KIMBERLITIC DYKE IN KEITH TOWNSHIP, ONTARIO

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ABSTRACT

A narrow post-orogenic kimberlitic dyke occurring about 80 km southwest of Timmins consists mainly of olivine and altered olivine (40%), phlogopite (25%), and carbonate minerals (20%), and lesser amounts of spinels, ilmenite, clinopyroxene, serpentine, perovskite, and apatite. Among the principal constituents, olivine crystallized first, followed by phlogopite, and then by carbonate. The spinel-group minerals increased in Fe, especially Fe^{3+}, and Ti and generally decreased in Cr and Al as crystallization proceeded. Phlogopite crystals with dark rims and normal pleochroism decreased in Mg/Fe, Ti, and Al and increased in Si during crystal growth. The ilmenite, unlike that characteristic of kimberlite, is very low in Mg, Fe^{3+}, and Cr. The clinopyroxene is non-xenocrystic salite, low in Cr and Na and high in Ti. The carbonate is not a product of weathering; much of it may be late-crystallizing primary material, but possible formation by selective replacement cannot be dismissed.

SOMMAIRE

Un mince dike kimberlitique post-orogénique, situé 80 km au sud-ouest de Timmins, contient 40% d'olivine saine ou altérée, 25% de phlogopite, 20% de carbonates et des quantités plus faibles de spinelles, ilménite, clinopyroxène, serpentine, perovskite et apatite. Quant à la cristallisation des minéraux principaux, l'olivine a précédé la phlogopite, et les carbonates se sont formés après celle-ci. Les minéraux du groupe spinelle se sont enrichis en Fe, surtout Fe^{3+}, et en Ti, et appauvris en Cr et Al au cours de la cristallisation. Les cristaux de phlogopite à bordure sombre et à pléochroïsme normal ont subi une diminution de Mg/Fe, Ti, et Al, avec augmentation de Si durant leur croissance. Contrairement à celle que l'on trouve habituellement dans la kimberlite, l'ilménite est ici très pauvre en Mg, Fe^{3+} et Cr. Le clinopyroxène est une salite non-xénocristique, pauvre en Cr et Na et riche en Ti. Les carbonates résultent non pas d'une altération de surface, mais probablement (en grande partie du moins) de cristallisation primaire tardive, quoique l'hypothèse d'un remplacement sélectif ne puisse pas être écartée.

(Traduit par la Rédaction)

INTRODUCTION

During the course of exploration for metal deposits, an ultrabasic dyke showing many of the mineralogical, chemical, and textural characteristics of kimberlite was intersected in a drill hole in Keith Township, Ontario, approximately 80km southwest of Timmins. Similar narrow post-orogenic kimberlite and kimberlitic dykes occur elsewhere in the Canadian Shield, *e.g.*, in Michaud and Gauthier Townships, Ontario (Satterly 1949; Lee & Lawrence 1968) and in Lesueur Township and the Arvida area, Quebec (Watson 1955; Gittins *et al.* 1975). The dykes in Gauthier tp., Arvida area, and Lesueur tp. have been dated by K/Ar in phlogopite as 151±8, 564, and 1100 m.y., respectively (Wanless *et al.* 1967; Doig & Barton 1968; Watson 1967). Despite the great range, these ages are all much younger than the times of last major deformation, metamorphism, and granitic intrusion which affected the enclosing rocks.

The dyke, which was intersected at a vertical depth of 53m, is only 0.4m thick. It intrudes completely recrystallized, well-laminated rhyolitic tuff, rich in quartz and sericite.

NOMENCLATURE

In a critical reappraisal of the petrographic nature of kimberlite and its features of petrogenetic significance, Mitchell (1970) proposed the following definition: "Kimberlite is a porphyritic, alkalic peridotite, containing rounded and corroded phenocrysts of olivine (serpentinized, carbonatized, or fresh), phlogopite (fresh or chloritized), magnesian ilmenite, pyrope and chrome-rich diopside set in a fine-grained groundmass composed of second-generation olivine and phlogopite together with calcite (and/or dolomite), serpentine (and/or chlorite), magnetite, perovskite, and apatite. Diamond and garnet peridotite xenoliths may or may not occur."

