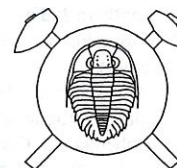


## Geochemical and isotope characteristics of representative carbonates in young alkaline volcanites from northern Bohemia



### Geochemická a izotopická charakteristika vybraných karbonátů v mladých alkalických vulkanitech ze severních Čech (Czech summary)

(6 text-figs.)

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Carbonates of young alkaline volcanics from northern Bohemia have carbon of primary magmatic character with a shift to light isotopes, in association with fractionation processes. The oxygen isotopes show equilibration with meteoric - hydrothermal water at low temperatures. Representative samples reveal the following characteristics:

- dolomites associated with melilititic lamprophyres
- polzenites of the Osečná Complex are characterized by high REE, high La/Yb ratio, and by  $\delta^{13}\text{C}$  values in the primary magmatic range (carbonatite affinity), but with  $\delta^{18}\text{O}$  values and  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios corresponding to lower-temperature processes and some crustal contamination
- calcites in phlogopitite, originated as alteration product of olivine melilitolite of the Osečná complex by late-magmatic fluids, are characterized by very low REE, low La/Yb ratio, low  $\delta^{13}\text{C}$  values and by  $^{87}\text{Sr}/^{86}\text{Sr}$  ratio corresponding to the parental rock; high  $\delta^{18}\text{O}$  values indicate lower-temperature origin
- calcites from the contact zone of polzenite dyke with sandstones of the Czech Cretaceous Basin, with geochemical characteristics typical for sedimentary origin, are characterized by low REE, low La/Yb ratio and very high  $\delta^{13}\text{C}$ ,  $\delta^{18}\text{O}$  values, and  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios
- rhodochrosite-dolomite-calcite series of post-magmatic hydrothermal origin, associated with base metal ore vein in the Roztoky Volcanic Centre of the České středohoří Mts., is characterized by moderate REE contents and Yb/La ratios, high Sr and Ba contents and by  $^{87}\text{Sr}/^{86}\text{Sr}$  ratio reflecting some crustal contamination;  $\delta^{13}\text{C}$  values indicate probably minor admixture of sedimentary C in carbon of deep-seated origin, while the O isotope data point to participation of a low  $\delta^{18}\text{O}$  fluid of meteoric derivation.

**Key words:** carbonates, volcanism, geochemistry, C, O, Sr isotopes

## Introduction

The importance of  $\text{CO}_2$  and  $\text{H}_2\text{O}$  in the generation of alkaline (ultra)mafic magmas is well-known and documented by Brey and Green (1976), Wendlandt and Eggler (1980a,b). The role of most probably mantle derived  $\text{CO}_2$  has been considered most explicitly for carbonatites (Wyllie - Tuttle 1960) and kimberlites (Wyllie 1980). The  $\text{CO}_2$  contents of these rocks are preferentially concentrated in carbonates. Bulk and trace elements chemistry, as well as C, O, Sr, Nd and Pb isotope composition of carbonatites and carbonate-bearing volcanites have been studied by many authors (Deines and Gold 1973, Le Bas 1977, Eby 1975, Mitchell and Brunnfelt 1975, Kresten 1979, Möller et al. 1980, Viladkar and Dulski 1986, Andersen 1987 a.o.). Studies on carbonatitic rocks of the Tertiary Central European Alkaline Province in Germany were published by Taylor et al. (1967), Wörner et al. (1986), Schleicher et al. (1990). Two papers based on C and O isotope studies of rocks with carbonatite affinity from the Ohře (Eger) Rift in the Bohemian Massif were published by Kopecký et al. (1987) and Pivec et al. (1991).

The aim of this paper is to present first complex data on bulk, minor and trace element chemistry and isotope composition on carbonates of supposed primary magmatic origin from alkaline rocks of the Bohemian Massif.

