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Na and K distribution in agpaitic pegmatites☆

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Abstract

Composition and zoning of amphibole in agpaitic pegmatites of the 1.16 Ga Ilímaussaq complex, South Greenland record the chemical evolution of the final stages of an already extremely fractionated melt. Our results show that the general differentiation trends found in the earlier rocks of the complex are continued in the pegmatites, albeit with some significant modifications: the dominating exchange mechanism of Na + Si ⇔ Ca + Al in the amphiboles of the magmatic stage changes to K + Si ⇔ Ca + Al and K ⇔ Na in some pegmatitic samples. Na/K ratios in amphiboles, which generally increase in the course of the Ilímaussaq fractionation, partly display a reversal during the crystallization of the most differentiated amphiboles.

The alkali trends are probably related to the buffering of $Na^+$and K^+activity by the co-crystallization of albite and microcline. This buffering favors Na^+in cooling fluids. This mechanism is lost when analcime replaces feldspar as a stable phase in the late stages of crystallization, e.g. due to locally elevated H_2O activity. Analcime does not incorporate significant amounts of K and accordingly, amphibole incorporates more K in analcime-bearing assemblages. The Na–K variation in amphiboles in the Ilímaussaq pegmatites allow a detailed view into the late-stage evolutionary trends of a textbook agpaitic complex. The transition from silicate melt to aqueous fluid is recorded by the change of the dominant alkali ion in the pegmatitic amphiboles from Na to K.

Only in the very latest stage, virtually K-free mineral assemblages in analcime–aegirine veins support the existence of a Na-dominated aqueous fluid.

Keywords: Agpaitic; Pegmatites; Na–K–feldspar buffer; Amphibole; Analcime

1. Introduction

The alkaline to agpaitic Ilímaussaq intrusion has been the subject of studies since the beginning of the 19th century. It is a world famous mineral locality and the type locality for agpaitic rocks, which are peralkaline nepheline syenites containing complex Ti–Zr silicates (Ussing, 1912; Sørensen, 1997). As Ilímaussaq is very well studied, it serves as a type example for differentiation processes in peralkaline magmas (e.g., Larsen and Sørensen, 1987; Markl et al., 2001). Agpaitic rocks are thought to be derived from highly fractionated alkali basaltic or nephelinitic melts (Sørensen, 1997) and volatiles are regarded as a major factor influencing the evolution of peralkaline magmas (e.g., Kogarko, 1974; Finch et al., 1995; Markl, 2001). In Ilímaussaq, late-stage fractionation led to decreasing SiO_2 activities, and rising activities of H_2O. Oxygen fugacity, which is buffered through co-crystallization of arfvedsonite, aenigmatite and aegirine, rose from values below

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☆ Contribution to the mineralogy of Ilímaussaq No. 133.

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FMQ to values close to the magnetite–haematite buffer (Markl et al., 2001). The ratios of Mg/Fe, Ca/(Na+K) and K/Na decline to almost zero during differentiation, both in mineral and whole-rock analyses (Larsen, 1976; Bailey et al., 2001; Markl et al., 2001).

Late fluids in alkaline to peralkaline intrusions are highly enriched in alkalis and incompatible elements, cause extensive fenitization and are important for the generation of some economic mineral deposits (Sørensen, 1992). Therefore, understanding the transition from late-magmatic to hydrothermal processes in peralkaline intrusions is of special interest.

Agpaitic pegmatites represent some of the most fractionated rock types of the Ilímaussaq intrusion and are especially suited to study this transition. Ilímaussaq contains a great number of them, from thick layers along the boundaries of different rock types to small lenses enclosed in the host rock. Although some have been petrographically described (e.g., Sørensen, 1962; Bohse et al., 1971), their detailed compositional evolution has not previously been studied in detail. Therefore, examination of the pegmatites sheds light on the differentiation processes in the last stages of the evolution of agpaitic melts, especially with regard to the alkalis Na and K. As the composition of the felsic minerals does not vary significantly in the pegmatites, we focus here on the chemical evolution of amphibole that record differentiation processes during their growth (e.g., Larsen, 1976; Markl et al., 2001; Marks et al., 2004).