In a review of kimberlite geology, Dawson (1971) stated that kimberlite "has an inequigranular texture, the porphyritic aspect being due to megacrysts of olivine, enstatite, chromediopside, pyrope, picro-ilmenite and phlogopite, set in a finer-grained matrix of which serpentine, carbonates, phlogopite magnetite and perovskite form the major part . . . The term 'megacryst' is used since it is apparent that some crystals are xenocrysts and others are phenocrysts." Dawson concluded that "many of the megacrysts are derived from fragmentation of mantle-derived garnet lherzolite (blocks of which are embedded in the kimberlite) and are in various stages of reaction with the kimberlite matrix" and he emphasized that "kimberlite is a hybrid rock that results from incorporation of xenocrysts and xenoliths of mantle origin into a liquid or fluid of very different chemical composition."

One might require that megacrysts of at least one, and preferably more, of the minerals pyrope, chromian diopside, and enstatite be present before considering a rock a true kimberlite. Usually, these minerals are sparse and erratically distributed in kimberlite; in some cases, their presence may be revealed only after a considerable amount of rock has been concentrated mechanically. Thus, in occurrences such as the one in Keith township, where the amount of sample available for examination is very limited, the requirement that one or more of the minerals pyrope, chromian diopside, and enstatite be present may be difficult to apply. Nevertheless, as none of these minerals has been observed in the rock from Keith township, and

as the ilmenite is not magnesian, we refrain from calling it kimberlite. Instead, we refer to it as a *kimberlitic* dyke, just as Brown *et al.* (1967) and Gittins *et al.* (1975) have done for somewhat similar rocks from the Abitibi River, Ontario and the Arvida area, Quebec, respectively. The designation 'alkaline ultramafic' is not suitable as an alternative to kimberlitic, as the term covers many rock types. Moreover, most of the alkaline ultramafic rock types contain abundant feldspathoids or melilite or both.

TEXTURE AND MINERALOGICAL COMPOSITION

The dyke consists mainly of olivine and altered olivine, phlogopite, and carbonate minerals; it contains lesser amounts of opaque spinel, ilmenite, chromite, clinopyroxene, perovskite, apatite, serpentine and in a few specimens, pyrite and quartz (Table 1). The rock is massive, medium- to fine-grained, and generally panidiomorphic; most of the olivine and its pseudomorphs, some of the phlogopite, and most of the spinel, clinopyroxene, perovskite, and apatite are euhedral to subhedral. Seriate texture, in which the larger grains consists of olivine, pseudomorphs after olivine, and phlogopite, is common. A few rounded megacrysts of olivine and altered olivine, up to 18mm in diameter, are present. Extremely fine-grained zones, containing carbonatized olivine phenocrysts, extend for a few mm from the contacts.

Almost all of the olivine is altered to talc or bowlingite or is partly replaced by carbonate. Electron-microprobe analyses of the core and rim of a megacryst of fresh olivine showed that it is almost uniform and has the following composition: SiO_2 38.7 wt.%, Al_2O_3 0.09, Cr_2O_3 0.01, FeO 18.9, MgO 42.1, CaO 0.17 (total 100.0 wt. %); Fe/Mg+Fe 0.201.

Nearly all of the phlogopite shows normal pleochroism (α pale yellow, β and γ orange-brown). Most of the grains show no zonation in color. A few thin sections, however, contain phlogopite crystals with narrow rims that are darker than their cores. A minute amount of the phlogopite shows reverse pleochroism (α deep orange-brown, β and γ pale yellow). This occurs as thin discontinuous rims on crystals of normal phlogopite or as separate fine plates. Electron-microprobe analyses of the cores of five zoned grains (Nos. 1, 3, 5, 7 & 9, Table 2) are very similar. Comparison of analyses of the narrow dark rims showing normal pleochroism (Nos. 2, 4 & 6, Table 2) with those of their cores (Nos. 1, 3 & 5, Table 2) shows that Mg/Fe, Ti and Al decreased, Si increased, and K remained approximately constant as crystallization pro-

