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

PAVEL BAČO[1], ZUZANA BAČOVÁ[1], ZOLTÁN NÉMETH[1] and MARTIN REPČIAK[1]

[1]State Geological Institute of Dionýz Štúr, RC, Jesenského 8, 040 01 Košice, Slovak Republic

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).

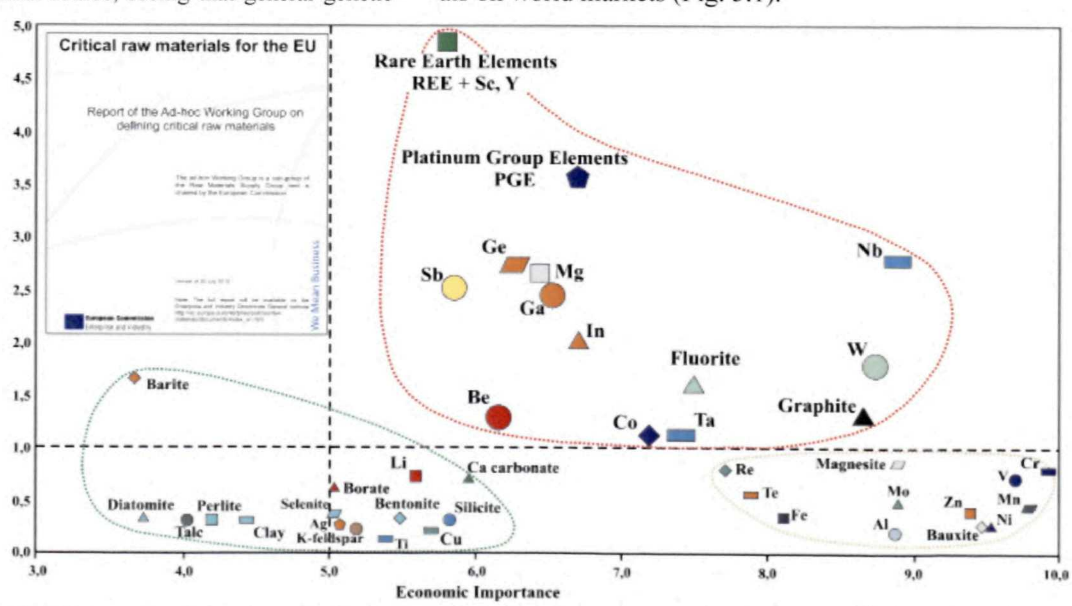


Fig. 5.1 The critical raw materials for the EU countries as being determined by the Ad-Hoc Working Group chaired by EC (modified after: http://ec.europa.eu/enterprise/policies/raw-materials/files/docs/communication_sk.pdf).

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

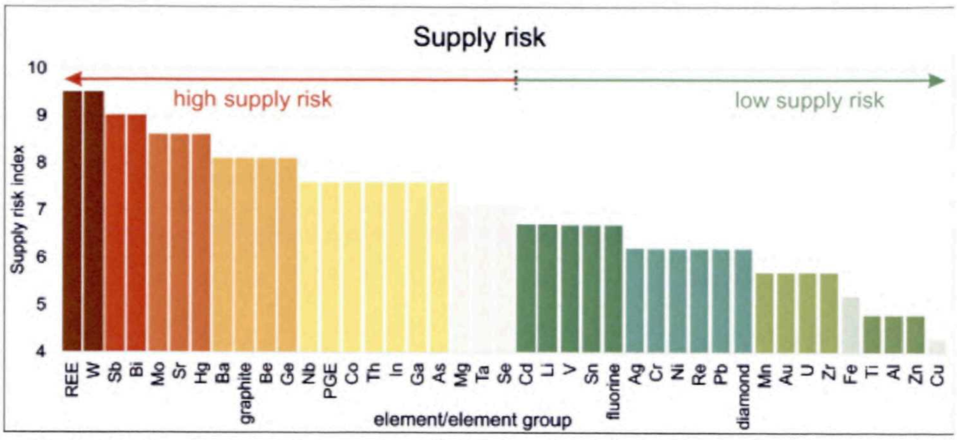


Fig.5.2 Distribution of monitored metals and minerals from the perspective of the final analyses. Source: NERC, 2012, BGS 2012; modified.

(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:

	deposits of metal possibly containing **In, Ge,** and **Ga** as accompanying metal
	deposits of metal possibly containing **Nb** and **Ta**, rarely also **REE** as accompanying metal
	deposits of metal, where in conditions of the W. Carpathians **Co** is present as a main, or accompanying metal
	deposit of metals with eventual presence of **PGE** as accompanying metals
	deposit of metals with eventual presence of **REE** as accompanying metals
	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*

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

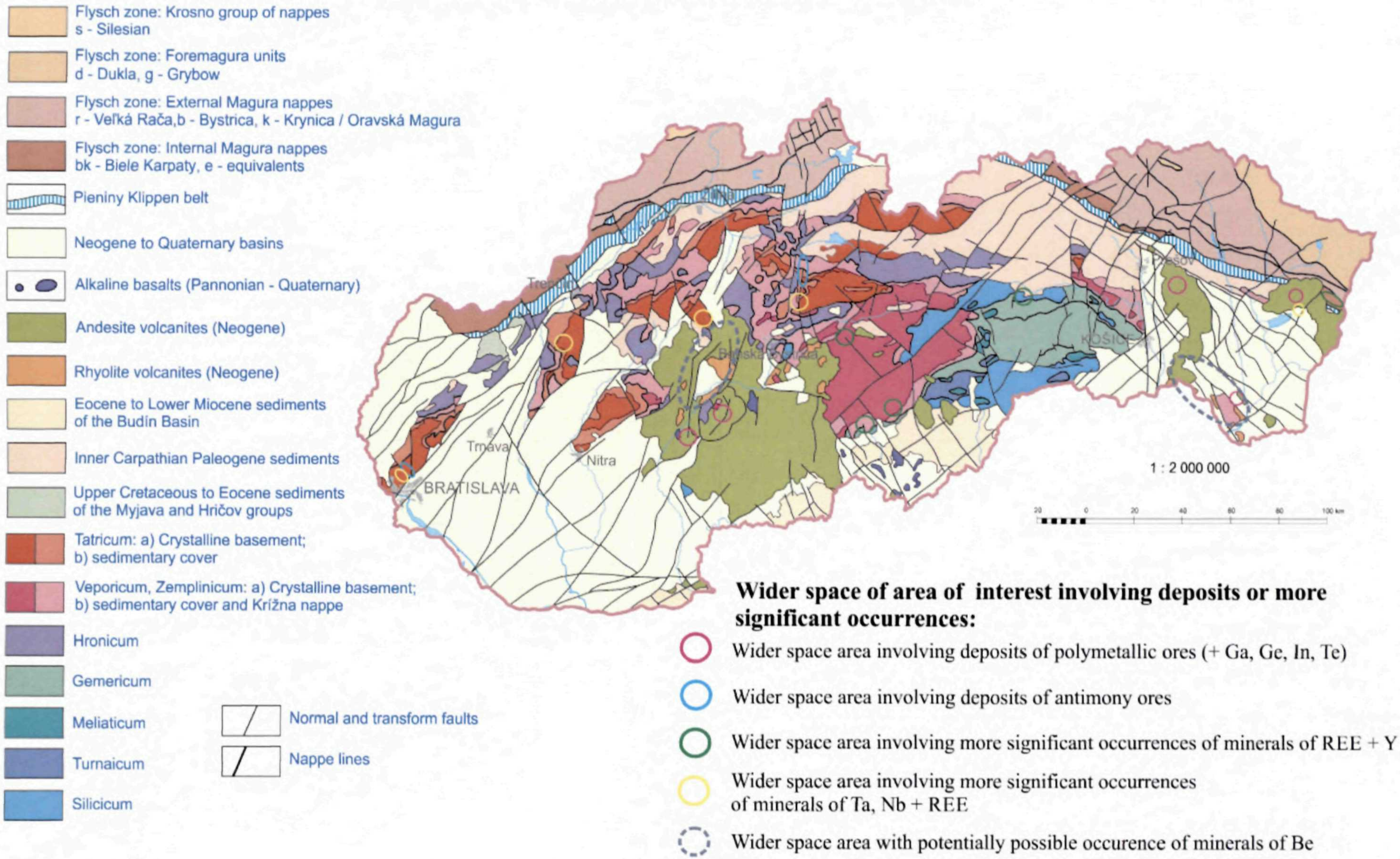
Group of three metals – **Ga**, **In** and **Ge** has no tradition in our mining history and no systematic research and prognostic evaluation. In the world these metals are obtained mostly as a by-product of mining of polymetallic epithermal ores (In, Ge and Ga, and also Te and Tl) or copper ores (In), 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).

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**	

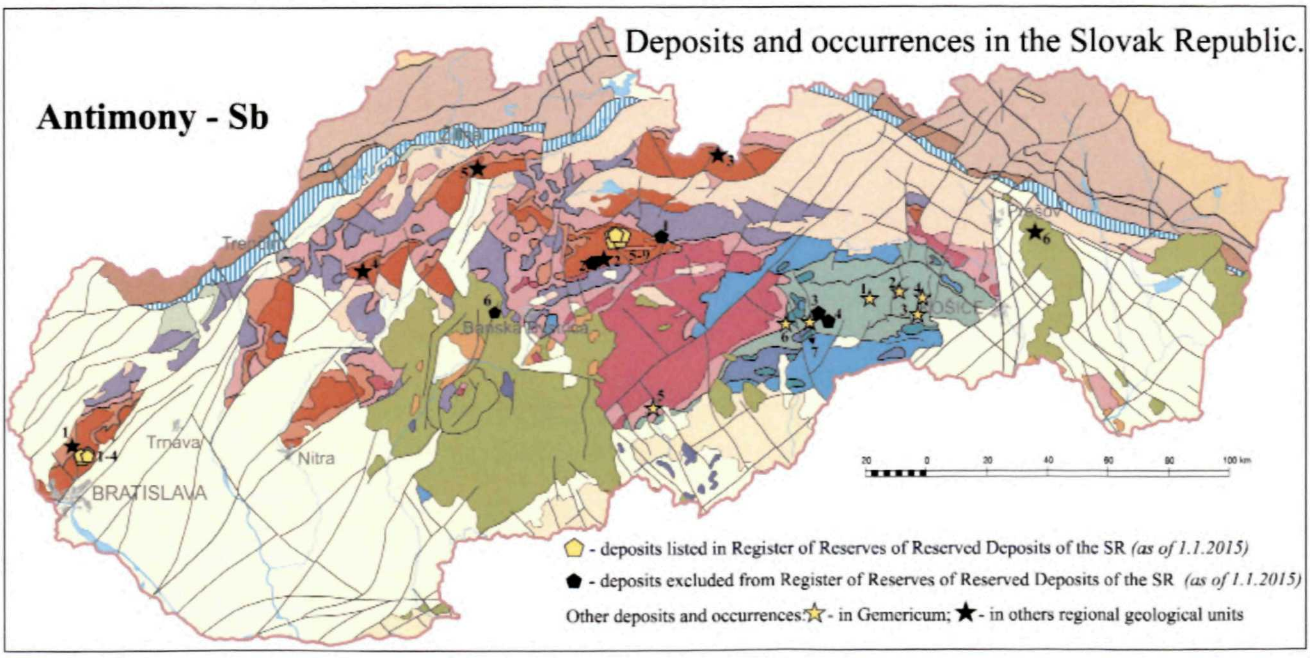


Fig. 5.4 Deposits and significant occurrences within individual geological units.

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 ⬠
	Pezinok-Sb (Pezinok I)	2 ⬠
	Pezinok-Vinohrad	3 ⬠
	Pezinok	4 ⬠
	Pernek-Jahodnisko	1 ★
	Dúbrava-Ľubeľská	5 ⬠
	Dúbrava-Martin štôlňa	6 ⬠
	Dúbrava-Matošovec	7 ⬠
	Dúbrava-Predpekelná	8 ⬠
	Dúbrava	9 ⬠
	Dolná Lehota-Lom	1 ⬟
	Lomnistá - Husárka	2 ⬟
	Nižná Boca	2 ★
	Kriváň-Krivánske bane	3 ★
	Chvojnica	4 ★
	Bystrička	5 ★

Explanations:
⬠ - 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

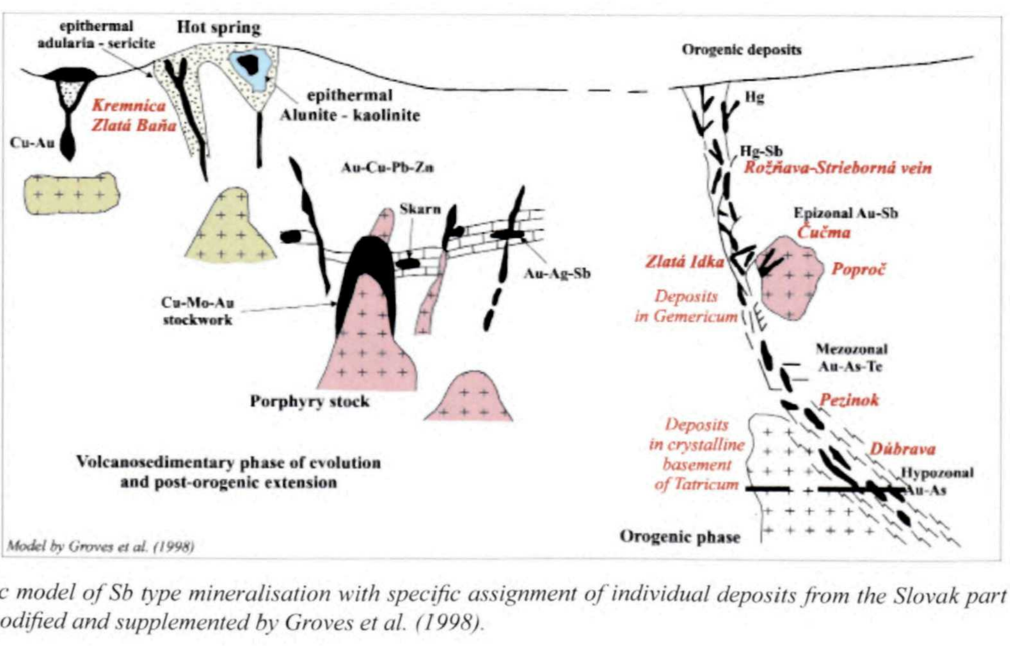


Fig. 5.6 Genetic model of Sb type mineralisation with specific assignment of individual deposits from the Slovak part of the Western Carpathians, modified and supplemented by Groves et al. (1998).

