PETROGRAPHY, MINERALOGY AND GEOCHEMISTRY OF KIMBERLITE AND ASSOCIATED LAMPROPHYRE DYKES NEAR SWARTRUGGENS, WESTERN TRANSVAAL, R.S.A.

E.M.W. SKINNER* and B.H. SCOTT†

**De Beers Consolidated Mines Limited: Geology Department, P.O. Box 616, 8300 KIMBERLEY*

†Anglo American Research Laboratories, P.O. Box 106, 2025 CROWN MINES, Transvaal

The discovery of diamonds in 1933 close to the town of Swartruggens in the Western Transvaal, South Africa, led to the location of a swarm of dykes, some of which yielded many diamonds while others were found to be barren. In the past, although some authors (e.g. Smith et. al., 1979) have recognised petrographic differences, all the dykes have been classified as kimberlites. In this study, detailed petrographic examination of five dykes, supported by mineral chemistry and whole rock geochemistry, clearly demonstrates that the barren dykes (Male and Female) are lamprophyres rather than kimberlites (Main, Changehouse and Normal). *Rb/Sr* age determinations by Allsopp & Kramers (1978) indicate a similar age of 150 ± 3 m.y. for the Main and Male dykes, however, field relationships and petrographic evidence clearly show the Main to be older than the Male.

The kimberlites are all phlogopite types (Modal Analyses, Table 1), but considerable variation in texture, degree of alteration and proportions of constituents are apparent in specimens collected from different dykes and from different parts (horizontally and vertically) of the same dykes. Besides phlogopite, other primary constituents include olivine (completely altered and partly replaced), anthophyllite (mostly altered), apatite, diopside, monticellite (?, mostly altered), spinels, calcite and serpentine. Several garnets and small, altered and corroded peridotitic xenoliths were encountered in some of the thin sections examined.

The lamprophyres consist essentially of variable proportions of altered olivine, diopside, phlogopite, altered leucite(?), nepheline, sanidine and zeolite which is probably mostly secondary after nepheline. Also present are lesser amounts of calcite, dolomite, spinels, apatite and a variety of secondary minerals, including: pyrite, barytes, quartz, chlorite, serpentine and other alteration products after nepheline and sanidine. Like the kimberlites, textural and compositional variations are also apparent in specimens of lamprophyre collected from different parts of the same dykes.

Textural and compositional variations result from a combination of flowage differentiation and differences in cooling rates across the widths of dykes. The former results in the separation of macrocrysts away from dyke margins in the case of the kimberlites as well as the development of foliation textures on macroscopic and microscopic scales in both the kimberlites and lamprophyres. The major textural and compositional differences, however, appear to be related to temperature differences across the widths of dykes.

In the case of the kimberlites, within contact zones, macrocrysts are rare and the texture is essentially microporphyritic; grain boundaries of most minerals are idiomorphic; small, euhedral, altered olivine crystals are common and often occur as aggregates of several grains; diopside and anthophyllite are relatively more abundant and less severely altered; and phlogopite occurs in a variety of modes, including an ultrafine-grained (glassy in parts) groundmass generation. Within the central zones, in hand specimen, macroporphyritic textures are evident with larger (up to 10 *mm*) anhedral grains of phlogopite and altered olivine set in a finer-grained matrix. This matrix has an equigranular texture resulting from the occurrence of abundant, more-or-less even-sized, (± 0,15 *mm*) grains of mainly phlogopite.

