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Reassessment of Aguapeí (Salto do Céu) paleomagnetic pole, Amazonian Craton and implications for Proterozoic supercontinents

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ABSTRACT

The Aguapeí paleomagnetic pole obtained for mafic sills and dykes from Salto do Céu region at the western margin of the Amazonian Craton constrains its links with Baltica and Laurentia in Rodinian reconstructions. A new U–Pb age on baddeleyite at 1439 ± 4 Ma for the intrusives, contrasts strongly with a previous Ar–Ar age at 981 ± 2 Ma, with important consequences for paleogeographic reconstructions. We report new paleomagnetic and magnetic anisotropy results for sills from the Salto do Céu region and reassess the paleomagnetic data in view of the new geochronological age. A total of 155 samples were collected from thirteen new paleomagnetic sampling sites, five of them corresponding to sedimentary rocks located at the borders of the sills in an attempt to perform baked contact tests. After thermal and alternating field demagnetization, the sills provided a characteristic magnetic component at $D_m = 208.2°$, $I_m = 68.5°$ ($N = 8$, $\alpha_{95} = 6.4°$), with a corresponding paleomagnetic pole at 46.4°S; 277.0°E ($A_{95} = 10.2°$). Directions obtained in this study are similar to those reported previously for other mafic sills and dykes in the same region. A pole integrating the new results for the sills with those of the previous Aguapeí pole is situated at 56.0°S; 278.5°E ($A_{95} = 7.9°$). This new combined Salto do Céu pole supersedes the previous Aguapeí pole. Magnetic mineralogy studies, optical and electronic microscopy indicates PSD magnetite as the main magnetic carrier in these rocks. The baked contact tests were inconclusive, but the similarity between Salto do Céu pole and other high-quality poles with ages around 1420–1430 Ma suggests they carry a primary thermoremanence of that age. The Salto do Céu and other coeval poles are compatible with a connection between Amazonia and Baltica at the Mesoproterozoic in a paleogeographic configuration slightly different from SAMBA (*S*outh *Am*erica-*Ba*ltica). At the same time, the new geochronological and paleomagnetic data imply that all paleogeographic interpretations for the position of Amazonia in Rodinia based on the previously published Aguapeí pole (and now renamed as Salto do Céu pole) must be revised.

1. Introduction

The supercontinent cycle seems to have operated since Archean times, with at least three supercontinents formed since then, at 1.85–1.60 Ga (Columbia or Nuna), at 1.0–0.9 Ga (Rodinia) and at 0.28 Ga (Pangea) (Meert, 2012). Earlier Neoarchean continental assemblies have also been proposed such as Vaalbara, Superia and Sclavia (see Bradley, 2011, and references therein), but cannot be considered as supercontinents due to their limited sizes (Bleeker, 2003; Meert, 2012). A Paleoproterozoic supercontinent existed at about 1.85 Ga ago (Rogers, 1996; Rogers and Santosh, 2002; Meert, 2002; Meert and Torsvik, 2003; Cordani et al., 2003, 2009; Pesonen et al., 2003; Zhao et al., 2003, 2004; Evans, 2009; Johansson, 2009, 2014; Evans and Mitchell, 2011; Meert, 2012), although recent ideas are that it was not fully formed until 1.6 Ga ago (Evans, 2013; Pisarevsky et al., 2014; Pehrsson et al., 2015). Its rupture preceded the assembly of Rodinia at ca. 1.0–0.9 Ga (e.g., Weil et al., 1998; D'Agrella-Filho et al., 1998; Dalziel, 1997; Li et al., 2008). The name of the Paleoproterozoic supercontinent has been disputed, with some authors using Nuna and others Columbia (see discussion in

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Meert, 2012; Evans, 2013). Here we adopt Nuna. Another fundamental question concerns the timing and mode of Nuna break-up and later Rodinia amalgamation (see Evans, 2013).

