Canadian Mineralogist
Vol. 26, pp. 89-95 (1988)

THE AMPHIBOLES OF POTASSIUM-RICH DYKES OF THE SOUTHEASTERN BORDER OF THE BOHEMIAN MASSIF

DUŠAN NĚMEC
Geoindustria, 586 01 Jihlava, Czechoslovakia

ABSTRACT

Potassium-rich dykes (peralkaline minettes, alkaline microsyenites and microgranites) of the southeastern border of the Bohemian Massif (Czechoslovakia and Austria) contain Al-poor calcic, sodic–calcic, and alkali amphiboles. In accordance with the chemical composition of their parent rock, tremolitic amphibole, winchite, richterite and arfvedsonite–riebeckite are present. Within individual dykes, the amphibole composition varies over a relatively broad range; locally, richterite and magnesio-arfvedsonite - riebeckite coexist. However, this is not due to a miscibility gap, but probably only to a sudden change of conditions during crystallization. Two trends of compositional changes are recognizable in amphiboles of individual dykes: a $NaFe^{3+}$ - $CaFe^{2+}$ coupled substitution and an increase of Na/K ratio with diminishing Ca. With the exception of the amphiboles of the microgranite, the potassium content of the amphiboles amounts to 25–50 at. % of the alkali total, not surpassing, however, one atom per formula unit. The K content exceeds that in amphibole from most lamproites and resembles that in kimberlitic richterite. The composition could have genetic significance.

Keywords: potassic amphibole, minette, alkaline microsyenite, microgranite, Czechoslovakia, Austria.

SOMMAIRE

Les roches relativement potassiques des dykes de la frontière Sud-Est du Massif Bohême, en Czechoslovaquie et en Autriche (minettes hyperalcalines, microsyénites et microgranites alcalins) contiennent une variété d'amphiboles, calcique et pauvre en Al, sodique-calcique et alcaline. L'amphibole qui apparaît, amphibole trémolitique, winchite, richtérite, ou riebeckite–arfvedsonite, est fonction du chimisme de la roche globale. A l'intérieur d'un seul dyke, l'amphibole peut varier largement, et on peut trouver richtérite et magnésio-arfvedsonite - riebeckite ensemble. Cette coexistence ne serait pas due à une lacune de miscibilité, mais plutôt à un changement soudain dans le milieu de cristallisation. Deux lignées compositionnelles caractérisent les amphiboles des dykes, l'une impliquant le couple $NaFe^{3+}$ - $CaFe^{2+}$, l'autre le résultat d'une augmentation dans le rapport Na/K à mesure que diminue Ca. Sauf dans l'amphibole des microgranites, le contenu de potassium atteint de 25 à 50% (atomique) du total des alcalins, ce qui ne dépasse pas un atome de K par unité formulaire, toutefois. Cette teneur en potassium surpasse celle des amphiboles de la plupart des lamproïtes, et ressemble à celle d'une richtérite kimberlitique. Ce fait pourrait être un indice pétrogénétique important.

(Traduit par la Rédaction)

Mots-clés: amphibole potassique, minette, microsyenite alcaline, microgranite alcalin, Czechoslovaquie, Autriche.

INTRODUCTION

Much attention has been given to the alkali amphiboles of intrusive rocks, carbonatites and kimberlites (*e.g.*, Fabriès 1978, Dawson 1980, Samoilov & Gormasheva 1975). However, amphiboles of potassium-rich subvolcanic rocks are only poorly known, with the exception of those of lamproites (Wagner & Velde 1986). This paper is concerned with the crystal chemistry of the amphibole of alkaline dykes of the southeastern border of the Bohemian Massif. These Variscan dykes occur in two areas rich in various dyke rocks; one of these areas covers the surroundings of Třebíč in western Moravia and includes specimens from Markvartice, Kožichovice, Šebkovice and Stařeč (Fig. 1). The other area is in the vicinity of Waidhofen in Austrian Waldviertel, and includes specimens from Karlstein, Jarolden and Thures. The potassium-rich dyke rocks examined are intermediate or felsitic and are associated with various dykes of syenite, granodiorite and diorite porphyries, microgranites and Ca-rich amphibole-bearing lamprophyric and lamproid types (Němec 1972, 1978). However, the potassium-rich dykes form a specific and distinct association that is not transitional into all the other types.

In both areas, all the dykes, both alkaline and nonalkaline, are associated with deep faults reaching perhaps as low as the upper mantle, in which considerable tectonic movements took place. The dykes fill tension fissures, mostly intersecting various gneisses of the Moldanubicum. The dykes are a few dm to some m thick and some are very long.

