Subsilicic magnesian potassium-hastingsite from the Prince Olav Coast, East Antarctica

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Abstract

Two subsilicic magnesian potassium-hastingsites (4.55 and 4.34 wt.% K_2O) and one magnesian potassium-hastingsite occur in calc-silicate pods in well-layered gneisses from the transitional amphibolite- and granulite-facies terrain of a Cambrian metamorphic complex, East Antarctica. Subsilicic magnesian potassium-hastingsite is the most K-rich Ca-amphibole yet reported:

$$(K_{0.85}Na_{0.11}Ca_{0.02})_{0.98}(Ca_{1.98}Mn_{0.02})_{2.00}(Mn_{0.01}Mg_{1.92}Fe^{2+}_{1.20}Fe^{3+}_{1.11}Ti_{0.13}Al_{0.64})_{5.0}\text{-}(Si_{5.64}Al_{2.36})_8O_{22.48}(OH,F,Cl)_{1.52}.$$

KEYWORDS: subsilicic magnesian potassium-hastingsite, amphibole, East Antarctica

Introduction

THE Prince Olav Coast (68.5°S, 40–44.5°E) is in the eastern part of the Cambrian Lützow-Holm Complex (Hiroi *et al.*, 1983; Shiraishi *et al.*, 1987; Hiroi *et al.*, 1991, Shiraishi *et al.*, 1994). The Lützow-Holm Complex is composed of a series of pelitic to psammitic and volcanogeneous well-layered gneisses with minor granodioritic migmatite. The Complex is subdivided into three zones: upper amphibolite-facies, a transitional zone, and granulite-facies from east to southwest (Hiroi *et al.*, 1987; 1991). $P-T$ conditions of the transitional zone are estimated to be 780°C and 0.7 GPa on the basis of various geothermo-barometers (Shiraishi, 1986).

In this paper, we describe the occurrence, petrography and composition of K-rich Ca-amphiboles from calc-silicate pods in granulites from the transitional zone between amphibolite- and granulite-facies.

Mode of occurrence and petrography

Two samples were collected from Cape Omega and Daruma Rock, about 10 km from one another, in the Prince Olav Coast (Suzuki and Moriwaki, 1979; Shiraishi *et al.*, 1989).

Sample 77010721 (abbreviated to 721) from Cape Omega is a spindle-shaped calc-silicate pod, 70 cm long and enclosed in well-layered hornblende gneiss and biotite gneiss. The gneisses

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TABLE 1. Chemical compositions of amphiboles

Sample no.-domain	77010721-3		77010721-1	80D10-3
Mineral	SMPH		MPH	SMPH
SiO_2	36.84		39.43	36.58
TiO_2	1.10		1.03	1.65
Al_2O_3	16.61		14.31	16.12
Cr_2O_3	0.02		0.02	0.01
Fe_2O_3	9.66		9.88	
FeO	9.35		8.38	17.92
MnO	0.21		0.45	0.17
MgO	8.40		9.02	7.97
CaO	12.21		12.23	12.31
Na_2O	0.37		0.96	0.20
K_2O	4.34		3.07	4.55
H_2O^+	1.08			
H_2O^-	0.28			
F	0.24		0.20	0.23
Cl	0.14		0.10	0.03
O≡F,Cl	−0.13		−0.11	−0.11
Total	100.72		98.97	97.63
	Atomic formulae			
	(1)	(2)	(1)	(3)
Si	5.561	5.639	5.900	5.663
Al^{IV}	2.439	2.361	2.100	2.337
T	8.000	8.000	8.000	8.000
Al^{VI}	0.516	0.635	0.424	0.606
Cr	0.002	0.002	0.002	0.001
Ti	0.125	0.127	0.116	0.192
Fe^{3+}	1.097	1.113	1.112	0.341
Mg	1.890	1.917	2.012	1.839
Fe^{2+}	1.180	1.197	1.049	1.979
Mn	0.027	0.008	0.057	0.022
M1,2,3	4.837	5.000	4.772	4.980
Mn	–	0.019	–	–
Ca	1.975	1.981	1.961	2.000
Na	0.025	–	0.039	–
M4	2.000	2.000	2.000	2.000
Ca	–	0.022	–	–
Na	0.083	0.109	0.240	0.060
K	0.836	0.847	0.586	0.899
A	0.919	0.978	0.826	0.959
Total	15.756	15.978	15.598	15.939
O	22	22.48	22	22
OH	2	1.36	2	2
F	–	0.12	–	–
Cl	–	0.04	–	–
	Cell dimensions			
a Å	10.007(3)		9.941(4)	10.002(3)
b Å	18.107(5)		18.110(8)	18.112(7)
c Å	5.368(5)		5.337(3)	5.356(4)
β°	105.66(5)		105.25(5)	105.54(4)

