A newly discovered kimberlitic rock from Pakistan

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Abstract

This first report of the occurrence of a kimberlitic rock in Pakistan is supported by its field relations, textures and mineral chemistry. Linear dykes, lenses, conical and pipe-like bodies, plugs and sills intrude non-orogenic, early Jurassic limestone near the SW extremity of an Eocene-emplaced ophiolite on the transform-type Indian plate margin; far away from the stable Precambrian craton. The rock resembles 'micaceous kimberlites' petrographically and contains olivine, phlogopite, perovskite, chromian spinel, monticellite, chlorite, serpentine, calcite, apatite, pectolite, clinopyroxene, amphibole, nepheline, magnetite and titanomagnetite. The minerals and their microprobe analyses resemble those of kimberlitic rocks.

KEYWORDS: kimberlites, mineral chemistry, olivine, phlogopite, monticellite, perovskite, Baluchistan, Pakistan

Introduction

KIMBERLITES are rare but are important for a number of reasons: as a primary source of diamonds; as a source of unassimilated upper mantle sampled from its pathway during magma ascent and found as xenoliths of garnet lherzolite and eclogite; and as rocks formed by rapid ascent of highly mobile, fluidized gaseous solids originating more than 150 km deep, in areas of high pressure. Until now, no kimberlitic rocks have been described from Pakistan. Most of Pakistan is covered by the younger fold mountain belts. The stable portion of the Indian craton outcrops mostly in India where kimberlites occur and many are diamantiferous (e.g. Kresten and Paul, 1976). However, in Pakistan, this stable cratonic area occurs to a limited extent and is mostly alluvium covered.

In this communication, kimberlitic rocks are reported to occur in an area outside the craton. The identification of the rock as kimberlitic is based on its mode of occurrence, textures, structures and microprobe analyses. These features are compared to those displayed by already known kimberlitic rocks.

The area, about 60 km NE of Quetta city, stretches from 67°11′E to 67°13′E longitude and from 30°29′N to 30°30′N latitude. The rock is referred as the 'Spangar kimberlitic rock' after a mountain peak of the same name located (67°13′E; 30°29′30′N) on the east end of the area included in Fig. 1.

Geological setting

The kimberlitic sites are mostly, but not exclusively, the Precambrian cratonic areas. However, the kimberlitic area described here is away from the Indian craton, and lies in the Tethyan suture zone defined by a belt of ophiolites, formerly called the 'Axial Belt' region (Hunting Survey Corporation Ltd., 1960). The SW extremity of the Zhob Valley ophiolite (Ahmed, 1986) outcrops just north of this kimberlitic rock. The ophiolite, emplaced during Paleocene–early Eocene (Allemann, 1979) cuts across the Maastrichtian age Parh limestone formation. The kimberlitic rock intrudes the Shirinab formation of early Jurassic age. In this region, all the pre-Middle Jurassic rocks are considered to be non-orogenic. The kimberlitic rock outcrop is in the form of a cluster of small intrusive bodies, the majority being dykes. Others form lensoid, conical and pipe-like bodies, plugs and sills. The dyke-form-
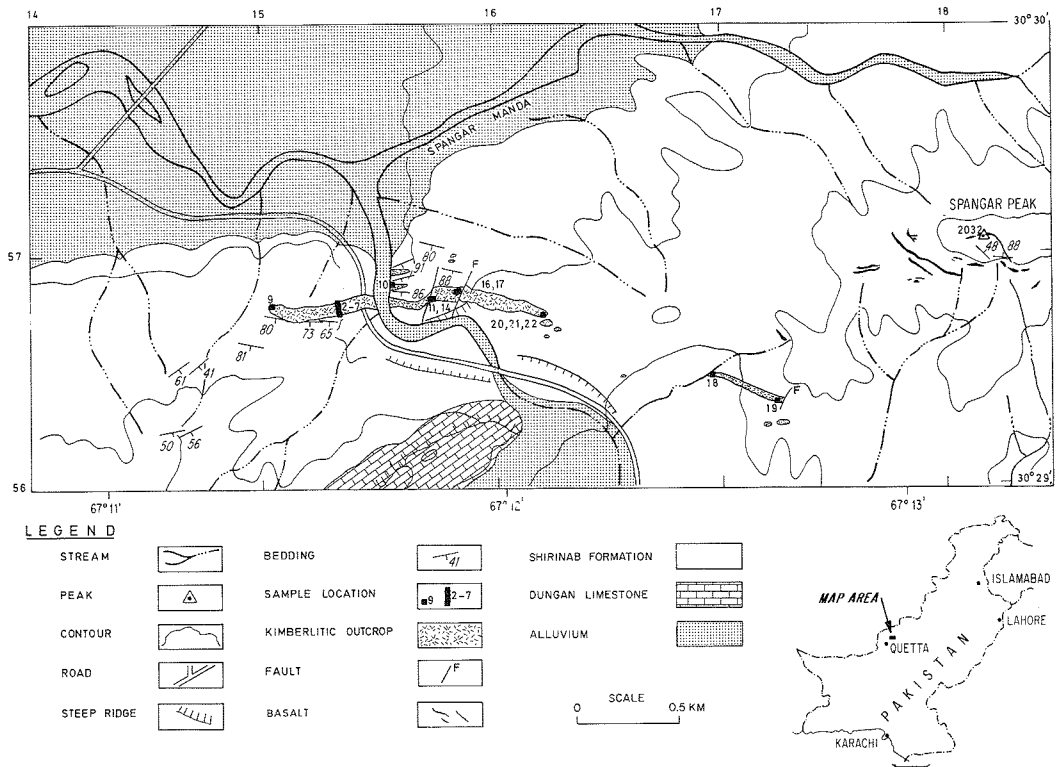
FIG. 1. Map showing location of the Spangar kimberlitic outcrops and the samples collected.

