significant deposits in France, but as in the case of our deposits, these are currently closed.
3. It is evident that the deposits in the EU countries had been largely extracted and depleted already in the (distant) past, at the time of the industrial revolution on the European continent.
4. The metallogenic evolution of the antimony as chalcophile element, occurs clearly in a rather low temperature hydrothermal conditions. Among other facts this means that its development is concentrated in the higher horizons of hydrothermal systems. This fact, as well as erosion, allowed its early discovery.
5. China has clearly the largest reserves with a relatively large number of registered (Hu et al., 1996) and currently mined deposits.
6. Relatively low recycling rate (about 11% – Tab. 5.1) makes this metal and its resources commodities of permanent interest.

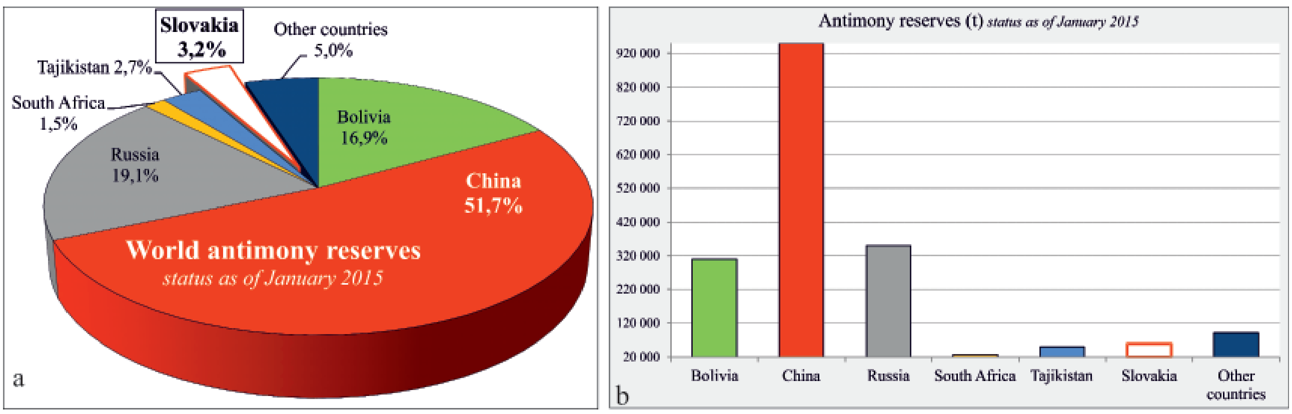

Fig. 5.11a, b Comparison of the Sb (metal) reserves on deposits in individual countries as of January 2013, stated by USGS. The status of reserves in Slovakia was grossed up on the basis of reserves of the metal on our deposits. Data source: USGS, MCS, 2015; Baláž & Kúšik, 2014; edited and compiled

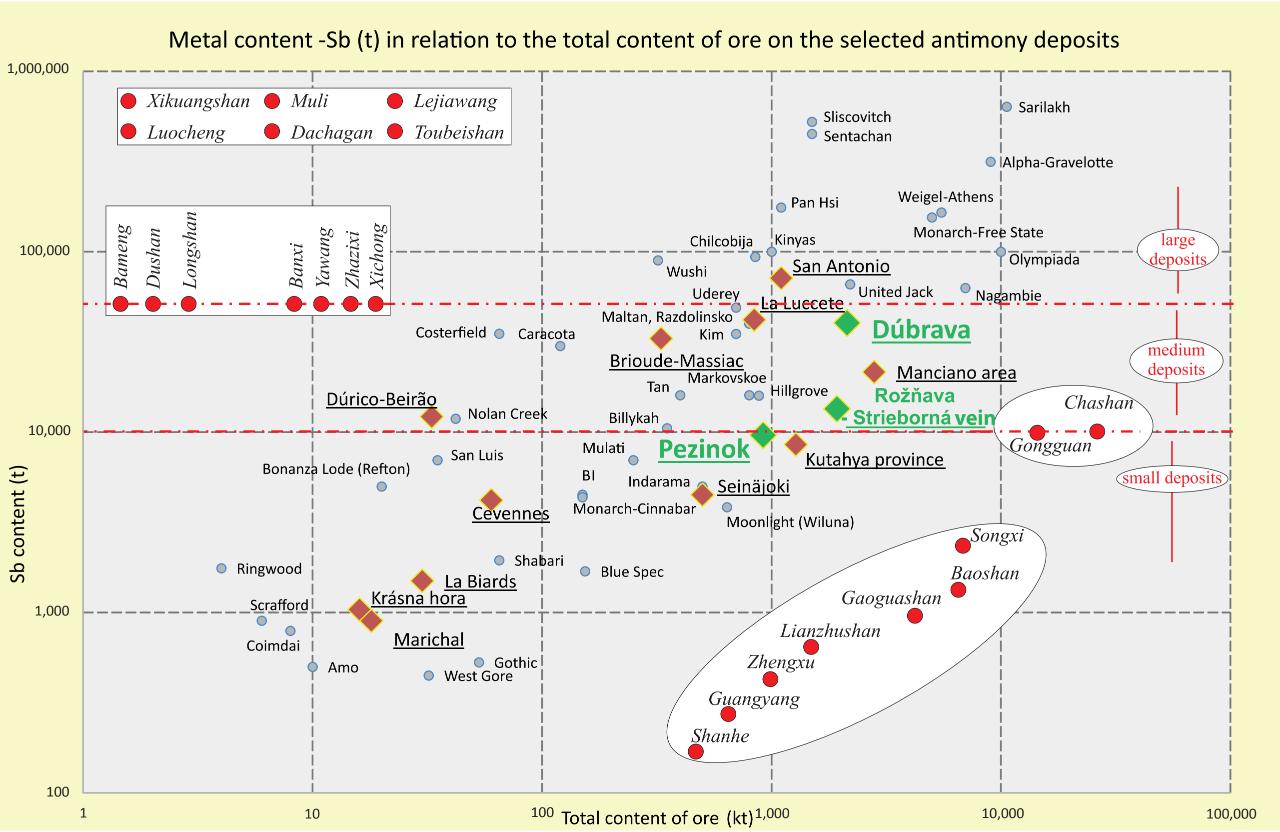

Fig. 5.12 The graph in the figure shows a selection of international deposits with the amount of ore and the calculated amount of metal in the deposit. Sb amount was calculated on the basis of alleged metal content. The underlined names and stained symbols of deposits are the deposits located in the EU. The deposits marked with a small red circle are deposits in China, of which the only available information is the one about their size, divided into categories according to the amount of metal on small deposits to 10,000 t Sb, medium deposits 10,000 to 50,000 t Sb, and large deposits over 50,000 t Sb. The graph shows a position of the deposits Dúbrava, Pezinok and Rožňava – Strieborná Lode. Data source: Berger, 1993; Hu et al., 1996; Baláž & Kúšik, 2014. www.bgr.bund.de/DERA_Rohstoffinformationen-Antimon (2013); modified and compiled

5.3.2 W - deposits and occurrences in Slovakia

In Slovakia, the tungsten ores were not previously mined separately and W was not acquired as an accompanying metal within other ores mining. However, two deposit locations were explored (Tab. 5.5; Fig. 5.13) with calculated reserves. Smaller deposits and particularly mineralogical occurrences (preferably scheelite) are known at numerous localities (Ďuďa & Ozdín, 2012).

From the metallogenic point of view in Slovakia two genetic types of W mineralisation are examined – the hydrothermal vein and the stockwork-impregnation scheelite mineralisation with gold in the Tatricum crystalline – deposit Jasenie – Kyslá (Bláha et al., 1993). Quartz veins with scheelite of N-S direction and quartz veins and stockworks within mylonitised zones of NE-SW direction are linked to tectonic zone of NE-SW direction about 650 m wide and 1 km long. The host rocks are migmatites, gneisses and amphibolites. Scheelite is in association with ferberite less with cassiterite, accompanied by various sulphide minerals (Bláha et al., 1993).

Scheelite as accompanying mineral occurs in multiple quartz vein sulphide mineralisations in Tatricum, Veporicum and Gemericum (Pecho et al., 1981; Ďuďa & Ozdín, 2012).

The second genetic type of mineralisation is porphyry-hydrothermal, represented by the explored deposit of poor Mo-W ores Ochtiná I (Rochovce, Lörincz et al., 1993). The tungsten mineralisation is represented by scheelite and to a lesser extent by wolframite (but larger than at the Deposit Jasenie – Kyslá). It is concentrated in the outer, exocontact granite zone, within the environment of silicified phyllites with metavolcanites positions of basal composition. In the inner zone of the granite body there is developed extensive molybdenite mineralisation and the Mo forms the main component of the utility deposit. The porphyry system is also accompanied by subsequent hydrothermal mineralisation present mainly in more external zones. At present, at this deposit, or in its immediate vicinity, the deposit exploration is being carried out.

Tab. 5.5 Tungsten – occurrences and deposits in the Slovak Republic, source: Lexa et al. (2007) and Tréger in Lexa et al. (2002); compiled and modified

Metal	Unit of measure	Mineralogical occurrence	Deposit occurrence	Deposit		
				small	medium	large
W	kt	< 0.1	0.1 – 1	1 – 10	10 – 100	> 100
	number	7	3	**2**		

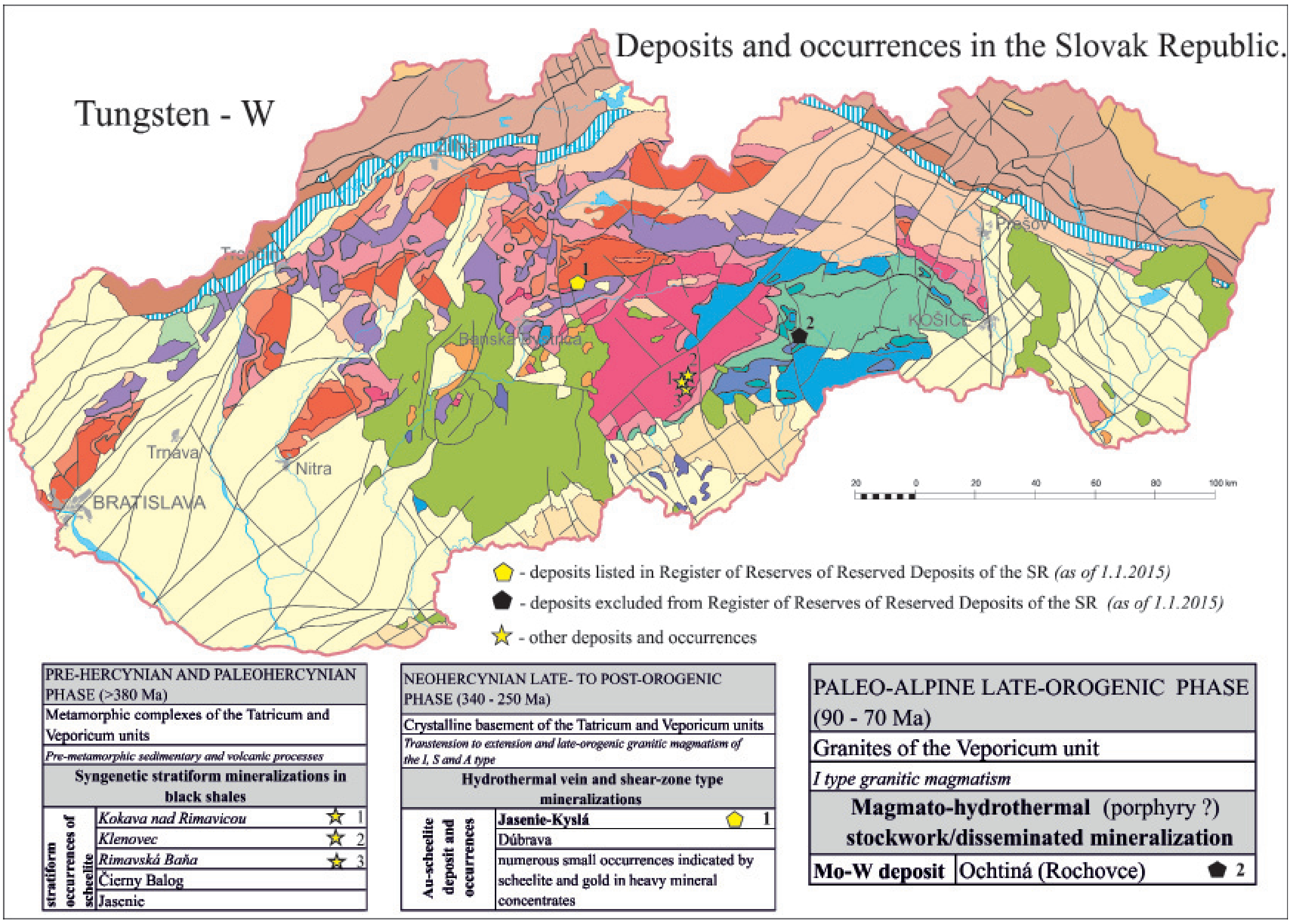

Fig. 5.13 Tungsten deposits and significant occurrences within individual geological units with their list and some metallogenic attributes. Pentagons show deposit objects with calculated reserves. Source: Lexa et al., 2007; modified

Among the basic genetic types of W mineralisation in Slovakia there was defined also a stratiform type of scheelite mineralisation. It is present in metamorphic black shales especially in Veporicum – Kokava nad Rimavicou, Rimavská Baňa and others (Fig. 5.13), and less in Tatricum and Gemericum (Lexa et al., 2007).

Tungsten ore reserves and the potential amount of metal in the deposits of SR – according to the inventory of the exclusive deposits of this metal there are registered 2,846,000 tonnes of ore containing 6,546 t of W (Baláž & Kúšik, 2014). This concerns only the deposit Jasenie – Kyslá. Along with the deposit body Ochtiná-I (deposit exempted from registered reserves) it should, however, equal to about 10,251 kt of ore and a metal content of 14,691 t of W. Only because of an alternative view of the calculated reserves (Fig. 5.14a, b) we can say that in the case of variant calculations of reserves at the deposit Ochtiná-I the ore supplies at both deposits could reach the value of 103,273 kt and 41,093 t of W at the most extreme alternative calculation of reserves (of course, with very low levels for marginal sample).

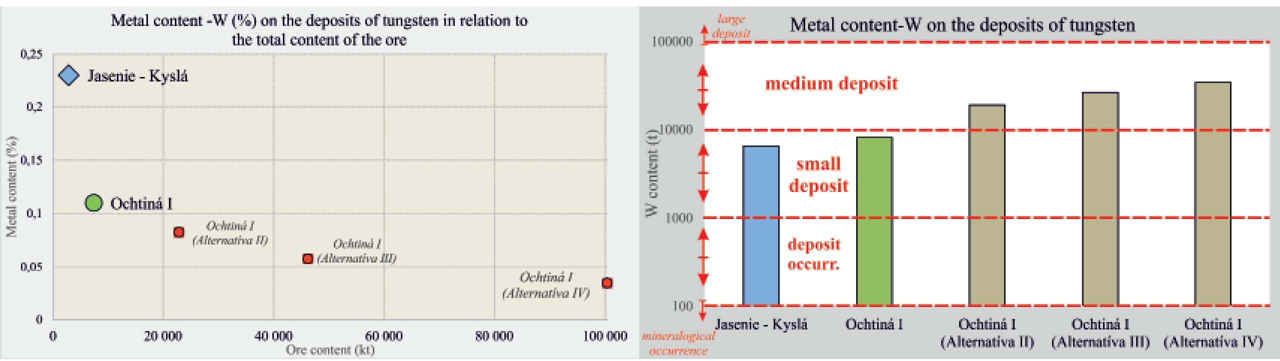

Fig. 5.14a, b The ore supplies for individual deposits in the Slovak part of the Western Carpathians, classified by size criteria. In the case of the deposit Ochtiná-I the chart includes data from alternative – variant calculations of the deposit (gradual reduction of the metal content of the peripheral specimen – part a). For porphyry type (part c) this way of fading-out mineralisation is characteristic. However, the volume of ore increases significantly, and thus the amount of the reported utility metal (part b) Data source: Lörinc et al., 1993; Lexa et al., 2002; Tréger in Lexa et al., 2002; Baláž & Kúšik, 2014.

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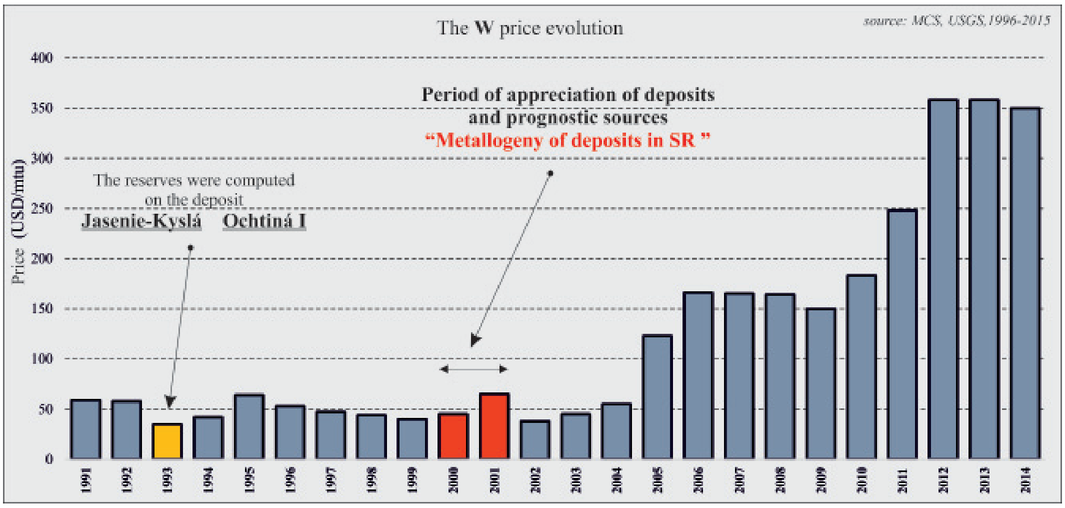

Fig. 5.15 W-prices development on the world market with consequences in different time frames. Data source: © Kitco USGS and Mineral Commodity Summaries 1996-2015; supplemented, adjusted. Note: Price per mtu WO_3 = 10 kg WO_3 or 7,93 kg W

The overview shows that within the EU the Slovak Republic has non-negligible reserves of tungsten, mainly scheelite ores.

The damping programme in the 90s of last century, of course, had no influence on W ores mining, because the ores were not mined at all. The analysis of price developments W (or, WO_3) on world commodity markets again refers to similar matters of interest such as the development of Sb prices, but also other metals.

At the time of alternative calculations of the two deposits, the price of 1 mtu of WO_3 was around 38 USD, which has been historical low for tungsten (Fig. 5.15). Similar situation was also in the case when the economic value of some deposits was reassessed.

Significant multiple increase in the price of metals on world markets (especially recently) justifies reassessment of particularly variant calculations of the two deposits, but especially of the deposit Ochtiná-I, which in view of the genetic type of mineralisation has a greater potential to expand the reserves for economic reasons.

The first one, hydrothermal vein scheelite mineralisation genetic type is accompanied by gold (Fig. 5.9). Again, the synergy of deposit value is the same as in the case of accumulation of antimony. The presence of other metals (from CRM Group – Fig. 5.1) at the both deposits is not sufficiently important from the viewpoint of industrial by-product.

Comparison of the amount of ore reserves and metal in the tungsten deposits in SR and in selected deposits world-wide

Based on the evaluation of deposits of this metal in our country and in the world, we can conclude that:

1. To date, calculated reserves on two deposits at the territory rank Slovakia to the small circle of EU countries (Portugal, Czech Republic, Austria and others) which have roughly comparable reserves of this metal ores (Fig. 5.16, b).
2. The potential of finding and extending the reserves in the territory of Slovakia is mainly in the existing deposit genetic types – mainly the porphyry type. For the time being remains the potential of tungsten mineralisation (scheelite – ferberite) of the occurrence of Gemerská Poloma – Dlhá dolina under-evaluated (Malachovský et al., 1983).
3. The presence of minerals of tungsten – scheelite and wolframite (hübnerite and ferberite) in ore and other

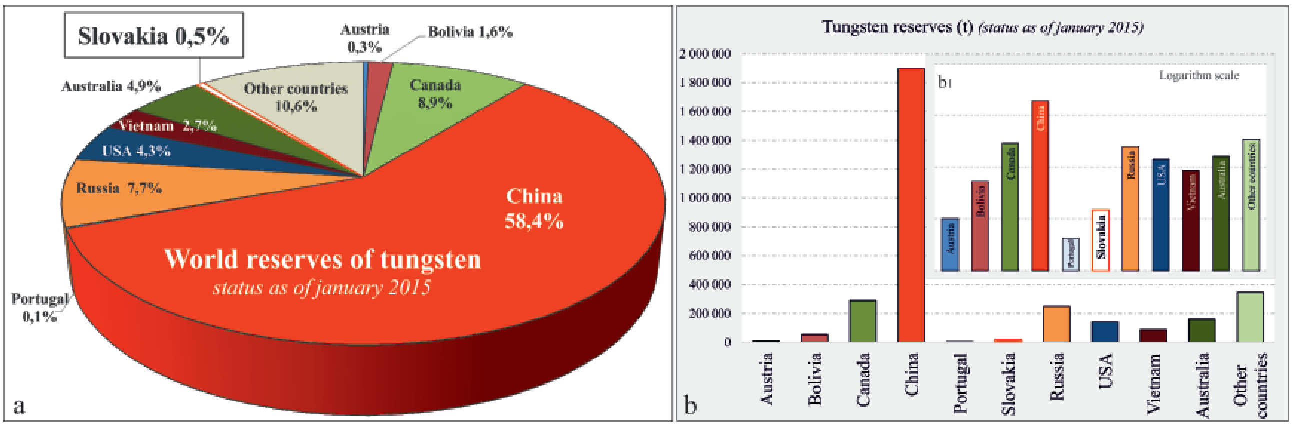

Fig. 5.16a, b Comparison of tungsten supplies (metal) on deposits in individual countries as of January 2015. Data source: USGS, MCS, 2015; Baláž & Kúšik, 2014; modified and compiled

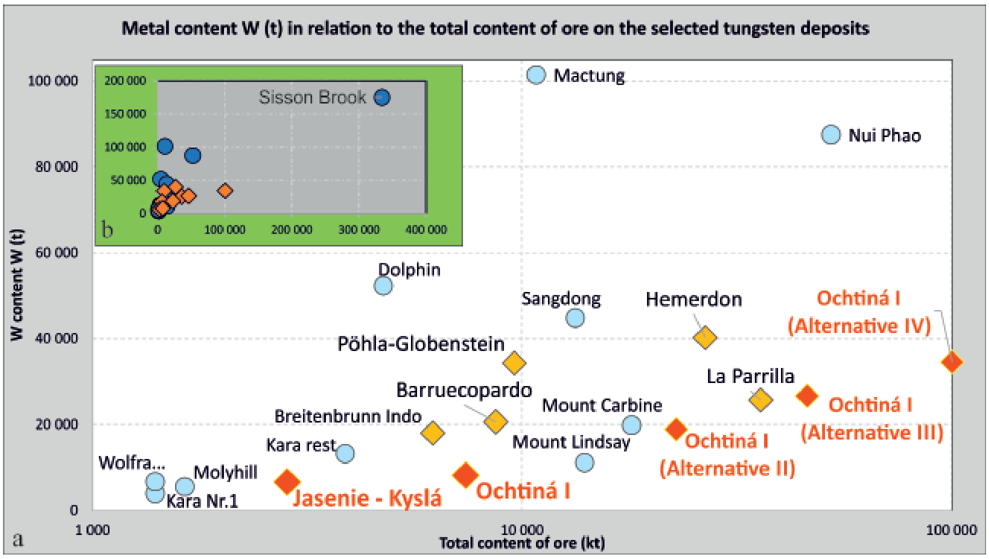

Fig. 5.17 The figure shows a selection of international deposits with the amount of ore and calculated amount of metal in the deposit. W amount was calculated on the basis of alleged metal content for individual deposits. Coloured rhombic symbol represents the deposits which are located in the EU. The chart ranks deposits Jasenie – Kyslá and Ochtiná-I, including its alternative calculation of reserves. Data source: Bláha et al., 1993; Lörincz et al., 1993; Baláž & Kúšik, 2014; www.bgr.bund.de/DERA_Rohstoffinformationen-Wolfram (2014); modified and compiled

metal structures in Slovakia does not reach the quantitative parameters of accompanying metal at possible exploitation of the main metal, e.g. on Sn greisen mineralisation types.

4. The actual W-mineral (especially ferberite) can be a bearer of the precious metals elements (Nb, Ta) in some specific genetic types of mineralisation, for example alkalized granite intrusions in the vicinity of Gemerská Poloma.
5. W shows substantially greater distribution of deposits as well as the increasing number of countries (Fig. 5.17), which exploit the metal from their deposits.
6. This metal is also dominated by China (Fig. 5.16 b), both in terms of the reserves of ores and the W production, as well.

Distinct is perhaps relatively high recycling rate of metal (Tab. 5.1 – 37%) – the highest of the CRM Group.

5.3.3 Co – deposits and occurrences in Slovakia

In the Slovak part of the Western Carpathians the Co-ores don’t create deposits. However, Co occurs commonly on the ore structures of other metals, especially Ni, and it forms previously mined deposits – single vein structures and systems. We know several occurrences (Tab. 5.6), where Co represents one of the essential accompanying metals (Lexa et al., 2007; Ďuďa & Ozdín, 2012).

Based on geological and metallogenic evolution there have been identified two more significant genetic types of ore mineralisation with Co in the territory of Slovakia. The first is the vein metamorphic-hydrothermal mineralisation type, with Co-minerals (particularly cobaltite) occurring in sulphide-siderite veins or metasomatic siderite lenses – type Dobšiná and several other occurrences in Gemericum (Figs. 5.18 – 19).

The second type are the residual accumulations of “Co-ores” in lateritic weathering crusts on serpentinised peridotite body Hodkovce – Komárovce (Fig. 5.20). This type of mineralisation is in quantitative terms the economically most promising at the territory of Slovakia. It is perspective due to a large extent (over 100 km^2) of the body, which was exposed to weathering in Paleogene and Neogene. Subsequently, in the Late Neogene the weathered scree was partially relocated by denudation processes, which led to further enrichment on Co content. The weathering crust is the best preserved in the paleo-elevations in the western part of the body.

Other economically important genetic types of Co mineralisation in the geological conditions of the Western Carpathians in Slovakia are not anticipated.

Co-ores reserves and potential amount of metal in the deposits of SR. In Slovakia there is currently not accounted for reserves of this metal. However, there are registered 2 deposits and 2 deposit and mineralogical occurrences involving Co as utility component (Lexa et al., 2007).

In the past there were calculated residual reserves on multiple veins in Dobšiná, in particular the vein Martini, with about 2,700 kt of ore containing 0.092 % Co. Later survey of a wide area has not confirmed Co-ores, or it has been declared a high rate of depletion of the known Ni-Co vein structures (Zlocha, et al., 1986; Mesarčík, et al., 1992; Mesarčík, et al., 2000).

Tab. 5.6 Ni, **Co** – occurrences and deposits in the Slovak Republic, source: Lexa et al. (2007) and Tréger in Lexa et al. (2002); compiled and modified

Metal	Unit of measure	Mineralogical occurrence	Deposit occurrence	Deposit		
				small	medium	large
(Ni) Co	kt	< 0.5	0.5 – 5	5 – 50	50 – 500	> 500
	number	7	3	1	1	

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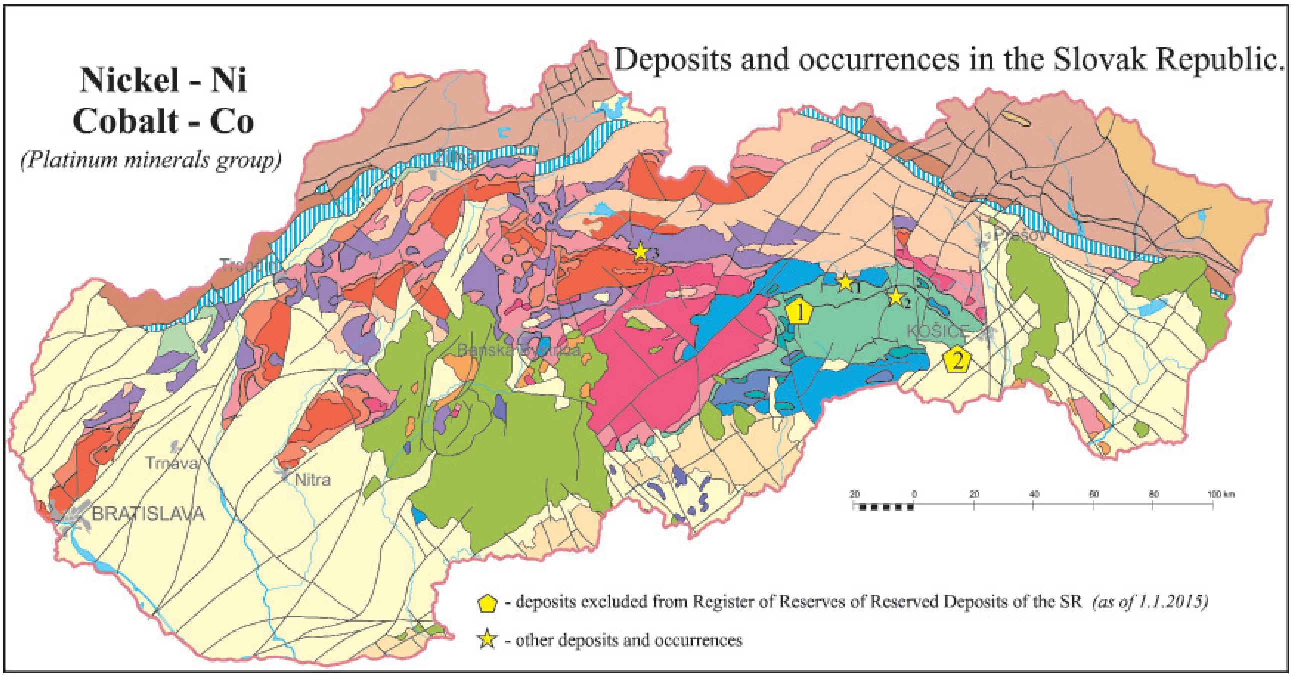

Fig. 5.18 Deposits and significant occurrences within individual geological units.

