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ROZTOKY INTRUSIVE CENTRE IN THE ČESKÉ STŘEDOHOŘÍ MTS.: DIFFERENTIATION, EMPLACEMENT, DISTRIBUTION, ORIENTATION AND AGE OF DYKE SERIES

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Abstract: The Roztoky Intrusive Centre (RIC) is formed by a trachytic crater vent, hypabyssal intrusions, together with more than 1000 almost radially arranged dykes and more rare cone sheets. Hypabyssal Weakly Alkaline Series of essexite (33–31 Ma)–monzodiorite (33–30 Ma)–sodalite syenite (30–28 Ma) and two coexisting weakly [camptonite (31 Ma)/gauteite I?–sodalite syenite porphyry–gauteite II? (24 Ma)/trachyte?] and strongly alkaline dyke series [camptonite (28 Ma)/monchiquite (26 Ma)–phonolite/tinguaite (26 Ma)/nepheline syenite porphyry cone sheet (30 Ma)] were recognized. Four principal dyke groups were distinguished: I — lamprophyres (58 %) dominated over II — semilamprophyres (28 %), minor III — basaltic rocks (6 %) and IV — felsic derivatives (9 %). Both radial steeply dipping dykes of lamprophyres, semilamprophyres, basaltic and rare phonolitic rocks and flat dipping cone sheets of trachyte and phonolite/nepheline syenite porphyry are present. Dykes of (semi)lamprophyres, and basaltic rocks show similar preferred strikes of 90° and 0°; felsic derivatives of 330° and 0°. Majority (91–98 %) of dykes (100 % of felsic dykes) are present within a distance of 7 km from the Roztoky main centre. Joint and dyke patterns are controlled by the regional paleostress field existing in the upper crust during magma ascent, by orientations of pre-existing fracture sets in the region and by the superimposed local stress field exerted by the rising intrusion. For the interval of 31–26 Ma in the RIC, the analysis of dyke geometries indicates the dominance of regional stress characterized by N–S tension (lamprophyres ≈ semilamprophyres > basaltic rocks > felsic derivatives).

Key words: N Bohemia, České středohoří Mts., Cenozoic Roztoky Intrusive Centre, dyke rocks, differentiation, orientations, age relations.

Introduction

The *Ohře (Eger) Rift* (OR) is an integral part of the Cenozoic Central European Rift System (Wimmenauer 1974). The *České středohoří Mts.* (CSM) represent the most significant region of Cenozoic intraplate alkaline volcanism within the OR (Hibsch 1926; Kopecký 1978; Ulrych 1998). The *Roztoky (Rongstock) Instrusive Centre* (RIC) is the largest and the best known polyphase volcanic centre of central type in the CSM (Kopecký 1977, 1987; Ulrych et al. 1983; Ulrych 1998; Jelínek et al. 1989; Mrlina 1998). The Atlantic Province of Becke (1903) — type area of alkaline volcanic rocks — were recognized in this very region.

Dykes associated with volcanic apparatus are found in several places. They reach their highest concentration in dyke swarms, which may be radial or parallel. Radial dykes invariably converge on a volcanic centre or an igneous intrusion. The principal problem in the development of central-type intrusions accompanied by systems of radial and concentric dykes is the interpretation of differentiation, emplacement, distribution, orientation, and age relations of individual rock series. A regular system of radially orientated joints filled with dykes is usually interpreted as resulting either from an active role of basement structures or the active role of magmatic diapirism of hypabyssal intrusions.

Kaiserstuhl represents the sole similar volcanic centre with central hypabyssal intrusions in the Cenozoic Central European Volcanic Province (CEVP). Despite the presence of advanced carbonatite differentiates Kaiserstuhl volcanism (Wimmenauer 1974) reveals a more simple history of development.

Intrusions of central type were also developed in the Permian *Oslo Rift* (Dons & Larsen 1978). Structural development of the Alnö carbonatite intrusion (Sweden) was studied by Eckermann (1966). Based on new structural and geophysical data, Kresten (1980) reinterpreted individual dyke systems associated with the central carbonatite intrusions. The older conception of emanation of radial dyke swarms from a single distinct centre and a simple diapiric genetic evolved into a conception of emplacement-induced up-doming of the overlying country rock accompanied by radial dykes with several centres and two sets of cone sheets. The stress field created by the upward movement of magma gave rise to the formation of two sets of joints: tensional joints and cone sheets and shear joints. The shear joints seems to contain no magmatic fill. Two preferred strikes (N–S and E–W) are most typical for the radial dyke set. Predisposition of the dyke system by fracturing pattern in the host rock and major structural inhomogeneities of the area is highly probable. The emplacement of radial dykes is associated with intrusive stage of the RIC history and up-doming of the whole area. Pairs of mutually perpendicular joints evolved in two independent systems. Joint formation is associated with the mechanism of magmatic diapirism, however, the dyke emplacement (sensu Kresten 1980) associated with intrusive stage (radial dykes and cone sheets) and subsidence stage (ring dykes and cone sheets). A depth of the roof of magma chamber is supposed to be less than 2 km in the time of emplacement.

Analogous intrusions of central type and associated dyke swarms were also found in the late Cretaceous *Serra de Monchique, Mount Ormode Complexes* (Rock 1982) and Algarve Littoral Province, Portugal (Martins 1999). Igneous provinces of the *Monteregian Hills* (Canada) and the near White Mountains (USA) of Mesozoic age (Eby 1985, 1987) also reveal features in differentiation development similar to those of the RIC. Distribution, orientation and ages of mafic dyke systems were presented by McHone (1978).

Geological setting

The CSM represents the largest erosional relict of the Cenozoic volcanosedimentary complex (42–16 Ma) within the OR. About 60 vol. % are represented by massive volcanics only. Volumetrically dominant relicts of superficial volcanics (45 vol. %) are formed primarily by primitive volcanic products of an alkali basalt affinity. The following volcanostratigraphical formations were recognized on the basis of volcanological and geochemical investigations in the central CSM (Cajz et al. 1999): (i) the Lower Formation — lavas and volcaniclastites of basanitic character (36–26 Ma), (ii) the Upper Formation — lavas and pyroclastics of trachybasaltic composition (31–25 Ma) and the problematic (iii) Uppermost Formation — flows of basanite (24 Ma). The more differentiated shallow Intrusive Complex (43–16 Ma) is represented (Ulrych et al. 1997; Ulrych et al. 1999) by two coeval rock associations of the prevailing weakly alkaline series — WAS (basanite/trachybasalt–trachyte) and the minor strongly alkaline series — SAS (olivine-poor nephelinite/tephrite–phonolite). The boundary drawn by Shrbený (1995) for Cenozoic volcanics of the Bohemian Massif was used for the discrimination of trachyte–phonolite in TAS diagram.

The RIC lies according to Kopecký (1978) at the intersection of hypothetical central faults of the OR (ENE–WSW) and the Labe Tectono-Volcanic Zone (WNW–ESE). A deeply eroded central part of the RIC formed by an elliptic crater vent (3 by 1.5 km) is filled with trachytic breccia with carbonate cement and presumed hidden carbonatite intrusion (Kopecký 1987). However, the extent of the polyphase RIC including an olivine nephelinite intrusion at Dobkovice and mondhaldeite breccia at Neštěmice is probably even larger than 6 by 2.5 km as supposed by Kopecký (1977).

The occurrences of hypabyssal stocks and particularly the above mentioned dense (more than 1000) dyke swarms make the RIC an important structure. Dykes associated with the intrusive centre reveal to some degree a radial, fan-shaped arrangement to the centrally located crater vent and associated hypabyssal intrusions (Hibsch 1926, 1936) of monzodiorite–essexite (Fig. 1). Nevertheless, the hypabyssal bodies of monzodiorite–essexite–sodalite syenite series are also partly linear-arranged, forming two subparallel lines striking NNW–SSE in the central part of the CSM, transverse to the course of the OR (ENE–WSW), see Strnad (1965), Kopecký (1978) and Ulrych & Novák (1989).

Strongly differentiated dyke rocks form a predominantly radially orientated dyke system reaching to a distance of 10–15 km from the RIC. The dyke system of the RIC is composed of mafic derivatives — (semi)lamprophyres totally prevailing over felsic derivatives and basaltic dykes (Ulrych 1998). Hypabyssal Weakly Alkaline Series and two coexisting dyke series Weakly Alkaline and Strongly Alkaline Series were recognized by Ulrych (1998). Monzodiorite ("rongstockite" of Tröger 1935) forms a singular hypabyssal strongly tectonized intrusion located at Roztoky (Rongstock). Three elliptic stocks of essexite near Malé Březno and three laterally positioned sodalite syenite bodies (Malé Březno, Svádov, Zubrnice) represent rocks of the Hypabyssal Weakly Alkaline Series (HWAS). Hornblendite is a typical cumulate in the sodalite syenites, camptonites and "gauteites" — semilamprophyres sensu Wimmenauer (1973). The Roztoky crater vent with a trachytic filling is younger than the subvolcanic body of monzodiorite and (semi)lamprophyre dykes with the exception of felsic dykes penetrating the trachyte breccia.

The RIC is accompanied by the Tertiary Pb–Zn–Cu(Ag,Te) hydrothermal mineralization (Pivec et al. 1984, 1998).

Methods of study

The average data on chemical composition of principal rock types of the RIC were modified from Ulrych (1989). Chemical analyses were performed by wet methods, trace element concentrations were analysed by XRF and INAA methods. For conditions of measurement see Ulrych (1989).

K-Ar ages were measured at the Institute of Nuclear Research of the Hungarian Academy of Sciences, Debrecen. Crushed rock samples were washed and their aliquots were pulverized for K determination. The samples were degassed by high-frequency induction heating, the usual getter materials (titanium sponge, getter pills of SAES St 707 type) were used for cleaning of Ar. The ^{38}Ar spike was introduced to the system from a gas-pipette before the degassing was started. The cleaned Ar was directly introduced into the mass spectrometer. The mass spectrometer was a magnetic sector type of 150 mm radius and 90° deflection operating in static mode. The argon extraction line and the mass spectrometer were constructed at the Institute of Nuclear Research. Potassium concentrations were measured by flame photometry using Na and Li as buffers and internal standards. The interlaboratory standards Asia 1/65, HD-B1, LP-6 and GL-O as well as atmospheric Ar were used for controlling and calibrating the determinations. Details of the instruments, the applied methods and results of calibration were described by Balogh (1985) and Odin et al. (1982).

