

E. STUDY OF ISOTOPES AND PALAEOFLUIDS

E.1. THE DISTRIBUTION OF CARBON, OXYGEN AND SULPHUR ISOTOPES IN ROCKS AND ORE DEPOSITS OF THE TEPLÁ-BARRANDIAN UNIT AND THE MOLDANUBIAN ZONE

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One of the aims of the project "Geological model of the western part of the Bohemian Massif" was to gather sulphur, carbon and oxygen isotope data from different mineralization types and their host rocks in order to estimate the age, physico-chemical conditions of ore deposition and sources of hydrothermal fluids of vein and metasomatic deposits. Published isotope data from stratiform and vein mineralization types of the study area in western Bohemia were re-evaluated and substantially complemented.

New sulphur isotope data have been obtained, especially for stratiform mineralizations of the Varied Unit of the Moldanubian Zone and for some new localities with stratiform mineralizations in the Teplá-Barrandian Unit (TBU).

Carbon and oxygen isotope compositions of carbonate-rich rocks have been studied in the Upper Proterozoic and Lower Palaeozoic units of the TBU and in the Varied Unit of the Moldanubian Zone.

Data characterizing individual rock units were used to evaluate possible hydrothermal fluid sources of vein and metasomatic types of late-Variscan and post-Variscan hydrothermal deposits. The stable isotope studies were focused mainly on the vein mineralizations of the Stříbro ore district and on the hydrothermal uranium deposits in western Bohemia.

The sulphur isotopic data were used by Hladíková (1993) to reconstruct the sedimentary conditions during the formation of the TBU alum-shales and of graphite-rich rocks of the Moldanubian Zone. The combination of stable isotope (C, O, S), radiogenic isotope (Pb, Sr), and fluid inclusion data was used by Žák et al. (1993). Special attention was paid to the comparison of the lithological, geochemical and isotopic evolution of the rocks and mineralizations in the TBU and Moldanubian units.

E.1.1. Sulphur isotopic composition of sulphides from rocks and stratiform mineralizations of the Teplá-Barrandian Unit and the Moldanubian Zone

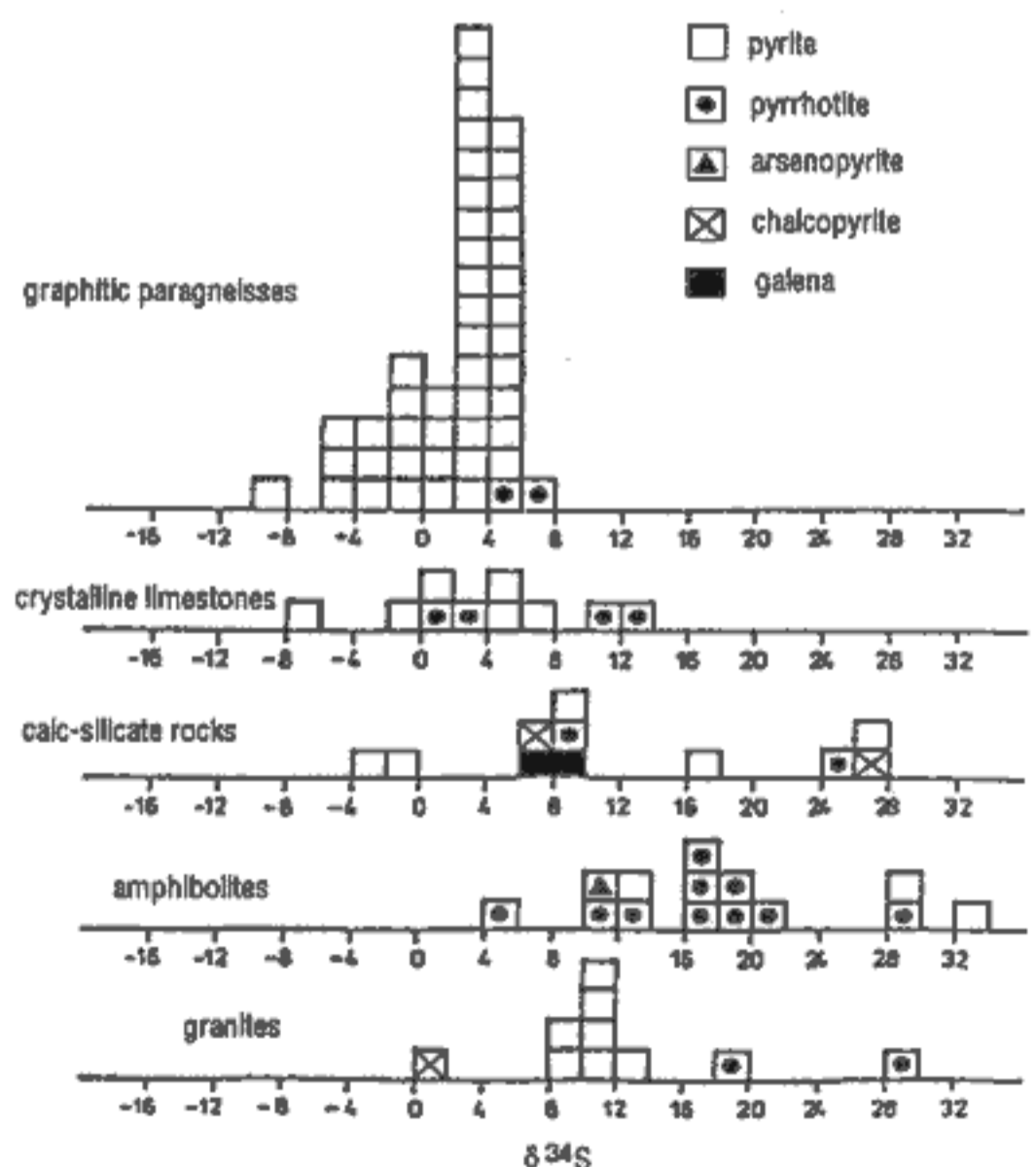
The Moldanubian Zone and the TBU were compared from a metallogenetic point of view by Pouba-Zoubek (1986) and by Pertold-Suk (1986). Stratiform sulphidic mineralizations associated with metasediments or metavolcanites occur in both units. The character of stratiform mineraliza-

tions and some of their geochemical parameters (e.g., C_{org}/S_{sulph} ratio) indicate that pyrite from the stratiform mineralizations was formed mainly by the bacterial reduction of sulphate under anoxic conditions. All available sulphur isotope data for the sulphides from metasediments and metavolcanites in both regions are summarized. Sulphur isotope data on metasediments are also used for the description of sedimentary environments in which pre-metamorphic equivalents (precursors) of the studied rocks were deposited.

E.1.1.1. The Varied Group of the Moldanubian Zone

The ^{34}S values of sulphides from graphitic paragneisses (rich in carbon) and surrounding rocks (with a low content of carbon) are shown in Fig. 163.

The S_{sulph} contents in paragneisses that contain more than 2% C_{org} are directly proportional to the organic carbon content and follow the trend typical of anoxic sediments. This implies that pyrite was derived from hydrogen sulphide formed during the bacterial reduction of a marine sulphate. The ^{34}S values of sulphides (from -6 to +8 ‰) indicate that the reduction took place under conditions closed to sulphate, i.e., the rate of sulphate reduction was higher than the rate of its supply to the system. In the



163. Histograms of sulphur isotope data of sulphides from rocks of the Moldanubian Zone.

pre-metamorphic stage the graphite deposits represented huge accumulations of organic matter that were not degraded aerobically so that they contained even the components that could be oxidized very easily by bacteria. These factors probably caused the acceleration of sulphate reduction and the subsequent decrease in sulphur isotope fractionation between sulphate and hydrogen sulphide. The distribution of the ^{34}S values of pyrite with low variability and significant maximum between +2 and +6 ‰ implies that the accumulated H_2S was precipitated as sulphides in a system with a low concentration of Fe^{2+} ions (Hladíková et al., 1993).

In sharp contrast to graphitic paragneisses, the pyrite and pyrrhotite samples from amphibolite and amphibole-biotite gneisses show a wide range of ^{34}S values, from +3.9 to +33.2 ‰ (Fig. 163). The amphibolites are thought to be derived from basic volcanic rocks, and amphibole-biotite gneisses are regarded as metamorphosed equivalents of basic tuffs or mixed sediments. It should be noted that ^{34}S values of magmatic sulphides of uncontaminated mantle-derived volcanic rocks range from -1 to +3 ‰. The original basalts were probably contaminated by sedimentary sulphides which originated through sulphate reduction in a system closed to sulphate.

The distribution of ^{34}S values of sulphides in crystalline limestones and calc-silicate rocks shows a transitional character between graphite-rich paragneisses and the amphibolites. In both rock types the distribution of ^{34}S values corresponds to a system closed to sulphate.

Based on isotopic, geochemical and lithological data, the most likely recent analogues of the environment, where the rocks of the graphite deposits originated, are partly open or fully barred lagoons communicating with the open sea by seepage through barrier carbonate muds or sands or by intermittent floods. The presence of metamorphic equivalents of volcanites and tuffs indicate that the genesis of graphite deposits was probably connected with volcanic activity (Hladíková et al., 1993).

E.1.1.2. The Teplá-Barrandian Unit

The first set of sulphur isotope data on stratiform sulphidic mineralizations from the (TBU) was published by Šmejkal et al. (1974). Later this data set was enlarged and all results are summarized in Fig. 164. It is evident that the range of ^{34}S data is very wide and that negative ^{34}S values prevail. It is assumed that sulphides were precipitated from hydrogen sulphide formed during bacterial reduction of a marine sulphate. It is important to note that sulphides with negative ^{34}S values were found not only in metasediments but also in metavolcanic rocks. Such sulphur isotopic compositions were found in metavolcanites from the localities Trnčí near Klatovy, Lomany, Kamenec near Radnice and Svržno (Hladíková et al. 1986; Hladíková-Mrázek, 1988; Kopecký-Hrochová 1989). These sulphides were precipitated from hydrogen sulphide formed during bacterial reduction and dissolved in aqueous solution, which penetrated into basalts during burial. This process was studied in detail at Trnčí, and a model of interaction between sea water and

basalt was proposed using isotopic and chemical data (Hladíková-Mrázek 1991). However, sulphides with high positive ^{34}S values (close to +20 ‰) were found in metabasalts from Struhadlo (Hladíková-Mrázek 1988). Disseminated sulphidic accumulations were probably formed during postvolcanic submarine exhalative processes at this locality.

A large variability of ^{34}S values of sulphides from metasediments of the TBU supports the idea of separate sedimentary basins existing in this area. Some of these basins communicated with the open Proterozoic sea during the whole time of the accumulation of sulphidic mineralizations (e.g., Trnčí, Kamenec, Struhadlo, Pocinovice), while the communication of some other basins with the open sea was possibly undergoing restriction (e.g., Lomany, Liblín, Hromnice). Shallow water environments are characterized by the spatial association of pyritic black shales with stromatolite horizons. Larger sulphidic accumulations were formed as a consequence of a higher concentration of reactive iron in basinal or pore waters. Iron could be produced during submarine alteration of volcanic rocks or their tuffs or during postvolcanic hydrothermal processes.

E.1.2. Carbon and oxygen isotopic composition of carbonate-rich rocks in the Moldanubian Zone and the Teplá-Barrandian Unit

Carbon and oxygen isotope data of carbonate-rich rocks (i.e., limestones, calc-silicate rocks) can provide information on their formation conditions and on conditions of their metamorphic transformations. A more detailed discussion of processes which influenced carbon and oxygen isotopic compositions of carbonates from all regions with carbonate rocks in the Bohemian Massif were compiled by Hladíková et al. (1989).

The normal marine sedimentary carbonate material shows a very low variability of ^{13}C values, being usually in the range from -2 to +2 ‰. During diagenetic and low-grade metamorphic processes of carbonate-rich rocks, the original ^{13}C values were not significantly changed. Subsequent processes connected with high-grade metamorphism can lower the ^{13}C and ^{18}O values of pre-metamorphic carbonates as a result of:

- decarbonation reactions
- isotopic exchange reactions between carbonate and organic carbon
- isotopic exchange reactions with metamorphic fluids
- combination of these processes.

All carbon and oxygen isotope data on carbonate rocks from the studied regions of the Bohemian Massif are summarized in Fig. 165. Palaeozoic limestones of the Barrandian area (Prague basin) have carbon and oxygen isotopic compositions which were not significantly affected by diagenetic and metamorphic processes.

Very pure Moldanubian crystalline limestones (i.e., crystalline limestones with a very low admixture of silicate minerals or graphite) show $\delta^{13}\text{C}$ values in the range typical of marine limestones. Calc-silicate rocks of this unit show

significant changes in carbon and oxygen isotopic composition due to decarbonation reactions and interactions with fluids (Žák-Sztacho 1994). Moldanubian crystalline limestones rich in graphite usually show a decrease in $\delta^{13}\text{C}$ values as a result of exchange reactions between carbonate-carbon and graphite-carbon. Isotope fractionation between both (reduced and oxidized) forms of carbon at some graphite deposits of the Varied Group of the Moldanubian Zone probably reached nearly isotope equilibrium and $\delta^{13}\text{C}$ values of crystalline limestones and graphites were used for the calculation of metamorphic temperature conditions. Temperatures in the range from 580 to 610 °C were obtained by Čížek et al. (1984).

Massive carbonate rocks (limestones) are practically not known in the Upper Proterozoic sequence of the Teplá-Barrandian Unit. Only locally, especially in the vicinity of centres of submarine volcanism, small layers of carbonate-rich rocks corresponding to carbonatized tuffs and tuffaceous rocks occur. The very low grade of metamorphism of this unit excludes any greater changes of C and O isotopic composition during metamorphism. Therefore, the obtained $\delta^{13}\text{C}$ values of carbonates are very close to their

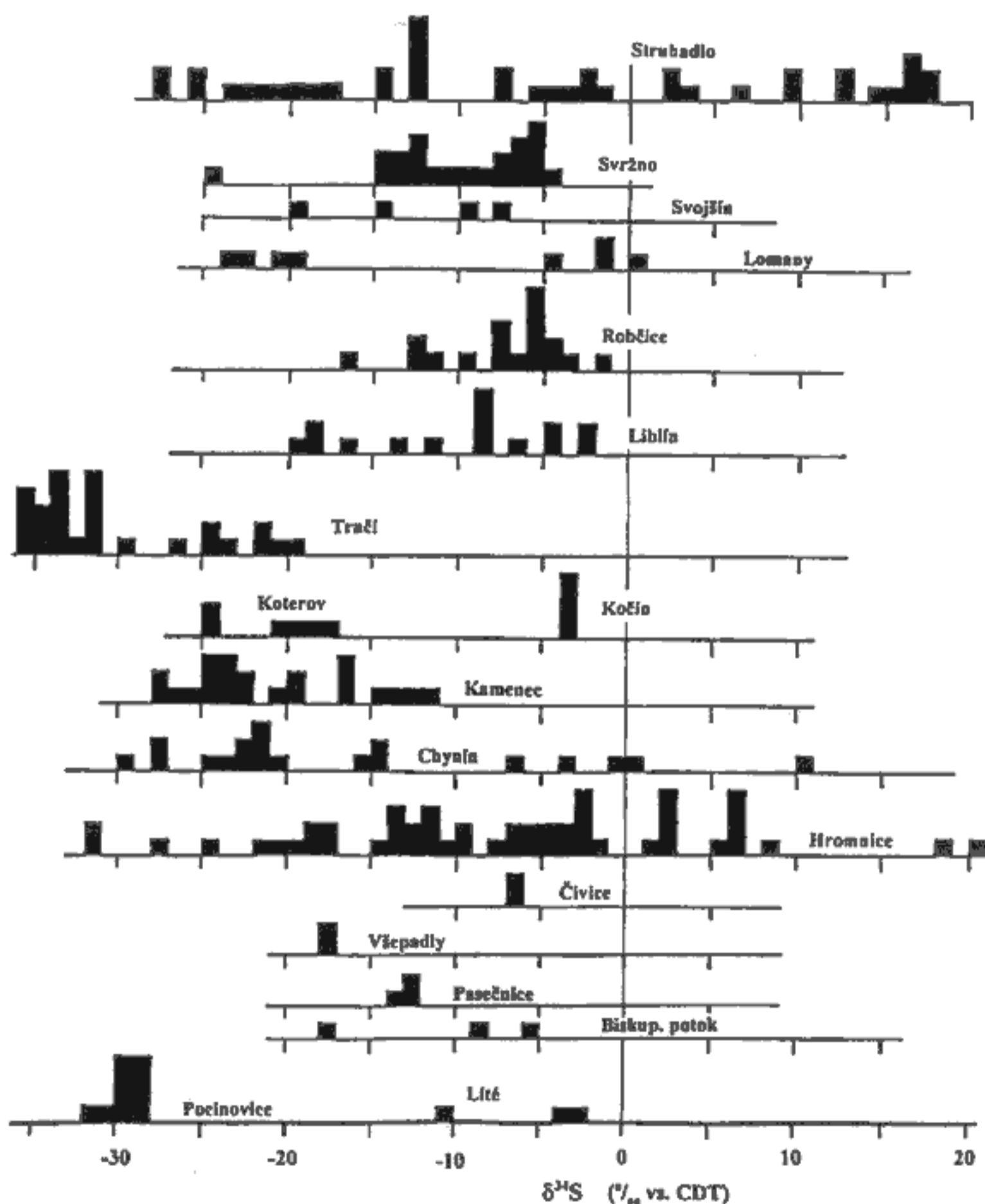
pre-metamorphic $\delta^{13}\text{C}$ values. Carbon isotopic composition of the mentioned carbonates shows that these rocks could not have been formed from marine bicarbonate with a $\delta^{13}\text{C}$ value close to 0 ‰. All carbonate-rich rocks of this unit are probably a result of submarine hydrothermal activity during which the dominant portion of carbon dioxide originated through the oxidation of organic matter.

