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VLADIMÍR BOUŠKA* — EMIL JELÍNEK* — MAGDALÉNA PAČESOVÁ* —
ZDENĚK ŘANDA** — JAROMÍR ULRYCH*

RARE EARTH ELEMENTS AND OTHER TRACE ELEMENTS IN THE ROCKS OF THE CENTRAL BOHEMIAN PLUTON

(Figs. 9, Tabs. 4)

Abstract: Thirty four samples of selected rocks from the Central Bohemian Pluton were analyzed in order to determine the distribution especially of the rare earth elements, alkali metals, uranium, thorium and transition metals. The complicated differentiation development of the rocks, ranging from the basic types through the intermediate to the acid ones is also evidenced by the distribution of trace elements. The durbachitic rocks could represent the remelted upper earth's crust. The hybrid granitoids represent the mixed types. By their trace elements content they are closest to acid or intermediate rocks, and by their REE distribution they approach durbachites. The contamination by the mantle rocks of the pluton is their characteristic feature.

Резюме: В целях определения распределения элементов особенно редких земель, алкалических металлов, урана, тория и переходных металлов было анализировано 34 проб избранных пород Среднечешского плутона. Сложное дифференциационное развитие пород с основных через переходные до кислых типов вытекает из распределения элементов примесей. Дурбахитовые породы вероятно представляют переплавленную верхнюю земную кору. Гибридные гранитоиды смешанным типом. По содержанию примесей элементов они ближе всего кислым или переходным породам, и по содержанию элементов редких земель они похожи на дурбахиты. Для них характерна контаминация породами мантии плутона.

Introduction

The Central Bohemian Pluton belongs to massifs of a complex structure, occurring not only within the area of the Bohemian Massif but also throught the Variscan orogene. This several-phase polymagmatic complex occupies a significant position in the structural plan of the Bohemian Massif. The Central Bohemian Pluton constitutes a body triangular in shape, covering an area of about 3200 km^2. In dependence on the tectonic position it stretches NE—SW.

Its contacts with various adjacent structural units are of different characters. Its sharp thermal contact is characteristic of its western boundary at the junction with the Proterozoic of the Barrandian, but less at that with the Palaeozoic. The contact line is sharp in the sense of Raguin's "massifs circonscrit" (1957). Its eastern and southern boundaries, i. e. that with the Moldanubian rocks, are of different type. It is irregular contact displaying numerous apophysal projections which follow the structures of the adjacent metamorphic rocks

*Doc. RNDr. V. Bouška, DrSc., RNDr. E. Jelínek. CSc., M. Pačesová, MSc., RNDr. J. Ulrych, CSc., Faculty of Natural Sciences, Charles University, Albertov 6, 128 43 Praha 2.

** RNDr. Z. Řanda, CSc., Institute of Mineral Raw Materials, 284 03 Kutná Hora-Sedlec.

in the sense of Raguin's "massifs d'anatexie" (1957). The development of an irregular migmatite aureole and the occurrence of the rocks of the durbachitic type are typical for this contact.

The problems of the origin of the Central Bohemian Pluton were solved from two principal points of view. Up to 1970, a magmatic-differentiation approach dominated throughout (Kettner, 1930, 1933; Orlov, 1935, 1938; Kodym in Svoboda, 1966; Steinocher, 1969).

A quite different view is expressed in the paper by Palivcová (1965). It is based on the transformistic ideas of Raguin's (1957) concept, on Mehnert's (1960) considerations of selective mobilization, and on the experiments with anatectic melts (Winkler and Platen, 1961).

The authors of mineralogical-petrological papers rather prefer the magmatic origin of the Central Bohemian Pluton, whereas the results of petrological-structural papers are closer to the opinions of its metasomatic development.

Vejnar (1973, 1974 a) has distinguished two main crystallization phases in the rocks complex of the Central Bohemian Pluton. The first, having the distinct Mg-Fe fractionation, is of a shallow-intrusive character (especially the basic rocks) and corresponds to the earlier pre-Variscian phase. The later phase, the Variscian phase proper, is of a plutonic character (comprising the other mostly granitoid rocks); its Mg-Fe fractionation is less important and K content dominates over Na. According to Vejnar, tholeiitic magma derived from the upper mantle could represent the source of the first-phase rocks, whereas the second-phase rocks originated rather from the palingenetic magma of the Earth's crust.

The trace elements in the rocks of the Central Bohemian Pluton were studied by Vejnar (1974 b). He has found that the distribution of Be, Li, Rb and Zr and to a certain extent also Cr and Ni is influenced rather by the K/Na ratio than by the basicity of the rocks, expressed by the Larsen differentiation index.

The geochemistry of the Central Bohemian Pluton was also studied by Bubeníček et al. (1967) and by Fatková (1967). Tauson et al. (1977) and Minařík et al. (1979) have delimited four groups of rocks. The first group comprises gabbro and diorite rocks (Pecerady, Teletín and Starý Knín), the second group includes tonalite rocks and granodiorites (tonalite of the Sázava type, granodiorite from Blatná etc.), the third group consists of leucocratic granites (Požáry trondhjemite, Říčany granite etc.), and fourth group is formed by durbachite rocks (Tábor syenite and melanocratic granites to monzonite of the Čertovo břemeno type etc.).

The K/Rb ratios occurring in the rocks of the Central Bohemian Pluton have been found to range from 100 to 300. The highest ones are those in tonalites and gabbros, whereas the low values (about 100) belong to the rocks of the Říčany granite and Písek leucogranite.

Minařík et al. (1979) also report that the Ba/Cs ratio is the most sensitive indicator of differentiation in the Central Bohemian Pluton rocks; it decreases during crystallization. The authors distinguished the rocks of a Ba/Cs ratio < 100 (e. g. the Říčany granite, the Čertovo břemeno durbachites etc.) and the rocks of a Ba/Cs ratio > 100 (gabbros, tonalites, granodiorites of Blatná and Červená, and the granite of a marginal type).

In this paper an attempt is made to discuss the distribution of REE, U, Th and some other trace elements in the rocks to find out their variation in the individual rock types and also to reveal the known polyphase development of the Central Bohemian Pluton and its zonality.

Methods

For the investigation, 34 samples were taken from the characteristic localities representing the main rock types and the bodies of the Central Bohemian Pluton. A survey of the samples is given in Table 1 where the specimens are already ranged into groups, subgroups and types using Palivcová (1965) classification as well as the mineralogical and geochemical characteristics resulting from this paper.

The samples were analyzed using the non-destructive neutron activation analysis. The analytical technique and the sample preparation were described by Řanda et al. (1972 and 1978). The accuracy resulting from the reproducibility of the series of repeated analyses is expressed for the elements as follows: accuracy exceeding 5 % — La, Sc, Fe, Th, 10 % — Sm, Cr, Co, Hf, U, 15 % — Rb, Ce, 20 % — Cs, Eu, Yb, Lu, 30 % — Tb.