*total Fe as FeO; MPH: Magnesian potassium-hastingsite;
SMPH: Subsilicic magnesian potassium-hastingsite
(1) 23 oxygen calculation; (2): 24(O,OH,F,Cl) oxygen calculation; (3): Recalculated after Spear and Kimball (1984)

are permeated by pinkish granitic material, resulting in a migmatitic structure. The gneiss that is adjacent to the calc-silicate pod contains magnesian potassium-hastingsite, clinopyroxene (Cpx), plagioclase (An_{94-96}) (Pl), magnetite (Mag), and apatite (Ap) with granoblastic texture (Fig. 1*a*). The outermost layer (up to 0.5 cm) of the calc-silicate pod is composed of clinopyroxene, plagioclase (An_{95-97}), magnetite and titanite (Ttn) with secondary muscovite and epidote. The interior part of the calc-silicate pod is dominantly garnet (Grt) which occurs as symplectic intergrowths with plagioclase (An_{98-99}) and subordinate aluminian clinopyroxene, subsilicic magnesian potassium-hastingsite, magnetite and apatite. The Ca-amphibole and clinopyroxene tend to form dark vein-like patches in this domain. Secondary epidote occurs as anhedral grains replacing garnet and plagioclase in the symplectite and forms a mantle around garnet and clinopyroxene adjacent to plagioclase in some cases. Plagioclase and garnet are partly replaced by chlorite, muscovite, calcite and scapolite (Me_{98}).

Sample 80D10 (abbreviated to D10) from Daruma Rock is a 10 cm long calc-silicate pod in migmatitic hornblende-biotite gneiss. This sample has a granoblastic texture and appears heterogeneous (Fig. 1*b*). It can be divided into the following domains consisting of different mineral assemblages:

Domain D10-1: Cpx, Pl(An_{51-53}), Kfs, Scp(Me_{77-78}), Mag, Ttn

D10-2: Cpx, Pl(An_{84-89}), Scp(Me_{80-83}), Mag, Ttn

D10-3: Ca-amph, Grt, Cpx, Pl(An_{94-99}), Mag, Ttn, Hem, Ap

More than a half of the pod is made of D10-3. Subsilicic magnesian potassium-hastingsite with or without clinopyroxene forms thin veinlets and pools in the dominant garnet and plagioclase aggregate of Dl0-3.

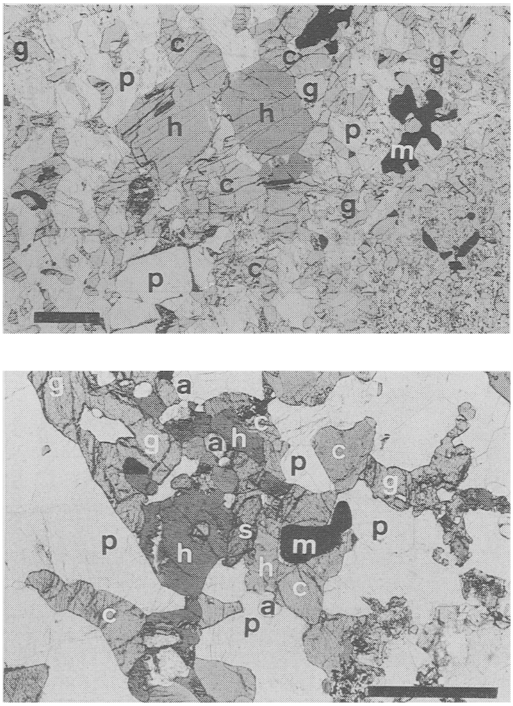

FIG. 1. Photomicrographs of subsilicic magnesian potassium-hastingsites: (*a* top) 77010721. Note the symplectic intergrowth of garnet, epidote and plagioclase in the lower-right corner; (*b* bottom) 80D10; h: subsilicic magnesian potassium-hastingsite; a: apatite; c: clinopyroxene; g: garnet; m: magnetite; p: plagioclase; s: titanite. Scale bars are 0.5 mm.

Ca-amphiboles

The amphibole is pleochroic in grayish green to light yellowish green. Chemical composition was determined with the JXA-733 Superprobe; data were processed by the Bence-Albee method, and with the JXA-8800 Superprobe at JEOL Co. Ltd, where data were processed by the ZAF correction method. Fe^{2+} contents of two amphiboles (in domains 721-1 and 721-3) were analysed by the $K_2Cr_2O_7$ titration method. The two analyses show higher Fe^{3+} contents than those calculated using the RECAMP program (Spear and Kimball, 1984). H_2O was estimated from loss of ignition extracted Cl and F contents.

