A NEW 1.42 GA PALEOMAGNETIC POLE FROM THE AMAZONIAN CRATON: IMPLICATIONS FOR THE COLUMBIA SUPERCONTINENT CONFIGURATION.

Invited

Manoel S. D'Agrella-Filho[1*], Ricardo I.F. Trindade[1], Sten-Åke Elming[2], Eder Yokoyama[1] Franklin Bispo-Santos[1]

[1]Universidade de São Paulo, IAG, São Paulo, Brazil

[2] Luleå University of Technology, 95187 Luleå, Sweden

Abstract

Paleomagnetic studies carried out on the 1.42 Ga Indiavaí mafic intrusive rocks, that crop out in the SW Mato Grosso State provides a great opportunity to test the proposed paleogeographic models for Columbia. Paleomagnetic AF and thermal treatment revealed south/southwest magnetic directions with downward inclinations for sixteen analyzed sites. These directions are probably carried by SD/PSD magnetite with high coercivities and high unblocking temperatures as indicated by additional magnetic tests, including thermomagnetic curves, hysteresis loops and the IRM acquisition curves. A different magnetization obtained for host mafic rocks from the basement ca. 10 km NW away from the Indiavaí intrusive, further attests to the primary origin of the characteristic magnetic component. A mean site direction was calculated at Dm=209.8°, Im=50.7° (α_{95}=8.0°, K=22.1), which yielded a paleomagnetic pole located at 249.7°E, -57.0°N (A_{95}=8.6°). Comparison of this pole with other paleomagnetic poles of similar age from Baltica and Laurentia provides evidence for a link of north-northeastern Amazonian craton, southwestern Baltica and Laurentia, as previously suggested from the similar Mesoproterozoic geological evolution of their margins.

Introduction

The existence of a Paleo- to Mesoproterozoic supercontinent (Columbia) is well-accepted in the literature, although its configuration is intensively debated, partly due to the scarcity of paleomagnetic data (e.g., Pesonen et al., 2003). Similarities in the Mesoproterozoic geological evolution of Laurentia, Baltica and Amazonian Craton led several authors to propose a possible link of these cratonic blocks (e.g. Johansson, 2009). In this model, continuous subduction-related Mesoproterozoic mobile belts evolved across the border of this large continental mass. However, this configuration did not pass the paleomagnetic test at Paleoproterozoic times (Pesonen et al., 2003, Bispo-Santos et al., 2008). Instead, a well-dated 1.78 Ga paleomagnetic pole from the Amazonian Craton suggested a latitudinal gap between this craton and the Laurentia-Baltica block, which would be filled by another large landmass, the North China craton (Bispo-Santos et al., 2008).

Recently, Bispo-Santos et al. (2011) reported new paleomagnetic and geochronological results for the 1418.5 ± 3.5 Ma Nova Guarita dyke swarm from northern Mato Grosso State (southwestern Amazonian craton). These new data provided a test for the longevity of the previously proposed Columbia pelogeography. The mismatch between Laurentia-Baltica and Amazonian poles led the authors to conclude for a break-up of Columbia before 1.42 Ga. In the present study, we report paleomagnetic data collected in southern Mato Grosso State, ca. 600 km away from the Nova Guarita region, in the coeval Indiavaí mafic intrusive, which was recently dated at 1415.9±6.9 Ma (Teixeira et al., 2011). Here, we use the new paleomagnetic data to test different paleogeographic configurations of Columbia for

Mesoproterozoic (and also Paleoproterozoic) times, and speculate on their viability given the present paleomagnetic and geological evidence.

Geological setting

The focus of this work is an area situated to the SW of the Mato Grosso State, within the Jauru terrane (1.78-1.42 Ga). The Figueira Branca Intrusive Suite (FBIS) consists of differentiated mafic-ultramafic lithotypes comprising dunites, anortosites, troctolites, norites, and gabbros. The FBIS is formed by several bodies intruded into the Paleoproterozoic granite-gneisses terranes and in the metavolcano-sedimentary rocks of the Alto Jauru Group (1.76-1.72 Ga) (Bettencourt et al., 2010). One of them, the Indiavaí intrusive is exposed to the north of the Indiavaí City. Recently, Teixeira et al. (2011) reported ^{40}Ar^{39}Ar and U-Pb (SHRIMP) geochronological data for these rocks. An U-Pb (SHRIMP) zircon age of 1415.9±6.9 Ma from the Indiavaí intrusive was interpreted as crystallization age. But ^{40}Ar-^{39}Ar dating on biotites of gabbros from the Indiavaí body yielded much younger ages of 1275±4 Ma, 1.268±4 Ma and 1.222±3 Ma (Teixeira et al., 2011) suggesting either these rocks were affected by a younger tectonothermal event or they reflect very slow regional uplift and cooling.

