Geochemistry of Early Paleozoic Volcanics of the Barrandian Basin (Bohemian Massif, Czech Republic): Implications for Paleotectonic Reconstructions

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With 17 Figures and 3 Tables

Tschechische Republik
Varisziden
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Barrandium
Altpaläozoikum
Vulkanite
Geochemie
Paläotektonik

Contents

Geochemie altpaläozoischer Vulkanite im Barrandium (Böhmische Masse): Ihre Bedeutung für paläotektonische Rekonstruktionen

Zusammenfassung

Der Chemismus der kambrischen Vulkanite im Barrandium ist mit der Zusammensetzung der vulkanischen Gesteine der Inselbögen und aktiven Kontinentränder gut vergleichbar. Am Anfang des Paläozoikums – wahrscheinlich auch im Barrandium – herrschten vom jungproterozoischen Entwicklungsstadium der ganzen Teplá-Barrandium-Einheit übernommene tektonische Bedingungen, wie sie rezenten Plattengrenzen entsprechen. Das Fehlen mancher Eigenschaften von Intraplatten-Magmatiten in der Zusammensetzung der kambrischen Vulkanite deutet jedoch auf den Beginn der Extension der kontinentalen Kruste im Liegenden des Barrandiums. Vom Ordovizium bis zum Ausklang im mittleren Devon weist der barrandische Vulkanismus schon reinen Intraplatten-Charakter auf; das tektonische Milieu des Barrandiums wurde damit dem Milieu känozoischer Zerrungsbecken vergleichbar. Der Entwicklungtrend von ausschließlich alkalischen Vulkaniten bis zu einer Assoziation von alkalischen, Übergangs- und tholeiitischen Typen (am deutlichsten in der vulkanischen Folge während des ordovizisch-silurischen Zeitabschnittes) war wahrscheinlich eine Begleitwrscheinung der fortschreitenden Ausdehnung des Beckens, die ihr Maximum im Silur hatte. Die Mächtigkeit der durch Extension verdünnten Kontinentalkruste im Liegenden des Barrandiums überschritt nicht 30–35 km.

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Abstract

The geochemistry of Cambrian volcanics of the Barrandian Basin is comparable with the composition of island arc and active continental margin volcanic rocks. The Basin tectonic setting at the very beginning of the Paleozoic thus probably was inherited from the Late Proterozoic evolution stage of the whole Teplá-Barrandian Unit, which corresponded to the tectonic setting of modern convergent plate boundary. However, some features of within-plate igneous rocks present in the composition of Cambrian volcanics indicate the onset of continental crust extension in the basement of the Barrandian Basin. Since the Ordovician the Barrandian volcanism displayed solely within-plate characteristics until its waning out in the Middle Devonian. The tectonic setting of the Barrandian Basin thus became comparable with that of Cenozoic extensional basins. The evolution trend from exclusively alkaline rocks to the association of alkaline, transitional and tholeiitic ones, apparent in the Barrandian volcanic sequence during the Ordovician–Silurian time span, was very likely a concomitant phenomenon of the Basin progressive extension, culminating in the Silurian. The thickness of the extension-thinned continental crust beneath the Barrandian did not exceed 30 to 35 km.

1. Introduction

In the geological structure of central Bohemia the largest area is occupied by the Late Proterozoic and Early Paleozoic rocks of the Barrandian. The name of this region was proposed by FRANZ POŠEPNÝ (cf. POŠEPNÝ, 1895) in memory of French paleontologist JOACHIM BARRANDE (1799–1883). The investigations carried out by BARRANDE classified the Early Paleozoic of Central Bohemia among the world-known geological regions. Since the mid-19th century it became a subject of intensive interest of stratigraphers and paleontologists, but less attention was paid to petrographic investigations. A systematic study on volcanic rocks of the Barrandian Basin has begun only during a couple of last decades. Summarizing works on the Ordovician, Silurian and Devonian volcanics of the Barrandian were published by FIALA (1970, 1971); WALDHAUSROVÁ (1968, 1971) described the Late Cambrian volcanics and VLAŠIMSKÝ (1971, 1976) the dyke rocks in the southern part

of the Barrandian, i.e. in the Příbram area. These papers provided detailed geologic and petrographic characteristics of the volcanic rocks but only little interest was devoted to their geochemistry (e.g. MACHÁČEK & VLAŠIMSKÝ, 1979).

The aim of this paper is to present a fundamental characteristic of Early Paleozoic volcanic and dyke rocks of the Barrandian Basin; special attention is paid to the trace element as well as REE contents, including their tectonic setting implications. The analyses employed in this study have been chosen with the purpose to embrace the whole variation range of the Early Paleozoic magmatism (Tables 1, 2 and 3); the stratigraphic, petrographic and (where possible) also volcanologic aspects have been considered. The petrographic names of the rocks mentioned in the text and in Table 1 have been preserved in the form used by the authors cited.

2. Geology

For the basic data on the Barrandian Basin geology we refer to the papers by SVOBODA et al. (1966). The effusive and subsurface intrusive magmatism of various intensity accompanied the Barrandian evolution since the Early Cambrian to the Middle Devonian.

2.1. Early Cambrian

The sediments assigned to the Early Cambrian are continental, unfossiliferous, represented pre-
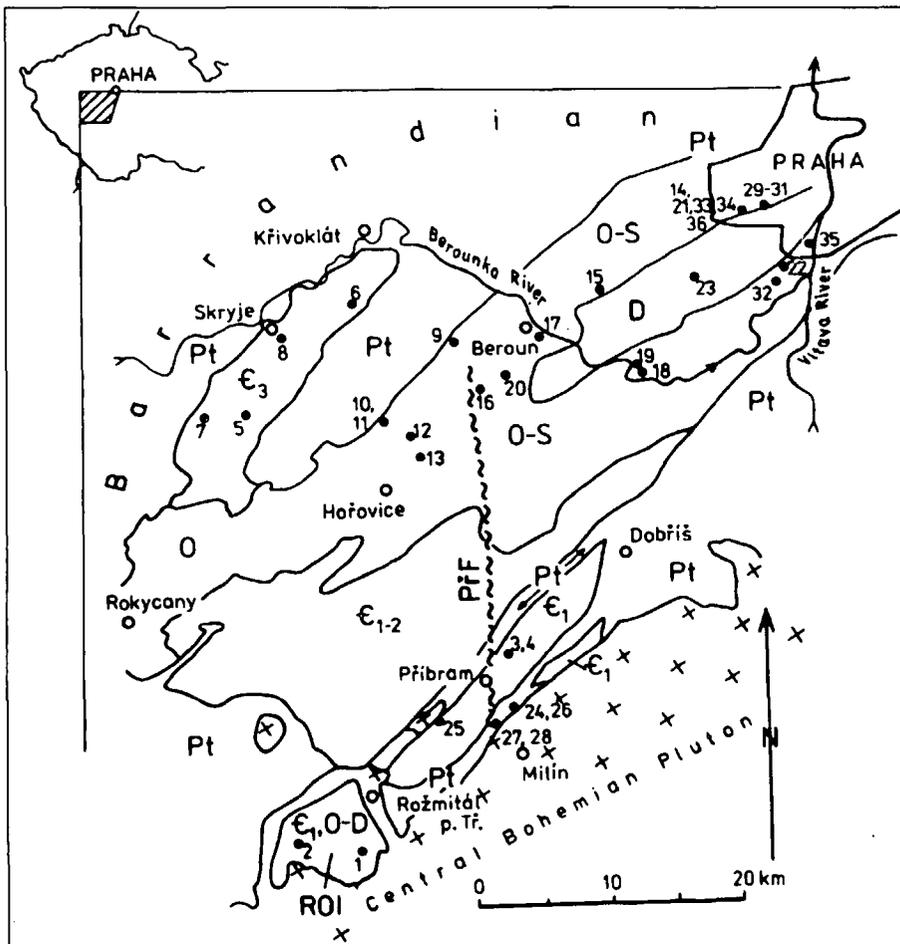
Text-Fig. 1.
Scheme of the Central Bohemian region showing the sample locations. (sample numbers identical to these in Tables 1, 2 and 3, Text-Figs. 2 to 17).
Principal geological units: Barrandian: volcano-sedimentary and sedimentary sequence of Late Proterozoic to Middle Devonian age; Central Bohemian Pluton: Middle to Late Paleozoic complex intrusive body (marked by crosses); ROI: s.c. Rožmitál Islet (relict of the Central Bohemian Pluton Paleozoic Mantle); Pt: Upper Proterozoic; ϵ_1 = Lower Cambrian; ϵ_2 = Middle Cambrian; ϵ_3 = Upper Cambrian; O: Ordovician; S: Silurian; D: Devonian; PřF: Příbram Fault (HAVLÍČEK, 1981).

dominantly by conglomerates and sandstones. They set unconformably on the Late Proterozoic (Vendian ?) sequences and are overlain by the Middle Cambrian evidenced paleontologically (HAVLÍČEK, 1971). Throughout the Early Cambrian profile there occur sporadic products of subaeric explosive volcanism – laminae to beds of tuffs and tuffites, unworn lapilli and crystals of volcanogenic quartz in conglomerates. Our set contains four samples from the Early Cambrian of the Příbram area and the adjacent Rožmitál "Islet" (Text-Fig. 1 – ROI), which represents a relict of the Central Bohemian Pluton mantle.

2.2. Late Cambrian

During the Late Cambrian a system of fissure volcanoes, elongated in the NE–SW direction, developed in the axial part of the Barrandian Basin (WALDHAUSROVÁ, 1968, 1971). They produced a complex of dominantly subaeric effusive rocks called the Křivoklát-Rokycany Belt (Text-Fig. 1 – KRB). Its age is given by contacts with Middle Cambrian and Tremadocian sediments, both of them dated paleontologically. The most abundant rocks are andesites and rhyolites, representing the youngest component of the sequence. According to VIDAL et al. (1975), the Křivoklát-Rokycany Belt is a product of both lower-crustal source and upper-mantle one. Further volcanics of Late Cambrian age occur in the Strašice Belt, situated towards the SE of the KRB; this belt, also trending NE–SW, is formed chiefly of basaltic andesites (WALDHAUSROVÁ, 1968, 1971). In the SE limb of the Barrandian (Příbram and Dobříš areas) the Upper Proterozoic and Lower Cambrian are pierced by numerous N–S trending diabase dykes. The area of their occurrence is also elongated from NE to SW. In many places the dykes are cumulated into swarms, locally forming up to 20 vol. % of the rock mass. Geological evidence indicates their origin within Middle Cambrian to Silurian time span. According to VLAŠÍMSKÝ (1976) Late Cambrian age is the most probable. This author assumes that the dykes represent feeding channels of surface volcanoes and that some basic enclaves in the nearby Central Bohemian Pluton (Text-Fig. 1) are relics of their effusive and/or pyroclastic equivalents. The diabase dykes formed prominent mechanical inhomogeneities in the country rocks. During the Variscan orogeny they were cut across by open fissures, subsequently filled with Ag-Pb-Zn ores (Březové Hory and Bohutín ore deposits, etc.). In the Příbram area the rhyolites, somewhat younger than the diabase dykes, also belong to the Early Paleozoic magmatism (VLAŠÍMSKÝ, l.c.).

2.3. Ordovician, Silurian and Devonian

Upon the termination of the Cambrian sedimentation and volcanism an inversion of relief developed in the Barrandian; the Cambrian sedimentary basin in the Barrandian SE limb became an elevation and in the Barrandian axial part in the N and NW a new sedimentary area – the Prague Basin – was formed (HAVLÍČEK in SVOBODA et al., 1966). The Prague Basin was filled gradually with Tremadocian to Givetian sedimentary complexes. The Devonian is mostly represented by carbonate rocks of various types (known as "the Devonian of Bohemian development"). There is an abundance of submarine effusions and subvolcanic bodies of basic rocks. According to HAVLÍČEK (1981) the Prague Basin is divided by the deep N–S trending Příbram Fault into two segments showing different lithological, volcanic and tectonic developments. In the W segment there is an Ordovician volcanic complex, adjoining the Late Cambrian volcanic belts (see above and Text-Fig. 1).
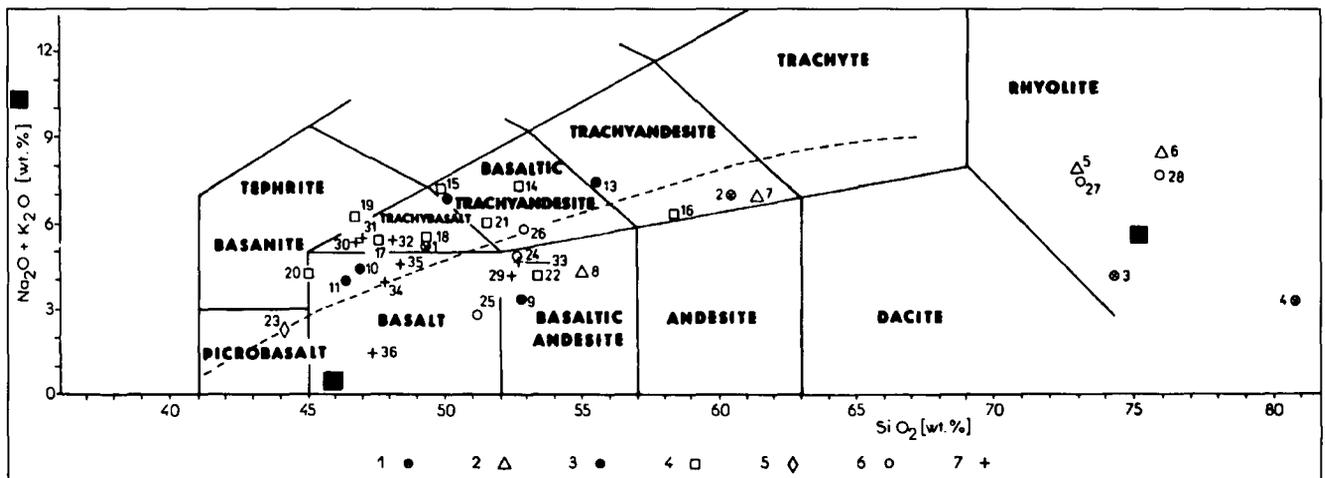
During the Silurian the Barrandian volcanic centers were relocated into the E segment of the Prague Basin. The volcanism – after an absence in the latest Ordovician (Králodvorian and Kosovian) – became rather intensive in the Early Silurian. It may be linked up with the global event at the Ordovician–Silurian boundary (cf. CHLUPÁČ & KUKAL, 1988). The basal part of the Silurian sequence is formed beside the volcanic facies by black graptolitic shales (Liteň Formation) with up to 3 wt. % of C-org., indicating s.c. anoxic event (linked up with the global event at the Ordovician–Silurian boundary; cf. CHLUPÁČ & KUKAL, l.c.). We assume that the black shale origin was related to basic volcanism in analogy to the common occurrence of volcanic bodies with C-org. enriched sediments at many places of the Barrandian Upper Proterozoic. Compared with the Ordovician volcanism, the Silurian one is more varied; volcanic effusions are situated chiefly in the NE part of the Prague Basin. The volcanic center between Beroun and Loděnice (Text-Fig. 1) comprises subvolcanic rocks, submarine effusives and possibly even subaeric ones (FIALA, 1971). Concordant intrusive bodies (locally also laccoliths?) are abundant in the Silurian: FIALA (l.c.) termed them as doleritic – i.e. coarse-grained – types. They are frequently differentiated into alkali diabases, essexite-diabases to essexites and ultrabasites. The last named rocks probably belong to the youngest Silurian volcanics, as can be inferred from a similar ultrabasic affinity of the Middle Devonian effusive diabases. They represent the aftermath of Early Paleozoic volcanic activity; they are developed within an area of about 5 km^2 on the NE margin of the Devonian sedimentary basin (FIALA, 1970).

