

# Potassium pargasite from Einstödingen, Lützow-Holm Bay, East Antarctica

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**ABSTRACT.** Potassium pargasite containing 3.19 wt. %  $K_2O$  was found in a skarn from the islet of Einstödingen, Lützow-Holm Bay, East Antarctica, together with some high potassium pargasitic amphiboles. A positive correlation is shown between  $Fe^{2+}/(Mg + Fe^{2+})$  and  $K/(K + Na(A))$  ratios in pargasitic amphiboles suggesting that the increase of  $Fe^{2+}$  serve to stabilize high-K pargasites under the metamorphic conditions of the granulite facies.

**KEYWORDS:** amphiboles, pargasite, Einstödingen, Antarctica.

IN 1983 we collected some potassium-rich amphiboles in skarn and marble intercalated with garnet-biotite gneisses in the islet of Einstödingen, Lützow-Holm Bay, East Antarctica, during the geological survey as a part of the 24th Japanese Antarctic Research Expedition. The amphibole in a skarn which is overlain by a marble is found to be extremely rich in  $K_2O$  (up to 3.19 wt. %), enabling it to be termed a potassium pargasite after the amphibole nomenclature system (Leake, 1978). The present contribution also reports a linear relationship between  $Fe^{2+}/(Mg + Fe^{2+})$  and  $K/(K + Na(A))$  ratios in pargasitic amphiboles.  $Fe^{2+}/(Mg + Fe^{2+})$  is one of the dominating factors in stabilizing high-potassium pargasite, which is unknown synthetically beyond the point  $K/(K + Na) = 0.5$  along with  $Fe^{2+}$ -free pargasites.

**Occurrence.** Einstödingen is an islet in Lützow-Holm Bay, East Antarctica (long.  $38^\circ 51' E.$ , lat.  $69^\circ 39' S.$ ) located about 78 km SSW of Syowa Station (fig. 1). The ice-free rocks in the north include garnet-biotite gneiss, pyroxene gneiss, and marble with a skarn which was metamorphosed to granulite facies in late Proterozoic time. There are two major ( $< 15$  m) layers of marble in the skarn, which itself occurs in garnet-biotite gneiss with sillimanite-rich layers. The marble consists of calcite and

dolomite with minor forsterite, spinel, phlogopite, and hornblende, and includes numerous nodules of spinel-phlogopite and diopside-hornblende-phlogopite. The skarn consists of aluminous diopside, potassium pargasite, and phlogopite, and

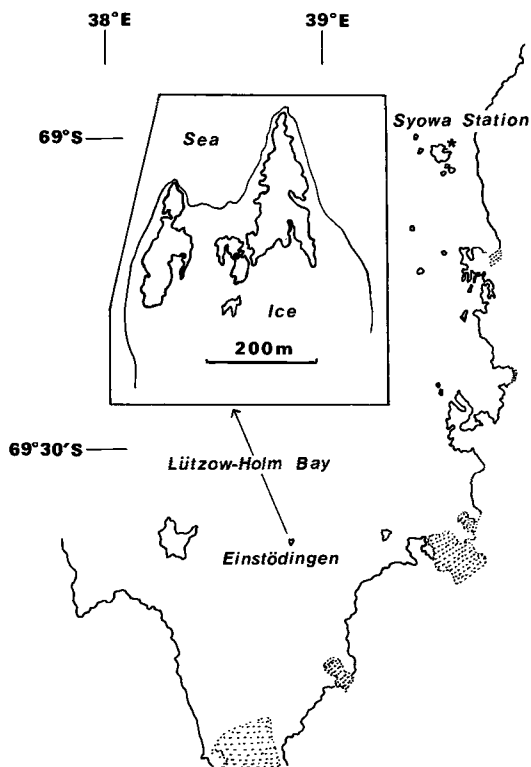
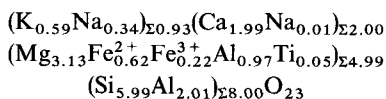


FIG. 1. The index map of Einstödingen (solid circle is potassium pargasite locality).