The Amazonian Craton is one of the greatest Precambrian cratons in the world and a key piece of Earth's paleogeography. Recently, some Proterozoic paleomagnetic poles were reported for the Amazonian Craton with important implications to Nuna (Bispo-Santos et al., 2008, 2012, 2014a; D'Agrella-Filho et al., 2012; Reis et al., 2013) and Rodinia (Tohver et al., 2002; D'Agrella-Filho et al., 2008; Elming et al., 2009a). The 1780 Ma Avanavero paleomagnetic pole from northern Guiana Shield (Amazonian Craton) published recently by Bispo-Santos et al. (2014a) supports a SAMBA-like connection (Johansson, 2009) where the southern boundary of Baltica faces the northwestern boundary of the Amazonia (see Pisarevsky et al., 2014 for alternative models). According to Bispo-Santos et al. (2014a) and also Evans (2013) and Evans and Mitchell (2011), Laurentia, Baltica, proto-Amazonian Craton and West Africa formed the nucleous of Nuna. The duration of this nucleous is still controversial. Some authors suggest it broke up soon after its amalgamation, at 1.78 Ga (e.g., D'Agrella-Filho et al., 2012), others suggest the break-up occurred later at about 1.5 Ga (e.g., Zhao et al., 2004; Rogers and Santosh, 2009), and others suggest that it was yet more long-lived (e.g., Vigneresse, 2005; Evans, 2013; Hou et al., 2008). Nuna has been characterized by a peculiar tectonic style, with decrease in subduction flux and subduction-related magmatism (Silver and Behn, 2008) and major emplacement of anorogenic rapakivi granites between 1.6 and 1.3 Ga (e.g. Hoffman, 1989; Anderson and Morrison, 1992; Åhäll and Connelly, 1998; Bettencourt et al., 1999; Karlstrom et al., 2001; Rämö et al., 2003; Vigneresse, 2005).

Concerning Rodinia, Tohver et al. (2002) proposed an oblique collision of the Amazonian Craton in the Texas area (the Grenvillian age Llano belt) of Laurentia at 1.2 Ga, based on the Nova Floresta pole from the Amazonian Craton. This idea was further reinforced by geological and isotopic data (Tohver et al., 2004a, 2004b, 2005a, 2005b, 2006), and new paleomagnetic data obtained for sedimentary rocks from the Fortuna Formation (the basal unit of the Aguapeí Group) dated at 1.15 Ga by U–Pb systematics on diagenetic xenotime overgrowths in zircon grains (D'Agrella-Filho et al., 2008), and for mafic sills and dykes dated at 0.98 Ga by ^{40}Ar–^{39}Ar on whole rock (Elming et al., 2009a). This model was also followed by Ibanez-Mejia et al. (2011) to explain the ca. 1.15 Ga Colombian-Oaxaquian fringing-arc accretion onto the northern margin of Amazonia and the final collision between Amazonia and Baltica at ca. 1.00–0.98 Ga along the Sveconorwegian orogen. Alternatively, using the opposite polarity of Amazonian poles and considering a long-lived Nuna, Evans (2013) suggested the Amazonia and Baltica performed clockwise rotations before their final collisions along the Grenvillian/Svecovergian/Sunsás orogens at about 1.0 Ga (model B in his Fig. 3) (see also Johansson, 2014).

An important piece of evidence for the first model is the paleomagnetic pole obtained by Elming et al. (2009a) for mafic sills and dykes that cut sedimentary rocks around Rio Branco town (Mato Grosso state), which are traditionally included in the intermediate unit (Vale da Promissão Formation) of the Aguapeí Group (Saes and Fragoso-Cesar, 1994). These sills and dykes belong to the Salto do Céu Intrusive Suíte (Araújo-Ruiz et al., 2005, 2007), but Elming et al. (2009a) called them Aguapeí (hereafter we will use the original Salto do Céu name). Paleomagnetic analysis revealed southwest (northeast) directions with moderate to steep downward (upward) inclinations for samples from ten sites. A mean direction $D_m = 11.3°$; $I_m = -57.9°$ ($\alpha_{95} = 8.1°$; $K = 37$) was calculated which yielded a paleomagnetic pole at 64.3°S; 271.0°E ($A_{95} = 9.2°$) (Elming et al., 2009a). The limited number of sites and the absence of a baked contact test for the Salto do Céu intrusives motivated a resampling of this area. Meanwhile, a new U–Pb age on baddeleyite of 1439 ± 4 Ma was obtained (Teixeira et al., 2015) that contradicts the previous Ar–Ar age on whole rock of 981 ± 2 Ma (Elming et al., 2009a). In this work, paleomagnetic analyses were performed for other mafic sills in the same region in order to improve statistics of the previously published paleomagnetic pole. At five outcrops, good exposures of sills in contact with host sedimentary rock allowed sampling for baked contact tests. We integrate these new results into a more robust paleomagnetic pole and discuss the tectonic implications to Nuna in view of the new U–Pb in baddeleyite age.

