

Geochemistry and mineralogy of kimberlites from the Brauna Kimberlite Province, São Francisco Craton, NE Brazil

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Introduction

Intense exploration and studies for kimberlite and lamproite, using the tracers chemistry of heavy mineral concentrates and geophysics (gravity, magnetic, electromagnetic), over the past two decade has resulted in the discovery of twenty one kimberlite bodies that form the Brauna kimberlite province (BKP) in Brazil. The BKP is situated in the northeast of São Francisco Craton, Bahia State, Brazil (Fig.1A). The kimberlites lobes are 100% on-craton, and they are diamondiferous. The BKP is comprised by three kimberlite pipelike bodies and eighteen complex dyke system trending about N30W. Pipe morphologies are strongly controlled by joints and faults. The most important pipe is the Brauna 03, comprising three lobes with a combined surface area of circa 1.75ha, and the adjacent Brauna 04 and 07 pipe-like bodies and eighteen dyke-like bodies (Donatti Filho et al. 2008). The BKP has K-Ar ages about 682 ± 20 Ma (Pisani et al, 2001) and occurs as discrete intrusions, crosscutting a 2155 ± 9 Ma-old TTG granodiorite batholith (Cruz Filho et al., 2003) of the Paleoproterozoic Rio Itapicuru greenstone belt (Kishida and Riccio, 1980) (Fig.1B).

segregationary texture and brecciated texture with >15% of xenoliths, mostly kimberlitized granodiorite (Donatti Filho et al. 2008).

Mineralogy

Olivine is the most abundant macrocryst phase, ranging from 0.1 to 2cm in size and is typically rounded to subangular (ellipsoidal) and anhedral. It is generally pervasively altered and can be completely serpentinized, kelyphitized or calcified. Despite the extensive alteration caused by magmatic fluids around rims and along fractures, fresh olivine (macro and phenocrysts) cores are preserved in some samples. Olivine megacrysts can reach sizes about 3.5cm and frequently has garnet inclusions. Phlogopite is another important phenocryst phase in all samples. Phlogopite macrocrysts, often with corroded or altered rims (or very fine-grained kimberlitic halo), can reach more than 5% of the kimberlite mode and be up to 0.5-5cm long. The largest phlogopite (>4cm) may have formed by influence of metasomatic fluids. Eclogitic and peridotitic garnets, including harzburgitic and lherzolitic are commonly observed and they range from 0.2 to 4cm in size. Green-brown Cr-spinel macrocrysts are in general anhedral and occur in the groundmass of a few samples. Perovskite is euhedral to anhedral and is abundant in the kimberlite groundmass, where it is associated with ilmenite, titanite and magnetite, and is pervasively altered.

Bulk Chemistry

Only the hypabyssal facies kimberlite is exposed within the BKP, and the selected samples for analysis include dykes and pipes and all facies varieties. Eighteen samples of the most visibly fresh kimberlite were selected for chemical analysis. Major elements were analysed on a Philips PW-2404 X-ray fluorescence (XRF) spectrometer using fusion beads. The trace elements Cu, Ni, Co, Cr, V, Zn and Nb were also analysed by XRF using pressed powder pellets. Seven samples were selected for rare earth elements (REE) analysis using a Thermo X Series ICP-MS. Kimberlites exhibit high compatible and incompatible trace element abundances. Transition trace elements correlate positively with Mg#. Ni and Cr (Ni = 940-1655 ppm, Cr = 984-1520 ppm) define tightly constrained correlations, and Cu (Cu = 6.4 – 88 ppm) a broader correlation. High field strength elements (HFSE) and light rare earth elements (LREE) are all high in abundance (e.g. La = 113.9 ppm). The pipe samples have similar major element compositions. On

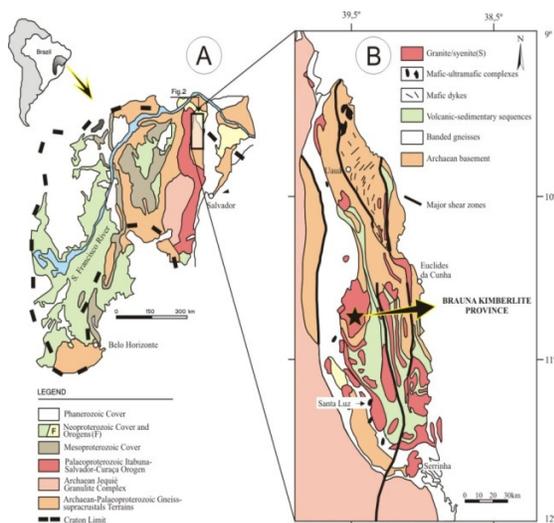


Fig. 1: A) Geological map of the São Francisco Craton. B) Geological map of the Rio Itapicuru greenstone belt with location of the BKP.

