Age Relations and Geochemical Constraints of Cenozoic Alkaline Volcanic Series in W Bohemia: A Review

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ABSTRACT: The following Cenozoic alkaline volcanic rock series were recognized in W Bohemia:

1. *Early Oligocene–Early Miocene (31–20 Ma) volcanics of the Ohře Rift (OR) in (i) the Doupovské hory Mts.: ol. nephelinite – leucite/analcime basanite to tephrite – (phonolite) (31–26 Ma); (ii) the western Ohře Graben and in the adjacent Krušné hory and Smrčiny/Fichtelgebirge Mts.: melilite-bearing ol. nephelinite – (± ol.) nephelinite – tephrite (24–20/16/ Ma); (iii) the westernmost continuation of the rift as far as to the Franconian Line: ol. nephelinite – basanite (/29/26–20 Ma – Lüttig 1988).*
2. *Middle to Late Miocene (16.5–8.3 Ma) volcanics (not dated yet and poorly known in W Bohemia) synchronous with the graben formation dated by its pre-Middle Miocene? (> 11.7 Ma) up to the Late Pliocene sedimentary fill associated with the NE flank of the Cheb-Domažlice Graben (CDG) developed in two series (i) weakly alkaline: basanite – trachybasalt – (basaltic) trachyandesite – trachyte – (rhyolite?) (15.9–11.4/6.5/ Ma), and (ii) strongly alkaline: (melilite-bearing) ol. nephelinite – tephrite (/17.0/16.5–8.3 Ma). These volcanics coincide with the rare intrusions in the České středohoří Mts. (13–9 Ma), Germany (11–6 Ma) and the tectonic phase that caused a change from calc-alkaline to alkaline volcanism in the Carpathians.*
3. *Pleistocene (0.43–0.11 Ma) volcanics of the OR and the CDG junction (area of the Cheb Basin) with melilite-bearing ol. nephelinite – ol. nephelinite series.*

Parental magmas of all these rocks series are inferred to have originated by low-degree melting of metasomatized sub-rift mantle initiated at >31 Ma. The mantle source was probably lithospheric mantle metasomatized by plume-like material. Volcanic activity pulsated afterwards from the Early Oligocene to the Pleistocene. Mafic rocks of the W Bohemian area give evidence of a limited degree (Mg# 51–78) of primary magma fractionation. Fractional crystallization (crustal assimilation was insignificant) only played a substantial role in the formation of the weakly alkaline series (Mg# 8–69) of the CDG and very rare phonolites of the Doupovské hory Mts. (Mg# 18–20). Gas emanations rich in CO_2 containing mantle-derived He are spatially and genetically associated with Pleistocene volcanoes that are characterized by primitive magmas and products of explosive character.

KEY WORDS: Cenozoic, Ohře (Eger) Rift, Cheb-Domažlice Graben, W Bohemia, K-Ar ages, geochemistry.

Introduction

The western Ohře (Eger) Rift (OR) area (W Bohemia) is possibly, besides the French Massif Central and the Eifel area, Germany the third important area in Central and Western Europe with active magmatic/fluid processes in the upper mantle and in the lithosphere. Arguments coming from gas geochemistry and isotope research (Weinlich et al. 1999 and citations therein) and from geophysical research support the presence of mantle plumes beneath the Massif Central (Granet et al. 1995), the Eifel area (Ritter et al. 2001) and possibly W Bohemia (Geissler et al. subm.). A proposed model is that of a series of small-scale mantle plumes upwelling from a thermally and geochemically anomalous layer (superplume?) at ca. 400 km depth beneath the European lithosphere (Granet et al. 1995). The "hot finger" with its base elongated to the OR corresponds to the volcanic field. Goes et al. (1999) interpreted the low-speed structures at depths of 660–2000 km as an upwelling in the upper mantle beneath Central Europe, which is a feeder for individual small mantle plumes. Wilson and Patterson (2001) supposed that the primitive-magma spectrum of the whole Cenozoic European Volcanic Province represents variable degrees of partial melting of a uniform HIMU-like reservoir at the base of the upper mantle, the European asthenospheric reservoir, which provides a common source component to the magmatism throughout Europe. In order to understand this active process, it is necessary to refer back to the magmatic activity in the Cenozoic. If the results of Weinlich et al. (1999) and Geissler et al. (subm.) are correct, W Bohemia is a new reference area in Central Europe for presently active mantle-crust interaction. Understanding this presently active process, we have the possibility to re-consider the magmatic activity in the whole Cenozoic period (cf. Griffiths and Campbell 1990).

The W part of the Bohemian Massif (BM) is characterized by two prominent neotectonic structures: the NE–SW-trending OR and the NNW–SSE-trending Cheb-Domažlice Graben (CDG), see Fig. 1. The OR belongs to the Cenozoic major rift system of Europe and displays intense intraplate alkaline volcanism characteristic of the Cenozoic Central European Volcanic Province. The CDG belongs probably to the N–S Naab-Pritzwalk lineament marked by CO_2 plumes and the Ultramafite-Carbonatite Complex of Delitzsch (Kämpf et al. 1991, 1992).

This work, presenting a complex concise view on Cenozoic volcanic series of the W Bohemian region, benefits mostly from analytical data presented in Wilson et al. (1994) and Ulrych et al. (1999, 2000, 2002, 2003, in print).

Geological setting

The territory of W Bohemia is assumed to represent one of the most mobile zones of the BM being at the supposed intersection/junction of two prominent above mentioned Cenozoic structures. Recent earthquake swarms underline the mobility of the region (Špičák et al. 1999 and citation therein). The sub-Recent volcanism (see below), dry gas vents (mofettes) and sparkling mineral water with CO_2, He, N_2 (?) from a deep-seated magmatic source input to an aquifer of meteoric ground water (Weinlich et al. 1999, Pačes et al. 2001) contribute to the active manifestations in the region. Gas escape centres mark the intersection of the two main structures (Weinlich et al. 1999).

Asthenospheric upwelling by plume activity with concomitant underplating by upward migrating plume melts (see Geissler et al. subm.) have contributed to the uplift and subsequent rifting in addition to reactivation of old lines (in particular the boundary between the Saxothuringicum and the Bohemicum blocks) of crustal weakness in W Bohemia by the Alpine events.

The OR is characterized by higher values of surface heat flow (~80 mWm^{-2}, Čermák et al. 1996). Surface heat flow in the OR is a combination of (i) lithosphere thinning (~80 km) beneath the OR (Babuška and Plomerová 2001), (ii) first-order K-U-Th Variscan granitoids (Förster and Förster 2000) and (iii) locally probably also Cenozoic magmatic reservoirs located at the mantle-crust boundary (Čermák et al. 1996).

The western Ohře Rift (sensu Weinlich et al. 1999) involving the Sokolov (and Cheb?) basins does not correspond to the basic concept of the OR setting. The Central Rift Fault, responsible for the production of the largest volume of volcanics in the OR (sensu Kopecký 1978), might be seen in this

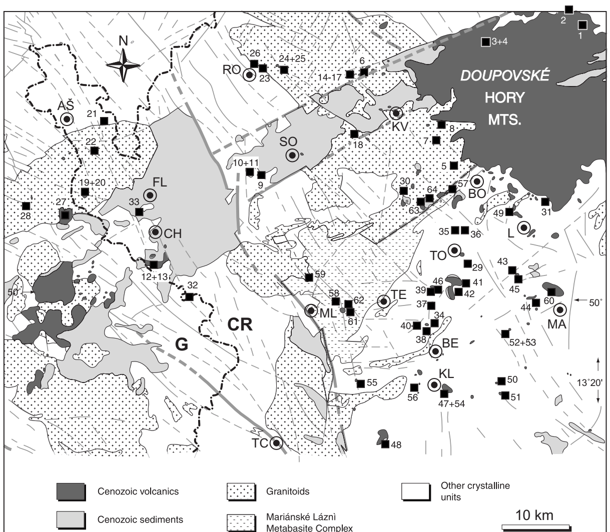

Fig. 1. Geological sketch of W Bohemia (adapted after the map of Cajz in Ulrych et al. 2002) with the Tertiary volcanics marked. Filled circles denote major towns: AŠ – Aš, FL – Františkovy Lázně, CH – Cheb, RO – Rotava, SO – Sokolov, KV – Karlovy Vary, BO – Bochov, TO – Toužim, TE – Teplá, ML – Mariánské Lázně, TC – Tachov, BE – Bezdružice, KL – Konstantinovy Lázně, MA – Manětín, ŽL – Žlutice; filled squares denotes sampling sites (Nos. 1–62, see caption for Table 1). Lines: heavy – major faults, thin – minor faults.

area as the S limit of the Sokolov Basin but does not cross the CDG. Upon the basis of distribution of gas fluxes, Weinlich et al. (1999) argued for shifting of the southern master fault of the OR (Litoměřice Deep Fault) along the Mariánské Lázně and subparallel Horní Slavkov faults to the NW.

Continuation of the Litoměřice Deep Fault (sensu Kopecký 1978) was not proved in W Bohemia. However, primitive volcanics of melilite-bearing olivine nephelinite composition (16.5 Ma), commonly associated with the Litoměřice Deep Fault in N Bohemia, have been reported from the area of Český Chloumek (Wilson et al. 1994) in near proximity to the supposed course of the Litoměřice Deep Fault Zone. The surface manifestation of the OR in the Ohře Graben is limited in the western part by the CDG, particularly by the Mariánské Lázně Fault Zone (Ulrych et al. 2000). Nevertheless, the OR structure extends as far as to the Franconian Line (Behr et al. 1992, Peterek and Schröder 1997) accompanied by occurrences of Cenozoic volcanics. Geochemical signatures and age distribution of the primitive volcanics of the whole W Bohemian (Ulrych et al. 1999) and Upper Palatinate areas (Lüttig 1998) are very similar.

The CDG represents a young asymmetric structure limited by the Mariánské Lázně Fault Zone – MLFZ. The oldest sediments of the CDG might be younger than Oligocene as they are overlain by the Late Miocene basanite flow (11.7 Ma – Wilson et al. 1994) of Vlčí hora Hill volcano near Černošín. The youngest graben sediments are of Upper Pliocene age. The deep-seated disposition of the CDG is evidenced by the geochemical data of gas emanations and mineral springs (Weinlich et al. 1999).