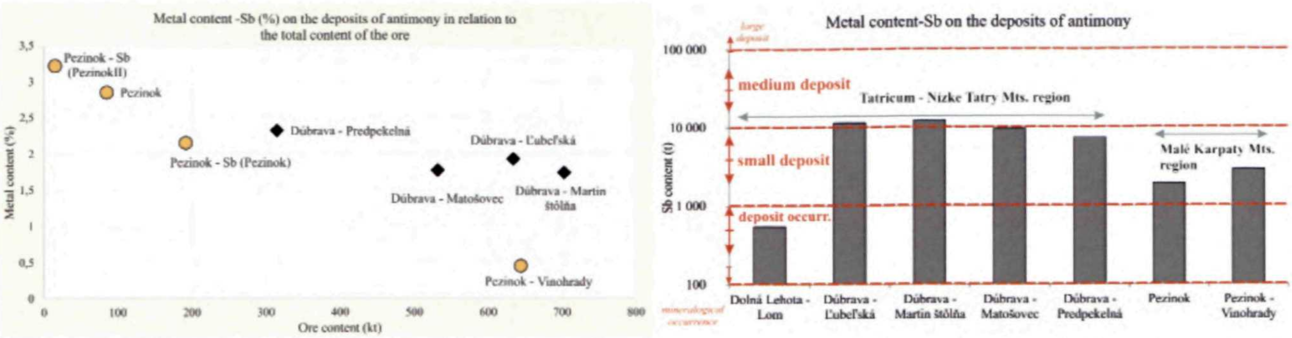


Fig. 5.7a, b Reserves of Sb ores on individual deposits in the Slovak part of the Western Carpathians, classified by size criteria. Data source: Tréger in Lexa et al.; 2002, Baláž & Kúšik, 2014

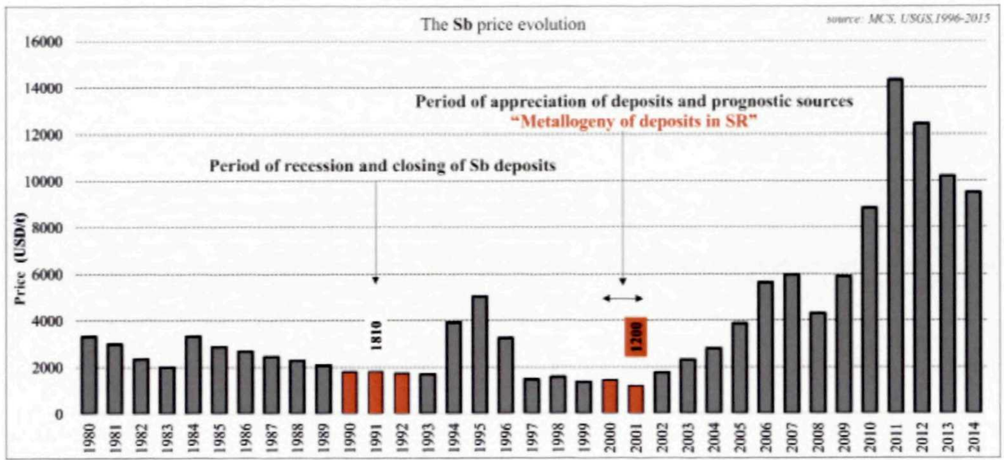


Fig. 5.8 Sb price developments in world markets with consequences in different time frames. Data source: © Kitco USGS and Mineral Commodity Summaries 1996-2015; supplemented, modified

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.

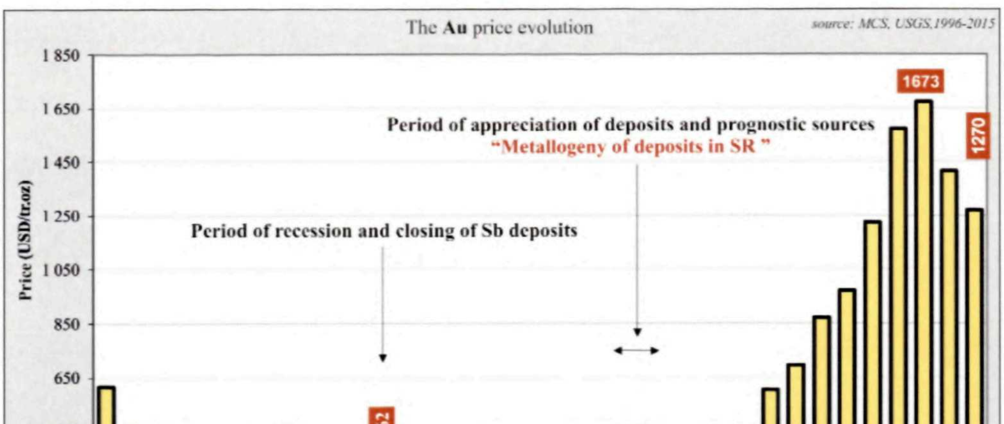


Fig. 5.9 Development of prices on world markets in relation to the various important social and geological activities since deposits closure in Slovakia until the present. Data source: © Kitco USGS and Mineral Commodity Summaries 1996-2015; supplemented, modified

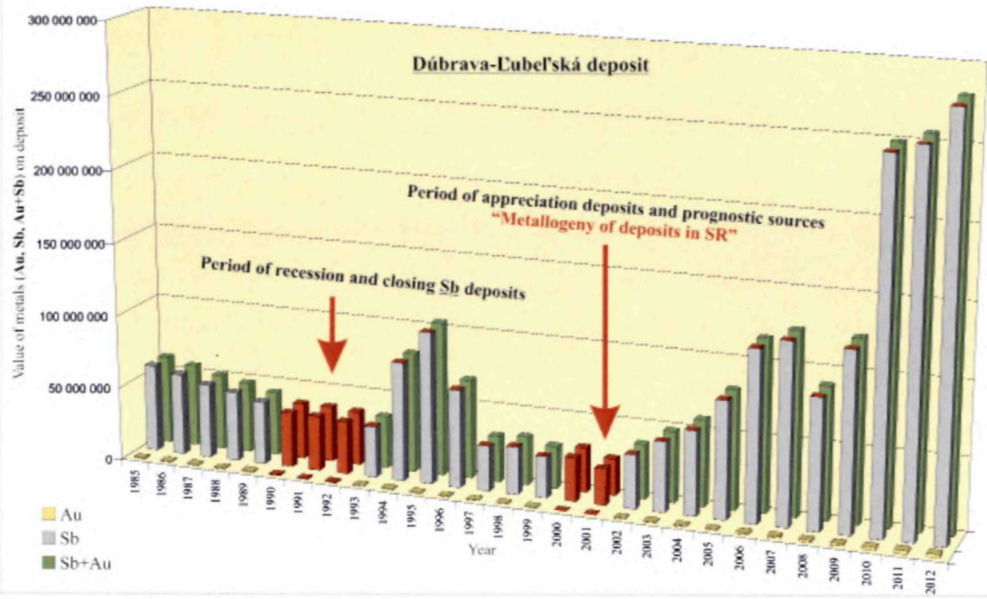


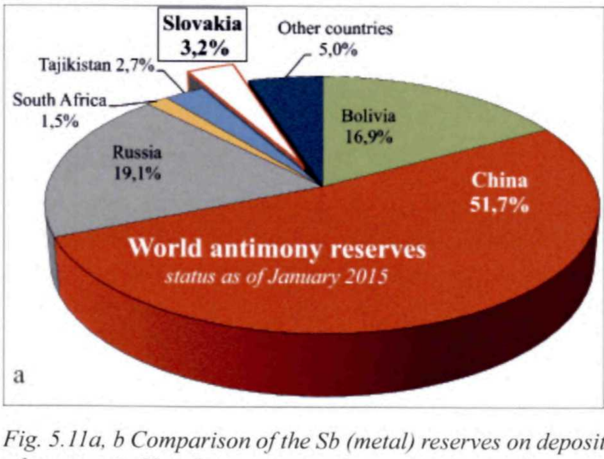
Fig. 5.10 Indicative calculated evolution of net asset value of residual metals – Sb and Au at the deposit Dúbrava – Ľubeľa after damping in the 90s of the last century. We point out that this is the value of the measure of the balance of the metal therein, without accounting for the cost of any physical 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.



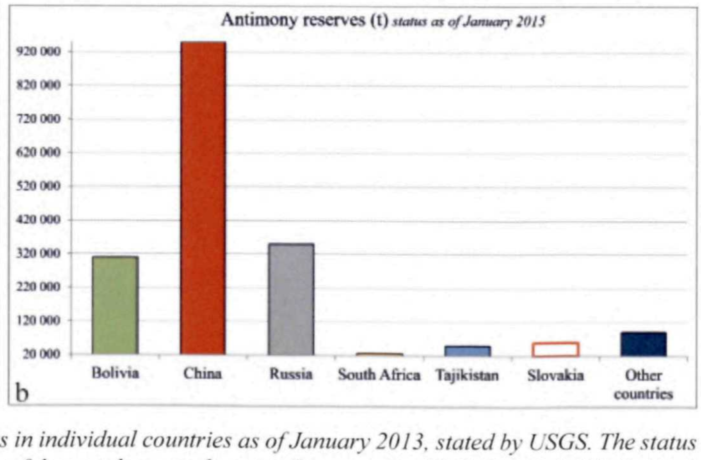


Fig. 5.11a, b Comparison of the Sb (metal) reserves on deposits in individual countries as of January 2013, stated by USGS. The status of reserves in Slovakia was grossed up on the basis of reserves of the metal on our deposits. Data source: USGS, MCS, 2015; Baláž & Kúšik, 2014; edited and compiled

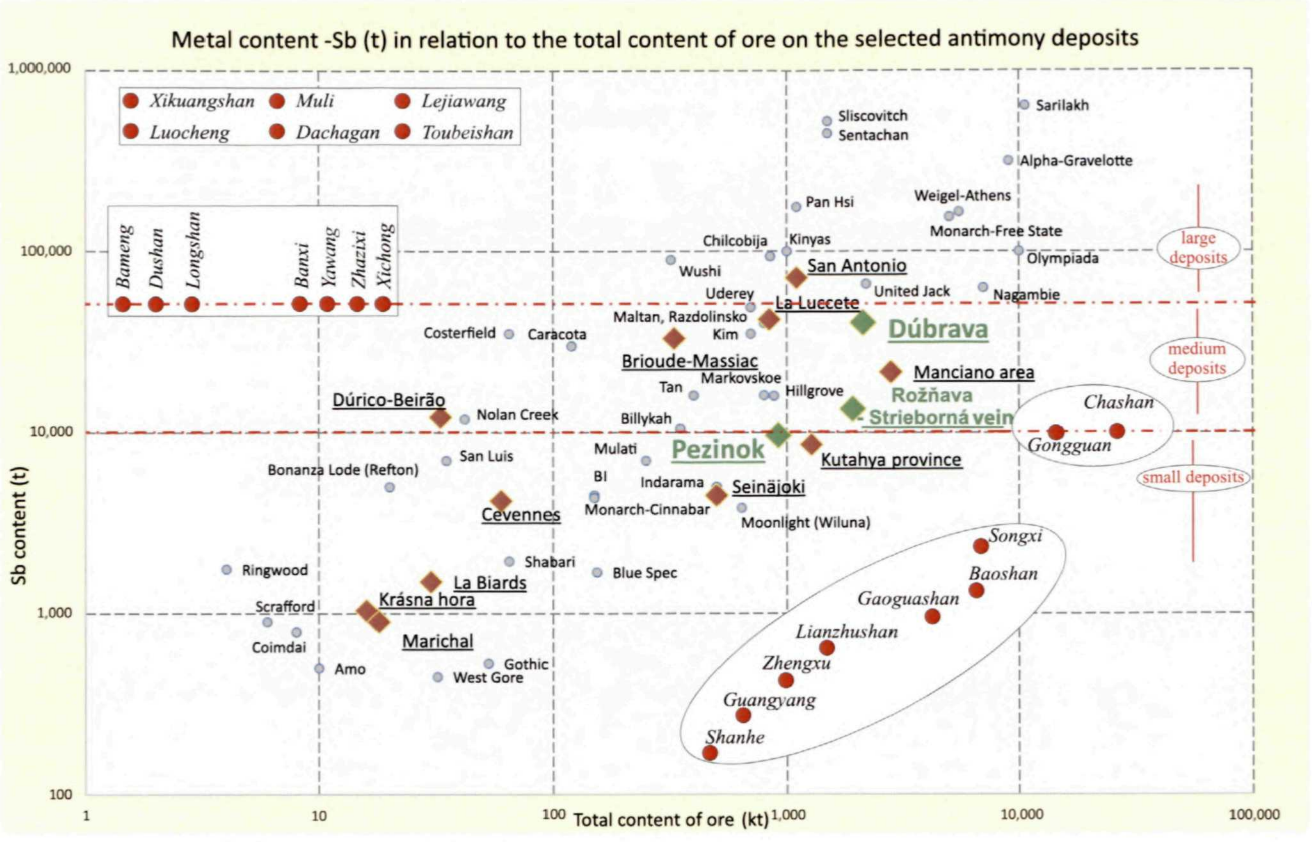


Fig. 5.12 The graph in the figure shows a selection of international deposits with the amount of ore and the calculated amount of metal in the deposit. Sb amount was calculated on the basis of alleged metal content. The underlined names and stained symbols of deposits are the deposits located in the 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**		

