THE RINCÓN DEL TIGRE MAFIC-ULTRAMAFIC COMPLEX, SOUTHEASTERN BOLIVIA - A PALEOMAGNETIC STUDY

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ABSTRACT

Paleogeographic reconstructions at 1100 Ma involving the Amazonian Craton are controversial due to the absence of key paleomagnetic poles. Trying to elucidate the participation of this Craton in the continental cycle, this work presents a paleomagnetic study on 15 sites of the 1100 Ma Rincón del Tigre (RT) Complex from southwestern Amazonian Craton. The AMS results indicate nearly horizontal magnetic fabric for many of the analyzed sites and a NW/SE k1 direction, which suggests these rocks were tectonically affected by the Sunsás orogen. After AF and thermal treatments coherent magnetic directions were disclosed for much of the specimens from each site. However, the same consistency was not observed for the between-site directions. Tectonic corrections were applied for the site mean directions, which yielded a positive fold test for a group of sites (pole at 271.7° E, 28.6° N, α95 = 17.6°). Supposing an original horizontal magnetic fabric (k_3 = 90°) for the layered sills, the AMS data was also used to correct site mean magnetization directions. After correction, another group of sites yielded consistent directions (pole at 28.5° E, 30.0° S, α95 = 12.8). Paleogeographies were constructed based on the RT and other selected poles from Amazonia and Laurentia, which support the model where soon after Columbia rupture at around 1270 Ma, the Amazonian Craton executed a clockwise rotation until it collides again with Laurentia at 1000 Ma, forming Rodinia.

Keywords: Rincón del Tigre Complex, Paleomagnetism, Columbia, Rodinia

RESUMO

Modelos de reconstruções paleogeográficas envolvendo o Cráton Amazônico são controversos devido à carência de dados paleomagnéticos. Com intuito de esclarecer a participação deste Cráton na evolução do ciclo continental, apresentamos estudo paleomagnético realizado para o Complexo Rincón del Tigre (RT) (1100 Ma, sudoeste do Cráton Amazônico). Os dados de ASM indicam trama magnética aproximadamente horizontal coerente com a colocação de sills e direções do eixo k1 para NW/SE, as quais indicam que estas rochas sofreram influência tectônica da orogênese Sunsás. Os tratamentos por campos alternados e térmico foram eficientes para separar componentes coerentes para cada sítio. Todavia, a mesma coerência não é observada para as direções médias por sítio. Assim, correções tectônicas foram efetuadas e para um grupo de sítios obteve-se um teste de dobra positivo (polo em 271.7° E, 28,6° N, α95 = 17.6°). Supondo trama magnética horizontal (k_3 = 90°) para os sills acamadados, os dados de ASM foram utilizados para corrigir as direções de magnetização. Após esta correção, outro grupo de sítios apresentou direções consistentes (polo em 28,5° E, 30.0° S, α95 = 12.8). Com base nos polos determinados para RT e polos selecionados para o Cráton Amazônico e Laurentia são propostas paleogeografias que apoiam o modelo que propõe a ruptura do supercontinente Columbia, por volta de 1270 Ma atrás, e posterior movimento de rotação horária do Cráton Amazônico até a sua colisão com a Laurentia há 1000 Ma atrás, formando o Rodínia.

Palavras Chave: Complexo Rincón del Tigre, Paleomagnetismo, Columbia, Rodinia

Introduction

The Amazonian Craton had a relevant participation into the Meso-Neoproterozoic Rodinia supercontinent configuration. According to geological models during Rodinia formation, Amazonian Craton collided with Laurentia along the Sunsas and Grenville orogenic belts, respectively. Basically, two contrasting models have been proposed for this collision: the first assumes an oblique collision of Amazonian Craton with Laurentia, followed by transcurrent movements of Amazonia (Tohver *et al*., 2004). The second proposes that, after break-up of the core of Columbia supercontinent at ca. 1270 Ma ago, Amazonian Craton performed a clockwise rotation until its final collision with Laurentia, approximately 1000 Ma ago (Evans, 2013). In this way, determination of new paleomagnetic data for the Amazonian Craton in the 1200-1000 Ma time interval are critical in order to define the kinematics between Amazonia and Laurentia in the formation of Rodinia. Here we present paleomagnetic data from the 1110 Ma mafic-ultramafic RT Complex located at southeastern Bolivia.

