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Geochemical and Sr–Nd–Pb isotope constraints on the petrogenesis of the K-rich Pedra Branca Syenite: Implications for the Neoproterozoic post-collisional magmatism in SE Brazil

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ABSTRACT

The Pedra Branca Syenite is a 610 Ma post-collisional pluton intrusive in the Socorro–Guaxupé Nappe, an allochthonous terrain emplaced at the SW border of the São Francisco craton, Brazil. The pluton is largely dominated by laminated syenites with colour index 20–25 displayed in a zoned structure, with a first unit of marginally peralkaline silica-saturated syenites exposed at its E and N border intruded by silica-oversaturated metaluminous syenites making up its core. Mafic to ultramafic coarse-grained enclaves and lenses are frequent in the laminated units, and must correspond to disrupted cumulate layers. Fine-grained enclaves are rare, and vary from microsyenites, which seem to be products of new magma pulses frozen within mushy portions of the magma chamber, to monzonites and diorites, which reflect the existence of contemporaneous "basalt" (plagioclase-bearing) magmas that interacted with the syenitic magmas at greater depths and were carried up during ascension.

All syenitic units share important geochemical signatures with high contents of LILE such as Ba (4000–10,000 ppm) and Sr (2000–4500 ppm), as well as P_2O_5 (1–2%) and have strongly fractionated LREE patterns ($(La/Yb)_N = 40–120$; La = 100–400 ppm). An important contrast between silica-oversaturated and saturated syenites is the higher Al_2O_3 content in the former, reflected in higher normative anorthite, mostly hosted in high temperature alkali feldspar. The Pedra Branca syenites have $^{87}Sr/^{86}Sr_{(t)} = 0.7077$ to 0.7078 and unradiogenic Nd ($\varepsilon Nd_{(t)} \sim -8$) and Pb ($^{206}Pb/^{204}Pb = 17.2–17.3$); this isotope signature, associated with high LREE/HFS ratios indicates that the parent melts were generated in enriched (metasomatic phlogopite–clinopyroxenite) portions of the shallow (lithospheric) continental mantle affected by previous subduction. The chemical characteristics of the silica-oversaturated syenites and their association with microgranular dioritic enclaves are suggestive that their contrasts with the more oxidized, marginally peralkaline silica-saturated syenitic magmas, may have resulted from interaction with plagioclase-rich ("basalt") magmas at greater depths.

1. Introduction

Potassic to ultrapotassic rocks are relatively rare and, even when present, are minor components of the magmatic output of orogenic systems. However, they are recognized as typical of the post-collisional period in archetypal areas such as the Alpine–Himalayan belt (Guo et al., 2005; Prelević et al., 2005) and, since they derive from strongly enriched mantle domains, which control their trace-element and isotope signature, their geochemistry may preserve precious information on mantle processes (Prelević et al., 2012).

Voluminous granitic magmatism of high-K calc-alkaline affinity characterizes the prolonged history of convergent tectonics that generated the Ribeira and Brasília Fold Belts in S–SE Brazil in the late Neoproterozoic–Cambrian (680–500 Ma; Janasi and Ulbrich, 1991; Campos Neto and Caby, 2000; Heilbron et al., 2004, 2008; Reno et al., 2009). The high-K magmatism, although showing geochemical signatures typical of subduction-related environments, is dominated by felsic rocks largely derived from ancient continental crust, and its spatial and temporal position relative to ocean closure and continental collision is often ambiguous (cf. Florisbal et al., 2012; Heilbron et al., 2013; Leite et al., 2007). In this context, the study of mantle-derived potassic and ultrapotassic rocks of clear post-collisional positioning can help elucidate fundamental issues related to source contributions and tectonic evolution. Amid these rare occurrences, the 610 Ma Pedra Branca Syenite (Carvalho and Janasi, 2012), intrusive into migmatites and high-K calc-alkaline granites of the Socorro–Guaxupé Nappe (Campos Neto and Caby, 1999), is unique. It is composed of varied set of rock types that includes silica-oversaturated and undersaturated syenites of metaluminous to mildly peralkaline character, and a variety of cumulate

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and microgranular enclaves that may bring information on magma chamber processes. Sampling and the study of structural features are facilitated by exposures of exceptional quality in quarries exploited for ornamental stone.