Numerous diabase dykes are described by BLECHOVÁ (1985) from the area built by the Silurian sequence (in the NW part of Prague) not far from the occurrences of the Devonian volcanic rocks. Petrography, geochemistry and a large number of diabase bodies point to their possible link to Silurian volcanism, which was far more intensive than the Devonian volcanic activity. They differ markedly from the biotite lamprophyre dykes probably of Variscan age (FIALA, 1971), which pierce the Ordovician sediments of the Prague Basin in the neighbourhood of Zdice and in the Prague area (Text-Fig. 1).

The overview given above demonstrates that during the Early Paleozoic the volcanic centers were shifting progressively from S-SW to NE as follows: the Early Cambrian – Rožmitál and Příbram areas; the Late Cambrian – Rožmitál and Příbram areas, surroundings of Strašice, Skryje and Křivoklát; the Ordovician – Komárov area, western vicinity of Zdice; the Silurian – Beroun area, south-western part of Prague area; the Devonian – southwestern neighbourhood of Prague. Volcanic activity took place since the Early Cambrian to the Middle Devonian, with major pauses in the Middle Cambrian, the Late Ordovician and the Late Silurian to Early Devonian.

3. Analytical Methods

The samples of the Barrandian volcanics were taken predominantly from active quarries, boreholes, mining works and large outcrops, that the set comprises only

Text-Fig. 2.

SiO_2 vs $Na_2O + K_2O$ diagram for Early Paleozoic volcanics of the Barrandian; the volatile-free contents are plotted.
1 = Lower Cambrian; 2 = Upper Cambrian; 3 = Ordovician; 4 = Silurian; 5 = Devonian; 6 = dyke rocks of the Central Bohemian Pluton contact zone; 7 = diabase dykes of the Prague Basin Silurian sequence.
Dashed line separates the field of alkaline and subalkaline rocks (IRVINE & BARAGAR, 1971), solid lines bound the fields of common volcanic types (LE BAS et al., 1986). The sample numbers from Tables 1, 2 and 3 are given with the symbols.

rocks unaffected by weathering. The contents of major elements were determined using the classic wet analysis, performed in laboratories of the Geological Survey, Prague (analysts M. HUKA and co-workers). The trace element concentrations were obtained by the XRF method in the Unigeo laboratories in Brno (analysts M. JANÁČKOVÁ and co-workers). The REE were detected by INAA in the Central laboratories of Geoindustria, Prague (analysts J. MOUČKA and co-workers).

4. Geochemistry

### 4.1. Effusives and Subvolcanics

4.1.1. Early Cambrian

The Barrandian Early Cambrian volcanics are represented in the set examined by four pyroclastic rocks from the Příbram area. According to petrography one of them is designated as basic porphyritic tuff, one as andesite tuff and two are termed lapilli and ash porphyry tuffs to tuffites, affected by diagenetic silicification (Nos. 1 to 4 in Tables 1, 2 and 3).

The low proportion of SiO_2 (less than 50 wt. %) in the basic porphyritic tuff – No. 1) and the relation of volatile-free silica and alkali contents indicate that the rock has a character of moderately alkaline basalt to trachybasalt (Text-Fig. 2). However, it should be added that the Al_2O_3 concentration (almost 20 wt. %) is rather high for such a rock type, so that contamination by a certain amount of sedimentary material cannot be excluded.

The rare earth elements in the basic porphyric tuff are fractionated: the

abundances of light lanthanides are about 80 times higher than in chondrites, the concentrations of heavy ones are only 30 times above the chondritic values (Text-Fig. 4a). The REE distribution pattern in the porphyritic tuff is similar to that of alkali basalts (cf. BASALTIC VOLCANISM STUDY PROJECT, 1981).

The comparison of trace element contents with the mid-ocean ridge basalt (MORB) composition after PEARCE (1982) clearly shows that the basic porphyritic tuff is remarkably enriched in K, Rb, Ba and Th and moderately enriched in Sr, Ta, Nb, Ce, P, Zr, Hf, Sm, Ti and Yb; the Y, Sc and Cr contents are almost equal to those in MORB (Text-Fig. 5). In this aspect the tuff resembles within-plate alkaline basalts.
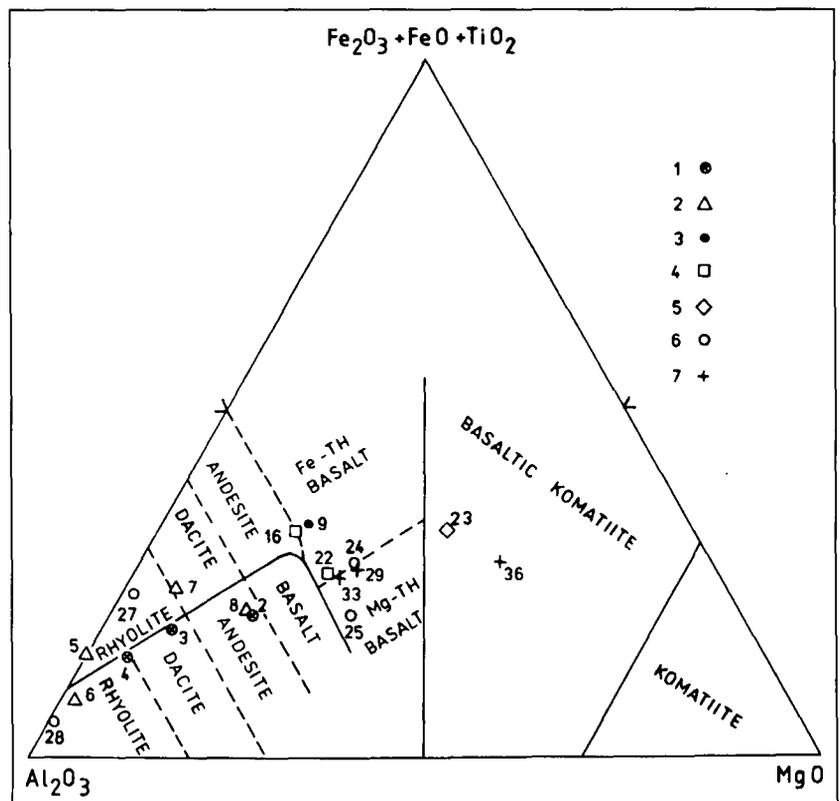
Text-Fig. 3.
Early Paleozoic subalkaline volcanics of the Barrandian Basin in cation plot after JENSEN (1976).
For symbols see Text-Fig. 2.

Lower Cambrian; continental pyroclastics - Příbram and Rožmitál areas

1	porphyry tuff	Volenice	Rožmitál "islet".
2	andesite tuff	Třemšín	Rožmitál "islet"
3	lapilli and ash porphyry tuff to tuffite	Květná ·	Příbram syncline
4	lapilli and ash porphyry tuff to tuffite	Květná	Příbram syncline

Upper Cambrian; subaeric effusives - Křivoklát-Rokycany Belt

5	porphyritic rhyolite	Třebnuška	4th eruption group
6	fluidal rhyolite	Karlova Ves	4th eruption group
7	acid andesite	Hlohovičky	2nd eruption group
8	basic andesite	Skryje	2nd eruption group

Ordovician; submarine effusives - Prague Basin

9	pillow lava	Hudlice	Lower Ordovician (Arenigian, Llanvirnian)
10	pillow lava	Točník	Lower Ordovician (Arenigian, Llanvirnian)
11	amygdaloidal diabase	Točník	Lower Ordovician (Arenigian, Llanvirnian)
12	diabase	Chlustina	Upper Ordovician (Berounian)
13	hyaloclastite	Otmíče	Upper Ordovician (Berounian)

Silurian; submarine effusives and subvolcanic bodies - Prague Basin

14	pillow lava	Řeporyje	Wenlock-Ludlowian boundary, effusive
15	olivine diabase	Bubovice	Ludlowian?, sill
16	coarse-grained quartz diabase	Lounín	Ludlowian?, sill
17	coarse-grained teschenite-diabase	Zavadilka	Ludlowian?, sill
18	coarse-grained essexite-diabase	Hlásná Třebáň	Ludlowian?, sill
19	essexite	Klučice	Ludlowian?, laccolith
20	picrite-diabase	Křižatky	Ludlowian?, sill?
21	spilite-diabase	Řeporyje	Ludlowian, effusion
22	spilite-diabase	Lochkov	Ludlowian, effusion

Devonian; submarine effusive - Prague Basin

23	hyaloclastite	Chýnice	Eifelian

Early Paleozoic dyke rocks of the Central Bohemian Pluton Contact Zone

24	hornblende diabase	Bohutín Mine	contact zone of the Central Bohemian Pluton
25	diabase	Brod Mine	contact zone of the Bohutín body
26	leucocratic porphyritic diabase	Brod Mine	contact zone of the Central Bohemian Pluton
27	quartz porphyry	Lešetice Mine	contact zone of the Central Bohemian Pluton
28	quartz porphyry	Lešetice	contact zone of the Central Bohemian Pluton

Early Paleozoic dykes; Silurian sequence of the Prague Basin - Prague

29	diabase	Kotol	
30	teschenite-diabase	Kotol	
31	teschenite-diabase	Kotol	
32	teschenite-diabase	Radotín	
33	teschenite-diabase	Řeporyje	
34	teschenite-diabase	Řeporyje	
35	teschenite-diabase	Velká Chuchle	
36	diabase-picrite	Řeporyje	

Table 1.
Early Paleozoic volcanic rocks of the Barrandian Basin.
Petrographic and stratigraphic terms in the table are taken from the following papers: BLECHOVÁ (1985): samples Nos. 21, 22 and 29 to 36; FIALA (1970, 1971): samples Nos. 9 to 20 and 23; KUKAL (1970): samples Nos. 2 to 4; VLAŠIMSKÝ (1971, 1976): samples Nos. 24 to 28; VONDROVÁ et al. (1964): sample No. 1; WALDHAUSROVÁ (1968, 1971): samples Nos. 5 to 8.

	1	2	3	4	5	6	7
SiO_2	48.96	60.45	71.24	77.42	73.02	76.00	60.95
TiO_2	3.19	1.42	0.25	0.32	0.24	0.13	0.59
Al_2O_3	19.44	15.94	13.91	12.06	12.98	12.70	16.23
Fe_2O_3	6.39	4.75	1.45	1.62	1.04	1.08	5.87
FeO	6.37	2.46	3.38	1.19	1.71	0.57	2.05
MnO	0.21	0.10	0.03	0.03	0.06	–	0.06
MgO	3.13	3.81	1.45	0.70	0.03	0.20	1.24
CaO	1.94	1.23	0.61	0.31	0.88	0.08	2.03
Na_2O	2.96	6.40	0.70	1.00	2.59	2.76	5.56
K_2O	2.22	0.58	3.28	2.13	5.27	5.64	1.28
P_2O_5	0.48	0.22	0.05	0.05	0.04	–	0.24
CO_2	0.02	0.02	0.38	0.13	0.78	–	0.68
H_2O	4.06	2.50	3.77	3.16	1.06	0.94	2.46
total	99.38	99.88	100.50	100.12	99.70	100.10	99.24
K_2O/Na_2O	0.75	0.09	4.69	2.13	88.19	7.71	0.23
FeO^t/MgO	3.87	1.77	3.23	3.78	2.03	2.04	5.91

	8	9	10	11	12	13	14
SiO_2	50.95	42.24	38.66	41.30	47.48	47.22	40.49
TiO_2	0.63	2.15	2.75	3.05	2.55	2.27	2.37
Al_2O_3	18.08	13.87	14.67	15.21	15.60	14.04	14.07
Fe_2O_3	5.18	1.86	6.01	4.20	5.48	4.23	1.46
FeO	3.35	9.70	4.94	6.17	7.44	4.61	5.20
MnO	0.14	0.09	0.12	0.11	0.11	0.17	0.12
MgO	4.18	4.33	9.78	7.11	3.08	2.69	2.75
CaO	8.72	8.83	6.89	10.24	5.55	7.48	13.40
Na_2O	3.34	2.26	3.38	2.17	3.80	5.33	5.04
K_2O	0.64	0.46	0.22	1.42	2.66	0.94	0.52
P_2O_5	0.11	0.62	0.73	0.66	0.75	1.10	0.42
CO_2	2.11	5.96	4.50	2.50	1.12	4.23	7.18
H_2O	2.81	6.51	7.13	4.59	3.84	4.56	6.65
total	100.24	99.88	99.77	98.73	100.12	98.87	99.67
K_2O/Na_2O	0.19	0.20	0.07	0.65	0.70	0.18	0.10
FeO^t/MgO	1.92	2.63	1.06	1.40	4.02	3.13	2.37

	15	16	17	18	19	20	21
SiO_2	47.43	54.72	44.51	46.90	44.20	40.58	37.70
TiO_2	1.91	1.51	3.65	2.49	2.73	2.26	2.45
Al_2O_3	17.70	12.94	12.77	11.50	10.12	13.88	14.61
Fe_2O_3	3.43	4.79	4.33	5.00	4.74	2.50	2.66
FeO	8.00	5.84	9.29	11.16	9.98	8.24	4.79
MnO	0.07	0.13	0.21	0.27	0.29	0.25	–
MgO	3.72	3.55	6.27	4.53	7.00	13.11	3.50
CaO	6.16	4.45	6.95	8.55	9.52	5.34	15.50
Na_2O	3.67	4.00	3.32	4.27	4.96	3.04	4.00
K_2O	3.14	2.00	1.70	0.82	0.89	0.75	0.38
P_2O_5	0.67	0.52	0.50	0.26	0.19	0.29	0.29
CO_2	1.10	0.57	0.30	0.61	0.05	0.10	9.63
H_2O	2.93	4.58	5.36	3.43	5.70	9.34	4.31
total	99.93	99.60	99.16	99.79	100.37	99.58	99.52
K_2O/Na_2O	0.86	0.50	0.51	0.19	0.18	0.25	0.10
FeO^t/MgO	2.98	2.86	2.10	3.46	2.04	0.80	2.05

	22	23	24	25	26	27	28
SiO_2	44.20	35.54	48.32	49.86	52.87	73.07	75.88
TiO_2	1.70	2.70	1.30	1.23	1.68	0.16	0.04
Al_2O_3	15.80	9.95	15.19	16.77	14.75	12.31	12.92
Fe_2O_3	2.63	8.51	1.14	1.15	1.24	0.15	0.12
FeO	7.69	4.28	9.59	7.39	8.38	5.00	0.80
MnO	–	0.16	0.20	0.16	0.13	0.04	0.06
MgO	6.58	9.42	6.32	8.27	5.13	0.25	0.11
CaO	6.95	13.11	8.17	9.91	7.01	0.81	1.08
Na_2O	3.30	1.03	3.28	2.53	4.26	3.65	3.60
K_2O	0.18	0.87	1.21	0.23	1.56	2.83	4.10
P_2O_5	0.59	0.87	0.10	0.14	0.25	0.06	0.01
CO_2	4.90	4.81	2.38	0.17	0.40	0.14	0.22
H_2O	4.90	8.15	1.58	1.56	1.64	0.55	0.62
total	99.43	99.41	99.69	99.37	99.25	99.98	99.56
K_2O/Na_2O	0.05	0.84	0.37	0.09	0.37	1.05	1.14
FeO^t/MgO	1.53	1.27	1.68	1.02	1.85	20.54	8.25

	29	30	31	32	33	34	35
SiO_2	49.52	42.60	43.58	45.68	49.20	45.25	45.78
TiO_2	2.25	2.60	2.40	1.96	1.65	2.05	2.40
Al_2O_3	15.66	15.90	15.12	15.99	15.04	14.31	15.57
Fe_2O_3	1.88	3.12	4.44	4.21	2.68	3.29	5.56
FeO	9.87	9.15	9.44	7.26	7.28	9.87	7.40
MnO	–	–	–	–	–	–	–
MgO	7.58	8.10	7.20	6.48	6.56	5.77	6.36
CaO	3.33	6.10	6.40	8.00	6.66	10.80	6.93
Na_2O	3.70	4.00	4.50	4.00	3.74	3.00	3.55
K_2O	0.20	0.80	0.50	1.10	0.64	0.70	0.75
P_2O_5	1.05	0.52	0.42	0.85	0.80	0.68	0.89
CO_2	0.40	1.50	1.05	0.40	0.60	0.80	0.40
H_2O	4.16	5.06	4.61	3.72	3.97	4.94	3.86
total	99.60	99.45	99.66	99.65	98.82	101.46	99.45
K_2O/Na_2O	0.05	0.20	0.11	0.28	0.17	0.23	0.21
FeO^t/MgO	1.53	1.48	1.87	1.70	1.48	2.22	1.95

	36
SiO_2	35.40
TiO_2	1.02
Al_2O_3	9.63
Fe_2O_3	2.31
FeO	11.62
MnO	–
MgO	12.93
CaO	10.79
Na_2O	0.80
K_2O	0.22
P_2O_5	0.31
CO_2	8.00
H_2O	7.04
total	100.07
K_2O/Na_2O	0.28
FeO^t/MgO	1.06

Table 2.
Major element composition of Early Paleozoic volcanic rocks of the Barrandian Basin.
For explanation of the sample numbers see Table 1.