ing rock is more massive than the other forms of small outcrops which contain tuffs and breccias. The area has numerous faults, and is located in the northern part of the western, transform-fault bounded, marginal region of the Indian continental plate. The kimberlitic rock emplacement may be fault controlled. The faults and fractures in the area persist at depth, and trend parallel to the dykes. The host rock is mainly a grey, thin-bedded limestone with minor shale component. The dykes exhibit only slight baking, brecciation and metasomatic effects at the contact. Chilled margins are noticeable at some points. The weathering effects on the kimberlitic rocks are not as strong as generally observed (e.g. Ferguson, 1980) and the pristine mineralogy and chemistry of the rock is not obscured. However, brecciated material is abundant, as often found in the gas fluidized transported rocks. The presence of fragmental and tuffaceous rock indicates a turbulent and fluidized origin. The breccia may have formed by disruptive auto-brecciation.

Petrography

The rock displays conspicuously the porphyritic texture typical of kimberlites (Fig. 2). Even macroscopically, the inequigranular texture characteristic of kimberlites (e.g. Scott-Smith et al., 1984) is evident in all the outcrops. Among macrocrysts, olivine is the most abundant, followed by phlogopite. However, in parts, macrocrysts of phlogopite predominate over those of olivine. Monticellite and chromian spinel also form macrocrysts. Nepheline is present in very few samples. Pectolite laths are present in patches. Garnet megacrysts of andraditic composition are present; pyralspite garnet has not been found and may be restricted to xenoliths. Microscopic examination reveals some clinopyroxene crystals, but they remain to be confirmed by microprobe and XRD.

The groundmass is dark and fine textured and contains abundant perovskite in addition to second generation olivine and phlogopite. Two generations of olivine indicate kimberlites (Scott-Smith et al., 1984). There is abundant apatite and monticellite. Other groundmass minerals include
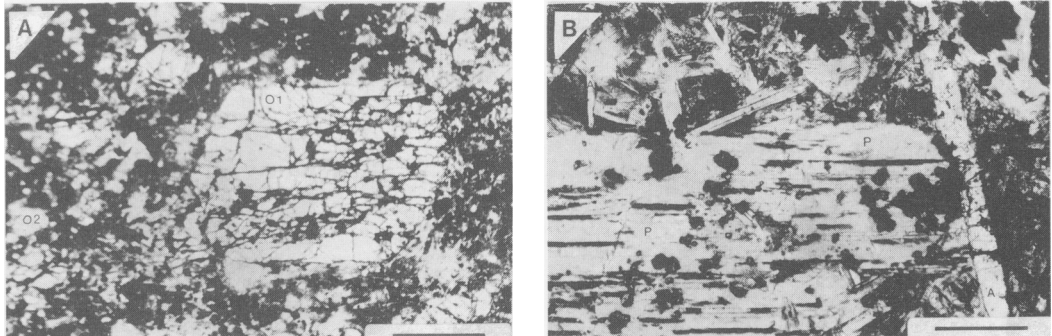
Fig. 2. (A) Photomicrograph showing the porphyritic rock with an olivine macrocryst (O1) surrounded by fine grained matrix containing, inter alia, second generation olivines (O2). Plane polarized light. Scale bar = 0.5 mm. (B) Photomicrograph with a phlogopite (P) macrocryst with abundant included perovskite (black euhedra) and a few apatite needles (A). Phlogopite also forms second generation, smaller flakes, in the matrix. Plane polarized light. Scale bar = 0.2 mm.

magnetite, titanomagnetite, serpentine, chlorite, calcite and pectolite. The rock is partly serpentinized and carbonatized. However, common olivine grains exhibit only slight alteration.

Petrographically, most of the samples are akin to the 'micaceous kimberlite' category, rather than the 'basaltic kimberlites'. Xenoliths of ultramafic rock occur in the kimberlitic rock, but are not yet characterized. So far, diamonds have not been found.

Olivine grains showing only a small amount of alteration are abundant. Unaltered grains of equant habit are common and show resorption on grain boundaries. Euhedral xenocrysts of olivine are also present. In some samples, partial to complete alteration is indicated as the grains are pseudomorphed by carbonate, serpentine and chlorite. Some unaltered olivine is mantled by alteration products.