In the case of the lamprophyres, within contact zones, although mineralogical banding and grain-size variations due to flow, are locally evident, the main texture, both macroscopically and microscopically, is essentially porphyritic. Altered leucite, translucent spinel and veinlets, containing nepheline, sanidine and zeolites, are particular abundant in these parts. Altered olivine grains which are up to 3 *mm* in size and commonly occur as aggregates of several crystals, are remarkably euhedral, but some hopper crystals also occur. Besides olivines, other constituents tend to be very finegrained and, microscopically, cannot be easily distinguished from one another. Towards the centre of the dykes, grain-size gradually increases and olivine crystals, which tend to be subhedral, reach up to 6 *mm* in size. No hopper olivines were seen and anhedral macrocrysts do not occur. The dominant texture of centrally located specimens is sub-ophitic with many altered olivine and diopside crystals being partly, and in some instances, completely enclosed by phlogopite laths. All these minerals are set in a groundmass interpreted as originally consisting of either nepheline or leucite or both. Some specimens contain oblate spheroids (up to ± 6 *mm*) and irregular segregations (up to ± 20 *mm*) which are aligned in the direction of flow and which consist mainly of the last minerals to have crystallised, including: sanidine, nepheline and zeolite plus alteration products of these minerals.

Two variations of the Main Fissure (the 'Blue' and 'Brown' types) are locally recognised. The 'Blue' Main and the Normal Fissures are extensively altered and contain abundant chlorite (after phlogopite) plus introduced quartz and calcite. Compared to the Changehouse and Normal dykes, the Main Fissure contains less diopside and, in parts, more calcite, spinels and apatite. The Female dyke is generally finer-grained than the Male Fissure.

In the kimberlites, olivine is altered to a variety of products including talc, serpentine, calcite, clay minerals, quartz, baryte, magnetite, pyrite and millerite(?). In the lamprophyres, olivine alteration products are mainly serpentine and clay minerals Extensive replacement of altered olivine by phlogopite is evident in the kimberlites. The low proportions of olivine, compared with kimberlites elsewhere, is partly explained by this phenomenon.

Phlogopite occurs in a variety of modes in the kimberlites, including anhedral macrocrysts (up to >10 *mm*), euhedral to subhedral crystals of variable size, as microlites and possible mica-glass, as constituents of mica xenoliths, and lastly as a secondary generation after olivine, diopside and garnet. In the lamprophyres phlogopite crystals are all perfectly euhedral and range in size from up to 1 mm to much less than 0,05 *mm*. Larger grains poikilitically enclose earlier crystallizing minerals. In the kimberlites, phlogopite alteration is highly variable and apparently inconsistent. Within a single thin-section different grains may exhibit green (chlorite) and dark brown(?) streaks, 'blebs' and 'zones' located not only within the cores of grains but also at grain margins and as one or more randomly oriented patches. Some grains, especially those surrounding large olivine pseudomorphs, are 'bleached' of all colour. Most relatively fresh grains exhibit normal pleochroism but reversed pleochroic, darker rims are almost ubiquitous in euhedral and subhedral crystals. Lamprophyre phlogopites are darker brown than the kimberlite phlogopite and most are distinctly unaltered. A few grains are partly chloritized. Darker brown margins are ubiquitous, but unlike the kimberlite phlogopites these margins exhibit normal pleochroism as do the grain centres.

In the kimberlites, diopside occurs as larger (up to 0,7 *mm*) corroded grains and as smaller, euhedral crystals and crystal aggregates. In the lamprophyres, diopside is considerably more abundant and occurs as euhedral prisms of variable size. Acicular laths (generally <1,0 x 0,05 *mm*) are conspicuous in coarser-grained specimens.

Mineralogically the most unusual feature of these kimberlites compared with others, is the presence of relatively abundant (up to 12 volume %) anthophyllite. It occurs mainly as altered, elongate laths generally less than 1 *mm* x 0,1 *mm* in size. Rare, fresh relicts are, however, present and these exhibit optical properties indicative of anthophyllite.

Primary phlogopites of different generations have been analysed from all five dykes and representative analyses are given in Table 2. The phlogopite from the lamprophyres have higher TiO_2 and Cr_2O_3 contents and have lower $Mg/Mg+Fe$ ratios (Figure 1). The lamprophyre phlogopites have variable $Mg/Mg+Fe$ ratios, but fairly constant TiO_2 contents A large proportion of the phlogopite from the three kimberlite dykes have similar compositions with approximately 1,5 wt.%. TiO_2 and a $Mg/Mg+Fe$ ratio of 0,91. It can be seen from Figure 1 that some phlogopites are richer in FeO and form a scatter away from the main cluster. These are mainly small groundmass laths from the Changehouse and a few from the Main Fissure. Other analyses with higher FeO contents are considered to represent altered phlogopite.