Different geochemical characteristics and ages were revealed by volcanics associated with the uplifted flank of the CDG in the Tepelská vrchovina Highland and Slavkovský les Mts. (Ulrych et al. 1999, 2002, 2003), and are usually classified within the CDG. Quaternary volcanism is spatially associated with the CDG and OR structures, but no major tectonic lineament controls their emplacement.

Sampling and analytical methods

Sixty-four representative rock samples were used for the geochemical and mineralogical studies (Ulrych et al. 2002, 2003). Sampling sites are presented in Fig. 1 together with short petrographic and geological characteristics of the rocks in Table 1. For more details see the above given publications.

The rock samples were analysed by wet methods by P. Povondra (Charles University) and V. Chaloupský (Acad. Sci. CR). Analyses of rock standards GM, TB, BM, and repeated analyses of samples showed errors within ±5% (1σ). Trace element abundance was determined by XRF using the automated Philips PW 1404 equipment on pressed powder pellets by J. Štrublová, Gematest. The precision of XRF determinations varies about ±5% (1δ) as checked by a series of duplicate analyses. Accuracy was tested against the rock standard USGS BCR-1. Additional trace element determinations were performed by INAA in the Gematest laboratory (analyst P. Hanžlík) and Acad. Sci. CR (analyst J. Frána). The precision (1δ) was better than ±10 % for REE, and better than ±5–10 % for other trace elements. Accuracy of the INAA analyses was checked with the use of international reference rock samples.

K-Ar isotope measurements were taken in Hungarian Acad. Sci., Debrecen. An Ar extraction and its measurement were made on the mass spectrometer by the method of isotope dilution ^{38}Ar according to the procedure described by Balogh (1985).

Age relations of the volcanic series

The new K-Ar data for the Cenozoic volcanics from W Bohemia are given in Table 2 together with the data of Wilson et al. (1994). A comparison of volcanic rock series associated with the OR (Doupovské hory Mts., Ohře Graben, Krušné hory and Smrčiny Mts.) and the CDG is presented in Fig. 2. Based on the distribution scheme of Cenozoic volcanism in the Bohemian Massif (Ulrych et al. 1999), new K-Ar data and additional geochemical data, the following alkaline volcanic series were recognized in W Bohemia:

1. **Oligocene-Miocene** (30.6–20.5/15.5/ Ma) **volcanics of the Ohře Rift** (as far as to the Mariánské Lázně Fault Zone) continuing WSW (to the Franconian Line).

1.1. **The Doupovské hory Mts.** volcanics are characterized by the unimodal (partly bimodal) series of olivine nephelinite – leucite/analcime basanite/tephrite – (phonolite) (30.6–25.8 Ma). The age of the basanite flow from Dětaň (32.6 Ma) slightly broadens the above presented span (Ulrych et al. eds. 2002). New K-Ar data reveal the presence of additional older volcanics in the NE flank area of the CDG (olivine nephelinite from Políkno – 29.5 Ma). However, younger (16.5 Ma) volcanics of primitive melilite-bearing olivine nephelinite composition also occur in the same area near Český Chloumek (Ulrych et al. 2002). A new insight in the volcanic series relations in the W Bohemian region was provided by the first data on phonolites (25.8–27.2 Ma) from the boundary of the Doupovské hory Mts. and the CDG flank areas. These data positively confirmed their affinity to the oldest volcanic series of the area represented by the Doupovské hory Mts. On the other hand, tephrite from Mokrá near Žlutice, also on the periphery of the Doupovské hory Mts., revealed an age of 20.4 Ma, characteristic of the proximal western Ohře Graben region. The Střela River valley is conventionally defined as the boundary of the volcanics of the Doupovské hory Mts. against the Tepelská vrchovina Highland.

1.2. **The western Ohře Graben** volcanics between the Doupovské hory Mts. and the Mariánské Lázně Fault Zone are characterized by the unimodal strongly alkaline suite of melilite-bearing olivine nephelinite – olivine nephelinite – tephrite (23.9–19.9/15.5/ Ma). K-Ar data on tephrites from the locality of Hory in Karlovy Vary (15.5 Ma; Wilson et al. 1994) in the OR and from Horní Rotava (14.8 Ma) in the Krušné hory Mts. indicate that the Middle Miocene volcanism in W Bohemia was not restricted to the CDG only.

1.3. **The southernmost continuation of the rift** volcanics as far as to the Franconian Line reveals primitive olivine nephelinite – basanite composition (/29/26–20 Ma; Lüttig 1998).

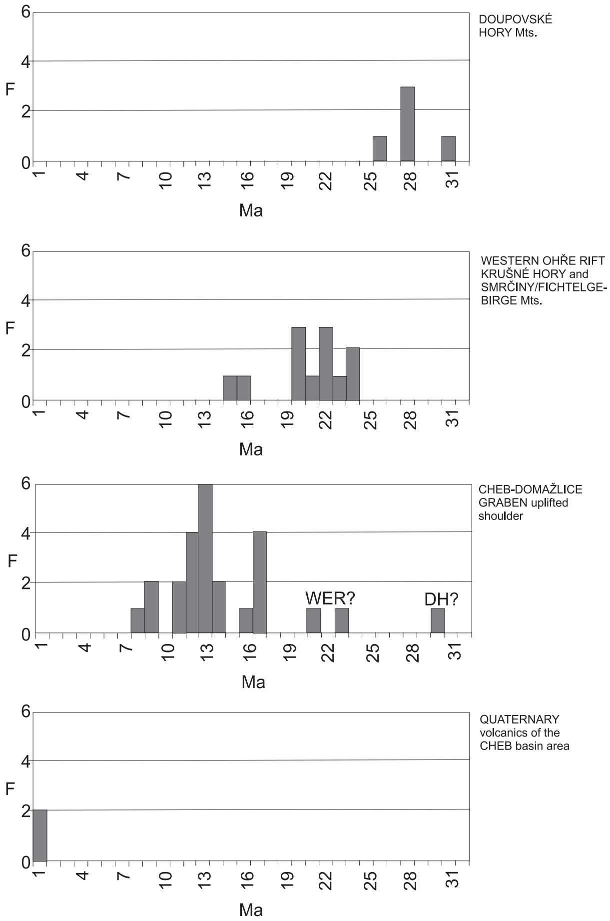

Fig. 2. K-Ar age distribution of the rock series in W Bohemia. Vertical axis – frequency of K-Ar experimental data. WER – western Ohře Rift, DH – Doupovské hory Mts.

2. **Middle Late Miocene (/17.0/16.5–8.3/6.5/ Ma) volcanics** are composed of two coexisting series in the Tepelská vrchovina Highland and the Slavkovský les Mts. at the NE flank of the Cheb-Domažlice Graben (Ulrych et al. in print 2003):

2.1. **Weakly alkaline series** (WAS) of basanite – trachybasalt – (basaltic) trachyandesite – trachyte – rhyolite (15.9–11.4/ 6.5/ Ma) and;

2.2. **Strongly alkaline series** (SAS) of (melilite-bearing) olivine nephelinite – tephrite (/17.0/16.5–8.3 Ma).

Volcanism of the NE flank of the CDG thus parallels the development of the graben structure as follows from the Late Miocene (?) relicts of its sedimentary fill in the Lažany–Vlčí hora Hill area preserved beneath the basanite flow (11.7 Ma – Wilson et al. 1994). The age-related Late Miocene intrusives (13–9 Ma) are rarely present also in the České středohoří Mts. (Cajz et al. 1999) and in many areas of the Central European Volcanic Province in Germany (11–6 Ma, Lippolt 1983). The recurrence of volcanism and a change in its chemical characteristics coincide in time with the tectonic phase (Downes 1996) that caused a fundamental change from calc-alkaline to alkaline volcanism in the Carpathians, reflecting the Late Miocene E–W compression in the Alpine Orogen linked with the entry of continental crust into the subduction zone.

Co-existing geochemically similar SAS (undersaturated) and WAS (saturated to oversaturated) are known from the Central European Volcanic Province, e.g., from the Siebengebirge (Vieten et al. 1988) and Cantal, Massif Central (Wilson et al. 1995).

3. **Quaternary volcanics (0.43–0.11? Ma)** occur at the junction of the Ohře Rift and Cheb-Domažlice Graben structures near Cheb in the Cheb Basin. This young volcanism consists of a unimodal series of melilite-bearing olivine nephelinite to olivine nephelinite forming small volcanoes of Komorní hůrka/Kammerbühl (scoria cone and lava flow – Gottsmann 1999) and explosive volcano of the Železná hůrka/Eisenbühl hills (scoria cone – Schwarzkopf and Tobschall 1997). The Pleistocene ages of their activity show a wide scatter due to different methods, precision of determination and alteration of the samples: (i) using conventional K-Ar technique, 1.8? Ma (Todt and Lippoldt 1975), 0.85 Ma (Bellon and Kopecký (1977), 1.0–0.26/5.0?/ (Šibrava and Havlíček 1980), 0.4 Ma /0.43–0.11? Ma/ (Wilson et al. 1994); (ii) using a complex of thermoluminescence, electron spin resonance and alpha-recoil track methods, 0.9–0.17 Ma (Wagner et al. 1998); and (iii) by alpha-recoil track dating, 0.3 Ma Gögen and Wagner (2000).

Geochemistry

Petrography and rock-forming mineral characteristics were presented by Shrbený (1979) and Ulrych et al. (in print). Chemical analyses of the rocks studied mostly cluster in the tephrite/basanite and foidite fields; rocks of the WAS alone plot in the trachybasalt, (basaltic) trachyandesite, trachyte, and rhyolite fields in the TAS diagram (cf. Fig. 3a, b – Le Maitre ed. 2000). Three samples plot as alkali-basalts because they contain numerous microxenoliths of granitic rocks.

Samples of Quaternary volcanics and rare samples of other Tertiary volcanic rocks reveal geochemical characteristics of primitive mantle magmas, i.e., high Mg-values, contents of compatible elements and presence of mantle xenoliths (cf. Frey et al. 1978).

The contents of incompatible elements in the rocks of all volcanic series are similar to OIB (Sun and McDonough 1989), pointing to the influence of enriched mantle in the magma source. Principal geochemical differences between the series are perceptible from the PM-normalized multielement variation diagrams (cf. Ulrych et al. in print 2002, 2003). Mafic alkali rocks of all compared series are depleted in Rb, K, Sr, Zr and enriched in Th, Nb, REE and P. On the other hand, negative spikes of Ba, Sr, P and Ti are characteristic of felsic rocks represented by phonolites of the Doupovské hory Mts. and trachytes/rhyolite of the WAS (Ulrych et al. in print 2003). The same rocks yield positive spikes of Rb, Th, K, REE and Zr. The distributions of incompatible elements presented above can be explained by differentiation processes of individual magmatic series. However, additional gains of Th, REE, Zr and other HFSE in a fluid phase cannot be excluded, particularly in highly evolved derivatives of phonolite/trachyte-rhyolite type. The Rb and K depletion in all rocks is consistent with a residual K-rich hydrous phase (amphibole, phlogopite?) in the mantle source. Th and U values correspond with statistical data for alkali rocks and testify for prevailing equilibrium relation of these elements.