Phlogopite is considered a characteristic mineral of kimberlites. Commonly, the kimberlites are known to contain 6 to 8% phlogopite, although higher amounts are also reported. For instance, 20 to 25% Mg-mica is present in the kimberlites of Bachelor Lake, Quebec (Watson, 1955); 27.2% in the Orroroo kimberlites (Scott-Smith et al., 1984) and 30 to 40% in the Blue Ball kimberlite (Salpas et al., 1986). Phlogopite is present in various samples of Spangar rock in amounts varying from 8 to 35%. It forms very coarse microcrysts, some of which are poikilitic. Most macrocrysts have rectangular sections. Grain embayments and fretted edges are common. Medium and fine-sized flakes or flaky aggregates are also abundant in the groundmass. The

phlogopite is pale brown and mildly but distinctly pleochroic in thin sections.

Monticellite is a common constituent of the Spangar kimberlitic rock and forms coarse equant grains bearing the curving cracks typical of olivine. The presence of monticellite also supports the kimberlitic nature of the rock as the kimberlitic–alnoitic group of rocks form one of the most important parageneses of monticellite.

Perovskite is present mostly as tiny euhedra. Some crystals are subhedral. All perovskite is fine grained, but in addition to its abundance in the groundmass, it is included in the phlogopite macrocrysts and is thus a part of the phenocrystic assemblage of the rock. Some inclusions in phlogopite occur in clusters. Perovskite is an important constituent of most kimberlitic rocks and has been found in the diamantiferous kimberlite pipes and breccias. A perovskite–melilite association is very common, but in the present set of samples, melilite is absent. This also points to the kimberlitic rather than the alnöitic nature of the Spangar rocks.

Pectolite laths are common in the Spangar rock and are not unexpected in a kimberlitic rock although pectolite is a Na-rich mineral. The mineral has been reported from mica peridotites (Franks, 1959), serpentinites (Deer et al., 1978) and alkaline igneous rocks such as tinguaite and microfoyaite (Shand, 1928). It was recorded from kimberlite in 1931 (Kruger, 1982) in addition to recent finds in kimberlites of Kimberley and Lesotho regions by Kruger (1982) and Scott-Smith et al. (1983). Pectolite in kimberlites may occur as apparently primary groundmass mineral crystallized from kimberlite magma modified by

TABLE 1. Microprobe analyses of olivine from the Spangar kimberlitic rock. All iron is assumed bivalent. mg = 100×Mg/(Mg+Fe^{2+}+Mn). In all analyses, zero values were found for TiO_2 and Cr_2O_3.

Analysis No.	1	2	3	4	5	6	7	8	9	10	11	12
Sample No.	Z2	Z2	Z2	Z3	Z4	Z5	Z5	Z5	Z7	Z7	Z14	Z16
SiO_2	39.64	39.99	40.37	39.99	39.95	40.02	40.58	40.18	40.05	39.77	40.45	40.24
Al_2O_3	0.10	0.09	0.07	0.00	0.18	0.23	0.08	0.09	0.00	0.00	0.00	0.11
FeO	11.21	11.14	8.84	9.23	9.12	9.67	8.78	9.05	10.44	9.04	10.63	10.56
MnO	0.14	0.20	0.29	0.22	0.31	0.00	0.28	0.25	0.12	0.00	0.32	0.17
MgO	47.24	47.43	48.38	48.02	47.96	48.85	47.99	48.42	47.49	48.30	47.83	47.87
CaO	0.08	0.00	1.46	0.45	1.17	0.09	1.23	0.12	0.00	0.43	0.14	0.51
NiO	0.37	0.26	0.00	0.27	0.18	0.25	0.08	0.20	0.22	0.26	0.12	0.13
Total	98.78	99.11	99.41	98.18	98.87	99.11	99.02	98.31	98.32	97.80	99.49	99.59

Number of ions on the basis of four (O) :

Si	0.993	0.997	0.996	0.999	0.993	0.991	1.003	1.000	1.002	0.996	1.001	0.996
Al	0.003	0.003	0.002	0.000	0.005	0.006	0.002	0.003	0.000	0.000	0.000	0.003
Fe	0.235	0.232	0.182	0.193	0.190	2.000	0.182	0.188	0.218	0.189	0.220	0.219
Mn	0.003	0.004	0.006	0.005	0.006	0.000	0.006	0.005	0.003	0.000	0.007	0.004
Mg	1.763	1.761	1.778	1.787	1.776	1.802	1.768	1.796	1.771	1.802	1.764	1.765
Ni	0.007	0.005	0.000	0.005	0.004	0.005	0.002	0.004	0.000	0.005	0.002	0.003
Ca	0.002	0.000	0.039	0.012	0.031	0.002	0.033	0.003	0.000	0.012	0.004	0.014
mg	88.11	88.18	90.44	90.02	90.06	90.01	90.39	90.30	88.91	90.51	88.60	88.78

digestion of, and reaction with, xenoliths; or, it may occur as a secondary mineral formed by metasomatic replacement. In the Spangar kimberlitic rock, pectolite forms discrete fresh crystals and as yet their spatial relation to digested xenoliths has not been observed. However, in an unmetamorphosed, sedimentary, accidental xenolith in a kimberlite pipe from Sierra Leone (Hubbard and McGill, 1982), rounded, compacted, polycrystalline aggregates made of unoriented, felted fibres and plates of pectolite are present in calcite matrix. Hubbard and McGill (1982) support a volcano-exhalative sedimentary origin for such pectolite.

Garnets of dark reddish brown colour in hand specimen are haphazardly distributed in the Spangar rock. Apatite is an abundant accessory, making up to 6% of the Spangar samples. It mostly forms colourless, fresh crystals of acicular to prismatic hexagonal habit.