Geological context, sampling and methods

The RT Complex is comprised by mafic-ultramafic layered sills, approximately 4.5 km thick (Teixeira et al., 2015). It shows intrusive relationships with sedimentary rocks from the Sunsás and Vibosí Groups, which are part of Sunsás orogenic belt. Recently, baddeleyites from the RT Complex were dated (U-Pb) at 1110.4 ±1.8 Ma (Teixeira *et al*., 2015). For this study 101 oriented cylindrical cores from 15 sites were sampled. A total of 359 specimens were prepared for Anisotropy of Magnetic Susceptibility (AMS) measurements. The samples were then submitted to alternating field (AF) and thermal treatments to separate magnetic components. The magnetic mineralogy was studied by isothermal remanent magnetization (IRM), hysteresis, and thermomagnetic experiments.

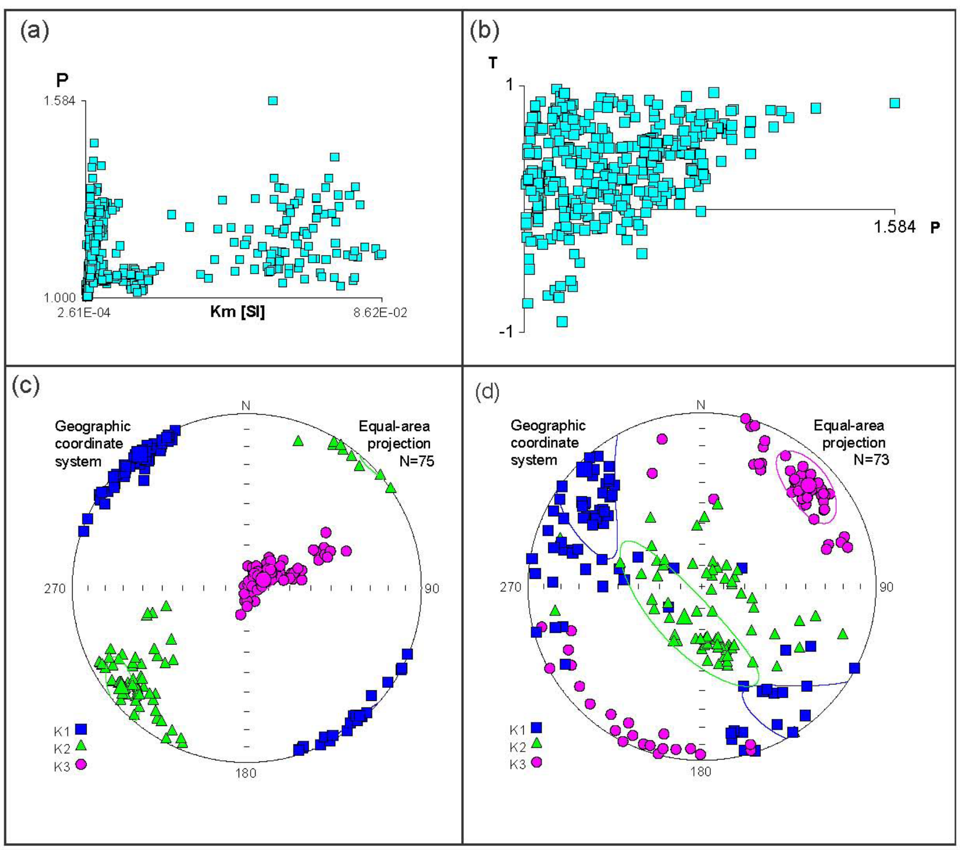

Figure 1. (**a**) Anisotropy degree (P) versus mean susceptibility (Km=[(*k1*+*k2*+*k3*)/3]. (**b**) Jelinek parameter (T) versus anisotropy degree (P). (**c**) Stereogram showing *k1*, *k2* and *k3* susceptibility axes for samples with nearly horizontal fabric. (d) Stereogram showing k1, k2 and k3 susceptibility axes for samples with inverted *k2* and *k3* axes.