Elevated Ti contents in the studied rocks and the primary mineral chemistry (Mg-rich olivine and clinopyroxene) are also typical for intra-plate volcanism with enriched mantle component. Substantially higher TiO_2 (max. TiO_2 = 5.8 wt.%), in particular in olivine-poor/-free nephelinites/melilite nephelinites of the Krušné hory Mts. region, is most characteristic.

Medium to high ΣREE contents (318–472 ppm) together with substantial LREE enrichment (La_N/Yb_N = 30 – 52) are hallmarks of the W Bohemian volcanic series (cf. Ulrych et al. in print 2002, 2003). The high values of La_N/Yb_N (32–46 and 26–39) together with low values of Gd/Gd* (0.11 and 0.15–0.16) are characteristic for phonolites and trachytes, respectively. Low to medium REE contents can be explained by titanite fractionation (Wilson et al. 1995). No expressive Eu/Eu* (0.7–1.1) anomalies were observed, with the exception of the WAS rhyolite (0.33), see Ulrych et al. (in print 2003). Chondrite-normalized REE patterns of rocks of individual series indicate very similar distribution patterns for principal mafic rocks of all series (cf. Ulrych et al. in print 2002, 2003).

Discussion and Conclusions

The Cenozoic intraplate continental alkaline volcanism in W Bohemia is genetically associated with (i) the OR and (ii) uplifted NE flank of the CDG. Volcanic activity continued intermittently with different intensity in individual parts of W Bohemia from the Early Oligocene (>31 Ma) to the Pleistocene (≈0.1? Ma).

Three series of alkaline volcanic rocks have been recognized there:

1. **Early Oligocene–Early Miocene (31–20 Ma)** volcanics of the western Ohře Rift (OR) in (i) the Doupovské hory Mts., (ii) the western Ohře Graben and in the adjacent Krušné hory and Smrčiny Mts., (iii) the westernmost continuation of the OR in the Upper Palatinate as far as to the Franconian Line. They represent near-primary to weakly differentiated melts (Mg# 51–78) coinciding with the volcanic maximum (32–19 Ma) of the Bohemian Massif (Ulrych et al. 1999). Only rarely do they show all parameters postulated by Frey et al. (1978): (i) high Mg-value (68–75), (ii) high contents (in ppm) of Cr>500, Ni>300, Co>70, Sc>30 and (iii) the presence of lherzolite xenoliths of undifferentiated upper mantle melts. Only very rare salic differentiates, in particular phonolites of the Doupovské hory Mts. (Mg# 18–20) are likely to represent products of intensive fractional crystallisation.
2. **Middle to Late Miocene (16.5–8.3 Ma)** volcanics (not recognized in W Bohemia yet and poorly known) are associated with the uplift of the CDG shoulder and are synchronous with

Area	A	A	A	A	A	A	A	A	B	B	B	B	B
Sample No.	1	2	3	4	5	6	7	8	9	10	11	12	13
	P11	P12	P13	P13a	P14	Z1	P19	P20	Z8	Z9	Z9a	Z33	P7
Rock type	TE	BA	ON	ON	ON	OL	PH	PH	ON	BA	BA	BA	OB
SiO_2 (wt.%)	41.94	41.12	37.41	38.72	38.02	38.62	57.85	58.11	37.75	43.48	41.15	43.26	44.49
TiO_2	3.40	4.18	5.55	4.75	4.78	2.49	0.21	0.32	4.36	2.22	2.70	2.22	2.29
Al_2O_3	12.97	11.55	10.92	12.44	11.81	11.96	20.84	20.50	11.06	12.46	11.56	12.42	12.51
Fe_2O_3	5.28	5.13	7.13	6.73	6.02	6.57	1.85	1.80	7.62	4.10	4.69	3.99	3.81
FeO	7.22	6.80	8.90	7.00	8.75	6.16	0.43	0.72	6.66	6.86	7.68	6.93	7.99
MnO	0.23	0.18	0.21	0.20	0.25	0.20	0.18	0.14	0.18	0.16	0.20	0.17	0.18
MgO	6.59	8.15	7.85	7.61	7.14	10.53	0.25	0.25	8.07	12.22	11.73	10.21	12.40
CaO	12.95	14.80	16.02	12.98	15.12	14.99	2.04	2.09	15.86	11.68	12.37	12.29	10.97
Na_2O	2.31	3.57	2.70	3.59	3.95	2.79	8.40	7.53	2.04	2.87	3.24	2.94	2.65
K_2O	2.41	0.62	1.21	1.75	1.15	1.05	5.73	6.62	0.86	1.38	0.81	1.45	1.21
P_2O_5	2.37	0.71	0.86	0.91	1.44	2.05	0.05	0.05	0.68	0.61	0.89	0.62	0.67
H_2O^+	1.52	2.10	0.90	1.52	1.10	1.67	1.22	1.34	2.90	1.32	2.72	1.84	0.71
H_2O^-	0.54	0.90	0.28	0.69	0.58	0.47	0.70	0.43	1.25	0.63	0.31	0.82	0.28
CO_2	0.22	0.35	0.20	1.23	0.02	0.00	0.21	0.25	0.39	0.11	0.03	0.16	0.02
Total	99.95	100.16	100.14	100.12	100.13	99.55	99.96	100.15	99.68	100.10	100.08	99.32	100.18
Rb (ppm)	77	59	27	36	56	24	161	220	40	37	14	42	32
Cs	1.66	1.52	0.49	0.61	0.59	0.25	2.00	1.60	1.50	0.72	5.30	3.10	2.90
Sr	1598	786	708	512	1240	1159	615	230	581	532	686	568	701
Ba	1002	633	641	580	777	603	1321	322	733	637	535	678	498
Ga	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	20	27	n.a.	n.a.	n.a.	n.a.	n.a.
As	2.3	1.7	1.9	1.7	1.3	0.8	2.0	2.2	7.2	1.9	1.7	8.2	8.9
Sc	18.0	38.0	35.0	37.0	26.0	28.8	0.5	0.5	58.4	28.5	28.7	28.1	23.0
Y	26	19	26	23	39	23	17	21	16	17	18	17	20
La	118.2	69.8	100.0	89.2	138.1	121.7	134.3	138.6	84.4	50.0	67.6	51.1	57.7
Ce	169.0	144.1	205.2	183.7	210.5	211.2	148.7	154.5	148.0	82.8	118.5	83.5	91.9
Nd	74.3	76.6	85.4	80.0	86.3	100.6	31.0	35.0	74.0	46.3	64.3	42.1	44.8
Sm	14.0	10.2	14.9	13.6	13.2	15.3	3.5	3.5	11.5	7.8	10.3	7.8	8.0
Eu	3.69	2.93	4.22	4.00	3.42	4.66	0.70	0.88	3.31	2.47	3.27	2.50	2.55
Gd	11.7	11.2	12.5	12.0	9.8	14.4	2.9	3.0	10.3	6.9	9.7	7.1	7.2
Tb	1.25	1.20	1.45	1.40	1.14	1.43	0.34	0.32	0.98	0.87	1.03	0.85	0.88
Yb	2.20	1.65	1.98	1.70	2.00	2.37	3.00	2.15	1.62	1.63	2.05	1.59	1.60
Lu	0.39	0.37	0.47	0.40	0.36	0.34	0.52	0.37	0.25	0.27	0.28	0.21	0.19
Th	22.0	14.2	13.5	12.6	17.2	9.6	31.7	20.0	8.3	6.6	5.9	6.6	10.1
U	3.5	2.1	2.0	1.9	2.2	2.4	6.8	3.1	2.6	1.6	1.5	1.9	1.9
Zr	301	285	335	315	412	203	478	750	216	137	235	138	200
Hf	8.4	7.1	14.2	12.2	18.0	6.0	13.6	18.4	7.8	4.3	7.4	4.3	6.4
V	358	399	436	497	437	169	16	12	302	158	180	162	178
Nb	121	92	129	112	130	77	100	113	71	47	67	48	66
Ta	4.3	4.1	5.8	5.1	5.7	5.7	4.4	5.4	5.7	6.3	6.2	3.4	4.1
Cr	75	88	31	57	41	168	4	3	109	392	326	388	330
Co	43	49	51	52	47	48	1	1	50	55	56	57	71
Ni	41	55	19	39	38	113	4	4	40	282	153	282	66
Cu	158	144	280	127	99	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	298
Zn	118	112	122	142	131	120	72	113	93	105	116	102	105
K/Rb	259.84	87.24	372.05	403.57	170.49	363.21	295.47	249.81	178.49	309.64	480.33	286.62	313.92
Rb/Sr	0.05	0.08	0.04	0.07	0.05	0.02	0.26	0.96	0.07	0.07	0.02	0.07	0.05
Th/U	6.29	6.76	6.75	6.63	7.82	4.00	4.66	6.45	3.19	4.13	3.93	3.47	5.32
Zr/Hf	35.83	40.14	23.59	25.82	22.89	33.83	35.15	40.76	27.69	31.86	31.76	32.09	31.25
Nb/Ta	28.14	22.44	22.24	21.96	22.81	13.51	22.73	20.93	12.46	7.46	10.81	14.12	16.10
ΣREE (ppm)	394.73	318.05	426.12	386.00	464.82	472	324.96	338.32	334.36	199.04	277.03	196.75	214.79
La_N/Yb_N	38.54	30.34	36.23	37.64	49.53	36.83	32.11	46.24	37.37	22.00	23.65	23.05	25.87
Eu/Eu*	0.85	0.83	0.91	0.93	0.88	0.94	0.65	0.80	0.91	1.00	0.98	1.00	1.00
Gd/Gd*	0.39	0.44	0.35	0.38	0.27	0.39	0.11	0.11	0.40	0.46	0.46	0.47	0.44
#Mg	53.58	59.95	51.80	55.00	51.38	64.65	20.02	18.30	55.59	70.84	67.39	67.05	69.49
Age (Ma)			27.9*		27.3*	30.6	27.2	25.8		23.9		21.5*	21.5*

Tab. 1. Chemical analyses of volcanic rocks from W Bohemia.