E.1.3. Sulphur isotopic composition of sulphides from vein mineralizations in western Bohemia

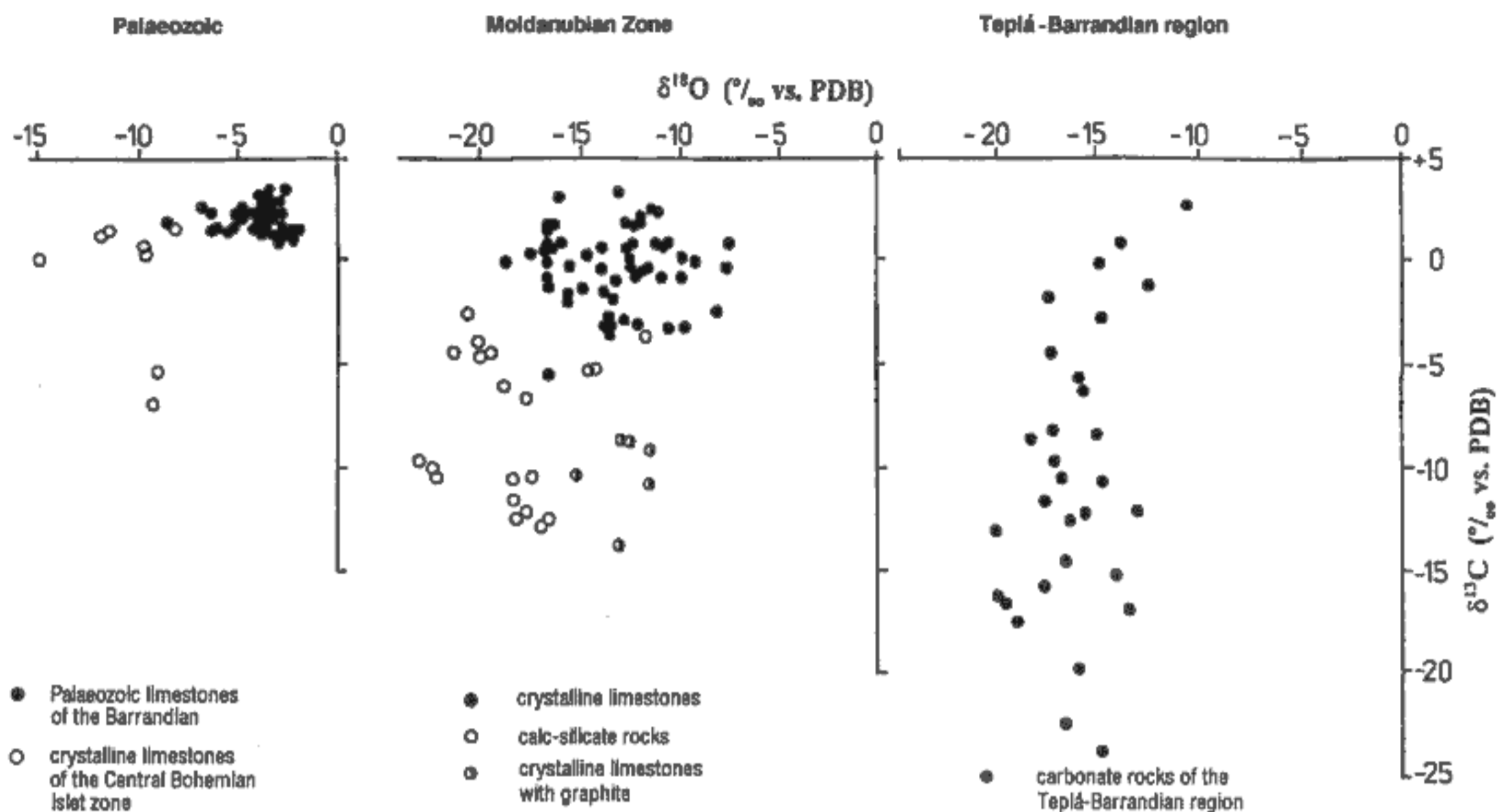
Generally, the sulphur isotopic composition of hydrothermal sulphides and barite reflects:

- sulphur source(s) of hydrothermal fluids, and
- isotopic fractionation between oxidized and reduced species of sulphur in hydrothermal solutions and between fluid species and hydrothermal minerals formed.

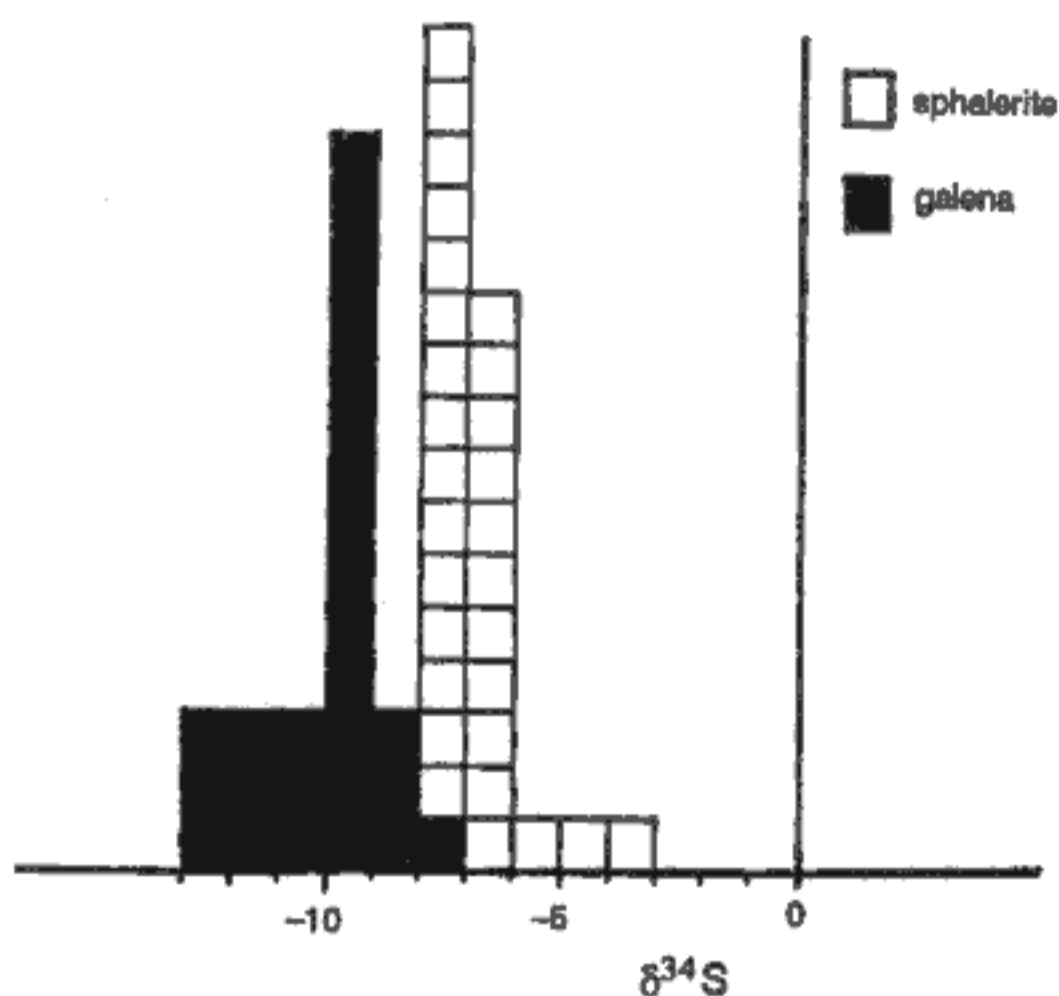
During the mobilization of sulphur from rock reservoirs, sulphur isotopic fractionation usually does not occur. An exception is the separation of magmatic fluids from granitic magmas under very high oxygen fugacity. The other proc-



164. Histograms of sulphur isotope data of sulphides from rocks of the Teplá-Barrandian Unit.



165. Carbon and oxygen isotopic composition of carbonate rocks from the Teplá-Barrandian Unit Proterozoic, Moldanubian Zone, and Barrandian Palaeozoic.



166. Sulphur isotopic composition of sphalerite and galena.

esses, i.e., the separation of magmatic fluids under lower oxygen fugacity, the mobilization of sulphur from sulphides by aqueous solutions, the oxidation of sulphides, and the dissolution of sulphates are not accompanied by measurable sulphur isotopic fractionations.

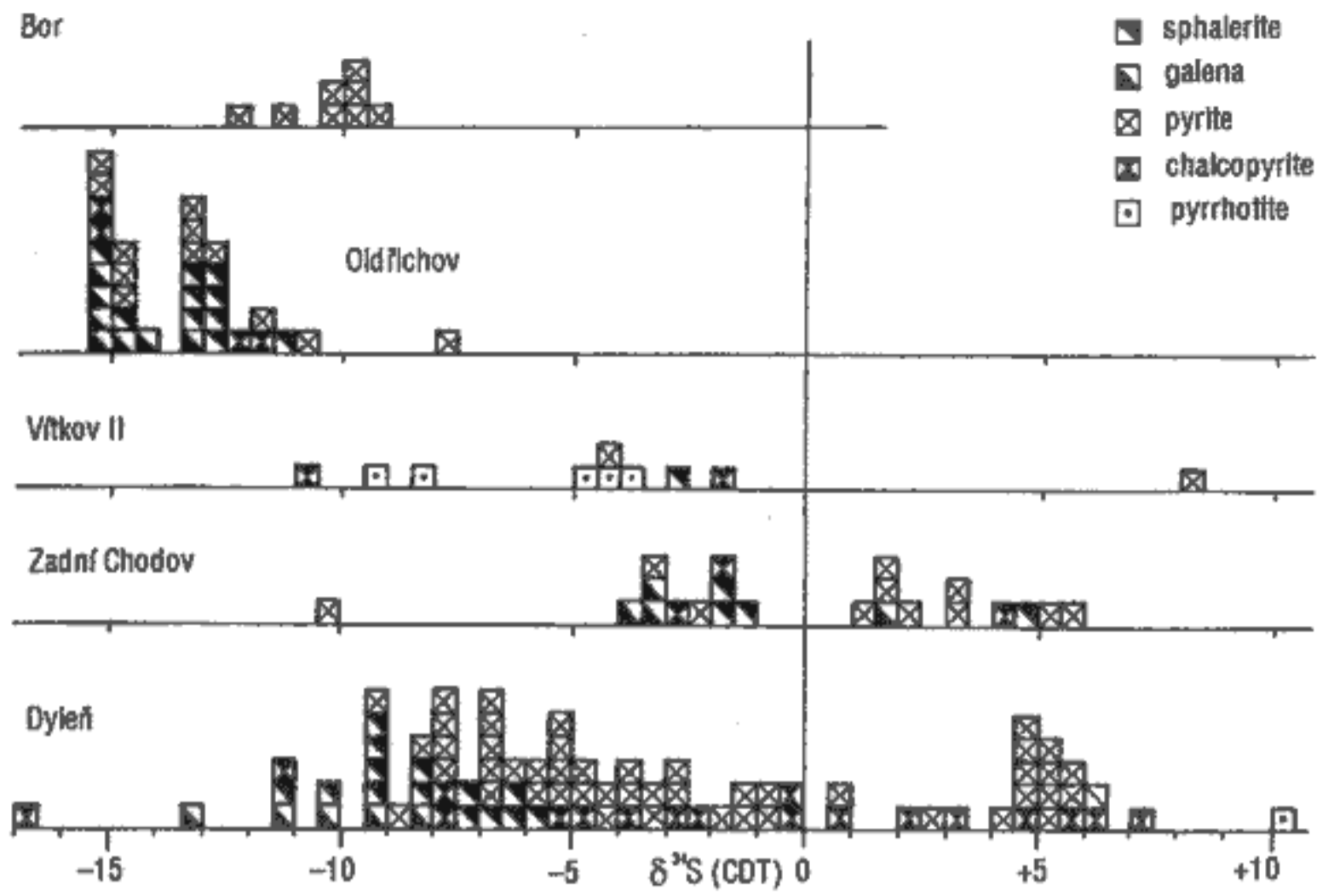
If hydrothermal sulphides are deposited under low oxygen fugacity, i.e., sulphate ions are practically not present in hydrothermal fluids, the sulphur isotopic composition of

the fluid sulphur reduced species is nearly the same as the isotopic composition of the total sulphur of the fluid. Under such conditions the sulphur isotopic compositions of precipitated sulphides is close to that of the total sulphur of the fluid and small differences in $\delta^{34}\text{S}$ values of different sulphides (e.g., in galena and sphalerite) can be used for the calculation of the temperature of sulphide formation. If both sulphate and sulphidic ions are present in the fluids, the situation is more complicated and the interpretation of the data very complex. Sulphur isotopic exchange reactions between sulphidic and sulphate species start at temperatures above approximately 250 °C, while under lower temperature the behaviour of both sulphur compounds could be regarded as relatively independent.

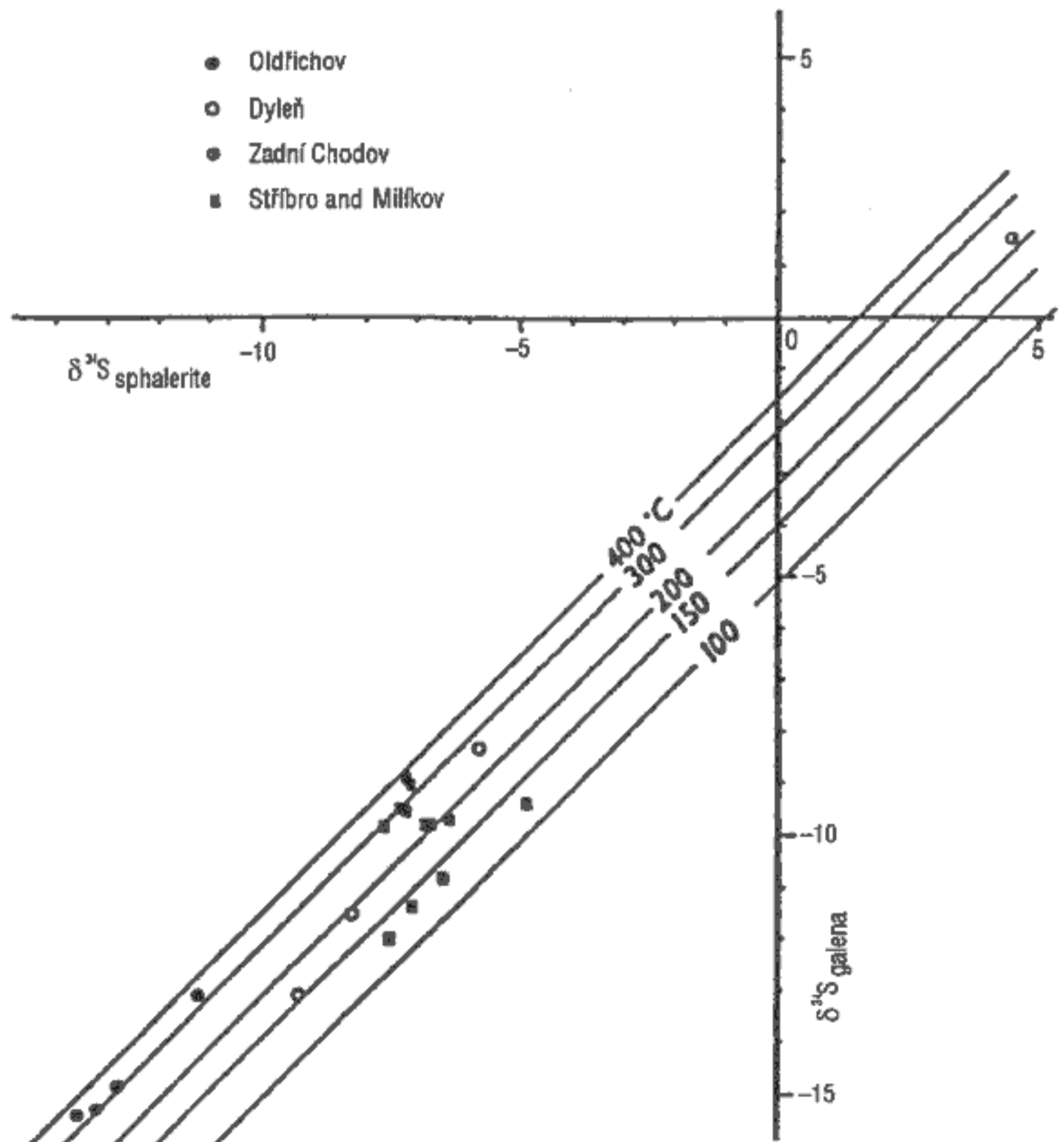
Significant differences in sulphur isotopic compositions of accessory sulphides of the rocks of the TBU and of the Moldanubian Zone were demonstrated above. While the accessory and stratiform sulphides of the Moldanubian Zone usually show positive $\delta^{34}\text{S}$ values, those of the TBU are mostly negative. This conspicuous difference in sulphur isotope composition of rock sulphides is reflected in the sulphur isotopic composition of ore-forming fluids of late-Variscan and post-Variscan hydrothermal mineralizations in both units. e.g., the sulphidic minerals of hydrothermal vein deposits of the Střibro ore district (TBU) were formed from fluids with a $\delta^{34}\text{S}$ value of source sulphur of about -7 ‰ (Fig. 166). These low $\delta^{34}\text{S}$ values of sulphides were already interpreted as a result of a mobilization of bacteriogenic sulphur from the host rocks of the TBU by Šmejkal et al. (1974).

