Vinařická hora Hill Cenozoic Composite Volcano, Central Bohemia: Geochemical Constraints

Zdeněk ŘANDA[1], Jiří K. NOVÁK[2], Kadosa BALOGH[3], Jaroslav FRÁNA[1], Jan KUČERA[1] and Jaromír ULRYCH[2]

[1] Nuclear Physics Institute, Acad. Sci. CR, CZ-250 68 Řež, Czech Republic
[2] Institute of Geology, Acad. Sci. CR, Rozvojová 135, CZ-165 02 Praha 6, Czech Republic
[3] Institute of Nuclear Research of the Hungarian Academy of Sciences, P.O. Box 51, H-4001 Debrecen, Hungary

ABSTRACT: Olivine-poor nephelinite of Vinařická hora Hill substantially differs from both olivine nephelinite and olivine-free nephelinite of the Cenozoic volcanic province of the Bohemian Massif. Vinařická hora Hill represents a volcanic relict 31.0–25.5 Ma in age located in the Bohemian Cretaceous Basin in central Bohemian area. The very low Mg-values (46.6–49.7), low contents of compatible elements such as Cr (4.9–23.3), Ni (3–55), Co (39–43), Sc (17.0–18.6) (all data in µg g^{-1}) and the lack of mantle-type xenoliths evidence differentiation of primary mantle magma. Anomalous enrichment in incompatible elements, particularly in ΣREE (523–589), Zr (601–842), U (2.1–3.1), Th (11.6–13.0), Nb (176–188), Ta (10.5–11.2), is associated with magmatic differentiation manifested in crystallization of apatite, Ti-magnetite ± hauyne(?). Olivine-poor nephelinite could be derived from carbonated nephelinite magma with high $CO_2/H_2O + CO_2$ volatile fraction resulting in high viscosity and consequent stopping of magma associated with differentiation and contamination in a crustal reservoir during its ascent to the surface. Such magma could be associated with a highly explosive pyroclast-rich complex volcano of stratovolcanic type. The olivine-poor nephelinite of Vinařická hora Hill belongs to a specific group of nephelinites of the Bohemian Massif characteristically developed in central Bohemia.

KEY WORDS: Bohemian Massif, central Bohemia, Vinařická hora Hill, olivine-poor nephelinite, geochemistry, age.

Introduction

Vinařická hora Hill (VH) is situated N of Vinařice near Kladno, about 30 km NW of Prague (Fig. 1). It represents an eroded flat relict of a composite volcano (1.2 km in diameter, 414 m and 406 m a.s.l.) rising up to 40 m above the surrounding plateau. This plateau is formed by marlstone-sandstone sediments of the Bohemian Cretaceous Basin covering Carboniferous and Proterozoic sediments of the Teplá-Barrandian terrane. Numerous publications deal with the volcanology, petrography and amygdale mineralogy characteristic of VH volcanic products of olivine-poor nephelinite composition (see an overview in Kopecký 1959), but no relevant geochemical data have been published.

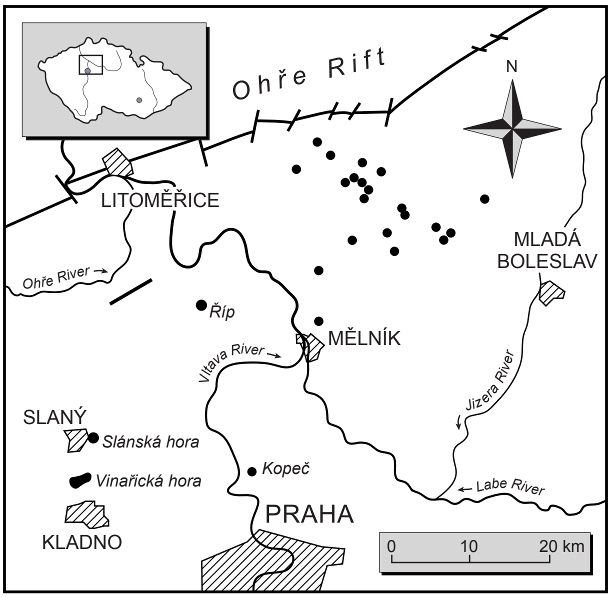

Fig. 1. The distribution of the olivine-poor rock association in central Bohemia (individual occurrences marked by dots).

Olivine-poor nephelinites, sometimes analcimized and containing minerals of the sodalite group, occur only in the central part of the Bohemian minerals of the sodalite group ± (OH)-bearing mineral phase (amphibole/biotite) are characteristic only for the central part of the Bohemian Cretaceous Basin between Mělník and Doksy. Chemical composition of (olivine-poor) nephelinites of central Bohemia is substantially different from both (i) olivine nephelinite to basanite widespread in the České středohoří Mts., N Bohemia etc. (Ulrych and Pivec 1997) and (ii) olivine-free to olivine-poor Ti-rich nephelinites (TiO_2 max. 5.8 wt.%) in the Krušné hory Mts. (Shrbený 1980).