Representative analyses with atomic formulae show the amphiboles to be magnesian potassium-hastingsite, and subsilicic magnesian potassium-hastingsites (Table 1). Individual amphibole grains show no detectable compositional zoning.

Unit-cell parameters were obtained from ten reflections (131, 240, 310, 221, 330, 151, 061, $\bar{2}02$, 350, 261) recorded on an X-ray diffractometer (Table 1).

Associated minerals

Representative compositions of associated minerals are given in Tables 2 and 3. K-feldspar occurs in the margin of sample D10 (D10-1). Apart from the amphibole, there is no K-rich mineral in sample 721. Pinkish-orange garnet shows no detectable compositional zoning.

TABLE 2. Representative microprobe analyses and mineral formulae of associated minerals in 77010721

Mineral	Garnet		Clinopyroxene						Plagioclase			Epidote	Scapolite
Domain	721-3	721-1	721-2	721-3	721-1	721-2	721-3	721-3	721-3				
Position	core	rim	core	rim	core	rim	core	rim					
SiO_2	36.97	37.19	47.68	49.11	44.29	45.15	40.44	40.46	43.84	43.65	42.81	37.73	42.98
TiO_2	0.81	0.67	0.56	0.57	0.74	0.61	1.28	1.43	0	0.03	tr.	0.28	tr.
Al_2O_3	13.28	13.03	5.25	3.06	6.79	5.61	11.59	11.67	35.33	35.63	36.19	24.88	24.03
Cr_2O_3	0.02	0.04	0	0.05	0.05	0.13	0.02	0.03	0	0.05	tr.	0	0
$Fe_2O_3^{*}$	17.09	17.38	11.95	10.48	17.73	17.29	14.61	14.14	–	–	–	10.57	–
FeO^{**}	–	–	–	–	–	–	–	–	0.21	0.33	0.12	–	0.43
MnO	0.64	0.72	0.50	0.54	0.51	0.60	0.20	0.16	0.06	0.03	0	0.05	tr.
MgO	0.62	0.57	10.78	11.58	6.87	7.09	7.73	7.66	0	0	tr.	0.06	0
CaO	30.80	30.90	23.41	23.71	22.87	22.95	23.88	23.75	19.03	19.81	19.98	23.60	26.99
Na_2O			0.35	0.40	0.34	0.34	0.20	0.26	0.66	0.50	0.11	tr.	0.12
K_2O			0	0	0	0	0	0	tr.	tr.	0.03	0	0
Total	100.23	100.50	100.48	99.50	100.19	99.77	99.95	99.56	99.13	100.03	99.24	97.17	94.55
	O = 12	O = 12	O = 6	O = 6	O = 6	O = 6	O = 6	O = 6	O = 8	O = 8	O = 8	O = 25	Si + Al = 12
	R = 8	R = 8	R = 4	R = 4	R = 4	R = 4	R = 4	R = 4					
Si	2.940	2.953	1.807	1.871	1.736	1.776	1.599	1.564	2.046	2.025	2.000	5.999	7.233
Al^{IV}	0.060	0.047	0.193	0.129	0.264	0.224	0.441	0.436	0	0	0		
Al^{VI}	1.186	1.173	0.041	0.009	0.049	0.037	0.086	0.096	1.944	1.948	1.993		
Al												4.662	4.767
Ti	0.048	0.040	0.016	0.016	0.022	0.018	0.037	0.042	0	0.001	0	0.033	0.004
Cr	0.001	0.003	0	0.002	0.002	0.004	0.001	0.001	0	0.002	0	0	0
Fe^{3+}	0.776	0.791	0.148	0.115	0.195	0.173	0.295	0.275				1.265	
Fe^{2+}	0.247	0.248	0.193	0.185	0.327	0.339	0.129	0.136	0.008	0.013	0.005		0.060
Mn	0.043	0.048	0.016	0.017	0.017	0.020	0.007	0.005	0.002	0.001	0	0.007	0.010
Mg	0.073	0.067	0.609	0.658	0.401	0.416	0.444	0.441	0	0	0	0.014	0
Ca	2.625	2.629	0.950	0.968	0.960	0.968	0.987	0.984	0.952	0.985	1.000	4.020	4.866
Na			0.026	0.030	0.026	0.026	0.015	0.019	0.060	0.045	0.010	0.006	0.039
K			0.001	0	0	0	0	0	0	0	0.002	0	0
$Fe^{2+}/(Fe^{2+}+Mg)$	0.771	0.786	0.241	0.220	0.449	0.449	0.225	0.236	An94	An96	An99		Me99
$Fe^{3+}/(Fe^{3+}+Al)$												0.213	
$Fe^{3+}/(Fe^{2+}+Fe^{3+})$	0.758	0.761	0.433	0.383	0.374	0.337	0.695	0.668					

