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MINERALOGY OF INDIAN KIMBERLITES — A THERMAL AND X-RAY STUDY

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Abstract

X-ray and thermal analyses of kimberlite samples from the major occurrences in India show the presence of serpentine, vermiculite, chlorite and smectites in the matrix. Palygorskite is recorded from one kimberlite pipe. Distinct mineralogical differences exist in the kimberlites of the petrographic provinces of central and southern India. Vermiculite is fairly abundant in the former but for the most part is absent in the latter. However, there is no clear variation in mineral assemblages with depth, and the alteration products are thought to have formed during the last stages of emplacement.

Sommaire

Les analyses thermiques et par rayons X d'échantillons de kimberlite provenant des gîtes principaux de l'Inde indiquent que la matrice contient de la serpentine, de la vermiculite, de la chlorite et des smectites. Une cheminée de kimberlite contient de la palygorskite. Il existe des différences minéralogiques nettes entre les kimberlites des provinces pétrographiques de l'Inde (centrale et méridionale). La vermiculite est assez abondante dans la première, mais elle est absente dans la plus grande partie de la seconde. Par contre, on n'observe clairement aucune variation des associations minérales en fonction de la profondeur, et on peut penser que les produits d'altération se sont formés aux stades ultimes de la mise en place.

(Traduit par la Rédaction)

Introduction

Kimberlites are ultrafamic rocks which incorporate a wide variety of inclusions of deep-seated origin. The matrix of kimberlite is mainly serpentine and phlogopite, with subordinate chlorite and carbonate. Thermal analyses of the matrices of kimberlites from southern Africa have shown the presence of saponite, vermiculite, chlorite and other minerals, which has been ascribed to late-emplacement alteration, as opposed to post-emplacement weathering (Kresten 1973). A detailed knowledge of the mineralogy of the kimberlite matrix is important, both for the understanding of the petrogenesis of kimberlite, and because the chemical characteristics of kimberlites depend on the extent of alteration.

Although kimberlites have been known in India for a long time, no detailed account for the mineralogical variations among pipes from different petrographic provinces has yet been given. A general classification of the known occurrences is given by Paul *et al.* (1975), and a mineralogical study of one pipe was reported by Dasgupta & Phukan (1971).

In this paper, DTA, TG, and X-ray diffraction studies are reported for 20 samples from all the major kimberlite occurrences in India. The opaque minerals will be discussed in a later paper. The main objectives of the present study were to investigate sequential mineralogical changes, and to attempt to classify Indian kimberlites according to matrix mineralogy.

Sample Description

Kimberlites occur in two petrographic provinces in central and southern India (see map of Paul *et al.* 1975). In central India two major kimberlite diatremes are known at Majhgawan and Hinota. The Majhgawan diatreme is at present mined for diamonds. Recently, the Geological Survey of India located other diatremes with kimberlitic affinity in this province. All the diatremes of central India intrude the Kaimur sandstone of the Upper Vindhyan System (Proterozoic). In southern India, four kimberlite pipes are known; these intrude Precambrian granite and granite gneiss, and a kimberlite dyke occurs within the Proterozoic Cuddapah sediments. Recent K-Ar age determinations on seven whole-rock samples from five occurrences have shown ages ranging from 974 to 1170 m.y. (Paul *et al.* 1975).

The majority of the samples used for the present study is from the central Indian province (Table 1). The Majhgawan samples were collected from an open-pit mine and from a shaft 100 metres deep. The samples are yellowish grey at the surface but greenish black at depth. The kimberlites are generally agglomer-

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TABLE 1. MINERALOGICAL COMPOSITION OF INDIAN KIMBERLITES

		Depth from surface, m	oli-vine	cal-cite	phlogo-pite	vermi-culite	serpen-tine	chlorite	smec-tites	paly-gorskite	F-apatite
Southern India											
Wajrakarur Pipe	WK2/5	0	++	+	++	-	++	++	-	-	++
	WK2/7	0	+++	+	++	-	++	++	-	-	+
Lattavaram Pipe I	LM3/5	0	-	++	-	+	++++	-	-	-	-
Lattavaram Pipe II	LM4/6	0	++	++	++	-	++	++	-	++	++
	LM4/14	0	++	++	++	-	++	++	-	++	++
Central India											
Hinota Pipe	HV4/1	30.8	-	-	++	+++	+	++	++	-	-
	HV4/3	55.3	-	-	++	+++	+	++	++	-	+
	HV4/5	64.5	-	-	++	+++	+	+	+	-	+
	HV4/7	96.9	-	-	++	++	-	-	-	-	-
Majhgawan Pipe	MG11	11.5	-	++	-	+++	-	++	-	-	-
	MG21	11.5	-	-	+	++	+++	-	+	-	-
	MG32	14.0	-	-	+	+	++++	-	+	-	-
	MG26	18.5	-	++	-	++	+++	-	-	-	+
	MG39	18.5	-	++	+	+	++	++	++	+	-
	MG25	19.5	-	+	-	++	+++	+++	-	-	+
	MG50	19.5	-	-	++	++	+++	++	++	-	-
	MG36	21.0	-	-	-	++	++	-	-	-	-
	MGUG20	100.0	-	-	++	-	+++	-	+	-	-
	MGUG71	100.0	-	-	++	-	++	++	++	-	-
	MGUG84	100.0	-	-	+	++	+	-	+	-	-

