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Larnitic kirschsteinite from the Kotakonda kimberlite, Andhra Pradesh, India

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OLIVINES from igneous rocks generally have low calcium contents. However, olivines crystallized from strongly silica-undersaturated magmas occasionally contain large amounts of kirschsteinite (Ki: CaFeSiO_4) and monticellite (Mo: CaMgSiO_4) components. The purpose of this note is to report the first natural occurrence of kirschsteinite crystals that have larnite (La: Ca_2SiO_4) in the mineralogical norm.

These kirschsteinites are found as groundmass minerals within a kimberlite from Kotakonda in southern India. The compositions of the kirschsteinites in this rock range from $\text{Mo}_1\text{Ki}_{75}\text{La}_{24}$ to $\text{Mo}_{36}\text{Ki}_{61}\text{La}_3$, the molar $\text{Fe}/(\text{Fe}+\text{Mg})$ ratio of these crystals ranges from 0.63 to 0.99. Before these analyses, no larnite-normative olivines had been found in nature, and the most iron rich member of the Ki–Mo series was a magnesian kirschsteinite ($\text{Ki}_{69}\text{Mo}_{23}\text{Fo}_8$) reported from a melilite nephelinite (Sahama and Hytönen, 1957). The kirschsteinites found in meteorites all have a

lower Ki content and are forsterite-normative (Dodd, 1971; Prinz et al., 1977).

The Kotakonda kimberlite ($16^\circ 45' 30''\text{N}$; $77^\circ 38' 30''\text{E}$) is located about 50 km WNW of Mahbubnagar, in the state of Andhra Pradesh, India. It occurs as a 1.25 km-long E–W-trending dyke which intrudes biotite granites of Archaean age. The exposed rock is fresh and hard and constitutes the harde bank of the kimberlite. Crustal xenoliths of country rock are few while mantle xenoliths appear to be absent. A preliminary account of its geology was presented by Kameswara Rao and Sharma (1994).

Petrographic studies of thin sections of this kimberlite reveal the presence of two generations of forsteritic olivines – anhedral macrocrysts and the euhedral micro-phenocrysts, which are restricted to the groundmass. However, both types of forsteritic olivine are thoroughly serpentinised (Table 1). The

TABLE 1. Microprobe analyses of kirschteinites from the Kotakonda kimberlite (in wt. %), together with an analysis of the whole rock composition determined by XRF

Sample	Ks-1	Ks-2	Ks-3	Ks-4	Ks-5	Ks-6	Ks-7	Ks-8	Ks-9	Ks-10	Ks-11	Ks-12	M-1	SH-13	F-14	KK
Oxide (wt. %)																
SiO ₂	35.6	34.1	36.0	34.9	36.6	35.6	37.1	34.9	35.2	38.4	39.9	36.3	39.75	32.7	43.7	38.19
TiO ₂	bd	0.2	0.2	0.1	0.2	0.7	0.1	0.1	0.2	0.2	0.1	0.4	0.21	0.1	0.1	0.77
Al ₂ O ₃	0.4	1.1	0.4	0.9	0.7	2.4	0.3	0.3	0.9	1.2	0.2	2.5	0.05	0.3	1.4	2.62
FeO*	27.9	27.8	28.6	27.4	28.1	24.8	27.4	28.3	26.8	24.8	23.3	23.1	8.19	29.3**	0.1	11.86
MnO	0.1	0.1	bd	bd	0.1	0.1	bd	bd	bd	0.1	bd	0.1	0.10	1.7	0.1	0.17
MgO	0.2	0.2	0.4	0.9	1.1	2.0	2.3	2.3	2.4	5.1	7.4	7.5	30.36	5.0	43.5	30.22
CaO	34.5	35.6	33.9	34.4	34.8	33.9	33.3	33.3	32.9	29.8	29.7	30.1	21.75	29.3	0.1	9.18
Na ₂ O	bd	0.3	0.1	bd	0.2	0.1	0.1	0.1	0.1	bd	0.1	bd	0.41	bd	0.4	0.11
Total	98.7	99.4	99.6	98.7	101.8	99.6	100.6	99.4	98.5	99.6	100.7	100.0	100.82	99.0	90.4	101.89
Number of cations on the basis of 4 Oxygens																
Si	1.074	1.029	1.075	1.051	1.065	1.042	1.083	1.046	1.054	1.100	1.118	1.034	1.0210	0.995	1.124	
Fe	0.704	0.702	0.714	0.69	0.684	0.607	0.669	0.709	0.671	0.594	0.546	0.55	0.176	0.761	0.002	
Mg	0.009	0.009	0.018	0.04	0.048	0.087	0.100	0.103	0.107	0.218	0.309	0.318	1.162	0.227	1.667	
Ca	1.116	1.151	1.085	1.11	1.085	1.063	1.042	1.069	1.055	0.916	0.892	0.919	0.598	0.957	0.003	
Total	2.903	2.891	2.892	2.891	2.882	2.799	2.894	2.927	2.887	2.828	2.865	2.821	2.985	2.940	2.769	
Mol %																
Ki	77.0	75.4	78.6	75.0	75.3	69.1	73.9	75.4	73.2	68.8	62.5	61.6	20.86	78.3	Fe99.8	
Mo	1.0	1.0	2.0	4.3	5.3	9.9	11.0	11.0	11.7	25.2	35.4	35.6	47.05	23.3	Fa0.01	
La	22.0	23.6	19.4	20.7	19.4	21.0	15.1	13.7	15.1	6.0	2.1	2.9	32.09	0	0	
Molar (Fe/Fe+Mg)	0.99	0.98	0.97	0.94	0.94	0.88	0.87	0.95	0.86	0.73	0.73	0.63	0.15	0.77		