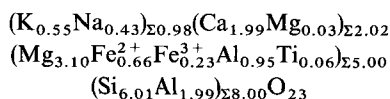
includes some nodular masses of spinel-anorthite and ferroan diopside–scapolite. The schematic profile of these rocks is given in fig. 2. Potassium pargasite occurs as aggregates of coarse subhedral crystals up to 10 mm across. The crystals are devoid of any inclusions or alteration products.

*Physical and optical properties.* Potassium pargasite is dark greyish green in colour with a very light greenish grey streak. Hardness is 5.5 to 6 on Mohs' scale. The specific gravity measured by a Berman microbalance is 3.12, which is very close to the calculated density 3.13 g/cm<sup>3</sup>. It is biaxial positive with  $2V = 75(5)^\circ$ . Refractive indices are:  $\alpha = 1.648(2)$ ,  $\beta = 1.654(2)$ ,  $\gamma = 1.664(2)$  by the immersion method. It shows weak pleochroism, from colourless to very pale green.

*Chemical analyses.* The chemical analyses of the principal minerals in the skarn, nodular spinel-anorthite rock, marble, and sillimanite-bearing garnet–biotite gneiss were made using a Link Systems energy-dispersive X-ray spectrometer. H<sub>2</sub>O and Fe<sub>2</sub>O<sub>3</sub> for potassium pargasite were determined by wet methods. The results of selected analyses are given in Table I. The empirical formulae of potassium pargasites (nos. 1 and 2 in Table I) are respectively



and



on the basis of O = 23. They show a higher potassium content in pargasite than any other published pargasite analysis. Three other amphiboles were recognized (fig. 3): pargasite in the nodular spinel-anorthite rock in the skarn is poorer in potassium, iron, and chlorine than the potassium pargasite; pargasitic hornblende occurs sporadically in the marble; and tremolite is often found in rim of the pargasitic hornblende. Garnet associated with sillimanite is a pyrope (Py<sub>55.3</sub>Alm<sub>38.3</sub>Gr<sub>6.4</sub>), which is the first find in the Lützow–Holm Bay area.

*X-ray powder study.* The X-ray powder diffraction data were obtained by an X-ray diffractometer using Ni-filtered Cu radiation (Table II). The calculated unit cell parameters are:  $a = 9.917$ ,  $b = 18.020$ ,  $c = 5.321$  Å,  $\beta = 105.49^\circ$ ,  $V = 916.3$  Å<sup>3</sup> for potassium pargasite (Na<sub>37</sub>K<sub>63</sub> pargasite) and  $a = 9.887$ ,  $b = 17.961$ ,  $c = 5.299$  Å,  $\beta = 105.52^\circ$ ,  $V = 906.7$  Å<sup>3</sup> for potassiumian pargasite (Na<sub>64</sub>K<sub>36</sub> pargasite). Due to the presence of a little Fe<sup>2+</sup>

