Neues Jahrbuch Miner. Abh. | 161 | 2 | 193–225 | Stuttgart, Oktober 1989

Lamproites and Kimberlites in India

By

B. H. Scott Smith, North Vancouver (Canada)

With 10 figures and 4 tables in the text

Smith, B. H. Scott: Lamproites and Kimberlites in India. – Neues Jahrbuch Miner. Abh. **161:** 193–225; Stuttgart 1989.

Abstract: New petrographic and mineral chemistry data are presented to show that the Majhgawan and Hinota pipes are olivine lamproite lapilli tuffs and not kimberlites as suggested elsewhere. These bodies, therefore, comprise a newly recognized province of diamondiferous olivine lamproites. Other intrusions in India have been proposed in the literature as being lamproites or kimberlites. Available information for these localities is discussed and, where possible, augmented by new data (Wajrakarur/Lattavaram, Angor, Jungel, Chelima). The Wajrakarur/Lattavaram bodies are classified here as kimberlites. Although two of these bodies appear to be extreme varities they do not represent a different rock type and are not lamproites. The Chelima and Gondwana coalfields dyke swarms could include lamproites. There are no data to support suggestions of other lamproites or kimberlites in India. This study highlights the need for further detailed petrological investigations of many of these localities.

Key words: Lamproite, kimberlite, diamond, lamprophyre, minette, India, Majhgawan, Wajrakarur, Lattavaram.

Introduction

Until recently, kimberlite was considered to be the only important, primary source of diamond. Various diamondiferous bodies in Australia, Arkansas, Zambia and the Ivory Coast, all of which were originally referred to as kimberlites, have now been shown to be lamproites (Jaques et al., 1984; Atkinson et al., 1984; Scott Smith & Skinner, 1984 a, b, c; Scott Smith et al., 1989; Mitchell, 1985; Bergman, 1987). Kimberlites and lamproites are distinct rock types exhibiting differences in near surface emplacement, petrography and petrology. These differences have both petrogenetic and economic considerations.

The occurrence of diamond in secondary deposits in India has been known since ancient times. The Majhgawan pipe in Madhya Pradesh (Fig. 1) was the first primary source of diamond to be recognized (Sinor, 1930). One important objective of this paper is to show that this and the nearby Hinota pipes, which are generally referred to as kimberlites are, in fact, lamproites. In the

0077-7757/89/0161-0193 $ 8.25

light of this conclusion, other bodies in India which have been proposed as either lamproites or kimberlites are reviewed, where possible in the context of new petrographic data (Wajrakarur/Lattavaram, Angor, Jungel, Chelima) and some preliminary mineral chemistry data (determined using an ARL SEMQ electron microprobe). The intrusions are described in order of the notation in Fig. 1. The definitions and classifications for lamproites are based on Scott Smith & Skinner (1984 a, c), Jaques et al. (1984) and Mitchell (1985) and for

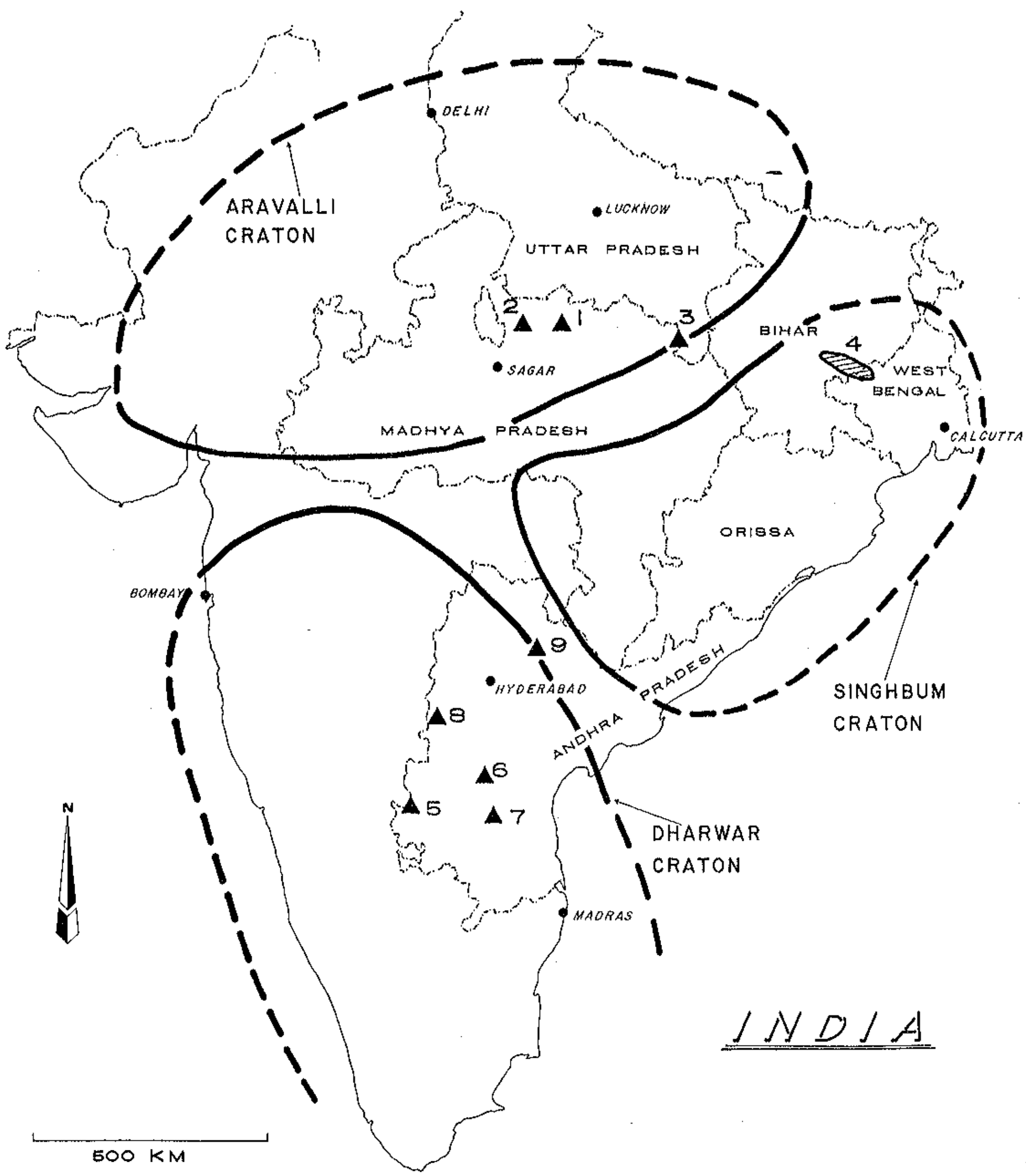

Fig. 1. Localities of suggested lamproites and kimberlites in India. Legend: (1) Majhgawan Mine and Hinota, (2) Angor, (3) Jungel, (4) Gondwana Coalfields, (5) Wajrakarur and Lattavaram, (6) Chelima, (7) Zangamrajupalle, (8) Maddur and (9) Warangal. Also shown are the cratons after Naqvi et al. (1974) but also see Fig. 18 a of Bergman (1987).

kimberlites on CLEMENT et al. (1984), SKINNER & CLEMENT (1979), CLEMENT & SKINNER (1985) and MITCHELL (1986).

Majhgawan and Hinota

The diamondiferous Majhgawan pipe occurs 25 km southwest of Panna in Madhya Pradesh (Fig. 1). The pipe, which was found by diggers before 1827 (HALDER & GHOSH, 1974), was known to be different from the nearby secondary diamond deposits, but it was only much later that it was recognized as a volcanic rock ("agglomeratic tuff"; SINOR, 1930). Majhgawan, a 9 ha pipe, underwent major exploitation during the period 1937–1964 and is currently in operation (BANERJEE & AGARAWAL, 1980). It is the only significant primary diamond deposit in India with reported grades of 8 to 15 cts/100 tonnes and an average stone size of 0.78 cts (BANERJEE & AGARAWAL, 1980; DESHPANDE, 1980). Hinota, about 3 km from Majhgawan, was discovered in 1959 (HALDER & GHOSH, 1974). Hinota is 2 ha in size with a grade of less than 1 cts/100 tonnes (DESHPANDE, 1978). These bodies have been referred to as kimberlites (e.g. MATHUR & SINGH, 1971) although differences from kimberlites elsewhere (e.g. those in South Africa) were often noted (e.g. GRANTHAM, 1964).

Majhgawan and Hinota intrude the Kaimur sandstone of the Proterozoic, lower Vindhyan Group which are thought to overlie Archaean basement of the Aravalli craton (Fig. 1). The Archaean Bundelkhand gneisses (2500 Ma) are exposed less than 10 km to the north. Upper Vindhyan sediments carry diamonds in the Panna area. Numerous age determinations have been made for Majhgawan and range from 840–1140 Ma (LOVERING in GRANTHAM, 1969; CRAWFORD, 1969; CRAWFORD & COMPSTON, 1970; MCDOUGALL in CRAWFORD & COMPSTON, 1973; PAUL et al., 1975). PAUL (1979) also gives a whole-rock Rb–Sr age of 1630 Ma. The single age determination for Hinota is 1170 Ma (PAUL et al., 1975).

Majhgawan is a circular body with a small pointed bulge to the west (e.g. HALDER & GHOSH, 1974). The pipe has been drilled to 120 m and has the shape of an inverted cone with contact dips of 70–75° (SINOR, 1930; HALDER & GHOSH, 1974). MATHUR & SINGH (1971) refer to different rock types as yellow-green pipe rock, dark coloured volcanic rock (below 27 m) and weathered tuffaceous material. The latter, which occurs in the bulge and along the north and northwest margins of the main pipe, is unworked because of lower diamond grades. Other variations in rock type, e.g. basaltic kimberlite and kimberlite breccia, both with and without phlogopite, are also noted (SINOR, 1930; HALDER & GHOSH, 1974). Hinota is a circular intrusion. A cross section suggests that it has a shallow (80 m) crater (HALDER & GHOSH, 1974). No mention of a bedded texture was found in the literature for either body.

Petrography and Mineral Chemistry

Majhgawan: The sixteen samples examined are similar. Most of them derive from the open pit, which is presumed to be the diamondiferous area of the pipe. One sample is from borehole core sample at 100 m. One of the samples was extensively altered, and cut by veins of secondary carbonate while the other samples are fresher. They all have macroscopic fragmental textures (typically the fragments are < 15 mm in size but range up to 40 mm) and are generally clast supported. The fragments are mainly igneous and have macrocrystic textures with olivine pseudomorphs set in a fine grained (often brown) groundmass. The occasional xenolith was observed. Microscopically, the igneous fragments have irregular shapes, are composed of abundant olivine pseudomorphs and a finer grained to glassy groundmass (Table 1). The glassy base and plastic deformation, albeit rare, of the fragments show that they are juvenile lapilli. The lapilli usually have macrocrystic textures (Fig. 2). The macrocrystal olivines (typically < 5 mm but occasionally up to 10 mm) are mostly anhedral and occasionally subhedral. They commonly have serrate margins which, in detail, are euhedral (Fig. 2) and probably represent imposed morphology (as discussed by SCOTT SMITH et al., 1989). Macrocrysts also occur as discrete grains between the lapilli. The second generation of olivine occurs as smaller (< 0.5 mm), generally euhedral grains which display both simple and complex shapes (Figs. 2 to 5). The latter suggest the presence of crystal aggregates. All the olivine is altered and has been predominantly replaced by pale green serpentine (Table 2) but other secondary products are present.

Two main varieties of groundmass occur (Figs. 2 and 3). The first is brown, turbid indiscernible material (Fig. 4) which contains innumerable, virtually cryptocrystalline laths of mica. This groundmass probably represents the incipient crystallization of glass. Occasionally the groundmass mica may be coarser grained (up to 0.5 mm). Vesicles may be present. The second type of lapilli has a clear, virtually isotropic, glassy base and typically contains abundant vesicles and slender needles of apatite (Figs. 3 and 5). Some vesicles are filled by serpentine (Table 2). In a few instances both varieties of groundmass were noted within the same lapilli. The compositions of the base in the two types of

Table 1. Modal analyses.

Pipe/sample	Majhgawan 1	Wajrakarur/Lattavaram P1/1	P2/2	P5/1
olivine	43.3	56.2	26.6	32.8
monticellite		14	36.4	9.6
phlogopite		9.8	1	19.8
oxides		7.7		6.8
perovskite		1.7		7.4
serpentine		6.1		5.4
carbonate		3.8		0.4
melilite				6.6
other	56.6		35	11.2

Majhgawan: 1 – single large juvenile lapilli as Fig. 2. "other" is glassy or cryptocrystalline groundmass. Wajrakarur/Lattavaram: P2/2 and P5/1 – "other" is indiscernible groundmass.

