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### H3 RICHTERITE-ARFVEDSONITE-RIEBECKITE-ACTINOLITE ASSEMBLAGE FROM MARID DIKES ASSOCIATED WITH ULTRAPOTASSIC MAGMATIC ACTIVITY IN CENTRAL WEST GREENLAND

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#### Introduction

Dawson & Smith (1977) proposed that a mica-amphibole-rutile-ilmenite-diopside (MARID) suite of xenoliths in kimberlites were cumulates from a highly oxidized kimberlitic magma in the upper part of the mantle (above 100 km). This letter reports lamproite dikes with MARID-type mineralogy from central West Greenland believed to have been emplaced as a magma and crystallized in the upper crust at a depth of less than 10 km. Systematic Ti-zoning trend in the alkali amphiboles points to a low valence of titanium and consequently reducing crystallization conditions.

#### Regional setting

Alkalic plutonic activity in the Sisimiut (Holsteinborg) area of central West Greenland is well known (Scott 1979, 1981; Larsen 1980), including ultrapotassic micaceous lamproites (1227 m.y.) and micaceous kimberlitic dikes (587-500 m.y.). The regional distribution of the rocks from these two intrusive events is still poorly understood. However, kimberlitic dikes seem to be related to the Sarfartôq carbonatite complex (Larsen 1980) and to an area around Sisimiut (Scott 1981). Ultrapotassic lamproites are more widespread and may be related to a regional intrusive event, although the main reported occurrences are related to the Ikertôq and Ndr. Strømfjord shear zones (e.g. Scott 1981) within the Nagssugtoqidian mobile belt (Bak et al. 1975). A third type of ultrapotassic dikes containing high amounts of alkali amphiboles are reported here. Their regional distribution and age relation to the micaceous lamproites and kimberlites are unknown. The few recorded dikes are distributed over the same area as the kimberlites (e.g. Larsen 1980, p. 67).

#### Petrography of the amphibole lamproites

Large euhedral clinopyroxene macrocrysts occur showing partial resorption and neocrystallization to actinolite. Alkali amphiboles, phlogopite and K-feldspar are ubiquitous groundmass phases together with ilmenite, rutile, actinolite, apatite, quartz and carbonate. Subhedral to euhedral groundmass microphenocrysts of K-feldspar are often replaced by a fine-grained turbid mixture of secondary minerals. Alkali amphiboles are dominated by brown to yellow-green richterite which may be interstitially zoned toward either nearly opaque arfvedsonite or greenish bluish magnesio-arfvedsonite. A blue fibrous riebeckitic mineral occurs as a late crystallizing phase overgrowing zoned richterite. Rutile occurs as a discrete anhedral groundmass phase and as rims on subhedral to euhedral groundmass ilmenite.

#### Crystal chemistry of the alkali amphiboles

The amphibole chemistry is calculated according to the general formula  $A_{0-1}B_2C_5T_8O_{22}(OH)_2$ . Estimation of  $Fe^{3+}$  shows the main part of the amphiboles to contain excess cations for charge balance. In assigning cations to structural positions Ti is therefore assumed to fill the tetrahedral position. This scheme is consistent with chemical analyses of natural richterites (e.g. Prider 1939).

The dominant alkali amphibole is a potassium-titanian-richterite with the simplified formula (Table 1)  $K_{0.7}NaCa(Mg,Fe)_5(Si,Ti)_8O_{22}(OH)_2$ . Only limited Al substitution is observed, whereas Ti occupancy of tetrahedral sites is high. The B sites are occupied by equal amounts of Ca and Na, and the A sites are nearly filled ( $Na_A + K_A = 0.9$ ). The highest Mg/(Mg+Fe) ratio obtained is 0.8. Two important zoning trends have been detected and texturally related to a volumetrically minor interstitial crystallization.

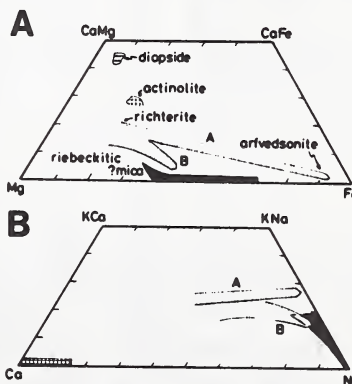


Figure 1. Ca-Mg-Fe (A) and K-Ca-Na (B) trends for alkali amphiboles from amphibole lamproites, central West Greenland. Two zoning trends are identified in the groundmass (A and B).

Zoning A (Fig. 1): Complete solid solution occurs between the richterite and the potassium-titanian-arfvedsonite (Table 1). The tetrahedral sites are nearly filled by Si while Ti occurs mostly as an octahedral coordinated cation in the Fe-rich amphiboles.