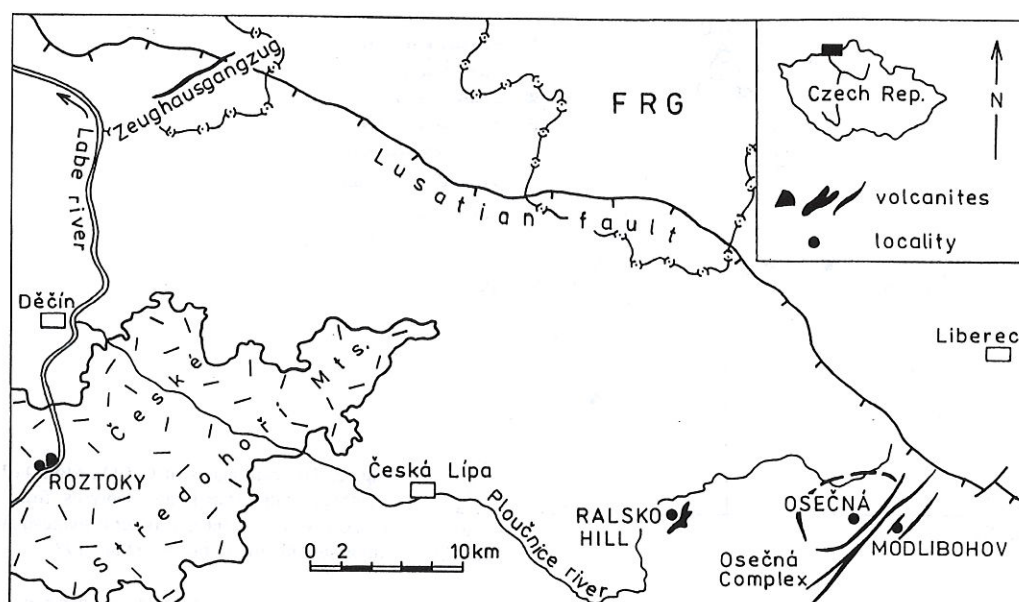
## Geological setting

Limited number of volcanics with carbonatite affinity occur in the Bohemian Massif. Most of them are related to the young (Upper Cretaceous-Quaternary) volcanism of the Ohře Rift. The most characteristic rock association are

- melilititic rock suite of the Osečná Complex (OC) in northern Bohemia (Ulrych et al. 1988, Pivec et al. 1991)
- rocks of the Roztoky Volcanic Centre (RVC), České středohoří Mts. (CS) (Ulrych et al. 1983, Ulrych 1992, Pivec et al. 1984 and in prep.) formed by a trachytic breccia filling of diatreme (caldera with hidden carbonatite intrusion of Kopecký 1977, 1987-1988), subvolcanic monzodiorite intrusion accompanied by differentiated alkaline dyke rock suites and base metal Pb-Zn-Cu(Ag,Te) ore veins (late carbonatite dykes of Kopecký op. cit.)
- monzosyenites of the Býčkovice Volcanic Centre, CS (Novák 1987, Ulrych - Novák 1989)
- basaltic breccia filling of the Linhorka Hill diatreme, CS (Mihaljevič 1988)
- carbonatite xenoliths in a basaltic diatreme of the Košťál Hill spatially associated with the Litoměřice deep fault, CS (Kopecký et al. 1970, Kopecký 1987-1988).



Fig. 1. Geological sketch of northern Bohemia with sampling sites



### Sample description

Five representative carbonate samples have been separated for chemical analysis and C, O and Sr isotope measurements from the young volcanic rocks of the Bohemian Massif (see Fig. 1).

- No. 1 Yellowish to ochreous dolomite with a calcite admixture (up to 10 vol.%) from a polzenite dyke, Ralsko Hill-Pavln (borehole, depth 26.8 m), 3 km NE of Mimoň.

Carbonate forms an irregular (up to 10 cm thick) upper margin of the polzenite dyke (thickness about 30 cm) sharply separated from the wall rock (Middle Turonian sandstone). The dyke belongs to the Ralsko Hill Volcanic Centre forming one of the accompanying centres of the OC (Pivec et al. 1986 and in press, Ulrych et al. 1988). The chemical composition of the polzenite dyke is presented by Ulrych et al. (1990). Excepting monomineral fine-grained (0.4-1 mm) marginal part of the dyke, carbonates penetrate along grain boundaries and fill small cavities in the polzenite.

- No. 2 Translucent to whitish pure calcite from a phlogopite layer of the subsurface olivine melilitolite intrusion, OC, Osečná, borehole (depth 128.1 m).

Carbonate occurs in form of irregular nests and dykelets (up to 5 cm thick) and coarse-grained aggregates (2-6 mm) together with radiated lamellar aggregates of sodian thomsonite (Ulrych et al. 1991) concentrated mostly in marginal parts of phlogopite layer. Metasomatic phlogopite layers (up to 15 cm thick) are typical for the upper marginal part of the central lopolitic olivine melilitolite intrusion (thickness 23-60 m) of the OC. Bulk and trace element analyses of both rock types are presented by Ulrych et al. (1990).