Area	B	B	B	B	B	C	C	C	C	C	C	C	C
Sample No.	14	15	16	17	18	19	20	21	22	23	24	25	26
	Z2	Z2a	Z3	Z3a	P10	Z10	P9	Z6	Z7	Z4	Z5	Z5a	Z18
Rock type	BA	BA	ON	BA	TE	OB	ON	BA	MON	ON	BA	BA	BA
SiO_2 (wt.%)	43.07	43.56	39.83	43.42	43.41	44.90	39.97	42.35	37.38	38.34	41.06	40.48	42.46
TiO_2	2.23	2.32	2.66	2.24	2.49	2.45	2.65	1.74	2.60	1.85	2.70	2.73	2.64
Al_2O_3	12.21	11.97	9.72	12.25	12.88	13.61	12.12	10.73	11.71	8.74	11.95	11.66	12.90
Fe_2O_3	5.28	2.86	4.10	3.65	3.19	4.19	4.11	3.90	5.63	4.94	5.95	5.85	3.92
FeO	5.91	7.65	8.51	7.10	8.23	6.54	8.66	6.97	6.94	6.43	6.62	6.93	8.33
MnO	0.16	0.18	0.19	0.18	0.15	0.16	0.23	0.18	0.22	0.18	0.19	0.19	0.20
MgO	10.80	12.48	17.15	11.23	10.90	7.49	10.69	12.98	11.84	18.57	11.63	12.29	10.12
CaO	11.50	11.02	10.64	11.41	11.78	12.30	14.88	13.15	15.18	13.84	11.42	11.49	11.57
Na_2O	3.15	3.05	2.43	2.91	4.29	4.19	3.22	3.86	2.54	2.44	3.56	3.43	3.52
K_2O	2.10	1.52	0.88	1.55	0.54	1.44	0.74	1.06	0.77	0.71	0.66	1.09	1.35
P_2O_5	1.31	0.59	1.35	0.60	0.82	1.02	1.58	1.08	1.12	1.19	0.86	0.92	0.85
H_2O^+	1.25	1.68	1.54	2.02	0.88	0.64	0.82	0.69	2.40	1.67	2.36	1.95	1.45
H_2O^-	0.56	0.40	0.59	0.60	0.37	0.37	0.28	0.54	0.70	0.55	0.64	0.53	0.60
CO_2	n.a.	0.14	n.a.	0.90	0.10	0.21	0.12	0.27	0.49	n.a.	n.a.	n.a.	0.18
Total	99.53	99.42	99.59	100.06	100.03	99.51	100.07	99.50	99.52	99.45	99.60	99.54	100.09
Rb (ppm)	44	33	24	36	31	34	39	48	30	32	15	16	33
Cs	1.40	2.50	0.47	3.20	0.68	0.99	0.55	3.10	0.70	1.20	5.50	5.50	0.76
Sr	749	562	604	593	833	935	1324	1091	1000	1007	724	692	690
Ba	859	645	422	666	698	976	601	1297	801	626	488	561	697
Ga	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
As	2.0	2.3	20.5	20.8	3.3	2.2	2.1	3.2	2.1	2.1	1.0	0.8	2.9
Sc	28.9	27.3	29.0	27.4	18.0	21.3	20.0	24.9	34.9	34.9	29.8	30.4	22.0
Y	19	15	19	16	26	18	36	21	23	20	19	19	18
La	93.8	89.2	59.9	50.2	140.0	99.9	100.8	127.3	119.9	117.9	65.6	69.7	66.4
Ce	150.3	140.0	105.0	79.1	205.1	159.7	165.6	200.1	200.6	194.9	117.0	126.1	108.8
Nd	67.0	60.0	56.6	41.9	84.0	73.1	75.5	85.0	98.3	86.9	61.4	68.3	57.0
Sm	10.7	10.4	9.8	7.4	17.2	11.0	11.4	13.4	14.6	12.8	10.5	10.9	9.8
Eu	3.20	3.60	3.11	2.31	4.08	3.41	3.49	3.92	4.27	3.84	3.36	3.48	3.11
Gd	11.7	10.9	6.7	8.8	12.2	9.7	10.0	12.8	12.8	10.7	7.0	7.5	10.7
Tb	1.00	0.90	0.98	0.86	1.41	1.04	1.08	1.23	1.30	1.16	1.08	1.12	0.97
Yb	1.84	1.80	1.72	1.65	1.80	1.69	1.71	2.10	2.65	1.78	1.98	2.08	1.50
Lu	0.25	0.24	0.26	0.22	0.41	0.25	0.28	0.29	0.38	0.26	0.28	0.28	0.24
Th	10.9	6.4	5.5	6.0	12.6	11.3	14.5	14.4	13.1	12.6	5.6	6.2	8.0
U	3.0	1.5	1.8	1.4	2.2	2.9	2.0	4.0	3.5	2.7	1.5	1.7	2.0
Zr	161	144	316	145	216	166	255	157	238	173	236	233	201
Hf	5.0	4.4	9.5	4.3	5.0	4.9	6.9	4.5	7.2	4.8	7.3	7.7	5.7
V	156	179	148	175	199	130	216	129	202	150	169	160	191
Nb	70	47	94	88	88	59	99	68	97	88	68	67	63
Ta	4.1	3.5	5.6	5.0	5.4	3.8	5.1	4.2	6.9	5.2	6.0	6.5	4.4
Cr	300	411	652	388	275	161	159	291	366	1031	325	319	209
Co	48	55	66	56	52	43	45	45	49	64	54	56	54
Ni	194	270	437	274	222	122	158	228	143	485	138	151	119
Cu	n.a.	n.a.	n.a.	n.a.	55	n.a.	86	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Zn	107	108	115	102	98	117	119	111	117	114	122	121	121
K/Rb	396.23	382.40	304.41	357.45	144.62	351.61	157.53	183.34	213.08	184.20	365.29	565.57	339.63
Rb/Sr	0.06	0.06	0.04	0.06	0.04	0.04	0.03	0.04	0.03	0.03	0.02	0.02	0.05
Th/U	3.63	4.27	3.06	4.29	5.73	3.90	7.25	3.60	3.80	4.67	3.73	3.65	4.00
Zr/Hf	32.20	32.73	33.26	33.72	43.20	33.88	36.96	34.89	33.06	36.04	32.33	30.26	35.26
Nb/Ta	17.07	13.43	16.79	17.60	16.30	15.53	19.41	16.19	14.06	16.92	11.33	10.31	14.32
ΣREE (ppm)	339.79	317.04	244.07	192.44	466.2	359.79	369.86	446.14	454.8	430.24	268.2	289.46	258.52
La_N/Yb_N	36.57	35.55	24.98	21.82	55.79	42.40	42.28	43.48	32.45	47.51	23.77	24.04	31.75
Eu/Eu*	0.86	1.02	1.10	0.87	0.81	0.98	0.97	0.90	0.93	0.97	1.12	1.11	0.92
Gd/Gd*	0.44	0.56	0.36	0.62	0.34	0.35	0.35	0.37	0.36	0.32	0.34	0.33	0.56
#Mg	67.99	71.91	74.67	69.40	67.31	60.37	64.46	72.20	67.41	78.17	67.07	67.88	64.15
Age (Ma)	19.9		20.5		15.5*		22.2*	23.9	21.3	20.0	19.8		14.8

Tab. 1. Chemical analyses of volcanic rocks from W Bohemia cont. 1.

