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Insights into the late-stage differentiation processes of the Catalão I carbonatite complex in Brazil: New Sr–Nd and C–O isotopic data in minerals from niobium ores

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ABSTRACT

The Late Cretaceous Catalão I carbonatite complex consists of ultramafic silicate rocks, phoscorites, nelsonites and carbonatites. The latest stages of the evolution of the complex are characterized by several nelsonite (magnetite–apatite rock) and carbonatite dykes, plugs and veins crosscutting earlier alkaline rocks. The interaction between the latter and late-stage carbonatites and/or carbo-hydrothermal fluids, converted the original dunites and bebedourites to metasomatic phlogopitites. Late-stage nelsonites (N1), pseudonelsonites (N2) and various types of dolomite carbonatites (DC) including norsethite-, magnesite- and/or monazite-bearing varieties show significant whole-rock Nd and Sr isotopic variations. To elucidate whether magmatic or metasomatic processes, or both, were responsible for these isotope variations we characterized the Nd and Sr isotope compositions of major mineral phases (i.e. apatite, dolomite, norsethite, pyrochlore and tetraferriphlogopite) in these late-stage rocks. Mineral isotope data recorded the same differences observed between N1 and N2 whole-rocks with N2 minerals showing more enriched isotopic signatures than minerals from N1. Sr isotopic disequilibrium among minerals from N2 pseudonelsonites and spatially related dolomite carbonatite pockets implies formation from batches of carbonate melts with distinct isotopic compositions. A detailed investigation of Nd and Sr isotopes from whole-rocks and minerals suggests that the most evolved rocks of the Catalão I complex probably derive from two different evolution paths. We propose that an earlier magmatic trend (path A) could be explained by several batches of immiscible and/or residual melts derived from carbonated-silicate parental magma (e.g. phlogopite picrite) contaminated with continental crust to a variable extent, in an AFCLI-like process. A second trend (path B) comprises highly variable $^{143}Nd/^{144}Nd_i$ at nearly constant $^{87}Sr/^{86}Sr_i$ coupled with high $\delta^{18}O$ in carbonates. This is interpreted here as the result of the interaction of previously-formed dolomite carbonatites with carbo-hydrothermal fluids.

1. Introduction

The isotope compositions of carbonatites have established important constraints on the petrogenetic processes involved in the origin and evolution of alkaline–carbonatite complexes worldwide (e.g. Andersen, 1987; Bell, 1998; Ray, 2009; Simonetti and Bell, 1994). Radiogenic, stable and noble gas isotopic data show that: (a) carbonatites originate directly from the mantle or from mantle-derived magmas; (b) parts of subcontinental mantle may remain virtually undisturbed over billions of years (~3.0 Ga) and; (c) most worldwide carbonatites younger than 200 Ma have isotope signatures that can be explained in terms of mixtures of HIMU, EM-I and FOZO mantle components (Bell and Simonetti, 2010 and references therein).

Recent works have reported radiogenic isotope studies in minerals from carbonatites and associated alkaline rocks providing new insights into the complicated histories for some alkaline–carbonatite complexes (e.g. Bell, 2001; Bizzarro et al., 2003; Chen and Simonetti, 2015; Dunworth and Bell, 2001; Tichomirowa et al., 2006; Wu et al., 2011, 2013; Ye et al., 2013; Zaitsev and Bell, 1995). Open-system behaviour involving interaction between melts or fluids derived from mantle and/or crust levels, isotopically heterogeneous mantle sources, magma recharge, and crustal assimilation have been proposed to explain the major isotopic ratio variations. Therefore, mineral isotopic compositions may offer valuable information to clarify the evolution of some carbonatite complexes, particularly where isotope disequilibria have already been detected in whole-rock analyses.

Significant Nd and Sr isotopic variations have been reported in the niobium ores from the Catalão I complex (Cordeiro et al., 2010, 2011b). Late-stage magmatic and/or metasomatic processes could

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explain such isotope signatures, but a detailed mineral isotope investigation may provide further insights into the mechanisms associated with these variations. Hence, in this study, the Sr and Nd isotopic composition of several individual mineral phases separated from the samples described in Cordeiro et al. (2010, 2011b) are characterized in order to verify for isotopic equilibrium, provide additional stable (C, O) isotope data, and propose new constraints on the final stages of the Catalão I evolution.

2. Geological setting

Catalão I is one of the northernmost alkaline–carbonatite complexes of the Late Cretaceous Alto Paranaíba Igneous Province (APIP). The APIP comprises ultrapotassic dykes, pipes, plugs and diatremes of kamafugitic, kimberlitic and rare lamproitic compositions along with extensive kamafugitic lava flows and pyroclastic deposits, and large carbonatite-bearing intrusions (Araújo et al., 2001; Gibson et al., 1995; Gomes and Comin-Chiaramonti, 2005). The carbonatites of the province belong to the rare carbonatite–kamafugite association (Brod et al., 2000). The alkaline magmas were emplaced into the Neoproterozoic metasedimentary rocks of the Brasília Belt, between the SW border of the São Francisco Craton and the NE margin of the Phanerozoic Paraná Basin (inset Fig. 1). Such magmatism is attributed to the impact of the Trindade mantle plume beneath the previously metasomatized subcontinental lithospheric mantle in this region (Araújo et al., 2001; Gibson et al., 1995, 1997; Sgarbi et al., 2004; Thompson et al., 1998). However, some authors have argued against the plume hypothesis and claimed that APIP magmatism could be explained by long-lived deep mantle thermal anomalies (e.g. Riccomini et al., 2005), or due to elevated homologous temperature (Guarino et al., 2013).