The andesite tuff (No. 2) corresponds to trachyandesite – very near to andesitic composition – according to the content of ca. 60 wt. % SiO_2 and the ratio of $Na_2O + K_2O$ vs SiO_2 abundances (Text-Fig. 2). The similarity with calc-alkaline andesite s.s. is also demonstrated by the sample position in the cation plot (JENSEN, 1976) (Text-Fig. 3).

The andesite tuff displays the lowest REE abundances of all Early Cambrian volcanics studied: its lanthanide contents are only 15 times (HREE) to 45 times (LREE) higher than in chondrites. The LREE vs HREE fractionation is almost the same as in the foregoing sample. Likewise, the REE distribution pattern lacks a negative Eu-anomaly (Text-Fig. 4a, Table 3). In these features the andesite tuff resembles medium-K calc-alkaline andesites (GILL, 1981).

Relative to the ocean-ridge granite (ORG) (PEARCE et al., 1984) the andesite tuff has highly increased Ba and Th contents and substantially decreased Hf, Sm and Yb concentrations (Text-Fig. 6a). It can thus be correlated with the volcano-plutonic arc magmatites (PEARCE et al., l.c.).

Porphyry tuffs to tuffites (Nos. 3 and 4) are characterized by high SiO_2 contents (71 and 77 wt. %) and a predominance of K_2O over Na_2O – the K_2O/Na_2O ratios shown by these rocks are 2.1 and 4.7 respectively. The sample having a higher value of the ratio has also a higher portion of Al_2O_3 (ca. 14 wt. %); in such a case some amount of sedimentary component (clay minerals) may be assumed. The relations between volatile-free silica and alkali concentrations rank the porphyry tuffs to subalkaline rhyolites (Text-Fig. 2). However, the proportions among Al_2O_3, $FeOt+TiO_2$ and MgO indicate a similarity with calc-alkaline dacites to rhyodacites (Text-Fig. 3).

The porphyry tuffs display very high concentrations of lanthanides (LREE in particular) and prominent negative Eu anomalies. A striking feature of these rocks are low LREE/HREE ratios, i.e. only moderately steep shapes of rare earth distribution patterns (provided that the Eu-anomalies are neglected) (Text-Fig. 4a, Table 3). The distribution of REE in the porphyry tuffs seems to be transitional between the rare earth distributions in tholeiitic and calc-alkaline rhyolites (cf. CAMPBELL et al., 1982).

Table 3.
Trace element composition of Early Paleozoic volcanic rocks of the Barrandian Basin.
For explanation of the sample numbers see Table 1.

	1	2	3	4	5	6	7
Sr	302	115	38	65	123	43	154
Rb	52	<10	91	119	136	144	42
Ba	813	193	830	955	1124	1350	761
Th	3.40	4.32	11.50	10.50	8.00	9.90	4.60
Ta	1.50	<1	1.28	<1	–	–	<1
Nb	13	–	–	17	23	16	13
Zr	313	–	–	594	227	425	336
Hf	8.30	5.73	9.47	8.10	10.10	8.50	8.40
Sc	36.10	17.30	7.80	7.90	13.40	8.61	6.97
Cr	232	43	10	9	–	–	4
La	27.10	14.60	46.50	51.80	32.90	44.80	21.50
Ce	66.2	42.6	111	93.5	72.2	138	38.3
Sm	8.75	4.25	13.30	10.70	9.91	12.00	8.12
Eu	3.39	1.59	1.74	1.60	1.89	1.51	2.35
Tb	1.09	1.33	2.18	1.80	1.67	1.66	1.56
Yb	6.70	2.88	7.72	7.60	–	6.68	2.44
Lu	0.60	0.47	1.21	1.11	1.18	0.97	<0.1
Y	47	–	–	123	54	75	54
Σ REE	113.83	67.72	183.65	168.11	122.81	205.62	≈74.30
Ce/Yb	9.9	14.7	14.4	12.3	–	20.6	15.7
Eu/Eu*	1.27	0.95	0.40	0.46	0.59	0.41	0.86

	8	9	10	11	12	13	14
Sr	113	166	219	2072	1274	364	513
Rb	11	35	<10	<10	25	20	<10
Ba	334	83	251	745	1894	920	28
Th	1.60	4.37	6.21	4.60	4.66	5.18	<1
Ta	–	3.54	4.68	3.89	4.14	3.71	<1
Nb	–	52	83	71	59	66	19
Zr	–	211	244	180	315	357	113
Hf	3.68	5.56	2.41	1.98	7.70	7.20	7.20
Sc	25.0	17	20.5	20.9	3.85	6.72	26.0
Cr	128	236	229	222	25	140	297
La	4.59	22.90	43.60	47.00	40.10	43.10	14.60
Ce	30.0	43.4	66.6	61.5	66.9	83.9	17.0
Sm	4.34	5.59	8.87	7.62	9.76	11.60	6.05
Eu	1.17	1.95	2.54	2.50	3.37	2.94	1.91
Tb	<1	<1	<1	<1	<1	<1	<1
Yb	2.62	1.81	2.27	2.21	1.41	1.25	–
Lu	0.29	0.24	0.38	0.31	0.13	0.13	0.69
Y	–	24	30	35	26	18	23
Σ REE	≈44	≈76	≈65	≈122	≈122	≈143	≈42
Ce/Yb	11.4	24.1	29.5	27.9	47.6	66.9	–
Eu/Eu*	0.81	1.14	0.96	1.09	1.20	0.89	1.08

	15	16	17	18	19	20	21
Sr	882	339	351	537	189	254	–
Rb	<10	38	10	<10	17	<10	3.40
Ba	210	385	2050	2800	557	518	–
Th	1.37	3.42	1.82	<1	<1	<1	1.92
Ta	1.82	3.23	2.31	<1	<1	<1	–
Nb	30	18	50	19	25	17	–
Zr	175	446	155	113	179	88	–
Hf	3.79	10.6	3.54	2.59	2.60	<1	–
Sc	21.3	10.8	24.4	26.9	28.5	22.9	27.0
Cr	533	310	243	237	34	360	301
La	21.10	36.20	20.60	12.10	18.30	12.00	17.30
Ce	30.2	65.2	37.9	16.9	–	14.7	46.0
Sm	6.63	12.80	7.66	4.90	7.20	4.40	7.10
Eu	2.0	3.92	3.25	1.62	2.94	1.48	2.10
Tb	<1	1.71	<1	<1	1.50	<1	0.97
Yb	2.28	5.37	1.72	2.19	<1	2.48	2.10
Lu	0.23	0.85	0.25	0.37	0.46	0.29	0.28
Y	30	16	63	36	41	32	–
Σ REE	≈63	126.05	≈82	≈39	≈31	≈36	75.85
Ce/Yb	13.2	12.1	21.9	7.7	–	5.9	21.9
Eu/Eu*	0.98	0.99	1.44	1.04	1.19	1.03	0.95

	22	23	24	25	26	27	28
Sr	–	672	360	230	350	123	122
Rb	3.30	<10	10	<10	54	122	130
Ba	–	231	385	44	–	2172	1970
Th	2.26	6.32	1.90	<1	<1	63	17
Ta	–	4.80	–	<1	–	–	–
Nb	–	93	<10	–	<10	10	9
Zr	–	340	90	80	167	52	43
Hf	–	4.38	–	<1	<1	1.4	2.0
Sc	31.0	18.2	–	27.8	34.0	4.3	2.0
Cr	472	294	240	208	127	–	–
La	13.40	51.20	8.50	6.86	14.00	13.00	22.00
Ce	43.0	100.0	24.0	19.5	33.0	55.0	40.0
Sm	6.70	9.43	1.70	3.73	–	1.54	–
Eu	1.62	2.93	–	1.12	1.40	0.40	0.40
Tb	0.76	<1	–	<1	<1	1.4	<1
Yb	2.00	1.87	2.10	2.82	3.00	1.50	2.00
Lu	0.27	0.17	0.25	0.46	0.80	<0.1	0.20
Y	–	32	27	25	48	17	15
Σ REE	67.75	≈166	36.55	≈35	≈53	≈72.9	≈65
Ce/Yb	21.5	53.7	11.4	6.8	11.0	36.6	20.1
Eu/Eu*	0.81	1.06	–	0.86	–	0.38	–

	29	30	31	32	33	34	35
Sr	–	–	–	–	–	–	–
Rb	4.4	13.2	13.2	12.1	9.9	7.7	7.7
Ba	–	–	–	–	–	–	–
Th	2.29	1.30	1.46	1.61	1.59	2.18	2.64
Ta	–	–	–	–	–	–	–
Nb	–	–	–	–	–	–	–
Zr	–	–	–	–	–	–	–
Hf	–	–	–	–	–	–	–
Sc	30	25	31	53	44	41	35
Cr	404	472	445	424	349	322	233
La	8.90	12.50	10.30	17.00	9.30	–	15.10
Ce	28.0	33.0	32.0	44.0	30.0	34.0	44.0
Sm	5.8	5.0	5.8	8.4	6.1	6.5	7.4
Eu	1.90	1.47	1.55	2.20	1.60	1.70	2.10
Tb	0.62	0.75	0.65	1.00	0.85	0.90	0.91
Yb	1.90	1.78	2.00	2.70	2.20	2.30	2.00
Lu	0.14	0.23	0.30	0.33	0.37	0.34	0.28
Y	–	–	–	–	–	–	–
Σ REE	47.25	54.73	52.60	75.63	50.42	45.74	71.79
Ce/Yb	14.7	18.5	16.0	16.3	13.6	14.8	22.0
Eu/Eu*	1.11	0.93	0.90	0.87	0.84	0.84	0.94

	36
Sr	–
Rb	4.4
Ba	–
Th	1.74
Ta	–
Nb	–
Zr	–
Hf	–
Sc	19.9
Cr	1122
La	5.20
Ce	13.0
Sm	2.9
Eu	0.71
Tb	0.43
Yb	1.18
Lu	0.17
Y	–
Σ REE	23.59
Ce/Yb	11.0
Eu/Eu*	0.78

Table 3 (continued).

The large ion lithophile elements (LILE – in the case discussed K, Rb, Ba and Th) are present in the porphyry tuff samples in considerably higher abundances than in ocean ridge granite (PEARCE et al., 1984); the Ce contents are also fairly high. The high field strength (HFS) elements, in this case Ta, Hf, Zr and Sm, and the mantle compatible elements (Y and Yb) are present in slightly higher than or even in the same concentrations as in ORG (Text-Fig. 6a). Owing to these characteristics the porphyry tuffs may be regarded as equivalents of volcano-plutonic arc acid rocks, showing slightly higher magmatic differentiation degree. However, an analogous trace element distribution relative to ORG is also typical for within-plate igneous rocks emplaced within the attenuated continental lithosphere tectonic setting (PEARCE et al., l.c.).

4.1.2. Late Cambrian

The Late Cambrian volcanic rocks are represented in the set studied by four samples from the Křivoklát-Rokycany Belt. Petrographically two are identified as rhyolites (one porphyritic, the other fluidal) the third as acid andesite and the last one as basic andesite (Nos. 5 to 8 in Tables 1, 2 and 3).

The rhyolites of Late Cambrian age contain 73 and 76 wt. % of SiO_2 and despite the relatively high alkali abundances they are ranked to subalkaline rocks (Text-Fig. 2). The relation between Na and K (the K_2O/Na_2O ratio is about 2.0 in both samples) reveals their affinity to K-rich calc-alkaline rhyolites (cf. WHITFORD et al., 1979; K.L. CAMERON & M. CAMERON, 1986). Porphyritic rhyolite (No. 5) is considerably enriched in Fe (the FeOt/MgO ratio is about 90) compared with fluidal one (No. 6), displaying FeOt/MgO ratio ca. 8. Such high values of the ratio mentioned are characteristic for tholeiitic rhyolites (CARMICHAEL, 1964). In the cation plot (JENSEN, 1976) both rhyolites are very close to each other; nevertheless, the porphyritic one lies in the tholeiitic field (Text-Fig. 3).