Results

AMS measurements show two distinct intervals of mean magnetic susceptibility (Km) (Fig. 1a): the first, between 3×10-4 and 220x10-4, and the second, between 2.5×10-2 and 8.6×10-2. The anisotropy degrees (P) vary from values compatible with undeformed mafic rocks (P <1.1) up to high values (maximum of 1.584) suggesting the rocks were submitted to deformation. Jelinek parameters (T) show predominance of oblate ellipsoids (0<T<1) suggesting that magnetic foliation prevails over magnetic lineation (Fig. 1b). The maximum (k_1), intermediate (k_2), and minimum (k_3) axis indicate approximately horizontal magnetic fabric for 10 sites (Figure 2c), coherent with sill's emplacements. Three of the remaining 5 sites show inverted k_2 and k_3 axis, when compared with the sites described above (Fig. 2d). The k1 axis for these sites, however, trend to NW/SE, which agrees with the fold axes, observed in the geological map scale. For the two remaining sites, one did not present well-defined fabric, and the other is an exception, since k_1 axis is almost vertical.

Thermomagnetic curves were grouped according to their reversibility or irreversibility during heating and cooling. The first group shows reversible trajectories, with Curie temperatures (CT) close to 580° C, accentuated Hopkinson peak, and a well-characterized Verwey transition (Fig. 2a), which indicate the presence of magnetite as the main magnetic carrier. The other two groups are characterized by irreversible curves (Figs. 2b and 2c). The first (Fig. 2b) indicates CT lightly above 600° C, and a decrease in susceptibility