$Fe_2O_3^{*}$: Total Fe as Fe_2O_3, FeO^{**}: Total Fe as FeO

TABLE 3. Representative microprobe analyses and mineral formula of associated minerals in 80D10

Mineral	Garnet		Clinopyroxene						Scapolite				Plagioclase			K-feldspar
Domain	D10-3	D10-1	D10-2		D10-3		D10-1		D10-2		D10-1		D10-2	D10-3		D10-1
Position	core	rim	core	rim	core	rim	core	rim	core	rim	core	rim	core	core	rim	core
SiO_2	36.67	37.04	45.91	47.15	46.60	45.63	41.68	42.00	44.62	42.84	43.74	43.48	53.22	46.14	42.71	64.46
TiO_2	0.59	0.79	0.28	0.19	0.44	0.22	1.15	1.10	0	0	0	0.03	0.02	0	0.02	0
Al_2O_3	14.43	12.87	3.53	2.54	4.12	4.09	9.28	8.89	26.41	27.40	27.85	28.69	27.98	33.46	35.97	18.44
Cr_2O_3	0	0.10	0	0	tr.	tr.	0	0.05	0	0	0.06	0.02	0	0	0.05	tr.
$Fe_2O_3^*$	17.14	17.88	23.09	22.38	22.54	23.14	18.04	17.78	–	–	–	–	–	–	–	–
FeO^{**}	–	–	–	–	–	–	–	–	0.32	0.32	0.37	0.44	0.29	0.35	0.41	0.05
MnO	0.81	0.67	0.51	0.54	0.52	0.46	0.18	0.11	0.04	0.08	0	0.08	0	0	0.06	0.13
MgO	0.61	0.52	5.23	5.26	5.18	5.11	6.64	6.69	0	0.02	0.04	0.06	tr.	tr.	tr.	0
CaO	30.72	31.04	22.70	21.81	22.21	22.84	23.29	23.50	18.05	18.66	20.05	20.07	11.04	17.49	19.70	0.05
Na_2O			0.57	0.58	0.56	0.55	0.22	0.30	3.01	3.02	2.52	2.28	5.50	1.72	0.26	0.73
K_2O			tr.	0	0	0	0	0	0.13	0.11	0.15	0.10	0.19	0.04	0	14.67
Total	100.97	100.91	101.82	100.45	102.17	102.64	100.48	100.42	92.58	92.45	94.78	95.19	98.24	99.20	99.18	98.53
	O=12	O=12	O=6	O=6	O=6	O=6	O=6	O=6	Si+Al=12	Si+Al=12	Si+Al=12	Si+Al=12	O=8	O=8	O=8	O=8
	R=8	R=8	R=4	R=4	R=4	R=4	R=4	R=4								
Si	2.889	2.935	1.813	1.887	1.831	1.797	1.627	1.638	7.070	6.842	6.855	6.750	2.455	2.144	2.000	3.002
Al^{IV}	0.111	0.065	0.187	0.113	0.169	0.203	0.373	0.362								
Al^{VI}	1.230	1.138	0	0.007	0.022	0	0.054	0.047								
Al									4.930	5.158	5.145	5.250	1.521	1.832	1.985	1.012
Ti	0.035	0.047	0.008	0.006	0.013	0.007	0.034	0.032	0	0	0	0.004	0.001	0	0.001	0
Cr	0	0.006	0	0	0	0	0	0.002	0	0	0.007	0.002	0	0	0.002	0
Fe^{3+}	0.811	0.826	0.238	0.138	0.163	0.245	0.269	0.272								
Fe^{2+}	0.205	0.240	0.449	0.536	0.503	0.440	0.261	0.250	0.042	0.043	0.048	0.058	0.011	0.013	0.016	0.002
Mn	0.054	0.045	0.017	0.018	0.017	0.015	0.006	0.004	0.006	0.010	0	0.011	0	0	0.002	0.005
Mg	0.072	0.061	0.308	0.314	0.303	0.300	0.386	0.389	0	0.005	0.009	0.005	0.001	0.001	0.001	0
Ca	2.594	2.636	0.960	0.936	0.935	0.964	0.974	0.982	3.064	3.194	3.366	3.338	0.545	0.871	0.988	0.003
Na			0.044	0.045	0.043	0.042	0.017	0.023	0.924	0.936	0.765	0.688	0.492	0.115	0.024	0.065
K			0	0	0	0	0	0	0.027	0.022	0.029	0.019	0.011	0.002	0	0.871
$Fe^{2+}/(Fe^{2+}+Mg)$	0.741	0.796	0.593	0.631	0.624	0.595	0.403	0.392	Me77	Me77	Me81	Me83	An52	An85	An98	
$Fe^{3+}/(Fe^{2+}+Fe^{3+})$	0.798	0.775	0.346	0.206	0.245	0.358	0.507	0.520					Ab47	Ab15	Ab 2	Ab 7
													Or 1			Or93