The potassium content has been determined by the atomic absorption spectrometry.

The results are given in Table 2 and 3.

Table 1

List of samples

Group A — durbachitic rocks

Tábor type — medium-grained pyroxene-biotite syenite:
sample 5 — Klokoty near Tábor, the quarry in the Lužnice river valley
Čertovo břemeno type — porphyritic amphibole-biotite syenodiorite:
sample 1 — Petrovice near Milevsko, the quarry,
sample 2 — Votice, the quarry at the railway station
Červená type — (porphyritic) amphibole-biotite granodiorite:
sample 3 — Malé Nepodřice, the quarry at the elevation point 430.2, near Písek,
sample 4 — Horažďovice, the quarry at the railway station

Group B — basic rocks

B/1 — pyroxene-amphibole gabbros:
sample 30 — Svárov, abandoned quarry,
sample 31 — Pecerady, abandoned quarry,
sample 34 — Velké Popovice, quarry
B/2 — amphibole-biotite (quartz) gabbrodiorites (Nos. 32, 33) to quartz diorites (No. 35):
sample 32 — Vavřetice, abandoned quarry,
sample 33 — Brtnice, canal of the Želivka river,
sample 35 — Teletín, the main abandoned quarry

Group C — intermediate rocks

C/1 — medium-grained biotite-amphibole granodiorites (Nos. 10, 11, 12) to quartz diorites (tonalites): (No. 14)
Bohutín type

sample 14 — Bohutín mine, the Rudné doly Příbram

Sázava type
sample 10 — Prosečnice, quarry,
sample 12 — Teletín, the main abandoned quarry,
sample 11 — Mrač near Benešov, quarry

C/2 — (amphibole-) biotite (porphyritic) granodiorites:

Klatovy type — medium grained
sample 20 — Klatovy, the quarry W of Luhy

Sedlčany type — porphyritic
sample 18 — Vrchotovy Janovice, quarry

Těchnice type — porphyritic
sample — 17 — Těchnice, the left bank of the Vltava river

Blatná type — medium-grained
sample 13 — Blatná, quarry of the Konstruktiva enterprise

Vltava type — medium grained
sample 15 — Kozárovice, quarry,
sample 16 — Solopysky, quarry

Group D — acid rocks

Marginal type — porphyritic amphibole-biotite granite:
sample 22 — Nepomuk, abandoned uqarry
sample 22 — Nepomuk, abandoned uqarry

Říčany type — porphyritic muscovite-biotite granite:
sample 25 — Žernovka, abandoned quarry,
sample 26 — Březí near Říčany, abandoned quarry,
sample 27 — Vyžlovka, quarry

Něčín type — medium grained biotite granodiorite:
sample 8 — Něčín, quarry

Mrač type — fine-grained biotite granodiorite:
sample 29 — Mrač near Benešov, quarry

Požáry type — medium-grained biotite granodiorite — quartz diorite (trondhjemite):
sample 23 — Prosečnice, quarry

Group E — hybrid rocks

Kosova Hora type — fine-grained muscovite-biotite granite:
sample 19 — Kosova Hora, quarry,
sample 36 — Kosova Hora, quarry

Sedlec type — fine-grained biotite granodiorite:
sample 9 — Prčice, abandoned quarry 1 km E of the village

Benešov type — fine-grained biotite granodiorite:
sample 6 — Dlouhé Pole, quarry at the road,
sample 7 — Bařiny, elevation point 532, S of Kozmice

Results

The rocks of the Central Bohemian Pluton have been tested according to their contents of REE, alkali metals, transition metals, uranium and thorium.

Alkali metals

In general, the alkali metals (K, Rb, Cs) contents increase from the more basic to acid granitoids in dependence on the mineral composition of the rocks (Tables 3 and 4). In the basic rocks of the group B, the potassium content is lower in pyroxene-amphibole gabbros (subgroup B/1) than in the

Table 2

Rare earth element, Th and U abundances (in ppm) in the rocks of the Central Bohemian Pluton

Group	A — durbachitic rocks					B — basic rocks					
Subgroup						B/1 pyroxene-amphibole gabbros			B/2 amph.-biot. (quartz) gabbrodiorites to quartz diorites		
Type	Tábor	Čertovo břemeno		Červená							
Sample No.	5	1	2	3	4	30	31	34	32	33	35
La	37.6	35.1	30.8	46.0	23.5	10.4	6.2	< 6	4.2	12.8	14.2
Ce	118	80	68	98	63	< 15	38	< 12	< 13	< 20	47.5
Sm	10.4	7.0	6.3	4.8	4.8	1.5	3.6	1.3	1.3	6.4	4.1
Eu	1.98	1.60	1.97	1.40	1.30	< 1.0	0.75	0.40	0.45	1.47	1.40
Tb	1.0	0.92	0.7	0.45	0.5	0.3	0.65	0.3	0.34	0.88	0.75
Yb	2.9	2.0	1.9	1.94	1.9	< 1	< 1	< 0.8	< 0.85	3.1	3.2
Lu	0.26	0.17	0.44	0.21	0.19	< 3.5	—	—	—	—	< 3
Th	23.3	32.9	16.4	13.2	7.9	4.1	2.9	2.5	1.9	2.0	4.6
U	7.7	16.2	6.3	3.3	6.4	< 1.7	—	—	—	—	—
Ce_N/Yb_N*)	9.2	9.1	8.10	11.4	7.5						3.4
Σ REE	172.14	126.79	110.11	152.8	95.19						
La/Th	1.6	1.1	1.9	3.5	3.0	2.5	2.1		2.2	6.4	3.1
Th/Yb	8.0	16.5	8.6	6.8	4.2					0.6	1.4
Th/U	3.0	2.0	2.6	4.0	1.2						
Th/Sc	1.4	3.1	1.1	0.9	0.5	0.05	0.04	0.05	0.09	0.08	0.15

* N refers to chondrite normalized value (chondrite data of Wedepohl, 1975).

