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Experimental anatexis, fluorine geochemistry and lead-isotope constraints on granite petrogenesis in the Seridó Belt, Borborema Province, northeastern Brazil

Ricardo Sallet [a,*], Jonathan D. Price [b], Marly Babinski [c], Robert Moritz [d], Zorano S. Souza [a], Massimo Chiaradia [d]

[a] Departamento de Geologia, Universidade Federal do Rio Grande do Norte, Campus Universitário, CP 1639, Natal, RN 59078-970, Brazil
[b] Kimbell School of Geosciences, Midwestern State University, 3410 Taft Blvd., Wichita Falls, TX 76308, USA
[c] Instituto de Geociências, Universidade de São Paulo, Rua do Lago, 562, São Paulo, SP 05508-080, Brazil
[d] Earth and Environmental Sciences, University of Geneva, 13 Rue des Maraîchers, Ch-1205 Geneva, Switzerland

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ABSTRACT

The Neoproterozoic Seridó Belt of northeastern Brazil is characterized by low-pressure, high-temperature metamorphism, large transcurrent shear zones and voluminous plutonic activity. The belt consists of a thick sequence of Neoproterozoic metasedimentary rocks overlying Paleoproterozoic metaigneous basement rocks. Both units were intruded by plutonic rocks related to two main magmatic episodes: large Neoproterozoic high-K calc-alkaline bimodal plutons and small intrusions of peraluminous pegmatitic granites and zoned pegmatites of Cambrian age. In this study, we partially melted samples of the potential protoliths (orthogneiss, paragneiss, mica schist and micaceous quartzite) as analogs for the sources of the magmas belonging to the felsic intrusions. Short-duration (24 h) experiments assessed the composition of disequilibrium melts in both H_2O-fluxed and fluid-absent conditions. Experiments with added water at 0.4 and 1.0 GPa and 725 °C produced strongly peraluminous and Ca-rich rhyolitic glass; these compositions are not observed in the natural rocks. In contrast, fluid-absent melting at 0.6 GPa and 930 °C produced mildly peraluminous rhyolitic glass with major-element compositions similar to those of the felsic intrusions in the Seridó Belt. The elevated F content of the glasses approximates that of the Neoproterozoic granites but is higher than that of the Cambrian pegmatitic granites. Mass balance calculations modeled the fractionation from initially enriched melts into exsolving fluids during the late-stage crystallization of the pegmatitic granites. The Pb-isotope compositions of the Seridó Belt felsic rocks show substantial variation from non-radiogenic mantle-like to high-radiogenic signatures. The basement gneisses and the metasedimentary belt rocks can be considered as the principal lead sources for several pegmatitic granite intrusions and zoned pegmatites. However, the high-radiogenic Neoproterozoic Acari granite and Cambrian pegmatitic granites are derived from an unknown lithologic unit and/or to the dissolution of zircon and monazite in high-temperature anatectic melts. These results place constraints on the crustal origin of most of the SiO_2-rich plutons in the region.

1. Introduction

Over the past 30 years, field, theoretical and experimental efforts have firmly linked the generation of felsic rocks to crustal anatexis (e.g., Fyfe, 1973; Thompson, 1982; Clemens and Vielzeuf, 1987; Walker et al., 1989; Harris and Inger, 1992; Nabelek et al., 1992; Shearer et al., 1992; Krogstad et al., 1993; Patiño Douce, 1995; Thompson and Connolly, 1995; Clemens and Droop, 1998; Pickering and Johnston, 1998; Sawyer, 1998; Harris et al., 2000; London, 2005; Castro, 2013). While the fluid-absent melting of micas and amphibole is considered by many petrologists to be the main process for generating H_2O-undersaturated felsic liquids (e.g., Clemens and Vielzeuf, 1987; Le Breton and Thompson, 1988; Vielzeuf and Holloway, 1988; Skjerlie and Johnston, 1993, 1996; Patiño Douce, 1995; Patiño Douce and Beard, 1995; Montel and Vielzeuf, 1997; Stevens et al., 1997; Castro et al., 2000; Nair and Chacko, 2002), numerous geochemical and phase stability assessments suggest that melting may also involve H_2O-fluxed reactions (Wickham, 1987; McLellan, 1988; Yardley and Barber, 1991; Mogk, 1992; Jung et al., 2000; Barnes et al., 2002; Slagstadt et al., 2005; Acosta-Vigil et al., 2006; Ward et al., 2008; Genier et al., 2008; Berger et al., 2008; Sawyer, 2010; Weinberg and Hasalová, 2014).

