Preliminary data of magnetic susceptibility and geomagnetic field variations from sediment records of Lagoa dos Patos, Rio Grande do Sul State, Brazil

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This paper was prepared for presentation during the 14th International Congress of the Brazilian Geophysical Society held in Rio de Janeiro, Brazil, August 3-6, 2015.

Abstract

The Earth's magnetic field over the past few millennia is studied from archeological and geological records obtained from different places around world. The southern hemisphere contributes with less than 5% of the global database for the past three millennia. Here, we will present preliminary directional and magnetic susceptibility results from sedimentary records of Lagoa dos Patos, Rio Grande do Sul State (Brazil) dated to the past six millennia. Results indicate stable remanent magnetization, which can be confidently used to understand the variations of the geomagnetic field in South America for the past few millennia.

Introduction

The geomagnetic field can be studied from direct and indirect observations (Hulot et al., 2010). Direct measurements are limited to intervals of time from the XVI century to the present, through data from ships, magnetic observatories and satellites. Older data of the Earth's magnetic field are determined through indirect observations, from archaeological artifacts (e.g. ceramics, building materials) and/or geological materials (e.g. sediments, lava flow, etc.). These materials allow obtaining the declination, inclination and intensity of the geomagnetic field in different time intervals (Merrill et al., 1998). Geological materials most used are volcanic and sedimentary rocks, as well as lacustrine and marine sediments.

The past variations of the geomagnetic field provide information about the magnetic field generation. However, there is an imbalance between the contributions from the southern and northern hemispheres. The southern hemisphere, for example, contributes with less than 5% of magnetic intensity data in the global database and less than 3% of directional data over the past 4000 years (Genevey et al., 2008; Donadini et al., 2009).

Given this discrepancy, continuous magnetic records from South America typically provided by sedimentary data, can be very useful to the description of the Earth's magnetic field. In this work, we will present preliminary results of magnetic susceptibility and directional data from three cores collected on the Lagoa dos Patos, Rio Grande do Sul State (Brazil). Based on stratigraphic correlations, local sea level curve, and ^{14}C dating the muddy Holocene lagoon deposits retrieved on those cores present ages reaching 6000 years BP (Toldo Jr. et al., 2000; 2006).

Materials and methods

Core sampling

Sediment cores were collected at different places in the Lagoa dos Patos in 2014 (Figure 1). Core samples were extracted from the lagoon and they are preserved in the core repository of the Centro de Estudos de Geologia Costeira e Oceânica (CECO-IG) of the Universidade Federal do Rio Grande do Sul (UFRGS). Core samples consist of Holocene sediments with a low energy depositional environment of the bottom of the lagoon (Toldo Jr. et al, 2000). Paleomagnetic samples were collected by using cubic plastic boxes of 8 cm^3 placed side-by-side continuously in each core with orientation to the bottom-top. A total of 184 specimens from Core PT-03, 160 specimens from Core PT-04 and 148 specimens from Core PT-06 were collected for magnetic analysis. Table 1 shows details from the three analyzed cores.

Table 1: Location and depth of collected cores.

Core	Lat S (°)	Lon W (°)	Depth (m)
PT-03	30° 48' 34.89000"	51° 07' 24.36300"	6.22
PT-04	31° 01' 55.00000"	51° 18' 04.00000"	5.69
PT-06	31° 16' 44.94690"	51° 26' 36.12122"	6.12

Magnetic analysis

Paleomagnetic and magnetic susceptibility measurements were performed at the Laboratorio de Geomagnetismo e Paleomagnetismo of the Instituto de Astronomia, Geofisica, e Ciencias Atmosféricas, Universidade de São Paulo (IAG/USP). Data analyses were carried out at the Laboratório de Geofísica Aplicada à Exploração e Produção de Petróleo (LGAEP) of the IPECI-UNISANTOS by using the software Remasoft (AGICO, LTD).