- not detected, + present, ++ fairly abundant, +++ abundant, ++++ very abundant

atic. Olivine is almost completely replaced by serpentine. Phenocrysts of phlogopite, up to 5 mm across, are common. Secondary calcite veins are found at the surface only. The samples from the neighboring Hinota pipe are from bore holes. They are soft, friable and very altered even at 90 metres depth.

The south Indian samples are from three pipes: Wajrakarur (WK2), Lattavaram I (LM3), and Lattavaram II (LM4). The samples are hard and dark grey, resembling the "hardebank" of southern Africa. Despite serpentinization, fresh olivines are present. They vary in size and habit, and preliminary microprobe analyses indicate a compositional range from Fo_{85} to Fo_{91}. Some phlogopite is present in the matrix.

METHODS

The samples were crushed in a Tema grinder. Xenoliths and xenolithic fragments were rejected, but megacrysts, mostly olivine, are included in the samples.

X-ray powder diffractograms were obtained with a JEOL DX-GO-S diffractometer using Cu$K\alpha$ radiation and a scanning speed of 2° (2θ)/min. from 2 to 65°(2θ). Thrmogravimetric curves were obtained with a Stanton HT thermobalance. About 500 mg of sample were run at a heating rate of 6°/min. in alumina crucibles in static air atmosphere. Differential thermal analyses were carried out with a Linseis L-62 instrument. Alumina crucibles (volume 0.09 cm^3, sample weight about 60 mg) served as sample holders. Alumina was used as inert material. Static air atmosphere and a heating rate of 10°/min. were used throughout the runs. The Pt-Pt10%Rh thermocouples, located outside the sample, were calibrated against I.C.T.A. standard materials with reference to temperature and peak area.

RESULTS

The results of X-ray and thermal analyses are summarized in Tables 1 and 2. Mineral assemblages of Table 1 were determined by a combination of all techniques used. The kimberlites of southern India show appreciable amounts of olivine, and do not contain any detectable amounts of vermiculite (Table 1). The kimberlites of central India do not contain detectable olivine, but vermiculite and some smectite (montmorillonite?) are present.

TABLE 2. THERMOGRAVIMETRIC DATA FOR INDIAN KIMBERLITES

Sample	Total loss, wt.%	H_2O-300 wt.%	wt. loss in % of total wt. loss: -300°C	300-600°C	600-800°C	800-1000°C	
WK2/5	5.0	0.7	13.8	22.4	44.6	19.2	Southern India
WK2/7	6.7	1.1	17.2	14.0	48.3	20.5	
LM3/5	16.9	1.8	10.4	15.6	66.9	7.1	
LM4/6	6.7	1.0	14.2	12.4	42.4	31.0	
LM4/14	8.7	1.5	17.4	16.1	53.1	13.4	
HV4/1	11.4	5.8	51.3	6.3	12.5	29.9	Central India
HV4/3	8.5	4.1	48.3	13.3	14.6	23.8	
HV4/5	11.1	5.2	47.3	5.9	13.3	33.5	
HV4/7	12.5	4.0	31.8	9.4	31.8	27.0	
MG11	22.5	8.7	38.9	8.9	20.4	31.8	
MG21	13.4	4.2	31.3	12.0	52.6	4.1	
MG32	11.6	3.0	25.8	17.9	49.3	7.0	
MG25	14.1	5.8	41.3	15.5	36.2	7.0	
MG36	11.3	3.4	30.4	13.1	47.9	8.6	
MGUG20	11.3	4.0	35.3	10.1	43.4	11.2	
MGUG71	9.6	2.8	28.7	24.3	42.5	4.5	
MGUG84	11.3	4.0	35.6	14.2	39.1	11.1	

Wajrakarur pipe. Both surface samples studied (WK2/5 and WK2/7) contain olivine, phlogopite, serpentine, chlorite, and little calcite and apatite (Table 1). Thermogravimetry (Table 2) shows the lowest loss of weight recorded, both with respect to total loss and loss up to 300°C. Most of the loss occurs between 600 and 800°C, which is consistent with data on the thermal decomposition of both serpentine and chlorite (Mackenzie 1970). DTA results (Fig. 1) suggest that chlorite exceeds serpentine, as is