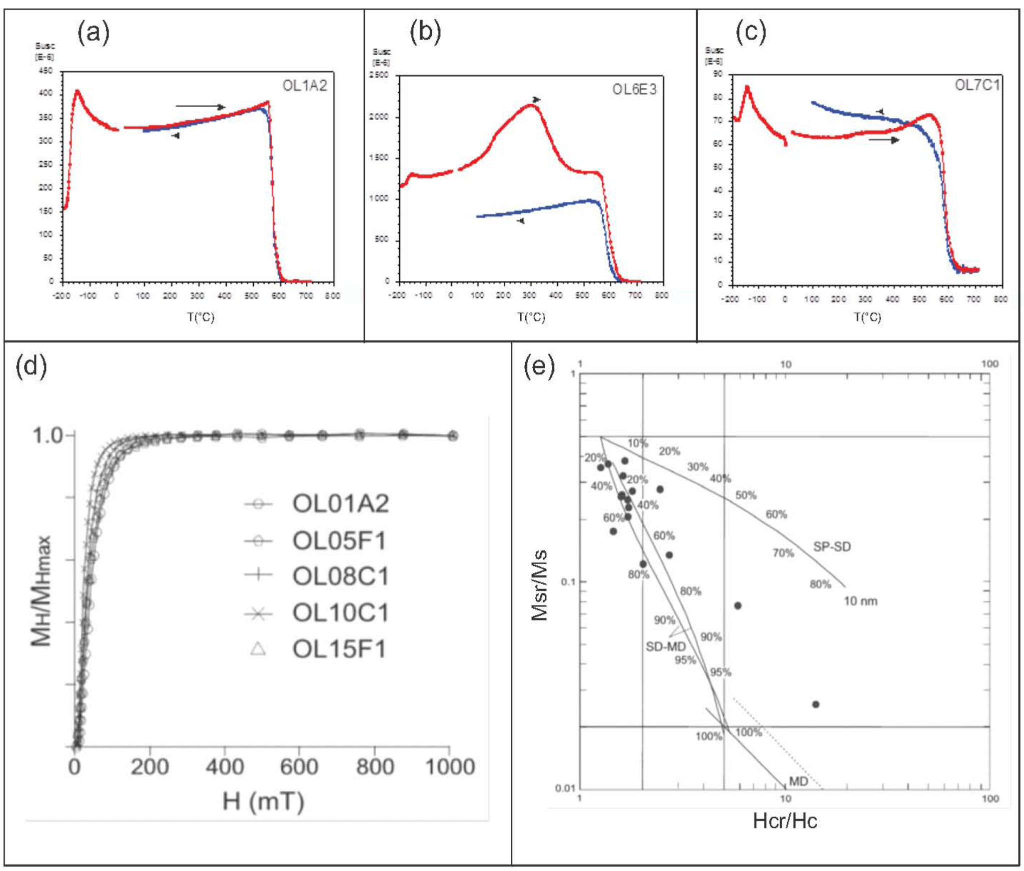

Figure 2. (a) - (c): Thermomagnetic curves. (d) IRM curves. (e) Day's plot after Dunlop (2002). Ms, Mrs, Hc, Hcr are, respectively, saturation magnetization, saturation remanent magnetization, bulk coercivity and coercivity of remanence. SD-MD - theoretical curves indicating mixtures of single domain (SD) grains with different percentage of multidomain (MD) grains. SP-SD – theoretical curve indicating mixtures of SD grains with different percentage of superparamagnetic (SP) grains, 10 nm in diameter.

at around 350° C suggesting the presence of maghemite, besides magnetite partially oxidized. This is corroborated by the decrease in the susceptibility during cooling, and the less accentuated Verwey transition at low temperature (Fig. 2b). The third group is also characterized by CT slightly above 600° C, but with an increase in susceptibility during cooling. Also, the Verwey transition is more evident in these samples. IRM experiments indicate saturation at fields lower than 300 mT (Fig. 2d), typical of magnetite. Most samples presented hysteresis loops typical of magnetite, indicating coecivities between 2.3 mT and 27 mT. Figure 2e shows the Day's plot for all samples. Most samples fall along the theoretical curves proposed by Dunlop (2002) which indicate mixtures of SD grains with different percentage of MD grains.

AF and thermal demagnetization were efficient to separate stable and coherent magnetic directions for almost all samples from each site. However, the same coherence were not observed when mean directions are compared between sites (Fig. 3a).

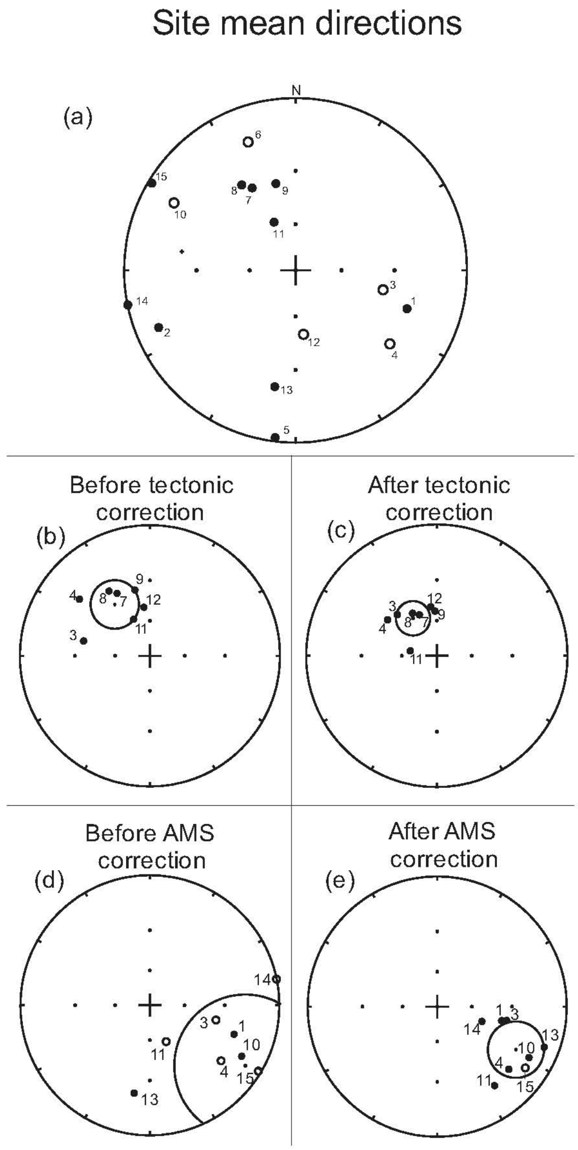

Figure 3. Site mean directions (a). Open (full) circles represent negative (positive) inclinations. Site mean directions before (b) and after tectonic corrections (c). Site mean directions before (d) and after AMS correction (e). + represents the mean directions with the respective cone of confidence.

