PALEOMAGNETISM AND CYCLOSTRATIGRAPHY OF UPPER-CARBONIFEROUS GLACIAL RHYTHMITES OF MAFRA FORMATION, PARANÁ BASIN, BRAZIL

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ABSTRACT

A Carboniferous paleomagnetic pole was calculated from a sequence of glacial rhythmites from the Itararé Group from Paraná Basin in Southern Brazil. Samples were taken from a section of Mafra Formation (Upper Pennsylvanian). Ciclostratigraphy based on magnetic susceptibility measurements of 201 lithologic levels along 3.6 meters identified the presence of Milankovich cycles, indicating that the sedimentation occurred in millenial scale. Alternating fields demagnetization of to 112 studied stratigraphic levels, revealed two magnetization components, one viscous of low coercivity, compatible with the present field (present in most of the analyzed samples) and a more coercive component identified in all samples; this component is of reversed polarity, compatible with the Kiaman geomagnetic quiet interval - the Late Paleozoic Reversed Superchron. Thermomagnetic curves indicated the presence of magnetite as the main magnetic carrier. The paleomagnetic pole calculated for the Mafra rhythmites is in accordance to other Carboniferous poles, and is far from the Rio do Sul pole, another rhythmite section from the upper part of the Itararé Group.

Keywords: Paleozoic, glacial rhythmites, paleomagnetism, cyclostratigraphy, Itararé Group.

Introduction

The distribution and scattering of the available South American paleomagnetic poles for Late Paleozoic allows two interpretations for the apparent polar wander paths (APWP), depending on the filter we use to select poles (Brandt *et al*., 2009; Tomezzoli *et al*., 2009). The two proposed APWPs for the Late Carboniferous to Permian interval (Fig. 1) are based on high quality paleomagnetic poles, therefore, much more work is still needed in order to understand the reasons for such scattering, and infer which curve represents the contiental path. Furthermore, the Carboniferous is still very poorly known in terms of paleomagnetic information. In this paper we present new paleomagnetic results on a section of glacial rhythmites of the Mafra Formation (Upper Pennsylvanian), belonging to the Itararé Group of the Paraná Basin, southern Brazil. A cyclostratigraphic study has also been performed in order to infer the elapsed time for the accumulation of the layered sediments.

The Paraná Basin is an extensive intracratonic basin located in the central eastern portion of South America (Fig. 2A), covering regions from southern Brazil, Uruguay, Argentina and Paraguay. According to Milani (1997) six super-sequences are recognized in the Basin: Rio Ivaí (Rio Ivaí Group, Ordovincian-Silurian), Paraná (Lochkovian-Frasnian), Gondwana I (Itararé, Guatá and Passa Dois Groups, Pennsylvanian to Permian), Gondwana II (Rosario do Sul Group, Middle to Upper Triassic), Gondwana III (São Bento Group, Jurassic - Cretaceous) and Bauru (Bauru Group, Cretaceous). The glacial deposits of the Itararé Group are well exposed in the east and northwest borders of the Paraná Basin (Fig. 2); they correspond to the third

