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MODELLING OF METALLOGENIC DEVELOPMENT OF THE BOHEMIAN MASSIF

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Abstract: The contribution presents a model of metallogenic evolution of the Bohemian Massif. The model has been developed on the basis of an analysis of mineral and element assemblages. It describes the evolution of individual metallogenic systems in relation to the block structure. Clustering statistical methods have been applied in the development of the model. The temporal evolution has been derived from the evaluation of isotopic compositionon of lead and it has been correlated with other geochronological methods. From the interpretation of the model it follows that the metallogenic evolution was irregular, the character of crust and activation of the block having been different in different times. Marked features are repeating of metallogenic activities, multiphase evolution and regeneration, prominent especially in peripheral blocks. From the Moravian-Silesian group of blocks metallogenic point of view considerably differs from the rest of the Bohemian Massif.

Key words: metallogenic and geochronologic model, Bohemian Massif, clustering statistical methods, isotopic composition of lead, metallogenic successions, metallofactors.

Introduction

One of the basic premises for the prognostic evaluation of mineralization is a model of metallogenic activities and their evolution in the studied region. In the year 1982, specialists working in the Centre of Applied Geochemistry, Geoindustria st. ent., branch Jihlava, developed for the purposes of a project of Geological Survey – Prognostic evaluation of the Bohemian Massif (Vacek et al. 1983) – a model of metallogenic systems of the Bohemian Massif. The model has been developed above all for the purpose of unifed description of ore accumulations of various genetic types as models of their metallogenic systems. It was derived from the evaluation of relationships in mineral and element assemblages of 85 principal ore accumulations in the Bohemian Massif. On the basis of these models, a database register of ore indications and deposits came into being (1200 records) and an evaluation of metallogenic activity of the Bohemian Massif has been carried out on the scale of 1 : 500 000. After gaining some experience with other applications of the model on more detailed scales, the model was actualized (Procházka and Grym 1986) and partial systems have been distinguished within it, taking into consideration the development of metallogeny in relation to evolution stages of the Bohemian Massif. In the year 1988 it was further adjusted for the purpose of computer processing of a metallogenic map on the scale 1 : 50 000 and complemented by typology of isotopic lead in galenites which is presented here.

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Classification and modelling of metallogenic systems

The problems of the Bohemian Massif have been dealt with by a number of authors or teams. A basic modern conception of metallogeny of the Bohemian Massif has been presented by Koutek (1964). It was followed by works of Sattran et al. (1966). Chrt and Bolduan et al. (1966) and especially by works of Bernard (1967, 1981). The most complete description of metallogeny in the Bohemian Massif has been given by Pouba and Bernard (1986) and for uranium deposits by a team of authors from Gelogical Survey of the Uranium Industry (1964). The first paragenetic classification has been introduced by Bernard (1967) as a result of paragenetic analysis of deposits in the Bohemian Massif. The basis of the classification are 36 isogenetic mineral assemblages by which every ore deposit can be classified as a whole. This classification however in many cases (polygenic deposits) is not unambiguous and it has limited possibilities to describe objects. Therefore, a systematic classification of ore accumulations has been created, which allows to make models of an ore body as well as of a district or region.

The basic idea in our classification was the assumption that each ore accumulation is the result of a concentrating process connected with a metallogenic system. When making a model of a concrete object it is necessary to determine its material structure and its evolution. The study of structure of a metallogenic system means the definition of its components and their interrelationships. In the analysis of structures for the purpose of developing models of metallogenic systems of the Bohemian Massif, 130 mineral assemblages of principal accumulation have been reevaluated. Clustering methods allowed to determine that 30 natural element groups,