Geological setting

The origin of the VH volcano is associated with the Cenozoic volcanic activity of the Bohemian Massif. The VH occurs as a solitary volcano associated – according to Kopecký (1987–88) – with the hypothetical NE–SW-striking fault system parallel to the Litoměřice Deep-seated Fault. The central Bohemian region shows many occurrences of petrologically similar olivine-free nephelinitic to olivine-poor nephelinitic rocks, primarily at Říp, Kopeč, Chloumek, Špičák, Slánská hora and Šibenec hills and at Horní Zimoř, but only a single occurrence of olivine nephelinite at Jenišovická hůrka Hill, see Fig. 1.

The stratovolcanic character of VH with periclinal fabric was first presented by Lipold (1862). Kopecký (1959) recognized the presence of 2 different phases at the VH volcano: (i) older explosive phase producing allothigenous agglomerates and (ii) younger phase of both explosive and effusive character producing 3 main lava flows and adequate pyroclastic material with stratovolcanic arrangement. However, Kopecký (1987–88) stressed the diatreme character of VH, accentuating the finds of the now eroded Cretaceous sediments and fossilized fragments of wood in the near shafts exploiting Carboniferous coal.

Element	BVH-0-1	BVH-0-2	BVH-1	BVH-2	BVH-3	TVH-0	TVH-1	BCR-1	
								This paper	Liter.
SiO_2 wt%	40.000	40.380	39.100	39.88	41.150	61.000	80.70	55.60	54.11
u	1.860	1.860	1.850	1.86	1.870	2.020	2.20	2.14	
TiO_2 %	3.290	3.490	3.450	3.44	3.420	1.830	0.67	2.20	2.24
u	0.130	0.130	0.150	0.15	0.150	0.070	0.03	0.09	
Al_2O_3 %	11.300	11.110	11.130	11.26	11.170	9.150	5.76	13.23	13.64
u	0.330	0.310	0.350	0.35	0.350	0.280	0.18	0.44	
Fe_2O_3 %	7.200	ND	8.400	8.20	8.150	ND	ND	ND	
std									
FeO %	8.460	ND	8.060	8.45	7.780	ND	ND	ND	
Fe tot %	11.770	12.00	12.300	12.200	11.470	6.980	1.61	9.32	9.379
u	0.370	0.410	0.380	0.380	0.360	0.410	0.07	0.30	
MnO %	0.374	0.358	0.359	0.371	0.376	0.256	0.0053	0.183	0.180
u	0.012	0.011	0.011	0.012	0.012	0.008	0.000	0.006	
MgO %	6.880	7.200	7.090	6.920	5.780	2.490	0.61	3.43	3.48
u	0.270	0.340	0.330	0.340	0.290	0.130	0.03	0.22	
CaO %	11.370	10.940	11.570	11.540	11.770	4.670	0.76	7.15	6.95
u	0.450	0.650	0.550	0.550	0.530	0.290	0.07	0.33	
Na_2O %	3.450	4.070	4.000	4.610	4.850	1.140	0.19	3.20	3.27
u	0.110	0.120	0.160	0.160	0.310	0.040	0.01	0.10	
K_2O %	1.600	2.050	1.260	1.370	1.600	1.690	0.83	1.73	1.69
u	0.240	0.260	0.250	0.260	0.260	0.280	0.11	0.08	0.2
P_2O_5 %	1.270	ND	1.390	1.410	1.390	ND	ND	ND	
H_2O+ %	2.090	ND	1.880	0.740	1.460	3.710	4.58	ND	
H_2O- %	ND	ND	0.830	0.840	0.970	2.910	2.56	ND	
Total	97.284		98.519	99.031	99.866				
Cl µg g^{-1}	1300	1988	2016	2806	1418	268	60	59	59
u	107	128	100	138	89	41	12	17	
Sc	17.0	18.2	18.6	18.6	18.4	10.9	4.7	32.5	32.6
u	0.5	0.5	0.5	0.5	0.5	0.5	0.3	1.0	
V	256	265	250	262	246	147	53.1	469	407
u	9	8	9	9	9	6	2	15	
Cr	23.3	18.5	15.6	7.4	4.9	28.0	16.9	11.5	16
u	1.6	1.1	1.0	2.5	2.0	1.0	0.9	1.5	
Co	36.3	40.5	40.7	39.8	38.2	25.0	4.0	36.7	37
u	1.1	1.4	1.1	1.1	1.1	1.5	0.2	1.1	

BCR-1 International rock standard
Liter. : data taken from Govindaraju (1994)
u: combined uncertainty (coverage factor=1)
BVH-0-1 :massive rock, the uppermost part at the highest elevation point of 414 m a.s.l. (northern summit), Kopecký (1959)
BVH-0-2: massive rock taken at a distance of 20 m from sample BVH-0-1, face of an old quarry, western side of volcano
BVH-1: massive rock of the middle lava flow in the new quarry, eastern side of volcano
BVH-2: massive rock underlying lava sample BVH-1
BVH-3: massive rock overlying lava sample BVH-1
TVH-0: volcaniclastic material underlying lava sample BVH-0-2
TVH-1: volcaniclastic material overlying lava sample BVH-1
ND: not determined

Tab. 1. Chemical composition of rocks from Vinařická hora Hill.