The alkaline minette (in the sense of Bachinski 1986), alkaline microsyenite, and microgranite form a specific association of potassium-rich rock, which in the same association recurs in other regions of the

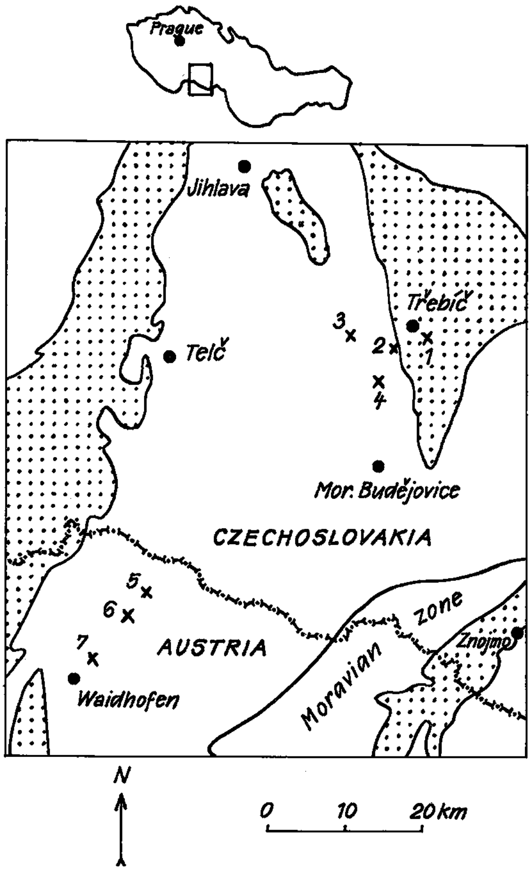

FIG. 1. Sketch map of the area studied. Dykes mentioned in the text: 1 Kožichovice, 2 Stařeč, 3 Markvartrice, 4 Šebkovice, 5 Thures, 6 Karlstein, 7 Jarolden. Dotted areas - intrusive rocks (granite, granosyenite, syenite). The Moravian zone: area of epizonal metamorphism. Crystalline schists of the catazonally metamorphosed Moldanubikum are left without designation.

TABLE 1. CHEMICAL COMPOSITION OF THE AMPHIBOLE-BEARING ROCKS

	1	2	3	4	5
SiO_2 wt.%	58.83	54.92	57.45	60.16	71.81
TiO_2	0.58	2.30	1.86	2.27	1.44
Al_2O_3	11.78	7.66	9.91	9.20	9.45
Fe_2O_3	2.24	3.00	1.46	3.68	2.56
FeO	2.44	2.16	2.20	2.80	1.07
MnO	0.17	0.09	0.08	0.03	0.07
MgO	5.95	7.38	6.01	3.78	0.93
CaO	4.56	5.49	4.60	3.00	0.66
BaO	0.71	1.08	0.32	0.73	0.55
Na_2O	2.00	2.07	1.81	2.22	1.23
K_2O	8.40	9.20	9.40	9.66	8.35
P_2O_5	1.43	2.82	2.90	1.12	0.12
F	0.40	0.60	0.48	0.02	0.10
CO_2	-	-	-	0.29	-
H_2O^+	0.97	0.75	0.70	0.53	0.40
H_2O^-	0.36	0.17	0.10	0.26	0.13
total	100.82	99.69	99.28	99.75	98.87
F ≡ O	0.17	0.25	0.20	-	0.04
	100.65	99.44	99.08	99.75	98.83
A.I.	1.04	1.73	1.33	1.53	1.17

Analysts: H. Červená, Geoindustria Jihlava, except for 4, by O. Hackl (Waldmann & Hackl 1940). The analyses were made by wet-chemical methods. A.I.: agpaitic coefficient. Samples: 1 alkaline microsyenite, Markvartice, 2 alkaline microsyenite, Šebkovice, 3 alkaline minette, Kožichovice, 4 alkaline microsyenite, Jarolden, 5 alkaline microgranite, Karlstein.

Bohemian Massif (in central Bohemia and especially typically in the Orlické hory Mountains in eastern Bohemia; Němec 1975). These rocks are always linked by transitions (some within a single dyke) to normal minette, which are realized in the following way. In the normal minette, some sodic–calcic amphibole is present in addition to phlogopite (alkaline minette); the amount of the amphibole increases until phlogopite completely disappears (alkaline microsyenite) and eventually quartz adjoins it (alkali microgranite). All the rocks are potassium-rich and silica-saturated or oversaturated. Their alkalinity derives from an aluminium rather than a silica deficiency (compare their agpaitic coefficients, Table 1).