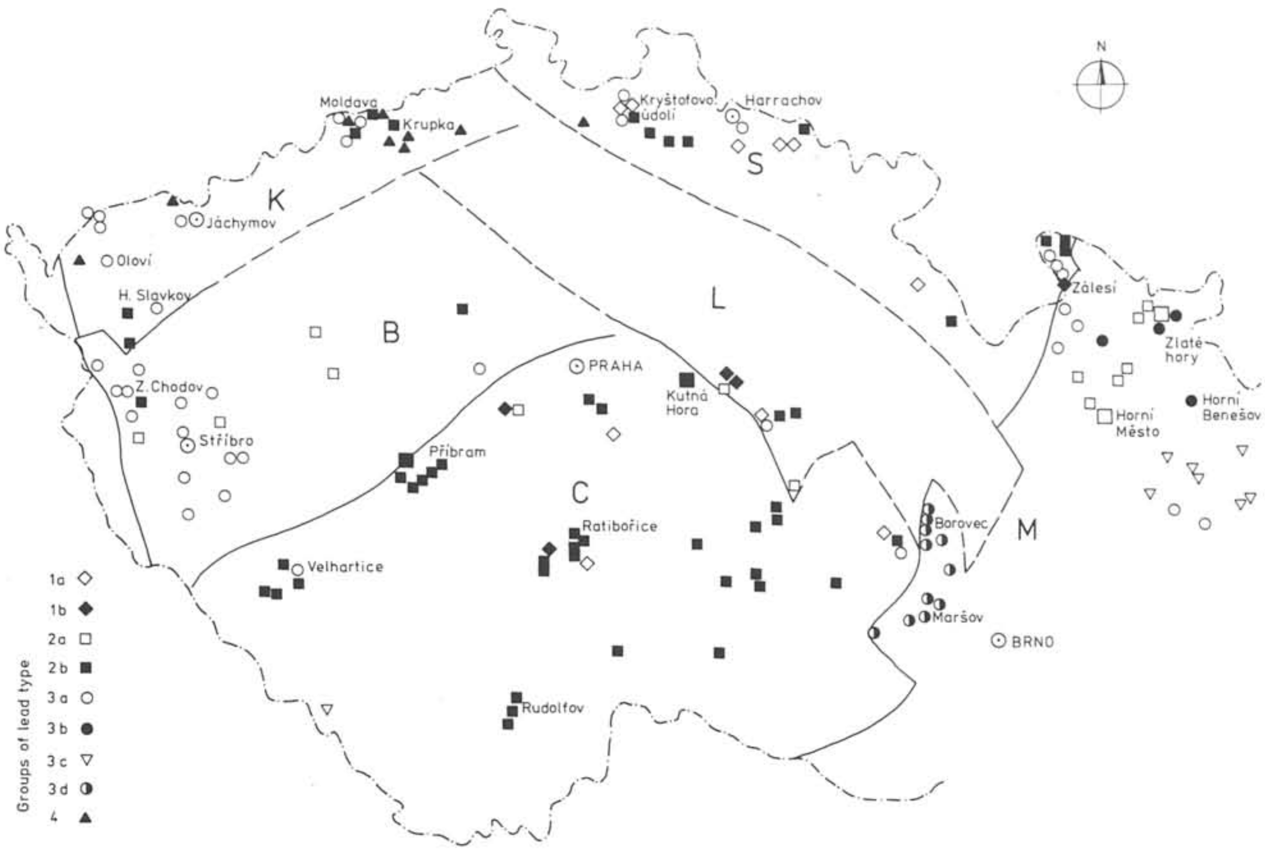


Fig. 1. Modelling of metallogenetic systems in the Bohemian Massif. Distribution of isotopic lead types.
Legend: B – "Barrandien" block, C – "Central" block, K – "Krušné Hory" block, L – "Labe" block, M. – "Moravian-Silesian" block, S – "Kladsko-Lugiko-Sudetian" block.

coinciding with the evolution stages of mineral assemblages, took part in the formation of all objects. These groups have been called „metallofactors" and we defined them by the element and mineral composition of the studied mineralization (Tab. 1). Their combinations allow then to descibe any ore accumulation. By an analysis of relationships between individual metallofactors we distinguished formation successions of these metallofactors. Each formation succession is specific not only as far as its mineral and element assemblage is concerned, but also by its relationship to the development of its surroundings in a time interval.

Already when making previous models it was discovered that there are two basic metallogenic systems in the Bohemian Massif. In the first one, a limited number of chemical elements (Cr, V, Mn, Fe, Ni, Co, Cu, Zn, Ba, Pb) are active from the viewpoint of metallogeny. This type is usually related to positive gravity field and to unsialized and poorly differentiated crust. It forms simple systems. On the other hand, the second type of systems, having close relationship to negative gravity field, is a product of Variscan platform stabilization connected with well-differentiated and sialized crust. Besides the above mentioned group of elements, further elements (W, Mo, Au, Te, Bi, As, Sn, Li, F, Nb, Ta, In, Ag, Sb, U) became gradually activated during sialization in these systems. The second type forms complex systems connected usually with magmatic activity. However, it is not uniform; two basic succesions can be distinguished within the system – the Sn succession markedly related to negative gravity field and Au succession related to the margins of blocks characterized by negative gravity field.

Age of metallogenic systems of the Bohemian Massif

The temporal development of metallogenic systems in the Bohemian Massif, as it follows from works of Legiersky (1973) and others, is very long. A reinterpretation of 280 isotopic lead analyses in galenites from the Bohemian Massif has been carried out by Patočka et al. (1985) and Vaněček et al. (1985). Authours of these synthetic works evaluated the data by statistical methods, above all by trend as well as factor analysis, and applied the plumbotectonic model in the sense of Doe and Zartmann (1979). Pertold and Stehlík (1978) based their study on the assumption of a non-uniform, complicated geological evolution of the Bohemian Massif and they revised the model age of a number of locations with stratiform mineralization according to the evolution curve of Doe and Stancey (1974). Variances in model ages based on isotopic composition of lead in galenites led the authors to a revision of the age of metallogenic systems. For the evaluation of results they apllied non-parametric methods. These methods in the last time substitute parametric methods when multipopulation sets are concerned.

The methodologic verification of the suitability of these

Table 1. Specifications of metallofactors in the Bohemian Massif.