Geochemical characteristics of subvolcanic rocks series

The mineral, petrographic and geochemical characteristics, including Sr and Nd isotope studies, of the individual subvolcanic rocks of the RIC were presented by Ulrych et al. (1983, 1998, 2000) and Jelínek et al. (1989). For chemical composi-

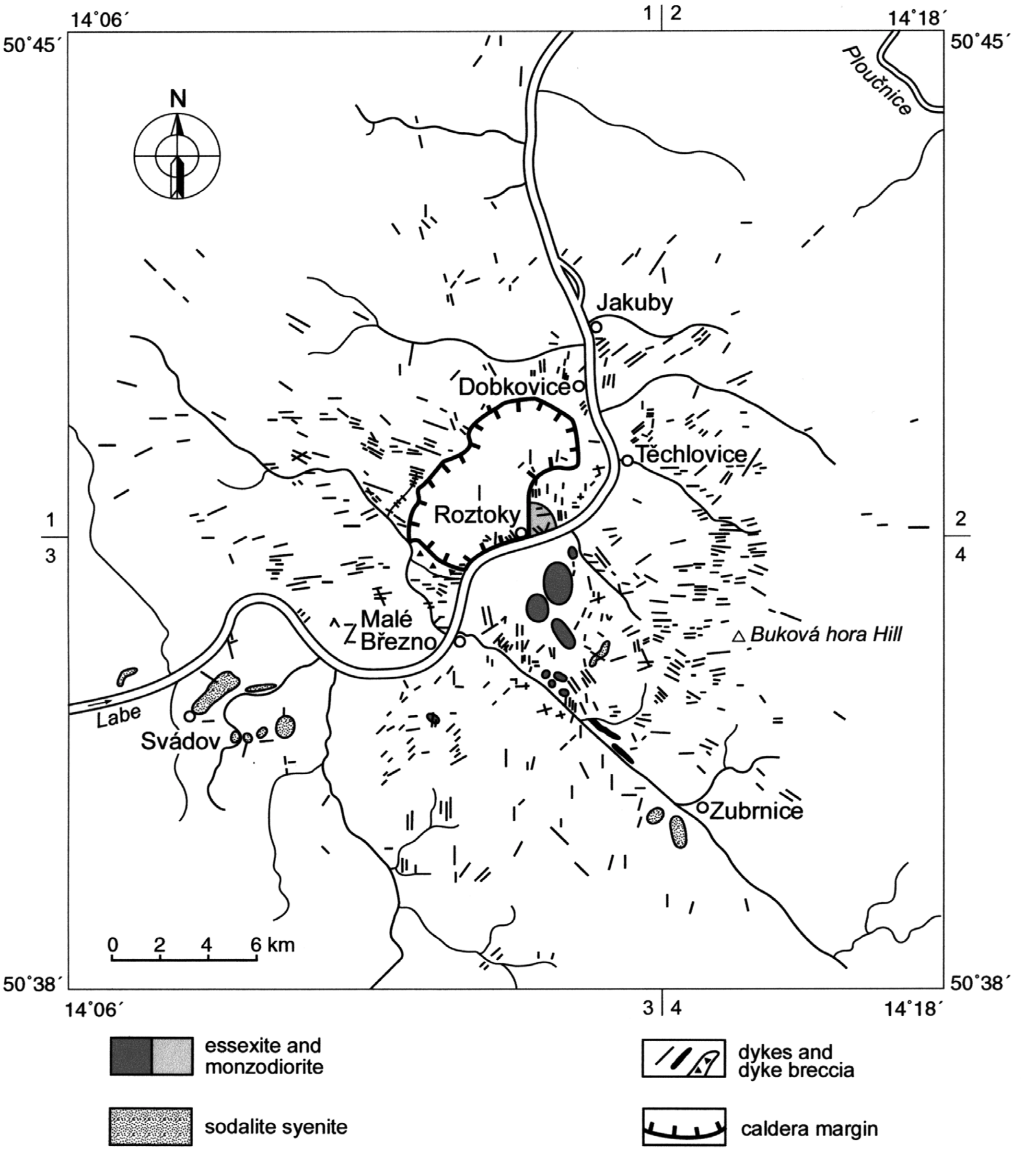

Fig. 1. A sketch of the Roztoky Intrusive Centre with special attention to dyke distribution (Hibsch 1930 adapted). Map sheets 1 : 25,000. **1** — Roztoky-Podmokly, **2** — Benešov nad Ploučnicí, **3** — Velké Březno, **4** — Verneřice.

tions of the rocks see Table 1a,b,c. Three main alkaline rock series of the RIC were recognized by Ulrych (1998) and the fourth series by Ulrych et al. (2000) see TAS diagram in Fig. 2:

— **Hypabyssal weakly alkaline plutonic series (HWAS)** formed by essexite-monzodiorite-sodalite syenite is characterized by D.I. = 46–64, Mg # = 44–52, A.I. = 0.60–0.78; a dyke of leucomonzonite is the most highly differentiated product of monzodiorite (D.I. = 80; Mg # = 32; A.I. = 0.81); hornblendite cumulates are the most mafic products of the RIC suite (D.I. = 30; Mg # = 60; A.I. = 0.53). The A.I. increases in the monzodiorite-sodalite syenite-leucomonzonite hypabyssal rock series (0.60–0.81) and from mafic to felsic types in both dyke series. The fO_2 value of mineral assemblages increases with decreasing depth of their crystallization level in the (monzodiorite-essexite-sodalite syenite)-dyke rock series (Ulrych et al. 1983).

— **Weakly alkaline dyke series (WAS)** formed by (trachybasalt ?)-camptonite/gauteite I-sodalite syenite porphyry-gauteite II-(trachyte ?) (D.I. = /39/65–81; Mg # = 32–41; A.I. = 0.57–0.75).

— **Strongly alkaline dyke series (SAS)** composed of (tephrite/basanite?)-camptonite/monchiquite-(tephriphonolite-phonolite/tinguaite/nepheline syenite porphyry ?) (D.I. = /39/47–87; Mg # = 16–50/55/; A.I. = /0.53/0.57–1.04). Coexisting SAS and WAS are similar to rock associations described from Cantal, Massif Central, France by Wilson et al. (1995), Siebengebirge, Germany by Vieten et al. (1988) and the Teplá Highland, Bohemia by Pivec et al. (in print).

— **Old felsic series (OFS)** (42.7–38.2 Ma) formed by bostonite I-nepheline phonolite corresponding to “older phonolite” of Hibsch (1926). Rhyolites known as xenoliths (?) in bostonite I dykes originated by melting of gneisses from the crystalline basement (Ulrych et al. 2000).

Table 1a: Average chemical composition of hypabyssal rock series of the Roztoky Intrusive Centre.

Rock	E			MD			LM			SS			H			SMS		
wt. %	x	s	n	x	s	n	x	s	n	x	s	n	x	s	n	x	s	n
SiO_2	46.40	0.94	16	47.03	2.14	11	54.23	0.91	2	51.06	1.44	13	42.42	1.23	14	49.83	1.30	14
TiO_2	3.24	0.62	16	2.46	0.57	11	1.20	0.04	2	1.76	0.43	13	4.34	0.70	14	1.73	0.27	14
Al_2O_3	14.61	1.96		16.68	0.68	11	17.68	0.26	2	16.25	1.34	13	11.91	1.35	14	17.21	0.79	14
Fe_2O_3	5.57	1.78	16	5.35	1.08	11	3.78	0.97	2	5.56	1.04	13	5.50	0.78	14	2.94	0.24	14
FeO	5.30	1.20	16	5.11	1.17	11	1.69	1.10	2	2.36	0.59	13	7.06	1.01	14	3.78	0.27	14
MnO	0.21	0.06	16	0.26	0.05	11	0.09	0.05	2	0.28	0.20	13	0.22	0.53	14	0.16	0.04	14
MgO	5.13	1.02	16	3.79	0.49	11	1.15	0.03	2	2.70	0.68	13	8.60	1.65	14	1.94	0.46	14
CaO	9.32	1.20	16	8.80	0.64	11	3.49	0.60	2	6.53	1.44	13	11.83	0.68	14	6.40	0.62	14
Na_2O	3.88	0.79	16	4.00	0.42	11	4.99	0.05	2	5.25	1.01	13	2.93	0.77	14	4.14	0.82	14
K_2O	3.28	0.56	16	3.18	0.51	11	5.63	0.57	2	3.78	0.54	13	1.42	0.43	14	3.98	0.23	14
P_2O_5	0.59	0.20	16	0.95	0.95	11	0.32	0.05	2	0.43	0.16	13	1.37	0.22	14	0.53	0.07	14
H_2O^+	1.54	1.02	16	1.45	0.60	11	2.14	0.09	2	3.08	0.95	13	1.42	0.51	14	2.28	0.60	14
H_2O^-	0.50	0.33	16	0.42	0.24	11	0.48	0.25	2	0.73	0.45	13	0.99	0.60	14	1.70	0.99	14
CO_2	0.31	0.24	10	0.72	0.37	8	2.87	1.03	2	1.00	0.67	9	0.77	0.23	14	2.91	1.48	10
F	0.10	0.02	10	0.13	0.03	8	0.05	0.03	2	0.08	0.03	9	0.15	0.02	14	0.10	0.03	10
S	0.03	0.01	6	0.15	0.13	5	0.31	0.06	2	0.04	0.02	5	0.08	0.03	5	0.05	0.01	4
Total	100.01			100.48			100.10			100.89			99.44			99.68		
Q							2.39									2.43		
C							3.77									2.42		
Or	19.83			19.13			34.29			23.06			8.54			24.64		
Ab	17.51			24.72			43.42			35.43			17.80			36.62		
An	13.00			18.43			0.83			9.87			15.37			10.75		
Ne	8.67			5.23						5.60			4.00					
Ac																		
Ns																		
Di	22.36			12.38						11.22			24.44					
Hy							2.96									7.11		
Ol	2.04			3.70						1.24			8.54					
Mt	8.25			7.89			2.33			3.52			8.11			4.46		
Hm							2.29			3.31								
Il	6.29			4.75			2.35			3.45			8.38			3.44		
Ap	1.32			2.11						0.97			3.04			1.21		
Li ppm	28.00	1.00	3	23.00	3.00	7	27.00		1	39.00	1.00	3	10.00	1.00	3	31.00	4.00	6
Rb	74.00	14.00	7	58.00	11.00	7	114.00		1	98.00	29.00	13	9.40	6.30	3	108.00	4.00	10
Cs	0.85	0.09	3	1.30	1.10	4	1.90		1	2.20	0.30	3	0.11	0.03	3	22.00	0.40	6
Sr	970.00	287.00	7	1,012.00	168.00	7	575.00		1	1,518.00	237.00	13	330.00	165.00	3	1,350.00	95.00	10
Ba	1,035.00	113.00	7	936.00	57.00	7	485.00		1	1,296.00	137.00	13	558.00	33.00	3	1,407.00	50.00	10
Ga	19.00	5.80	3	18.30	1.30	7	21.10		1	21.00	1.00	3	11.00	1.10	3	19.00	1.70	3
Pb	2.30	5.80	3	1.50	1.70	7	1.00		1	8.00	1.70	3	-	-	3	5.00	1.30	3
As	10.00	1.00	3	10.70	2.70	7	9.20		1	7.70	1.20	3	18.00	1.40	3	6.00	1.00	3
Sc	17.30	1.40	3	13.00	2.20	5	5.10		1	4.80	0.40	3	73.00	12.00	3	6.80	0.30	6
Y	22.00	2.00	3	25.00	3.00	4	27.00		1	33.00	1.00	3	7.50	4.30	3	21.00	2.00	10
La	65.00	2.00	3	52.00	6.00	5	79.00		1	114.00	3.00	3	24.00	3.30	3	85.00	3.00	6
Ce	145.00	6.00	3	128.00	30.00	5	171.00		1	224. 00	11.00	3	81.00	14.00	3	150.00	5.00	6
Pr									1									
Nd	55.00	6.00	3	42.00	21.00	5	65.00		1	50.00	1.00	3	35.00	4.00	3	41.00	5.00	6
Sm	9.10	0.50	3	9.60	2.80	5	9.90		1	10.50	0.30	3	7.20	1.90	3	9.00	0.33	6
Eu	2.50	0.10	3	2.60	3.50	5	2.70		1	2.90	1.60	3	2.60	0.60	3	2.60	0.05	6
Gd	6.60	0.40	3	6.50	0.60	5	6.90		1	7.80	0.40	3	6.22	0.50	2	6.90	0.40	3
Tb	0.97	0.07	3	0.89	0.14	5	1.00		1	1.02	0.06	3	0.93	0.10	3	0.96	0.04	6
Dy									1									
Ho	1.02	0.16	3	0.98	0.50	4	1.10		1	1.13	0.23	3	0.85	0.25	2	1.04	0.21	6
Er									1									
Tm	0.39	0.14	3	0.36	0.23	4	0.40		1	0.47	0.08	3	0.21	0.11	3	0.22	0.10	6
Yb	2.40	0.10	3	1.90	0.40	4	2.50		1	2.50	0.20	3	1.01	0.21	3	1.80	0.20	6
Lu	0.40	0.10	3	0.51	0.01	4	0.48		1	0.44	0.07	3	0.22	0.17	3	0.16	0.10	6
Th	11.10	3.20	7	7.10	1.20	5	10.20		1	15.60	3.80	13	0.89	0.20	3	12.40	0.40	6
U	4.10	0.80	3	2.50	0.70	4	4.40		1	6.00	0.20	3	0.14	0.10	3	3.00	0.90	6
Zr	369.00	85.00	7	330.00	66.00	7	402.00		1	519.00	35.00	13	112.00	17.00	3	314.00	13.00	10
Hf	10.20	0.40	3	8.00	1.70	5	10.00		1	10.00	0.50	3	1.80	0.50	3	8.70	0.20	6
V	243.00	37.00	7	211.00	21.00	7	181.00		1	143.00	48.00	13	434.00	73.00	3	122.00	27.00	3
Nb	74.00	31.00	7	71.00	15.00	7	110.00		1	140.00	14.00	13	48.00	14.00	3	185.00	15.00	10
Ta	5.90	0.30	3	5.30	1.40	4	7.20		1	9.40	0.50	3	2.90	1.80	3	14.00	0.10	6
Cr	27.00	6.00	3	16.90	4.80	7	5.10		1	4.70	1.20	3	40.00	6.00	3	6.90	3.20	6
Co	31.00	18.00	7	41.00	26.00	7	19.00		1	22.00	14.00	13	47.00	17.00	3	6.60	1.90	10
Ni	8.70	1.50	3	7.10	2.20	7	2.90		1	3.00	1.00	3	209.00	44.00	3	4.10	0.60	3
Cu	35.00	5.00	3	17.10	4.60	7	7.10		1	11.30	0.60	3	32.00	11.00	3	12.70	3.10	3
Zn	89.00	19.00	7	97.00	26.00	7	7.30		1	91.00	17.00	13	60.00	7.00	3	91.00	6.00	6
D.I.	46.02			49.09			80.10			64.09			30.34			63.68		
C.I.	36.95			28.72			7.63			19.43			49.47			15.20		
Mg#	51.06			44.47			32.14			43.67			60.02			20.63		
A.I.	0.68			0.60			0.81			0.78			0.53			0.65		
K/Rb	368.00			455.00			414.00			320.00			1,254.13			318.00		
Rb/Sr	0.08			0.06			0.20			0.05			0.03			0.08		
Th/U	2.71			2.84			2.32			2.60			6.36			4.13		
Zr/Hf	41.30			36.20			40.20			51.90			62.22			36.10		
Nb/Ta	12.54			13.40			15.28			14.89			16.55			13.21		
Ti/V	69.90			79.80			39.70			73.80			60.00			85.00		
Σ REE	288.38			245.34			340.18			414.76			159.24			298.68		
(La/Yb)	19.43			19.63			22.67			32.71			17.04			36.95		
Eu/Eu*	0.94			0.95			0.95			0.94			1.16			0.97		