PRE-HERCYNIAN AND PALEOHERCYNIAN PHASE (>380 Ma)	
Ultramafic rocks of the Tatricum and Veporicum units	
Pre-metamorphic magmatic processes	
Magmatic to hydrothermal mineralizations	
Ni-Cu occurrences	Pohronská Polhora
	Beňuš
	Filipovo
	Mýto pod Ďumbierom
	Veľká Lúka

PALEO-ALPINE OROGENIC PHASE (110-90 Ma)			
Crystalline basement of the Tatricum (T) and Veporicum (V) units, metasedimentary and metavolcanic rocks of the Gemericum unit			
Tectono-thermal reactivation in the collision orogen			
Metamorphic-hydrothermal vein type and metasomatc mineralization			
Cu-Ni-Co occurrences	Gemericum	*Dobšiná*	1 (pentagon)
	Gemericum	Rudňany	1 (star)
	Gemericum	Gelnica	2 (star)
	Gemericum	Úhorná	
	Gemericum	Prakovce	
	Gemericum	Rožňava	
	Gemericum	Turčok	
	V	Hnúšťa-Cerberus	
	T	Vyšná Boca	3 (star)

PALEO-ALPINE POST-OROGENIC / EARLY NEO-ALPINE STAGE (70-24 Ma)		
Ultramafic rocks		
Late Cretaceous and Paleocene weathering		
Residual mineralizations		
Ni occurrences	Hodkovce	2 (pentagon)

edited by Lexa et al. (2007) and Register of Reserves of Reserved Deposits of the SR (as of 1.1.2015)

Explanations: (pentagon) - deposits excluded from Register of Reserves of Reserved Deposits of the SR (as of 1.1.2015); (star) - other deposits and occurrences

Fig. 5.19 Co deposits and significant occurrences within individual geological units. Pentagons show deposit objects with calculated reserves. Source: Lexa et al., 2000, 2007

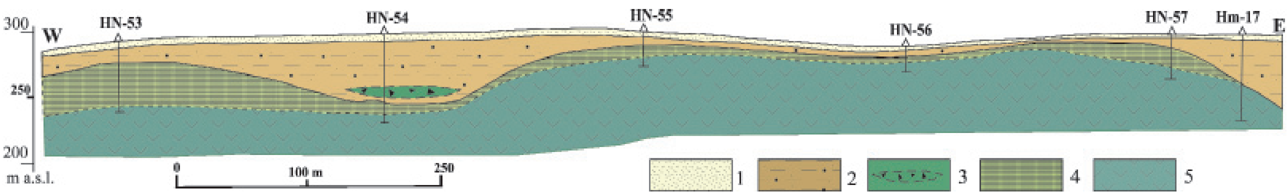

Fig. 5.20 Geological section through the deposit of Co-lateritic ores Hodkovce. 1. loam – Quaternary; 2. clays, gravel, sand; 3. allochthonous decomposed serpentinite; 4. decomposed serpentinite in situ; 5. serpentinised peridotite; Compiled by J. Zlocha 1975; modified

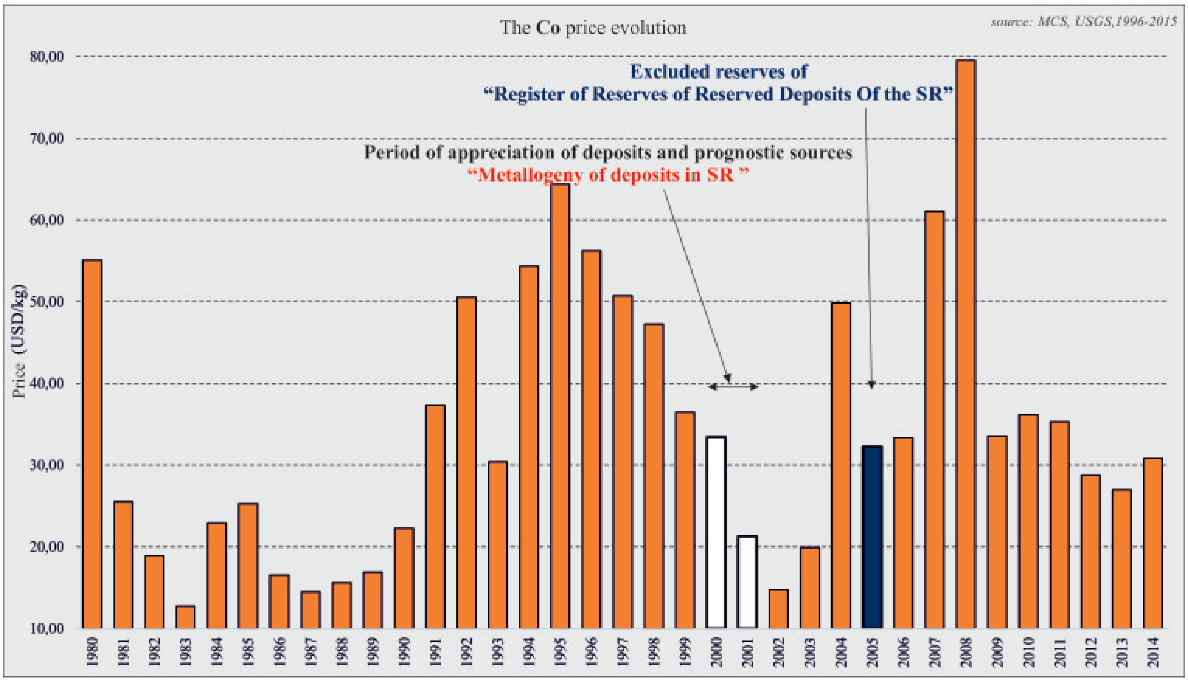

Fig. 5.21 Co price developments in world markets with consequences in different time frames. Data source: © KITCO and USGS Mineral Commodity Summaries 1996-2015; supplemented, modified.

The most important reserves (forecast resources) represent the weathering crust of the serpentinised peridotite in the wider area of Hodkovce – Komárovce. After several alternatives of reserves calculating (internal and extrapolated area, marginal metal content and other parameters), the calculation is stabilized at ca 17,000 kt of reserves with an average metal content of 0.378 % Ni and 0.016 % Co (Zlocha, 1975, 1982). In terms of Ni it presents a medium deposit, with about 3 kt of Co.

Analysis of the evolution of prices at the global commodity markets (Fig. 5.21) points to the other factors such as the price development of Sb, W, and also of other metals. Its price shows the relative stagnation of the review period compared to re-assessment of the reserves of ore resources in Slovakia. However, our opinion is that the presence of cobalt minerals, but also other potential metals (e.g. PGE) within the weathering crusts on the serpentinised ultramafic body Hodkovce – Komárovce makes this genetic type Ni and Co mineralisation significantly more attractive.

Comparison of the amount of Co ore reserves and metal in the deposits in SR and selected deposits world-wide

Based on the evaluation of deposits of this metal in our country and in the world, we can conclude that:

1. In the territory of Slovakia there are developed two genetic types of cobalt mineralisation of industrial importance. The first one is the hydrothermal vein (metamorphic-hydrothermal) type, which is essentially worked-out – type Dobšiná. The second type is the residual lateritic type, which represents also globally significant genetic type of Co mineralisation.
2. Residual accumulations of Co (along with Ni ± PGE) in the weathering crust of serpentinised peridotite in the broader area of Hodkovce are the most important and perspective Co deposits in Slovakia.
3. In a pan-European or global level, dominated by the Democratic Republic of Congo (Fig. 5.22 b), the Slo-

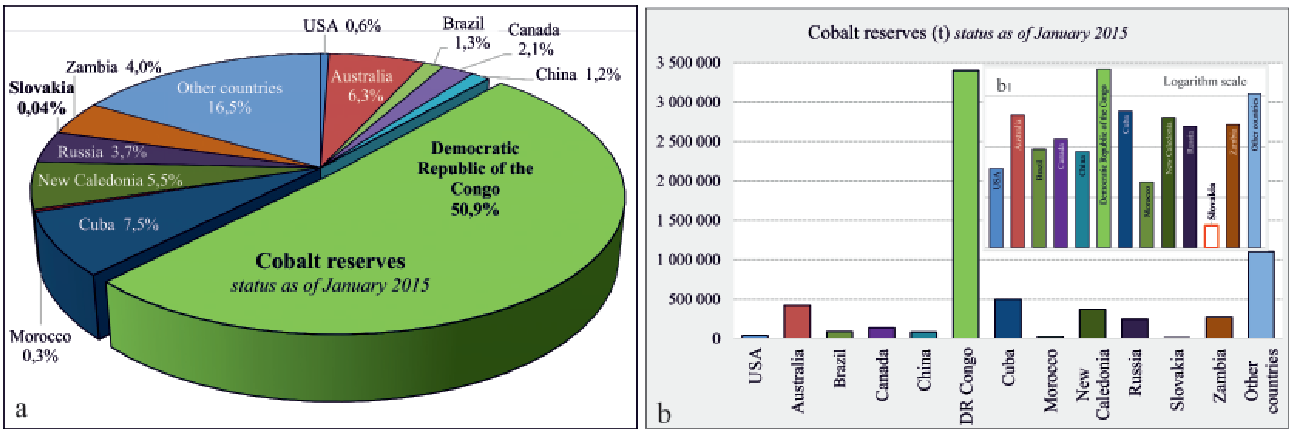

Fig. 5.22a, b Comparison of Co (metal) reserves on deposits in individual countries. Data source: USGS, MCS, 2015; Zlocha, 1975; modified

vak Republic has very limited reserves of low-quality cobalt ores.

For Slovakia promising sources of cobalt ores may become nodules from the seabed. Our country is member of the association Interoceanmetal, which carries out research in the area of Pacific Ocean – this option is discussed in subchapter dealing with polymetallic nodules.

5.3.4 Graphite – deposits and occurrences in the territory of Slovakia

Of the four basic genetic groups, the graphite occurrences in Slovakia belong to a metamorphic type (Fig. 5.23). Magmatic and skarn types are not confirmed, even mineralogically. Rather common is the presence of graphite (Tab. 5.7) in the veins of different types of mineralisation, mainly the metamorphic-hydrothermal ones.

The deposit of graphite Kokava nad Rimavicou is hosted by metaquartzites, which are characterized by a higher degree of metamorphism. Graphite is technologically macrocrystalline (flakes up to 0.8 mm), of very easy technological processing. Similar type of graphite is at the site Muránska Dlhá Lúka. Macrocrystalline graphite, but in mica schists and paragneisses, occurs at the sites Čavoj – Gápeľ and Brezno – Kozlovo.

Microcrystalline (flakes 0.1-0.001 mm) and cryptocrystalline ("amorphous", flakes <0.001 mm) graphite is a component of numerous graphitic schists in Tatricum, Veporicum and Gemericum. It occurs often in the deposits of magnesite in the form of fine impregnations. It is relatively abundant also in metasomatic ankerite and siderite at the locality Vlachovo.

Tab. 5. 7: Graphite occurrences and deposits in the Slovak Republic, source: Lexa et al. (2007); compiled and modified

Metal	Unit of measure	Mineralogical occurrence	Deposit occurrence	Deposit		
				small	medium	large
graphite	kt					
	number	X-X0	3	1		

Reserves of graphite and its potential amount at the deposits in SR

The explored deposit of graphite is the site Kokava nad Rimavicou on which, according to BZVL SR, 294 kt of graphitic rocks are registered with average 3.4% graphite content. The graphite is macrocrystalline, flaky (0.02 to 0.4 mm, on average 0.085 mm).

The proven deposit is the best explored site and it is also the deposit with the "highest quality" graphitic rock – "ore". The Čavoj – Gápeľ occurrence has maximum enriched positions containing 4.5 to 5.7% of graphite, but their extent is minimal. At the site Brezno – Kozlovo the macro- and micro-crystalline graphite is impregnated in transitional rocks – hybrid granite and migmatite and containing up to 3.5% of graphite. At the above sites it has not

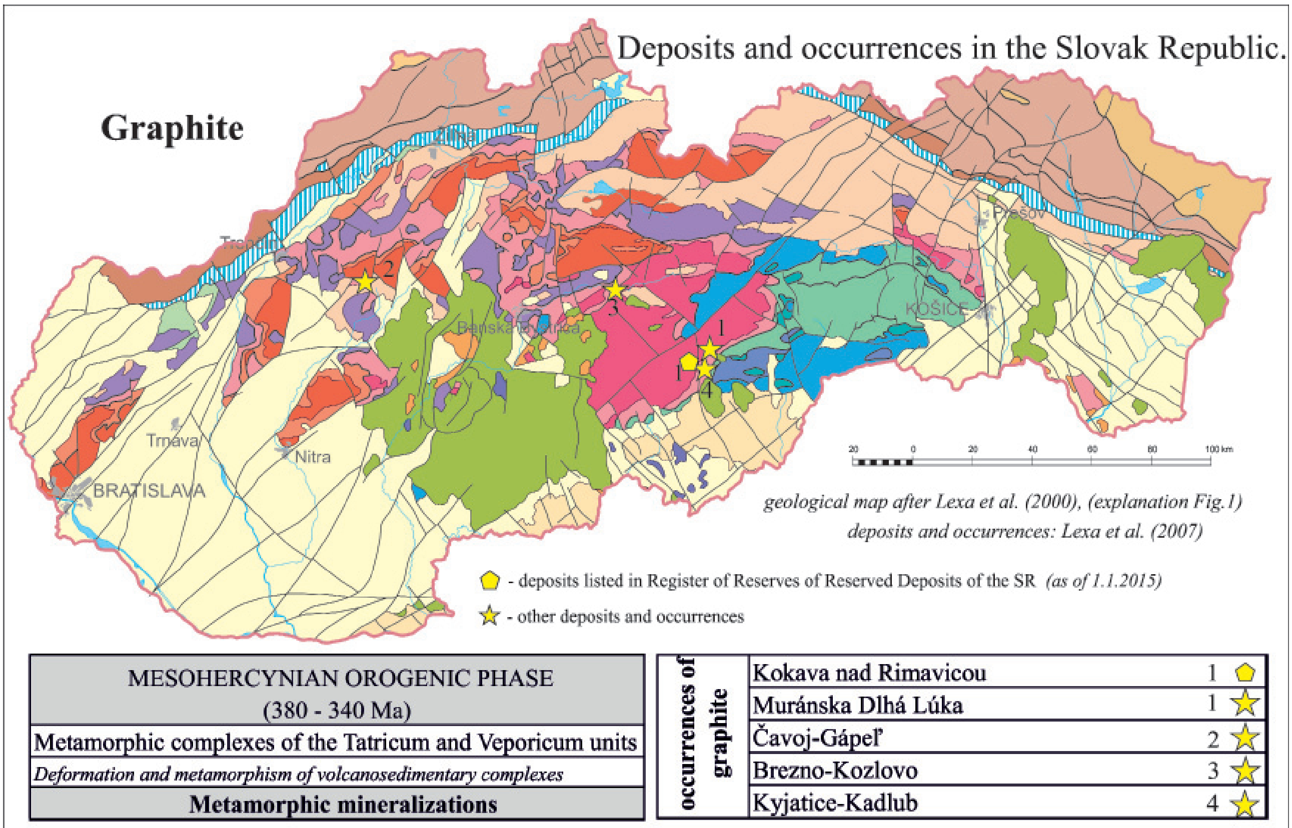

Fig. 5.23 Deposits and significant occurrences of graphite in different geological formations and some of their geological and genetic attributes. The pentagon shows a deposit object with calculated reserves.

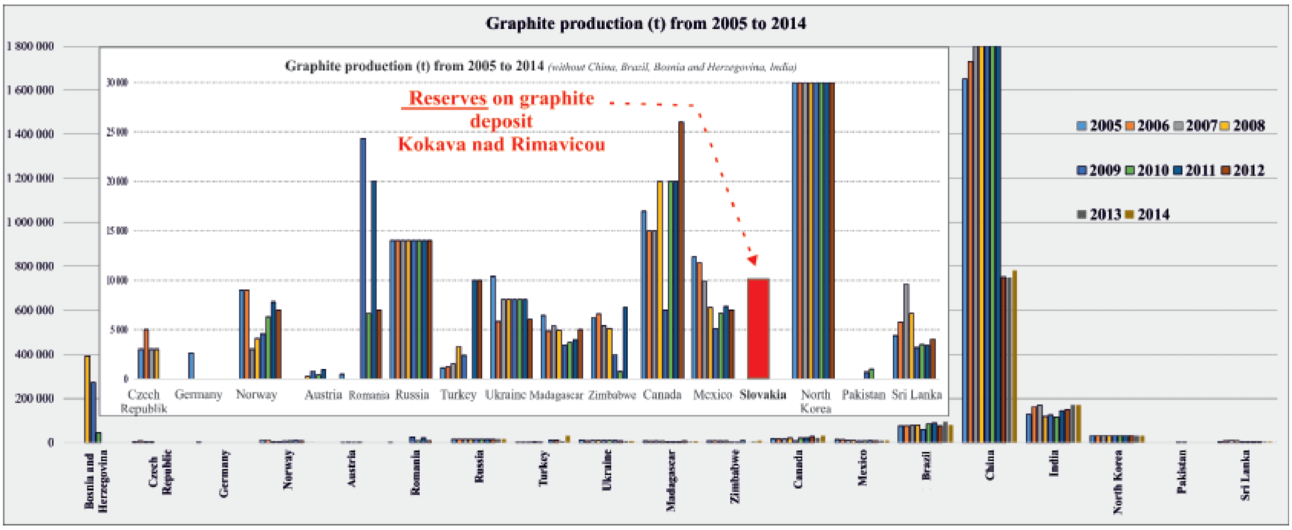

Fig. 5.24a, b Production of graphite world-wide. From the chart it is clear that there are deposits of a higher order than the reserves calculated on the deposit Kokava nad Rimavicou. Source: USGS, MCS, 2010-2015; modified and compiled

been implemented processing potential (yield) of graphitic rocks as it was in the case of the deposit Kokava nad Rimavicou.

Based on current knowledge and achievements we can state that the deposit locations in Slovakia are among small to very small deposits of low to very low quality. The genetic type of Kokava nad Rimavicou is easy-to-process with high yield of graphite concentrate without impurities (mainly sulphides).

Comparison of graphite reserves in the deposits in SR and in selected deposits world-wide

In the Slovak territory the graphite deposit accumulations are not comparable in quantitative and qualitative terms with other world deposits. The largest reserves are in the territory of China (Fig. 5.24) and China is also its largest producer. Other countries contribute to the world production to a much lesser extent (Fig. 5.24b).

The overview shows the relative size of our deposit accumulations.

Graphite deposits are not accompanied by other types of raw materials.

5.3.5 Metal Mg – deposits and occurrences of source raw materials in Slovakia

In Slovakia, magnesium has not been industrially produced yet. The first laboratory to pilot plant trials of its production using silicothermic reduction were carried out in the 90s of the last century (Blahút et al., 1994; Tomášek, 1994). The source raw materials were the products obtained from the processing of magnesite deposits Jelšava – Dúbrava Massif. The result of the test was acquisition

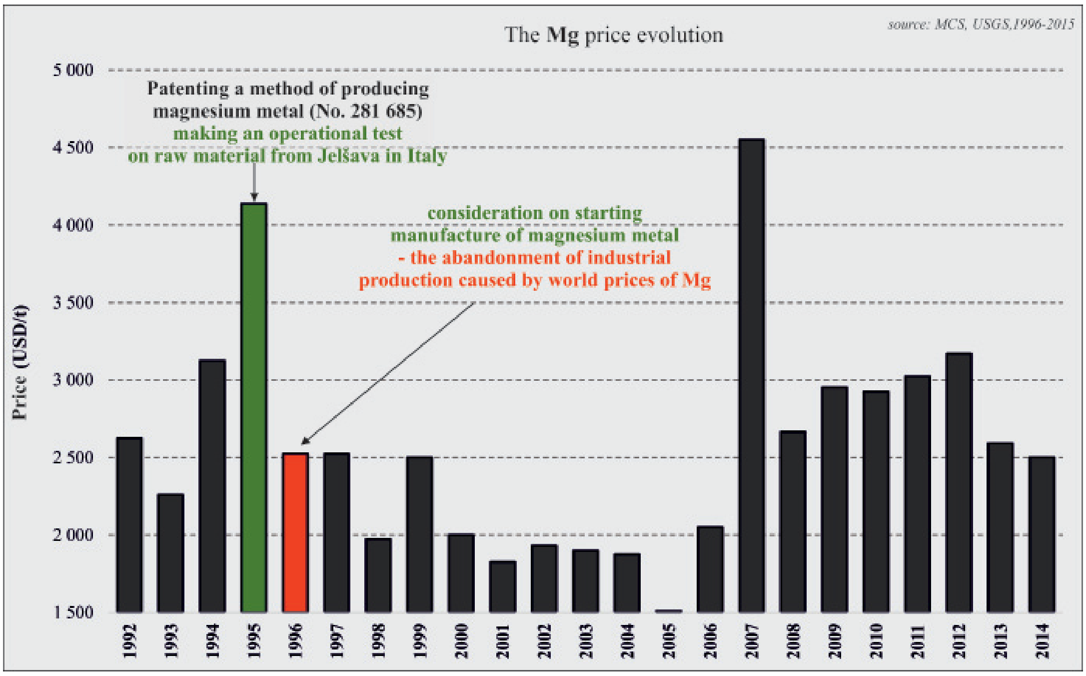

Fig. 5.25 Development of Mg metal prices on world commodity exchanges, period of laboratory tests and the production of raw materials based on Slovak magnesites in Jelšava.

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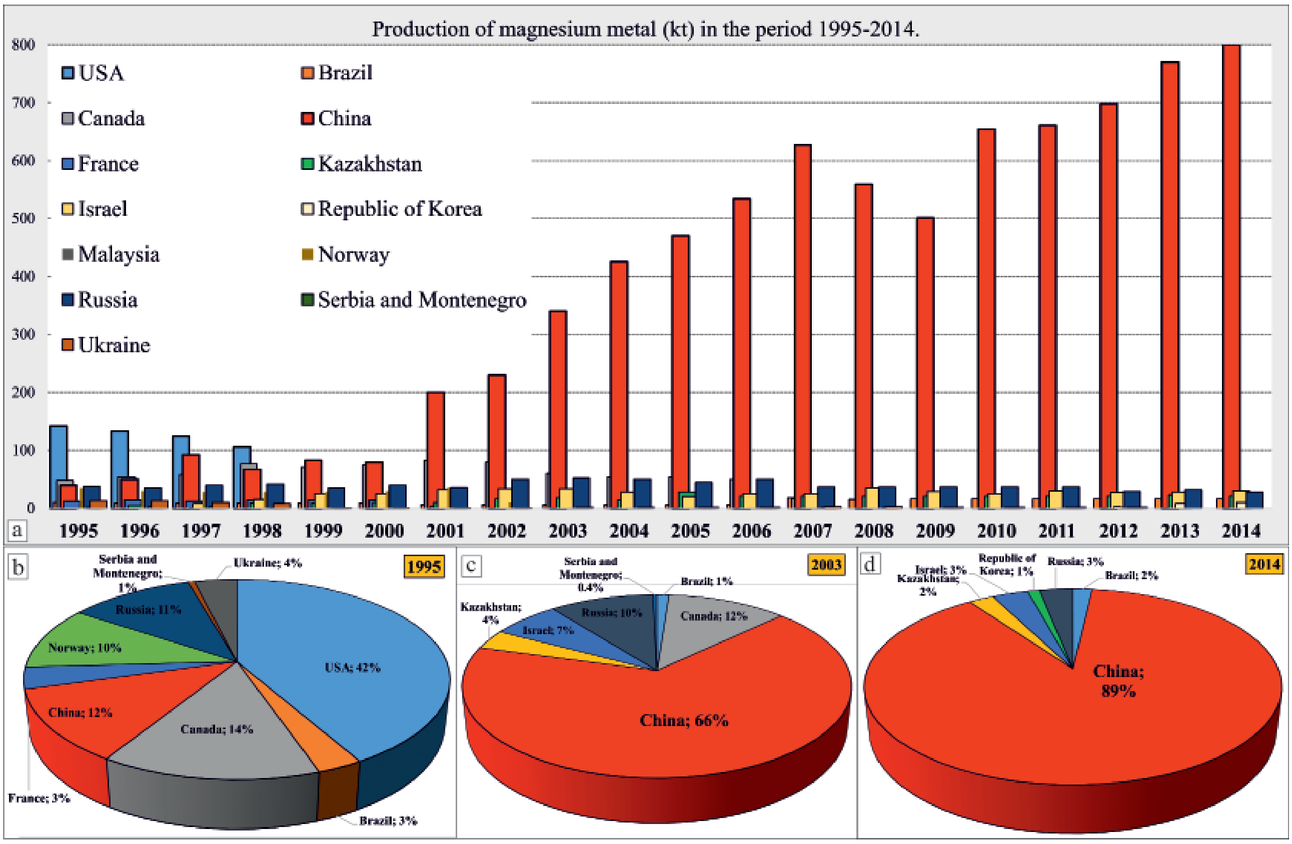


Fig. 5.26 Countries that have mastered the technology of production of magnesium metal and its production in the defined period. Gradual development of China's dominance of production is recorded since the beginning of the millennium. Source figures: T.G. Brown, 2013; USGS, 2013.

of the real magnesium metal in a plant for its production of the Italian company Societa Italiana per il Magnesio Bolzano. In 1997, its production in the plant Jelšava should have been launched with a relatively high initial financial investment. Due to sudden drop in metal prices on commodity exchanges (Fig. 5.25) and its subsequent long-term stagnation the idea of the production of magnesium metal has been abandoned (Immer, 1998).

The Slovak Republic has on its territory large reserves of suitable raw minerals containing the magnesium components, which are the starting raw material ("ore") for the production of magnesium metal. They are dolomites and magnesites and partly serpentinites, which are used in the countries, producing magnesium metal (Fig. 5.26).

Although they are relatively simple input raw materials – dolomites ($CaMg(CO_3)_2$) and magnesites (Mg_2CO_3), the technology of its production is rather difficult and highlights the technological maturity of the country.

The deposits of crystalline magnesite in the Western Carpathians belong to the largest and the most important in Europe. They are located mainly in the Early Carboniferous sequences of the Ochtiná Group in the northern rim of Gemericum. More specifically these deposits include: Podrečany, Burda, Cinobaňa, Ružiná, Lubeník, Jelšava – Dúbrava Massif, Ochtiná, Ratkovská Suchá, Košice-Bankov and Košice-Medvedza. The largest deposit represents the Jelšava – Dúbrava Massif. The magnesite deposits and occurrences in Veporicum are located in Sinec shear zone around Hnúšťa: Kokava, Sinec, Samo, Mútnik and Polom (Zuberec et al., 2005).

The dolomites in Slovakia constitute separate formations in the Middle and Late Triassic, up to several hundred meters thick, or they are present as intercalations, horizons, lenses, or bodies irregularly overlapping with surrounding limestones. They are represented in all the geological formations, the Tatricum envelope sequences and the tectonic nappes. The most abundant are the Middle- to Late Triassic dolomites of Hronicum. Significant deposits are located in the Strážovské vrchy Mts. in the Choč Nappe (l.c.).

Reserves of source raw materials for the production of metallic Mg and its potential amount in the deposit of SR

The Slovak Republic has great reserves of raw materials – magnesite and dolomite, which are the initial source of the metallic Mg. So far, however, our raw material resources have not been studied and evaluated in detail from the technological point of view of the production of this metal.

According to recent data (Baláž & Kúšik, 2014), 10 magnesite deposits are registered in Slovakia representing a total of 1,158,515 kt of geological reserves and 21 dolomite deposits with 670,398 kt of geological reserves. The potential for dolomite raw materials in Slovakia is quite large also out of the reserves on individual deposits. However it may be limited from an environmental point of view.

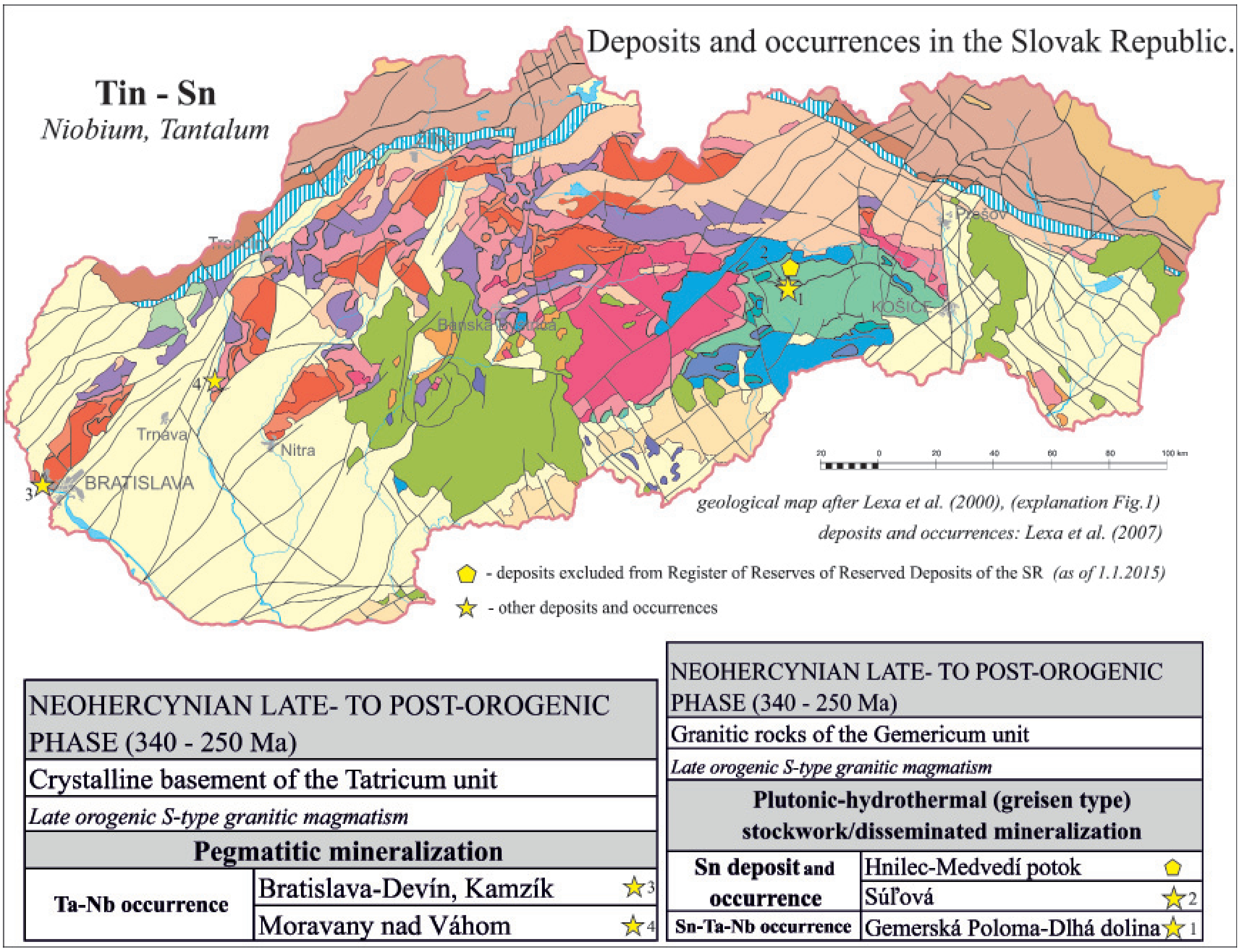


Fig. 5.27 Deposits and significant occurrences of mineralisation with the presence of Nb and Ta minerals in different geological formations and some geological and genetic attributes. The pentagon shows a deposit object with calculated Sn reserves. Source: Lexa et al., 2000; Broska et al., 2012.

5.3.6 Nb-Ta – as accompanying, secondary metals in deposits and occurrences of other metals in Slovakia

In Slovakia there are neither separate Nb and Ta deposits nor the deposits on which within the processing of the ore (or other major commercial species) the metals Nb and Ta have been registered as accompanying raw materials. In the scope of exploration for cassiterite mineralisation at the deposit Hnilec – Medvedí potok there were found contents of Nb and Ta, and later identified the single minerals of these elements (Drnzíková et al., 1975). On the occurrence of greisens in the wider area of Gemerská Poloma – Dlhá dolina, there were already identified Nb-Ta minerals (Malachovský et al., 1983) at several locations (Tab. 5.8). Detailed and systematic study of accessory minerals in granitoid rocks has identified in the current period a variety of Nb-Ta minerals with many occurrences (Broska, in Uher et al., 2012), significant occurrences are also earmarked on Fig. 5.27.

Based on the genetic model, the Nb-Ta mineralisation is mainly bound to carbonatite or special types of granite rock environment. From this point of view, of special interest to us, are the occurrences of Ta and Nb minerals, which are linked to greisenised granitic rocks. For these types we can expect exploitable accumulations of key element Sn – cassiterite and Nb-Ta mineralisation may be accompanying by-product.

The potential amount of metal in the deposits of SR – analytical results are the most comprehensive in the area of Gemerská Poloma – Dlhá dolina (Malachovský et al., 1992). Systematic study of the Ta and Nb content was carried out in exogenous greisen and at the top of albitised granites (Fig. 5.28).