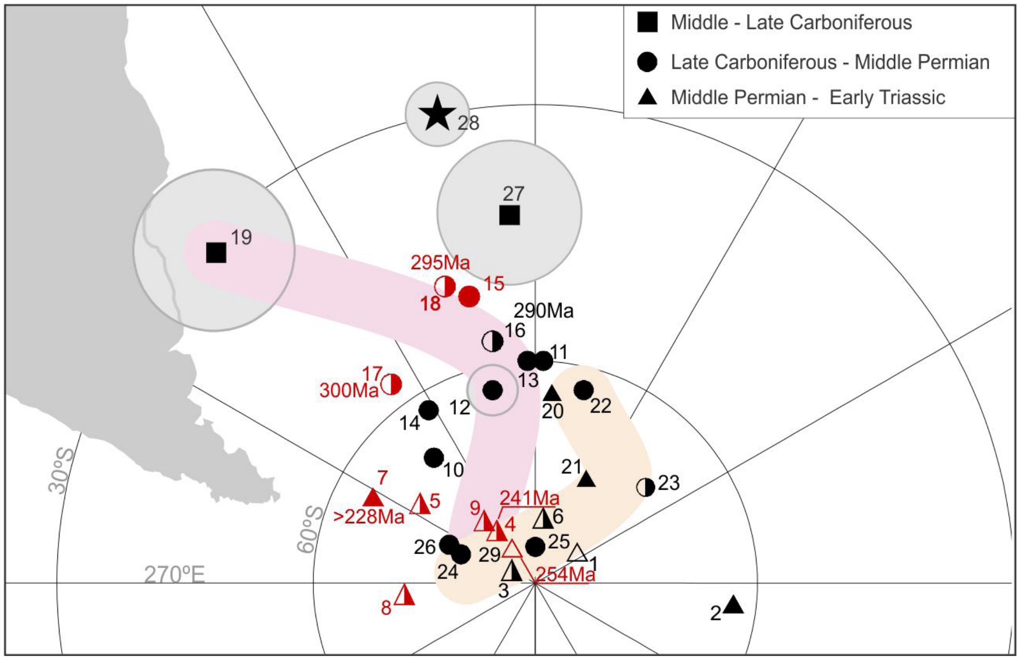

Figure 1. Plot of the late Paleozoic paleomagnetic poles for South America. Symbols are as follows: red, igneous rocks; black, sedimentary rocks; half solid, mixed polarities. Radiometric ages are indicated when available. Apparent polar wander paths of Brandt *et al*. (2009) and Tomezzoli (2009) are plotted in pink and orange curves, respectively. Pole coding according to Brandt *et al*. (2009); pole 12 (Rio do Sul Fm.) was updated by Franco *et al*. (2012), and pole 29 is the Araguainha pole (Yokoyama *et al*., 2014).

glaciation cycle that affected the Gondwana supercontinent, and was the most extensive of the Phanerozoic glaciations (Caputo and Crowell, 1985; Eyles, 1993; Remane *et al*., 2000; Isbell *et al*., 2003). In the Santa Catarina State, the sedimentation of the Itararé Group began in the Bashkirian (Middle Carboniferous) with the Lago Azul Formation, which rests on the Campo do Tenente Sequence (Weinschutz and Castro, 2004), and finished at the Sakmariano-Artinskian limit with the Rio do Sul Formation. The Mafra Formation lays between the Campo do Tenente and Rio do Sul formations, corresponding to the Kasimovian to Gzhelian interval, and showing diamictites, brown sandstones and rhytmites. The rhythmites are made of pairs of light-coloured sandstone/silt and thinner, dark lamina of silt/clay which repeats regularly with variable thicknesses.

Methodology and results

The paleomagnetic sampling was performed at Olsen quarry near the city of Mafra in the Santa Catarina State (Figure 2A). Hand samples were taken from 112 consecutive lithological pairs. Cores of 2.5 cm in diameter were drilled in the laboratory from each hand sample, and specimens of 2.2 cm in thickness were prepared in a way that each specimen corresponds to only one lithological pair; specimens exceeding 2.2 cm were cut into two specimens. For the cyclostratigraphic study thickness measurement of each pair was performed along 3.6 meters, corresponding to 206 consecutive levels (Figs. 2B and C).

Most of the analyses were conducted at the paleomagnetic laboratory of the University of São Paulo. Magnetic susceptibility (MS) and anisotropy of magnetic susceptibility (AMS) were measured in a MFK1-FA Kappabridge from Agico. Figure 2D shows the variation of susceptibility through the Olsen quarry. The susceptibility tends to increase with de degree of anisotropy which in turn does not exceed 1.094. The k1 axes are all contained in the horizontal plane indicating that the layers are completely flat, and a general trend in the NW-SE direction may be associated to current flows.