E — essexite, MD — monzodiorite, LM — leucomonzonite, SS — sodalite syenite, H — hornblendite, SMS — sodalite monzosyenite; x — mean, s — standard deviation, n — number of samples. (D.I. — differentiation index sensu Thornton & Tuttle 1960; Mg# = Mg/(Mg + Fe2+); Fe3+/Fe = 0.15; A.I. — alkalinity index sensu Shand 1922).

Table 1b: Average chemical composition of dyke rocks of the WAS of the Roztoky Intrusive Centre.

Rock	Tb			Mh			SSP			G			Bo			T			R
wt. %	x	s	n	x	s	n	x	s	n	x	s	n	x	s	n	x	s	n	x_1
SiO_2	45.59	1.58	3	46.87	0.34	2	47.20	0.32	2	53.26	2.78	20	55.41	0.85	5	55.23	3.59	15	66.70
TiO_2	2.84	0.33	3	2.78	0.09	2	1.76	0.78	2	1.66	0.47	20	1.38	0.44	5	0.88	0.60	15	0.35
Al_2O_3	14.28	1.05	3	17.24	0.04	2	18.54	0.21	2	18.04	2.31	20	17.75	0.97	5	19.15	1.57	15	16.25
Fe_2O_3	5.95	1.94	3	5.18	0.11	2	3.20		1	3.78	1.42	12	4.19	0.95	5	2.82	1.69	11	0.06
FeO	5.68	0.58	3	3.54	0.13	2	2.64		1	2.54	1.34	12	1.40	1.75	5	1.50	1.22	11	1.65
MnO	0.20	0.79	3	0.18	0.01	2	0.16	0.01	2	0.18	0.08	20	0.25	0.20	5	0.12	0.07	15	0.02
MgO	4.97	1.86	3	2.23	0.04	2	1.22	0.04	2	1.97	0.77	20	1.32	0.63	5	0.91	0.81	15	0.55
CaO	10.92	1.72	3	5.76	0.25	2	7.00	0.27	2	5.04	1.33	20	4.45	0.66	5	3.12	1.47	15	2.90
Na_2O	3.33	0.19	3	4.02	0.02	2	4.66	0.07	2	4.48	1.36	20	5.15	0.68	5	4.74	1.08	15	4.15
K_2O	2.43	0.69	3	3.77	0.06	2	4.47	0.15	2	5.12	1.25	20	4.42	0.77	5	5.77	1.34	15	2.70
P_2O_5	0.81	0.34	3	0.60	0.02	2	0.35	0.01	2	0.38	0.11	20	0.47	0.21	5	0.17	0.14	15	0.03
H_2O^+	2.63		1	1.33	0.09	2	3.82		1	2.25	1.06	7	0.65	0.69	5	3.07	1.23	11	3.55
H_2O^-	0.62		1	0.56	0.02	2	0.51		1	0.49	0.37	7	2.33	0.47	5	0.66	0.54	11	1.25
CO_2	0.18		1	4.83	0.15	2	3.45		1	1.19	1.58	12	1.46	0.96	5	2.22	1.97	11	
F																0.10	0.03	7	
S																0.10	0.08	7	
Total	100.43			98.89			98.98			100.38			100.63			100.56			100.16
Q				6.78									2.29			4.19			25.37
C				7.46			2.14						0.79			5.09			1.34
Or	14.79			22.99			27.93			31.03			26.77			35.32			16.75
Ab	18.84			35.03			35.62			38.17			44.57			41.46			36.78
An	17.29			1.98			11.51			14.20			10.35			0.48			14.91
Ne	5.49						3.23			0.34									
Ac																			
Ns																			
Di	25.45									1.13									
Hy				5.75									3.38			2.35			4.00
Ol	1.48						2.26			3.17									
Mt	8.88			4.05			4.15			4.06			1.36			2.77			0.09
Hm				2.54			0.52			1.08			3.35			1.01			
Il	5.55			5.45			3.53			3.23			2.69			1.73			0.70
Ap	1.82						0.81			0.85			1.05			0.38			0.07
Li ppm																			
Rb	67.00	24.04	3	145.00	12.00	2	124.50	14.85	2	112.77	37.93	15	115.50	20.51	4	145.71	19.21	10	61.00
Cs							1.40		1	1.50	0.42	2	4.10		1				1.53
Sr	1192.50	342.95	3	794.50	21.92	2	1258.00	195.16	2	899.12	171.22	15	1012.50	194.50	4	812.86	391.35	3	677.00
Ba	1349.50	338.72	3	1146.00	93.34	2	1010.00	14.14	2	1190.77	303.19	15	1154.50	24.75	4	1287.50	286.79	10	1194.00
Ga	37.00		1	24.00		1	23.00	0.00	2	26.20	3.27	7	18.00		1	26.00		1	18.00
Pb	5.33	2.08	3	10.50	3.54	2	8.50	0.71	2	10.25	9.02	8	23.50	2.12	2	14.00		1	21.00
As										6.50	0.50	2	1.50		1				13.00
Sc				6.17		1	3.80		1	7.44	1.07	2	5.19	1.26	2				3.40
Y	26.00	8.48	3	32.00		1	23.00		2	23.75	5.40	15	30.50	0.71	2	20.00		1	22.00
La	61.00		1	81.00		1	65.00		1	61.30	2.40	2	58.50	1.41	2	93.00		1	137.00
Ce	129.00		1	161.00		1	173.00		1	134.50	21.92	2	163.50	0.71	2	109.00		1	82.00
Pr																			
Nd				47.80		1	52.00		1	59.00	11.30	2	63.50	3.54	2				20.00
Sm				10.10		1	10.40		1	10.40	2.55	2	15.00	0.00	2				3.90
Eu				2.98		1	2.50		1	2.60	0.14	2	2.50	0.06	2				1.00
Gd				7.90		1	6.90		1	6.80	0.22	2	6.00	0.17	2				2.60
Tb				1.00		1	0.79		1	0.83	0.04	1	0.90	0.09	2				0.37
Dy						1	4.30		1	5.40		1							
Ho				0.99		1	0.90		1	0.88		1	1.05	2.13	2				
Er										2.10		1							
Tm				0.30		1	0.24		1	0.21		1							
Yb				1.80		1	1.10		1	1.20	0.14	2	1.00	0.15	2				0.90
Lu				0.31		1	0.15		1	0.12	0.17	2	0.14	0.02	2				0.12
Th	12.00	4.24	3	11.50		1	12.00	1.41	2	15.83	5.04	7	14.80	3.11	2	11.20		1	27.00
U	3.00	0.24	3	2.50	2.12	2	4.00		2	2.50	2.12	3	3.10	0.17	2	2.80	2.12	3	3.50
Zr	395.50	34.65	3	420.00	38.18	2	549.00		2	434.50	80.28	15	452.50	28.73	4	556.86	100.68	10	239.00
Hf				6.20		1	8.60			9.10	0.71	2	6.90		1				5.00
V	260.00		1	245.00	7.07	2	230.00		2	205.71	35.52	7	150.50	41.72	4	225.71	59.68	10	170.00
Nb	81.00		1	71.00		1	110.00		1	88.00	25.13	7	119.00		1	125.00	21.21	10	21.00
Ta				4.00		1	4.60		1	5.30	0.57	2	5.50		1				0.60
Cr	41.50	2.12	3	22.50	9.19	2	9.00	1.41	2	16.31	8.05	15	10.50	0.71	4	11.00	6.53	10	24.00
Co	32.33	0.58	3	21.00	2.83	2	10.50	6.36	2	13.71	4.56	15	17.00	3.15	4	11.86	11.31	10	2.10
Ni	25.33	9.29	3	15.00	1.41	2	2.50	0.71	2	10.25	9.02	7	6.05	2.83	4	5.89	3.76	10	22.00
Cu	49.67	0.17	3	19.50	6.36	2	12.50	7.78	2	17.00	13.06	15	10.51	0.73	4	3.71	1.98	10	12.00
Zn	80.67	2.08	3	70.50	28.99	2	69.50	41.75	2	69.13	13.14	15	90.50	7.78	4	35.43	11.96	10	40.00
D.I.	39.12			64.79			66.80			69.53			73.64			80.96			78.90
C.I.	41.36			15.25			9.94			11.58			7.42			6.85			4.78
Mg#	48.57			36.31			31.67			41.01			34.87			32.09			40.36
A.I.	0.57			0.57			0.67			0.72			0.75			0.73			0.60
K/Rb	301.10			215.85			298.07			376.93			317.70			328.75			367.47
Rb/Sr	0.06			0.18			0.10			0.13			0.11			0.18			0.09
Th/U	4.00			4.60			3.00			6.33			4.77			4.00			7.71
Zr/Hf				67.74			63.84			47.75			65.58						47.80
Nb/Ta				17.75			23.91			16.60			21.64						35.00
Ti/V	65.48			68.02			45.87			48.38			54.97			23.37			12.34
Σ REE	190.00			315.18			317.28			285.34			312.09			202.00			247.89
$(La/Yb)_N$				32.28			42.39			36.64			41.96						109.19
Eu/Eu*				0.80			0.85			0.89			0.68						0.74

Tb — trachybasalt, Mh - mondhaldeite, SSP — sodalite syenite porphyry, G — gauteite, Bo — bostonite, T — trachyte, R — rhyolite.