Methodology

Six to nine oriented drill cores were taken from 16 sites from gabbros of the Indiavaí Intrusive located to the north of the Indiavaí city. In addition, 70 oriented drill cores (13 sites) were taken from the basement rocks, here represented by metabasic rocks from the Jauru Group. These outcrops are located to the west of the Jauru River, northwest of the Indiavaí sites (~10 km distant). In laboratory, cylindrical specimens (2.2 x 2.5 cm) were cut from each sample. Specimens were submitted to stepwise thermal and alternating field (AF) demagnetization in the paleomagnetic laboratories of the University of São Paulo (USP), Brazil, and the Luleå University of Technology, Sweden. In both laboratories, magnetic remanence was measured using a 2G cryogenic magnetometer after step-wise treatment by alternating fields (AF) or thermal demagnetization. AF demagnetization was carried out using an automated three-axis AF-demagnetizer (upper limit of 170 mT) and thermal demagnetization was carried out in a Magnetic Measurements (MMTD60) or a Schonsted oven. For samples with very high NRM intensities a Molspin Spinner magnetometer was used to measure remanent magnetization. Such samples were demagnetized using a Molspin AF-demagnetizer. Magnetic components for each specimen were identified in orthogonal plots, and calculated using least-squares fits. Fisherian statistics was used to calculate vector mean directions and paleomagnetic poles. Additional magnetic measurements were performed in a Moslpin vibrating sample magnetometer for hysteresis curves, and a Magnetic Measurements pulse magnetizer was used for isothermal remanent magnetization (IRM) acquisition curves. Low and high-temperature thermomagnetic curves were obtained for several samples using a CS-4 apparatus coupled to the KLY-4S Kappabridge instrument (Agico, Czech Republic).

Results and Analysis

Indiavaí gabbros

Thermal demagnetization revealed a discrete range of unblocking temperatures (Tub) for most of the sites, where more than 70% of the NRM was erased in temperatures within ~50-70°C below the Curie temperature. Both reversible and irreversible thermomagnetic curves were found, most of them with a characteristic Verwey transition at low temperatures and a pronounced Hopkinson peak at high temperatures, just below a strong drop in susceptibility at around 580°C, suggesting SD/PSD magnetite as the main magnetic carrier in the rocks (Fig. 1a). Isothermal remanent magnetization (IRM) acquisition curves (Fig. 1b) show saturation fields less than 300 mT, which are also typical of magnetite. Hysteresis loops performed for selected samples yielded coercivities (H_c) varying from 5.2 to 11.5 mT, which are typical of magnetite. Figure 1e shows the Day's diagram, which plots the M_{rs}/M_s and H_{cr}/H_c ratios. The boundaries between the SD, PSD and MD fields and the SD-MD and SD-SP mixing lines are those proposed by Dunlop (2002). Most gabbro samples fall along a trend parallel to the theoretical SD-MD magnetite mixing curves with only one sample plotting in the MD field. Also, some samples fall in the SP-SD field close to or between the theoretical curves traced for different percentages of 10 nm and 15 nm SP grains, respectively.

The Indiavaí gabbros carry natural remanent magnetization (NRM) intensities varying from 1 A/m up to values as high as 340 A/m. The high intensities observed in some samples are probably related to lightning, although this effect did not prevent the effectiveness of alternation field (AF) demagnetization in isolating the characteristic remanent magnetization (ChRM) in some of the samples. AF and thermal demagnetization was efficient in isolating southwestern directions with moderate to high positive inclinations. This component is carried by high coercivity, SD/PSD-magnetite grains. Site mean directions are shown in Fig. 2a. A mean ChRM direction was calculated at $D_m = 209.8°$; $I_m = 50.7°$ ($N = 16$, $\alpha_{95} = 8.0°$, $K = 22$), which yielded a paleomagnetic pole (IG) at 249.7°E; 57.0°S ($A_{95} = 8.6°$, $K = 20$). The statistical parameters associated with the moderate dispersion of site mean directions suggest that secular variation has been averaged out.