Analyses of 29 amphibole samples were carried out by Dr. D. Ackermand, Institute of Mineralogy and Petrology, University of Kiel (localities Šebkovice and Karlstein) and by Ing. Z. Kotrba, Laboratory of the Geological Survey, Prague (localities Markvartice, Kožichovice and Jarolden), using an 85-CAMEBAX Microbeam CD and an ARL–SEMQ microprobe (15 kV, 50 nA), and artificial compounds and natural analyzed minerals as standards. The structural formulae were calculated on the basis of 13 cations exclusive of (Ca + Na + K), and the atoms were recast to groups according to the Leake's (1978) scheme (Table 2). However, to account for the recent investigations of Waychunas (1987), all titanium was added to the octahedrally coordinated ions. All potassium was alotted to the *A* site. As recommended by Leake (1978), the Fe^{2+}/Fe^{3+} ratio was adjusted to bring oxygen to 23. The Fe^{2+}/Fe^{3+} ratio thus obtained approximately equals that found by the wet-chemical method (Němec 1973a) in similar amphiboles from two other microsyenite dykes in the areas examined (Stařeč and Thures; Fig. 1; both not discussed in the present paper). The nomenclature of amphiboles used here follows the classification of Leake (1978).

CHARACTERISTICS OF AMPHIBOLE AT INDIVIDUAL LOCALITIES

Markvartice

The rock was found only as fragments in a gneiss area (Fig. 1); its geological setting is not known. The rock, a fine-grained microsyenite consisting of 43 vol.% amphibole, 3 vol.% biotite, and 54 vol.% K-feldspar, is only slightly alkaline (agpaitic index 1.04; Table 1). The amphibole, evidently at least partly of subsolidus origin, is microscopically columnar to fibrous, dirty brown-green and weakly pleochroic. Some larger crystals are zoned with a light green rim and a darker core. The amphibole covers a wide range of compositions from ferrowinchite to a near-tremolite type (Figs. 2–4). The latter, which consists of dense felt-like aggregates, probably pseudomor-

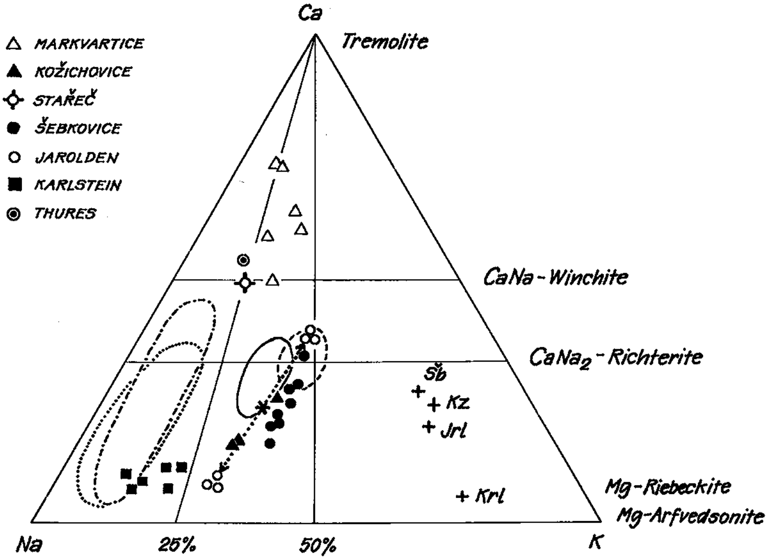

FIG. 2. Ca–Na–K ratios (atomic) of the analyzed amphiboles. Double arrow joins plots of the amphiboles from Jarolden (asterisk marks the average amphibole composition). Crosses – plots of the parent rocks (Krl Karlstein, Jrl Jarolden, Kz Kožichovice, Sb Šebkovice). Fields of amphiboles from kimberlites and their xenoliths (enclosed by dashed line), from lamproites (solid outline), from syenites, Kerguelen (dash-dot line) and from carbonatites (dotted line).

phous after forsteritic olivine, is easily distinguishable from the amphibole richer in alkalis by its higher birefringence.

