OXIDE AND SILICATE MINERALS IN THE KIMBERLITES OF MINAS GERAIS, BRASIL

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Several intrusions in the region of Coromandel, Minas Gerais, have been reported to be kimberlites on the basis of the heavy mineral contents (i.e. pyrope garnet, magnesian ilmenite) of weathered rock and overlying soils. In view of the presence of several other types of alkalic rock (e.g. carbonatites) in the region it is important to establish the true identity of the possible kimberlites. Accordingly, a detailed examination of groundmass phases, particularly spinels, has been undertaken on a number of the intrusions from which fresh, relatively unaltered rock has been obtained. For example, the rocks constituting the Limeira I and Indaia I intrusions consist of numerous irregular macrocrysts of olivine, Mg-ilmenite, rare phlogopite and clinopyroxene set in a fine grained groundmass of calcite, serpentine, spinels, perovskite, monticellite and apatite.

Olivine (Fo_{92-86}) varies in size between 5 and 0.25 mm and may be angular, especially the larger grains, or display euhedral hexagonal shapes, usually those <1 mm. Some olivines contain Mg-ilmenite, and also consist of compound grains. Olivine probably constitutes 30 to 35% of the rock (Table 1). Mg-ilmenite ($\sim$13 wt.% MgO) is ubiquitous and ranges between 1 and 0.1 mm. Most grains are rounded but in detail have ragged margins due to replacement by perovskite and spinel. Pseudomorphs of calcite, monticellite and serpentine after phlogopite macrocrysts up to 1.5 mm in length are present. Rare remnant cores of mica occur in some of the pseudomorphs (Table 1). The groundmass perovskite is often euhedral with rhombic or rectangular shapes (<0.05 mm), and apatite is present as laths up to 0.25 mm long. Spinels are generally <0.04 mm in size, angular and/or rounded.

In contrast to the above rocks those constituting the Limeira II and Indaia II intrusions are much finer grained and consist of olivine macrocrysts, generally between 0.5 and 0.05 mm in size, and some small Mg-ilmenites (<0.25 mm) with little or no alteration to perovskite at the margin. The groundmass has a flow texture in which euhedral perovskite (<0.01 mm), spinels and apatite are randomly scattered throughout the very fine grained felty aggregate of thin lath shaped crystals of clinopyroxene composition (Table 1). In Indaia II small plates of phlogopite occur that poikilitically enclose numerous crystals of the groundmass (Table 1).

Spinels in both Limeira I and Indaia I are usually small, somewhat less than 0.04 mm in size, and show varying shapes from rectangular to irregular or rounded. No atoll spinels are observed. Angular orange-red spinels that are aluminous magnesian chromites are rare. They probably represent fragments from disaggregated spinel peridotites that occur as xenoliths in both intrusions. The groundmass spinels in Limeira I have Al_2O_3 < 2 wt%, MgO between 11 and 14 wt%, and TiO_2 6 to 19 wt%. In some instances cores of spinels have higher Cr_2O_3 than the rims (40 vs. 1 wt%), whereas TiO_2 and FeO_T are higher in the rims. Similar compositional variations occur in the spinels in Indaia I (Table 2). When plotted in the reduced spinel prism (Haggerty, 1976; Mitchell, 1986) the overall trend for Limeira spinels is from titanian chromites to magnesian ulvospinel-ulvospinel-magnetite (MUM) at a fairly constant Mg/(Mg+Fe) of 0.3. Indaia I spinels show a similar trend, but a slightly higher Mg/(Mg+Fe) of 0.4. Comparable trends, but at Mg/(Mg+Fe) between 0.5 and 0.7 are to be observed in the Jos (Mitchell and Meyer, 1980), Green Mountain (Boctor and Meyer, 1979) and Benfontein (Boctor and Boyd, 1981) kimberlites. In the Wesselton (Shee, 1984) and De Beers (Pasteris, 1982) spinels in different kimberlite events although having similar trends vary in Mg/(Mg+Fe). The absence of aluminous and for the most part chrome-rich spinels, and the dominance of MUM type which plot close to the Mg_2TiO_4 (qandilite)-Fe_2TiO_4 (ulvospinel) apex of the condensed spinel prism suggests crystallization from a highly evolved magma. A feature of the spinels in support of this suggestion are the relatively high MnO contents (>1 wt%) a feature also noted for spinels in the Green Mountain kimberlite. Also noted in the Green Mountain kimberlite, and in kimberlites from the Premier Mine and Lesotho are reaction rims of perovskite on the Mg-ilmenite. MUM spinels in kimberlites are usually confined to serpentine, calcite, moticellite and diopside kimberlites and the first three minerals are major components in Limeira I and Indaia I rocks. Mica is notably absent in the groundmass, and MUM spinels usually do not occur in micaceous kimberlites, particularly in the Group II variety (Smith, 1983; Mitchell, 1986).

