Peraluminous sapphirine from the Aileron district, Arunta Block, central Australia

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Abstract

Specimens collected from a small lens of phlogopite-rich rock in the granulite-facies terrain of the Arunta Block, central Australia, have unusual bulk compositions and mineral assemblages. One sample consists of phlogopite enclosing blue spinel (*mg* 96) with minute granules of corundum and sapphirine at the margins; a second of phlogopite enclosing porphyroblasts of corundum and peraluminous sapphirine. In the first the sapphirine is close to the 7:9:3 composition; in the other it is markedly peraluminous, e.g. $(Mg_{1.628}Fe_{0.028})Al_{4.714}Si_{0.636}O_{10}$, intermediate between the 7:9:3 and 3:5:1 members. The texture suggests that this sapphirine is a stable phase in equilibrium with eastonitic phlogopite and corundum. The very potassic, very magnesian bulk composition of the rocks is attributed to potassium metasomatism of a protolith consisting of magnesian chlorite and quartz.

KEYWORDS: sapphirine, phlogopite, corundum, Arunta Block, Australia

Introduction

Two sapphirine-bearing specimens with unusual, very magnesian bulk compositions and mineral assemblages have been collected from a small lens of phlogopite rock within granulite-facies rocks of the Arunta Block. The bulk chemistry of the rocks (Table 1) is not compatible with any normal protolith; and one of the specimens contains porphyroblasts of peraluminous sapphirine several millimetres across.

Naturally occurring sapphirines have a considerable range of compositions expressed in terms of $(MgO.FeO):(Al_2O_3.Fe_2O_3.Cr_2O_3):SiO_2$ ($RO:R_2O_3:SiO_2$), usually in the range 2:2:1 to 7:9:3 (Deer *et al.*, 1978). Sapphirines more aluminous than 7:9:3 are relatively rare. Such sapphirines have been termed peraluminous by Schreyer and Abraham (1975) who first described them and suggested from the fine-grained nature of the example they studied that peraluminous sapphirine may be metastable. The Aileron occurrence is one of several natural examples now described (Cameron, 1976; Friend, 1982; Arima and Barnett, 1984) that provide evidence that peraluminous sapphirine is a stable phase in rocks of appropriate bulk composition.

Geological setting

The specimens were collected in the northern tectonic zone of the Arunta Block at approximately 22° 35′ S, 135° 22′ E, about 5 km north of Aileron and 135 km north northwest of Alice Springs in central Australia (Fig. 1) from a lens of phlogopite rock about 10 m by 1 m wide. The immediately adjacent unit consists of well-layered leucocratic quartzose rocks with phlogopite, cordierite, and K feldspar. Surrounding paragneisses are predominately layered quartzofeldspathic gneiss, with minor quartzose layers, which crop out as a small body of a few hundred square metres within the Boothby Orthogneiss, a porphyroblastic metagranite. All units are older than 1680 Ma (from Black *et al.*, 1983).

Metamorphic evolution in this part of the Arunta Block seems to have followed the same pattern as in the central tectonic zone: an early high-*T* low-*P* stage was followed by early hydration and near-isobaric cooling, after which hydration and

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Table 1. Microprobe analyses 72921235 A

(Sapphirine-corundum-spinel-phlogopite assemblage)

	1	2	3	4	5	6
SiO_2	12.41	13.57	71.19	38.53	39.86	39.89
TiO_2				0.20	0.28	0.23
Al_2O_3	66.63	64.87		18.68	18.51	18.43
FeO*	0.55	0.68	1.80	0.50	0.61	0.60
MgO	20.40	20.72	26.38	24.91	26.27	26.24
ZnO			0.64			
Na_2O					0.49	0.48
K_2O				9.70	10.22	10.07
F					0.49	0.61
Cl					0.16	0.17
Total	99.99	99.98	100.01	92.52	96.67	96.42
Si	1.430	1.574		5.499	5.498	5.511
Ti				0.021	0.029	0.024
Al	9.052	8.890	2.007	3.143	3.008	3.002
Fe^{2+}	0.053	0.066	0.036	0.059	0.071	0.069
Mg	3.509	3.596	0.942	5.300	5.400	5.405
An			0.011			
				0.130	0.128	
K			1.766	1.799	1.775	
F				0.239	0.266	
Cl				0.038	0.040	
Total	14.044	14.104	2.996	15.790	16.206	16.221
Oxygen	20	20	4	22	22	22

*All iron as ferrous iron

Analyses 1-4 Energy dispersive microprobe, analyses 5 and 6 Spectrometer probe.