The amphiboles are relatively rich in Ca, some of them representing the sporadically occurring transitional members from tremolite to ferrowinchite. Similar types were also reported from some kimberlites and nordmarkites (Aoki *et al.* 1972, Brooks & Gill 1982). As expected, Mn shows a pronounced positive correlation with Σ Fe. Ti and Al vary con-

TABLE 2. REPRESENTATIVE CHEMICAL COMPOSITIONS OF AMPHIBOLE

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SiO_2	wt.%	55.30	56.43	55.37	55.32	55.90	56.64	57.34	55.18	56.32	54.36	53.70	52.48	53.47	54.33	54.16
TiO_2		0.24	0.41	0.90	1.57	1.67	1.25	0.99	2.70	1.93	1.14	0.94	2.52	2.19	0.40	0.74
Al_2O_3		1.69	0.71	2.79	0.85	0.25	0.55	1.60	0.40	0.36	0.56	0.60	0.21	0.06	0.06	0.32
FeO*		9.48	9.40	11.23	12.30	9.00	5.44	6.61	9.30	9.04	7.02	11.18	17.27	17.52	19.70	21.08
MnO		0.37	0.43	0.54	0.64	0.19	0.14	0.16	0.17	0.13	0.17	0.36	0.43	0.39	0.59	0.61
MgO		17.66	18.34	16.73	17.35	17.43	20.33	18.40	17.34	17.89	20.94	17.58	12.79	12.56	11.28	10.32
CaO		9.18	9.46	7.81	6.24	4.10	6.26	4.55	2.79	2.96	6.31	6.48	1.52	1.15	2.14	1.18
Na_2O		1.36	1.43	1.45	2.23	4.64	3.54	4.26	5.34	5.50	2.95	2.91	5.55	5.59	6.20	7.23
K_2O		0.75	0.72	1.48	1.79	5.00	4.76	4.40	3.90	4.04	4.04	4.14	3.70	3.86	3.31	1.97
Total		96.04	97.32	98.29	98.29	98.18	98.91	98.31	97.11	98.17	97.51	97.90	96.46	96.79	98.04	97.65
Cations based on 13 (T+C) ions and 23 atoms of oxygen																
Si	T	7.79	7.86	7.64	7.62	7.97	7.90	8.00	7.83	7.90	7.58	7.66	7.70	7.82	7.98	7.95
Al		0.21	0.12	0.36	0.12	0.03	0.09	-	0.07	0.07	0.08	0.10	0.04	-	0.01	0.05
Fe^{3+}		-	0.02	-	0.26	-	0.01	-	0.10	0.03	0.32	0.24	0.26	0.18	0.01	-
Al	C	0.08	-	0.09	-	0.01	-	0.27	-	-	-	-	-	-	-	-
Ti		0.03	0.04	0.09	0.17	0.18	0.13	0.10	0.29	0.20	0.12	0.10	0.28	0.24	0.04	0.08
Fe^{3+}		0.74	0.74	1.04	1.15	0.20	0.13	0.22	0.56	0.59	0.50	0.62	1.00	1.04	0.87	1.08
Fe^{2+}		0.38	0.33	0.25	-	0.87	0.50	0.55	0.44	0.44	0.00	0.47	0.85	0.91	1.54	1.50
Mn		0.04	0.05	0.07	0.07	0.03	0.02	0.02	0.02	0.02	0.02	0.04	0.05	0.05	0.07	0.08
Mg		3.74	3.83	3.46	3.59	3.70	4.22	3.85	3.69	3.76	4.38	3.77	2.82	2.76	2.47	2.26
Ca	B	1.39	1.41	1.20	0.92	0.63	0.94	0.68	0.43	0.45	0.95	0.47	0.24	0.91	0.34	0.19
Na		0.37	0.38	0.38	0.60	1.29	0.95	1.15	1.46	1.50	0.80	0.80	1.58	1.58	1.66	1.81
Na	A	-	-	-	-	-	-	-	-	-	-	-	-	-	0.11	0.25
K		0.14	0.13	0.26	0.31	0.91	0.85	0.79	0.72	0.71	0.72	0.75	0.69	0.72	0.62	0.37

* Total Fe expressed as FeO. Analysts: D. Ackermand and Z. Kotrba. Localities: samples 1 to 4 are from Markvartice, 5 and 6 from Šebkovice, 7, 8 and 9 from Kožichovice, 10 to 13 from Jarolden, and 14 and 15 from Karlstein.