Table 1c: Average chemical composition of dyke rocks of the SAS of the Roztoky Intrusive Centre.

Rock	Te/Ba			M			C			Tp	TiP			NSP			P	Ti			TiA
wt. %	x	s	n	x	s	n	x	s	n	x_1	x	s	n	x	s	n	x_1	x	s	n	x_1
SiO_2	43.12	1.90	3	44.01	1.81	24	45.78	2.30	30	50.43	52.93	2.30	3	53.13	0.37	3	54.85	56.54	0.80	4	59.32
TiO_2	2.87	1.10	3	3.02	0.75	24	2.65	0.47	30	1.27	1.22	0.08	3	0.85	0.35	3	0.47	0.41	0.18	4	0.27
Al_2O_3	15.81	2.87	3	15.09	1.50	24	16.21	1.43	30	18.22	18.07	1.46	3	19.58	1.19	3	20.88	20.08	0.87	4	18.30
Fe_2O_3	5.07	0.40	3	5.72	1.35	18	5.31	0.69	24	2.64	3.82	2.12	3	1.96	0.22	3	2.13	1.53	0.61	4	1.45
FeO	5.53	0.25	3	5.14	1.20	18	4.46	0.90	24	2.41	2.57	0.78	3	1.73	0.40	3	1.24	1.53	0.43	4	1.04
MnO	0.20	0.03	3	0.21	0.08	24	0.18	0.04	30	0.19	0.24	0.11	3	0.34	0.31	3	0.19	0.22	0.16	4	0.30
MgO	6.03	1.67	3	4.81	1.23	24	4.34	1.21	30	1.03	0.79	0.21	3	0.80	0.15	3	0.46	0.34	0.14	4	0.05
CaO	9.91	2.05	3	9.62	1.86	24	9.07	1.68	30	5.29	4.50	0.69	3	3.26	0.35	3	2.83	2.13	0.59	4	1.06
Na_2O	3.31	0.48	3	3.93	0.61	24	3.34	1.29	30	6.31	6.77	0.48	3	7.72	1.14	3	7.99	7.81	1.43	4	8.49
K_2O	2.78	0.65	3	3.37	1.08	24	3.46	0.93	30	4.86	4.91	0.19	3	4.16	0.26	3	5.40	5.69	0.48	4	4.95
P_2O_5	0.57	0.15	3	0.68	0.18	24	0.63	0.18	30	0.27	0.24	0.04	3	0.08	0.02	3	0.10	0.15	0.10	4	0.04
H_2O^+	2.66	1.17	3	2.27	1.34	8	2.34	0.42	14	4.96	1.69	0.36	3	3.59	0.72	3	2.29	0.97	0.33	4	0.65
H_2O^-	0.83	0.38	3	1.58	1.21	8	0.78	0.26	14	0.98	0.63	0.17	3	0.45	0.21	3	0.39	1.57	1.34	4	2.81
CO_2	0.55	0.14	3	1.75	1.43	18	0.95	1.11	24	0.39	1.80	2.01	3	1.57	1.04	3	0.28	0.87	0.98	4	0.32
F																					
S	0.04	0.01	3	0.07	0.04	8	0.08		1									0.14		1	
Total	99.28			101.27			99.58			99.25	100.18			99.22			99.50	99.84			99.05
Q																		15.42			30.21
C														0.21							
Or	17.17			20.48			21.23			30.85	29.68			25.84			32.00	43.77			30.63
Ab	12.09			17.53			21.13			31.62	37.63			43.42			39.44				
An	20.92			13.91			19.68			7.50	4.47			6.19			5.12				
Ne	9.28			8.99			4.42			13.88	11.30			13.60			15.29				
Ac																		5.54			4.38
Ns																		13.91			16.32
Di	18.33			15.31			13.18			5.97	4.12						2.67	3.63			2.78
Hy																		2.59			0.78
Ol	6.23			3.76			3.61				0.80			2.09							
Mt	7.68			8.52			7.55			0.67	5.65			3.02			3.09				
Hm							0.30			5.25	0.01										
Il	5.70			5.89			5.22				2.37			1.70			0.89	0.78			0.54
Ap	1.30			1.52			1.43			0.63	0.54			0.18			0.22	0.33			0.09
Li ppm																					
Rb	47.00		1	75.50	26.80	10	82.29	35.51	23	111.00	133.00	12.73	2	162.00		1	138.00	168.00		1	733.00
Cs				3.10	1.41	2	0.91		1		10.20		1	6.20		1		3.00		1	
Sr	1058.00		1	872.33	260.94	10	927.10	218.21	23	1403.00	912.00	305.47	2	1830.00		1	1969.00	1315.00		1	92.00
Ba	1210.00		1	760.40	257.35	19	1038.57	357.57	23	1180.00	1429.00		2	1581.00		1	1668.00	1154.00		1	23.00
Ga	29.00		1	25.33	3.25	10	23.67	2.83	10	27.00	31.00		1	33.00		1	28.00	29.00		1	51.00
Pb	3.00		1	8.94	3.70	19	9.87	4.59	23	15.00	20.50	10.61	2	14.00		1	17.00	42.00	24.09	2	76.00
As																		2.00		1	
Sc				12.77	1.46	2	15.58	4.43	4		141.00		1	1.81		1		2.25		1	
Y	19.00		1	27.44	6.00	10	25.05	4.65	23	22.00	22.00	5.66	2	20.00		1	33.00	30.00		1	29.00
La	57.00		1	60.00	12.52	4	54.88	7.96	4	97.00	100.00		1	87.00		1	110.00	94.60		1	198.00
Ce	89.00		1	147.33	40.67	4	135.25	14.59	4	131.00	147.00		1	181.00		1	134.00	137.00		1	213.00
Pr				18.40		1	14.45	0.49	2		11.90		1								
Nd				66.00	16.37	4	53.00	8.04	4		31.50		1	39.00		1		20.00		1	
Sm				11.90	3.54	4	11.70	3.65	4		3.40		1	7.50		1		4.64		1	
Eu				2.67	0.55	4	2.68	0.19	4		1.00		1	1.70		1		1.43		1	
Gd				6.25	0.35	4	6.50	2.17	4		2.50		1	5.10		1		4.70		1	
Tb				0.73	0.04	4	0.96	0.35	4		0.42		1	0.70		1		0.81		1	
Dy				4.20		1	5.38	0.35	2		2.40		1								
Ho				0.88		1	1.02	0.94	4		0.50		1					1.20		1	
Er				2.20		1	2.52	0.25	2		1.60		1								
Tm				0.31		1	0.31	0.28	2		0.30		1					0.15		1	
Yb				2.33	0.67	4	1.75	1.06	4		2.30		1	2.30		1		3.10		1	
Lu				0.30		1	0.30	0.00	2		0.40		1					0.43		1	
Th	10.00		1	11.50	3.55	10	13.00	5.38	10	13.00	16.00		1	19.00		1	17.00	23.20		1	146.00
U	2.00		1	3.00	0.00	2	3.00	0.00	3	2.00	6.00		1	3.00		1	4.00	4.30		1	38.00
Zr	354.00		1	363.67	83.18	10	355.24	85.10	10	481.00	550.50	21.92	2	598.00		1	584.00	639.00		1	1479.00
Hf				6.85	1.34	4	6.56	1.06	2		8.50		1	8.60		1		11.90		1	
V	310.00		1	270.00	64.03	10	222.78	58.48	10	200.00	245.00	77.78	2	110.00		1	190.00	64.00		1	
Nb	63.00		1	70.83	17.83	10	95.29	47.85	10	86.00	131.00		1	118.00		1	75.00	113.00		1	721.00
Ta			1	5.30	0.42	4	4.65	0.21	2		6.30		1	3.00		1		4.10		1	
Cr	11.00		1	35.94	23.18	19	30.78	2.00	23	5.00	5.00	0.00	2	15.00		1	19.00	6.00	2.83	2	4.00
Co	55.00		1	33.37	8.81	19	24.35	7.01	23	5.00	9.50	1.73	2	8.20		1	4.00	6.00	5.66	2	7.00
Ni	23.00		1	15.24	8.64	19	20.18	8.28	23	3.00	4.50	2.12	2	6.00		1	3.00	2.00	1.41	2	8.00
Cu	32.00		1	47.82	35.03	19	36.61	16.28	23	8.00	11.50	6.39	2	17.00		1	8.00	11.10	0.72	2	9.00
Zn	75.00		1	71.18	23.36	19	78.00	22.36	23	75.00	70.75	35.54	2	102.00		1	55.00	110.00	16.97	2	251.00
D.I.	38.55			47.00			46.78			76.35	78.60			82.87			86.73	59.20			60.84
C.I.	37.94			33.49			29.56			6.63	12.21			6.80			6.65	7.00			4.09
Mg#	55.61			49.50			49.62			31.09	21.61			32.44			23.41	15.63			4.28
A.I.	0.53			0.67			0.57			0.86	0.91			0.88			0.91	1.04			1.06
K/Rb	491.05			370.57			349.07			363.49	306.49			213.19			324.86	281.18			56.06
Rb/Sr	0.04			0.09			0.09			0.08	0.15			0.09			0.07	0.13			7.97
Th/U	5.00			3.83			4.33			6.50	2.67			6.33			4.25	5.40			3.84
Zr/Hf				53.09			54.15				64.76			69.53				53.70			
Nb/Ta				13.36			20.49				20.79			39.33				27.56			
Ti/V	55.50			67.06			71.31			38.07	29.85			46.33			14.83	38.41			
Σ REE	146.00			323.50			290.70			228.00	305.22			324.30			244.00	268.06			411.00
$(La/Yb)_N$				18.47			22.49				31.19			27.13				21.89			
Eu/Eu*				0.85			0.85				1.13			1.20				1.13			

Te/Ba — tephrite/basanite, M — monchiquite, C — camptonite, Tp — tephriphonolite, TiP — tinguaite porphyry, NSP — nepheline syenite porphyry, P — phonolite, Ti — tinguaite, TiA — anomalous tinguaite.

