



Sulfur isotopes from Brazilian alkaline carbonatite complexes



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ABSTRACT

This work presents the first sulfur isotope data for the Tapira, Araxá, Salitre, Serra Negra, Catalão I and Catalão II alkaline–carbonatite complexes of the Alto Paranaíba Igneous Province (APIP) and the Jacupiranga complex of the Ponta Grossa Province, in central and southeast Brazil, respectively. The APIP complexes are composed of alkaline silicate rocks (bebedourite, alkali clinopyroxenite, minor syenite), phoscorites, nelsonites, and carbonatites. The Jacupiranga complex is composed of ijolite-series rocks, syenites, carbonatites and alkaline gabbros. Many of these rocks contain sulfides and the carbonatites contain both sulfides and sulfates.

Although there is extensive overlap, the $\delta^{34}\text{S}$ decreases in sulfides from ultramafic rocks through phoscorites to carbonatites in each complex. Initially, this variation may be controlled by the temperature dependence of the sulfur isotope fractionation between crystallizing sulfides and magma, but in later stages it is dominated by the increasing oxidation state of the magma and crystallization of ^{34}S -enriched sulfate minerals.

Core to rim isotopic variation in quenched individual pyrite crystals indicates that $\delta^{34}\text{S}$ increases with degassing. Metasomatic sulfides have low $\delta^{34}\text{S}$, resulting from the interaction of late-stage carbonatite fluids with the host rock.

On a regional scale, the APIP complexes have a wider sulfur isotopic range than Jacupiranga, suggesting a more extensive interplay between magma evolution, degassing and metasomatism, probably due to a shallower emplacement of the APIP intrusions and/or a less evolved character of the Jacupiranga magmas.

Sulfur isotope ranges for the studied complexes are comparable with other worldwide carbonatite and alkaline provinces, but the APIP results extend to lower $\delta^{34}\text{S}$.

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1. Introduction

Sulfur isotopes have been applied to assess petrological and metallogenetic questions in carbonatite complexes, such as those in the Superior Province, in Canada (Farrel et al., 2010), Swartbooisdrif, in Namibia (Drüppel et al., 2006), and Magnet Cove, Bearpaw and Mountain Pass, in the USA (Mitchell and Krouse, 1975). Various authors (e.g. Mitchell and Krouse, 1975; Deines, 1989; Farrel et al., 2010) pointed out that each carbonatite appears to have its own mean sulfide or sulfate isotopic composition. Deines (1989) compiled the $\delta^{34}\text{S}$ composition of sulfides from carbonatites and found a -20% to $+5\%$ range suggesting that some differences between carbonatite complexes may reflect S isotope heterogeneity in the mantle. Sulfur isotopes have also

been successfully used to assess the magmatic or hydrothermal origin of sulfur-bearing fluids (Nikiforov et al., 2006), the temperature, oxygen fugacity and differentiation stage of magmas, the mechanisms of fenitization and mineralization (Drüppel et al., 2006) and the degassing of magmatic SO_2 and H_2S (Zheng, 1990).

Sulfur is an important volatile constituent in alkaline magmas together with CO_2 and halogens (Bailey and Hampton, 1990; Samson et al., 1995; Brooker et al., 2011). The sulfur species present depends largely on the redox conditions, and may provide important insights into the evolution of magmas and mineralizing fluids.

Carbonatite complexes and alkaline rocks from the Alto Paranaíba Igneous Province (APIP) and other alkaline provinces peripheral to the Paraná Basin have been the subject of studies comprising geochemistry, mineralogy, and stable (mostly C, O) and radiogenic (Sr, Nd, Pb, Os, Hf) isotopes (e.g. Gibson et al., 1995a; Santos and Clayton, 1995; Comin-Chiaromonte and Gomes, 2005; Carlson et al., 2007; Cordeiro et al., 2011). In spite of the common occurrence of sulfides and/or sulfates

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in these rocks, their sulfur isotopic composition and its petrogenetic implications have not been studied so far.

In this work we report the first sulfur isotope data for Brazilian carbonatites and discuss the petrogenetic implications for various rock types and minerals in the light of field and petrographic evidence. We determined the sulfur isotope composition of sulfides in ultramafic alkaline rocks, phoscorites, nelsonites and carbonatites from the Catalão II, Catalão I, Serra Negra, Salitre, Araxá and Tapira complexes, in the APIP, and Jacupiranga in the Ponta Grossa Alkaline Province (see Fig. 1 for locations). We also report and discuss sulfur isotope data on some sulfide–sulfate associations and a few metasomatic sulfides from the APIP.

2. Alkaline magmatism in central and southeast Brazil

Alkaline rocks and alkaline–carbonatite associations include highly variable petrographic types and a correspondingly extensive nomenclature (Sahama, 1974; Le Bas, 1987; Yegorov, 1993; Le Maitre et al., 2002; Wall and Zaitsev, 2004; Barbosa et al., 2012), a table summarizing rock names used in this work, with definitions and the corresponding references is given in the online supplementary material. Some specific terms, such as nelsonite and bebedourite are kept because they are familiar to those working in the area and because these rocks have no correspondence at all within the set of root names recommended by the IUGS Subcommittee on the Systematics of Igneous Rocks (Le Maitre et al., 2002). The term nelsonite is used in the sense of Yegorov (1993) and a recent discussion on bebedourites can be found in Barbosa et al. (2012).