In contrast to the spinels in Limeira I and Indaia I those in Limeira II and Indaia II are small, irregular and have cores corresponding to titanian magnesian chromites. These cores are replaced in whole or part by mantles of titanomagnetite containing minor ulvospinel. These spinels appear to be highly evolved and contain MnO between 1 and 2 wt% (Table 2). In the reduced prism the spinels plot close to the Fe-rich side of the diagram in view of the high Fe/(Fe+Mg) of 0.9. A compositional gap appears to be present between the cores and mantles. The overall trend is somewhat similar to that observed in spinels from Bellsbank kimberlite (Boctor and Boyd, 1982) and to the later part of the Zagadochnaya kimberlite (Rozova et al.,1982) although the Brazilian spinels have higher Fe/(Fe+Mg).

Most kimberlites with spinels that display this trend (Trend 2; Mitchell, 1986) are micaceous and it has been suggested the spinel trend results from crystallization of phlogopite which removes Al and Mg. However, in the case of Indaia II the mica is a late stage phase and poikilitically encloses both spinel and groundmass clinopyroxene. The trend for spinels in Limeira II and Indaia II is also mirrored by spinels in the Matinha intrusion, also in Minas Gerais. This rock is a petrographic variant of those from both Limeira and Indaia in that macrocrysts of olivine of various sizes, and rare phlogopite, are set in a felty groundmass of lath shaped pyroxene (Table 1), spinel and perovskite. Some intersertal glass is present. Apart from the absence of flow texture in Matinha, plus its coarser groundmass nature, the rock is akin to that of Limeira II and Indaia II. These latter rocks are different to those of Limeira I and Indaia I in that they are much finer grained, show flow texture, have a groundmass of clinopyroxene in which late stage mica is present, and also have a different evolutionary spinel trend. This trend from titanian magnesian chromites to ulvospinel-titanomagnetites is not unique to kimberlites, and has analogs in other types of rock, e.g. lamproites (Mitchell, 1986a,b) and other alkaline rocks (Haggerty, 1976).

Outcrops of the Japecanga intrusion, in the Coromandel area of Minas Gerais, are deeply weathered and associated minerals are extensively altered. Spinels (0.01 to 0.02 mm) form the dominant opaque oxide (1-2%) but show extensive modification to fretted hematite, oriented intergrowths of magnesioferrite and possibly hydrated ferric oxide (e.g. goethite). Remnants of gray, Cr-rich spinel cores, mantled by Mg-rich titanomagnetite is the prevalent association (Table 2) and is thus analogous to the overall spinel trends in the Limeira and Indaia intrusions and is more typical of kimberlites than other alkaline rocks. Although composite analyses of altered intergrowths yield consistently low analytical totals, it is nontheless evident that spinel core compositions are most unusual (Table 2), being high in MnO (up to 5 wt.%) with moderate Cr_2O_3 (13-26 wt.%), reflecting an evolved and carbonate-rich magma source. Spinel rims are depleted in MnO and are either titanomagnetites or magnesian-titanomagnetites.

Discrete ilmenite grains (1-5 mm) from eluvial soils are rounded and remarkably unaltered with MgO contents in the range 7.5 to 11 wt.% and Cr_2O_3 between 0.2 and 2.7 wt.%. Trace but significant amounts of Nb and Zr are present (Table 1), and high Fe^{3+} are consistent with kimberlites having a carbonate affinity (e.g. Tompkins and Haggerty, 1985).