- No. 3 Ochreous calcite (with about of 25 vol.% of quartz) from the contact of the polzenite dyke associated with the OC (type locality of its modlibovite variety of Scheumann 1913), Pelousek Hill, 1 km SW of Modlibohov, abandoned excavation of polzenite dyke.

Carbonate forms the compact transitional zone (about 25 cm thick) between the polzenite dyke (about 1 m thick) and surrounding calcareous sandstones of the Middle Turonian age. The fine-grained (0.2-0.8 mm) carbonates often enclosed poikilitic quartz grains described from the surrounding sandstone. This carbonate is probably composed of two compounds: mobilized sedimentary carbonate and postmagmatic hydrothermal material.

- No. 4 Pinkish to gray pinkish rhodochrosite with an admixture of dolomite (about 20 vol.%) from the base metal ore vein in monzodiorite, Rožtoky, gallery Anna (Pivec et al. in prep.).

Carbonates (rhodochrosite-dolomite-calcite) substantially dominate as gangue minerals with minor contribution of chalcedony, quartz and barite (2-3 vol.%). The gangue carbonates form nearly 50 vol.% of the ore vein with following paragenesis of hypogene minerals: sphalerite > galena > pyrite > chalcopryrite > tetrahedrite > hessite etc. The fine-grained (<2 mm) gangue carbonates are massive with rare vugs. Rhodochrosite, representing the oldest carbonate generation of the main vein (thickness 5-60 cm) of the RVC in the CS, forms symmetrical marginal bands in the vein (Pivec et al. 1984 and in prep.). Three known base metal ore veins of the Rožtoky silver deposit are mostly located in the monzodiorite body (29.5 Ma, Kopecký 1987-1988), partly in the Upper Turonian marlstones of its mantle. The vein follows the older bostonite dyke and both are intersected by a younger trachyte dyke. This confirms the spatial and genetic association of the polymetallic mineralization with the Tertiary volcanism of the RVC (Pivec et al. 1984 and in prep.).

- No. 5 Bluish gray to white-gray calcite intergrown with dolomite (1:1) forms the central part of the same vein as rhodochrosite No. 4.

This younger carbonate reveals a similar character of aggregates as older rhodochrosite (No. 4), however, it is locally coarse-grained (up to 3 mm).



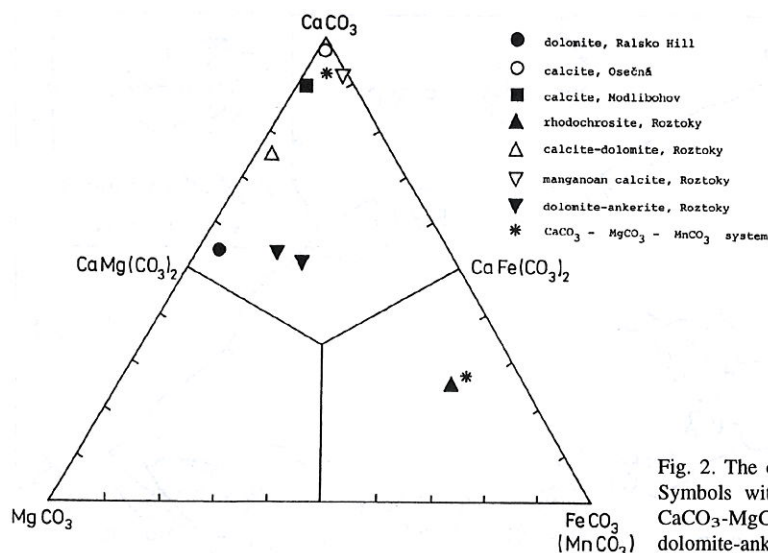


Fig. 2. The carbonates in  $\text{CaCO}_3\text{-MgCO}_3\text{-FeCO}_3$  diagram (in mol. %). Symbols with asterisk are analyses from Roztoky projected into the  $\text{CaCO}_3\text{-MgCO}_3\text{-MnCO}_3$  system: manganian calcite (Pivec et al. 1984), dolomite-ankerite (Kopecký et al. (1987)

### Analytical methods

Carbonates were analysed using wet chemical methods. By sorption from a 1.8 M-HCl on a strongly acidic cation exchanger, REE and Y were separated from all other cations and anions. After their elution from the ion exchanger by a 6 M-HCl and evaporation of the eluate and uptake in 25 ml of 2. M HCl, individual REE were determined by the ICP-OES method with a Plasma II Perkin Elmer.