In the greisen (on the surface, Fig. 5.28), the Nb content ranged from 50 – 450 g.t^{-1} and Ta content reaches only tens g.t^{-1}. The upper part of albitized granites (quartz-albititives) contained up to 65 g.t^{-1} Nb and 120 g.t^{-1} Ta. The metal content at the site of "Li-F granite" is 90 g.t^{-1} Nb

Tab. 5.8: Sn (±Nb-Ta) occurrences and deposits in the Slovak Republic, source: Lexa et al. (2000) and Tréger in Lexa et al. (2002); compiled and modified

Metal	Unit of measure	Mineralogical occurrence	Deposit occurrence	Deposit		
				small	medium	large
(Sn)	kt	< 0.1	0.1 – 1	1 – 10	10 – 100	> 100
Nb-Ta	number	11-X0	2			

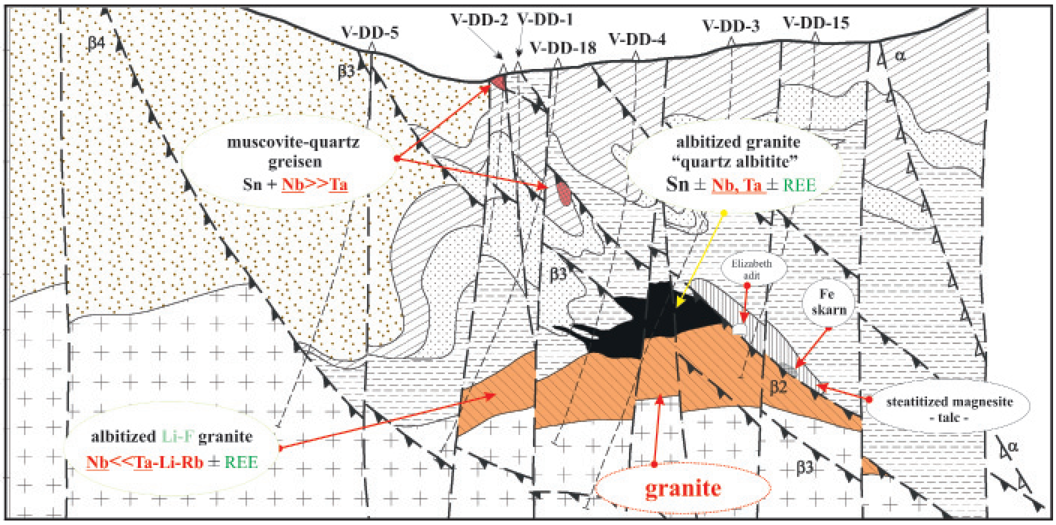
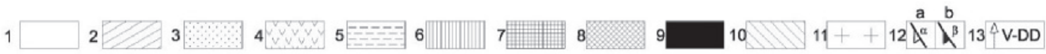


Fig. 5.28 Cross-section depicting interpreted geological setting in the area of deposit occurrence Gemerská Poloma – Dlhá dolina with position of cassiterite, magnetite and talc mineralisation as well as albitized Li-F granites with the rare-element mineralisation. The cross-section visualizes the muscovite-quartz greisen with Sn+Nb>>Ta, position of upper – intensively albitized part with Sn ± Nb, Ta mineralisation, as well as apical albitized part of granite with element association Li, F + Ta>>Nb, Rb. (In the middle right is the idealized position of Elizabeth Adit). Compiled by Malachovský (1992a); modified, completed and digitized by Bačová in Bačo et al. (2013).



1 – m. psammites; 2 – mp. rhyolite; 3 – mp. dacite and trachyte; 4 – m. basalt; 5 – phyllite; 6 – steatitized magnesite and dolomite; 7 – skarn; 8 – greisen; 9 – albitized granite; 10 – Li-F granite with Nb, Ta, Li, Rb mineralisation; 11 – coarse-grained porphyry; 12 – overthrust; 13 – borehole; m. – meta; mp. – metapyroclastics.

a 73 g.t⁻¹ Ta. There were estimated prognostic resources P1 of 1,200 kt at 0.37% Sn content and then variants of 3,893 kt at 0.139% Sn and 18,762 kt at 0.059% Sn. For all estimates, it is necessary to count on the presence of Ta-Nb mineralisation. Based on the above estimated (calculated) prognostic resources, we can assume the presence of adequate sources of Ta and Nb on the deposit. Based on individual ore amounts variations of prognostic sources estimates and metal content 90 $g.t^{-1}$ Nb a 73 $g.t^{-1}$ Ta the site can be hypothetically depicted among some of world deposits of Nb-Ta ores (Fig. 5.29). From the position of the site it is clear that even based on the historical exploration of the occurrence the object can be regarded as potentially interesting.

The other, quite numerous occurrences of the Ta-Nb mineralisation in pegmatites will not be of other than min-

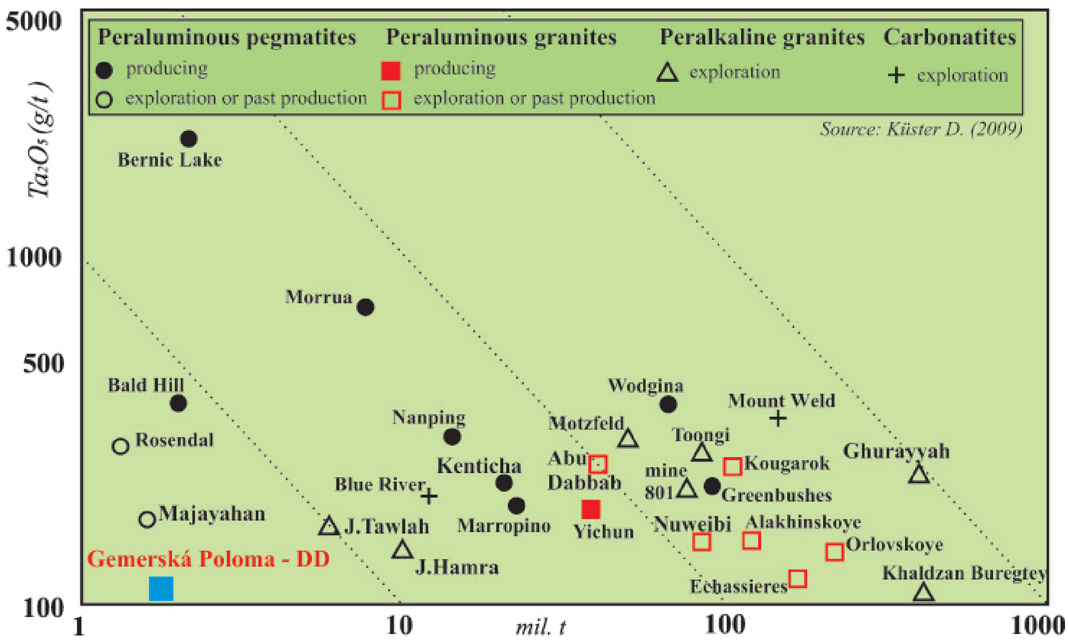


Fig. 5.29 Reserves and metal content of individual Ta deposits world-wide. In the displayed deposits dominate genetic types with disseminated mineralisation. It points out a trend, when the amount of metal increases the amount of reserves without changes in metal content, or metal content also decreases. An example is deposit Khaldzan Buregtey in Mongolia, with metal content almost the same as in the case of the deposit Gemerská Poloma – Dlhá dolina. However it is a mountain massif of peralkaline granites, with widely dispersed mineralisation. Relevant data (or at least approximate) of pegmatite occurrences in Slovakia are not yet available.

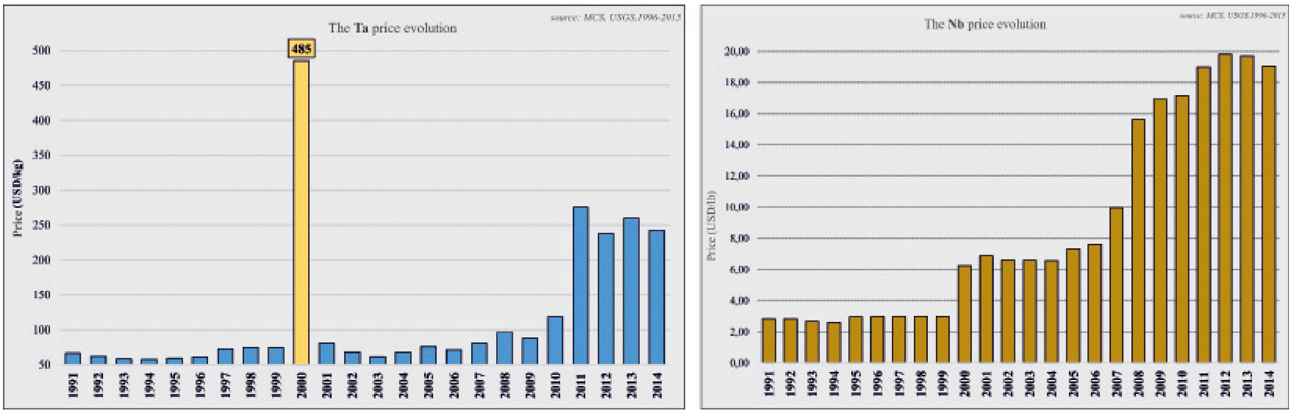


Fig. 5.30 The development of prices on the world market with consequences in different time frames. Variant "calculation" of prognostic resources was conducted in the years 1991 to 1992, thus in the period of lowest price of the observed metals. Data source: © KITCO and USGS Mineral Commodity Summaries 1996-2015; modified.

eralogical importance in the foreseeable future. The reason is, out of a very low metal content (low, respectively accessory presence), the small size of pegmatite bodies. High concentrations are characteristic for this type, as seen also from Fig. 5.29.

Occurrences in Slovakia are particularly evident from Fig. 5.29. We have no significant assumptions of a deposit finding with similar qualitative and quantitative parameters typical for deposits in alkaline massifs and peraluminous granites. However there is the possibility of extending the existing "reserves" in the deposit occurrence Gemerská Poloma. It is one of the areas with the widest representation of prognostic criteria.

described (Uher, et al., 2007) a number of Nb-Ta minerals with the expected link to pegmatites. In the association of Nb and Ta minerals the Ta minerals slightly dominated, which was confirmed by the analysis of the heavy fraction of the panned concentrate samples. Such a high content of Ta in the panned concentrate samples indicates, among other factors, that it is likely a quantitatively substantial incidence of Ta-Nb mineralisation with a predominance of Ta. This differs the occurrence from the sites with different genetic types of mineralisation. The greisen type mineralisation is dominated by Nb> Ta content as can be seen from locations in Gemerská Poloma (Tab. 5.9), from which also lithogeochemical panned concentrate sample analysis with rich greisen cassiterite mineralisation has a significantly higher content of Nb.

Tab. 5.9 Ta and Nb content in some recent panned concentrate samples from the Limbach stream sediments in the Malé Karpaty Mts. and Dlhodolinský stream at Gemerská Poloma. The trial sample is from the natural exposure of greisen with cassiterite mineralisation in Dlhá dolina

Sample	Sample type	Ta	Nb	Sample	Sample type	Ta	Nb
		mg.kg^{-1}	mg.kg^{-1}			mg.kg^{-1}	mg.kg^{-1}
Malé Karpaty Mts. – Limbašský potok Brook				Gemerská Poloma – Dlhá dolina			
MK – 2	panning	771	766	GP – 1	panning	141	604
MK – 4		5,281	4,878	GP – 3	fragment	433	1,087

The reason for the positive assessment of the area are also constantly rising prices of Ta and Nb metals (Fig. 5.30), which in the future will certainly still increase due to the increased consumption and the need for this metal in the electronics and information industry.

Quantitative chemical analysis of the Nb and Ta from panned concentrate samples have not yet been carried out and the content of the bearers of these elements in panned concentrate samples has not been studied. Relatively high amounts of Nb and Ta have been detected in the samples from the panned concentrate samples from the Limbach stream near Bratislava (Tab. 5.9). There was previously

5.3.7 REE + Y, Sc as accompanying, secondary metals in deposits and occurrences of other metals in Slovakia

Ore deposits and mineral resources from which the rare earth elements are extracted (the Explanatory Notes to Table 5.2) have not been recorded in Slovakia. Single occurrence is known – Čučma, in which after the implementation of geological exploration works the LREE reserves were calculated, but especially the HREE contents,

Tab. 5.10 REE and Y, Sc occurrences and deposits in the Slovak Republic, source: Lexa et al. (2000) and Tréger in Lexa et al. (2002); compiled and modified

Metal	Unit of measure	Mineralogical occurrence	Deposit occurrence	Deposit		
				small	medium	large
REE *and Y, Sc*	kt		< 1,000	1,000 – 20,000	20,000 – 100,000	> 100,000
	number	X0	1			

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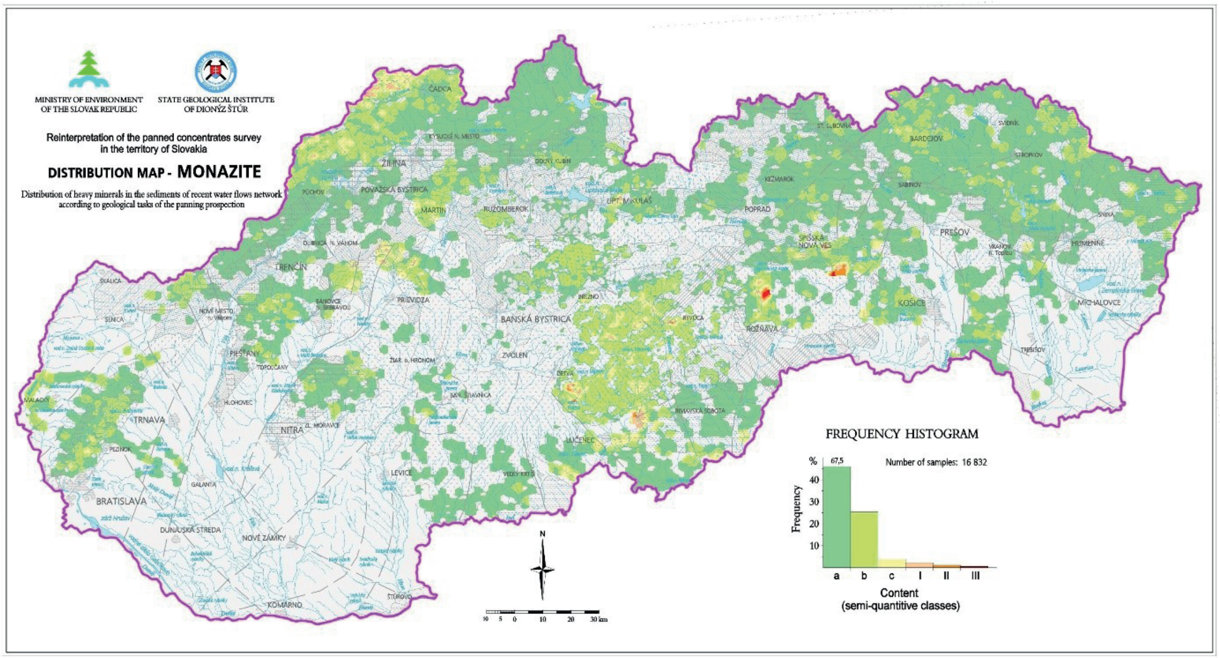

Fig. 5.31 The map displays markedly increased occurrence of monazite in the sediments of the river network. Increased concentration is in Veporicum. Anomalous concentrations are in parts of Gemericum, where source areas provide granitoid rocks of the type Gemerská Poloma – Dlhá dolina (leucogranite of S_s-type – Broska et al., 2012).

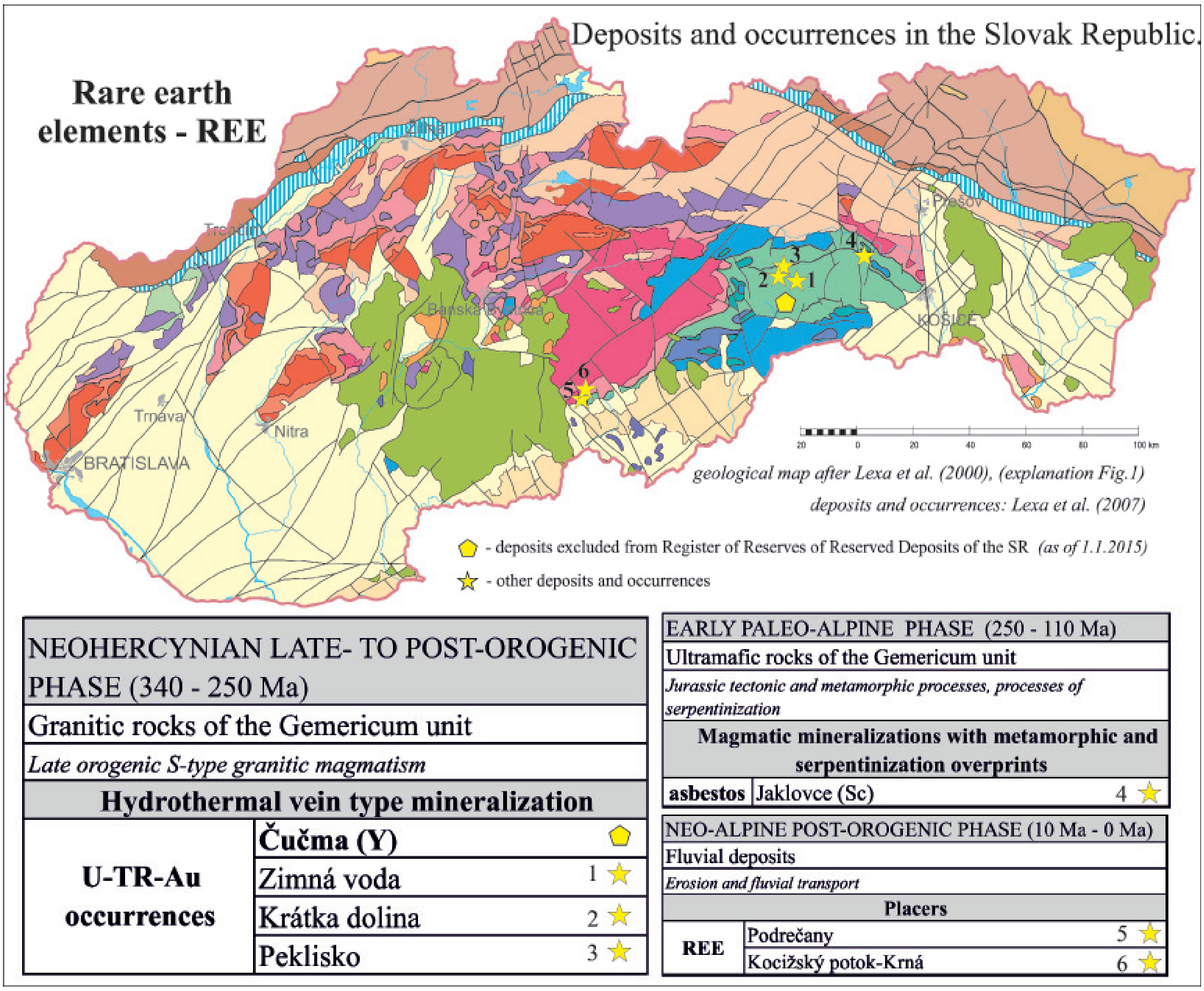

Fig. 5.32 Deposits and significant occurrences of mineralisation with the presence of REE and Y minerals, in different geological formations and some geological and genetic attributes. The pentagon shows a deposit object with calculated reserves. Source: Lexa et al., 2000; 2007; Ďuďa & Ozdín, 2012.

including Y. Occurrences of mineralogical importance are fairly numerous (tab. 5.10 and Figs. 5.31 and 5.32.), and they are found mainly in the area of the granite bodies, in which they regularly create an accessory component (Broska, et al., 2012).

The implementation of works in the scope of the regional project of panned concentrate prospecting (Bačo et al., 2004) indicated a relatively high prevalence of monazite in recent fluvial network sediments (Fig. 5.31).

Geological structure and metallogenic evolution of Slovakia have not provided favourable conditions for large accumulations and deposits of rare-earth metals. They are bound like precious metals especially to intrusive carbonatite bodies of so-called bästnesite type of mineralisation – Mt. Pass in the USA or Bayan Obo in Inner Mongolia in China.

The second genetic group is associated with alkaline granitoid rocks. The occurrence of accessory rare earth minerals in these rocks forms a large part of the secondary dispersion aureoles with a higher content of monazite and xenotime, in particular. Associate with them zirconia and less, apatites. We know a number of areas where monazite is an essential part of the heavy concentrate of the panned concentrate samples, as evident from the map on Fig. 5.31. This is a territory in the wider area of Gemericum granites from Gemerská Poloma to the south to a wider area of Hnilec to the north. The most interesting and most promising at the same time is the area around Gemerská Poloma where there is a concentration of several types of mineralisation.

Interesting are increased concentrations of REE in some altered rocks of high-sulphidation systems – Remetské Hámre – Kapka and Poruba pod Vihorlatom – Porubský potok stream (Bačo in Lexa et al., 2000). Spaces for this type of mineralisation are mainly in central zones of the stratovolcano.

Secondary accumulations in placers are most prevalent genetic types of deposit objects that could be potentially located in Slovakia (Fig. 5.31). So far, the greatest concentration in secondary dispersion aureoles of monazite (and REE and other minerals – xenotime, apatite and others) were found in the southern region of Veporicum. The source area is formed by the periphery of leucocratic granite body and increased accumulations are known from several locations – Krná, Kociha, Selce, Podrečany (see also the previous article).

Reserves of REE ores and potential amount of metal in the deposits of SR

In some deposits and deposit occurrences it had been found the presence of REE minerals – deposit Hnilec, deposit occurrence Gemerská Poloma – Dlhá dolina. A single object on which reserves of rare earth elements were calculated, is the site Čučma (Donát, 1998). The mineralisation is present on a quartz vein, which is developed in porphyroids at the contact with Gemericum granites. The vein has irregular development both in lateral and vertical directions and its thickness is highly variable from 0.5 to 3.0 meters. From the beginning the ore structure was verified for uranium – with detection of uraninite, autunite, torbernite. Subsequently there was identified also REE mineralisation represented by the association of apatite, xenotime-Y, monazite-Ce. At the site reserves have been verified and calculated equalling to 7.8 kt of rare earth ore with average quality of 0.2% of HREE and LREE (Fig. 5.33). Locally, however, there were sections containing more than 1% of the metals. Position of the Čučma deposit among the selected deposits world-wide is displayed in Fig. 5.33.

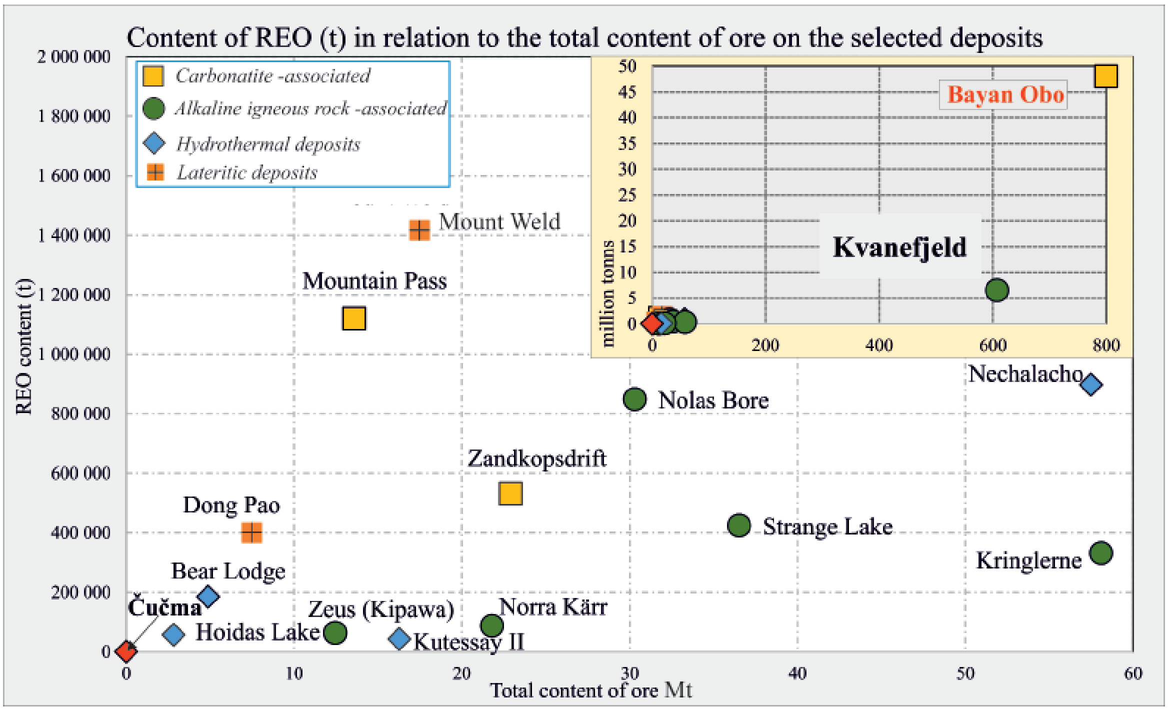

Fig. 5.33 Reserves and metal content of selected world REE deposits, indicating the position of the deposit Čučma. Modified after Walters & Lusty (2010), Gunn ed. (2014), Paspaliaris (2013)

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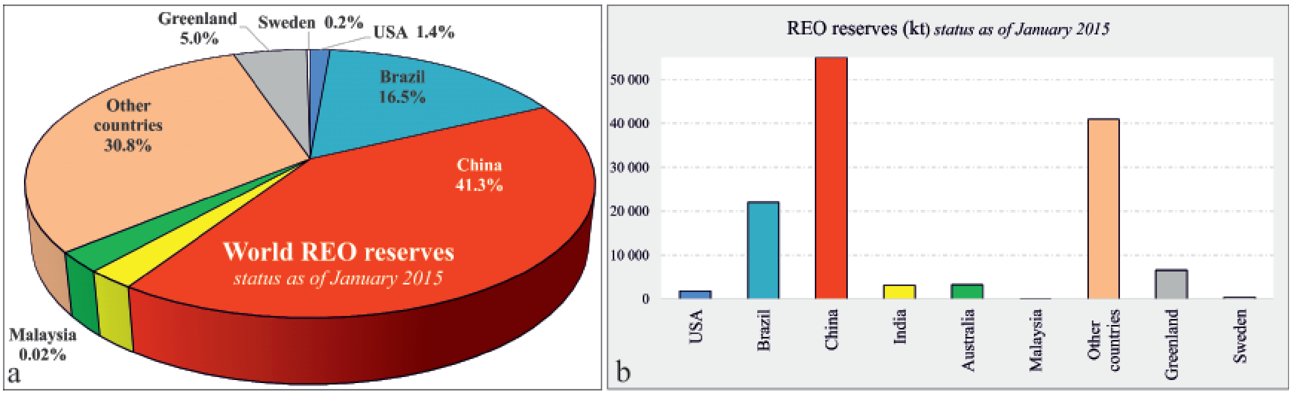

Fig. 5.34 Comparison of REE (metal) reserves in the deposits in individual countries. Many countries have non-significant REE reserves in the pegmatite deposits but also in placers (sea-beach monazite sands). Source: USGS Mineral Commodity Summaries 2015, Paspaliaris (2013)

Comparison of reserves of REE ores in the deposits of SR and selected deposits world-wide

The main REE ore source allocation displays Fig. 5.34. Almost half of sources are recorded in the deposits in China, with dominating deposit Bayan Obo in Inner Mongolia province. A similar genetic type, with the major minerals bastnäsite, is the deposit Mountain Pass in the USA. This genetic type binds the largest REE reserves in the world (Fig. 5.35). Extraction of the ores of this genetic type and especially the subsequent processing is ecologically very difficult for the surrounding environment. And this was the original reason for waiving the bastnäsite exploitation at the deposit Mountain Pass in the USA at the beginning of the millennium (Fig. 5.36). However, real "unavailability" at the market has caused the reopening of mining in the USA and intensive search for REE resources in other parts of the world including Europe. One result is the discovery and pre-mining of the deposit Kvanefjeld in Greenland (Paspaliaris, 2013).

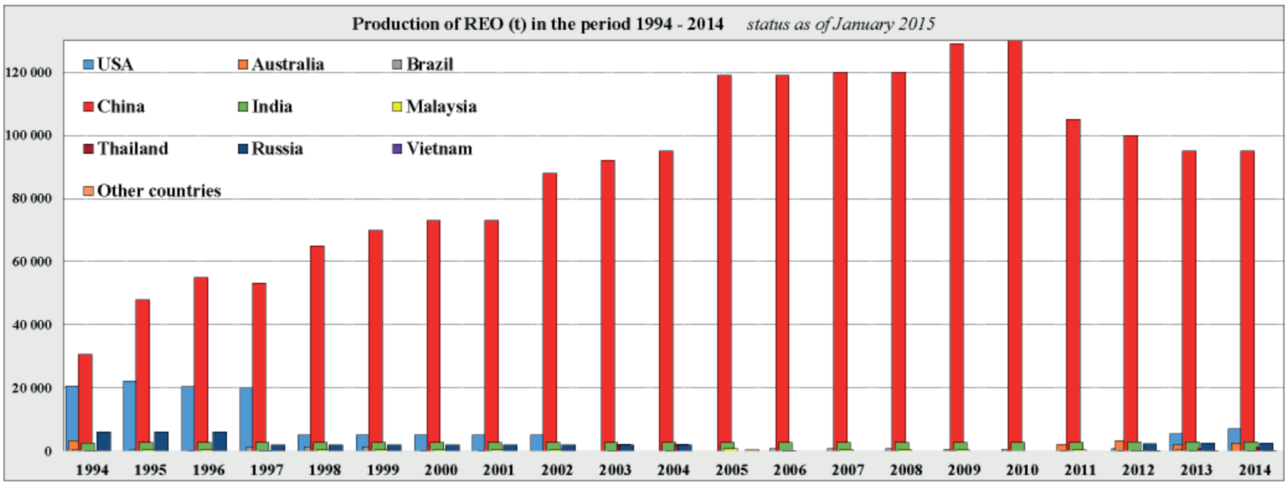

Fig. 5.35 REE production in different time periods. End of 80s and beginning of the 90s marked the turning point in the production of REE. The Bayan Obo deposit discovery, but especially learning the technology of obtaining metals from ore has resulted in taking production hegemony by China to the extent that they have become almost a monopoly producer. Increased demand for the rapidly developing automotive technology and "scientific" industry made from REE metals, especially the HREE ones, a strategic resource. Demand for it is not outweighed by offer and the price does not play a decisive role. It is crucial to finalize their production, which is not very acceptable for countries with advanced technologies to valuation of the already mined and processed metals. Source: USGS, MCS, 2015; modified and compiled

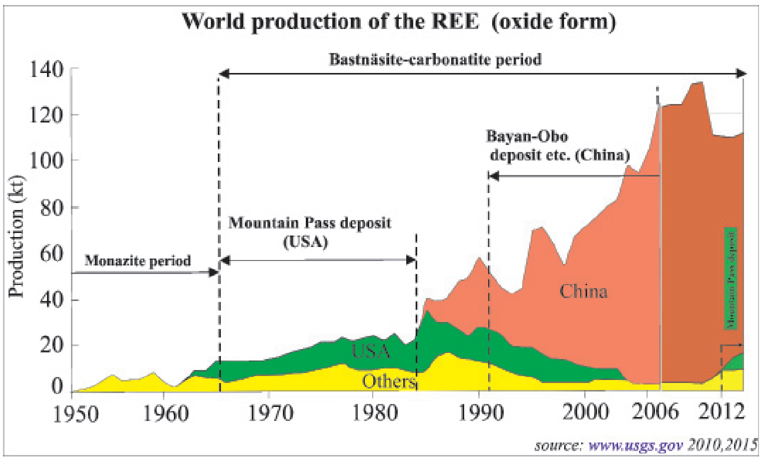

Fig. 5.36 Historical development of mining of two main genetic types of source materials – monazite and bastnäsite. The monazite is extracted from sea-beach sands, this means placer genetic type. The bastnäsite originates from the carbonatite rock environment and a large volume of surrounding rocks has to be extracted. www.usgs.gov

5.3.8 In, Ga, Ge as accompanying, secondary metals in the deposits and occurrences of other metals in Slovakia

The In, Ge and Ga minerals don’t form separate deposits and single metals are obtained during the extraction of other raw minerals. Polymetallic mineralisations are often a source of these elements. Therefore, these types of deposits are also referred to as metal deposits. In Slovakia there is a relatively large number of deposits and occurrences of polymetallic ores (Tab. 5.11). They are concentrated in the Eastern Slovakia area (Zlatá Baňa, Brehov), but especially in the Central Neovolcanites (Figs. 5.37; 5.38). Smaller occurrences of polymetallic ores were mined in the past also in Gemericum and recorded are smaller occurrences in Veporicum. During the prospecting and mining the ore was usually not analysed for these metals, or point samples were analysed for mineralogical studies (e.g. Košuth, 2009). Rock cutting samples based on which the reserves were calculated, were not analysed for these metals.