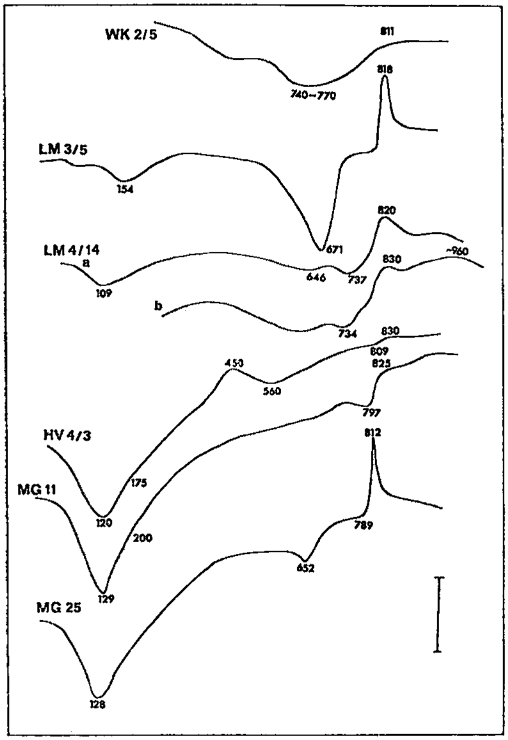

FIG. 1. Differential thermal analyses of Indian kimberlites. For sample LM 4/14, curve 'a' represents the untreated material, curve 'b' after treatment with 0.5*N* $AlCl_3$ solution. The additional exothermic effect at 960°C on curve 'b' is ascribed to palygorskite. Scale bar corresponds to 1°C for temperature difference.

indicated by the fairly shallow exothermic effect at 811°C (see also SCIFAX 15,18 and 17,14). Chlorite, probably after olivine, constitutes the bulk of the "iddingsite" reported (Paul *et al.* 1975).

Lattavaram pipe I. One sample, LM3/5, contains large amounts of serpentine, some calcite and little vermiculite (Table 1). In contrast to other kimberlites from southern India, this kimberlite does not contain detectable olivine, but vermiculite is present. Thermogravimetry (Table 2) shows a pronounced weight loss of 16.9%, most of which occurs between 600 and 800°C. The DTA curve (Fig. 1) corresponds to those obtained for pure serpentine (Caillère & Hénin 1957; Mackenzie 1970; SCIFAX 16,19Ex). It is estimated that more than 2/3 of the sample weight is due to serpentine.

Lattavaram pipe II. Both samples, LM4/6 and LM4/14, contain olivine, calcite, phlogopite, serpentine, chlorite, apatite, and another mineral identified as palygorskite. The following X-ray lines, arranged in order of decreasing intensity, are ascribed to palygorskite (Å): 3.24, 10.1, 4.25, 2.56, 2.46. These values are in excellent agreement with those given by Smirnov (1962) for palygorskite from the kimberlites of Yakutia.

DTA curves vary for palygorskite, depending on whether the fibrous or the massive variety is present (Caillère & Hénin 1957; Smirnov 1962). The DTA curve of sample LM4/14 does not show the characteristics of fibrous palygorskite, such as the endothermic effect at 450°C. Caillère & Hénin (1957) found that palygorskite treated with $AlCl_3$ solution displays an additional diagnostic exothermic effect at about 900°C for massive, and 1050°C for fibrous palygorskite. A sample of LM4/14 treated with 0.5*N* $AlCl_3$ solution gave a broad exothermic effect with a maximum at about 960°C (LM4/14b, Fig. 1), thus confirming the presence of palygorskite, probably of the massive variety. Palygorskite minerals from kimberlites have been described by Wagner (1914), Smirnov (1962) and Kresten (1973; serpentine and palygorskite in an ultrabasic nodule). All these refer to discrete mineral aggregates, which form stringers, crusts or coatings. Whether palygorskite in the kimberlites of Lattavaram pipe II occurs as discrete aggregates or as a matrix constituent remains uncertain.

Hinota pipe. Four samples from various depths have been investigated. Phlogopite and Mg-vermiculite (d_{002}=14.4Å) occur in all samples, and serpentine, chlorite and smectite (montmorillonite?) are present in all but the deepest sample (Table 1). The decrease in vermiculite and smectite with depth is reflected by the decrease of the relative amounts of H_2O^{-300} with depth (Table 2).

TG and DTA traces are typical for mixtures of vermiculite, chlorite and serpentine (Table 2, Fig. 1). The slightly doubled endothermic peak at low temperatures, and the s-shaped endothermic-exothermic peak system at about 800°C are characteristic for vermiculite. The endothermic peak at 560°C, broadened and doubled (Fig. 1) and accompanied by a marked weight loss (Table 2) is typical for chlorite mixed with serpentine (Mackenzie 1970).