Sulphur with a similar isotopic composition is typical of

167. Sulphur isotopic composition of hydrothermal sulphides from uranium deposits in western Bohemia. Names of the mines are given on the left side of the diagram.



168. Sulphur isotopic fractionation of galena-sphalerite from different hydrothermal mineralization phases in western Bohemia.



the majority of sulphidic mineralizations in the West Bohemian shear zone (Fig. 167). Nevertheless, due to the variable and sometimes higher oxygen fugacity of these hydrothermal processes it is sometimes difficult to determine if $\delta^{34}\text{S}$ values of hydrothermal sulphides decreased due to bacteriogenic sulphide mobilization or isotopic exchange reactions in the fluid itself.

Sulphides from the localities which are situated in or close to the Moldanubian Zone (e.g., Zadní Chodov and Dyleň) show higher $\delta^{34}\text{S}$ values as a consequence of mobilization of sulphidic sulphur from Moldanubian rocks. The higher $\delta^{34}\text{S}$ values are typical here especially for sulphides of pre-uranium stages.

Sulphur isotopic fractionation between co-existing galena and sphalerite from the studied vein deposits is shown in Fig. 168. A wide range of temperature data from some localities shows that non-contemporaneous depositions of sulphides frequently pose a serious problem.

E.1.4. Carbon and oxygen isotopic compositions of hydrothermal carbonates, oxygen isotopic composition of hydrothermal quartz and the calculation of carbon and oxygen isotopic composition of source fluids for vein and metasomatic deposits in western Bohemia

Using the $\delta^{13}\text{C}$ values of hydrothermal carbonates and the temperature data obtained from fluid inclusion studies, $\delta^{13}\text{C}$ values of hydrothermal fluids between -10 and -15 ‰ can be estimated for the vein deposits of the Stříbro ore district. These low $\delta^{13}\text{C}$ values indicate the significant influence of oxidized organic carbon on the hydrothermal fluids (Bernard-Žák 1992). Based on the available data, it is difficult to determine if these low $\delta^{13}\text{C}$ values of hydrothermal fluids are a result of the mobilization of isotopically

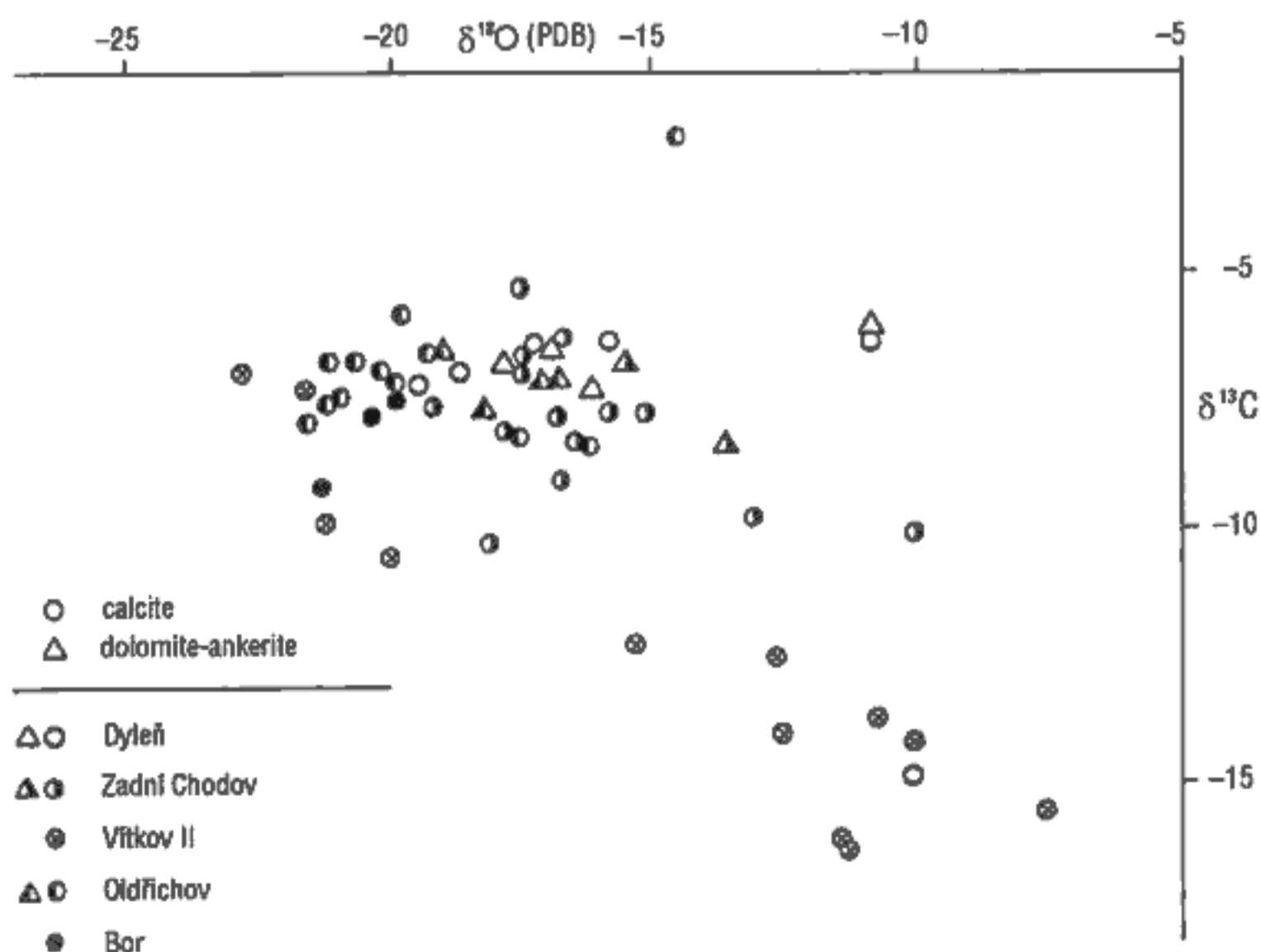
anomalous carbonate-rich rocks of this unit (see above) or a result of direct oxidation of carbonaceous compounds in sediments. Both processes could have been combined.

Oxidized carbon species characterized by low $\delta^{13}\text{C}$ values were present also in hydrothermal fluids of some uranium deposits in western Bohemia. Carbonates with low $\delta^{13}\text{C}$ values were found at the Vítkov II deposit and Zadní Chodov. Nevertheless, numerous carbonate $\delta^{13}\text{C}$ data (and calculated carbon isotope fluid compositions) from the deposits Zadní Chodov, Oldřichov, and Dyleň, which plot in the range typical of "deep-seated" carbon, indicate that this carbon source could have been also important in the area of the West Bohemian shear zone.

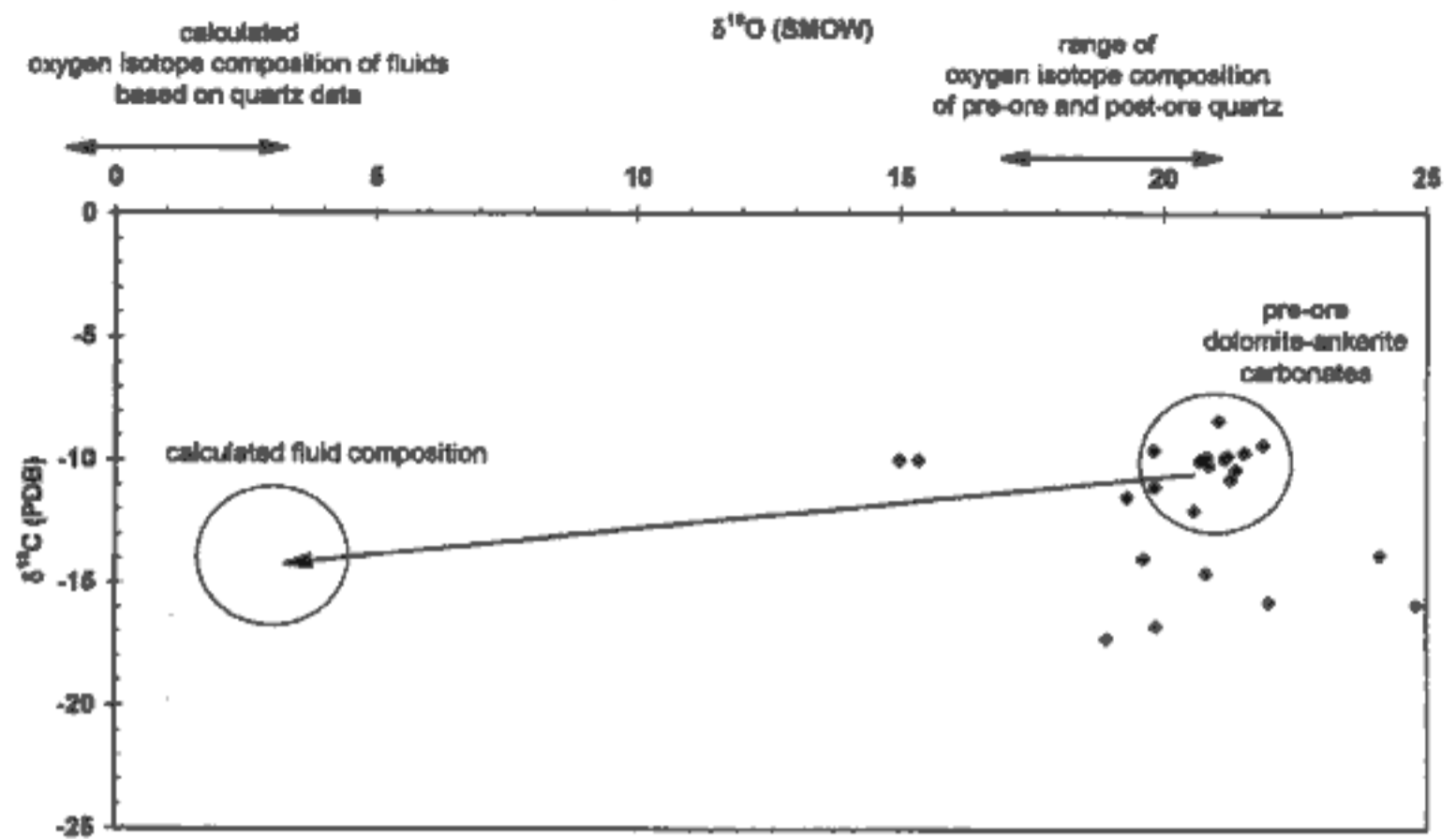
A wide range of $\delta^{18}\text{O}$ values of carbonates from the west Bohemian uranium deposits indicates either the mixing of different fluid types or changes in the oxygen isotopic composition of the fluids as a result of fluid/rock interactions. The pronounced trend of carbonate data from the deposit Vítkov II in the diagram $\delta^{13}\text{C}$ vs. $\delta^{18}\text{O}$ is probably a result of the mixing of two fluid types. The first fluid was characterized by a higher temperature, a deeper circulation and by carbon with low $\delta^{13}\text{C}$ values, while the second fluid was characterized by lower temperature, the presence of meteoric water and carbon from a deep source (see Fig. 169).

Regarding the relatively low temperatures of deposition (i.e., from 100 to 200 °C), which were obtained from fluid inclusions, and the observed $\delta^{18}\text{O}$ values of carbonates of west Bohemian uranium deposits, it is evident that hydrothermal fluids had, in some cases, low $\delta^{18}\text{O}$ values, in the range typical of fluids of meteoric origin which underwent fluid/rock interactions at low temperature and/or high fluid/rock ratios.

Using $\delta^{18}\text{O}$ values for carbonates and quartz and the temperature data obtained from fluid inclusion studies,



169. Carbon and oxygen isotopic composition of hydrothermal carbonates from uranium deposits in western Bohemia.



170. Carbon and oxygen isotopic composition of hydrothermal carbonates and hydrothermal fluids from the Střibro ore deposits.

oxygen isotopic compositions of hydrothermal fluids at the Střibro deposit were also calculated. Quartz from the pre-ore stage of mineralization at the Dlouhá vein was deposited from fluids with $\delta^{18}\text{O}$ values between -1 and $+5$ ‰ (SMOW). Drusy quartz, which belongs to the post-ore stage, was deposited from fluids with a $\delta^{18}\text{O}$ value between 0 and $+6$ ‰ (SMOW). Dolomite-ankerite carbonates from the Střibro locality (Fig. 170) were formed from similar fluids ($\delta^{18}\text{O}$ values were in the range $+1$ and $+5$ ‰). Two dominant fluid types were recognized in the Střibro ore district. The $\delta^{18}\text{O}$ values of the dominant component, the CaCl_2 -rich brines, which probably originated by an interaction between fluids and plagioclase at deep crustal levels (Behr et al. 1990; Bennet-Barker 1992), are a result of fluid/rock interactions at low fluid/rock ratios. Generally, fluids with these $\delta^{18}\text{O}$ values, especially with respect to higher salinity in the later mineral stages, are probably not shallow circulating water of meteoric origin. Rather, these fluids probably reflect deep fluid circulation through open tensional fault zones in well consolidated and relatively cold crust.

E.1.5. Conclusions

The stratiform sulphidic mineralizations and disseminated sulphides in rocks of the Teplá-Barrandian Unit were formed by the bacterial reduction of marine sulphates in open or semi-isolated basins, with restricted basins evolved only exceptionally. This resulted in dominantly low $\delta^{34}\text{S}$ values of stratiform sulphides.

The stratiform sulphidic accumulations and accessory sulphides of the Varied Group of the Moldanubian Zone were formed by the bacterial reduction of marine sulphates mostly in basins with significantly limited communication with open sea. These basins can be compared with present-day lagoons. This resulted in positive $\delta^{34}\text{S}$ values of sulphides.

The differences in sulphur isotopic compositions of sulphides from both regions reflect differences in sedimentary

conditions. Unfortunately, these data can not be used to elucidate geochronological relationships in both units.

Different sulphur isotopic compositions of dominant sulphur reservoirs of the Moldanubian Zone and the Teplá-Barrandian Unit were reflected in differences in the sulphur isotopic composition of hydrothermal fluids of late-Variscan and post-Variscan veins and metasomatic mineralizations of both units.

In these hydrothermal processes, fluids of many types were involved. One end member is represented by a higher salinity fluid with deep circulation in the crust. The second important fluid type is a low-salinity low- $\delta^{18}\text{O}$ fluid with shallow circulation, important especially during some phases of formation of West Bohemian uranium deposits.