Element	BVH-0-1	BVH-0-2	BVH-1	BVH-2	BVH-3	TVH-0	TVH-1	BCR-1 This paper	Liter.
Ni	**38**	**66**	**55**	**45**	**50**	**45**	**31**	**<58**	**13**
u	8	8	11	12	12	9	8		
Zn	**179**	**206**	**206**	**204**	**200**	**133**	**37.7**	**129**	**129.5**
u	8	7	7	7	7	8	1.9	7.0	
As	**6.1**	**3.3**	**1.7**	**3.6**	**2.2**	**2.2**	**2.6**	**<0,7**	**0.65**
u	0.5	0.3	0.5	0.7	0.6	0.4	0.4		
Br	**2.4**	**5.0**	**4.6**	**6.5**	**3.8**	**<1.9**	**0.44**	**<1,7**	**0.072**
u	0.4	0.3	0.5	0.6	0.6	0.0	0.0		
Rb	**73.6**	**63.0**	**64.2**	**59.0**	**60.0**	**49.5**	**29.7**	**44.6**	**47.2**
u	7.0	6.2	5.8	4.2	3.7	2.6	1.8	5.7	
Sr	**1420**	**1467**	**1748**	**1722**	**1695**	**785**	**185**	**344**	**330**
u	43	59	54	55	54	46	21	55	
Y	**39.8**	**ND**	**45.6**	**46.1**	**35.4**	**ND**	**ND**	**27.3**	**38**
u	5.1		6.9	7.9	6.1			9.6	
Zr	**842**	**814**	**630**	**627**	**601**	**482**	**312**	**203**	**190**
u	32	35	21	22	20	38	26	13	
Nb	**251**	**ND**	**185**	**188**	**176**	**ND**	**ND**	**15**	**14**
u	8		7	8	6			6	
Sb	**1.60**	**0.37**	**0.30**	**0.20**	**0.32**	**0.42**	**0.35**	**0.64**	**0.62**
u	0.21	0.04	0.09	0.05	0.08	0.03	0.04	0.12	
Cs	**1.37**	**1.17**	**1.07**	**1.16**	**1.73**	**1.41**	**0.76**	**0.93**	**0.96**
u	0.16	0.05	0.04	0.04	0.04	0.10	0.06	0.05	
Ba	**970**	**1008**	**1030**	**1150**	**1008**	**876**	**208**	**647**	**681**
u	85	42	73	87	85	37	13	63	
Hf	**13.6**	**15.2**	**15.1**	**15.1**	**14.8**	**9.6**	**6.4**	**5.1**	**4.95**
u	0.4	0.7	0.5	0.5	0.5	0.4	0.3	0.2	
Ta	**11.25**	**10.37**	**10.68**	**10.92**	**10.55**	**5.30**	**1.98**	**0.75**	**0.81**
u	0.40	0.32	0.32	0.32	0.32	0.22	0.07	0.08	
Th	**11.6**	**12.6**	**12.8**	**13.0**	**12.7**	**10.1**	**6.4**	**5.8**	**5.98**
u	0.4	0.5	0.4	0.4	0.4	0.5	0.7	0.3	
U	**2.1**	**3.5**	**2.8**	**2.4**	**3.1**	**2.7**	**1.7**	**1.1**	**1.75**
u	0.3	0.3	0.4	0.5	0.4	0.3	0.4	0.4	
La	**126**	**139**	**143**	**142**	**138**	**82.6**	**36.8**	**29.4**	**24.9**
u	4	4	5	5	5	2.7	1.4	1.0	
Ce	**219**	**249**	**247**	**249**	**244**	**147**	**66.0**	**53**	**53.7**
u	6	7	7	7	7	5	2.5	2	
Nd	**98**	**109**	**112**	**114**	**108**	**65.2**	**29.1**	**27**	**28.8**
u	4	5	4	4	4	2.9	2.6	3.1	
Sm	**16.5**	**19.0**	**19.7**	**19.2**	**16.9**	**11.3**	**5.0**	**6.52**	**6.59**
u	0.5	0.6	0.5	0.5	0.4	0.40	0.2	0.20	

BCR-1 International rock standard
Liter.: data taken from Govindaraju (1994)
u: combined uncertainty (coverage factor=1)
BVH-0-1 :massive rock, the uppermost part at the highest elevation point of 414 m a.s.l. (northern summit), Kopecký (1959)
BVH-0-2: massive rock taken at a distance of 20 m from sample BVH-0-1, face of an old quarry, western side of volcano
BVH-1: massive rock of the middle lava flow in the new quarry, eastern side of volcano
BVH-2: massive rock underlying lava sample BVH-1
BVH-3: massive rock overlying lava sample BVH-1
TVH-0: volcaniclastic material underlying lava sample BVH-0-2
TVH-1: volcaniclastic material overlying lava sample BVH-1
ND: *not determined*

Tab. 1. Chemical composition of rocks from Vinařická hora Hill, *continued*.