Tab. 5.11 Zn (Ga, Ge, In) deposits and occurrences in the Slovak Republic, source: Lexa et al. (2007) and Tréger in Lexa et al. (2002); compiled and modified

Metal	Unit of measure	Mineralogical occurrence	Deposit occurrence	Deposit		
				small	medium	large
(Zn) Ga, Ge, In	kt	< 1	1 – 10	10 – 100	100 – 1,000	> 1,000
	number	38	11	10	2	1

Based on general models (Fig. 5.39) these ores are present as the identical genetic types of polymetallic ores in the neovolcanic areas. Indium is often in the isomorphic position in the Fe-sphalerite – marmatite, Ge is more common in the galenite. With increasing depth, thus increasing thermal grade of the solutions the isomorphism of In in the sphalerite increases; likewise, in the case of isomorphic presence in the chalcopyrite.

For the time being, in the present state of knowledge and based on own analyses we are unable to objectively demonstrate immediate bond of In to Zn ore on our base metal deposits. The presence of single accessory In minerals (roquesite – $CuInS_2$) was observed in quartz sulphide veins by a borehole-proven “skarn” mineralisation at Gemerská Poloma (Fig. 5.28; Malachovský et al. 1997). This is a very promising metallogenic area with several critical metals in the broader area of Gemerská Poloma.

Similarly to In, neither the presence of Ga in our deposits has been systematically studied. The presence of gallium was recorded in the polymetallic mineralisation at the Brehov deposit in the Eastern Neovolcanites in secondary quartzite of the Morské oko Lake in Vihorlat mountains. A quite systematic study was devoted to contents in the boreholes of Au porphyry deposit Detva – Biely vrch. The contents are within the range of 10 ppm. Nevertheless, these values indicate the presence of metals in hydrothermal processes at monitored sites.

In the past, Ga was extracted partially from the processing of Al – bauxite ores in the aluminum plant in Žiar nad Hronom.

Very occasionally, the minerals of the ores mined in the past were examined on the Ge presence. The higher contents (over X0 ppm) have not been observed (Košuth, 2009, Bačo, et al., 2013). The presence of single Ge minerals has so far been detected (mineral argyrodite – Ag_8GeS_6) in the deposit of polymetallic ores Zlatá Baňa (Košárková and Ďuďa, 1999).

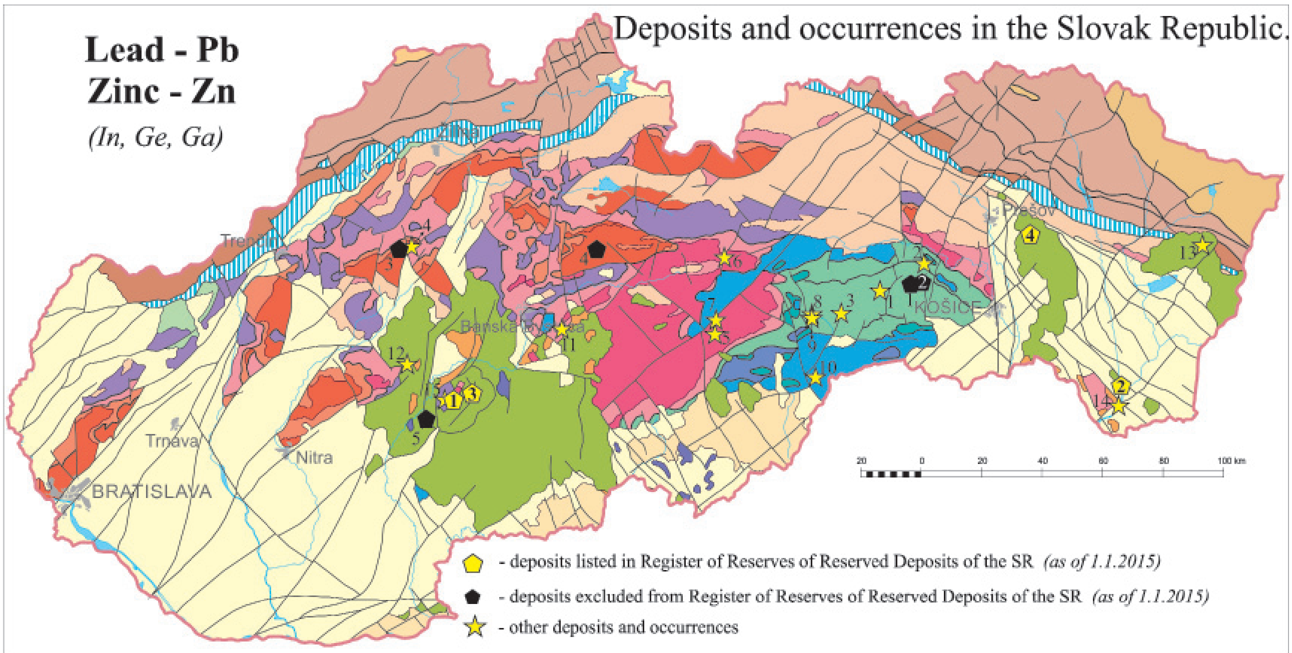

Fig. 5.37 Deposits and significant occurrences of base metals (Pb, Zn + Cu ± Au, Ag) in different geological units of the Slovak part of the Western Carpathians.

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PRE-HERCYNIAN AND PALEOHERCYNIAN PHASE (>380 Ma)		
Metamorphosed volcanosedimentary formations of the Gemericum unit		
Pre-metamorphic sedimentary and volcanic processes		
Syngenetic volcanic massive sulphide mineralizations		
Pb-Zn-Cu occurrences	Mníšek nad Hnilcom	⬟ 1
	Prakovce	⬟ 2
	Bystrý potok	☆ 1
	Slovinky-Lacemberská dolina	☆ 2
	Gemerská Poloma	☆ 3

NEOHERCYNIAN LATE- TO POST-OROGENIC PHASE (340 - 250 Ma)		
Crystalline basement of the Tatricum unit		
Transtension to extension and late-orogenic granitic magmatism of the I, S and A type		
Hydrothermal vein and shear-zone type mineralizations		
Pb-Zn-Ag occurrences	Čavoj	⬟ 3
	Chvojnica	☆ 4
	Jasenie-Soviansko	⬟ 4

PALEO-ALPINE LATE-OROGENIC PHASE (90 - 70 Ma)		
Crystalline basement of the and Veporicum units		
Thermal reactivation in the transtension and extension regime, sporadic granitic magmatism		
Metamorphic-hydrothermal vein and stockwork/disseminated mineralizations of shear zones		
base metal occurrences	Hnúšťa-Ostrá	☆ 5
	Pohorelská Maša	☆ 6
	Tisovec-Dúhovo	☆ 7
Granites of the Veporicum unit		
I type granitic magmatism		
Hydrothermal vein/stockwork ± metasomatic mineralization		
base metal occurrences	Rochovce	☆ 8
	Ochtiná-Dúbrava,O.-Lašanka, O.-Margita	☆ 9
Limestones and dolomites of higher nappes		
Erosion, extension and thermal reactivation		
Hydrothermal vein type and metasomatic mineralizations		
Pb-Zn occurrences	Ardovo	☆ 10
	Poníky-Drieňok	☆ 11
	Veľké Pole - Píla	☆ 12

NEO-ALPINE OROGENIC PHASE (24-10 Ma)		
Neogene volcanites		
Andesite and rhyolite volcanism accompanied by subvolcanic intrusive complexes and the evolution of volcanotectonic depressions		
Intrusion related mineralizations		
Stockwork/disseminated base metal deposits and occurrences	Hodruša	⬠ 1
	Pukanec	⬟ 5
	Brehov	⬠ 2
Volcanic hosted low sulphidation epithermal mineralizations		
Base metal ± Ag, Au deposits and occurrences	Banská Štiavnica	⬠ 3
	Zlatá Baňa	⬠ 4
	Morské oko	☆ 13
	Zemplín	☆ 14
Ag-Au-base metal deposits and occurrences	Hodruša	☆ 15

⬠ - deposits listed in Register of Reserves of Reserved Deposits of the SR *(as of 1.1.2015)*
⬟ - deposits excluded from Register of Reserves of RD of the SR *(as of 1.1.2015)*
☆ -other deposits and occurrences

edited by Lexa et al. (2007) and Register of Reserves of Reserved Deposits of the SR (as of 1.1.2015)

Fig. 5.38 Selection of deposits and major occurrences of polymetallic mineralisation and their metallogenic attributes.

Reserves of Zn ore and the potential amount of metal in the deposits of SR – currently we cannot assess the status of In, Ge and Ga reserves. However, the main base metals at the deposits could be potential source of these critical metals. In the balance of reserved deposits there are registered 4 deposits with calculated reserves (Fig. 5.40). According to their current volume (in case of Zn) they belong to two medium and two small deposits in terms of the amount of metal. In the deposit Brehov the potential may be even greater (or maybe smaller); the deposit has not been explored yet. The classification of the reserves as non-economic was valid in the mid-90s of the last century.

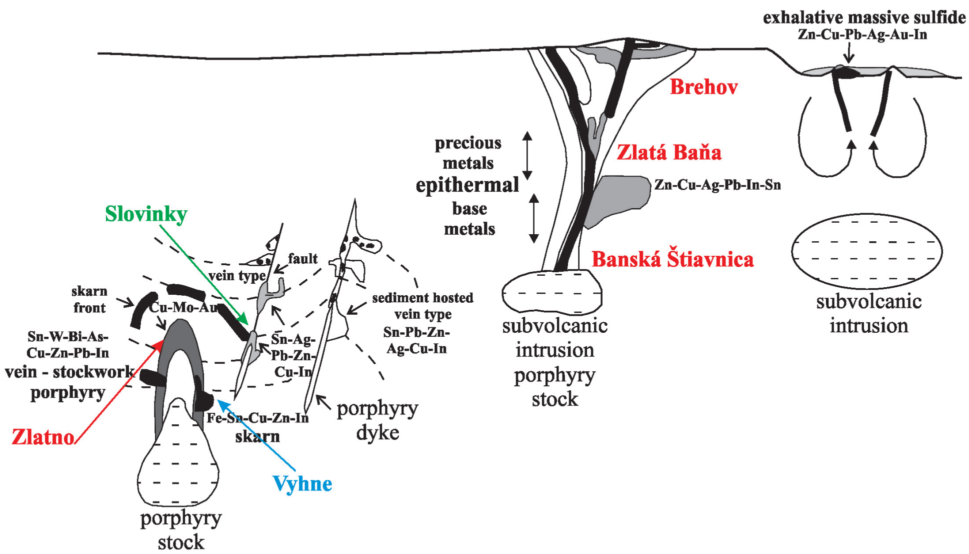

Fig. 5.39 Genetic model of polymetallic mineralisation types with specific assignment of individual deposits from the Slovak part of the Western Carpathians. According to Schwarz-Schamper, 2002, supplemented and modified.

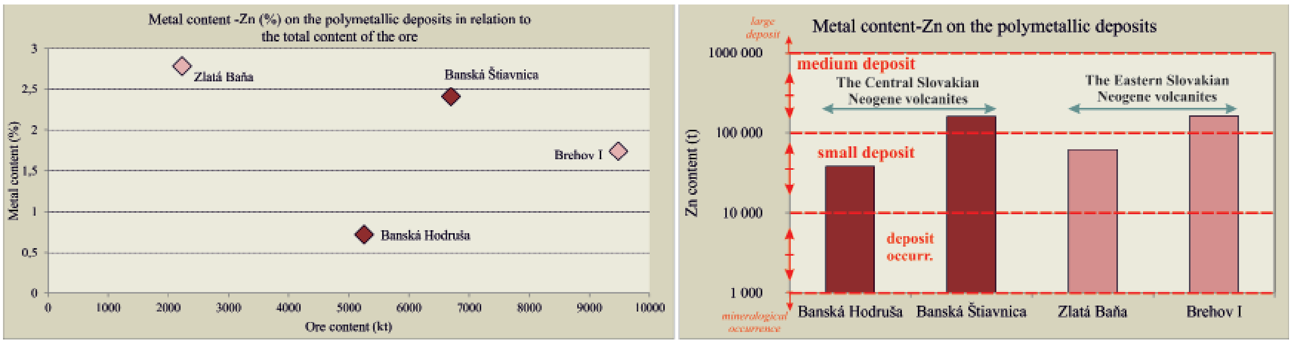

Fig. 5.40 Reserves of base metal ores in individual deposits in the Slovak part of the Western Carpathians, classified by size criteria.

Even in the case of the prices of these metals (Figs. 5.41 – 43) the findings apply, which were explicitly mentioned at the Sb subchapter.

At the current prices the value of deposits would be disproportionately higher. Even in the case of In prices (Fig. 5.42) similar consequences are valid.

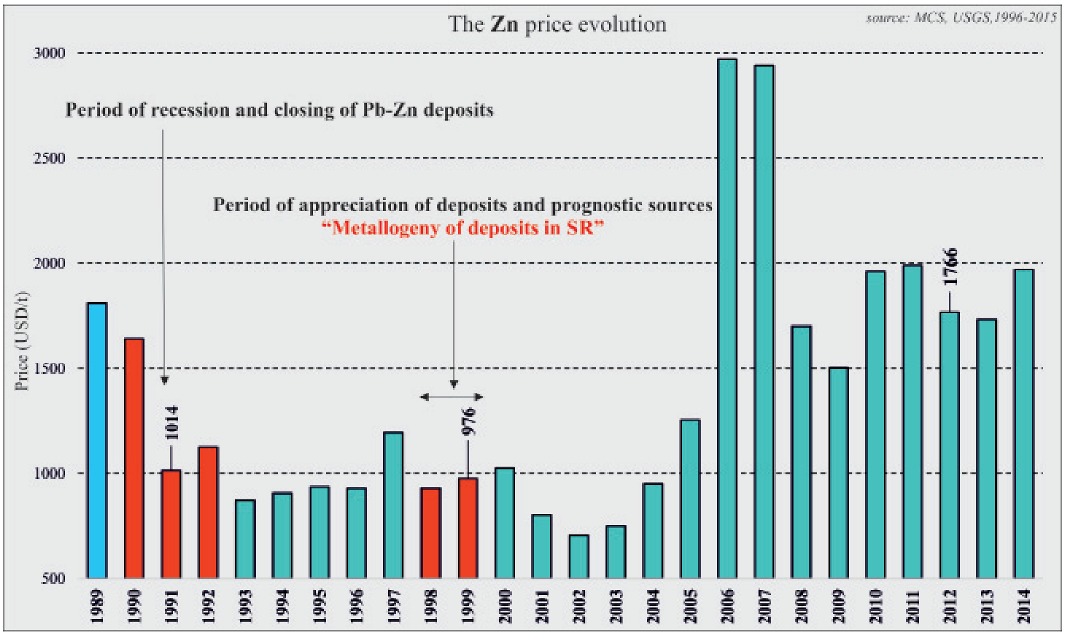

Fig. 5.41 Development of Zn prices on the world markets. Displayed are the important implications for our ore mining. The evaluation of deposits was also impacted and mainly the re-evaluation of earlier estimated prognostic resources (Lexa et al., 2002) in the ore deposits fields and several newly discovered deposits or more significant occurrences. Data source: © KITCO and USGS Mineral Commodity Summaries 1996-2015; supplemented, modified

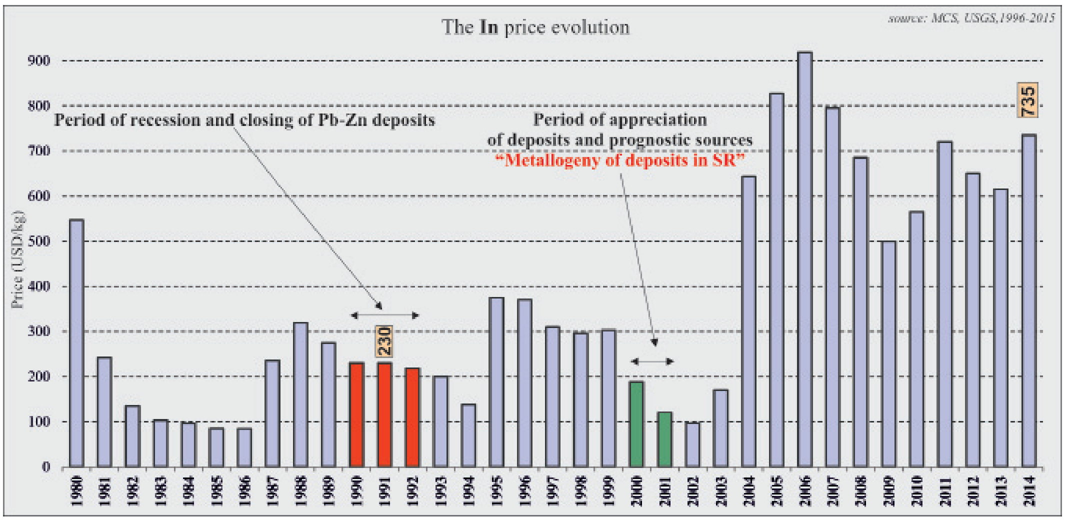

Fig. 5.42 Development of In price in world markets followed the trend of the main metals. Data source: © KITCO and USGS Mineral Commodity Summaries 1996-2015; supplemented, modified

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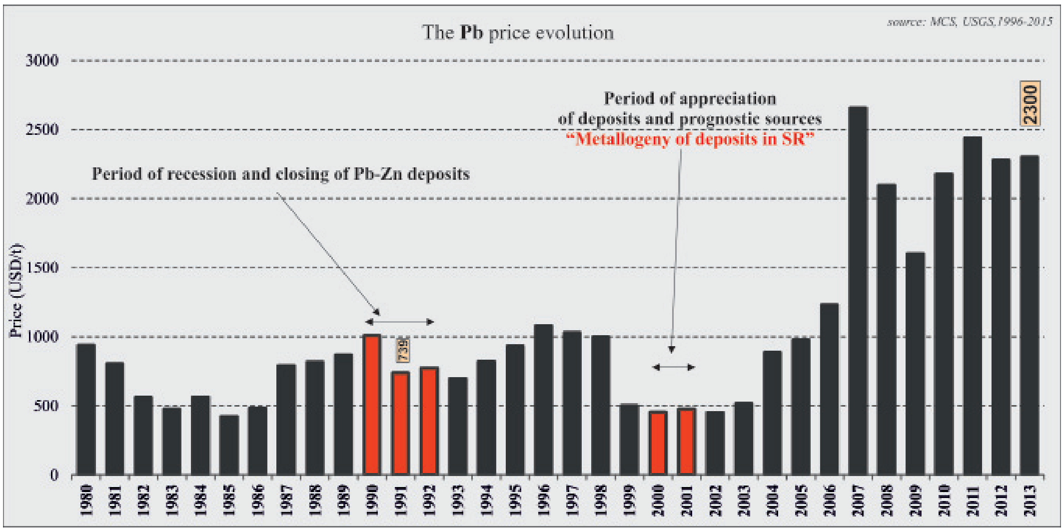

Fig. 5.43 Development of Pb prices on the world markets. The collapse of prices in 2000-2002 was very significant. As mentioned earlier, it was the period of the last reassessment of remaining reserves at the attenuated deposits (Lexa et al., 2002). There were also reconsidered prognostic sources of several areas that have been treated in early 90s. In hindsight, it was the period of very low prices of many metals on world markets with consequences in different time frames. Data source: © KITCO and USGS Mineral Commodity Summaries 1996-2015; supplemented, modified.

5.3.9 Fluorite – accompanying mineral in the deposits of other mineralisation types

In Slovakia, the fluorite is present as accompanying mineral with a relatively large number of occurrences (Ďuďa & Ozdín, 2012), but mostly of only mineralogical significance. Its greater concentrations were registered in the deposit of cassiterite Hnilec – Medvedí potok and the tourmalinite deposit Zlatá Idka (Figs. 5.44; 5.45).

Basic genetic types of fluorite deposit accumulations (Bide et al., 2011) in the conditions of the Western Carpathians have neither significant extent or they didn't occur at all. According to current knowledge, we do not assume potential possibility of a separate occurrence or sufficient contents for the by-product from the aforementioned deposits or deposit occurrences. The identification of fluorite, however, is an important sign of the possible presence of other types of mineral resources. In our particular geological conditions it is mainly the presence of Sn (Ta-Nb) mineralisation types. Fluorite in the acidic environment of volcaniclastic and extrusive bodies is also an important type indicating Be-bertrandite mineralisation. From this perspective, the study of its presence in specific geological conditions is up to date issue.

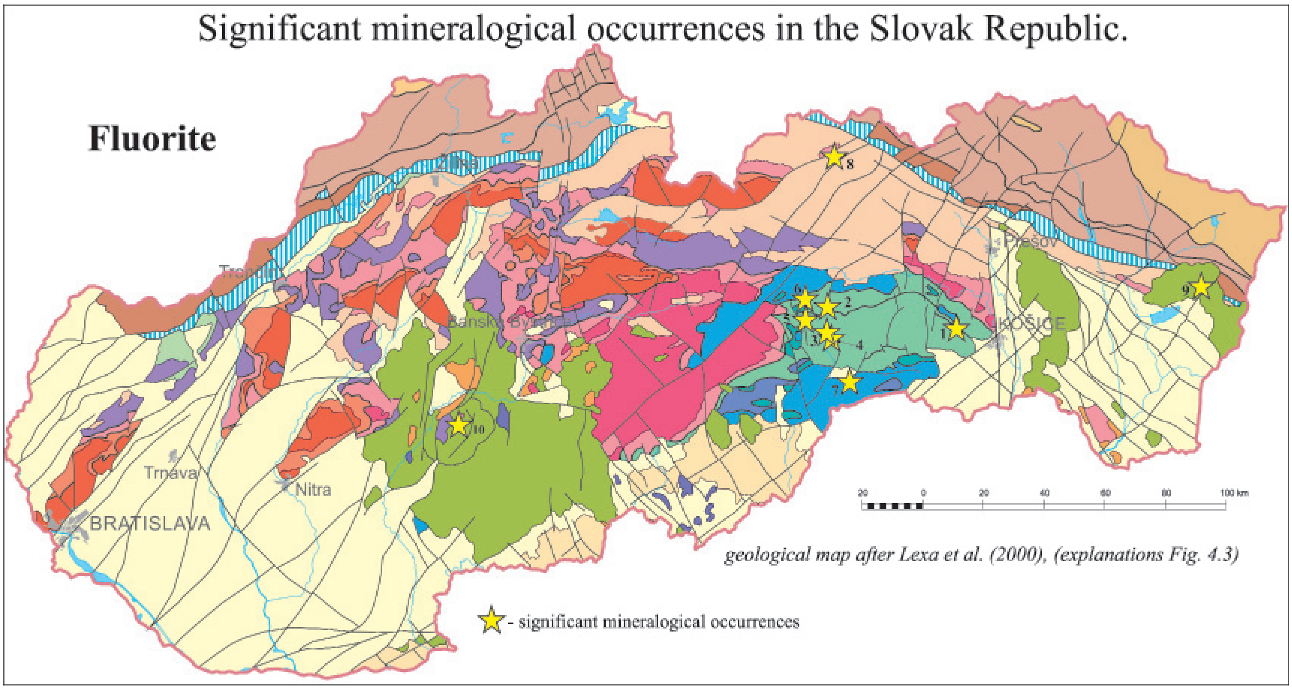

Fig. 5.44 Deposit occurrences and mineralogical occurrences of significant mineralisation with fluorite in different geological formations and some of their geological and genetic attributes. Source: Lexa et al., 2000; Ďuďa & Ozdín, 2012.

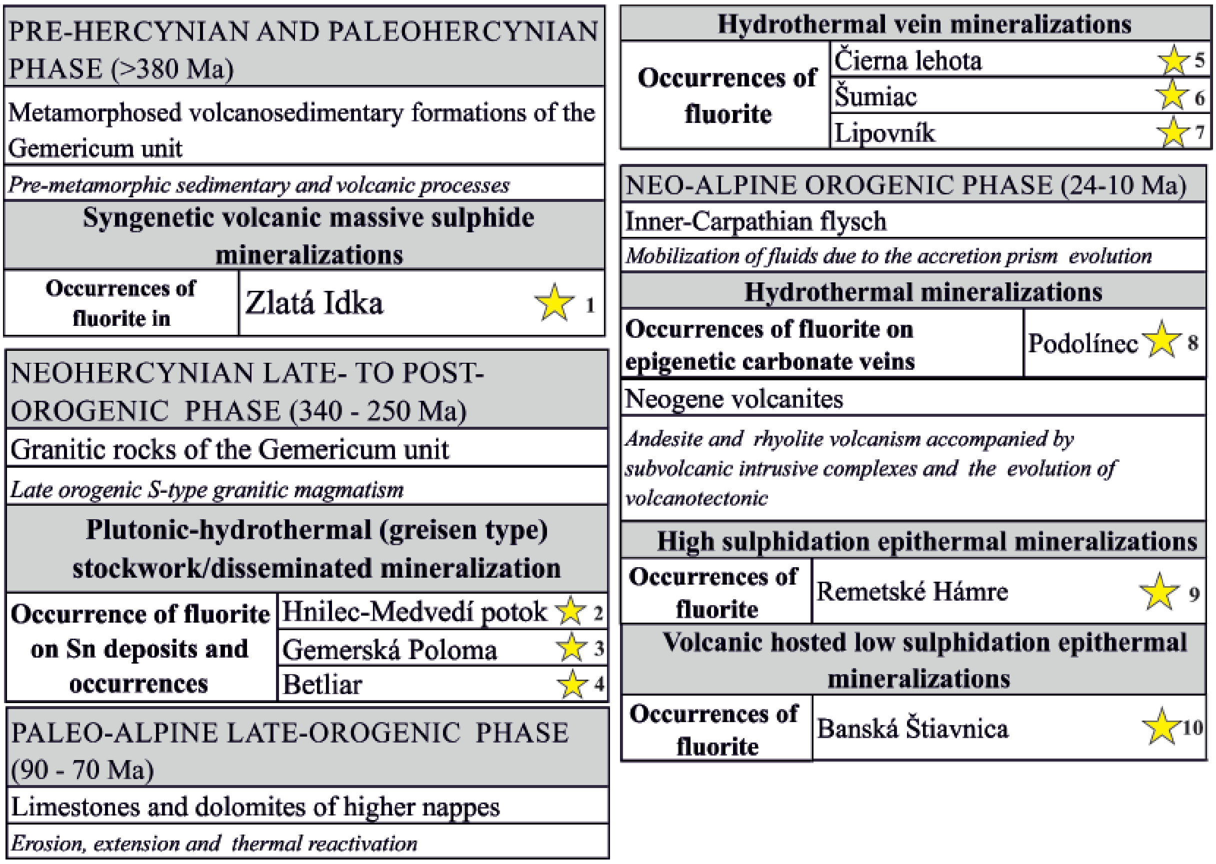

Fig. 5.45 Deposit occurrences and mineralogical occurrences of significant mineralisation of fluorite in different geological formations and some of their geological and genetic attributes. Source: Lexa et al., 2007, Ďuďa & Ozdín 2012.

World production of fluorite (Fig. 5.46) is concentrated mainly in China. Interesting is the fact that China is not a country with the greatest potential of calculated reserves of fluorite (Fig. 5.47).

Its extensive extraction (Fig. 5.46) is probably related to metallurgy activities in the country demanding the fluorite as an additive raw material.

5.3.10 Be minerals based on bertrandite, possible occurrences in rhyolitic volcaniclastic rocks

In Slovakia there is no tradition in acquiring this metal and only in recent decades the first description of the occurrence of beryl was published (Pitoňák and Janák, 1983; Ďuďa & Ozdín, 2012). All findings originated from pegmatites of Core Mountains (Malé Karpaty, Považský Inovec, Žiar and Nízke Tatry) and they have only mineralogical significance.

A relatively large amount of genetic types of Be mineralisation (Tab. 5.12) largely reflects the sources of beryl, or helvite and phenakite that were previously the main source of beryllium. Currently, the dominant industrial sources of beryllium bertrandite – $Be_4Si_2O_7(OH)_2$ mineralisation is bound to acidic young volcaniclastic rocks, Pliocene in age, with type deposits in the area Spor Mt., Utah, USA (Tab. 5.12, Fig. 5.48).

Deposits in this area are the major Be producers and worldwide the search is focused in this genetic type for industrial extraction (Fig. 5.49), although still the other genetic types are registered.

In the Slovak part of the Western Carpathians conditions could theoretically exist for volcanogenic epithermal type of bertrandite mineralisation. In 1992 it was completed the first study dealing with the possibility of the presence of this type of Be mineralisation (Knéslová et al., 1992) in Slovakia. There was sampled a portion of the acidic environment of volcaniclastic rocks in the

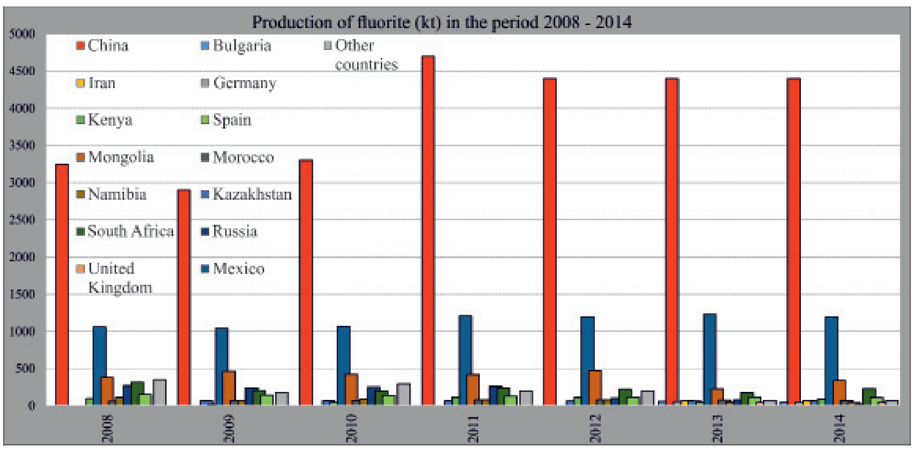

Fig. 5.46 Production of fluorite world-wide. Dominance of China and its stable high production in 2011 are obvious. Source: USGS, Mineral Commodity Summaries, years 2010-2015; modified and compiled.

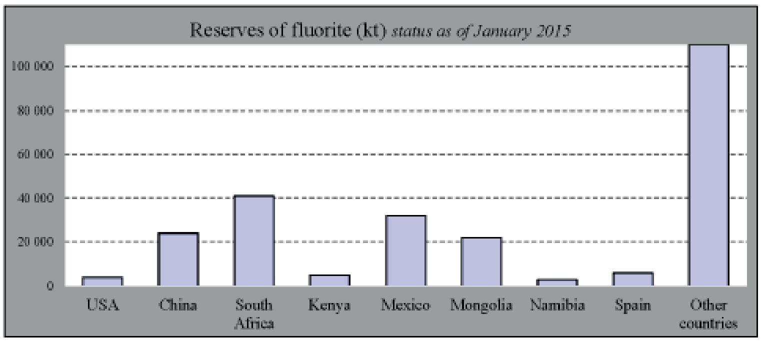

Fig. 5.47 Fluorite reserves world-wide. China is not a country with the greatest potential of calculated reserves of fluorite although it is the greatest producer. Source: USGS, Mineral Commodity Summaries 2015; modified and compiled

Central Slovakia Neovolcanites, and later Eastern Slovakia volcaniclastic rocks (Bačo et al., 2013). In both cases, however, manifestations of bertrandite mineralisation, or increased levels of Be (10 ppm – as prognostic occurrence, or other prognostic criteria) in the rock environment have not been recorded yet. Genetic attributes (Fig. 5.48), however, could be met in some paleorhyolites.

