Ilmenite generations in orangeite from Banankoro, Guinea: implications for exploration

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Introduction

Ilmenite is one of the classic diamond indicator minerals (DIMs) and for long it has been used as a guide for kimberlite exploration. Mg-rich ilmenite is commonly found either as a xenocryst or as a replacement product of ilmenite xenocrysts. However, ilmenite is not present in all kimberlites worldwide, and Mg-ilmenite is rarely documented as a euhedral crystal component of the kimberlite groundmass (Boctor and Boyd, 1980; Haggerty, 1975). The discovery of euhedral Mg-ilmenite crystals in the groundmass of a pipe in the Banankoro area (Guinea) offers a good opportunity to study the textural relations between the different ilmenite generations and the rest of the minerals.

The kimberlites from Banankoro (Guinea) are found in the Man craton, West Africa. The Banankoro kimberlite age was obtained by $^{40}Ar/^{39}Ar$ for phlogopite about 139 ± 3 Ma (Skinner et al., 2004). Most of the Man craton kimberlites were classified as phlogopite kimberlites, although K contents are relatively low (Skinner et al., 2004).

Petrography

The samples studied here are hypabyssal, and they consist of corroded xenocrysts of olivine (30% modal), phlogopite (<1% modal) and geikielite (<1% modal) settled in a groundmass (68% modal). On its turn, the groundmass is made up of olivine microphenocrysts altered to serpentine group minerals (40%), phlogopite (38%), calcite (16%), spinel-group minerals (6%) and lesser amounts of perovskite, apatite and ilmenite.

Phlogopite macrocrysts (about 2mm, phlogopite 1) show a reaction rim (phlogopite 2), and they are replaced by a second rim (phlogopite 3). Similarly, groundmass phlogopite has a rounded core of Ti-rich phlogopite (phlogopite 4) replaced by a tetraferriphlogopite rim (phlogopite 5).

Many textural populations of the spinel-group minerals occur in the groundmass. The first one is hemihedral, atoll-shaped and frequently zoned, with a chromite core (spinel 1). It is replaced by another euhedral chromite (spinel 2). Another chromite with different composition (spinel 3) is found together with the spinel 2 included in phlogopite 3. Both spinels may also be mantled by a zoned titanomagnetite rim (spinel 4 and 5). Titanomagnetite (spinel 6) replaces geikielite xenocrysts. Euhedral unzoned titanomagnetite (spinel 7) occurs in rounded massive cloudy aggregates, along with phlogopite.

Four compositional-textural ilmenite types are discriminated. Type 1 Mg-rich ilmenite is anhedral and it is replaced by spinel 6. Type 2 ilmenite is Mg-rich, it occurs as euhedral tabular crystals (about 200 µm), which grew in small cavities along with earlier calcite. This ilmenite may replace spinel and it is replaced by a late generation of Mn-rich ilmenite (type 3) along the borders and fractures. Type 4 ilmenite is Mn-rich ilmenite and it replaces the perovskite margins.

Perovskite in groundmass is euhedral to hemihedral and it is slightly zoned. It is replaced by type 4 Mn-rich ilmenite.

Mineral chemistry

Spinel 1 do not follow the typical spinel trends, and it has lower Al (0,13-0,15 apfu), Mg (0,40-0,43 apfu), and Ti (0,05-0,07) but higher Fe^{2+} (0,59-0,64 apfu) and Fe^{3+} (0,46-0,54 apfu) contents than spinel 2 (0,16-0,32 apfu Al, 0,57-0,61 apfu Mg and 0,12-0,19 apfu Ti; 0,49-0,58 apfu Fe^{2+} and 0,22-0,42 apfu Fe^{3+}). Spinel 2 is magnesiochromite with 0,79-0,89 Cr#. There is an increase in Ti/(Ti+Al+Cr), $Fe^{2+}/(Fe^{2+}+Mg)$ and $Fe^{3+}/(Fe^{3+}+Al+Cr)$ from spinel 2 to spinel 5. This compositional trend crosses the T1 and T2 fields established by Mitchell (1986), as well as the kimberlite trend and Fe-Ti trend defined by Barnes and Roeder (2001). Titanomagnetite (spinel 6) replaces Mg-rich ilmenite and hence it is enriched in Mg. The euhedral titanomagnetite (spinel 7) has a composition between spinel 3 and spinel 4.