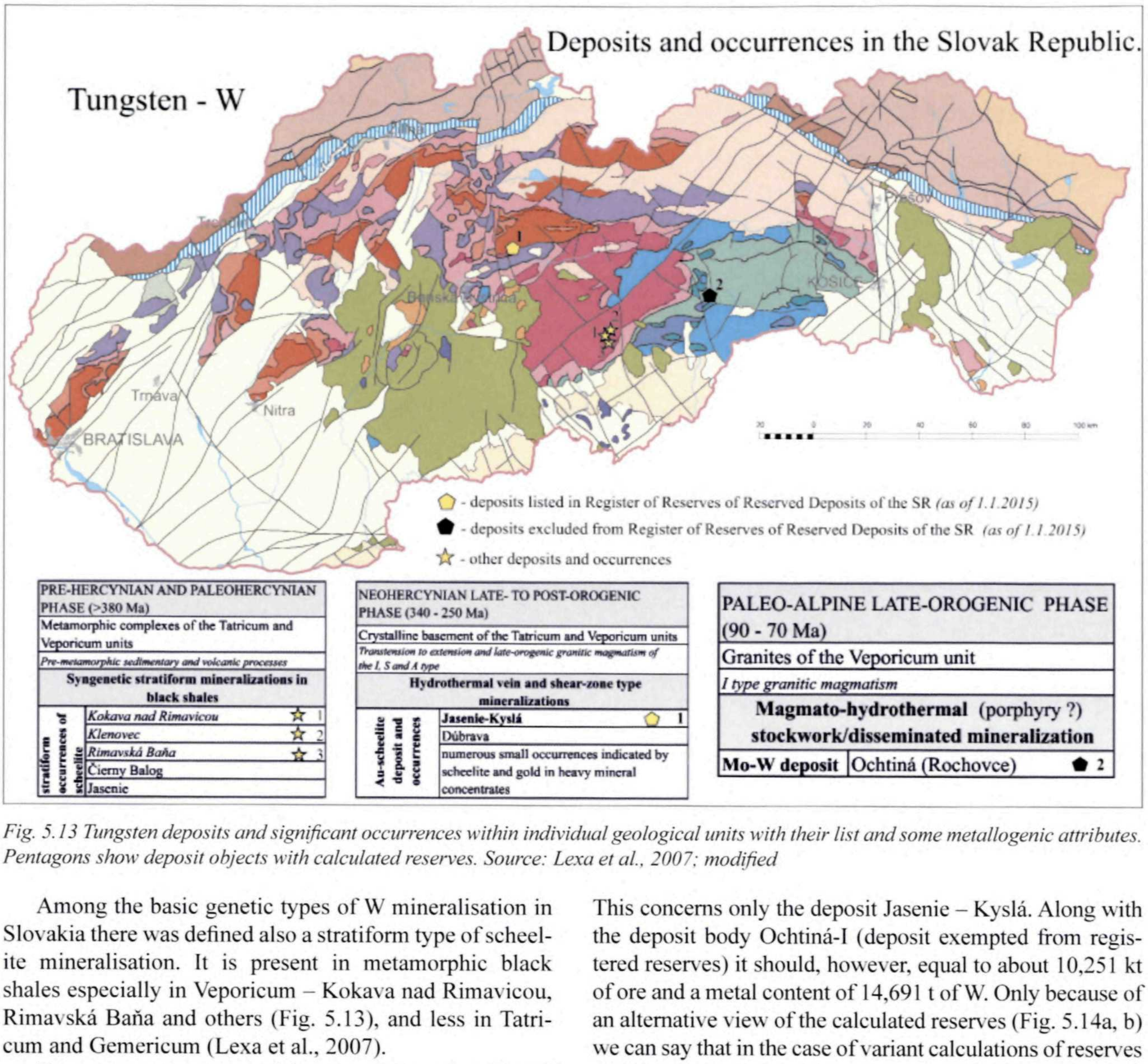
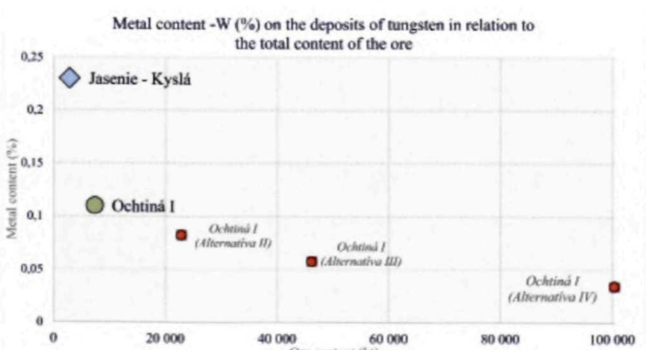


Fig. 5.13 Tungsten deposits and significant occurrences within individual geological units with their list and some metallogenic attributes. Pentagons show deposit objects with calculated reserves. Source: Lexa et al., 2007; modified

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).



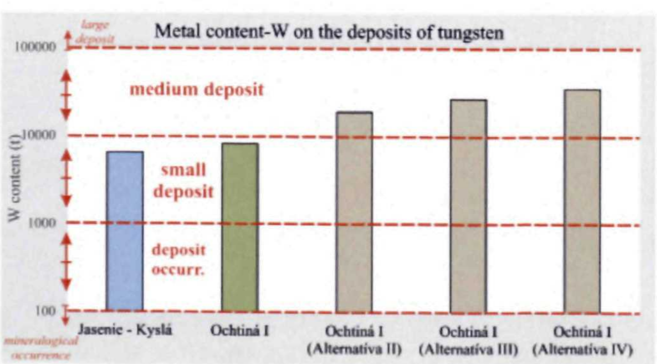


Fig. 5.14a, b The ore supplies for individual deposits in the Slovak part of the Western Carpathians, classified by size criteria. In the case of the deposit Ochtiná-I the chart includes data from alternative – variant calculations of the deposit (gradual reduction of the metal content of the peripheral 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.

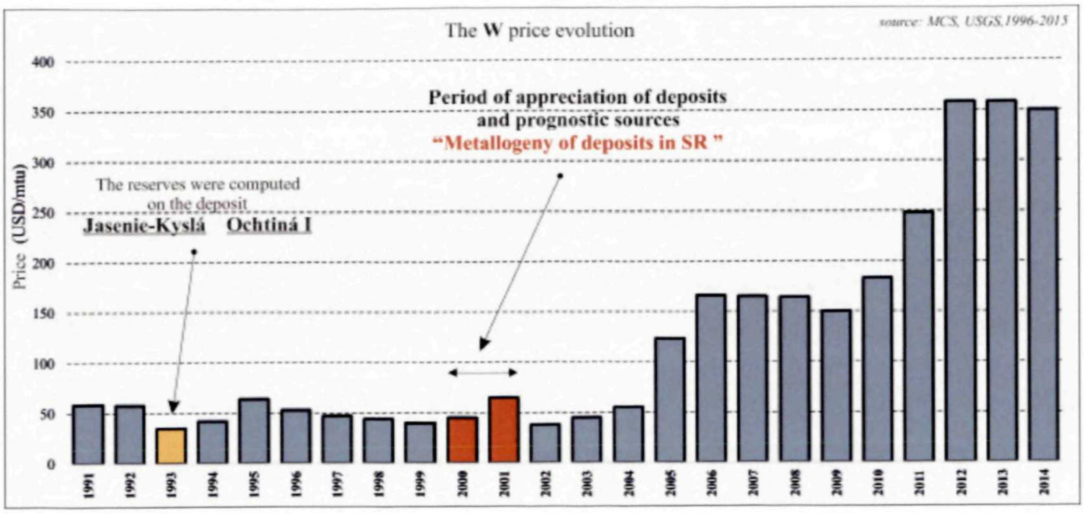


Fig. 5.15 W-prices development on the world market with consequences in different time frames. Data source: © Kitco USGS and Mineral Commodity Summaries 1996-2015; supplemented, adjusted. Note: Price per mtu WO_3 = 10 kg WO_3 or 7,93 kg W

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.

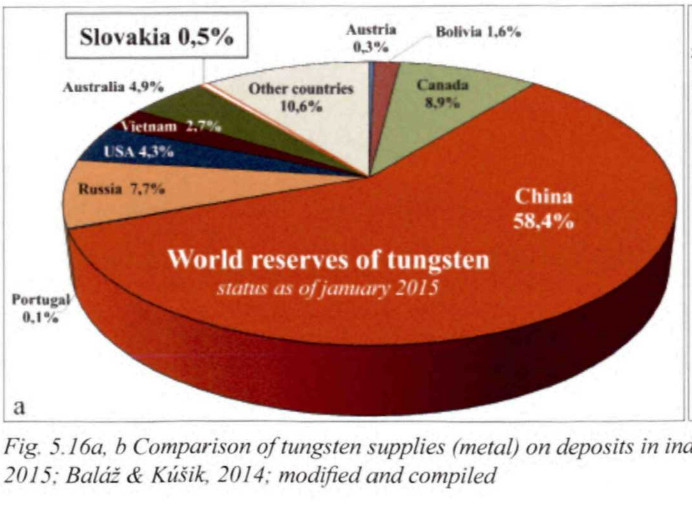
Significant multiple increase in the price of metals on world markets (especially recently) justifies reassessment of particularly variant calculations of the two deposits, but especially of the deposit Ochtiná-I, which in view of the genetic type of mineralisation has a greater potential to expand the 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



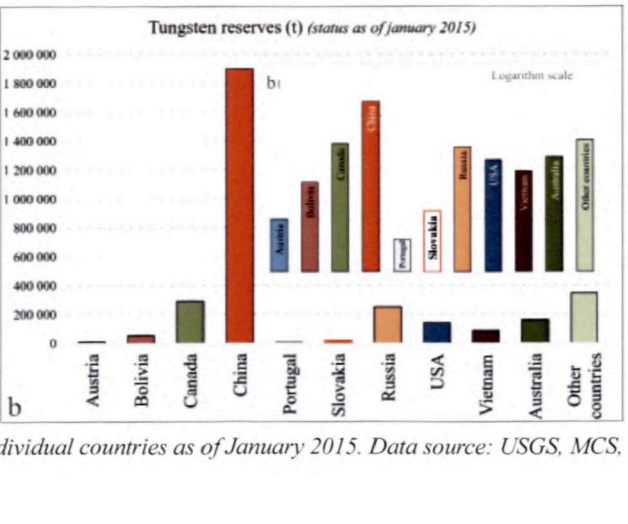


Fig. 5.16a, b Comparison of tungsten supplies (metal) on deposits in individual countries as of January 2015. Data source: USGS, MCS, 2015; Baláž & Kúšik, 2014; modified and compiled

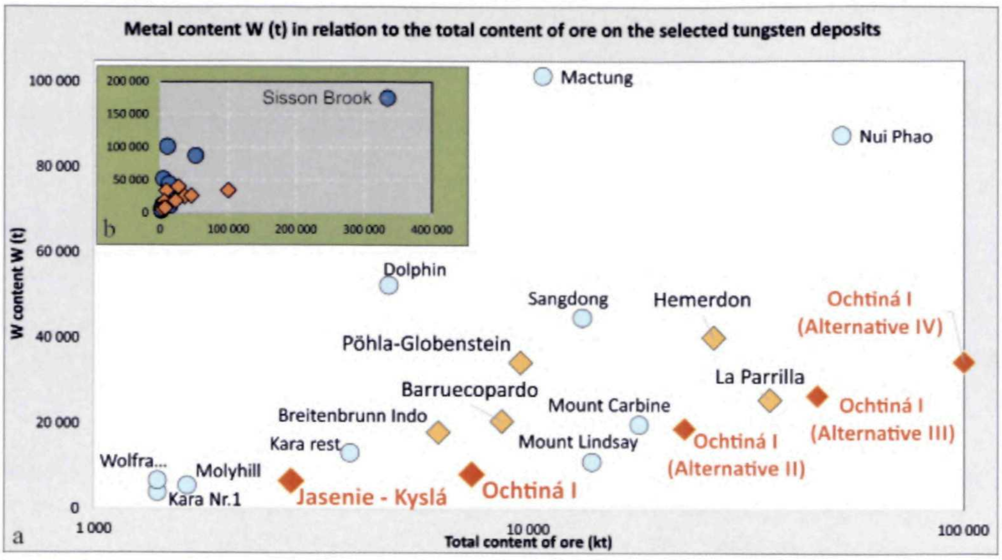


Fig. 5.17 The figure shows a selection of international deposits with the amount of ore and calculated amount of metal in the deposit. W amount was calculated on the basis of alleged metal content for individual deposits. Coloured rhombic symbol represents the deposits which are located in the EU. The 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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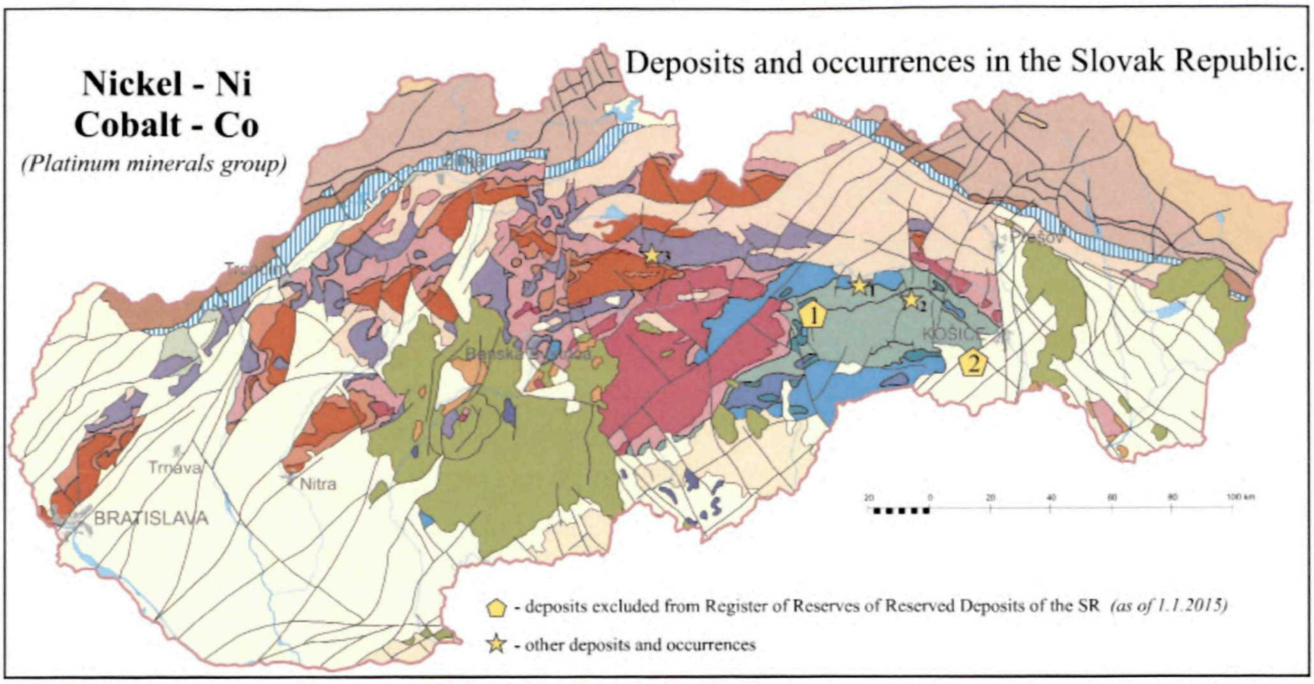


Fig. 5.18 Deposits and significant occurrences within individual geological units.