TABLE 1. MINERALOGICAL COMPOSITION OF KIMBERLITIC ROCK AND KIMBERLITE (PERCENTAGE BY VOLUME)

	1	2	3	4	5	6
Olivine and altered olivine	41	41	31	41	38	21
Phlogopite	25	27	25	20	20	24
Carbonate minerals*	20	20	-	22	20	39
Calcite and serpentine§	-	-	35	-	7	-
Ilmenite	2	2	-	4	-	
Opaque spinel	4	4	5	-	5	8
Chromite°	0.4	0.3		-	-	
Perovskite×	0.4	0.3	4	3	1	2
Clinopyroxene	2	2	tr	0.3	6	-
Apatite	0.2	0.3	tr	1	2	4
Serpentine and chlorite	3	2	-	2	1	2
Pyrite	2	1	-	-	-	-
Pyrrhotite	-	-	tr	-	-	-
Pyrope	-	-	tr	-	-	-

* Dolomite and minor magnesite in Nos. 1 & 2; calcite in Nos. 4-6.
§ Includes some fine olivine and phlogopite in No. 3; may also include some shortite--$Na_2Ca_2(CO_3)_3$--in No. 3 (Watkinson & Chao 1973); may be pseudomorphous after melilite in No. 5.
° Includes both distinctly translucent reddish brown chromite and very weakly translucent spinel associated with opaque spinel in Nos. 1 & 2.
× May include some leucoxene after ilmenite in Nos. 1 & 2.

1 and 2. Keith Township, Ontario
3. Gauthier Township, Quebec (Lee & Lawrence 1968).
4-6. Lesueur Township, Quebec; No. 4 is average of four samples (Watson 1955); No. 6 is average of two samples (Brookins & Watson 1969).

ceeded. Analyses of the thin discontinuous rims with reverse pleochroism (Nos. 8 & 10, Table 2) show that with respect to their cores, the rims are higher in Mg/Fe and Si, lower in Ti and Al, and very similar in K (Nos. 7 & 9, Table 2). Unlike a phlogopite with reverse pleochroism analyzed by Emeleus & Andrews (1975), that from Keith township is not unusually low in Al nor high in Fe. Reverse pleochroism in phlogopite has been ascribed to the presence of tetrahedrally coordinated Fe^{+3}; accordingly, the name 'tetraferriphlogopite' has been proposed (Hogarth 1964; Rimskaya-Korsakova & Sokolova 1964; Faye & Hogarth 1969; Hogarth et al. 1970).

Much of the carbonate forms a matrix of anhedral grains in which predominantly euhedral to subhedral crystals of other minerals are embedded. The carbonate itself is generally euhedral where it is in contact with the fine-grained serpentine of the matrix. X-ray examination of two specimens shows that the carbonate is dolomite with minor magnesite.

The occurrence of the colorless clinopyroxene as minute euhedral to subhedral grains indicates that clinopyroxene crystallized from the magma and is not xenocrystic. The clinopyroxene is salite (Table 3), somewhat similar chemically to the titaniferous aluminous salite occurring as a minor constituent in the groundmass of kimberlitic-carbonatitic dykes in the Arvida area, Quebec (Gittins et al. 1975) and to the euhedral groundmass diopside that forms as much as 23% of some kimberlite sheets in southwest Greenland (Emeleus & Andrews 1975). On the other hand, the salite is markedly dissimilar from the bright green chromian diopside that occurs as xenocrysts and as a constituent of garnet lherzolite xenoliths in some kimberlites. The latter is much higher not only in Cr_2O_3 but also in Na_2O, much lower in TiO_2, and lower in CaO/MgO than the clinopyroxene of the Keith township rock (see Ahrens et al. 1975, and Nixon 1973, for numerous analyses of chromian diopside).