1 Sapphirine, 2 Sapphirine, 3 Spinel, 4 Phlogopite, 5 Phlogopite, 6 Phlogopite

retrogression were confined to fault zones (Warren, 1984). The local metamorphic grade reached granulite facies at peak conditions: two-pyroxene mafic granulites and migmatitic gneiss with orthopyroxene-orthoclase occur in the Aileron Metamorphics about 4 km to the west of the lens.

Sapphirine

One specimen (Bureau of Mineral Resources registered specimen 78921235B, abridged to 1235B) consists of white opalescent laths and knots of sapphirine and corundum set in a matrix of grey phlogopite ($mg = 100MgO/[MgO+FeO] = 98.5$–$99.0$). The sapphirines in 1235B are amongst the most aluminous sapphirines known to exist in natural rocks (Fig. 2, Table 2). The second specimen (72921235A abridged to 1235A) consists of pale blue spinel (*mg* 96, Table 3) set in a matrix of pale green phlogopite (*mg* 99). Minute granules of corundum and sapphirine occur at the margin of some spinel grains.

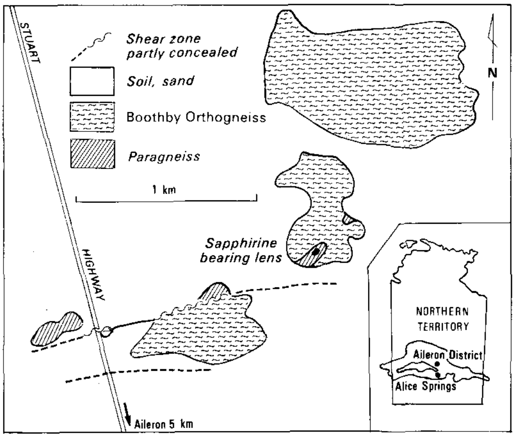

FIG. 1. Sketch map showing the location of the Aileron sapphirine lens.

Sapphirine in both specimens is very magnesian: in 1235A *mg* ranges from 98.2 to 98.5 (average of 5 is 98.3) and in 1235B the *mg* of the sapphirine is slightly higher, ranging from 98.2 to 98.9 (average of 26 is 98.6). If the analyses of the sapphirine are plotted in the RO-R_2O_3-SiO_2 triangle (Fig. 2), all show a slight excess of divalent cations. Estimation of ferric iron by the method of Higgins *et al.* (1979) or from the editing routine in the program used in the microprobe analyses (Ware, 1981) indicates that nearly all the iron is ferric, bringing the actual value of *mg* very close to 100. Extremely magnesian sapphirine is unusual but not unique: e.g. Schreyer and Abraham (1975) described iron-free sapphirine from Sar e Sang, Afghanistan, and sapphirine from Mawson, Antarctica has *mg* of 98.6-99.1 (Sheraton *et al.*, 1982).

Sapphirine in 1235A coexisting with phlogopite, spinel and corundum has compositions in the normal substitution range (Moore, 1969) close to the 7:9:3 member of the series; but the sapphirine in 1235B is more aluminous, plotting well beyond the 7:9:3 composition in the peraluminous field (Fig. 2). Markedly peraluminous sapphirine has been found at several localities since first being