Element	BVH-0-1	BVH-0-2	BVH-1	BVH-2	BVH-3	TVH-0	TVH-1	BCR-1 This paper	Liter.
E*u*	**5.02**	**5.11**	**5.30**	**5.23**	**5.14**	**2.75**	**1.20**	**1.91**	**1.95**
u	0.15	0.18	0.17	0.17	0.17	0.09	0.06	0.05	
Gd	**12**	**16**	**10.4**	**10.4**	**9.6**	**9**	**<3**	**6.8**	**6.68**
u	2	2	0.5	0.8	0.4	2		0.6	
Tb	**1.57**	**1.77**	**1.84**	**1.76**	**1.75**	**1.07**	**0.47**	**1.02**	**1.05**
u	0.16	0.08	0.09	0.09	0.09	0.07	0.02	0.08	
Dy	**10.20**	**10.78**	**10.75**	**10.58**	**10.93**	**7.47**	**5.41**	**7.51**	**6.34**
u	0.58	0.68	0.46	0.49	0.47	0.46	0.17	0.46	
Ho	**1.58**	**1.71**	**1.47**	**1.28**	**0.80**	**1.06**	**0.43**	**1.40**	**1.26**
u	0.17	0.35	0.25	0.25	0.22	0.19	0.08	0.18	
Tm	**ND**	**1.10**	**ND**	**ND**	**ND**	**0.82**	**0.29**	**ND**	
u		0.14				0.11	0.06		
Yb	**2.90**	**3.36**	**3.45**	**3.34**	**3.29**	**2.36**	**1.04**	**2.93**	**3.38**
u	0.14	0.20	0.19	0.22	0.22	0.24	0.11	0.31	
L*u*	**0.44**	**0.44**	**0.58**	**0.54**	**0.50**	**0.37**	**0.18**	**0.53**	**0.51**
u	0.03	0.08	0.04	0.05	0.05	0.05	0.02	0.03	
Ce_N/Yb_N	20.98	20.58	19.89	20.71	20.60	17.30	17.63		

BCR-1 International rock standard
Liter. : data taken from Govindaraju (1994)
u: combined uncertainty (coverage factor=1)
*B*VH-0-1 :massive rock, the uppermost part at the highest elevation point of 414 m a.s.l. (northern summit), Kopecký (1959)
BVH-0-2: massive rock taken at a distance of 20 m from sample BVH-0-1, face of an old quarry, western side of volcano
BVH-1: massive rock of the middle lava flow in the new quarry, eastern side of volcano
BVH-2: massive rock underlying lava sample BVH-1
BVH-3: massive rock overlying lava sample BVH-1
TVH-0: volcaniclastic material underlying lava sample BVH-0-2
TVH-1: volcaniclastic material overlying lava sample BVH-1
ND: *not determined*

Tab. 1. Chemical composition of rocks from Vinařická hora Hill, *continued*.

Sampling and analytical procedures

Four rock samples from natural outcrops of VH were collected and studied. For petrographic and chemical characteristics see Table 1.

Geochemical investigation of the rock samples was performed using wet chemical analyses (V. Chaloupský, Institute of Rock Structure and Mechanics AS CR) for the determination of SiO_2, FeO, Fe_2O_3, P_2O_5, H_2O^+ and H_2O^-, and instrumental neutron and photon activation analyses (INAA and IPAA) using HPGe coaxial and planar detectors under standard conditions published by Řanda et al. (1972) and Řanda et al. (1981) for the determination of other elements. Determination of K/Ar age was performed in the INR HAS, Debrecen, using the mass spectrometry and isotope dilution method. For analytical conditions see Balogh (1985).

Petrographic characteristics

Massive rocks are characterized by inexpressive (micro)porphyritic texture. Rare subhedral microphenocrysts are formed dominantly by clinopyroxene (0.5 by 0.1 mm) and rarely by olivine (0.5–2 mm). Hemicrystalline matrix is mostly formed by anhedral grains of prevailing clinopyroxene and nepheline. Nepheline and glass present in variable contents are partly decomposed, both anacimized and both partly analcimized and natrolitized. A mineral of sodalite group occurs in poikilitic form more rarely in rounded pseudomorphs. Numerous titanian magnetite grains and ilmenite laths are present in the matrix, too. Other minerals of matrix such as apatite, biotite, and carbonates (ankerite) and anorthoclase (xenocrystic?) occur rarely.

The rock of VH was described by different authors (for review see Kopecký 1959) under different names, as a consequence of difficulties associated with optical determination of foids.