Continuation of Tab. 2

Group	C — intermediate rocks									
Subgroup	C/1 biotite-amphibole granitoids (amphibole ⩾ biotite)				C/2 (amphibole-) biotite granodiorites (biotite ≫ amphibole)					
Type	Bohutín	Sázava			Klatovy	Sedlčany	Těchnice	Blatná	Vltava	
Sample No.	14	10	12	11	20	18	17	13	15	16
La	17.4	28.0	25.6	21.9	21.9	40.6	28.6	32.5	30.2	34.2
Ce	39	56.5	55	66	59.5	80.1	54.5	84	64	79.5
Sm	5.0	3.6	3.5	3.8	2.3	9.7	7.5	5.2	5.9	4.6
Eu	1.18	1.20	1.30	1.27	0.54	0.97	0.68	1.11	1.20	1.39
Tb	0.77	0.45	< 0.2	0.53	0.62	< 0.5	< 0.3	0.4	0.5	0.7
Yb	2.4	1.5	1.3	< 0.8	2.4	1.9	1.6	1.9	1.9	2.2
Lu	—	0.26	0.19	—	0.27	0.21	0.23	0.19	0.25	0.32
Th	6.3	8.7	7.2	12.7	23.5	24.0	18.0	17.7	—	15.8
U	—	< 0.7	1.7	—	6.0	11.9	8.0	8.3	6.7	7.9
Ce_N/Yb_N	3.7	8.5	9.6		5.6	9.5	7.7	10.0	7.6	8.1
Σ REE		91.51			87.53			125.30	103.95	122.91
La/Th	2.8	3.2	3.6	1.7	0.9	1.7	1.6	1.8		2.2
Th/Yb	2.6	5.8	5.5		9.8	12.6	11.3	9.3		7.8
Th/U			4.2		3.9	2.0	2.3	2.1		2.0
Th/Sc	0.3	0.5	0.5	0.5	4.1	2.2	1.6	2.0		0.9

Continuation of Tab. 2

Group	D — acid rocks								E — hybrid rocks				
Subgroup													
Type	Marginal		Říčany			Něčín	Mrač	Po-žáry	Kosova Hora		Sedlec	Benešov	
Sample No.	21	22	25	26	27	8	29	23	19	36	9	6	7
La	29.0	34.8	24.3	24.3	17.5	17.8	34.0	40.5	29.7	72.3	36.2	33.3	21.9
Ce	54	49	71.5	51.0	50	36	104.3	107.0	90.5	153	42	94	61
Sm	4.2	3.1	4.6	4.0	4.1	1.5	7.4	1.4	7.13	10.6	5.7	9.7	3.8
Eu	0.89	0.92	0.92	<1.6	0.55	0.60	1.04	0.86	1.26	1.58	1.45	1.49	0.64
Tb	0.20	0.60	0.35	<0.3	0.25	<0.3	0.41	<0.3	0.90	<0.3	0.90	0.60	0.46
Yb	1.3	1.9	<0.5	<0.5	0.8	1.4	2.0	0.7	2.5	1.8	2.2	2.6	1.4
Lu	0.12	0.30	0.04	0.10	0.03	0.15	0.23	0.12	0.28	0.19	0.25	0.31	0.16
Th	15.0	19.1	32.5	21.2	32.1	6.8	18.1	16.9	25.3	22.0	15.3	24.8	10.4
U	6.0	3.7	12.5	3.5	11.7	3.0	4.6	3.0	14.8	11.5	3.4	3.7	2.3
Ce_N/Yb_N	9.5	5.8			14.2	5.8	11.8	34.4	8.2	19.2	4.3	8.2	9.8
$\sum$ REE	89.71	90.62			73.23		149.38		132.27		88.70	142.00	89.36
La/Th	1.9	1.8	0.75	1.1	0.55	2.6	1.9	2.4	1.2	3.2	2.4	1.3	2.1
Th/Yb	11.8	10.1			40.1	4.9	9.1	24.1	10.1	12.2	7.0	9.5	7.4
Th/U	2.5	5.2	2.1	6.1	2.7	2.3	3.9	5.6	1.7	1.9	4.5	6.7	4.5
Th/Sc	3.2	2.5	6.9	4.2	13.4	1.8	1.9	4.6	2.5	1.6	1.1	2.4	2.9

Table 3

Concentration of alkalies, transition metals, Hf, Sb and Ta (in ppm) in the rocks of the Central Bohemian Pluton

Group	A — durbachitic rocks					B — basic rocks					
Subgroup						B/1 pyroxene-amphibole gabbros			B/2 amph.-biot. (quartz) gabbrodiorites to quartz diorites		
Type Sample No.	Tábor 5	Čertovo břemeno 1	 2	Červená 3	 4	30	31	34	32	33	35
K (wt.%)	5.16	5.26	4.09	3.04	3.07	0.88	0.83	0.52	0.62	1.15	0.94
Rb	282	344	205	146	149	<60	<56	<49	<59	<55	<58
Cs	20.6	30.6	9.1	8.0	8.0	—	—	—	—	—	—
K/Rb	183	153	200	208	206						
K/Th	2215	1599	2494	2303	3886	2146	2862	2080	3263	5750	2043
Sc	16.2	10.8	14.9	14.8	15.9	75.8	80.7	54.7	21.5	23.9	30.3
Cr	308	255	225	78	93	161	105	70	59	—	47
Fe (wt.%)	3.9	2.9	3.6	3.8	3.9	6.6	7.2	4.8	5.1	7.4	7.0
Co	19.5	16.2	16.3	13.7	11.7	36.9	34.5	31.5	23.9	12.7	18.5
Sc/Co	0.8	0.7	0.9	1.1	1.4	2.1	2.3	1.7	1.9	1.9	1.6
Hf	11.3	8.0	6.9	5.2	5.0	<7.6	<7.3	<6	<7	<6.3	<6.8
Sb	—	—	—	—	—	1.0	0.9	—	0.9	1.4	1.4
Ta	—	—	—	—	—	0.13	—	—	—	0.1	0.26

Continuation of Tab. 3

Group	C — intermediate rocks									
Subgroup	C/1 biotite-amphibole granitoids (amphibole ≫ biotite)				C/2 (amphibole-) biotite granodiorites (biotite ≫ amphibole)					
Type	Bohutín	Sázava			Klatovy	Sedlčany	Těchnice	Blatná	Vltava	
Sample No.	14	10	12	11	20	18	17	13	15	16
K (wt.%)	1.73	1.30	1.19	1.95	3.88	4.31	3.65	3.30	3.25	3.50
Rb	80	<40	58	<50	129	338	177	150	146	141
Cs	—	<1	—	3.9	9.1	33.2	13.0	10.7	9.5	7.6
K/Rb	216		205		301	127	206	219	223	248
K/Th	2768	1494	1653	1542	1651	1796	2028	1864		2215
Sc	19.4	19.3	14.0	24.7	5.78	10.9	11.6	8.84	15.1	17.8
Cr	—	—	—	—	—	133	40	24	67	75.4
Fe (wt.%)	5.0	4.9	4.8	5.8	2.0	2.8	3.2	2.45	3.8	4.1
Co	20.6	11.8	11.6	17.2	5.1	12.1	9.3	6.33	11.5	13.8
Sc/Co	0.9	1.7	1.2	1.4	1.1	0.9	1.2	1.4	1.3	1.3
Hf	5.0	2.9	4.5	4.0	3.5	7.4	3.6	4.5	3.2	4.6
Sb	0.88	—	—	—	—	—	2.3	—	—	—
Ta	0.76	—	—	0.14	—	—	—	—	—	—