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
		Rudňany	1
		Gelnica	2
		Úhorná	
		Prakovce	
		Rožňava	
		Turčok	
	V	Hnúšťa-Cerberus	
	T	Vyšná Boca	3

PALEO-ALPINE POST-OROGENIC / EARLY NEO-ALPINE STAGE (70-24 Ma)		
Ultramafic rocks		
Late Cretaceous and Paleocene weathering		
Residual mineralizations		
Ni occurrences	Hodkovce	2

edited by Lexa et al. (2007) and Register of Reserves of Reserved Deposits of the SR (as of 1.1.2015)

Explanations: - deposits excluded from Register of Reserves of Reserved Deposits of the SR (as of 1.1.2015); - 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

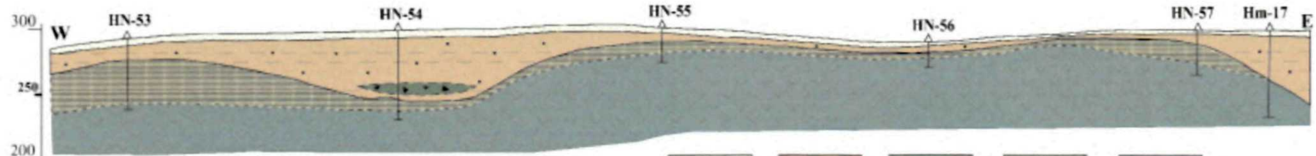


Fig. 5.20 Geological section through the deposit of Co-lateritic ores Hodkovce. 1. loam – Quaternary; 2. clays, gravel, sand; 3. allochthonous decomposed serpentinite; 4. decomposed serpentinite in situ; 5. serpentinised peridotite; Compiled by J. Zlocha 1975; modified

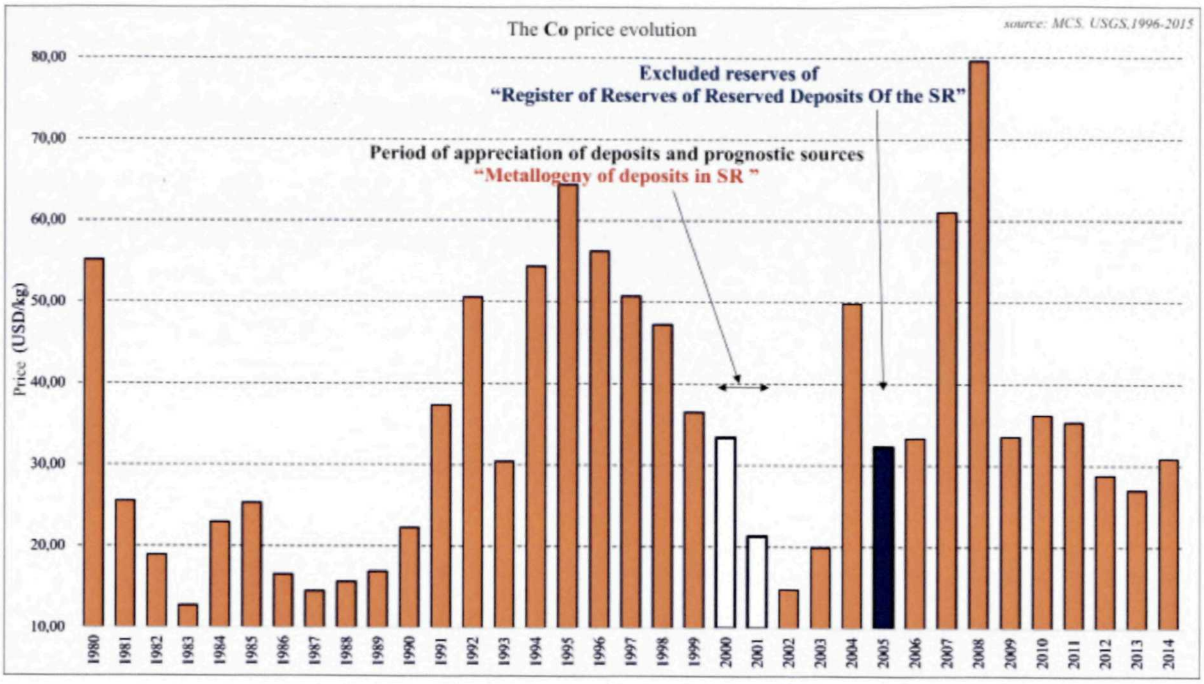


Fig. 5.21 Co price developments in world markets with consequences in different time frames. Data source: © KITCO and USGS Mineral Commodity Summaries 1996-2015; supplemented, modified.

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-

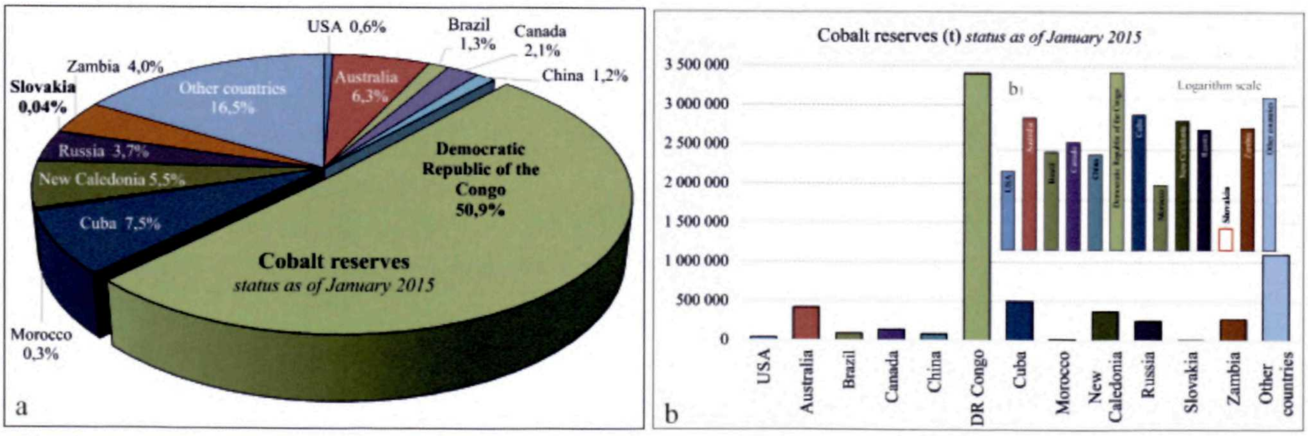


Fig. 5.22a, b Comparison of Co (metal) reserves on deposits in individual countries. Data source: USGS, MCS, 2015; Zlocha, 1975; modified

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.

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).

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		

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

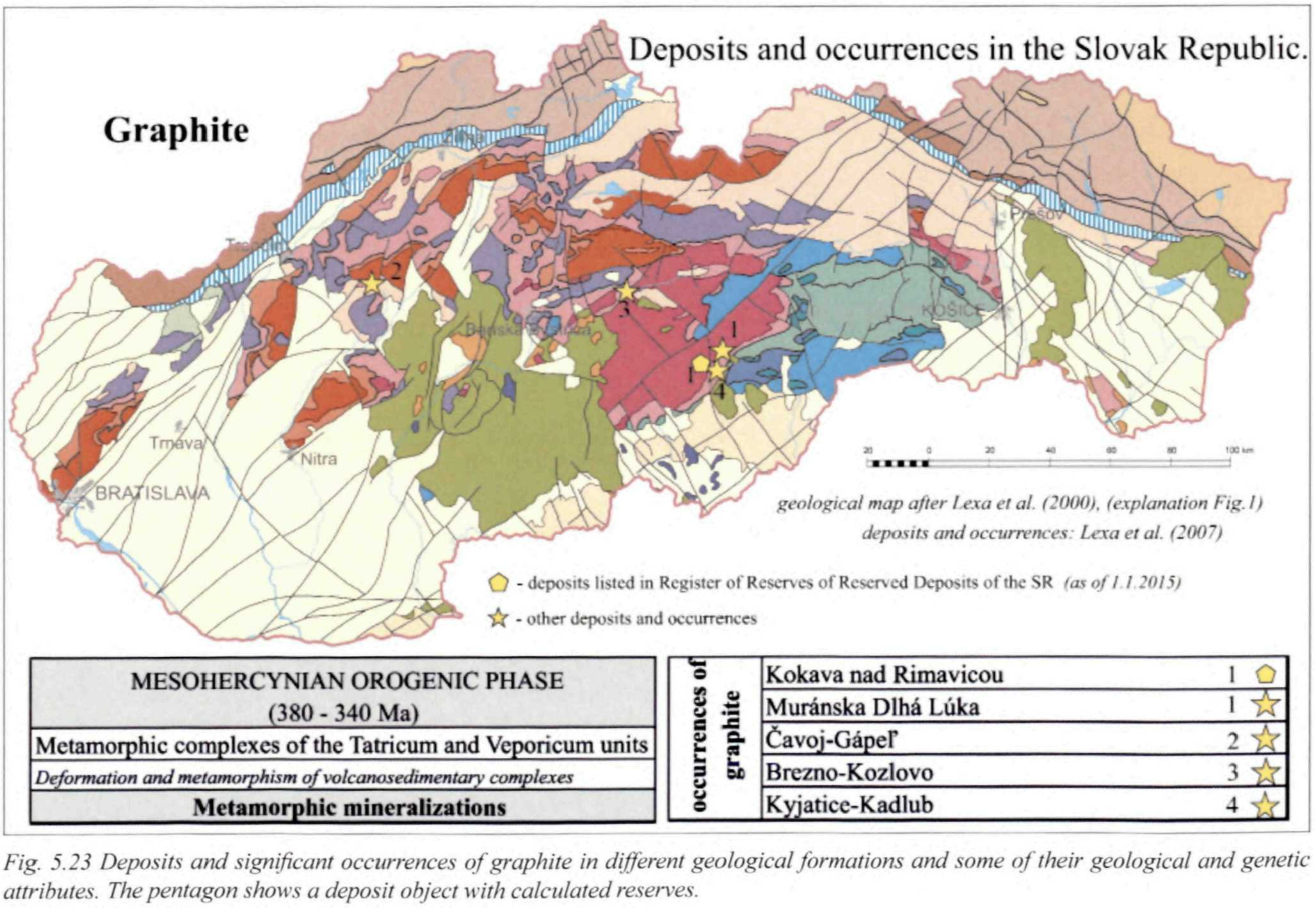


Fig. 5.23 Deposits and significant occurrences of graphite in different geological formations and some of their geological and genetic attributes. The pentagon shows a deposit object with calculated reserves.

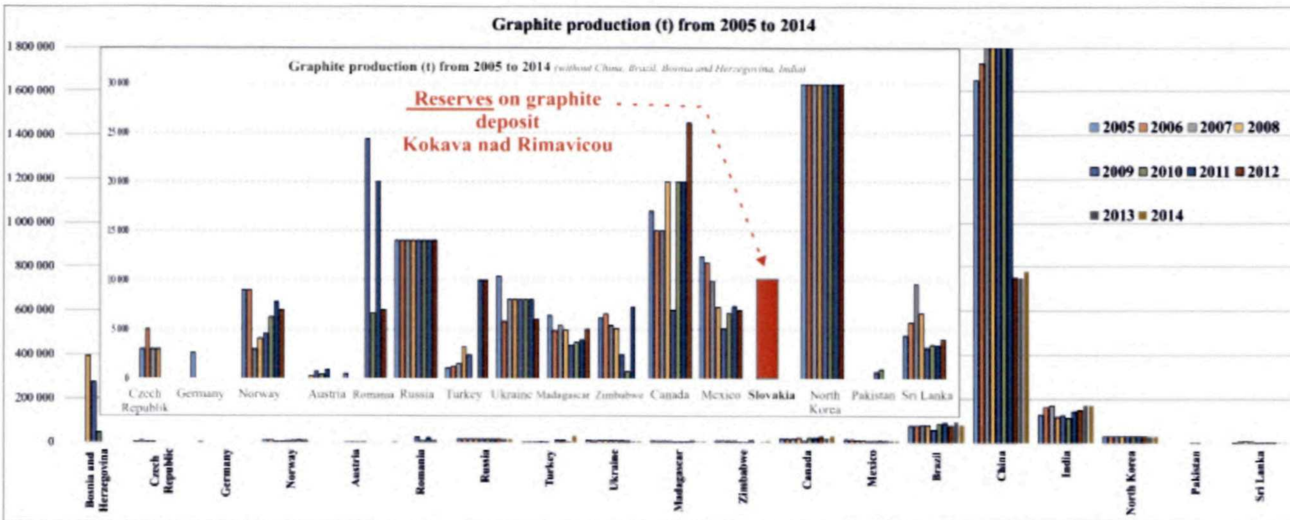


Fig. 5.24a, b Production of graphite world-wide. From the chart it is clear that there are deposits of a higher order than the reserves calculated on the deposit Kokava nad Rimavicou. Source: USGS, MCS, 2010-2015; modified and compiled

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

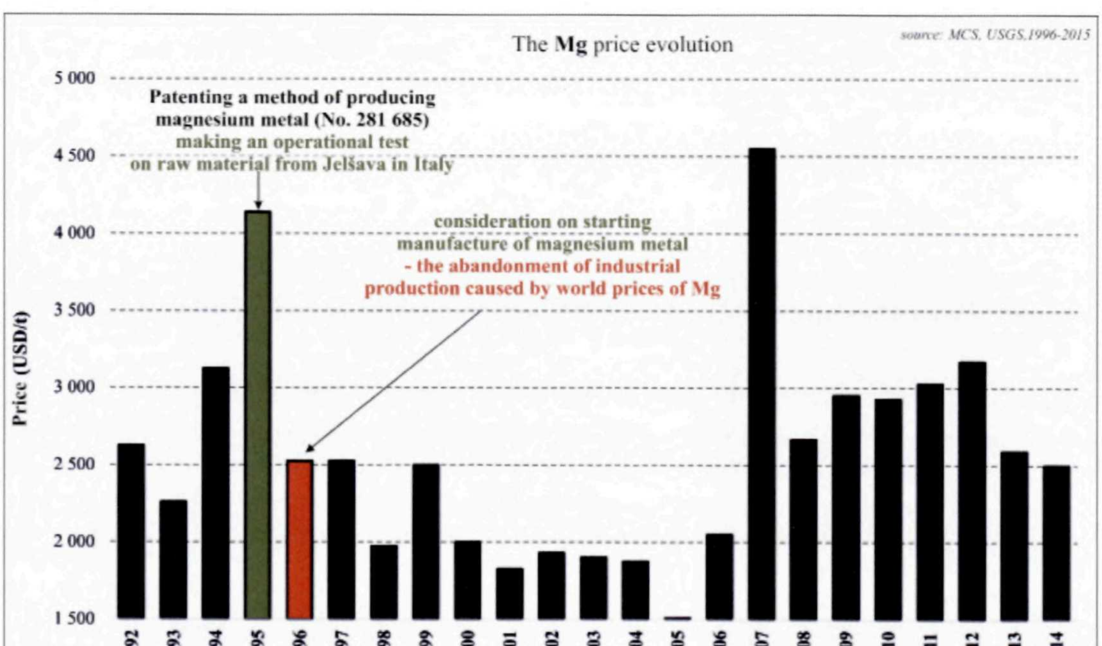


Fig. 5.25 Development of Mg metal prices on world commodity exchanges, period of laboratory tests and the production of raw materials based on Slovak magnesites in Jelšava.

