Neutron and photon activation analyses of anomalous phonolites from Lusatian Mountains in Bohemian Massif, Czech Republic

Zdeněk ŘANDA, Jiří MIZERA, Ivana KRAUSOVÁ

Nuclear Physics Institute, Academy of Sciences of the Czech Republic
Řež 130, 250 68, Czech Republic
E-mail: randa@ujf.cas.cz

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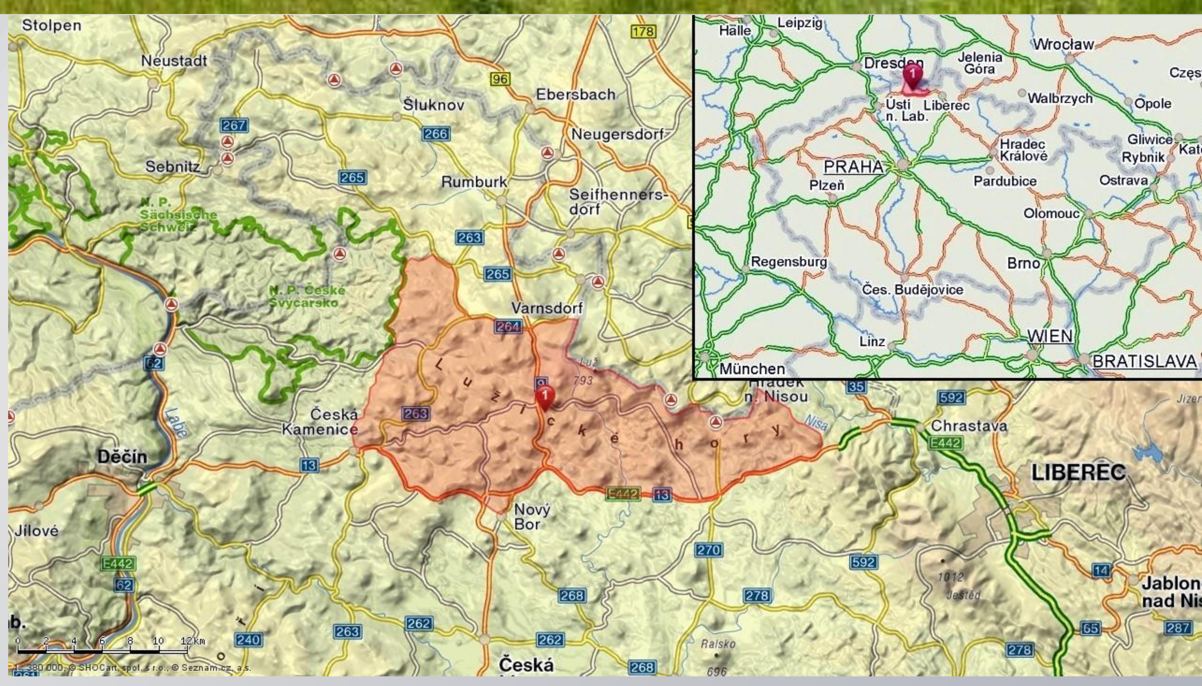


Map and position of the Lusatian Mountains (Lužické hory).

Summary

Phonolites from the Lusatian Mountains in northern part of the Czech Republic are tertiary, highly evolved alkaline volcanic rocks associated with continental interplate magmatism with anomalous contents of incompatible and volatile components. From the geochemical point of view, these rocks are residue of parent magma concentrating many incompatible and volatile elements. Phonolites solidified at relatively low temperature similarly to other residue liquids, and thus during ascent of magma towards the Earth surface such rocks consolidated in shallow depths (less than one kilometer) in the upper bed. Therefore, phonolites can be classified among the so-called subvolcanic (or hypabyssal) rocks. Elucidation of source materials and processes leading to formation of these anomalous phonolites (partial melting and contamination by crust materials) requires their detailed chemical characterization.

For a detailed geochemical study of 8 samples of the phonolites, various modes of nondestructive neutron (including the epithermal and fast neutron mode) and photon activation analyses were employed using the LVR-15 reactor of the Nuclear Research Inst., Řež, plc., and the MT-25 microtron of the Nuclear Physics Inst. ASCR, respectively. Combination of these modes allowed assaying major elements as well as most trace elements (48 elements in total). The studied anomalous phonolites are strongly depleted by compatible elements as Mg, V, Cr, Fe, Ni, Sr, whereas contents of Al, alkaline elements Na, K, Rb, incompatible elements such as Zr, Nb, Hf, Ta, Th, U, rare earth elements, and halogens reach extremely high values. Potential host accessory minerals for some abundant elements have been discussed.