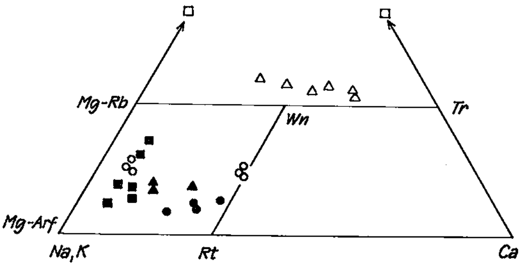

FIG. 3. Na,K–Ca–vacancies (atoms per formula unit) in the amphiboles studied. See Figure 2 for legend. Tr tremolite, Wn winchite, Rt richterite, Arf arfvedsonite, Rb riebeckite.

siderably without any pronounced relation to other components. Mg varies only slightly. The main variations are in alkalis, Ca, and Fe^{3+}. With increasing (Na+K), Ca drops and Fe^{3+} increases significantly (Fig. 5). This trend is consistent with a coupled $CaFe^{2+} \rightarrow NaFe^{3+}$ substitution, controlling the transition from tremolite–ferroan tremolite to ferrowinchite. The same substitution, characteristic of the transition from richterite–ferrorichterite to magnesio-arfvedsonite, is also known in alkali amphiboles richer in aluminium (Fabriès 1978).

Šebkovice

The dyke intersects paragneiss. Its geological setting is unknown, but the dyke is well traceable according to rock fragments for a distance of a few hundred meters. Judging from the relatively small number of fragments, the dyke is thin. The rock is a fine-grained alkaline microsyenite composed approximately of one-third amphibole and two-thirds microcline, with some scarce relict phlogopite, and abundant accessory apatite and the Ba–Ti silicate baotite (Němec 1987). Amphibole is felty to fibrous and displays a brown-violet to yellow-green pleochroism. It is a richterite. Its TiO_2 is mostly high, 1.2 - 1.8 wt.%, but is as low as 0.18 wt.%. Ti shows no relation to the other main components. The Al_2O_3 content is low, averaging 0.31 wt.%. This derives from the Al_2O_3 paucity of the rock (Table 1), which is also manifested, for instance, in the composition of the K-feldspar by an enhanced Fe_2O_3/Al_2O_3 substitution (up to 2.7 wt.% Fe_2O_3). The *A* site of the amphibole structure is highly occupied, which apparently is due to a high alkalinity of the rock (see the agpaicity index in Table 1). Ca varies considerably. Concomitantly with decreasing Ca, the Na/K value increases strongly by 0.08 per 0.1 Ca atom (Fig. 6). Similar relations are also observed in magnesio-arvedsonite in the alkaline minette of Pendennis (Hall 1982), in which the Na/K value increased still more drastically with dropping Ca (1.3 per 0.1 atom Ca; Fig. 7). Apparently, this is a common trend at the transition from more calcic to alkali-enriched types: Ca, vacating M_4 sites, provides a new location spatially suitable only for Na ions, but not for bigger K ions, which can enter in considerable amount only the *A* site (Table 2).

Kožichovice

The dyke intersects the coarse-grained granosyenite of Třebíč. It is steeply (70°) dipping and 0.5 m thick. Typically, it shows parallel structure. The rock is an alkaline minette, forming petrographically a link between normal minette and the alkaline dykes proper. It is porphyritic, having phlogopite (19.7 vol.%) and diopside (1.5 vol.%) phenocrysts in a very fine-grained groundmass consisting of 50.3 vol.% K-feldspar and 21.2 vol.% alkali amphibole. Apatite (3.5%) and titanite (3.8%) are abundant accessories. Amphibole is dispersed in the rock in minute needles and replaced phlogopite as dense felty reaction rims. The amphibole is

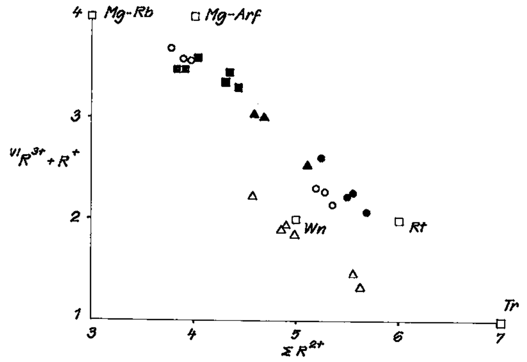

FIG. 4. R^{2+}- ($^{VI}R^{3+}+R^{+}$) plot (atoms per formula unit) in the amphiboles studied. See Figures 2 and 3 for legend.

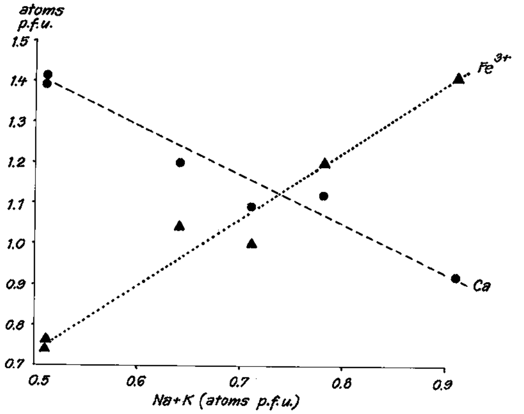

FIG. 5. Fe^{3+}, Ca, and alkalis (atoms per formula unit) in the amphiboles of Markvartice.

strongly pleochroic (violet-brown to light green). Chemically, it falls between richterite and magnesio-arfvedsonite. Some of the amphibole is rich in TiO_2.