Different sources of hydrothermal carbonate carbon were also recorded. For deposits in the Teplá-Barrandian Unit, a source with very low $\delta^{13}\text{C}$ values is typical, indicating the importance of oxidized organic carbon in the fluids. Hydrothermal carbonate types in (or close to) the West Bohemian Shear Zone frequently have a carbon isotopic composition in the deep-seated range of $\delta^{13}\text{C}$ values.

E.2. CHARACTER OF PALAEOFLUIDS IN THE WESTERN PART OF THE BOHEMIAN MASSIF, A FLUID INCLUSIONS STUDY

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The main method of the fluid inclusion study, carried out in the laboratory of the Czech Geological Survey, was optical microthermometry (Ďurišová-Hurai 1991). New methodical approaches based on a combination of optical microthermometry and micro-Raman spectrometry of fluid inclusions were applied as a result of the co-operation between the CGS laboratory and the laboratory of the CREGU in Nancy. The data obtained enabled to calculate compositions of fluids, to constrain the possible P-T conditions of their existence (calculations of isochores of fluids

of known composition) and to determine redox conditions under the activity of these fluids (calculations of oxygen and sulphur fugacity).

The new data on palaeofluids from mineral associations of rocks from several geological units of the western part of the Bohemian Massif obtained within the framework of the project "Geological model of Western Bohemia in relation to the deep borehole KTB in the FRG" were correlated with previous data from metamorphic rocks of the Silesian zone (Jeseníky Mts. area) and the eastern part of the Moldanubian Zone (locality Orlík near Humpolec).

E.2.1. Review of the results of fluid inclusion study in selected mineral associations

E.2.1.1. Fluid inclusions in granulites

The granulites of the Moldanubian Zone of southern Bohemia formed under the conditions of high-pressure granulite-facies metamorphism (up to 1.4 GPa and 950 °C, Vrána 1992) about 340–350 Ma ago (e.g., Aftalion et al. 1989). Granulite rocks underwent the polyphase retrograde metamorphism under the conditions of amphibolite facies metamorphism and lower during their ascent to a relatively high level in the Earth's crust (Fiala et al. 1992). Fluid inclusions were studied in quartz porphyroclasts, garnet and exceptionally in mesoperthite from the Prachatic, Křišťanov, Lišov and Blanský les granulite massif (Dobeš 1993a). Based on a distribution of inclusions in relation to their host mineral, the composition and density

of trapped fluids, several types of fluid inclusions were distinguished: three generations of CO₂-rich (\pm CH₄, N₂) inclusions with a gradually decreasing density from 0.94 to 0.58 g.cm⁻³, several generations of H₂O-CO₂ (\pm CH₄, N₂) inclusions with variable volume fractions and density of CO₂ (the bulk density of inclusions is in the range from 0.17 to 0.92 g.cm⁻³ and bulk homogenization temperature reaches up to 340 °C), H₂O-rich inclusions with homogenization temperatures between 146 and 323 °C and salinity up to 5.5 wt. % NaCl equiv., and N₂-CH₄ vapour-rich inclusions with a very low density. Only the CO₂ with high density (0.94 to 0.89 g.cm⁻³) occurs in the relatively earliest inclusions, and the portion of water solution increases in the later generations of fluid inclusions up to H₂O-rich inclusions without detectable CO₂. The inclusions filled with water or a CH₄-N₂ mixture are considered to be the latest.

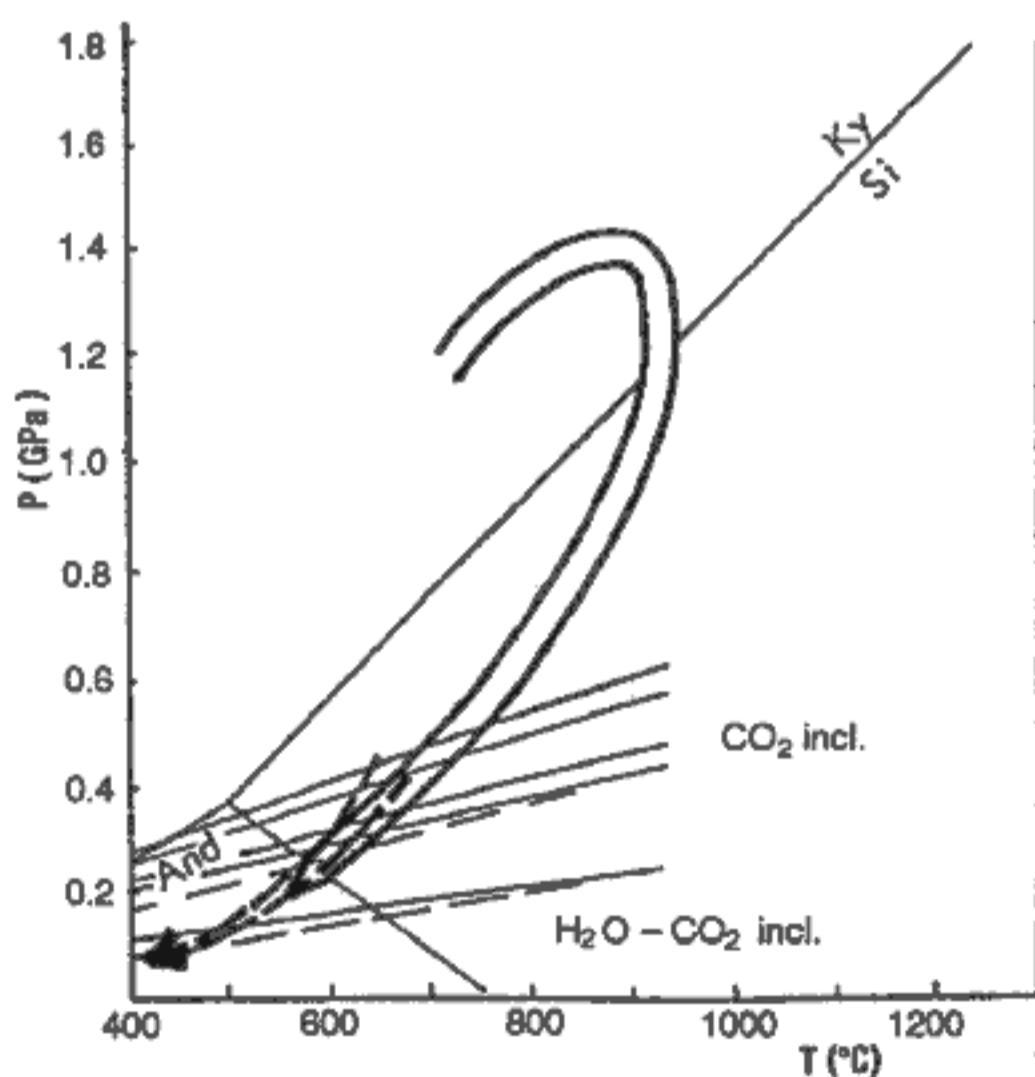
The isochores of fluids, calculated from fluid inclusions of a known composition and density, do not reach the conditions of peak granulite-facies metamorphism. The data can be explained by the trapping or re-equilibration of inclusions during the superimposed retrograde metamorphism and tectonic processes connected with the uplift of granulite massifs to the higher crustal position. P-T trajectory, reconstructed from the fluid inclusion data, is convex towards the T axis, i.e., it indicates a decompression regime and an adiabatic uplift of the granulite massifs (Fig. 171). The influx of water to the fluid system during the uplift and the mixing of H₂O-rich fluid with CO₂-rich fluid probably enhanced the superimposed plastic deformation of the granulite bodies.

E.2.1.2. Fluid inclusions in quartz veins of the Moldanubian Zone, Šumava (Kašperské Hory)

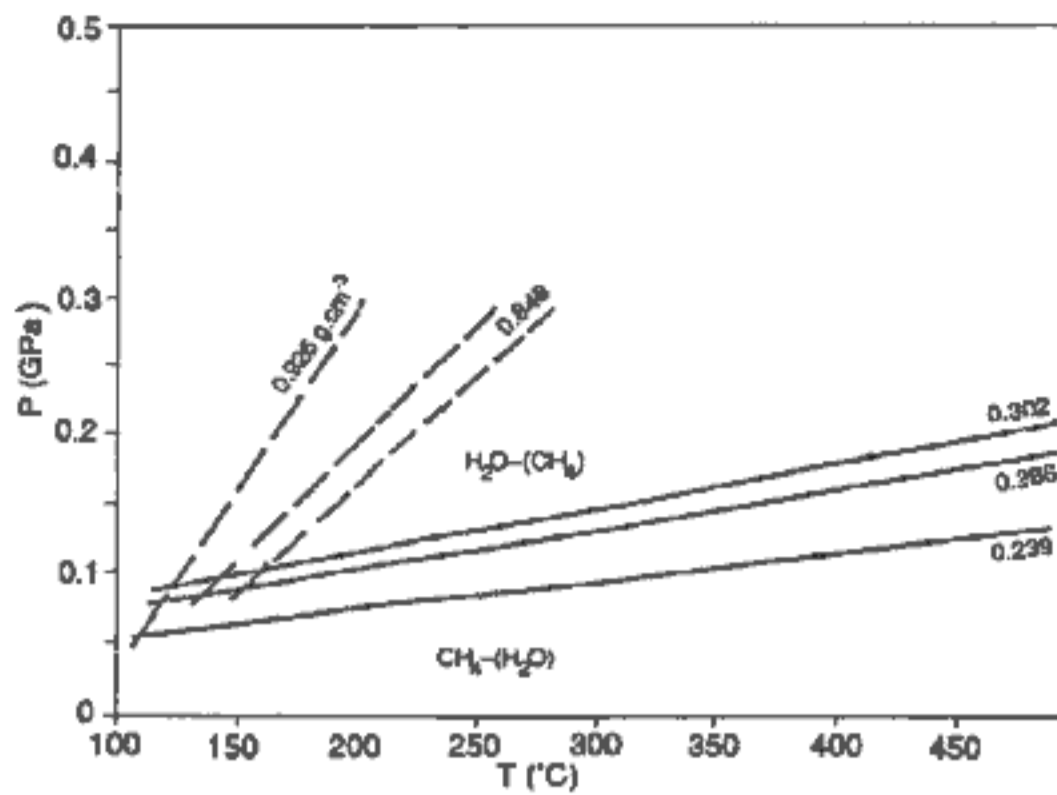
Fluid inclusions from various types of quartz veins (partly Au-bearing) at Kašperské Hory were studied in oriented sections, mainly from the point of view of correlation of palaeofluids with tectonic and metamorphic processes (Ďurišová et al. 1993a, b, Pertold et al. 1993, Strnad 1994).

The locality occurs at the boundary of the Varied and Monotonous Group. The quartz samples were collected in the "Naděje" gallery from vein structures with complicated morphologies in the area of an extensive shear zone in biotite gneisses. In all types of veins and in quartz from gneisses, fluid inclusions with analogous character were found. Three main types were distinguished: H₂O-CO₂ inclusions (early fluids, a content of liquid CO₂ + N₂? app. 60–80 mole %, appreciable variability of CO₂ density from 0.60 to 0.98 g.cm⁻³), H₂O-rich inclusions (late fluids on fissures, c = 2–8 wt. % NaCl equiv., T_h = 170–205 °C) and N₂-(CH₄) inclusions (late fluids on fissures, sometimes occur together with H₂O-rich inclusions, N₂ in vapour phase with an admixture of CO₂?, CH₄?).

The quartz veins formed during D₂ deformation, which is connected with the uplift of the rock complex, are therefore, considered to be retrograde. The microthermometric data suggest that the origin of the vein system is probably connected with huge changes in pressure during the exten-



171. Comparison of the P-T trajectory of the evolution of granulites in the Moldanubian Zone of southern Bohemia (summarized in Vrána 1992) with the P-T conditions of trapping of fluid inclusions in the granulites (shown by dashed line). The fluid inclusion isochores do not reach the peak P-T conditions of the granulite facies metamorphism.



172. Isochores of H₂O-(CH₄) and CH₄-(H₂O) inclusions from inter-pillow matrix; P-T parameters on crossing of the isochores represent the conditions of trapping of inclusions under immiscibility of H₂O-rich and CH₄-rich fluids (locality Mítov).

sion deformation. If we take into account the origin of veins at temperatures of about 400 °C, then based on densities of the CO₂ phase, the pressures oscillated in the range from 400 to 160 MPa. Under the conditions of lithostatic pressure, the earliest veins would have already formed at depths of about 14 km and during the successive uplift, the vein filling would have continued up to depths app. 6 km and were probably still under the conditions of lithostatic pressure. The circulation of H₂O-rich and N₂-rich fluids, probably of meteoric origin, took place during the late brittle deformations. The vapour phase, rich in N₂, could have been released during the oxidation of biotite accompanied by a reduction in cations of chloride solutions of meteoric origin (Shepherd et al. 1989).

E.2.1.3. Fluid inclusions in rocks of the Barrandian Upper Proterozoic (locality Mítov)

The rocks of the volcano-sedimentary complex of the Barrandian Upper Proterozoic at the Mítov locality (metabasalts of andesitic composition, carbonatized volcanites, silicites, greywackes, siltstones, black pyritic shales etc.) underwent sea floor metamorphism (e.g., Mrázek 1991) and were successively affected by the Cadomian metamorphism under actinolite-pumpellyite up to the chlorite zone (Cháb-Suk 1977).

Fluid inclusions were studied in quartz and calcite from an inter-pillow matrix (a quartz-calcite-chlorite-pyrite assemblage) and from oblique quartz-calcite veins with axinite (a thickness to 0.5 m).

Fluid inclusions in quartz and calcite of the inter-pillow matrix are mostly composed of a water solution or liquid methane, or mixtures of these phases (Dobeš 1993b). Primary inclusions in both minerals contain a water solution with a low salinity ($c < 10$ wt. % NaCl equiv.), and homogenization temperatures between 200 and 315 °C with a maximum value range of about 250 °C. In dark-coloured quartz with small aggregates of anthraxolite and in coarse

grained calcite with an admixture of organic matter, secondary inclusions with a mixture of H₂O and CH₄ were found. These inclusions are believed to be the relics of a heterogeneous environment under the conditions of the immiscibility of a water solution and methane. Either H₂O or CH₄ expressively predominate (up to 94 mole %) in inclusions. Methane ($d = 0.162$ to 0.363 g.cm⁻³) contains a small admixture of CO₂, N₂ and H₂S. The homogenization temperatures of H₂O-CH₄ inclusions (135 to 207 °C) can be, in this case, considered to be the temperatures of trapping of these inclusions, and the corresponding pressure (derived from isochore data of CH₄-rich and H₂O-rich inclusions) 50 to 100 MPa (Fig. 172). Inclusions of the same character were also found in later calcite veins (0.5 to 2 mm thick) inside the inter-pillow matrix.

Quartz, calcite and axinite of the oblique veins contain the H₂O-rich inclusions with temperatures of homogenization from 190 to 270 °C and variable salinity from 1 to 23 wt. % NaCl equiv. H₂O-CO₂ inclusions with a variable content of both phases ($d_{CO_2} = 0.615$ to 0.741 g.cm⁻³, admixture of CH₄ up to 20 mole %) only rarely occur in vein quartz. Based on the fluid inclusion study, it can be assumed that in the inter-pillow matrix the relics of fluids of various stages of the basalt-sediment-sea water interaction were trapped. The thermal effect of a submarine basalt extrusion provoked pyrolysis of the organic matter of sediments (at 350–400 °C, after Křfbek et al. 1993) and initiated the circulation of sea water, which reacted with the sedimentary organic matter to produce methane. The methane, owing to a limited miscibility with water solution at decreasing temperatures, formed an isolated liquid phase.

The primary H₂O-rich inclusions in calcite and quartz (T_h to 315 °C) probably represent the initial stage of inter-pillow filling formation during the basalt-sea water interaction, whereas later H₂O-CH₄ inclusions were trapped during the successive circulation of water solution and methane (together with organic particles) under lower temperatures of about 200 °C and pressures not exceeding 100 MPa. The low content of CO₂ and N₂ in inclusions indicates a reduction environment during the water-rock interaction. On the other hand, the formation of oblique veins with axinite is probably connected with other types of fluids: changes in the oxidation state in the rock environment are evidenced by the presence of CO₂-rich fluids (not CH₄-rich), and the infiltration of high salinity fluids took place at the end of the crystallization of the vein filling (calcite, the latest vein mineral, contains H₂O-rich inclusions with salinity up to 23 wt. % NaCl equiv.).

E.2.1.4. Fluid inclusions in minerals from veins of the Střibro type in the Upper Proterozoic

In the phyllitic Upper Proterozoic rocks, the sulphidic vein mineralizations are well known. Their formation is connected with post-metamorphic tectonic processes and the filling of tensional open faults. There is no reliable dating for these Pb-Zn mineralizations (Žák et al. 1993). Their age is estimated by Bernard (1991) to be Triassic or near the Permian/Triassic boundary.