For  $\delta^{13}\text{C}$  and  $\delta^{18}\text{O}$  measurements on carbonates, the conventional reaction with 100%  $\text{H}_3\text{PO}_4$  (McCrea 1980) was used. Carbonates were, based on their chemical composition, reacted at 25 °C (calcite) or 100 °C (rhodochrosite, dolomite) for 2 hours and corrections to measured  $\delta^{18}\text{O}$  values were made depending upon the chemical composition of carbonates and the temperature of reaction. Measurement were done using a Finnigan MAT 251 mass spectrometer. Reproducibility of  $\delta^{13}\text{C}$  and  $\delta^{18}\text{O}$  measurement on carbonates was  $\pm 0.1\%$ . Sr for the  $^{87}\text{Sr}/^{86}\text{Sr}$  ratio measurement was isolated on quartz columns filled with BioRad cation exchange resin AG 50W-X8 (200-400 mesh hydrogenform). Mass spectrometry was done by a Finnigan MAT 262 mass spectrometer. The double Re filament ionization technique was used. Measured  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios were normalized to the value 0.1194 for  $^{86}\text{Sr}/^{88}\text{Sr}$ .

### Mineralogical and geochemical characteristics

Bulk chemistry as well as minor and trace element contents of the carbonates are presented in Table 1. The carbonates have been plotted in the  $\text{CaCO}_3\text{-MgCO}_3\text{-FeCO}_3\text{-MnCO}_3$  diagram (Fig. 2).

The host rocks of the studied carbonates reveal the sympathetic REE pattern, however, enhanced by one order. Contents of REE in the Roztoky carbonates are slightly elevated (101-132 ppm) with lower contents in younger calcite-dolomite (No. 5), if comparing with the older rhodochrosite (No. 4). On the other hand, the lowest REE

(18-23 ppm) and the SrO (0.05-0.06 wt.%) and BaO (0.01-0.04 wt.%) contents are characteristic for the calcites (No. 2 - phlogopitite and No. 3 - contact zone of polzenite dyke). Dolomite (No. 1) from the polzenite dyke reveals the highest contents of REE (201 ppm).

For all the carbonate samples the dominance of LREE is characteristic (see Fig. 3) with the highest La/Yb ratio (273.5) in dolomite No. 1. However, Viladkar and Dulski (1986) give for carbonatites a broader range (67-674). Samples Nos. 2-5 display low ratios (30-63). The positive Eu/Eu\* anomaly is present in samples Nos. 4 and 5 (2.11-2.16) and No. 1 (1.13). This anomaly is not typical for carbonates from carbonatites (Viladkar - Pawaskar 1989).

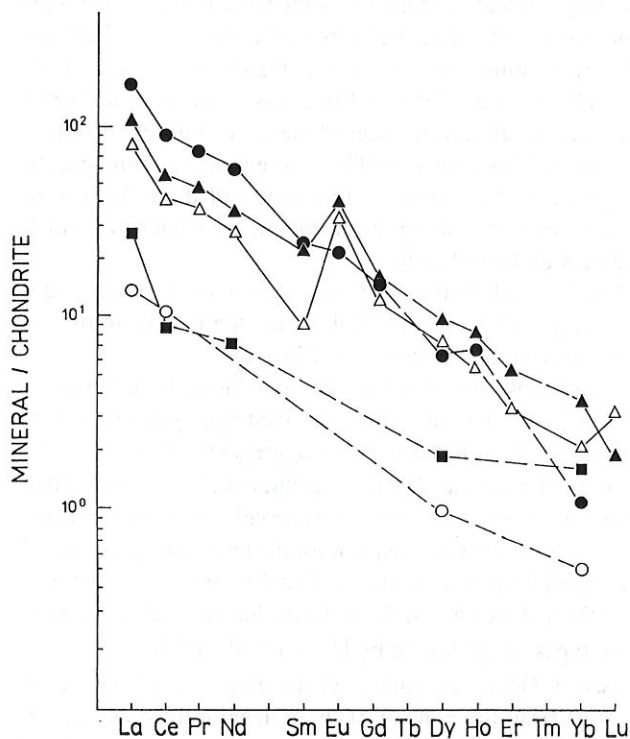


Fig. 3. Chondrite-normalized REE patterns of the carbonates. Normalization constants from Nakamura (1974). For explanations of symbols see Fig. 2