Representative analyses of clinopyroxenes from the five dykes are given in Table 3, and the compositions are illustrated in Figure 2. The diopsides from the three kimberlites have constant $Mg/Mg+Fe$ ratios, but are somewhat variable in their CaO content. These diopsides have very similar compositions to primary groundmass clinopyroxene from other kimberlites (Dawson et. al., 1979). Figure 2 shows that the lamprophyric clinopyroxenes have lower, but variable $Mg/Mg+Fe$ ratios and Table 3 shows that they have higher Al_2O_3 and TiO_2 contents than those analysed from the kimberlites.

Sixteen analyses of the mineral tentatively optically identified as anthophyllite, appear to confirm this identification and show that the mineral is partially altered. A typical analysis gives the following results (wt.%): SiO_2 = 52,54; TiO_2 = 0,02; Al_2O_3 = 1,98; Cr_2O_3 = 0,06; FeO = 5,39; MnO = 0,09; MgO = 26,61; CaO = 0,58; Na_2O = 0,19; K_2O = 0,60 (total = 88,07).

Analyses from the groundmass in the Male Fissure include potassium feldspar, zeolite(?) and opaque oxides. The potassium feldspar has no sodium in solid solution, but has a relatively high FeO content (up to 3,15 wt.%) which has been noted in other similar lamprophyres. A typical analysis of these minerals (in wt.%) is SiO_2 = 63,65; Al_2O_3 = 17,78; Cr_2O_3 = 0,08; FeO = 1,98; Na_2O = 0,09; K_2O = 15,66 (total = 99,26 and TiO_2, MnO, NiO, MgO and CaO not detected).

The third main, but possibly secondary, interstitial groundmass constituent, apart from the potassium feldspar and nepheline, appears to be a zeolite generally with similar amounts of CaO and Na_2O. A typical analysis is (in wt.%): SiO_2 = 41,97; Al_2O_3 = 30,00; FeO = 0,15; CaO = 5,88; Na_2O = 8,45 (total = 86,45; TiO_2, Cr_2O_3, MgO, K_2O not detected).

The opaque groundmass minerals of the lamprophyres include both titanomagnetites and chromites. The titanomagnetites appear to contain up to 10 wt.% TiO_2 and the following is a typical analysis (wt.%): TiO_2 = 9,70; Al_2O_3 = 0,37; Cr_2O_3 = 0,17; FeO (total) = 79,66; MnO = 0,78; MgO = 2,54; CaO = 0,17 (total = 93,40). The small (~0,1 mm) and often euhedral chromites have Cr_2O_3 contents of 51-58 wt.%, Al_2O_3 between 4,3-6,7 wt.% and MgO between 10,9 and 13,6 wt.%.

Heavy mineral concentrates (+28#) were obtained from large samples of the Main, Changehouse and Male fissures. The kimberlites contain abundant garnets and spinels. A few chrome diopsides were recovered from the Changehouse and 'Blue' Main fissures. Garnet is considerably more abundant in the Changehouse Fissure compared with the Main (333 as opposed to 36-74 grains per 10 kg of sample). The heavy mineral abundances varied between the 'Brown' and 'Blue' Main fissures; the former containing approximately half the amount of garnet and spinel and no chrome diopside. No ilmenites were recovered from these kimberlite samples. Both the colour and chemistry of the garnets from the Changehouse and Main fissures indicate that both peridotite and eclogitic varieties are present and the assemblage is therefore typical of kimberlites. The chromites have unusual compositions and many have compositions typical of diamond-inclusions chromites. Between 35 and 70% of the grains analysed from these samples have Cr_2O_3 contents greater than 60 wt.% and several are over 67 wt.% (up to 68,95 wt.%). The average Cr_2O_3 content of the chromites from each sample ranged from 59 to 61 wt.%. The Al_2O_3 contents of 2-10 wt.%, TiO_2 of 0-3,5 wt.% and MgO of 12-14,5 wt.%, also emphasize the similarity of many of these grains to diamond inclusions chromites.