Ks 1-12 = kirschteinites from the Kotakonda kimberlite.

SH-13 = 'magnesian kirschteinite' (Sahama and Hytonen, 1957)

F-14 = Groundmass serpentinized forsterite from the Kotakonda kimberlite

KK: Kotakonda Kimberlite, whole rock, average of five samples, analysis includes K₂O 1.09 wt.% and L.O.I. 6 wt.%.

M-1 = Monticellite

bd = below the level of detection.

* = Total iron expressed as FeO

** = Analysed mineral also included 0.66 wt.% Fe₂O₃.

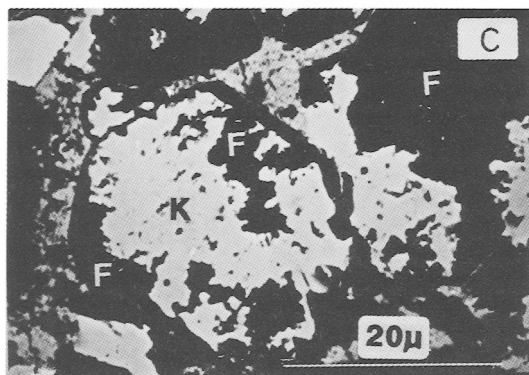
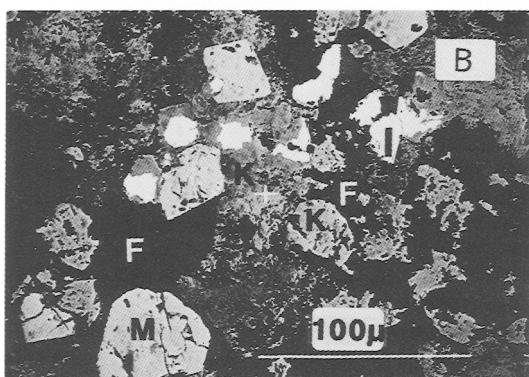
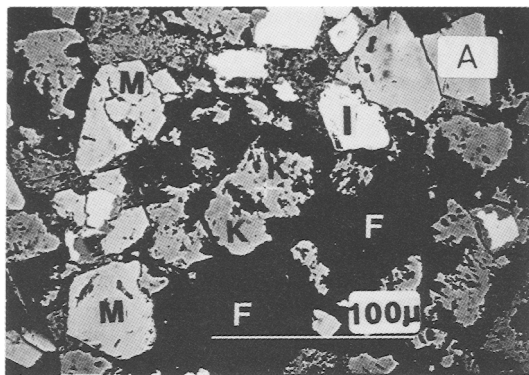


FIG. 1. Back scattered electron microscope images (BSE) of groundmass of the Kotakonda Kimberlite showing kirschsteinite (K), forsteritic olivine (F), monticellite (M) and ilmenite (I). The dark inclusions in the kirschsteinites are of almost pure forsterite. The textures of these inclusions (see Fig. 1C) suggest that they have formed by subsolidus exsolution of the host kirschsteinite.