Tab. 5.12 Basic characteristics and examples of the types of beryllium deposits, modified according Barton & Young (2002)

Type	Brief description	Minerals	Grade	Major examples
Granite pegmatites	Crystals in block zone and metasomatite zone	beryl, bertrandite	0.1% BeO	Bernic Lake (Manitoba, Canada), Mozambique
Hydrothermal subvolcanic	Dissemination in rhyolite tuffs	bertrandite	0.1-0.5% BeO	Spor Mountain (Utah, USA)
Be-albitites	Stripes of fenites and linear albitites	helvite	0.01-1% BeO	Seal Lake (Labrador, Canada)
Greisens with Be	Veins and stockworks Sn-W-Mo paragenesis	beryl	0.01-0.5% BeO	Shizhuyuan (Dongpo, China), Aqshatau (Kazakhstan)
Skarns with Be	Nests and lentils in contact zones	helvite, bertrandite	0.01-1% BeO	Iron Mountain (New Mexico, USA)

5.3.11 Polymetallic nodules – concretions from the oceanic floor of the Pacific Ocean

Slovakia deliberates a source of non-traditional mineral resources – "polymetallic" concentrations from the ocean floor (Fig. 5.50). The Slovak Republic participates in geosubaquatic exploration activities of Interoceanmetal (IOM), of which Slovakia is a member (Baláž & Franzen, 2014). The territory stretches between Mexico and the Hawaiian Islands in the Clarion and Clipperton tectonic zones.

The analysed samples of nodules are from the space of the southern exploration area (Fig. 5.50 – location of MD-1). Size of nodules was 4 cm on average. They are formed by a porous material with an irregular nodular shape of pale-grey colour (Fig. 5.51). On the cross-section a concentric structure is distinct reflecting mineral composition of individual zones (Fig. 5.51b).

The test results (Tab. 5.13) confirmed the anticipated state of the content of the metal main – Mn, Cu, Ni (Mackových et al., 2013; Baláž & Franzen, 2014). Alongside them interesting are contents of the group of critical metals and REE, mainly Co. They are comparable to the Co-content of the nodules with enriched crust (Gunn, 2014). The contents of rare earth elements at the moment show that the analysed samples don't contain significant proportion of these elements.

5.4 Conclusions

Based on the assessment of the Slovak Republic territory in terms of the presence of critical raw materials we can conclude that:

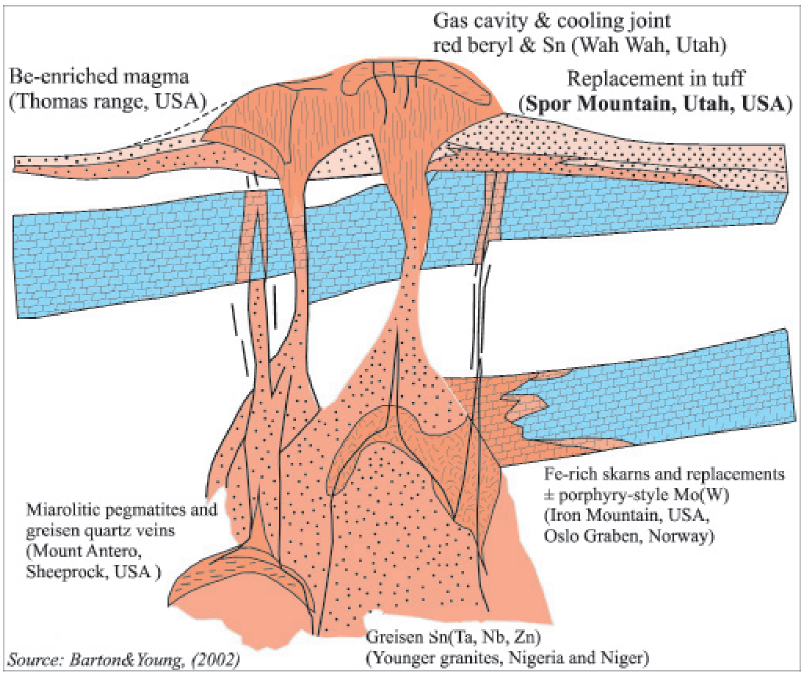

Fig. 5.48 Genetic type model of Be mineralisation of metaluminous and poorly peraluminous systems. According to Barton and Young, (2002), modified.

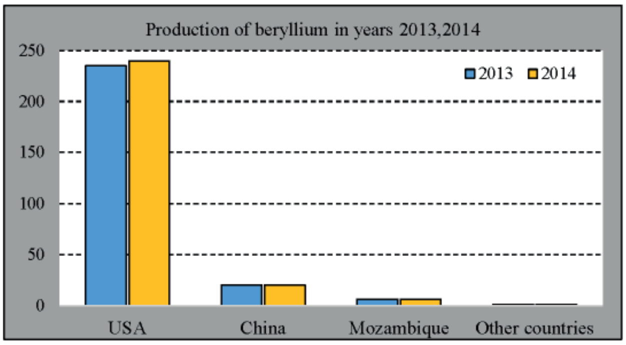

Fig. 5.49 Be production world-wide. Dominance of the USA is obvious along with high production in 2013 and 2014. Source: USGS, Mineral Commodity Summaries 2015; modified and compiled

1. The territory of the Slovak Republic has the potential for occurrence of some critical mineral resources – these are mainly **Sb** and **W** sources, which form separate deposits with calculated reserves of metallic ores.

When considering Sb re-evaluation of antimony, mineralisation is currently possible in Gemericum, especially in the area between the eastern and western branch of Sb stripe – wider area of Zlatý stôl. In the case of tungsten it is necessary to pay attention especially to the porphyry type, type Ochtiná I with accompanying Mo-mineralisation (possibly accompanying the scheelite mineralisation in a given Mo-deposit).

The development of prices of these metals has increased several times since the last assessment of remaining reserves and is steadily high, which increases the price of the metal deposits. Accompanying metal at the Sb-deposits and partly at the W-deposits is the gold, its value has increased several times, and this metal in the deposit increases its value and hence the potential of economic viability of a deposit mining.

2. To date **cobalt** is critical metal. Its vein type mineralisation in Slovakia had been mined out in the past along with Ni (they had common occurrence within the ore structures) and later prospecting works were unsuccessful. Interesting, however, is its occurrence in lateritic weathering crusts of peridotite body Hodkovce – Komárovce. Also in this genetic type it occurs with Ni. It is necessary to return to the revision of the object in which last work was done more than 40 years ago. When considering cobalt nodules from the seabed, they are interesting to us and Slovakia participates in their survey under umbrella of Interoceanmetal activities.
3. The source materials for **magnesium metal** in geological conditions of the Western Carpathians are mainly magnesite and dolomite. Supplies of these raw materials in Slovakia are of European importance. However, the raw material potential must be verified from the technological point of view (which is currently being addressed by the project of geological works), in order to provide the starting material for the national production of magnesium metal.
4. **Graphite –** accounting for quantitative parameters of potential accumulations in the conditions of the Western Carpathians, of interest can be only areas with higher metamorphic grade. However, we can expect only objects with very small resources (up to several X00 kt) of relatively low quality (5-10%). Interesting, however, makes them easy treatability and good to very good yield (85%).
5. Deposits of polymetallic ores may become a source of accompanying metals **In**, **Ge**, but also Te and Bi and others (out of the traditional Au and Ag). Although quantitative parameters do not reach higher levels, their comprehensive utilization with accompanying metals, which is enabled by the current technologies, ranks them also among prospective objects. Based on the assessment of the general genetic models there were tested selected polymetallic mineralisation sites of deposits with ore reserves on the possible presence of metals: In, Ga, Ge. The to-date results have not demonstrated their unequivocal presence. However, this type of mineralisation is still considered as potential source, as the general genetic models and the specific deposits defined them as one of the most important sources.

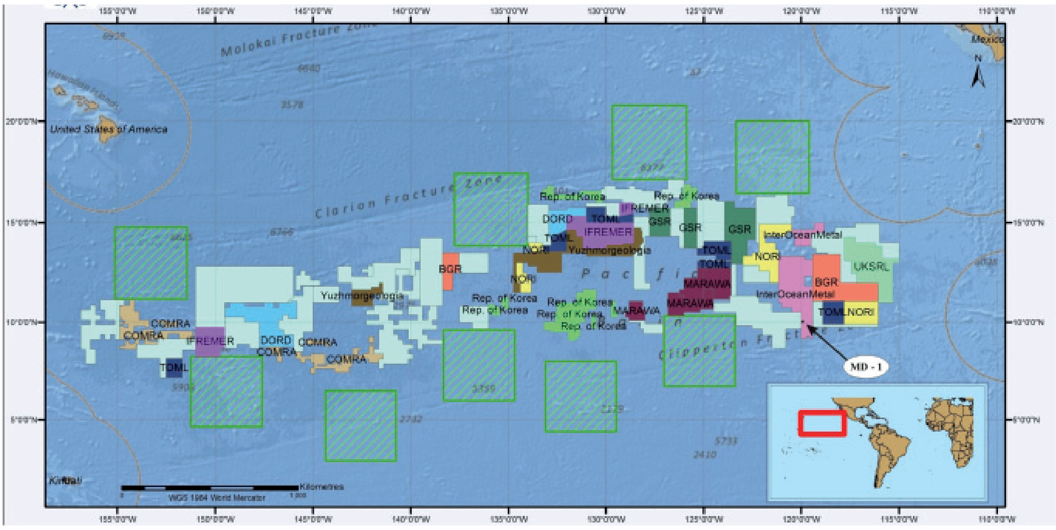

Fig. 5.50 The geographical position of exploration areas of oceanic floor between the Clarion and Clipperton tectonic zone in the Pacific Ocean. Two irregular polygons of pink colour are the exploration areas of Interoceanmetal. The place of Mn nodules sampling is indicated – identification of the analysis MD-1.

6. A comparison of raw material resources for **REE + Sc** and **Y** and Nb-Ta in the world with the geological conditions of Slovakia has confirmed, on the one hand, the absence of the host rocks for the genetic type of

the largest source – carbonatite rock environment. On the other hand, the areas of specific granites containing precious elements in Gemericum, appear promising.

From this perspective, among the most promising mineralisation there can be classified the “Gemerská Poloma type”. Designation of this type has no genetic meaning, but rather denotes the concentration of a broad spectrum of mineralisation in this area. Of these, a large proportion is associated with granite containing precious elements. Hidden, very rich greisen cassiterite mineralisation (tectonically exposed at the current surface) is associated with the Nb-Ta and W (scheelite) mineralisation. Apical part of the granite body consists of Li-rich albitic metasomatite (which can be an important resource of Li and also Rb) and is a very promising deposit object. In the altered granite, often in contact with the talc, REE (Nb) + fluorite mineralisation was found on separate quartz veins. Their spatial extent remains still unknown. The immediate surrounding of Fe–mineralisation of the “skarn” type with In, and in particular, the talc deposit itself and accompanying magnesite makes this area one of the most promising in Gemericum.

7. So far, the evaluation has remained insufficient, or rather negative assessment of the area from the viewpoint of the presence of **Be** – bertrandite mineralisation within volcaniclastic rocks of rhyolite composition. Since this issue is only at the beginning of the solution, it should be further continued and the study of genetic type has to be extended to Paleozoic rock environment.
8. **Fluorite** is among the critical raw materials with plenty of mineralogical occurrences, but it is not promising raw material for the Western Carpathians space.
9. The database of relevant data has been created, allowing continuous comparison of identified resources (Sb, W, Co, graphite) with known qualitative and quantitative parameters, with the resources in other EU countries or with global deposits of various genetic types. This has formed a platform for an objective view of the raw material possibilities of the territory of Slovakia.

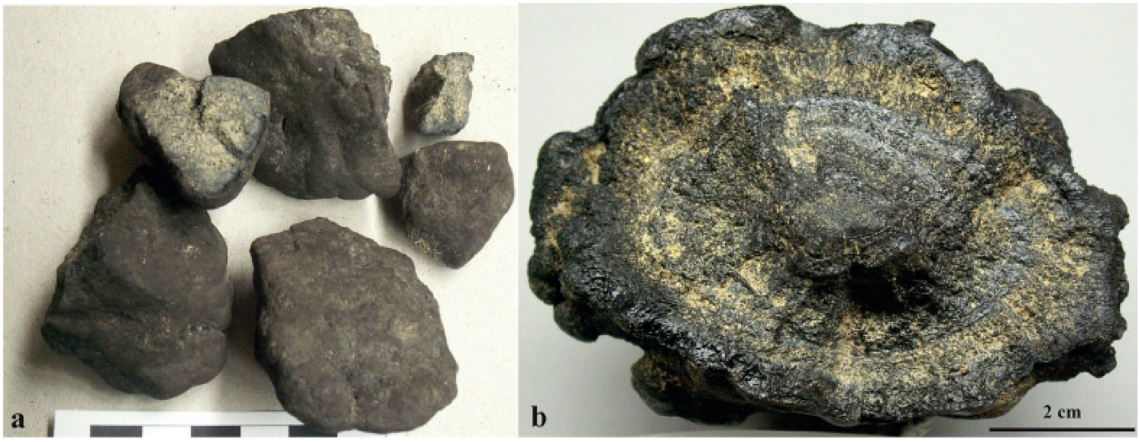

Fig. 5.51 Deposit of polymetallic nodules – Pacific Ocean. Samples (a) come from the ocean floor defined by coordinates of the W longitude 120° and N latitude 10°; depth is about 4.5 km. Analysis designation MD-1; Photo: Bačo

Tab. 5.13 Contents of selected elements from the nodules from the ocean floor.

Sample	La	Ce	Dy	Er	Eu	Gd	Ho	Lu
	[mg/kg]	[mg/kg]	[mg/kg]	[mg/kg]	[mg/kg]	[mg/kg]	[mg/kg]	[mg/kg]
MD-1	83	297	81.2	9.81	5.39	29.4	4.3	1.92
	Nd	**Pr**	**Sm**	**Tb**	**Tm**	**Yb**	**Y**	**Sc**
	[mg/kg]	[mg/kg]	[mg/kg]	[mg/kg]	[mg/kg]	[mg/kg]	[mg/kg]	[mg/kg]
	91.2	27.1	20.1	5.49	2.09	9.5	101	9
	Zn	**In**	**Ga**	**Ge**	**Te**	**Sb**	**Pb**	**Cu**
	[mg/kg]	[mg/kg]	[mg/kg]	[mg/kg]	[mg/kg]	[mg/kg]	[mg/kg]	[mg/kg]
	1300	< 50	25	< 10	10	46	210	12,150
	Ni	**Co**	**Cr**	**V**	**Mn**			
	[mg/kg]	[mg/kg]	[mg/kg]	[mg/kg]	[mg/kg]			
	12,220	1,440	7	396	30.1			

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References

Andráš P., Križáni I. & Jeleň S., 2006: First occurrence of Pt-mineralisation in Western Carpathians. In Stanley, Ch. (editor). Mineral Deposits Studies Group Annual Meeting, 4-6 January 2006. London: Natural History Museum and Imperial College, 2006 p. 44-46.

Bačo P., Bačová N., Bakoš F., Fodorová V., Derco J., Dzurenda Š., Hricová M., Hvožďara P., Kovaničová Ľ. Križáni I., Lučivjanský P., Ondíková H., Repčiak M. & Smolka J., 2004: Reinterpretácia šlichového prieskumu na území Slovenska (Re-interpetation of panned concentrate prospecting at the territory of Slovakia), Final report, SGIDŠ, MoE SR, 119 p. (In Slovak).

Bačo P., Bačová Z., Németh Z., Radvanec M. & Repčiak M., 2013: Kritické nerastné suroviny. (Critical Raw Materials). Final report, SGIDŠ, MoE SR, 123 p. (In Slovak).

Baláž P. & Kúšik D., 2014: Slovak Minerals Yearbook 2014. SGIDŠ, Vydavateľstvo D. Štúra, 150 p., ISBN 978-80-8174-004-6.

Berger V. I., Singer D. A., Orris G. J., 2009: Carbonatites of the world, Explored deposits of Nb and REE – Database and Grade and Tonage models: US Geological Survey, Open-File Report 2009-1139, 20 p.

Bide T., Gunn G., Brown T. & Rayner D., 2011: Fluorspar, Commodity profile, British Geological Survey, 18 p.

Bláha M., et al., 1993: ZS a výpočet zásob – Jasenie, W a Au rudy. Final report and reserves calculation – Jasenie, W and Au ores). Manuscript, Geofond Archive, Bratislava. (In Slovak).

Blahút I., Rabatin Ľ., Tomášek K. & Kocúr J. 1994: Možnosti výroby kovového horčíka z dolomitov a odpadových magnezitových surovín. (Possibilities of production of magnesium metal from dolomite and magnesite raw materials). Uhlí-Rudy-Geolog. Průzkum, Nr. 6, p. 207-210. (In Slovak).

Broska I., Petrík I. & Uher P., 2012: Akcesorické minerály granitických hornín Západných Karpát. (Accessory minerals of granitic rocks of the Western Carpathians). VEDA – SAV, Bratislava, 236 p., ISBN 978-80-224-1255-1. (In Slovak).

Donát A., 1998: Ocenenie výskytov anomálií prvkov vzácnych zemín v perme gelnickejskupiny SGR. (Valuation of anomalies occurrences of rare earth elements in Permian of the Gelnica Group of SGR). Uranpres, Manuscript, Geofond, Archive number 83224, 319 p. (In Slovak).

Drnzík E., Drnzíková L., Valko, P. & Mandáková K., 1982: ZS – VZ Hnilec – Medvedí potok – VP, Sn-W-Mo rudy, I. – II. Časť VP, stav k 30.6. 1982. Manuscript, Geofond Archive, Bratislava. (In Slovak).

Drnzíková L., Mandáková K., Drnzík E. & Baran J., 1975: Criteria of tin-bearing and metallogenetic specialisation of selected granites of SGR Mts. Miner. Slov., 7, p. 53-59. (In Slovak).

Ďuďa R. & Ozdín D., 2012: Minerály Slovenska. (Minerals of Slovakia). Vydavateľstvo Granit, s.r.o., Praha, First edition, 480 p. (In Slovak).

Grecula P., Abonyi A., Abonyiová M., Antaš J., Bartalský B., Bartalský J., Dianiška I., Drnzík E., Ďuďa R., Gargulák M., Gazdačko Ľ., Hudáček J., Kobulský J., Lörincz L., Macko J., Návesňák D., Németh Z., Novotný L., Radvanec M., Rojkovič I., Rozložník L., Rozložník O., Varček C. & Zlocha J., 1995: Ložiská nerastných surovín Slovenského rudohoria zväzok 1. (Deposits of the Slovenské rudohorie Mts. Volume 1). Geocomplex, Bratislava, 829 p. (In Slovak).

Groves D. I., Goldfrap D. J., Gerbe – Mariam N., Hagemann S.G. & Robert F., 1998: Orogenic gold deposits: A proposed clasification in the context of their crustal distribution and relationship to other gold deposit types, Ore Geology Reviews, Volume 13, p. 7-27.

Gunn G. ed., 2014: Critical Metals Handbook, John Wiley & Sons Ltd., 439 p.

Hu X., Murao S., Shi M. & LI B.,1996: Classification and Distribution of Antimony deposits in China, Resource Geology,46, volume 5, p. 287-297.

Hvožďara P., Fejdi P., Ženiš P., Krištín J., Bačo P., Pankuch K., Vdenská N., Prcúch J. & Iró S., 1994: Vzácne zeminy v kryštaliniku Západných Karpát – Veporikum. (Rare earths in the crystalline basement of the Western Carpathians – Veporicum). Final report, Manuscript, Geofond Archive, Bratislava, 84 p. (In Slovak).

Immer J., 1998: Slovenské magnezitové závody Jelšava zvyšujú export svojích výrobkov. (Slovak Magnesite Works Jelšava increase the export of their products). Týždenník Trend, 17.06.1998. (In Slovak).

Knéslová A., Knésl J. & Havelka J., 1992: Stredoslovenské neovulkanity – Bertrandit, VP, GP SNV. (Central Slovakia Neovolcanites – Bertrandite). Manuscript, Geofond Archive number 78967. (In Slovak).

Kobulský J., Kovaničová Ľ. & Repčiak M., 2000: Turmalínovce (Tourmalinites). Final report, Manuscript, Geofond Archive, Bratislava, 97 p. (In Slovak).

Koděra M., Andrusovová-Vlčeková G., Belešová O., Brietková D., Dávidová Š., Fejdiová V., Huraj V., Chovan M., Nelišerová E. & Ženiš P., 1989: Topografická mineralógia Slovenska. (Topographical mineralogy of Slovakia). Veda, Vydavateľstvo SAV, Bratislava, I., II., a III. volume. (In Slovak).

Košárková M. & Ďuďa R., 1999: Argyrodite – the first finding in Slovakia. Bull. Mineral.-petrolog. Odd. Nar. Muz., Praha, 7, p. 163-164. (In Slovak).

Košuth M., 2009: Drahé kovy a vzácne prvky v sulfidických rudách SR, Habilitačná práca. (Precious metals and rare elements in sulphide ores SR Habilitation thesis). Faculty BERG TU, Košice, 112 p. (In Slovak).

Küster D., 2009: Granitoid-hosted Ta mineralisation in the Arabian–Nubian Shield: Ore deposite types, tectono-metallogenetic setting and petrogenetic framework, Ore geology Rewievs 35, Elsevier, p. 68-86.

Lexa J., Bačo P., Bahna B., Bakoš F., Baláž P., Bezák V., Bystrická G., Cicmanová S., Ferenc Š., Gazdačko Ľ., Grecula P., Háber M., Helma J., Hojstričová V., Hraško Ľ., Hurai V., Huraiová M., Chovan M., Jeleň S., Kobulský J., Koděra P., Kohút M., Kollárová V., Konečný P., Konečný V., Kováčik M., Kráľ J., Kyselica M., Luptáková J., Marsina K., Mackových D., Maťo Ľ., Michalko J., Mikuš T., Moravanský D., Németh Z., Ozdín D., Petro M., Pršek J., Radvanec M., Rojkovič I., Rojkovičová Ľ., Tréger M., Smirnov A., Smolka J., Šesták P., Žák K., Žáková E. & Žec B., 2002: Metalogenetické hodnotenie územia Slovenskej republiky. (Metallogenic evaluation of the Slovak Republic). Final report. Manuscript. Bratislava, Geofond Archive. (In Slovak).

Lexa J., Bačo P., Hurai V., Chovan M., Koděra P., Petro M., Rojkovič I. & Tréger M., 2007: Vysvetlivky k metalogenetickej mape Slovenskej republiky (Explanatory notes to the metallogenic map of the Slovak Republic). SGIDŠ, Bratislava, 178 p. (In Slovak).

Lörincz L., Švantnerová E., Bachňák M., Jeleň M., Filo M., Sovíček S., Radvanec M. & Pramuka S., 1993: ZS a VZ Ochtiná – Rochovce, Mo-W. Manuscript. Bratislava, Geofond Archive. (In Slovak).

Mackových D., Majchrák A., Nováková J. & Uhrinová K., 2013: Kvalitatívne zloženie polymetalických konkrécií. (Qualitative composition of polymetallic nodules). In Zborník vedeckých príspevkov z konferencie Analytika v geológii a v životnom prostredí 2013, Spišská Nová Ves 13.-15. 11. 2013. Štátny geologický ústav Dionýza Štúra. p. 119-122. (In Slovak).

Malachovský P., Tréger M. & Potančok V., 1987: Th-U anomálie – indikátory vzácne prvkovej mineralizácie v rakoveckej skupine Spišsko-gemerského Rudohoria. (Th-U anomalies – rare elemental mineralization indicators in Rakovec Group of Spiš-Gemer Rudohorie Mts.). Zborník prednášok: Mineralógia uránových a s nimi súvisiacich nerastných surovín, Spišská Nová Ves. 233 p. (In Slovak).
Malachovský P., Dianiška I., Grecula P. & Varga I., 1983: ZS SGR – vysokotermálnej mineralizácie – VP, Sn, W, Mo rudy, stav k 18.8.1983. Manuscript, Geofond Archive, Bratislava. 233 p. (In Slovak).
Malachovský P., Dianiška I. & Varga I., 1992a: Gemerská Poloma – Sn a vzácne prvky. (Gemerská Poloma – Sn and precious elements). Final report and reserves calculation. Manuscript, archív ŠGÚDŠ, 187 p. (In Slovak).
Malachovský P., et al., 1992b: Hnilec okolie. (Hnilec – surroundings). Final report, Manuscript, Geofond Archive, Bratislava, 153 p. (In Slovak).
Malachovský P., Jeleň S. & Ďuďa R., 1997: Minerály india z lokality Gemerská Poloma – Dlhá dolina (Slovenské rudohorie). Minerals of indium from the site Gemerská Poloma– Dlhá dolina. Natura Carpatica, 38, p. 17 – 22. (In Slovak).
Mesarčík I., Švantnerová E. & Bachňák, M., 1992: Final report Dobšiná Ni-Co, Geofond Archive, Bratislava, 98 p. (In Slovak).
Mesarčík I., Lörincz L., Kilik J., Čapo S. & Bajtoš P., 2000: Komplexné zhodnotenie zastaveného ložiska Dobšiná, stav k 31.12.2000. (Comprehensive evaluation of the closed deposit Dobšiná, as of 31.12.2000). Manuscript, Geofond Archive, Bratislava. 220 p. (In Slovak).
Očenáš D., 1982: Slovensko – grafit, Štúdia. (Slovakia – graphite, study). Manuscript, Geofond Archive, Bratislava, 153 p. (In Slovak).
Paspaliaris I., 2013: Development of a sustainable exploitation scheme for Europe's REE ore deposits, EURARE meeting, presentation.
Pecho J., Beňka J., Böhmer M., Hvožďara P. & Matula I., 1981: Scheelitovo-zlatonosné zrudnenie v Západných Karpatoch. (Scheelite-gold-bearing mineralisation in the Western Carpathians). Manuscript, 151 p. (In Slovak).
Petro M., Radvanec M., Kováčik M., Mudráková, Bezák V., Očenáš D., Tréger M., Mihálik F., Fiľo M. & Lukaj M., 1998: Kokava nad Rimavicou – grafit, vyhľadávací prieskum, stav k 31.3.1998. (Kokava nad Rimavicou – graphite, a search survey, as of 31.3.1998). Manuscript. Geofond Archive, Bratislava. (In Slovak).
Pitoňák P. & Janák M., 1983: Beryl – nový minerál nízkotatranských pegmatitov. Beryl as a new mineral in pegmatites of the Low Tatra Mts. Miner. Slov., 15, p. 231 -232. (In Slovak).
Repčiak M., Németh Z., Návesňák D., Očenáš D., Čechovská K., Kovaničová Ľ., Derco J. & Komoň J., 1997: Rejdová – Hnilčík, vzácne zeminy. (Rejdová – Hnilčík, rare earths). Final report, Manuscript, Geofond Archive, Bratislava, 96 p. (In Slovak).
Sasvari T., Kondela J., Maťo Ľ. & Slowakiewicz M., 2003: Indication of Pt-PGE mineralization of the Strieborná vein and throughout of the wider domain of Rožňava ore field area (Spiš-Gemer ore mountains, Western Carpathians). Sborník vědeckých prací Vysoké školy báňské – Technické univerzity Ostrava, Řada hornicko-geologická, Volume XLIX, No.1, p. 129-136, ISSN 0474-8476. (In Slovak).
Schwarz-Schamper U. & Herzig P. M., 2002: Indium: Geology, Mineralogy and Economics, Heidelberg, Springer, 263 p.
Sombathy L., 1949: Ložisko grafitu Kyjatice – Kadlub. (Graphite deposit Kyjatice – Kadlub). Manuscript, Geofond Archive, Bratislava. (In Slovak).
Tomášek K. 1994: Surovinová báza pre výrobu kovového horčíka na Slovensku. (Raw material basis for the production of magnesium metal in Slovakia). Uhlí-Rudy-Geolog. Průzkum, Nr. 5, p. 187-189. (In Slovak).
Tomášek K., Rabatín R., Špeťuch V., Šeševička O., Urban Ľ. & Siták R., 2001: Patentová listina SR č. 281 685, Spôsob výrobu horčíka z magnezitových surovín. (Patent Certificate Nr. 281 685, The method of production of magnesium from magnesite raw materials). Úrad priemyselného vlastníctva, Banská Bystrica SR, published 09.07.1997, C 22B 26/22; 5 p. (In Slovak).
Uher P., Žitňan P. & Ozdín D., 2007: Pegmatitic Nb-Ta oxide minerals in alluvial placers from Limbach, Bratislava massif, Western Carpathians, Slovakia: compositional variations and evolutionary trend. J. Geosci. 52, 133-141.
U.S. Geological Survey: Mineral commodity summaries, annuals, 1996-2015.
Walters A. & Lusty P. 2010: Rare earth elements, British Geological Survey, Report of Commodity Profiles, 45 p. (In Slovak).
Zlocha J., Tomko I. & Valko P., 1975: ZS a VZ Hodkovce – nikel, VP, stav k 1.3.1975. Manuscript. Bratislava, archív Št. Geol. Úst. D. Štúra. (In Slovak).
Zlocha J. & Valko P., 1982: Slovensko – rudy, prehodnotenie zásob, Hodkovce VP Ni-Co ruda, stav k 31.12.1981. Manuscript. Geofond Archive, Bratislava. (In Slovak).
Zlocha J., Hurný J., Pramuka S. & Gurínová E., 1986: ZS – Dobšiná, Ni, Co, surovina, štúdia, stav k 30. 5. 1986. (Dobšiná, Ni, Co, raw materials, a study of 30. 5. 1986). Final report. Manuscript. Geofond Archive, Bratislava. (In Slovak).
Zuberec J., Tréger M., Lexa J. & Baláž P., 2005: Nerastné suroviny Slovenska (Mineral resources of Slovakia). SGIDŠ Bratislava, 350 p.
Register of reserves of reserved deposits of the SR, as of January 2013, SGIDŠ, Bratislava, 220 p.

EU documents

2009/C 27/19: Opinion of the European Economic and Social Committee on the 'Non-energy mining industry in Europe'
2009/C 277/19: Opinion of the European Economic and Social Committee on the Communication from the Commission to the European Parliament and the Council: The raw materials initiative – meeting our critical needs for growth and jobs in Europe
Report of Ad-hoc Working Group, June 2010: Critical raw materials for the EU (http://ec.europa.eu/enterprise/policies/rawmaterials/documents/index_en.htm)
COM (2011) 25 of 2.2.2011: Opinion of the European Economic and Social Committee on the 'Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions – Tackling the challenges in commodity markets and on raw materials'
Report for the EU Commission "Critical raw materials for the EU" – 30.7.2010

http://ec.europa.eu/enterprise/policies/rawmaterials/documents/index_en.htm
www. usgs.gov
www.bgr.bund.de/DERA_Rohstoffinformationen-Antimon (2013)
www.bgr.bund.de/DERA_Rohstoffinformationen-Wolfram (2014)

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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).

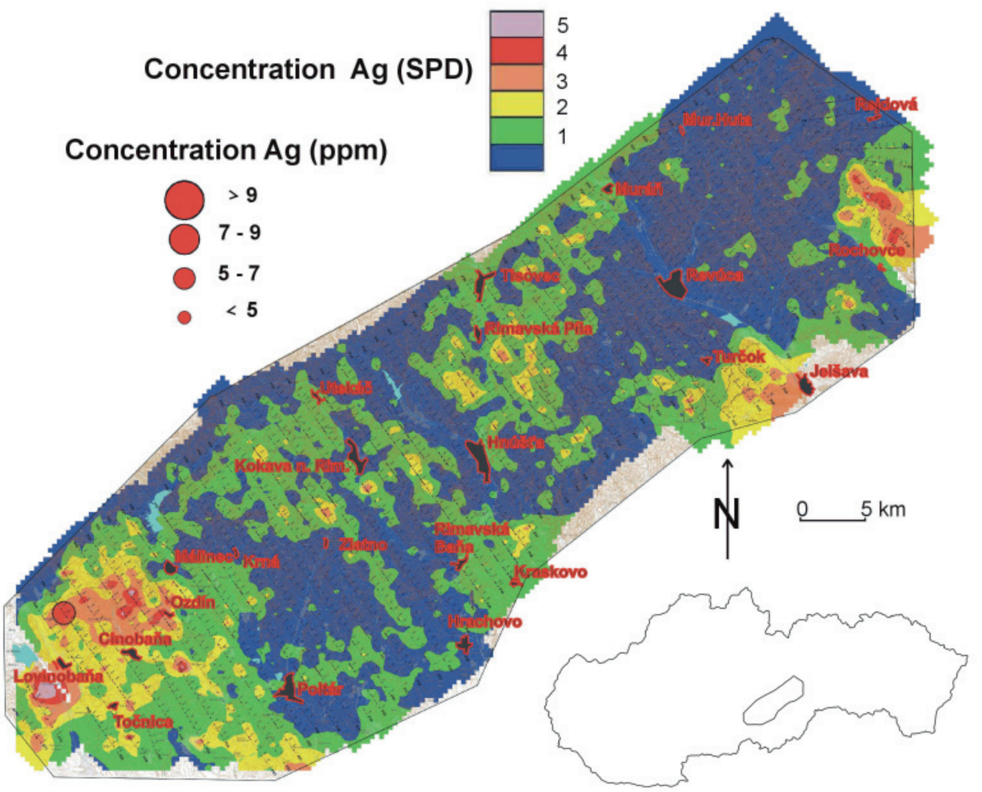

Fig. 6.1 Distribution of Ag (in SPD scale – isolines, and in quantitative values in ppm – red circles) in soil horizon B. Anomalies in E part of territory are situated in Veporicum Late Paleozoic metasediments (Slatvina ad Rimava Fms.). Anomaly between Jelšava and Tučok belongs to metasediments with 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).