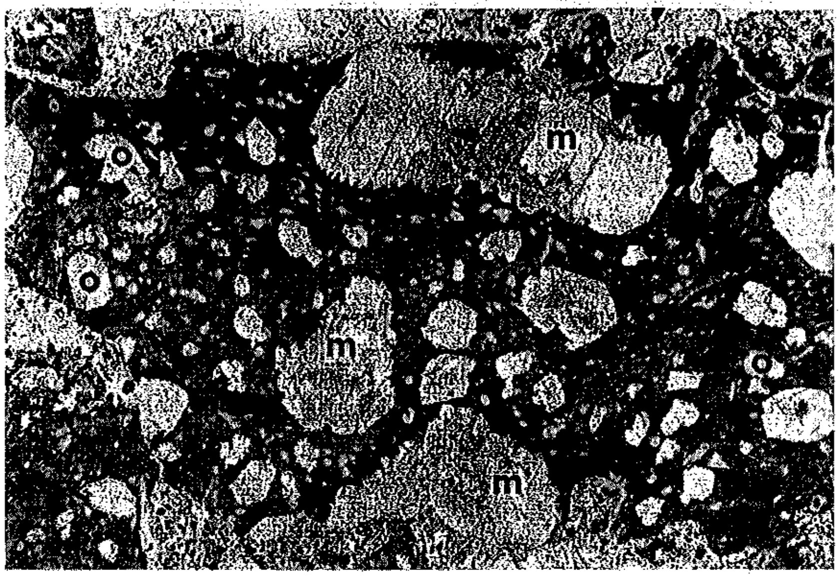

Fig. 2. Majhgawan lamproite. Sample 1. Field of view = 10 mm. PPL. Part of a large juvenile lapilli which is composed of two generations of altered olivine set in a dark brown, turbid, very fine grained groundmass. Olivines macrocysts (m) with an overall anhedral shape often have serrate (in detail euhedral) margins. Numerous smaller euhedral phenocrysts (o) are present and complex shapes often suggest that they are aggregates. Contrast the nature of the olivines with Fig. 8.

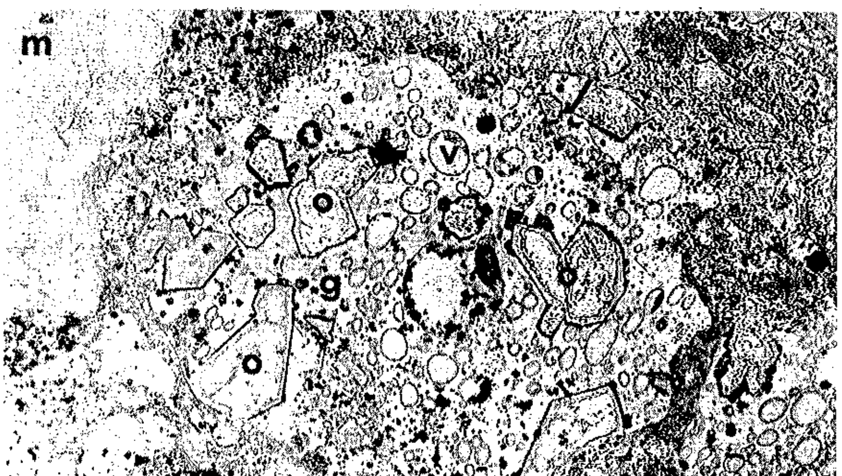

Fig. 3. Majhgawan lamproite. Sample 1. Field of view = 1.6 mm. PPL. A juvenile lapilli which is composed of olivine pseudomorphs set in a colourless, vesicular (v), glassy (g) groundmass. Contrast the nature of the groundmass with Fig. 2. The outlines of the olivines are highlighted by a necklace of secondary minerals. Note the complex shapes of the olivine phenocrysts (o). An olivine macrocryst (m) and another similar lapilli (bottom right) are also present.

juvenile lapilli (Table 2) are different. If the areas analysed are unaltered and representative of the magma, which seems likely, the data suggest that they are

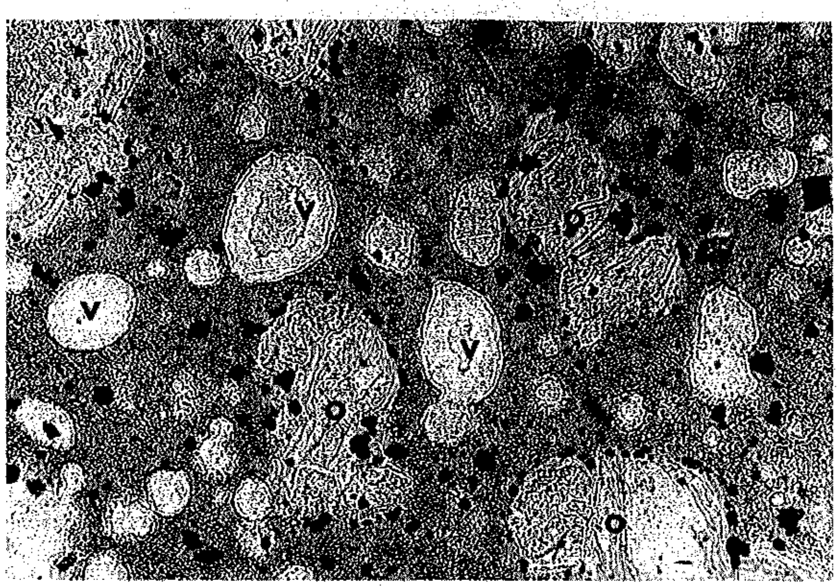

Fig. 4. Majhgawan lamproite. Sample 1. Field of view = 0.6 mm. PPL. Part of a juvenile lapilli with the dark, brown coloured groundmass. It contains pseudomorphs of olivine phenocrysts (o), vesicles (v), high relief perovskite, in an almost cryptocrystalline turbid groundmass in which minute laths of phlogopite can just be discerned. Contrast the nature of the groundmass with Fig. 5.

not only petrographically, but also compositionally, distinct. Presumably this reflects two episodes of eruption.

Scattered grains of phlogopite occur in both types of lapilli but in a few samples they are more common (Fig. 5). Rare discrete grains occur between lapilli. The phlogopite is generally pleochroic ranging from pale brown to a somewhat darker orange brown colour. Phlogopite occurs as macrocrysts (up to 4 mm), phenocrysts (up to 1.5 mm) and groundmass crystals (<0.05 mm). Most of the macrocrysts are anhedral to subhedral, in some cases rounded, plates and are generally distorted with undulose extinction. They are usually invaded along cleavage partings or occasionally totally replaced by secondary material which is generally opaque to translucent orangy red (?hematite of MATHUR & SINGH, 1971). Rare polycrystalline grains appear to be partially recrystallized. Some of the larger phlogopite grains have pitted cores (alteration, reaction, incipient melting?). The phenocrysts are typically slender laths (Fig. 5) which commonly display polysynthetic twinning. The groundmass mica, when discernible, is present as lath-like or more equant crystals.

The phenocrystal phlogopites (Table 2), with high TiO_2 and fairly low Al_2O_3 contents, fall outside the main field for kimberlites but are similar to micas from lamproites (cf. Fig. 7 of SCOTT SMITH & SKINNER, 1984 a; Fig. 6.3 of MITCHELL, 1986). Except for slightly higher TiO_2 values, they are similar to the phenocrysts in the juvenile lapilli from Ellendale in Western Australia (JAQUES et al., 1986) and Prairie Creek, Arkansas (SCOTT SMITH & SKINNER, 1984 a). They are different in composition from groundmass micas in olivine lamproites (e.g. JAQUES et al., 1986; SCOTT SMITH et al., 1989). Groundmass

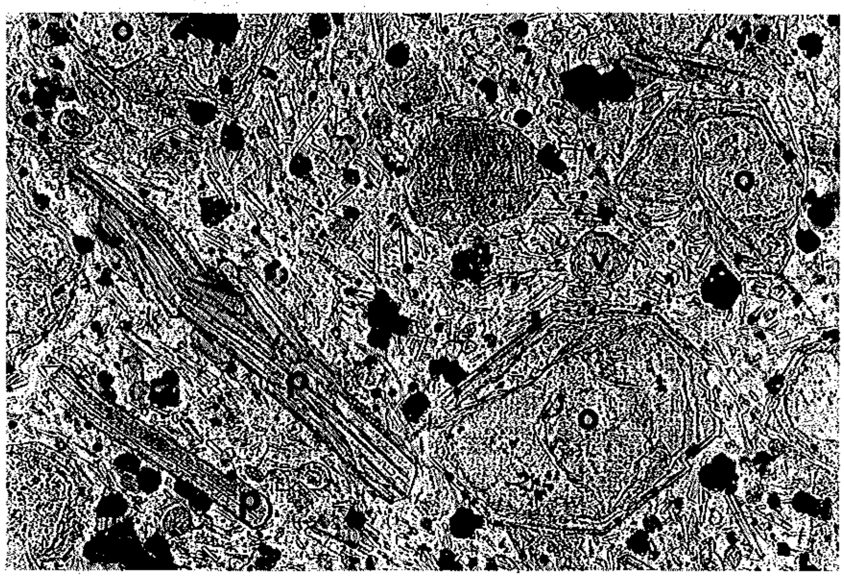

Fig. 5. Majhgawan lamproite. Sample 8. Field of view = 0.6 mm. PPL. Part of a juvenile lapilli. It is composed of microphenocrysts of altered, euhedral olivine (o) and phlogopite (p), fine grained acicular needles of apatite, high relief perovskite, the occasional vesicle (v) and a clear, colourless, glassy groundmass.

mica at Majhgawan is too fine grained to analyse using an electron microprobe.

Only minor differences in composition were found between the grains denoted petrographically as macrocrysts and phenocrysts. The phenocrysts and small crystals (neoblasts) within the recrystallized areas of polycrystalline macrocrysts have higher Cr_2O_3 (up to 1.24 wt.%), Al_2O_3 and TiO_2 contents than the macrocrysts. Paul (1980) notes the opposite variation in TiO_2 and Al_2O_3 between, what he terms, larger xenocrysts (macrocrysts?) and the smaller, subhedral groundmass grains (phenocrysts?). Limited published data are mostly similar to those presented here (Middlemost & Paul, 1984; Paul, 1980; Gupta et al., 1986) except for those of Naik (1985) which have, in particular, lower TiO_2 contents (0.87 – 1.64 wt.%).

Most lapilli contain small cubic, hexagonal or star-like (<0.1 mm) grains which are pale grey, colourless or turbid, have high relief and moderately high birefringence. They are distributed uniformly throughout the sample or occur within, or form necklaces around, olivine pseudomorphs. Some of these high relief grains are composed of approximately 95 wt.% TiO_2 and are therefore probably anatase (perhaps hydrated). These grains could be secondary after perovskite. In one sample a second unidentified high relief, yellowish mineral occurs as overgrowths on the probable anatase perhaps indicating a more complex original mineralogy. Rare, small spinels occur. Some opaque material is manganoan ilmenite. Minor secondary carbonate was noted in a few samples.

The nature of the matrix between the lapilli is difficult to discern but in some cases it is composed of serpentine-like material. Occasionally it has a glassy appearance and contains minerals which resemble those found within the lapilli (olivine, altered perovskite, spinel). This suggests that such a sample is an autolithic breccia. In another instance clinopyroxene microlites occur within the serpentine matrix (suggesting crystallization from later related fluids?). Serpentine which occurs in olivine pseudomorphs, infilled vesicles and the matrix between lapilli is similar in composition (Table 2).

Many of the petrographic features discussed above have been noted previously (e.g. MATHUR & SINGH, 1971). Other minerals, not noted in this study, have been referred to in the literature (mainly for Majhgawan). These include possible melilite, fresh olivine (MATHUR & SINGH, 1971), rare perovskite, rutile, spinels (Mg–chromite), titanomagnetite, baryte, pectolite and dolomite (MIDDLEMOST & PAUL, 1984; GUPTA et al., 1986). Pyrope garnet is noted as being rare (GRANTHAM, 1964; 1969; MATHUR & SINGH, 1971). Magnesian ilmenite is reported as being absent by GRANTHAM (1964, 1969) while MIDDLEMOST & PAUL (1984) report some high Cr_2O_3 (2.5–6.8 wt.%) and high MgO (14.5–16.2 wt.%) ilmenite. Other, probably secondary, minerals reported include illite, talc (DAS GUPTA & PHUKAN, 1971), vermiculite, chlorite, smectites and calcite (KRESTEN & PAUL, 1976). Calcite only occurs as secondary veins in near surface samples (MATHUR & SINGH, 1971; PAUL, 1980).

Hinota: The nature of the seven samples (including borehole core from 96 m) examined from Hinota are all broadly similar to those from Majhgawan. The samples are generally more altered, including extensive carbonatization. The juvenile lapilli are similar to those at Majhgawan. They usually have macrocrystic to porphyritic textures but the olivine pseudomorphs, notably the macrocrysts, are less abundant than at Majhgawan but do exhibit similar morphologies. Coarser mica occurs but is not common. It has a distinctive orange-brown colour and displays polysynthetic twinning. Possible sanidine was observed in one instance. Parts of two altered samples appear to be composed of glass shards suggesting the presence of glassy ash material. In addition KRESTEN & PAUL (1976) note vermiculite, chlorite and smectites which are probably secondary minerals.

Discussion

The petrographic classification of these samples is problematic because of their glassy nature and the resulting paucity of primary groundmass minerals. Majhgawan and Hinota have been termed kimberlites in many publications based mainly on the occurrence of diamond, the abundance of olivine and ultramafic geochemistry. Various petrographic features at Majhgawan and Hinota, however, are different from those found in kimberlites. Glass and, in particular, scoriaceous juvenile lapilli have not been observed in kimberlites but are typical of lamproites (compare Fig. 3 with Fig. 3 of SCOTT SMITH & SKINNER, 1984 a and Fig. 30 A of JAQUES et al., 1986). Two generations of olivine as found at Majhgawan and Hinota occur in both kimberlites and olivine lamproites. Generally in kimberlites the olivine macrocrysts are

Table 2. Some mineral analyses from Majhgawan.