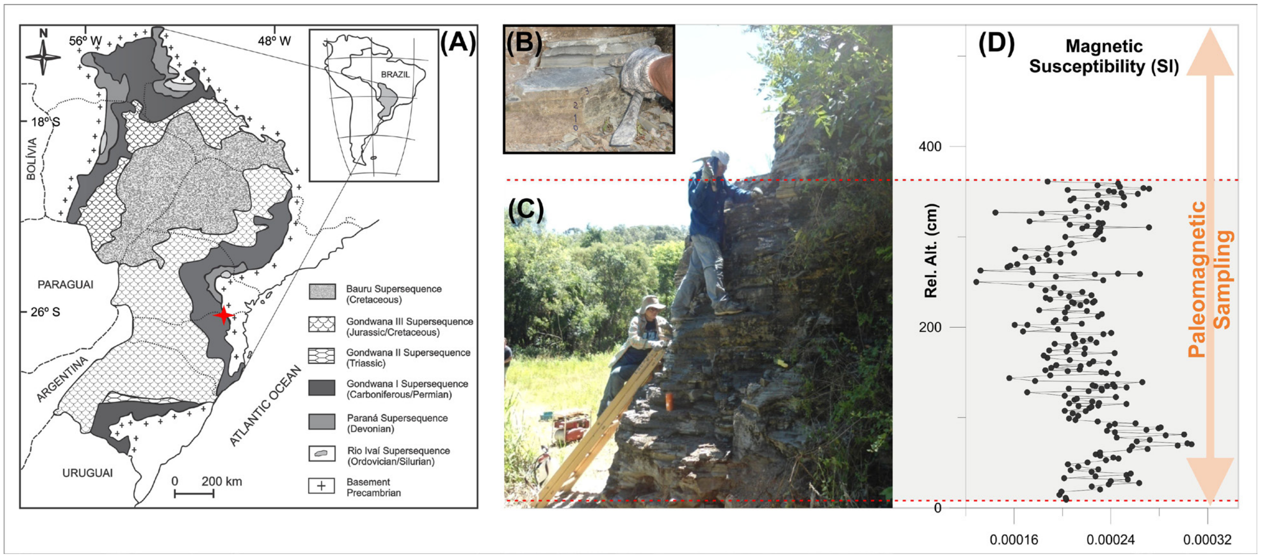

Figure 2. A) The Parana Basin map indicating the sampling site (red star). B and C) Overview of the outcrop and a closer view of the lithological pairs. D) Variation of the magnetic susceptibility along 3.6 m of the outcrop.

The harmonic content in the magnetic susceptibility data were evaluated, and the obtained spectrum (Fig. 3) was compared to the spectrum displaying the Milankovitch cycles evaluated for 300Ma ago (Berger *et al.*, 1992). The good proportionality between both spectra indicates that the astronomical forcing parameters (eccentricity, precession and obliquity) were active and influencing the climatic conditions during the deposition of the Mafra rhythmites.

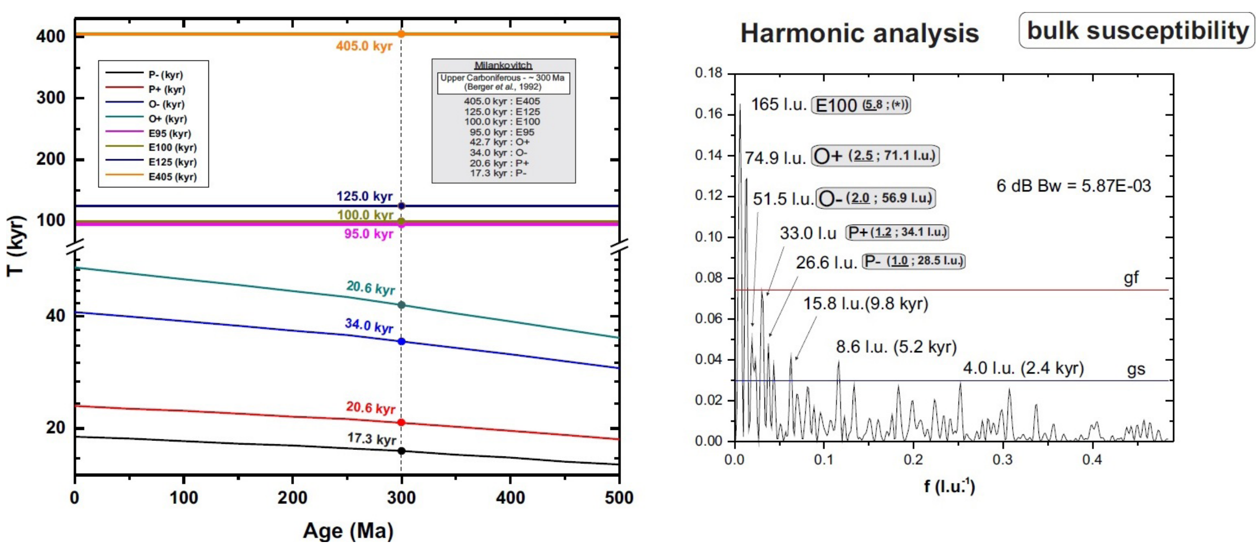

Figure 3. The length of the Milankovich cycles according to age (Berger *et al.*, 1992), and results of the harmonic analysis of bulk susceptibility of Mafra rhythmites (Olsen Quary).

Specimens from 112 pairs were submitted to demagnetization by alternating field in a superconducting rock magnetometer from 2G Enterprises. Twenty-four steps of demagnetization up to 160 mT were efficient to remove about 90% of the remanence of majority of samples, which permitted the identification of the magnetization components. Some examples of the a.f. demagnetization are shown on Figure 4.