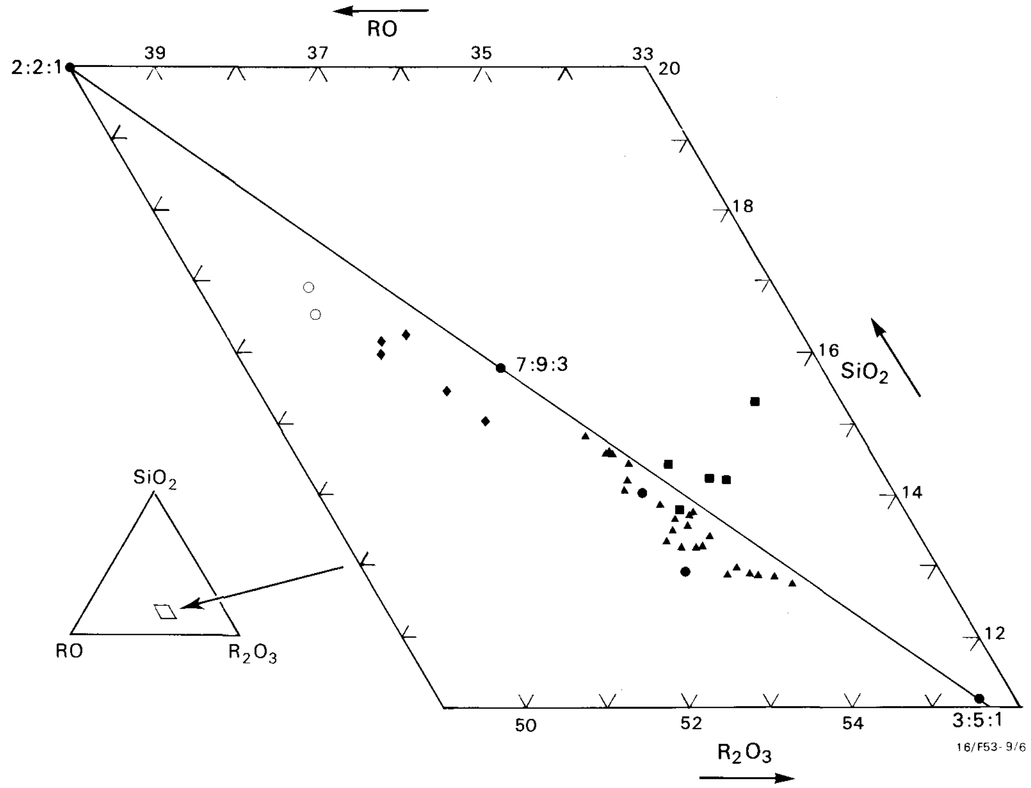

FIG. 2. Sapphirine analyses plotted in the RO–R_2O_3–SiO_2 triangle: ◆ 72921235A, ▲ 78921235B, ■ peraluminous sapphirine from Sar e Sang (Schreyer and Abraham, 1975), ● peraluminous sapphirine from an inclusion in the Bushveld intrusion (Cameron, 1976), ○ normal very magnesian sapphirine from the Mawson sapphirine lens (Sheraton *et al.*, 1982).

described by Schreyer and Abraham in 1975. Cameron (1976) described peraluminous sapphirine coexisting with mullite and sillimanite in a contact metamorphic rock. Other examples are from high-grade terrains in Greenland and Canada (Friend, 1982; Arima and Barnett, 1984).

Using available data from experiments and natural occurrences, Higgins *et al.* (1979) suggested that peraluminous sapphirine would be more likely to exist stably in a high-temperature, low-pressure environment: subsequently Smart and Glasser (1981) synthesized extremely aluminous sapphirine at 1453 °C and 1 bar. Thus sapphirine appears to behave similarly to orthopyroxene in which increasing Al_2O_3 is linked with increasing temperature, all else being equal. However, some observations of natural occurrences (Ellis *et al.*, 1980, and Warren, 1982) suggest that lower-temperature sapphirines may be more aluminous than high-temperature sapphirines.

The composition of sapphirine at fixed P, T and f_{O_2} is controlled by mineral assemblage. From consideration of the topology of the SiO_2–RO–R_2O_3 triangle (Fig. 3) the relative Al_2O_3 contents of sapphirine in various divariant assemblages can be predicted. The topology in Fig. 3 shows that the most aluminous sapphirine possible is that which is in equilibrium with corundum and spinel (and a K-bearing phase such as the phlogopite in the Aileron material). Thus the peraluminous sapphirine in the examples described by Friend (1982) and Arima and Barnett (1984) coexists with spinel and corundum. The Aileron samples therefore appear anomalous in that, under identical physical conditions, the four-phase assemblage in 1235A should contain the more peraluminous sapphirine. The fact that the large subhedral peraluminous sapphirines in 1235B occur in a rock lacking spinel and therefore with unbuffered Al_2O_3 suggests that this peraluminous sapphirine may have formed at higher

Table 2. Microprobe analyses 78921235 B (Corundum-Sapphirine-phlogopite assemblage)