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-

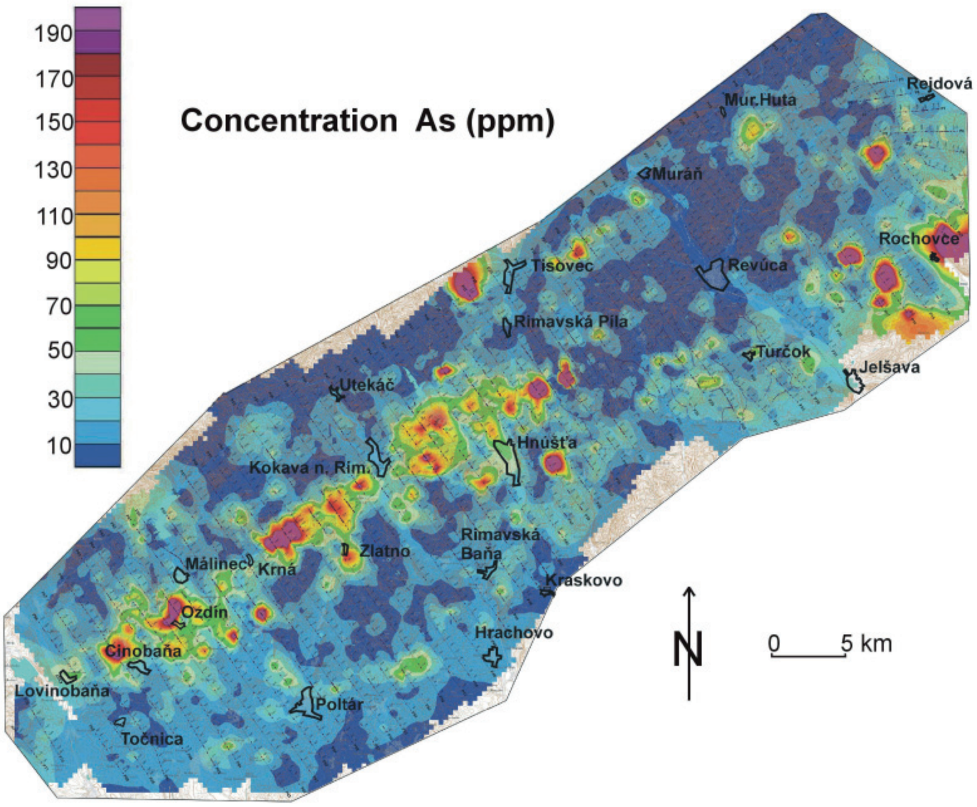

Fig. 6.2 Concentration of As (in ppm) in soil horizon B revealed continuous As concentration in the Southern Veporicum region. Linear As anomaly of SW-NE direction in the W part of the region is connected with the pronounced Alpine shear zone accompanied by magnetic anomaly.

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).

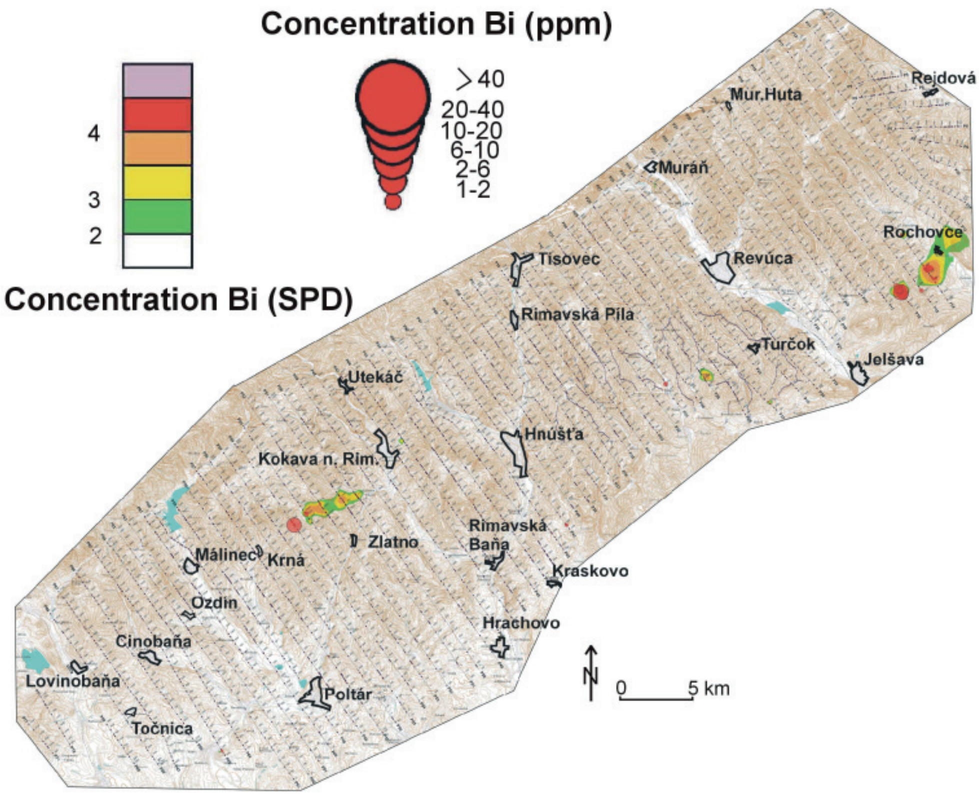

Fig. 6.3 Concentration of Bi (in ppm) in soil horizon B is strictly connected with the Late Cretaceous Rochovce (W-Mo deposit) granite and with the Permian Klenovec type granite (NW of Zlatno village) here incorporated into the Alpine shear zone.

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.

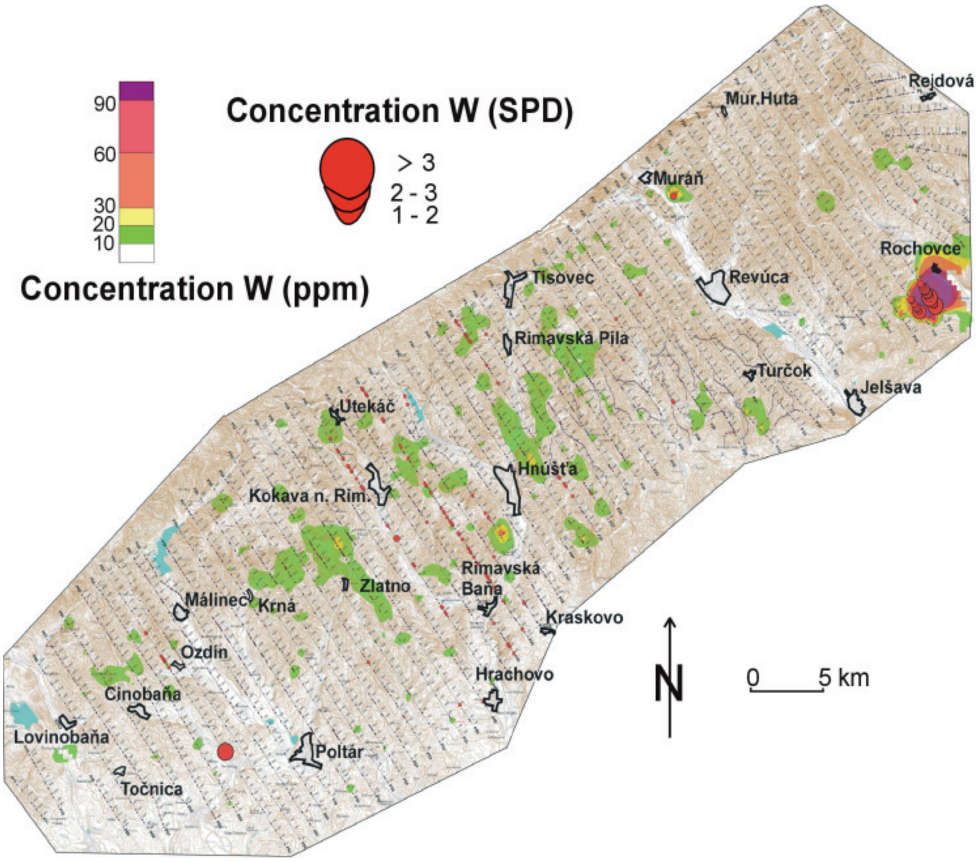

Fig. 6.4 Concentration of W (in ppm) in soil horizon B is strictly connected with the Late Cretaceous Rochovce (W and Mo bearing) granite.

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

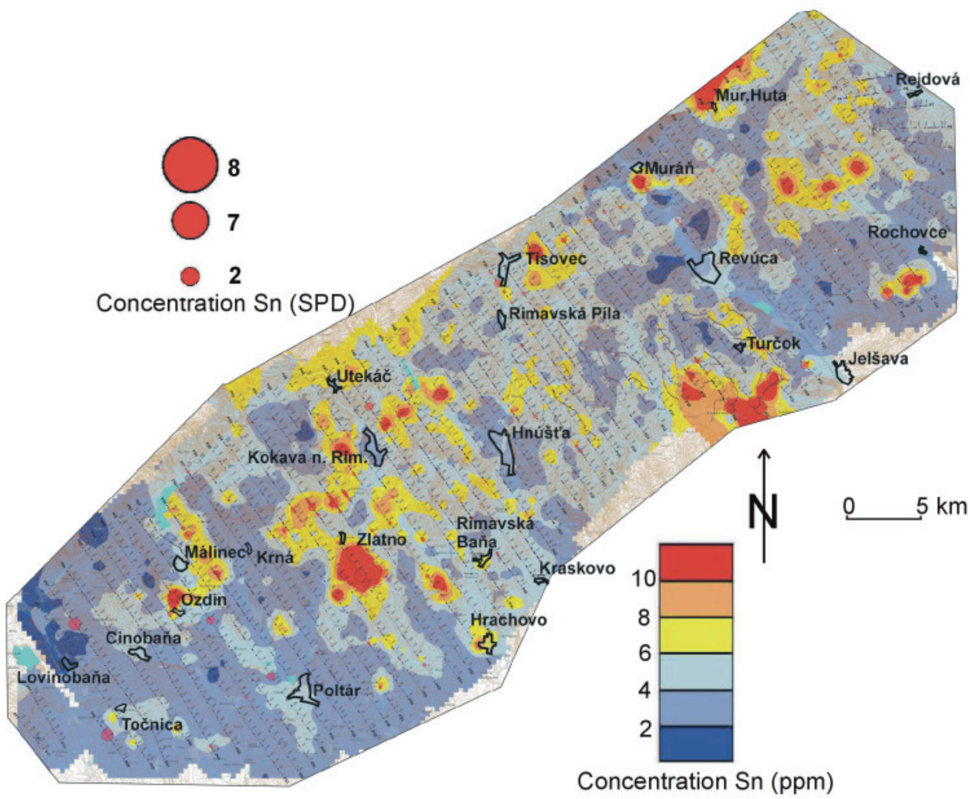

Fig.6.5 Concentration of Sn in soil horizon B (isolines in ppm and red circles in SPD scale)

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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 (Gargulák & 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

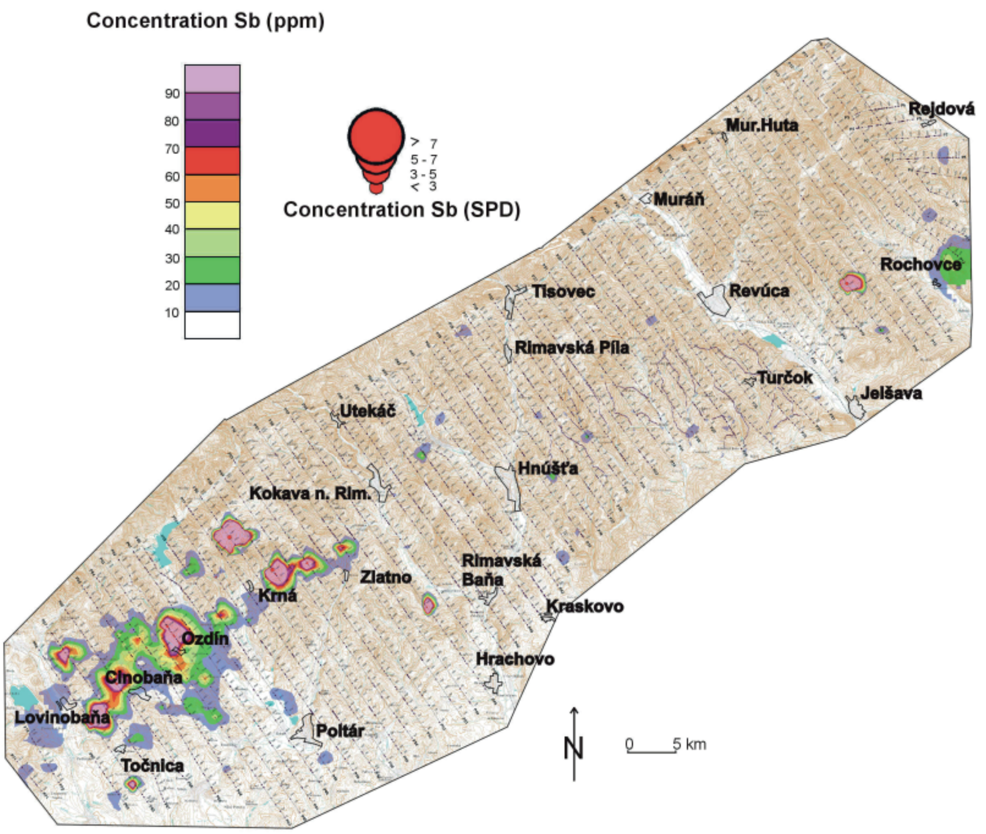

Fig. 6.6 Concentration of Sb (in ppm) in soil horizon B shows more pronounced anomaly in the W part of the Southern Veporicum region. Sb anomaly of the SW-NE direction in the W part of the region corresponds to the part of As anomaly and it is connected with the Alpine shear zone accompanied by magnetic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

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.

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

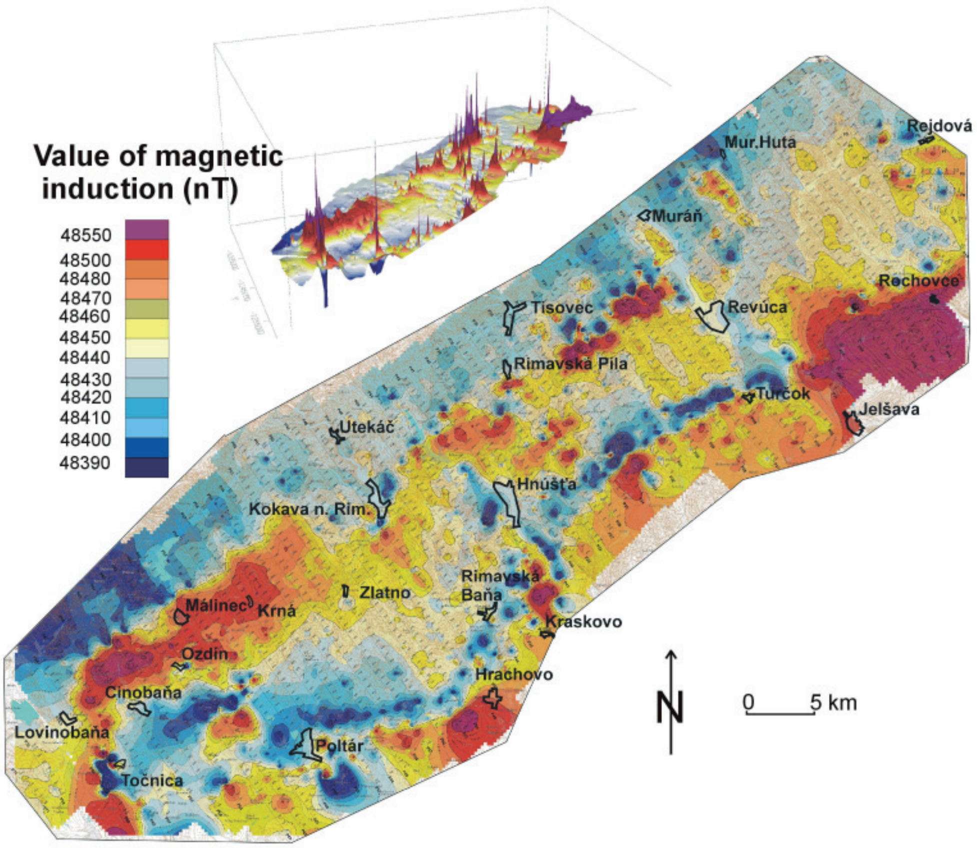

Fig. 6.7 Map of the total vector of the earth magnetic field. Magnetic anomalous zones are represented by anomaly caused by granite enriched in magnetite in the depth in the Rochovce area; magnetic masses as a part of the Ochtiná Fm. (serpentinites, metasediments with pyrrhotite) in the SE belt of anomalies; 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".

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.

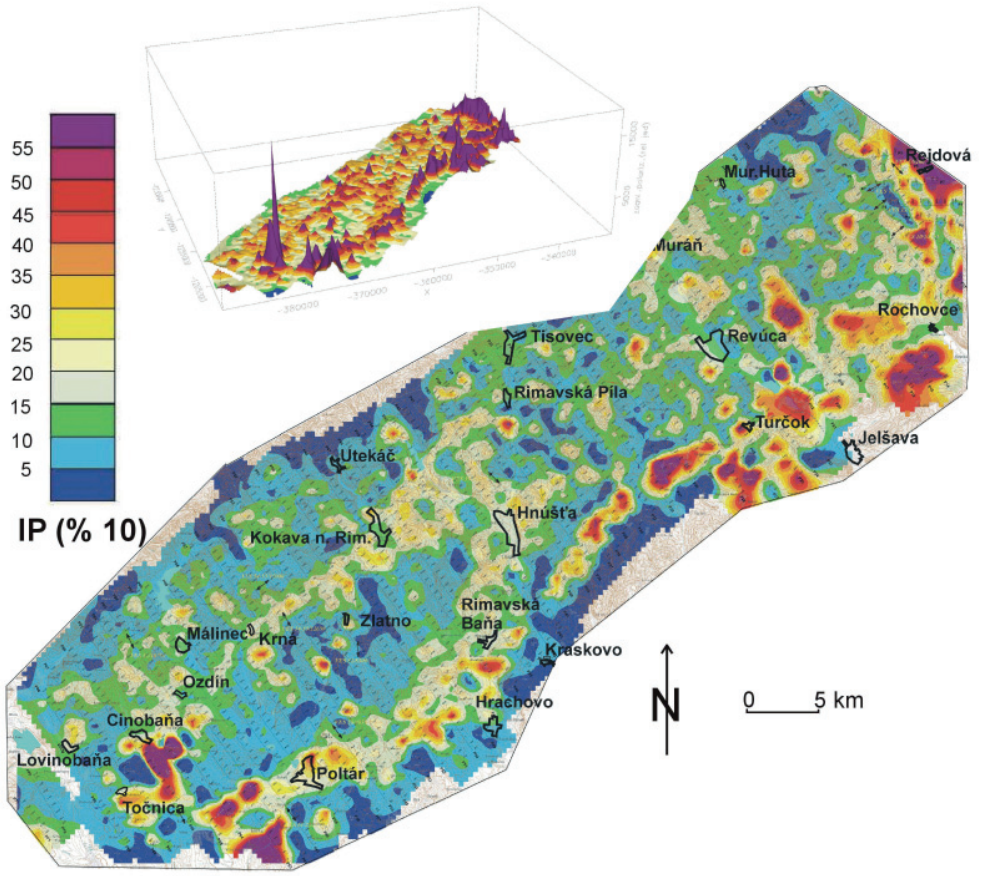

Fig. 6.8 Black and dark pelite-psammite rock complexes are reflected in the map of the induced polarization.

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).

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 $\delta^{34}S$ values are very different from those of $\delta^{34}S$ found in sulphide minerals from some other types of mineralisation in Veporicum. $\delta^{34}S$ 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* (Garguľák 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).

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.

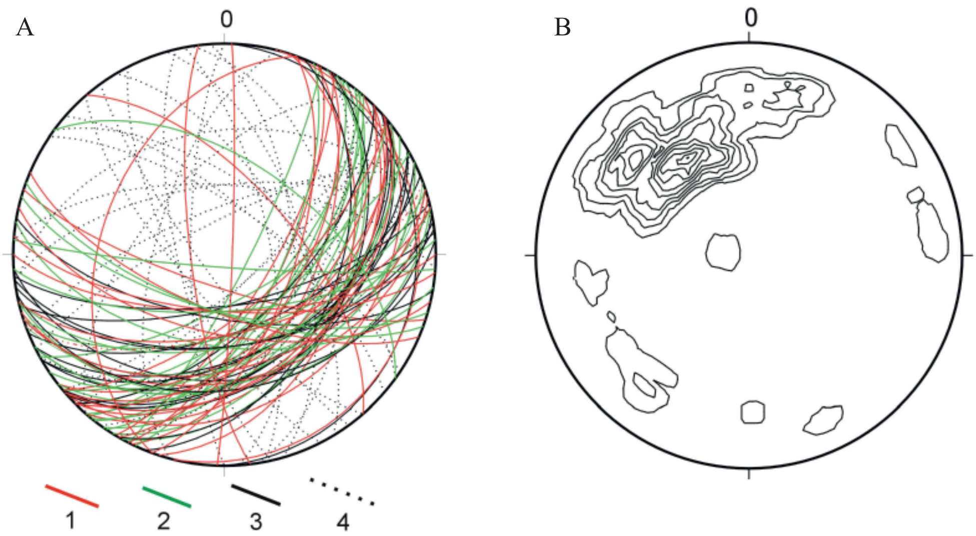

Fig. 6.9 A) Summary tectonogram of the Alpine deformation structures of the studied sites in the south-western Veporicum. B) Contour diagram of pole structures (Ferenc, 2008).

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.

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.

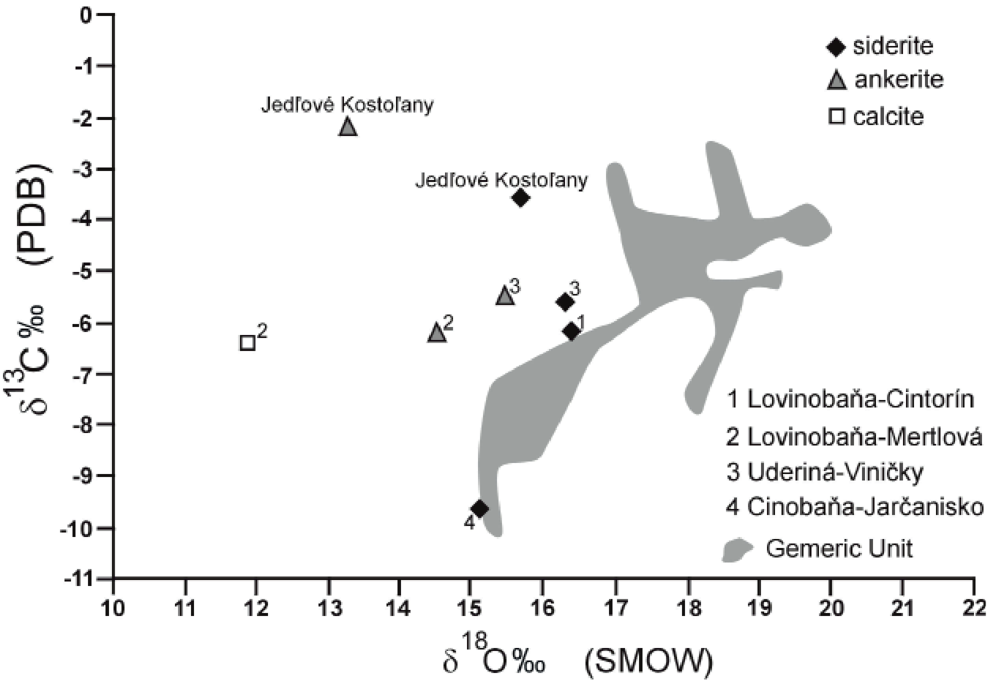

Fig. 6.10 O/C isotope ratios in carbonates veins of the area Lovinobaňa-Uderiná-Cinobaňa, compared to the occurrences in northern Veporicum (Ozdín, 2008) and Gemericum (Hurai et al., 2008a, b). According to (Ferenc et al., 2014)

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** *Turíčky – 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

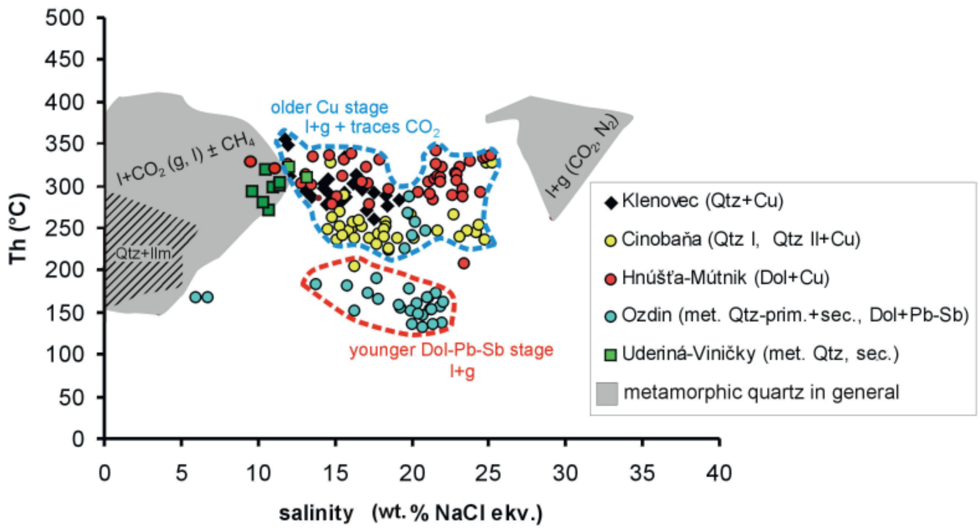

Fig. 6.11 The dependence of total homogenization temperatures and salinity of fluid inclusions in quartz and dolomite that carry ore mineralisation, compared with metamorphic quartz mineralisation (grey area) in the Southern Veporicum (Kohút zone), studied by Ferenc and Bakos.

°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-

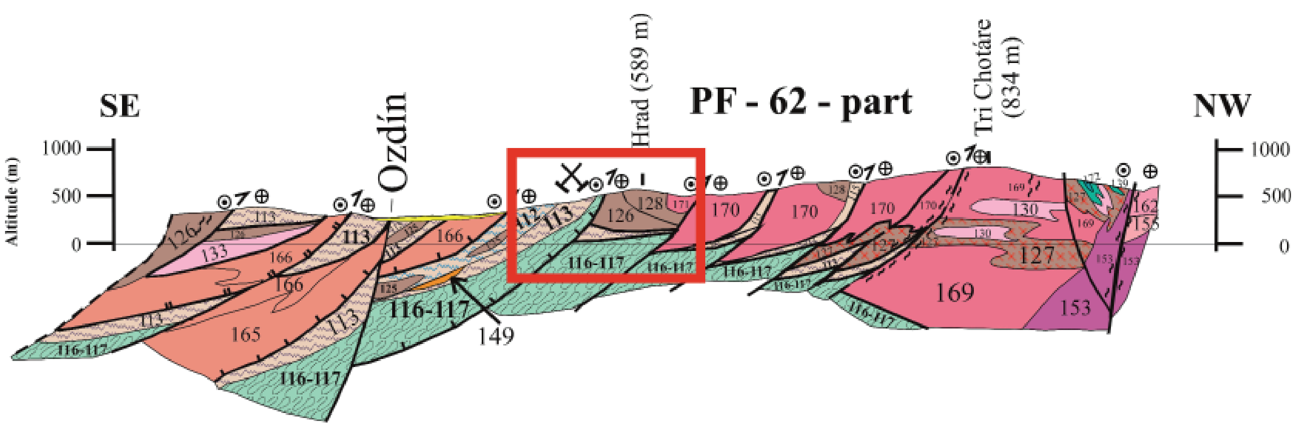

Fig. 6.12 Geological cross-section along a part of the profile no. 62 in the area south of Ozdín village toward Tri Chotáre Hill.

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; Gargulák 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

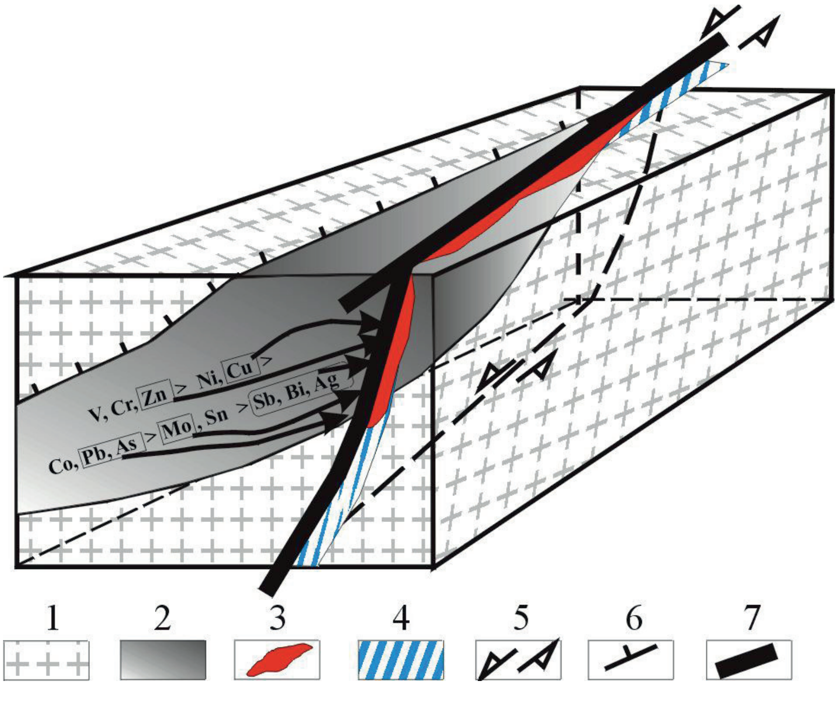

Fig. 6.13 Schematic expression of linkage of sulphide mineralisation on meta-sediments/ Hercynian granitoids within the Alpine shear zone. Metal elements under the influence of fluids migration and deformation are concentrated within a shear zone in lithotype with appropriate content of sulphophile metallic 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 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

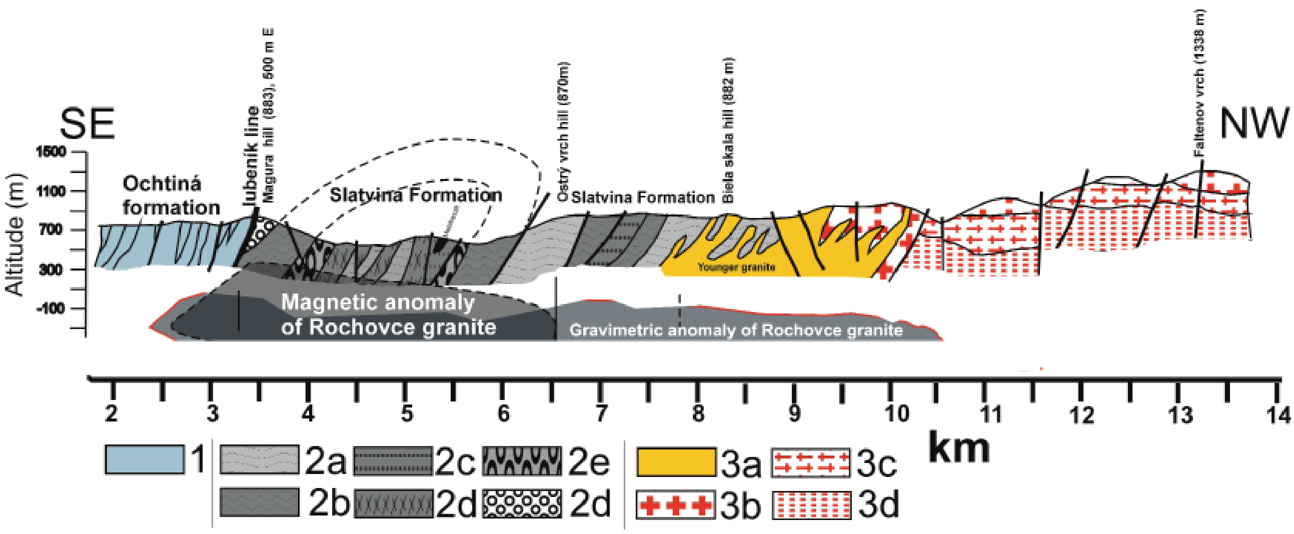

Fig. 6.14 Geological cross-section in the eastern part of the Southern Veporicum zone at the contact zone with Late Cretaceous Rochovce granite (part of profile No 16). Source of metals in the contact zone has combined origin – in metasediments of Slatvina/Ochtiná Formations and in the granite itself.