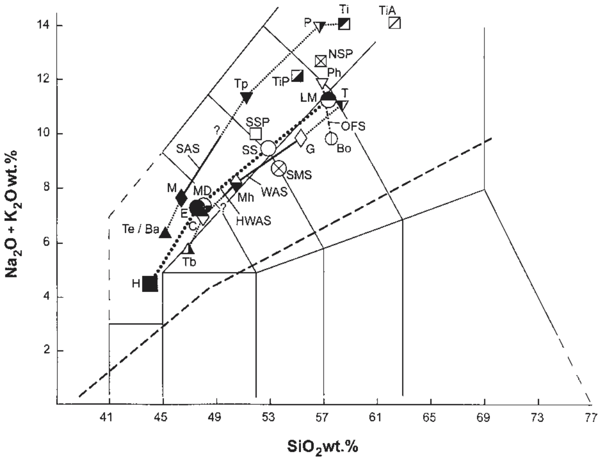

Fig. 2. Position of rocks from the RIC in TAS diagram (Le Maitre Ed. 1989) showing three differentiation series. Dykes of SAS: (**Ba/Te** — basanite/tephrite?), **M** — monchiquite, **C** — camptonite, **Tp** — tephriphonolite, **TiP** — tinguaite porphyry, **Ti** — tinguaite, **TiA** — anomalous tinguaite, **NSP** — nepheline syenite porphyry. Dykes of WAS: (**Tb** — trachybasalt?), **Mh** — mondhaldeite, **SSP** — sodalite syenite porphyry, **SMS** — sodalite-bearing monzosyenite, **G** — gauteite, (**Bo** — bostonite I? and II), **T** — trachyte, (**R** — rhyolite-xenolith?) (small symbols). Hypabyssal series: **H** — hornblendite, **E** — essexite, **MD** — monzodiorite, **SS** — sodalite syenite, **Lm** — leucomonzonite (large symbols). Dashed line discriminates alkaline from subalkaline fields.

Principal dyke rock characteristics

The study of the distribution of dyke rocks in the RIC was based on field measurements and geological maps 1: 25,000 of Hibsch (1897–1927). Four principal dyke rock types were distinguished by Hibsch (1936) in the central part of the CSM: I (L) — lamprophyres, II (SL) — semilamprophyres, III (BR) — basaltic rocks and IV (FD) — felsic derivatives.

Emplacement of dykes

Geological setting of the RIC showing central arrangement is similar to that of the Alnö Complex (Kresten 1980). Trachytic breccia of the Roztoky crater vent, with hidden hypabyssal body/ies together with forceful diapiric essexitic and syenitic intrusions (with signs of magmatic stoping), caused up-doming of the overlying country rocks and formation of several systems of joints. The passive intrusions are represented by the radial dyke system dominating the RIC, representing fillings of radial joints around the central intrusion(s). Tensional joints and, to a limited extent, probably also shear joints originated during the upward movement of magma. After mass reduction and degassing of the volcanic system ($p_{\text{magma chamber}} < p_{\text{overlying rocks}}$), subsidence of the wall-rocks occurred being associated with an another set of tensional and shear joints above the central intrusion. These two paired joint systems (sensu Kresten 1980) may be intruded by magma forming ring dykes, and cone sheets. However, these systems in the RIC are scarce. Cone sheets dipping to the presupposed centre at moderate or steep dip angles are rare in the RIC. Kopecký (1977, 1987) suggested that the “ring” dykes are represented by the moderately dipping (50°–30°) dykes of trachytic composition. However, the presence of ring dykes was not approved. Rare cone sheets are formed by young felsic derivatives (trachyte, phonolite, nepheline syenite porphyry, and tinguaite?). Their strikes are mostly straight and characteristic semicircular forms are absent. They do not represent classical cone sheets and rather correspond to the definition of tangential dykes of Heinrich (1966). It is noteworthy that no ring dykes and cone sheets have been recognized in Kaiserstuhl (Keller & Schleicher 1990).

Moderate dip angles (50°) of a group of nepheline syenite porphyries (up to 13 m thick) would bring cone sheets to a common shallow focus about 3 km below the present surface. Taking erosion into account, the depth of the focus would be not deeper than 3.6 km. The depth of the top of the magma source is, however, estimated generally at deeper than 6.5 km (at the time of intrusion), an exception being the unusual cone sheet-like structures associated with the Homa Mountain carbonatite complex in Kenya (King et al. 1972), where the focus lies at a depth of 1–2 km and the cone sheets appear to have been emplaced by explosive activity. Trachytic cone sheets of irregular geometries in the RIC commonly display dip angles between 30° and 45°. There is probably a tendency for the inclination to be lower towards the outer side of the set and higher towards the centre of the complex.

Quantitative distribution

Dykes presented in the geological maps by Hibsch (1897–1927) were affiliated to the above mentioned principal rock types (I–IV), and dyke strikes and dips were verified in outcrops. However, less than 70 % of dykes from the maps were found in outcrops and are measurable today. New, yet unknown dykes (20) were found in new artificial outcrops. Maximum dyke concentration (more than 94 % of dykes) is observed on four map sheets (see Fig. 1) of Hibsch (1899; 1897; 1902; 1910), figures in parentheses denote the numbers of dykes present: Roztoky-Podmokly/Rongstock-Bodenbach (221), Benešov nad Ploučnicí/Bensen (70), Velké Březno/Großpriesen (344) and Verneřice/Wernstadt (144). Dyke rocks occur less frequently also on 9 other map sheets of Hibsch (1897–1927). The concept of genetic association of all dykes in the central part of the CSM with the RIC (Hibsch 1930, 1936), including the Měrunice-Třebenice sheet with dykes 27 km from the centre, is disputable. An overview of principal dyke rocks types (altogether 816 dykes) recognized in the CSM (according to Hibsch 1930 associated with the RIC ?) is presented in Table 2.

The properties of dykes of the individual types (I–IV) of Hibsch (1936) revealed:

I (L) — dominance of **lamprophyric rocks** (sensu Rock 1991) — camptonite, monchiquite, mondhaldeite (58 %).

II (SL) — marked presence **of semilaprophyric rocks** (sensu Wimmenauer 1973) — gauteite, bostonite II and I? (28 %).

III (BR) — minor presence of **basaltic rocks** (with sodalite group minerals) — sodalite/hauyne tephrite/basanite — trachybasalt (6 %).

IV (FD) — minor presence of young **felsic derivatives** — trachyte, phonolite, tinguaite, tinguaite porphyry, nepheline syenite porphyry (9 %).

Table 2: Distribution of dyke rock types in the Roztoky Intrusive Centre based on Hibsch's (1926) data.

Dyke rock types	Number of dykes	Number of dykes
	n	in %
Camptonite	52	6.37
Monchiquite	460	56.37
Hauyne monchiquite	25	3.06
Leucite monchiquite	11	1.35
Mondhaldeite	10	1.23
Total dark derivatives	558	68.38
Gauteite	161	19.73
Sodalite gauteite	28	3.43
Bostonite	65	7.97
Sodalite bostonite	3	0.37
Leucomonzosyenite	1	0.12
Total light derivatives	258	31.62
Total	816	100.00

Table 3. Distribution of principal dyke rock types (I–IV) in the Roztoky Intrusive Centre.

Along strike dyke length (m)	Rock type				
	I(L)	II(SL)	III(BR)	IV(FD)	Total I–IV
	Number of dykes — n				
0–100	122	37	5	6	170
100–200	176	100	23	35	334
200–300	72	42	4	13	131
300–400	9	9	4	4	26
400–500	18	4	2	4	28
500–600	2	2	0	1	5
600–700	4	0	1	0	5
700–800	1	0	0	0	1
Total	404	194	39	63	700
Total (%)	57.71	27.70	5.60	9.00	100.01
Cumulative length	864	431	96	157	1548
Cumulative length	55.81	27.84	6.20	10.14	99.99

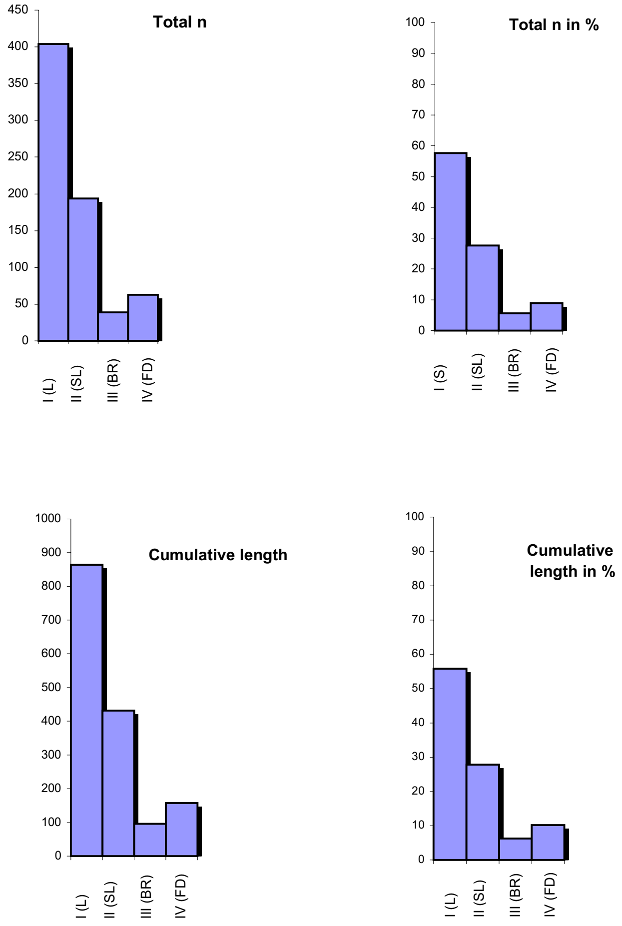

Fig. 3. Distributions of principal dyke rock types (I–IV) in the Roztoky Intrusive Centre. Total n — not considering the alongstrike lengths of dykes, cumulative length — considering the alongstrike lengths of dykes. **L** — lamprophyres, **SL** — semilamprophyres, **BR** — basaltic rocks, **FD** — felsic derivatives.

The study of quantitative distribution of dyke rocks associated with the RIC was performed on four map sheets mentioned above in two modes: (i) not considering the alongstrike lengths of dykes, (ii) considering the alongstrike lengths of dykes. The quantitative distributions of dykes into four rock types using the two methods are presented in Table 3 and Fig. 3. Minor differences were established in the distribution of individual dykes using the two methods (cf. Fig. 3).

Space distribution

A plot of strikes for radial dykes from the RIC area shows several maxima of constructed dyke intersections. The supposed main centre of the RIC is located in the area between the Roztoky monzodiorite intrusion (Vysoký kopec Hill) and the near group of essexite bodies forming Líska Hill at Malé Březno and in the trachyte caldera filling (cf. Kopecký 1987). A minor centre is located at Hradiště Hill at Svádov. The high number of dyke rock derivatives on map sheet Zálezly (15) indicates the possible presence of a hitherto unknown intrusive centre; the most distant dyke differentiates (sheet Měrunice–Třebenice) lying ca. 27 km from the RIC may be associated with this centre.

Frequences of individual dyke-rock types (I–IV) were calculated for different 10 km wide zones centered around the RIC. With respect to the substantial drop in the number of dykes at distances exceeding 10 km, such dykes were evaluated as a single category. The numbers and cumulative numbers of all dyke-rock types (I–IV) and their frequences in the different zones, total numbers for the individual dyke-rock types and their proportions are given in Table 4 and Fig. 4 together with the total and cumulative total number of dykes (700) and their proportions in percent.