Basement rocks

Thermal demagnetization revealed a discrete range of unblocking temperatures (Tub) for all analyzed samples, where more than 60% of the NRM was erased in temperatures within ~50-70°C below Curie temperatures typical of magnetite. Both reversible and irreversible thermomagnetic curves have been found, most of them with a pronounced Hopkinson peak, a characteristic Verwey transition, and Curie temperatures around 580°C, suggesting SD/PSD magnetite as the main magnetic carrier (Fig. 1c). Isothermal remanent magnetization (IRM) acquisition curves (Fig. 1d) show saturation fields less than 300 mT which are also typical of magnetite minerals. Hysteresis loops yielded coercivities (Hc) varying from 1.8 to 14.7 mT, which are typical of magnetite. In the Day's diagram (Fig. 1e) most samples fall along a trend parallel to the theoretical SD-MD magnetite mixing curves (Dunlop, 2002) with two samples plotting in the MD field. Some samples plot close to the SP (10 nm)-SD mixing curve defined by Dunlop (2002).

The basement rocks present natural remanent magnetization (NRM) intensities varying from 4 A/m up to 57 A/m. Some sites (7) did not present within-site consistent results and were discarded. AF and thermal demagnetization was efficient to isolate either south-southwestern, upward inclination directions or northwestern, downward inclination directions after removal of low-coervivity secondary components. Site mean directions are shown in Fig. 2b. Consistent directions were isolated for samples from only six sites, and the downward directions are more scattered than the upward directions (Fig. 2b). Also, these directions do not form exactly antipodal groups of reversed and normal directions suggesting they recorded the geomagnetic field at quite different times. The downward directions seem to define two groups of directions, which are denoted as components A and B, and the upward directions are denoted as component C. Although the basement rocks yielded more complicated results than the Indiavaí intrusives, the A, B and C components are significantly different from both the present geomagnetic field and from the southwestern, downward directions found in the intrusives, located ca. 10 km from the sites of the basement rocks. This demonstrates that no regional event of remagnetization affected the studied area after Indiavaí rock intrusion.

Discussion and conclusions

‘Reversed’ south/southwestern stable directions were disclosed in samples from the Indiavaí Intrusive rocks. Some evidences suggest a primary origin for this component: (i) magnetic experiments indicate it is carried by SD/PSD magnetite grains with high-Hc and high-unblocking temperatures (> 500°C), denoting its high magnetic stability; (ii) petrographic analysis shows magmatic cubic euhedral magnetites as the main magnetic carrier - rims of biotite probably formed at the late stages of rock crystallization are the only observed alteration; (iii) country rocks at ca. 10 km to NW of the Indiavaí Intrusive show different magnetic components, which demonstrate that no later regional event of remagnetization occurred. Note that these directions are also much different from the present geomagnetic field. These facts implies that the Indiavaí component is most probably a thermo-remanent magnetization acquired during rock cooling at about 1415.9±6.9 Ma ago, as determined by the U-Pb SHRIMP analysis (Teixeira et al., 2011). Moreover, similar directions were obtained for mafic dykes at ca. 600 km NE of the Indiavaí region, whose age is well defined at 1418.5 ± 3.5 Ma by ^{40}Ar-^{39}Ar geochronology (Bispo-Santos et al., 2011). So, magnetic experiments, petrographic analysis, and the different component of the basement rock attest to the primary origin of the Indiavaí Intrusive rocks.