Electron-microprobe analyses of spinel-group minerals are listed in Table 4. These spinels include sparse, distinctly translucent, reddish brown chromite, which occurs as small euhedral inclusions in olivine. This chromite is high in Al_2O_3 and MgO (Nos. 1 & 3, Table 4). Analyses of three different parts of a single chromite grain are almost identical (No. 1). Opaque rims on these reddish brown grains contain much more Fe (especially Fe_2O_3), much more TiO_2, less Cr_2O_3, and in one case, less Al_2O_3 than the cores (Nos. 2 & 4, Table 4). Similar compositions have been reported for aluminous red chrome spinels and their mantles of titaniferous opaque chrome

spinel occurring in kimberlite from Somerset Island, N.W.T. (Clarke & Mitchell 1975).

In contrast to this sparse, distinctly translucent chromite, most of the spinel in the rock is either opaque or almost so, and strongly magnetic. Much of this spinel forms 0.01 to 0.02mm euhedra that are included in phlogopite and carbonate. Some of these spinel grains have dark grey, very weakly translucent cores and somewhat lighter grey opaque rims. The analyses show that most of these opaque and almost opaque spinels are high in Cr_2O_3 but contain more Fe_2O_3 and TiO_2 and generally less Al_2O_3 than the distinctly translucent ones (Nos. 5-16,

TABLE 2. ELECTRON-MICROPROBE ANALYSES OF PHLOGOPITE

	1	2	3	4	5	6	7	8	9	10
SiO_2	35.7	38.8	36.6	39.1	35.3	39.2	37.3	40.6	37.2	39.7
TiO_2	3.89	2.96	3.72	2.25	3.79	2.33	3.44	1.31	3.64	1.23
Al_2O_3	17.4	13.0	16.5	11.6	16.9	12.0	15.3	11.2	16.6	12.7
Cr_2O_3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FeO*	8.86	12.5	8.96	11.7	8.78	10.4	8.88	8.22	9.10	8.49
MgO	19.7	19.3	20.0	20.3	19.9	21.3	20.6	23.4	20.2	22.7
CaO	0.13	0.16	0.10	0.15	0.10	0.15	0.08	0.09	0.11	0.22
Na_2O	0.21	0.21	0.23	0.21	0.23	0.25	0.27	0.19	0.22	0.20
K_2O	9.39	9.65	9.70	9.86	9.50	9.77	9.83	9.89	9.37	9.64
H_2O**	4.75	3.44	4.18	4.85	5.53	4.63	4.29	5.11	3.57	5.10
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

NUMBER OF CATIONS ON THE BASIS OF 24 OXYGENS

	1	2	3	4	5	6	7	8	9	10
Si	5.126	5.741	5.296	5.686	5.037	5.677	5.395	5.789	5.411	5.655
Ti	0.421	0.330	0.405	0.247	0.407	0.254	0.374	0.140	0.398	0.132
Al	2.953	2.260	2.815	1.994	2.844	2.046	2.607	1.877	2.844	2.145
Cr	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Fe^{2+}	1.065	1.549	1.086	1.427	1.049	1.268	1.075	0.980	1.106	1.012
Mg	4.223	4.255	4.329	4.393	4.245	4.600	4.454	4.975	4.363	4.830
Ca	0.021	0.025	0.016	0.023	0.016	0.023	0.012	0.014	0.017	0.034
Na	0.058	0.059	0.066	0.060	0.064	0.069	0.074	0.052	0.062	0.056
K	1.723	1.821	1.792	1.830	1.731	1.731	1.806	1.815	1.799	1.753
H	4.588	3.423	4.063	4.743	5.314	4.511	4.166	4.897	3.485	4.890
Total	20.178	19.463	19.868	20.403	20.707	20.254	19.972	20.523	19.423	20.507
Mg/Fe	3.965	2.747	3.986	3.079	4.047	3.628	4.143	5.077	3.945	4.773

*Total Fe as FeO. **Difference between total of electron-microprobe analysis and 100.0%.
Nos. 2, 4, and 6 are dark rims with normal pleochroism on core Nos. 1, 3 and 5, respectively.
Nos. 8 and 10 are rims with reverse pleochroism on core Nos. 7 and 9, respectively.