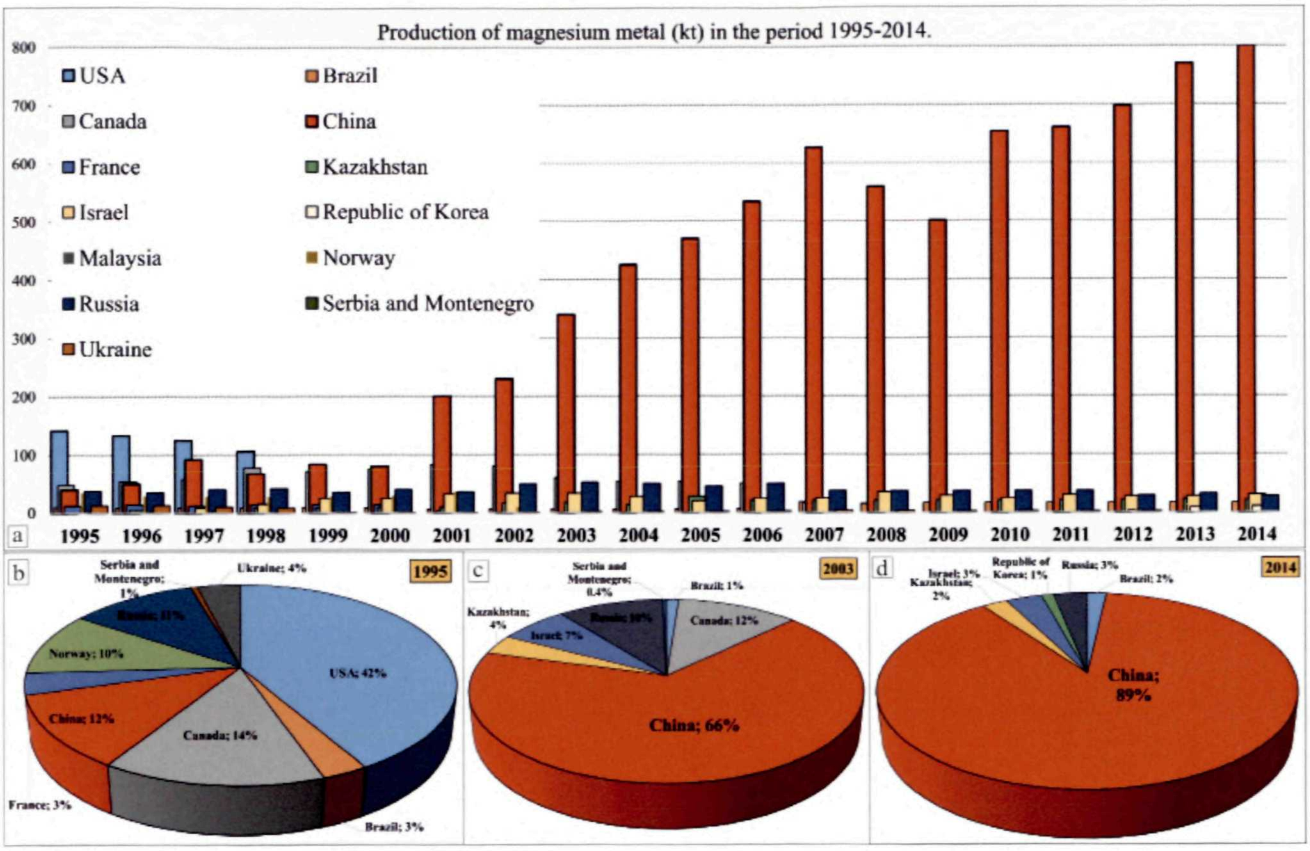


Fig. 5.26 Countries that have mastered the technology of production of magnesium metal and its production in the defined period. Gradual development of China's dominance of production is recorded since the beginning of the millennium. Source figures: T.G. Brown, 2013; USGS, 2013.

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.

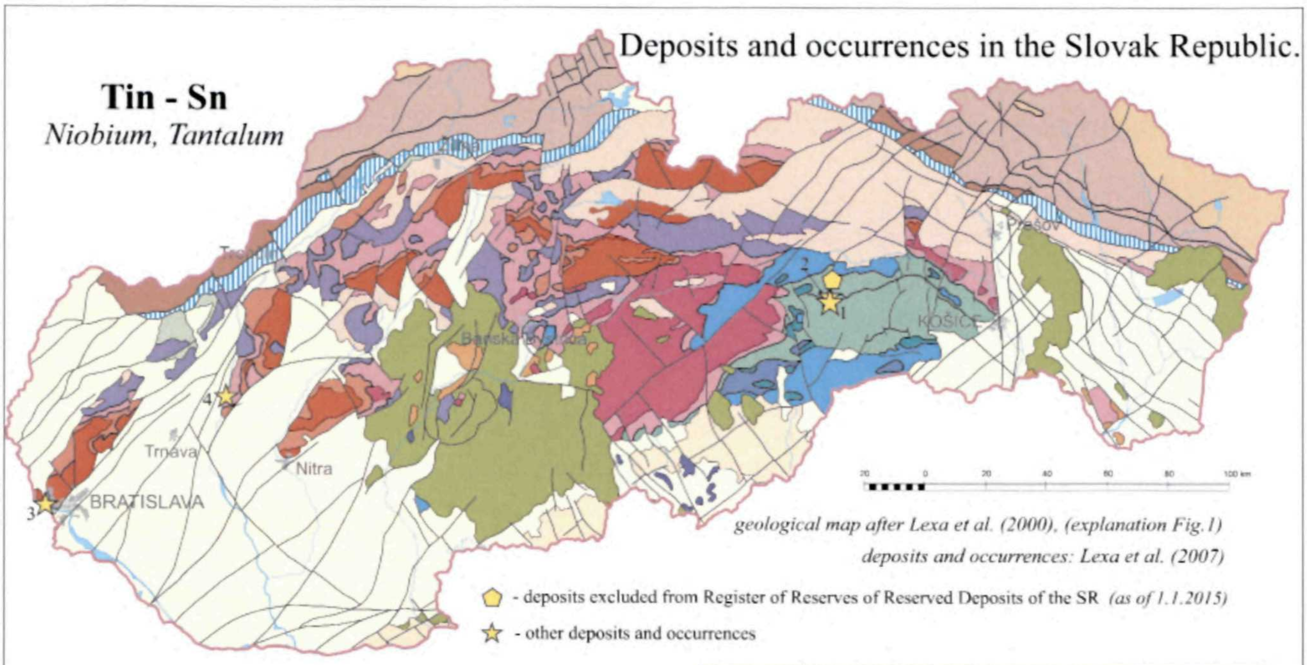
The deposits of crystalline magnesite in the Western Carpathians belong to the largest and the most important in Europe. They are located mainly in the Early Carboniferous sequences of the Ochtiná Group in the northern rim of Gemericum. More specifically these deposits include: Podrečany, Burda, Cinobaňa, 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.



NEOHERCYNIAN LATE- TO POST-OROGENIC PHASE (340 - 250 Ma)		
Crystalline basement of the Tatricum unit		
Late orogenic S-type granitic magmatism		
Pegmatitic mineralization		
Ta-Nb occurrence	Bratislava-Devín, Kamzík	3
	Moravany nad Váhom	4

NEOHERCYNIAN LATE- TO POST-OROGENIC PHASE (340 - 250 Ma)		
Granitic rocks of the Gemericum unit		
Late orogenic S-type granitic magmatism		
Plutonic-hydrothermal (greisen type) stockwork/disseminated mineralization		
Sn deposit and occurrence	Hnilec-Medvedí potok	
	Súľová	2
Sn-Ta-Nb occurrence	Gemerská Poloma-Dlhá dolina	1

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 albititised 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			

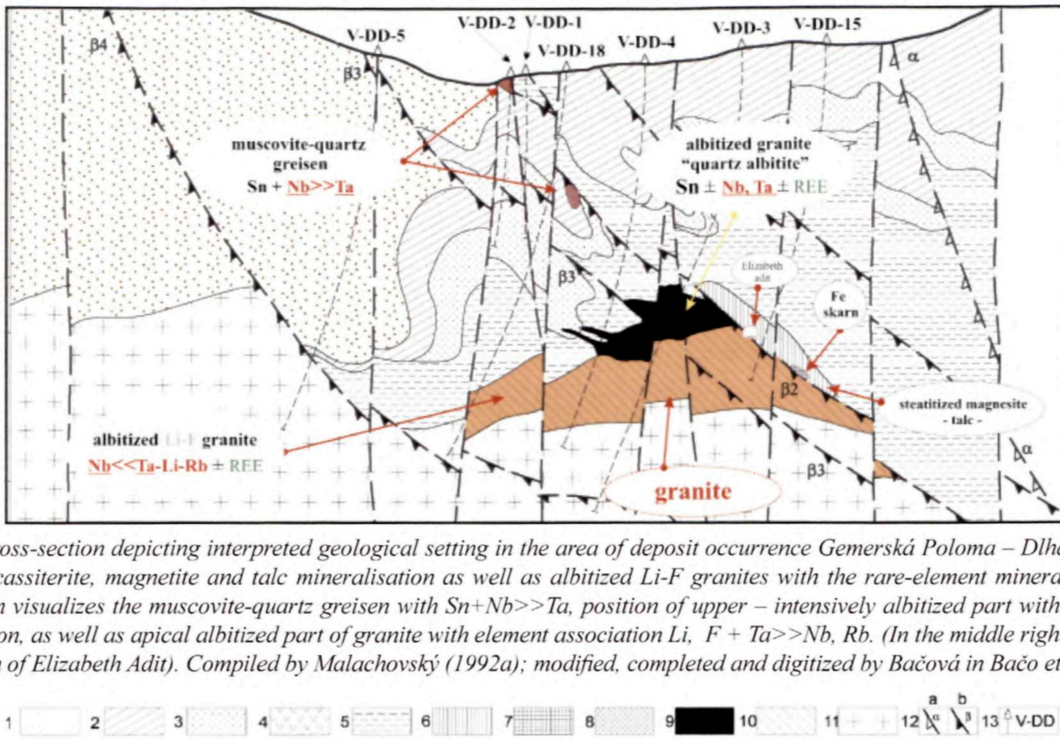


Fig. 5.28 Cross-section depicting interpreted geological setting in the area of deposit occurrence Gemerská Poloma – Dlhá dolina with position of cassiterite, magnetite and talc mineralisation as well as albitized Li-F granites with the rare-element mineralisation. The cross-section visualizes the muscovite-quartz 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-

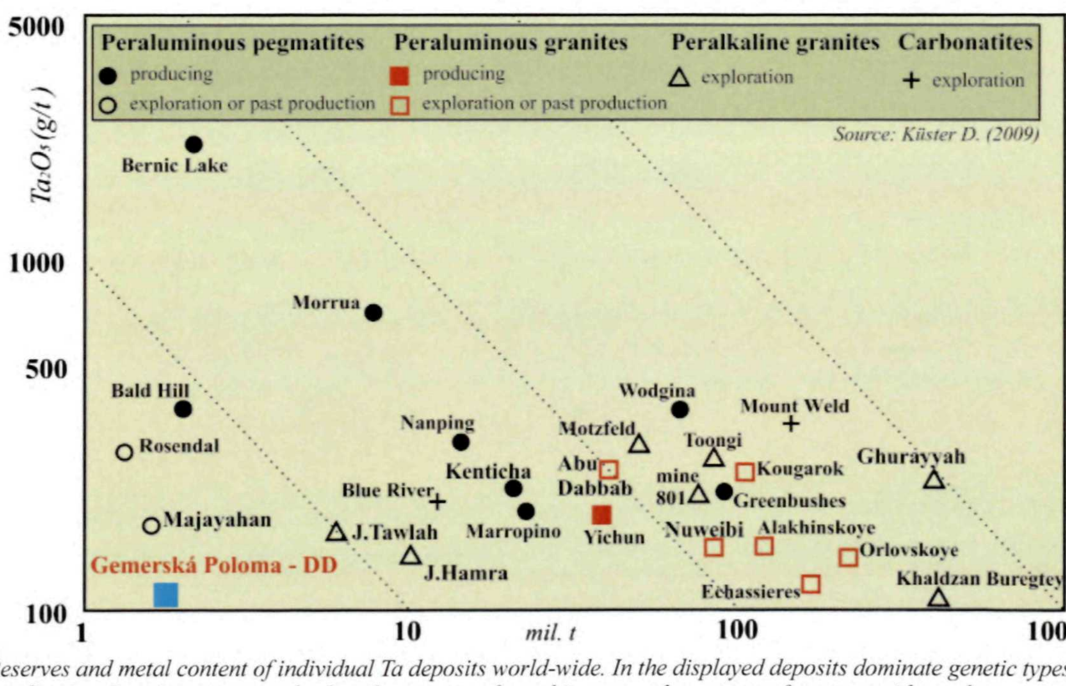
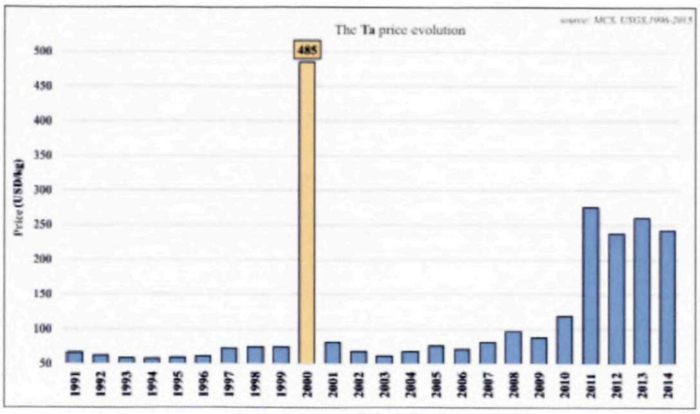


Fig. 5.29 Reserves and metal content of individual Ta deposits world-wide. In the displayed deposits dominate genetic types with disseminated mineralisation. It points out a trend, when the amount of metal increases the amount of reserves without changes in metal content, or metal content also decreases. 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.