The Male fissure heavy mineral suite is different from those derived from the kimberlites. In the lamprophyre fewer heavy minerals were recovered (e.g. 0,36 garnet grains per 10 kg). The fifteen garnets analysed, although different in appearance and colour, included both peroditic and eclogitic types with similar compositions to those in the kimberlites. In contrast to the kimberlites, eighteen grains of ilmenite, but no spinel were found in the +28# concentrate. The ilmenites have 7,5-12,5 wt.% MgO, 0,05-0,97 wt.% Cr_2O_3 and hence are similar to kimberlitic ilmenites.

These results indicate that heavy minerals recovered from both the lamprophyre and kimberlite dykes are mantle-derived.

Whole rock analysis of the Main and Male Fissures, given in Table 4, reflect the differences between the kimberlite and lamprophyre dykes.

The lamprophyres are notably different from the kimberlites in their higher Na_2O/Na_2O+K_2O ratios. The higher Na_2O (and Al_2O_3) contents reflect the occurrence of nepheline and a sodic zeolite in the groundmass.

REFERENCES

ALLSOPP H.L. AND J.D. KRAMERS Extended Abstracts, 2nd International Kimberlite Conference, Sante Fe, New Mexico, 1977.

DAWSON J.B., J.V. SMITH AND R.L. HERVIG Late-stage diopside in kimberlite matrix. Neues Jahr. Mineral, pp. 529-543, 1977.

SMITH J.V., RUTH BRENNESHOLTZ AND J.B. DAWSON Chemistry of micas from kimberlites and zenoliths - I. Micaceous kimberlites, Geochim. Cosmochim. Acta. 42, pp. 959-971.

TABLE 1 MODAL ANALYSES (VOLUME%) BASED ON 500 COUNTS OVER SINGLE THIN SECTIONS

Specimens	KIMBERLITES							LAMPROPHYRES							
	K1/2 Contact	K1/27 Central	K1/28 Contact	K1/29 Central	MS66 Contact	K2/2a Contact	K2/26 Central	L1/1 Central	L1/4 Contact	L1/7 Central	L1/8 Contact	L1/9 Central	L1/10 Central	L1/14 Contact	L2/1 Centra
Olivine (All Altered)	12	11	16	15	21	11	28	32	14	27	18	28	29	13	25
Phlogopite	58	78	57	65	57	52	48	22	15	20	18	9	20	18	19
Diopside	tr.	-	tr.	tr.	2	5	2	23	33	26	26	35	24	>28	22
Various groundmass minerals*	9	2	10	2	3	20	10	22	37	25	35	25	26	<39	33
Amphibole (Mostly altered)	10	tr.	9	3	10	12	10	tr.	tr.	tr.	tr.	tr.	tr.	tr.	-
Apatite	-	4	2	tr.	tr.	tr.	tr.	tr.	tr.	2	tr.	tr.	tr.	tr.	tr.
Spinel	1	tr.	4	2	1	tr.	tr.	tr.	tr.	tr.	tr.	2	tr.	tr.	tr.
Carbonates (Mainly Calcite)	10	5	2	5	6	tr.	2	1	1	tr.	3	2	tr.	tr.	tr.
Monticellite (Mostly altered)	-	-	-	8†	-	-	-	-	-	-	-	-	-	-	-

K1 = Main Fissure K2 = Changehouse Fissure L1 = Male Fissure L2 = Female Fissure

Specimens MS66 & K1/2 supplied by J. Davidson, supposedly derived from the Main Fissure. Specimens L1/10 and L2/1 from 3 level; L1/1, L1/4, L1/14, K1/27 and K1/28 from 4 level; and L1/7, L1/8, L1/9 and K1/29 from 7 level, Helam Mine. Specimen K2/2 supplied by the Helam Mine management.