Previous studies describe the kimberlite geotherm about 40mW/m^2 (Pisani et al. 2001). The hypabyssal Brauna kimberlite textural varieties include: aphanitic texture, macrocrystic and megacrystic textures with frequent cumulate olivine grains (>2cm),

the other hand, the dyke samples are more enriched in incompatible trace elements than the pipe samples. In general, both varieties exhibit REE similarities with the African group II kimberlites. Chondrite-normalized REE patterns are shown in Fig.5A, where it is evident that all samples show smooth, sub-parallel patterns and are strongly enriched in the light REE relative to the heavy REE (HREE; $(La/Sm)_N = 8.4$; $(La/Yb)_N = 182.8$). Normalized La abundances range between 480.5 and 1123.8 chondrite, whereas Lu ranges between 2.8 and 4.7 chondrite. The REE patterns for individual samples are parallel, with the Brauna 04 and 7 pipes samples displaced to uniformly higher overall concentrations relative to Brauna 03 pipe samples. Ba, Rb and Pb concentrations are high and variable (e.g. Ba = 493-2917 ppm, Rb = 54-279 ppm, Pb = 2.5–21.6 ppm) but show no correlation with one another, nor with immobile elements such as Sr (172-1632 ppm), Nb (110-182 ppm) or Zr (162-1304 ppm) (Fig.5B). La concentrations (113.9-266.3 ppm) do positively correlate with Nb; however, this may be a feature of crustal contamination or metasomatic fluid enrichment. Negative Rb, K, Sr anomalies are larger for the sources of Group II kimberlites, and the BKP show close relation with these geochemical features (Fig.5B).

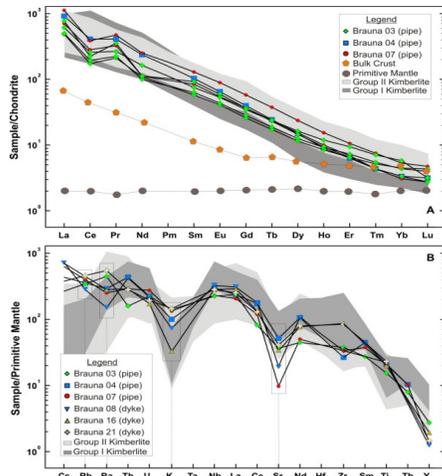


Fig. 5: A) Chondrite-normalized REE abundances in BKP. B) Primitive mantle-normalized trace element patterns of BKP. Chondrite from Sun and McDonough (1989). Primitive mantle and bulk crust from Taylor and McLennan (1985). Group I and II from Becker and le Roex (2006).

A summary of selected major (Ca,Al), minor (K,P) compositions of the BKP is given in Fig. 6, and is compared with similar rocks worldwide. In the Al_2O_3 - K_2O - P_2O_5 ternary diagram (Fig.6A) almost all of the Brauna kimberlite samples (both pipes and dykes) fall in the global field of group II kimberlites, and just one sample from Brauna 16-dyke falls on the group I kimberlite field, a characteristic that may be interpreted as Al and P contamination by crustal material. Fig. 6B shows the same feature, with almost all Brauna kimberlite samples falling in the group II kimberlites field, and barely touches the area of olivine

lamproites field, in spite of the fact that many of the Brauna kimberlite samples in this study are phlogopite-bearing.

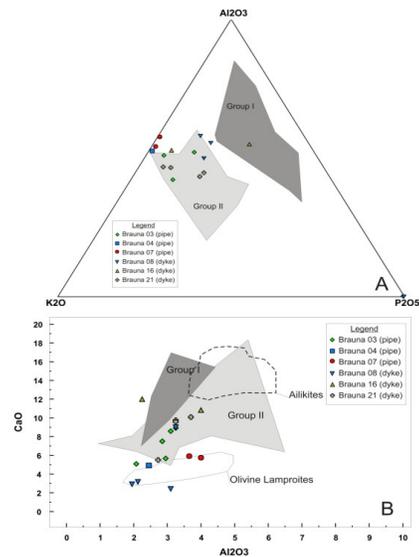


Fig. 6: A) Ternary comparative diagram for BKP. B) Binary comparative diagram for BKP. Olivine lamproites and ailikites (Taylor et al. 1994). Group I and II kimberlites (Becker and le Roex, 2006).