Continuation of Tab. 3

Group	D — acid rocks								E — hybrid rocks				
Subgroup													
Type	Marginal		Říčany			Něčín	Mrač	Požáry	Kosova Hora		Sed-lec	Benešov	
Sample No.	21	22	25	26	27	8	29	23	19	36	9	6	7
K (wt.%)	3.17	3.50	4.92	4.38	2.12	1.89	3.45	1.50	2.15	2.19	3.15	4.09	3.01
Rb	112	121	255	347	218	<37	160	49	248	189	197	227	120
Cs	—	6.6	22	60	9.1	3.1	7.1	2.3	28.3	20.4	8.2	14.7	7.7
K/Rb	283	289	193	126	97		215	306	87	116	160	180	251
K/Th	2113	1832	1514	2066	611	2800	1906	888	850	995	2059	1649	2894
Sc	4.7	7.6	4.7	5.08	2.4	3.74	9.37	3.66	10.1	13.9	14.2	10.3	3.65
Cr	—	26	32	35	—	—	32	—	91	63	89	65	—
Fe (wt.%)	2.2	2.7	1.2	1.38	0.75	2.4	2.5	2.3	2.3	3.3	3.2	2.65	1.43
Co	5.0	6.2	3.6	2.3	<3	2.2	7.3	3.7	12.1	13.3	12.2	7.6	2.0
Sc/Co	0.9	1.2	1.3	2.2		1.7	1.3	1.0	0.83	1.1	1.2	1.4	1.8
Hf	4.1	4.6	6.8	4.1	4.4	2.6	4.5	2.8	6.0	10.2	4.6	6.6	2.6
Sb	1.3	—	—	—	—	—	—	—	—	—	—	—	—
Ta	—	—	—	8.0	—	—	—	—	2.4	—	—	—	—

Table 4

Average values of the chemical data for the rocks of the Central Bohemian Pluton (in ppm)

Group	A-durbachitic rocks	B-basic rocks		C-intermediate rocks		D-acid rocks	E-hybrid rocks
Subgroup		B/1	B/2	C/1	C/2		
	$\bar{x}$ (n = 5)	$\bar{x}$ (n = 3)	$\bar{x}$ (n = 3)	$\bar{x}$ (n = 4)	$\bar{x}$ (n = 6)	$\bar{x}$ (n = 8)	$\bar{x}$ (n = 5)
La	34.6	8.3 (2)	10.4	23.2	31.3	27.8	38.7
Ce	85.5	38 (1)	47.5 (1)	54.1	70.3	65.4	88.1
Sm	6.6	2.1	3.9	4.0	5.8	3.8	7.4
Eu	1.65	0.58 (2)	1.1	1.24	0.98	0.83 (7)	1.28
Tb	0.71	0.42	0.66	0.58 (3)	0.56 (4)	0.36 (5)	0.72 (4)
Yb	2.13		3.15 (2)	1.73 (3)	1.98	1.35 (6)	2.1
Lu	0.25			0.23 (2)	0.25	0.14	0.24
Th	18.7	3.2	2.8	8.7	19.8	20.2	19.5
U	8.0			1.7 (1)	8.1	6.0	7.1
Ce_N/Yb_N	9.05		3.4 (1)	7.3 (3)	8.1	13.6 (6)	9.9
Eu/Eu*	0.81	0.78	0.84	0.96	0.56	0.73	0.57
Σ REE	131.5			91.51 (1)	109.9 (4)	100.7	113.0 (4)
La/Th	2.5	2.4 (2)	3.9	2.8	1.6 (5)	1.6	2.0
Th/Yb	8.8		1.0 (2)	4.6 (3)	10.2 (5)	16.7 (6)	9.2
Th/U	2.6			4.2 (1)	2.5	3.8	3.9
Th/Sc	1.4	0.05	0.11	0.44	2.2	4.8	2.1
K (wt.%)	4.12	0.74	0.90	1.54	3.65	3.12	2.9
Rb	225			69 (2)	180.2	180.3	196.2
Cs	15.3			3.9 (1)	13.8	15.8 (7)	15.8
K/Rb	190			210.5 (2)	220.7	215.6	158.8
K/Th	2499	2363	3685	1864	1911 (5)	1723	1689
Sc	14.5	70.4	25.2	19.3	11.7	5.16	10.4
Cr	192	112	52.8 (2)		67.9 (5)	31.3 (4)	77 (4)
Fe (wt.%)	3.6	6.2	6.5	5.1	3.1	1.93	2.6
Co	15.5	34.3	18.4	15.3	9.7	4.3 (7)	9.4
Sc/Co	0.98	2.0	1.8	1.3	1.1	1.4 (7)	1.3
Hf	7.3			4.1	4.5	4.2 (7)	6.0

N refers to chondrite normalized value (chondrite data of Wedepohl, 1975).

Ratio of normalized Eu value to that obtained by interpolation between Sm and Tb.

Numbers in parentheses at $\bar{x}$ column show actual number of samples used for the calculation of the average.

amphibole-biotite rocks of the subgroup B/2. By the potassium content the subgroups C/1 and C/2 could also be distinguished in intermediate rocks. With increasing biotite content in the rocks of the groups B and C the potassium amounts also increases. Lower potassium concentrations in the granites of the group D, ranging from 1.50 wt.% to 4.92 wt.%, depend on the proportion of micas and potassium feldspar.