A peculiar feature of the Pedra Branca pluton is the coexistence of silica-oversaturated and silica-saturated to (locally) undersaturated syenites, which brings out the classical petrological problem of crossing the thermal barrier in the nepheline-silica system (e.g., Foland et al., 1993; Riishuus et al., 2008). In a previous work (Carvalho and Janasi, 2012) we characterized the mineral chemistry of representative samples from the main varieties of the Pedra Branca Syenite, showing that compared to the quartz-bearing syenites, the silica-saturated to undersaturated rocks are characteristically more oxidized, and bear mafic minerals with a distinctive chemistry (clinopyroxene, amphibole and phlogopite with higher mg#; higher Na contents in clinopyroxene; Ilm-Hem_{ss} with higher proportions of hematite). Moreover, the residence of some key trace-elements was shown to be critically dependent on subtle contrasts in melt and mineral chemistry (e.g., Sr, Eu and Pb are concentrated in the An-richer alkali feldspar typical of silica-oversaturated syenites, while in the silica-saturated syenites are split between alkali feldspar, clinopyroxene, apatite and titanite; a large proportion of Zr and Hf may be accommodated in clinopyroxene and titanite in the latter, but they reside only in zircon in quartz-bearing syenites).

This manuscript presents a detailed account of the geology, petrography and whole-rock elemental and isotope (Sr–Nd–Pb) geochemistry of the Pedra Branca Syenite, integrating these data with our previous mineral chemistry results to investigate the petrogenesis of the pluton, and its implications for the post-collisional evolution of the Socorro–Guaxupé Nappe and its surroundings.

2. Geological setting

The Socorro–Guaxupé Nappe (SGN) in SE Brazil is part of a nappe system related to late Neoproterozoic plate convergence at the SW border of the São Francisco Plate (Campos Neto and Caby, 1999). It is interpreted as a magmatic arc developed at a continental margin, and is largely dominated by Neoproterozoic (~660–610 Ma) plutonic rocks with dominantly Mesoproterozoic to Palaeoproterozoic (1.4–2.2 Ga) Sm–Nd model-ages (e.g., Janasi, 2002). The SGN is thrust over the Amparo Domain, which may correspond to the SW continuity of the São Francisco Plate, and comprises a basement terrain (Archean Amparo grey gneiss and ~2.1 Ga orthogneisses; Fetter et al., 2001; Campos Neto et al., 2004, 2011) covered by Meso- to Neoproterozoic metasupracrustal sequences (Campos Neto et al., 2011).

Migmatites are the most abundant rocks in the northern segment of SGN (Guaxupé Domain), and are products of partial melting of metaplutonic and metasupracrustal rocks (corresponding to the Pinhal and Caconde Metamorphic complexes, respectively; Campos Neto and Caby, 1999, 2000). Granulites predominate in the northernmost portion of the Guaxupé Domain, where deeper levels (P up to 14 kbar; Campos Neto and Caby, 2000) are exposed.

Voluminous Neoproterozoic granitic rocks intrude the Guaxupé Domain migmatites, and may be grouped in four major associations (Fig. 1):