2. Geological setting

The Amazonian Craton is exposed in the Guiana and Brazil-Central (or Guaporé) shields, which are bisected by sedimentary rocks of the Amazon basin (Fig. 1a). According to Cordani and Teixeira (2007) its Precambrian evolution is marked by Archean primitive nuclei whose collision originated the Maroni-Itacaiunas Province (2.25–2.05 Ga), followed by successively younger accretionary magmatic events with minor or major juvenile crust involvement along its southwestern border. These accretionary events were divided in geochronological provinces: Ventuari-Tapajós Province (1.98–1.81 Ga), Rio Negro-Juruena Province (1.78–1.60 Ga), Rondonian-San Ignacio Province (1.60–1.30 Ga) and Sunsás-Aguapeí Province (1.20–0.95 Ga). The latter forms the southwestern tip of the Amazonian Craton (Fig. 1a).

The Aguapeí Group, whose type area is situated at the Brazil/Bolivia border near Vila Bela (Fig. 1b), represents a basin predominantly composed of clastic sediments typical of a continental shelf, showing transgressive–regressive phases related to a marine environment (Menezes et al., 1991; Saes et al., 1992). Saes and Fragoso-Cesar (1994) subdivided this unit from base to top into three formations: Fortuna, Vale da Promissão and Morro Cristalino. According to these authors the depositional history of the Aguapeí Group can be described by three stages: rift stage, marine stage with subsidence, and inversion stage with reworking. The Aguapeí Group is correlated with the Huanchaca Group that is exposed in the southern extremity of the Paraguá Terrain in Bolivia (Saes and Fragoso-Cesar, 1994, Fig. 1b). U–Pb datings of zircon grains from Fortuna Formation at São Vicente gold mine (Mato Grosso state) yielded a youngest age of 1165 ± 27 Ma for one of the grains which sets the maximum deposition age of this formation (Santos et al., 2001). U–Pb SHRIMP analysis on authigenic xenotime rims on detrital zircons yielded an age of 1149 ± 7 Ma for the diagenisis of red beds from the Fortuna Formation (D'Agrella-Filho et al., 2008). These data constrain the age of the basal formation of the Aguapeí Group to between 1165 ± 27 Ma and 1149 ± 7 Ma.

The Salto do Céu Intrusive Suite is represented by a set of mafic sills and dykes exposed in the Rio Branco, Salto do Céu and Vila Progresso regions (Araújo-Ruiz et al., 2005, 2007). These diabase rocks intrude undeformed siliciclastic sedimentary rocks (Fig. 1b). These rocks have been correlated to the Vale da Promissão Formation of the Aguapeí Group, mostly on the basis of K–Ar ages for the sills and dykes (on plagioclase and whole rock) that vary between 1015 ± 17 and 875 ± 21 Ma (Barros et al., 1982; Ruiz, 1992, 2005). ^{40}Ar–^{39}Ar dating on whole rock yielded a plateau age at 981 ± 2 Ma for the same rocks (Elming et al., 2009a). Recently, however, baddeleyites separated from a sill at Salto do Céu region yielded a U–Pb concordia age of 1439 ± 4 Ma, which is interpreted as the crystallization age of the sill (Teixeira et al., 2015). This age implies that the sedimentary rocks intruded by the sills and dykes are older than 1440 Ma and did not belong to the intermediate unit of the Aguapeí Group, as previously believed. U–Pb determinations on 100 detrital zircons separated from one sample from sediments in the same Salto do Céu region yielded age populations ranging from 2515 Ma to 1544 Ma which set a maximum age for the sedimentation at 1544 Ma (Geraldes et al., 2014). Another evidence for an older age for these sedimentary rocks is the occurrence of them as