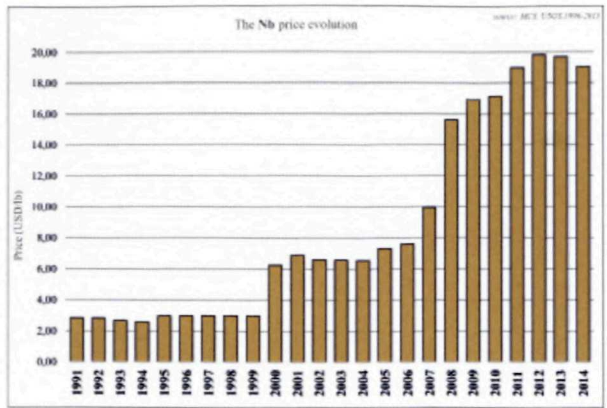


Fig. 5.30 The development of prices on the world market with consequences in different time frames. Variant "calculation" of prognostic resources was conducted in the years 1991 to 1992, thus in the period of lowest price of the observed metals. Data source: © KITCO and USGS Mineral Commodity Summaries 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

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

rich greisen cassiterite mineralisation has a significantly higher content of Nb.

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			

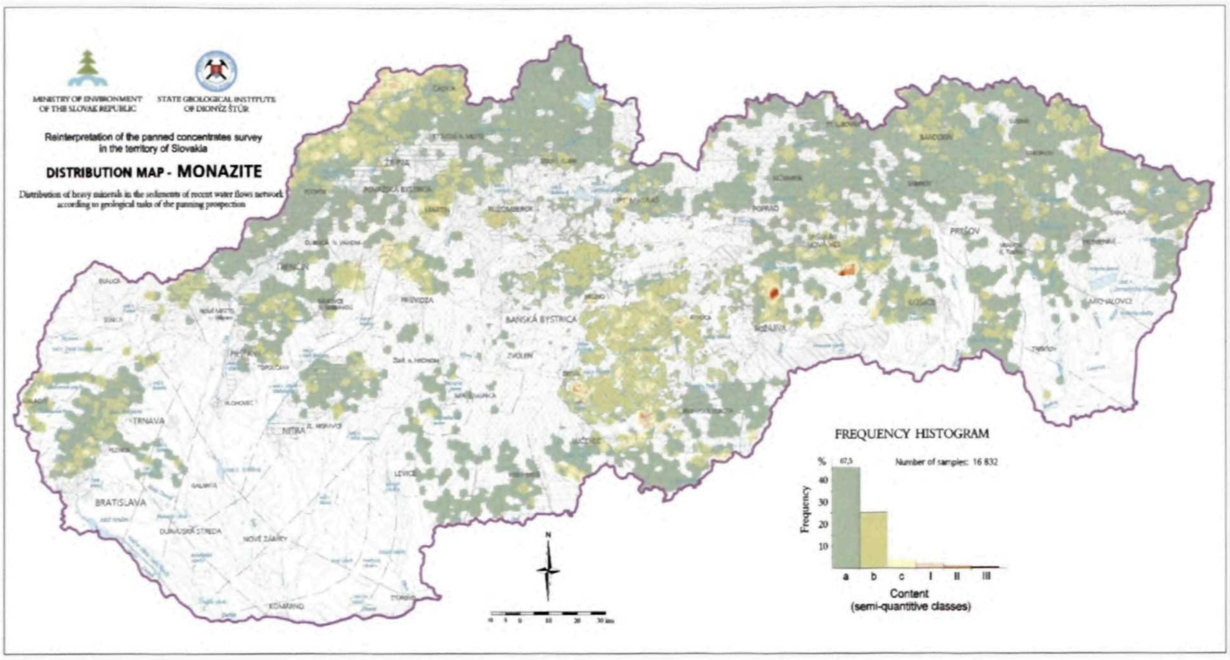
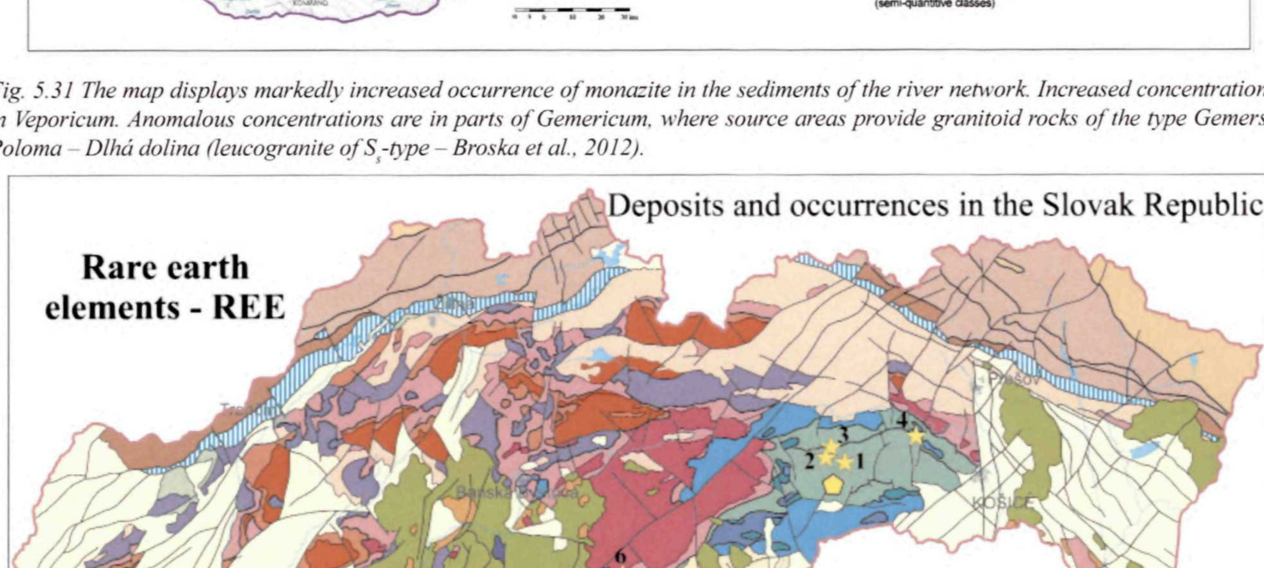


Fig. 5.31 The map displays markedly increased occurrence of monazite in the sediments of the river network. Increased concentration is in Veporicum. Anomalous concentrations are in parts of Gemericum, where source areas provide granitoid rocks of the type Gemerská Poloma – Dlhá dolina (leucogranite of S_s-type – Broska et al., 2012).



NEOHERCYNIAN LATE- TO POST-OROGENIC PHASE (340 - 250 Ma)		
Granitic rocks of the Gemericum unit		
Late orogenic S-type granitic magmatism		
Hydrothermal vein type mineralization		
U-TR-Au occurrences	**Čučma (Y)**	⬠
	Zimná voda	1 ☆
	Krátka dolina	2 ☆
	Peklisko	3 ☆

EARLY PALEO-ALPINE PHASE (250 - 110 Ma)		
Ultramafic rocks of the Gemericum unit		
Jurassic tectonic and metamorphic processes, processes of serpentinization		
Magmatic mineralizations with metamorphic and serpentinization overprints		
asbestos	Jaklovce (Sc)	4 ☆

NEO-ALPINE POST-OROGENIC PHASE (10 Ma - 0 Ma)		
Fluvial deposits		
Erosion and fluvial transport		
Placers		
REE	Podrečany	5 ☆
	Kocižský potok-Krná	6 ☆

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.

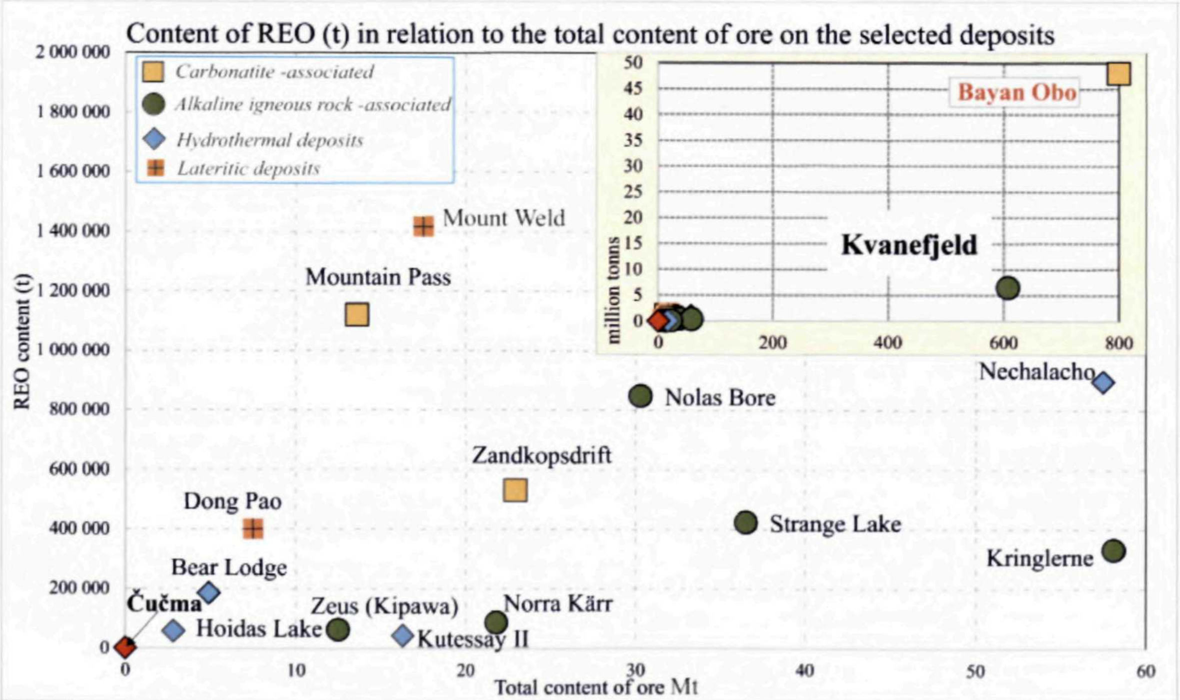


Fig. 5.33 Reserves and metal content of selected world REE deposits, indicating the position of the deposit Čučma. Modified after Walters & Lusty (2010), Gunn ed. (2014), Paspaliaris (2013)

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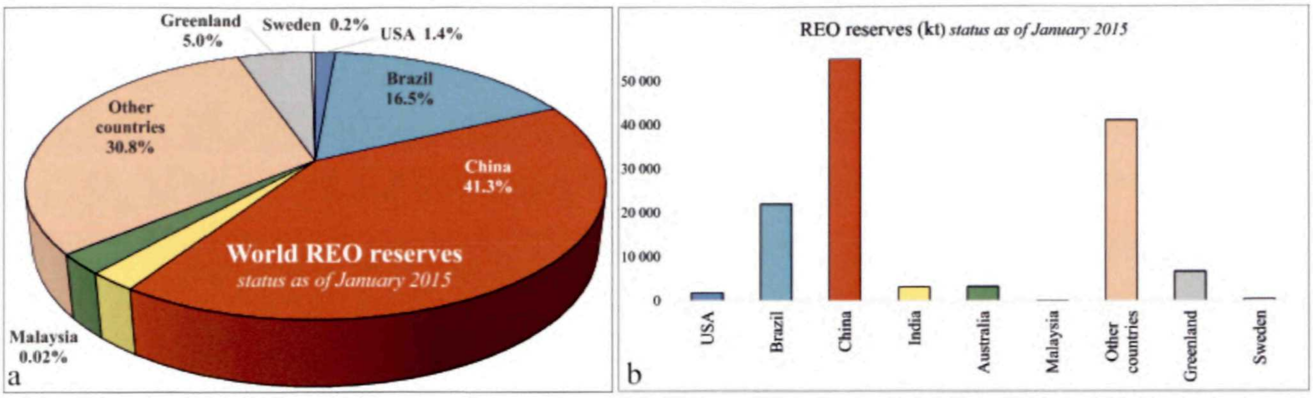

Fig. 5.34 Comparison of REE (metal) reserves in the deposits in individual countries. Many countries have non-significant REE reserves in the pegmatite deposits but also in placers (sea-beach monazite sands). Source: USGS Mineral Commodity Summaries 2015, Paspaliaris (2013)

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 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).

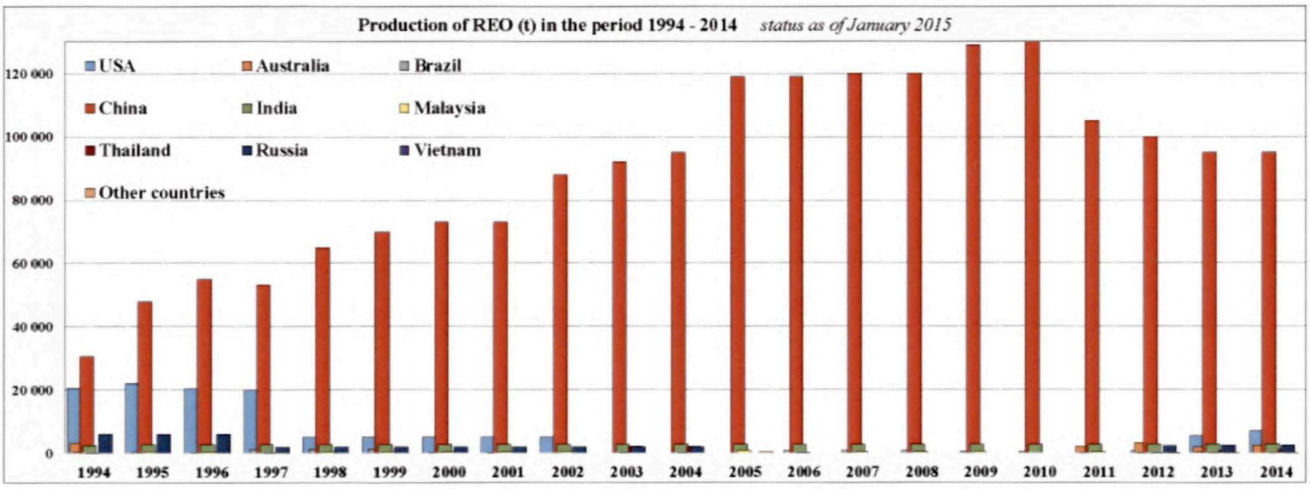

Fig. 5.35 REE production in different time periods. End of 80s and beginning of the 90s marked the turning point in the production of REE. The Bayan Obo deposit discovery, but especially learning the technology of obtaining metals from ore has resulted in taking production hegemony by China to the extent 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

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

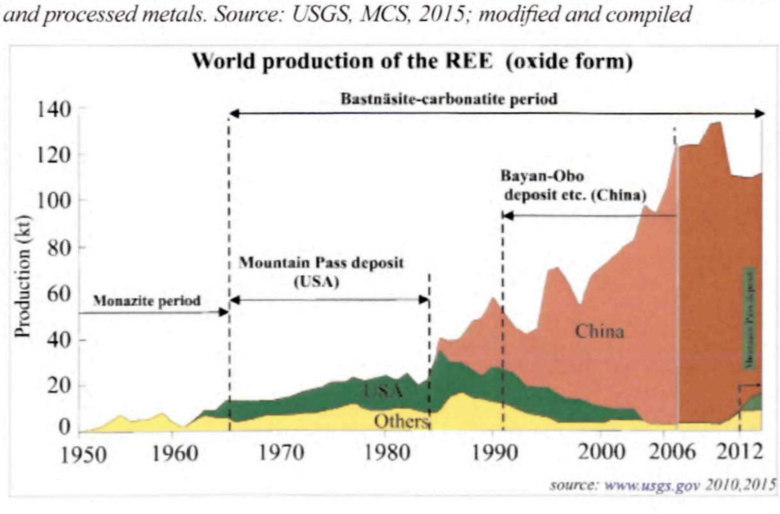

Fig. 5.36 Historical development of mining of two main genetic types of source materials – monazite and bastnäsite. The monazite is extracted from sea-beach sands, this means placer genetic type. The bastnäsite originates from the carbonatite rock environment and a large volume of surrounding rocks has 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).