The bulk chemical and trace element compositions of the studied VH samples are shown in Table 1. In the classification of Le Maitre ed. (1989) the rock plots to the boundary of the foidite and tephrite fields, Fig. 2. According to the special terminology of foiditic (nephelinitic rocks) of Le Bas (1989), the rock from VH can be specified as nephelinite with transitions to melanephelinite (sub-root), and nephelinite to pyroxene melanephelinite (species), i.e., olivine-poor nephelinite or nephelinite (Group II sensu Le Bas 1978, 1987). Position of the rock from VH in the CaO vs. MgO plot (Fig. 3) illustrates its

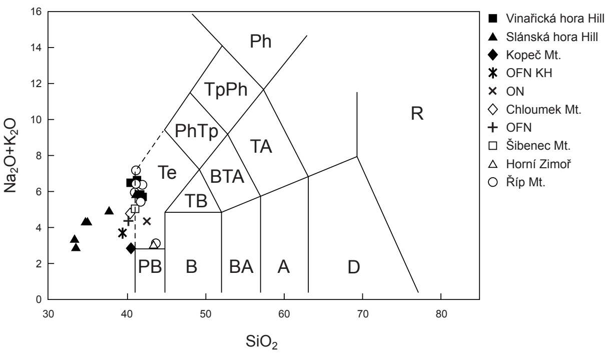

Fig. 2. Position of olivine-poor nephelinite from VH and other cognate rocks in the TAS diagram (Le Maitre ed. 1989). ON and OFN – average chemical composition of the olivine nephelinite and olivine-free nephelinite, of the Bohemian Massif (Shrbený 1995), respectively.

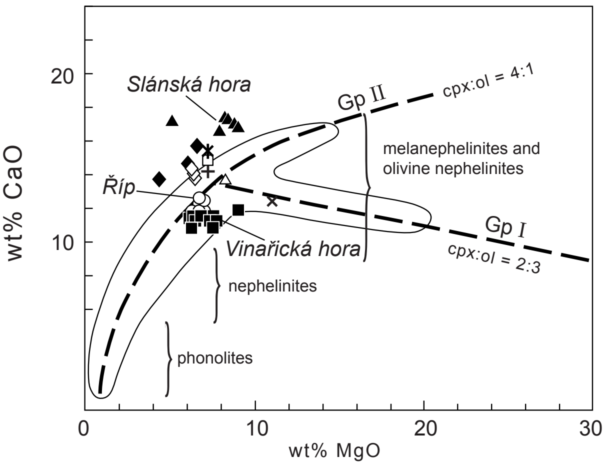

Fig. 3. Olivine-poor nephelinite from VH and other cognate rocks in the CaO – MgO plot (Le Bas 1987).

character and affinity to nephelinites (rather transitional olivine-poor nephelinites) sensu Le Bas et al. (1987). The whole set of analyses reveals a homogeneous character. Compared to the average alkali contents in young olivine nephelinite – ON and olivine-free nephelinite – OFN (both ca. 4.2 wt.%, see Fig. 2), the VH samples show substantially higher total alkali contents (5.5–6.2 wt.%). All samples are Ne-normative. Ol-normative contents (0.0–3.4, 1.1 mol.% on average) correspond to the average value of OFN of the Bohemian Massif (Shrbený 1995).

Petrology and geochemistry

Olivine-poor nephelinites (Group II sensu Le Bas 1989) are characterized by the presence of clinopyroxene and rarely of olivine phenocrysts, low contents of MgO (6.3–7.7 wt.%), low Mg# (46.6–49.7) and high 100K/Na+K mol. ratio (15–25), by the absence of associated basalts and mantle-type xenoliths, strong fractionation, problematic presence of phonolite derivatives, formation of large volcanic structures and rich pyroclastic products. These features are prevalently characteristic for the olivine-poor nephelinite of VH. The nearest phonolitic derivatives are, however, present in the České středohoří Mts. Mantle magma of olivine-poor nephelinite volcanoes apparently stopped in a high-level magma reservoir during its ascent. This is corroborated by the low Mg# (about 48) sensu Frey at al. (1978) and low contents of compatible elements including Cr (4.9–23.3), Ni (3–55), Co (39–43), Sc (17.0–18.6) (all data in μg g^{-1}) in the samples studied. The relatively low contents of the above elements are due to low content of olivine, which is their host mineral. Stopping of magma can be probably explained by its mechanical behaviour resulting from its chemical composition. Nephelinites associated with carbonatites due to liquid immiscibility represent products of carbonated nephelinite magma and hence have a high CO_2/H_2O s+ CO_2 volatile fraction resulting in high viscosity that causes stopping of magma in a crustal reservoir during its ascent to the surface (Le Bas 1987). Pyroclastic products of such magma are naturally of frequent occurrence.