Mineral chemistry

The mineral analyses were obtained on Cameca microprobe at the University of Chicago, Illinois, by EDS at 15 kV and 200 nA. Spots analysed were of 1 2 μm in size. Detection level for all elements was about 0.2 wt. %. The procedures of Reed and Ware (1975) were followed for background and peak counts; and of Bence and Albee (1968) for correction factors. Standards used were: P-140 olivine glass (Si, Mg, Ni); TiO_2 (Ti); anorthite glass (Al); CrO_2 (Cr); manganese hortonolite (Fe, Mn); diopside (Ca); asbestos microcline (K); and Amelia albite (Na).

Olivine. Electron microprobe analyses of forsteritic olivine are given in Table 1. TiO_2 and Cr_2O_3 were not found. NiO average is 0.2%, its range is from nil to 0.37%. Al_2O_3 does not exceed 0.23 wt. %, and is absent in most cases. Like most Mg-rich olivines, the Mn content is below 0.32 wt. % (Table 1). The CaO content is often small, and its rise to 1.46% is difficult to explain. Similar values, however, have been reported from kimberlite-related rocks (e.g. Deer *et al.*, 1982, Table 5). A triangular plot of analyses in the forsterite–fayalite–larnite system is shown in Fig. 3. In the forsterite–fayalite series, the forsterite component varies from 88.11% to 90.51%. This falls well within the usual compositional range of Fo_{95}–Fo_{85} for olivines from kimberlites (Deer *et al.*, 1982; Scott-Smith *et al.*, 1984). This olivine is slightly less magnesian than that found as inclusions in diamonds and which carries Fo_{92} to Fo_{95} and contains characteristic Cr, 0.02 to 0.09% (Deer *et al.*, 1982). The NiO/MgO distribution of olivine (Table 1) is similar to that of the upper mantle peridotites compiled by Fleet *et al.* (1977).

Phlogopite. Most of the phlogopite analyses (Table 2) show total lack of Mn. Al^{vi} and Ti show reciprocal variation. Al^{vi} varies from nil to 0.278. Ti varies from 0.21 to 0.66 atoms per formula unit, and the range of TiO_2 is rather wide (cf. Farmer and Boettcher, 1981, Fig. 5). The maximum amount of Na_2O is 0.47% and is low relative to phlogopite from other kimberlites (Deer *et al.*, 1962*a*). The high phlogopitic K/(K + Na) ratios (0.94, Table 2) resemble those of the garnet peridotite xenoliths in kimberlites, and not the spinel or plagioclase peridotites as given by Arai (1986).

TABLE 2. Phlogopite microprobe analyses from Spangar kimberlitic rock. All iron is considered bivalent.

Analysis No.	1	2	3	4	5	6	7
Sample No.	Z2	Z2	Z5	Z7	Z14	Z20	Z21
SiO_2	36.07	37.21	37.61	37.62	38.27	38.60	35.52
TiO_2	3.29	1.97	1.90	2.36	0.41	1.93	6.05
Al_2O_3	15.95	15.55	16.47	14.82	16.20	12.78	15.16
Cr_2O_3	0.00	0.00	0.00	0.00	0.14	0.00	0.00
FeO	6.13	6.10	3.88	6.14	5.04	8.05	4.78
MnO	0.00	0.00	0.00	0.00	0.00	0.00	0.25
MgO	21.60	22.18	23.32	22.51	23.58	22.88	22.93
NiO	0.10	0.11	0.00	0.10	0.00	0.12	0.09
CaO	0.00	0.00	0.00	0.08	0.06	0.00	0.13
Na_2O	0.35	0.36	0.47	0.36	0.19	0.24	0.28
K_2O	9.88	10.35	10.48	10.33	10.78	9.55	8.33
Total	93.37	93.83	94.13	94.32	94.67	94.15	93.52

Cations on the basis of 22 oxygens:

Si	5.315	5.455	5.432	5.490	5.523	5.664	5.171
Al^{iv}	2.685	2.545	2.568	2.510	2.477	2.210	2.601
Al^{vi}	0.085	0.142	0.235	0.039	0.278	–	–
Ti	0.364	0.217	0.206	0.259	0.045	0.213	0.662
Cr	0.000	0.000	0.000	0.000	0.016	0.000	0.000
Fe	0.755	0.748	0.469	0.749	0.608	0.988	0.582
Mn	0.000	0.000	0.000	0.000	0.000	0.000	0.031
Mg	4.742	4.845	5.019	4.894	5.071	5.002	4.974
Ni	0.012	0.013	0.000	0.012	0.000	0.014	0.011
Ca	0.000	0.000	0.000	0.013	0.009	0.000	0.020
Na	0.100	0.102	0.131	0.102	0.053	0.068	0.079
K	1.857	1.936	1.931	1.923	1.985	1.787	1.547
$100Mg/(Mg+Fe)$	86.26	86.63	91.45	86.73	89.29	83.51	89.03
$100 K/(K+Na)$	94.89	94.99	93.65	94.96	97.40	96.33	95.14

The phlogopite possesses Mg-rich composition with the ratio $Mg/(Mg+Fe^{2+})$ varying between 83.51 and 91.45%. Phlogopite contains very limited amount of annite, aluminous phlogopite or siderophyllite end-members.