	Metallofactor	Ore minerals	Vein rock	Typical manifestations at the localites	Note
1	Fe	magnetite, hematite, limonite, leptochlorites	–	Krušná Hora, Králová, Županovice, Vlastějovice	sumary factor
2	Fe Mn	hematite, Mn-oxides, Mn-phosphates, pyrite	–	Chvaletice, Moldava, Kovářská	sumary factor
3	Fe Cu	chalcopyrite, pyrrhotine, cubanite, pyrite	–	Tisová, Zlaté Hory – Žebračka, Staré Ransko	
4	Fe Cu Zn	chalcopyrite, pyrrhotite, sphalerite, pyrite	–	Svržno, Županovice, Staré Ransko – Obrázek	
5	Fe Co Ni	pyrrhotite, pentlandite	–	Staré Ransko, Rožany	
6	Fe As Cu Zn Pb	pyrite, arsenical pyrite, galenite, sphalerite, chalcopyrite	quartz, carbonate	Jílové, Javorník	without stanine
7	Ba	–	barite, quartz	Moldava, Harachov, Pernárec, Hor. Benešov, Malovidy	sumary factor
8	Pb Zn	galenite, sphalerite	–	Oloví, Stříbro, Hor. Benešov, Švařec, Zlaté Hory	little Ag at galenite
9	W	wolframite, scheelite	quartz, muscovite	Rotava, Vrbík, Kasejovice, Ovesná Lhota, Obří důl	sumary factor
10	Mo	molybdenite	quartz	Hůrky u Čisté, Telnice, Krupka, Černá Hora	sumary factor
11	Sn	cassiterite, arsenopyrite, pyrite	quartz ± muscovite	Rolava, Zlatý kopec, Boží Dar	sumary factor
12	Li F Sn W	cassiterite, wolframite	quartz, topaz, zinwaldite	Cínovec, Horní Slavkov	
13	Fe As Sn Cu	stannine, chalcopyrite, arsenopyrite, cassiterite	quartz	Kutná Hora, Cínovec, Freiberg	
14	Fe As Zn Pb Ag	arsenopyrite, galenite, sphalerite	quartz	Kutná Hora, Freiberg, Dlouhá Ves, Stříbrná Skalice	silver-bearing galenite
15	Fe Cu Pb Zn Ag	galenite, sphalerite, chalcopyrite	siderite, carbonate, quartz	Příbram, Kynžvart, Stará Vožica	silver-bearing galenite
16	As Sb Cu Pb Ag	tetraedrite, boulangerite, pyrargyrite, proustite	carbonate > quartz	Příbram, Freiberg, Kutná Hora	silver-bearing tetraedrite
17	Fe As Co Ni	arsenides, diarsenides, triarsenides Fe Co Ni	carbonate > quartz	Příbram, Jáchymov, Zálesí	
18	Au	pure gold, pyrite	quartz	Písek, Humpolec	without arsenopyrite
19	Fe As Au	arsenopyrite, pyrite, pure gold	quartz	Mokrsko, Jílové, Kasejovice, Kašperské Hory	
20	Bi Te Au	bismuth-telluride	quartz > carbonate	Jílové, Kasejovice	
21	As Sb Bi Ag	pure As, Sb, Bi, Ag, argentite, proustite, pyrargyrite	carbonate > quartz	Jáchymov, Horní Slavkov	
22	Sb	antimonite, berthierite, pyrite	carbonate > quartz	Milešov, Příbram, Bohutín	
23	Cu	chalcopyrite, bornite, cuprite	–	Běloves, Tři Sekery, Borovec, Ludvíkov, Rybniště	sumary factor
24	Hg	cinnabarite	–	Jedová Hora, Luby	sumary factor
25	F	–	fluorite, quartz	Moldava, Harrachov, Běstvina, Sněžník, Vrchoslav	sumary factor
26	U–CO_2	uranite	carbonate > quartz	Jáchymov, Rožínka, Bytíz	
27	U–SiO_2	coffinite, brannerite, edisonite	albite, chlorite, quartz	Borský masív, Rožínka	
28	U–ZrO_2	antraxolite, zircon	–	Stráž pod Ralskem	
29	Se Cu Pb Ag	berzelianite, umangite, clausthalite	carbonate > quartz	Bukov, Předbořice, Borský masív, Bytíz	
30	Sb As Au	antimonite, arsenical pyrite, pure gold	carbonate > quartz	Krásná Hora, Příčovy	

methods has been done by an application of the clustering diagnostic method PASIANS, developed in the Centre of Applied Geochemistry in Jihlava, to a set of isotopic analyses. The set included non-averaged original data from the works of Legierský (1973), Legierský and Pošmourný (1966) and Legierský and Vaněček (1967).

The first step in the application of this method was an analysis of statistical distribution. On the basis of an evaluation of distribution tables, the following class limits have been determined:

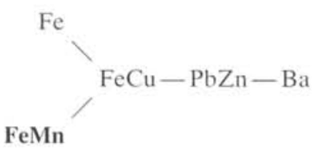
Class	0 1	1 2	2 3	3 4	4 5
Pb 204	1.330	1.345	1.360	1.377	
Pb 206	24.55	24.75	24.95	25.10	25.30
Pb 207	21.10	21.24	21.40	21.60	
Pb 208	51.95	52.10	52.25	52.40	

Using the above mentioned limits, a class has been assigned to each value. A combination of classes – combination word – has been determined for each observation. The numeric codes in the combination word used by the authors are in the order of isotopes Pb 205, 206, 207, 208. The locations were then on the basis of these combination words classified into natural groups, and models of metallogenic systems have been made for each group. **The first** one contains lead with basically high content of the isotopes Pb 204 and 207, this group can be further divided into two basic subgroups.