Directional and intensity data were acquired through stepwise alternating field (AF) demagnetizations from oriented specimens (e.g. Tauxe, 2010). NRM measurements were carried out using a 2G Enterprise

SQUID Magnetometer. In the AF demagnetization, the variation of the natural remanent magnetization (NRM) components is measured by the magnetic moment after each step of demagnetization. A specimen is submitted to a peak field of amplitude H and then it is slowly reduced to zero-field. After this process, the magnetic grains with remanent coercivities lower than H will present null remanent magnetization. The peak field H is successively increased decomposing totally the NRM vector. If only one magnetic component contributes to the NRM, no change in the direction will be observed during the AF demagnetizations. On the other hand, if two or more magnetic components are observed and present different directions, then a vectorial directional change will occur. Generally, a stable magnetic component is the one remaining at the last AF demagnetization steps. To identify a stable magnetic component vectorial analyses (Zijderveld, 1967) and principal component analyses (Kirschvink, 1980) are performed.

Low-field magnetic susceptibility of each specimen was measured using a Kappabridge MFK1-FA (AGICO Ltd) system with two excitation frequencies (976 and 15616 Hz) in a 200 A/m field at room temperature. Magnetic susceptibility (χ, mass specific in m^3/kg) is an indicative of the contribution of all magnetic materials (ferromagnetic, paramagnetic, and diamagnetic) to the bulk sample (e.g. Evans and Heller, 2003; Liu et al., 2012). Frequency dependent susceptibility can help in identifying samples with grains in the superparamagnetic range (very fine-grained nanometric particles) (Liu et al., 2012).

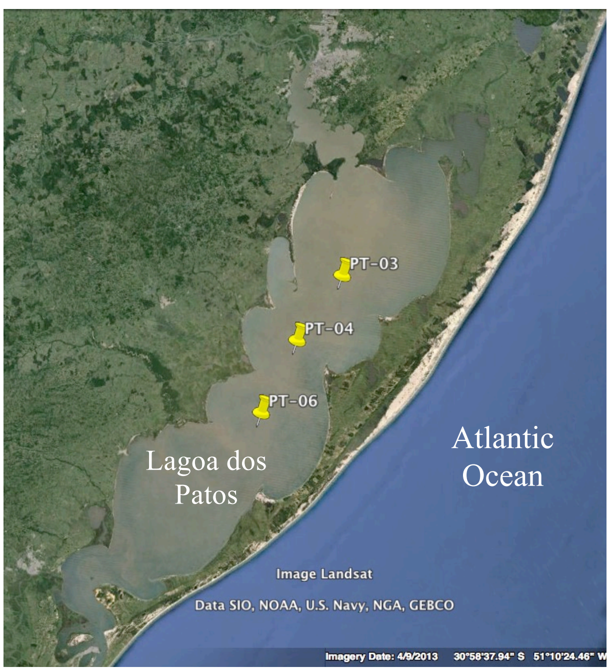

Figure 1: Location map of Lagoa dos Patos in southern Brazil and location of collected cores.

Preliminary results

Magnetic susceptibility measurements were performed on all specimens from the three cores (Cores PT-03, PT-04 and PT-06). Figure 2 shows results of magnetic susceptibility by using two different frequencies. Results indicate that magnetic susceptibility does not change when comparing both frequencies, which suggests that the contribution of superparamagnetic grains is too low to be discriminated by this technique in all three cores (e.g. Liu et al., 2012).