The lanthanide concentrations in rhyolites of the Křivoklát-Rokycany Belt are high: La and Ca abundances are about 100 to 150 times above the chondritic values, those of HREE only ca. 35 times. The fractionation degree of light and heavy rare earths in the fluidal rhyolite is roughly the same as in the Early Cambrian porphyry tuffs from the Příbram area; in the porphyritic rhyolite it is somewhat lower. The REE distribution patterns of both rhyolites, show marked negative Eu-anomalies (Text-Fig. 4b, Table 3). The lanthanide distribution in the Late Cambrian rhyolites thus reveals the affinity of these rocks to K-rich calc-alkaline acid volcanics as well as to tholeiitic ones, displaying a high fractionation degree (cf. CAMPBELL et al., 1982).
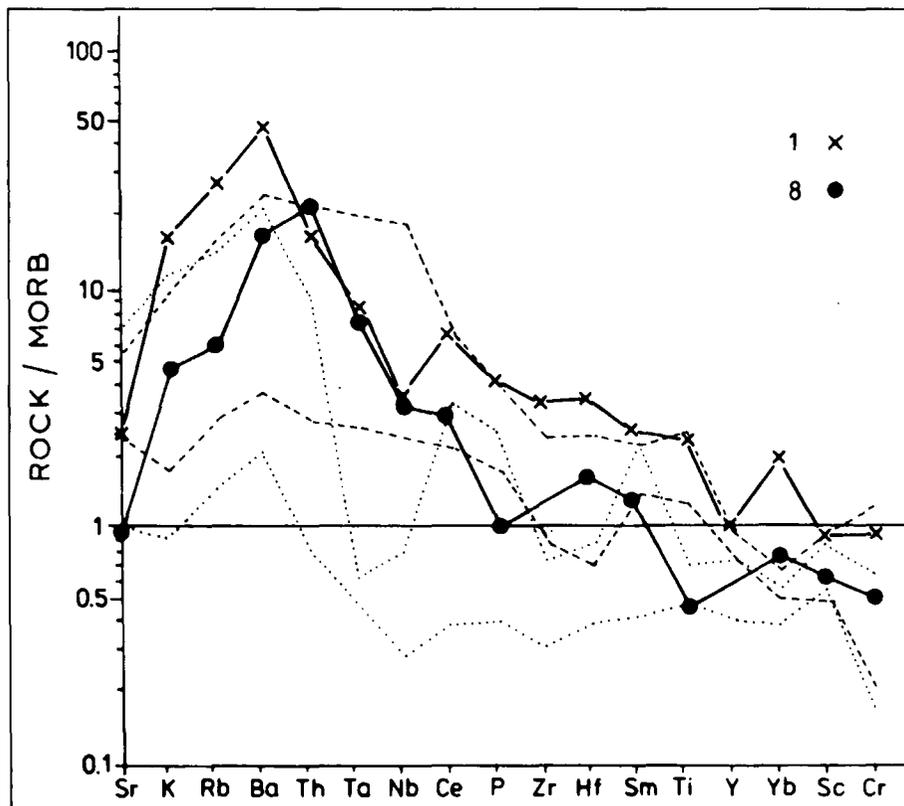
The trace element distribution relative to the ORG composition (PEARCE et al., 1984) in the Křivoklát-Rokycany Belt
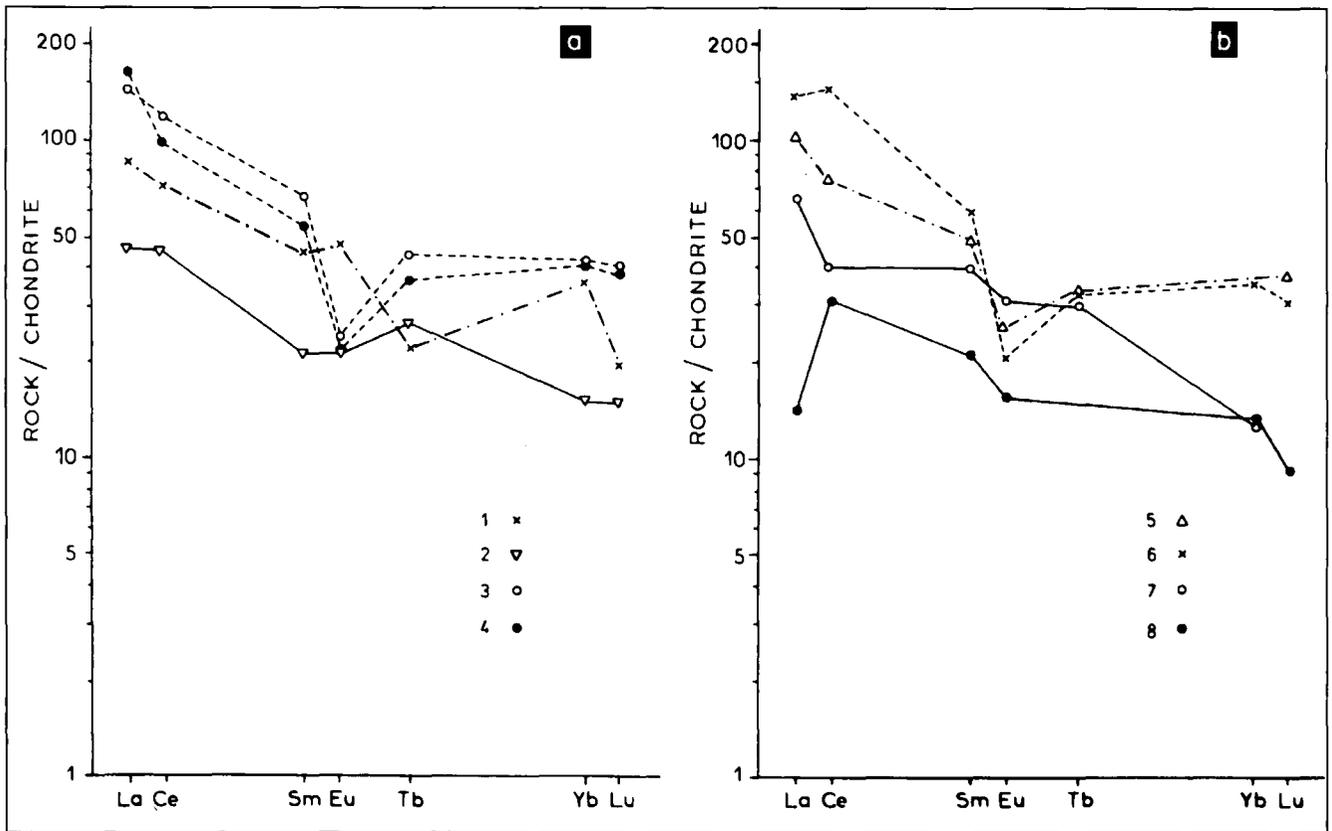
Text-Fig. 4.
Chondrite-normalized REE distribution patterns in the Cambrian volcanics of the Barrandian.
a = Lower Cambrian; 1 = basic porphyritic tuff; 2 = andesite tuff; 3 and 4 = lapilli and ash porphyry tuffs to tuffites; b = Upper Cambrian; 5 = porphyritic rhyolite; 6 = fluidal rhyolite; 7 = acid andesite; 8 = basic andesite.
Numbers given with graphic symbols correspond to the sample numbers in Tables 1, 2 and 3. Chondrite REE contents taken from HERRMANN et al., (1970).

rhyolites seems to be similar to that shown by the Příbram area Early Cambrian porphyry tuffs, too (Text-Fig. 6b). Following that, the Late Cambrian rhyolites can be similarly interpreted either as highly fractionated acid volcanics of volcano-plutonic arcs or as within-plate magmatites from the tectonic setting of continental lithosphere extension.

The lanthanide concentrations in rhyolites of the Křivoklát-Rokycany Belt are high: La and Ca abundances are about 100 to 150 times above the chondritic values, those of HREE only ca. 35 times. The fractionation degree of light and heavy rare earths in the fluidal rhyolite is roughly the same as in the Early Cambrian porphyry tuffs from the Příbram area; in the porphyritic rhyolite it is somewhat lower. The REE distribution patterns of both rhyolites, show

Text-Fig. 5.
Trace element (including K) abundances in the Cambrian Barrandian basic volcanics, normalized to mid-ocean ridge basalt composition (PEARCE, 1982).
Numbers with graphic symbols correspond to the sample numbers in Tables 1, 2 and 3: 1 = basic porphyritic tuff (Lower Cambrian), 8 = basic andesite (Upper Cambrian).
Dashed lines show the envelope of the within-plate basalt composition, dotted lines bound the envelope of volcanic-arc basalts (PEARCE, l.c.).
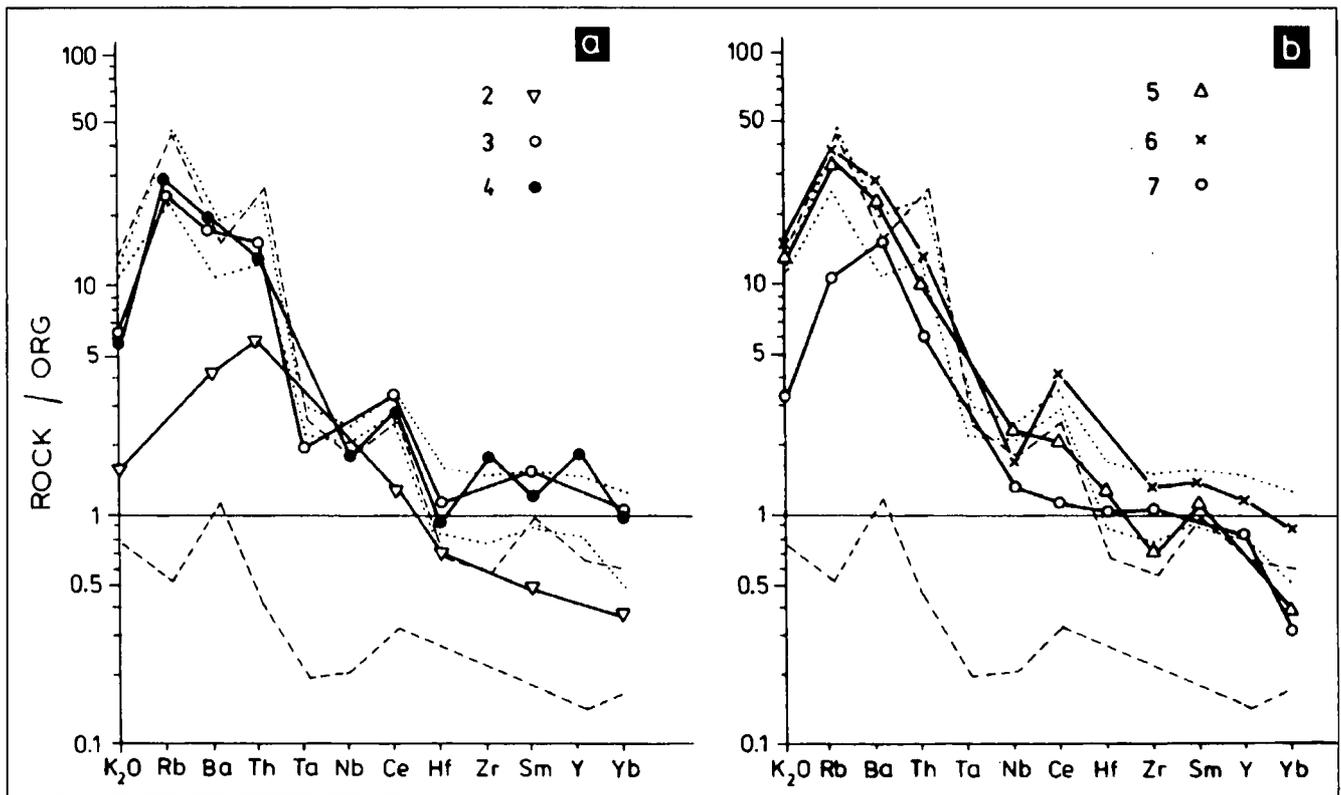
Text-Fig. 6.
Trace element (including K) contents in the Cambrian intermediate and acid volcanics of the Barrandian normalized to ocean-ridge granite composition (PEARCE, et al., 1984).
a = Lower Cambrian; 2 = andesite tuff; 3 and 4 = lapilli and ash porphyry tuffs to tuffites; b = Upper Cambrian; 5 = porphyritic rhyolite; 6 = fluidal rhyolite; 7 = acid andesite.
Numbers with graphic symbols correspond to the sample numbers in Tables 1, 2 and 3. Dashed lines show the envelopes of acid igneous rocks of volcano-plutonic arcs, dotted lines bound the envelopes of acid rocks from the setting of thinned continental crust (PEARCE et al., l.c.).

marked negative Eu-anomalies (Text-Fig. 4b, Table 3). The lanthanide distribution in the Late Cambrian rhyolites thus reveals the affinity of these rocks to K-rich calc-alkaline acid volcanics as well as to tholeiitic ones, displaying a high fractionation degree (cf. CAMPBELL et al., 1982).

The trace element distribution relative to the ORG composition (PEARCE et al., 1984) in the Křivoklát-Rokycany Belt rhyolites seems to be similar to that shown by the Příbram area Early Cambrian porphyry tuffs, too (Text-Fig. 6b). Following that, the Late Cambrian rhyolites can be similarly interpreted either as highly fractionated acid volcanics of volcano-plutonic arcs or as within-plate magmatites from the tectonic setting of continental lithosphere extension.

The sample No. 7 regarding petrography described as acid andesite, can be defined as subalkaline andesite according to SiO_2 content and the $NaO_2 + K_2O$ sum ratio to SiO_2 value (Text-Fig. 2, Table 2); however, the Al_2O_3, FeOt + TiO_2 and MgO value relations point to its affinity to tholeiitic dacites, too (Text-Fig. 3).

In this sample the LREE and HREE are less fractionated than in rhyolites just described; the negative Eu-anomaly is almost absent (Text-Fig. 4b). The lanthanide distribution pattern of the acid andesite resembles that of medium-K calc-alkaline andesites (cf. EWART et al., 1977; FUJINAWA, 1988 etc.).

The ORG-normalized acid andesite composition shows some depletion in LIL elements (K and Rb in particular) compared with the Křivoklát-Rokycany Belt rhyolites and nearly the same concentrations of HFS and mantle com-

patible elements (Text-Fig. 6b). In contrast to the rhyolites, characterized by equivocal composition as to the tectonic setting interpretation, the andesite can be considered rather as an equivalent of magmatic arc rocks (e.g. PEARCE et al., 1984).

In the basic andesite (No. 8) the volatile-free silica concentration is about 55 wt. %; according to the alkali sum vs SiO_2 content ratio, a low K_2O/Na_2O ratio (0.20) and position in the cation plot (JENSEN, 1976), this rock corresponds to K-poor calc-alkaline basaltic andesite (Text-Figs. 2 and 3).

Compared with the average mid-ocean ridge basalt (PEARCE, 1982) the basic andesite is markedly enriched in K, Rb, Ba, Th, Ta, Nb and Ce; the abundances of Sr, P, Hf and Sm are equal to or slightly higher than in MORB composition, and the Ti, Yb and Cr contents are lower (Text-Fig. 5). As to the shape of the trace element distribution pattern the rock is similar to within-plate transitional basalts; however, except for the enrichment in Ta, Nb and Hf, it also resembles island-arc calc-alkaline basalts (cf. PEARCE, 1983).

The basic andesite has the lowest total REE concentration of the four rock samples from the Křivoklát-Rokycany Belt – only ca. 20 times higher than in chondrites. The fractionation of light and heavy lanthanides is low and the negative anomaly of Eu is almost absent in the REE distribution pattern (Text-Fig. 4b). In the distribution of the rare earths the basic andesite is fairly similar to island-arc tholeiitic and medium-K calc-alkaline andesites (cf. GILL, 1981; HUTCHISON, 1982 etc.).

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4.1.3. Ordovician

The effusive rocks, extruding on the Barrandian Basin floor in the Ordovician, are represented in the set studied by two samples of pillow lavas and by one single sample of amygdaloidal diabase, diabase s.s. and hyaloclastite, respectively (Nos. 9 to 13 in Tables 1, 2 and 3).

According to the volatile-free alkali sum vs silica abundance relation (Text-Fig. 2) and to the position in Al_2O_3 - $FeOt+TiO_2$ - MgO cation diagram (Text-Fig. 3) the first sample (No. 9) falls within the range of tholeiitic basalts to basaltic andesites (K_2O/Na_2O ratio is 0.20). The other two samples (Nos. 10 and 11) belong to alkali basalts and remaining ones (Nos. 12 and 13) correspond to trachybasalts and basaltic trachyandesites to trachyandesites s.s.

The Ordovician volcanics are mutually closely related as to the distributions and total REE contents – all of them are considerably enriched in light lanthanides. Two samples (Nos. 12 and 13), characterized by high $Na_2O + K_2O$ values (ca. 6 wt. %), also show more advanced fractionation of REE (the Ce/Yb ratio is 48 and 67, resp.) whereas the volcanics with lower alkali concentrations display Ce/Yb ratios within the range of 24 to 30 (Text-Figs. 2 and 7, Table 3). In the distribution of rare earths the Ordovician effusives are similar to alkaline basic to intermediate volcanic rocks (BASALTIC VOLCANISM STUDY PROJECT, 1981).

In Text-Fig. 8 the contents of trace elements (including K) in the Ordovician Barrandian volcanics are plotted relative to the MORB composition (PEARCE, 1982, 1983). The samples displaying more fractionated rare earth abundances differ also in this case, principally in having lower concentrations of mantle-compatible elements (Y, Yb, Sc and Cr). From the shapes of distribution patterns a close similarity between the Ordovician volcanic rocks and within-plate transitional basalts (sample No. 9) to alkaline ones (samples Nos. 10 to 13) can be assumed.

4.1.4. Silurian

The Silurian volcanics are represented in the rock set investigated by the largest number of samples (Nos. 14 to 22). According to the petrography they are described as pillow lava (No. 14), olivine diabase (No. 15), coarse-grained quartz diabase (No. 16), coarse-grained teschenite-diabase (No. 17), coarse-grained essexite-diabase (No. 18), essexite (No. 19), picrite-diabase (No. 20) and spilite-diabase (Nos. 21 and 22) (Tables 1, 2 and 3).

Owing to the relatively low mobility of REE during secondary processes (subaquatic weathering, hydrothermal alteration and low-grade metamorphism) (e.g. HERRMANN et al., 1974; MENZIES et al., 1979; LUDDEN et al., 1982; VIVALLO, 1985) the rare earth contents and fractionation degree were chosen as a basis for the classification of the Silurian Barrandian volcanic rocks. Regarding these criteria, three principal types of volcanics were distinguished (Text-Fig. 9, Table 3).

The first type (samples Nos. 14, 18 and 20) is characterized by relatively flat REE distribution patterns. The total lanthanide concentrations in these three samples are low, except for La they are about 10 to 30 times above the chondritic level. Light and heavy rare earths are slightly fractionated (Ce/Yb ratio is up to 8). In REE distribution this type of the Silurian volcanics corresponds to tholeiitic and/or K-poor calc-alkaline basalts (BASALTIC VOLCANISM STUDY PROJECT, 1981; WHELLER et al., 1987 etc.).