Area	C	C	D	D	D	E	E	F	F	F	F	F	F
Sample No.	27	28	29	30	31	32	33	34	35	36	37	38	39
	Z11	Z12	Z17	P15	P18	P6	P8	202	ZC-30B	ZC-30A	ZC-20A	180	186
Rock type	BA	ON	ON	TE	TE	MON	MON	RY	RY	TR	TR	TR	TR
SiO_2 (wt.%)	43.00	40.03	39.63	42.81	40.01	40.09	38.56	70.18	74.45	65.66	65.39	65.77	62.91
TiO_2	2.13	2.57	3.91	2.68	4.79	2.95	3.18	0.03	0.08	0.24	0.40	0.31	0.55
Al_2O_3	12.42	9.65	12.10	13.21	13.03	10.68	11.18	15.12	13.76	17.98	17.82	17.57	18.20
Fe_2O_3	5.22	3.49	5.89	4.09	5.61	7.01	8.59	1.23	1.29	1.51	1.43	1.93	1.08
FeO	5.80	8.78	6.55	7.19	8.03	4.82	3.52	0.08	0.05	0.07	0.13	0.08	0.14
MnO	0.17	0.20	0.19	0.17	0.23	0.22	0.22	0.04	0.02	0.05	0.06	0.24	0.12
MgO	10.28	16.11	8.83	10.11	6.60	14.02	12.19	0.05	0.16	0.06	0.10	0.14	0.06
CaO	12.55	11.59	13.63	12.80	13.89	12.46	13.40	0.41	0.20	0.80	1.25	0.76	2.13
Na_2O	3.01	2.43	2.42	3.68	3.27	3.44	4.55	6.60	3.06	7.39	6.79	6.27	7.40
K_2O	1.75	0.74	0.53	1.41	2.00	1.91	2.17	4.48	4.91	5.92	6.00	5.56	4.91
P_2O_5	0.92	0.84	0.73	0.80	0.95	0.90	0.99	0.03	0.09	0.03	0.06	0.07	0.10
H_2O^+	1.81	2.15	3.12	0.89	1.12	1.12	0.93	1.17	1.20	0.44	0.30	0.42	1.24
H_2O^-	0.50	0.45	0.85	0.12	0.48	0.27	0.44	0.04	0.22	0.12	0.09	0.32	0.34
CO_2	0.13	0.03	1.12	0.14	0.05	0.10	0.18	0.19	0.03	<0.01	0.05	0.40	0.44
Total	99.69	99.06	99.50	100.10	100.06	99.99	100.10	99.65	99.52	100.27	99.87	99.84	99.62
Rb (ppm)	40	16	49	59	45	50	56	436	282	153	213	191	133
Cs	1.50	0.59	0.68	0.70	0.59	0.71	0.71	6.5	6.2	2.8	2.6	2.2	1.5
Sr	757	636	710	851	1189	849	922	126	n.a.	n.a.	n.a.	128	1270
Ba	946	431	652	133	161	945	1029	420	215	143	564	434	1546
Ga	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	34	n.a.	n.a.	n.a.	35	28
As	1.1	1.1	1.2	2.8	2.3	2.3	2.8	6	n.a.	n.a.	n.a.	6	11
Sc	26.9	28.2	40.0	22.0	27.0	20.0	28.0	0.3	5.6	1.6	1.2	1.4	6.7
Y	18	15	16	28	29	22	25	35	n.a.	n.a.	n.a.	35	36
La	88.9	60.0	75.8	130.1	72.7	128.9	135.9	84	10	156	101	132	171
Ce	140.0	106.9	137.5	165.5	138.8	199.8	207.5	115	21	216	155	220	152
Nd	64.6	55.9	69.8	77.2	70.1	86.0	99.0	16.0	10.0	40.0	37.0	71.0	14.0
Sm	9.9	9.8	11.5	14.4	10.6	12.8	12.9	2.8	2.2	2.9	4.3	9.2	4.4
Eu	2.90	3.00	3.29	3.71	2.98	3.35	3.39	0.3	0.2	1.0	1.2	1.9	1.5
Gd	10.6	9.4	8.6	10.8	10.6	10.7	10.8	2.7	n.a.	n.a.	n.a.	6.2	4.1
Tb	0.93	0.96	1.17	1.27	1.22	1.08	1.11	0.47	0.40	0.50	0.50	0.95	0.71
Yb	1.58	1.52	1.66	1.80	1.70	1.80	1.82	3.7	3.6	3.3	2.8	3.7	3.1
Lu	0.27	0.21	0.24	0.40	0.48	0.22	0.26	0.51	0.43	0.48	0.41	0.58	0.45
Th	10.3	5.5	9.8	14.5	16.2	15.1	17.3	72.3	9.0	33.0	33.0	26.3	21.4
U	2.5	1.4	2.0	2.9	4.2	2.5	2.6	5.4	7.0	7.1	6.3	7.8	5.1
Zr	159	324	261	260	423	255	300	380	n.a.	n.a.	n.a.	517	661
Hf	4.7	9.5	8.6	10.0	18.7	7.7	8.1	14.5	2.9	11.7	13.2	12.8	14.6
V	173	166	320	251	386	264	289	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Nb	68	92	73	118	125	128	161	139	n.a.	n.a.	n.a.	160	133
Ta	3.8	9.0	6.0	5.6	5.6	5.9	7.0	8.7	n.a.	n.a.	n.a.	10.2	9.1
Cr	301	575	172	378	28	477	301	7	n.a.	n.a.	n.a.	12	10
Co	49	61	45	50	36	49	45	0.5	3.7	0.5	1.1	0.6	1.2
Ni	195	364	60	178	27	260	202	5	n.a.	n.a.	n.a.	5	5
Cu	n.a.	n.a.	n.a.	75	177	65	75	5	n.a.	n.a.	n.a.	5	5
Zn	100	112	107	112	119	118	124	115	56	72	46	63	200
K/Rb	363.21	383.97	89.80	198.40	368.98	317.14	321.70	85.28	144.51	321.15	233.80	241.61	306.41
Rb/Sr	0.05	0.03	0.07	0.07	0.04	0.06	0.06	3.46				1.49	0.10
Th/U	4.12	3.93	4.90	5.00	3.86	6.04	6.65	13.40	1.29	4.65	5.24	3.37	4.20
Zr/Hf	33.83	34.11	30.35	26.00	22.62	33.12	37.04	26.20				40.39	45.27
Nb/Ta	17.89	10.22	12.17	21.07	22.32	21.70	23.00	15.98				15.69	14.62
ΣREE (ppm)	319.68	247.69	309.56	405.18	309.18	444.65	472.68	225.48	47.80	420.21	302.16	445.53	351.26
La_N/Yb_N	40.36	28.31	32.75	51.84	30.68	51.37	53.56	16.28	1.99	33.91	25.87	25.59	39.57
Eu/Eu*	0.85	0.94	0.96	0.87	0.84	0.85	0.85	0.33	0.41	1.87	1.41	0.73	1.06
Gd/Gd*	0.43	0.50	0.36	0.37	0.44	0.31	0.30	0.13	0.00	0.00	0.00	0.16	0.15
#Mg	67.25	73.92	60.98	66.11	51.42	72.54	69.44	8.12	21.70	8.09	12.89	13.91	10.17
Age (Ma)			29.5	22.1*	20.4*	0.43*	0.11*	12.4				12.5	11.9

Tab. 1. Chemical analyses of volcanic rocks from W Bohemia cont. 2.

Area	F	F	F	F	F	F	F	F	F	F	F	F	F
Sample No.	40	41	42	43	44	45	46	47	48	49	50	51	52
	203	251	251a	255a	256	255	Z-13	P-3	P-1	P-19	Z-20	Z-22	Z-23
Rock type	TR	TA	TA	TA	BTA	BA	BA	BA	BA	BA	TB	TB	TB
SiO_2 (wt.%)	62.90	53.46	55.17	55.57	51.83	45.24	42.24	42.91	43.81	41.43	47.32	45.66	45.89
TiO_2	0.30	1.67	1.41	1.76	1.68	2.68	2.46	3.37	3.11	3.90	2.55	2.89	2.86
Al_2O_3	19.14	18.22	17.70	17.75	18.83	16.33	12.64	11.99	12.49	11.27	16.14	15.80	15.28
Fe_2O_3	2.99	4.64	3.28	5.10	5.29	6.21	5.14	5.12	4.59	5.02	4.80	6.12	4.77
FeO	0.10	1.92	3.00	1.56	2.18	4.50	5.99	5.88	6.56	7.21	5.65	5.25	6.45
MnO	0.10	0.18	0.19	0.17	0.22	0.21	0.22	0.18	0.20	0.22	0.22	0.23	0.23
MgO	0.12	2.36	1.82	1.63	2.02	4.22	11.19	11.11	9.60	9.25	4.00	4.34	5.41
CaO	1.03	5.63	5.60	6.09	6.81	9.73	11.54	13.97	13.30	14.61	9.81	9.93	10.73
Na_2O	6.49	5.15	5.02	4.98	4.85	3.79	3.85	2.39	3.16	2.98	4.24	4.23	3.59
K_2O	5.55	3.74	4.09	3.50	3.02	1.47	1.41	1.70	1.77	1.74	1.90	1.13	2.21
P_2O_5	0.04	0.55	0.43	0.50	0.62	0.79	0.82	0.57	0.69	0.75	1.00	1.08	0.94
H_2O^+	0.67	1.28	1.26	0.86	1.11	2.01	2.02	0.59	0.29	1.32	2.06	1.73	1.01
H_2O^-	0.63	0.82	0.40	0.28	0.96	1.43	0.52	0.21	0.27	0.22	0.21	0.61	0.34
CO_2	<0.10	0.05	0.01	0.02	0.04	0.91	0.03	0.13	0.07	0.20	0.07	0.02	0.04
Total	100.06	99.67	99.38	99.77	99.46	99.52	100.07	100.12	99.91	100.12	99.97	99.02	99.75
Rb (ppm)	162	110	90	102	83	61	49	39	40	39	52	53	50
Cs	1.40	1.9	1.3	0.9	0.87	0.78	0.94	0.57	0.66	0.61	0.79	0.86	0.73
Sr	480	1338	1189	1040	1287	1069	1002	728	877	941	1046	979	858
Ba	1242	1455	1290	1451	1258	906	828	487	580	788	814	787	718
Ga	25	18	17	14	16	14	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
As	n.a.	4	5	4	3	2	3.1	n.a.	n.a.	n.a.	1.9	1.7	2
Sc	0.9	6.3	6.9	7.9	6.2	16.0	23.4	34.0	17.0	33.0	14.0	16.0	19.7
Y	25	40	34	34	39	31	21	22	26	21	31	29	22
La	131	144	160	140	121	95	114	121	137	113	106.7	106.1	84.5
Ce	186	251	241	218	228	176	177	180	211	171	185	182	144.0
Nd	54.0	102.0	99.0	100.8	106.0	87.0	78.3	79.0	84.0	75.1	92.0	89.1	70.3
Sm	5.9	14.3	14.7	15.3	15.6	13.7	11.4	13.3	16.9	13.9	14.5	14.7	11.9
Eu	1.6	4.2	3.8	3.6	4.6	4.2	3.4	3.4	4.4	3.7	4.1	4.2	3.46
Gd	5.0	12.3	10.2	9.4	12.5	12.1	13.8	10.9	12.1	11.6	13.1	13.3	11.8
Tb	0.59	0.85	1.43	1.36	1.60	1.40	1.06	1.44	1.58	1.22	1.45	1.45	1.17
Yb	2.8	2.9	3.9	3.9	3.4	2.6	2.19	3.01	4.50	3.00	3.3	3.5	2.49
Lu	0.47	0.51	0.38	0.44	0.58	0.45	0.33	0.33	0.41	0.38	0.49	0.49	0.36
Th	27.6	15.6	14.1	15.9	14.0	10.2	13.2	10.0	12.0	13.0	9.7	9.5	9.4
U	3.4	4.0	4.5	6.6	3.2	2.7	3.2	2.1	1.9	1.0	3.1	2.7	2.5
Zr	626	460	505	363	512	322	252	243	288	299	426	403	285
Hf	14.9	12.4	11.8	10.5	11.5	9.2	6.8	9.9	9.4	8.9	10.9	10.8	8.2
V	15	n.a.	n.a.	n.a.	n.a.	n.a.	198	301	310	330	166	202	212
Nb	126	122	154	123	149	116	89	70	85	117	89	88	74
Ta	8.8	10.5	10.1	7.7	9.2	6.8	5.4	6.1	7.1	7.6	6.0	6.0	5.6
Cr	4	11	26	21	16	15	219	175	230	258	22	27	45
Co	1.0	5.7	11	14	3.6	5.0	51	54	45	41	16	21	24
Ni	5	6	10	17	7	13	237	157	120	99	11	13	17
Cu	0.2	37	17	29	11	21	n.a.	155	87	150	n.a.	n.a.	n.a.
Zn	98	137	95	143	195	129	128	70	90	95	143	150	139
K/Rb	284.35	282.20	377.19	284.80	302.00	200.02	238.84	361.79	367.28	370.31	303.27	176.96	366.86
Rb/Sr	0.34	0.08	0.08	0.10	0.06	0.06	0.05	0.05	0.05	0.04	0.05	0.05	0.06
Th/U	8.12	3.90	3.13	2.41	4.38	3.78	4.13	4.76	6.32	13.00	3.13	3.52	0.06
Zr/Hf	42.01	37.10	42.80	34.57	44.52	35.00	37.06	24.55	30.64	33.60	39.08	37.31	34.76
Nb/Ta	14.32	11.62	15.25	15.97	16.20	17.06	16.48	11.48	11.97	15.39	29.67	29.33	19.47
ΣREE (ppm)	587.36	532.06	534.51	492.71	493.28	392.45	402.27	412.49	472.36	392.65	420.62	414.38	329.98
La_N/Yb_N	33.56	35.62	29.45	25.67	25.53	26.21	37.47	28.86	21.89	26.97	22.98	22.06	24.34
Eu/Eu*	0.88	0.94	0.90	0.85	0.97	0.98	0.83	0.84	0.89	0.85	0.88	0.90	0.88
Gd/Gd*	0.15	0.28	0.24	0.24	0.31	0.39	0.44	0.34	0.32	0.38	0.40	0.41	0.46
#Mg	8.27	44.81	39.07	35.73	37.90	46.73	68.85	68.96	65.32	62.32	45.69	45.83	51.39
Age (Ma)		12.1		11.4	12.9		12.8	6.5	11.7*	15.9*	10.4	13.5	13.0

Tab. 1. Chemical analyses of volcanic rocks from W Bohemia cont. 3.