K/Ar age of 31.0–25.5 Ma (see Table 2) links the volcanism of VH with the main episode (42–16 Ma) of the Cenozoic activity within the Bohemian Massif, which is characteristically developed in the near České středohoří Mts. (Ulrych 2000).

Sample	Age in Ma
BVH-0-2	31.0
BVH-1	26.4
BVH-2	29.6
BVH-3	25.5

Tab. 2. K/Ar age of rocks fromVinařická hora Hill.

The $^{87}Sr/^{86}Sr$ (0.7036–0.7038) and $^{143}Nd/^{144}Nd$ (0.51278) ratios of the cognate olivine-poor nephelinite of Říp Hill (Ulrych et al. 1998) are consistent with HIMU OIB from a sublithospheric source; ε^{t}_{Nd} (+3.4) value implies a depleted mantle source.

The considerable heterogeneity of the lithospheric part of upper mantle (sensu Wilson and Downes 1991) beneath the Bohemian Massif is highly probable as a consequence of partly preserved relicts of Hercynian fabrics or of ancient subduction zone associated with the Hercynian orogeny (Hoernle et al. 1995). Data available at present give support to the model of melt generation preferentially in a heterogeneous mantle rather than to selective magma contamination by crustal-derived components. However, Le Bas (1987) mentioned that indistinctly differing contents of trace elements in nephelinites and olivine nephelinites do not support the argument of expressive mantle chemical heterogeneity. No substantial lateral variation of the lithosphere is apparent in any of the provinces and therefore the answer may be in the different volatile content of both magmas, especially in the $CO_2/H_2O + CO_2$ ratio (Le Bas 1987). The Litoměřice Fault represents the most substantial discontinuity in the Bohemian Massif limiting the Teplá–Barrandian terrane block with scarce volcanism (e.g., of VH) and the Saxothuringian terrane with the Ohře Rift and numerous volcanic products, e.g., of the České středohoří Mts.

Primitive mantle-normalized contents of incompatible elements in samples from VH are presented in spidergrams, see Fig. 4. This diagram suggest compositional homogeneity of the rocks at VH. Depletion of the olivine-poor nephelinite in Rb and K can

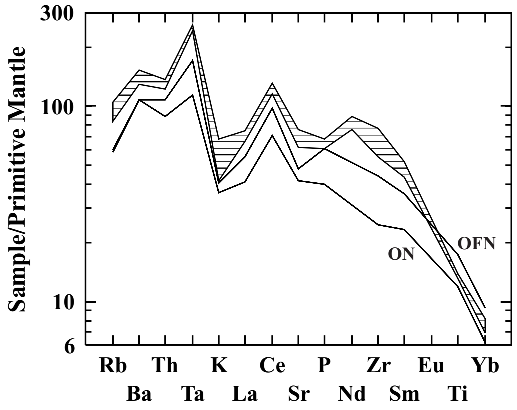

Fig. 4. Spidergrams of olivine-poor nephelinite from VH. Average olivine nephelinite (ON) and olivine-free nephelinite (OFN) of the young volcanism of the Bohemian Massif (Shrbený 1995). Normalization constants of PM from Sun and Mc Donough (1989).

be explained by the presence of residual phlogopite in the mantle source. Troughs of Sr and Ti are probably associated with fractionation of plagioclase and titanian magnetite (Ti-rich clinopyroxene?). Apatite represents a solitary host mineral concentrating incompatible elements (REE, U, Th) in the rocks of VH. Enrichment in P is characteristic for the whole petrographically distinctive group of olivine-poor nephelinites from central Bohemia (Ulrych et al. 1998). Nevertheless, the high content of normative apatite exceeding 10 vol.% (up to 4.5 wt.% P_2O_5) in olivine-poor nephelinite from Slánská hora Hill (Novák and Matějka 1999) has rare analogues among basaltic rocks. According to Exley and Smith (1982), generation of P-anomalous magmas is probably associated with clinopyroxene fractionation producing P-enriched liquids which might subsequently crystallize as amphibole- and apatite-rich cumulates. During the generation of the later primary magma, apatite-rich materials might preferentially contaminate the liquids to yield positive phosphorus anomalies. The proposed model requires that magmas undergo a prolonged fractionation at a considerable depth (about 100 km), i.e., in subcontinental environments (Exley and Smith 1982). The presence of the P-rich olivine-poor nephelinites in central Bohemia thus might reflect a presence of metasomatized upper mantle (cf. Lloyd and Bailey 1975, Wass and Rogers 1980). The progressive fractionation and/or liquation (Ulrych et al. in press) rather than contamination (Vaněčková et al. 1993) may be responsible for this trend.

However, both ON as well as OFN (average data from the Bohemian Massif by Shrbený 1995) in Fig. 4 show lower concentrations of incompatible elements. Lower concentrations of compatible elements in the olivine-poor nephelinite of VH fit well with the characteristics of compared average composition of OFN presented by Shrbený (1992).