Statistical evaluation of dyke-rock distribution around the RIC revealed:

— small proportions of dykes (2–5 %) at distances smaller than 1 km, with the exception of felsic derivatives (20 %); basaltic dykes do not occur at this distance at all,

— the highest proportions of dykes of all groups at distances between 2–4 km (51–55 %),

— strikes of radial dykes indicate the main intrusive centre in the area of the monzodiorite–essexite intrusions (Roztoky–Malé Březno) and a minor centre in the area of sodalite syenite intrusions at Svádov,

— high frequency (91–98 %; felsic derivatives 100 %) of dykes of all groups at distances smaller than 7 km from the postulated Roztoky centre; this distance correlates with the oc-

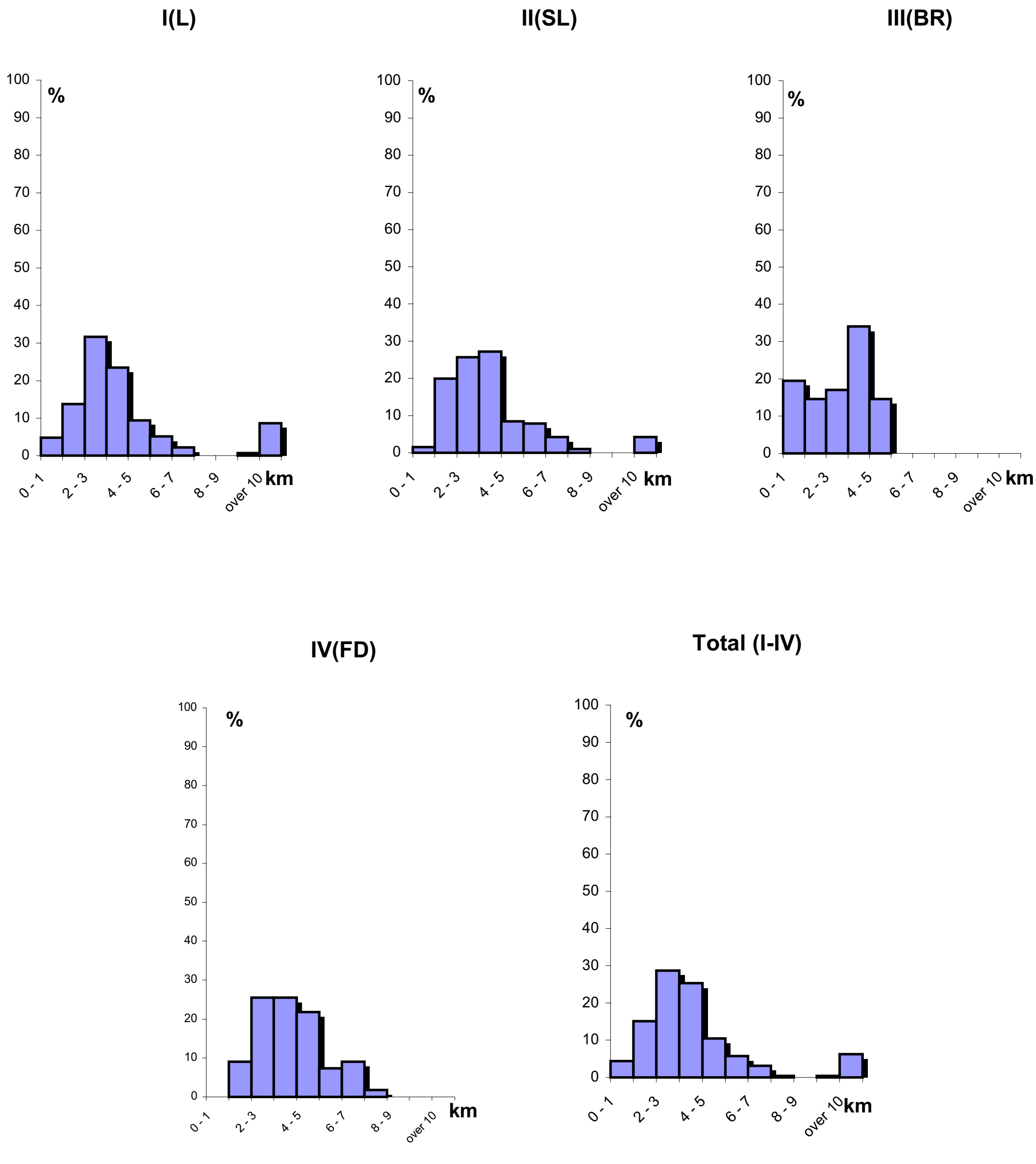

Fig. 4. Distributions of principal dyke rock types (I–IV) given by their frequencies of different distances from the Roztoky Intrusive Centre. **L** — lamprophyres, **SL** — semilamprophyres, **BR** — basaltic rocks, **FD** — felsic derivatives.

currences of sodalite syenite bodies which, according to Kopecký's (1977) interpretation, have signs of ring-dyke arrangement,

— accumulation of foid (semi)lamprophyres, to a lesser extent also of sodalite bostonites I (and sodalite trachybasalts), are spatially associated (Hibsch 1926) with sodalite syenite bodies,

— dyke differentiates at distances of >15–20 km can be hardly associated with the RIC — a problem of opening of joints and penetration of liquids at such distances,

— another volcanic centre in the CSM with differentiated dyke suite is the Býčkovice Intrusive Centre (Ulrych & Novák 1989); the most distant dyke differentiates in the Měrunice–Třebenice area may be associated with a yet unknown volcanic centre located on the neighbouring map sheet Zálezly, with a higher concentration of dyke derivatives,

— quantitative distribution of dykes of all groups at different distances from the RIC centre is similar for all types of dyke rocks with the exception of felsic derivatives, which occur at distances of < 5 km only, with a cumulative maximum (85 %) within the range of 4 km; other dyke groups reveal cumulative maximum (82–83 %) within the range of 5 km only — high viscosity may cause the lower mobility of acid magma.

Dyke orientations

Strikes of the dykes were estimated with a precision of 10° from the above mentioned four map sheets 1: 25,000; strikes of less than 70 % of dykes only could be tested in the field. Dips of the radial dykes can be measured only rarely (15 % of dykes), with totally prevailing dip angles of 90–80°. Pre-

Table 4: Distribution of principal rock types (I–IV) given by their frequencies at different distances from the Roztoky Intrusive Centre.

Distance (km)	Rock type																Total (I–IV)		Cumulative total (I–IV)	
	I(L)				II(SL)				III(BR)				IV(FD)							
	n	n in %	Σn	Σn in %	n	n in %	Σn	Σn in %	n	n in %	Σn	Σn in %	n	n in %	Σn	Σn in %	n	n in %	n	Σn
0–1	20	4.8	20	4.8	3	1.5	3	1.5	8	19.5	8	19.5					31	4.4	31	4.4
1–2	57	13.8	77	18.6	38	19.9	41	21.4	6	14.6	14	34.1	5	9.1	5	9.1	106	15.1	137	19.6
2–3	131	31.7	208	50.4	49	25.7	90	47.1	7	17	21	51.2	14	25.5	19	34.6	201	28.7	338	48.3
3–4	97	23.5	305	73.9	52	27.2	142	74.3	14	34.1	35	85.4	14	25.5	33	60.1	177	25.3	515	73.6
4–5	39	9.4	344	83.3	16	8.4	158	82.7	6	14.6	41	100.0	12	21.8	45	81.9	73	10.4	588	84.0
5–6	21	5.1	365	88.4	15	7.9	173	90.6				100.0	4	7.3	49	89.2	40	5.7	628	89.7
6–7	9	2.2	374	90.6	8	4.2	181	94.8				100.0	5	9.1	54	98.3	22	3.1	650	92.9
7–8	0	0	374	90.6	2	1	183	95.8				100.0	1	1.8	55	100.0	3	0.4	653	93.3
8–9	0	0	374	90.6	0	0	183	95.8				100.0				100.0			653	93.3
9–10	3	0.7	377	91.3	0	0	183	95.8				100.0				100.0	3	0.4	656	93.7
over 10	36	8.7	413	100.0	8	4.2	191	100.0				100.0				100.0	44	6.3	700	100.0
Total	413				191				41				55				700			

ferred orientations at the individual dyke groups are given in Table 5; all measured strikes of the dykes are presented in rose diagrams (Fig. 5). Strikes of dykes exposed on the right and the left banks of the Labe River (Souček et al. 1985) are shown in the same figure. Variations in strikes of all dyke groups in all four sectors of the RIC (Hobl 1987 data are used) are presented in Fig. 6.

Analysis of the Tertiary paleostress history obtained from field work and paleostress analysis of shear faults in the region of the central part of the Ohře Rift in the CS was made by Adamovič & Coubal (1999). The mechanical model of magma emplacement into an elastic host rock formulated by Pollard (1973) based on Anderson's presumption was used by the above mentioned authors as a basis for the determination of the direction of maximum principal stress component from the intrusion shape in horizontal cross section. Magma inhibition and solidification occurred after magma pressure equilibrated with the regional stress in the host rock. The present geometries of intrusive bodies result from this equilibrated stress field, thus giving evidence of the effects of both the magma pressure and regional stress (Pollard et al. 1975; Delaney & Pollard 1981). Adamovič & Coubal (1999) distinguished b extension-dominated period in the Ohře Rift in the Middle Eocene to Middle Miocene:

— b_1 — paleostress field characterized by E–W to NE–SW extension, effective in the eastern part of the Ohře Rift in the interval of 40–26 Ma,

— b_2 — paleostress field characterized by N–S extension progressively spreading from its central part in the Most Basin (onset at 34 Ma) to its eastern part (onset at 26 Ma), and

— b_3 — paleostress field characterized by NW–SE extension, commenced at 24 Ma.

The evaluation of dyke strikes of all types (I–IV) revealed that:

— dyke orientation was controlled (i) by the paleostress field existing in the upper crust during magma ascent (Adamovič & Coubal 1999), (ii) by orientations of pre-existing fracture sets in the region, and (iii) by the superimposed local stress field exerted by the rising intrusion(s). The pre-existing fracture sets used as pathways for magma ascent were primarily represented by ruptures formed as reverse faults in the latest Cretaceous and earliest Tertiary (Sub-Hercynian and Laramide phases sensu Ziegler (1982)), and later modified as normal faults. To a lesser degree the dyke strikes may be controlled by pre-Cretaceous ruptures at deep crustal level (Saxothuringian Crystalline basement),

— similar orientation maxima for steeply dipping radial dykes (90–80°) of the (semi)lamprophyres and basaltic dykes, with totally prevailing strikes of 90° and 0°; similar preferred strikes are also present in the Alnö Complex (Kresten 1980).

— independent structural plan of the felsic derivatives (FD) with prevailing dyke strikes of 330° and 90°,

— preferred strikes of the (semi)lamprophyres (L and SL) and basaltic dykes (BD) are neither parallel, nor perpendicular to the eminent structures of the Roztoky area, i.e. the axis of the Ohře Rift (70°), Labe Tectono-Volcanic Zone (300°) or other structures; FD dykes (330°) reveal structural affinity to the Zubrnice Fault (320°), and ore veins in the Roztoky monzodiorite (20–30°) and FD dykes (10°) to the fault dislocating the Roztoky monzodiorite body (20°),

— partly different strike maxima of the dykes on the right and the left banks of the Labe River can be probably explained by the primarily(?) asymmetrical development of the RIC dykes and/or, more probably, by the different representation of dykes of the individual groups (I–IV) having characteristic strikes on the two Labe River banks. The right bank poses a relatively better preserved, tectonically subsided block with a higher number of dykes, however, practically with no exposed dykes of the youngest LD group.