	Phlogopite							Glassy base		Serpentine		
Anal. No.	80–213	80–214	80–222	80–223	80–224	80–225	80–226	80–231	80–219	80–208	80–227	80–216
SiO_2	39.68	39.73	40.13	39.29	39.90	38.85	39.19	36.64	41.88	41.40	38.28	40.72
TiO_2	6.37	6.85	6.20	5.33	6.01	7.24	6.95	4.24	0.15	0.38	0.45	0.53
Al_2O_3	12.26	12.61	11.97	10.97	12.02	12.81	12.40	5.92	3.62	1.29	2.77	1.83
Cr_2O_3	nd	0.32	nd	nd	nd	1.24	0.84	nd	nd	nd	nd	nd
FeO	4.70	4.38	4.75	6.74	4.78	4.53	4.76	7.80	6.81	6.30	7.18	7.03
MnO	0.02	0.03	0.04	0.06	0.02	0.03	0.04	0.08	0.06	0.05	0.06	0.05
NiO	0.09	0.14	0.11	0.07	0.08	0.13	0.11	0.06	0.12	0.04	0.08	0.02
MgO	22.32	22.11	22.76	23.90	23.21	21.22	21.78	22.74	30.44	38.31	30.40	37.61
CaO	0.01	nd	nd	0.05	nd	0.02	0.03	5.37	0.13	0.02	4.11	0.04
Na_2O	0.09	0.06	0.09	0.08	0.08	0.08	0.08	0.07	0.04	0.02	0.05	0.01
K_2O	10.32	10.52	10.55	9.09	10.18	10.16	10.36	5.81	0.11	0.01	0.37	0.02
Total	95.86	96.75	96.60	95.58	96.28	96.31	96.54	88.73	83.36	87.82	83.75	87.86
Mg/(Mg+Fe)	0.894	0.900	0.895	0.863	0.897	0.893	0.891					

Legend: nd – not detected. 80–213 – centre of main crystal within 3 mm polycrystalline, deformed macrocryst with pitted core; 80–214 – 0.5 mm lath within macrocryst 80–215; 80–222 – centre of 0.6 mm plate with undulose extinction and pitted core, macrocryst; 80–223 – edge of 80–222; 80–224 – centre of 1 mm subhedral plate with undulose extinction and pitted core, macrocryst; 80–225 – centre of 0.6 mm lath, phenocryst; 80–226 – centre of 0.3 mm lath, microphenocryst; 80–231 – brown coloured fine groundmass containing numerous microlites of mica within a juvenile lapilli; 80–219 – clear, isotropic glassy base of another lapilli; 80–208 – serpentine after olivine; 80–227 – possible serpentine-like matrix to lapilli; 80–216 – centre of infilled vesicle in same lapilli as 80–219.

anhedral and rounded and the phenocrysts have simple euhedral shapes (e.g. Fig. 8 this paper; Fig. 2.1 of Mitchell, 1986; Fig. 2 of Scott Smith et al., 1984; Fig. 13 a of Clement et al., 1986). The complex shapes of the olivine macrocrysts (probably imposed morphology) and phenocrysts (crystal aggregates) at Majhgawan and Hinota are typical of lamproites (cf. Fig. 2 of this paper with Fig. 2.8 of Mitchell, 1986; Fig. 1 of Scott Smith & Skinner, 1984 a; Fig. 2 of Scott Smith & Skinner, 1984 b; Fig. 80 D of Jaques et al., 1986). Also, polysynthetically twinned mica is unusual in kimberlites.

All the petrographic features of Majhgawan and Hinota, including those that are atypical of kimberlites, are similar to those of the crater-facies rocks found in olivine lamproites from Ellendale and Argyle in Western Australia (Jaques et al., 1986), Prairie Creek in Arkansas (Scott Smith & Skinner, 1984 a) and Kapamba in Zambia (Scott Smith & Skinner, 1989). The mineral compositions support classification of these bodies as lamproites.

No new whole-rock analyses were obtained during this study because of the lack of suitable material. Data are given for Majhgawan and Hinota by Sinor (1930), Mathur & Singh (1960), Mathur (1962), Paul et al. (1975), Middlemost & Paul (1984 – average only) and Gupta et al. (1986). The major element data (e.g. high MgO up to 27.4 wt.% and low Na_2O <0.6 wt.%) are similar to both kimberlites and olivine lamproites although the low CO_2 values are more characteristic of lamproites. The samples with high CO_2 contents (up to 10 wt.%) may represent altered surface samples. Some of the trace element data, albeit sparse, suggest that the rocks may be lamproites (e.g. 1174–2035 ppm Sr, 1033–1649 ppm Zr, 210 ppm Nb, 3634–27300 ppm Ba and high La, Ce, Nd; Gupta et al., 1986; Middlemost & Paul, 1984) when compared to data for other kimberlites and lamproites (cf. Table 6 of Bergman, 1987).

The samples examined from Majhgawan and Hinota are therefore termed *glassy olivine lamproite lapilli tuffs* although some autolithic breccias may be present. Crater-facies lamproites elsewhere typically contain abundant xenolithic material, generally as single grains of quartz. In contrast, at Majhgawan and Hinota xenolithic material is a very minor constituent of the samples examined here but Mathur & Singh (1971) note that accidental inclusions (up to 10 cm in size) are often encountered. Most of the samples from Majhgawan examined here probably compare with the "dark coloured volcanic rock" (below 27 m) of Mathur & Singh (1971) who also classified the rocks from Majhgawan as tuffs, albeit tentatively. The one altered sample derives from the upper part of the pipe (12 m) and corresponds to the "yellow-green pipe rock".

Angor

This body is located near Angor about 100 km west of Majhgawan in Madhya Pradesh (Fig. 1). It has been referred to as a diamondiferous kimberlite (Puri, 1972). The intrusion is 400 × 200 m in size (Nane, 1971; Puri, 1972; Mathur, 1981). It intrudes the Archaean Bundelkhand granite on the Aravalli craton (Fig. 1). Dolerite dykes occur in the immediate area of Angor. NANE (1971) reports that 1000 tonnes of material produced no diamonds while PURI (1972) and MATHUR (1986) note the recovery of a few diamonds and DESHPANDE (1978) reports a grade of 0.67 cts/100 tonnes.

Petrography

The five samples examined are extensively altered, carbonatized and veined. Secondary quartz, serpentine and iron oxides were noted. Patches of secondary carbonate probably represent olivine pseudomorphs (up to 4 mm) which make up 40–50 modal % of the rock. Interstitial areas largely consist of fan-like aggregates of an acicular mineral which displays a quench (or spinifex-like) texture. Probable spinel and altered pyroxene? also occur in these areas.

Angor was first reported by JHINGRAN & PURI (1956) who noted a similarity with Majhgawan and it was therefore referred to as a kimberlite (PURI, 1972). NANE (1971) reported that Angor is composed of olivine, augite, enstatite with minor magnetite and ilmenite. Olivine and pyroxene occur in approximately equal proportions. MATHUR (1981, 1986) suggests that Angor is not a kimberlite but a peridotite–pyroxenite–gabbro complex.

Discussion

The samples examined in this study are altered ultramafic rocks. Olivine, although abundant and coarse grained, does not occur as the two generations typical of kimberlites and olivine lamproites; namely anhedral macrocrysts and smaller euhedral phenocrysts are not present. Although the primary nature of the interstitial areas is not understood, features such as the spinifex-like textures, are not observed in kimberlites or lamproites. Also abundant enstatite and abundant coarse-grained augite as reported by NANE (1971) do not occur in kimberlites or lamproites. Angor, therefore, is considered not to be a kimberlite or lamproite. It is not possible to classify the rock with the information presented here but the observed features are more consistent with the suggestion of MATHUR (1981, 1986) that Angor is a layered peridotite–pyroxenite–gabbro complex.

Banda

HUKKU (1971) reports evidence for volcanism about 100 km northeast of Majhgawan. He notes a similarity of "calc-tufa" deposits in the suspected calderas with kimberlites in South Africa and at Majhgawan. None of the information presented supports the suggestion that these rocks have kimberlitic or lamproitic affinities.

Jungel

The Jungel bodies occur close to the border of Uttar Pradesh and Madhya Pradesh in NE India, about 280 km east of Majhgawan (Fig. 1). The occurrence of kimberlitic rocks at Jungel was first suspected by TEWARI (1971). Jungel has been referred to as a kimberlite (e.g. CHATTOPADHYAY & VENKATARAMAN, 1977) and as a possible lamproite by J. B. DAWSON (public communication; Fourth International Kimberlite Conference, Perth, 1986). Most publications refer to four oval pipes occurring in a linear E–W arrangement; Jungel 1, Jungel 2 (100 × 200 m), Jungel East (900 × 300 m) and Jharkarua (KRISHNA MURTY, 1980). Some authors refer to a fifth pipe Jharkarua 2 in the west (CHATTOPADHYAY & VENKATARAMAN, 1977). The Jungel bodies occur close to the margin of the Aravalli craton. BALASUBRAHMANYAN et al. (1978) report on age of 919 ± 21 Ma (Jungel 2). In 1973 a diamond exploration project was initiated (BEHAL & SRIVASTAVA, 1980). Two diamonds are reported from plug 2 (KRISHNA MURTY, 1980) but none from plug 1 (from which at least a total of 2026 tonnes was treated; TYAGI, 1980). Possible Mg–ilmenite (CHATTOPADHYAY & VENKATARAMAN, 1977) and garnet, probably spessartine–almandine (CHATTOPADHYAY & KUMAR, 1977) are mentioned.

Petrography

The five samples examined are metamorphosed and altered. They are now composed predominantly of chlorite, talc, tremolite, carbonate and mica. This mineralogy was confirmed by X-ray diffraction which also showed that feldspar and zeolite were present. Rare possible primary olivine pseudomorphs were observed in only one sample (Jungel 2).

CHATTOPADHYAY & KUMAR (1977) report that serpentine (53 modal%), which occurs as a groundmass mineral and in olivine pseudomorphs, and calcite (17 %) are the dominant minerals. Opaque minerals, tremolite–actinolite, chlorite, magnetite, ilmenite, fine mica, a few Cr- and red-spinels, trace perovskite, talc, pyrite and glass are also noted. KRISHNA MURTY (1980) reports a similar mineralogy but also notes the presence of epidote, sphene, almandine–spessartite garnet and pseudomorphs of clinopyroxene phenocrysts. Spherulitic, porphyritic, porphyroclastic, glassy and tuffaceous to agglomeratic textures are described.

Discussion

The rocks examined (four samples from pipes 1, 2 and 5) display no affinities with kimberlites or lamproites. For example, they lack the macrocrystic textures, two generations of olivine and finer grained igneous groundmass that are diagnostic of kimberlites or olivine lamproites. Abundant chlorite and tremolite–actinolite, even of secondary origin, are unusual minerals in kimberlites or lamproites. If the reported diamonds were derived from such rocks, their occurrence would be extremely unusual. The rocks are more likely to be metavolcanic rocks. Perhaps parts of the Baiwar group, which form the country rock and contain volcanic rocks, have been misidentified as kimberlite.

Gondwana Coalfields

Numerous dykes and sills (up to 2 m wide) occur in the Permian to lower Cretaceous Gondwana Coalfields near Bokaro, Jharia and Raniganj in the Damodar Valley (Bihar and West Bengal; Fig. 1). They have been described by numerous authors (e.g. HOLLAND, 1894; HOLLAND & SAISE, 1895; FOX, 1930; CHATTERJEE, 1937; GHOSE, 1949; BANERJEE, 1953; MUKHERJEE, 1961; SARKAR et al., 1980; PAUL & SARKAR, 1986; GUPTA et al., 1983; MIDDLEMOST et al., 1988). The dykes show considerable variation within individual intrusions, between intrusions of each province and between the provinces. They are reported to range from ultrabasic mica-peridotite (olivine, mica, alkali feldspar, apatite) through lamprophyres (minettes, kersantite, vogesite) to micro-syenite (leucite, orthoclase, albite, apatite). MUKHERJEE (1961) reports a single dyke which is zoned from olivine lamprophyre in the centre to feldspathic lamprophyre to micro-syenite near the contact, suggesting that the different rock types are co-eval. They appear to have been emplaced between 121 and 105 Ma (data for lamprophyric samples only, SARKAR et al., 1980).

Some of these dykes have been suggested to be lamproites (PAUL & SARKAR, 1986; BERGMAN, 1987; MIDDLEMOST et al., 1988). The occurrence of priderite, potassium feldspar, titaniferous phlogopite (up to 9.8 wt.% TiO_2; GUPTA et al., 1983; MIDDLEMOST et al., 1988), amphibole (pleochroic from claret red to straw yellow), leucite and a glassy base (HOLLAND, 1894) support the suggestion that some of these dykes may be lamproites. BERGMAN (1987) notes that the leucite-bearing dykes, which are more mafic than typical minettes, are similar to lamproites but have unusually high TiO_2, P_2O_5 and CO_2. Features inconsistent with the classification of the Gondwana lamprophyres as lamproites are the reported occurrence of primary plagioclase (e.g. PAUL & SARKAR, 1986), quartz (GHOSE, 1949), carbonate (e.g. GUPTA et al., 1983), ilmenite (BANERJEE, 1953) and rutile (GUPTA et al., 1983). These dykes are complex and obviously deserve re-examination in light of the suggestion that some may be lamproites. Other lamprophyres occur in India (e.g. PAUL & SARKAR, 1986; DESSAI, 1987) but do not appear to show any particular lamproitic affinities.