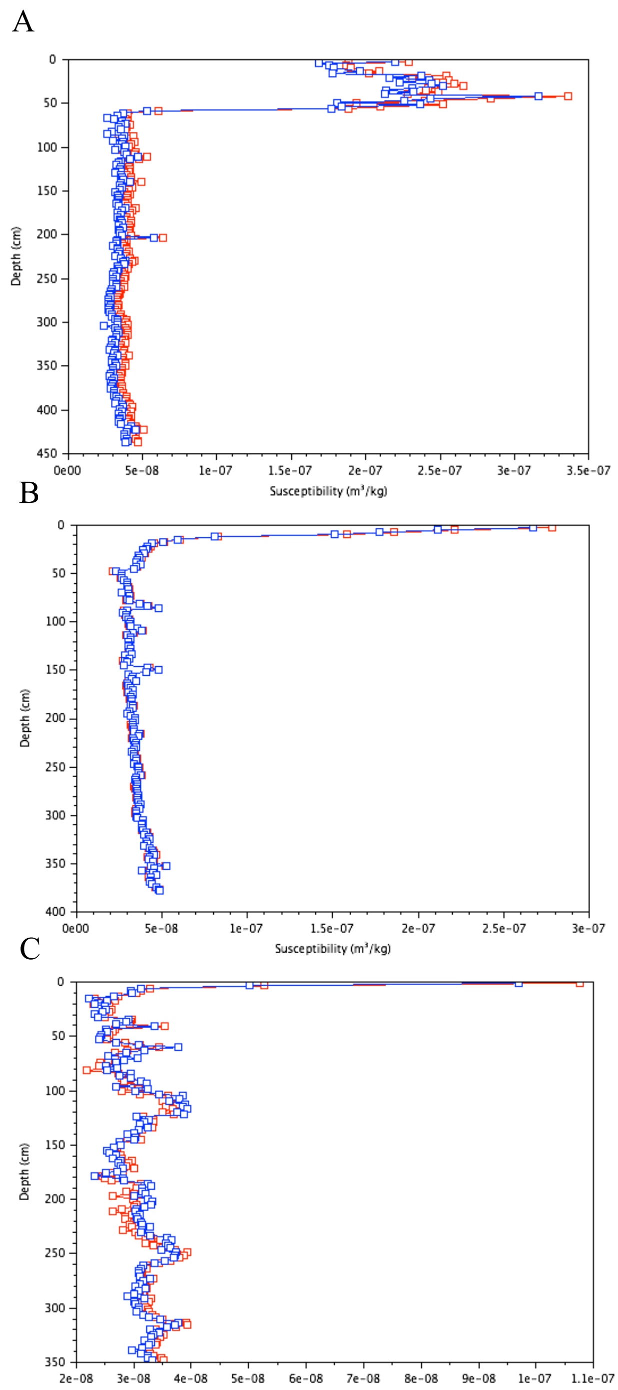

Figure 2: Magnetic susceptibility with depth for Cores PT-03 (A), PT-04 (B) and PT-06 (C). Red color represents magnetic susceptibility at frequency 976 Hz and blue at frequency 15616 Hz.

Remanent magnetic measurements were obtained on two cores (PT-03 and PT-04). Results indicate a stable remanent magnetization with intensities varying from

$0.3.10^{-6}$ A/m to $2.5.10^{-6}$ A/m, which suggests the presence of strongly magnetic minerals (ferrimagnetic), such as magnetite and titanomagnetite with low-titanium content (Figure 3).

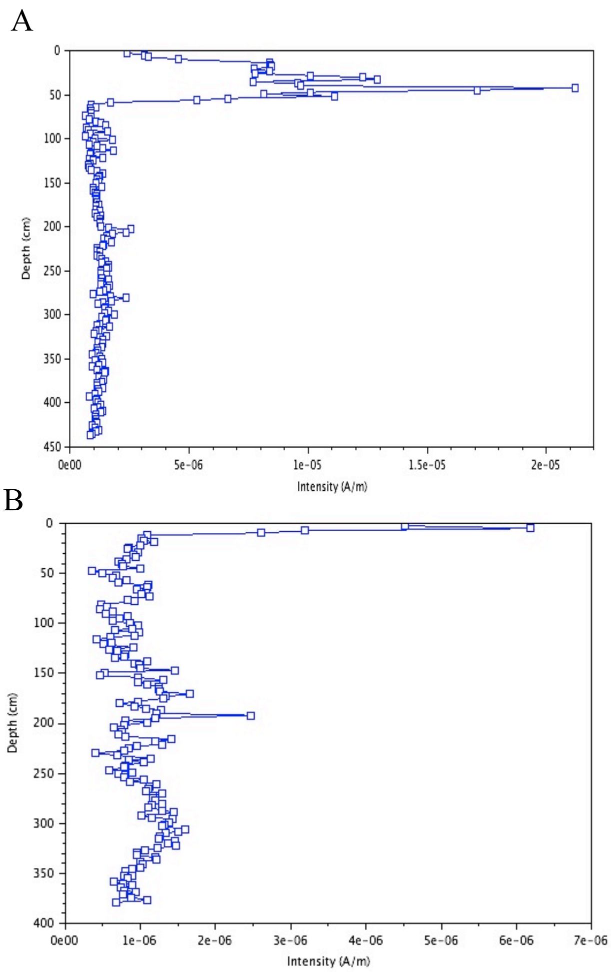

Figure 3: Intensity of NRM in function of depth from Core PT-03 (A) and Core PT-04 (B).