K/Rb ratios range between 173–368 with the average value of 241. Shrbený (1994) gives the average values 216 for ON and 245 for OFN of the Bohemian Massif. However, these values may be partly affected by late magmatic processes.

Relatively high contents of Sr and Ba are probably associated with the glass phase and apatite (see high contents of P and REE in Tab. 1).

Contents of U (2.6–3.9 μg g^{-1}) and Th (14.5–17.2 μμg g^{-1}) are considerably high compared to average contents from the České středohoří Mts. and comparable with those of nephelinitic and melilititic rocks from the Osečná Complex (Ulrych et al. 1988). The Th/U ratios of VH rocks display equilibrial range between 3.1–5.6 corresponding to the developed continental alkali basalts (Lutc 1975). REE contents and Ce_N/Yb_N ratios are fairly high (cf. Table 1). It seems that the contents of REE, as well as U, Th, Nb, Ta are associated with magmatic crystallization (apatite ± Ti-magnetite and hauyne?). The source of these elements is linked with metasomatized mantle material (Hanson 1977, Brooks et al. 1976b). High contents of REE are comparable with those of melilitic rocks of the Osečná Complex (Ulrych et al. 1988), where they were associated with late magmatic fluids. Chondrite-normalized REE patterns with characteristic dominance of LREE ($Ce_N/Yb_N = 20.7$) are presented in Fig. 5.

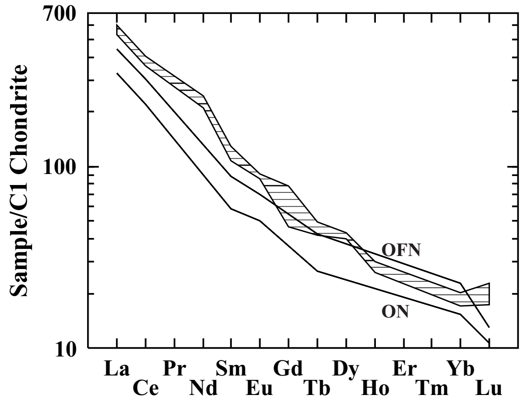

Fig. 5. Chondrite-normalized REE contents of the olivine-poor nephelinite from VH. Average olivine nephelinite (ON) and olivine-free nephelinite (OFN) of the young volcanism of the Bohemian Massif (Shrbený 1994). Normalization constants from Sun and Mc Donough (1989).

Conclusions

According to the classification of Le Maitre ed. (1989), the rock of VH corresponds to nephelinite, however, in a special nephelinitic rocks classification of Le Bas (1989) it belongs to nephelinite with transitions to melanephelinite. Olivine-poor to olivine-free nephelinites with specific chemical composition represent a rare group among the Cenozoic volcanics in the Bohemian Massif, characteristic of the central part of the Bohemian Cretaceous Basin. The results of K-Ar determinations are not compatible with the geological model presented by Kopecký (1959) and call for its re-consideration.

The low Mg# (about 48), low contents of compatible elements such as Cr, Ni, Co, Sc and the lack of any mantle-type xenoliths evidence the development of the VH rock by differentiation of primary magma from the upper mantle. Both clinopyroxene and olivine microphenocrysts are rare (max. 5 vol.%). The olivine-poor nephelinite of VH is geochemically anomalous with distinct high ΣREE (523–589 μg g^{-1}) and significant domination of LREE, high Sr, Ba, U, Th, Zr, Hf, Nb and Ta contents and high Th/U, Nb/Ta and Zr/Hf ratios

Considering the geochemical character of the VH magma, it corresponds to a typical olivine-poor nephelinite type (Group II sensu Le Bas 1989). Genetic association with carbonatitic and phonolitic derivatives and formation of large volcanic structures with frequent pyroclastic products are characteristic features of these rocks. Nephelinites of Group II are characterized by a high $CO_2/H_2O + CO_2$ volatile fraction resulting in high viscosity. Their association with highly explosive central stratovolcano is most characteristic. Mantle magma of such volcanoes apparently stopped in a crustal magma reservoir during its ascent and differentiated. Its stopping could have been caused by its mechanical behaviour, reflecting its nephelinitic highly viscose character.

Acknowledgements

This work was supported by Grant A IAA3048201 of the AS CR. The authors wish to thank the reviewers E. Jelínek and V. Cajz for their thoughtful review of the manuscript.

References

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

BROOKS C., JAMES D.E. and HART S.R., 1976. Ancient lithosphere: its role in young continental volcanism. *Science*, 193: 1086-1094.

EXLEY R.A. and SMITH J.V., 1982. The role of apatite in mantle enrichment processes and in the petrogenesis of some alkali basalt suites. *Geochim. Cosmochim. Acta*, 46: 1375-1384.

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

GOVINDARAJU K., 1994. Compilation of Working Values and Sample Description for 383 Geostandards. *Geostandards Newsletter*, 18: Special Issue.

HANSON G., 1977. Geochemical evolution of suboceanic mantle. *J. Geol. Soc. London*, 134: 235-253.