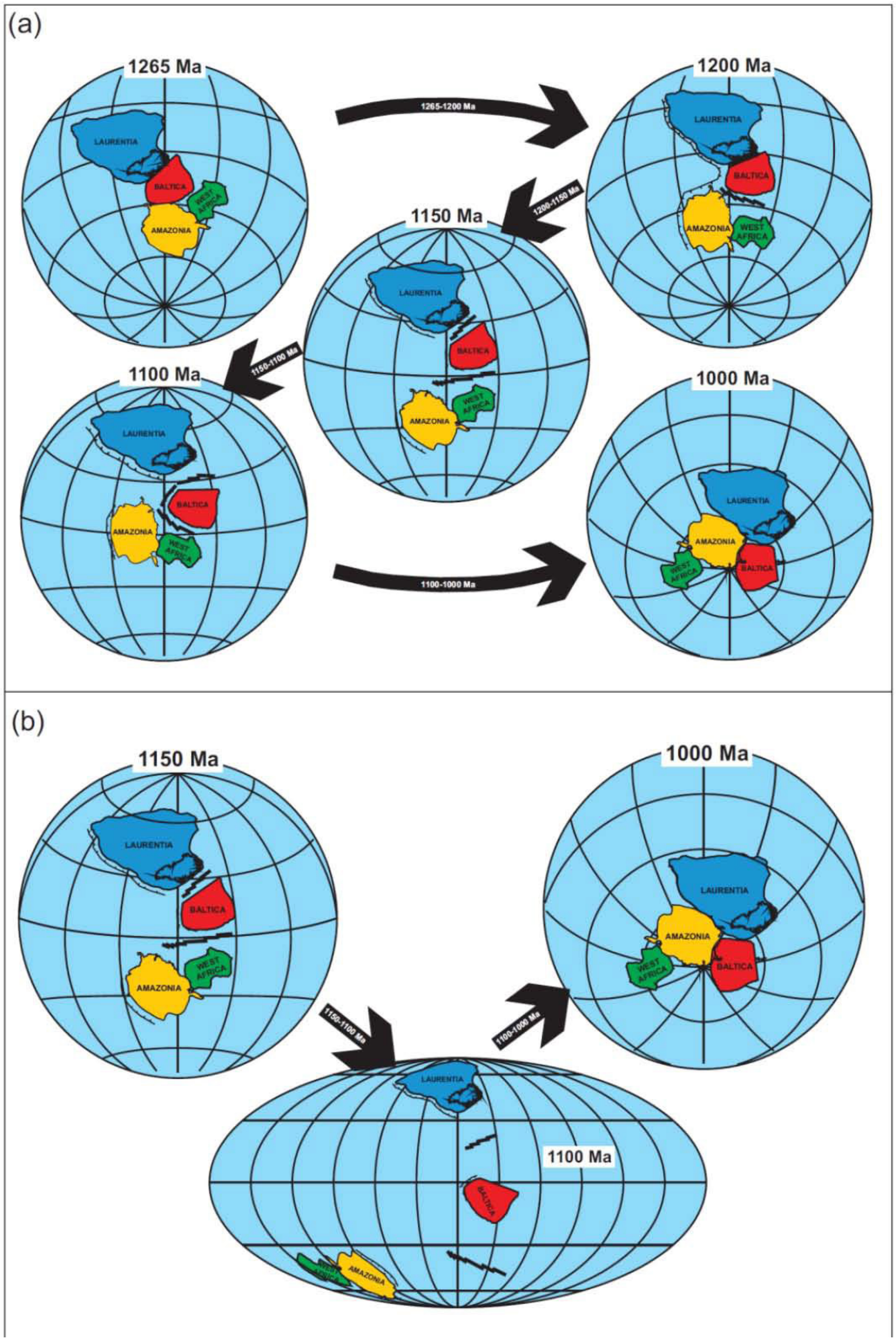

Figure 4. (a) Paleogeographic reconstructions at 1265, 1200, 1150, 1100 and 1000 Ma. At 1265 Ma Columbia (Bispo-Santos *et al.*, 2014) was constrained by the MacKenzie pole. At 1200, 1150 and 1100 Ma, Laurentia and Amazonia were constrained by poles from Upper Bylot (1204 Ma), Abitibi dykes (11441 Ma) and Logan sills (1109 Ma), and Nova Floresta (1201 Ma), Fortuna Formation (1149 Ma) and RT Complex (1100 Ma – AMS corrected), respectively. Paleogeography at 1000 Ma is the same as proposed by Li *et al.* (2008) for Rodinia. (b) paleogeographies at 1150 and 1000 Ma as in (a). At 1100 Ma the tectonic corrected RT pole was used.

Discussion

The RT Complex was affected by the Sunsás orogeny, whose fold axis shows NW-SE trend. The AMS results indicate k1 axis in this direction showing this event affected the studied rocks. However, petrographic analysis indicates igneous texture, which suggests that magnetic mineralogy must also be preserved. A fold test was then applied using the fold plane directions available in published geological maps (Teixeira *et al*., 2015, Litherland *et al*., 1989). Figure 3b and 3c shows the best group of site directions before and after tectonic corrections, whose mean directions are, respectively, Dm = 325.5°, Im = 39.0° (α95 = 17.2, K = 13.3, N = 7), and Dm = 327.9°, Im = 53.5° (α95 = 13.1, K = 22.6, N = 7). Fisher statistical parameters indicate a significant clustering of site directions after tectonic correction, suggesting a positive fold test. The mean of virtual geomagnetic poles (VGPs) yielded a pole at 271.7°, 28.6° (α95 = 17.6°).

The tectonic correction for each site mean direction was inferred from some places where fold plane were determined. However, it is difficult to assert if the tectonic correction used for each site is correct since geographic positions of the paleomagnetic site and the measured fold plane, normally, do not coincide. Another way to correct tectonic movements makes use of AMS measurements. Supposing that the RT is composed by layered intrusions, we would expect a horizontal fabric for the AMS measurements. This really occur for most of the measured sites, although the k_3 axis normally present