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Sedimentary petrology and detrital zircon U–Pb and Lu–Hf constraints of Mesoproterozoic intracratonic sequences in the Espinhaço Supergroup: Implications for the Archean and Proterozoic evolution of the São Francisco Craton

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ABSTRACT

The Espinhaço Basin is one of the largest Precambrian intracratonic basins in the Brazilian Shield, and it comprises three tectonostratigraphic megasequences, i.e., the Lower, Middle, and Upper Espinhaço sequences, deposited from 1.8 to 1.68 Ga, 1.6 to 1.38 Ga, and 1.2 to 0.9 Ga, respectively. Each megasequence contain detrital materials derived from the denudation of basement and/or cover units and can be used to decipher the paleogeographic evolution of the São Francisco Craton, together with the vertical and lateral stratigraphic architecture. Sandstone compositions and detrital zircon U–Pb ages and Lu–Hf isotopes from the Middle and Upper Espinhaço sequences were investigated, in conjunction with stratigraphic data, to reveal distinct provenance patterns. Sandstones in the lower units of the Middle Espinhaço sequence were recycled from sedimentary sources and were found to contain Paleoproterozoic zircon grains, either juvenile or evolved from Mesoarchean or Neoarchean crustal sources. This pattern is succeeded by sandstones derived from recycled sedimentary sources that contain juvenile and remelted zircon grains formed in the Paleoarchean, Neoarchean, and Paleoproterozoic eras. The overlying units of the Middle and Upper Espinhaço sequences include significant inputs from Statherian and Calymmian zircon grains, in addition to the Archean and Paleoproterozoic grains. This points to both a stratigraphic inversion of the source area due to the denudation of Archean basement terrain in the lower sections and a change of provenance with the input of Statherian and Calymmian zircons in the upper sections. In addition, the ages and Hf isotopic compositions of zircon grains older than 1.8 Ga match the evolution of the continental crust within the São Francisco Craton. A possible chronocorrelation between the late Paleoproterozoic to Mesoproterozoic cratonic sequences in the Congo–São Francisco Craton and those sequences preserved within the Fennoscandian and Indian shields as well as in the North American, West Australian, and North China Cratons implies similar evolutions for these regions after ca. 1.8 Ga. Such a similarity is probably related to the evolution of the Columbia supercontinent and its transition to the Rodinia supercontinent.

1. Introduction

Cratonic basins are large elliptical continental areas located away from tectonic plate boundaries and subjected to prolonged subsidence associated with very low-rates of continental stretching (Armitage and Allen, 2010; Allen and Allen, 2013). The initial forming mechanism of cratonic basins is commonly replaced by others during the lifetime of these long-lived basins, which leads to long periods of subsidence punctuated by episodes of uplift (e.g., DeRito et al., 1983; Leighton, 1990; Allen and Armitage, 2012; Pinet et al., 2013). The subsidence/uplift pattern of cratonic basins results in the preservation of continental to shallow-water marine deposits through several sequences delimited by regional unconformities (Sloss, 1963; Einsele, 2000; Lindsay, 2002; Roberts and Bally, 2012).

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The stratigraphic record of these basins reveals the evolution of the sedimentary environments through time, and the terrigenous grains provide important clues about the composition, age, and tectonic setting of the source areas, in addition to information about the paleoclimatic conditions and sedimentary transport processes (e.g., Dickinson et al., 1983; Ross et al., 1992; McLennan et al., 1993; Cawood et al., 2003; Najman, 2006; Garzanti et al., 2009; von Eynatten and Dunkl, 2012). Cratonic basins were often considered to be formed after a supercontinent assembly and controlled by subsequent tectonic evolution, as in the case of the Paraná, Karoo, Central European, West Siberian, Central Australian, and Hudson basins (Lindsay, 2002; Vyssotski et al., 2006; Maystrenko et al., 2008; Milani and De Wit, 2008; Pinet et al., 2013). Indeed, the study of cratonic basins can provide unique paleogeographic information on past continents and the evolution of supercontinents (Leighton, 1996; Lindsay, 2002; Sears et al., 2004).

During the time period between ca. 2.2 and 1.8 Ga, a series of orogenies supposedly assembled most of the Archean terrains to form a single continental mass. These orogenies serve as a geological evidence for the existence of Columbia supercontinent (e.g., Rogers and Santosh, 2002; Zhao et al., 2002a; Leite et al., 2009; Meert, 2012; Zhang et al., 2012; Ma et al., 2013; Wu et al., 2014). The Archean terrains that comprise the basement of the present-day São Francisco and Congo cratons were agglutinated during this time period by the Transamazonian/Eburnean orogenies (Barbosa and Sabaté, 2002, 2004; Zhao et al., 2002b). However, the participation of the Congo–São Francisco paleoplate in the Columbia supercontinent is not completely understood primarily because of the lack of reliable age constraints and paleomagnetic poles (Zhao et al., 2002b; Pisarevsky et al., 2014). Through the identification of large igneous provinces, mainly occurring as regional-scale radiating dyke swarms, Ernst et al. (2013) proposed a connection between the Congo–São Francisco Craton and the Siberia Craton during the Mesoproterozoic Era. Pisarevsky et al. (2014) tested this hypothesis with reliable paleomagnetic data and concluded that this connection is possible but not completely provable with the available data.