Kimberlites generally carry a significant xenolithic amount. In terms of Clement (1982) contamination index, using major elements (Si,Al) the Brauna kimberlite samples from pipes are almost uncontaminated. On the other hand, the kimberlite dyke samples appear to have interacted significantly with foreign material (Fig.7A), confirmed by the high grade of brecciated facies on kimberlite dyke-like bodies. This feature is shown in Fig 7B where the major element variations in the dyke samples are consistent with xenolith and megacryst mineral entrainment, suggesting greater involvement of ilmenite (Ti-rich macrocryst kimberlite). This is consistent with the African group II kimberlites, suggesting similarities on both geochemistry and source regions. On the Becker and le Roex (2006) diagram, estimated source regions in equilibrium with close to primary Group II kimberlite magmas are all enriched relative to chondrite, with the LREE being more enriched than the HREE. The Brauna kimberlite pipe varieties are likely to represent liquid compositions, whereas the Brauna kimberlite dyke varieties are more doubtful in this regard and were possibly contaminated by crustal material. It is also suggested that the magma sources for the BKP were metasomatically enriched to different degrees prior to kimberlite generation. Modeling of mantle melting processes suggests that the primary BKP magma formed by low degrees of partial melting, around 0.2-0.3% melting of a depleted garnet lherzolite source that had been enriched in volatiles and highly incompatible elements prior to melting (Fig.8A). Depletion in Rb, Ba, K and Sr relative to elements of similar incompatibility is interpreted to be a feature of the

primary kimberlite magma and the source region. The sources of the BKP are more enriched in the incompatible elements, with high La/Sm and Gd/Yb ratios, suggesting that they are possibly low degree partial melts, similar to the group II kimberlites as showed in the Becker and le Roex (2006) diagram.

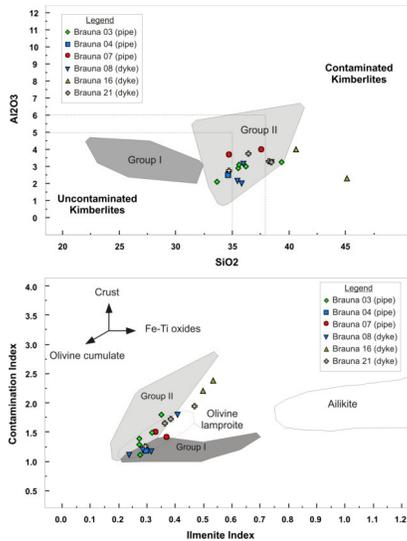


Fig. 7: A) Contamination diagram from Clement (1982) for the BKP. B) Taylor et al. (1994) diagram for the BKP. Groups I and II kimberlites from Becker and le Roex (2006).

Calculated sources are also enriched in the highly incompatible LILE and HFSE and depleted in the less incompatible elements relative to primitive mantle (e.g. Th = 15.3 – 32.2 ppm, Yb = 0.75 – 0.9 ppm, Zr = 162 – 1304 ppm, Nb = 110 – 182 ppm). Kimberlites are formed under high pressure conditions in the mantle region as defined in the literature. According to the SiO₂/Al₂O₃ versus MgO/CaO diagram (Rock, 1991), the Brauna kimberlites show a pressure conditions value up to 5 Gpa, i.e. close to the kimberlite field conditions (Fig.8B).

Conclusions

The BKP pipes and dykes have the same mineralogical and textural characteristics. The kimberlite dykes appear to have evolved by contamination processes. On the other hand, the kimberlite pipes are closed to primary magma compositions. The kimberlite bodies are iron-rich with Mg# = 80.1 - 90.1, and they have geochemical characteristics similar to Group II kimberlites and less often to olivine-lamproites. The low Al₂O₃, high Ni and Cr contents, and high Mg# in the Brauna kimberlites indicate strongly depleted lherzolitic–harzburgitic mantle sources. The BKP have overall high trace element abundances and highly fractionated REE patterns, suggesting low degree of partial melt and/or a moderate enriched source. Melting models indicate 0.2 to 0.3% melting, and derivation of the primary kimberlite magma from a source previously enriched in LREE. These characteristics indicate that the Brauna kimberlites could be the

product of sub-continental lithospheric mantle melting, previously enriched by metasomatic fluids (subduction zone associated?).

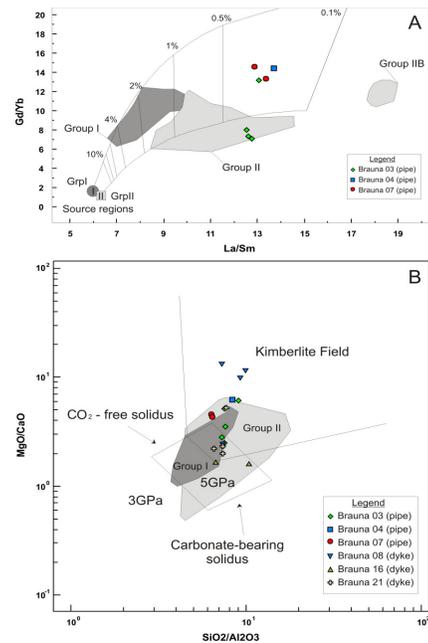


Fig. 8: A) Becker and le Roex (2006) source diagram compared with the BKP. B) Binary diagram for kimberlite pressure region source (Rock, 1991).

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