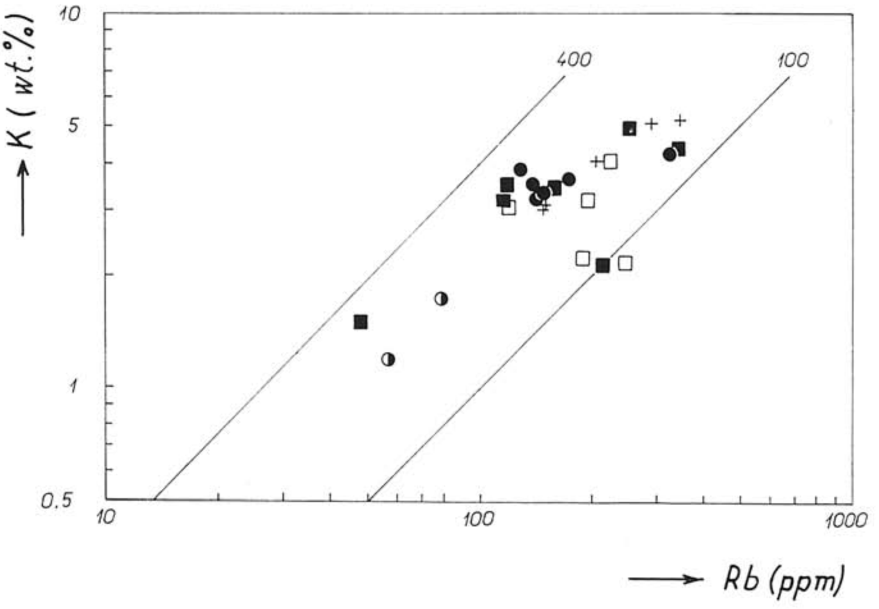

Fig. 1. Correlation diagram of the potassium and rubidium contents of the rocks of the Central Bohemian Pluton.
Key for Figs. 1—9: + — durbachitic rocks of the group A; ◭ — basic rocks of the subgroup B/1 (pyroxene-amphibole gabbros); ▲ — basic rocks of the subgroup B/2 (amphibole-biotite gabbrodiorites to quartz diorites); ◑ — intermediate rocks of the subgroup C/1 (amphibole ≥ biotite); ● — intermediate rocks of the subgroup C/2 (biotite ≫ amphibole); ■ — acid rocks of the group D; □ — hybrid rocks of the group E.

Because of low concentrations of rubidium and cesium in the basic rocks they were not determined. However, the concentrations of Cs increase in the row C/1 — C/2 — D rock groups (average values are 3.9 — 13.8 — 15.8 ppm Cs; Table 4). As to rubidium, its notable increase is perceptible between C/1 and C/2 group, but the intermediate rocks with dominating biotite over amphibole (C/2) have its average amounts equal to those of the acid rocks of the group D.

The K/Rb ratio in intermediate and acid rocks (groups C and D) varies in the individual samples ranging from 97 to 306 (see also Minařík et al., 1979), but on average it is equal in both these groups, i. e. about 215 (Fig. 1).

Positive correlation between the potassium and thorium concentrations is illustrated in Fig. 2. The same also holds for the potassium and uranium abundances. Thorium and uranium contents increase from the relatively "primitive" basic rocks to geochemically more differentiated ones. Heier and Rogers (1963) have pointed out that in a great number of various igneous rocks the K/Th ratio ranges from 1500 to 3000 only. In the rocks of the Central Bohemian Pluton the K/Th ratio is ~ 2000. In the basic types with a low potassium, this ratio is higher, whereas in acid rocks with a higher potassium con-

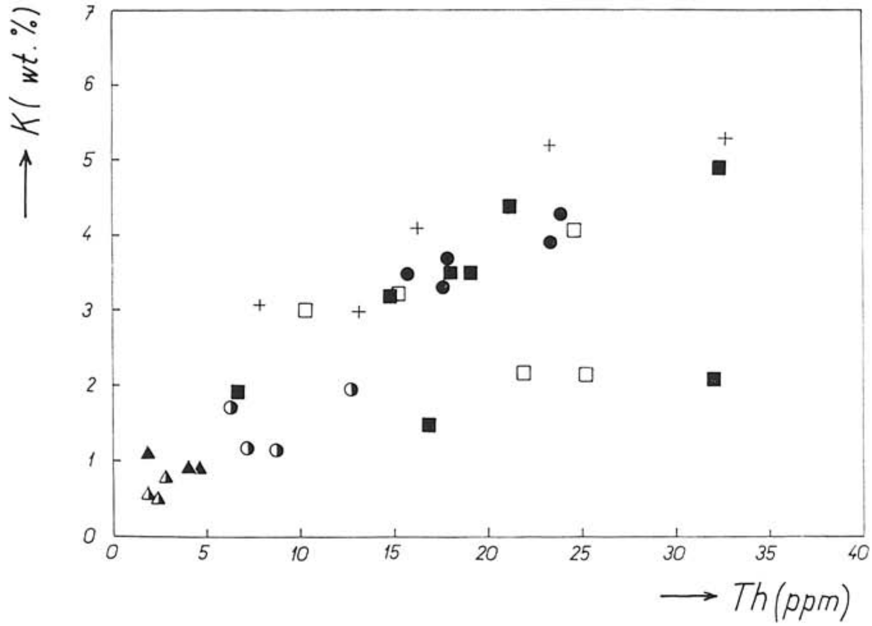

Fig. 2. Relation between potassium and thorium contents in the rocks of the Central Bohemian Pluton.

tent the K/Th ratio is lower. In Fig. 2, due to the K and Th contents, the group of basic rocks (B) and the subgroups C/1 and C/2 of intermediate rocks are separated. As in other correlation diagrams the samples of the rock groups C/2 and D overlap. In Fig. 2 the acid rocks are scattered considerably and behave similarly as the hybrid rocks of group E.

The similar pattern is shown in K vs. La diagram (Fig. 3).

Rare earth elements

Many papers have been devoted to solve the distribution of REE in connection with the genesis of granitic rocks as e. g. the geochemical studies by Buma et al. (1971), Arth and Hanson (1975), de Albuquerque (1978), Fourcade and Allegre (1981) and Gromet and Silver (1983).

The REE distribution exhibits the similar pattern through the all types of the rocks of the Central Bohemian Pluton (Fig. 4):

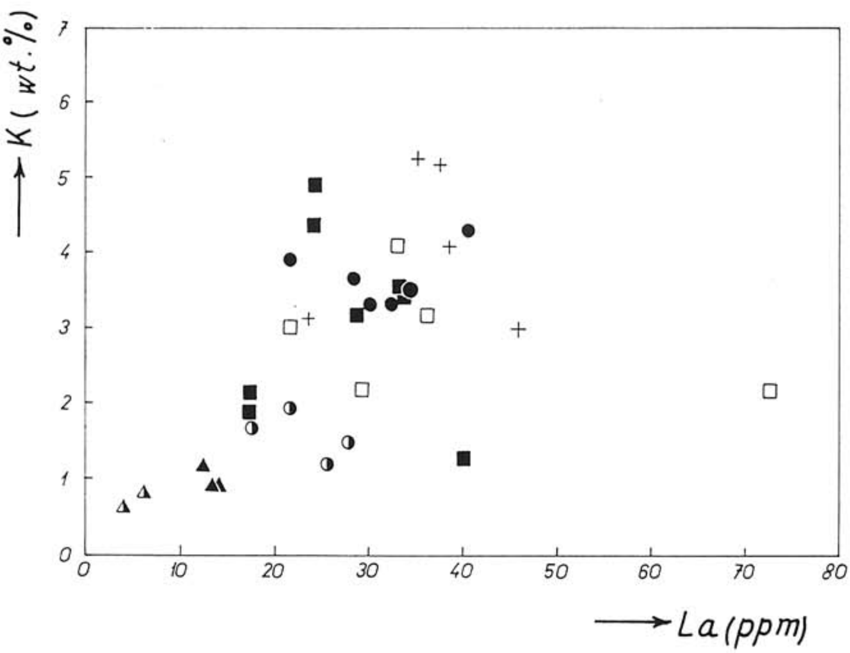

Fig. 3. Diagram of the relation of potassium to lanthanum in the rocks of the Central Bohemian Pluton.