TABLE 3. ELECTRON-MICROPROBE ANALYSES OF CLINOPYROXENE

	1	2	3	4	5	6	7	8
SiO_2	50.1	49.2	49.1	50.1	50.1	50.7	51.0	51.6
TiO_2	2.20	2.67	1.89	2.82	2.15	2.46	2.58	1.60
Al_2O_3	2.12	1.85	3.07	2.63	1.78	1.95	2.01	1.51
Cr_2O_3	0.02	0.00	0.02	0.03	0.00	0.00	0.00	0.00
FeO*	7.37	7.08	6.70	7.50	7.05	7.21	7.80	6.94
MnO	0.30	0.25	0.26	0.33	0.32	0.32	0.32	0.35
MgO	14.3	13.4	13.7	13.4	13.9	14.0	13.6	14.0
CaO	23.7	23.6	24.0	23.7	23.6	23.9	23.3	23.7
Na_2O	0.60	0.58	0.52	0.63	0.56	0.62	0.70	0.58
Total	100.7	98.6	99.3	101.1	99.5	101.1	101.3	100.3

NUMBER OF CATIONS ON THE BASIS OF SIX OXYGENS

	1	2	3	4	5	6	7	8
Si	1.867	1.873	1.853	1.860	1.886	1.879	1.886	1.919
Ti	0.062	0.077	0.054	0.079	0.061	0.069	0.072	0.045
Al	0.093	0.083	0.137	0.115	0.079	0.085	0.088	0.066
Cr	0.000	0.000	0.001	0.001	0.000	0.000	0.000	0.000
Fe^{2+}	0.230	0.223	0.212	0.233	0.222	0.224	0.241	0.216
Mn	0.009	0.008	0.008	0.010	0.010	0.010	0.010	0.011
Mg	0.793	0.758	0.770	0.741	0.781	0.774	0.751	0.778
Ca	0.948	0.963	0.970	0.941	0.953	0.948	0.923	0.945
Na	0.042	0.043	0.039	0.045	0.041	0.044	0.050	0.042
Total	4.044	4.028	4.044	4.025	4.033	4.032	4.021	4.022

*Total Fe as FeO.

TABLE 4. ELECTRON-MICROPROBE ANALYSES OF SPINEL

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
SiO$_2$	0.00	0.07	n.d.	n.d.	0.00	0.06	0.07	0.06	0.07	0.07	0.10	0.06	0.26	0.08	0.09	0.08	0.25
TiO$_2$	0.09	4.51	0.48	3.89	0.85	1.11	0.03	3.82	3.46	4.70	4.61	5.17	5.57	5.23	3.67	6.61	14.4
Al$_2$O$_3$	27.4	20.9	19.8	20.1	16.9	19.7	27.2	15.9	15.9	15.7	17.3	17.1	18.5	21.4	30.1	22.3	3.34
Cr$_2$O$_3$	40.5	31.3	47.5	33.1	47.2	43.7	42.1	41.1	41.1	37.0	36.1	35.2	31.4	25.7	25.5	20.1	1.51
Fe$_2$O$_3$*	4.80	11.7	4.02	12.4	7.27	6.60	2.08	8.20	9.50	10.8	9.79	11.5	12.1	15.6	7.66	16.6	35.0
FeO	13.0	18.3	16.1	17.4	13.2	17.2	12.3	17.9	17.5	18.2	19.3	19.1	20.0	17.4	14.4	18.3	43.0
MnO	0.23	0.27	0.49	0.50	0.24	0.31	0.21	0.27	0.30	0.30	0.30	0.32	0.29	0.29	0.26	0.21	0.04
MgO	15.4	13.6	12.6	13.7	14.4	12.4	15.9	13.2	13.0	13.1	12.6	13.3	13.3	14.6	16.2	14.6	0.73
CaO	0.07	0.21	n.d.	n.d.	0.03	0.04	0.05	0.09	0.31	0.24	0.08	0.17	0.06	0.11	0.02	0.04	0.81
Total	101.5	100.9	101.0	101.1	100.1	101.1	101.4	101.5	101.1	100.1	100.2	101.9	101.5	100.4	97.9	98.9	99.1