Within the zoned region, Mg/(Mg+Fe) ranges from 0.8 to zero. Ti increases from 0.5 to 0.8 formula units, whereas Al decreases from 0.2 to below the detection limit. Ca varies from 1 to 0 and shows a positive correlation with Na (1 to 2), while K remains constant or increases slightly (Fig. 1).

**Zoning B (Fig. 1):** A solid solution between richterite and a potassium-titanian magnesio-arfvedsonite also occurs (Table 1). The Mg/(Mg+Fe) ratio extends to only 0.60 and hence contrasts significantly from the Fe-enrichment of the arfvedsonites of trend A (Fig. 1). Tetrahedral sites are almost fully occupied by Si and Ti occurs only as octahedrally coordinated cations. Ti varies from 0.5 to 0.3 with decreasing Mg/(Mg+Fe). The Ca  $\rightleftharpoons$  Na substitution is identical to that of trend A. The main difference between the two trends is the degree of iron and titanium enrichments.

Some analyses show a significant decrease in K and, overgrowing the magnesio-arfvedsonite often occurs a fibrous riebeckitic mineral (Table 1). Calculated as a amphibole the mineral contains excess silica (Si=8.2-8.5). The analyses are best calculated as a mica with the general formula  $\text{Na}_2(\text{Fe,Mg})_5\text{Si}_8\text{O}_{20}(\text{OH})_4$  but, however, with a rather unusual composition for a mica.

**Cation substitution:** Estimation of  $\text{Fe}^{3+}$  from charge balance shows the Ti and Fe-rich amphiboles to contain excess cations. It is possible that excess Ti was incorporated in the structure at high temperature and then exsolved as rutile during cooling, now seen as a very fine pigmentation of the grain margins. When this 'excess' Ti is extracted from the calculations  $\text{Fe}^{3+}$  can still not be satisfactorily calculated. Another possibility is that Ti occurs with a lower valence than assumed or alternatively the amphibole contains excess oxygen. The latter possibility is, however, considered unlikely as no indication of a highly oxidized environment is seen from the other oxide and silicate groundmass phases. Calculating all Fe as  $\text{Fe}^{2+}$  and charge balance the formula with  $\text{Ti}^{3+}$ :

TABLE 1: Analysis and structural formula of richterite, arfvedsonite, actinolite and riebeckitic ?mica.

	1	2	3	4	5
SiO <sub>2</sub>	51.84	49.45	53.09	54.59	55.05
TiO <sub>2</sub>	4.26	6.92	2.72	0.06	1.83
Al <sub>2</sub> O <sub>3</sub>	1.22	0.08	0.38	0.25	0.24
Cr <sub>2</sub> O <sub>3</sub>	0.09	0.02	0.05	0.03	0.09
FeO	9.65	29.19	15.24	11.90	18.44
MnO	0.20	0.50	0.13	0.21	
MgO	16.05	0.67	12.44	16.83	10.78
CaO	6.32	0.16	1.88	11.86	
Na <sub>2</sub> O	4.17	6.81	6.37	0.31	6.32
K <sub>2</sub> O	3.64	3.35	3.08		0.39
Total	97.44	94.15	95.38	96.04	93.14
K <sub>A</sub>	0.68	0.68	0.59		0.07
Na <sub>A</sub>	0.17	0.14	0.16		
Na <sub>B</sub>	1.01	1.97	1.70	0.09	1.78
Ca <sub>B</sub>	0.99	0.03	0.30	1.85	
Fe <sub>C</sub>	1.18	3.89	1.92	1.45	2.24
Mn <sub>C</sub>	0.03	0.07	0.02	0.03	
Mg <sub>C</sub>	3.49	0.16	2.80	3.65	2.34
Ti <sub>C</sub>	0.14	0.74	0.31		0.20
Al <sub>C</sub>			0.07		0.04
Si <sub>T</sub>	7.56	7.89	8.00	7.95	8.01
Al <sub>T</sub>	0.21	0.02		0.04	
Ti <sub>T</sub>	0.33	0.09		0.01	
O	22	22	22	22	20
OH	2	2	2	2	4

1. Potassium-titanian-richterite. Core of zoned groundmass phase.
2. Potassium-titanian-arfvedsonite. Nearly opaque rim of zoned richterite.
3. Potassium-titanian-magnesio-arfvedsonite. Blue coloured rim of zoned richterite.
4. Actinolite. Groundmass phase.
5. Riebeckitic mineral calculated as a mica. Blue coloured fibrous phase overgrowing zoned richterite.

