Orbicular Oxides in Carbonatitic Kimberlites: High Pressure Autoliths or Low P Liquid Immiscibility?

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Although there are considerable uncertainties in the origin of kimberlites, and in the genesis of carbonatites, the issue that has fueled the most vigorous debate is on the potential relation between kimberlitic and carbonatitic magmas in petrogenetic models: one perspective is consanguinity; whereas the alternative view contends that there is a complete separation in the evolution of these two exotic rock types from the upper mantle (e.g. Mitchell, 1986; Bell, 1989). Liquid immiscibility between conjugate carbonate and silica undersaturated liquids has both supporters and detractors among experimentalists, but also among petrographers in studies of alkali fields and mantle xenolith settings (Pyle and Haggerty, 1994); and views on fluidization (i.e. gas-expansion and droplet formation in liquids, Sutherland, 1980) should be revisited in light of the widespread spherulitic and orbicular structures reported in carbonatites (Keller, 1981; Lapin and Vartiainen, 1983; Moore, 1984). We report on two unusual occurrences of spherical oxide assemblages that bear on the relation between kimberlites and carbonatites, and on oxide liquid immiscibility in phosphorous- and carbon-rich systems. The assemblages show similarities and contrasts to orbicular, rapakivi-like, structures in carbonatites and related rocks from Uganda, Finland, Germany and Russia. The locations featured in our study are in the central Namibian, 'non-diamondiferous', kimberlite field, which trends N-S and lies between the Mt. Brukkaros carbonatite (Janse, 1969), and the town of Mariental.

Ilmenite at Mukurob

The first location at Mukurob (60 km NNE of Brukkaros), has a small outcrop of kimberlite and a 0.5m wide carbonatitic dike that is exposed for ~200m (Frankel, 1956): The buff carbonatite (~0.5 wt% FeO) is saturated in black, oblate spheroidal pellets, 1x2 cm in average diameter. The pellets are matrix-supported and have cores of olivine (now replaced by serpentine, with minor calcite and quartz), concentrically overgrown by one or two layers of ilmenite. These ilmenite bands are supported by delicate whiskers or coarser pedestals of ilmenite, that are radial in cross-section and normal to the bands; the intervening volumes are filled by strained calcite (Fig.1a). Ilmenite (Ilm_{55} $Geik_{40}$ Hem_5) is polycrystalline and exhibits 120^0 equilibrated dihedral angles. The matrix to the spherules has xenocrystic serpentine after olivine, set in a medium grained assemblage of calcite, serpentine, abundant oxides, minor apatite (F~1.5wt%), and barite; crystals inferred to be melilite (Frankel, 1956) were not observed. Xenocrystic MgAl-chromite (55wt% Cr_2O_3) is mantled by ilmenite ($Ilm_{51}Geik_{43}$ Hem_6) and groundmass spinel is MgAlTi-magnetite. The ilmenites (11-12wt% and 2-3wt% Cr_2O_3 , Fig 1b- c) and spinels, although set in a carbonate-serpentine matrix, are distinctly kimberlitic (Haggerty, 1991).

Magnetite at Hatzium

The second example is from the carbonatitic facies of the Hatzium kimberlite, located ~100 km due N of Brukkaros. MgAlTi-magnetite spheroids (2-3 cm in diam.) have cores of massive magnetite, calcite, and serpentine that are overgrown by rythmically layered, alternating bands of wide (~1 mm) and thin (~0.25 mm) concentric rings of magnetite (Fig.2a), that are nucleated on, and dispersed within a complex mixture of calcite (FeO~ 1wt%) and serpentine (~4 wt% MgO and 0.5-1wt% Al_2O_3). The silicate was possibly olivine + minor pyroxene or monticellite with some Ca added by an invasive fluid or partial melt. The matrix assemblage of serpentine + calcite + MgAlTi-magnetite has minerals and mineral compositions similar to the spheroids, but the matrix is distinguished by the presence of Ba-phlogopite and abundant fibrous apatite (F=2 wt%). Phlogopite (BaO=2-10 wt%) is spectacularly zoned (dominantly in Ba, Si, K) in patches and coarse laths parallel to cleavage; the mica is kinked banded and splayed by penetrative calcite, and contains inclusions of MgAlTi-magnetite. Phlogopite compositions from Hatzium are compared in oxide and cation plots to barian-titanian micas in a variety of undersaturated rocks in Figs. 2b-c (Mansker et al., 1979; Gaspar and