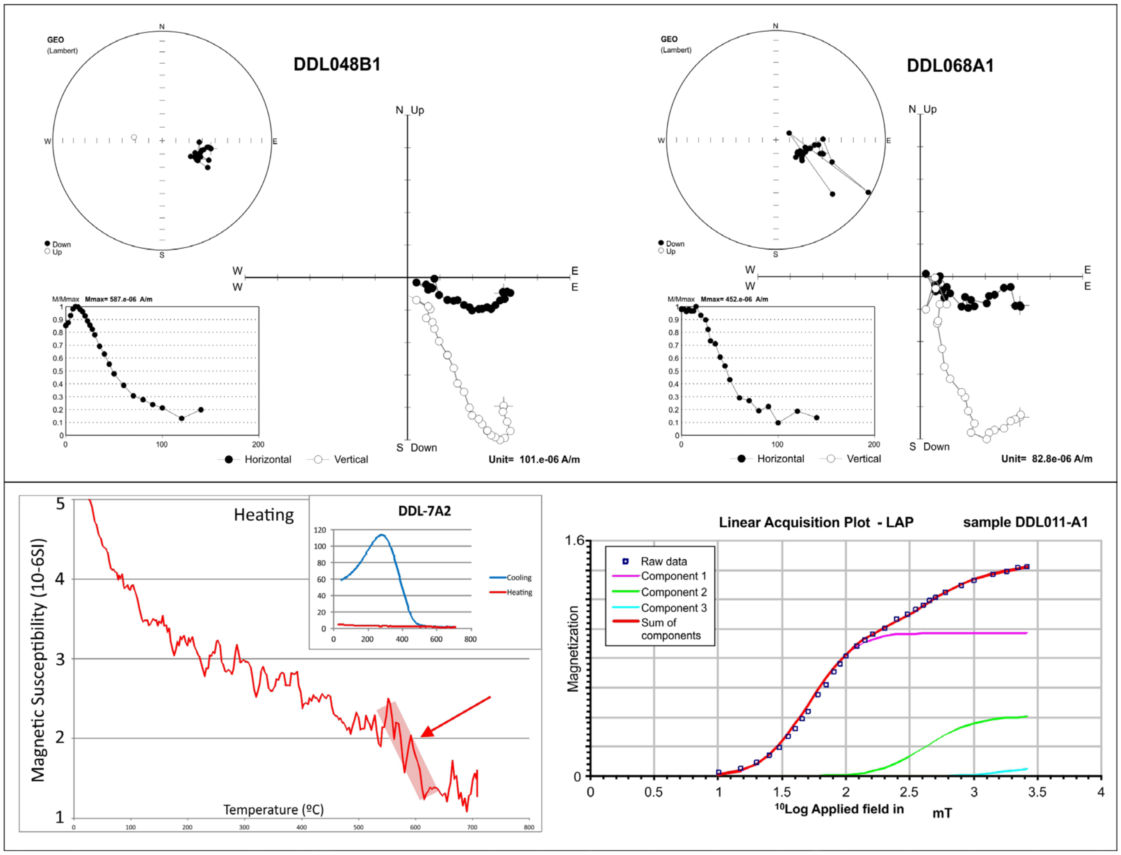

Figure 4. Examples of stereographic projections, orthogonal plots and intensity variation curves for the alternating field demagnetizations (samples DDL048B1 and DDL068A1). Examples of thermomagnetic (sample DDL-7A2) and isothermal remanent magnetization (sample DDL011-A1) curves.

Zijderveld (1967) vetorial projections and Kirschvink (1980) least squares method were used to determine the principal magnetic components for the demagnetized samples. Principal component analyses revealed the presence of two magnetic components: the characteristic component to the whole collection is the most coercive, of reversed polarity ,and of high inclination; a secondary component less coercive, and eliminated with fields of up to 20 mT, was identified in the majority of samples, corresponds to the present geomagnetic field. The presence of reversed directions in all analyzed samples is in agreement to a paleofield inserted in the Permo-Carboniferous Reversed Superchron, which is in accordance to Mafra's age.

Themomagnetic curves were performed in a CS-3 furnace coupled to the Kapapabridge KLY4 from AGICO, and the heating and cooling cycles were between 50º and 700º C. The 580º C transition (Dunlop and Özdemir, 1997) in the curves indicated the presence of magnetite as the main magnetic carrier. However, more than one magnetic carrier (Fig. 4) was inferred by the analysis of the isothermal remanent magnetization (IRM) curves using the method of Kruiver *et al*. (2001). These analyses were performed at the laboratory of the Universidad Nacional Autonoma do Mexico.

Discussion and conclusions

Despite the weak remanent magnetization (about 10^{-7} emu/cm³) the rhythmites revealed a stable and very likely primary magnetization; remanence in all investigated layers are of reverse polarity, and they are carried by magnetite. Cyclostratigraphy indicated the presence of the Milakovitch cycles, as was already verified in other rhythmites of the Itararé Group (Franco *et al*., 2012) garanteeing a millenial-scale time interval covered by the sampled section. As a consequence, the mean magnetization direction is probably not affected by the secular variation effects.

The calculated paleomagnetic pole is compared to other Carboniferous poles (Fig. 1) from South America - Tepuel (Rapalini *et al*., 1994) and Royada Verde (Rapalini and Vilas, 1991), the last one being closer to Mafra pole although the confidence circles do not intercept. The Mafra pole and the Rio do Sul pole (Franco *et al*., 2012) are about 30º distant in latitude, and this is compatible with the stratigraphic positions of the two glacial rhythmite sections as the Rio do Sul is at the upper part of the Itararé Group and Mafra is at the base.

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