Ti<sup>4+</sup> give results indicating most titanian as Ti<sup>3+</sup>, and a positive correlation between Ti<sup>4+</sup> and total Ti. It is therefore considered most likely that the strong Ti-Fe trend in the alkali amphiboles record a reducing melt. In the Mg-rich amphiboles, however, minor Fe<sup>3+</sup> contents can be calculated, with all titanium as tetravalent, and increasing with total Fe. This indicates that the cation substitutions differ in the two observed zoning trends and can be related to variable redox conditions.

The main substitution observed in the Fe-enrichment trend (A) is a Ca  $\rightleftharpoons$  Na exchange in the B sites coupled with octahedral Mg  $\rightleftharpoons$  (Fe,Ti) and minor tetrahedral Al  $\rightleftharpoons$  Si substitution in order to obtain charge balance. The end-members in the cation substitution can be best written as  $\text{KCa}_2\text{Mg}_5\text{Si}_7\text{AlO}_{22}(\text{OH})_2$  and  $\text{KNa}_2\text{Fe}_4\text{TiSi}_8\text{O}_{22}(\text{OH})_2$ . The latter formula is only charge balanced if Ti occur as Ti<sup>3+</sup>.

For the magnesio-arfvedsonite trend (B) again a Ca  $\rightleftharpoons$  Na substitution in the B sites is the dominating exchange and most likely coupled with a Fe<sup>2+</sup>  $\rightleftharpoons$  Fe<sup>3+</sup> exchange. This gives a riebeckite end-member  $\text{Na}_2\text{Fe}_3^{2+}\text{Fe}_3^{3+}\text{Si}_8\text{O}_{22}(\text{OH})_2$ . This consideration neglect minor Al  $\rightleftharpoons$  Si and K  $\rightleftharpoons$  Na substitution. It is interesting that the latter occur as a late crystallizing phase.

#### Other minerals

Groundmass actinolite occurs with a Mg/(Mg+Fe) ratio between 0.8 and 0.7 and only minor amounts of other elements (Table 1). The clinopyroxene macrocrysts are diopside ( $\text{Wo}_{41}\text{Fs}_{58}\text{En}_{51}$ ). The Cr<sub>2</sub>O<sub>3</sub> content ranges from 0.1 to 2 wt%. The phlogopite groundmass phase shows little variation and is comparable to other analyses from ultrapotassic rocks. However, the TiO<sub>2</sub> content is significantly higher (7-10 wt%) and Cr<sub>2</sub>O<sub>3</sub> and Mg/(Mg+Fe) lower than in the phlogopites from MARID nodules from kimberlites (Dawson & Smith 1977). The oxide assemblage consist mainly of ilmenite with a low hematite content. The MnO content reaches 7 wt% and MgO is generally below the detection limit. These ilmenites contain the highest Mn content recorded from magmas of kimberlitic affinities (Vartiainen et al. 1978). Rutile contains also low Fe<sub>2</sub>O<sub>3</sub> and generally low Cr<sub>2</sub>O<sub>3</sub>. Apatite is a fluor-apatite and the flourine content of the mafic minerals are generally low.

#### Conditions of crystallization

The total pressure during solidification can be estimated as not exceeding 3 kbar (Bak et al 1975). Total vapour pressure was most likely equal to load pressure to account for abundant crystallization of hydrous minerals. Crystallization of clinopyroxene and phlogopite occurs in ultrapotassic magmas around 1100-900°C (e.g. Edgar et al 1976). Final consolidation must have occurred at very low temperature (quartz and K-feldspar).

Several lines of evidence suggest that oxygen fugacity was low in the original magma. Low Fe<sub>2</sub>O<sub>3</sub>/FeO in the bulk rock (0.25), low hematite in ilmenite and systematically low Ti<sup>4+</sup> and Fe<sup>3+</sup> calculated in the amphiboles are the main reasons. Crystallization of richterite also requires low f<sub>O<sub>2</sub></sub> and temperature (Ernst 1968; Charles 1975). However, the high Mn in ilmenite seems to contradict this conclusion.

A tentative model can be outlined: a low f<sub>O<sub>2</sub></sub> trend from richterite, arfvedsonite to actinolite (trend A in Fig. 1), and a high f<sub>O<sub>2</sub></sub> trend (B in Fig. 1) from richterite, magnesio-arfvedsonite towards a riebeckitic mineral. The main difference could relate to local elevation in oxygen fugacity in the interstitial melt-fluid system.

#### Implication for the origin of MARID nodules

Dawson & Smith (1977) described a MARID suite of xenoliths (or glimmerites) in kimberlites. They suggested that part of these were cumulates from a highly oxidized kimberlitic magma. It is clear from the present work that their conclusion need revision. The mineralogical similarities between the present dikes

and MARID xenoliths suggest that the latter are either fragments or cumulates from, compared to a kimberlite, a very distinct non-oxidized magma type. Differences in minor elements in most minerals, as well as modal constituents, may reflect that the studied dikes represent a slightly more evolved composition than that from which MARID xenoliths are either fragments or cumulates. K-feldspar in the groundmass is the main difference between MARID nodules and the West Greenland lamproites.