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.

References:

Bakos F., Ferenc Š. & Hraško Ľ., 2006: New occurrence of hydrothermal Au-Bi-Te mineralization in the vicinity of Krokava (Slovenské rudohorie Mts., Veporic tectonic unit). Mineralia Slovaca, 38, p. 241-252. (In Slovak).

Bezák V., 1982: Metamorphic and granitoid complexes in Kohút zone of Veporides (Western Carpathians). Geologické práce, Správy, 78, p. 65-70. (In Slovak).

Bezák V., Jacko S., Janák M., Ledru P., Petrík I. & Vozárová A., 1997: Main Hercynian lithotectonic units of the Western Carpathians. In: Grecula P. et al. (Eds.): Geological evolution of the Western Carpathians. Mineralia Slovaca, Bratislava, p. 261-268.

Chovan M., Hurai V., Putiš M., Ozdín D., Pršek J., Moravanský D., Luptáková J., Záhradníková J., Kráľ J., & Konečný P., 2006: Sources of fluids and genesis of mineralisations in Tatricum and Northern Veporicum. Interim final report. Manuscript. 254 p. (In Slovak).

De Ronde C., E., J., Faure K., Bray C., J. & Whitford D., J., 2000: Round Hill shear zone-hosted gold deposit, Macraes Flat, Otago, New Zealand: evidence of a magmatic ore fluid. Economic Geology, 95, p. 1025-1048.

Ferenc Š. & Bakos F., 2006: Au-Bi-Te mineralization in the Sinec shear zone, Kokava nad Rimavicou: New type of mineralization in the Western Carpathians. Mineralia Slovaca, 38, p. 223-240. (In Slovak).

Ferenc Š. & Dzúrová M., 2015: Mineral phases of the berthierite-garavellite series from the Klenovec-Medené occurrence (Slovenské Rudohorie Mts. – Veporic Unit), Slovak Republic. Acta Geologica Slovaca, 7, 1, p. 29–36.

Ferenc Š. & Maťo Ľ., 2003: Epigenetic gold and sulphides mineralization in the southwestern part Veporicum. In: Mineralogie Českého masivu a Západních Karpat, Olomouc, p. 10-16. (In Slovak).
Ferenc Š. Bakos F. & Vavrová J., 2006a: Supergene Au-mineralization in Katarínska Huta (Slovak Ore Mts., Veporic Unit). Mineralia Slovaca, 38, p. 99-108. (In Slovak).
Ferenc Š., 2008: Metallogenic aspects of the Alpine collision-extension zone Veporicum (West Side). Manuscript, Archive PRIF UK – Bratislava, Archive SGIDS, Bratislava, 306 p. (In Slovak).
Ferenc Š., Bakos F., Demko R. & Koděra P., 2014: Siderite (Fe carbonate) and quartz-sulphidic mineralization occurrences near Lovinobaňa and Uderiná (Slovenské Rudohorie Mts.-Veporic Unit), Slovak Republic. Bull. mineral.-petrolog. Odd. Nár. Muz. (Praha) 22, 1, p. 25-41. (In Slovak).
Ferenc Š., Bakos F. & Maťo, Ľ., 2004: Metallogenetic development of ore mineralization in the Northern and North-western parts of the Sinec Mt., Slovenské Rudohorie Mts, the Veporic (preliminary results) In: Mineralógia Západných Karpát a Českého Masívu, Bratislava, p. 25-29. (In Slovak).
Ferenc Š., Ozdín D., Bakos F. & Siman P., 2006b: Siderite and sulphidic mineralization at the Cinobaňa – Jarčanisko occurrence, Slovenské Rudohorie Mts., Slovak Republic. Mineralogia Polonica, Krakow, p. 69-71.
Ferenc Š., Uher P. & Spišiak J., 2011: Mineralogy of listvenite from Muránska Zdychava at Revúca (Slovenské rudohorie Mts., Veporicum. In: Verner, K., Budil, P., Buriánek, D., Sborník abstraktů z II. otevřeného kongresu České Geologické Společnosti a Slovenské Geologické Společnosti, Monínec, 21. – 25. 9. 2011, p. 33. (In Slovak).
Finger F., Broska I., Haunschmid B., Hraško Ľ., Kohút M., Krenn E., Petrík I., Riegler G. & Uher P., 2003: Electron-microprobe dating of monazites from Western Carpathian basement granitoids: plutonic evidence for an important Permian rifting event subsequent to Variscan crustal anatexis. Int. Jour. Earth Sci., 92, 2003, 1, p. 86-98.
Galko I., Michálek J., Gembalová M., Ilkanič A., Čunderlík M., Filo J., Plašienka D., Marko F., Soták J., Mudráková M., Smrek M., Tuček Ľ., Šucha V., Müller R., Detko M., Pitoňak P., Verseghy R., Bartek J. & Blašková I., 2002: Search of surface workable deposit of magnesite in Central Slovakia. SGIDŠ Archive. 88 p. (In Slovak).
Gargulák M. & Rojkovičová Ľ., 1993: Mineralogical and geochemical paragenetic research and prospection in the contact zone of Gemericum and Veporicum. Interim final report. SGIDŠ Archive Bratislava, 63 p. (In Slovak).
Gargulák M., Hraško Ľ., Vozárová A., Hók J., Madarás J., Maťo Ľ., Beňka J., Határ J., Repčok I., Harčová E., Kovarová A., Ferenčíková E., Slavkay M., Kanda J., Drlička R., Boorová D. & Novotný L., 1995: Patterns and locations of ore deposits in the contact zone of Veporicum and Gemericum). Interim final report. Geofond Bratislava, 99 p. (In Slovak).
Grecula P., 1982: Gemericum – segment of riftogenic basin of Paleothetys. Mineralia Slovaca. Monogr. Alfa, Bratislava, 263 p. (In Slovak).
Grecula P., Abonyi A., Abonyiová M., Antaš J., Bartalský B., Bartalský J., Dianiška I., Drnzík E., Ďuďa R., Gargulák M., Gazdačko Ľ., Hudáček J., Kobulský J., Lörincz L., Macko J., Návesňák D., Németh Z., Novotný L., Radvanec M., Rojkovič I., Rozložník L., Rozložník O., Varček C. & Zlocha J., 1995: Deposits of the Slovenské rudohorie Mts., Vol. 1. Mineralia Slovaca, Košice, 829 p. (In Slovak).
Határ J., Hraško Ľ. & Václav J., 1989: Hidden granite intrusion near Rochovce with Mo(-W) stockwork mineralization (first object of its kind in the West Carpathians). Geol. Zbor. Geol. Carpath., Bratislava, 40, 5, p. 621-654.
Hodgson C., J., 1989: The structure of shear-related, vein type gold deposits: a review. Ore Geology Reviews, 4, p. 231-273.
Hraško Ľ., Bezák V. & Molák B., 1997: Postorogenic peraluminous two-mica granites and granite-porphyries in the Kohút zone of the Veporium (Klenovec-Zlatno area). Mineralia Slovaca., 29, p. 113-135. (In Slovak).
Hraško Ľ., Határ J., Michalko J., Huhma H., Mäntäri I. & Vaasjoki M., 1999: U/Pb zircon dating of the Upper Cretaceous granite (Rochovce type) in Western Carpathians. Krystalinikum, (Brno), 25, p. 163-171.
Hraško Ľ., Kucharič Ľ., Maťo Ľ., Ferenc Š., Findura Ľ. & Konečný P., 2005: Estimation of geological resource potential of the Slovenské rudohorie Mts. - West and the possibility of its use for the development of the region, Part 3 – soil-geochemical part. Final report SGIDŠ Archive, 130 p. (In Slovak).
Hraško Ľ., Madarás J., Németh Z., Kováčik M., Siman P., Demko R., Kráľ J., Maglay J., Šimon L., Nagy A., Vozárová A., Radvanec M. & Putiš M., 2005: Estimation of geological resource potential of the Slovenské rudohorie Mts. – West and the possibility of its use for the development of the region, Part 1 – geology. In. Hraško, Ľ. et al. Final report. SGIDŠ Archive, 130 p. (In Slovak).
Hurai V. & Horn E. E., 1992: A boundary-layer induced immiscibility in naturally re-equilibrated H_2O-CO_2-NaCl inclusions from metamorphic quartz (Western Carpathians, Czechoslovakia). Contrib. Miner. Petr. 112, p. 414-427.
Hurai V., 1983: Fluid inclusions in quartz from alpine type fissures of Veporic crystalline and their genetic interpretation. Mineralia Slovaca, Bratislava, 15, 3, p. 243-260. (In Slovak).
Hurai V., Harčová E., Huraiová M., Ozdín D., Prochaska W. & Wiegerová V., 2002: Origin of siderite veins in the Western Carpathians I. P–T–X–$\delta^{13}C$–$\delta^{18}O$ relationship in ore-forming brines of the Rudňany deposit. Ore Geol. Reviews, 21, p. 67-101.
Hurai V., Klaus S. & Bezák V., 1997: Contrasting chemistry and H, O, C isotope composition of greenschist-facies, Hercynian and Alpine metamorphic fluids (Western Carpathians). Chemical Geology, 136, p. 281-293.
Hurai V., Lexa O., Schulmann K., Montigny R., Prochaska W., Frank W., Konečný P., Kráľ J., Thomas R. & Chovan M., 2008b: Mobilization of ore fluids during Alpine metamorphism: evidence from hydrothermal veins in the Variscan basement of Western Carpathians, Slovakia. Geofluids 8, p. 181-207.
Hurai V., Prochaska W., Lexa O., Schulmann K., Thomas R. & Ivan P., 2008a: High-density nitrogen inclusions in barite from a giant siderite vein: implications for Alpine evolution of the Variscan basement of Western Carpathians, Slovakia. Jour. Metam. Geol. 26, p. 487-498.
Hvožďara P., 1979: Strata-bound scheelite in the Veporide crystalline. Mineralia Slovaca, 11, Bratislava, p. 77-78. (In Slovak).
Hvožďara P., 1999: Gold placers in the Western Carpathian area. Mineralia Slovaca, 3-4/31, p. 241-248. (In Slovak).
Jeřábek P., Faryad W.S., Schullmann K., Lexa O. & Tajčmanová L., 2008: Alpine burial and heterogenous exhumation of Variscan crust in the West Carpathians: insight from thermodynamic and argon diffusion modeling. Jour. Geol. Soc., 165, p. 479-498.
Kantor J. & Ďurkovičová J., 1977: Isotope composition of sulphur and structural modifications of pyrrhotite from sulphidic deposits of various genetic types. Západné Karpaty, sér. miner., petr., geoch., ložiská, 3, p. 7-56. (In Slovak).
Kantor J. & Petro M., 1976: On some sulphidic mineralization in the Veporide crystalline from Ratkovské Bystré and Revúca and their isotopic composition. Geol. zborník, 27, 1, Bratislava. (In Slovak).

Kantor J., 1955: Finding of hübnerite near Chyžné in the Spiš-Gemer Ore Mountains. Geol. Pr. Spr., Bratislava, 3., p. 58-78. (In Slovak).

Klinec A., 1966: Problems of the setting and evolution of Veporicum crystalline. Sbor. geol. vied, Západ. Karpaty, Bratislava, 6, p. 7-28. (In Slovak).

Klinec A., Macek J. & Dávidová Š., 1980: Rochovce granite in continuous zone between Gemeric and Veporic zone. Geol. Práce-Správy, Bratislava, 74, p. 103-112. (In Slovak).

Kohút M., Stein H., Uher P., Zimmerman A. & Hraško Ľ., 2013: Re-Os and U-Th-Pb dating of the Rochovce granite and its mineralization (Western Carpathians, Slovakia). Geologica Carpathica, Vol. 64, No 1, p. 71-79.

Kováčik M. & Husák Ľ., 1996: Petrographic-geochemical characteristic, hydrothermal effects and magnetic properties of rocks from KH-1 borehole. Manuscript, SGIDŠ Archive. 45 p. (In Slovak).

Kováčik M. 1996a: Kyanite – Mg-chlorite schist and its petrogenetic significance (Sinec Massif, Southern Veporic Unit, Central Western Carpathians). Geol. Zb. Geol. Carpathica, 47, p. 245-255

Kováčik M., 1996b: Metamorphic rocks in the Souther Veporicum basement: their Alpine metamorphism and thermochronologic evolution. Mineralia Slov., Bratislava, 28, p. 185-202. (In Slovak).

Kováčik M., 2000: Petrogenesis of metamorphosed ironstones near Kokava nad Rimavicou (Veporicum, Western Carpathians). Slovak Geol. Mag., 6, 4, p. 367-376.

Kucharič Ľ., Kubeš P., Hraško Ľ. & Maďar D., 2005: Estimation of geological resource potential of the Slovenské rudohorie Mts. - West and the possibility of its use for the development of the region, Part 2 - geophysics. In: Hraško, Ľ. et al. Final report. SGIDŠ Archive, 89 p. (In Slovak).

Lexa J., Bačo P., Hurai V., Chovan M., Koděra P., Petro M., Rojkovič I. & Tréger M., 2007: Explanations to the metallogenetic map of SR. SGIDŠ, Bratislava p. 1-178. (In Slovak).

Maťo Ľ. & Maťová V., 1993: Gold mineralization of shear zones of the Uderiná prospect, southwestern part of the Veporicum crystalline complex, Central Slovakia. Mineralia Slovaca, 25, p. 327-340. (In Slovak).

Maťo Ľ. & Maťová V., 1994: Mineralization near Ozdín, occurrence of gold with Sb-Ni content in black shales, southwestern part of the Veporicum crystalline complex, Central Slovakia. Mineralia Slovaca, 26, p. 30-37. (In Slovak).

Molák B., Hraško Ľ. & Dovina V., 1990: Thematic geological mapping and petrographic research in the W part of the contact zone of Veporicum and Gemericum. Manuscript – SGIDŠ Archive, Bratislava, 92 p. (In Slovak).

Németh Z., Prochaska W., Radvanec M., Kováčik M., Madarás J., Koděra P. & Hraško Ľ., 2004: Magnesite and talc origin in the sequence of geodynamic events in Veporicum (Inner Western Carpathians, Slovakia). Acta Petrologica Sinica, China, 20, 4, p. 837-854.

Ondrejka M., Uher P., Pršek J. & Ozdín D., 2007: Arsenian monazite-(Ce) and xenotime-(Y), REE arsenates and carbonates from the Tisovec-Rejkovo rhyolite, Western Carpathians, Slovakia: Composition and substitutions in the $(REE,Y)XO_4$ system (X = P, As, Si, Nb, S). Lithos, 95, 1-2, p. 116-129.

Ozdín D., 2008: Mineralogy and genetical study of hydrothermal siderite-quartz-sulphidic veins in Jedľové Kostoľany, the Tribeč Mts. (Slovak Republic). Mineralogia-spec. papers 32, 122 p.

Petro M., Komoň J., Filo M., Mudráková M., Kráľ J., Kováčik M., Hraško Ľ., Očenáš D., Lafférs F. & Lukaj M., 1998: Muráň – Tisovec – Mo, exploration. SGIDŠ Archive, 254 p. (In Slovak).

Platt J., P., 1984: Secondary cleavages in ductile shear zones. Journal of Struct. Geol., 6, p. 439-442.

Radvanec M., 2000: Metapelite, amphibole schists and origin of magnetite-graphite mineralization in Veporicum near Kokava nad Rimavicou. Mineralia Slovaca, 32, p. 1-16. (In Slovak).

Slavkay M. & Petro M., 1993: Metallogenesis and ore formations of the Veporicum. Mineralia Slovaca, 25, p. 313-317. (In Slovak).

Slavkay M., 2005: Geochemical properties of selected Paleozoic formations - bearers of stratiform mineralization in Veporicum and Tatricum. Slovak Geological Magazine, 11, 2-3, p. 77-90.

Slavkay M., Beňka J., Bezák V., Gargulák M., Hraško Ľ., Kováčik M., Petro M., Vozárová A., Hruškovič S., Knésl J., Knéslová A., Kusein M., Maťová V. & Tulis J., 2004: Deposits of the Slovenské rudohorie Mts., Vol. 2. SGIDŠ, Bratislava, 286 p. (In Slovak).

Uher P., Ferenc Š. & Spišiak J., 2013: Cr-Ni rich muscovite in listvenite from Muránska Zdychava near Revúca (Slovenské rudohorie Mountains, Central Slovakia). Bull. mineral.-petrolog. Odd. Nár. Muz., Praha, 21, 1, p. 62-66. (In Slovak).

Urban E., E., Thomas R., Hurai V., Konečný P. & Chovan M., 2006: Superdense CO_2 inclusions in Cretaceous quartz-stibnite veins hosted in low-grade Variscan basement of the Western Carpathians, Slovakia. Miner. Dep. 40, p. 867-873.

Vozárová A. & Vozár J., 1982: New lihostratigraphy units in the southern part of Veporicum. Geol. Práce, Spr., 78, GIDŠ, Bratislava, p. 169-194. (In Slovak).

Vozárová A. & Vozár J., 1988: Late Paleozoic in West Carpathians, GIDŠ, Bratislava, 314 p.

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7. Internet Applications of Exploration Areas, Deposits and Old Mining Works in the Slovak Republic

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Abstract: The paper is devoted to the history and creation of registers of exploration areas, deposits, old mining works and deposits exploration. It describes the Internet applications of deposits registers and their functionality and shows possibilities of development of Internet applications in the future. The assessment of the importance of deposits applications for different user groups is presented.

Key words: Deposits, exploration areas, deposits applications, old mining works, deposits exploration level

7.1. Introduction

The raw mineral deposits Internet applications developed by SGIDŠ were discussed in brief in the previous issue of SGM (Káčer et al., 2015). However, we think that this SGM issue, which is thematically focused on the results of economic geology in Slovakia, should discuss the deposits problematics in detail to complement the mosaic of knowledge. In the present article, we will go back into the history of deposits registers creation, which are the basis of the recent Internet applications. We will try to bring forward our vision for the potential development of applications in the future.

The registers and their creation are directly defined in the Act. 569/2007 on Geological Works (Geological Act), as amended by further legislation. Deposits (exclusive and non-reserved) and old mining workings are described in detail in the Act. 44/1988 Coll. on the Protection and Utilization of Mineral Resources (hereinafter referred to as the Mining Act).

In a Department of Geological Exploration there are kept 10 registers of various themes within geology. Of this number three registers were published by April 15, 2009, through Internet applications. These registers were associated with raw mineral deposits, namely the registers of Exploration Areas, Deposits and Old Mining Works (Kúšik, 2010). In 2014 the last Internet application was launched – deposits exploration level.

7.2 History of deposit registers

7.2.1. Register of Exploration Areas

The institute of exploration area was introduced in the geological legislation of the Slovak Republic. The exploration area (EA) shall be determined for organizations applying for a permission to survey a proposed territory for selected exclusive raw mineral(s). The whole process from design to licensing or rejecting the EA is supervised by the Ministry of Environment of the Slovak Republic (MoE), Section of Geology and Natural Resources, through administrative proceedings. The Department of Geological Exploration is authorised to keep a register of proposed, determined, blocked/cancelled EAs. Since the launching of the register the process of digitisation of EAs layer for the needs of statements on the proposals for determination has begun. At the end of the 90s of the 20th century it was created the first fully functional geographic information system (hereinafter referred to as GIS) of EAs, which with minor modifications (due to the then software options) is functional today. Currently (by October 2015) the register keeps 9 proposed EAs and 97 determined EAs.

7.2.2. Deposits Register

Deposits Register currently keeps the records of the exclusive deposits (deposits of reserved minerals; the deposits are the property of SR) and deposits of non-reserved raw minerals (the deposit is the property of the owner of the land). This register was developed since the establishment of Geofond, i.e. since the beginning of 60s of the 20th century. The whole register was kept in analogue form on passports of deposits in which there were processed data about individual raw minerals. Mining areas (MAs), protected deposit areas (PDAs), as well as the calculated blocks of exclusive deposits were drawn in military maps at 1:25 000 scale. First attempts with digitisation of this information layer are dated back to 90s, but complete GIS was established only in 2002 in the scope of the geological project "Relationship between Rock Environment and Nature and Landscape Protection" (Kúšik, Lamoš, 2002), whose main objective was to create layers of mining areas (MA) and the protected deposit areas (PDAs) and finding their intersections with protected areas of nature and landscape (small scale and large scale protected areas). Register of reserved deposits is a "living" system (new deposits are incorporated, some deposits are cancelled, and some deposits are changing their boundaries, owners, etc.) and therefore it was necessary to ensure regular updating of data in a digital version (Kúšik, 2010). This shall be ensured on the basis of the decision to change the boundaries of MAs, PDAs and depreciation of reserves that are within the competence of individual district mining offices (DMO), as well as the statistical statements Geo 3-01 that are regularly sent out by the Department of Geological Exploration to mining organizations at the beginning of calendar year. Based on them "Balance of Deposits of Exclusive Raw Minerals in SR" is published each year. In 2006 a layer of non-reserved minerals (NRM) was added into the GIS, which are the property of the land owner (Kúšik, Mižák, 2009). The layer of non-reserved mineral deposits is compiled based on statistical statements Geo 3-01 that are regularly sent to mining organizations at the beginning of the calendar year. On their basis "Evidence of Deposits of Non-Reserved Minerals in SR" is issued yearly. Currently (by October 2015), the register consists of 641 exclusive deposits and 497 non-reserved deposits.

7.2.3. Register of Old Mining Works

The register in its present form has been built based on the results of the project "Slovakia - Design of Remediation of Old Mining Works (OMW) – Inventory, Search Survey, as of 31.12.1996" (Repčiak et al., 1996), whose main purpose was assessment and inventory of OMW occurrences throughout the country outside the designated MAs, evaluation of their impact on the environment and design of remediation in the case of their current negative status and manifestations at the surface. After the project completion the results of the inventory were digitally processed in Geofond Bratislava. When updating the register in the following years we have tried to incorporate in the register the mining works located within determined MAs, for example, Kremnica, Banská Štiavnica, Liptovská Dúbrava, which are currently under the Mining Act perceived as the main mining works. Within the determined MAs, we have managed to process the portion of mine works in the form of galleries courses as a line layer, which has been integrated into the GIS (Fig. 7.7). Other old workings are kept as a point layer. Currently (by October 2015), the register consists of 19,068 objects.

7.2.4. Register of Deposits Exploration

The register of deposits exploration has been developed along with the deposit register since the beginning of 60s of the 20[th] century. It was formed based on final reports with the calculation of reserves and deposits studies. It includes deposits written-off from the register of deposits of reserved minerals, forecast of deposits sources as well as other non-balanced deposits, occurrences, negative surveys and worked-out deposits (historical sites). The register is kept in analogue form on passports and situations are plotted in military maps at 1:25,000. The first attempts of a complex processing of the register into a functional GIS are dated back at the turn of the 20[th] and 21[st] centuries. The register in GIS environment was completed in 2013. At present (by October 2015), the register consists of 7,922 objects of deposits exploration, plotted in the form of polygons, points and lines.

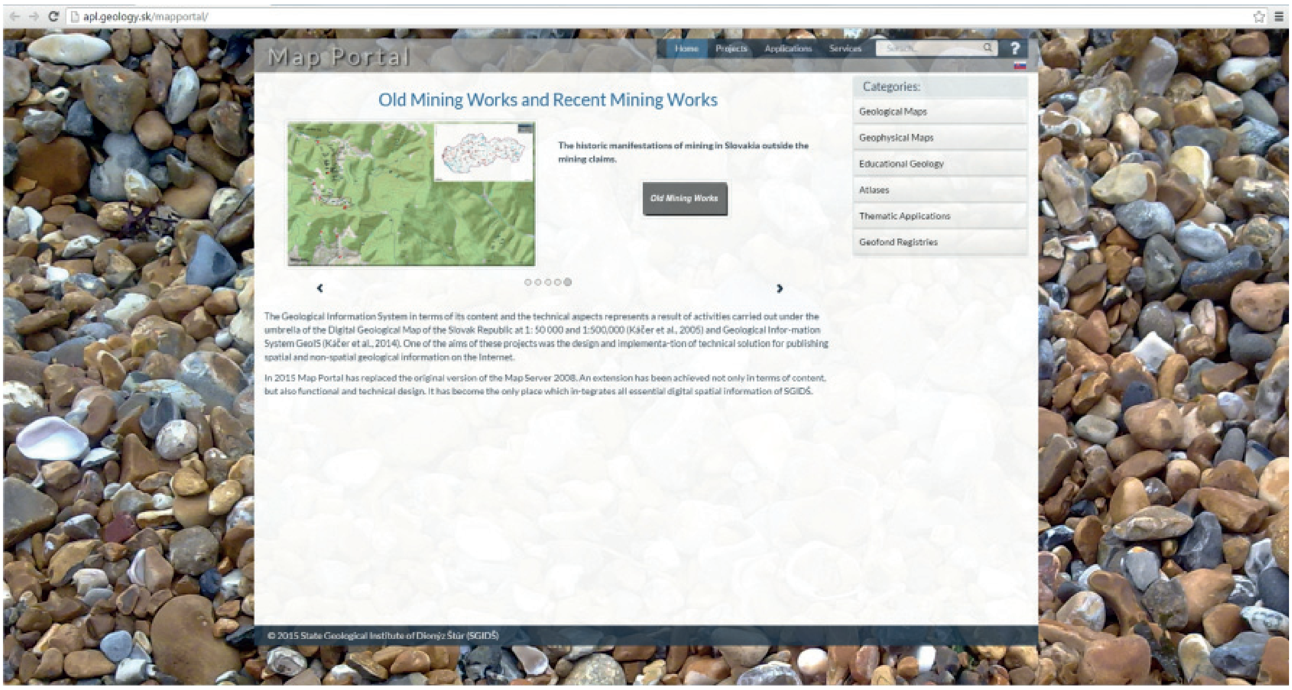

Fig.7.1 "Gateway" of redesigned Map Portal of SGIDŠ on www.geology.sk.

7.3. Internet Applications of Deposits Registers

All of the register applications are included on the Map Portal of SGIDŠ under button "Geofond Registries".

We will not discuss the technical solutions, cataloguing and data models in this article because these issues were described in detail in the previous issue of the SGM magazine (Káčer et al., 2015). We would like to point out that all the applications presented in the article are viewable without any installation and using any web browser.

All deposit applications offer a navigation menu that is almost the same for all applications, slight variations are explained in the individual applications. The naviga-

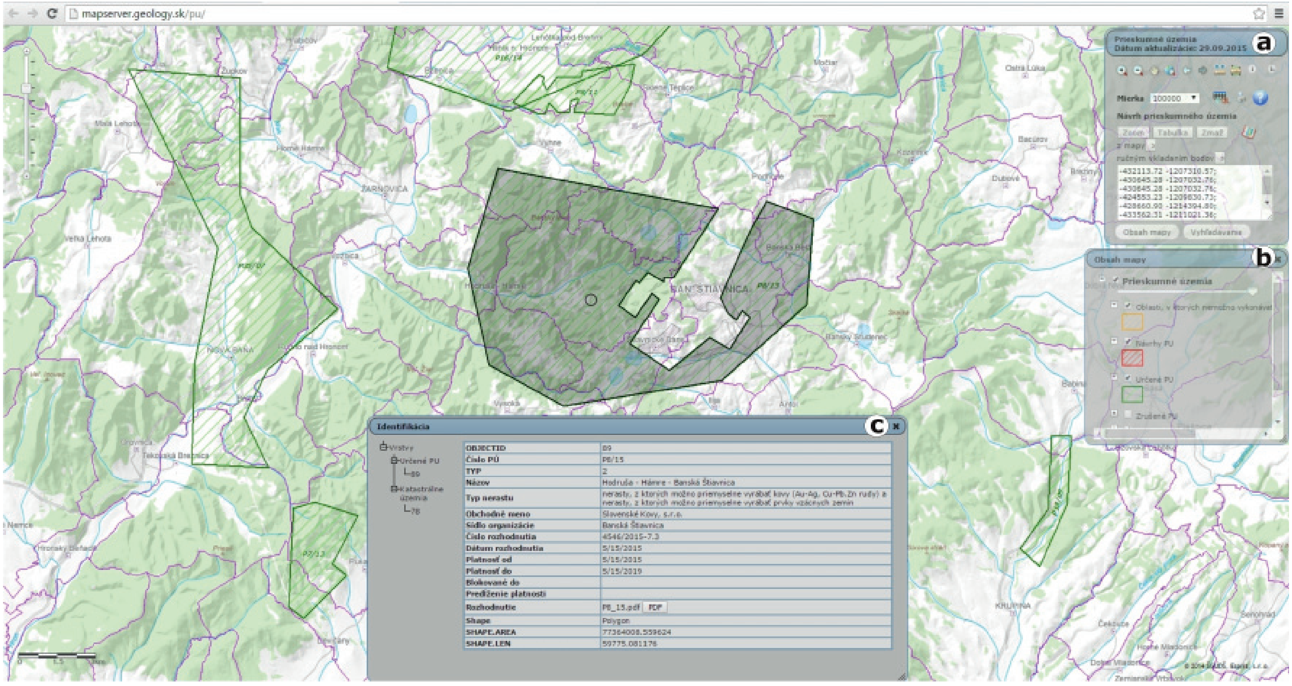

Fig. 7.2 Visualisation of exploration area Hodruša – Hámre – Banská Štiavnica. a – Navigation menu of Exploration Areas; b – Map Legend; c – Identification – fundamental attribution table with the "explanation" of the reference.

tion menu contains: the zoom function (magnifying glass "zoom in"), distancing function (magnifying glass "zoom out"), the function enabling to shift a map with hand (pan), the function return to the initial screen depiction (full extent), function of previous display (zoom previous), function of next display (zoom next), function distance measurement, function of measurement of areas, key ID when pressed pops attribution table, key identification for the selected area by pressing pops attribution table of all objects in a designated area, the fixed scale, function SQL search box, button printing and with the question mark button that redirects us to the metadata for the application.