Majhgawan pipe. Several samples from Majhgawan pipe, comprising both surface (MG) and underground (MGUG) samples, have been studied. Vermiculite, serpentine and chlorite are most abundant; phlogopite and smectite (montmorillonite?) are fairly abundant in some samples. One specimen (MG39) contains minor amounts of palygorskite (Table 1). In contrast to vermiculite from Hinota pipe, all vermiculite specimens from Majhgawan seem to be saturated with Ca, rather than Mg, as indicated by a basal spacing of 15.0—15.1Å (d_{002}).

Calcite has been detected in surface samples only. The proportions of vermiculite, serpentine and chlorite vary considerably. For example, sample MG11 is composed mainly of vermiculite (estimated to 45 wt. %), sample MG25 has fairly abundant serpentine and chlorite with subordinate vermiculite (Table 1, Fig. 1), and sample MG32 contains mainly serpentine (Table 1).

Discussion

On heating to 1000°C, the kimberlites of central India usually lose more water than the kimberlites of southern India (Table 2). The content of H_2O^{-300} has been found previously to be related to the mineralogical composition (Kresten 1973). For the kimberlites of central India, H_2O^{-300} is always greater than 2 wt. %. Weight losses exceeding 2% up to 300°C indicate the presence of vermiculite or other clay minerals (Kresten 1973). This study indicates that vermiculite is the most characteristic constituent of the kimberlites of central India.

The kimberlites of southern India show a small weight loss up to 300°C. With the exception of Lattavaram pipe I, south Indian kimberlites therefore do not contain detectable vermiculite.

The two-fold division suggested by the presence or absence of vermiculite parallels the traditional two-fold division of kimberlites into basaltic and micaceous types, although the bases of classification are entirely different. Both the kimberlite varieties are obviously altered. Olivine is replaced by serpentine, and possibly by chlorite and vermiculite; phlogopite has been replaced by vermiculite. If one assumes that all serpentine in the kimberlites is an alteration product of olivine, the southern Indian samples would fall into the field of basaltic kimberlites. On the other hand, the central Indian kimberlites would be classified as micaceous. However, several samples (e.g., MG21, MG32, MGUG20) would fall into the field of basaltic kimberlites.

There is no systematic difference in the potassium content of the two groups (Paul *et al.* 1975). This could be explained by alteration. The composition of vermiculite resembles those of phlogopite or magnesian biotite, and vermiculite is derived from these by replacement of K^+ by Mg^{2+} or Ca^{2+} (Foster 1963).

In conclusion, thermal and X-ray analyses of Indian kimberlites have shown that distinct mineralogical differences are observed in kimberlites of the two petrographic provinces of central and southern India. Vermiculite is fairly abundant in the former province, whereas it is for the most part absent in the latter. The mineral assemblages reported correspond to the "vermiculite stage" and "serpentine stage" of Kresten (1973). Subordinate contents of smectite minerals might be ascribed to weathering in a tropical climate (Fairbairn & Robertson 1966). Most of the vermiculite is suggested to have formed during the late stages of evolution and emplacement of the kimberlites.

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References

Caillère, S. & Hénin, S. (1957): The serpentine and related minerals. The sepiolite and palygorskite minerals. Pp 220-247 in *The Differential Thermal Investigation of Clays* (R. C. Mackenzie, ed.). Mineral. Soc. London.

Dasgupta, S. P. & Phukan, S. (1971): Mineralogy of the altered diamondiferous pipe rock at Panna, M.P. *Geol. Surv. India, Misc. Publ.* **19**, 114-119.

Fairbairn, P. E. & Robertson, R. H. S. (1966): Stages in the tropical weathering of kimberlite. *Clay Minerals* **6**, 351-370.

Foster, M. G. (1963): Interpretation of the composition of vermiculites and hydrobiotites. *Clays Clay Minerals* **10**, 70-89.

Kresten, P. (1973): Differential thermal analysis of kimberlites. Pp. 269-278 in *Lesotho Kimberlites* (P. H. Nixon, ed.). LNDC, Maseru, Lesotho.

Mackenzie, R. C. (1970): Simple phyllosilicates. Pp 489-537 in *Differential Thermal Analysis* (R. C. Mackenzie, ed.). Academic Press, London & New York.

Paul, D. K., Rex, D. C. & Harris, P. G. (1975): Chemical characteristics and K-Ar ages of Indian kimberlites. *Geol. Soc. Amer. Bull.* **86**, 364-366.

Scifax, Differential Thermal Analysis Data Index (R. C. Mackenzie, compil.). Cleaver-Hume, London, 1962, 1964.

Smirnov, G. I. (1962): Ferrous palygorskite (xylotile) in kimberlites. *Geol. Geofiz. AN SSSR, Sibirsk. Otd.* vtfb (1), 129-134 (in Russ.).

Wagner, P. A. (1914): The diamond fields of southern Africa. *The Transvaal Leader*, Johannesburg.

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