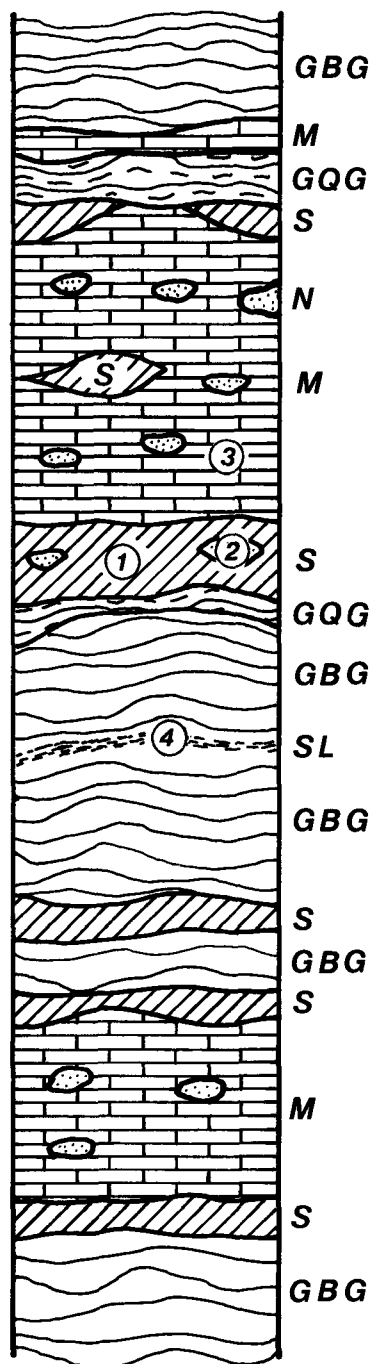


FIG. 2. The schematic profile of marble and skarn intercalating with gneiss (GBG: garnet–biotite gneiss, M: marble, GQG: garnet–quartz gneiss, S: skarn, N: nodule or nodular mass, SL: sillimanite-bearing layer). Numbers are collecting sites and correspond to those in Table I.

Table I. Chemical analyses of potassium pargasite and associated minerals

	⊙ EI A 118			⊙ EI A 118'				⊙ EI B 118		
	1	2	3	4	5	6	7	8	9	
SiO <sub>2</sub>	41.03	41.08	50.80	41.85	0	43.77	40.93	45.10	57.90	
TiO <sub>2</sub>	0.42	0.53	0.33	0	0	0	0.42	1.59	0	
Al <sub>2</sub> O <sub>3</sub>	17.34	17.05	6.26	19.60	69.32	35.58	18.42	13.94	1.11	
Fe <sub>2</sub> O <sub>3</sub>	1.96	2.10	-	-	-	-	-	-	-	
FeO	5.04	5.38	3.23*	2.06*	7.03*	0	2.05*	0.76*	0.47*	
MgO	14.39	14.36	14.31	17.54	23.61	0	24.44	19.92	24.46	
CaO	12.71	12.72	24.98	13.22	0	20.02	0	13.48	13.51	
K <sub>2</sub> O	3.19	2.94	0	2.08	0	0	10.48	0.77	0	
Na <sub>2</sub> O	1.21	1.51	0	2.37	0	0	0	3.03	1.06	
Cl	0.05	0.01	0	0.27	0	0	0.18	0.22	0	
H <sub>2</sub> O	1.15	1.15	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	
-O=Cl <sub>2</sub>	0.15	0.14	-	-	-	-	0.04	0.05	-	
Total	98.94	98.29	99.81	98.91	99.96	99.37	96.88	98.76	98.51	

	⊙ EI B 118				⊙ EI B-D 118			
	10	11	12	13	14	15	16	17
SiO <sub>2</sub>	0	42.87	0	0	41.43	41.53	39.53	38.11
TiO <sub>2</sub>	0	0	0	0	0	0	4.25	0
Al <sub>2</sub> O <sub>3</sub>	70.87	0	0	0	22.91	22.80	15.34	50.85
Fe <sub>2</sub> O <sub>3</sub>	-	-	-	-	-	-	-	1.10*
FeO	2.15*	2.03*	0.44*	0	18.72*	18.68*	8.66*	-
MgO	26.41	55.07	21.65	2.47	15.22	14.05	17.56	0
CaO	0	0	31.90	55.01	2.44	2.39	0	0
K <sub>2</sub> O	0	0	0	0	0	0	9.81	0
Na <sub>2</sub> O	0	0	0	0	0	0	0	0
Cl	0	0	0	0	n.d.	n.d.	n.d.	n.d.
H <sub>2</sub> O	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
-O=Cl <sub>2</sub>	-	-	-	-	-	-	-	-
Total	99.43	99.77	53.99	57.48	100.72	99.85	95.15	99.88

\*total Fe

- ⊙ EI A 118: 1,2 potassium pargasite 3 diopside
- ⊙ EI A 118': 4 pargasite 5 spinel 6 anorthite 7 phlogopite
- ⊙ EI B 118: 8 pargasitic hornblende 9 tremolite 10 spinel 11 forsterite 12 dolomite 13 calcite
- ⊙ EI B-D 118: 14,15 pyrope 16 biotite 17 sillimanite

replacing Mg, both cell volumes are significantly larger than the estimated values for Na-K pargasite series synthesized by Hinrichsen and Schürmann (1977).