(1) a high-K calc-alkaline diorite–quartz monzonite–syenogranite suite, forming the Pinhal–Ipuiúna batholith (Haddad, 1995) and several minor bodies, dated at ~620 Ma (Janasi et al., 2007);
(2) two charnockite suites dated at ~625 Ma: (a) the mangeritic–syenogranitic São Pedro de Caldas suite, more felsic and derived from granulites with Sm–Nd model ages of ~1.5 Ga, and (b) the mangeritic Divinolândia suite, more mafic (with associated diorites and bearing a lesser amount of granites) and derived from granulites with greater crustal residence (Sm–Nd model ages >1.8 Ga) (Janasi, 2002);
(3) "Pinhal type" equigranular to inequigranular biotite granites (Wernick and Penalva, 1980), directly associated with migmatites, and derived from partial melting of orthogneisses, with ages in the range 625–610 Ma (Janasi, 1999);
(4) Pedra Branca and Capituva K-rich syenites, dated at ~610 Ma (Janasi, 1999; Töpfner, 1996), which constitute the youngest Neoproterozoic magmatic manifestations in the Guaxupé Domain.

3. The Pedra Branca Syenite

3.1. Main plutonic units

The Pedra Branca Syenite (Fig. 2) has an ellipsoidal shape with an area of ~90 km^2, and its western half was cut by the intrusion of the Cretaceous alkaline rocks of the Poços de Caldas Massif. An inward-dipping high-angle (usually >60°) magmatic foliation, defined by orientation of tabular alkali feldspar, is conspicuous in all rock types, and it is arranged parallel to the external contacts with country-rock migmatites and high-K calc-alkaline granites.

The main pluton is constituted of three syenite units. A quartz-free syenite (laminated silica-saturated syenite unit, LSS) with purple-brown platy-like alkali feldspar (aspect ratio, Ra ~ 3.5) and colour indices (CI) 20–25 (locally up to 30) constitutes most of the pluton's border (Fig. 3A). It is truncated by the internal quartz-bearing syenites (laminated silica-oversaturated syenite unit, LSO) with less elongated pinkish alkali feldspar (Ra ~ 2), and slightly lower CI (18–22) (Fig. 3B). These medium to coarse-grained laminated syenites make up most of the pluton, including the topographically elevated areas that form the Pedra Branca Hill (elevations up to 1780 m). The contact between the LSS and LSO is sharp, and at angle with the magmatic foliation in the NE portion of the pluton, where LSO is in direct contact with the country rocks (Fig. 2). A third unit of fine- to medium-grained quartz-bearing syenites makes up the topographically lower areas of the pluton's centre (centre silica-oversaturated syenite unit, CSO) (Fig. 3C). Isolated crescent-shaped bodies of quartz-bearing medium-grained syenite with CI ~ 25 occur to the east of the main pluton, and constitute a fourth unit (external silica-oversaturated syenite, ESO; Fig. 3D).

Mafic and accessory minerals visible to the naked eye are similar in all syenite units, although with differences in composition and relative abundance. Pyroxene or amphibole is predominant, while dark mica, is present in nearly all varieties, but its abundance is always less than 5%. Fe–Ti oxides, apatite and titanite are conspicuous accessory minerals. Apart from the presence of modal quartz, a significant petrographic feature distinguishing the silica-oversaturated syenites (especially LSO) is the presence, in some outcrops, of scarce corroded plagioclase cores within alkali feldspar (Fig. 3G). These plagioclase crystals show features indicative of textural disequilibrium, and in some cases appear in samples bearing microgranular enclaves of dioritic to monzonitic composition (see below), which suggests that they may correspond to xenocrysts.

3.2. Enclaves

Enclaves are common in all units of the Pedra Branca Syenite. The most frequent are mafic to ultramafic cumulate enclaves (Fig. 3F), with grain sizes similar to the host syenites (medium- to coarse-grained). Fine-grained (microgranular) enclaves of syenitic to dioritic composition are much less frequent, and mostly restricted to LSO.

Mafic to ultramafic enclaves occur especially in LSS and LSO as layers (Fig. 3E), veinlets or less regular bodies usually concordant with the magmatic foliation, with dimensions up to 40 cm. These cumulate enclaves are interpreted as results from the reworking of original cumulate layers during magmatic flow and contain 40–60% clinopyroxene, 15–20% dark mica, plus apatite (up to 8%), titanite (up to 5%), and