Area	F	F	F	F	F	F	F	F	F	F	F	F
Sample No.	53	54	55	56	57	58	59	60	61	62	63	64
	Z-24	Z-19	P-2	P-4	Z-26	Z-15	Z-14	226	M-1	M-2	P-16	Z-16
Rock type	TE	TE	TE	TE	ON	TE	ON	ON	ON	ON	BA	BA
SiO_2 (wt.%)	44.91	45.55	40.27	41.59	44.98	43.67	43.98	40.99	39.58	40.60	40.90	39.19
TiO_2	2.85	3.07	3.91	3.66	1.99	3.51	2.10	4.18	1.98	1.95	2.20	2.70
Al_2O_3	15.83	15.20	13.65	14.79	12.04	13.87	12.21	13.76	10.20	10.87	11.60	11.39
Fe_2O_3	4.99	4.93	4.80	5.17	2.48	5.62	4.18	7.51	6.39	4.34	4.08	3.99
FeO	6.45	6.14	8.12	8.93	8.05	5.40	6.33	7.56	5.85	6.83	7.10	7.99
MnO	0.23	0.21	0.24	0.25	0.17	0.18	0.17	0.23	0.22	0.21	0.19	0.20
MgO	5.07	6.11	7.90	6.25	12.46	6.98	13.02	6.42	15.02	14.52	12.50	12.49
CaO	11.10	11.05	12.39	12.02	11.22	11.80	11.33	11.24	12.45	12.13	13.59	15.81
Na_2O	2.84	3.65	3.49	3.97	2.62	3.69	3.33	3.75	3.93	3.64	2.74	3.00
K_2O	2.34	2.19	2.22	0.87	1.31	0.72	0.94	1.89	1.33	0.97	1.10	1.11
P_2O_5	0.91	0.74	0.92	0.90	0.60	0.51	0.52	0.94	0.97	0.88	0.82	0.88
H_2O^+	1.14	0.95	0.50	1.09	1.69	2.23	1.69	0.80	1.23	1.78	2.64	1.12
H_2O^-	0.29	0.35	0.02	0.20	0.14	0.79	0.26	0.20	0.82	0.51	0.33	0.31
CO_2	0.08	0.07	0.49	0.37	0.07	0.02	0.13	0.03	0.08	0.28	0.07	0.03
Total	99.03	100.21	98.92	100.06	99.82	98.99	100.19	99.50	100.05	99.51	99.86	100.21
Rb (ppm)	46	51	55	65	32	70	52	47	31	27	52	37
Cs	1.10	0.71	0.80	0.41	0.5	1.70	1.90	0.57	0.42	0.44	3.30	3.30
Sr	967	829	1088	1190	594	895	600	1254	988	836	816	1151
Ba	644	642	691	731	501	616	611	985	849	627	964	1005
Ga	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	11	11	n.a.	n.a.
As	1.6	1.4	n.a.	n.a.	1.8	2.3	1.5	n.a.	n.a.	n.a.	n.a.	n.a.
Sc	19.7	25.1	22.0	16.0	26.4	n.a.	28.0	25.0	24.0	24.4	28.4	26.6
Y	20	21	31	30	17	21	16	32	23	20	17	25
La	83.3	81.9	99.2	118.9	43.6	70.4	52.9	110.0	99.4	83.1	76.9	89.7
Ce	146.0	142.9	138.9	166.2	71.8	122.4	85.6	181.1	142.0	126.0	122.4	137.1
Nd	72.1	70.0	66.0	73.2	37.1	64.7	43.7	73.2	55.7	53.1	61.9	66.0
Sm	11.7	11.5	12.5	14.1	6.94	10.4	7.48	16	9.1	9.1	10.3	12.8
Eu	3.52	3.33	3.31	3.57	2.26	3.08	2.35	3.62	2.73	2.52	3.18	2.64
Gd	11.8	11.6	10.7	11.0	7.8	9.6	8.9	8.7	8.7	6.7	11.2	10.1
Tb	1.16	1.11	1.19	1.19	0.89	1.03	0.88	1.52	1.03	0.92	1.07	1.09
Yb	2.49	2.42	2.66	2.91	1.50	1.87	1.68	2.48	1.66	1.66	1.71	1.79
Lu	0.34	0.34	0.28	0.33	0.25	0.32	0.24	0.31	0.25	0.27	0.22	0.18
Th	8.4	8.6	16.0	9.0	5.0	6.5	6.4	8.1	10.5	9.3	9.3	14.0
U	2.4	2.4	1.0	1.0	0.9	1.7	1.6	1.9	5.2	4.8	1.9	1.9
Zr	280	279	361	366	138	230	135	243	177	159	283	231
Hf	8.2	8	8.1	8.5	4.1	7.1	4.1	8.9	3.9	3.8	5.4	7.0
V	210	240	321	389	158	278	179	288	133	150	192	233
Nb	73	71	122	112	43	55	48	104	85	76	102	144
Ta	5.7	5.4	7.0	6.4	2.8	4.1	3.5	6.1	5.2	4.6	6.5	6.1
Cr	48	62	44	33	422	67	370	354	410	445	324	271
Co	25	30	41	40	56.0	38	55	42	52	55	49	56
Ni	17	30	57	37	162	45	249	207	236	271	173	222
Cu	n.a.	n.a.	81	66	n.a.	n.a.	n.a.	73	83	67	n.a.	77
Zn	160	115	117	112	103	94	101	116	69	93	108	115
K/Rb	422.22	356.41	335.02	111.09	339.78	85.37	150.04	333.77	356.10	298.19	175.58	249.00
Rb/Sr	0.05	0.06	0.05	0.05	0.05	0.08	0.09	0.04	0.03	1.09	0.75	0.62
Th/U	3.50	3.58	16.00	9.00	5.56	3.82	4.00	4.26	2.02	1.94	4.89	7.37
Zr/Hf	34.15	34.88	44.57	43.06	33.66	32.39	32.93	27.30	45.38	41.84	52.41	33.00
Nb/Ta	26.07	26.30	17.43	17.50	30.71	26.19	28.24	17.05	16.35	16.52	31.88	23.61
ΣREE (ppm)	332.41	325.10	334.74	391.40	172.13	283.79	203.68	396.95	320.56	283.39	288.88	321.40
La_N/Yb_N	24.00	24.28	26.75	29.31	20.85	27.00	22.59	31.82	42.95	35.91	32.26	35.95
Eu/Eu*	0.91	0.87	0.85	0.85	0.94	0.93	0.88	0.85	0.93	0.94	0.9	0.69
Gd/Gd*	0.45	0.46	0.43	0.37	0.60	0.44	0.58	0.27	0.35	0.30	0.52	0.42
#Mg	49.31	54.78	57.11	49.11	71.76	58.33	73.01	48.46	73.08	73.93	70.88	69.34
Age (Ma)	10.5	9.0*	11.8*	8.3*	16.5*		16.2		17.0	12.4*	16.5*	

Tab. 1. Chemical analyses of volcanic rocks from W Bohemia cont. 4.

Tab. 1. **Areas:** A – Doupovské hory Mts., B – western Ohře Rift, C – Krušné hory and Smrčiny/Fichtelgebirge Mts., D – Teplelská vrchovina Highland and Slavkovský les Mts. (volcanics older than 20 Ma only), E – Quaternary volcanics of the Cheb Basin area, F – Cheb-Domažlice Graben uplifted shoulder.

Rock types: TE – tephrite, BA – basanite, OL – olivine leucitite, ON – olivine nephelinite, MON – melilite-bearing olivine nephelinite, TB – trachybasalt, OB – olivine basalt, PH – phonolite, RY – rhyolite, TR – trachyte, TA – trachyandesite, BTA – basaltic trachyandesite.

Sample Nos. (Q – quarry, AQ – abandoned quarry, NO – natural outcrop, B – boulder):

A – Doupovské hory Mts.: 1 – tephrite, Úhošťany, Q; 2 – basanite, Mikulovice, AQ; 3 – olivine nephelinite, Stráž nad Ohří, Q; 4 – olivine nephelinite, Stráž nad Ohří, Q; 5 – olivine nephelinite, Rumisko near Horní Tašovice, Q; 6 – olivine leucitite, Děpoltovice near Karlovy Vary, Q; 7 – phonolite, Andělská hora Hill near Karlovy Vary, NO; 8 – phonolite, Šemnická skála Hill near Karlovy Vary, NO.

B – western Ohře Rift: 9 – olivine nephelinite, Hlavno near Sokolov, Q; 10 – basanite, Dasnice near Sokolov, Q; 11 – basanite, Dasnice near Sokolov, Q; 12 – basanite to olivine basalt, Slapany Q; 13 – olivine basalt, Slapany, Q; 14 – basanite, Hutnický vrch Hill near Děpoltovice (older intrusion), Q; 15 – basanite, Hutnický vrch Hill near Děpoltovice (older intrusion), Q; 16 olivine basalt, Hutnický vrch Hill near Děpoltovice (younger intrusion), Q; 17 – basanite, Hutnický vrch Hill near Děpoltovice (younger intrusion), Q; 18 – tephrite, Hory near Karlovy Vary, AQ.