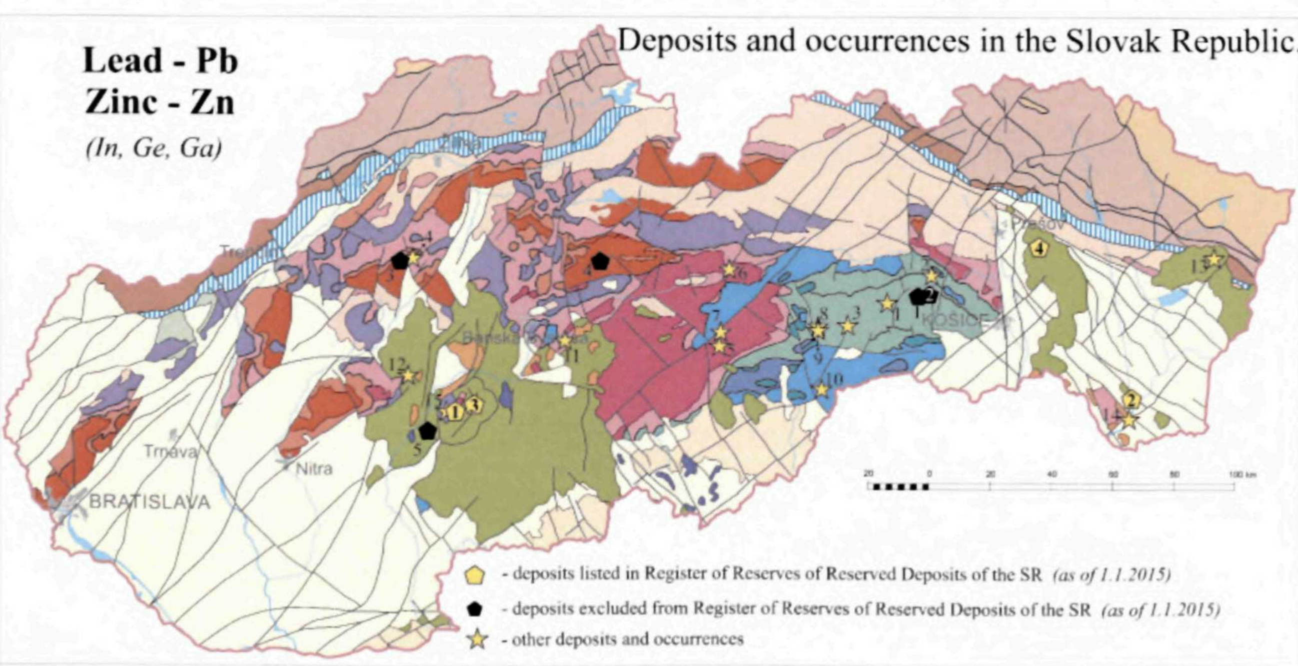

Fig. 5.37 Deposits and significant occurrences of base metals (Pb, Zn + Cu ± Au, Ag) in different geological units of the Slovak part of the Western Carpathians.

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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.

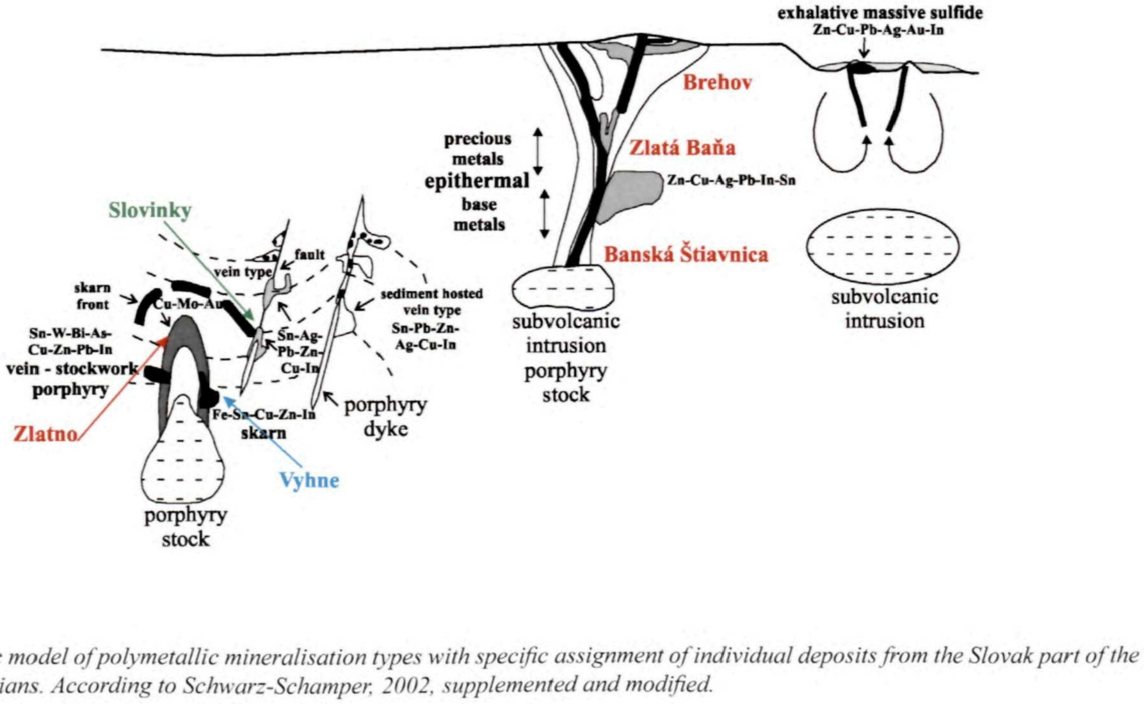

Fig. 5.39 Genetic model of polymetallic mineralisation types with specific assignment of individual deposits from the Slovak part of the Western Carpathians. According to Schwarz-Schamper, 2002, supplemented and modified.

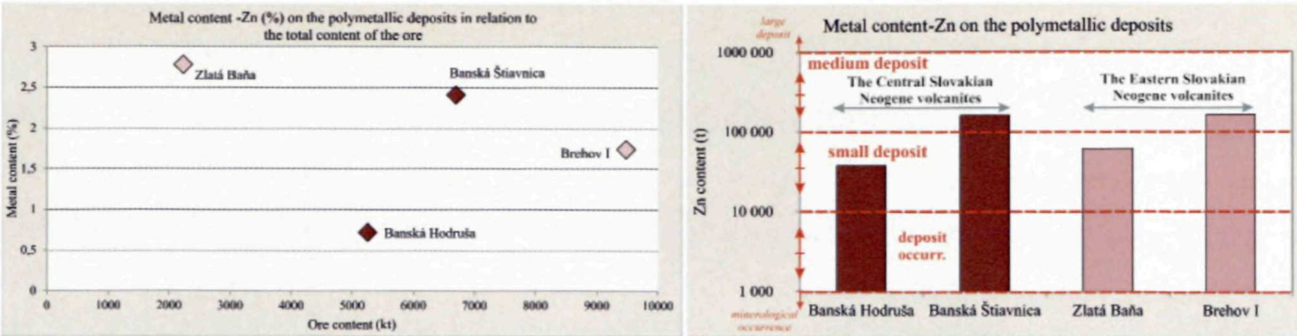

Fig. 5.40 Reserves of base metal ores in individual deposits in the Slovak part of the Western Carpathians, classified by size criteria.

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.

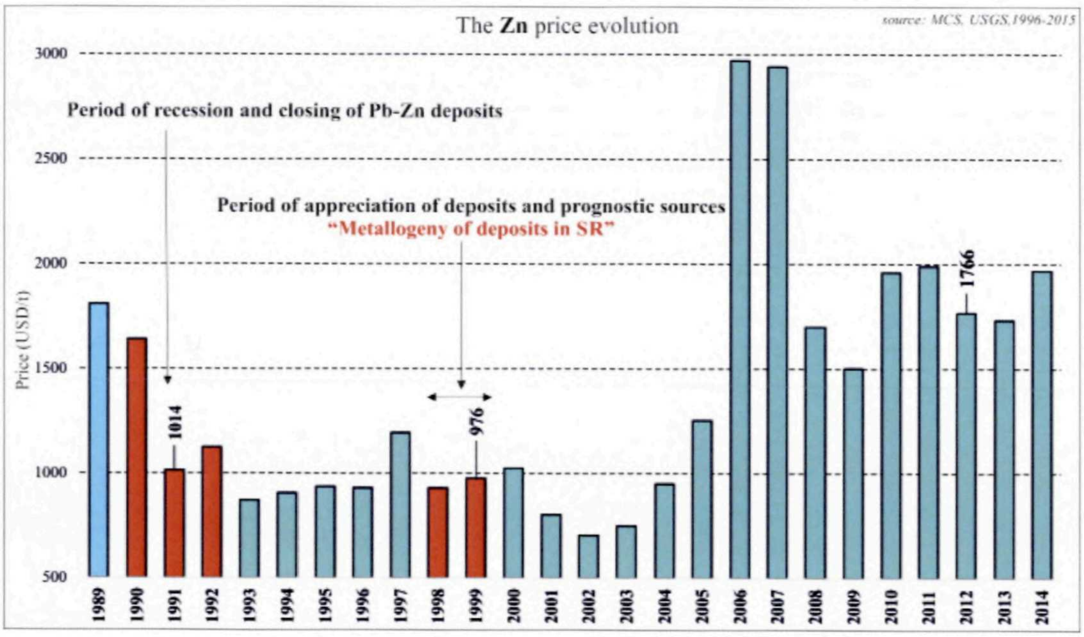

Fig. 5.41 Development of Zn prices on the world markets. Displayed are the important implications for our ore mining. The evaluation of deposits was also impacted and mainly the re-evaluation of earlier estimated prognostic resources (Lexa et al., 2002) in the ore deposits fields and several newly discovered deposits or more significant occurrences. Data source: © KITCO and USGS Mineral Commodity Summaries 1996-2015; supplemented, modified

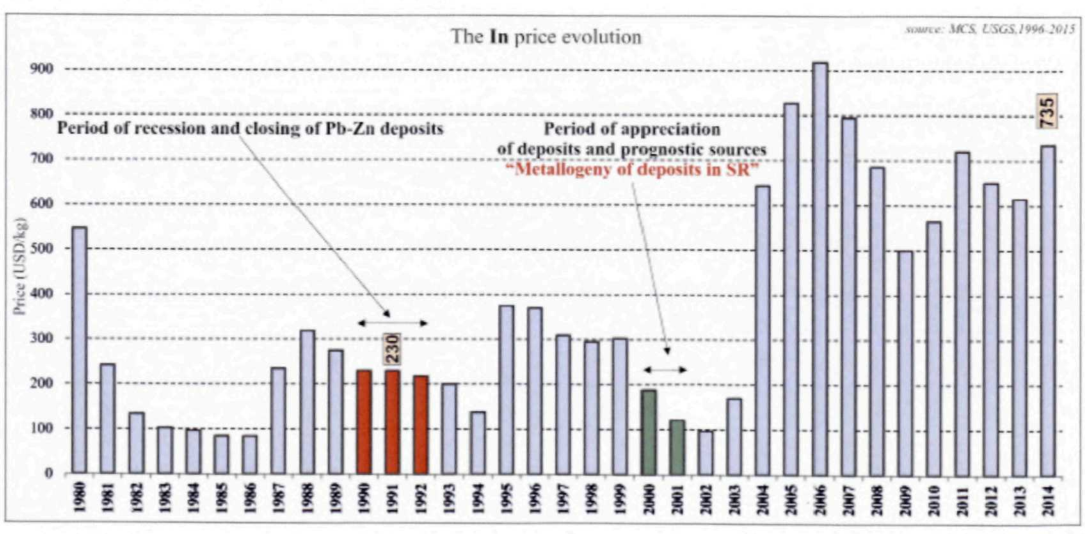

Fig. 5.42 Development of In price in world markets followed the trend of the main metals. Data source: © KITCO and USGS Mineral Commodity Summaries 1996-2015; supplemented, modified

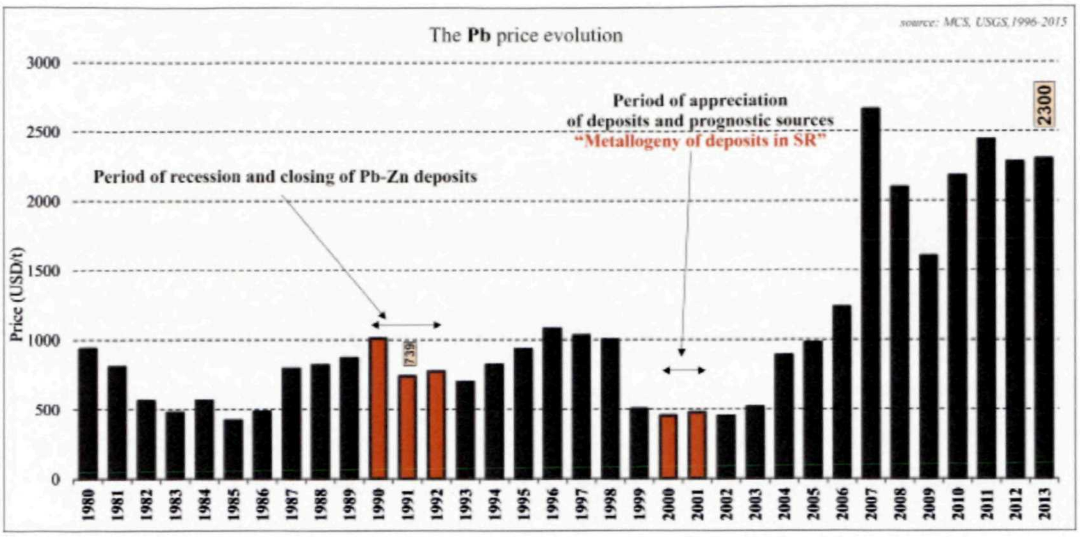

Fig. 5.43 Development of Pb prices on the world markets. The collapse of prices in 2000-2002 was very significant. As mentioned earlier, it was the period of the last reassessment of remaining reserves at the attenuated deposits (Lexa et al., 2002). There were also reconsidered prognostic sources of 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.