7.3.1. Internet Application – Exploration Areas

The first application is also a symbolic first step in finding the accumulation of reserved minerals - mineral deposits. The basic EAs division is also respected in the present application, with separate layers of proposed, designed, blocked/cancelled EAs (Fig. 7.2.a,b). Separate information layer represent areas without a permission to carry out geological exploration for deposits of oil and natural gas. For each object (polygon) in the designated EAs it is assigned a simple base table (Fig. 7.2.c) with the following information on EA: ID of EA, Name, Type of mineral, the Name of the holder of EA and its seat, Number of the decision on the determination, Decision date, Valid from to, Blocked until, Extension. To the base table there is attached all written agenda (scanned documents on the determination, modification, cancellation of EA) in the pdf.format (Acrobat Reader). Part of the application is also SQL search according to selected various search criteria, as well as other interesting tools useful especially for the applicants of EAs. A unique tool that enables a rapid design of map annexes to the proposed EA is a key Draft of exploration area on the map, or manual insert of points (Fig. 7.3 a,b). This button also allows the calculation of the percentage of municipalities and areas intersecting with proposed EA after drawing a polygon on the map and pressing the "Tabuľka" [Table] button (Fig. 7.3 c). Application for less experienced users also includes a key "Príručka" [Manual] (Fig. 7.3 a) in which there are described all the possibilities for applications. The application is constantly updated – the date of the last update is part of the application. (Kúšik, 2010).

7.3.2. Internet Application - Deposits

Deposits application is represented by layers of mining areas (MAs), protected deposit area (PDAs), deposits with issued certificates on exclusive deposit (CED), which fall within the category of exclusive deposits. Specific layer displays deposits of non-exclusive minerals. For each object (polygon) there is assigned a simple base table with the following information on the deposit: ID of a deposit from the publication BZVL SR (Balance of Reserves of Exclusive Minerals Deposits of SR), Name of deposit, Mineral, Organization name and address, Recent status of the deposit in terms of its exploiatation. In the external table (Fig. 7.4. b), which is linked to the basic one by pushing the key "Chemická kvalita" [Chemical quality] we will get essential data on industrial minerals. The button "Prevod" [Transfer] (Fig. 7.4 c) allows the user to get an overview of transfers among mining organizations. Legal status is represented by buttons "Určenie" [Designation], "Zmena" [Amendment] and "Zrušenie" [Cancellation of EA/PDA], reserves Z and ABC. Key "Z rozhodnutia" [Decision] gives us information on reserves as of the Decision approving the reserves at a certain date (these are freely available) and the current reserves of the last BZVL SR hide the button "Aktuálne" [Current] (these are intended only to authorized users). The

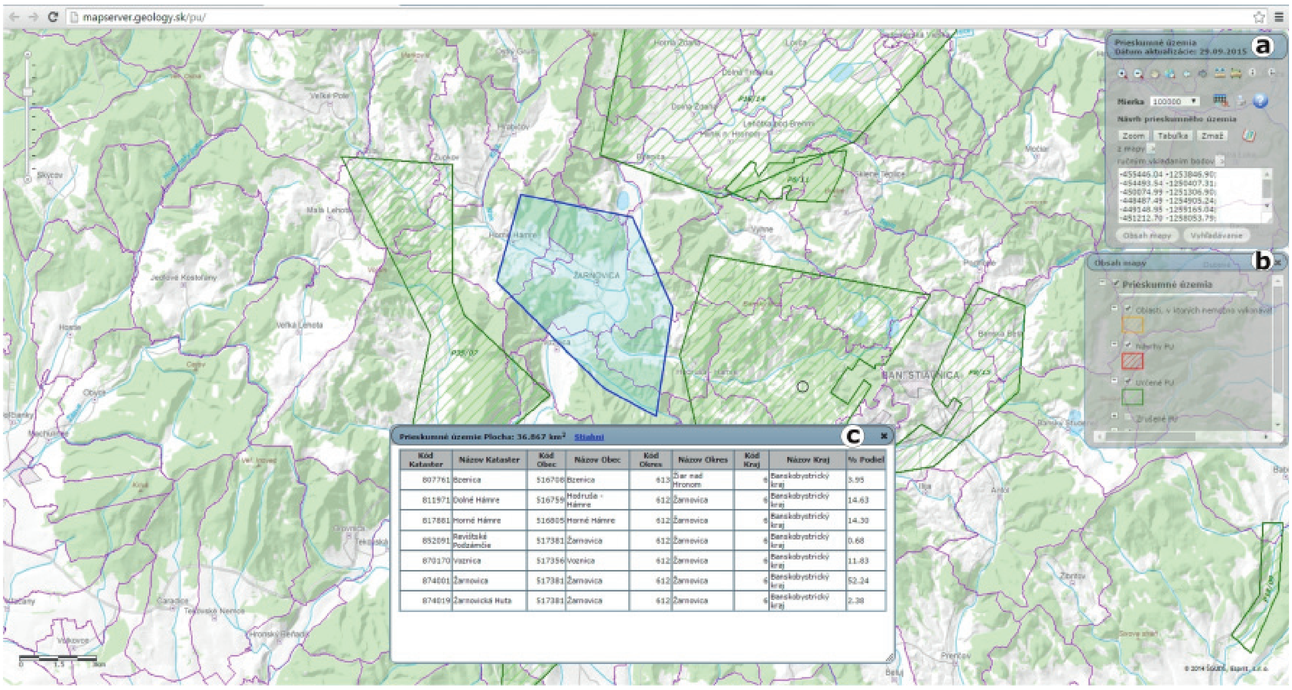

Fig. 7.3 A simple example of the map data to EA design to the table shares villages a – Navigation menu of Exploration Areas; b – Map Legend; c – Identification – fundamental attribution table.

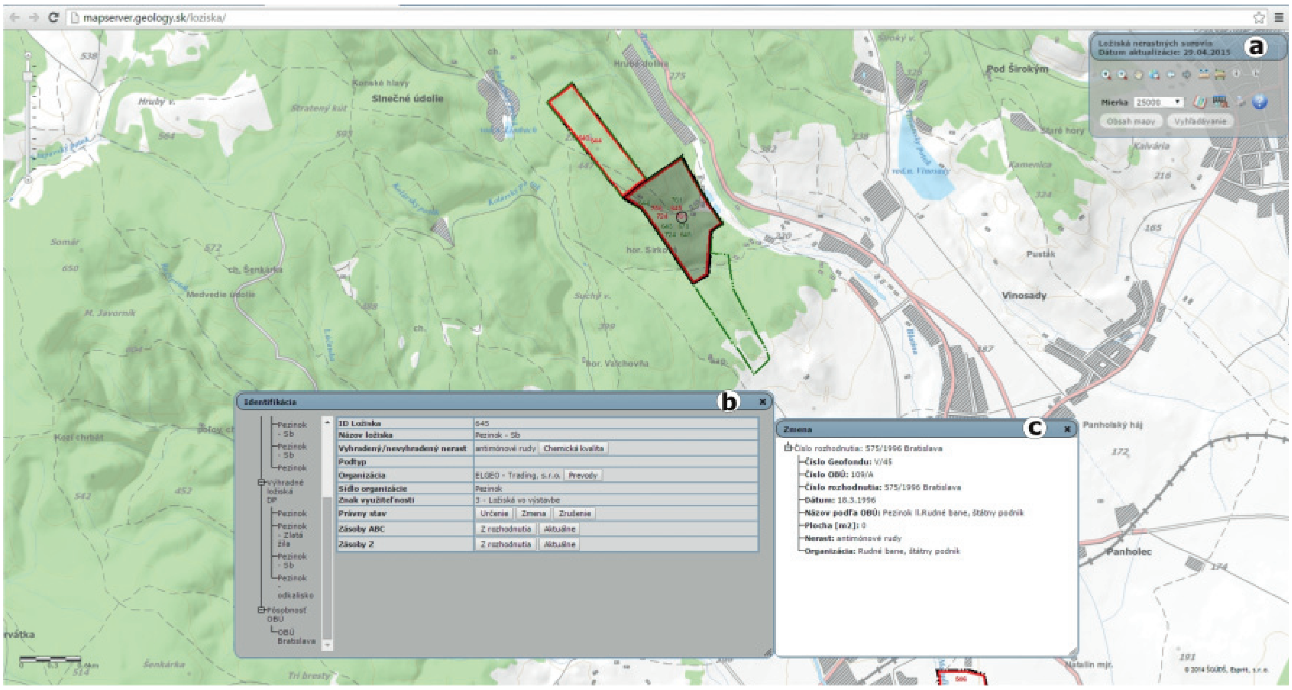

Fig. 7.4 Basic table with "highlighted" Sb ore deposit Pezinok on the map. a – Navigation menu of Raw Minerals Deposits; b – Identification – fundamental attribution table, c – Attribute table documenting any amendments of status.

application includes also the SQL search by various selected search criteria, as well as printing of a displayed map window with an automatically generated Legend (deposits located in the reporting cutout, Fig. 7.5 b). The application is being continuously updated – last updated is part of the application (Kúšik, Mižák, 2009).

7.3.3. Internet Application – Old Mining Works and Recent Mining Works

The Old Mining Works (OMW) application introduces the manifestations of historical mining activities in the Slovak Republic with the exemption of Exploration areas and Mining areas as of 1996 (for clarity they are included in the application as separate layers). For the purpose of the application the tags (Fig. 7.6 b) were created for different types of OMWs, which are based on mining geodesy regulations. Each object (point, line) has assigned a simple base table with the basic characteristic of OMW: Object ID, Name, Object Type, Specification of raw materials, Remediation and Estimated size of the object (Fig. 7.6 c). Similarly to previous applications there can be used SQL search and printing of displayed composition (Kúšik, 2010).

7.3.4. Internet Application – Deposit Exploration Level

Application Deposit Exploration Level is a component of particular application Exploration Degree along with the geological mapping and geophysical works. For each object (polygon, line and point) there is assigned a simple attribution table with the following information on the deposit: Object ID, Type – distinguishing among the U-ores, industrial minerals, coal, ores and construction materials, Mineral – further geological characteristics according to the Geological Law, Category – Prognose, Deposits with reserves, Occurrences, Negative exploration, Object`s name, Archival number and map sheet (Fig. 7.8 c). The field Archive Number displays in the form of a text string all the final reports applicable to a given deposit object. In the event that we do not want to view the objects one by one, but we want to get information on a larger area, this is enabled by the key “Formulár” [Form] (Fig. 7.9 c). The user shall press the icon polygon to select the area of interest and draw the map of the territory from which he

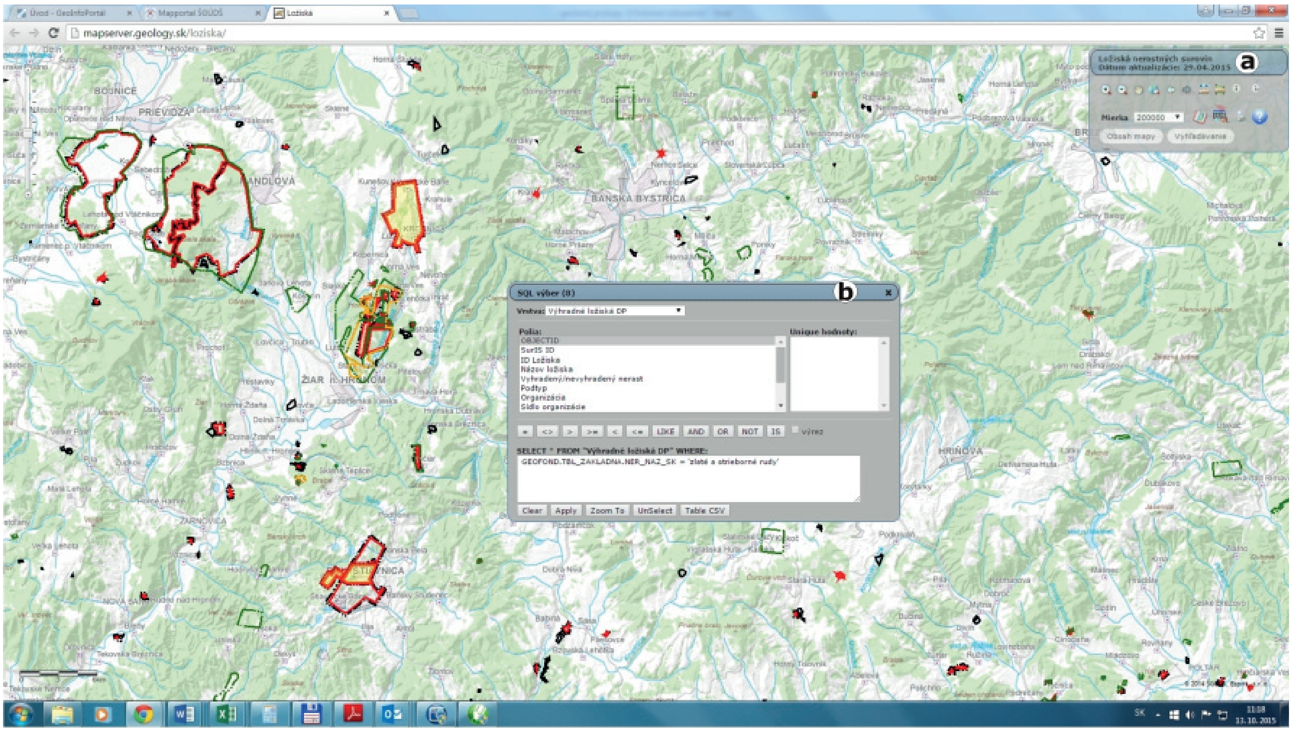

Fig. 7.5 SQL search demonstrated by the example of the yellow highlighted mining areas Kremnica and Banská Hodruša Au, Ag ores. a – Navigation menu of raw minerals deposits; b – Identification – fundamental attribution table.

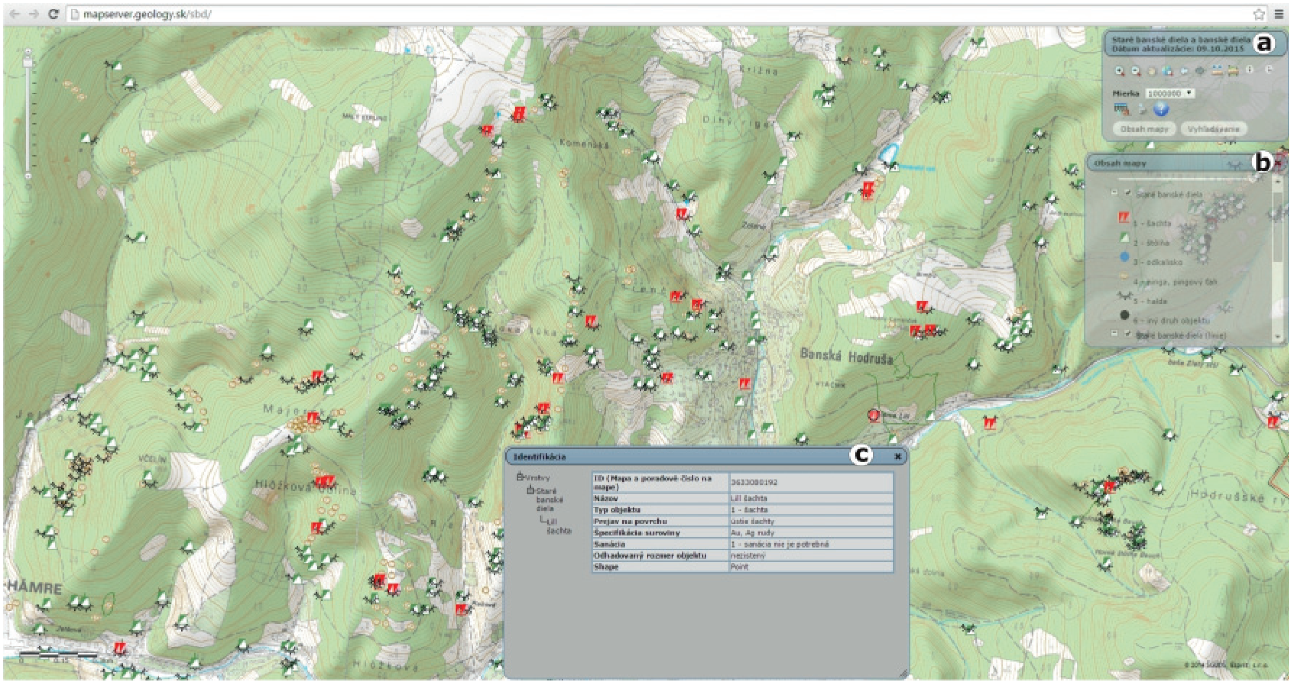

Fig. 7.6 Basic attribution table for historical shaft Lill exploited for Au, Ag ores. a – Navigation menu of Old Mining Works; b – Map Legend; c – Identification – fundamental attribution table.

Slovak Geol. Mag., 15, 2 (2015), 145 – 152

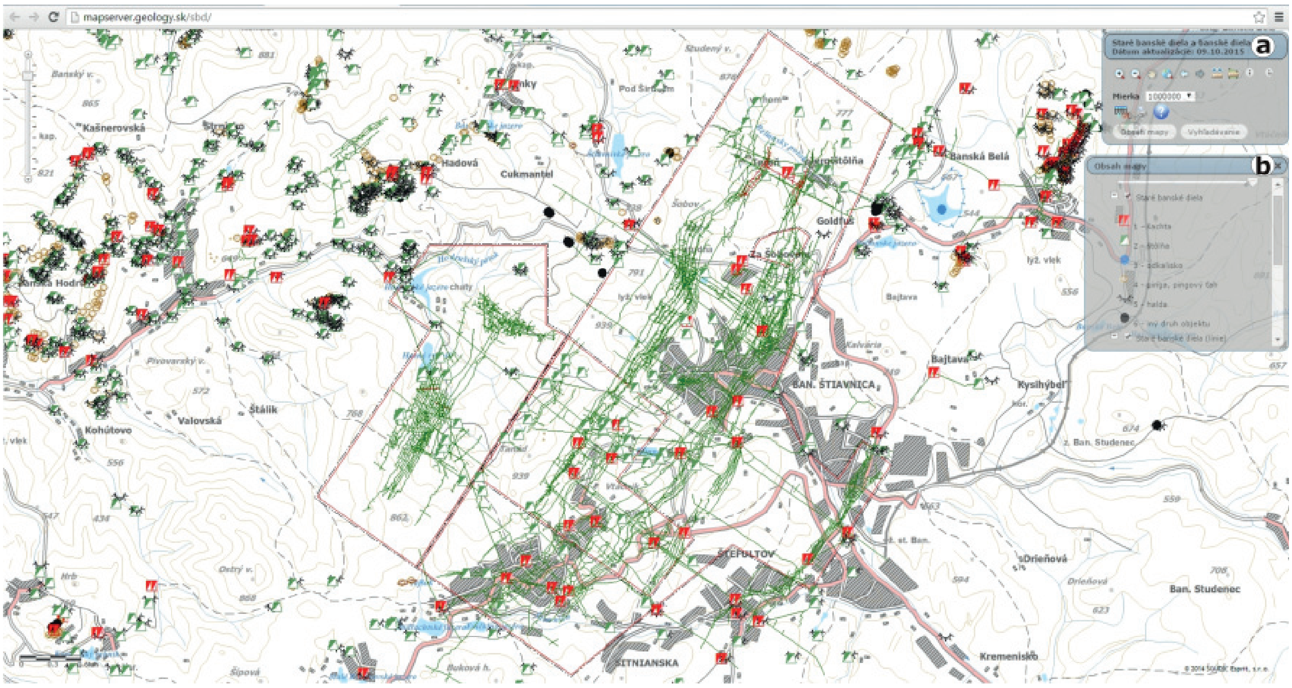

Fig. 7.7 Processing of mining workings in the determined mining area Banská Štiavnica in the form of point and line layers. a – Navigation menu of Old Mining Works; b – Map Legend.

wants to receive an information. After the conclusion of the polygon we press the button "Formulár" [Form] and the table appears offering downloadable files for point, line and polygon layers (Fig. 7.9 d). The generated table in the MS EXCEL form displays information on deposits or deposit occurrences within the delineated territory of interest and the archive number of reports stored in Geofond (Fig. 7.10). For a better understanding of the application it is advisable to consult the enclosed Manual (in Slovak, Fig. 7.9 e).

7.4. Possibilities of Further Development of Deposit Applications

In 2016, we plan to launch the application of reports GEO 3-01 and 3-01 completion by the organizations directly via internet application Form GEO, which is currently being prepared. This would greatly simplify the process of communication with mining organizations, minimize the occurrence of errors in the accounts and, naturally, facilitate creating the publications "Balance of

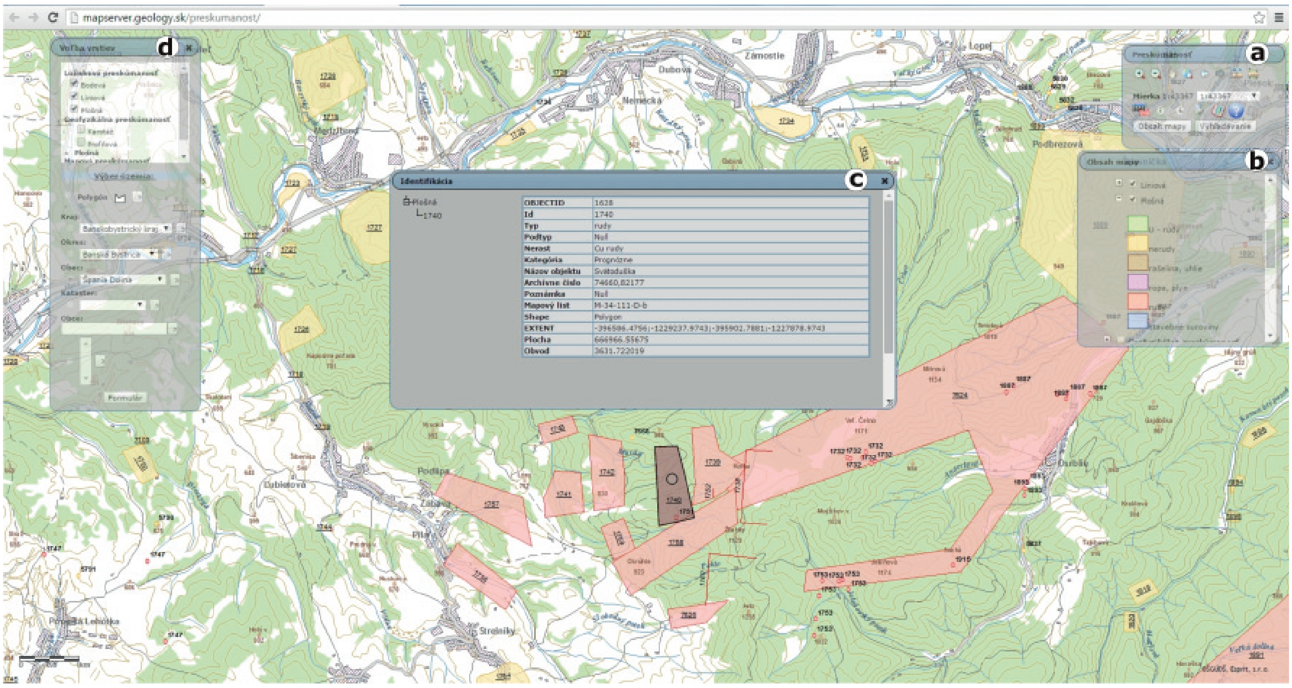

Fig. 7.8 Basic attribution table to the object of mining field Svätodušná in the district of historic mining of copper ores. a – Navigation menu of Deposits Exploration Status; b – Map Legend, c – Identification – fundamental attribution table, d – Panel of Forms creation.

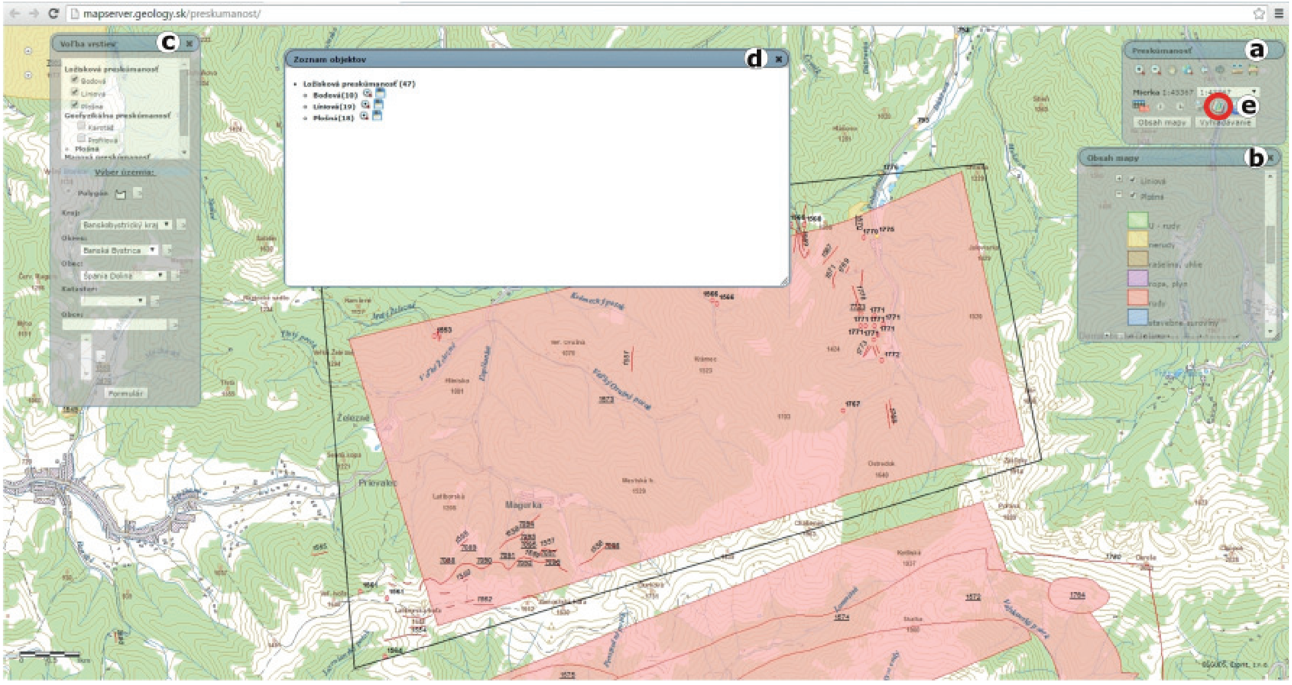

Fig. 7.9 An example of generated form ready to be downloaded – mining field Liptovská Dúbrava and Magurka, historic mining of Sb and Au ores. a – Navigation menu of Deposits Exploration Degree; b – Map Legend, c – Panel of Forms creation, d – List of Objects, e – Manual.

Deposits of Exclusive Areas in Slovakia" and "Evidence of Non-Reserved Minerals in Slovakia". Data shall be inserted in the system by mining organizations using the Internet form through an authorized access. The new data will be checked and approved by a relevant annotator from the Department of Geological Exploration of SGIDŠ and incorporated into the parent database. This database will not be available in the online environment to non-authorized users, so it will not serve the public for viewing. It shall serve exclusively for the needs of the state geological administration and partly to the mining authority.

for elaboration of statements to the investments and spatial planning for municipalities (ÚPN O, in Slovak) and higher territorial units (ÚPN VÚC, in Slovak) under Law no. 50/1976 on land planning and building regulations (Building Act), as amended by further legislation. All Internet applications presented in this article are the unique source of information on the Slovak territory in terms of mineral resources. The application Exploration Areas is the only published Internet application of its kind in the whole of Europe, with specific functionality enabling quick preparation of proposals on determination of exploration areas for organizations that are interested in obtaining a particular exploration area. The Internet deposits applications are also relatively frequently attended. Annually we register all together on average 20,000 unique entries outside SGIDŠ interested in the deposits applications. We will be very happy when there will not only increase the number of entries, but especially when it will be adequate extension of the services provided today by the unique Map Portal.

	A	B	C	D
1	ID	NERAST	NAZOVOBJEKTU	ARCHIVNECISLORETAZEC
2	1775	Au rudy	Dúbrava odkalisko	28180
3	1564	stavebný kameň	Jasenie Latiborská II	3926,7817
4	1771	Fe rudy	Dúbrava Predpekelná	1709,1788,3569,3603,8160,8758,8901,11057,51954,75363
5	1568	stavebný kameň	Dúbrava Ľubela	1709,2477,3569,3603,8160,45865,52265,52276,79889,75363,77701,84789
6	1767	Sb rudy	Dúbrava pod Chabencom sever	1709,2477,3603,8160
7	1770	Au rudy	Dúbrava Dechtárka	3569,8160,8758,8901,11057,13696,52275,82808
8	1566	stavebný kameň	Dúbrava Sedlistá	744,1709,3603,8160
9	1561	štrkopiesky	Magurka hrebeň Prašivej I	3442
10	1553	keramické suroviny	Železnô, Malé Železnô	6724

Fig. 7.10 Demonstration of downloaded form from the query point layer made from the territory of the previous image. Columns: A – ID, B – Type of raw mineral, C – Object designation, D – Geofond reports archive numbers

7.5. Conclusion

The deposit applications presented in this article in their present form serve a broad professional and lay public as a geological-mining information on the Slovak territory. The most important subjects interested in the information on the deposits applications via Internet include the municipalities, regional governments and investment companies. The applications are also used

Acknowledgements:

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References:

Káčer Š., Antalík M., Bodiš D., Cibula R., Gargulák M., Gluch A., Hraško Ľ., Liščák P., Malík P., Mižák J., Pauk J., Rapant S. & Slaninka I., 2014: Geologický informačný systém GeoIS (Geological Information System), Záverečná správa geologickej úlohy, Manuskript. Štátny geologický ústav Dionýza Štúra, Bratislava, 76 p. (In Slovak).

Káčer Š., Antalík M., Cibuľa R. & Bystrická G., 2015: WEB Services and Applications of Map Portal, Slovak Geological Magazine, ISSN 1335 – 096X, 1/2015, 82 p.

Kúšik D. & Lamoš A., 2002: Vzťah horninového prostredia ku ochrane prírody a krajiny, regionálny geologický výskum. (Relationship between Rock Environment and Nature and Landscape Protection). Manuscript, Geofond Archive, 51 p., 1 Annex. (In Slovak).

Kúšik D. & Mižák J., 2009: Internetová aplikácia registrov Geofondu – Ložiská nerastných surovín, Zborník zo Spoločného kongresu Slovenskej a Českej geologickej spoločnosti (Internet Application Registers of Geofond – Mineral Deposits), Proceedings of the Joint Congress of Czech and Slovak Geological Society, p. 116-117. (In Slovak).

Kúšik D., 2010: Súčasné ložiskové web aplikácie SGIDŠ a možnosti ich rozvoja. In: Zborník prednášok z konferencie Nerastné suroviny a životné prostredie. (Current Deposits Web Application at SGIDŠ and Opportunities for Their Development). In: Proceedings of the Conference of Raw Materials and the Environment). Repiská, ISBN 978-80-970521-0-2, p. 116-121. (In Slovak).

Repčiak M., Záviš V., Pristašová Ľ., Caudt Ľ., Hubač P., Sandanus M., Fodorová V. & Hudáček J., 1996: Slovensko – návrh sanácie starých banských diel – inventarizácia, vyhľadávací prieskum, stav k 31.12.1996, (Slovakia – Design of Remediation of Old Mining Works (OMW) – Inventory, Search Survey, as of 31.12.1996). Manuscript, Geofond Archive, 197 p., 70 Annexes. (In Slovak).

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The text should be arranged as follows: full name of the author(s); title of the paper, number of supplements (in brackets, below the title, e.g. 5 figs., 4 tabs.); key words - maximum 6 key words arranged successively from general to special terms; abstract (max. 300 words presenting principal results, without references); in a footnote of the first page, name of the author(s) as well as her/his/their professional or private address.

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Journal

Vrba P., 1989: Shear zones in the metapelite complexes. Mineralia Slov., 21, 135-142.

Anniversary volume

Návesný D., 1987: High-potassium rhyolites. In: Romanov, V. (ed.): Stratiform deposits of Gemericum. Spec. publ. Slov. Geol. Soc. Košice, 203-215.

Manuscript

Radvanský F., Slivka B., Viktor J. & Srnka T., 1985: Vein deposits of the Jedľovec nappe of Gemericum. Final report from the project SGR-geophysics. Manuscript-archive ŠGÚDŠ Spišská Nová Ves, 28.

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