**Includes pseudoleucite, nepheline, sanidine, zeolite and alteration products of these minerals in the lamprophyres but mainly serpentine and chlorite in the kimberlites.*

†The presence of monticellite is apparent only in doubly polished thin sections at high magnification.

TABLE 2 *PHLOGOPITE ANALYSES FROM THE SWARTRUGGENS DYKES*

Dyke	MAIN				CHANGEHOUSE			NORMAL	MALE			FEMALE	
Analysis Number	842	845	878	881	704	678	684	876	601	627	625	898	900
Sample No.	K1/1	X1/1	K1/26	K1/26	K2/2 (iv)	K2/2 (ii)	K2/2 (ii)	K3/1	L1/2	L1/7	L1/7	L2/1	L2/1
SiO_2	40,80	40,12	41,94	39,69	40,35	40,03	40,17	40,04	37,23	36,89	36,86	37,32	37,33
TiO_2	1,57	1,40	1,57	1,84	1,47	1,56	1,39	1,60	4,17	3,80	3,80	3,75	3,01
Al_2O_3	12,94	12,54	12,58	10,47	7,50	11,87	10,19	12,12	12,22	12,34	11,86	11,61	11,03
Cr_2O_3	0,51	1,25	0,18	0,12	1,12	0,87	0,19	0,69	0,09	0,08	0,08	0,18	0,10
FeO	4,48	5,08	4,72	8,22	4,50	4,93	7,53	4,55	8,21	9,60	10,27	8,94	10,51
MnO	0,01	0,06	n.d.*	0,05	0,03	0,04	0,04	-	0,03	0,07	0,07	0,08	0,08
NiO	-	-	-	-	0,08	0,07	0,08	-	0,05	0,07	0,04	0,04	0,08
MgO	23,76	24,60	24,47	24,47	27,62	25,71	24,00	24,25	21,94	20,54	20,61	20,47	20,63
CaO	0,01	0,09	0,06	0,08	0,07	0,04	0,04	0,14	0,04	0,05	0,06	0,07	0,07
Na_2O	0,09	0,19	0,02	n.d.	0,15	0,12	0,13	0,18	0,09	0,05	0,07	0,15	0,11
K_2O	9,91	9,80	9,85	9,52	9,34	9,94	10,34	8,95	9,94	9,77	9,94	9,64	9,69
TOTAL	94,06	95,12	95,38	94,47	92,73	95,69	94,52	92,51	94,51	93,27	93,66	92,17	92,64
$\frac{Mg}{Mg+Fe}$	0,904	0,896	0,902	0,841	0,916	0,903	0,850	0,905	0,826	0,792	0,781	0,803	0,778

*n.d. = *not detected*

842 - centre of 0,6 mm phenocryst
845 - euhedral groundmass lath, 0,1 mm long
878 - centre large macrocryst - 1,5 mm
881 - small, euhedral lath - 0,1 mm long

704 - rim 3R phenocryst (0,24 wt.%, BaO, 0,02 wt.% P_2O_5 and 0,38 wt.% F)
678 - small groundmass (0,22 wt.% BaO, 0,01 wt.% P_2O_5, and 0,46 wt.% F)
684 - groundmass lath - ⅓R
876 - 0,1 mm bleached lath