1a) Characterized by lead types 4044, 4043, 4144, 4143. Metallogenic system related to this subgroup has a simple model: FeCu – **PbZn – Ba**

Into this subgroup belong especially mineralizations in metamorphosed carbonate rocks – Chýnov, Český Šternberk, Rokytnice, Zdobnice. The age is probably Cadomian, maybe older.

1b) Characterized by lead types 4142, 4241, 4242. Metallogenic system connected with this subgroup has the model:



Into this group belong mineralizations in volcanosedimentary formations, such as Chvaletice, Jílové, Hraničná. The age is probably Cadomian.

The group **2** is characterized by lead types with increased content of the isotopes Pb 204 and 206. This group can be divided into two subgroups:

2a) consists of lead types 3331, 3431, 3332, 3341. Metallogenic models are not uniform, into this subgroup belong especially the ore deposits Horní Město, Nová Ves u Rýmařova, Rejvíz, with the model

FeCu – **PbZn** – Ba

Jílové

W – FeAs (CuPbZn – **Au**) – TeBiAu

Hůrky u Čisté

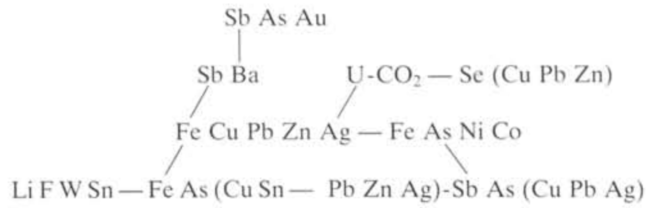
FeAs **(Mo – CuPbZn – Au – Sb)**

Staré Ransko

FeCuZn – PbZn – **Ba**

Probable age is Early to Middle Variscan (derived from the stratigraphic position).

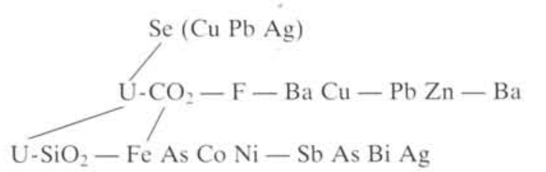
2b) consists of lead types 3233 and 3232. It is the most frequent type in the Bohemian Massif. The metallogenic system has a complicated structure and its model can be expressed by the oriented graph:



Its age has been determined by the Pb/U method at 260–280 Ma. This system is typical of regions with negative gravity field and sialized upper crust. Main representatives of this system are in the central group of blocks Kutná Hora and Příbram. In the Krušné Hory region they are Freiberg, Cínovec, Horní Slavkov. It is present also in Jáchymov as an early phase.

The group **3** is characterized by lead types with low contents of the isotope Pb 204. This group is divided into 4 subgroups:

3a) It is formed by lead types 2323, 2322, 2422, 2421. This subgroup is the second most frequent one in the Bohemian Massif. In regions with strong negative gravity field it creates a complicated metallogenic system which can be illustrated by the following oriented graph:



This system represents above all the deposit Jáchymov, where the system is superimposed on the system **2b,** similarly as in the ore district Rožná. Further it is manifested on the deposits of the Borský Massif. Into this subgroup belong also principal deposit accumulations of F-Ba, such as Běstvina, Harrachov and Moldava. Manifestations of this subgroup can be found in areas of positive gravity field. It usually has simple development expressed by the model

Cu – PbZn+Ba

A typical representative is the Stříbro district. Model age of this group is estimated on the basis of U/Pb method at 190–140 Ma, i. e. Kimmerian.

3b) It is formed by lead type 2431. It has a specific position. It has been determined exclusively in Silesian blocks, where it is represented by the deposits Zlaté Hory and Horní Benešov. The model is simple:

FeCu – PbZn± Ba

An anomaly of this group is that its age according to the ratio of Pb 204 and Pb 207 should be Kimmerian. However, according to the geological criteria it is not younger than Late Variscan.

This subgroup is related to positive gravity field.

3c) The subgroup is defined by lead types 2232, 2332, 2331. Similarly as the previous one, this group has been determined only in the Silesian block. It is represented by minor occurrences in the Kulmian and by a simple model

$$Cu - PbZn \pm Ba$$

3d) The subgroup with lead types 2520, 2521, 2512, 15111, 1520 is specific for Moravicum. The most important representatives – Borovec, Švařec and Heroltice, have a simple model

$$Cu - PbZn - Ba \pm F$$

The age cannot be determined unambiguously.