The Congo–São Francisco paleoplate evolved between 1.8 and 0.9 Ga through the development of a series of long-lived cratonic basins that recorded unconformity bounded sequences. The Espinhaço Supergroup (ES) corresponds to one of these Paleoproterozoic to Mesoproterozoic cratonic basins (Pedreira and De Waele, 2008; Alkmim and Martins-Neto, 2012; Chemale et al., 2012; Fernandez-Alonso et al., 2012; Ribeiro et al., 2013; Santos et al., 2013; Guadagnin et al., 2015). These sequences recorded the landscape evolution in the interior of the Congo–São Francisco paleoplate from the amalgamation in the Paleoproterozoic Era to its partial break-up in the early Neoproterozoic Era. The study of the ES sequences can potentially aid paleogeographic reconstructions of the Columbia supercontinent (Danderfer et al., 2014).

This paper presents the findings of a provenance analysis conducted on sandstones from the ES by identifying the location, composition, and tectonic setting of the source areas, which helps in improving the available paleogeographic models. The studied interval crops out in the Chapada Diamantina basin, where it corresponds to the least-deformed and well-exposed sectors of the ES in the São Francisco craton. Based on a sequence stratigraphic framework, the sandstone samples were collected in specific stratigraphic intervals deposited from ca. 1.6 to 0.9 Ga during the Mesoproterozoic to early Neoproterozoic Eras. Stratigraphic information, combined with U–Pb geochronology and Lu–Hf isotope geochemistry in detrital zircon grains, and petrography and whole-rock geochemistry, allowed identifying the main source areas, age, and tectonic setting of the source rocks, as well as the evolution of the source areas through time. Moreover, the implications of the provenance analysis for the Congo–São Francisco paleoplate paleogeographic evolution during the Mesoproterozoic Era are discussed.

2. Geologic setting

The São Francisco Craton is formed through accretion of Archean–Paleoproterozoic igneous and metamorphic rocks, comprising the craton basement and the Paleoproterozoic–Phanerozoic sedimentary cover (e.g., Almeida, 1977; Barbosa et al., 2004; Cruz and Alkmim, 2006; Alkmim and Martins-Neto, 2012). The craton regional configuration is marked by a western and an eastern domain separated by the central Paramirim Aulacogen (Fig. 1a and b; Alkmim and Martins-Neto, 2012 and references therein). Each of these three features is composed of basement rocks and cover sequences (Fig. 1b). In the study area, the ES is exposed in the Paramirim Aulacogen, which corresponds to a NS trending structure developed after 1.75 Ga (Cruz and Alkmim, 2006; Alkmim and Martins-Neto, 2012).

The basement of the São Francisco Craton in the eastern domain presents several NS striking shear zones separating the four major geologic and isotopic distinct terrains: the Gavião, Serrinha, and Jequié blocks, and the Itabuna–Salvador–Curaçá Belt (Figs. 1c and S1). These blocks generally include Archean tonalite–trondhjemite–granodiorite suites (TTG) and Archean–Paleoproterozoic greenstone belt terrains that were partially reworked during the Neoarchean (Jequié Cycle) and Paleoproterozoic Eras (Transamazonian/Eburnean Cycle; Barbosa and Sabaté, 2004; Barbosa et al., 2004; Cruz et al., 2012).

The Gavião Block is the oldest tectonic unit and occurs in three domains of the São Francisco Craton. In the Paramirim Aulacogen, the Gavião Block formed the substratum for the ES deposition (Fig. 1c). The Gavião Block was formed in the Paleoarchean Era by the emplacement of juvenile TTG gneisses and the formation of greenstone belt associations (Marinho, 1991; Peucat et al., 2002; Barbosa and Sabaté, 2004; Barbosa et al., 2004). The TTGs yielded crystallization ages (U–Pb) between 3.38 and 3.2 Ga and Nd model ages (TDM) between 3.6 and 3.3 Ga (Nutman and Cordani, 1993; Santos-Pinto, 1996; Bastos Leal et al., 1998; Santos-Pinto et al., 2012; Table S1). In the Neoarchean Era, from 2.74 to 2.68 Ga, during the Jequié Cycle, the Gavião Block was metamorphosed and partially recycled in migmatites and intruded by alkaline magmas, which were produced from the partial melting of the Paleoarchean crust (Cruz et al., 2012; Santos-Pinto et al., 2012). In addition, the formation of the Umburanas greenstone belt occurred during the Neoarchean Era (ca. 2.74 Ga; Bastos Leal et al., 2003). The final developmental stages of the Gavião Block were marked by intrusions of pre- and syntectonic granites, such as the Guanambi Batholith (Rosa et al., 2000), and crustal reworking during the Paleoproterozoic Era (Transamazonian/Eburnean Cycle; Santos-Pinto, 1996; Peucat et al., 2011; Santos-Pinto et al., 2012).

The Jequié Block is separated from the Gavião Block by a narrow fault zone (Fig. 1c). The Jequié Block corresponds to a granulite terrain composed of enderbite to charnockite suites, heterogeneous granulites with migmatites, and inclusions of supracrustal rocks. The granite suites crystallized between 2.8 and 2.45 Ga (U–Pb age) with Nd TDM between 3.1 and 3.0 Ga. The granulite facies metamorphism in the Jequié Block occurred at ca. 2.0 Ga (Barbosa and Sabaté, 2004; Barbosa et al., 2004).

The Serrinha Block occurs at the NE portion of the craton and consists of basement complexes and supracrustal sequences intruded by Paleoproterozoic granitoids (Oliveira et al., 2013; Fig. 1c). The basement encompasses Mesoarchean (3.15–2.9 Ga) and Neoarchean migmatites (2.7–2.6 Ga), banded gneisses, orthogneisses, mafic dykes, and mafic-ultramafic complexes (Oliveira et al., 2013).