Fluid inclusions were studied in pre-ore dolomite-ankerite, fluorite and quartz with radial microtexture, in sphalerite, and post-ore coarse-grained quartz, barite and calcite from the Dlouhá vein of a NNW-SSE strike. The inclusions in virtually all the minerals have variable liquid to vapour ratio. Only-liquid, only-vapour, or two-phase inclusions can be found. This is interpreted as a result of continued healing and necking of inclusions at low temperature after the vapour phase had nucleated (Bodnar et al. 1985) and not as a result of boiling.

Vein mineralization deposited at epithermal environment under temperatures from 140 °C to less than 100 °C. Salinity of the solution varied gradually during the deposition of minerals. K, Mg and Ca chlorides are components of solution in addition to NaCl; the content of CaCl₂ increases in high salinity fluids. Pre-ore minerals mostly deposited from low salinity fluids (*c* = 0.2 to 6.7 wt. % NaCl equiv.), whereas the deposition of ore minerals and the large quantity of quartz was connected with influx of high salinity fluid or with mixing of two fluids [*c* = 4.2 to 25 wt. %, eutectic temperature (*T_e*) varies from -45.5 to -68 °C]. Salinity decreased again towards the latest stages of the mineralization (salinity in barite and calcite is from 0.2 to 14.3 wt. % NaCl equiv.).

Vein minerals formed at a shallow level, therefore the homogenization temperatures are close to the real temperatures of trapping of inclusions. CaCl₂ content, observed in high salinity fluid inclusions, is thought to be a result of the interaction of water solutions with plagioclase at deep crustal levels (Behr et al. 1990, 1993).

E.2.2. Correlation of the fluid inclusion results from different mineral associations

E.2.2.1. Composition of palaeofluids

Several main types of fluid inclusions can be distinguished with respect to their composition from all the associations studied:

H₂O-rich – unsaturated water solutions

H₂O-multi-phase – water solutions with salt crystals and hardly soluble phases

H₂O-CO₂ – water solutions with a variable portion of CO₂(+CH₄, N₂)

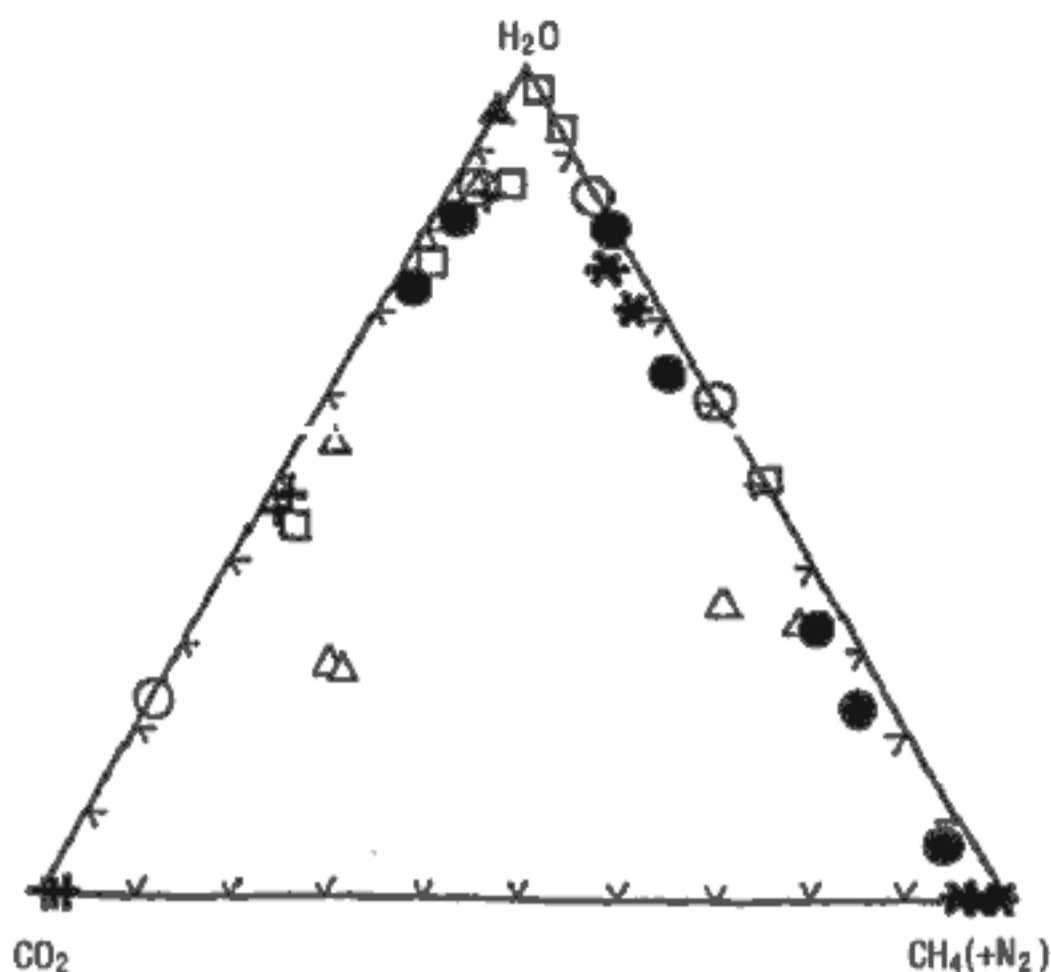
CO₂-rich – mostly liquid-only, water-free CO₂

H₂O-CH₄ – water solutions with a variable portion of CH₄(+CO₂, N₂)

N₂(+CO₂, +CH₄) – vapour mixtures.

All the types of fluid inclusions (C-O-H-N composition) mentioned so far were found in minerals from the metamorphic mineral associations, whereas in the post-metamorphic associations only water-rich fluid inclusions were found.

The data obtained are shown in Fig. 173. It seems to be apparent that fluids are enriched either in CH₄ or in CO₂. The content of all three phases (H₂O, CO₂, CH₄+N₂) is quite variable in metamorphic minerals. In inclusions where CO₂ predominates, the CH₄ content did not exceed 15



173. Molar composition of selected fluid inclusions (calculated from the microthermometric and micro-Raman spectrometric data)

Explanation:

cross – quartz from granulites

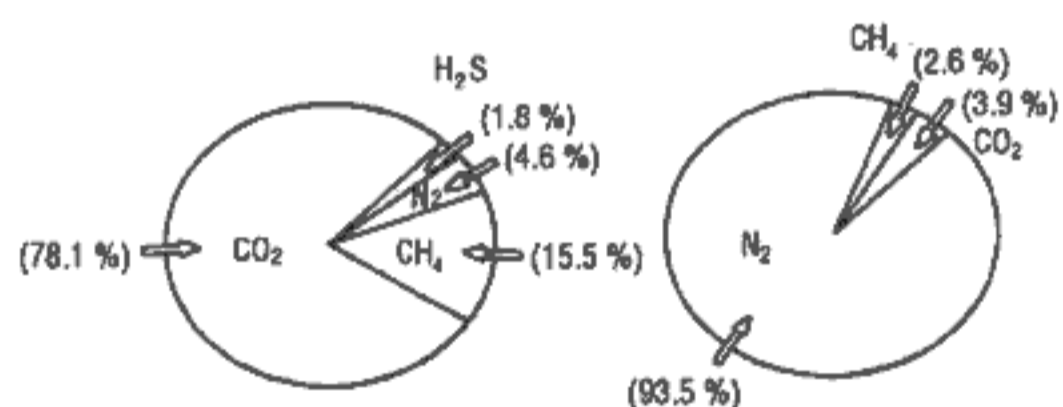
box – quartz and scheelite from sillimanite gneisses and skarnoids of the Moldanubian Zone (locality Orlick)

open triangle – quartz from gneisses and skarnoids in the Moldanubian Zone (locality Kašperské Hory)

solid circle – quartz from mica schists and quartzites of the Silesicum (localities Zlaté Hory and Zlatý Chlum)

asterisk – quartz from inter-pillow matrix from the Teplá-Barrandian Upper Proterozoic (locality Mftov)

solid triangle – quartz from the cassiterite-bearing quartz vein from the Krušné hory granite.



174. Composition of the vapour phase of selected fluid inclusions in quartz from gneisses of the Moldanubian Zone (locality Kašperské Hory). Micro-Raman spectrometry was carried out in CREGU, Nancy. Data in mol. %.

mole %; on the other hand, in inclusions with prevailing CH₄, the CO₂ content is lower than 12 mole %. N₂ was also observed in metamorphic fluids: in samples from the Moldanubian Zone, fluids with an equal portion of CH₄ and N₂ (CH₄ = 24 mole %, N₂ = 26 mole %, H₂O = 50 mole %) were observed. In a quartz vein from skarnoid rocks in the Kašperské Hory area, inclusions with a content of 93.5 mole % of N₂ in vapour phase were found (Fig. 174). Nevertheless, the bulk composition (with 10 vol. % of H₂O in inclusion) is represented by fluid composed of 34 mole % of H₂O, 61 mole % of N₂ and 4 mole % of CO₂+CH₄. From the distribution of fluid inclusions in

minerals of the metamorphic associations, it can be deduced that fluids of different composition are preserved in different generations of inclusions. It was proved that the amount of CO₂ in fluids increased with the grade of metamorphism. The inclusions of water-free liquid CO₂ are typical, especially of minerals in granulites. The fluids with CH₄ and N₂ belong to the relatively late generations of inclusions which originated under conditions of lower temperatures (350 °C) and pressures (100 MPa). The presence of CH₄-rich fluid in minerals from the inter-pillow matrix from the Proterozoic rocks (locality Mítov) is connected with a basalt-sediment-sea water interaction.

In contrast to metamorphic fluids, the inclusions from the quartz veins from the Preisselberg granite represent the water solution with a CO₂ content not exceeding 4 mole % (in Fig. 173 the composition of these fluids is shown by a filled triangle). The salinity of these fluids is low (5 wt. % NaCl equiv.), and a typical feature is a very low fluid density (~ 0.3 g.cm⁻³). The common occurrence of these fluids within the inclusions of highly concentrated solutions (~ 40 wt. %) is likely to be a result of heterogenization of an originally homogeneous fluid (magmatic origin?) to a vapour and a liquid phase with distinctly different densities and concentrations of salts. Such phenomena were already described in a fluid inclusion study of minerals from quartz veins and greisens from the Eastern and Western Krušné hory Mts., and were also recently observed in quartz phenocrysts of the Teplice rhyolite and in the vein aplite from the Preisselberg granite (the Vrchoslav locality).

The late Variscan palaeofluids which took part in the origin of the vein mineralizations (the Stříbro type) represent the unsaturated chloride solutions, in which Mg is probably cation in addition to Na, but locally dominant Ca chlorides can be found.

E.2.2.2. Thermobarometric constraints for the existence of fluids

The calculations of isochores of trapped fluids enabled the establishment of P-T conditions under which a fluid of known composition could have existed and be preserved as fluid inclusions.

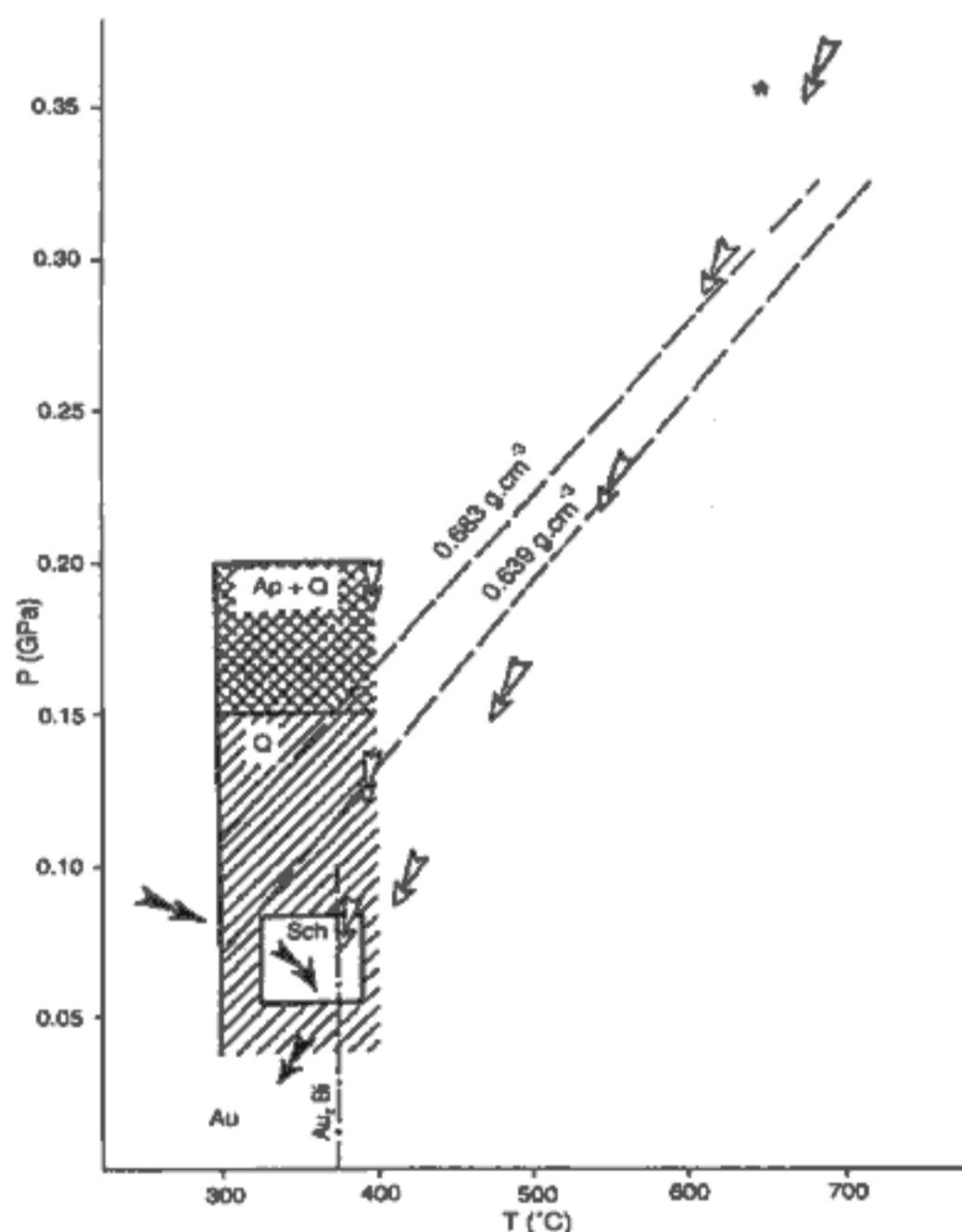
Fluid inclusions in granulites represent the conditions of retrograde development of these rocks under the conditions of amphibolite facies grade metamorphism. Pressure at an estimated temperature of about 600 °C corresponded to 400–450 MPa (Fig. 171).

The isochore calculations from rocks of the Moldanubian Zone give evidence that pressure during the origin of the sillimanite-cordierite-biotite gneisses at a temperature of about 650 °C reached 350 MPa (Ďurišová et al. 1992, 1993a, b, Fig. 175). The origin of a vein system during the uplift of the Moldanubian rocks in the Kašperské Hory area under the conditions of retrograde metamorphism (if we take into account a temperature indicated by mineral assemblages app. 400 °C) started at pressures close to 400 MPa and continued under the successive uplift to pressures of about 160 MPa (corresponding to a depth 14–6 km below the surface under the lithostatic pressure). In good agreement

with the data from the Moldanubian Zone are fluid inclusion isochores calculated from quartz of metamorphic rocks of the Silesian zone, where the pressure at the sillimanite zone (under 500 °C) reached 300–450 MPa (Ďurišová et al. 1993a).

In comparison to the P-T conditions during metamorphic processes, the quartz veins from the Krušné hory granite were formed under low pressure. Under the assumed temperatures of the origin of the veins of about 400 °C (based on homogenization temperatures of different types of fluid inclusions), fluids were under a pressure of app. 30 MPa (Ďurišová et al. 1993b), which corresponded to depth of about 1 km under the lithostatic pressure. These data are supported by the geological position of greisens and ore-bearing veins in the Krušné hory Mts., which suggests a relationship with the granite plutons which intruded at a shallow level below the surface. This can also be supported by a relationship with the extrusions of the Teplice rhyolite.

Low temperatures (130–200 °C) and relatively low pressures (50–100 MPa) are characteristic of the late palaeofluids in minerals from the inter-pillow matrix from the volcano-sedimentary complex of the Barrandian Proterozoic (Dobeš 1993b).