In Fig. 4, the TiO_2 versus Al_2O_3 plot for the phlogopites after Scott-Smith and Skinner (1984) has been drawn to distinguish between the lamproitic and the kimberlitic phlogopites. The Spangar phlogopites plot in or adjacent to the kimberlites field, and on the side farther away from the lamproites field.

In general, these phlogopites have lower SiO_2 and higher Al_2O_3 than most known kimberlitic and mantle-peridotitic phlogopites (e.g. Boctor and Boyd, 1982; Farmer and Boettcher, 1981). In Table 2, analyses 1 to 5 contain sufficient $Si+Al$ to fill all the tetrahedral sites and chemically correspond with the phlogopites showing normal pleochroism as defined by Farmer and Boettcher (1981). Analyses 6 and 7 contain $Si + Al + Ti$ sufficient for the tetrahedral sites. Therefore, the Spangar phlogopites may be considered to have crystallized in kimberlitic rather than mantle-peridotitic environments as distinguished by Farmer and Boettcher (1981).

Monticellite. A representative monticellite analysis is reported in Table 4 showing the $Mg/(Mg + Fe + Mn)$ value of 79.54. This coexists with olivine of 90.02% Fo in the same sample (Table 1). The triangular plot with forsterite, fayalite and larnite end-members (Fig. 3) shows that the monticellite and olivine analyses plot with a tie line parallel to a constant fayalite content. The low Mn content of monticellite reflects that of the parent liquid. As Ca does not enter the Ml site, it is below 1 in the formula unit.

Perovskite. Shows a high content of lime and a low content of SiO_2 of the parent liquid of the kimberlitic rock. The EDS spectra does not show Na, *REE*, Th and Nb, which commonly substitute in the perovskite structure (Deer *et al.*, 1962b; Salpas *et al.*, 1986). Nb and *REE* are more frequently found in perovskites from carbonatites and leucite madupite lavas (Mitchell, 1972) than kimberlites. Analyses of perovskites are given in Table 4. The perovskite is poor in Na_2O and FeO. The lack of FeO substitution for Ti in kimberlitic perovskite has been shown to indicate its formation under reducing conditions (Mitchell, 1972). Both CaO and TiO_2 are high, and analytical totals exceed 98% (Table 4), indicating little substitution by other elements.
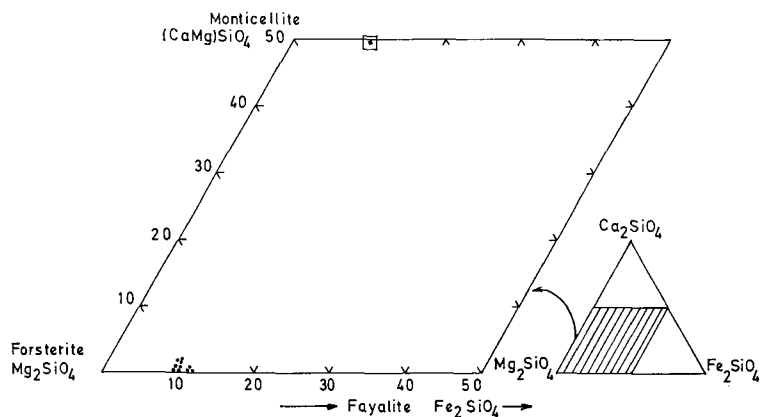
Chromian spinel. Chromian spinel is present

FIG. 3. Plot of olivine and monticellite compositions in the forsterite–fayalite–larnite triangle.

in three modes: (i) as opaque, usually anhedral, groundmass grains that are melt-derived and probably largely altered, (ii) as inclusions in phlogopite or olivine phenocrysts, and (iii) as rare, discrete, euhedral to subhedral grains, reddish brown and translucent in thin sections and bordered by crusts of black opaque 'ferritchromit' (Ahmed and Hall, 1981). Such grains in kimberlites may represent the groundmass grains, or the melt-derived xenocrysts. The composition of unaltered part of the third type of grains from one sample is represented in Table 3. It is a Cr-

TABLE 3. Microprobe analysis of chromian spinel from sample no. Z2, assuming RO = R_2O_3.

		Ions to 32 (O):	
SiO_2	0.34	Si	0.079
TiO_2	1.62	Ti	0.284
Al_2O_3	32.80	Al	8.984
Cr_2O_3	27.49	Cr	5.051
Fe_2O_3	8.06	Fe^{3+}	1.410
FeO	14.60	Fe^{2+}	2.838
MnO	0.13	Mn	0.025
MgO	14.99	Mg	5.193
NiO	0.27	Ni	0.050
CaO	0.00		
Total	100.30		

$100 \times Mg / (Mg + Fe^{2+})$	=	64.66
$100 \times Cr / (Cr + Al + Fe^{3+})$	=	32.70
$100 \times Al / (Cr + Al + Fe^{3+})$	=	58.17
$100 \times Fe^{3+} / (Cr + Al + Fe^{3+})$	=	9.13
$100 \times Cr / (Cr + Al)$	=	35.99
Fe^{2+} / Mg	=	0.55

ceylonite. Comparison with the chromian spinel trends summarized by Haggerty (1976) puts it in his field of 'kimberlite trend 2'. It also exhibits

the special features of kimberlitic spinels in that it continues to show relatively high MgO contents with increasing concentrations of Fe^{3+} + Ti. The composition is unlike spinels from alpine-type peridotites, in being relatively richer in Fe^{3+} + Ti, and in not being confined to the spinel prism base (Haggerty, 1976). With the exception of inclusions in diamonds (Haggerty, 1976), the high Al/Cr ratio indicates a high pressure regime attendant upon the crystallization of chromian spinel (e.g. Yamamoto, 1983). Similar composition are known from other kimberlites (e.g. Tompkins and Haggerty, 1985, Table 2; Pasteris, 1982).