2. Geological setting

During the Mid-Proterozoic, the Gardar Province was a zone of rifting during the break-up of Palaeopangaea (Emeleus and Upton, 1976). A trans-Laurentian rifting event is also recorded by mafic magmatism in North America (Mackenzie Igneous event, Keweenawan and Coppermine flood basalts) and in the Baltic shield (Upton et al., 2003). The Gardar province is believed to be a branch of this large rift system, similar in type to the East African rift system (Paslick et al., 1993). The magmatism associated with this failed rift probably follows older Ketilidian (Early-Proterozoic) structures (Upton et al., 2003).

The ten major alkaline intrusions of the Gardar province are composed predominantly of alkaline rocks and can be divided into two groups: the silica-oversaturated and the silica-deficient ones. As an exception, the Ilímaussaq intrusion contains both over- and under-saturated rocks. The complex measures some

Table 1
Petrography of investigated pegmatite samples

Sample	Pegmatite type/host rock	First liquidus phases	Main crystallization stage	Interstitial phases	Alteration products
ILM 102a	Kakortokite	Eud	Cpx[a]+Fsp	Aeg	Ntr+Ms
XL 1	Segregation pegmatite kakortokite – augite syenite	Sod+Ne+Eud	Cpx[a]+Arf[b]+Fsp		Arf+Aeg+Fl+Anl+Ntr+Cat
XL 2	Segregation pegmatite kakortokite – augite syenite	Sod+Eud	Arf+Mic	Fl+Cpx[a]+Rnk	Aeg+Anl+Cat
XL 18	Segregation pegmatite kakortokite – naujaite	Sod	Cpx[a]+Fsp+Arf	Fl+Anl	Aeg+Anl+Ntr+Zr+Chl+He
XL 30	Segregation pegmatite kakortokite – naujaite	Fl	Arf+Fsp	Ab+Cpx[a]	Aeg+He+Ilm+Bt
XL 64	Segregation pegmatite kakortokite – naujaite	Sod+Eud+Ne	Mic+Arf+Cpx[a]+Mnz		Aeg+Anl+Bt+Cat+He+Ast
ILM 137	Border pegmatite	Sod+Ne+Eud+Fl	Arf+Cpx[a]+Fsp		Aeg+Anl+Ntr+Cat+Zr
ILM 19	Naujaite	Eud	Arf+Cpx[a]+Fsp	Ab+Rnk+Anl	Aeg+Ntr+Bt+Zr+Fl
ILM 21	Naujaite	Ne+Sod	Arf+Fsp+Cpx[a]+Aen	Ab	Anl+Bt
ILM 51	Naujaite	Ne+Eud+Gal+Sph	Arf[b]+Cpx[a]+Fsp+Aen	Anl	Aeg+Mnz+Ntr
ILM 70a	Naujaite in lujavrite		Arf[b]+Anl	Bt+Zr+Sph	Aeg+Chl
GM 1390	Lujavrite		Arf[b]+Mic+Anl	Zr	Aeg

Ab = albite; Aeg = aegirine; Anl = analcime; Arf = arfvedsonite; Ast = astrophyllite; Bt = biotite; Cat = catapleite; Chl = chlorite; Cpx = clinopyroxene; Eud = eudialyte; Fl = fluorite; Fsp = feldspar; Gal = galena; He = hematite; Ilm = ilmenite; Mic = microcline; Mnz = monazite; Ms = muscovite; Ne = nepheline; Ntr = natrolite; Rnk = rinkite; Sod = sodalite; Sph = sphalerite; Zr = zircon.

[a] Cpx in this stage contains more augite-component than the Aeg of the next stage, although it is still also aegirine.

[b] Arf in this sample exhibits the K-enrichment trend discussed in the text.