175. P-T conditions of crystallization of apatite (Ap), quartz (Q) and scheelite (Sch) from sillimanite gneisses of the Moldanubian Zone (locality Orlick – Ďurišová et al. 1992). Isochores of CO₂-rich fluids are shown by dashed line. The asterisk represents the metamorphic P-T conditions of sillimanite-cordierite-biotite gneisses (T=650 °C, P=0.3–0.4 GPa). The open arrows indicate two possible variants of development of the P-T conditions during crystallization of minerals, based on the data from various generations of inclusions. The solid arrows show the conditions of probable influx of CH₄-rich fluids related to scheelite crystallization.

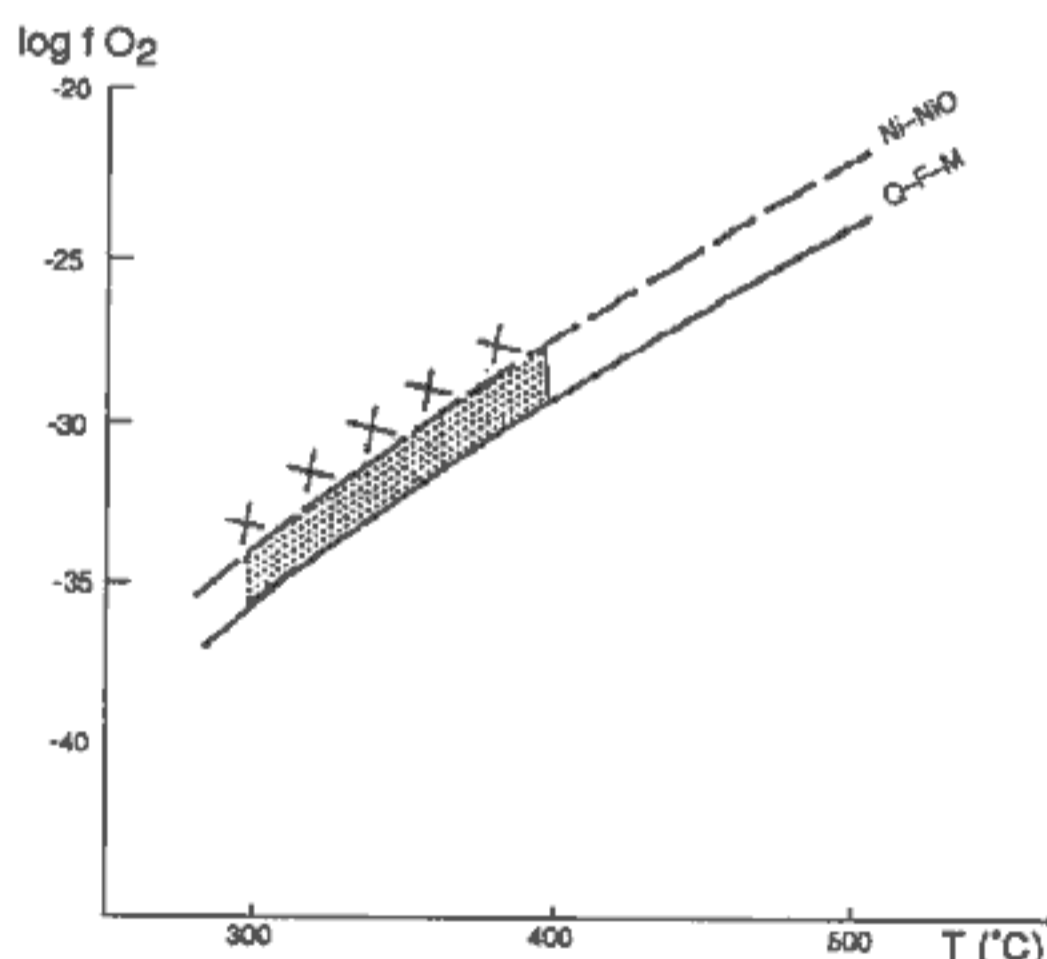
E.2.2.3. Redox conditions

Oxygen fugacities of palaeofluids were calculated from the fluid inclusion data obtained from selected samples.

Oxygen fugacity values of metamorphic fluids are relatively low ($\log f_{O_2} = -31$ to -32 at 350°C) and correspond to the values close to the Q-F-M buffer (Fig. 176). These values give evidence of a reduction environment influenced by the occurrence of organic matter in rocks. The calculated values from the CO_2 -rich inclusions correspond to the fugacities at the chemical equilibrium of fluid with graphite. A breakdown of this equilibrium occurs under temperatures below 400°C . This fact was observed in the inclusions in scheelite and quartz (the Orlick locality – Ďurišová et al. 1992), which formed at temperatures of 360 – 380°C and were filled with a CH_4 -rich fluid, in contrast to CO_2 -rich inclusions, which were trapped under higher temperatures. From the fluid inclusion study of selected localities, it can be stated that CH_4 -rich inclusions formed as a result of a reaction between water-rich fluids and graphite-bearing rocks, and not as the relics of the reaction CO_2 -rich fluid + CH_4 -rich fluid, which, under conditions of isobaric cooling, could have caused the graphitization of rocks accompanied by the origin of water-rich fluids (Behr et al. 1991). Increased CH_4 content gives evidence of the fluid reduction in late generations of CH_4 -rich inclusions.

The oxygen fugacities ($\log f_{O_2} = -30.5$ at 350°C) calculated for fluids from a quartz vein from the Preisselberg granite are by one order of magnitude higher in comparison with the fugacity of metamorphic fluids and indicate that fluids were not in equilibrium with graphite.

The calculated sulphur fugacity values of metamorphic



176. Changes of oxygen fugacity with temperature (calculated from data on fluid inclusions in quartz). The dotted area shows the data on metamorphic fluids (gneisses of the Moldanubian Zone – locality Orlick, vein quartz from metamorphic rocks of the Silesicum – localities Zlatý Chlum and Zlaté Hory). The crosses show the values of post-magmatic fluid from veins in the Krušné hory granite (locality Horní Krupka).

fluids of the Silesian zone ($\log f_{S_2} \sim -8$ at 350°C) are relatively high and in agreement with the occurrence of pyrite and pyrrhotite in rocks.

E.3. EPIGENETIC HYDROTHERMAL MINERALIZATION

I. VAVŘÍN

The main aim of the chapter is to provide a basic systematic review of the hydrothermal mineralization in the region. This review should enable us to follow regional distribution and the succession of distinct types of mineral assemblages, their relations to regional tectonics, principal fault zones, intrusive and plutonic bodies and to the main lithostratigraphic units. To some extent and indirectly, the data bring information on activity of hydrothermal fluids through a number of stages of geological evolution.

The study is mainly based on the metallogenic map of Czechoslovakia 1 : 500 000 (Satran-Ilavský 1976), on metallogenic reviews by Bernard-Pouba (1986), Bernard et al. (1990), Bernard (1991) and books on topographic mineralogy by Kratochvíl (1956–1966), Tuček (1970), and Oswald (1959). In several instances, new data and data from recent reports and papers have been used.

Occurrences of epigenetic hydrothermal mineralization have been listed within southern and western Bohemia in 56 map sheets at a scale 1 : 50 000. The following features have been collected for each occurrence: the genetic type of mineralization, age of mineralization, size of accumulations, mineral index, and references. A detailed evaluation of the data obtained is given in Vavřín (1993). The database INDICIE (Vavřín 1993) is available within the final report of the project "Geological Model of Western Bohemia in Relation to the Deep Borehole KTB in FRG".

E. 3. 1. Metalliferous mineralization

Polymetallic assemblage (+ Ag)

A) Silver-poor polymetallic assemblages (Oloví, Stříbro) are connected mainly to quartz veins, and less frequently to quartz-carbonate and quartz-barite veins. Low-Ag galena, sphalerite, minor pyrite, chalcopyrite and marcasite are the most common ore minerals. Calcite, and less often dolomite-ankerite and fluorite, prevail among gangue minerals.

The polymetallic assemblage occurs also in numerous veins with uranium and with the so-called five-element (Ag-As-Bi-Co-Ni) formation in the central part of the Krušné hory Mts. as a younger mineralization stage (e.g., Abertamy, Jáchymov). Polymetallic mineralization in the Příbram uranium district is older in comparison to the predominating uranium mineralization.

B) Polymetallic silver-bearing mineralization (Příbram, Michalovy Hory, and the area between Horažďovice and

Klatovy) is bound on quartz, also partly on carbonate or barite veins with galena, sphalerite, chalcopyrite, tetrahedrite and Ag-minerals. The main source of silver is most frequently Ag-bearing galena. The assemblage was indicated in a number of places; it occurs more frequently in the vicinity of Klatovy and Horažďovice. The richest accumulations of silver-bearing polymetallic ores occurred in the Příbram ore district and its deposits in Březové Hory, Bohutín, Vrančice, Radětice, etc. The main type of mineralized structures is represented by complex symmetric veins with several stages of mineral filling. The principal ore component is Ag-rich galena associated with several generations of sphalerite, Ag-bearing tetrahedrite, bournonite, and boulangerite. Arsenides of Ni and Co (skutterudite, niccolite, smaltite etc.) are rare. Argentite, pyrargyrite, proustite, stephanite, diaphorite, polybasite, pyrostilpnite and other Ag-minerals are typical of the Příbram deposit. Siderite, calcite, dolomite, barite and quartz form the characteristic vein filling.

The second type of mineralization is represented by finely disseminated ores in quartz veins. Galena, boulangerite, jamesonite, sphalerite, abundant pyrite and arsenopyrite, silver-bearing tetrahedrite and diaphorite are common. Cassiterite, stannite, scheelite, and wolframite associate exclusively with this disseminated mineralization. At the Vrančice deposit there are also Cu-ores like chalcocite, tetrahedrite and chalcopyrite with barite in some veins beside galena and sphalerite. Mixing and hybridization of individual stages of mineralization, resulting in disseminated ores, is characteristic of the Příbram polymetallic ore district.

C) Polymetallic mineralization with silver and gold (Hory Matky Boží, Velhartice, Nalžovské Hory, Záblatí, and Volyně) (Morávek et al. 1992). It is associated with quartz veins corresponding to the B-type mineralization.

Copper mineralization

Occurrences are concentrated around Mariánské Lázně, and only scarcely in the central and southern part of the region studied. Tisová near Kraslice is considered as sulphidic stratiform Cu-deposit. A post-metamorphic hydrothermal stage, including chalcopyrite, pyrrhotite and pyrite, was described by Bernard-Pouba (1986).

Copper mineralization associated with chalcopyrite in quartz veins of the Mariánské Lázně fault system is developed near Mutěňín and Chodová Planá. Quartz veins with chalcopyrite and minor barite, chalcocite and covellite occur at Tři Sekery, Drmoul and Broumov. Some polymetallic deposits provided Cu as a by-product (e.g., Příbram, Vrančice).

The occurrence of chalcopyrite, pyrite, pyrrhotite in fractures of the Štěnovice-type granodiorite near Nebílovský Borek, where sulphides are associated with minerals of the Alpine-type veins, i.e., epidote, laumontite, chlorite and calcite, is of an unclear genesis.

Gold-bearing mineralization

Accumulations of gold are concentrated in two areas:

1) The Central Bohemian region comprises a part of the Central Bohemian Pluton, its roof pendants (metamorphic "islets"), and the adjacent Upper-Proterozoic volcanosedimentary unit. The Central Bohemian Suture delimits this area in the West, the Benešov fault in the East. This area provides the biggest accumulations of gold in the Bohemian Massif, which are divided into two main, mostly monomineral types:

a) The Au-quartz assemblage with gold of high fineness, also called the "quartz early-Variscan mineralization" (Bernard-Pouba 1986). Gold is accompanied by accessory pyrite, arsenopyrite, pyrrhotite, scheelite, and rare galena, chalcopyrite and molybdenite. Minor Bi-minerals closely associated with gold include native bismuth, maldonite, bismutite, several sulphosalts, tellurides and sulphotellurides of Bi. In Krásná Hora nad Vltavou and Milešov, Au-Sb mineralization in quartz-antimonite veins carries disseminated gold and rare aurostibite, native antimony, and allemontite.

b) The Au-quartz assemblage with gold of a low fineness occurs in the Moldanubian Zone near Písek and Vodňany, along the periphery of the Central Bohemian Pluton. Gold is accompanied by minor sulphides, especially pyrite and arsenopyrite. Minerals with Bi, Te, Mo, and W are absent.

2) Gold-bearing mineralization in the Moldanubian Zone controlled by lithology: Au (W) mineralization occurs in lithological layers or veins, as in the Kašperské Hory and Hartmanice regions. A synmetamorphic origin or at least a metamorphic enrichment of these accumulations is probable (Morávek et al. 1992). Gold of high fineness is accompanied by arsenopyrite and pyrite, accessory galena, pyrrhotite, chalcopyrite, and molybdenite. Bi-bearing minerals represented by native Bi, maldonite, and hedleyite are typomorphic of this mineralization, as well as other tellurides and sulphotellurides, and accumulations of scheelite.

Molybdenite mineralization

Accumulations of molybdenite were found (together with Au-quartz veins) at Hůrky near Čistá, where massive molybdenite and pyrite impregnations occur in the mylonitized contact between two different granitoids. Minor molybdenite along fractures in granitoids, pegmatites and aplites in the Central Bohemian Pluton is locally accompanied by pyrite and other sulphides. It tends to accumulate along the ascent line of the Central Bohemian Pluton without any special relation to lithologic types (Bernard-Pouba 1986). Accessory molybdenite accompanies gold in some deposits.

Tin-tungsten, and lithium-tin-tungsten mineralization

These two types occur mostly in the Saxothuringian Zone, associated with the Variscan granite intrusions, namely Karlovy Vary granite. An admixture of cassiterite, stannite, and wolframite with disseminated sulphides is present in quartz veins of the Březové Hory deposit in the Příbram

district. Gold deposits bound to the Central Bohemian Pluton (e.g., Kasejovice, Kocelovice) locally contain some wolframite and scheelite. The Moldanubian gold deposits at Kašperské Hory and Hartmanice contain substantial quantities of scheelite. The genesis of the latter occurrences, as well as of scheelite near Horažďovice, has not been satisfactorily explained yet.

Sb mineralization

Antimonite mineralization is represented only in the Krásná Hora-Milešov district. Quartz veins with massive antimonite accompanied by native gold and aurostibite contain also pyrite, arsenopyrite, pyrrhotite, sphalerite, rare tetrahedrite, berthierite, native antimony and allemontite. Antimonite was mined in the Bohutín mine (the Příbram district), where it is associated with accessory berthierite, pyrite, and in places barite, at the Klementska vein. Small localities include Boněnov SE of Chodová Planá, Chřč near Kralovice, Planá near Radnice, Padrč near Rožmitál, and Kamýk nad Vltavou. At these localities, antimonite with pyrite and arsenopyrite appears in quartz veins.

A supposed antimonite in occurrence near Mirovice was identified by Litochleb-Šrein (1993) as a mixture of boulangierite and jamesonite.

Hg mineralization

Almost monomineral accumulations of cinnabar occur in three lithologically distinct areas:

1) Cinnabar accumulations are bound to the Ordovician volcanosedimentary rocks in the Barrandian (Jedová hora near Hořovice, Krušná hora, Březina). Hg mineralization was discovered in the ferriferous Komárov and Klabava horizons of the Lower-Ordovician Šárka sequence, where cinnabar often forms monomineral veinlets and impregnations, in places accompanied by pyrite, antimonite, carbonates, quartz, and barite.

2) Cinnabar accumulation in weakly metamorphosed Early Palaeozoic rocks of the western part of the Krušné Hory Mts. and Smrčiny near Luby. Minor indications were found in the vicinity of Aš (Trojmezí). Mineralized zones with cinnabar veinlets and impregnations with quartz, pyrite, and minor carbonate follow the original bedding in the Lower Ordovician or Cambrian volcanosedimentary rocks.

3) The oldest stage of Hg-mineralization is known from the Proterozoic phyllites near Bezdrůžice. Extensive heavy-mineral anomalies with cinnabar located near this village have not been explained yet.

Cinnabar mineralization is usually interpreted as associated with late-Variscan stages. Some authors suggest that cinnabar concentrated directly from Cambrian and Ordovician volcanites and that it subsequently migrated and redeposited during late-Variscan processes.

"Five-element" As, Ag, Bi, Co, Ni mineralization

A strongly defined and rather uniform assemblage with As, Ag, Bi, Co and Ni prevails in the Krušné hory Mts., east of the Karlovy Vary pluton (Jáchymov, Abertamy) while in the Horní Slavkov region this mineralization appears in minor accumulations (Horní Slavkov, Krásno, Prameny, and Smrkovec) and further S of Mariánské Lázně in Michalovy Hory and Svatá Anna. The arsenide mineralization in Svatá Anna shows a prevalence of As and Co over Ag and Ni; Bi is almost absent. Arsenides form a minor admixture in the Příbram uranium and base-metal deposits. A typical feature of the five-element formation is its close relationship to several stages of U-mineralization. This assemblage is quite common not only in the Bohemian Massif, but also in some other ore belts (e.g., the Canadian Shield).