Table 1 Chemical composition and isotope data of carbonates

No.	1	2	3	4	5
MgO	18.12wt. %	0.57	3.60	5.23	9.11
CaO	32.28	55.36	51.22	11.66	43.05
SrO	0.02	0.06	0.05	0.12	0.15
BaO	0.055	0.01	0.04	0.88	0.215
MnO	0.24	0.02	0.03	39.83	2.11
FeO	2.75	0.11	0.89	1.37	2.14
CO <sub>2</sub>	47.01	44.21	43.73	41.27	43.50
insol.	(2.40)	(1.64)	(24.71)	(1.45)	(0.70)
Σ	100.475	100.34	99.56	100.36	100.275
La	54.7ppm	4.4	9.0	34.3	25.2
Ce	86.4	10.0	8.4	51.9	39.9
Pr	8.7	<1.9	<1.9	5.6	4.3
Nd	35.7	<1.4	4.4	21.0	16.7
Sm	4.8	<0.9	<0.9	4.7	3.7
Eu	1.6	<0.1	<0.1	3.0	2.4
Gd	4.4	<0.9	<0.9	4.8	3.7
Tb	<1.6	<1.6	<1.6	<1.0	<1.0
Dy	2.0	0.3	0.6	3.0	2.3
Ho	0.5	<0.4	<0.4	0.6	0.4
Er	<0.8	<0.8	<0.8	1.1	0.7
Tm	<0.2	<0.2	<0.2	<0.2	<0.2
Yb	0.2	0.1	0.3	0.7	0.4
Lu	<0.1	<0.1	<0.1	0.06	0.1
Y	8.3	1.6	4.0	16.9	10.7
ΣREE	201	18	23	132	101
La/Yb	273.5	44.0	30.0	49.0	63.0
Eu/Eu*	1.13	-	-	2.11	2.16
δ <sup>13</sup> C PDB	-5.5	-9.5	+1.0	-3.0	-5.0
δ <sup>18</sup> O SMOW	+21.7	+20.9	+24.3	+3.0	+7.0
<sup>87</sup> Sr/ <sup>86</sup> Sr	0.705494	0.704305	0.707430	0.705237	0.705104
± 2σ	14	10	15	9	10

Nos.:

- 1 - dolomite (with calcite admixture), polzenite dyke, Ralsko Hill;
  - 2 - calcite, phlogopite layer in olivine melilitolite, Osečná;
  - 3 - calcite (with admixture of quartz), polzenite, Pelousek Hill, Modlibohov;
  - 4 - rhodochrosite (with dolomite admixture), base metal ore vein, Roztoky;
  - 5 - calcite intergrown with dolomite, ditto.
- REE contents corrected for admixture; C and O isotope analyses by J. Hladíková and K. Žák

In the discrimination diagram La/Yb vs. La (Fig. 4) the carbonates plot mostly outside fields of magmatic rocks. Rhodochrosite (No. 4) from Roztoky projects only inside the carbonatite field and calcite-dolomite (No. 5) do not fall far from its boundary. In the Yb/Ca vs. Yb/La diagram the carbonates from Roztoky plot in the same marginal position, whereas dolomite (No. 1) from Ralsko Hill is in a central part of the carbonatite field (cf. Fig. 5). Other carbonates are plotting outside the depicted fields and thus probably reflect mixtures of magmatic, hydrothermal and sedimentary components.

According to their C and O isotope composition, Pivec et al. (1991) range rocks of the OC to the NSA (near surface association) of Deines and Gold (1973). The isotope composition is substantially influenced by wall rock contamination of surrounding Upper Cretaceous sediments (Hladíková et al. 1979). The δ<sup>18</sup>O values of these sedimentary rocks (-6.4 ‰ PDB) indicates a reequilibration with meteoric water. However, δ<sup>18</sup>O of the studied carbonates reveals substantially lower values in comparison with that (+26.9 to +34.2 ‰ SMOW) from volcanics of Rhön (Utzmann 1996). Variation of the isotope composition of carbon probably represents changes in the CO<sub>2</sub>-bearing fluids. Prevailing δ<sup>13</sup>C = -2 to -9 ‰ PDB is laying in the array typical for "deep-seated" carbon with a shift to isotope light carbon.

Carbonates of both the RVC rocks and the Košťál Hill

xenoliths (Kopecký et al. 1987) plot into the NSA and INA (intrusive association) fields, respectively, and only two samples fall in the PIC (primary carbonate field of Deines and Gold 1973).