CATIONS NORMALIZED TO 24 PER FORMULA UNIT

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Si	0.000	0.015	n.d.	n.d.	0.000	0.015	0.015	0.015	0.017	0.017	0.026	0.014	0.063	0.019	0.022	0.021	0.074
Ti	0.016	0.834	0.089	0.720	0.159	0.206	0.006	0.718	0.654	0.895	0.875	0.965	1.037	0.963	0.662	1.229	3.232
Al	7.590	6.059	5.785	5.824	4.982	5.756	7.524	4.671	4.706	4.698	5.136	5.404	5.172	6.172	8.451	6.503	1.192
Cr	7.529	6.083	9.290	6.445	9.332	8.570	8.065	8.319	8.158	7.410	7.203	6.899	6.145	4.984	4.805	3.917	0.356
Fe^{3+}	0.849	2.160	0.749	2.289	1.368	1.232	0.367	1.542	1.796	2.068	1.857	2.150	2.254	2.880	1.374	3.078	7.838
Fe^{2+}	2.550	3.762	3.326	3.591	2.751	3.569	2.404	3.736	3.673	3.852	4.068	3.963	4.114	3.557	2.875	3.789	10.720
Mn	0.045	0.055	0.103	0.104	0.051	0.065	0.043	0.056	0.063	0.064	0.068	0.062	0.062	0.054	0.041	0.064	0.009
Mg	5.405	4.976	4.657	5.028	5.349	4.576	5.565	4.921	4.848	4.931	4.746	4.906	4.906	5.343	5.765	5.389	0.322
Ca	0.017	0.056	n.d.	n.d.	0.008	0.011	0.012	0.023	0.084	0.065	0.022	0.045	0.015	0.028	0.006	0.011	0.258

* Calculated assuming stoichiometry, by the method of Finger (1972).

Nos. 1 and 3 are distinctly translucent reddish brown chromite.

Nos. 2 and 4 are opaque rims on Nos. 1 and 3, respectively.

Nos. 5-17 are opaque and almost opaque spinels.

No. 15 is core, No. 16 intermediate zone, and No. 17 magnetite rim of one grain.

n.d. - not determined

Table 4). The titaniferous magnetite rim of one grain contains relatively little MgO, Cr$_2$O$_3$, and Al$_2$O$_3$ (No. 17, Table 4). Most of the opaque spinels could be considered members of the chromite series, as Cr is their dominant trivalent ion (Deer et al. 1962), but they are listed separately from the translucent chromites as "opaque spinel" in the modal analyses (Table 1).

In a thorough study of opaque minerals in kimberlite, Haggerty (1975) has found that: (1) complex zoning is common in the spinels; (2) early formed spinels are enriched in the components FeCr$_2$O$_4$, MgCr$_2$O$_4$, FeAl$_2$O$_4$ and MgAl$_2$O$_4$; (3) the overall trend with increasing crystallization or solid-state reaction is toward enrichment in Ti and Fe, especially Fe^{3+}; (4) kimberlite spinels are characteristically high in MgO, FeO, Fe$_2$O$_3$, and TiO$_2$. In general, the observations made in our limited study of the spinels agree with those of Haggerty.

Ilmenites occurring in kimberlite are characterized chemically by high MgO content (commonly > 10 wt.%), intermediate to high Fe$_2$O$_3$ content (commonly > 5 wt.%), and Cr$_2$O$_3$ contents commonly > 1 wt.% (e.g., Haggerty 1975; Mitchell 1973; Boyd & Nixon 1973). In contrast, those from the Keith township kimberlitic dyke are very low in MgO, Fe$_2$O$_3$, and Cr$_2$O$_3$ (Table 5). Analyses of core and rim of the same grain are almost identical (Nos. 1 and 2, Table 5). Many of the ilmenite grains are partly altered to leucoxene and display optically and chemically the alteration stages recognized by Bailey et al. (1956).