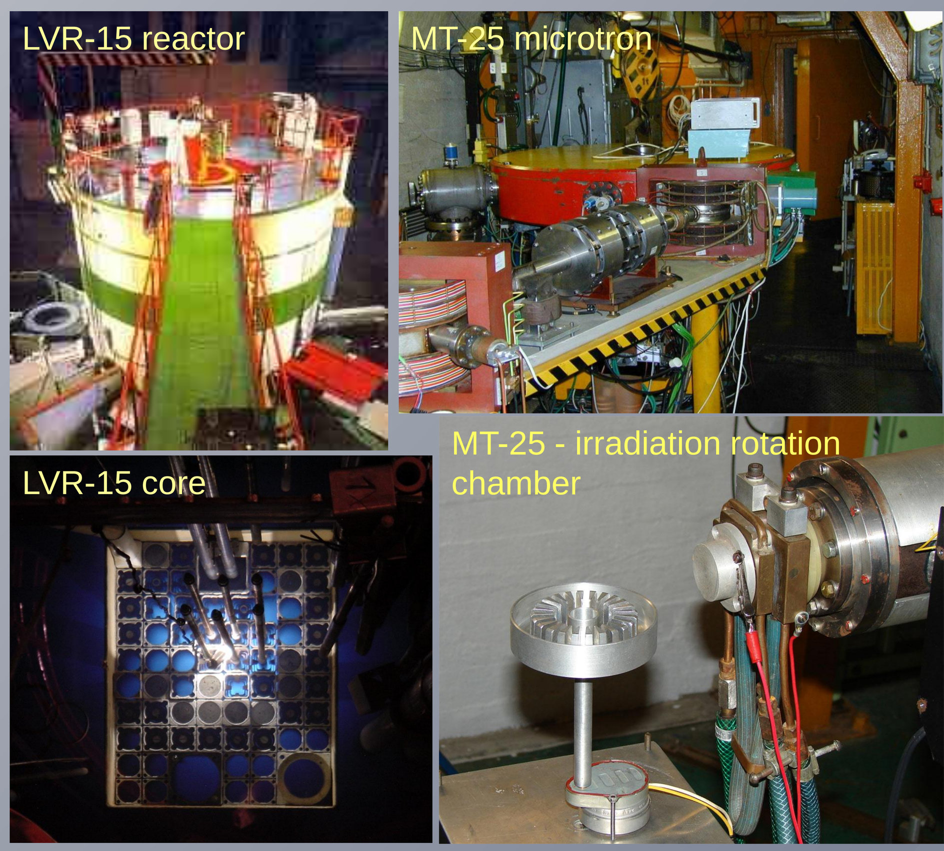
View of the Lusatian Mountains from the Klíč hill (760 m).

Analytical mode No.	Mode description	Sample mass	Irradiation - decay - counting times	Irrradiation operating parameters	Elements determined
1	Short-time INAA, activation with reactor-pile neutrons	~50 mg	1 - 12 - 12 min	LVR-15 reactor 9 MW neutron fluence rates 3e13 - 5e12 n $cm^{-2}s^{-1}$ (th – fast)	Na, K, Mg, Ca, Ba, Al, Ti, V, Mn, Dy, Cl
2	Short-time INAA, activation in Cd shielding (ENAA + FNAA)	~100 mg	0.75 - 13 - 13 min		Si, U
3	Long-time INAA, activation with reactor-pile neutrons - 1st count - 2nd count - 3rd count	200-300 mg	2 h – 5 d – 20 min 2 h – 13 d – 45 min 2 h – 30 (80[a]) d – 2 (8[a]) h	LVR-15 reactor 9 MW neutron fluence rates 8e13 - 2e13 n $cm^{-2}s^{-1}$ (th - fast)	Na, K, As, Sb, Br, La, Sm Rb, Cs, Ca, Ba, Sb, Sc, Cr, Fe, Co, Hf, La, Ce, Nd, Sm, Eu, Yb, Lu, Au, Th Rb, Cs, Ba, Sb, Sc, Cr, Fe, Co, Zn, Hf[a], Ta[a], Ce, Eu[a], Tb[a], Yb[a], Gd[a], Tm[a],Th
4	Long-time INAA, activation in Cd shielding - 1st count - 2nd count - 3rd count	200-300 mg	2 h – 4 d – 30 min 2 h – 7 d – 45 min 2 h – 25 d – 2 h	LVR-15 reactor 9 MW neutron fluence rates 8e13 - 2e13 n $cm^{-2}s^{-1}$ (th - fast)	As, Ga, Br, Mo, W, Ho Rb, Ca, Ba, As, Sb, Br, Mo, Au, Nd, Sm, Yb, Th, U Rb, Cs, Ba, Sr, Sb, Co, Ni, Zr, Hf, Ta, Nd, Tb, Tm, Yb
5	IPAA - 1st count - 2nd cound - 3rd count - 4th count	1-2.5 g	6 (2[b]) h - 5-7 h - 15 min 6 h - 1 d – 30 min 6 h - 7 d – 1 h 6 h - 20 d – 5 h	MT-25 microtron E_γ = 22 (17[b]) MeV I = 15 μA	Sr, Ti, F[b], Cl[b], Nd Mg, Ca, Ba, Ti, Ni, Zr, Th Cs, Ca, Rb, Zr, Nb, Ce, Nd, Sm Na, Rb, Cs, Sr, Mn, Y, Nb, Ce