Wyllie, 1982; Field et al., 1987; Guo and Green, 1990; Edgar, 1992). The most striking similarity to phlogopites in the Hatzium kimberlite are phlogopites from the Jacupiranga carbonatite in Brazil (Gaspar and Wyllie, 1982), in which both correspond to an exchange of Ti + 2Al = Mg + 2Si in the broader framework of Ba + 3Ti +4Al = 2K + 4(Mg,Fe) + 4Si + [] (Mansker et al., 1979; Guo and Green, 1990; and Fig. 2c). Apart the high concentrations of Ba in phlogopite, which is more typically associated with nephelinites, carbonatites, and metasomitized harzburgites in kimberlites, the Hatzium assemblage is typically kimberlitic.

Summary and conclusions

The spinel spheroidal association at Hatzium is similar to phoscorites or camaforites (magnetite + calcite + apatite) in carbonatites worldwide, but the ilmenite spheroids have not previously been reported, except at Mukurob. Our tentative interpretation is that both types are possibly the result of oxide liquid immiscibility in phosphorous- and carbon-rich silica undersaturated melts, as demonstrated experimentally by Philpotts (1967) for P, and by Weidner (1982) for C. The effect of these elements is to dramatically lower the liquidus temperatures of oxide melts, which for carbon can be as low as 815-1000° C at 0.1 GPa. An autolith origin for the ilmenite spheroids, however, is equally plausible based on olivine nucleii, and the compositional similarities of the Mukurob ilmenites to high GPa ilmenite megacrysts in diamondiferous kimberlites (Fig. 2a-b); this model is also supported by strongly equilibrated ilmenite crystallization textures. These two examples of off-craton intrusions have marked affinities to the LILE and HFSE signatures of mantle metasomites entrained in kimberlites (Haggerty, 1991), and imply a relation, between kimberlites and carbonatites, spatially and petrologically, driven by alkali and carbonate mantle metasomatism.

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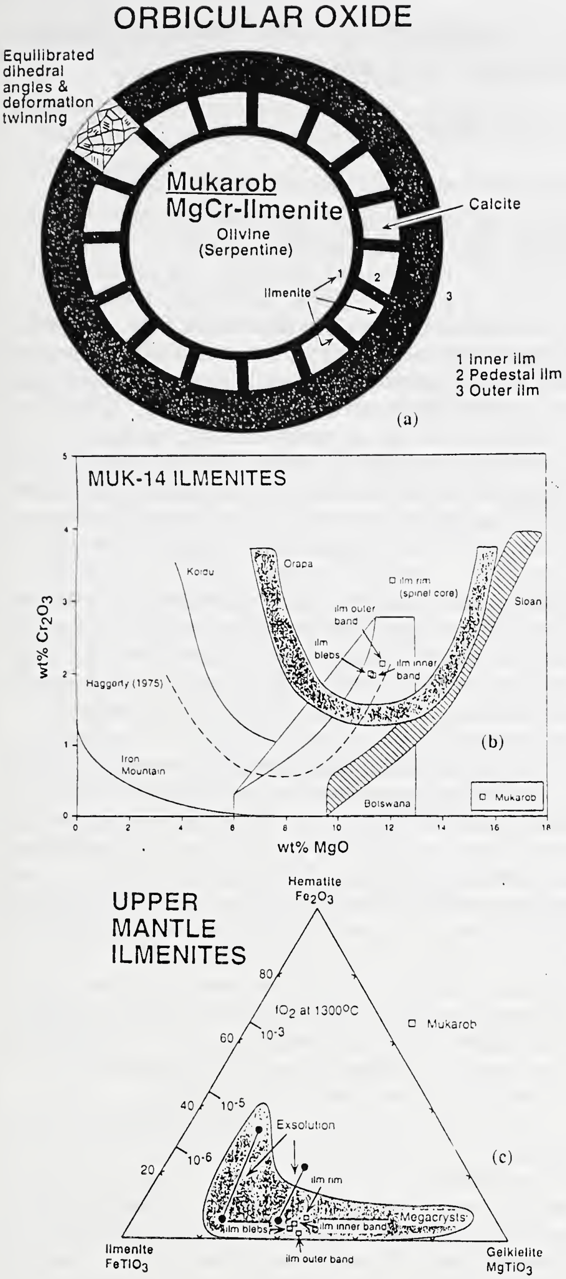
ORBICULAR OXIDE
Equilibrated dihedral angles & deformation twinning
Mukarob
MgCr-Ilmenite
Olivine
(Serpentine)
Calcite
Ilmenite
1
2
3
1 inner ilm
2 Pedestal ilm
3 Outer ilm
(a)
MUK-14 ILMENITES
wt% Cr2O3
wt% MgO
Kordu
Orapa
ilm rim
(spinel core)
ilm outer band
ilm blebs
ilm inner band
Sloan
Haggerty (1975)
Iron Mountain
Botswana
Mukarob
(b)
UPPER MANTLE ILMENITES
Hematite
Fe2O3
IO2 at 1300°C
Mukarob
Exsolution
ilm rim
ilm blebs
ilm inner band
Megacrysts
ilm outer band
Ilmenite
FeTiO3
Geikielite
MgTiO3
(c)