Wajrakarur and Lattavaram

Several intrusions, referred to as pipes 1 to 8 (Fig. 6), occur in the vicinity of Wajrakarur and Lattavaram in Andhra Pradesh on the Dharwar craton (Fig. 1). The first pipe, probably discovered in the late 19th century (CHAPPER, 1880 cited by MURTY et al., 1980; LAKE, 1890; FOOTE, 1889) was not classified as kimberlite until 1966 by RAO & PHADTRE. Pipes 2, 3, 4 and 5 were discovered in the 1960's by the Geological Survey of India and more recently pipes 6, 7 and 8 were found (MURTY et al., 1980; GUPTASARMA et al., 1986; SUBRAHMANYAM & PURI, 1986 respectively). A variety of ages have been obtained for these bodies (Table 4) ranging from 840 to 1505 Ma (PAUL et al., 1975; 1979; MEHNERT in BASU & TATSUMOTO, 1979). All these bodies are generally referred to as kimberlites but

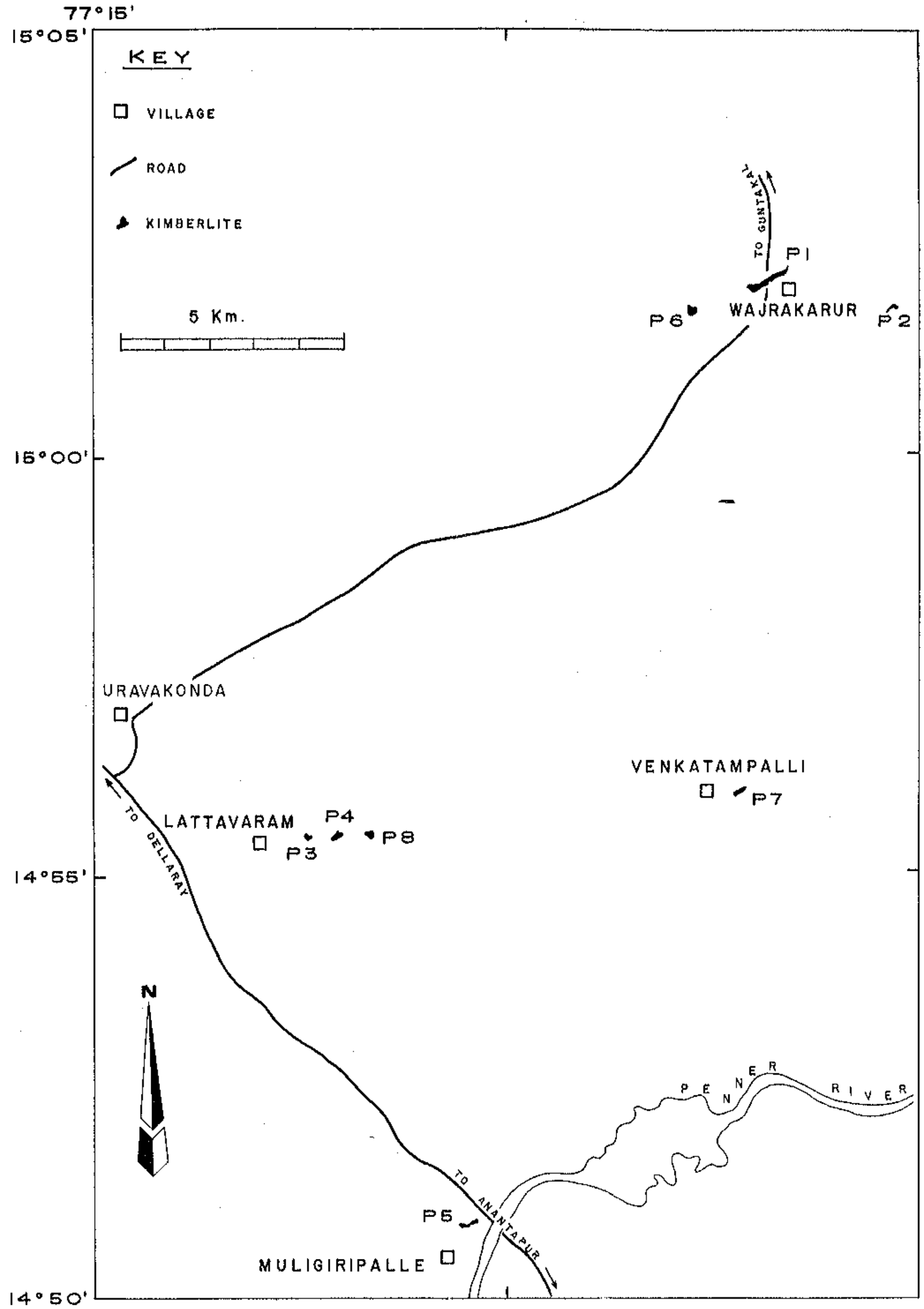

Fig. 6. Location of the kimberlites near Wajrakarur and Lattavaram, Andhra Pradesh (after GUPTASHARMA et al., 1986; NAGABHUSHANAM & VENKATANARAYANA, 1985; SUBRAHMANYAM & PURI, 1986).

recently it has been suggested that pipes 2 and 5 are lamproites (REDDY, 1987). Very little information and no samples are available to the author for pipes 7 and 8 and they will not be discussed further.

Apparently all of the bodies are less than 5.5 ha in size, except for Pipe 1 which is the largest at 19.4 ha (NAGABHUSHANAM & VENKATANARAYANA, 1985;

REDDY, 1987; GUPTASARMA et al., 1986; SUBRAHMANYAM & PURI, 1986). Pipe 1 might comprise four coalesced pipes (RAO & PHADTRE, 1966). Some contradictory data (e.g. pipe sizes) are reported elsewhere (e.g. MURTY et al., 1980). The bodies are mostly composed of hypabyssal-facies rocks but breccias (e.g. REDDY, 1987) and tuffs (KARUNKARAN et al., 1976) have been described. Rocks containing up to 60 % xenoliths are reported (MURTY et al., 1980; KARUNKARAN et al., 1976).

Pipes 1, 3, 4 and 6 appear to be diamondiferous (NAGABHUSHANAM & VENKATANARAYANA, 1985; REDDY, 1987) while pipes 2 and 5 appear to be barren. MURTY et al. (1980) notes (1) grades for pipes 1 and 6 of up to 2 and 3 cts/100 tonnes respectively, (2) that pipe 3 is poorly diamondiferous and (3) that the material from pipes 2 and 5 was too hard to treat. Diamonds are reported from pipe 8 (SUBRAHMANYAM & PURI, 1986) but there is no information for pipe 7. Pyrope garnet and chrome diopside occur in all the pipes but garnet is rare in pipes 2 and 5 (MURTY et al., 1980; REDDY, 1987). The garnets from pipes 1 and 6 include G9 and a few G1 varieties (GUPTA et al., 1986; classification of DAWSON & STEPHENS, 1975; 1976). Ilmenite occurs as rounded macrocrysts (AKELLA et al., 1979).

Mantle-derived xenoliths are present in pipes 1, 3, 4 and 6 but absent or rare in pipes 2 and 5. The xenoliths include harzburgite and lherzolite (both ± garnet and phlogopite), garnet wehrlite, dunite, olivine clinopyroxenite, eclogite and richterite-, ilmenite- and/or chromite-bearing rocks (RAO & PHADTRE, 1966; AKELLA et al., 1979; NEHRU & REDDY, 1986; REDDY, 1987; GANGULY & BHATTACHARYA, 1987). Most of the nodules have granular textures but sheared examples are recorded. Geothermometry and geobarometry suggests that they have originated within the diamond stability field (GANGULY et al., 1983 – 125 to 200 km; NEHRU & REDDY, 1986 – up to 225 km; GANGULY & BHATTACHARYA, 1987 – 100 to 185 km).

Petrography and mineral chemistry

Pipe 1 or Wajrakarur 01: There are two distinct rock types among the samples examined. The first is an extensively altered hypabyssal-facies rock. It has a macrocrystic texture typical of kimberlite (sensu stricto; after CLEMENT & SKINNER, 1985). Altered olivine occurs as both macrocrysts (up to 6 mm) and phenocrysts. Discernible primary groundmass minerals are fine grained mica, perovskite and probably a few spinels. A few altered xenoliths are present. These samples are classified as altered, *mica-bearing hypabyssal-facies kimberlites*.

The second rock type encountered is very different from that described above. It contains abundant country rock fragments, is altered and has a pelletal lapilli texture (after CLEMENT & SKINNER, 1985). Two generations of altered olivine are present. The macrocrysts (up to 5 mm) are anhedral and generally rounded while the phenocrysts (up to 1 mm) are euhedral. The groundmass of the lapilli includes fine grained (up to 0.05 mm) abundant needles of clinopyroxene and rare phlogopite. The matrix between the lapilli is composed of serpentine and microlitic clinopyroxene. Minor calcite is present. Some angular autoliths of previously crystallized kimberlite occur. These samples are classified as altered, *diatreme-facies, pelletal tuffisitic kimberlite breccias*. This pipe is the only sizeable pipe in the province (20 ha) and the occurrence of diatreme-facies material is therefore not unexpected.

Additional features recorded include plagioclase (Rao & Phadtre, 1966), ilmenite, chlorite, talc, glass (Nagabhushanam & Venkatanarayana, 1985), ilmenite, groundmass chlorite and glass (Reddy, 1987). The reported occurrence of plagioclase and glass, if primary, is at variance with the results of this investigation and with the classification of this body as a kimberlite.

Pipe 2 or Wajrakarur 02: Olivine, which is sometimes fresh (Table 3), occurs in two generations. Some macrocrysts (up to 5 mm) may be subhedral and have serrate margins. The well developed undulose extinction and, in some instances, polycrystalline nature shows that they are xenocrysts. Numerous smaller (< 0.5 mm) phenocrysts are present. The groundmass is composed of granular monticellite (Fig. 7; up to 0.1 mm), spinel (< 0.1 mm), euhedral brown perovskite (< 0.05 mm), interstitial cryptocrystalline serpentine, interstitial poikilitic plates (up to 0.7 mm) of very pale orange-brown phlogopite (Table 3) and apatite. The phlogopite encloses other groundmass minerals. A lath-like mineral probably representing altered melilite also occurs. Abundant pseudomorphed groundmass monticellite is clearly discernible in some samples (Table 1). Mineral compositions confirm the presence of olivine, phlogopite and probable altered melilite (Table 3). The samples are classified as al-

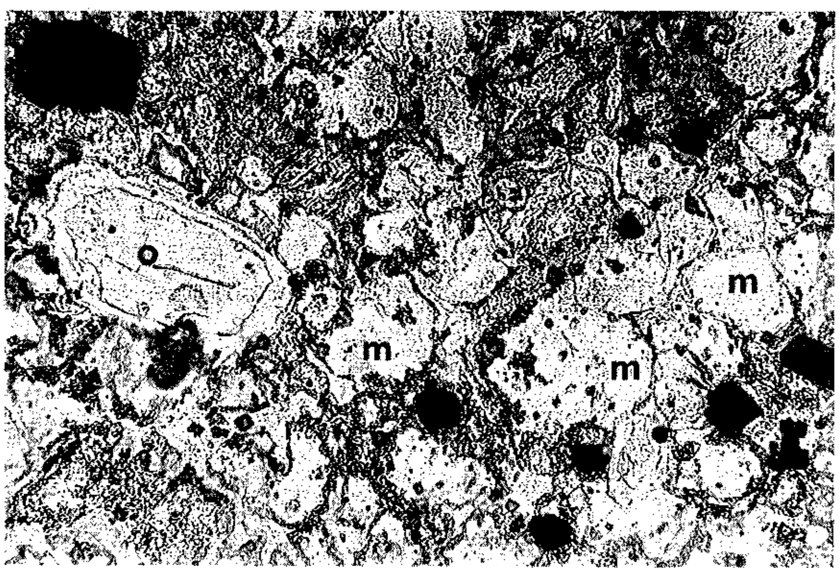

Fig. 7. Pipe 2 – Wajrakarur kimberlite. Sample P2/4. Field of view = 0.4 mm. PPL. A subhedral, partly altered olivine microphenocryst (o) is set in a groundmass composed predominantly of granular, fresh monticellite (m). Also present are primary opaque spinels, fine translucent perovskite, interstitial serpentine and some secondary minerals which often have high relief.

tered *hypabyssal-facies monticellite kimberlite* (Table 1). The mineralogy is typical of kimberlites but the paucity of macrocrysts (compare pipe 2 with the more typical kimberlite of pipe 3 in Table 1) and the shapes of the olivines in these samples are somewhat unusual.

Other features noted in the literature include ilmenite, carbonate, glass (RAO & PHADTRE, 1966), chlorite, calcite (KRESTEN & PAUL, 1976), ilmenite, calcite, chlorite, talc, glass (NAGABHUSHANAM & VENKATANARAYANA, 1985), phenocrysts of sanidine and ilmenite, groundmass sanidine, diopside, richterite, ilmenite, magnetite, carbonates and glass (REDDY, 1987). Sanidine, richterite and glass were not observed here but are features not found in kimberlites except for some unusual contaminated Group 2 kimberlites in South Africa.