4. This is a group with strongly increased content of the isotope Pb 206 and decreased contents of isotopes Pb 204 and Pb 207. It is characteristic of the region of the Ohárecký rift and it is connected with neoid matallogenic reactivation. The principal representatives of these systems are Roztoky (Cu-PbZn), Sněžník (F-Ba) and the most important one is Hamr (U-Zr-Cu-PbZn-F-Ba). Indications of these mineralization systems are superimposed mineralizations on the deposits Potučky and Cínovec.

Metallogenic regions of the Bohemian Massif

In the presented paper, the development of metallogenic systems is evaluated in groups of blocks with similar evolution and character of crust.

The Bohemian Massif appears to be a region with alternating belts of blocks, their direction being aprox. NE, with different gravity characteristics of the crust in which the different material and energetic development is reflected. The blocks in individual belts are then distinguished by their geological evolution, metamorphism, volcanism, magmatism and tectonic regime. The differences in crust development influence also the evolution of metallogenic systems.

The metallogenic regions of the Bohemian Massif have been dealt with by several authors. We consider the most important ones to be the regional classifications of Pouba and Sattran (in Sattran et al. 1966) and Bernard (1978). For the purpose of the presented study we based our metallogenic regional classification on the basic division of the Bohemian Massif into regions after Mísař et al. (1983), which has been modified considering common metallogenic development. The regions of Krušné Hory, Lužice and Moravian-Silesian have been left without changes. The regions Moldanubian and Kutná Hora-Svratka have been joined into the central group of blocks and the central Bohemian region has been divided into the Labe and Barrandien group of blocks. Starting from partial models of lower-order blocks, models of development of metallogenic systems have been made for each group of blocks, according to lead types. Geological criteria were applied for the classification of especially those systems in which classification on the basis of geochronological methods has not been possible.

Simplified models of the development of metallogenic systems in individual regions are presented in Tab. 2.

Development of metallogenic systems in the Bohemian Massif

The metallogenic development of the Bohemian Massif depended on the development of crust in each of the blocks an it was not uniform. This is documented by the variety of deposit types. The most different development is that of the Moravian-Silesian group of blocks, the metallogenic systems of which differ from others not only by their types of

Table 2. Models of metallogenic systems in the Bohemian Massif at the blocks of second order.

AGE MA	„CENTRAL" BLOCK (C)	„BARRANDIEN" BLOCK (B)	„LABE" BLOCK (L)	„KRUŠNÉ HORY" BLOCK (K)	„KLADSKO-LUGIKO-SUDETIAN" BLOCK (S)	„MORAVIAN-SILESIAN" BLOCK (M)
15				F Ba F - Ba U ZrO_2 (4) Cu - PbZn	(4) F - Ba U - ZrO_2 (4) FeAsCuPbZn Cu - PbZn	
63						
104	(3a)	SeCuPbAg FeAsCoNi	AsSbCuPbAg	FeMn Ba ------ PbZn (3a)	PbZn - Ba	F - PbZn - Ba (3d)
190	PbZn - Ba U - SiO_2 - F	U - CO_2 PbZn (3a) U - SiO_2 Cu Ba	PbZn U - SiO_2 F - Ba (3a)	F ------ AsSbBiAg FeAsCoNi - U - CO_2	Ba Sb Cu (3b) (3a) F - PbZn U - CO_2 FeAsCoNi	U - CO_2 Cu Sb-Hg Cu-PbZn-Ba F (3a)
230	(2b) Sb - U - CO_2 - Se(CuPbAg) FeCuZnPb - FeAs(CoNi) FeAs(CuSn,PbZn)>SbAs(PbCuAg)			U - CO_2 - FeMn (2b) FeAs(CuSn,PbZn) SbAs(PbZnAg)	U-CO_2 - FeMn Cu (2b) FeAsSnCu	Cu-PbZn - Ba (3c)
280	Sn - W Ba FeAs(CuPbZn) - FeAsAu		FeCu - PbZn - Ba (2b) FeAs (PbZnCu)-Au Mo-W	LiF (SnW) W-Mo-Sn	Fe As(SnCu,PbZn Ag, Au) W - Mo	Fe-FeCu-PbZn Au (3c) W - Mo - FeCu
350	TeBiAu FeAs(CuPbZn) - FeAsAu (2a)	Sb FeAs(CuPbZn)- FeAsAu	PbZn FeCuZn - Ba (2a)	W		(2a) Fe-FeCu-PbZn-Ba
435	W - Mo	Mo - Au (2a)		FeCu - Hg		
500		Mo U - SiO_2 Fe - FeCu - PbZn - Hg				
570	W Au? FeCu - PbZn - Ba (1b)	Fe	FeMn-FeCu-PbZn-Ba (1b)	W FeCu Fe—FeCuZn	Fe - FeCu - PbZn (1b) FeCoNi - FeCu	
670	W Au FeCu - PbZn - Ba (1a) Fe - FeCu - ZnPb		FeNiCo-FeCu FeCu FeCu - PbZn (1a)		FeCu - PbZn - Ba (1a)	Fe - FeCu FeCu ± Mo

formations, but also by the isotopic lead types. Therefore this region will be evaluated separately.