*Discussion.* The relationship of the  $Fe^{2+}/(Mg + Fe^{2+})$  and  $K/(K + Na(A))$  ratios for the four amphibole species is indicated in fig. 4. Apart from the potassium pargasite, the analyses are plotted using total Fe/(Mg+total Fe) instead of  $Fe^{2+}/(Mg + Fe^{2+})$ , as their total iron contents are low, and  $Fe^{3+}/(total\ Fe)$  ratios are considered to be small

by analogy with potassium pargasite ( $Fe^{3+}/(total\ Fe) = 0.26$ ). The relation is near linear with a positive gradient, indicating that the potassium pargasite was possibly stabilized by the presence of a proportion of the ferro-pargasite molecule, a conclusion in agreement with the well-known K-rich nature of many hastingsites. This could be at least one of the reasons why Hinrichsen and Schürmann (1977) failed to synthesize  $Fe^{2+}$ -free potassium pargasite. Except for tremolite, the other amphiboles discussed here include appreciable

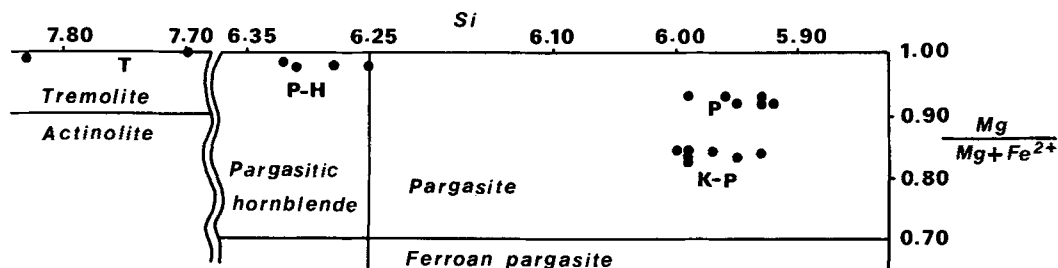


FIG. 3. Composition of amphiboles on the classification diagram of calcic amphiboles after Leake, 1978 (K-P: potassium pargasite, P: potassian pargasite, P-H: pargasitic hornblende, T: tremolite).

Table II X-ray powder data for potassium pargasite

d(obs.)	d(calc.)	I	hkl	d(obs.)	d(calc.)	I	hkl
9.04	9.02	5	020	2.352	2.352	10	351
8.47	8.45	80	110	2.345	2.345	12	421
5.10	5.10	2	130	2.301	2.301	5	171
4.94	4.93	2	111	2.255	2.254	2	331
4.52	4.50	5	040	2.228	2.228	2	042
4.23	4.22	4	220		2.227		242
3.90	3.90	1	131	2.161	2.159	8	281
3.38	3.38	15	131	2.111	2.111	5	440
3.280	3.277	30	240	2.046	2.043	4	202
3.138	3.137	100	310	2.039	2.041	8	402
2.949	2.949	12	151		2.037		280
2.815	2.815	45	330	2.016	2.015	6	351
2.759	2.758	8	331	2.002	2.002	5	370
2.706	2.704	10	151	1.980	1.980	2	190
2.593	2.592	7	081	1.901	1.901	10	510
2.564	2.564	6	002	1.885	1.885	2	191
	2.562		202	1.822	1.821	5	530
2.389	2.389	18	400	1.802	1.802	2	0100
	2.387		350	1.689	1.689	5	550

amounts of chlorine, and the relationship between the chlorine and total iron contents is nearly linear with a positive gradient (fig. 5).

