# Understanding Kimberlite Crystallisation and Emplacement: Insights from Reaction Products on Ilmenite and Chromite.

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## Introduction

Kimberlites entrain diamonds and other mantle minerals (e.g., ilmenite, chromite, garnet) and transport them from the mantle to the surface, inducing dissolution and/or development of diffusion-controlled compositional zoning. Congruent dissolution forms resorbed mineral surfaces and incongruent dissolution produces reaction rims (coronae) of secondary phases. The objective of this research is to use the reaction products formed on ilmenite and chromite to examine crystallisation and emplacement conditions of kimberlites, and their implications for diamond preservation. This goal is pursued through: 1) study of the reaction products on ilmenite and chromite from kimberlites; 2) examining the conditions for their formation in controlled experiments; and 3) applying these findings to a range of kimberlite localities to explore variations in crystallisation and emplacement conditions.

## Reaction products on ilmenite and chromite from the BK1 and AK15 kimberlites in the Orapa cluster

The study of ilmenite and chromite from the BK1 and AK15 kimberlites in the Orapa cluster (Botswana) using scanning electron microscopy (SEM) demonstrated that composition of reaction coronae on ilmenite depends on kimberlite lithology. Ilmenite in coherent kimberlite units (CK) shows perovskite and magnetite coronae with varying textures including: (i) euhedral crystals of perovskite and magnetite (Fig. 1A) and (ii) the full replacement of ilmenite by a perovskite and magnetite symplectite (Fig. 1B). Ilmenite is well preserved in massive volcaniclastic kimberlite (MVK) where it is surrounded by a corona of titanite (± perovskite) and magnetite (Fig. 1C). The composition of the corona phases obtained with electron probe micro-analyser (EPMA) give crystallisation temperatures between 730-1275 °C and oxygen fugacity ($f$O2) between +0.5 to -3.5 ΔNNO (Fairhurst et al., 2024). The observed differences in the ilmenite corona phases show an excellent correlation with specific dissolution textures on diamonds from the same kimberlite units (Fedortchouk et al. 2017). Fedortchouk et al. (2017) suggest that MVK formed explosively from a fluid-rich magma head that resulted in glossy features on diamonds while CK emplaced passively from a fluid-poor melt tail as suggested by corrosive features observed on diamonds.

## Experimental constraints on kimberlite crystallisation and emplacement

The factors controlling the stability of ilmenite, the presence of perovskite *versus* titanite in ilmenite coronae, and the textures of the coronae were examined in experiments using synthetic kimberlite melts (after Brooker et al., 2011) with a range in $SiO_2$/CaO content in piston-cylinder apparatus at 1000-1200 °C, 0.5-2.5 GPa. All experiments with kimberlitic compositions produced perovskite and magnetite coronae, the texture of which depended on the run conditions. Coronae with euhedral crystals resembling those in BK1 and AK15 (Fig. 1D) formed at 1200 °C, whereas symplectitic coronae (Fig. 1E) formed at 1100 °C

depending on pressure and $SiO_2/CaO$ content. We also saw development of an aggregate texture and domination of dissolution over development of coronae in some experiments (Fig. 2).
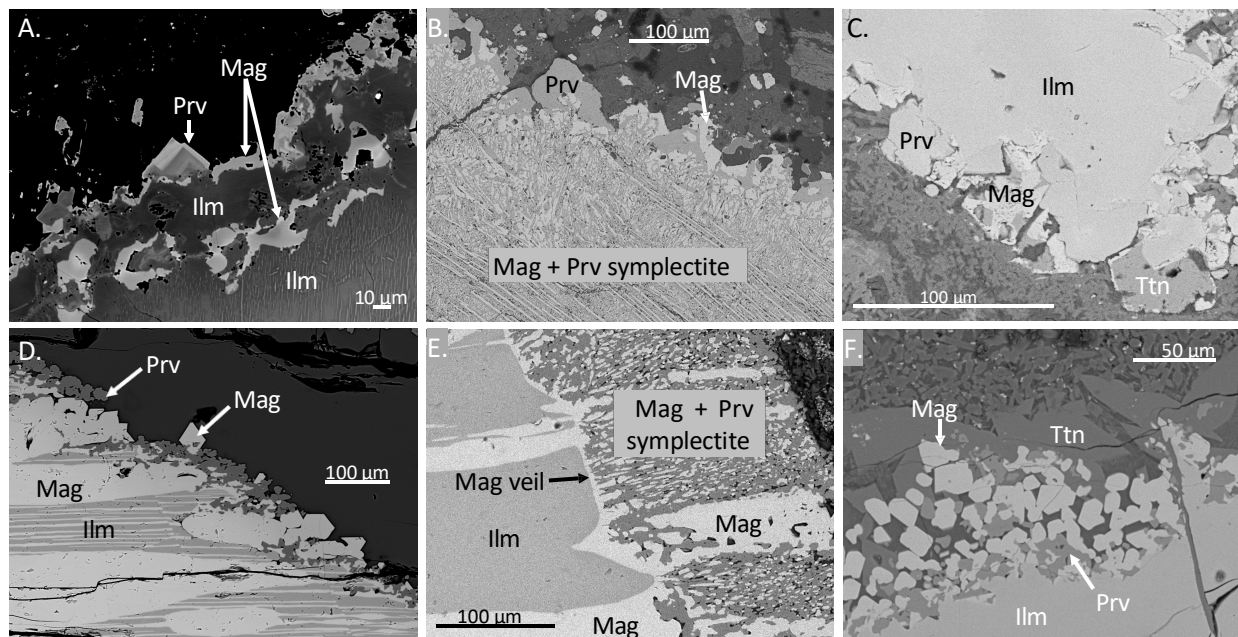


Fig 1. Backscatter electron (BSE) images of reaction coronae in A-C. Natural kimberlites from the Orapa cluster (BK1 and AK15) and D-F. Experiments. Ilm = ilmenite, Mag = magnetite, Prv = perovskite, Ttn = titanite.