Pipe 3 or Lattavaram 03: All the samples examined are altered and display different secondary mineralogies. They contain a few xenoliths up to 15 mm in size and have macrocrystic textures. Pseudomorphs after olivine are abundant (Table 1) and include anhedral macrocrysts (up to 10 mm) and phenocrysts (up to 2 mm). Primary groundmass minerals include altered probable monticellite (up to 0.02 mm), apatite (up to 0.1 mm), spinel (up to 0.01 mm), perovskite (up to 0.05 mm) and serpentine (Table 1). Carbonate which appears to be primary is also present. Macrocrysts of garnet and picroilmenite occur in heavy mineral concentrates. Most of the rocks are classified as *hypabyssal-facies, monticellite kimberlite* (Table 1). One of the samples contains more abundant phlogopite as pale coloured laths.

Additional minerals recorded include rare enstatite, glass, chlorite, plagioclase pseudomorphs (RAO & PHADTRE, 1966), vermiculite (KRESTEN & PAUL, 1976), glass (NAGABHUSHANAM & VENKATANARAYANA, 1985), ilmenite phenocrysts, groundmass ilmenite, chromite, magnetite, glass REDDY (1987), partly serpentinized olivine (up to 1 mm, Fo_{92}), fresh monticellite, pectolite and Ti-bearing magnetites (AKELLA et al., 1979 for Lattavaram 1, presumed to be pipe 3).

Pipe 4 or Lattavaram 04: All the samples are relatively fresh and have macrocrystic textures resulting from the presence of abundant anhedral, often rounded, macrocrysts (up to 4 mm) of olivine (Fig. 8). The macrocrysts display undulose extinction and include polycrystalline examples. These features indicate that these grains are xenocrysts. Some olivines contain translucent brown spinels as inclusions. Macrocrysts of garnet, picroilmenite and spinel occur in heavy mineral concentrates. Altered, euhedral olivine phenocrysts (up to 1.5 mm) are abundant (Fig. 8). Other coarse grained constituents include a few small altered xenoliths which appear to have reacted with the host magma (Figs. 8 and 9). The groundmass minerals have a patchy distribution (Figs. 8 and 9) which precludes meaningful modal analyses. Relatively dark areas of the groundmass are composed of clinopyroxene (up to 0.1 mm and Table 3), phlogopite (laths up to 0.14 mm), serpentine (Table 3), perovskite (<0.3 mm), spinel (<0.15 mm), pectolite and carbonate. These samples are classified as *hypabyssal-facies mica-bearing clinopyroxene kimberlites*.

Table 3. Some mineral analyses from the Wajrakarur and Lattavaram kimberlites.

	Olivine				Phlogopite				Montic	Clinopyroxene		Melilite			Serp	Spinel			Perovs
Pipe/sample	P2/1	P2/1	P4/1	P5/1	P2/1	P5/1	P5/1	P5/2	P5/1	P4/1	P5/2	P2/1	P5/1	P5/1	P4/1	P5/1	P5/1	P5/1	P5/1
Anal. No.	80−285	80−288	80−269	80−310	80−297	80−312	80−315	88−244	88−242	80−279	88−243	80−301	80−320	80−264	80−276	80−252	80−328	80−329	80−317
SiO_2	39.13	39.65	39.36	40.55	42.69	41.74	42.19	41.74	38.50	53.44	51.84	28.60	32.57	36.81	39.05	nd	nd	0.04	nd
TiO_2	0.03	0.04	0.03	0.01	1.82	1.90	1.88	2.38	0.07	0.74	2.32	0.25	0.04	0.17	0.22	0.09	10.29	13.05	57.23
Al_2O_3	0.02	0.03	0.05	0.01	5.86	7.81	7.05	7.54	0.01	0.31	0.90	14.83	21.06	7.37	5.70	15.33	3.51	1.11	0.15
Cr_2O_3	nd	0.03	nd	nd	nd	nd	nd	0.01	0.03	nd	0.02	nd	nd	nd	nd	54.14	16.62	0.21	0.02
FeO	13.14	10.21	13.42	6.89	6.25	8.01	8.25	8.44	7.40	4.10	5.55	9.06	5.67	9.33	7.41	15.30	59.59	76.39	1.15
MnO	0.16	0.16	0.14	0.12	0.02	0.06	0.06	0.07	0.32	0.15	0.15	0.12	0.14	0.09	0.06	0.33	0.89	1.94	0.01
NiO	0.30	0.32	0.32	0.43	nd	0.03	0.04			0.02		0.01	nd	0.02	0.19	0.10	0.16	0.14	nd
MgO	47.45	49.82	46.96	52.03	23.39	24.32	23.68	23.65	29.38	16.78	14.92	4.42	2.24	31.33	33.15	14.07	6.26	0.54	0.05
CaO	0.09	0.21	0.10	0.02	0.05	0.01	0.03	0.03	24.66	23.60	22.96	34.03	32.00	0.81	0.13	0.02	0.12	0.31	40.98
Na_2O	0.01	nd	0.03	nd	1.47	0.49	0.59	0.71	0.06	0.87	1.22	0.05	nd	0.02	nd	nd	nd	nd	0.20
K_2O	nd	nd	nd	nd	9.99	10.32	10.43	10.23	0.01	0.02	nd	0.04	0.08	0.90	0.73	nd	nd	nd	0.03
Total	100.34	100.46	100.42	100.06	91.54	94.70	94.20	94.80	100.44	100.02	99.88	91.40	93.80	86.86	86.64	99.39	97.44	93.73	99.82
Mg/(Mg+Fe)	0.865	0.897	0.862	0.931	0.869	0.844	0.836	0.833											

Legend: Montic – monticellite; Serp – serpentine; Perovs – perovskite; nd – not detected; 80−285 – centre of 3.5 mm anhedral macrocryst; 80−288 – centre of 0.4 mm euhedral phenocryst; 80−269 – close to edge of 4 mm macrocryst, centre has very similar composition; 80−310 – centre of 3 mm anhedral macrocryst; 80−297 – centre of 0.6 mm subhedral lath; 80−312 – centre of 0.55 mm zoned poikilitic grain; 80−315 – edge of grain 80−312; 88−244 – centre of 0.25 mm interstitial poikilitic grain, defocussed beam; 88−242 – centre of 0.09 mm subhedral grain; 80−279 – centre groundmass grain; 88−243 – centre of groundmass grey coloured lath in sheaf; 80−301 – possible melilite; 80−320 – lath; 80−264 – lath altered to pale green serpentine; 80−276 – primary interstitial base in groundmass; 80−252 – centre of 1.5 mm anhedral translucent cherry red grain; 80−328 – centre groundmass grain; 80−329 – edge of 80−328; 80−317 – centre of 0.2 mm grain.

Fig. 8. Pipe 4 – Lattavaram kimberlite. Sample P4/5. Field of view = 10 mm. PPL. Two generations of olivine are present. Several mainly fresh, rounded anhedral macrocrysts (m) are conspicuous. Numerous smaller, generally altered, euhedral phenocrysts occur in the matrix. Two small extensively altered xenoliths (x) are present. The dark coloured contaminated groundmass around these xenoliths contrasts with the lighter coloured, "cleaner" groundmass (right of centre) away from the xenoliths. Note the alteration in the bottom left macrocryst adjacent to the xenolithic material.

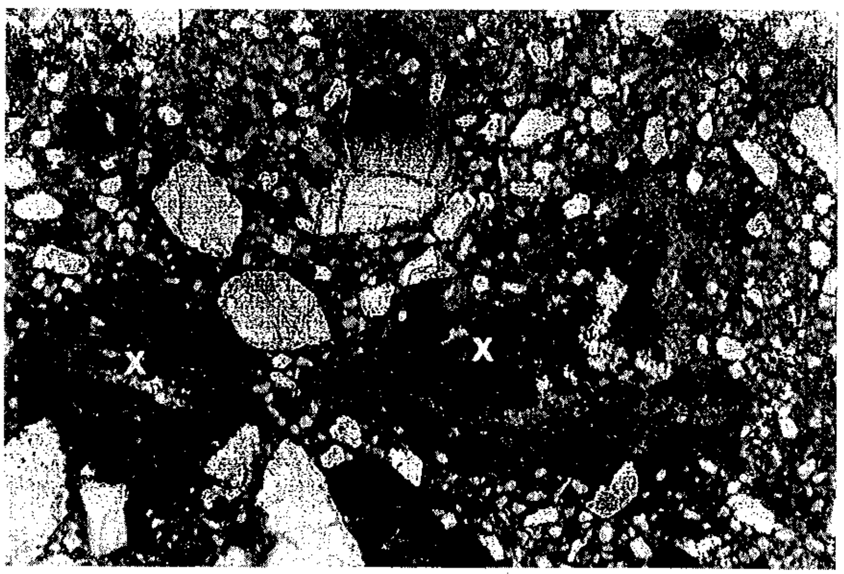

Fig. 9. Pipe 4 – Lattavaram kimberlite. Sample P4/8. Field of view = 10 mm. PPL. Two "kimberlitized" or zonally altered xenoliths (x). The dark groundmass around these xenoliths has been contaminated.

In some samples the distribution of the clinopyroxene and pectolite is related to the presence of xenoliths. It is considered that the occurrence of these minerals probably results from contamination of the magma by partial or total late stage digestion of xenolithic material (a process similar to that described by Scott Smith et al., 1983). Other (lighter) areas of the groundmass contain little or no pectolite and clinopyroxene but are composed of very abundant serpentine. The serpentine occurs both as a primary late stage groundmass mineral and as pseudomorphs after common groundmass monticellite. These areas are thought to represent uncontaminated kimberlite and are classified as *hypabyssal-facies mica-bearing monticellite kimberlite.*

Additional reported minerals include chlorite, palygorskite (KRESTEN & PAUL, 1976), glass (NAGABHUSHANAM & VENKATANARAYANA, 1985), ilmenite phenocrysts, groundmass ilmenite, chromite, magnetite and glass (REDDY, 1987). AKELLA et al. (1979) note two types of ilmenite present namely; (1) high Cr_2O_3 (4 wt.%), high MgO (16 wt.%) and (2) low Cr_2O_3 (0.8 wt.%), lower MgO (10 wt.%) varieties.

Pipe 5 or Muligiripalle or Lattavaram 05: Olivine is abundant, commonly fresh (Table 3) and occurs in two generations. The larger macrocrysts (up to 6 mm) display undulose extinction and a few polycrystalline examples are present indicating that they are xenocrysts. They are similar to, but less abundant than, olivine macrocrysts in typical kimberlites (Table 1). Numerous phenocrysts (mostly < 0.5 mm) are present. Constituent groundmass minerals are phlogopite, perovskite, spinel, clinopyroxene, carbonate, serpentine, pectolite, apatite and pseudomorphs after probable melilite and monticellite (Fig. 10).

Phlogopite occurs either as abundant, relatively coarse grained (up to 1 mm), orange-brown poikilitic plates (Fig. 10) or as less abundant smaller (0.2 mm) interstitial grains (Table 3). Relatively coarse-grained (up to 0.2 mm) euhedral perovskite and spinel are common in all the samples examined (Fig. 10, Table 3). Perovskite has a purply brown colour and is optically zoned. In some cases it occurs as necklaces around olivine grains.

Fig. 10. Pipe 5 – Muligiripalle kimberlite. Sample P5/1. Field of view = 0.6 mm. PPL. Part of an olivine pseudomorph (o) is surrounded by phlogopite (p) which poikilitically encloses laths of probable melilite (indicated by arrows), zoned translucent high relief perovskite and opaque spinel.

The other minerals present in these samples have a patchy distribution. Clinopyroxene occurs as laths (up to 0.5 mm in length) which commonly form sheaf-like aggregates. This mineral has an unusual and distinctive smoky grey colour and sometimes occurs in pool-like segregations. Pectolite has an erratic distribution related to the presence of altered xenolithic material. Its presence is therefore considered to reflect contamination of the magma as discussed above and described by SCOTT SMITH et al. (1983). In some instances textural features suggest that some clinopyroxene has a similar origin. Carbonate and cryptocrystalline serpentine appear to be late-stage primary groundmass minerals and sometimes form pool-like segregations. Some serpentine in the groundmass appears to replace melilite (up to 0.25 mm in size) and monticellite (up to 0.2 mm in size). The altered melilites occur as tabular grains often with the so-called peg structure preserved (Fig. 10). Mineral analyses (Table 3) support the identification as melilite. Monticellite is altered to clear pale green serpentine that can be distinguished from the serpentine replacing the olivine. The olivine pseudomorphs have a distinctive yellow green core with a pale green to colourless rim and contain numerous needle-like inclusions that resemble millerite.

Texturally these rocks are *hypabyssal-facies kimberlite*. Mineralogically they are difficult to classify as the groundmass minerals have a patchy distribution but *monticellite and probable melilite* are important primary minerals. *Pectolite and clinopyroxene*, although modally abundant, are considered not to represent true primary minerals.

Other data reported include serpophite, glass (NAGABHUSHANAM & VENKATANARAYANA, 1985), phlogopite containing 2 wt.% TiO_2, salite to diopsidic pyroxene, potassic richterite with unusually low Na_2O values (GUPTA et al., 1986), phenocrysts of sanidine and ilmenite, groundmass sanidine, diopside, richterite, ilmenite, magnetite, carbonates and glass (REDDY, 1987). The occurrence of sanidine, richterite and glass are features not observed here or in kimberlites, except for some unusual contaminated Group 2 kimberlites in South Africa.