Three principal metallogenic phases can be distinguished in the Bohemian Massif:

The first phase of metallogenic development is pre-stabilization. It is manifested mainly in pre-Cadomian, Cadomian to Late Paleozoic metallogenic systems.

Several types of ore formations can be distinguished among them:

Polymetallic mineralizations bound to:

a) Metamorphosed carbonate rocks. Lead type **1a** (Český Šternberk, Chýnov, Nová Ves, Rokytnice) corresponding model:

$$\text{FeCu} - \textbf{PbZn} - \text{Ba} \quad (1)$$

b) Volcanosedimentary rocks. Lead type **1b** (Chvaletice, Jílové), corresponding model:

$$\pm \textbf{FeMn} - \text{FeCu} \pm \text{PbZn} - \text{Ba} \quad (2)$$

c) Skarn Fe deposits (Županovice, Vlastějovice, Měděnec etc.), with the model:

$$\textbf{Fe} - \text{FeCu} \pm \text{PbZn} \quad (3)$$

d) Ordovician Fe deposits (Krušná Hora, Mníšek etc.) with the model

$$\textbf{Fe} \pm \text{FeCu} \pm \text{PbZn} \pm \text{Hg} \quad (4)$$

wolframite mineralization bound to quartz veins in orthogneisses (Cetoraz) with the model

$$\textbf{W} - \text{FeCuZn?} - \text{Sn?} - \text{Au?} \quad (5)$$

CuNi mineralization bound to ultrabasics (Staré Ransko, Rožany) with the model

$$\text{FeCoNi} - \text{FeCu} \quad (6)$$

As it is evident from the overview of ore formation types, no other elements, with infrequent exceptions, than Mn, Fe, Co, Ni, Cu, Zn, Ba, Pb are active. This trend suddenly changes in blocks affected by Variscan sialization. With progressing sialization, further elements are mobilized and activated in stages, forming more and more complex systems. In unsialized blocks the former trend is preserved, which can be demonstrated on the following ore formation types:

Early to Middle Variscan polymetallic mineralization related to metasomatic phenomena in ultrabasic rocks (Staré Ransko, Vinařice), lead type **2a,** with the model

$$\textbf{FeCuZn} - \textbf{Ba} \pm \text{PbZn} \quad (7)$$

Middle to Late Variscan polymetallic mineralization related to metasomatic quartzites (Křižanovice) lead type **2b,** with the model

$$\text{FeCu } \textbf{PbZn} - \text{Ba} \quad (8)$$

Late Variscan Cu mineralization in Permian–Carboniferous volcanosedimentary rocks (Běloves, Rybniště), with the model

$$\textbf{Cu} - \text{PbZn} - \text{Ba?} \quad (9)$$

These simple ore formation types are in sharp contrast with ore formation types related to sialization metallogenic activity giving rise to the following succession of ore formations:

Early Variscan Au formation succession (Jílové) lead type **2a,** with the model

$$\text{Mo} - \text{W} - \text{FeAs(CuPbZn} - \text{Au)} - \text{TeBiAu} \quad (10)$$

Middle Variscan Au formation succession (Roudný, Hůrky) with the model

$$\text{FeAs (CuPbZn} - \text{Au)} - \text{AsSbAu} - \text{Ba} \quad (11)$$

Both above Au successions are typical of the central group of blocks. In blocks characterized by negative gravity field, especially in the Krušné Hory group of blocks, there are manifestations of the Middle Variscan SnW formation succession (Rotava, Telnice, Krupka, Tehov, Ovesná Lhota), which can be described by the model

$$\text{W} \pm \text{Mo} \pm \text{FeAs (Sn} \pm \text{CuPbZn)} \quad (12)$$

The Early to Middle Variscan mineralization in the surroundings of the Čistec Massif has an independent position (Chříč, Hůrky), lead type *2a,* the succession has the model

$$\text{Mo} - \text{FeAs (CuPbZn} - \text{Au)} - \text{AsSbAu} - \text{Ba} \quad (13)$$

The most intensive and most varied metallogenic system was the Variscan one. This system affected sialized blocks and at their margins it was influenced by various phenomena, so that its components operated to a various degree. Its general model corresponds to the lead type *2b;* for an illustration we shall apply it to several deposits where this system underwent different development.

Příbram – Březové Hory

$$\text{FeAs (CuSn, PbZnAg)} - \textbf{FeCu PbZnAg-SbAsCuPbAg} - \text{FeAsCoNi} - \text{U-}CO_2 \quad (14a)$$

Příbram – Bytíz

$$\text{FeCuZnPbAg} - \text{SbAsCuPbAg} - \text{FeAsCoNi} - \textbf{U-CO}_\mathbf{2} - \textbf{Se} \text{ (CuPbAg)} \quad (14b)$$

Kutná Hora

$$\textbf{FeAs (CuSn, PbZnAg)} - \textbf{FeSbCuPbAg} \quad (14c)$$

Cínovec

$$\text{W} - \textbf{LiFSnW} - \textbf{FeAs (CuSn} - \text{PbZnAg)} \quad (14d)$$