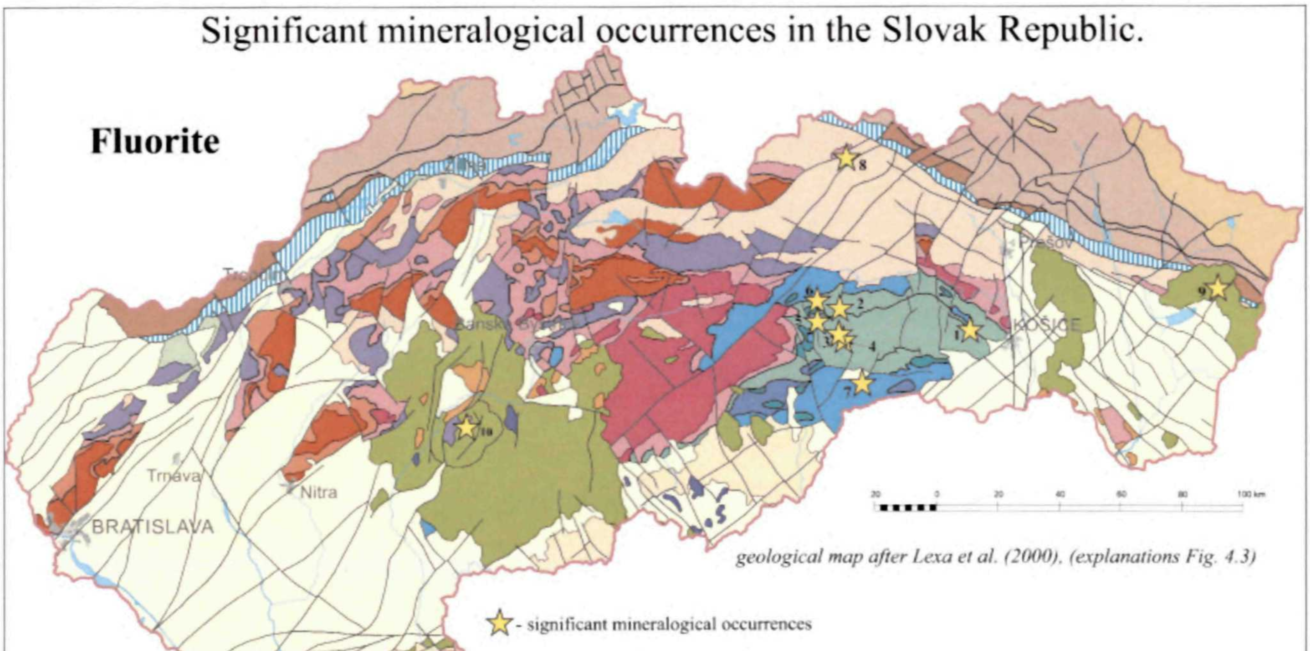

Fig. 5.44 Deposit occurrences and mineralogical occurrences of significant mineralisation with fluorite in different geological formations and some of their geological and genetic attributes. Source: Lexa et al., 2000; Ďuďa & Ozdín, 2012.

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	
Occurrences of fluorite in	Zlatá Idka 1

NEOHERCYNIAN LATE- TO POST-OROGENIC PHASE (340 - 250 Ma)	
Granitic rocks of the Gemericum unit	
Late orogenic S-type granitic magmatism	
Plutonic-hydrothermal (greisen type) stockwork/disseminated mineralization	
Occurrence of fluorite on Sn deposits and occurrences	Hnilec-Medvedí potok 2
	Gemerská Poloma 3
	Betliar 4

PALEO-ALPINE LATE-OROGENIC PHASE (90 - 70 Ma)	
Limestones and dolomites of higher nappes	
Erosion, extension and thermal reactivation	
Hydrothermal vein mineralizations	
Occurrences of fluorite	Čierna lehota 5
	Šumiac 6
	Lipovník 7

NEO-ALPINE OROGENIC PHASE (24-10 Ma)	
Inner-Carpathian flysch	
Mobilization of fluids due to the accretion prism evolution	
Hydrothermal mineralizations	
Occurrences of fluorite on epigenetic carbonate veins	Podolínec 8
Neogene volcanites	
Andesite and rhyolite volcanism accompanied by subvolcanic intrusive complexes and the evolution of volcanotectonic	
High sulphidation epithermal mineralizations	
Occurrences of fluorite	Remetské Hámre 9
Volcanic hosted low sulphidation epithermal mineralizations	
Occurrences of fluorite	Banská Štiavnica 10

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.

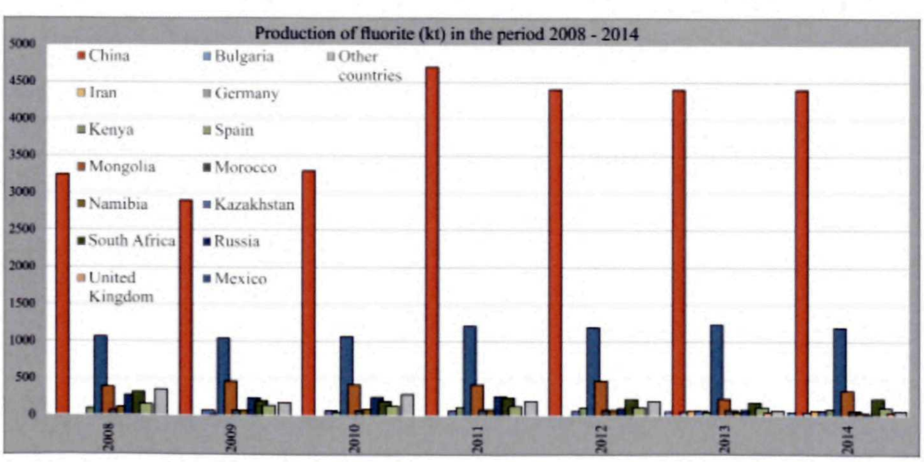

Fig. 5.46 Production of fluorite world-wide. Dominance of China and its stable high production in 2011 are obvious. Source: USGS, Mineral Commodity Summaries, years 2010-2015; modified and compiled.

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

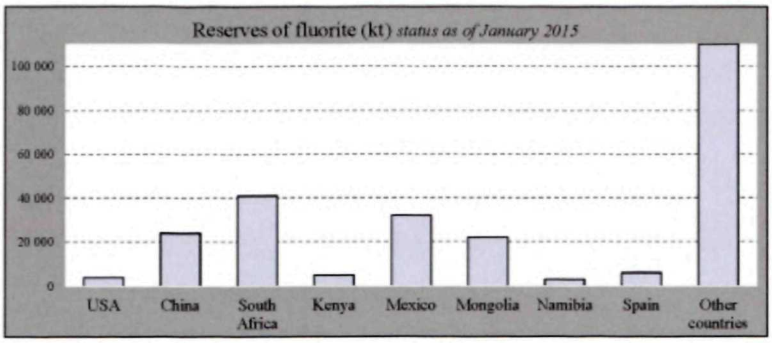

Fig. 5.47 Fluorite reserves world-wide. China is not a country with the greatest potential of calculated reserves of fluorite although it is the greatest producer. Source: USGS, Mineral Commodity Summaries 2015; modified and compiled

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:

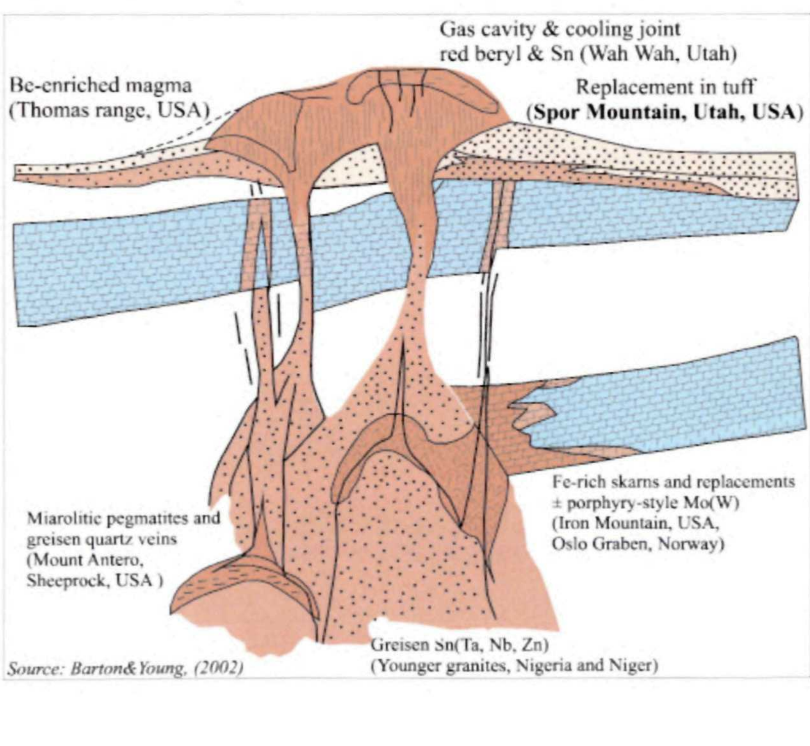

Fig. 5.48 Genetic type model of Be mineralisation of metaluminous and poorly peraluminous systems. According to Barton and Young, (2002), modified.

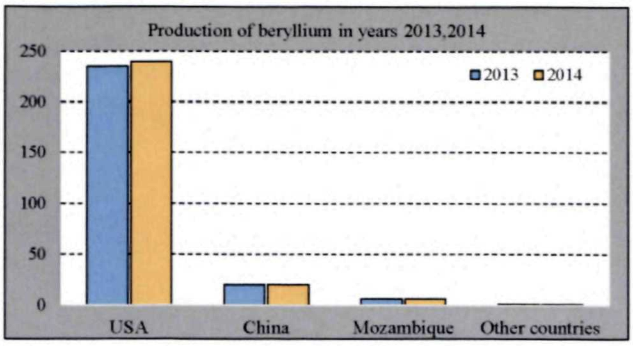

Fig. 5.49 Be production world-wide. Dominance of the USA is obvious along with high production in 2013 and 2014. Source: USGS, Mineral Commodity Summaries 2015; modified and compiled

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.
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

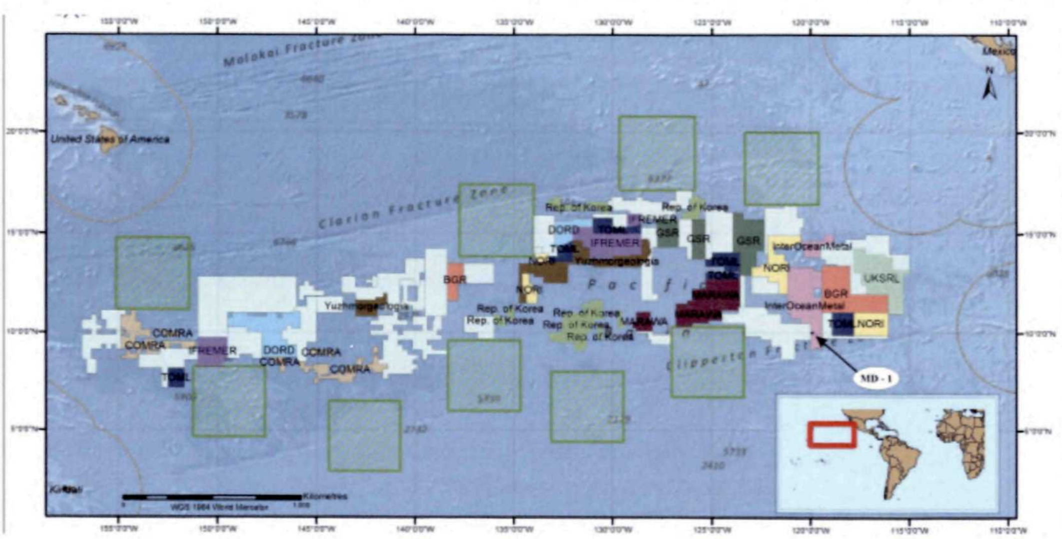

Fig. 5.50 The geographical position of exploration areas of oceanic floor between the Clarion and Clipperton tectonic zone in the Pacific Ocean. Two irregular polygons of pink colour are the exploration areas of Interoceanmetal. The place of Mn nodules sampling is indicated – identification of the analysis MD-1.

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.

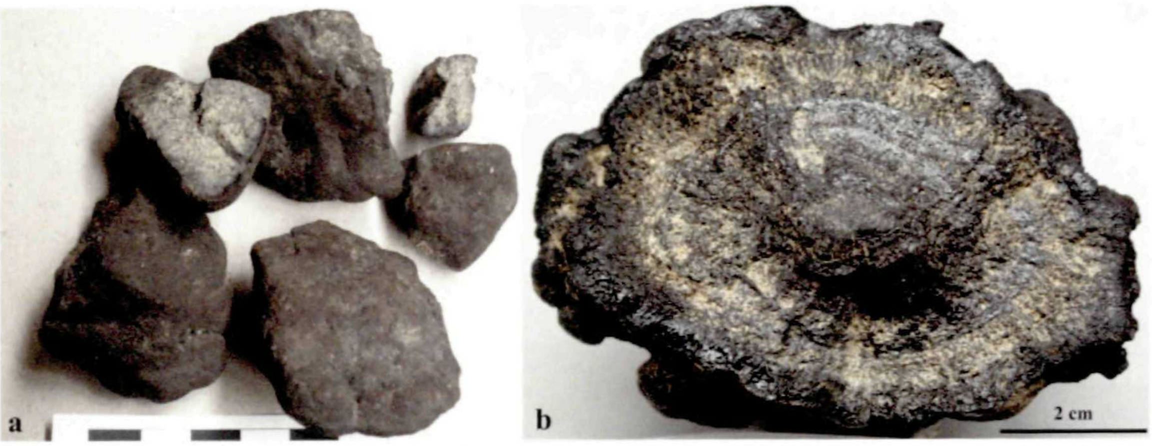

Fig. 5.51 Deposit of polymetallic nodules – Pacific Ocean. Samples (a) come from the ocean floor defined by coordinates of the W longitude 120° and N latitude 10°; depth is about 4.5 km. Analysis designation MD-1; Photo: Bačo

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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