Pipe 6 or Wajrakarur 06: The one sample examined is extensively altered by clay mineralization and carbonatization. Some primary features, however, are discernible. The sample has a macrocrystic texture resulting from the presence of numerous olivine pseudomorphs up to 4 mm in size. Rare altered xenoliths are also present. Pseudomorphs after olivine phenocrysts occur in the matrix. The groundmass has been completely replaced by carbonate. Small patches of green chlorite occur in probably represent primary mica. In some cases, however, chlorite appears to be associated with xenolithic material. None of the noted features preclude classification of this rock as a kimberlite. It is a clay mineralized, carbonatized, probable *hypabyssal-facies kimberlite*. NAGABHUSHANAM & VENKATANARAYANA (1985) report the presence of spinel, chlorite, talc and glass while ilmenite, chlorite and glass are noted by REDDY (1987).

Discussion

The twenty eight samples examined here from six of the eight known bodies all contain two generations of olivine. The xenocrysts (macrocrysts) are anhedral grains which are generally rounded while the phenocrysts exhibit simple euhedral shapes. Such olivines are characteristic of kimberlites (compare Fig. 8 with Fig. 2.1 of MITCHELL, 1986; Fig. 2 of SCOTT SMITH et al., 1984; Fig. 13 a of CLEMENT et al., 1986). The main groundmass constituents are phlogopite, monticellite, spinel, perovskite, serpentine, carbonate, clinopyroxene, pectolite and probably melilite. Among the many published reports concerned with the Wajrakarur/Lattavaram kimberlites monticellite is only mentioned by AKELLA et al. (1979; confirmed by mineral chemistry). In contrast this study shows that monticellite is an important groundmass mineral (Table 1). It has been identified optically (compare Fig. 7 with Fig. 1 of SKINNER & CLEMENT, 1979; Fig. 3.19 of MITCHELL, 1986; and Fig. 13 c of CLEMENT et al., 1986) and from its composition (Table 3). Lath-like pseudomorphs suspected to be melilite occur in many kimberlites elsewhere, so the occurrence of limited amounts of melilite in pipes 2 and 5 do not preclude them from being kimberlites. The primary mineral assemblage phlogopite, monticellite, oxide minerals, perovskite, serpentine and carbonate are characteristic of kimberlite (CLEMENT et al., 1984; MITCHELL, 1986; compare modal analyses in Table 1 with Table 1 of SKINNER & CLEMENT, 1979), in particular of Group 1 kimberlites (SMITH, 1983; SKINNER, 1986). These rocks are therefore classified as *mica-bearing monticellite kimberlites*. A second rock type, *pelletal tuffisitic kimberlite breccia* was found in pipe 1. The occurrence of these two rock types and the irregular shapes of most of the intrusions suggests that these bodies represent the root zones of diatremes (cf. CLEMENT, 1982). Most other authors (e.g. AKELLA et al., 1979; MIDDLEMOST & PAUL, 1984; NAGABHUSHANAM & VENKATANARAYANA, 1985) also classify pipes 1 to 6 as kimberlites.

The reported occurrence of primary glass, plagioclase, phenocrystic and groundmass sanidine, amphibole and probable leucite (not observed here) is at variance with the classification of these rocks as kimberlites. Some of these minerals may rather be xenocrysts derived from accidentally included xenolithic material which include granite (± amphibole), hornblende gneiss, granulite (plagioclase + potassium feldspar), eclogites and peridotites (REDDY, 1987; KARUNKARAN et al., 1976; GANGULY & BHATTACHARYA, 1987). Feldspar and quartz have been described as xenocrysts derived from granite xenoliths (KARUNKARAN et al., 1976; MURTY et al., 1980). Plagioclase may correspond to the laths interpreted here as melilite.

Pipes 2 and 5 have been noted to be different from the others. For example, MURTY et al. (1980) refer to pipes 2 and 5 as micaceous kimberlites while the other pipes are termed "basaltic" kimberlites. Pipes 2 and 5, however, were shown here to contain monticellite and abundant spinel and perovskite (Table 1); minerals that do not occur in the Group 2 or micaceous kimberlites of

South Africa (SKINNER, 1986). REDDY (1987) uses the presence of sanidine, richterite, glass and probable leucite as a basis for classifying rocks from pipes 2 and 5 as "macrocrystic kimberlitic olivine lamproites". If these phases, which were not observed here, are present then the rocks may be classified as lamproites with good reason. REDDY (1987) and others, however, note phenocrystal and groundmass ilmenite in pipes 2 and 5 which is rare in lamproites (e.g. JAQUES et al., 1986) but common in kimberlites. Monticellite, melilite, abundant and coarse-grained perovskite and spinel observed here in pipes 2 and 5 also do not occur in lamproites. REDDY (1987) also uses whole rock compositions of pipes 2 and 5 to show that they are somewhat different and have lamproitic affinities. Compared to his or other data for lamproites (e.g. BERGMAN, 1987), pipes 2 and 5 are not typical of lamproites and in some cases fall outside the range given for them (e.g. Al_2O_3). The higher K_2O contents for pipes 2 and 5 (1.9 and 2.2 wt.%; REDDY, 1987) are well within K_2O ranges documented for kimberlites (e.g. BERGMAN, 1987).

In this investigation a few features observed in pipes 2 and 5 are not typical of kimberlites. The complex olivine shapes, paucity of olivine macrocrysts, the presence of melilite, together with some of the limited mineral chemistry data available (such as the high FeO content of the monticellite and the low Mg/[Mg + Fe] ratio and Al_2O_3 content of the phlogopite – Table 3; c.f. MITCHELL, 1986) suggest that the rocks from pipes 2 and 5 are more evolved or extreme varieties of kimberlite.

Chelima

A suite of dykes occurs near Chelima, Andhra Pradesh (Fig. 1; BERGMAN, 1987; VEMBAN, 1946). BERGMAN & BAKER (1984, in preparation) and BERGMAN (1987) suggest that they may be lamproites. These dykes previously have been referred to as minette, kimberlite and/or carbonatite (APPAVADHANULU, 1962; SEN & NARISIMHA RAO, 1970, 1971; SARMA, 1983). The dykes are composite, enechelon bodies, 1–4 m wide, up to 7 km long (SARMA, 1973; BERGMAN & BAKER, in preparation). Magmatic rocks predominate but some "autolithic breccias" along dyke margins have been noted (BERGMAN & BAKER, in preparation; SEN & NARISIMHA RAO, 1970). The Chelima dykes are Proterozoic (1340 Ma – CRAWFORD, 1969; 1225 Ma – CRAWFORD & COMPSTON, 1973). They intrude the Proterozoic shales in the Cuddapah Basin (Fig. 18 b of BERGMAN, 1987) of the Dharwar craton (Fig. 1). LEELANANDUM (1981) shows that Chelima falls at the western extremity of a carbonatite–alkaline province (age unknown). Old (ancient?) opencast and underground workings in the dykes, nearby alluvial diamonds and the tentative identification of a microdiamond have been taken to suggest that the Chelima dykes carry diamonds (SEN & NARISIMHA RAO, 1970, 1971). The workings, however, might relate to other minerals such as galena (APPAVADHANULU, 1962).

Petrography and Mineral Chemistry

The only sample available to the author (CH-1, BERGMAN & BAKER, in preparation) is an altered, porphyritic rock. It is extensively carbonatized and cut by veins (1 mm wide) which are composed predominantly of carbonate, quartz and chlorite. Abundant phenocrystal laths of phlogopite (± 40 modal %; up to 3 mm) occur and are commonly distorted. In most cases they contain secondary minerals (opaque material, quartz, carbonate, talc) along cleavage partings and may be simply twinned. The primary colour of the mica is distinctive and the pleochroism ranges from a pale to deep orange-brown colour (characteristic of Ti–phlogopites). Thin and ill defined rims with reverse pleochroism are tetraferriphlogopite (BERGMAN & BAKER, in preparation). The laths are often intergrown and rare rosette-like aggregates occur. The mica appears to contain inclusions of altered primary groundmass minerals such as apatite, probable altered perovskite, possible spinel and perhaps clinopyroxene. Other grains (up to 4 mm) in the rock may be steatized, carbonatized olivines including a few anhedral macrocrysts with serrate margins and some smaller possible phenocrysts (1 mm) with complex shapes. Clinopyroxene may also have been present. The matrix to the coarse constituents contains a high relief mineral which is probably altered perovskite. Some apatite is also present. The rest of the matrix is composed predominantly of secondary carbonate and talc with some serpentine and quartz. The original nature of these areas cannot be discerned.

SEN & NARASIMHA RAO (1970, 1971) note that the most common dykes are composed of unevenly distributed olivine pseudomorphs, mica, ilmenite, magnetite, apatite, rutile, perovskite, carbonates, leucoxene, serpentine, chlorite and quartz with the general petrography being similar to that noted in this investigation. They note that other dykes also associated with the old workings are composed of quartz, biotite, magnetite, leucoxene after ilmenite, carbonate and glass. SEN & NARASIMHA RAO (1971) note the occurrence of olivine pseudomorphs that appear to be better preserved and more abundant than noted during this investigation. They suggest that the dykes are similar to kimberlite but the abundance of carbonate shows that they are transitional to carbonatite. BERGMAN & BAKER (in press) note that accessory phases include ilmenite and that glassy rocks occur at several exposures. APPAVADHANULU (1962) reports, for one dyke, the presence of biotite phenocrysts in a groundmass of carbonate, orthoclase, quartz, altered opaques and apatite and concludes that the rock is a minette.

BERGMAN (1987) and BERGMAN & BAKER (in preparation) present data for the optically and chemically zoned micas. Compared to the rims, the cores have higher Mg/(Mg + Fe) values (85 vs. 65–75) and Al_2O_3 (11–8 wt.%), TiO_2 (5.5–3.5 wt.%), Cr_2O_3 and BaO contents. The phlogopites, with high TiO_2 and fairly low Al_2O_3 contents, are similar to the mica in some lamproites and fall outside the main field for kimberlites (cf. BERGMAN, 1987; SCOTT SMITH &

SKINNER, 1984 a). Phlogopites in lamproites, however, do have compositions which grade into those of phlogopites in other rock types, in particular minettes. Micas from lamproites typically have lower Al_2O_3 contents than those in minettes (0 – 13 vs. 9.7 – 18 wt.%; BACHINSKI & SIMPSON, 1983; MITCHELL, 1985 and unpublished data). The Chelima micas unfortunately fall in the area of overlap hence the phlogopite compositions are not definitive.

Discussion

The sample examined here contains, as discernible primary constituents, abundant phenocrystal phlogopite, a few probable olivine macrocrysts and phenocrysts and groundmass perovskite, apatite, probable spinel and possibly also clinopyroxene. This sample lacks diagnostic features so it is not possible to classify the rock. The paucity of olivine together with the abundane and nature of the phenocrystal mica strongly suggest that the sample is not a kimberlite. The reported quartz, if primary, would preclude classification as lamprophyre, kimberlite or lamproite but the quartz observed during this investigation is considered to be secondary. Carbonate in the samples examined here is probably secondary suggesting that the dykes are not carbonatites. The rock is probably a lamprophyre and it may be a minette or a lamproite but none of the observed or reported features can resolve the classification further.

Zangamrajupalle

A rock located in a borehole core near Zangamrajupalle, Andhra Pradesh, about 80 km SSE of Chelima (Fig. 1) is referred as a kimberlite dyke (RAO, 1976). Constituent minerals are reported to be phlogopite, biotite, carbonate with subordinate apatite, chlorite, quartz, serpentine and leucoxene after ilmenite. Pseudomorphs after olivine are suspected. Again insufficient information is availabe to assess this suggestion but the apparent paucity of olivine and the low whole-rock MgO value suggest that this rock is not kimberlite.

Maddur and Narayanpet

Five bodies occur in the vicinity of Maddur and Narayanpet, Andhra Pradesh (Fig. 1; Geological Survey of India, 1985). Only limited information is given but they report the presence of two generations of olivine and possible ilmenite megacrysts. The similarity of an unreported whole rock analysis to Pipe 5 of the Wajrakarur province leads them to suggest that at least occurrence No. 1 is an olivine lamproite. Minerals noted in some of the other bodies include olivine/pyroxene, serpentine, perovskite, calcite, ilmenite, magnetite and phlogopite. There is obviously insufficient information available to assess critically the suggestion that one or more of these bodies are lamproites. However, the occurrence of calcite, primary serpentine, ilmenite and abundant groundmass spinel would be more consistent with the rocks being kimberlites than lamproites.

Warangal

Setti et al. (1978) suggest that "small bands or lenses" (from 3 cm up to 2 m) within the granite country rock near Warangal (about 150 km NE of Hyderabad in Andhra Pradesh; Fig. 1) are enclaves of kimberlite–carbonatite. They are considered not to be intrusive but rather represent xenoliths incorporated in the host rock. Reported constituent minerals are calcite, chlorite, opaque minerals, biotite, quartz, possible altered feldspar, apatite, tourmaline and veins of calcite. They note that some material may be pseudomorphous after olivine. The reported nature of these rocks is most unusual when compared to both kimberlites or lamproites. Obviously more detailed information is required for a more meaningful assessment.

Conclusions

The results of this study are summarized in Table 4. The *Majhgawan* diamond mine and its satellite *Hinota* are shown not to be kimberlites, contrary to common suggestions in the literature. The rocks examined in this study are classified as *olivine lamproite lapilli tuffs* (some autolithic breccias may also be present). These bodies, therefore, form a newly recognized province of diamondiferous olivine lamproites. Such rocks are rare elsewhere in the world (Western Australia, Atkinson et al., 1982; Jaques et al., 1986; Arkansas, Scott Smith & Skinner, 1984 a, b, c, and Zambia, Scott Smith et al., 1989).