C – Krušné hory and Smrčiny/Fichtelgebirge Mts.: 19 – olivine basalt, Libá, Q Blatná; 20 – olivine nephelinite, Libá, Q Blatná; 21 – basanite, Paseky near Aš, NQ; 22 – melilite-bearing olivine nephelinite, Skalka u Hazlova, NO; 23 – olivine nephelinite, Rotava, AQ Šterkovna; 24 – basanite, Větrník Hill near Heřmanov, B; 25 – basanite, Větrník Hill near Heřmanov, B; 26 – basanite, Horní Rotava, AQ; 27 – basanite, Steinberg, Bavaria, Q; 28 – olivine nephelinite, Thierstein, Bavaria, Q.

D – Teplá Highland and Slavkovský les Mts. (volcanics older than 20 Ma only): 29 – olivine nephelinite, Políkno, Q; 30 – tephrite, Hlinky, AQ; 31 – tephrite, Mokrá near Žlutice, Q.

E – Quaternary volcanics of the Cheb Basin area: 32 – melilite-bearing olivine nephelinite, Železná hůrka Hill near Cheb, AQ; 33 – melilite-bearing olivine nephelinite, Komorní hůrka Hill near Františkovy Lázně, AQ.

F – Cheb-Domažlice Graben uplifted shoulder: 34 – rhyolite, Stěnský vrch Hill near Teplá, AQ; 35 – rhyolite, Kojšovice (Vrána 2000), B; 36 – trachyte, Kojšovice (Vrána 2000), B; 37 – trachyte, Dobrá Voda (Vrána 2000), B; 38 – trachyte, Špičák Hill near Teplá, Q; 39 – trachyte, Prachometský vrch Hill near Teplá, AQ; 40 – trachyte, Berounský vrch Hill near Heřmanov, B; 41 – trachyandesite, Třebouňský vrch Hill near Teplá, AQ; 42 – trachyandesite, Branišovský vrch Hill near Teplá (Shrbený 1979), AQ; 43 – trachyandesite, Zbraslavský vrch Hill near Manětín (Shrbený 1979), AQ; 44 – basaltic trachyandesite, Doubravický vrch Hill near Manětín, AQ; 45 – basanite to trachybasalt?, Zbraslavský vrch Hill near Manětín, AQ; 46 – basanite, Prachomety II near Teplá, AQ; 47 – basanite, Okrouhlé Hradiště Hill near Konstantinovy Lázně, AQ; 48 – basanite, Vlčí hora Hill near Černošín, AQ; 49 – basanite, Holý vrch Hill near Ratiboř, Q; 50 – trachybasalt, Skupečský vrch Hill near Konstantinovy Lázně, AQ; 51 – trachybasalt, Vinice Hill near Konstantinovy Lázně, AQ; 52 – trachybasalt, Pekelský vrch Hill near Březín, Q; 53 – tephrite, Pekelský vrch Hill near Březín, Q; 54 – tephrite, Okrouhlé Hradiště Hill near Konstantinovy Lázně, AQ; 55 – tephrite, Homole Hill near Planá, AQ; 56 – tephrite, Krasíkov Hill near Konstantinovy Lázně, NO; 57 – tephrite to basanite (contaminated by crystalline rocks and magnetite xenoliths), Číhaná AQ; 58 – olivine nephelinite (contaminated by granite xenoliths), Polom in Mariánské Lázně, AQ; 59 – olivine nephelinite (contaminated by granite xenoliths), Lysina Hill near Kynžvart, NO; 60 – basanite to tephrite, Chlumská hora Hill near Manětín (Shrbený 1979), AQ; 61 – olivine nephelinite (massive rock), Podhorní vrch Hill near Mariánské Lázně, NO; 62 – olivine nephelinite (brecciated rock), Podhorní vrch Hill near Mariánské Lázně, AQ; 63 – melilite-bearing olivine nephelinite, Chloumecký kopec Hill near Český Chloumek, NO; 64 – melilite-bearing olivine nephelinite, Český Chloumek, AQ.

Ages designated by asterisk from Wilson et al. (1994), other from Ulrych et al. (in press a, b); n.a. – not analysed; n.d. – not determined.

the CDG formation, which is dated by its filling of pre-Middle Miocene? (>11.7 Ma) to Late Pliocene sediment. They form two simultaneous series, WAS and SAS, with fractional crystallization playing a substantial role only in the formation of the WAS (Mg# 8–69). These volcanics coincide with the rare local (Bílina–Most area) Late Miocene intrusions (13–9 Ma) in the České středohoří Mts. (Cajz et al. 1999), and young volcanism in Germany (11–6 Ma; Lippolt 1983). The recurrence of volcanism and the change in its chemical characteristics coincide in time (11–6 Ma) with the tectonic phase (Downes 1996) that caused a fundamental change from calc-alkaline to alkaline volcanism in the Carpathians. This phase reflects the Late Miocene E–W compression in the Alpine Orogen associated with the entry of continental crust into the subduction zone.

3. **Pleistocene (0.43–0.11 Ma)** volcanics of the OR and the CDG junction in the Cheb Basin area are the sole representatives of classical primary uniform (Mg# 69–73) mantle melts (sensu Frey et al. 1978) including their mantle xenoliths (Kämpf et al. 1998). These are products of the latest episode of a continu-

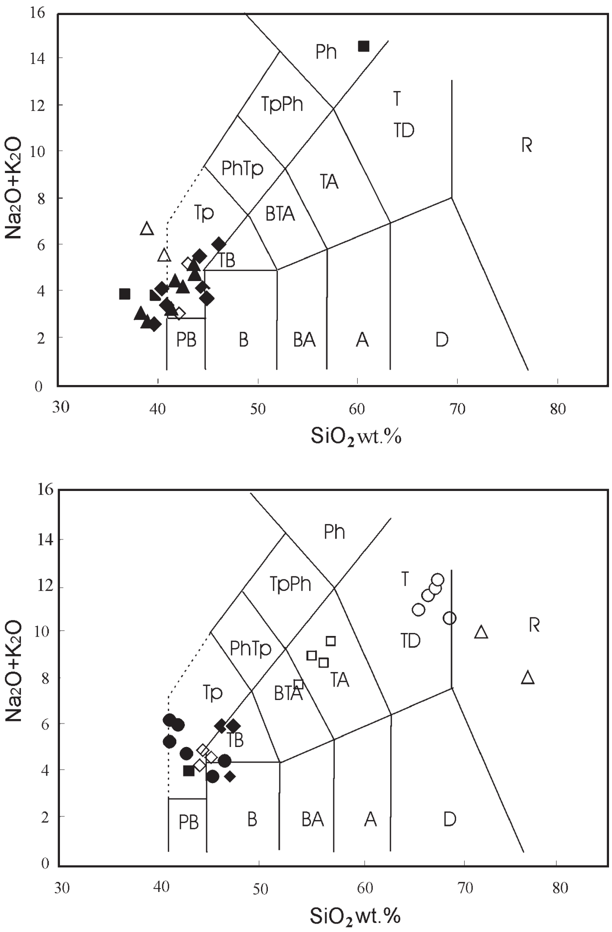

Fig. 3. Volcanic rock series from W Bohemia in the TAS diagram (Le Maitre ed. 2000) associated with:
3a – the Ohře Rift s.l. (Areas A, B, C, D, E in Table 1). "Older series": (filled symbols) squares – Doupovské hory Mts., diamonds – Ohře Rift, triangles – Krušné hory Mts.; (open symbols) diamond – Tepelská vrchovina Highland and Slavkovský les Mts. (volcanics older than 20 Ma only) and triangle – Quaternary volcanics.
3b – the Cheb-Domažlice Graben (Area F in Table 1) "Younger series": (open symbols) open circles – weakly alkaline series, filled circles – strongly alkaline series

ous volcanic activity intermittently manifested with different intensity in individual parts of W Bohemia (Ulrych et al. 1999) from the Early Oligocene (>31 Ma) to the Pleistocene (≈0.1? Ma). (Sub-)Recent fluxes of gases rich in CO_2 containing mantle-derived He are spatially and genetically associated with Pleistocene volcanoes (Weinlich et al. 1999) that are characterized by rapidly ascending primitive magmas and products of explosive character (Kämpf et al. 1993, Wilson et al. 1994).

Parental magmas of all volcanic series (sub 1–3) are inferred to have originated by low-degree melting (≈1 %) of sub-rift lithospheric mantle metasomatized by plume-like material and with amphibole, clinopyroxene, olivine and spinel in the residuum. For modelling of primitive members of both volcanic subseries of the CDG, see Ulrych et al. (in print 2003). Fractional crystallization, possibly accompanied by insignificant crustal contamination within the AFC processes, played an important role only in the formation of the WAS of the CDG (cf. Cantal – Wilson et al. 1995).

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References

BABUŠKA V. and PLOMEROVÁ J., 2001. Subcrustal lithosphere around the Saxothuringian-Moldanubian Suture Zone – a model derived from anisotropy of seismic wave velocities. *Tectonophysics,* 32: 185-199.

BALOGH K., 1985. K/Ar dating of Neogene volcanic activity in Hungary. Experimental technique, experiences and methods of chronologic studies, 277-278. ATOMKI Rep. D/1, Debrecen.

BEHR H. and co-authoren, 1992: Lineare Krustenstrukturen im Umfeld der KTB lokation. In *KTB Report,* 92-3: 3-82. Hannover.

BELLON H. and KOPECKÝ L., 1977. Spectres d'âges radiométriques du volcanisme du rift du Massif bohémien. *5ème Réunion annuelle des sciences da la terre, Rennes, Soc. géol. Fr. éd.*: 57.

CAJZ V., VOKURKA K., BALOGH K., LANG M. and ULRYCH J., 1999. Cenozoic volcanic complex of the České středohoří Mts.: volcanostratigraphy and geochemistry of the central part. *Geolines,* 9: 21-28.

ČERMÁK V., ŠAFANDA J., KREŠL, M. and KUČEROVÁ L., 1996. Heat flow studies in Central Europe with special emphasis on data from former Czechoslovakia. *Global Tect. Metallogeny*, 5: 109-123.

DOWNES H., 1996. Neogene magmatism and tectonics in the Carpatho-Pannonian region. In K. DECKER (Editor), *Pancardi Workshop 1996,* Mitt. Gesell. Geol.-Bergbaustud. Österr. 41: p. 104.