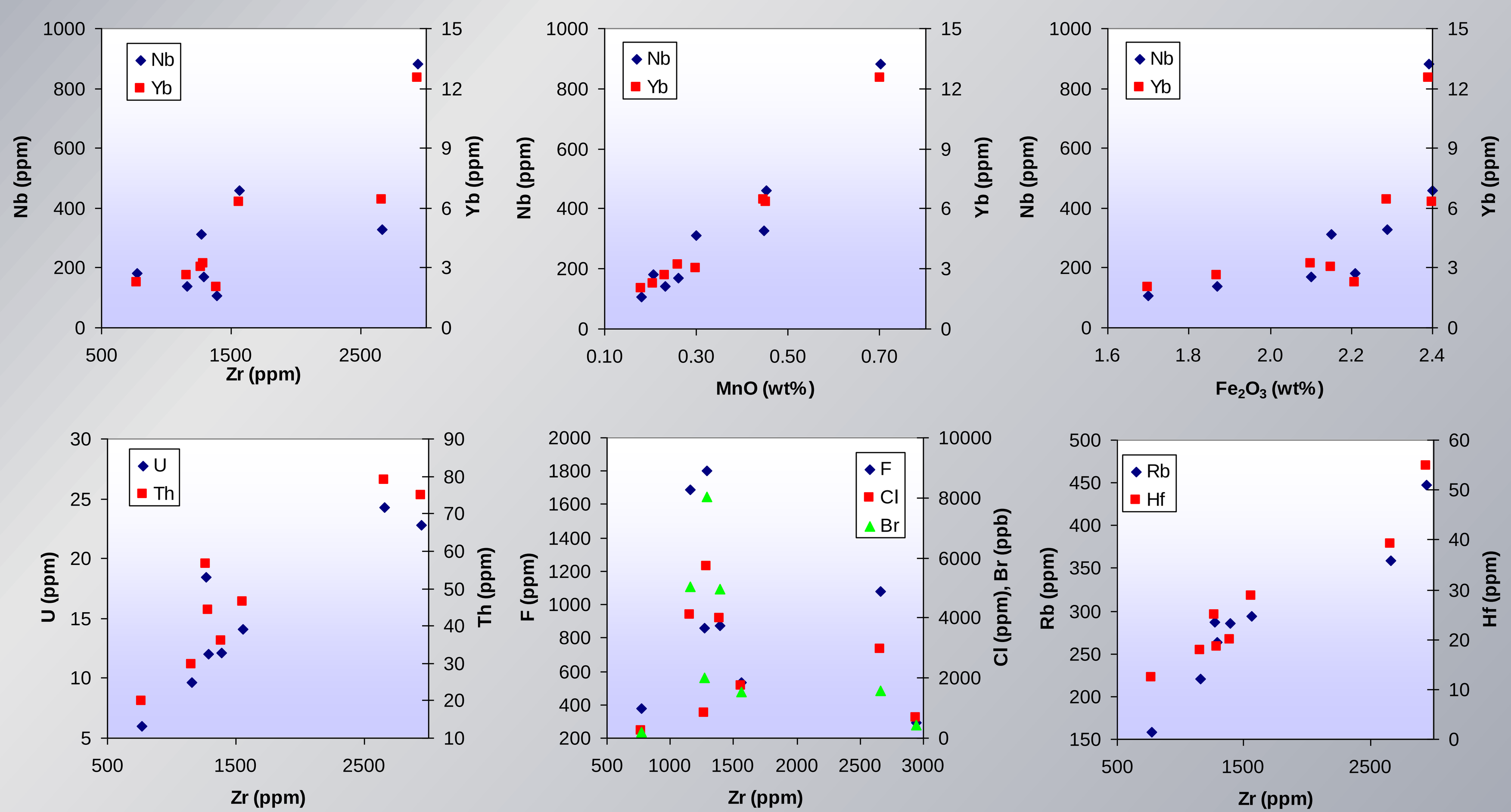
[a] – counting with planar HPGe detector; [b] – F assay – other details see in text