AF demagnetization was performed on all specimens from Cores PT-03 and PT-04. Figure 4 shows a representative sample of the AF demagnetization behavior (specimen 21, Core PT-03). Usually, specimens were completely demagnetized at around 70-90 mT, which suggests the presence of stable, low- to medium-coercivity magnetic carriers. This stability allows us to determine confidently the characteristic direction (at least the magnetic inclination) from the lagoon cores.

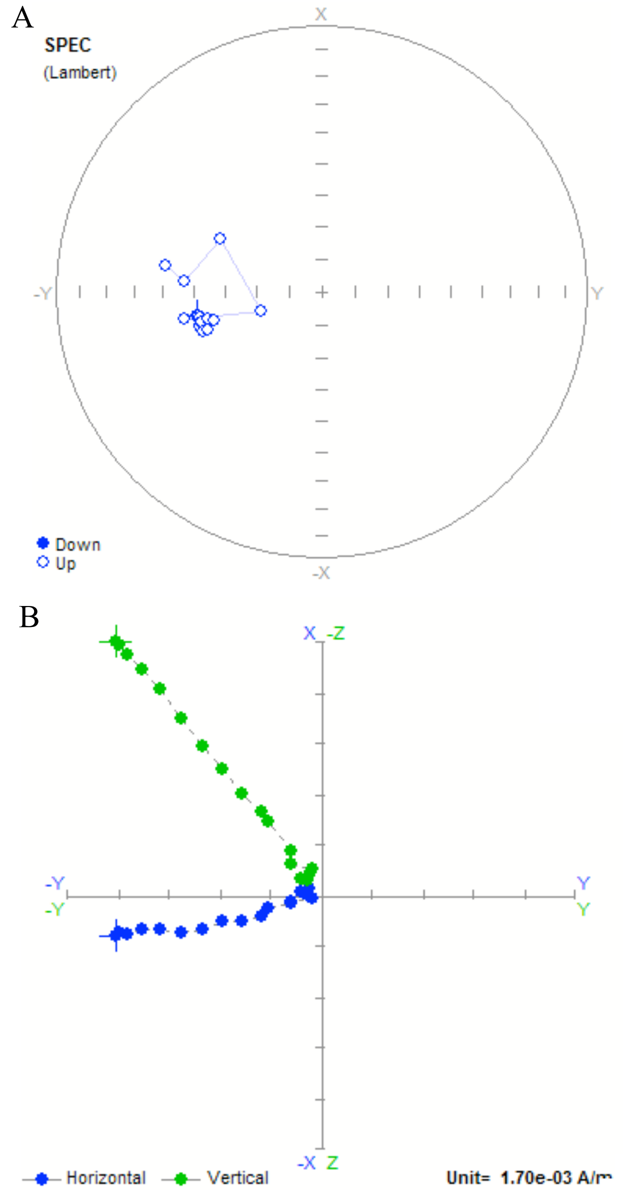

Figure 4: Example of AF demagnetization from specimen 21, Core PT-03. Spherical projection of vector direction (A) and orthogonal Zijderveld diagram (B).

Discussion

A total of 184 samples from core PT-03, 160 samples from core PT-04 and 148 samples from core PT-06 were submitted to susceptibility measurements. Results of magnetic susceptibility in function of depth show higher susceptibility values on the first 10-50 centimeters (Figure 2). Normally, that would be attributed to the movement of unconsolidated sediments on the upper section nearer to the bottom surface of the lagoon or modern sediment contamination by heavy metals from human activity. Variations in magnetic susceptibility values can be ascribed to environmental changes (Evans and Heller, 2003). This can be observed, for example, in the Core PT-03 which presents a strong susceptibility variation at ~50 cm depth and that variation decreases with distance to Bacia do Guaíba, the principal source of sediments in the lagoon (Andrade Neto et al, 2012). Below the superficial layer of sediments, the three cores show a similar pattern with susceptibility between $2X10^{-8}$ and $5X10^{-8}$ m^3/kg; their differences can be attributed to different sedimentation rates between the sites.