Jarolden

The dyke strikes northwest-southeast through the gabbro-amphibolite of Waidhofen (Waldmann & Hackl 1940). Details of the geological setting are not known. The rock is fine grained. Its modal composition is as follows (vol.%): 55.3 microcline, 5.9 quartz, 34.0 amphibole, 4.7 titanite. Thus, it is a quartz-bearing alkaline microsyenite. Two generations of amphibole are present in the rock: the older is columnar, pale dirty green; it forms cores in the larger crystals. The late amphibole is more abundant, of a deeper color (pleochroism violet-brown to dark green), and forms rims of larger crystals and isolated needles. In zoned crystals the color zones are sharply bounded. The older amphibole is a richterite (Table 2, nos. 10, 11), with formula Ca close to stoichiometric. The younger amphibole is a magnesio-arfvedsonite - riebeckite (Table 2, nos. 12, 13). Compositions similar to the latter amphibole are known in nature (Giret *et al.* 1980) and have also been prepared synthetically (Ernst 1968). The co-occurrence of separate magnesio-arfvedsonite and riebeckite is an exception (Hall 1982), caused probably genetically, for instance, by sudden change of conditions of crystallization or vapor composition.

The sequence of a more calcic amphibole and a more alkaline amphibole observed in the rock, represents a common trend of crystallization of minerals in magma. Of special interest is the fact that, as in the Kožichovice dyke, the richterite is higher in Al_2O_3 and lower in TiO_2 than the coexisting arfvedsonite amphibole. The enhanced TiO_2 content of magnesio-arfvedsonite could be related to the Fe_2O_3 content, considerably higher in the latter than in the richterite.

Karlstein

The geological setting of the dyke is well known because of trenching (Thiele 1960). The dyke is steeply (80°) dipping, 40 - 50 cm thick and about 4 km long. It fills fissures in the Gföhl gneiss. The rock is fine grained, in some places showing fluidal structure. The quartz content varies so that in some places the rock may be designated as alkaline microgranite, and elsewhere as alkaline microsyenite. The SiO_2 content varies from 72 to 62 wt.%. The modal composition of the microgranite is (vol.%): 20.0 amphibole, 2.5 baotite, 77.5 light constituents (about two-thirds microcline and one-third quartz). The amphibole forms strongly pleochroic needles (pale violet to dark green). Chemically, it is a magnesio-arfvedsonite relatively rich in FeO_{total}, but with nearly stable MgO/FeO_{total} ratio. MnO is relatively high and almost constant (0.57 - 0.65 wt.%). In contrast, TiO_2 varies considerably (0.41 - 1.48 wt.%). Al_2O_3 is always low, mostly in a range of 0.06 - 0.16 wt.%.

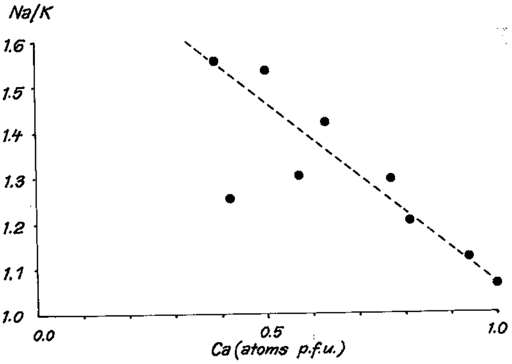

FIG. 6. Na/K ratio and Ca (atoms per formula unit) in the amphiboles from Šebkovice.

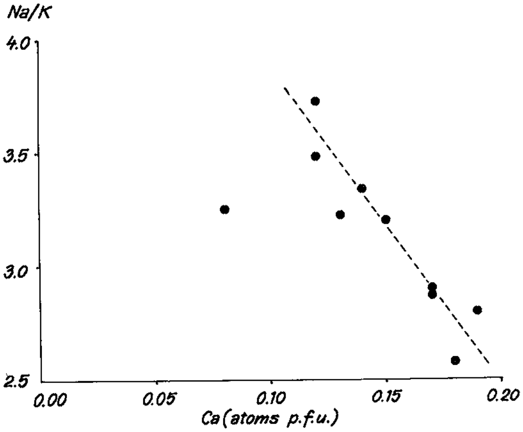

FIG. 7. Na/K ratio and Ca (atoms per formula unit) of arfvedsonite from the Pendennis minette (Hall 1982).