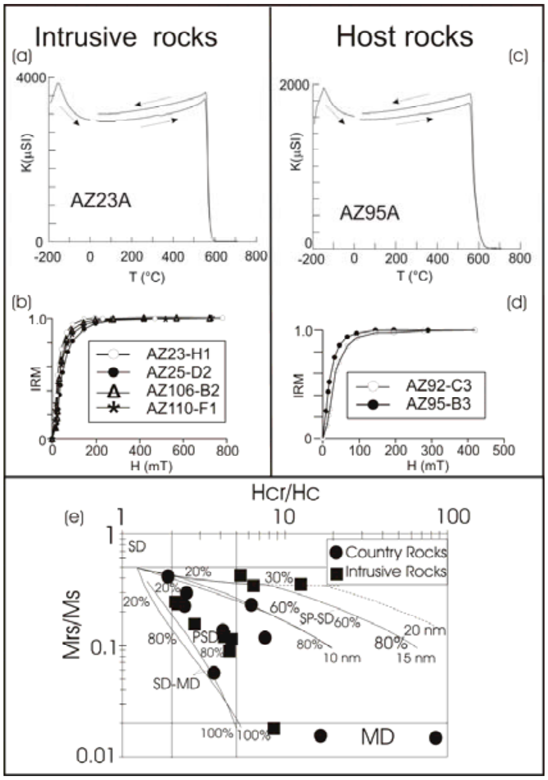

Figure 1. (a) and (c) Thermomagnetic curves (Susceptibility versus temperature) for samples from the Indiavaí and basement rocks, respectively; (b) and (d) IRM curves for samples from the Indiavaí and basement rocks, respectively; (e) Mrs/Mr versus Hcr/Hc ratios for samples from both Indiavaí and basement rocks. The limits between SD, PSD and MD fields are those proposed by Dunlop (2002). SD+MD and SP+SD (with SP grains sizes of 10, 15, and 20 nm) mixing curves are also shown.

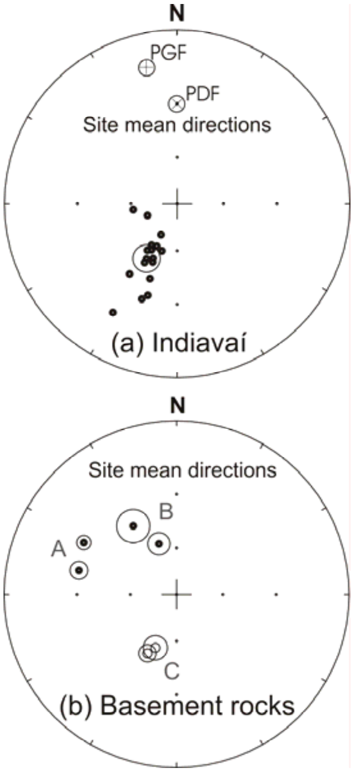

Figure 2. Site mean directions for the Indiavaí gabbros (a) and basement rocks (b). Full (empty) symbols represent downward (upward) inclinations. PDF – Present Dipolar Field; PGF – Present Geomagnetic Field. A, B, and C are basement components as defined in the text.

Figure 3 shows a possible reconstruction of Columbia. The Laurentia/Baltica connection is similar to that proposed by Salminen and Pesonen (2007), and the Baltica/Amazonia/West Africa link is similar to that proposed in the SAMBA model (Johansson, 2009). Selected paleomagnetic poles for the three cratonic blocks between 1.46 Ga and 1.41 Ga are also shown in Fig.3 after rotating them according to Columbia reconstruction. Confidence circles of the mean 1.46 Ga poles for Baltica (B-1460) and Laurentia (L-1460) overlap with each other providing paleomagnetic evidence they were linked together at that time, as already pointed out by Salminen and Pesonen (2007). Confidence circles for the 1416 Ma Indiavaí Intrusive pole (AC-1416) and the 1418 Ma Nova Guarita pole (AC-1418, Bispo-Santos et al., 2011) from the Amazonian Craton overlap with each other, and they are not far from the 1460 Ma mean poles representing Laurentia and Baltica. Taking into account the differences in age and associated uncertainties of all these poles, we can say they give some support for the configuration of Columbia presented in Fig. 3. This configurations is completely compatible with geological evidence for all the cratons.