FÖRSTER A. and FÖRSTER H.-J., 2000. Crustal composition and mantle heat flow: Implications from surface heat flow and radiogenic heat production in the Variscan Erzgebirge (Germany). *J. Geophys. Res*. 105: 27,917-27,938.

FREY F.A., GREEN D.H. and ROY S.D., 1978. Integrated models of basalt petrogenesis. A study of quartz tholeiites to olivine melilitites from South Eastern Australia utilizing geochemical and experimental petrological data. *J. Petrology,* 19: 463-513.

GEISSLER W., KÄMPF H., KIND R., KLINGE K., PLENEFISCH T., HORALEK J., ZEDNIK J. and NEHYBKA V. subm. Presently active magmatic underplating beneath the western Eger (Ohre) rift, Central Europe: Results from teleseismic receiver functions. *J. Geophys. Res.*

GOES S., SPAKMAN W., and BIJWAARD H., 1999. A lower mantle source for Central European Volcanism. *Science*, 286: 1928-1931.

GÖGEN K. and WAGNER G.A., 2000. Alpha-recoil track dating of Quaternary volcanics. *Chem. Geology,* 166: 127-137.

GOTTSMANN J., 1999. Tephra characteristics and eruption mechanism of the Komorní hůrka Hill scoria cone, Cheb Basin, Czech Republic. *Geolines*, 9: 35-40.

GRANET M., WILSON M. and ACHAUER U., 1995. Imaging a mantle plume beneath the Massif Central (France). *Earth Planet. Sci. Lett.*, 16:, 281-296.

GRIFFITHS R.W. and CAMPBELL I.H., 1990. Stirring and structure in mantle starting plumes. *Earth Planet. Sci. Lett.*, 99: 66-78.

JUNG S., 1999. The role of crustal contamination during the evolution of continental rift-related basalts: A case study from the Vogelsberg area (central Germany). *Geolines*, 9: 48-58.

KÄMPF H., FRANZKE H.-J., NEUNHÖFER H., MÄRTENS P, RÖLLIG G. and SCHAUER M., 1991. Zur strukturellen Bedeutung der Nord-Süd-Bruchzone Plauen/Klingenthal – Altenburg/Gera – Lepzig/Halle – Dessau/Bernburg. In H. KÄMPF (Editor), *Kurzfassungen der Vorträge und Poster zur Tagung: Geologisch-Tektonischer Bau der Gera-Jachymov (Joachimsthal)-Störungszone und die daran gebundenen Uranlagerstätten,* 12-13.

KÄMPF H., BRÄUER K., KOCH H., MALKOVSKÝ M., STRAUCH G., WEINLICH F.H. and WEISE S., 1992. Vulkanismus-Mineralwässer-Seismizität im Bereich der Marienbaden Störungszone. In P. BANKWITZ, H. KÄMPF and E. BIELFELD (Editors), *Münchberger Gneismasse und ihr geologischer Rahmen. Exkursionsführer,* 127-155. 1. Jahrestagung der GGW, Falkenstein/Vogtland, Berlin.

KÄMPF H., SEIFERT W. and DULSKI P., 1998. Mantle and crustal xenoliths from the Quaternary volcano Železná hůrka, western Eger Rift. In *Magmatism and Rift Basin Evolution – Excursion Guide. Abstracts, Czech Republic, Liblice, Sept. 7-11, 1998*. Czech Geological Survey, Prague, p. 74.

KÄMPF H., SEIFERT W. and ZIEMANN M. 1993. Mantel-Kruste-Wechselwirkungen im Bereich der Marienbader Störungszone, Teil 1: Neue Ergebnisse zum quartären Vulkanismus in NW-Böhmen. *Z. geol. Wiss.,* 21: 117-134.

KOPECKÝ L., 1978. Neoidic taphrogenic evolution of young alkaline volcanism of the Bohemian Massif. *Sbor. geol. Věd., Geol.*, 30: 91-107.

LE MAITRE R.W. ed., 2002 *Igneous Rocks A Classification and Glossary of Terms.* Second edition. Press Syndicate of the University of Cambridge, Cambridge.

LIPPOLT H.J., 1983 Distribution of volcanic activity in space and time. In K. FUCHS (Editor), *Plateau Uplift,* Springer, Berlin, pp. 112-120.

LÜTTIG G., 1998. Zum Alter der jungen Vulkanite in NE-Bayern (und Umgebung). *Geol. Bl. N-O-Bayern*, 48: 21-50.

PAČES T., MÖLLER P., GUGANTI A., MORTEANI G. and PĚČEK J., 2001. Sparkling mineral water at western rim of the Doupovské hory Mountains (Czech Republic): genesis by water-rock interaction and deep-seated CO_2. *Bull. Czech Geol. Surv.,* 76: 189-202.

PETEREK A. and SCHRÖDER B., 1997. Neogene fault activity and morphogenesis in the basement area north of the KTB drill site (Fichtelgebirge and Steinwald). *Geol. Rdsch.,* 86: 15-190.

RITTER J.R.R., JORDAN M., CHRISTENSEN U.R. and ACHAUER U., 2001. A mantle plume below the Eifel volcanic fields, Germany. *Earth Planet. Sci. Lett.*, 186: 7-14.

LÜTTIG G. 1998. Zum Alter der jungen Vulkanite in NE-Bayern (und Umgebung). *Geol. Bl. N-O-Bayern*, 48 (1-3): 21-50.

SCHWARZKOPF L. and TOBSCHALL H.J., 1997. Železná hůrka (Eisenbühl) – volcanology and geochemistry of a Quaternary scoria and lapilli cone in the Ohře- (Eger-) Rift. *J. Czech Geol. Soc. (MAEGS -10 Challenges to Chemical Geology. Abstracts),* 42: 73.

SHRBENÝ O., 1979. Geochemistry of the West Bohemian neovolcanites. *Čas. Mineral. Geol.*, 24: 9-21.

ŠIBRAVA V. and HAVLÍČEK, P., 1980. Radiometric age of Plio-Pleistocene volcanic rocks of the Bohemian Massif. *Věst. Ústř. Úst. geol.*, 55: 129-139.

ŠPIČÁK A., HORÁLEK J., BOUŠKOVÁ A., TOMEK Č. and VANĚK J., 1999. Magma intrusions and earthquake swarm occurrence in the Western part of the Bohemian Massif. *Studia geoph. geod.*, 43: 87-106.

SUN S.S. and MCDONOUGH W.F., 1989. Chemical and isotopic systematics of oceanic basalts: implications for mantle composition and processes. In Magmatism in the Ocean Basins. *Geol. Soc. Spec. Publ.*, 42: 313-345.

TODT W. and LIPPOLT H.J., 1975. K-Ar-Alterbestimmungen an Vulkaniten bekannter paläomagnetischer Feldrichtung. I. Oberpfalz und Oberfranken. *J. Geopys. Res.*, 41: 43-61.

ULRYCH J., BALOGH K., CAJZ V., NOVÁK J.K. and FRÁNA J., in print 2002. Cenozoic alkaline volcanic series in western Ohře (Eger) Rift: Age relations and geochemical constraints. *Acta Montana, Ser. A,* 21 (125), 55-76

ULRYCH J., CAJZ V., ADAMOVIČ J. and BOSÁK P., 2002. Hibsch 2002 Symposium 3-8 June 2002, Teplá, Ústí nad Labem, Mariánské Lázně, Czech Republic. Excursion Guide. Abstract. Czech Geological Survey, Prague.

ULRYCH J., CAJZ V., PIVEC E., NOVÁK J.K. and NEKOVAŘÍK Č., 2000. Cenozoic intraplate alkaline volcanism of western Bohemia. *Studia geoph. geod.,* 44: 346-351.

ULRYCH J., PIVEC E., LANG M., BALOGH K. and KROPÁČEK V., 1999. Cenozoic intraplate volcanic rock series of the Bohemian Massif: A review. *Geolines*, 9: 123-129.

ULRYCH J., ŠTĚPÁNKOVÁ J., LLOYD F.E. and BALOGH K., in print 2003. Middle to Late Miocene alkaline volcanic series associated with the Cheb-Domažlice Graben, W Bohemia: geochemistry and mineralogy. *Geologica Carpathica,* 54, 1, 53-64.

ULRYCH J., NOVÁK J.K., LLOYD F.E., BALOGH K. and BUDA G., in print. Rock-forming minerals of alkaline volcanic series associated with the Cheb-Domažlice Graben, W Bohemia. *Acta mineral. petrogr. (Szeged),* 25 pp.

VIETEN K., HAMM M. and GRIMMEISEN W., 1988. Tertiärer Vulkanismus des Siebengebirges Exkursionsführer 66. Jahrestagung der DMN in Bonn. *Fortschr. Mineral.*, 66: 1-42.

VRÁNA S., 2000. New occurrences of trachyte near Teplá in western Bohemia. *Zpr. geol. Výzk. v Roce 1999*: 84-85. (in Czech)

WAGNER G.A., GÖGEN K., JONCKHEERE R., KÄMPF H., WAGNER I. and WODA C., 1998. The age of Quaternary volcanoes Železná hůrka and Komorní hůrka (Western Eger Rift), Czech Republic: alpha-recoil track, TL, ESR and fission track chronometry. In *Magmatism and Rift Basin Evolution, Excursion Guide, Abstracts*, *Czech Rep., Liblice, Sept. 7-11, 1998*, Czech Geol. Survey, Prague, pp. 95-96.

WEINLICH F.H., BRÄUER K., KÄMPF H., STRAUCH G., TESAŘ J. and WEISE S., 1999. An active subcontinental mantle volatile system in the western Eger Rift, Central Europe: Gas flux. Isotopic (He, C, and N) and compositional fingerprints. *Geochim. Cosmochim. Acta,* 63: 3653-3671.

WILSON M. and PATTERSON R., 2001. Intraplate magmatism related to short-wavelength convective instabilities in the upper mantle: Evidence from the Tertiary-Quaternary volcanic province of western and central Europe. In R.E. ERNST and K.L. BUCHAN (Editors), Mantle plumes: Their Identification Through Time. *Geol. Soc. Amer. Spec. Paper*, 352: 37-58.

WILSON M., DOWNES H. and CEBRIA J.M., 1995. Contrasting fractionation trends in coexisting continental alkaline magma series, Cantal, Massif Central, France. *J. Petrology*, 36: 1729-1750.

WILSON M., ROSENBAUM J.M. and ULRYCH J., 1994. Cenozoic magmatism of the Ohře Rift, Czech Republic: geochemical signatures and mantle dynamics. *Abstracts IAVCEI*, Ankara.