	1	2	3	4	5	6	7	8	9	10
SiO_2	12.18	11.74	11.36	10.70	10.41	10.33	10.27	38.48	38.17	38.04
TiO_2								0.21	0.38	0.35
Al_2O_3	66.42	68.47	68.88	69.58	69.06	70.34	70.25	20.15	19.55	19.97
FeO*	0.55	0.56	0.39	0.51	0.74	0.52	0.44	0.72	0.80	0.83
MgO	20.15	19.30	19.42	19.13	18.37	18.88	18.62	24.68	24.71	24.81
Na_2O									0.49	0.52
K_2O								9.69	9.83	9.62
F									0.43	0.42
Cl									0.11	0.11
Total	99.31	100.07	100.05	99.92	98.58	100.07	99.58	93.94	94.26	94.51^{Φ}
Si	1.414	1.351	1.307	1.234	1.218	1.190	1.188	5.410	5.392	5.357
Ti								0.022	.041	0.037
Al	9.088	9.286	9.342	9.460	9.525	9.550	9.625	3.340	3.256	3.314
Fe^{2+}	0.054	0.054	0.037	0.049	0.073	0.050	0.043	0.085	.095	.098
Mg	3.488	3.314	3.335	3.293	3.2038	3.246	3.216	5.171	5.203	5.207
Na									0.134	0.142
K								1.767	1.772	1.727
F									0.192	0.026
Cl									0.026	0.026
Total	14.044.	14.006	14.021	14.036	14.019	14.035	14.030	15.767	16.110	16.098
Oxygens	20	20	20	20	20	20	20	22	22	22

* All iron as ferrous iron Φ includes 0.04 weight percent BaO.

Analyses 2,3,4,5,6,7,8 Energy dispersive microprobe, analyses 1,5,9, spectrometer microprobe

1, Sapphirine, 2, Sapphirine, 3, Sapphirine, 4, Sapphirine, 5, Sapphirine, 6, Sapphirine, 7, Sapphirine, 8 Phlogopite, 9, Phlogopite, 10, Phlogopite

temperature (following Higgins *et al.*, 1979) than the small granules of sapphirine at the edge of spinel in 1235A. Nevertheless sapphirine and phlogopite in the two specimens are in equilibrium in that the peraluminous sapphirine coexists with the more eastonitic phlogopite.

Whole-rock geochemistry

Whole rock analyses are given in Table 3, together with examples of phlogopite-rich rocks from Antarctica. The two specimens have important common characteristics: high K_2O, very high Rb, and low FeO, Cr, Ni, V and K/Rb.

Sapphirine-bearing rocks are part of the chemical suite of metamorphic rocks that includes cordierite–anthophyllite rocks and whiteschists so that most sapphirine-bearing rocks can be interpreted in terms of near-isochemical metamorphism of an original protolith of magnesian chlorite, illite and minor quartz. Protoliths to such rocks form either in a volcanogenic environment through hydrothermal alteration or in a sedimentary environment through diagenetic processes involving alteration of pelites in contact with hypersaline waters (e.g. Chinner and Fox, 1974; Schreyer and Abraham, 1976; Moine *et al.*, 1982; Sheraton, 1980; Moore, 1984; Warren and Shaw, 1985). Many of the other occurrences of sapphirine-bearing rocks in the Arunta Block appear to have formed in a volcanogenic environment (Warren, 1979; Warren and Shaw, 1985), and those in metasediments in the Reynolds Range west of Aileron probably formed through the action of hypersaline ground waters. The high Rb content is a compelling argument against an origin as a restite as was suggested by