a) Enrichment of light over heavy REE is found in all rock groups. It is expressed by Ce_N/Yb_N ratio which ranges from 3.4 (in basic rocks B/2), through 7.3 (in intermediate rocks C/1), 8.1 (in intermediate rocks C/2) to 13.6 (in acid

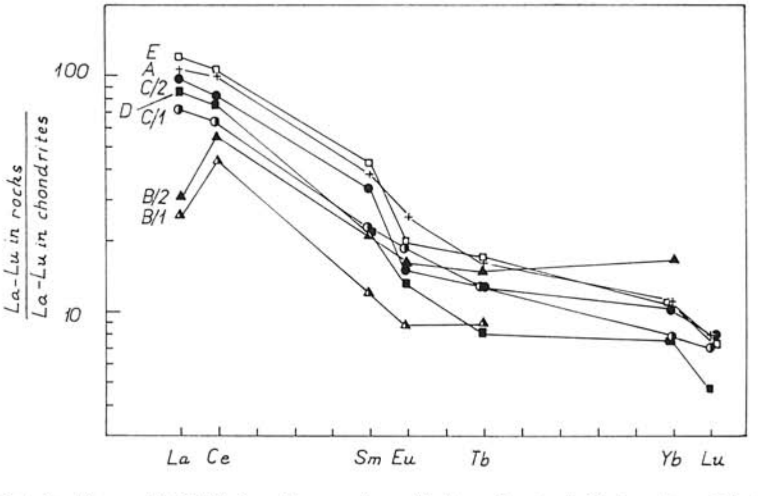

Fig. 4. Distribution of REE in the rocks of the Central Bohemian Pluton. The contents are normalized by chondrites (W e d e p o h l, 1975).

rocks D). Durbachitic rocks A ($Ce_N/Yb_N = 9.1$) and hybrid rocks E ($Ce_N/Yb_N = 9.9$) are closest to the group C/2 (Table 4.).

b) Although there is some overlap, the REE contents are lowest in the basic rocks and continuously increase through intermediate and acid rocks.

A rather slight decrease of the REE content may be observed in the rocks of the acid granitoids (group D). In this case the sum of REE is relatively low in comparison with the intermediate rocks (e. g. C/2). The same trend in analogous rocks from other massifs was observed e. g. by de Albuquerque (1978) or Fourcade and Allegre (1981).

Depletion of La to Ce in the basic rocks (B/1 and B/2) is due to presence of hornblende as one of the major mineral phase and major carrier of REE in these rocks (see also HREE).

c) In all rock types appears negative Eu anomaly ($Eu/Eu^* = 0.56—0.96$; see Table 4). The very small depletion of Eu is found in intermediate rocks (subgroup C/1) as a consequence of mineralogical composition of these rocks (plagioclase with low anorthite component).

According to the distribution of REE the durbachitic and hybrid rocks together with the acid ones would represent the most developed rocks throughout the pluton.

The continual increasing content of REE together with the decrease of the transition metals. (Table 4) in the series B, C/1, C/2 and D furnishes evidence of fractional crystallization in this series.

The differentiation trend of the rocks is express on Fig. 9 by the relation of compatibile (Co) and ratio of incompatibile (Ce_N/Yb_N) elements. The average value of hybrid rocks (group E) is plotted close to the main differentiation trend. The durbachitic rocks (group A) lie out of this trend.

The sum of LREE are highest in the hybrid rocks (E) and the durbachites (A) — see Fig. 4. The distribution of REE in these rocks is close to that of post-Archean shales (e. g. NASC — Nance and Taylor, 1976). This congruence permits the assumption that the rocks of the groups A and E were enriched by the sedimentary material or its metamorphic equivalent of the upper crust (hybrid rocks E), or arose by their granitization (durbachitic rocks A).

The La/Th ratio is low in whole series of rocks, not attaining 4; it is characteristic of the Phanerozoic earth crust with relatively felsic composition (Mc Lennan et al., 1980).

The Th/Yb ratio varies very sensitively through the series of magmatic rocks. Our data tend to have lower Th/Yb ratio in basic rocks (in B/2 group — 1.0), higher in intermediate rocks (in C/1 — 4.6, C/2 — 10.2) and acid rocks (D — 16.7). Durbachitic and hybrid rocks with Th/Yb = 8.8 and 9.2 are mostly similar to intermediate rocks of C/2 subgroup.

Thorium and uranium

These elements are in positive correlation, their content being higher in more acid rocks than in the basic ones (Table 4). The durbachitic (A) and the hybrid rocks (E) contain thorium and uranium amounts which are closest to those of the subgroup C/2. The Th/U ratio is similar between the durbachitic rocks (A) and the subgroup C/2. The Th/U ratio of the hybrid rocks is close to that of the acid rocks (D).

Thorium and scandium are in negative correlation (Fig. 5). The basic rocks of the B/1 and B/2 subgroups are separated from others possessing the Th/Sc ratio lower than 0.2. The intermediate rocks of the subgroup C/1 have this ratio lower than 1. In the other rocks the Th/Sc ratio is higher. The fields of the rocks C/2 and D partly overlap. In the diagram, the durbachites are grouped essentially in one closed and elongated field; this cannot be said of the hybrid rocks which are more scattered.