HOERNLE K., YU-SHEN ZHANG and GRAHAM D., 1995. Seismic and geochemical evidence for large-scale mantle upwelling beneath the eastern Atlantic and western and central Europe. *Nature*, 374: 34-39.

KOPECKÝ L., 1959. Tertiary volcanism of the Vinařická hora near Kladno. *Věst. Ústř. Úst. geol*., 34: 256-269, Praha.

KOPECKÝ L., 1987-88. Young volcanism of the Bohemian Massif, Part 1-6 (in Czech). *Geol. Hydrometal. Uranu*, 11-12: 30-67, 3-44, 3-40, 3-56.

LE BAS M.J., 1978. Nephelinite volcanism at plate interiors. *Bull. Volcan*., 44: 459-462.

LE BAS M.J., 1987. Nephelinites and carbonatites. In J.G. FITTON and B.G.J. UPTON (Editors) *Alkaline Igneous Rocks*. Blackwell Sci. Publ., Oxford, pp. 53-83.

LE BAS M.J., 1989. Nephelinitic and basanitic rocks. *J. Petrology*, 30: 1299-1312.

LE MAITRE R.W. ed. 1989. *A Classification of Igneous Rocks and Glossary of Terms*. Blackwell Sci. Publ., Oxford.

LIPOLD M.V., 1862. Das Steinkohlengebiet im nordwestlichen Theile des Prager Kreises in Böhmen. *Jb. k. k. geol. Reichsanst. Wien*, 1861-62: 517.

LLOYD F.E. and BAILEY D.K., 1975. Light element metasomatism of the continental mantle: the evidence and the consequences. *Phys. Chem. Earth*, 9: 389-416.

NOVÁK J.K. and MATĚJKA D., 1999. Apatite enrichment in nephelinite from Slánská hora Hill, central Bohemia. *Geolines*, 9: 104-109.

ŘANDA Z., BENADA J., KUNCÍŘ J., VOBECKÝ M. and FRÁNA J., 1972. Radioanalytical methods for the non-destructive analysis of lunar samples. *J. Radioanal. Chem.*, 11: 305.

ŘANDA Z., ŠPAČEK B., KUNCÍŘ J. and BENADA J., 1981. Nondestructive gamma activation analysis of mineral materials. CAEC, Nuclear Information Centre, Prague.

SHRBENÝ O., 1980. Chemical composition of alkaline neovolcanics of the Krušné hory Mts., Bohemia. *Věst. Ústř. Úst. geol*., 55: 1-10.

SHRBENÝ O., 1992. Chemistry of Tertiary alkaline volcanics in the central-western part of the Bohemian Cretaceous Basin and the adjacent area. *Čas. Mineral. Geol.*, 37: 203-217.

SHRBENÝ O., 1995. Chemical composition of young volcanites of the Czech Republic. *Czech Geol. Surv. Spec. Papers*, 4: 1-52. Czech Geol. Survey, Prague.

SUN S.S. and Mc DONOUGH W.F., 1989. Chemical and isotopic systematics of oceanic basalts: implications for mantle composition and processes In A.D. SAUNDERS and M.J. NORRY (Editors), Magmatism in the Ocean Basins. *Geol. Soc. London Spec. Publ.*, 42: 313-345. London.

ULRYCH J., 2000. Intrusive centres of Neoidic volcanism in the Bohemian Massif: Petrological, Geochemical and Mineralogical characteristics. DrSc. Thesis, Institute of Geology AS CR, Vol. I, 95 pp.

ULRYCH J. and PIVEC E., 1997. Age-related contrasting alkaline volcanic series in North Bohemia. *Chem Erde*, 57: 11-336.

ULRYCH J., PIVEC, E., LANGROVÁ A., JELÍNEK E., ÁRVASOS E., HÖHNDORF A., BENDL J. and ŘANDA Z., 1988. Geochemically anomalous olivine-poor nephelinite of Říp Hill, Czech Republic. *J. Czech Geol. Soc*., 43: 299-312, Praha.

ULRYCH J., POVONDRA P., RUTŠEK J. and PIVEC E., 1988. Melilitic and melilite-bearing subvolcanic rocks from the Ploučnice river region, Czechoslovakia. *Acta Univ. Carol., Geol.*, 1988: 195-231.

VANĚČKOVÁ M., HOLUB F.V., SOUČEK J. and BOWES D.R., 1993. Geochemistry and petrogenesis of the Tertiary alkaline volcanic suite of the Labe tectono-volcanic zone, Czech Republic. *Mineral. Petrol.,* 48: 17-34.

WASS, S.Y. and ROGERS, N.W., 1980. Mantle metasomatism – precursor to continental alkaline volcanism. *Geochim. Cosmochim. Acta*, 44: 1811- 1823.

WILSON M. and DOWNES H., 1991. Tertiary – Quaternary extensions-related alkaline magmatism in western and central Europe. *J. Petrology,* 32: 811-849.