The strong energetic activity of the sialization process connected with energetically demanding metallogenic system ended in the Permian, the third stage of platform evolution beginning at the same time. A manifestation of this was above all the Kimmerian reactivation. It has uniform lead type – **3a** – however, it is modified according to the crust type of the respective block. Unsialized crust preserves the features of simple systems (Stříbro, Oloví), with the model

$$\mathrm{Cu - \mathbf{PbZn} - Ba} \quad (15)$$

In unsialized blocks this system, accoridng to the influence of its environment and to the preceding systems, develops in several directions, as it is evidenced by typical deposits: Jáchymov, where the system is superimposed on the previous ones

$$\mathrm{- F - U\text{-}CO_2\text{-}FeAsCoNi - AsSbBiAg - Ba - PbZn - FeMn} \quad (16a)$$

Harrachov

$$\mathit{Fe} - \mathrm{Cu} - \mathbf{PbZn} - \mathrm{Ba} \quad (16b)$$

Dýleň

$$\mathbf{U\text{-}SiO_2} - \mathrm{Cu - PbZn - F - Se - (CuPbAg)} \quad (16c)$$

This metallogenic system is considerably less energetically active and it is basically a residue of the previous systems, in metallogenically active centres. Its manifestations are practically absent in the central group of blocks which were not reactivated. The metallogenic activity of the Bohemian Massif is concluded by manifestations of concentration systems related to volcanic and thermodynamic activity of the Oháreckỳ rift. It contains lead of the type **4** and several formation types can be distinguished in this system:

Roztoky with the model

$$\mathrm{FeCu - PbZn} \quad (17a)$$

Sněžník with the model F – Ba (17b)

Stráž pod Ralskem with the model

$$\mathrm{U\text{-}ZrO_2 - F - PbZn - Ba} \quad (17c)$$

The development of metallogenic system was different in the Moravian-Silesian blocks. Only Fe-mineralization of the type Sobotín, Švagrov can be classified as pre-Variscan. The type of Cu+Mo mineralization in the Brno Massif is dubious. The principal metallogenic activity is concentrated in the Silesian blocks and it is connected with products of Devonian spilite-keratophyre volcanic formation. This formation is connected with volcano-sediementary Fe-ores (Kralová, Benkov etc.) and stratabound polymetallic ore deposits. The lead-type analysis however suggests that their age is not uniform even though the metallogenic system was similar. According to lead type, two principal groups of occurrences can be distinguished:

Older type (Horní Město, Nová Ves u Rymařova, Rejvíz) with lead type **2a** and the model

$$\mathrm{Fe} - \mathbf{FeCu} - \mathbf{PbZn} \pm \mathrm{Ba} \quad (18a)$$

Younger type (Horní Benešov, Zlaté Hory) with lead type **3b** and the model

$$\mathrm{Fe} - \mathbf{FeCu} - \mathbf{PbZn} - \mathbf{Ba} \quad (18b)$$

The models and the mineralization do not differ too much, however, the ages are markedly different – in the first group it corresponds to Early to Middle Variscan, in the second one Late Variscan age is estimated, corresponding to remobilisation during regional metamorphism (Carboniferous–Permian). An important information is that both lead types can be documented on the main accumulation of this type (Zlaté Hory). An independent system of Au mineralization (Zlatý Chlum, Rejvíz, Zlaté Hory) is connected with the energetically active sialization centre of the Žulová Massif; its model being

$$\mathrm{W + Mo + Au \ldots\ldots\ldots Fe\ As\ (Au - Cu\ Pb\ Zn)} \quad (11a)$$

This system is either independent (Zlatý Chlum), or superimposed on the previous systems (Zlaté Hory), its age being estimated at Middle to Late Variscan.

The Kimmerian stage is represented in this group of blocks by several ore formation types:

Formation type corresponding to type 16 and lead type *3a* is documented (Nýznerov, Lipová)

$$\mathbf{Cu} - \mathrm{Pb\ Zn \pm Ba \pm F \pm Sb \pm Hg} \quad (16d)$$

Similar model characterizes minor mineralizations especially in the Kulmian (Fulnek, Hlubočky and Hyčince) with lead type **3c**

$$\mathrm{Cu} - \mathbf{Pb\ Zn} \pm \mathrm{Sb \pm Ba} \quad (19)$$

A totally specific position in this group of blocks is that of mineralization types with lead type *3d*. This mineralization type, apparently of Late Kimmerian age, which can be observed exclusively in the Moravian blocks, has a similar model like the previous type

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$$\mathbf{Cu - Pb\ Zn} - \mathrm{Ba \pm F \pm Sb \pm U\text{-}SiO_2} \quad (20)$$

This is the only type which bears U mineralization. Its topographic position however does not exclude the possibility of its origin in neighboring sialized blocks.

Conclusions

The analysis of the development of metallogeny in the Bohemian Massif leads to the following conclusions:

1. The Moravian-Silesian group of blocks markedly differs from the rest of blocks in the Bohemian Massif, by isotopic composition of lead in galenites as well as by the character of evolution of metallogenic system.

2. Two basic trends of metallogenic systems can be distinguished in the Bohemian Massif, depending on the sialization grade of the blocks.