The studied carbonates fit into three groups according to their δ<sup>13</sup>C and δ<sup>18</sup>O values (Fig. 6). To the first group

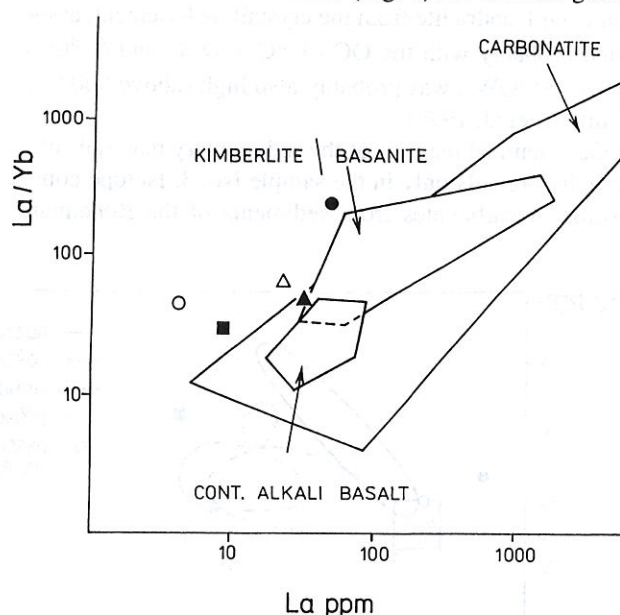


Fig. 4. The carbonates in discrimination diagram La/Yb vs. La (Andersen 1987). For explanation of symbols see Fig. 2



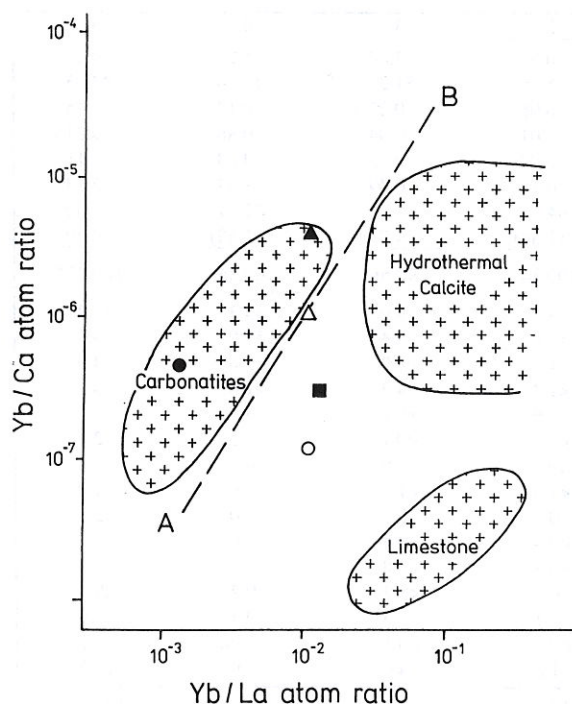


Fig. 5. The carbonates in discrimination diagram Yb/Ca vs. Yb/La (Maravich and Morteau 1980). For explanation of symbols see Fig. 2

belong samples Nos. 1 and 2 from volcanics associated with the OC. These are clustered with data given for these rocks by Pivec et al. (1991). All these  $\delta^{13}\text{C}$  data plot in the array (-2 to -9 ‰ PDB) given by Deines and Gold (1973) for deep-seated carbon. High  $\delta^{18}\text{O}$  values reflect either a contamination by carbonate mobilized from the host rock (Upper Cretaceous sandstones) and their variation could represent rather changes in the isotope composition of fluids than temperature changes (Pivec et al. 1991). Temperature of crystallization of uncontaminated calcite veinlet with andradite from the crystalline basement, associated probably with the OC ( $\delta^{13}\text{C} = -9$  ‰ and  $\delta^{18}\text{O} = +9.3$  ‰ SMOW), was probably also high (above 500 °C, Hladíková et al. 1979).

Geochemical features of the sedimentary material substantially prevails only in the sample No. 3. Isotope composition of carbonates from sediments of the Bohemian

Cretaceous Basin intruded by younger volcanic bodies could be characterized by  $\delta^{13}\text{C} = +1.6$  to  $+1.7$  ‰ and  $\delta^{18}\text{O} = -6.4$  ‰ PDB (Hladíková et al. 1979). These oxygen isotope data are probably influenced by reequilibration by meteoric water.