* Corresponding author.
E-mail address: ricardosallet@gmail.com (R. Sallet).

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The Seridó Belt of northeastern Brazil hosts several intrusions with distinct chemical affinities: Neoproterozoic high-K calc-alkaline granitoids and Cambrian peraluminous pegmatitic granites and zoned pegmatites (e.g., Ferreira et al, 1998; Nascimento et al., 2000; Neves et al., 2000; Hollanda et al., 2003, 2010; Guimarães et al., 2004; Baumgartner et al., 2006). The emplacement of these rocks is strongly controlled by transcurrent shear zones that cross the Neoproterozoic metasedimentary sequences and their Paleoproterozoic orthogneiss basement at the Seridó Belt (e.g., Archanjo and Bouchez, 1991; Corsini et al., 1991; Archanjo et al., 1992, 2013; Vauchez et al.;, 1995). The very extensive plutonism suggests that there was a strong and areally significant heat source in the lower crust that could promote conditions appropriate for either fluid-fluxed or fluid-absent partial melting of the metasedimentary belt and basement orthogneiss (e.g., Barboza and Bergantz, 2000; Droop et al., 2003).

This paper combines experimental anatexis, Pb-isotopes and F geochemistry to examine the petrogenesis of granites. We considered that various lithologies in the Seridó Belt may be protoliths to the felsic intrusions and compared the chemical compositions of experimental glass to those of the individual felsic intrusions. Despite the wide acceptance of fluid-present anatexis (Weinberg and Hasalová, 2014), the bulk of experimental investigations have evaluated the glass chemistry of fluid-absent partial melting. We therefore investigated water-saturated conditions in a series of short-duration experiments (24 h) using potential Seridó Belt protoliths. The short duration of our runs attempts to address disequilibrium melting which is appropriate for melts generated in the crust for which there was insufficient time to chemically or isotopically equilibrate with their sources (e.g., Johannes, 1978, 1980; Sawyer, 1991; Clemens and Mawer, 1992; Barbero and Villaseca, 1995; Harris et al., 1995; Davies and Tommasini, 2000; Petford et al., 2000; Brown, 2001; Zeng et al., 2005).

As a complementary petrogenetic constraint, we analyzed the F concentrations in the natural rocks and in the experimental glasses. Previous studies have demonstrated that F geochemistry can shed light on igneous, metamorphic and hydrothermal processes (e.g., Bailey, 1977; Munoz, 1984; Webster, 1990; Charoy and Raimbault, 1994; Finch et al., 1995; Icenhower and London, 1997; Price et al., 1999; Sallet, 2000; Dolejs and Baker, 2004). Along with experimental anatexis and F geochemistry, we further investigated potential melt–source relationships using Pb-isotope data. Such data may further resolve the petrogenetic links between anatectic melts and their protoliths (Vidal et al., 1982; Ayuso, 1986; Hogan and Sinha, 1991; Housh and Bowring, 1991; Krogstad et al., 1993; Sinha et al., 1996).

2. Geologic setting

The Seridó Belt is a Pan-African/Brasiliano tectonic unit of the Borborema Province that is characterized by a thick Neoproterozoic metasedimentary sequence overlying a Paleoproterozoic basement and by widespread Neoproterozoic and Cambrian plutonism (Fig. 1) (Ebert and Claro, 1970; Jardim de Sá, 1994; Vauchez et al., 1995; Corsini et al., 1998; Dhuime et al., 2003; Baumgartner et al., 2006; Archanjo et al., 2013). The belt occurs to the north of the Patos shear zone and has been recognized as a transpressional tectonic structure controlled by shear zones striking northeast–southwest with east–west flexure toward the south (Archanjo and Bouchez, 1991; Corsini et al., 1991, 1998; Caby et al., 1995; Archanjo et al., 2013). Thermobarometry of the metasedimentary rocks has revealed low-pressure and high-temperature conditions with an outer staurolite–andalusite zone, where $T = 550$ °C and $P = 0.20$–0.25 GPa, and an inner sillimanite zone, where $T = 650$ °C and $P = 0.4$ GPa (Lima, 1992; Cunha de Souza, 1996; Corsini et al., 1998).