Nevertheless, considering the volatile-free silica content and alkali sum relation, all samples of the first type belong to alkaline rocks – alkaline basalts, trachybasalts and basaltic trachyandesites (Text-Fig. 2). It should be added that their major element composition shows conspicuously high proportions of Na_2O (3 to 5 wt. % compared with only 0.5 to 0.8 wt. % K_2O), H_2O (up to 10 wt. %) and in one sample also CO_2 (ca. 7 wt. %) (Table 2). These features, together with low Rb concentrations (Table 3), can be a product of some alteration, most likely of the rock-seawater reaction (e.g. MENZIES & SEYFRIED, 1979). The sample positions in the field of alkaline rocks (Text-
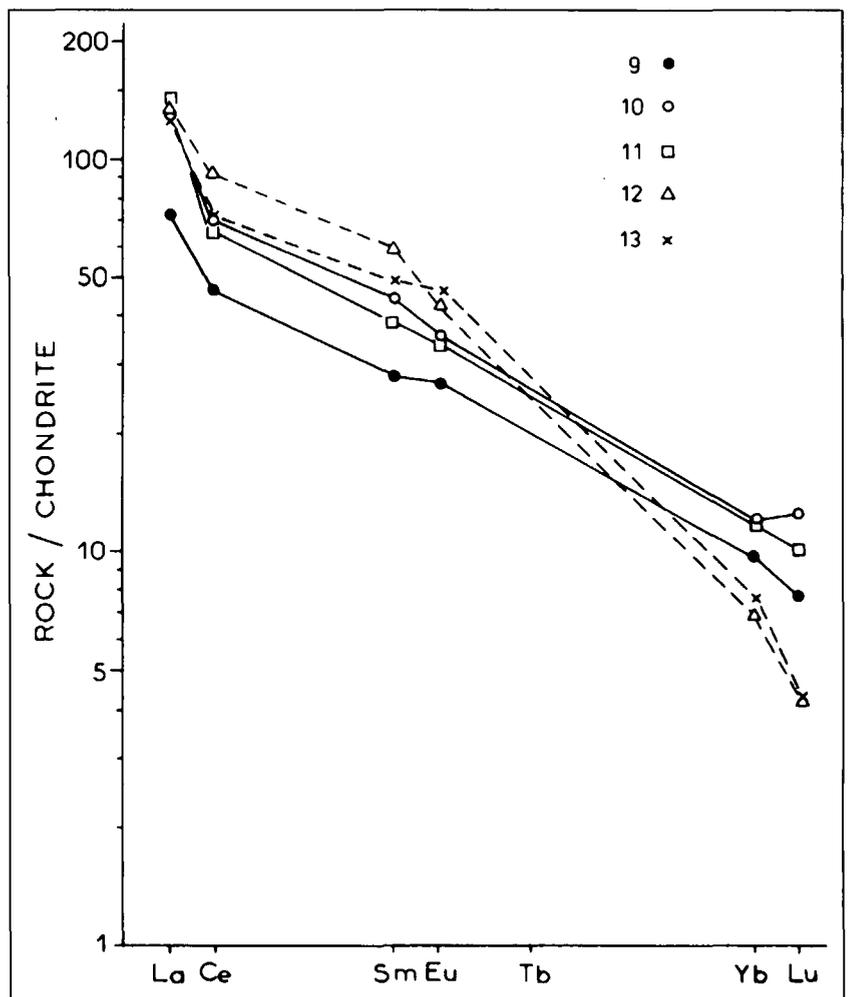
Text-Fig. 7.
Chondrite-normalized distribution patterns of REE abundances in the Ordovician Barrandian effusive rocks.
Numbers with graphic symbols correspond to the sample numbers in Tables 1, 2 and 3.
9 and 10 = pillow lavas; 11 = amygdaloidal diabase; 12 = diabase s.s., 13 = hyaloclastite.
Dashed lines denote samples with higher Ce/Yb ratios (see Table 3). Chondrite contents of REE taken from HERRMANN et al. (1970).

Fig. 2) very probably results from postmagmatic Na-enrichment (spilitization) (HERRMANN et al., 1974; HUMPHRIS & THOMPSON, 1978 etc.), which was described in the Silurian diabases e.g. by BLECHOVA (1985).

The Silurian volcanics of the first type strongly resemble within-plate tholeiitic to transitional basalts in the MORB-normalized trace element distribution, showing fairly high enrichment in LIL elements (except Rb), a moderate enrichment in HFS elements and depletion of some compatible elements (Text-Fig. 10a).

· The second type of the Silurian basic volcanic rocks (samples Nos. 15, 17, 19, 21 and 22) are characterized by a high degree of LREE and HREE fractionation – the Ce/Yb values range from 13 to 22 (Text-Fig. 9 and Table 3). In the shape and position of lanthanide distribution patterns these volcanics are similar to the transitional to alkaline basalts (cf. LANPHERE & FREY, 1987).

In the SiO_2 vs $Na_2O + K_2O$ diagram (Text-Fig. 2) all samples (except No. 22), representing the second type of Silurian volcanics, fall into the field of alkaline rocks, for the most part to the trachybasalt to basaltic trachyandesite fields.

The Silurian volcanic rocks of the second type, normalized relative to the mid-ocean ridge basalt composition, display the trace element distribution characteristic for within-plate transitional to alkaline basalts (PEARCE, 1982) (Text-Fig. 10b).

The last type of Silurian volcanics is represented by one sample only (No. 16). Considering the degree of LREE and HREE fractionation, this rock should belong to the previous type – nevertheless, it differs in a very high lanthanide content (126 ppm – Text-Fig. 9 and Table 3). The features described rank this sample to alkaline basalts (BASALTIC VOLCANISM STUDY PROJECT, 1981).
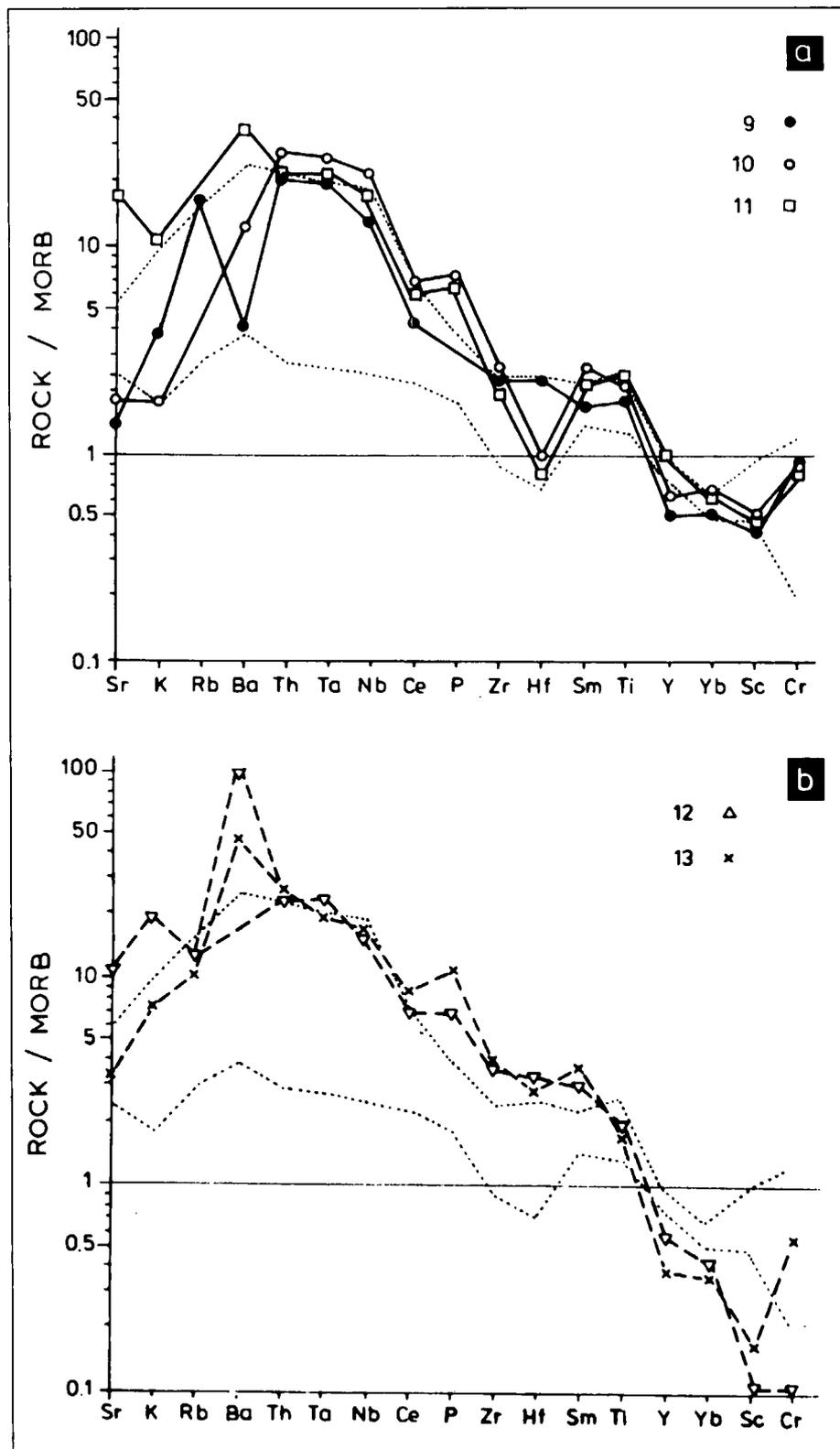
The volatile-free silica content (ca. 58 wt. %) and the alkali sum vs SiO_2 abundance ratio place the last Silurian volcanic type to the andesite-trachyandesite field boundary (Text-Fig. 2). The relatively high FeOt concentration (almost 11 wt. %) projects this sample onto the margin of the tholeiitic andesite field (Text-Fig. 3).

The enrichment in LIL and HFS elements apparent in MORB-normalized sample composition points to an affinity of the sample to alkaline within-plate volcanic rocks (cf. PEARCE, 1982) (Text-Fig. 10c).

4.1.5. Devonian

The Barrandian volcanic rocks of Devonian age are represented in the set studied by only one sample of hyaloclastite (No. 23). The volatile-free SiO_2 content is about 44 wt. %, so that the rock corresponds to picrobasalt at the boundary between basic and ultrabasic magmatites (Text-Fig. 2). Owing to high Fe and Mg abundances (13 wt. % FeOt and 12 wt. % MgO) this sample is located in the cation plot (JENSEN, 1976) near the basaltic komatiite field margin (Text-Fig. 3).

The Devonian hyaloclastite shows the highest enrichment in light lanthanides of all the rocks investigated (Ce/Yb ratio is 54) (Text-Fig. 11 and Table 3). According to the distribution pattern of rare earth it is identical to alkaline basalts (BASALTIC VOLCANISM STUDY PROJECT, 1981).

Normalized by MORB-composition (PEARCE, 1982), the distribution of microelement concentrations in this rock is very close to that of within-plate alkali basalt (Text-Fig. 12); this is indicated by high enrichment in LIL and HFS elements and depletion in some mantle-compatible elements.

4.2. Dyke rocks

4.2.1. Contact Zone
of the Central Bohemian Pluton

The studied set of Early Paleozoic Barrandian volcanics also comprises five samples of dyke rocks from the Příbram area, contact-metamorphosed by Variscan intrusives of the Central Bohemian Pluton. According to the petrography, they are described as hornblende diabase, diabase s.s., leucocratic porphyritic diabase and two quartz porphyries (Nos. 24 to 28 in Tables 1, 2 and 3). A comprehensive set of rock samples displaying identical mineral and chemical composition was investigated by VLAŠÍMSKY (1971, 1976) and MACHÁČEK & VLAŠÍMSKY (1979).

The hornblende diabase (No. 24) with a SiO_2 content less than 52 wt. % and the relation of SiO_2 abundance to alkali sum (both volatile-free) falls within the range of subalkaline basaltic andesites (Text-Fig. 2). The relationships
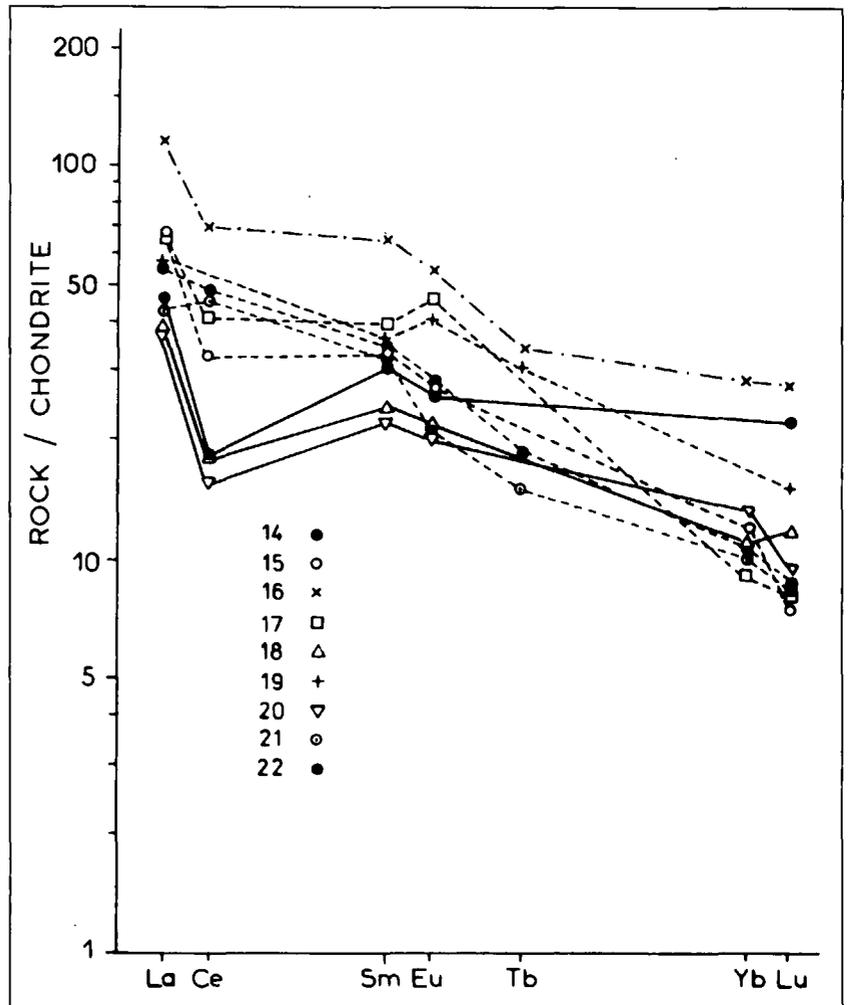
among Al_2O_3, FeOt+TiO_2 and MgO indicate the rocks affinity to tholeiitic basalts (Text-Fig. 3).
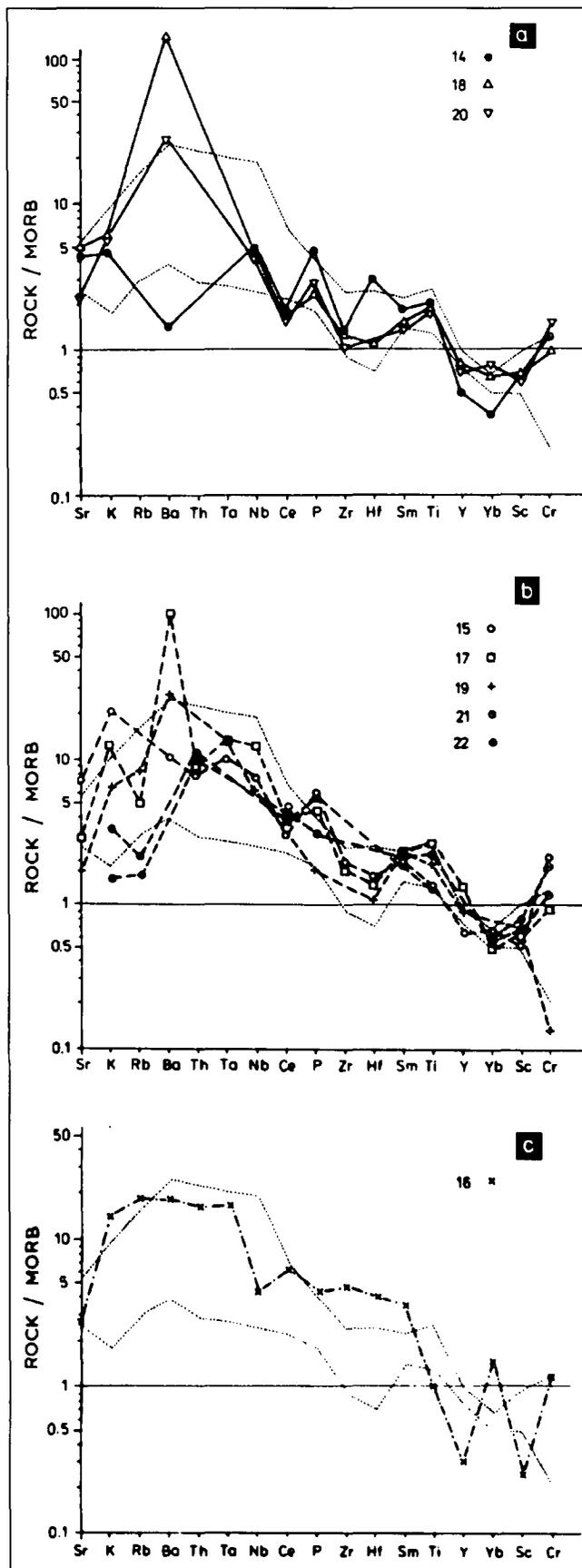
The REE concentrations in the hornblende diabase are low, only 10 to 25 times higher than in chondrites. The LREE vs HREE fractionation is relatively inexpressive (the Ce/Yb ratio value is ca. 11) (Text-Fig. 13, Table 3). The form and position of lanthanide distribution patterns are analogous to those of K-poor calc-alkaline andesites (cf. GILL, 1981).