The veins formed during several stages. The first one gave rise to a polymetallic assemblage with quartz. The major U-bearing stage followed, resulting in the deposition of uraninite, dolomite, quartz, and fluorite. The third stage resulted in the deposition of As, Ag, Bi, Co, Ni-rich phases; a late silver-bearing substage deposited argentite and sulpho-arsenides of Ag. The youngest stage brought realgar and tennantite, and calcite gangue.

The superposed mineralizations were influenced by a complex intra-vein metasomatism, remobilization and regeneration of some minerals (uraninite, native bismuth). The vein mineralization displays spatial zoning, namely in the Jáchymov district.

Uranium mineralization

The uranium mineralization is one of the most widespread within the area and includes ore districts exploited during the last decades. It is concentrated mainly in four regions:

- the Krušné hory Mts.
- western Bohemian region
- south-western Bohemia
- the Příbram district and Central Bohemia

A) The Krušné hory Mts.

Primary uraninite associated with the five-element mineralization and with late-Variscan polymetallic formations occurs in the Saxothuringian metallogenic belt and along its boundary. The most important ore district is Jáchymov. Uraninite was deposited during several stages. The first generation uraninite is accompanied by dolomite, lesser calcite, fluorite, quartz, and pyrite. The younger ones are frequently associated with Co- and Ni-arsenides and native silver.

In the Horní Slavkov district, vein mineralization is almost identical to that of Jáchymov, the ore-content is, however, far lower; silicification of carbonates from earlier stages is more extensively developed.

B) Western Bohemian region

The western Bohemian ore region with Zadní Chodov, Vítkov II and Dyleň deposits, and with occurrences at Svatá Anna, Vítkov I, Oldřichov, Ostrov near Tachov, Bor near Tachov etc., features mineralization in Moldanubian crystalline rocks, intruded by the Bor pluton. Occurrences are

controlled by faults of the West Bohemian shear zone and the Mariánské Lázně fault. The U-bearing assemblages comprise two types: a) metasomatic mineralization and b) classic vein mineralization.

All over the region, local conditions favoured ore metasomatism which, in general, predominates over the vein formation, especially in coarse-grained paragneisses and granitoids. Four stages of varying importance were recognized:

- 1) pre-ore, albite-sericite-chlorite stage
- 2) metasomatic ore-bearing brannerite-coffinite stage
- 3) vein ore quartz-hematite-uraninite stage
- 4) post-ore, carbonate-sulphidic stage, rarely with arsenides (Svatá Anna) and selenides (Oldřichov near Tachov, Hlinné).

According to a paragenetic and Pb-S-isotopic study, an early pre-uraninite substage with quartz and sulphides was recognized within the latter stage (Oldřichov near Tachov), and the U-minerals-selenides-arsenides succession of post-uraninite phases at the Svatá Anna deposit was determined by Vavřín (1993).

C) South-western Bohemia

Several occurrences are grouped along the contact of the Central Bohemian Pluton near Horažďovice, i.e., the Střelenské Hoštice and Chanovice intrusions. Uranium mineralization is bound to pennate veins of the main dislocations of the Moldanubian crystalline complex near their contact with the pluton (e.g., Ústaleč, Lipová Lhota, Velhartice), or directly in plutonic rocks (Nahošín, Mečichov). Calcite veins with uraninite and locally with coffinite, pyrite, chalcopyrite, hematite, galena, and sphalerite admixtures predominate. Accessory selenides are indicated at Ústaleč, Nahošín, and Těchonice.

D) The Přeboram uranium district and Central Bohemia

The Přeboram uranium district with deposits at Kamenná, Lešetice-Brod, Jerusalém, Bytíz, Skalka, and Obořiště extends 25 km along the NW contact of the Central Bohemian Pluton and Upper-Proterozoic rocks. Ore-bearing parallel veins with a characteristic carbonate-uraninite assemblage intersect this contact. The veins occur in Proterozoic greywackes and siltstones affected by contact metamorphism. Uraninite of several generations prevails among U-bearing minerals, and coffinite occurs only in traces. Four stages of mineralization were recognized:

- the oldest siderite-sulphidic stage with siderite, ankerite, galena, sphalerite, chalcopyrite, arsenopyrite, and tetrahedrite
- a pre-ore, carbonate stage with calcite, goethite, and hematite
- an ore-bearing, calcite-uraninite stage with several generations of calcite
- a post-ore, calcite-sulphidic stage with early calcite associated with late U-antraxolite, coffinite, uraninite, and subordinate common sulphides, allemontite, Ni- and Co-arsenides, montroseite and quartz. The latest calcite is accompanied by abundant pyrite.

U-mineralization near Novotný and Dlačov is localized along the Klatovy apophysis, in the SW continuation of the Přeboram U-district. Minor localities occur in granitoids of the Central Bohemian Pluton (Pechova Lhota, Petrovice,

Velká), along major tectonic faults trending N-S to NW-SE. A small deposit at Předbořice, in the Sedlčany metamorphic roof pendant, carried uranium mineralization with carbonates, selenides and gold.

The hydrothermal uranium deposits are largely of late-Variscan age and display close connections to Variscan granitoid intrusions, especially to their exocontacts, e.g., the eastern margin of the Karlovy Vary pluton, western contact of the Bor pluton, and NW and SW margins of the Central Bohemian Pluton. The most efficient factors for the location of U-mineralization were tectonic structures. Uranium deposition is generally controlled by major faults and their intersections, ore-minerals are concentrated mostly in the related parallel, subparallel or cross-cutting structures of lower orders. Potential for the U-mineralization is also influenced by variable lithological properties of rocks, e.g., amphibolites, pyrite-rich rocks.

Sulphide-selenide mineralization

This assemblage is spatially closely connected to the U-mineralization, namely to vein accumulations of coffinite and uraninite. It is known from three regions in the area studied:

1) Near Mariánské Lázně, occurrences of selenides of the clausthalite-galena isomorphous series, accompanied by a series of Pb-Bi selenides, are known at Oldřichov near Tachov, with poubaite and soucekite as newly described minerals. Rucklidgeite was found here for the first time in Bohemia (Čech-Vavřín 1978, 1979). A Se-analogue of ikonulite is described from Hlinné near Tachov (Litochleb et al. 1990), and paraquanajuatite from Bavarian Höhensteinweg near Poppenreuth, close to the Bohemian border (Dill 1981). Clausthalite has been recently found in the Svatá Anna deposit (Vavřín, 1993). There is no reliable up-to-date reference on the occurrence of selenides of Cu and Pb at Zadní Chodov (Group of authors, 1984).

2) The most notable locality in the Horažďovice region is Ústaleč, where, in addition to clausthalite, also berzelianite, umangite, eskebornite and rare bukovite were described. Minerals of the clausthalite-galena series in an assemblage with naumanite were recently described from Nahošín and Těchonice (Litochleb et al. 1990).

3) An exceptionally varied assemblage of selenides of Cu, Pb, Hg, Ag, Fe, Co, Ni, and Te is known from Předbořice, the locality situated in the Sedlčany metamorphic roof pendant on the Central Bohemian Pluton (Kvaček 1987). Hakite, a selenium-rich analogue of tetrahedrite, was newly described from here, together with permingeatite and fischerite, rare selenides of Ag and Au. Recently, a rare selenotelluride of Pd, merenskyite, was identified (Johan 1989). Berzelianite and clausthalite were recorded from adjacent Voltýřov.

Selenides were formed during the final stage of uranium mineralization, when an increased redox-potential enhanced their precipitation, especially under the deficiency of sulphur in hydrothermal fluids. The endogenous replacement of uraninite by coffinite, known from the majority of selenide occurrences, is characteristic of this stage.

Fe-Mn mineralization

This mineralization occurs in two distinct genetic types:

a) Abundant quartz veins containing Fe-Mn mineralization represented by hematite (mostly as bothryoidal aggregates), pyrolusite, minor polianite and psilomelane are developed in the Krušné hory Mts., mainly around the Karlovy Vary pluton and its mantle. The veins near Horní Blatná fill thick NW-SE trending tectonic zones and contain hematite as the single or strongly predominant ore mineral. Similar quartz veins with hematite also occur near Horní Slavkov.

b) Siderite veins without a substantial admixture of polymetallic sulphides occur mainly in the Příbram region (Narysov, Žežice). Their limonite gossans were mined in the past. Isolated shows of siderite veins are known from the vicinity of Železná Ruda and Rozvadov.

E.3.2. Hydrothermal non-metallic mineralization

Quartz veins

Only several economically important bodies, exploited as raw materials for the glass industry or for crushed stone, are mentioned in the literature. Occurrences of large and morphologically conspicuous, vertical quartz veins, so-called lodes, belong to this category. Occurrences near Pavlíkov, Babylon, Nový Kramolín and Tachov form part of the West Bohemian shear zone (Bohemian quartz lode), and other quartz veins are found, e.g., near Kočov in the Mariánské Lázně region, and Damětica in the Horažďovice region. A huge quartz vein at Černava and Tatrovce near Nejdeč in the Krušné hory Mts. was also exploited.

Quartz veins are located along principal tectonic discontinuities. They represent the oldest stage of mineralization filling extensional structures, that were later reactivated, and in places filled by later metalliferous mineralization.

Carbonate veins

Carbonate veins free of other minerals have not been systematically described in the literature. Carbonate veins carrying some metalliferous mineralization, including those with pyrite, are mentioned in the respective parts of this chapter, as well as siderite and ankerite veins.

Barite-fluorite mineralization

There are two zones in which barite-fluorite veins are found. The first one is in W part of the Krušné hory Mts., including minor deposits at Blahuňov, Hradiště and Kovářská N of Klášterec nad Ohří. The second zone is near Horní Slavkov and Sokolov (Lobzy, Novina, Staré Sedlo, Vítkov near Sokolov).

The mineralogical composition of the veins in both zones is similar. Quartz and fluorite, with variable amounts of barite, form major components. Hematite and accessory sulphides – galena, sphalerite, chalcopyrite, chalcocite,

marcasite, and pyrite also occur. Relatively abundant pyrite with an increased content of Tl, associated with bothryoidal hematite, is known from Hradiště. The age of the fluorite-barite assemblage in both cases is late-Variscan (Mesozoic).

Isolated quartz veins with fluorite (free of barite and sulphides), scattered throughout the area around Předbořice, Mutěnice, and Topělec, are classified by Bernard-Pouba (1986) as of a late-Variscan age. Fluorite mineralization within the Sn-W greisens in the Krušné hory Mts. is considered to be of late-Variscan age. Fluorite and also rarely barite occur as subordinate or accessory components in these rocks.

Barite mineralization

Isolated monomineral barite veins are found, e.g., in the Mariánské Lázně region in Dolní Kramolín, Pernarec near Stříbro and Smrkovice near Písek. Barite more frequently forms a counterpart of the sulphide assemblages in almost all metalliferous districts of the area (Cetyně, Kosobudy, Michalovy Hory, Stříbro, Černovice, Hory Matky Boží etc.). The biggest accumulations of barite in veins with the sulphidic assemblage were found in the Klement vein in the Příbram ore district. Barite is also associated with stibnite and Hg-bearing mineralization. A late-Variscan age is ascribed to these occurrences by Bernard-Pouba (1986).

E.3.3. Minerals of the Alpine-type veins and similar assemblages

The mineral assemblages of the Alpine-type veins are derived from chemical components released from the country rocks without any influx from hypogene sources. There is no sharp division between veins of the Alpine-type and the hydrothermal ones. According to numerous authors, the temperature of formation of the Alpine vein minerals lies within the same range as that of hydrothermal processes. Bernard et al. (1981) considered 5 groups of Alpine-type mineral assemblages. Several localities of quartz, albite, calcite, laumontite, epidote, chlorite, fluorite, and rarely pyrite- and chalcopyrite-bearing assemblage were found mainly in the Central Bohemian Pluton. This mineral assemblage best corresponds to the "B" assemblage in the classification of Bernard (l.c.). In some places sulphides, namely molybdenite, also occur together with other minerals in the Alpine-type veins (Nečín, Luby). These cases are probably due to cogenetic formation of the Mo-mineralization with other minerals of the veins. The small number of known Alpine-type vein occurrences is probably reflecting the fact that in many areas they arose little interest, particularly in absence of large, well-crystallized minerals.

E.3.4. Notes on metallogeny and tectonics of the region with regard to the occurrence of epigenetic hydrothermal mineralization

The presence of gold, silver, tin, and uranium vein deposits and the absence of Cr, Pt, and magnetite deposits of magmatic origin are characteristic of the Bohemian Massif. The following magmato-metallogenic cycles were outlined by Bernard-Pouba (1986):

- I. Pre-Variscan:
 - a) Pre-Cadomian
 - b) Cadomian
 - c) Early-Palaeozoic
- II. Variscan:
 - a) Early-Variscan
 - b) Middle-Variscan
 - c) Late-Variscan
 - d) Epi-Variscan (Saxonian)
- III. Post-Variscan

In terms of metallogenic zoning, the area studied belongs to two metallogenic belts:

A) the Saxothuringian metallogenic belt in the NW (the Krušné hory Mts. and Slavkovský les Mts.)

B) the Bohemian-Moravian metallogenic belt, divided into the Teplá-Barrandian subzone and the subzone of the western and central part of the Moldanubian unit. The latter belt forms a major part of the area studied.

Within the area, there is a clear relationship between the occurrence of epigenetic hydrothermal mineralization and the main tectonic structures, so called weak zones or sutures according to Bernard (1986). In the Krušné hory Mts., the As, Ag, Bi, Co, Ni mineralization, the U mineralization, and also partly the sulphidic and Sn-W mineralization are concentrated. The maximum concentration of metalliferous occurrences is located along the intersection of the Krušné hory fault with the Jáchymov fault, which are the two main metal-bearing structures of the region.

U-mineralization, associated with sulphide-selenide minerals, chalcopyrite, and minor As, Ag, Bi, Co, Ni mineralization is typical of western Bohemia. The Central Bohemian Suture is characterized by the presence of the early-Variscan gold-bearing mineralization, younger U mineralization, by shows of sulphide-selenide, and polymetallic mineralization, and subordinate antimonite mineralization. The Přeborná district is an example of enrichment in U, Cu, Pb and Zn at the intersection of transversal faults with this suture.

In places, the role of the supposed Střebro fault in controlling the sulphide mineralization and, in addition, barite and quartz veins, is apparent.

E.3.5. Conclusions

Mutual relationships of individual types of mineralization have been investigated, especially in districts of mining activity during the last decades. Several stages of mineralization have been recognized in many deposits. A succession

of gold-bearing, polymetallic and uranium-bearing mineralization has been established in the region of the Central Bohemian Pluton. A succession of older polymetallic, uranium-bearing, five-element and younger polymetallic formations has been determined in the Saxothuringian metallogenic province. Barite- and fluorite-barite mineralization forms the latest stages of mineralization in this province.

Selenide-bearing parageneses are always associated with uranium-bearing assemblages and represent the final stage of this type of mineralization. Individual stages of mineralization repeatedly enriched the multiply reactivated structures through which metalliferous fluids and brines were channelled.

The role of granitoids in the mineralization process is of two types: a) granitoids act as the direct source of metals and fluids, b) granitoids served as energy and fluid sources for the redistribution of elements from parent rocks, or of pre-existing metalliferous accumulations.

E.4. Sr AND Nd ISOTOPIC COMPOSITION OF YOUNG BASALTIC ROCKS IN BOHEMIA AND MORAVIA

K. VOKURKA, J. BENDL

Bohemian and Moravian Cenozoic basaltic rocks belong to the Central European Volcanic Province (CEVP) which forms a ca 750 km long volcanic belt spanning from Eifel in the west, through Germany, Bohemia, and Poland to Moravia. The easternmost occurrences of the basaltic rocks are located in Moravia. Volcanic rocks with the lowest, i.e., Quaternary age, occur in Eifel, western Bohemia and northern Moravia (Lippolt, 1982).

Radiogenic isotopic systems contained in minerals of peridotite rocks and brought to the surface by primitive melts derived from the Earth's mantle may potentially provide important constraints on the composition and history of the underlying lithosphere and asthenosphere.