The metasedimentary sequence includes three main stratigraphic units (Jardim de Sá and Salim, 1980; Jardim de Sá, 1984; Archanjo and Salim, 1986). The Jucurutu Formation consists of biotite- and hornblende-bearing epidote paragneiss with marble and calc-silicate intercalations. Muscovite-bearing quartzite dominates the Equador Formation, which also includes subordinate polymictic metaconglomerate along with schist, marble and calc-silicate lithologies. The Seridó Formation consists predominantly of biotite schist with subordinate marble and calc-silicate lenses; the biotite schist contains garnet, cordierite, sillimanite, andalusite, staurolite and muscovite. The youngest possible depositional age range of the protoliths of the metasedimentary rocks is 640–630 Ma based on the U–Pb dating of detrital and metamorphic zircons (Van Schmus et al., 2003; Kalsbeek et al., 2013).

The Paleoproterozoic basement of the Seridó Belt is composed of the Caicó Complex orthogneiss and migmatite formed during the Transamazonian/Eburnean orogeny (2.24–2.15 Ga) (Souza et al., 1993, 2007; Hollanda et al., 2011). The orthogneiss has dioritic to granitic composition with a high-K calc-alkaline affinity. Additionally, the basement contains several younger augen gneiss bodies with zircon U–Pb ages of 2.0–1.75 Ga (Jardim de Sá et al., 1988; Legrand et al., 1991; Hollanda et al., 2011). The eastern side of the Seridó Belt consists of the São José do Campestre cratonic fragment (3.4–2.7 Ga). It is composed of quartz dioritic to granodioritic, tonalitic, and granitic orthogneisses with minor exposures of garnet–cordierite–sillimanite-bearing paragneiss, marble, and banded iron formations (Dantas et al., 2004, 2013; Souza et al., 2006).

The Seridó Belt hosts numerous intrusive bodies (Fig. 1). There are two main groups, which are temporally and compositionally distinct: the voluminous Neoproterozoic high-K calc-alkaline plutons and the volumetrically minor Cambrian peraluminous pegmatitic granites and zoned pegmatites. The high-K calc-alkaline plutons are formed by mafic to intermediate rocks coexisting with abundant felsic rocks. These rocks show remarkable mingling and mixing features that are characteristic of the Borborema Province magmatism (Ferreira et al., 1998; Archanjo et al., 1992; Galindo et al., 1993; Jardim de Sá, 1994; Jardim de Sá et al., 1999; Nascimento et al., 2000; Neves and Vauchez, 1995, 2000; Campos et al., 2002; Hollanda et al., 2003; Van Schmus et al., 2003). U–Pb zircon ages indicate a first intrusive episode at 590 Ma with the emplacement of the mafic to intermediate rocks of the Tororó pluton. The emplacement of the nearby Acari pluton occurred at 575 Ma during the main dextral transpressive deformation (Leterrier et al., 1994; Jardim de Sá et al., 1999; Archanjo et al., 2013). In the Santa Luzia migmatitic dome, south of the Acari pluton, zircon from granitic neosome within the Caicó Complex yielded similar U–Pb ages and fabric patterns (Archanjo et al., 2013).

The Cambrian pegmatitic granites occur generally as sills and dykes, and more rarely as plugs, with up to 1 km^2 of surface exposure. A few more voluminous plutons have 4 to 40 km^2 of surface exposure (Araújo et al., 2001; Beurlen et al., 2007). These rocks intruded mainly into mica schist and quartzite and rarely into paragneiss. A few are hosted in the basement orthogneiss. The available monazite U–Pb ages are 528 ± 12 Ma (Baumgartner et al., 2006) and 520 ± 10 Ma (Beurlen et al., 2007). These intrusions typically contain either a biotite + magnetite ± garnet assemblage (hereafter referred to as the Bt + Mag facies) or a muscovite + biotite + garnet assemblage (the Ms + Grt facies). These two assemblages are mutually exclusive in a single intrusion.

Swarms of dykes and sills of homogeneous and zoned pegmatites intruded into the central part of the Seridó belt (Johnston, 1945; Rolff, 1946; Agrawal, 1986; Beurlen, 1995; Araújo et al., 2001; Beurlen et al., 2001, 2007, 2008). They are mainly Be and Li–Be pegmatites with volumetrically minor evolved pods of Li–Cs–Be–Ta pegmatite (Baumgartner et al., 2006). The columbo-