Compared with the mid-ocean ridge basalts (PEARCE, 1982) the hornblende diabase in enriched in LIL elements and Ce and contains the same or lower concentrations of HFS and mantle compatible elements (Text-Fig. 14a). Consequently, the rock can be compared to both mid-ocean ridge alkaline basalts (with high proportions of LIL elements) and transitional within-plate ones depleted in HFS elements.
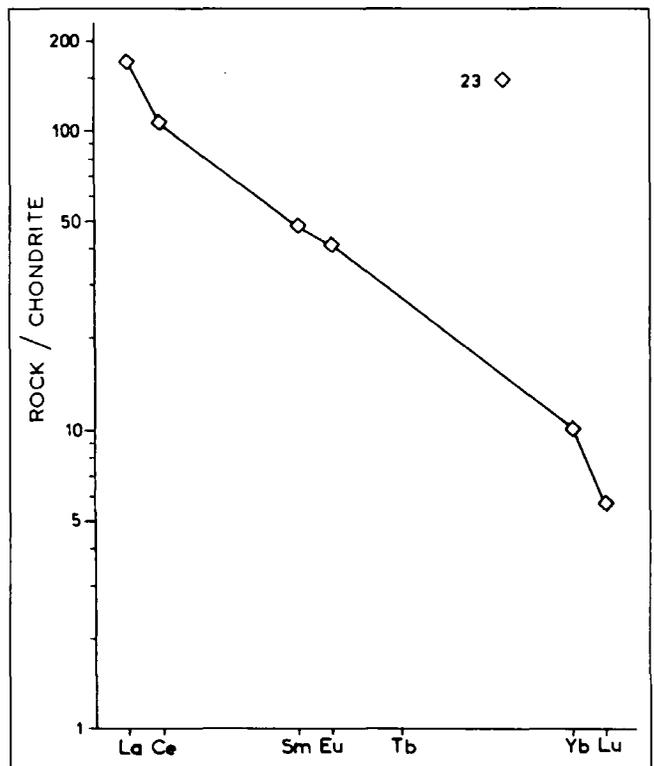
In the SiO_2 vs Na_2O + K_2O diagram the diabase s.s. (No. 25) is situated in the field of subalkaline basalts (Text-Fig. 2). The low K_2O/Na_2O ratio (about 0.1), as well as the sample's position in cation plot after JENSEN (1976), rank this rock to tholeiitic basalts (Text-Fig. 3).

The REE distribution pattern of diabase s.s. in Fig 13 is very flat (the Ce/Yb ratio value is ca. 7) and the lanthanide total concentration is only 20 times higher than in chondrites. Both these features show that this rock can be assigned as tholeiitic basalt (cf. LANPHERE & FREY, 1987).

Diabase s.s. is very similar to mid-ocean ridge basalt (PEARCE, 1982) in the content of trace elements (including K); in respect of a moderate enrichment in Sr, K, Ba and Ce

Text-Fig. 11.
Chondrite-normalized distribution pattern of REE abundances in the Devonian hyaloclastite from the Barrandian (No. 23 in Tables 1, 2 and 3). Chondrite REE contents taken from HERRMANN et al. (1970).

Text-Fig. 10.
Trace element (including K) contents in the Silurian Barrandian volcanics, normalized to mid-ocean ridge basalt composition (PEARCE, 1982).
a = samples with Ce/Yb ratio up to 8; b = samples with Ce/Yb ratio from 13 to 22; c = sample having a high REE content (126 ppm) (see Table 3). Dotted lines show the envelopes of within-plate basalts (PEARCE, l.c.). For explanation of numbers given with graphic symbols see Text-Fig. 9.

relative to MORB it may be specified as transitional type between tholeiitic basalts and alkaline ones. However, the analogy with within-plate tholeiitic basalts cannot be excluded either (Text-Fig. 14a).

The leucocratic porphyritic diabase (No. 26), corresponding to basaltic trachyandesite in the volatile-free silica and alkali abundances, lies at the boundary between subalkaline and alkaline volcanics established by IRVINE & BARAGAR (1971) (Text-Fig. 2).

The REE contents in the leucocratic diabase are higher than in both previous samples of dyke diabases (about 20 to 45 times higher than in chondrites); nevertheless, there is no marked difference in the LREE vs HREE fractionation degree (Ce/Yb ratio is 11) (Text-Fig. 13, Table 3). The type of lanthanide distribution is similar to that characterizing medium-K calc-alkaline andesites (WHITFORD et al., 1979; HUTCHISON, 1982 etc.).

The distribution pattern of MORB-normalized trace element abundances in the leucocratic diabase has a form typical of transitional to alkaline within-plate basalts and their differentiates (PEARCE, 1982) (Text-Fig. 14a).

The quartz porphyries (samples Nos. 27 and 28) can be regarded as subalkaline rhyolites on the basis of SiO_2 contents (73 and 76 wt. %) and the sum of alkali abundances. The first sample contains a strikingly high proportion of FeOt (more than 5 wt. %) and the FeOt/MgO ratio value above 20. In cation plot (JENSEN, 1976) the rock thus lies in the tholeiitic rhyolite field (Text-Fig. 3) despite its high K_2O/Na_2O (ca. 1.0). As it is evident from Text-Fig. 3 the other quartz porphyry sample corresponds to calc-alkaline rhyolite.

The total REE contents in the quartz porphyries are relatively low (ca. 73 and 65 ppm) but the fractionation degree of LREE and HREE is high (Ce/Yb ratio is 37 and 20, resp.) (Text-Fig. 13 and Table 3). The lanthanide distribution pat-

Text-Fig. 12.
Trace element (including K) contents in Devonian hyaloclastite from the Barrandian (No. 23 in Tables 1, 2 and 3), normalized against mid-ocean ridge basalt composition (PEARCE, 1982).
Dashed lines show the envelope of within-plate basalt composition (PEARCE, l.c.).

terns indicate the affinity to calc-alkaline rhyolites (cf. SUNDERS et al., 1980).

In the distribution of trace element concentrations (including K) relative to ocean ridge granite (ORG) (PEARCE et al., 1984) the quartz porphyries closely resemble the acid intrusives accompanying the collision of lithospheric plates (Text-Fig. 14b).

4.2.2. Silurian Sequence of the Prague Basin

The dyke rocks of the Prague Basin are represented in the set studied by eight samples; their petrography and geochemistry was described by BLECHOVÁ (1985). The first sample is diabase s.s. (No. 29 in Tables 1, 2 and 3), six samples belong to teschenite-diabases (Nos. 30 to 35) and the last sample is a diabase-picrite (No. 36).

According to the contents and distribution of REE three rock types can be distinguished, similarly as among the volcanics of Silurian age (Chapter 4.1.4.) (Text-Fig. 15).

The first type, characterized by a very low REE concentration (only 6 to 15 times higher than in chondrites, i.e. the lowest of all Barrandian volcanics studied) and a low LREE vs HREE fractionation degree (the Ce/Yb ratio value equals 11), is represented by a single sample – the picrite-diabase (No. 36). The flat shape of the lanthanide distribution pattern resembles that of tholeiitic basalt (BASALTIC VOLCANISM STUDY PROJECT, 1981).

According to SiO_2 and $Na_2O + K_2O$ volatile-free contents the picrite-diabase falls into the subalkaline basalt field (Text-Fig. 2). A considerable MgO proportion in this rock (Table 2) is a reason of its position in the komatiitic basalt field in Text-Fig. 3. Except for a depleted Ce content and a considerable excess of Cr,
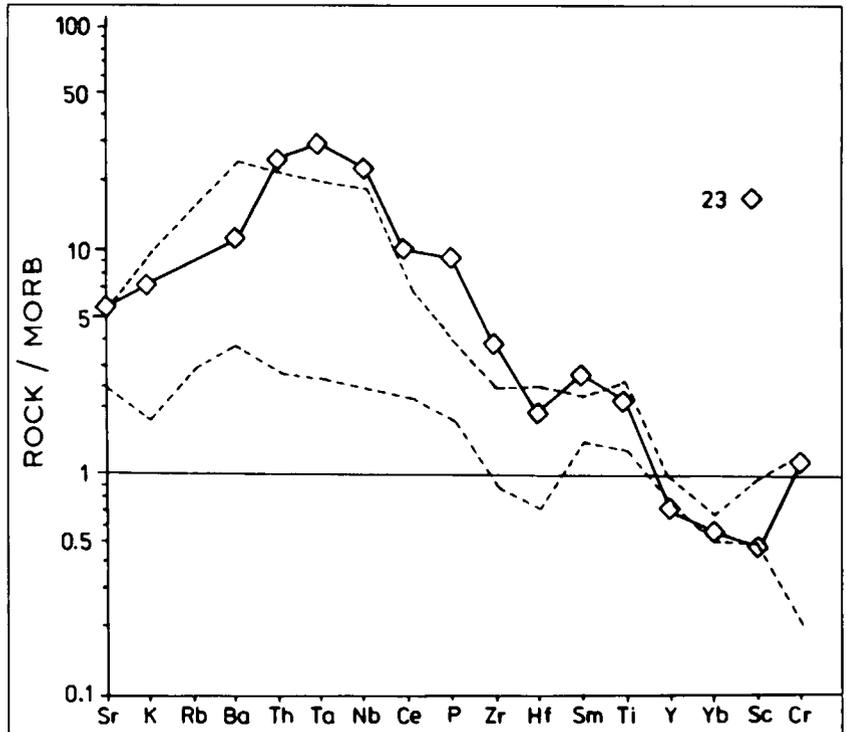
the distribution of MORB-normalized trace element abundances is relatively similar to the distribution patterns of tholeiitic to transitional within-plate basalts (PEARCE, 1982) (Text-Fig. 16a).
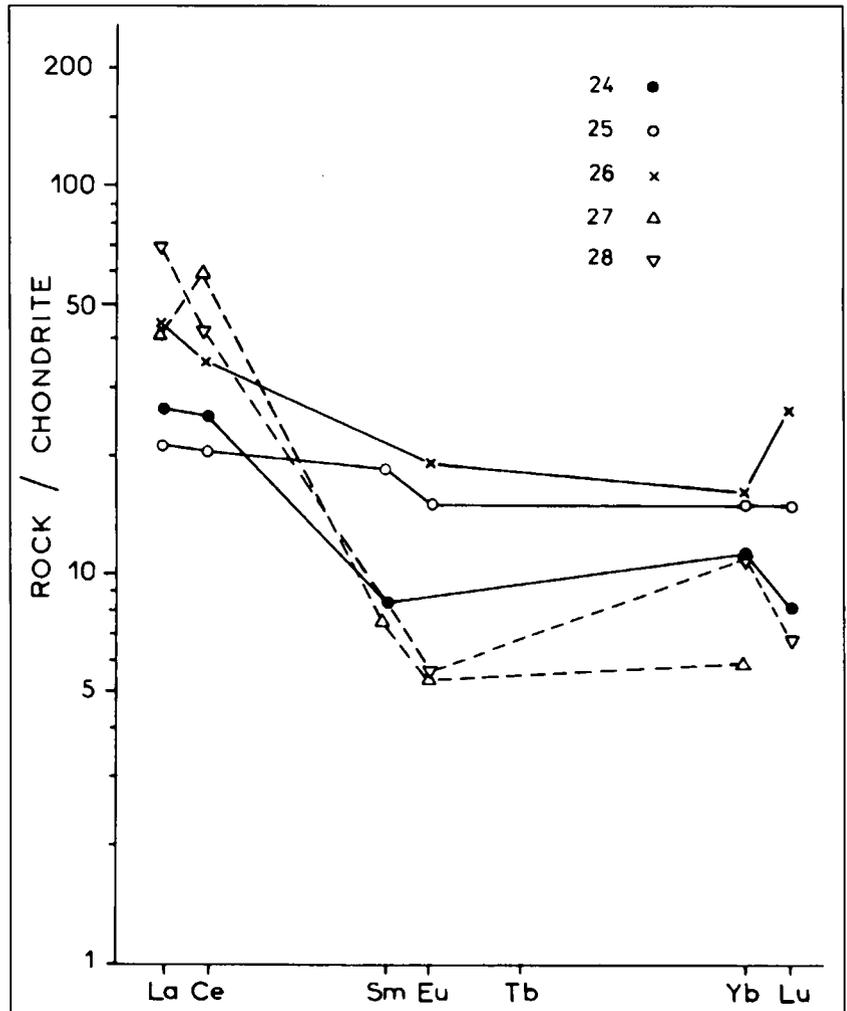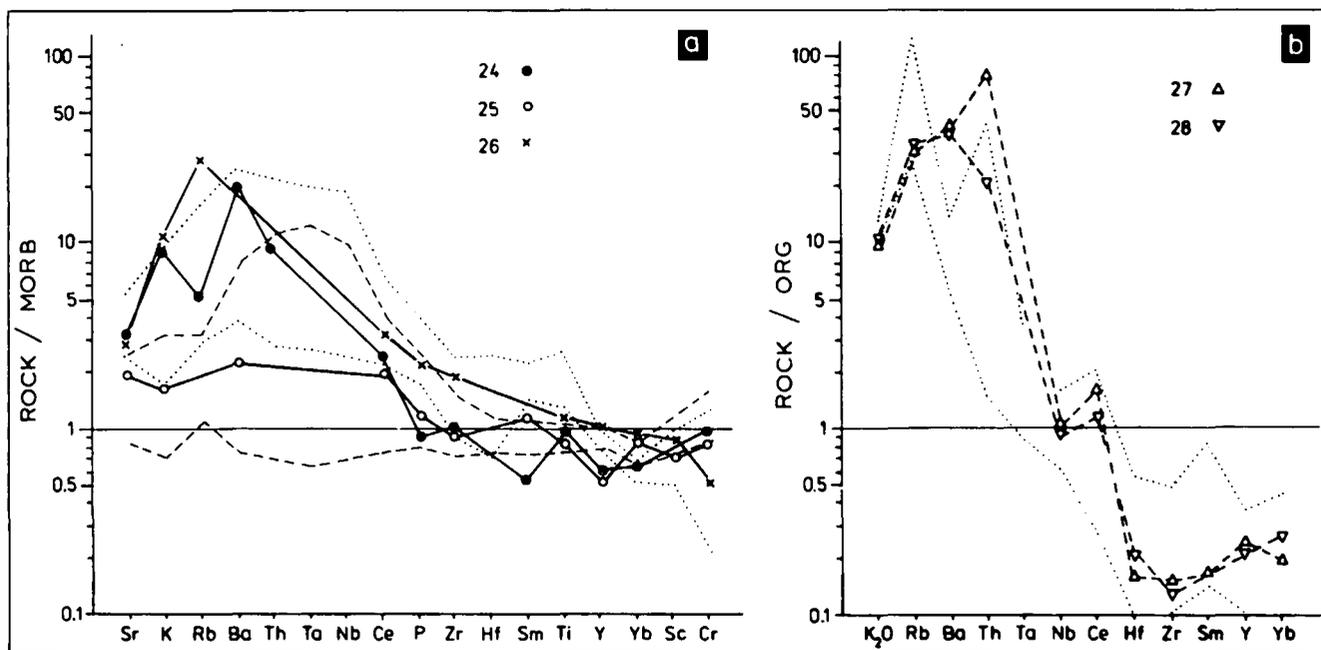

Text-Fig. 13.
Chondrite-normalized REE distribution patterns of the Early Paleozoic dyke rocks of the Central Bohemian Pluton contact zone.
Solid lines indicate basic to intermediate rocks, dashed lines show acid types. Numbers with graphic symbols correspond to sample numbers in Tables 1, 2 and 3.
24 = hornblende diabase, 25 = diabase s.s., 26 = leucocratic porphyritic diabase, 27 and 28 = quartz porphyries.
Chondrite REE contents taken from HERRMANN et al. (1970).