Voluminous Cretaceous alkaline magmatism occurred in central and southern Brazil, and in eastern Paraguay (Comin-Chiaramonti and

Gomes, 1996, 2005). Gibson et al. (1995a) interpreted the Early-Cretaceous alkaline magmatism (ca. 130 Ma) and the contemporaneous Paraná magmatism as related with the Tristan da Cunha mantle plume, whereas Gibson et al. (1995b, 1997) and Brod et al. (2005) correlated the Late-Cretaceous magmatism (ca. 85 Ma) at the north and northeast borders of the Paraná Basin with the impact of the Trindade mantle plume (Gibson et al., 1995b) at the sub-continental lithosphere of central Brazil.

The APIP results from an intense Late-Cretaceous alkaline magmatism that generated intrusive (dykes, conduits, diatremes, and carbonatitic complexes) and extrusive (lavas and pyroclastic rocks) bodies (Leonardos et al., 1991; Gibson et al., 1995b; Brod et al., 2000; Comin-Chiaramonti and Gomes, 2005; Carlson et al., 2007). It is one of the largest ultramafic–ultrapotassic provinces of the world (Gibson et al., 1995b). Kamafugite is by far the dominant rock-type in the province, forming one of the few known kamafugite–carbonatite associations (Brod et al., 2000).

The APIP alkaline–carbonatite complexes are multi-stage intrusions formed by rocks derived from the bebedourite, carbonatite and phoscorite petrogenetic series, which are related to each other by fractional crystallization, liquid immiscibility and degassing (Brod et al., 2004; Ribeiro, 2008; Barbosa, 2009; Cordeiro et al., 2010; Barbosa et al., 2012; Brod et al., 2012). The ultramafic rocks of all complexes show variable degrees of metasomatism by fluids resulting from extreme carbonatite differentiation. The relatively shallow character of the APIP intrusions is indicated by C and O isotopes (Santos and Clayton, 1995), within-magma chamber pyroclastic deposits (Ribeiro et al., 2005), and similarities with xenoliths in volcanic and sub-volcanic kamafugites in the province (Seer and Moraes, 1988; Brod et al., 2000).

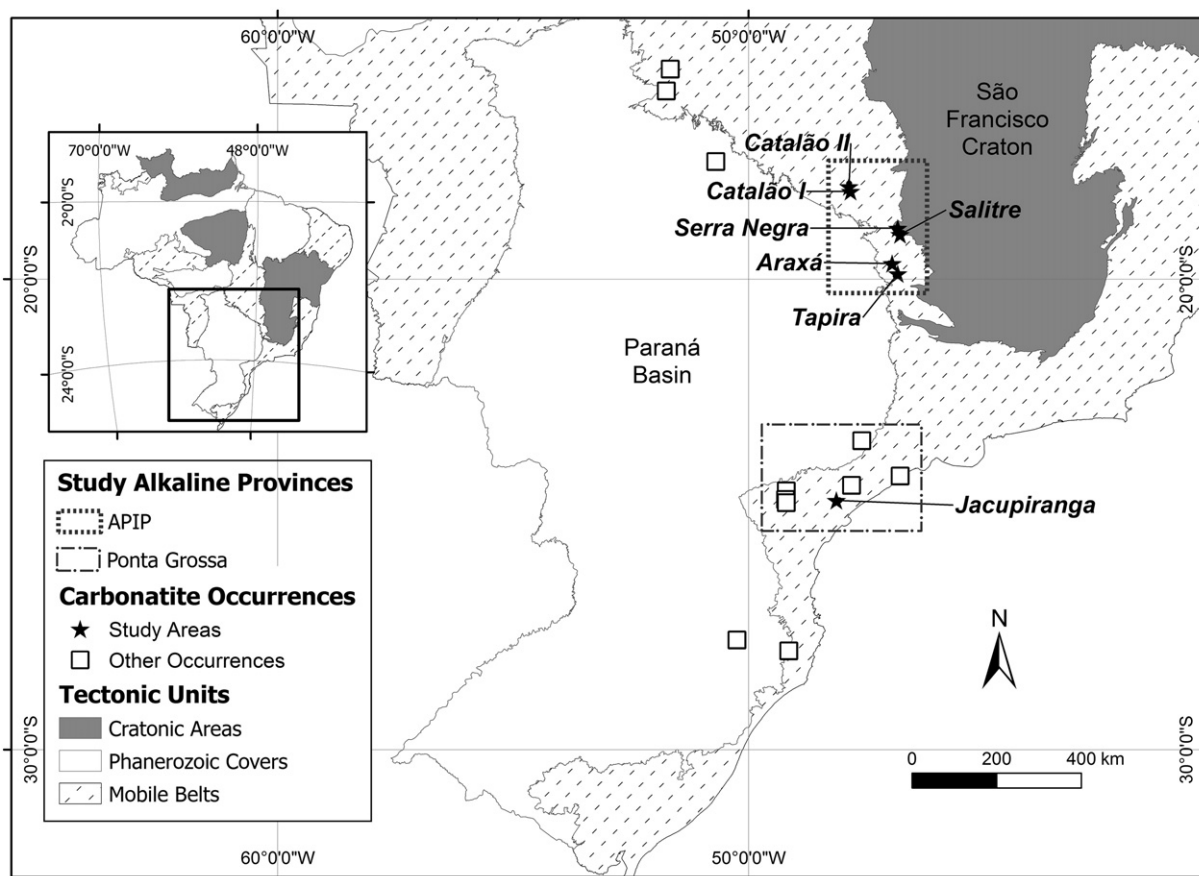


Fig. 1. Carbonatite occurrences surrounding the Paraná Basin. The carbonatite complexes studied in this work are shown as stars. Modified from Oliveira et al. (2004) and Woolley and Kjarsgaard (2008).

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