A little quartz, associated with carbonate, was seen in a few sections. Excellent evidence that quartz, in minor amount, may occur as a primary phase in kimberlite has been reported recently (Dawson & Hawthorne 1973).

TABLE 5. ELECTRON-MICROPROBE ANALYSES OF ILMENITE

	1	2	3	4	5	6	7	8
SiO$_2$	0.42	0.51	0.83	0.08	0.41	0.16	0.20	0.30
TiO$_2$	52.1	52.3	52.3	53.0	53.4	54.6	50.4	59.2
Al$_2$O$_3$	0.00	0.00	0.00	0.00	0.20	0.09	0.00	0.00
Cr$_2$O$_3$	0.04	0.03	n.d.	n.d.	n.d.	n.d.	0.00	0.02
Fe$_2$O$_3$*	0.26	0.00	0.00	0.00	0.00	0.00	2.23	0.00
FeO	46.6	46.2	43.7	44.8	44.5	44.5	45.3	37.9
MnO	0.21	0.02	0.14	0.17	0.35	0.38	0.24	0.14
MgO	0.04	0.19	0.86	0.06	0.27	0.13	0.09	0.20
CaO	0.30	0.10	1.00	0.79	0.32	0.35	n.d.	0.70
Total	100.0	99.4	99.3	98.9	99.5	100.2	98.5	98.5

CATIONS NORMALIZED TO FOUR PER FORMULA UNIT

	1	2	3	4	5	6	7	8
Si	0.020	0.028	0.042	0.004	0.021	0.008	0.010	0.015
Ti	1.976	1.994	1.972	2.031	2.031	2.068	1.946	2.292
Al	0.000	0.000	0.028	0.000	0.012	0.005	0.000	0.000
Cr	0.002	0.002	n.d.	n.d.	n.d.	n.d.	0.000	0.000
Fe^{3+}	0.010	0.000	0.000	0.000	0.000	0.000	0.086	0.000
Fe^{2+}	1.964	1.956	1.835	1.910	1.884	1.874	1.941	1.632
Mn	0.008	0.000	0.006	0.007	0.015	0.016	0.011	0.006
Mg	0.002	0.014	0.064	0.005	0.020	0.009	0.007	0.015
Ca	0.016	0.006	0.054	0.043	0.017	0.019	n.d.	0.038

* Calculated assuming stoichiometry, by the method of Finger (1972).

n.d. - not determined

TABLE 6. CHEMICAL ANALYSES OF KIMBERLITIC ROCK AND KIMBERLITE

	1	2	3	4
SiO_2	27.2	29.1	33.0	23.3
TiO_2	2.4	3.7	2.1	5.1
Al_2O_3	4.8	4.1	3.2	3.2
Fe_2O_3	2.6	8.9	4.0	7.0
FeO	7.1	7.2	5.8	7.1
MnO	0.2	0.4	0.2	0.2
MgO	15.6	16.3	31.6	20.8
CaO	16.0	13.5	8.2	14.8
Na_2O	0.5	1.6	0.5	0.3
K_2O	2.8	1.3	2.0	1.2
H_2O+	0.3	4.7	3.6	4.9
H_2O-	0.2	–	–	1.1
P_2O_5	1.0	1.3	0.4	0.7
CO_2	18.6	7.6	5.1	10.4
S	0.1	n.d.	n.d.	n.d.
Total	99.4	99.7	99.7	100.1

1. Kimberlitic rock, Keith Township, Ontario; W. H. Herdsman, analyst.
2. Kimberlitic rock, Arvida area, Quebec (Gittins et al. 1975).
3. Kimberlite, Gauthier Township, Ontario; average of two analyses (Lee & Lawrence 1968).
4. Kimberlite, Lesueur Township, Quebec; average of three analyses (Watson 1955).

n.d. – not determined

CHEMICAL COMPOSITION

Kimberlites show wide variation in content of major elements, but, as a group, they have several distinctive chemical traits (Dawson 1967). In general, the kimberlitic dyke of Keith township has a chemical composition characteristic of the group (Table 6). It is an ultrabasic rock that has, in comparison with other kinds of ultrabasic rock, an unusually high content of K_2O, CaO, CO_2, TiO_2, P_2O_5, and Al_2O_3, a low Mg/Fe ratio, and a high K/Na ratio.