Table 5: Preferred orientation of principal dyke rock types (I–IV).

Dyke rock types	max	→			min.
I(L) — lamprophyres	90°	0°	60°	290°	40°
II(SL) — semilamprophyres	90°	290°	0°	10°	40°
III(BR) — basaltic rocks	330°	90°	290°	10°	50°
IV(FD) — felsic derivatives	90°	0°	40°	320°	340°
Dykes total	90°	0°	290°	60°	40°
Dykes on right bank of Labe (SOUČEK et al. 1985)	90°	300°	0°	60°	
Dykes on left bank of Labe (SOUČEK et al. 1985)	60°	90°	0°	300°	
Ohře Rift (axis)	70°				
Labe Volcano-Tectonic Zone (axis)	300°				
Zubrnice Fault transverse to the Ohře Rift	320°				
Fault dislocating the Roztoky monzodiorite body	20°				
Polymetallic ore veins at Roztoky	20–30°				

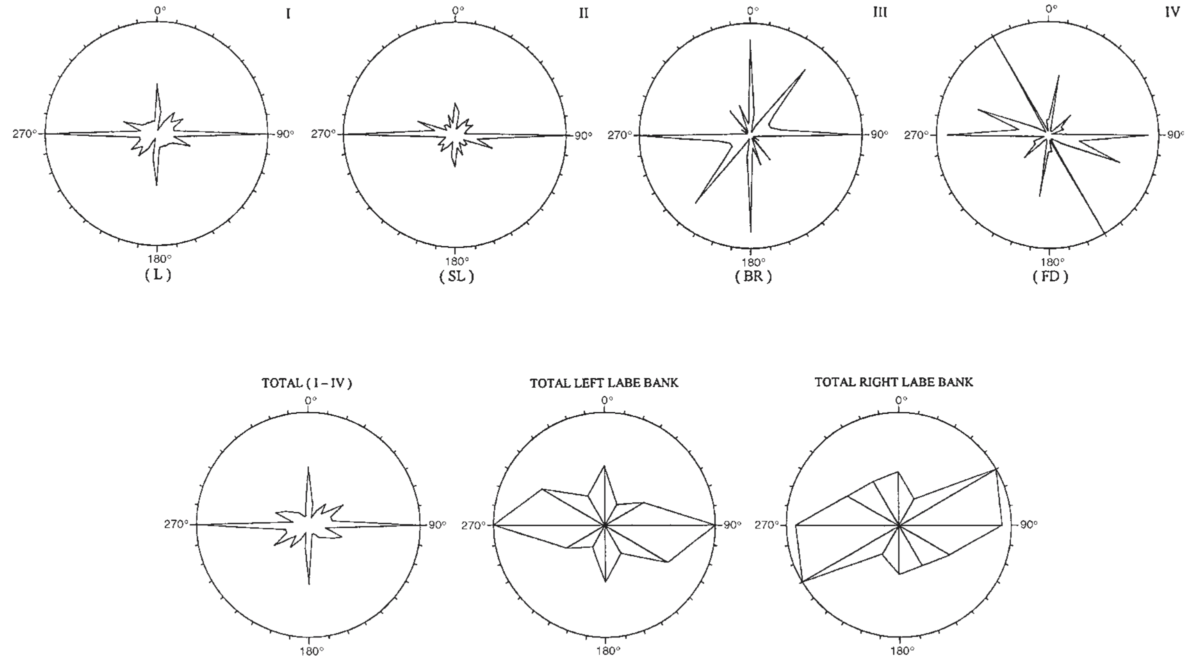

Fig. 5. Rose diagrams of strikes for principal dyke rock types (I–IV) in the Roztoky Intrusive Centre. **L** — lamprophyres, **SL** — semilamprophyres, **BR** — basaltic rocks, **FD** — felsic derivatives.

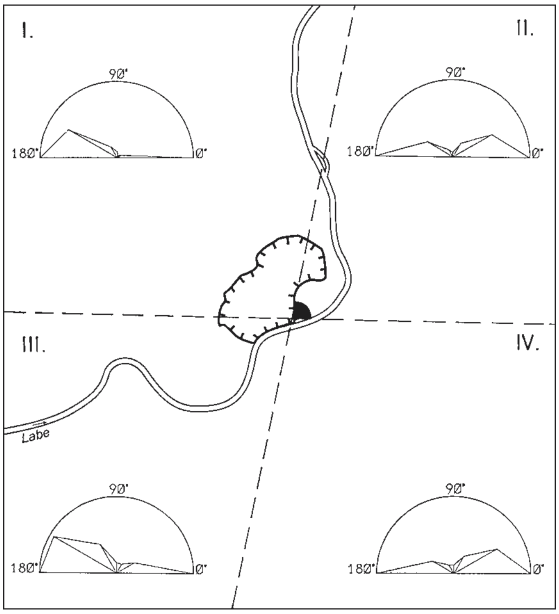

Fig. 6. A sketch of the Roztoky Intrusive Centre with rose diagrams of strikes for all dykes in four principal sectors of the centre.

— for the interval of 31–26 Ma, the analysis of dyke geometries indicates the dominance of regional stress characterized by the emplacement of E–W-striking dykes (L ≈ SL > BR > FD):

(i) the oldest BA dykes probably associated with the Lower Formation basanitic lavas (31–29 Ma in the central part of the CS) reveal, in addition to the prevailing E–W strike, also N–S and NW–SE strikes,

(ii) younger dykes (31–26 Ma) of groups L and SL are characterized by very similar pattern of dyke distribution with marked preference of E–W-striking dykes and minor N–S strikes,

(iii) a substantially different pattern is characteristic for the youngest (26–24 Ma) LD dykes with prevailing NW–SE strikes together with minor E–W, WNW–ESE and NNE–SSW strikes.

Age relations

Mutual geological age relations between principal dyke-rock types in the RIC were difficult to determine due to the absence of relevant outcrops and dyke intersections. Dyke dip angles are mostly high (80–90°) and dykes in individual outcrops are mostly subparallel. The following time succession (from older to younger) of the principal dyke-rock types was established: basanitic (also the adequate extrusive formation including a feeding channel of olivine nephelinite) > essexitic and syenitic plutonic intrusions > semilamprophyres (gauteite) > lamprophyres (camptonite, monchiquite) > trachybasaltic extrusive formation > felsic derivatives (bostonite II? > > trachyte ≈ tinguaite). All these field data are in agreement with radiometric K-Ar ages.

Multiple dykes consisting of several simple dykes adjacent to one another or intruded alongside or within each are considerably more frequent than classical dyke crossings. Multiple dykes are represented in particular by older gauteite “parental” dykes penetrated or paralleled by camptonites, or bostonite II dykes penetrated by tinguaite with glassy rims. Older basaltic dykes BA are exclusively cut by all dykes (L and SL). On the other hand, trachytes cut all dykes. This implies that L and SL intruded into a uniform joint system, older BA dyke groups into a partly different system, while the youngest FD group into a totally different joint system. No dyke-rock inclusions in other dykes were observed except of “rhyolite” xenoliths in bostonite (Ulrych et al. 2000).

Subvolcanic products of plutonic HWAS and dyke SAS and WAS represent various magmatic pulses of a crustal volcanic chamber. However, tephrites/basanites of SAS and trachybasalts of WAS probably belong to the extrusive Lower and Upper Formations. The pertinence of trachytic rocks to the WAS is also disputable. The individual above mentioned rock series may represent products of separate pulses mediated by a subcrustal magmatic chamber.

K-Ar ages were published for various RIC rocks (Arakelyanc et al. 1977; Bellon & Kopecký 1977; Wilson et al. 1994) These data together with sixteen new K-Ar datings (whole-rock and mineral ages) are presented in Table 6 and in Fig. 7. The ages of individual dyke groups (I–IV) of the intrusive volcanic series (sub 4–6) present in the RIC are distributed within a relatively narrow interval of 33–24 Ma (cf. 18–13 Ma Kaiserstuhl — Keller & Streicher 1990; 79–65 Ma Osečná Complex — Pivec et al. 1998; 281–265 Ma and 273–241 Ma plutonic intrusions of two segments of the Oslo Graben — Sundvoll et al. 1990). However, an influence of strong alteration processes (e.g. “propylitization” of Hibsch 1926) of the dyke derivatives and thermal effect of various younger intrusions can cause a loss of Ar. Excess of Ar can be associated with crystallization of some minerals — interceptors of Ar, e.g. sodalite. All the above mentioned effects may result in prolongation of magmatic activity in the RIC.

The following magmatic series were distinguished in the region of the RIC:

1 — **Old felsic series** (sodalite phonolites, sodalite trachytes - Shrbený & Vokurka 1985 and bostonites I) represent the pre-RIC intrusive activity (42.7–38.2 Ma) in the central part of the CSM.

2 — **Lower Formation** (basanitic lavas and volcaniclastites), representing extrusive volcanic products, pre-date (36.1–25.5 Ma) the beginning of RIC intrusive activity (HWAS); feeding channel of massive olivine nephelinite at Dobkovice revealed the age of 30.9–29.3 Ma; tephrite/basanite dykes are probably associated with this formation.

3 — **Upper Formation** (trachybasaltic lavas and pyroclastics) represents continued (partly overlapping with the Lower Formation) extrusive volcanic activity (30.8–24.7 Ma); a feeding channel at Vysoký Kámen Hill revealed the age of 27.1 Ma, a relict of the Vrabinec diatreme of 26.8 Ma (Pfeiffer et al. 1984); trachybasaltic dykes (with minerals of sodalite group) are **probably associated with this formation.**

4 — **Hypabyssal Weakly Alkaline Series** with simultaneous bodies of essexites (33.1–31.3 Ma), monzodiorite (32.7–29.5 Ma) and sodalite syenites (30.3–28.2 Ma) was emplaced synchronously with the extrusive volcanic activity; hornblendite cumulate in sodalite syenite revealed the age of 30.1 Ma.

5 — dykes of coeval (30.9–25.6 Ma), **Strongly and Weakly Alkaline Series**: camptonites/(gauteites I?) (30.9–28.2 Ma), monchiquites (25.6 Ma), nepheline syenite porphyries probably forming cone sheets (30.1 Ma), tinguaite porphyries (25.6 Ma) and gauteites II? (23.6 Ma)/trachytes?

6 — **trachytic breccia** with carbonate cement filling the main Roztoky crater vent (caldera with pseudotrachyte filling of Kopecký 1987) contains xenoliths of monzodiorite, lamprophyres etc.; however, it is intruded by felsic dyke rocks (dykes and/or cone sheets — tinguaite /porphyry/, trachyte, phonolite, nepheline syenite porphyry); hydrothermal polymetallic ore veins penetrating the Roztoky monzodiorite paralleled by bostonite dyke and intersected by younger trachytes.

7 — **Uppermost Formation** (flow/s/ of basanite) represents continued (partly overlapping the Upper Formation) extrusive volcanic activity (24.0 Ma).

8 — **youngest intrusive volcanic activity** in the RIC area is represented by small stocks of nepheline phonolites (17.0 Ma;

Table 6: K-Ar ages of the principal rock types from the Roztoky Intrusive Centre.