Fig. 1

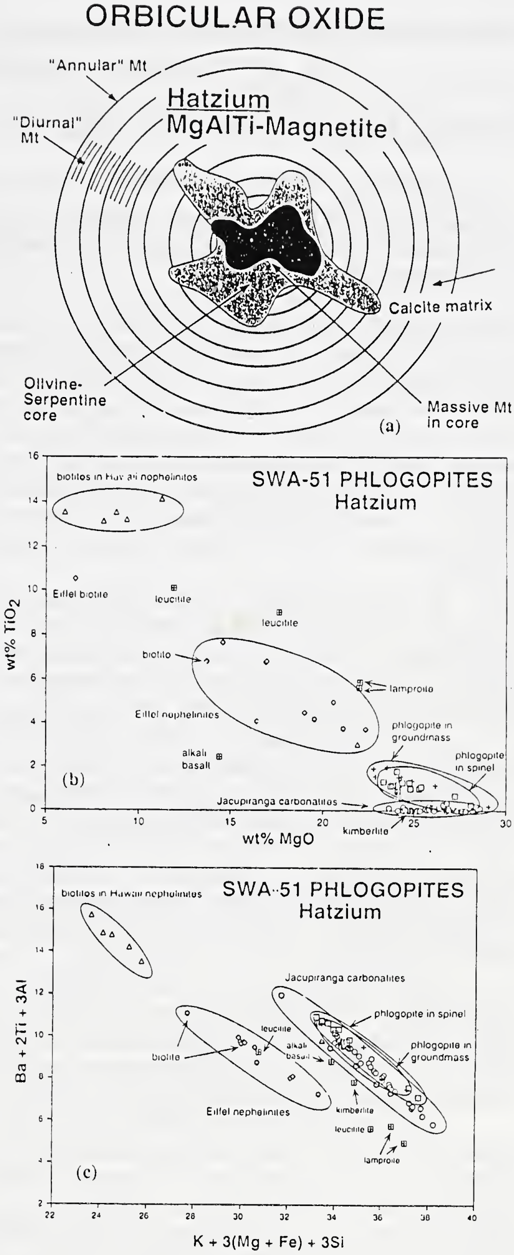
ORBICULAR OXIDE
"Annular" Mt
"Diurnal" Mt
Hatzium
MgAlTi-Magnetite
Calcite matrix
Olivine-Serpentine core
Massive Mt in core
(a)
SWA-51 PHLOGOPITES
Hatzium
wt% TiO2
wt% MgO
Eiflel biotite
leucitite
biotite
lamproite
Eiflel nephelinites
alkali basalt
phlogopite in groundmass
phlogopite in spinel
Jacupiranga carbonatites
kimberlite
(b)
SWA-51 PHLOGOPITES
Hatzium
Ba + 2Ti + 3Al
K + 3(Mg + Fe) + 3Si
Jacupiranga carbonatites
phlogopite in spinel
phlogopite in groundmass
leucitite
alkali basalt
biotite
Eiflel nephelinites
kimberlite
lamproite
(c)

Fig. 2