Experimental

- INAA and IPAA
- selective irradiation with epithermal/fast neutrons in Cd shielding included – interferences from fission suppressed (^{95}Zr, ^{99}Mo, ^{140}La, ^{141}Ce, ^{147}Nd)
- various irradiation - decay - counting modes
- F assay by IPAA based on counting non-specific line 511 keV of ^{18}F interfered by formation of other positron emitters (mainly ^{45}Ti and ^{34m}Cl) - analysis of decay curve from 3 counts (1-3, 4-6, 23-25 h decay) + correction standards applied
- RM used for QC: USGS GSP-1 granodiorite, SARM GS-N granite, SARM ISH-G trachyte



Irradiation facilities used for INAA and IPAA.



Results

	wt%	mode		ppm	mode		ppm	mode		ppm	mode
Na_2O	7.14 - 10.36	1,3,5	F	290 - 1802	5	Zr	771 - 2940	5,4	La	91.3 - 238	3
MgO	0.20 - 0.34	5,1	Cl	230 - 5715	1,5	Nb	108 - 880	5	Ce	84.4 - 351	3,5
Al_2O_3	19.84 - 22.86	1	Sc	0.068 - 0.38	3	Mo	1.6 - 5.5	4	Nd	10.2 - 82	3,4,5
SiO_2	54.56 - 59.48	2	V	4.6 - 15.2	1	Sb	0.4 - 1.72	4,3	Sm	0.684 - 11.7	4,3
K_2O	4.87 - 6.36	1,3	Cr	0.9 - 3.9	3	Cs	1.85 - 8.38	4,3,5	Eu	0.136 - 1.64	3
CaO	0.57 - 1.44	1,3,5	Co	0.21 - 0.64	3,4	Ba	67 - 1034	4,3,1,5	Gd	1.8 - 14	3
TiO_2	0.17 - 0.41	5,1	Ni	<1 - 2.7	5,4	Hf	12.4 - 54.9	3,4	Tb	0.131 - 0.356	4,3
MnO	0.18 - 0.70	1,5	Zn	102 - 360	3	Ta	1.39 - 42.0	4,3	Dy	1 - 15.9	1
Fe_2O_3[a]	1.70 - 2.40	3	Ga	19.3 - 56.7	4	W	0.68 - 2.63	4	Ho	0.27 - 3.52	4
LOI	1.17 - 4.99		As	2.04 - 10.16	4,3	Au	0.008 - 0.137	4,3	Tm	0.23 - 3.52	4
			Br	0.2 - 8.03	4,3	Pb	<15 - 63	5	Yb	2 - 1.99	3,4
total	*99.4 - 101.4*		Rb	158 - 447	4,3,5	Th	19.8 - 78.8	4,3,5	Lu	0.33 - 12.5	3
			Sr	2.8 - 242	5,4	U	6.0 - 24.3	4,2,5			
			Y	10.7 - 118	5						

Examples of interpretation of host accessory minerals for incompatible elements and halogens:

- Nb, Yb vs. Zr, MnO, Fe_2O_3 – REE hosting by columbite $(Fe,Mn)(Nb,Ta)_2O_6$ rather than zircon
- F vs. Zr – F hosting by previously suggested hainite $Na_4Ca_8(Ti,Zr,Mn)_3Si_2O_7F_4$ improbable
- U, Th vs. Zr – typical hosting of U and Th by zircon confirmed
- Rb vs. Zr – unusual perfect correlation – interpretation unknown

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