No.	Rock type	Locality	Age (Ma)	Method	Source
54	Essexite — dark, medium-grained, hbl-cpx	Lícha hill near Malé Březno	33.1	hornblende	this work
55	Essexite — light, medium-grained, hbl-cpx	Lícha hill near Malé Březno	31.3	alkali feldspar	this work
14	Monzodiorite — fine-grained, cpx-bi	Roztoky, railway cut	32.7	hornblende	this work
15	Monzodiorite — medium-grained, cpx-bi	Roztoky, railway cut	29.5	whole rock	Bellon & Kopecký (1977)
16	Monzodiorite coarse-grained, bi-cpx	Roztoky, railway cut	30.8	hornblende	this work
4	Monzodiorite fine-grained, cpx-bi	Roztoky, railway cut	30.9	clinopyroxene	this work
4	Monzodiorite fine-grained, cpx-bi	Roztoky, railway cut	30.7	biotite	this work
3	Sodalite syenite — fine-grained, hbl-cpx	Hradiště Hill near Svádov	28.0	whole rock	Arakelyanc et al. (1977)
59	Sodalite syenite — fine-grained, hbl-cpx	Hradiště Hill near Svádov	28.6	analcime	this work
60	Sodalite syenite — fine-grained, hbl-cpx	Giegelberg Hill, near Zubrnice, quarry	30.1	analcime	this work
115	Hornblendite — coarse-grained, cumulate in sod. syenite	Giegelberg Hill, near Zubrnice, quarry	30.8	hornblende	this work
8	Camptonite with hbl+phl phenocrysts	Dobkovice, quarry	28.2	whole rock	Wilson et al. (1994)
11	Monchiquite with cpx phenocrysts	Dobkovice, quarry	25.6	whole rock	Wilson et al. (1994)
9	Camptonite with hbl+phl phenocrysts	Leština, quarry	30.9	whole rock	Wilson et al. (1994)
99	Gauteite II? with hbl-bi-plag phenocrysts	Těchlovice, quarry	23.6	whole rock	Wilson et al. (1994)
152	Tinguaite porphyry — porphyritic with ne-fsp phenocrysts	Skrytín, water-tower	25.6	magnetic fraction	this work
13	Nepheline syenite porphyry — coarse-grained	Roztoky, railway cut	30.1	light fraction	this work
195	Bostonite — fine-grained	Malé Březno, borehole	38.6	whole rock	this work
98	Rhyolite — coarse-grained to porphyritic	Malé Březno, borehole	43.4	whole rock	this work
19	Olivine nephelinite — fine-grained	Dobkovice, quarry	29.3	whole rock	Wilson et al. (1994)
30	Olivine nephelinite — fine-grained	Těchlovice, quarry	30.9	whole rock	Wilson et al. (1994)
17	Tephrite — fine-grained	Vysoký kámen Hill near Neštěmice	27.1	whole rock	this work
96	Phonolite — fine-grained, plg phenocrysts	Kozí hora Hill near Neštěmice	42.7	whole rock	this work
24	Sodalite trachyte — fine-grained	Radešín Hill near Radešín	29.8	whole rock	this work

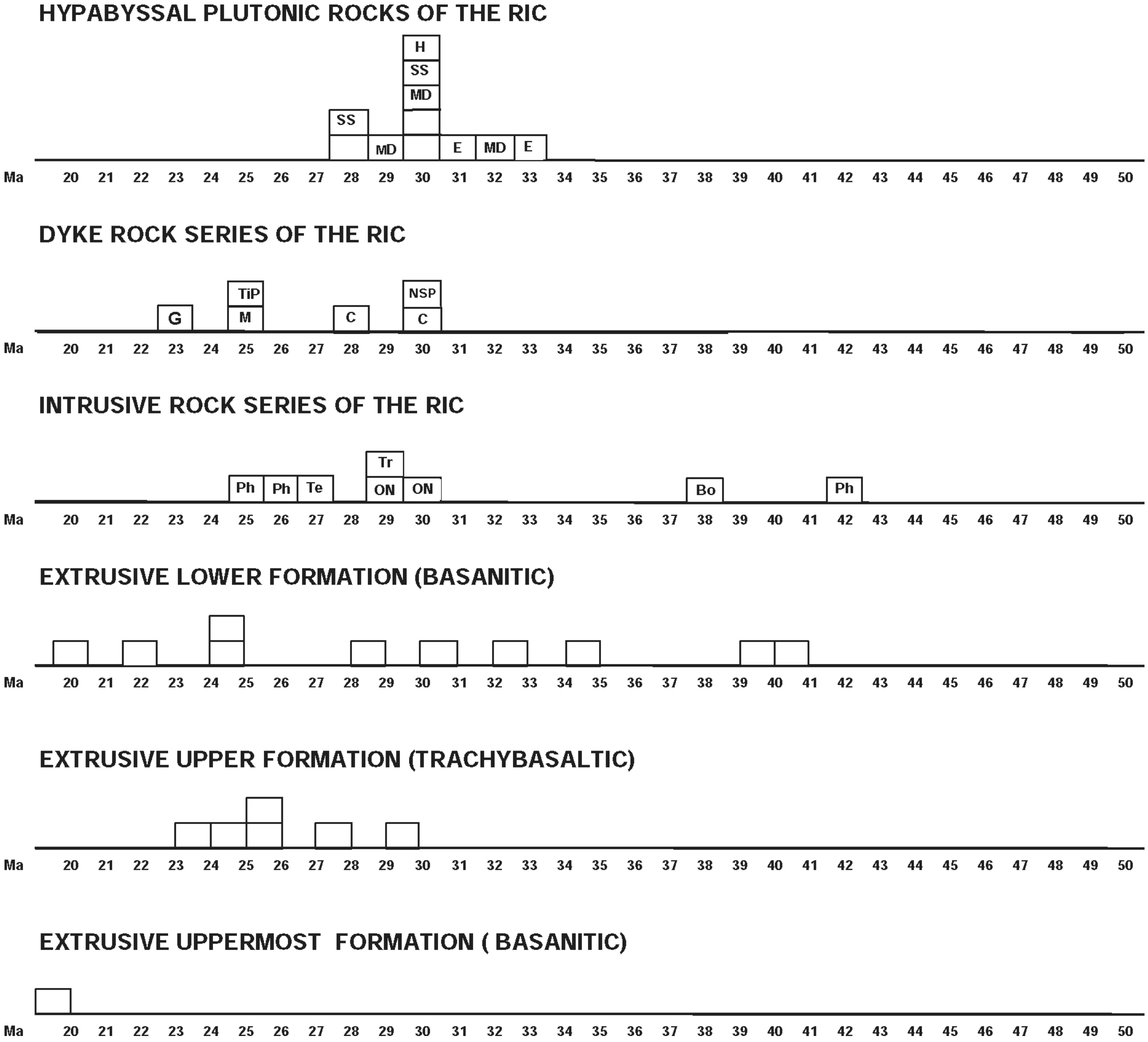

Fig. 7. Age histograms for principal rock types (I-IV) in the Roztoky Intrusive Centre. **E** — essexite, **MD** — monzodiorite, **SS** — sodalite syenite, **H** — hornblendite, **M** — monchiquite, **C** — camptonite, **G** — gauteite, **TiP** — tinguaite porphyry, **NSP** — nepheline syenite porphyry, **Tr** — trachyte, **Ba** — basanite, **Tb** — trachybasalt, **Bo** — bostonite I, **Ph** — phonolite.

Shrbený & Vokurka 1985) and leucite tephrites (16.1 Ma; Pfeiffer et al. 1984) lying at transitions to the basanite Late Miocene Intrusive Formation (13-9 Ma) known from the Teplice area, CSM (Ulrych et al. 1999; Cajz et al. 1999).

Discussion and conclusions

The RIC representing the main volcanic centre of the CSM is structurally predisposed by the intersection of two main tectono-volcanic structures of the Bohemian Massif (Kopecký 1978). It belongs to characteristic volcanic structures of central type. The ages of individual intrusive subvolcanic rock types of the RIC fall within a narrow interval of 33-24 Ma: (i) Hypabyssal Weakly Alkaline Series (33.1-28.2 Ma) of plutonic intrusions emplaced synchronously with coeval, (ii) Strongly and Weakly Alkaline Series (30.9-23.6 Ma) of dykes and intruded by (iii) felsic dykes and cone sheets (< 23.6 Ma).

The proportions of dykes of the individual rock types I-IV (I — lamprophyres, II — semilamprophyres, III — basaltic rocks, IV — felsic derivatives) indicate a pronounced dominance of (semi)lamprophyres forming together 83 % of all dykes. Lamprophyres represent potential parental magmas for hypabyssal intrusions (cf. similar situation in Monteregian intrusions — Bédard 1989). $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ ratios of the lamprophyres (0.70405-0.70435; 0.512627) and hypabyssal essexitic-syenitic (0.70446-0.70363) rocks show the same upper mantle source with minor crustal contamination (Ulrych et al., in print) with tephrite/basanite (0.7031-0.70353; 0.512738-0.512849) and trachybasalts (0.70443-0.70465; 0.512679-0.512742) extrusions (Cajz et al. 1999 and Ulrych et al. in print). Tephrite/basanite and trachybasalt dyke rocks (6 % of dykes in the RIC) probably associated with the Upper and Lower Formations sensu Cajz et al. (1999) do not belong to the RIC proper. Rare augitite represents the most primitive dyke derivative in the RIC (Jelínek et al. 1989). Minor felsic derivatives (9 %) of trachyte, and phonolite composition form cone sheets and radial dykes representing the younger products of the RIC. Their age is presumably similar to that of gauteites II? (24 Ma).

Statistical evaluation of the distribution of dyke rocks in the RIC area indicates low frequency of dykes (2–5 %) at distances of < 1 km, with the exception of felsic derivatives (20 %); basaltic dykes are completely missing within this distance. Frequency maxima (51–55 %) of all dykes characteristically occur at distances of 2–4 km. Substantial cumulative frequency of dykes of all groups (91–98 %; felsic derivatives even 100 %) is in distance up to 7 km from the RIC. This distance correlates with accumulations of sodalite syenite bodies which according to Kopecký (1977), show signs of ring-dyke arrangement. Dykes at distances of > 15–20 km (map sheet Měrunice–Třebenice) can be hardly genetically associated with the RIC and may be associated with a yet unspecified volcanic centre near Zálezly. Other minor volcanic centres with dyke suite are, e.g., the Býčkovice Intrusive Centre, CSM (Ulrych & Novák 1989) with associated lamprophyre swarm of mostly linear character in the Vinné–Třebušín Zone.

Strikes of radial dykes indicate that the main intrusive centre is present in the area between Roztoky and Malé Březno with monzodiorite–essexite intrusions with some marginal sodalite syenite intrusions, e.g. near Svádov. Dykes of sodalite (semi)lamprophyres, sodalite bostonites II and sodalite basaltic rocks are spatially often associated with the sodalite syenite bodies (cf. Hibsch 1926). Different strike maxima of the dykes on the right and the left banks of the Labe River can be probably explained by the different representation of dykes of the individual groups (I–IV) having characteristic strikes on the two Labe River banks. The right bank poses a relatively better preserved, tectonically subsided block with a higher number of dykes. For the interval of 31–26 Ma, the analysis of dyke geometries indicates the dominance of regional stress characterized by the emplacement of E–W-striking dykes. The oldest BA dykes probably associated with the Lower Formation basanitic lavas (31–29 Ma) reveal, in addition to the prevailing E–W strike, also N–S and NW–SE strikes. The younger dykes (31–26 Ma) of groups L and SL are characterized by very similar pattern of dyke distribution with marked preference of E–W-striking dykes and minor N–S strikes. A substantially different pattern is characteristic for the youngest (26–24 Ma) LD dykes with prevailing NW–SE strikes together with minor E–W, WNW–ESE and NNE–SSW strikes.

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