GENERAL CHARACTERISTICS OF THE AMPHIBOLES

The amphiboles of the studied rocks have the following features in common: high SiO_2 content (indeed, the Si value in the structural formula depends on the mode of recalculation; if it were done on the basis of 23 oxygens, the Si value would be higher than those of Table 2), low Al_2O_3, mostly considerable TiO_2 and high MgO/FeO_{total} ratios. The K_2O content is also considerable; with the exception of the amphibole of the microgranite, K constitutes 25 - 50% of total alkali content of the mineral. Yet K never increases over 1 atom per formula unit, attaining a maximum of 0.91 (Table 2, Fig. 2). Due to structural constraints K is evidently restricted to the *A* site (compare Huebner & Papike 1970, Fabriès 1978). All the samples examined have vacancies in the *A* site (Fig. 3), but these vacancies are lowest in the amphiboles of Šebkovice, derived from the rock with the highest agpaitic index.

All of the amphiboles are aluminium-poor, but divide distinctly into two different series (Figs. 3, 4), a tremolite - ferrowinchite series and a richterite - magnesio-arfvedsonite series, which evidently reflects the control by magma agpaicity. The amphiboles of the Markvartice dyke (agpaitic index 1.04) belong to the former series, and those with the agpaitic coefficients > 1.15 (Table 1) to the latter series. The sequence of amphiboles, characterized by gradual decrease in Ca with increasing alkalis, is visible not only in the entire rock suite, but also within the individual dykes. This sequence also is well known in the amphiboles of intrusive complexes (Fabriès 1978).

Practically all intermediate members between richterite and magnesio-arfvedsonite are present. Thus a complete solid-solution series may be suggested over the pressure range of crystallization. The co-occurrence of two amphiboles (richterite and alkali amphibole) observed in the dyke at Jarolden is known also from similar rocks at Plan d'Abart (Wagner & Velde 1985) and Smoky Butte (Velde 1975). Richterite invariably forms the core in the cited cases, and the alkali amphibole constitutes the rim of zoned crystals. Such an occurrence of two types of amphibole does not result from a miscibility gap, as amphiboles of intermediate composition do exist (Fig. 2). Not discussing the question from the structural point of view (*e.g.*, possible submicrocrystalline intergrowths), the cause of this phenomenon could perhaps be a sudden change of magma chemistry or *P*, *T* and fO_2 conditions during crystallization.

With the exception of the alkaline minette of Kožichovice, amphibole is, in all the other rocks examined, in practice the only constituent of strongly variable composition. Thus, in such petrographically simple rocks the amphibole reflects sensitively the bulk-rock chemistry (Němec 1973b). Only in the most evolved (siliceous) facies of the alkaline microgranite in the Karlstein locality was the content of Na and Fe^{3+} too high to be taken up by amphibole alone, and aegirine (Hackl & Waldmann 1935) appeared as an additional constituent.

In Figure 2 the amphibole compositions are plotted along with fields for amphiboles of other rocks, namely carbonatites (Samoilov & Gormasheva 1975), alkaline syenites and granites of Kerguelen (Giret *et al.* 1980; an example of an intrusion complex), kimberlites (Dawson & Smith 1977) and lamproites (Wagner & Velde 1986; however, lamproites comprise an insufficiently defined group of rocks). The amphiboles of Markvartice and of other similar slightly alkaline dykes of the region (Thures and Stařeč; both not discussed here) occupy a separate field, detached from those of the other amphiboles. The amphibole of the microganite of Karlstein is so Na-rich that is partly plots in the fields of amphiboles from Na-rich intrusive rocks and carbonatites. All the other samples examined belong to amphiboles particularly rich in K. They are even more potassic than amphibole of most lamproites, and are at the same level as the amphibole of kimberlites. Thus, they can be designated as potassian varieties, especially those of the Šebkovice dyke, whose K varies between 0.76 and 0.91 atoms per formula unit.

ACKNOWLEDGEMENTS

The author wishes to thank Dr. D. Ackermand and Ing. Z. Kotrba for microprobe analyses, Dr. P. Černý, University of Manitoba, for linguistic corrections of the manuscript, and Dr. D. Hogarth and other referees for many useful suggestions.

REFERENCES

AOKI, K.-I., FODOR, R.V., KEIL, K. & DOWTY, E. (1972): Tremolite with high richterite-molecule content in kimberlite from Buell Park, Arizona. *Amer. Mineral.* **57**, 1889-1893.