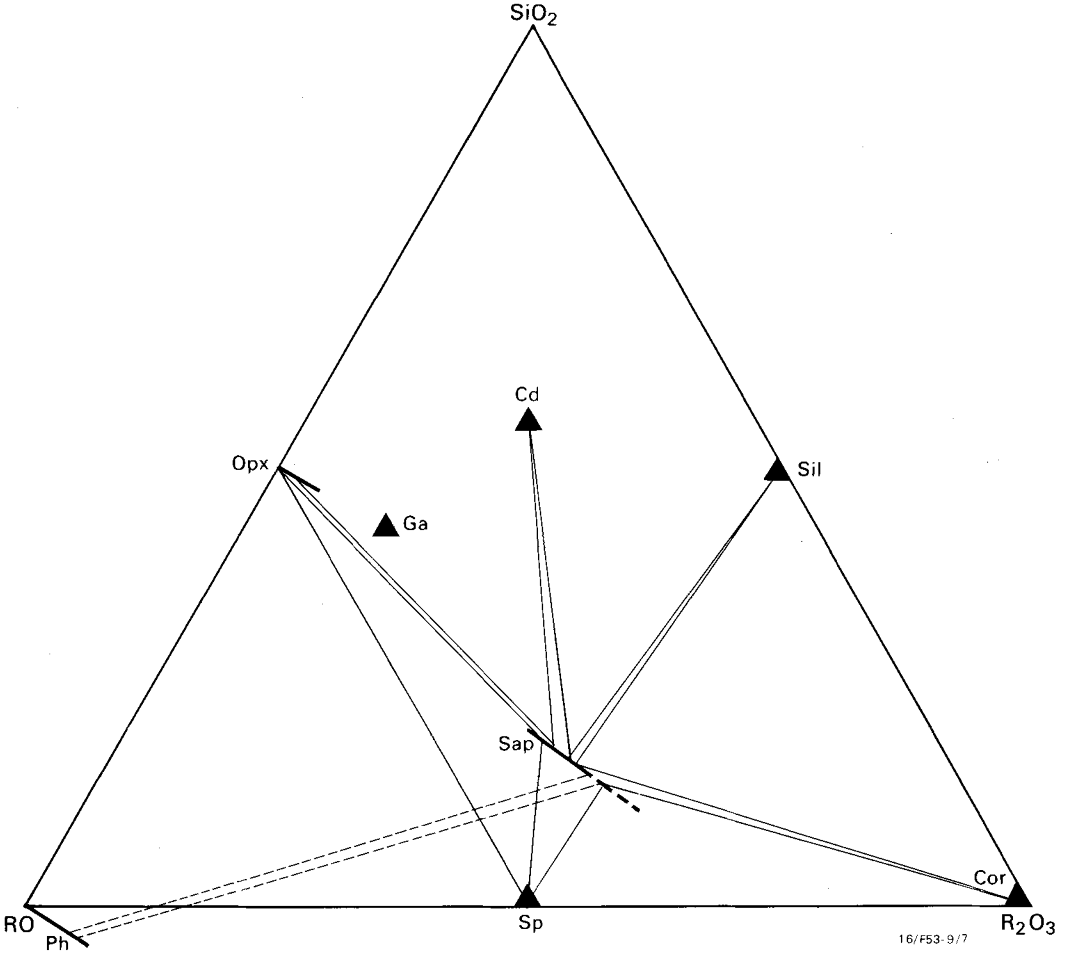

FIG. 3. Topology for sapphirine and coexisting phases in the RO-R_2O_3-SiO_2 triangle for very magnesian bulk compositions at low pressures. Note sapphirine compositions are fixed in the three-phase assemblages. The relative compositions of phlogopite that should coexist with sapphirine–corundum and sapphirine–spinel–corundum are indicated using the composition of phlogopite projected from $KAlSiO_3$. (Cd cordierite, Cor corundum, Ga garnet, Opx orthopyroxene, Ph phlogopite, Sap sapphirine, Sil sillimanite, Sp spinel.)

Clifford *et al.*, 1975, for sapphirine-bearing rocks from Namaqualand. Low Cr and Ni preclude an ultrabasic precursor.

The Aileron Metamorphics, to which the sapphirine lens and immediately surrounding paragneisses belong, probably represent metamorphosed acid and basic volcanics and pelites, calcareous, and quartzose sediments (Stewart, 1981). The pelitic and calcareous rocks in the Aileron Metamorphics are 10–15 km to the southeast: the paragneisses adjacent to the lens are quartzofeldspathic, suggesting volcanogenic affinities. However, although the very magnesian bulk composition of the rocks in the lens are more likely to have formed in evaporitic conditions (Moine *et al.*, 1982), very magnesian sapphirine-bearing rocks occur in the northern Strangways Range (central Arunta Block) in a volcanogenic association (Warren, 1982); and very magnesian rocks with bulk compositions suitable for the formation of sapphirine-bearing assemblages have been reported from a volcanogenic environment at Woodlawn (Malone *et al.*, 1976).

However, the bulk chemistry of the two samples from the Aileron lens cannot be reconciled with a mixture of illite, chlorite and quartz. This can be verified by a simple calculation based on the

Table 3
Bulk compositions of phlogopite-rich sapphirine-bearing rocks.

	1	2	3	4
SiO_2	34.85	32.96	46.80	36.20
TiO_2	0.22	0.29	0.97	0.12
Al_2O_3	24.56	29.80	18.15	26.70
Fe_2O_3	0.71	0.58	0.10	1.25
FeO	0.11	0.27	0.70	0.60
MnO	0.01	0.01	0.03	0.03
MgO	25.85	22.88	25.50	24.60
CaO	0.04	0.04	0.12	0.06
Na_2O	0.45	0.42	0.59	0.27
K_2O	8.75	7.75	4.70	6.80
P_2O_5	0.06	0.06	0.01	0.03
H_2O(tot)	1.92	3.11	0.70	1.29
Total	97.53	98.17	98.37	97.95
Ba	104	86	43	507
Ce	4	<3	9	37
Cr	6	7	8	4
F	4500	3400		
Ga	8	7	8	4
La	<2	<2	<2	22
Nb	10	16	147	10
Ni	19	17	5	45
Rb	1154	1029	375	530
Sn	9	10		
Sr	9	7	7	13
Th	6	10	5	23
U	4	<0.5	3.5	1.0
V	19	21	22	32
Y	<1	<1	21	38
Zr	163	165	765	103
mg	99.8	99.5	98.4	98.6

Chlorine not analysed, estimated chlorine content 1000 ppm.