$Fe_2O_3^*$: Total Fe as Fe_2O_3, FeO^{**}: Total Fe as FeO

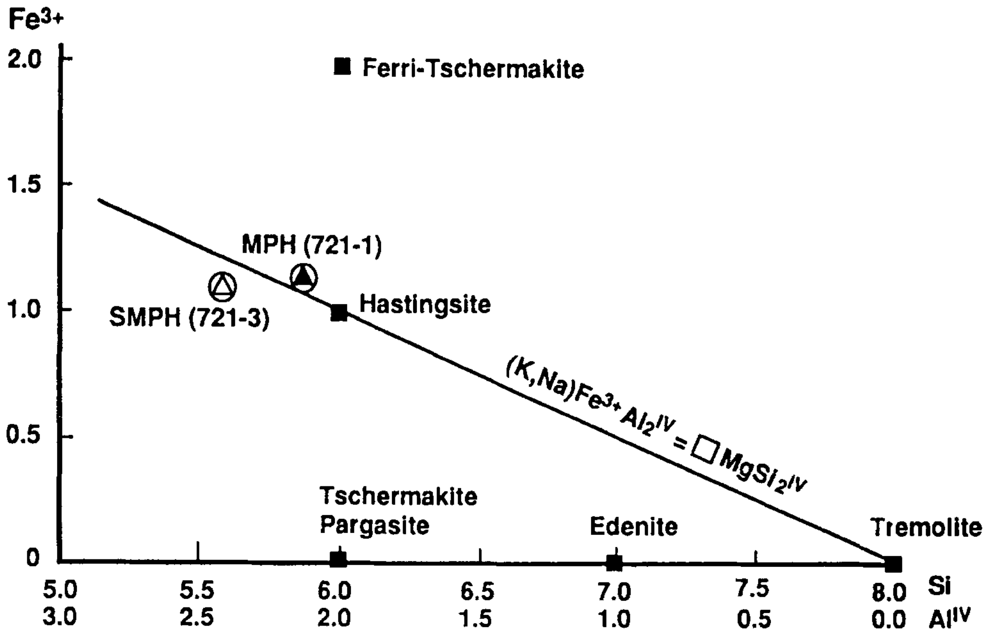

FIG. 2. Plots of K-rich Ca-amphibole on a Fe^{3+} *vs.* Al^{IV} diagram. Triangles with circles indicate a magnesian potassium-hastingsite (MPH)(721-1) and subsilicic magnesian potassium-hastingsite (SMPH)(721-3), respectively.

Clinopyroxene coexisting with the amphibole is pleochroic from light bluish-green to pale green. Sample D10 contains primary scapolite (Me_{77-82}) which does not coexist with the amphibole.

Discussion

In the granulite-facies terrain of the Lützow-Holm Complex, potassium pargasite- (0.65 wt.% Cl, 3.19 wt.% K_2O) and chlorine-rich potassium-hastingsite (3.27 wt.% Cl, 3.27 wt.% K_2O) were reported from Einstödingen(Matsubara and Motoyoshi, 1985) and West Ongul Island(Suwa *et al.*, 1987). In contrast, the Cl-content of the present samples is negligible. Two amphiboles(721-1, 721-3) are plotted near the line of

$(K, Na)Fe^{3+}Al_2^{IV} = \square MgSi_2^{IV}$ substitution in Fig. 2.

If we calculate the unit formula on the basis of $0 = 23$, the cation sum in M123 sites are 4.837 and 4.772 apfu (atoms per formula unit) (Table 1). Recalculation on the basis of 24(O, OH) gives a sum of M123 of 5.000 for the subsilicic magnesian potassium-hastingsite (Table 1). This supports the H_2O determination, which indicates that O(3) is occupied by O^{2-} as well as by monovalent anions.

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