The *Wajrakarur/Lattavaram* province consists of 8 known bodies but no information is available for pipes 7 and 8. This investigation shows that pipes 1 to 6 are kimberlites (sensu stricto). They are mostly *mica-bearing monticellite or Group 1 kimberlites*. In some cases they are modified by contamination from xenoliths to a kimberlite which contains modally abundant clinpyroxene and pectolite. Texturally they are predominantly *hypabyssal-facies* kimberlite. Pelletal tuffisitic kimberlite breccia, and hence *diatreme-facies* material, is present in Pipe 1. The pipes in this province are probably root zones of diatremes which may have been substantially eroded. Pipes 1, 3, 4 and 6 are typical kimberlites and contain some diamond and relatively common mantle-derived xenoliths and xenocrysts. Pipes 2 and 5 are thought to be more evolved or extreme varieties of kimberlite. They appear to be devoid of diamond and mantle-derived xenoliths while mantle-derived xenocrysts appear to be rare or absent. No features observed here support the suggestion that pipes 2 and 5 represent a separate rock type or are lamproites.

It has been suggested that the lamprophyre dykes both at Chelima and in the Gondwana Coalfields are, or include, lamproites. The single altered sample from *Chelima* examined here is a Ti–phlogopite-bearing lamprophyre and not

Table 4. Summary.

Locality Figure 1	Name	Ages Ma.	Published classifications	Classification this study
1	Majhgawan	840–1140 1630	kimberlite	ol lamproite lapilli tuff
1	Hinota	1170	kimberlite	ol lamproite lapilli tuff
2	Angor		kimberlite peridotite-ol-pyroxenite-gabbro	not kimberlite ?peridotite-gabbro
3	Jungel	919	kimberlite	not kimberlite ?metavolcanics
4	Gondwana coalfields	105–121	lamproites lamprophyres	should be investigated may include lamproite
5	Wajrakarur P1		kimberlite	mica-bearing hypabyssal kimberlite and pelletal tuffisitic kimberlite breccia
5	Wajrakarur P2	840 1350	lamproite kimberlite	hypabyssal monticellite kimberlite
5	Lattavaram P3	933 956	kimberlite	hypabyssal monticellite kimberlite (±phlogopite)
5	Lattavaram P4	962 1023 1505	kimberlite	hypabyssaal mica-bearing monticellite kimberlite contaminated to pectolite-cpx-bearing kimberlite
5	Muligiripalle P5		lamproite kimberlite	hypabyssal melilite- and monticellite-bearing phlogopite kimberlite contaminated to pectolite-cpx-bearing kimberlite
5	Wajrakarur P6		kimberlite	altered hypabyssal kimberlite
6	Chelima	1340 1225	minette kimberlite/carbonatite lamproite	minette or lamproite requires further study
7	Zangamrajupalle		kimberlite	requires further investigation
8	Maddur		ol-lamproite	reported data does not support classification as lamproite, further study necessary
9	Warangal		kimberlite/ carbonatite	reported data unusual for kimberlite or lamproite

Legend: ol – olivine; cpx – clinopyroxene.

a kimberlite. The rock may be a minette or lamproite. Published information for the dykes in the *Gondwana Coalfields* suggests that some of them could be lamproites.

Angor is not a kimberlite or a lamproite and the data presented here are more consistent with the suggestion that this body is a peridotite–pyroxenite–gabbro complex (MATHUR, 1981, 1986). Published information for the *Banda* rocks does not support the suggestion of any kimberlitic or lamproitic affinities. The samples examined here from the reportedly diamondiferous bodies at *Jungel* are also not kimberlites or lamproites. They are more likely to be metavolcanic rocks. Insufficient information is available for the intrusion at *Zangamrajupalle*, *Maddur* and *Warangal* to be adequately classified but it is doubtful whether they are kimberlites or lamproites.

It is noteworthy that the true lamproites (Majhgawan/Hinota) and kimberlites (Wajrakarur/Lattavaram) are all Proterozoic (900–1170 Ma) and similar in age to other lamproites, kimberlites and related rocks worldwide (SKINNER et al., 1985). Majhgawan/Hinota and Wajrakarur/Lattavaram also constitute the only confirmed primary sources of diamond in India. It is interesting to note that, like many diamondiferous kimberlites elsewhere, the Wajrakarur/Lattavaram province occurs well within the Dharwar craton (3200 Ma). Although the precise location of the craton boundaries do not seem to be well understood, it appears that Majhgawan and Hinota occur near the margin of the Aravalli craton. This setting may be comparable with that of other diamondiferous lamproites (BERGMAN, 1987).

Although there are numerous published papers on the "kimberlitic" and "lamproitic" bodies of India, this study shows a great need for new, detailed petrological studies of many of these localities. It is hoped that this paper will stimulate further research. Of particular interest is the newly recognized province of rare diamondiferous olivine lamproites. Majhgawan is particularly worthy of further study because of the good exposures that have resulted from mining operations.

Acknowledgements

The author is indebted to R. B. HARGRAVES, F. R. BOYD, P. KRESTEN and S. C. BERGMAN for donating and loaning samples. Without these samples this study would not have been possible. The preprint and numerous reprints sent by S. C. BERGMAN and comments or help from E. M. W. SKINNER, E. COLGAN, J. V. R. DUFF, K. J. STRACKE, F. R. BOYD and P. H. NIXON are gratefully acknowledged. A. K. GUPTA, A. N. SINGH and J. AKELLA are thanked for their help and maintaining my interest in these rocks. C. R. CLEMENT, R. H. MITCHELL, H. O. A. MEYER, and H. E. O'BRIEN are thanked for their comments on the first manuscript.

References

AKELLA, J., SATYANARAYANA RAO, P., MCCALLISTER, R. H., BOYD, F. R. & MEYER, H. O. A. (1979): Mineralogical studies on the diamondiferous kimberlite of the Wajrakharur area, southern India. – Proceedings of the Second International Kimberlite Conference, Santa Fe 1977. – In: Kimberlites, diatremes and diamonds: their geology, petrology and geochemistry, (Eds. BOYD, F. R. & MEYER, H. O. A.), American Geophysical Union. p. 172–177.

APPAVADHANULU, K. (1962): Minette and riebeckite–kalisyenite dykes in some Upper Cuddapah rocks, Kurnool district, Andhra Pradesh. – Rec. Geol. Surv. India **94** (2): 303–304.

ATKINSON, W. J., HUGHES, F. E. & SMITH, C. B. (1984): A review of kimberlitic rocks of Western Australia. – In: Kimberlites and related rocks, (Ed. KORNPROBST, J.), Proceedings of the Third International Kimberlite Conference, Vol. 1, Elsevier's Development in Petrology series, no. 11 **A**: 195–224.

BACHINSKI, S. W. & SIMPSON, E. L. (1983): Ti–phlogopites of the Shaw's Cove minette: a comparison with micas of other lamprophyres, potassic rocks, kimberlites and mantle xenoliths. – Amer. Mineral. **69**: 41–56.

BALASUBRAHMANYAN, M. N., MURTY, M. K., PAUL, D. K. & SARKAR, A. (1978): K–Ar ages of Indian kimberlites. – J. Geol. Soc. India **19** (12): 584–585.

BANERJEE, S. (1953): Petrology of the lamprophyres and associated rocks of the Raniganj Coalfield. – Indian Mining J. **1** (6–7): 9–29.

BANERJEE, P. K. & AGARAWAL, S. K. (1980): History of diamond mining with special reference to Panna, M. P. (India). – Papers and Proceedings of the seminar: The many facets of the Indian Diamond Industry, Bombay. Hindustan Diamond Co. Ltd. (unpaged–9 pages).

BASU, A. R. & TATSUMOTO, M. (1979): Samarium–neodymium systematics in kimberlites and in the minerals of garnet lherzolite inclusions. – Science **205**: 389–401.

BEHAL, S. C. & SRIVASTAVA, M. (1980): Mineral processing plant for recovery of diamonds at Jungel, Mirzapur district, U. P. – Spec. Publ., Geol. Surv. India No. **4**: 633–637.

BERGMAN, S. C. (1987): Lamproites and other potassium-rich igneous rocks: a review of their occurrence, mineralogy and geochemistry. – In: Alkaline Igneous Rocks, (Eds. FITTON, J. G. & UPTON, B. G. J.), Geol. Soc. Spec. Publ. No. **30**: 103–190.

BERGMAN, S. C. & BAKER, N. R. (1984): A new look at the Proteozoic dykes from Chelima, Andhra Pradesh, India: diamondiferous lamproite? – Geol. Soc. Amer. Abstr. **16**: 444.

– – (In preparation): The Chelima dikes, Andhra Pradesh, India: Proterozoic diamondiferous lamproites?.

CHATTERJEE, N. N. (1937): On a basic mica-trap dyke from the Raniganj Coalfield. – Quart. J. Geol. Min. Met. Soc. India **9** (2): 51–59.

CHATTOPADHYAY, P. B. & KUMAR, S. (1977): A note on the occurrence of garnet in the kimberlitic plug of Jungel, Mirzapur district, Uttar Pradesh. – Indian Minerals **31** (2): 40–41.

CHATTOPADHYAY, P. B. & VENKATARAMAN, K. (1977): Petrography and petrochemistry of the kimberlite and associated volcanic rocks of the Jungel Valley, district Mirzapur, U. P., India. – J. Geol. Soc. India **18** (12): 653–661.

CLEMENT, C. R. (1982): A comparative geological study of some major kimberlite pipes in the northern Cape and Orange Free State. – Ph. D. thesis (unpubl.), Univ. of Cape Town. 432 pp.

CLEMENT, C. R. & SKINNER, E. M. W. (1985): A textural genetic classification of kimberlites. – Trans. Geol. Soc. South Africa **88** (2): 403–410.

CLEMENT, C. R., SKINNER, E. M. W. & SCOTT, B. H. (1984): Kimberlite redefined. – J. Geol. **92**: 223–228.

CLEMENT, C. R., HARRIS, J. W., ROBINSON, D. N. & HAWTHORNE, J. B. (1986): The De Beers kimberlite pipe – A historic South African diamond mine. – In: Mineral deposits of southern Africa (Eds. ANHAEUSSER, C. R. & MASKE, S.), Vol II. Geol. Soc. South Africa, 2193–2214.

CRAWFORD, A. R. (1969): India, Ceylon and Pakistan: new age data and comparisons with Australia. – Nature **223**: 380–384.

CRAWFORD, A. R. & COMPSTON, W. (1970): The age of the Vindhyan system of peninsular India. – Q. J. Geol. Soc. Lond. **125:** 351–371.

– – (1973): An age of the Cuddapah and Kurnool systems, southern India. – J. Geol. Soc. Australia **19** (4): 453–464.

DATTA GUPTA, S. (1981): A note on the inclusions in diamonds from Panna area, Madhya Pradesh and Jungel Valley, Uttar Pradesh. – Indian Minerals **35** (3): 35.

DAS GUPTA, P. & PHUKAN, S. (1971): Mineralogy of the altered diamondiferous pipe rock at Panna M. P. – Proceedings of a Symposium on Diamond, Panna, 1969. Misc. Publ. No. **19:** Geol. Surv. India, 114–119.

DAWSON, J. B. & STEPHENS, W. E. (1975): Statistical analysis of garnets from kimberlites and associated xenoliths. – J. Geol. **83:** 589–607.

– – (1976): Statistical analysis of garnets from kimberlites and associated xenoliths – Addendum. – J. Geol. **84:** 495–496.

DESHPANDE, M. L. (1978): Exploration strategy for diamonds in India. – Proceedings of the Third Regional Conference on Geology and Mineral Resources of Southeast Asia, Bangkok, Thailand, **1978:** 857–861.

– (1980): Diamond bearing kimberlites. – Indian Minerals **34** (1): 1–9.

DESSAI, A. G. (1987): Geochemistry and petrology of xenolith-bearing lamprophyres from Murud-Janjira, Raigarh Dist., Maharashtra, India. – J. Geol. Soc. India **30:** 61–71.

FOOTE, R. B. (1889): Note of Wajrakarur diamonds and on Chaper's alleged discovery of diamonds in pegmatite near that place. – Rec. Geol. Surv. India **22** (1): 39–48.

FOX, C. S. (1930): Intrusive igneous rocks. – In: The Jharia Coalfield (Chapter 9, p. 113–127), Mem. Geol. Surv. India **56:** 255 pp.

GANGULY, J., BHATTACHARYA, P. K. & MURTY, M. K. (1983): Petrology and comparative P–T regime of garnet peridotite nodules from the Proterozoic kimberlites of south India. Abstract. – EOS **64** (45): p. 903.

GANGULY, J. & BHATTACHARYA, P. K. (1987): Xenoliths in Proterozoic kimberlites from southern India: petrology and geophysical implications. – In: Mantle xenoliths (Ed. NIXON, P. H.), John Wiley and Sons Ltd., 249–266.

Geological Survey of India (1985): A note on the olivine lamproites/kimberlites of Maddur-Narayanpet area, Mahbubnagar District, Andhra Pradesh. Indian Minerals **39** (4): 63–64. Author given as Director, Economic Geology Division, Southern Region.