The spinels from the Blue Ball kimberlite analysed by Salpas et al. (1986) occur in the first two types of the modes described above. Most spinels analysed by Tompkins and Haggerty (1985), however, differ in possessing higher Cr and Fe, and lower Mg and Al; and also they all belong to a finer grained population. The Spangar spinel is also different from the lamprophyric spinels (e.g. Platt and Mitchell, 1982). The upper mantle spinels from the Pakistani ophiolites generally do not contain such high TiO_2 and Al_2O_3 and such low Cr_2O_3 (Ahmed, 1982, 1986). The TiO_2 content of about 2% shown by the Spangar spinels is typical of kimberlitic spinels (Salpas et al., 1986).

Serpentine. The chemistry of serpentine (Table 4) indicates its secondary nature. The higher Na_2O compared to K_2O is unlikely for any primary kimberlitic serpentine, such as the one described by Mitchell and Putnis (1988). Its high CaO is probably related to the abundance of carbonates in the environment of serpentinizing solutions.

Pectolite. Analyses from two samples (Table 4) have been calculated assuming 6 cations per for-
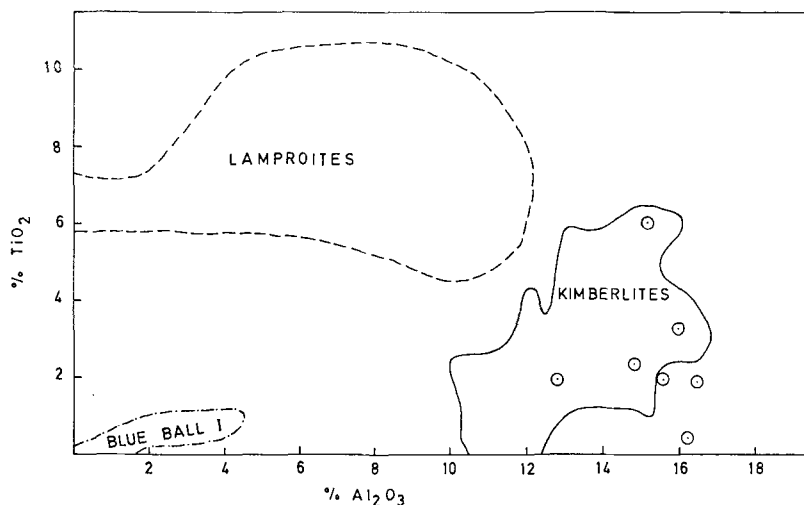
FIG. 4. Diagram of Al_2O_3 versus TiO_2 in phlogopites of Table 2 (circles) compared with fields of kimberlitic (solid line) and lamproitic (dashed line) phlogopites after Scott-Smith and Skinner (1984), and field of reversely-pleochroic micas from Blue Ball kimberlite (dash–dot line) after Salpas *et al.* (1986).

mula unit, following Papike (1987). The pectolite has very low MnO content and it is almost pure Ca end-member. There is no Mg, but one sample (anal.2, Table 4) contains exceptionally high FeO, as in similar analyses of kimberlitic pectolite by Scott-Smith *et al.* (1983).

Nepheline is very rare. Being rich in Na (Table 4), it is unusual for kimberlites; but may be explicable in a manner similar to that for the pectolite (Scott-Smith *et al.*, 1983).

Garnet. The microprobe analyses (Table 5), due to somewhat low analytical totals, might be taken to suggest that they are generally hydrous titanian andradites and may be named as andradite (anal. 1), Ti-rich hydroandradite (anal. 2,3) and 'hydromelanite' (anal. 4–6). Hydroandradites are known from very few occurrences worldwide. The TiO_2 content ranges from 0.71 to 5.64%. The kimberlitic garnets generally do not possess such compositions (Deer *et al.*, 1982). However, titanian garnets do occur in alkaline igneous rocks of low silica activity and serpentinites. Ti-rich hydroandradites of similar composition occur in metamorphosed ultramafic rocks of Sanbagawa area of central Japan (Onuki *et al.*, 1981). The crystal chemistry of Ti-rich hydroandradites is regarded as similar to that of Ti-rich andradites except the hydrous property of the former (Onuki *et al.*, 1982). This is supported by the association of both in the samples studied.

The three analyses from sample Z20 indicate considerable within-sample variation. Lower Fe^{3+} in one analysis (no. 4 in Table 5) is compen-

sated by higher Al and not Ti. H_2O in hydroandradites varies from 1 to 5.3 wt.% (Meagher, 1980). In the present occurrence, the H_2O content is 1 to 2%.