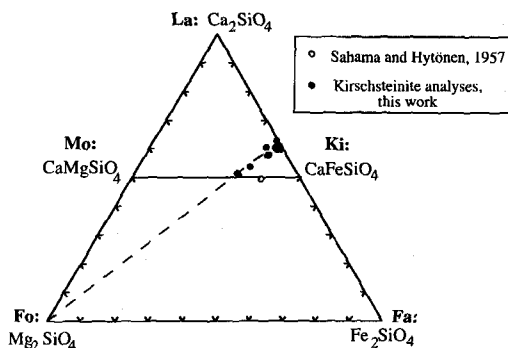


FIG. 2. Plot of the kirschsteinite analyses from this study (data in mole %) projected onto the Fa (Fe_2SiO_4)–Fo (Mg_2SiO_4)–La (Ca_2SiO_4) plane. All the analyses lie in the Ki (CaFeSiO_4)–Mo (CaMgSiO_4)–La field. The trend in Mo and La contents is consistent with exsolution of Fo from the host kirschsteinite, as shown by the dotted line. The most Ki-rich crystals have composition $\text{Mo}_2\text{Ki}_{79}\text{La}_{19}$.

other phases include abundant laths of Ti-poor (<1.5 wt.%) phlogopite, Cr-rich (29.24 wt.%) spinel, monticellite, kirschsteinite, ilmenite, perovskite, serpentine and primary calcite (occurring as lath shaped crystals in the groundmass). Kirschsteinite occurs as 20–70 μm grains. Their textural features are depicted in the Fig. 1. Monticellites are found as groundmass crystals, and not as overgrowths around olivines as described in other kimberlites by Kampata *et al.* (1994). The host rock may be classified as a hypabyssal facies macrocrystic monticellite–phlogopite kimberlite, following the criteria of Clement and Skinner (1985).

Compositions of the kirschsteinite from various grains are presented in Table 1. The magnesian kirschsteinite reported by Sahama and Hytönen (1957) is also presented for comparison. No natural kirschsteinites in the literature are larnite normative. However, as can be seen from the Ca_2SiO_4 – Mg_2SiO_4 – Fe_2SiO_4 ternary plot (Fig. 2), all the kirschsteinites from the Kotakonda kimberlite have significant larnite components. Kirschsteinite compositions span a range of molar $\text{Fe}/(\text{Fe}+\text{Mg})$ ratios from 0.63 to 0.99, and show an increase in the larnite component with increasing $\text{Fe}/(\text{Fe}+\text{Mg})$.

Discussion

The striking feature of the compositions of the kirschsteinites found in this rock is that the most magnesium-poor crystals have significant larnite

components, with larnite concentration ranging up to 23.6 mol.%. Bowen *et al.* (1933) and Wyderko and Mazanek (1968) showed that synthetic olivines in the system Fo–Fa–La could contain CaO concentrations of up to 38 wt.%. To date the highest CaO content in olivines produced in igneous environments is 29.3 wt.% (Sahama and Hytönen, 1957). The kirschsteinites described in this study contain up to 36 wt.% CaO, close to the maximum found experimentally.

In the calculations of the mineralogical norms of a mineral, the Ca_2SiO_4 component is referred to as a larnite component, and the kirschsteinites analysed in this study are therefore larnitic kirschsteinites. The high amounts of the larnite component of the kirschsteinite crystals might be surprising in view of the different space groups of the two end-members. However, the Ca_2SiO_4 polymorph bredigite is isostructural with kirschsteinite and has a molar volume that differs by less than 3%.

The most Mg-rich kirschsteinite has a composition close to the Mo–Ki join ($\text{Mo}_{36}\text{Ki}_{61}\text{La}_3$). The kirschsteinites contain forsterite inclusions whose textures indicate that these have formed by exsolution (see Fig. 1C). The range in kirschsteinite compositions is consistent with initial compositions identical to those of the Mg-rich crystals, with subsequent forsterite exsolution driving compositions towards the Ki–La join at ($\text{Mo}_1\text{Ki}_{75}\text{La}_{24}$), as demonstrated in Fig. 2.

The existence of 'larnitic' kirschsteinite in these rocks probably reflects the extreme silica under-saturation of the parent magma ($\text{Si}/\text{Mg}+\text{Fe}+\text{Ca} = 0.59$), precluding the precipitation of clinopyroxene and forcing the solution of Ca into the olivine structure.

KEYWORDS: kirschsteinite, kimberlite, Kotakonda, Andhra Pradesh, India.

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