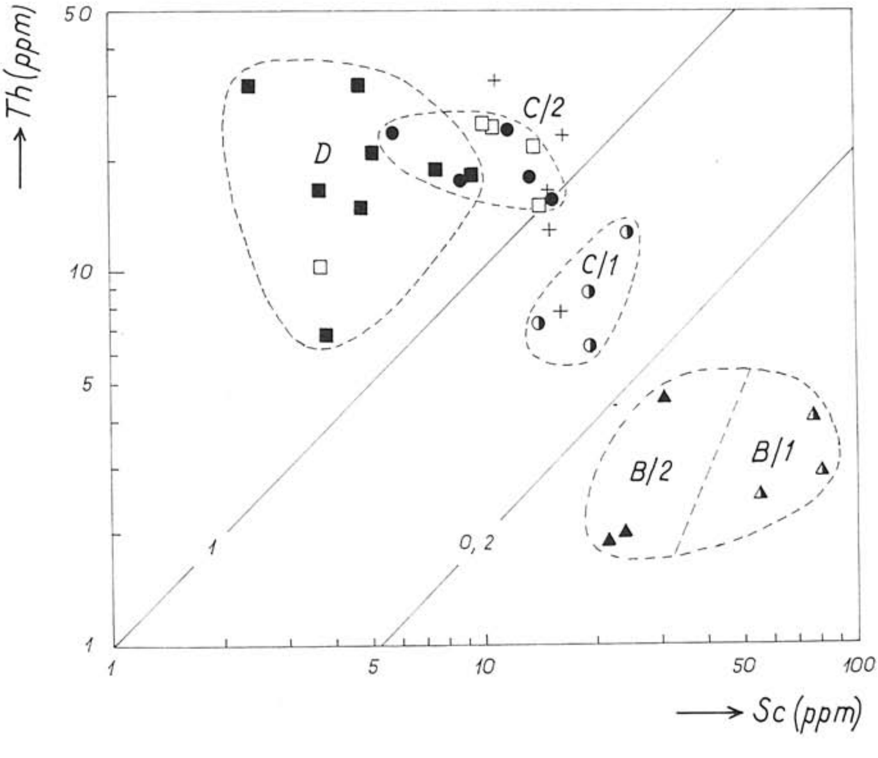

Fig. 5. Thorium vs. scandium plot of the rocks of the Central Bohemian Pluton. The basic rocks of group B and the intermediate rocks C/1 are markedly separated from the other rocks.

Transition metals

All the determined transition metals (Sc, Cr, Fe and Co) are concentrated mostly in the basic rocks and gradually decrease in B/1 — B/2 — C/1 — C/2 — D rock series (especially the Sc and Co contents) separating individual groups and subgroups (Tables 3 and 4, Figs. 6, 7 and 8). The lowest amounts of transition metals have been found in two-mica granites of the Říčany type with abundant quartz. The durbachites are characterized by high content of chromium (see also Tauson et al., 1977). In the hybrid rocks the content of transition metals is closed to that of the intermediate rocks C/2.

The other elements

Hafnium — Its contents vary only slightly in the individual samples. The highest contents of hafnium have been found in the durbachitic rocks (A) and the hybrid rocks (E).

In Table 3 few present data on Sb and Ta show the trend to increase their amount from basic to acid rocks.

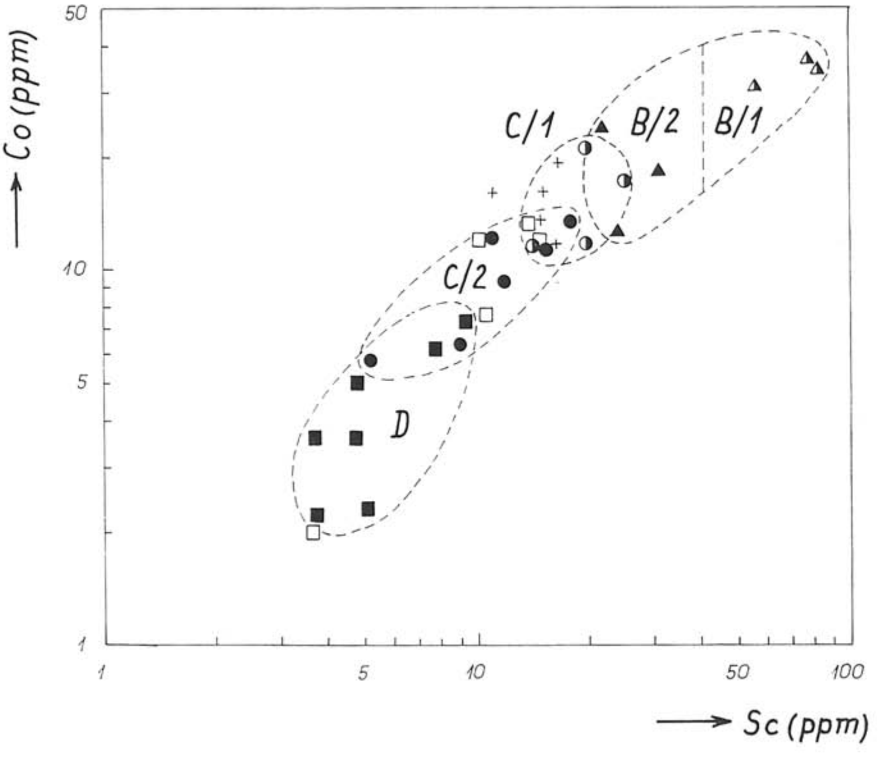

Fig. 6. Cobalt vs. scandium plot of the rocks of the Central Bohemian Pluton.

Characteristic of the rock groups

Group A — Durbachitic rocks containing relatively high amounts of potassium, rubidium and cesium with low K/Rb and K/Cs ratios display highest contents of REE. Their thorium and uranium contents are close to those of the acid rocks of the group D or those of the intermediate rocks of the subgroup C/2 and the hybrid rocks E. The La/Th ratio is typical of the developed upper earth crust. The K/Th ratio is higher than that of the acid rocks. The average hafnium content of the durbachitic rocks is the highest and close to this value for hybrid rocks. The durbachites have a high content of chromium.

Group B — In the basic rocks of the subgroup B/1 the Sc, Cr and Co contents are higher than are those of the subgroup B/2. The Sc and Co concentrations have been the highest throughout the set of all rocks. The basic rocks of the group B also differ in the lowest content of potassium and low thorium as well as REE distribution and very low Th/Sc ratios from the other rocks. The rocks of this group also display the highest value of the Sc/Co ratio.

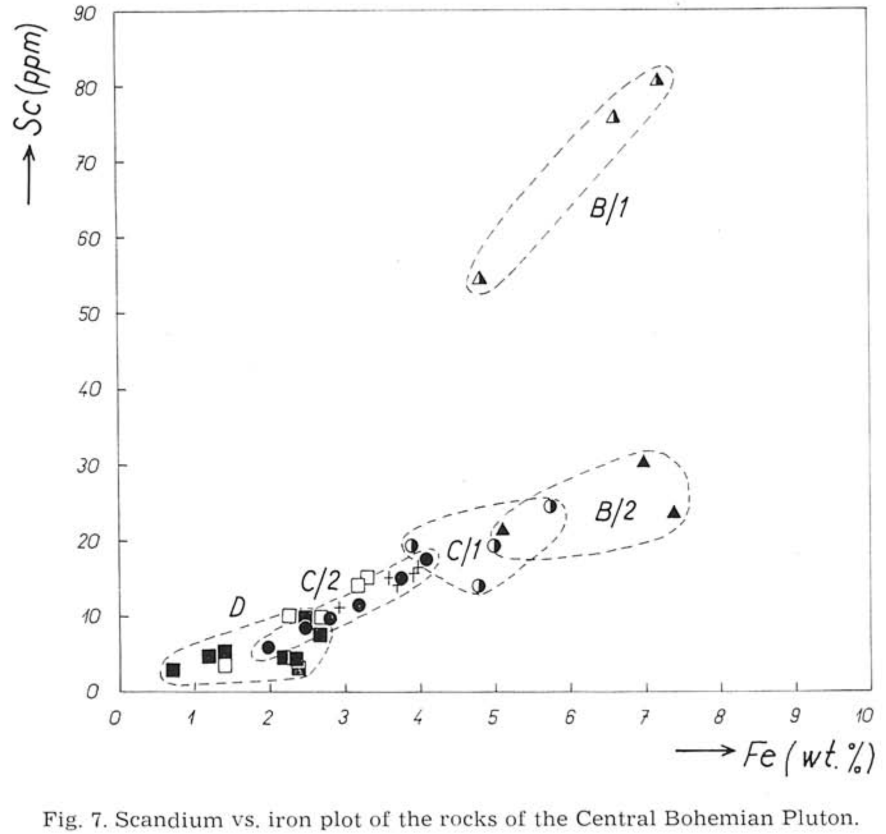

Fig. 7. Scandium vs. iron plot of the rocks of the Central Bohemian Pluton.