Text-Fig. 14.
Trace element (including K) contents in the Early Paleozoic dyke rocks of the Central Bohemian Pluton contact zone, normalized to mid-ocean ridge basalt composition (PEARCE, 1982) (a) and to ocean-ridge granite composition (b).
The envelope of the mid-ocean ridge basalts is shown by dashed line, envelope of within-plate basalts by dotted line (a) (PEARCE, 1982); the envelope of syn-collision acid magmatites is also denoted by dots (b) (PEARCE et al., 1984). (For explanation of numbers with graphic symbols see Text-Fig. 13).

The second type of the Prague Basin dyke rocks, diabase s.s. (sample No. 29) and three samples of teschenite-diabases (Nos. 31, 33 and 34), has an essentially higher lanthanide concentration: LREE content is about 30 to 35 times higher than in chondrites and the HREE abundance is only 10 to 15 times higher (Text-Fig. 15). The fractionation of light and heavy rare earths, however, is only slightly more advanced than in the first type of the dyke diabases (the Ce/Yb ratio value ranges from 13 to 16 – Table 3). The REE distribution patterns of this rock type resemble those of basalts transitional between tholeiitic and alkaline types (e.g. LANPHERE & FREY, 1987).

In the SiO₂ vs Na₂O + K₂O diagram the diabases of the second type belong to subalkaline, transitional and alkaline rocks – basalts, basaltic andesites and trachybasalts (Text-Fig. 2). In the Al₂O₃ – FeOt + TiO₂ – MgO diagram the subalkaline diabases lie in the field of tholeiitic basalts (Text-Fig. 3).

The dyke diabases discussed display a pattern of MORB-normalized trace element contents identical with that of transitional within-plate basalts (cf. PEARCE, 1982), except for the high P abundance (Text-Fig. 16a).
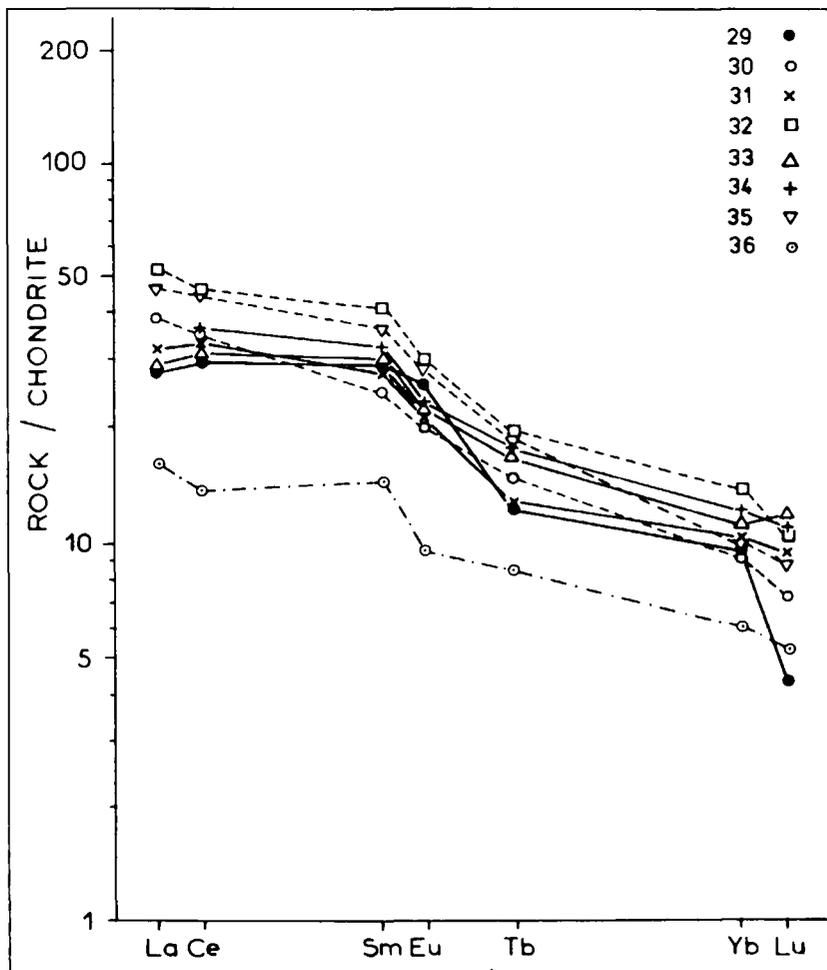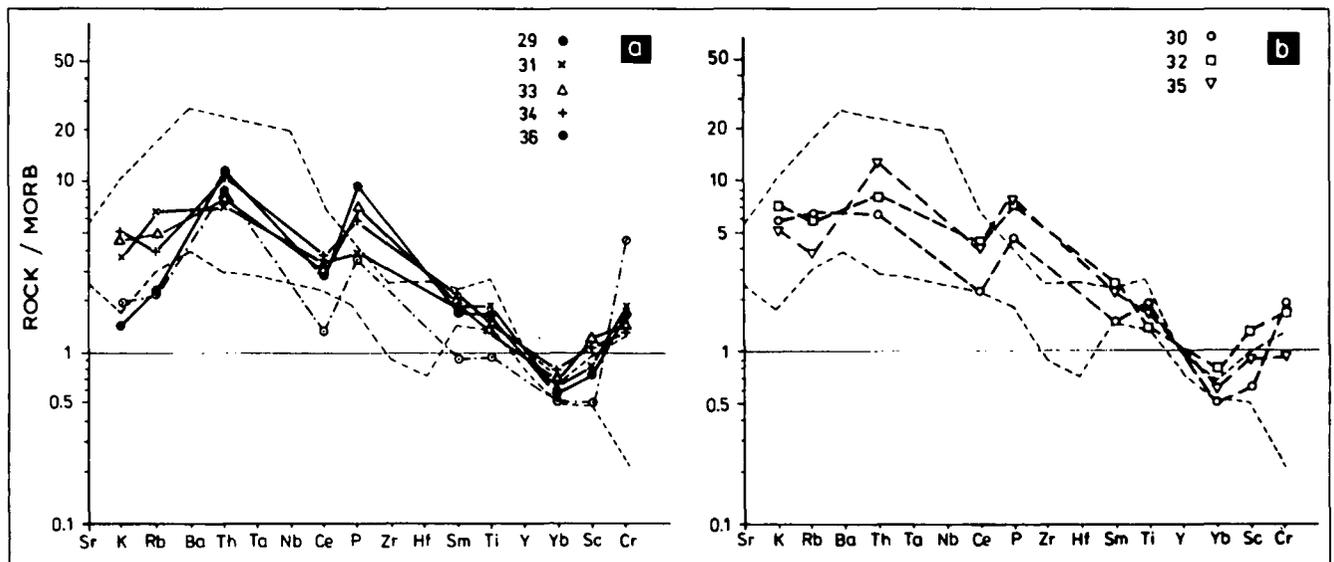

Text-Fig. 15.
Chondrite-normalized REE distribution patterns in the dyke diabase of the Prague Basin Silurian sequence.
Numbers with graphic symbols correspond to the sample numbers in Tables 1, 2 and 3.
29 = diabase s.s., 30 to 35 = teschenite-diabase, 36 = diabase-picrite.
Dot-dashed line indicates the sample having very low REE content (24 ppm), solid lines denote samples of Ce/Yb ratio from 13 to 16, and dashed lines represent samples having Ce/Yb ratios from 16 to 22 (see Table 3). Chondrite REE contents taken from HERRMANN et al. (1970).

Text-Fig. 16.
MORB-normalized contents of trace elements (including K) in the dyke diabases of the Prague Basin Silurian sequence.
Samples characterized by Ce/Yb ratio less than 16 are plotted separately (a) from samples showing higher values of this ratio (b). Thin dashed lines mark envelopes of within-plate basalts (PEARCE, 1982). For explanation of numbers with graphic symbols see Text-Fig. 15.

The third dyke diabase type of the Prague Basin (teschenite-diabases only – samples Nos. 30, 32 and 35) is characterized by the highest REE contents (the concentration of light lanthanides is 40 to 50 times above the chondritic level and the heavy lanthanide abundances are about 10 to 20 times above it) and by the most advanced REE fractionation degree (the Ce/Yb ratio is 16 to 22) (Text-Fig. 15, Table 3). In analogy to the second type these diabases also have a similar rare earth distribution as transitional tholeiitic to alkaline basalts (BASALTIC VOLCANISM STUDY PROJECT, 1981).

With respect to the relationship between volatile-free silica contents and the sum of alkalis the dyke diabases of the third type may be considered as alkaline basalts to trachybasalts (Text-Fig. 2).

The enrichment in LIL and HFS elements relative to MORB composition also reveals the affinity of the last diabase type to transitional within-plate basalts and their differentiates (PEARCE, 1982) (Text-Fig. 16b).

5. Discussion

5.1. Paleotectonic Implications

The Early Cambrian volcanics, in the set studied represented only by pyroclastics, for the most part (three of four samples) are in geochemistry related to volcanics of convergent plate margins. Nevertheless, two of the three mentioned samples (the porphyry-tuffs) can be also considered, with regard to some specific features, as the equivalents of within-plate acid volcanics formed in tectonic setting of thinned continental crust (Text-Figs. 4a and 6a). The only sample (basic porphyritic tuff) coresponds entirely to within-plate volcanic rocks – alkaline ocean-island basalts (Text-Figs. 4a and 5) or to continental tholeiites (Fig 17). The analogy with continental tholeiite follows in particular from the relatively low Nb content compared with the concentrations of other HFS elements (Text-Fig. 5) (cf. MESCHEDE, 1986; MARSH, 1989 etc.). The ana-
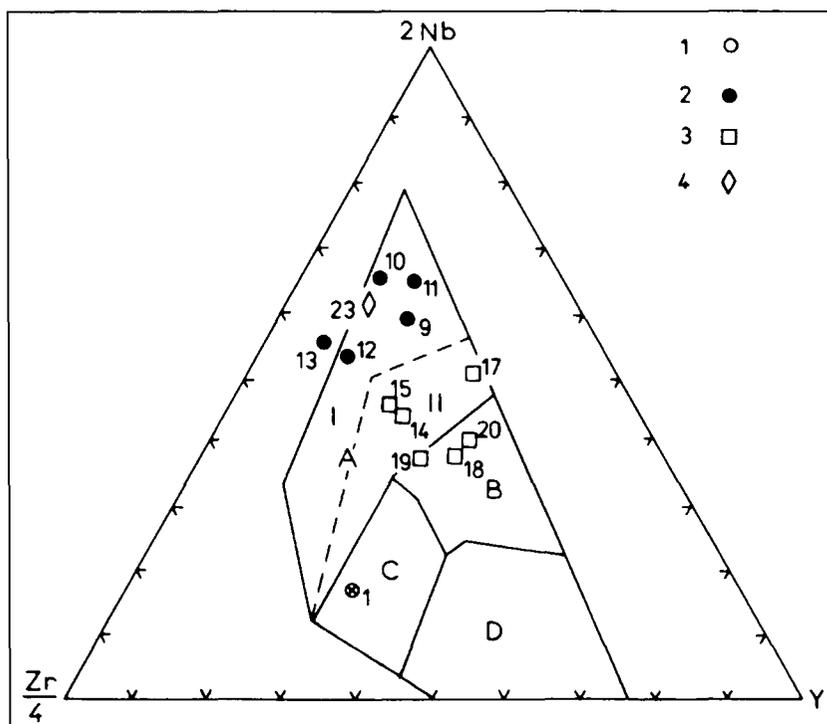
Text-Fig. 17.
Early Paleozoic volcanic rocks of the Barrandian in Zr-Nb-Y diagram (MESCHEDE, 1986). A = within-plate basalts (alkaline types lie within the whole field, tholeiitic basalts only in sub-field II); B = mid-ocean ridge basalts of P-type; C = within-plate tholeiites; D = mid-ocean ridge basalts of N-type (volcanic-arc basalts also plot in fields C and D); 1 = Early Cambrian basic porphyritic tuff; 2 = Ordovician effusive rocks; 3 = Silurian volcanics; 4 = Devonian hyaloclastite. Numbers with graphic symbols correspond to numbers of samples in Tables 1, 2 and 3.

lyses of all Early Cambrian pyroclastics (with respect to high Al and K contents) are fairly probably affected by a certain proportion of sedimentary admixture. The conclusions on the paleotectonic position of the Early Cambrian volcanics thus are necessarily constrained.

The principal feature of the Late Cambrian volcanic rocks (of the Křivoklát-Rokycany Belt) are well comparable with the composition of island-arc and/or active continental margin volcanics (Text-Fig. 6b). The same result was obtained by ŠINDELÁŘOVÁ (1982) not only for the Křivoklát-Rokycany Belt but also for the second Late Cambrian volcanic belt – the Strašice one. Also the $^{87}Sr/^{86}Sr$ ratios, measured in these rocks (average value 0.704 – VIDAL et al., 1975), resemble the Sr isotope values in I-granitoids, i.e. in the typical igneous rocks of volcano-plutonic arcs. Remarkable features of the Late Cambrian volcanics are the characteristics of tholeiitic series rocks – moderately steep REE distribution patterns (cf. CAMPBELL et al., 1982) and enrichment in Fe relative to Mg (cf. MIYASHIRO, 1974) in the rhyolites (Text-Figs. 3 and 4b, Tables 2 and 3) and low total lanthanide abundances combined with low Ce/Yb ratios (Text-Fig. 4b and Table 3) in the andesites (cf. GILL, 1981). It is noteworthy, however, that the samples of the Late Cambrian volcanics – in analogy to the Early Cambrian pyroclastics, having similar silica contents – in some features resemble within-plate magmatites from the regions of continental lithosphere extension, too (Text-Fig. 6b).

Regarding the described principal features of Cambrian volcanis it can be stated that in the Barrandian during this period outlasted the tectonic setting inherited from the Late Proterozoic stage of the whole Teplá-Barrandian Unit history. A number of authors (FIALA, 1978; CHÁB, 1979; JAKEŠ et al., 1979; MATĚJKA, 1981; HUSPEKA, 1989) compared this setting to that of recent convergent plate boundaries.

The within-plate geochemical features, shown in part by Cambrian Barrandian volcanics, do not disprove this conclusion. Rocks resembling within-plate types are described from the active plate margins e.g. by ORMEROD et al. (1988), REAGAN & GILL (1989) and RICHARDS et al. (1990). According to RINGWOOD (1990) it is possible to explain their specific composition by a genetic relationship to melting in deep parts of subducted lithospheric plate; also it can be interpreted as an indication of an initial stage of back-arc basin spreading, during which the basin-constituting igneous rocks gradually escape from a geochemical influence of subduction zone (FURNES et al., 1988).