Apatite. One sample (Z21) was analysed giving 55.39% CaO, trace amounts of SiO_2, Cr_2O_3, MgO, NiO, Na_2O and K_2O. There was no TiO_2, Al_2O_3, FeO, MnO, SrO or *REE*. The *REE* and other large ion lithophile elements are known to be concentrated in apatite and in perovskite. The analyses showed the apatite to be devoid of the *REE*.

Discussion

Kimberlites mostly occur in the Precambrian cratonic areas of the continental crust. Diamantiferous ones occur in the old cratonic nucleii undisturbed for the past 2500 Ma (Dawson, 1971). The Spangar kimberlitic rock occurs far from the stable cratonic area of the Indian continental plate; and lies in the orogenic, NW marginal part of this plate, in the SW neighbourhood of a large ophiolite of the Zhob Valley region (Ahmed, 1986).

The Spangar kimberlitic rock is a new addition to the family of a few kimberlitic rocks known from terrains younger than the Precambrian. One such example is in southeastern Australia where post-Proterozoic kimberlites were emplaced by fractures related to the early stages (80–60 Ma ago) of transform faulting duringthe beginning of the separation of the Tasman Sea (Stracke *et al.*,

TABLE 4. Microprobe analyses of monticellite (1), perovskite (2,3), pectolite (4,5), serpentine (6,7) and nepheline (8). All iron is expressed as FeO except in nepheline.

Analysis No.	1	2	3	4	5	6	7	8
Sample No.	Z3	Z5	Z21	Z4	Z5	Z14	Z21	Z7
SiO_2	36.06	0.37	0.43	51.78	50.03	39.07	41.79	40.68
TiO_2	0.12	55.45	55.53	0.00	0.00	0.00	0.00	0.09
Al_2O_3	0.11	0.00	0.00	0.78	0.46	1.61	2.07	34.40
Cr_2O_3	0.11	0.26	0.12	0.09	0.12	0.10	0.00	0.00
Fe_2O_3	–	–	–	–	–	–	–	1.18
FeO	8.43	1.46	1.42	0.37	3.61	5.16	4.65	–
MnO	0.50	0.13	0.18	0.00	0.19	0.37	0.45	0.00
MgO	19.49	0.00	0.00	0.00	0.00	36.77	36.22	0.29
NiO	0.19	0.33	0.29	0.26	0.00	0.26	0.19	0.00
CaO	33.77	40.07	40.23	33.69	33.42	0.68	0.31	0.24
Na_2O	0.28	0.00	0.00	9.42	8.19	0.65	0.41	15.27
K_2O	0.06	0.06	0.11	0.10	0.18	0.05	0.04	8.67
Total	99.12	98.13	98.31	96.49	96.20	84.72	86.13	100.82
Formulae normalized to	4(O)	3(O)	3(O)	6 cations	6 cations	14(O)	14(O)	32(O)
Si	0.989	0.009	0.010	2.886	2.839	3.849	3.997	7.906
Al^{iv}	–	–	–	–	–	0.151	0.003	–
Al^{vi}	–	–	–	–	–	0.036	0.230	–
Al	0.004	–	–	0.051	0.031	–	–	7.879
Ti	0.002	0.970	0.969	–	–	–	–	0.013
Cr	0.002	0.005	0.002	0.004	0.005	0.008	–	–
Fe^{3+}	–	–	–	–	–	–	–	0.173
Fe^{2+}	0.193	0.028	0.028	0.017	0.171	0.425	0.372	–
Mn	0.012	0.003	0.004	–	0.009	0.031	0.036	–
Mg	0.797	–	–	–	–	5.397	5.162	0.084
Ni	0.004	0.006	0.005	0.005	–	0.021	0.015	–
Ca	0.993	0.998	1.000	2.011	2.031	0.072	0.032	0.050
Na	0.015	–	–	1.018	0.901	0.124	0.076	5.753
K	0.002	0.002	0.003	0.007	0.013	0.006	0.005	2.149

1979). In Pakistan, the biggest transform fault zone, called the Chaman fault, lies only about 100 km westwards from the Spangar kimberlitic rock outcrop. In this area, many faults occur (Hunting Survey Corporation Ltd., 1960). Some of those may be sufficiently deep-seated to be infilled by the kimberlitic rock. The country rocks of the Spangar kimberlitic rock are pre-orogenic, although the age of the kimberlitic rock itself is not yet determined. Such rocks are absent from rocks younger than middle Jurassic.

The field relations, textures, structures and mineralogical data described in the foregoing confirm the identification of the rock as a kimberlitic rock. The whole-rock major element chemistry of kimberlites is characterized by high variation ranges (e.g. Hall, 1987). This is due to many factors, such as the primary variation, presence of comminuted xenolithic material, and variations in the abundance of megacrysts and volatiles. Therefore, the present study does not rely on the whole-rock analyses. The mineral chemistry fully supports the rock to be rich in elements typical of kimberlites such as Ti, P, Cr, Mn, Mg, K and Ca. Deficiency in SiO_2 is also obvious, for example, from the abundance of perovskite and

absence of titanite. The abundance of phlogopite indicates K enrichment.