3. Except small sialized centres, pre-Variscan metallogeny was related to originally unsialized crust. During the process, a limited number of elements (Cr, V, Fe, Co, Ni, Cu, Zn, Ba, Pb) became activated and simple systems developed. This trend was retained in unsialized blocks even in the following stages.

4. In blocks with Variscan sialization stabilization and differentiated crust, further elements, besides the above ones, became activated (W, Mo, Au, Te, As, Sn, Li, Nb, Ta, F, Ag, In, Sb and U), forming complex metallogenic systems. Their evolution is not uniform in time or space. Early Variscan and Middle Variscan Au-formation successions are dominant in the central group of blocks. On the other hand, Middle and Late Variscan Sn-formational successions are typical of peripheral blocks. In this way, the Sn-Au zoning of the Bohemian Massif has developed. The culmination of the metallogenic activity are uranium and polymetallic formation successions.

5. The Kimmerian reactivation respects in its formation successions the above mentioned concentration activity related to the character of the crust. It was often superimposed on previous systems modifying them at the same time. It is typical for the peripheral group of blocks. In the central group of blocks it is absent.

6. Neoid reactivation has its specific systems related to the development of the Ohárecký rift.

The presented paper cannot, in view of its extent, deal with all aspects of the relationship between metallogenic evolution and the evolution of the crust. However, the aim of the authors was above all to show the possibilities of the application of the system analysis method and of the modelling of systems in this branch of science.

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References

Bernard J. H., 1967: Kurze Übersicht der isogenetischen erzbildenden Mineralassoziationen hydrothermalen Ursprungs im tschechoslowakischen Teil der Böhmischen Masse. *Čas. Mineral. Geol.* (Praha), 12, 13–20.

Bernard J. H., 1978: Nové poznatky o metalogenetickém členění Českého masívu a možnosti prognóz. In: Sbor. *„Teoretické základy prognóz nerostných surovin v ČSSR". Fac. Natural. Sci., Charles Univ.*, Praha, 40–50.

Bernard J. H., 1981: Mineralogie Československa. 2nd ed., *Academia*, Praha.

Bernard J. H. & Pouba Z. et al., 1986: Rudní ložiska a metalogeneze československé části Českého masívu. 1st ed., *Academia*, Praha.

Doe B. R. & Stancey J. S., 1974: The application of lead isotopes to the problems of ore genesis and ore prospect evaluation. *Econ. Geol.* (Lancaster, *VA*), 69, 757–776.

Doe B. R. & Zartmann R., 1979: Plumbotectonics I. The Phanerozoic In: Barnes H. (ed.): *Geochemistry of hydrothermal ore deposits. J. Wiley*, New York, 2–70.

Chrt J. & Bolduan H. et al., 1966: Die postmagmatische Mineralization des Westteils der Böhmischen Masse. *Sbor. Geol. Věd, ložisk. Geol.* (Praha), 8, 113–192.

Koutek J., 1964: Geologie československých rudních ložisek, I. Ložiska českého jádra. Učeb. texty, Praha.

Legierski J., 1973: Model ages and isotopic composition of ore leads of the Bohemian Massif. *Čas. Mineral. Geol.* (Praha), 18, 1–24.

Legierski J. & Pošmourný K., 1966: Izotopické složení olova některých rudních výskytů v české části Západních Sudet. *Čas. Mineral. Geol.* (Praha), 11, 169–176.

Legierski J. & Vaněček M., 1967: Lead isotopic composition of some galenas from the Bohemians Massif. *Acta Univ. Carol., Geol.* (Praha), 2, 153–172.

Mísař Z. et al., 1983: Geologie ČSSR, I. Český masív. *St. pedag. nakl.*, Praha.

Patočka F. et al., 1982: Využití Pb-izotopických dat pro prospekci ve vulkanicko-sedimentárních oblastech Českého masívu. *Výzk. Práce Ústř. Úst. geol.* (Praha), 32.

Pertold Z. & Stehlík E., 1978: Modelové stáří stratiformních galenitů Českého masívu na základě izotopického složení olova. Korelace proterozoických a paleozoických stratiformních ložisek (V). *Inst. of Geol. Sci., Natural. Sci. Fac, Charles Univ.*, Praha, 195–208.

Procházka Z. & Grym V., 1986: Tvorba modelů metalogenetické aktivity Českého masívu. In: Sbor. *„Hornická Příbram ve vědě a technice*. Sekce G", Příbram.

Sattran V. et al., 1966: Problémy metalogeneze Českého masívu. *Sbor. geol. Věd, ložisk. Geol.* (Praha), 8, 7–112.

Vacek J. et al., 1983: Přehledné prognozní ocenění rudonosnosti Českého masívu. Závěr. zpráva úkolů C–52–347–207. Ústř. Úst. geol., Praha.

Vaněček M. et al., 1985: The use of isotopic composition of ore lead in metallogenic analysis of the Bohemians Massif. *Rozpr. Čs. Akad. Věd, Ř. mat. přír. Věd* (Praha), 95, 5.