L. M. Larsen reviewed the manuscript.

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## H4 TRIASSIC POTASSIUM-RICH BASALTS AND COEXISTING CARBONATE MELTS IN THE ECRINS-PELVoux AREA, FRENCH ALPS.

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Throughout the Ecrins-Pelvoux area, an explosive and effusive volcanism is essentially represented by series of sheets with a consistent stratigraphic position. Upper triassic to lower Jurassic sedimentary rocks interlayered with the volcanic sequence suggest a rifted passive continental margin. The pre-rift sedimentary sequence (argillites, black shales and dolomitic limestones) represents an upward transition from supratidal to intertidal deposits (Baron, 1981).

Numerous doleritic dikes up to several meters in thickness injected into the metamorphic basement (partly Hercynian in age) are the feeders of the overlying volcanic sequence. The mineralogical relationships and field evidence have established that the cogenetic dikes and lava flows derived from a single source. Doleritic volcanic rocks including dikes, rare sills, massive flows, tuffs and volcanic breccias are generally porphyritic, showing a change in texture from fine- to coarse-grained. The original basaltic paragenesis, based upon relict minerals (with the exception of rare fresh olivine), is alkaline in composition and have been subjected to low-grade regional metamorphism (greenschist facies; Adline, 1982).

The alkali basalts may be divided into two quite separate groups on the basis of their REE contents (fig.1): (1) alkali basalts (Na series) show a small light-REE enrichment, lesser heavy-REE depletions and positive Eu anomalies; (2) potassium-rich basalts (K series) - 8 to 10 % of  $K_2O$  and less than 45 %  $SiO_2$  - uniformly have high REE contents, are strongly LREE enriched, and have a small but distinct negative Eu anomaly. However, the difference in Eu anomalies between the two basaltic sequences can be accounted for by feldspar fractionation producing a small Eu depletion in the potassium-rich basalts. Accordingly, compared to ordinary alkali basalts (Frey, 1968), the Na sequence has a low, and the K sequence a high content of REE. The potassium-rich basalts cannot be clearly related to an effect of hydrothermal alteration or greenschist metamorphism.

These rocks present a close carbonate-basalt association in space and time: carbonate occurs as pseudomorphs after plagioclase, peridot and clinopyroxene, as amygdules and smaller blebs dispersed throughout the matrix and also as veins in the rocks. Secondary carbonates fill almost all available gas bubbles and extensive fissures and appear generally in various basaltic fragments with abundant interbedded triassic sediments.

Possibilities of complex interactions between

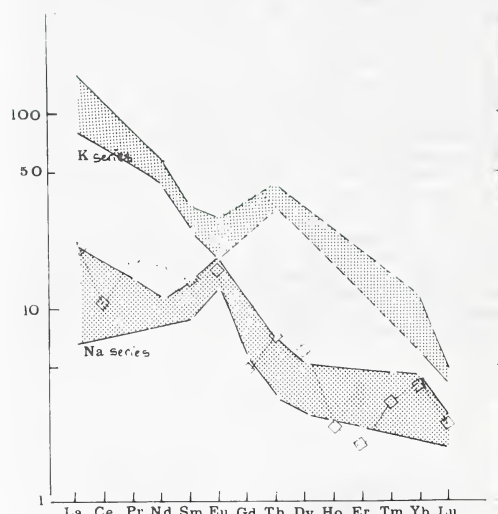


Fig. 1. Chondrite-normalized REE patterns for K series (9 potassium-rich basalts) and Na series (4 alkali basalts similar to hawaiites); the single line is a semi-quantitative determination.

the basaltic magma and the carbonate phase cannot be ruled out; the origin of the carbonate may result from a mechanism of magmatic separation during cooling

Volcanic pipe and associated dikes are confined to the area of the metamorphic basement and are genetically connected with the lava flows but no contact between these rocks has been found. A North-South volcanic pipe, more than 100 m thick, is essentially filled with polygenic breccias intruded by potassium-rich lavas. To the west a dike, 1-2 m thick and 1 km-long, locally exhibits a 10 cm thick margin with small-scale brecciation of the doleritic lava and a carbonate matrix. To the east an alkaline dike, 6 m thick, shows a doleritic texture with carbonate dissemination in the matrix and peridotite xenoliths now altered through complete carbonatation.

No traces of carbonatation could be observed in the gneisses intruded by pipe and dikes and the envi-