The Spangar kimberlitic rock is considered different from an alnöite, as melilite has not been found. Melilite is rare in kimberlites and kimberlitic magmas (Moore, 1983). Also, the presence of monticellite and serpentine in Spangar rocks distinguishes them from olivine-melilites in which these minerals are rare (Moore, 1983). A discrimination between alnöites and kimberlites on the basis of mica composition was made by Nixon et al. (1980) for the alnöitic rocks of Malaita, Solomon Islands, Melanesia. They found the alnöitic micas to be higher in Ti and Fe/(Fe + Mg). The phlogopite compositions of the Spangar rocks show variation that embraces both types of phlogopites, except the low Cr which resembles that of the alnöitic phlogopites. Some olivine analyses of Table 1 have a CaO content greater or equal to that from the alnöite suite of Nixon et al. (1980). However, the olivines in the Spangar rock suite have relatively higher MgO and lower FeO, and are not comparable.

In overall comparison of the mineral chemistry using criteria given by Nixon et al. (1980) for alnöitic rocks, the Spangar rock suite shows kimberlitic

TABLE 5. Garnet analyses. 1= Ti-bearing andradite; 2,3= Ti-rich hydroandradite; 4-6= hydrous melanite. Total iron is trivalent.

Analysis No.	1	2	3	4	5	6
Sample No.	Z16	Z3	Z21	Z20	Z20	Z20
SiO$_2$	36.00	33.52	33.08	33.30	33.19	32.66
TiO$_2$	0.71	1.48	1.91	3.59	4.65	5.64
Al$_2$O$_3$	6.69	7.19	6.25	10.88	7.23	6.86
Cr$_2$O$_3$	0.00	0.30	0.15	0.15	0.13	0.00
Fe$_2$O$_3$	20.79	19.32	20.33	13.04	16.65	16.58
MnO	0.00	0.00	0.00	0.00	0.10	0.13
MgO	0.07	0.00	0.00	0.00	0.00	0.00
NiO	0.00	0.24	0.15	0.20	0.08	0.12
CaO	35.09	35.21	35.30	36.20	35.26	35.50
Na$_2$O	0.00	0.00	0.00	0.00	0.00	0.00
K$_2$O	0.17	0.15	0.16	0.11	0.16	0.19
Total	99.52	97.41	97.33	97.47	97.45	97.68

Cations normalized to 12 oxygens :

Si	2.956	2.830	2.810	2.753	2.783	2.741
Al^{iv}	0.044	0.170	0.190	0.247	0.217	0.259
Al^{vi}	0.604	0.545	0.436	0.813	0.497	0.419
Cr	0.000	0.020	0.010	0.010	0.009	0.000
Fe^{3+}	1.285	1.227	1.300	0.811	1.051	1.047
Ti	0.044	0.094	0.122	0.223	0.293	0.356
Mn	0.000	0.000	0.000	0.000	0.007	0.009
Mg	0.008	0.000	0.000	0.000	0.000	0.000
Ni	0.000	0.016	0.010	0.013	0.005	0.008
Ca	3.086	3.184	3.213	3.206	3.167	3.191
K	0.018	0.016	0.017	0.011	0.017	0.020

features, although if melilite is discovered in future studies of these rocks then those parts of the rocks could be interpreted as alnöitic. The melilite may be thought of as having been originally present in some altered breccia kimberlite as proposed by Heinrich (1966), but at present it has not been observed in relatively unaltered rock.

In the kimberlites and associated alkaline ultramafics from southern Africa, McIver and Ferguson (1979) pointed out that olivine and pyroxene were the dominant fractionation phases during the early stages of kimberlite evolution, whereas the more evolved rocks showed olivine-dominated fractionation. The olivine dominated mineralogy of the Spangar rocks may be comparable to such more evolved kimberlites. Such comparison, however, may not hold good if one regards kimberlites as rocks without significant fractional crystallization (Dawson, 1971).

The composition of garnets in Spangar rocks (Table 5) does not conform to the pyrope–almandine species commonly found in kimberlites. However, the xenolithic garnet analyses, when available, may exhibit such compositions. The garnet presently found in the Spangar dykes is andradite, Ti-rich hydroandradite, or, 'hydromelanite'. Such compositions have been reported from kimberlitic rocks from elsewhere. The hydroandradites present in these samples do not form a part of the primary kimberlite mineralogy. They may have formed metasomatically or hydrother-

mally. Their patchy or haphazard distribution lends support to such origin.

The contact metamorphic effects outside the dyke walls perceptible in the field are slight baking and rare presence of globular structure showing the presence of an immiscible carbonate melt phase, similar to the texture described from the kimberlites of Alnö Island (Hall, 1987).

Conclusions

The occurrence of a kimberlitic rock from outside the stable cratonic area of the Indian continental plate is documented here for the first time. The rock displays features typical of kimberlitic rocks although it deviates in certain respects from the kimberlites sensu stricto. The majority of the outcrop at Spangar is as dykes, although smaller tuffaceous outcrops also occur. The porphyritic texture is prevalent and the rock belongs to the micaceous variety of kimberlitic rocks. In general aspect, the mineral assemblage and the mineral chemistry of the dominant phases in the Spangar rock is identical with those found in the kimberlitic rocks from other localities.

Acknowledgements

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