The Catalão I carbonatite complex, located ca. 20 km northeast of the city of Catalão in central Brazil (18°08′S; 47°48′W), comprises a ~30 km^2 roughly circular, dome-shaped multi-stage intrusion (Fig. 1) emplaced in quartzites and schists of the Araxá Group (Carvalho,

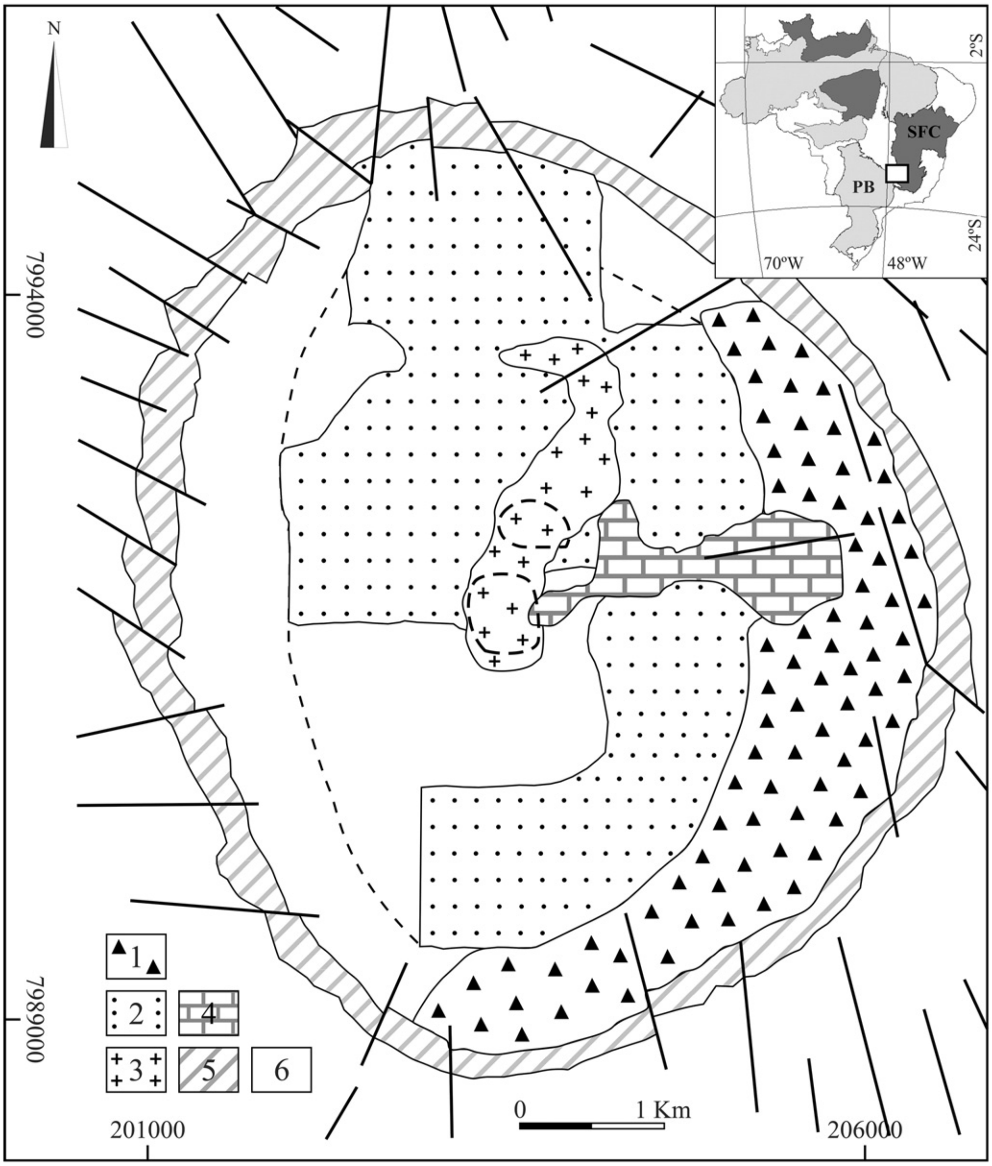

Fig. 1. Geological sketch from the Catalão I carbonatite complex (after Cordeiro et al., 2010; Ribeiro et al., 2014). (1) Early alkaline ultramafic rocks; (2) Phoscorites and early-stage carbonatites with minor alkaline ultramafic rocks; (3) Late-stage nelsonites and dolomite carbonatites; (4) Late-stage REE-rich and monazite-bearing carbonatites; (5) Fenitized quartzites; (6) Area without outcrops or drill-core information. Approximate sample locations are marked by dashed lines in the centre of the complex. Faults and fractures are shown by straight black lines. Inset shows the location of APIP (square) between the NE margin of the Phanerozoic Paraná Basin (PB — light grey) and the SW border of the São Francisco Craton (SFC — dark grey). Blank areas between cratons and basins are Neoproterozoic mobile belts.