Presumably, it may be suggested that the Cambrian Barrandian volcanics took origin in a complex tectonic setting comprising both waning stage of the Cadomian plate-convergence (e.g. CHÁB, 1979; RAST & SKEHAN, 1983) and incipient phase of the Early Paleozoic extension of the future Western and Central European plate (e.g. FRANKE, 1989; PIN, 1990).

Within the Bohemian Massif itself the timing of more advanced phase of the proposed extension can be identified roughly with the Cambrian-Ordovician boundary and/or with the lowermost Ordovician. It seems to be geochronologically dated by the MORB-like dark eclogites of the Münchberg Massif, displaying whole-rock Sm-Nd isochron 480±23 Ma, interpreted as the igneous origin age (STOSCH & LUGMAIR, 1990), as well as by ophiolite lithology possessing gabbros of the Mariánské Lázně Complex (KASTL & TONIKA, 1984) dated by U-Pb method on zircons of the protruding gabbro-pegmatites to 496 Ma (BOWES & AFTALION, 1991).

In the Barrandian Basin the tectonic setting had changed since an onset of the Ordovician, as indicated by geochemistry of volcanics; beginning with this period the major and trace element composition of the Barrandian volcanic rocks gained solely within-plate character and preserved it until the end of volcanic activity in the Middle Devonian.

The Barrandian mafic effusive rocks (pillow lavas and diabases) of Ordovician age correspond to modern within-plate alkaline basalts to basaltic trachyandesites in the principal geochemical features: an advanced fractionation of LREE relative to HREE (Text-Fig. 7 and Table 3), generally marked enrichment in LIL and HFS elements and depletion in mantle-compatible elements (Text-Fig. 8) (cf. PEARCE, 1982). The metabasites of probably Ordovician suites in the "Islet Zone" of the Central Bohemian Pluton mantle, which adjoins the SE limb of the Barrandian synclinorium, also show the within-plate basalt affinity (HUSPEKA, 1989).

The Barrandian volcanic rocks of the Silurian age (various diabases in general) comprise in addition to within-plate transitional and alkaline basalts, trachybasalts and trachyandesites (Text-Figs. 2, 9 and 10b, c) also tholeiitic basalts. According to the contents of silica and alkalies the latter belong to alkaline rocks, too (Text-Fig. 2); nevertheless, the flat REE distribution patterns and the trace element abundances place them close to within-plate tholeiitic basalts (Text-Text-Figs. 9 and 10a) but not to continental tholeiites because they are not depleted in Nb (Fig. 17; cf. DUPUY & DOSTAL, 1984). The position of these volcanics in the field of alkaline rocks is most likely caused by postmagmatic alteration (HERRMANN et al., 1974) increasing the Na, CO_2 and H_2O contents (Table 2). Similar differences in major and trace element geochemistry were described by BLECHOVÁ (1985) in some diabase types from the Prague Basin.

The single sample of the Devonian hyaloclastite cannot substantially contribute to the discussion. In the case it is sufficiently representative (Text-Figs. 11 and 12, Tables 2 and 3), it suggests a continuity of the Barrandian Basin Devonian volcanism with the Ordovician–Silurian one, producing dominantly within-plate transitional to alkaline basaltic rocks.

The within-plate volcanism is a consequence of the mantle diapir ascent, linked up with the extension of the overlying lithosphere (SCHILLING, 1973; HOUSEMAN & ENGLAND, 1986; KAMPUNZU et al., 1986 etc.). Within the Ordovician to Middle Devonian interval the tectonic setting of the Barrandian was, as demonstrated by exclusively within-plate volcanis (Text-Figs. 7 to 12 and Text-Fig. 17), comparable with that of Cenozoic extensional basins (e.g. BELLIENI et al., 1984; HODDER, 1984; HAMILTON, 1989).

The progressive extension of the lithosphere is accompanied by the evolution of a specific volcanic sequence, proceeding from alkaline rocks through types transitional between alkaline and tholeiitic ones and culminating with tholeiitic volcanics (TREUIL & VARET, 1973; LAMEYRE et al., 1983, 1985; KEEN 1987; MCKENZIE & BICKLE, 1988). The composition of the Barrandian volcanics displays analogous development in the Ordovician (characterized by an absolute dominance of alkaline effusives) (Text-Figs. 7 and 8) and in the Silurian (when the volcanic rocks of transitional and tholeiitic composition are more frequent; Text-Figs. 9 and 10).

An extension factor, i.e. a final-width/initial-width ratio of an extensional basin distinguished by volcanic activity just transient from alkaline to tholeiitic one, is estimated

by LAVECCHIA & STOPPA (1990) at 3 to 3.5; provided that these values are applicable to the development of the Barrandian Basin in the Silurian, when the ascent of tholeiitic volcanics suggests the extension peak, a considerable thinning of the underlying continental crust (consolidated and presumably thickened by Cadomian tectogenesis toward the end of the Late Proterozoic – e.g. CHÁB [1979]) can be assumed. The depth of tholeiitic melt separation from the upper mantle is probably less than 35 km (BAKER, 1973) and that of alkali basalt one is 35 to 80 km, respectively (LAVECCHIA & STOPPA, 1990). These data are in good agreement with the depth 30 to 50 km, estimated for the magmatic reservoir of Early Paleozoic Barrandian volcanics on the basis of Curie temperatures of homogenized titanomagnetites (BLECHA, 1979). It may thus be inferred that in the Silurian the thickness of the extension-thinned continental crust, forming the basement of the Barrandian Basin, did not exceed 30 to 35 km. Also the presence of tholeiitic volcanic rocks indicate that in this period the continental lithosphere beneath the Barrandian – in relation to the ascent of melt-generating mantle plume – was probably reduced to the crust; this is the typical feature of modern rift zones (e.g. ZORIN & LEPINA, 1985).

The pattern of the Ordovician to Middle Devonian tectonic setting of the Barrandian Basin, as reconstructed from the geochemistry of volcanic rocks, corresponds with the concept of the Early Paleozoic lithosphere extension in other regions of the present-day Central and Western Europe (PIN & LANCELOT, 1982; WEBER & BEHR, 1983; MATTE, 1986; FRANKE, 1989; LOESCHKE, 1989; PAQUETTE et al., 1989 etc.), culminating in the Silurian (PIN, 1990). It also agrees with the hypothesis that explains the history of the European Early Paleozoic sedimentary basins by the interaction of microcontinents (Precambrian fragments of Gondwana supercontinent northern margin) with the newly formed island arcs in the period terminated by Variscan tectogenesis (GEBAUER, 1986; ZIEGLER, 1986; ROBARDET et al., 1990 etc.). In this context the Barrandian can be interpreted – beginning with the Silurian – as a component of a back-arc basin of the Ligurian-Moldanubian Cordillera, which was the initial structure of the Variscan foldbelt (AUTRAN & COGNÉ, 1980; ZIEGLER, 1986 etc.).

The dyke rocks of the Central Bohemian Pluton contact zone show a heterogeneous nature. The basic members of this igneous group (diabases of several types) are corresponding to mid-ocean ridge basalts and within-plate basalts (Text-Figs. 13 and 14a). Acid dyke rocks (quartz porphyries) of the Pluton contact aureole are chemically very similar to syn-collision granitoids; however, low REE contents and missing depletion in Ba (relative to other LILE) demonstrate that these rocks are less fractioned than the syn-collision granitoid types described by PEARCE et al. (1984) (Text-Figs. 13 and 14b).

On the other hand, the Early Paleozoic diabase dykes emplaced in the Silurian sequence of the Prague Basin represent in general a uniform suite of rocks resembling in geochemistry both tholeiitic and transitional within-plate basalts (BLECHOVÁ, 1985) (Text-Figs. 15 and 16).

In a view of unsufficient data on the precise age of the Barrandian dyke rocks their geochemistry interpretation is of little importance for the paleotectonic history reconstruction. The only feasible conclusion seems to be that the origin of the Prague Basin dyke rocks was associated with the Early Paleozoic extension of the Barrandian Basin; it is supported by a close affinity between these dykes and the Silurian basaltic volcanics (Text-Figs. 9, 10, 15

and 16). The intrusive diabases of the Central Bohemian Pluton contact zone geochemically comparable with mid-ocean ridge basalts (Text-Fig. 14a), may be possibly linked up with the culmination of the Barrandian Basin basement extension (cf. TREUIL & VARET, 1973; LAMEYRE et al., 1983, 1985 etc.). Similarly "ad hoc" the acid dyke rocks of the Central Bohemian Pluton contact aureole can be interpreted as the products of intracrustal anatexis (Text-Fig. 14b), accompanying the microcontinent collisions in the zone of the developing Variscan foldbelt (BADHAM, 1982; ZIEGLER, 1986; ROBARDET et al., 1990).

5.2. Speculations on the "Scattered" Ophiolite Suite

The Early Paleozoic igneous rocks of the Central Bohemian region are characterized by a considerable predominance of basic magmatites, locally passing into ultrabasic ones. Besides volcanics dealt with in this paper, they also involve intrusives – the gabbroic rocks from the Milín area (Text-Fig. 1). So far these rocks have been regarded by most authors (e.g. SVOBODA et al., 1966) as the oldest member of the Central Bohemian Pluton igneous association. The Milín area gabbroic rocks for the most part form enclaves of meter to hundred-meter dimensions (sporadically more than 4 km in size) in the granitoids. Only two gabbro intrusions extend from the Pluton and steeply penetrate the Late Proterozoic flysch facies sediments (MALÍK & VLAŠÍMSKÝ, 1970; VLAŠÍMSKÝ, 1973). The intrusive bodies are composed of pyroxene-hornblende to hornblende gabbro (in places bearing olivine relics) and biotite-hornblende tonalite. In low REE and HFS element abundances, contrasting with high contents of mantle compatible elements, the gabbros resemble ocean-floor basalts; also, according to major element composition some of them are related to mafic cumulates of an ophiolite assemblage (VLAŠÍMSKÝ, 1984). The gabbroic intrusive bodies as well as enclaves embody randomly distributed minor fragments of olivine hornblendite and hornblendite s.s. (containing ca. 20 wt. % MgO and more than 1,000 ppm Cr – VLAŠÍMSKÝ [1975, 1984]). Judging from the spatial relationship, the gabbro bodies, extending from the Pluton, are younger than the Early Paleozoic diabases and quartz porphyry dykes discussed in the text above (VLAŠÍMSKÝ, 1976). The gabbroic rocks of the Milín area are presumably of early Variscan (Silurian ?) age. The only geochronological date – 370 Ma obtained by K-Ar method on hornblende – had likely got younger by the proximity of Variscan granitoids situated within a distance of less than 500 m (VLAŠÍMSKÝ et al., 1991). The K-Ar ages of the granitoids, forming the Central Bohemian Pluton NW margin, mostly range between 370 and 320 Ma (BERNARD & KLOMÍNSKÝ, 1975). The gabbros and related rocks, exposed in other parts of the Pluton, differ in petrography as well as in geochemistry from those of the Milín area; also they lack the ultrabasic rock fragments (SVOBODA et al., 1966).

In the relatively small area between Beroun in the N and Milín in the S (Text-Fig. 1) there are several basic and ultrabasic rock occurrences; the maximum distance among them is 30 to 35 km. The longest possible time span of all these rock emplacements was a period from the Middle Cambrian to Middle Devonian; however fairly shorter interval cannot be excluded (VLAŠÍMSKÝ et al., 1991). The sedimentary sequences in which the magmatites are located, i.e. the Late Proterozoic flysch facies up to Middle Devonian sediments, have a total thickness of 5 to 8 km

(SVOBODA et al., 1966). The nature of basite to ultrabasite occurrences differ according to the ambient rock complexes. In the axial part of the Barrandian built up of Ordovician to Devonian sedimentary rocks there occur pillow lavas as well as subvolcanic sills and dykes grouped into several volcanic centres (FIALA, 1971). Towards the SE, i.e. in the south-eastern limb of the Barrandian formed predominantly by Early Cambrian sediments, diabase dyke swarms are scattered over an extensive area between Rožmitál pod Třemšínem and NE neighbourhood of Dobříš. Farther to the SE – around Milín – the above-described gabbro intrusive bodies containing the hornblendite fragments occur in sediments even of Late Proterozoic age. This spatial association of the different forms of both volcanic and intrusive basic to ultrabasic rocks to a certain degree seems to resemble the classic ophiolite suite profile with ultrabasic magmatites in the basal part and pillow lavas in the upper part (cf. COLEMAN, 1977).

The speculation regarding the Early Paleozoic basic to ultrabasic magmatites, exposed in the area described, as members of a "scattered" ophiolite suite can be derived from two alternative considerations:

According to the first one the axial part of the Barrandian, its SE limb and the Milín area, considered as three individual segments, correspond to the original horizontal arrangement of both sedimentary sequences (Ordovician to Middle Devonian, Upper Cambrian and Upper Proterozoic) and various forms of basic to ultrabasic magmatic rocks, specific for each segment. The axial and SE parts of the Barrandian were distinguished by a thinning of the crust during the Lower Paleozoic; the crust thickness increased to the SE, where the Central Bohemian Pluton occurs at the present time (i.e. in the Milín area).

The second consideration presumes that the three segments mentioned above correspond to the original vertical profile of the Late Proterozoic to Devonian sedimentary sequence, which extended continuously from the Barrandian towards the SE, possibly making up the mantle of the Central Bohemian Pluton. The mantle was completely removed by denudation in post-Variscan times. This profile is thought to include (in the upward direction) basic to ultrabasic intrusions, diabase dyke swarms and pillow lavas and/or subvolcanic intrusive bodies. This alternative speculation would agree better with the ophiolite suite concept, but the Pluton mantle at least 5 km thick would be presumed; however, there is ample evidence available that the Pluton granitoids solidified at subsurface levels (VLAŠÍMSKÝ, 1986).

6. Conclusion

The study based on the set of major and trace element analyses from 36 samples of Early Paleozoic Barrandian volcanics allows only a broad outline of the principal feature of this basin volcanic activity development. The reliability of the conclusions is also negatively affected by the probable presence of a sedimentary admixture in some pyroclastics in the Early Cambrian volcanics and by the traces of postmagmatic alterations apparent in a part of the Silurian basic rocks.

Judging from the geochemistry of Cambrian volcanics, the tectonic setting of the Barrandian at the onset of the Paleozoic still preserved the character of Late Proterozoic setting of the whole Teplá-Barrandian Unit, probably corresponding to that of recent convergent plate boundaries.

Nevertheless, Cambrian volcanic rocks of the Barrandian also display some typical features of within-plate magmatites. These characteristics may be considered as indicators of the beginning change in the tectonic setting, implying the incipient extension of the Barrandian basement continental crust.

The Barrandian volcanism is of a purely within-plate nature since the Ordovician until its waning out in the Middle Devonian. As the within-plate volcanism generally accompanies a crustal extension, the Barrandian tectonic setting during this time span was likely comparable to that of modern extensional basins. Ordovician volcanics were dominated absolutely by alkaline rocks, whereas in the Silurian a major number of transitional and tholeiitic rock types appeared. The only sample of Devonian volcanics again shows the composition of within-plate alkaline basalt. The evident evolution sequence from alkaline volcanism in the Ordovician to alkaline, transitional and tholeiitic one in the Silurian suggests that the maximum of extension (which could increase the Barrandian Basin 3 to 3.5 times) may be placed most probably to the Silurian. The thickness of continental lithosphere (possibly reduced to crust) beneath thinned by extension, did not exceed 30 to 35 km. The latter reconstruction of the Ordovician to Middle Devonian tectonic setting of the Barrandian falls within the concept of the Early Paleozoic lithospheric extension of Central and Western Europe.

The spatial association of Early Paleozoic basic igneous rocks (both volcanic and intrusive types), exposed in the Central Bohemian region (i.e. – in the axial part of the Barrandian, its SE limb and along the Central Bohemian Pluton NW margin) is compared to ophiolite suite and speculatively interpreted as its "scattered" equivalent.

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