The third group is formed by carbonates originating from the Roztoky ore veins (Pivec et al. in prep.). C and O isotope determinations on carbonates from this locality have shown similar  $\delta^{13}\text{C}$  but lower  $\delta^{18}\text{O}$  values when compared with data of Kopecký et al. (1987), cf. Fig. 6. Some minor admixtures of carbon derived from the envelope of Upper Cretaceous marlstones is also possible. The data of Pivec et al. (in prep.) and Kopecký et al. (1987) form a linear trend in  $\delta^{13}\text{C}$ - $\delta^{18}\text{O}$  space, which, however, does not intersect the PIC field. This arrangement of data can be produced if the carbonates are deposited from hydrothermal fluid with constant C and O isotope composition under variable temperature (Pivec et al. op. cit.).

$^{87}\text{Sr}/^{86}\text{Sr}$  ratios of the carbonates, with exception of the sample No. 3, match primary magmatic character of the source material. Dolomite (No. 1) from the Ralsko Hill polzenite dyke, reveals some features of the sedimentary host rock contamination. Polzenite dykes (Vokurka and Bendl 1992, Wilson et al. 1995) are characterized by substantially lower  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios (0.7032-0.7035). The most primitive  $^{87}\text{Sr}/^{86}\text{Sr}$  ratio is typical for calcite (No. 2) from phlogopite in olivine melilitolite. This calcite probably represents a mixture of Sr originating from mantle derived material of the parental melilitolite and of the crustal contaminated post-magmatic fluids causing the phlogopitization (Ulrych et al. 1988). Wilson et al. (1995) give for the parental rock lower ratio of 0.7032, too. The Sr isotope ratio of calcite (No. 3) from the contact zone of the polzenite dyke with Turonian sandstones corresponds with an average data (0.7074) given for Turonian sediments by Burke et al. (1982).  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios of the carbonates from the Roztoky ore veins (Pivec et al., in prep.) yielded slightly higher values, in comparison with the alkali host rocks from the Roztoky Volcanic Centre (0.7036-0.7044). Sr contents of the hydrothermal fluids represent a mixture of Sr derived from the volcanic rocks and local crustal rocks.

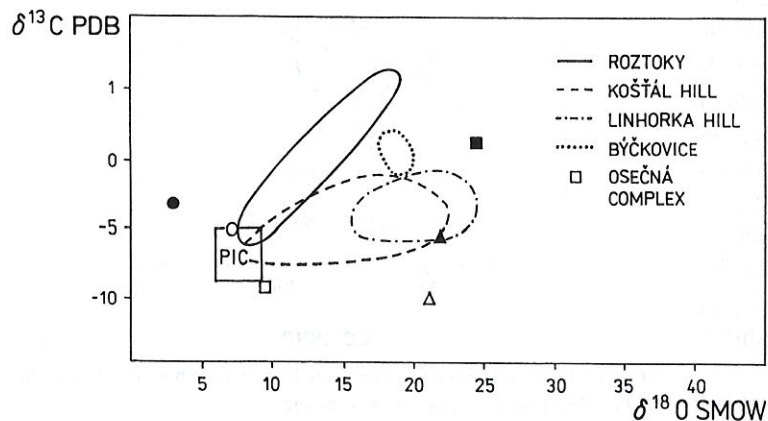


Fig. 6. Plot of  $\delta^{18}\text{O}$  vs.  $\delta^{13}\text{C}$  values of the carbonates. Roztoky and Košťál Hill data on carbonates by Kopecký et al. (1978), Linhorka Hill near Třebenice by Mihaljevič (1988), Býčkovice by Novák (1987), calcite-andradite veinlet from crystalline basement of the Osečná Complex by Hladíková et al. (1979). For explanations of symbols see Fig. 2



## Conclusions

Carbonates of late magmatic and hydrothermal origin, genetically associated with young volcanism, have been studied in the melilititic rock suite of the Osečná Complex and in the base metal ore veins associated with the Roztoky Volcanic Centre. According to crystal chemistry and isotope compositions the following characteristics could be derived:

- dolomite in polzenite dyke from Ralsko Hill displays a narrow affinity with a primary late magmatic hydrothermal carbonate of carbonatite character with high content of REE (201 ppm) and high La/Yb ratio (273.5) in the; Yb/La vs. Yb/Ca discrimination diagram it plots inside the carbonatite field, primary magmatic type ( $\delta^{13}\text{C} = -5.5\text{‰}$ ), however,  $\delta^{18}\text{O}$  (+21.7 ‰ SMOW) and  $^{87}\text{Sr}/^{86}\text{Sr}$  (0.7055) reveal some crustal contamination
- calcite of phlogopitite in olivine melilitolite from the OC represents most probably decomposition product of primary minerals (mostly melilite) of the parental rock affected by metasomatic fluids causing phlogopitization  $\pm$  garnetization. Very low content of REE (10 ppm), low La/Yb ratio (44), higher  $\delta^{13}\text{C}$  (-9.5 ‰) and  $\delta^{18}\text{O}$  (+20.9 ‰ SMOW), and the lowest  $^{87}\text{Sr}/^{86}\text{Sr}$  (0.7043) ratio correspond to a minor contaminated metasomatic mineral association of the parental olivine melilitolite ( $^{87}\text{Sr}/^{86}\text{Sr} = 0.7032$ )
- calcite from the contact zone of polzenite dyke with sandstones (Pelousek Hill) is mostly of sedimentary and mobilized character with traces of a magmatic source - low REE (23 ppm), and low La/Yb ratio (30), very high  $\delta^{13}\text{C}$  (+1.0 ‰),  $\delta^{18}\text{O}$  (+24.3 ‰ SMOW), and  $^{87}\text{Sr}/^{86}\text{Sr}$  (0.7074) ratios are most characteristic
- rhodochrosite and calcite-dolomite from base metal ore veins associated with monzosyenite of the RVC in the CS reveals characteristics of the post-magmatic hydrothermal products deposited from a meteoric-hydrothermal convection system. Volcanism acted here as a heat source for the movement of pore water from local sediments (cf. Pivec et al. in prep.). High incompatible element contents: REE (101-132 ppm), BaO (0.12-0.15 wt.%), SrO (0.215-0.88 wt.%), high La/Yb ratios (49-63) and low  $\delta^{13}\text{C}$  (-3.0 to -5.0 ‰) indicate the source joint with the alkali magma activity and deep-seated character of  $\text{CO}_2$ . However, the  $\delta^{18}\text{O}$  (+3.0 to +7.0 ‰ SMOW) and relatively low  $^{87}\text{Sr}/^{86}\text{Sr}$  (0.7051-0.7052) ratios reflect the dominance of heated meteoric water and limited crustal material contamination.

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## Geochemická a izotopová charakteristika vybraných karbonátů v mladých alkalických vulkanitech ze severních Čech

Karbonáty mladých alkalických vulkanitů ze severních Čech mají uhlík primárně magmatického charakteru s posunem, v souvislosti s frakcionačními procesy, k lehčím izotopům. Izotopy kyslíku vykazují ekvilibraci s meteorickými i hydrotermálními vodami. Reprezentační vzorky vykazují následující charakteristiky:

- dolomity spjaté s žilami melilitických lamprofytrů - polzenitů osečenského komplexu mají vysoké zastoupení TR,  $\delta^{18}O$  i poměry La/Yb v rozpětí primárně magmatických (karbonatitových) hodnot, avšak  $\delta^{13}C$  a  $^{87}Sr/^{86}Sr$  poměry odpovídají nízkoteplotním procesům a jisté korové kontaminaci
- kalcity ve flogopitech, vznikajících jako alterační produkt olivinitického melilitolitu osečenského komplexu vlivem pozdně magmatických fluid; vykazují velmi nízké zastoupení TR, nízké poměry La/Yb,  $\delta^{13}C$  i  $^{87}Sr/^{86}Sr$  odpovídající matečné hornině; vysoké hodnoty  $\delta^{18}O$  indikují nízkoteplotní vznik
- kalcity pocházející z kontaktní zóny polzenitové žíly s pískovci české křídové pánve s geochemickými charakteristikami typickými pro sedimentární původ mají nízké zastoupení TR, La/Yb a velice vysoké hodnoty  $\delta^{13}C$  a  $\delta^{18}O$  ‰ i poměru  $^{87}Sr/^{86}Sr$
- řada hydrotermálních karbonátů rhodochrozit-dolomit-kalcit, spjatá s polymetalickými rudními žilami roztokového vulkanického centra v Českém středohoří, vykazuje střední obsahy TR a Yb/La, vysoké zastoupení Sr a Ba i poměry  $^{87}Sr/^{86}Sr$  odrážející jistou korovou kontaminaci; hodnoty  $\delta^{13}C$  indikují patrně slabou příměs sedimentárního C v uhlíku hlubinného původu, zatímco izotopická data O ukazují na přítomnost fluid meteorického původu s nízkým  $\delta^{18}O$ .