Although these Brazilian rocks have been termed pseudo-kimberlites, the mineralogy and composition of certain groundmass phases are comparable with kimberlites from other worldwide localities. However, in detail some chemical signatures (e.g. MnO contents of some spinels) and petrographic features (e.g. Limeira II, Matinha) suggest these intrusions were derived from possibly highly evolved carbonate-rich magmas. It is conceivable these Brazilian rocks may be a link between those exemplified by the Group II (Smith, 1983) serpentine-calcite-monticellite kimberlites and others similar to the carbonate kimberlite sill of Benfontein.

Xenoliths in Limeira I are dunites and harzburgites of which some are metasomatized with the formation of spinel and associated phlogopite and diopside. This style of metasomatism is identical to that found in metasomatites in the Kaapvaal craton of southern Africa (e.g. Erlank et al., 1982). The subcratonic lithosphere beneath Minas Gerais is, therefore, depleted and in a similar manner to the Kaapvaal craton has been subsequently enriched. Although spinel peridotite xenoliths are common, no garnet-bearing varieties have been yet observed from this region of Minas Gerais. Perhaps this is a reflection of the tectonic setting of these intrusions within an ancient mobile zone and is also a clue to the highly evolved nature of the rocks.

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Table 1: Representative analyses of silicates and ilmenite

	Macrocrysts							Groundmass			
	1	2	3	4	5	6	7	8	9	10	11
	Olivine		Pyx.	Mica	Ilmenite			Monti.	Pyroxene		Mica
SiO_2	41.2	39.9	(52)	42.5	0.23	-	-	36.7	52.8	51.9	39.4
TiO_2	0.00	0.00	0.07	1.64	49.1	50.3	42.7	0.19	1.61	2.20	6.56
Al_2O_3	0.00	0.00	2.77	10.2	0.49	0.08	0.04	0.00	2.25	1.90	10.4
Cr_2O_3	0.00	0.00	0.31	0.23	1.46	0.24	2.65	0.32	0.08	0.06	0.10
FeO	8.51	13.2	1.67	6.41	36.1	36.5	43.4	3.27	5.76	6.11	5.51
MgO	50.6	46.4	17.8	24.0	12.3	10.8	7.77	24.0	13.9	15.0	21.2
CaO	0.04	0.08	25.7	0.00	0.18	0.00	0.00	33.4	20.6	21.2	0.04
MnO	0.12	0.12	0.06	0.02	0.59	0.41	0.39	0.33	0.16	0.11	0.13
NiO	0.31	0.12	-	0.00	0.00	-	-	0.06	0.00	0.00	0.00
Na_2O	0.11	0.00	-	0.35	0.00	-	-	0.00	1.72	0.89	0.21
K_2O	0.01	0.03	-	10.10	0.00	-	-	0.10	0.69	0.55	9.45
TOTAL	100.9	99.8	(100)	95.5	100.5	98.8*	97.9+	98.3	99.6	99.9	93.0

* Includes 0.28 ZrO_2 and 0.14 Nb_2O_5. + Includes 0.25 ZrO_2 and 0.63 Nb_2O_5.
1,3 - Limeira I; 2,4,5,8 - Indaia I; 6,7 - Japecanga; 9,11 - Indaia II; 10 - Matinha

Table 2. Representative Spinel Analyses

	Limeira I		Indaia I		Limeira II			Japecanga	
					Core	Margin		Core	Margin
TiO_2	17.3	11.3	14.3	22.8	3.37	12.3	10.6	10.2	21.9
Al_2O_3	0.97	1.40	1.03	0.79	4.38	0.54	0.39	2.94	1.94
Cr_2O_3	6.09	0.14	14.5	10.3	41.0	1.14	7.01	13.5	0.18
Fe_2O_3*	34.9	51.5	32.1	22.8	18.9	45.2	43.4	33.0	26.2
FeO*	27.4	20.7	22.4	21.8	24.0	33.7	32.0	23.1	42.6
MgO	11.8	12.2	13.2	18.4	6.52	4.50	4.78	8.00	5.21
CaO	0.34	0.48	0.21	0.69	0.27	0.56	0.40	-	-
MnO	1.10	1.12	1.13	1.17	1.05	0.95	1.05	4.5	0.95
TOTAL	99.9	98.8	98.9	98.8	99.5	99.0	99.5	95.2	99.0
mg	0.263	0.245	0.314	0.438	0.221	0.097	0.107	0.213	0.123

* Calculated on basis of 4 oxygen and 3 cations