an inclination somewhat different from 90°, which may indicate that the magnetic fabric (initially horizontal) was influenced by tectonic effects. So, the inclination of the k3 axis and the plane perpendicular to this axis was used to correct site mean directions. Figures 3d and 3e show the best group of site directions before and after AMS corrections, whose mean directions are, respectively, Dm = 122.3°, Im = -7.8° (α95 = 32.5, K = 3.9, N = 8), and Dm = 118.6°, Im = 20.7° (α95 = 16.5, K = 12.2, N = 8). Fisher statistical parameters also indicate a significant clustering of site directions after AMS correction. The mean of VGPs yielded a pole at 28.5°, 30.0° (α95 = 12.8°).

Paleogeographic implications for the Columbia break-up and Rodinia agglutination

Recently, Bispo-Santos et al. (2014) proposed a paleogeography for the core of Columbia (Laurentia, Baltica, proto-Amazonia and West Africa) based on paleomagnetic data. Long ago, interaction of Amazonia with Laurentia along Sunsás and Grenville belts, respectively, have been proposed in the formation of Rodinia. As already stressed above, basically two models have been proposed: the first suggests an oblique collision of Amazonia with Laurentia, followed by transcurrent movement of Amazonia (Tohver *et al*., 2004). The second proposes that Amazonia executed a clockwise rotation and docked with Laurentia after break-up of Columbia (Evans, 2013). The new data obtained for the RT Complex may be used to test these models. None of the two poles (after AMS and tectonic corrections) calculated in our study corroborate the model proposed by Tohver et al. (2004).

Based on the available paleomagnetic poles for Amazonia and Laurentia, two scenarios are proposed in Figure 4. For the reconstruction at 1100 Ma, the first model (Fig. 4a) uses the RT pole calculated after AMS correction, and the second model (Fig. 4b) uses the RT pole after tectonic correction. The first model (AMS correction) seems to be more appropriated to consider a clockwise rotation of Amazonia and Baltica. The second model (tectonic correction) implies in a larger distance between Amazonia and Laurentia at 1.1 Ga.

Acknowledgements

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