601 - 0,05 lath
627 - groundmass lath
625 - groundmass lath

898 - small groundmass lath
900 - small groundmass lath

TABLE 3 *ANALYSES OF CLINOPYROXENES FROM THE SWARTRUGGENS DYKES*

Dyke	MAIN				CHANGEHOUSE		NORMAL	MALE			FEMALE	
Analysis Number	975	896	970	971	960	964	983	607	630	862	897	901
Sample Number	K1/28	X1/29	K1/28	K1/28	K2/2	X2/2	K3/1	L1/2	L1/7	L1/3	L2/1	L2/1
SiO_2	54,19	53,50	55,07	52,47	53,52	54,21	53,88	50,86	52,35	51,83	52,99	52,76
TiO_2	0,57	0,37	0,59	0,20	0,76	0,64	0,51	1,58	0,88	1,24	0,78	0,75
Al_2O_3	0,29	0,21	0,27	1,61	0,29	0,18	0,18	1,42	0,87	1,16	0,71	0,72
Cr_2O_3	0,25	-	0,21	0,13	0,15	0,16	0,17	0,11	0,75	0,09	0,53	0,52
FeO	2,82	2,77	2,92	10,72	2,91	2,75	2,58	5,68	3,41	4,16	3,41	3,22
MnO	0,06	-	0,07	0,44	0,07	0,08	0,05	0,07	0,08	0,08	0,08	0,07
NiO*	0,05	-	0,05	0,05	0,03	0,04	0,04	0,02	0,02	-	0,01	0,03
MgO	17,36	17,26	16,28	11,71	17,18	16,96	16,86	15,82	16,78	16,16	16,79	16,52
CaO	24,50	23,66	25,04	22,21	24,63	24,93	24,92	23,93	24,25	24,23	24,22	24,19
Na_2O	0,34	0,28	0,26	0,75	0,24	0,22	0,18	0,34	0,14	0,23	0,22	0,22
K_2O	n.d.*	n.d.	0,01	0,02	0,02	0,01	n.d.	0,02	0,02	n.d.	0,24	0,22
TOTAL	100,44	98,05	100,77	100,31	99,80	100,18	99,37	99,86	99,55	99,14	99,79	99,02

*n.d. = *not detected*

TABLE 4 *WHOLE ROCK ANALYSIS OF THE MAIN AND MALE FISSURES*

Dyke	MAIN	MALE
Sample No.	MS66	MS67*
SiO_2	38,90	43,03
TiO_2	1,67	1,56
Al_2O_3	3,97	5,10
Cr_2O_3	0,31	0,33
$Fe_2O_3(t)$	8,57	9,32
MnO	0,15	0,15
MgO	19,92	17,67
CaO	7,06	8,88
Na_2O	0,28	1,19
K_2O	4,68	1,52
P_2O_5	1,34	0,72
LOI*	11,39	8,86
TOTAL	98,24	98,37
$\frac{Na_2O}{Na_2O+K_2O}$	0,06	0,44