Titanite appeared in ilmenite coronae only in the runs testing assimilation of crustal rocks (i.e. granodiorite) by the kimberlite melt. Our data suggest that a minimum of approximately 6 wt.% of granodiorite is required to stabilise titanite (Fig. 1F). For a kimberlite melt with 6 wt.% of granodiorite, perovskite is the low-pressure stable Ti-bearing phase and titanite the high-pressure phase (Fig. 3). We see that both Ti- phases are unstable towards higher temperature of 1200 °C, suggesting their liquidus is somewhere between 1150-1200 °C (Fig. 3A). However, reducing the water content of our kimberlite from 10 wt.% $H_2O$ (fluid-saturated) to 3 wt.% $H_2O$ (fluid-undersaturated) and correspondingly increasing liquidus temperature results in presence of Ti-bearing phases in the ilmenite coronae at a higher temperature of 1200 °C (Fig. 3B).
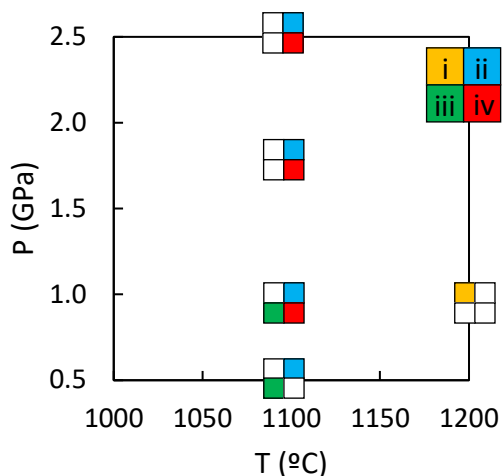


Fig 2. Textures of perovskite - magnetite corona on ilmenite in kimberlite melt at various experimental conditions. i) euhedral crystals, ii) aggregate, iii) symplectite and iv) dissolution.
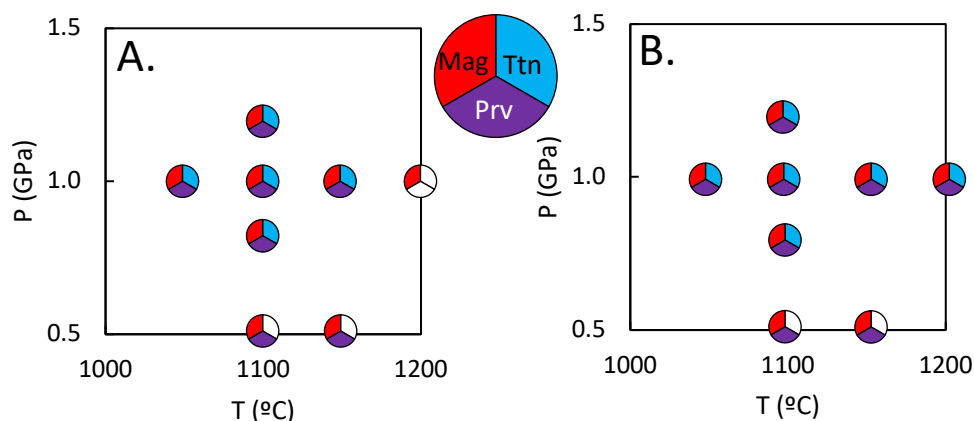
Fig 3. Ilmenite corona phases at experimental conditions with 6 wt.% granodiorite (GD) and (A) 10 wt.% $H_2O$ (water-saturated) or (B) 3 wt.% $H_2O$ (water-undersaturated). Mag= magnetite, prv = perovskite and ttn= titanite.

Fairhurst et al. (2024) suggest that reaction corona observed on ilmenite in the Orapa kimberlites are of magmatic origin (i.e., prior to kimberlite emplacement). This assertion is based in their observation that the corona are notably absent on broken surfaces of the ilmenite, which are likely to have broken during emplacement. This is in agreement with the magmatic temperature estimates ranging from 730 to 1275 °C for magnetite and perovskite found in the ilmenite corona. Experimental evidence further supports this interpretation, as the corona phases and textures observed in natural samples are replicated under magmatic conditions (1050-1200 °C) at depths corresponding to 15-75 km (0.5-2.5 GPa).

**Application to Ekati kimberlites**

We apply these results to Ekati kimberlites in the Northwest Territories, Canada, which host different kimberlite lithologies and show a range of diamond dissolution textures (e.g., Fedortchouk et al. 2010). Ekati VK (Panda, Koala, Beartooth and misery) host diamonds with low-relief features indicative of abundant C-O-H fluid. Ekati CK (Grizzly and Leslie) host diamonds, with sharp resorption features indicating volatile-undersaturated melt (Fedortchouk et al. 2010). Ilmenite are absent in CK from both kimberlites, but abundant in VK, exhibiting resorption features, zoning and often assicated with magnetite coronae. These preliminary results suggest that zoning and reaction textures on oxide minerals can be used in conjunction with diamond resorption features to elucidate kimberlite emplacement conditions.

**References**

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