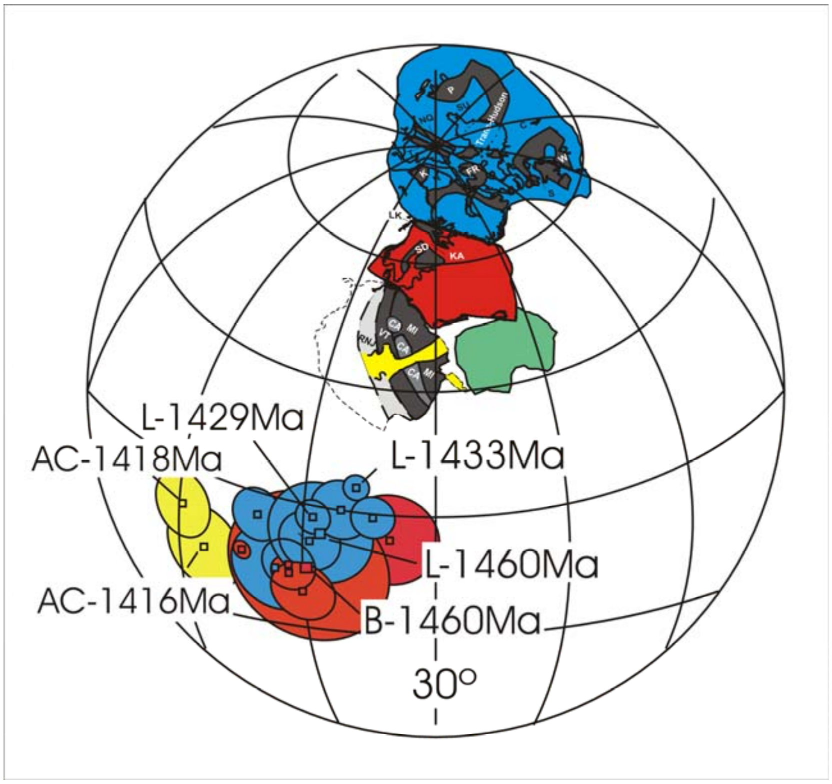

Figure 3. Columbia reconstruction at ~1.46 Ga, and selected paleomagnetic poles (Bispo-Santos et al., 2011) with their corresponding cone of confidence circles for Batica (blue), Laurentia (red), Amazonia (yellow), and West Africa (green) for the time interval 1.46 and 1.41 Ga. Baltica in its present position.

Acknowledgments

We thank FAPESP (grant 07/59531-4) for financial support. This research was performed as part of the INCT – GEOCIAM.

References

Bettencourt, J.S., Leite Jr., W.B., Ruiz, A.S., Matos, R., Payolla, B.L., Tosdal, R.M., 2010. The Rondonian-San Ignacio Province in the SW Amazonian Craton: Na overview. J. South Am. Earth Sci. 29, 28-46. Doi: 10.1016/j.jsames.2009.08.006

Bispo-Santos, F., D'Agrella-Filho, M.S., Pacca, I.I.G., Janikian, L., Trindade, R.I.F., Elming, S.-Ǻ., Silva, J.A., Barros, M.A.S., Pinho, F.E.C., 2008. Columbia revisited: Paleomagnetic results from the 1790 Ma Colíder volcanics (SW Amazonian Craton, Brazil). Prec. Res. 164, 40-49.

Bispo-Santos, F., D'Agrella-Filho, M.S., Trindade, R.I.F., Elming, S.- Å., Janikian, L., Vasconcelos, P.M., Perillo, B.M., Pacca, I.I.G., Silva, J.A., Barros, M.A.S., 2011. Tectonic implications of the 1419 Ma Nova Guarita mafic intrusives paleomagnetic pole (Amazonian Craton) on the longevity of Columbia. (submitted to Prec. Res.).

Dunlop, D.J., 2002. Theory and application of the Day plot (Mrs/Ms versus Hcr/Hc) 1. Theoretical curves and tests using titanomagnetite data. J. Geophys. Res. 107, B3, 4-1 - 4-22.

Johansson, A., 2009. Baltica, Amazonia and the SAMBA connection – 1000 million years of neighbourhood during the Proterozoic? Prec. Res. 175, 221-234.

Pesonen, L.J., Elming, S-A., Mertanen, S., Pisarevsky, S., D'Agrella-Filho, M.S., Meert, J. G., Schmidt, P.W. Abrahamsen, N., Bylund, G., 2003. Palaeomagnetic configuration of continents during the Proterozoic. Tectonophysics 375, 289-324.

Salminen, J., Pesonen, L. J., 2007. Paleomagnetic and rock magnetic study of the Mesoproterozoic sill, Valaam island, Russian Karelia. Prec. Res. 159, 212–230.

Teixeira, W., Geraldes, M.C., D'Agrella-Filho, M.S., Santos, J.O.S., Barros, M.A.S., Ruiz, A.S., Costa, P.C.C., 2011. Mesoproterozoic juvenile mafic-ultramafic magmatism in the SW Amazonian Craton (Rio Negro-Juruena province): SHRIMP U-Pb geochronology and Nd-Sr constraints of the Figueira Branca Suite. J. South Am. Earth Sci. (In press).