*LOI = H_2O^+, H_2O^- and CO_2

Fig.1 TiO_2 vs Mg / Mg+Fe of phlogopite from all five dykes

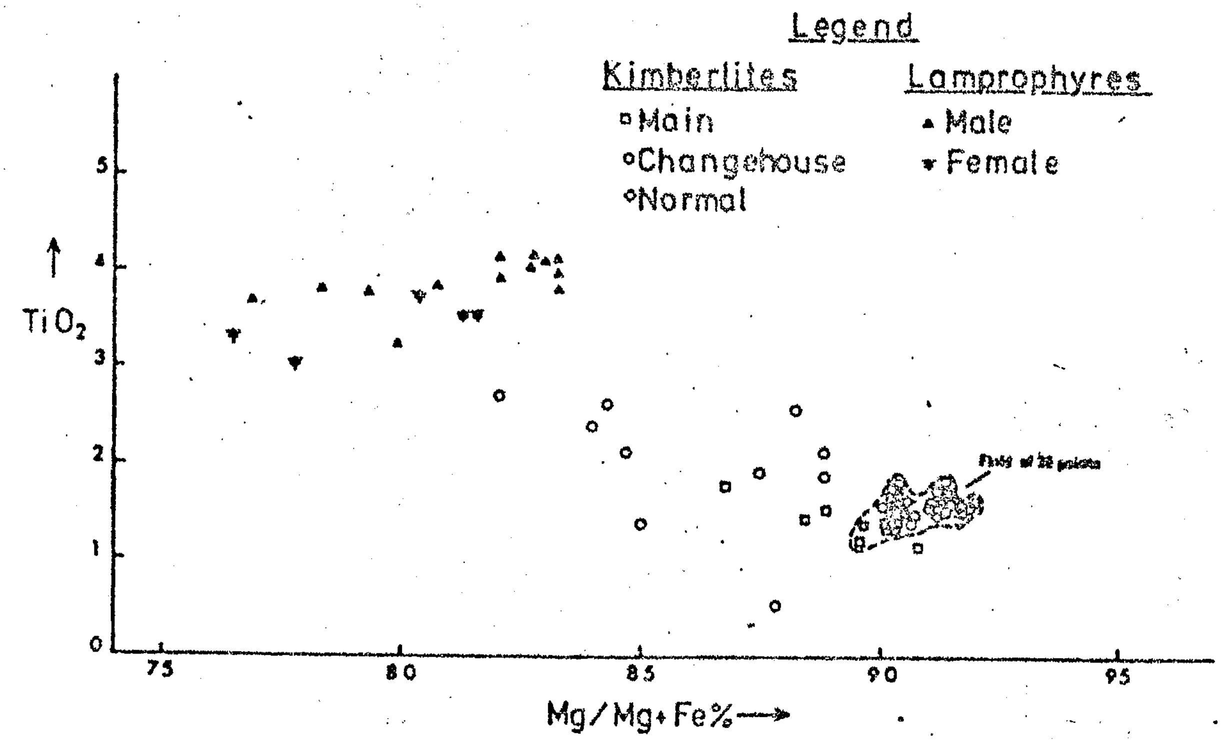
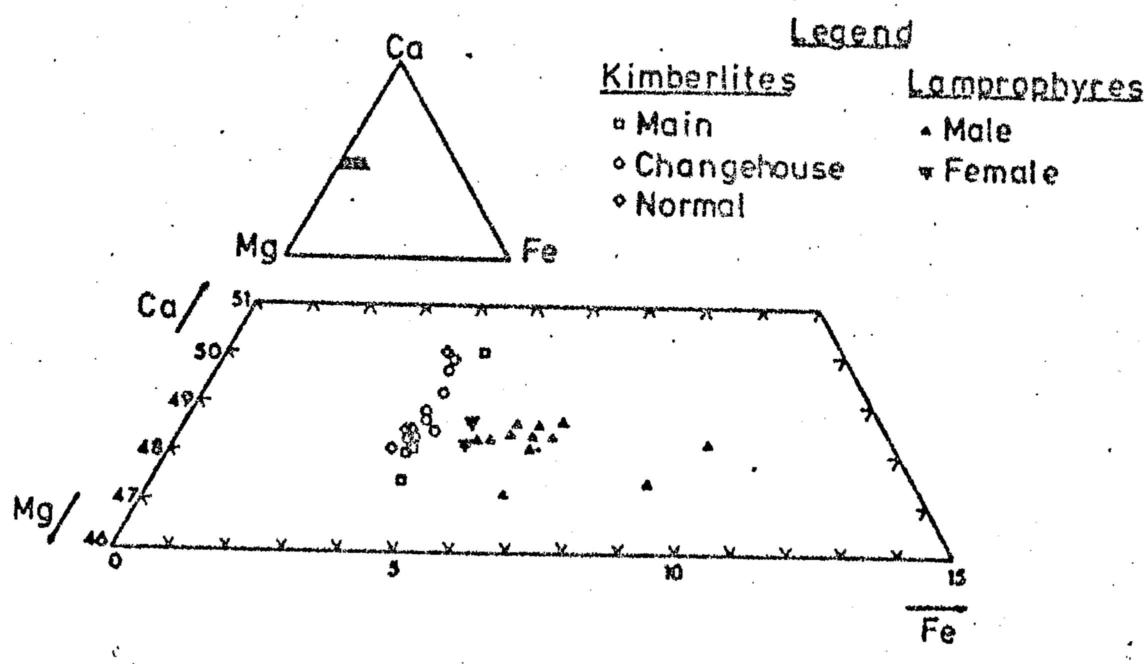


Fig. 2 Ca-Mg-Fe atomic proportion plot for clinopyroxenes from the five dykes.



KIMBERLITE SYMPOSIUM II

Cambridge July 1979