Sr, Nd and Pb isotopic data from the western part of the Central European Volcanic Province were presented by Wörner et al. (1986). Sr and Nd isotopes in mafic basaltic rocks from a limited area within Lower Silesia (DSB) were studied by Alibert et al. (1987). The isotopic composition of Sr, Nd and Pb were interpreted in terms of the genetic models by Blusztajn and Hart (1989). A large amount of isotopic data from the CEVP were summarized in the work by Wilson and Downes (1991). An important part of the CEVP is formed by the Bohemian Massif, but the regional systematics of the Sr and Nd isotopes in the Bohemian Massif have not been assessed yet. This contribution presents new Sr and Nd determinations on the Bohemian and Moravian basaltic rocks (BB and MB respectively) that are used for interpretations concerning the character of the source reservoirs of the basaltic magmas.



177. Localization of samples of Cenozoic basalts from Bohemia and Moravia analysed for $^{87}\text{Sr}/^{86}\text{Sr}$. Main occurrences of Tertiary volcanic rocks and also the location Silurian basalt from the Barrandian (no. 40) are shown. Numbers of samples correspond to those in Tab. 42. Samples 1 to 7 are Tertiary basalts from the Kozákov-Semily lava flow in NE Bohemia, 1 to 31 are Tertiary basalts from Bohemia, 32 to 39 are Tertiary basalts from northern Moravia.

E.4.1. Geological setting

The Bohemian basaltic rocks occur mainly in connection with the Ohře Rift structure. Concerning the estimated volume of the Cenozoic volcanic products, the most important are Doubovské hory and České středohoří (Fig. 177), with a total volume of 122 and 52 km³, respectively (Shrbený 1986, Hradecký-Shrbený this volume). A less important tectonomagmatic structure appears to be the Labe (Elbe) deep fault system. Localities of the studied samples are schematically shown in Fig. 177. Alkaline nepheline basalts, nepheline basanites, nephelinites and melilitites probably correspond to uncontaminated primary magmas. This idea is supported by the comparison of the Ni and Cr contents as well as the Mg/Fe ratios of the lavas containing peridotite xenoliths and those without them (Shrbený 1986). The present contribution deals mainly with rocks of this character. The case of trachytes and phonolites is different, as they represent more differentiated volcanic types occurring in the Bohemian Massif.

Occurrences of Moravian basaltic rocks are scattered all over northern Moravia but their overall area is rather small. They are located in a complicated fault system known as the North Moravian tectonovolcanic belt (Fediuk and Fediuková, 1988a).

E.4.2. Experimental methods

Fresh blocks of basaltic rocks with a minimum weight of 10 kg were crushed and homogenized into fine powders. Sr was isolated in quartz columns filled by cation exchange BioRad resin. The $^{143}\text{Nd}/^{144}\text{Nd}$ ratios were determined at the Czech Geological Survey. The bulk REE fraction was isolated in quartz columns filled by biobeads, previously saturated by di-(2-ethylhexyl) orthophosphoric acid (HDEHP). Sr and Nd analyses were performed on a Finnigan MAT 262 thermal ionisation mass spectrometer with a Re double filament assembly. The $^{87}\text{Sr}/^{86}\text{Sr}$ ratio was corrected for isotopic fractionation using $^{86}\text{Sr}/^{88}\text{Sr} = 0.1194$ and the $^{143}\text{Nd}/^{144}\text{Nd}$ ratio using $^{146}\text{Nd}/^{144}\text{Nd} = 0.7219$.

E.4.3. Results

Isotopic ratios of the analysed alkaline basaltic rocks from Bohemia and Moravia are summarized in Tab. 42. For the BB, the $^{87}\text{Sr}/^{86}\text{Sr}$ ratios fall into a range of 0.70313 to 0.70364. The total average of all Cenozoic basaltic rocks from Bohemia, presented in Tab. 42 (nos. 1–31), is 0.7035. No correlation of the Sr isotopic ratio with the rock type or geographic location was observed in the group of Bohemian basaltic rocks, despite the fact that some of the localities are as far as 200 km apart. The $^{87}\text{Sr}/^{86}\text{Sr}$ ratios of the

Table 42. Sr isotopic compositions and contents of some elements in Tertiary and Quaternary basaltic rocks from Bohemia and northern Moravia

No.	Locality	Rock	Age (Ma)	⁸⁷ Sr/ ⁸⁶ Sr	2S*	Na ₂ O (wt. %)	K ₂ O (wt. %)	Sr (ppm)	Rb (ppm)	Nb (ppm)	Ni (ppm)	Cr (ppm)	Note
1	Smrč	NB	3-7	0.70313	4	2.88	1.26	749	35.1	89	506	527	1, 2, 7
2	Proseč	NB	3-7	0.70345	5	3.03	1.30	853	43	90	373	439	1, 2
3	Kozákov	AB-AOB	3-7	0.70341	10	2.93	0.54	842	49	91	442	492	1, 2
4	Podmoklice	AOB	3-7	0.70353	2	3.02	1.27	734	24	68	263	324	1, 2
5	Komárov	AOB	3-7	0.70346	10	2.70	0.75	879	54	90	413	461	1, 2
6	Slap	NB	3.9-4.2	0.70348	2	3.00	1.31	795	30	88	466	498	1, 2
7	Pelechov	NB	3-7	0.70349	4	2.98	1.39	838	29	92	426	529	1, 2
8	Bukovec	ON	Tertiary	0.70343	5	3.45	1.3	749.2	50.4	103	135	182	1, 2, 7
9	Dobkovičky	ON	Miocene	0.70346	10	3.27	0.68	1004	26	61	234	404	3
10	Děvín	MM	77	0.70327	7	2.17	1.41	1389	26	155	417	701	4
11	Chrastenský vrch	POL	62	0.70353	15	2.85	1.45	1267	25	169	355	637	4
12	Říp-JZ	ON	Tertiary	0.70366	5	4.79	2.33	1679	18	213	24	37	
13	Studénka	AOBR	Cenozoic	0.70330	9	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	
14	Horní Paseky (Aš)	MON	Cenozoic	0.70347	12	2.32	0.86	906	28	132	221	415	5
15	Vlčí Hora near Krásná Lípa	AOBR	Tertiary	0.70344	7	2.97	1.15	1067	46.8	124	67	152	7
16	Partyzánský vrch	AOB	Tertiary	0.70347	3	3.31	1.28	765	20	92	169	377	
17	Říp-S	ON	Tertiary	0.70364	4	4.85	2.19	1438	27	206	38	46	
18	Vlčí Hora near Černošín	ON	Cenozoic	0.70355	5	3.02	1.49	823	42	81	123	333	5
19	Plešný vrch near Rumburk	OI	Tertiary	0.70335	4	n.d.	n.d.	641.4	33.6	85	491	677	7
20	Komorní hůrka near Cheb	MON	0.26	0.70343	3	3.75	2.04	879	46	133	218	382	6
21	Špičák near Česká Lípa	ON	Tertiary	0.70337	3	2.65	1.56	1132	29	99	254	381	3
22	Blatná near Libá	AOBR	Cenozoic	0.70335	2	3.46	0.85	1130	35.6	108	156	215	5, 7
23	Slapaný near Cheb	NB	Cenozoic	0.70346	3	2.98	1.20	664.7	24.9	57	318	463	5, 7
24	Vesec near Mimoň	POL	65	0.70353	4	0.91	1.15	1711	28	171	283	503	2, 4
25	Malá Čertova zeď	MON	65	0.70366	2	4.72	1.55	882	27	100	460	977	2, 4
26	Vinařická hora	ON	Tertiary	0.70366	5	5.54	0.78	1485	50	164	49	28	
27	Libochovany near Lovosice	ON	Tertiary	0.70324	2	3.14	0.75	883	32	78	99	162	3
28	Velká Čertova zeď	MON	65	0.70352	3	4.10	1.41	800	28	90	453	856	2, 4
29	Luhov near Mimoň	POL	Tertiary	0.70346	2	2.60	1.60	1537	30	174	373	528	1, 3
30	Útěchovický Špičák	picritic nephelinite	9	0.70344	4	1.9	0.79	789	14	49	685	777	8, 9
31	Svojkov	MM	65	0.70335	4	1.57	1.65	2142	38	164	299	461	8, 9
32	Venušina sopka	NB	1.94	0.70321	6	3.69	2.01	836	32	68	260	373	6, 1, 0
33	Malý Roudný	NB	Cenozoic	0.70325	3	4.24	1.13	986	24	74	239	333	1, 0
34	Volárna	NB	Pleistocene	0.70325	9	3.28	1.34	781	26	61	211	344	1, 0, 6
35	Hůrka near Štěplovec	NB	Cenozoic	0.70324	4	n.d.	n.d.	1143	15	115	206	283	
36	Zálesí near Javorník	ON	Cenozoic	0.70325	9	3.54	1.41	1136	39	101	268	345	1, 0
37	Kamenná hora near Otice	MON	20	0.70335	5	3.22	1.32	872	15	95	326	545	2, 1, 0
38	Velký Roudný	NB	1.5	0.70323	3	4.18	0.97	1052	30	85	201	234	6, 1, 0
39	Uhlířský vrch	NB	2.4	0.70333	3	3.81	1.39	958	41	83	212	289	6, 1, 0
40	Sv. Jan - Barrandian	AOB	420	0.70312	3	2.77	1.30	765	15.1	31	163	196	7, 1, 1, 1, 2

Rock type symbols: AOB - alkali olivine basalt, NB - nepheline basanite, ON - olivine nephelinite, AB - analcime basanite, MM - micro-melilitolite, MON - melilite-olivine nephelinite, POL - polzenite, AOBR - alkali olivine basaltic rock, OBR - olivine basaltoid, OI - basalt - olivine basalt

2S* error corresponding to last two digits in isotopic ratio

Notes: 1 - K₂O, Na₂O, and trace elements from Shrbený (1986), 2 - ages compiled by Shrbený-Vokurka (1985), 3 - K₂O and Na₂O from unpublished data, 4 - chemical data from Ulrych et al. (1990), 5 - chemical data and petrography from Shrbený (1979), 6 - ages from Šibrava-Havlíček (1980), 7 - Rb and Sr determined by isotopic dilution, 8 - ages from Ulrych et al. (1990), 9 - chemical data from Shrbený (1989), 10 - K₂O and Na₂O, petrography, and K-Ar age from Fiala et al. (1974), 11 - Fiala et al. (1974), 12 - isotopic composition from Vokurka-Kober (1989). Where not stated otherwise, Na₂O and K₂O were determined in the course of rock wet analysis, the chemical laboratory, Czech Geological Survey, Chief chemist M. Huka.

Moravian basalts fall into the interval 0.70312–0.70335, therefore showing less scatter than Bohemian basalts.

The $^{143}\text{Nd}/^{144}\text{Nd}$ ratios of the BB fall into a range of 0.512786(4) to 0.512870(62), and these ratios of the MB fall between 0.512874 and 0.512908. Sm concentrations vary a little, between 7.98 and 11.35 ppm, whereas the Nd concentration ranges between 39.50 and 66.67 ppm.

E.4.4. Discussion

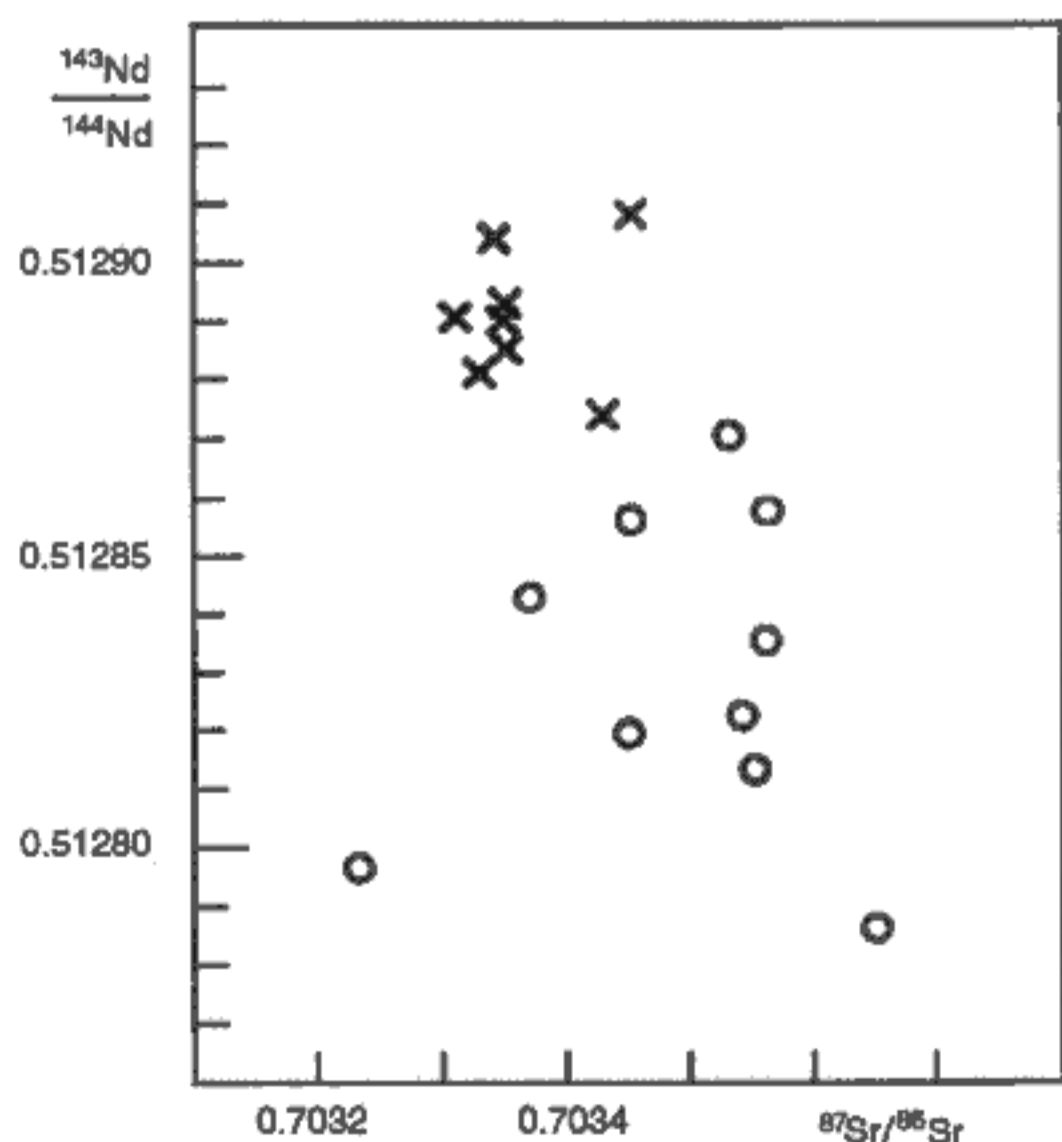
The content of the mantle peridotite xenoliths, the Mg/Fe ratios, as well as the concentration of Ni and Cr in BB and MB imply that the assimilation and fractional crystallization processes were likely to play only a limited role during the ascent of the basaltic magmas. The Nd isotopic composition of both BB and MB is greater, and Sr isotopic composition is less radiogenic when compared with the Bulk Earth. Although the differences in the isotopic composition are very limited, BB tend to fall into a field of less evolved Nd and more evolved Sr compared to MB (see Fig. 178).

Sr and Nd isotopic composition of the primitive basaltic rocks may reflect the geochemical variability of their mantle source reservoirs. Our results are in agreement with a hypothesis that the LIL enrichment of the mantle reservoirs becomes less important from the western margin of the CEVP towards the east. There is also a marked difference between the Bohemian and Moravian Cenozoic volcanic areas. The Moravian deep source reservoir appears to be

slightly depleted in terms of its LIL content when compared with the Bohemian part.

The primary magmas of the primitive mafic Cenozoic basaltic rocks from Bohemia and Moravia could have originated through the partial melting of source materials derived mainly from an asthenospheric component. The source reservoir could have had a similar composition to the HIMU component of Zindler and Hart (1986) due its high U/Pb ratio. From reservoirs of this type, some of the alkaline basaltic rocks of the oceanic islands and within plate mobile zones are thought to have been derived.

Slight differences in the $^{143}\text{Nd}/^{144}\text{Nd}$ ratios of the Bohemian, Moravian, and Lower Silesian basaltic rocks can be interpreted as a consequence of the changing character of their Upper Mantle sources. A depleted mantle component could have played an important role in the genesis of the DSB and, to a lesser extent, of the MB as well.



178. Crosses – $^{143}\text{Nd}/^{144}\text{Nd}$ versus $^{87}\text{Sr}/^{86}\text{Sr}$ plot. Moravian basalts, circles – Bohemian basalts. Nd isotope data for Moravian basalts are from Tab. 1, for Bohemian basalts from Bendl et al. (1993) and unpublished data. $^{87}\text{Sr}/^{86}\text{Sr}$ ratios are from Vokurka-Bendl (1992, Fig. 1).

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