Group C — The subgroup C/1 of intermediate rocks is low in K, Rb and Cs contents as compared with C/2, the K/Rb ratios being almost equal in both subgroups. The subgroup C/1 is poorer in thorium and uranium than C/2. The types with predominance of amphibole are somewhat richer in transition metals. As to the trace elements distribution the subgroup C/2 approaches the group D.

Group D — The acid granitoids of this group belong to the geochemically most differentiated rocks. Their REE content is relatively high, the LREE :

HREE ratio express by Ce_N/Yb_N being highest too. Of all samples, their average Th content is the highest, and their uranium content is also elevated. The contents of transition metals are on average the lowest throughout the studied rocks.

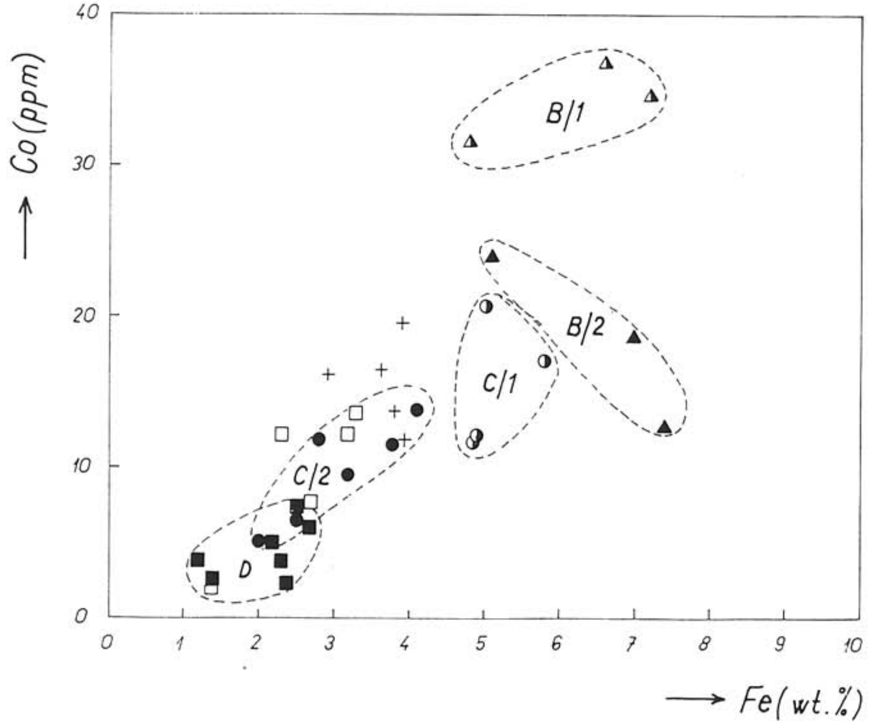

Fig. 8. Cobalt vs. iron plot of the rocks of the Central Bohemian Pluton.

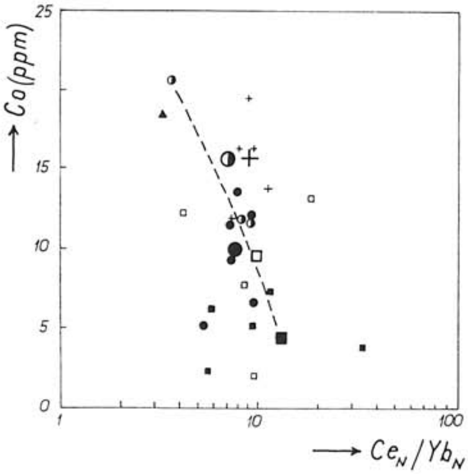

Fig. 9. Cobalt vs. Ce_N/Yb_N plot of the rocks of the Central Bohemian Pluton. The constructed curve represents the differentiation trend of the rocks in series B/2, C/1, C/2 and D. The large symbols are average values for rock groups.

Group E — According to their trace elements contents the hybrid rocks are most similar to the acid granitoids of group D and the durbachites of the group A. This position agrees with their assumed genesis. The hybrid rocks are enriched in REE and transition metals in comparison with group D. This may be due to the admixture of a portion of the upper-crust material probably derived from the sedimentary and metamorphic mantle of the pluton, which underwent partial melting or gradual granitization. In this case, the rocks are to a certain extent similar to the durbachitic rocks of the group A, as the distribution of alkali metals and some other trace elements in them is analogous.

Conclusions

The results presented in this paper may be summarized as follows:

1. Durbachitic rocks regarded as the earliest separate phase of the polymagmatic evolution of the Central Bohemian Pluton are — from the geochemical viewpoint — fairly fractionated. The contents of REE, the K/Rb ratio and the distribution of the other trace elements of these rocks correspond to a develope upper earth crust.

2. The further magmatic evolution of the Central Bohemian Pluton is represented by series of rocks, ranging from the basic (B/1 and B/2) through the intermediate (C/1 and C/2) to the acid types (D). The basic rocks are characterized by low contents of U, Th, alkali metals and REE and high amounts of transition metals (Sc, Fe and Co). The intermediate rocks with prevailing amphibole over biotite (C/1) display lower concentrations of K, Rb and Cs as compared with the intermediate rocks which contain more biotite than amphibole (C/2). The last differentiates are represented by acid granites enriched in U, Th, K, Rb, Cs and REE and having a low content of transition metals.

3. The last group comprises hybrid granitoids which represent a mixed type. The contamination by the rocks of the pluton's mantle is characteristic of them. Thus in many cases, e. g. as to the rare earth elements content, these rocks are close to durbachites. Their K/Rb ratio (= 159) is the lowest in the series of rocks and their content od some other trace elements is close to that of the acid rocks D, and as to transition metals contents they resemble the subgroup C/2. Their points in correlation diagrams are broadly scattered. It appears that the rocks of the E group represent a mixed type with varying proportions of trace elements and their ratios.

Translated by J. Košáková.

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