Type 1 Mg-rich ilmenite is classified as geikielite (0,52-0,58 apfu Mg), it has higher Cr than the other ilmenite types (up to 2,7 wt.% Cr_2O_3), and very low Mn and Nb contents (0,5-0,8 wt.% MnO and ~0,1 wt.% Nb_2O_5). Type 2 euhedral tabular ilmenite is Mg-rich (0.30-0.48 Mg apfu), with low Mn and Nb contents (1,5-2,4 wt. % MnO and 0,4-1,4 wt.% Nb_2O_5). Type 3 ilmenite is slightly enriched in Mn (2,57-4,5 wt. % MnO) but it has low Mg and Cr contents (0,5-2,7wt.% MgO and 0-0,4 wt.% Cr_2O_3). It has enrichment in Nb (0,7-2.5 wt. % Nb_2O_5), with high Fe^{2+} (0,8-0,9 apfu) and low Fe^{3+} (< 0,1 apfu). Type 4 ilmenite is poor in Mg and Cr but it is slightly enriched in Mn (3,2-4,9 wt.% MnO) and Nb. Type 1 ilmenite compositions plot in the kimberlitic domain (Wyatt et al., 2004), while types 2, 3 and 4 plot outside. However, it shows a Mn enrichment from type 2 to type 4 ilmenite. Type 1 has the highest Fe^{3+} and Mg contents.

The phlogopite macrocrysts (type 1) are Al-rich (1,95-1,98 apfu) and Ti-poor (0,02-0,03 apfu). Phlogopite 2 is Al-rich (about 2,42 apfu) and Ti-rich (0,40-0,41 apfu). Phlogopite 3 (outer rim) has the same composition as the core of groundmass phlogopite (phlogopite 4), which is Ti-rich (0,14-0,20 apfu) and Al-rich (1,58-1,80 apfu). These evolve to Al-free (0-0,07 apfu) and Ti-poor (0,02-0,04 apfu) tetraferriphlogopite, thus following the orangeite trend defined by Mitchell (1995). They have 1,49-1,70 apfu Fe^{3+} in the tetrahedral position.

Perovskite in groundmass is slightly zoned, the cores having higher LREE content (5,0- 5,7 wt.% Σ $LREE_2O_3$) than the borders (up to 1,2-3,9 wt.% Σ $LREE_2O_3$). Nb contents are quite constant and low (0,8-1,8 wt.% Nb_2O_5).

Discussion and conclusions

The high modal phlogopite and the tetraferriphlogopite trend (Tappe et al., 2005) are indicative of an orangeite affinity for this pipe. However, the occurrence of an early generation of phlogopite with an “alnoite or minette” trend would indicate the existence of an early different magma.

The diversity of spinel and ilmenite generations also records a very complex evolution of this magma. The origin of the type 1 spinel remains obscure, but since it is replaced by the younger chromite generations it could be produced by an early magma of unclear composition. However, the coexistence of type 2 and type 3 spinels (as demonstrated by their occurrence in same growth band of phlogopite) suggests the coexistence of two separate magmas (a possible magma mingling) in this intrusion. At the least, the chemical evolution of the zoned spinels (types 2, 4, 5) can fit the evolution of an orangeite magma, but the higher Mg compositions of the type 3 could also suggest the existence of a more kimberlitic magma. However, one must take into account that the composition of spinel 6 can be interpreted as produced by the same magma as type 4 spinel, but enriched in Mg because it replaces geikielite. Moreover, the occurrence of dense spinel aggregates with a distinct composition (type 7 spinel) can be indicative of another Fe-rich magma of nelsonitic affinity.

Mg-rich ilmenite is commonly found as macro- and megacryst in kimberlite, and it is interpreted as produced by primary magmatic crystallization (Moore,1987) or as xenocrysts (Armstrong et al., 2004). However, it is found in most of the cases as a replacement product of oxidized ilmenite xenocrysts (Robles-Cruz et al., 2009). Hence, type 1 ilmenite (geikielitic) from Banankoro could be produced by a similar mechanism, because its composition is typically within the kimberlitic domain of Wyatt et al. (2004). This process took place clearly before the crystallization of the groundmass spinel. However, euhedral Mg-rich ilmenite is very different to the other ilmenite generation, also in compositions. Firstly, type 2 euhedral tabular ilmenite from Banankoro plots out of the kimberlite domain in the compositional diagram of Wyatt et al. (2004), and it has a higher Mn contents. Moreover, type 2 ilmenite crystallised as a late product in association with calcite and serpentines, mantling spinels and other groundmass minerals. Therefore, it cannot have any relation with the metasomatic processes in the mantle producing the diamond growth.

Finally, although type 3 Mn-ilmenite has been suggested as a guide for diamond exploration, in Banankoro is clearly a late product replacing Mg-rich euhedral ilmenite and all the spinel minerals. Therefore, its formation is most likely linked to hydrothermal fluids given its systematic association with serpentines.

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