GHOSE, C. (1949): A petro-chemical study of the lamprophyres and associated intrusive rocks of the Jharia coalfield. – Quart. J. Geol. Mining Met. Soc. India **21:** 132–148.

GRANTHAM, D. R. (1964): The diamond deposits of Panna, Central India. – Industrial Diamond Rev. **24**, No. 279: 30–35.

– (1969): The age of the diamond-bearing rocks at Panna, Madhya-Pradesh. – Current Science **38** (16): 377–379.

GUPTA, A. K., LEMAITRE, R. W., HAUKKA, M. T. & YAGI, K. (1983): Geochemical studies on the carbonated apatite glimmerites from Damodar Valley, India. – Proc. Japan Academy **59** (5): 113–116.

GUPTA, A. K., YAGI, K., LOVERING, J. & JAQUES, A. L. (1986): Geochemical and microprobe studies of the diamond-bearing ultramafic rocks from central and south India. – Extended abstract for Fourth International Kimberlite Conference, Geol. Soc. Australia Abstracts No. **16:** 27–29.

GUPTASARMA, D., CHETTY, T. R. K., MURTHY, D. S. N., RAO, A. V. R., VENKATANARAYANA, B. & BAKER, N. R. (1986): Discovery of a new kimberlite in Andhra Pradesh by stream sediment sampling. – Jour. geol. Soc. India **27:** 313–316.

HALDER, D. & GHOSH, D. B. (1974): Tectonics of the kimberlites around Majhgawan, Madhya-Pradesh, India. – In: International Seminar on metallogeny and tectonics of South and East Asia and Far East (Ed. MURTY, M. V. N.). – Geol. Surv. India, Misc. Publ. No. 34, Pt. III: 1–13.

HOLLAND, T. H. (1894): Highly phosphatic mica peridotites intrusive in the lower Gondwana rocks of Bengal. – Rec. Geol. Surv. India **27:** 129–141.

HOLLAND, T. H. & SAISE, W. (1895): On the igneous rocks of the Giridih (Kurhurbaree) Coalfield and their contact effects. – Rec. Geol. Surv. India 28, part **4:** 121–138.

HUKKU, B. M. (1971): Evidence of volcanism and probable occurrence of volcanic plugs in the Lower Vindhyans of Banda District, U. P. and Rewa district, M. P. – Indian Minerals **33** (4): 120–121.

JAQUES, A. L., LEWIS, J. D. & SMITH, C. B. (1986): The Kimberlites and Lamproites of Western Australia. – Geol. Surv. Western Australia Bull. **132:** 268 pp.

JHINGRAN, A. G. & PURI, S. N. (1956): A new find of agglomeratic tuff in Bundelkhand granite area in Chahatarpur district, V. P. – Proc. 43rd Ind. Sci. Congr. Pt. 3 (Abstract), p. 169.

KARUNKARAN, C., MURTHY, S. R. N. & DAS GUPTA, S. P. (1976): Kimberlites of Wajrakarur and Lattavaram, Andhra Pradesh. – Geol. Surv. India Miscell. Publ. **23** (2): 538–547.

KRESTEN, P. & PAUL, D. K. (1976): Mineralogy of Indian kimberlites – a thermal and X-ray study. – Canadian Mineralogist **14:** 487–490.

KRISHNA MURTY, M. (1980): Tectonics and geochemistry of the diamondiferous kimberlites of the Jungel Valley, Mirzapur Dist. U. P. – an evolutionary model. – Papers and Proceedings of the seminar: The many facets of the Indian Diamond Industry, Bombay. Hindustan Diamond Co. Ltd. (unpaged–9 pages).

LAKE, P. (1890): The supposed matrix of the diamond of Wajra karur, Madras. – Rec. Geol. Surv. India **23** (2): 69–72.

LEELANANDUM, C. (1981): Some observations on the alkaline province in Andhra Pradesh. – Current Science **50** (18): 799–802.

MATHUR, S. M. (1962): Geology of the Panna diamond deposits. – Rec. Geol. Surv. India **87** (4): 787–818.

– (1981): The diamond deposits of India. – Presidential Address. Proc. 68th Indian Sci. Congress pt. 2: 1–30.

– (1986): Panna revisited. – Indiaqua **44** (2): 23–27.

MATHUR, S. M. & SINGH, H. N. (1960): Geology and sampling of the Majhgawan Diamond Deposits, Panna district. – Geol. Surv. India, Bull. Ser. A. No. **21,** 59 pp.

– – (1971): Petrology of the Majhgawan pipe rock. – Geol. Surv. India, Misc. Publ. No. **19:** 78–85.

MIDDLEMOST, E. A. K. & PAUL, D. K. (1984): Indian kimberlites and the genesis of kimberlites. – Chemical Geology **47:** 249–260.

MIDDLEMOST, E. A. K., PAUL, D. K. & FLETCHER, I. A. (1988): Geochemistry and mineralogy of the minette–lamproite association from the Indian Gondwanas. – Lithos **22:** 31–42.

MITCHELL, R. H. (1985): A review of the mineralogy of lamproites. – Trans. Geol. Soc. S. A. **88** (2): 411–438.

– (1986): Kimberlites: mineralogy, geochemistry and petrology. – Plenum Press.

MUKHERJEE, K. K. (1961): Petrology of lamprophyres of the Bokaro Coalfield, Bihar. – Quart. J. geol. Min. Met. Soc. Ind. **33** (2): 69–87.

MURTY, Y. G. K., RAO, M. G., MISRA, R. C. & REDDY, T. A. K. (1980): Kimberlite diatremes of Andhra Pradesh – their assessment and search for concealed bodies. – Papers and Proceedings of the seminar: The many facets of the Indian Diamond Industry, Bombay. Hindustan Diamond Co. Ltd. (unpaged–12 pages).

NAGABHUSHANAM, B. & VENKATANARAYANA, B. (1985): Geology and geochemistry of kimberlites of Wajrakarur area, Anantapur district, Andhra Pradesh. – Geophysical Research Bulletin **23** (1): 43–53.

NAIK, M. S. (1985): Phlogopite micas from kimberlite of Majhgawan, Panna, Madhya Pradesh. – Indian Mineralogist **26:** 8–11.

NANE, S. G. (1971): The Angore ultramafic intrusive and its potential with respect to diamonds – a review. – Proceedings of a Symposium on Diamond, Panna, 1969. Misc. Publ. No. **19,** Geol. Surv. India, p. 109–113.

NAQVI, S. M., RAO, V. D. & NARAIN, H. (1974): The protocontinental growth of the Indian Shield and the antiquity of its rift valleys. – Precambrian Research **1** (4): 345–398.

NEHRU, C. E. & REDDY, A. K. (1986): Ultramafic xenoliths from Vajrakarur kimberlites, India. – Extended abstracts of the Fourth International Kimberlite Conference, Perth, Australia. Geol. Soc. Australia Abstracts No. **16:** 81–83.

PAUL, D. K. (1979): Isotopic composition of strontium in Indian kimberlites. – Geochim. Cosmochim. Acta **43:** 389–394.

– (1980): Indian diamond and kimberlites. – Pub. Geol. Dept.-Extens. Serv., Univ. West. Australia, **5:** 15–23.

PAUL, D. K. & SARKAR, A. (1986): Petrogenesis of some Indian lamprophyres. – Proceedings of SYMPET, Jaipur 1981. Special Publ. Geol. Surv. India **12:** 45–54.

PAUL, D. K., REX, D. C. & HARRIS, P. G. (1975): Chemical characteristics and K–Ar ages of Indian kimberlite. – Geol. Soc. Amer. Bull. **86:** 364–366.

PURI, S. N. (1972): Notes on the Angor kimberlite. – Indian Minerals **26** (4): 133–134.

RAO, B. B. (1976): A note on the micaceous kimberlite dyke in the Cumbum Formations near Zangamrajupalle, Cuddapah District, Andhra Pradesh. – Indian Minerals **30** (1): 55–58.

RAO, S. R. & PHADTRE, P. N. (1966): Kimberlite pipe-rocks of Wajrakarur area, Anatapur district, Andhra Pradesh. – J. Geol. Soc. India **7:** 118–123.

REDDY, T. A. K. (1987): Kimberlite and lamproite rocks of Vajrakarur area, Andhra Pradesh. – J. Geol. Soc. India Journal **30:** 1–12.

SARKAR, A., PAUL, D. K., BALASUBRAHMANYAN, M. N. & SENGUPTA, N. R. (1980): Lamprophyres from Indian Gondwanas – K–Ar ages and chemistry. – J. Geol. Soc. India **21:** 188–193.

SARMA, B. S. P. (1983): A report on ground magnetic survey over Chelima dyke (Cuddapah Basin). – Nat. Geophys. Res. Inst. Hyderabad, India, Tech. Rep. 83–210.

SCOTT SMITH, B. H. & SKINNER, E. M. W. (1984 a): A new look at Prairie Creek, Arkansas. – In: Kimberlites and related rocks (Ed. KORNPROBST, J.), Proceedings of the Third International Kimberlite Conference, Vol. 1, Elsevier's Development in Petrology series, no. **11 A:** 255–284.

– – (1984 b): Kimberlite and American Mines, near Prairie Creek, Arkansas. – In: (Ed. KORNPROBST, J.) Kimberlite III: Documents Annal. Scientifiques de l'Univ. de Clermont Fd II, **74:** 27–36.

– – (1984 c): Diamondiferous lamproites. – J. Geol. **92:** 433–438.

SCOTT SMITH, B. H., SKINNER, E. M. W. & CLEMENT, C. R. (1983): Further data on the occurrence of pectolite in kimberlite. – Mineral. Mag. **47:** 75–78.

SCOTT SMITH, B. H., SKINNER, E. M. W. & LONEY, P. E. (1989): The Kapamba lamproites of the Luangwa Valley, eastern Zambia. – In: Kimberlites and Related Rocks, Vol. 1 – their composition, occurrence, origin and emplacement. Proceedings of the Fourth International Kimberlite Conference. Geol. Soc. Australian Spec. Publ. No. **14:** 189–205. Blackwell Scientific Publications.

SCOTT SMITH, B. H., DANCHIN, R. V., HARRIS, J. W. & STRACKE, K. J. (1984): Kimberlites near Orroroo, South Australia. – In: Kimberlites and related rocks (Ed. KORNPROBST, J.), Proceedings of the Third International Kimberlite Conference, Vol. 1, Elsevier's Development in Petrology series, no. **11 A:** 121–142.

SEN, S. N. & NARISINHA RAO, CH. (1970): Chelima dykes. – Proc. 2nd Symposium on Upper Mantle Project, Hyderabad. Session 5: Combined Geosurveys in Dharwar and Cuddapah Basin, p. 435–439.

– – (1971): Chelima dykes – a source for diamonds in Kurnool district, Andhra Pradesh. – Geol. Surv. India Misc. Publ. **19:** 92–94.

SETTI, D. N., RAO, T. S. & RAJU, M. S. (1978): A note on the occurrence of kimberlite–carbonatite enclaves in the "Peninsular gneiss", Warangal District, Andhra Pradesh. – Indian Minerals **33** (4): 53–55.

SINOR, K. P. (1930): The Diamond Mines of Panna State in Central India. – The Times of India Press, Bombay. 189 pp.

SKINNER, E. M. W. (1986): Contrasting Group 1 and Group 2 kimberlite petrology: towards a genetic model for kimberlites. – Extended abstract of Fourth International Kimberlite Conference, Geol. Soc. Australia No. **16:** 202–203.

SKINNER, E. M. W. & CLEMENT, C. R. (1979): Mineralogical classification of southern African kimberlites. – In: Kimberlites, diatremes and diamonds. Their geology, petrology and geochemistry (Eds. BOYD, F. R. & MEYER, H. O. A.), A. G. U. Washington. 399 pp., 129–139.

SKINNER, E. M. W., SMITH, C. B., BRISTOW, J. B., SCOTT SMITH, B. H. & DAWSON, J. B. (1985): Proterozoic kimberlites and lamproites and a preliminary age for the Argyle lamproite pipe, Western Australia. – Trans. Geol. Soc. South Africa **88:** 335–340.

SMITH, C. B. (1983): Pb, Sr and Nd isotopic evidence for sources of southern African Cretaceous kimberlites. – Nature **304:** 514–54.

SUBRAHMANYAM, B. & PURI, S. N. (1986): Discovery of kimberlite by new geophysical interpretation. – Jour. Assoc. Expl. Geophys. **7** (3): 147–150.

TEWARI, A. P. (1971): Search for possible diamondiferous formations in parts of southern Uttar Pradesh and part of Madhya Pradesh. – Proceedings of a Symposium on Diamond, Panna, 1969. Geol. Surv. India Miscell. Publ. **19:** 69–71.

TYAGI, S. R. C. (1980): Multidisciplinary exploration for diamondiferous kimberlites in the Jungel Valley, Mirzapur Dist. U. P. – Papers and Proceedings of the seminar: The many facets of the Indian Diamond Industry, Bombay. Hindustan Diamond Co. Ltd. (unpaged – 9 pages).

VEMBAN, N. A. (1946): Chemical and petrological study of some dyke rocks in the Precambrian (Cuddapah Traps). – Proc. India Acad. Sci. Sec. A Vol. **22** (6): 347–378.

Manuscript received by the editor May 5, 1989.

Address of the author:

BARBARA H. SCOTT SMITH, 2555 Edgemont Boulevard, North Vancouver, B. C., Canada V7R 2M9.