Analyses for some minor elements are listed in Table 7; average contents in some kimberlites and other ultrabasic rocks are included for comparison. In general, the minor elements of kimberlite consist of: (1) a group comprising Cr, Ni, Co and Ge, in which the elements occur in concentrations typical of ultrabasic rocks; and (2) a group that includes Rb, Ba, Sr, Y, Zr, Nb, La, Li, B, Sc, V, Cu, Ga, Cs, Ta, Pb, Th and U, in which the elements occur in concentrations greater than usual in ultrabasic rocks (Dawson 1967). The data on minor-element content of the kimberlitic dyke from Keith township agree with these generalizations.

CONCLUSIONS

The principal constituents of the kimberlitic rock are olivine (and altered olivine), phlogopite, and carbonate minerals. Textural relationships among these show that olivine crystallized first, followed by phlogopite, and then by car-

TABLE 7. MINOR ELEMENT CONTENT OF KIMBERLITIC ROCK AND KIMBERLITE (ppm)

	1	2	3	4	5
Cr	600	1550	1440	1000	2000
Ni	920	1100	1140	1200	2000
Co	37	78	77	50	200
Rb	n.d.	n.d.	21	250	2
Ba	1600	1950	740	1000	1
Sr	960	735	445	600	1
Y	n.d.	–	46	40	–
Zr	450	250	445	190	30
Nb	100	215	240	200	1
La	80	150	370	n.d.	–

1. Keith Township, Ontario; W. H. Herdsman, analyst.
2. Gauthier Township, Ontario; average of two kimberlite analyses (Lee & Lawrence 1968).
3. Lesotho; average of 14 kimberlite analyses (Dawson 1967).
4. South West Africa; average of four kimberlite analyses, except Y, which is average of two (Dawson 1967, after Janse 1964).
5. Ultrabasic rocks (Dawson 1967).

n.d. – not determined

bonates. The distinctly translucent, reddish brown chromite inclusions in olivine crystallized before the opaque and almost opaque spinels that occur as inclusions in phlogopite and carbonate. Comparison of analyses shows that Fe, especially Fe^{3+}, and Ti increased, Cr and Al generally decreased, and Mg remained about constant as crystallization of these spinel-group minerals proceeded. Although most of the phlogopite crystals are unzoned, some have narrow rims with normal pleochroism; these rims are darker than the cores. Comparison of compositions of rims and cores shows that Mg/Fe, Ti, and Al decreased, Si increased, and K remained about constant during crystal growth. The ilmenite, unlike that characteristic of kimberlite, is very low in Mg, Fe^{3+}, and Cr. The clinopyroxene is a non-xenocrystic salite, low in Cr and Na and high in Ti.

Geological, textural, and geochemical evidence indicates that carbonate minerals in kimberlites at some other localities (e.g., Brookins & Watson 1969; Dawson & Hawthorne 1973) are late-crystallizing primary (carbonatitic) material and not products of weathering or hydrothermal alteration. At Keith township, the depth of the intersection and the glacial scouring of the region preclude the possibility that the carbonate in the kimberlitic dyke was produced by weathering. Although some of the carbonate replaced olivine and phlogopite, much of it occurs as a matrix with textural relationships suggesting that it may be late-crystallizing primary material. One might argue that, as an alternative, such textural relationships could originate by selective carbonatization of a fine-grained groundmass in preference to coarser phenocrysts. This alternative gains some support from the occurrence of

highly carbonatized volcanic and ultramafic rocks in other parts of the drill core and elsewhere in the area (Prest 1951). It is not favored, however, by the fact that the rhyolitic tuff immediately adjacent to the dyke contains very little carbonate.

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