1. 72921235A Corundum - sapphirine - spinel - phlogopite granofels from the Aileron district.

2. 78921235B Corundum - sapphirine - phlogopite granofels from near Aileron.

3. 73282053 Sapphirine - orthopyroxene - spinel - phlogopite granofels, Mawson sapphirine lens, Antarctica (Sheraton *et al.*, 1982)

4. 77284340 Sapphirine - orthopyroxene - spinel - phlogopite granofels, Gage Ridge, Antarctica (Sheraton, 1980)

assumption that all potassium was contributed by illite: in 1235A the K_2O content would require more Al_2O_3 to have been contributed by illite than the rock actually contains. The projections of bulk chemistry from K_2O into the triangle (MgO+FeO)-Al_2O_3-SiO_2 (Fig. 4) lie very close to the join quartz-chlorite. This suggests the lens could have reached its present composition through potassium metasomatism of an original highly magnesian chlorite-rich rock, in a manner similar to the phlogopite-rich outer zone of the sapphirine lens at Mawson, Antarctica which was formed by metasomatism of a chlorite-quartz body during crystallization of enclosing granite (Sheraton *et al.*, 1982). In the case of the Aileron lens the metasomatic hypothesis is supported by the trace-element chemistry in that the rocks are very enriched in Rb, even more so than the phlogopite-rich rim of the Mawson lens. The K/Rb ratio for the rocks in the Aileron lens is lower than that for the Boothby Orthogneiss, for which unpublished data gives values of about 170, and, unlike the Mawson lens, the Aileron lens, at least not in the exposed section, is not in direct contact with intrusive orthogneiss. Neither of these points provides a strong argument against the Boothby Orthogneiss as a source of metasomatic fluid. Both rocks contain high variance assemblages, also consistent with metasomatism (Thompson, 1959).

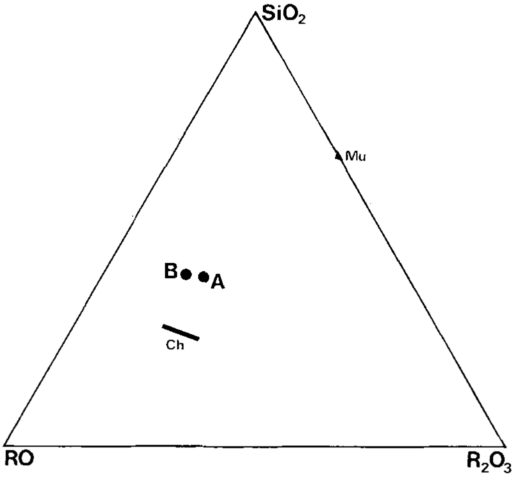

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FIG. 4. Bulk compositions of 1235A and B projected from K_2O into the RO-R_2O_3-SiO_2 triangle. The bulk compositions project into the join quartz-chlorite, indicating that the compositions can be resolved into chlorite, quartz and K_2O. If the bulk RO-R_2O_3-SiO_2 triangle. The bulk compositions project into the join quartz-chlorite, indicating that the compositions can be resolved into chlorite, quartz and K_2O. If the bulk compositions were projected from $K_2Al_6Si_6O_{20}(OH)_4$ they would fall outside the triangle, showing the bulk compositions cannot be resolved into illite, chlorite and quartz.

Conclusions

Rocks in the Aileron sapphirine lens have a bulk chemistry which is very magnesian and unusually potassic. This is attributed to a two-stage evolution in which an original magnesian chlorite-rich lens, possibly formed in a volcanic environment, was subsequently altered by potassium metasomatism.

The markedly peraluminous sapphirine in 1235B is coarse grained and appears to coexist stably with phlogopite and corundum. This is the third occurrence of stable peraluminous sapphirine to be reported from a high-grade terrain. A reasonable inference is that, given the correct bulk composition, sapphirine with compositions between 7:9:3 and 3:5:1 is a stable phase in high-temperature, low-pressure facies terrains.

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