The literature survey has confirmed that the K-rich nature of the present potassium pargasite is unique, except for potassium ferroan pargasite (Rock and Leake, 1984), which has  $Fe^{2+} > Mg$  and  $K > Na$  in the *A*-site, and was formed as the product of contact metamorphism together with sadanagaite and magnesio-sadanagaite (Shimazaki *et al.*, 1984). They consider that the incorporation of K is favoured by the substitution of  $Al^{IV}$  for Si, yielding a larger unit cell. Their conclusion comes from the nature of their materials, which are extremely poor in silica with an extensive Al-Si substitution and a rather narrow  $Fe^{2+}$ -Mg substitution range, validating their conclusion that emphasizes the role of Al-Si substitution rather than  $Fe^{2+}$ -Mg substitution under such contact metamorphic conditions. However, the present case indicates that the increasing  $Fe^{2+}/(Mg + Fe^{2+})$  ratio favours the incorporation of K in the *A*-site,

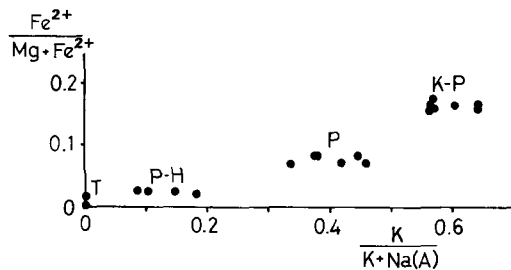


FIG. 4. Plots of amphiboles of  $Fe^{2+}/(Mg + Fe^{2+})$ - $K/(K + Na(A))$  diagram (with the same abbreviations as fig. 3).

but the range of Al-Si substitution is too narrow to determine its contribution to facilitating K substitution into the *A*-site. The present report enables a new factor favouring the incorporation of K into the *A*-site in pargasitic amphiboles to be recognized.

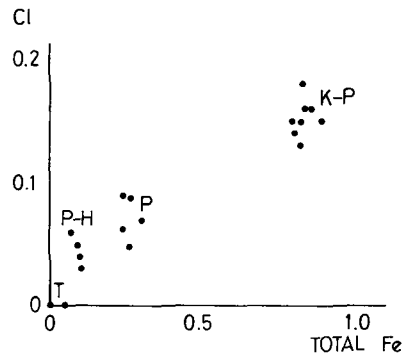


FIG. 5. Plots of amphiboles on Cl-total Fe diagram. Figures are represented as atom number on the basis of 0 = 23 (with the same abbreviations as fig. 3).

The present potassium pargasite is the product of granulite-facies metamorphism, as verified by the appearance of a pyrope-sillimanite assemblage in the garnet-biotite gneiss intercalated with the marble accompanied by skarn. Motoyoshi *et al.* (1984) analysed the composition of pyroxenes, garnet, and plagioclase in pyroxene gneiss underlain by the sillimanite-bearing garnet-biotite gneiss from Einstödingen. Their estimated metamorphic temperatures of the pyroxene gneiss by reference to the clinopyroxene-orthopyroxene geothermometer (Wood and Banno, 1973; Wells, 1977) are in the range of 795–834 and 802–844 °C. Also they estimated four metamorphic pressures based on different geobarometers, assuming the temperature to be 830 °C. The pressures are in the range of 8.1 kbar by garnet-orthopyroxene-plagioclase-quartz geobarometer (Perkins and Newton, 1981) to 9.7 kbar by garnet-orthopyroxene geobarometer (Harley and Green, 1982). Consequently, the physical conditions of formation of the potassium pargasite is estimated to be in the range of about 800–850 °C at about 8–10 kbar, and the termination of metamorphic reactions was within the stability field of sillimanite.

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