BACHINSKI, S.W. (1986): Reconsideration of 'soda-minettes'. *Mineral. Mag.* **50**, 199-204.

BROOKS, C.K. & GILL, R.C.O. (1982): Compositional variation in the pyroxenes and amphiboles of the Kangerdlungssuaq intrusion, East Greenland: further evidence for crustal contamination of the syenite magma. *Mineral. Mag.* **45**, 1-9.

DAWSON, J.B. (1980): *Kimberlites and Their Xenoliths.* Springer-Verlag, Berlin and New York.

———— & SMITH, J.W. (1977): The MARID (mica-amphibole-rutile-diopside) suite of xenoliths in kimberlite. *Geochim. Cosmochim. Acta* **41**, 309-323.

ERNST, W.G. (1968): *Amphiboles.* Springer-Verlag, Berlin and New York.

FABRIÈS, J. (1978): Les types paragénétiques des amphiboles sodiques dans les roches magmatiques. *Bull. Minéral.* **101**, 155-165.

GIRET, A., BONIN, B. & LEGER, J.-M. (1980): Amphibole compositional trends in silica-oversaturated and undersaturated alkaline plutonic ring-complexes. *Can. Mineral.* **18**, 481-495.

HACKL, O. & WALDMANN, L. (1935): Gesteine der

Kalireihe aus dem niederösterreichischen Waldviertel. *Jahrb. Geol. Bundesanst.* **85**, 259-285.

Hall, A. (1982): The Pendennis peralkaline minette. *Mineral. Mag.* **45**, 257-266.

Huebner, J.S. & Papike, J.J. (1970): Synthesis and crystal chemistry of sodium-potassium richterite $(Na,K)NaCaMg_5Si_8O_{22}\bullet(OH,F)_2$: a model for amphiboles. *Amer. Mineral.* **55**, 1973-1992.

Leake, B.E. (1978): Nomenclature of amphiboles. *Can. Mineral.* **16**, 501-520.

Němec, D. (1972): Ganggesteine aus der Umgebung von Raabs (Niederösterreichisches Waldviertel). *Verhandl. Geol. Bundesanst.* **1972**, 247-262.

______ (1973a): Richterit aus Alkalimikrosyenit von Stařeč bei Třebíč (Westmähren). *Časopis Mor. Musea* **58**, 53-56.

______ (1973b): Paragenetische Analyses der Ganggesteine der Minettengruppe. *Chem. Erde* **32**, 80-97.

______ (1975): Petrochemie und Genese der lamprophyrischen und lamproiden Ganggesteine im Nordteil der Böhmischen Masse. *Z. geol. Wiss.* **3**, 37-52.

______ (1978): Ganggesteine auf der Störung von Třebíč (als Beispiel einer an eine Tiefenstörung gebundenen Gangschar). *Z. geol. Wiss.* **6**, 1211-1217.

______ (1987): Baotite – a rock-forming mineral of Ba-rich hyperpotassic dike rocks *Neues Jahrb. Mineral. Monatsh.*, 31-42.

Samoilov, V.S. & Gormasheva, G.S. (1975): Alkali amphiboles of carbonatites and other genetically allied rocks. *Zap. Vses. Mineral. Obshch.* **104**, 145-159. (In Russian).

Thiele, O. (1960): Beitrag zur Kenntnis der Karlsteinite und Thuresite im niederösterreichischen Waldviertel. *Verhandl. Geol. Bundesanst.* **1960**, 283-284.

Velde, D. (1975): Armalcolite–Ti-phlogopite–diopside–analcite-bearing lamproites from Smoky Butte, Garfield County, Montana. *Amer. Mineral.* **60**, 566-573.

Wagner, C. & Velde, D. (1985): Mineralogy of two peralkaline, arfvedsonite-bearing minettes. A new occurrence of Zn-rich chromite. *Bull. Minéral.* **108**, 173-187.

______ & ______ (1986): The mineralogy of K-richterite-bearing lamproites. *Amer. Mineral.* **71**, 17-37.

Waldmann, L. & Hackl, O. (1940): Neue Analysen von kristallinen Gesteinen des Südrandes der Böhmischen Masse. *Mitt. Reichstelle F. Bodenforsch.* **1**, 237-239.

Waychunas, G.A. (1987): Synchrotron radiation XANES spectroscopy of Ti in minerals: effect on Ti bonding distances, Ti valence, and site geometry on absorption edge structure. *Amer. Mineral.* **72**, 89-101.

Received January 20, 1987; revised manuscript accepted June 25, 1987.