NRM data showed variation of intensity between $0.3.10^{-6}$ to $2.5.10^{-6}$ A/m for Cores PT-03 and PT-04, suggesting the presence of strongly magnetic and low-coercivity minerals such as magnetite and/or titanomagnetite. Core PT-04 showed more variation of intensity than core PT-03, which can be attributed to different geological parameters on the extraction site of the cores.

AF demagnetization results show stable remanent components in all analyzed specimens (Figure 4). In general, specimens present a well-defined magnetic direction, which suggests that no overprint magnetization exist on these samples.

The magnetic experiments performed on these cores indicate the potentiality for determining variations of the Earth's magnetic field over the past few millennia from the lagoon. The next step will be analyzing these directions and comparing with available geomagnetic field models for the past few millennia. Comparison between our results and other existing results from South America could help in understanding the dipolar and non-dipolar behavior of the geomagnetic field in our continent (e.g. Hartmann et al, 2009, 2010, 2011).

Acknowledgments

We would like to thank to CNPq (Grants 457802/2014-6 and 454609/2014-0) and CAPES (Grant 23038.007217/2012-61), for financial support, and IPECI-UNISANTOS and IAG-USP, for institutional support of this work.

References

Andrade Neto, J.S.D., Rigon, L.T., Toldo Junior, E.E., Schettini, C.A.F., 2012, Descarga sólida em suspensão do sistema fluvial do Guaíba, RS, e sua variabilidade temporal, Pesquisas em Geociências, Porto Alegre, Vol. 39, n. 2 (maio/ago. 2012), p. 161-171.

Donadini, F., Korte, M., Constable, C.G., 2009, Geomagnetic field for 0–3ka: 1, New data sets for global modeling, Geochem. Geophys. Geosyst., 10, 6, Q06007.

Evans, M.E., Heller, F., 2003, Environmental Magnetism: Principles and Applications of Enviromagnetics, Academic, San Diego, California.

Genevey, A., Gallet, Y., Constable, C.G., Korte, M., Hulot, G., 2008, ArcheoInt: An upgrated compilation of geomagnetic field intensity data for the past ten millennia and its application to the recovery of the past dipole moment, Geochem. Geophys. Geosyst. 9, 4, Q04038.

Hartmann, Gelvam A., Pacca, Igor G., 2009, Time evolution of the South Atlantic Magnetic Anomaly. An. Acad. Bras. Ciênc., Rio de Janeiro, v. 81, n. 2, June.

Hartmann, G.A., Genevey, A., Gallet, Y., Trindade, R.I.F., Etchevarne, C., Le Goff, M., Afonso, M.C., 2010, Archeointensity in Northeast Brazil over the past five centuries, Earth Planet. Sci. Lett., 296, 340-352.

Hartmann, G.A., Genevey, A., Gallet, Y., Trindade, R.I.F., Najjar, R., Etchevarne, C., Le Goff, M., Afonso, M.C., 2011, New historical archeointensity data from Brazil: Evidence for a large regional non-dipole field contribution over the past few centuries, Earth Planet, Sci. Lett., 306, 66-76, An. Acad. Bras. Ciênc., 81, 243-255.

Hulot, G., Finlay, C. C., Constable, C. G., Olsen, N., & Mandea, M., 2010, The magnetic field of planet Earth. Space science reviews, 152(1-4), 159-222.

Kirschvink, J.L., 1980, The least-squares line and plane and analysis of paleomagnetic data, Geophys. J. R. Astron. Soc., 62, 699-718.

Liu, Q., Roberts, A.P., Larrasoaña, J.C., Banerjee, S.K., Guyodo, Y., Tauxe, L, Oldfield, F., 2012, Environmental Magnetism: Principles and Applications, Rev. Geophys. 50, RG4002, doi: 10.1029/2012RG000393.

Merrill, R.T., McElhinny, M.W., McFadden, P.L., 1998, The Magnetic Field of the Earth: Palemagnetism, the Core, and the Deep Mantle, International Geophysics Series, 63, Academic Press.

Tauxe, L., 2010, Essentials of Paleomagnetism, Univ. of Calif. Press, Berkeley.

Toldo Jr., E.E., Dillenburg, S.R., Corrêa, I.C.S., Almeida, L.E.S.B., 2000, Holocene Sedimentation in Lagoa dos Patos Lagoon, Rio Grande do Sul, Brazil, Journal of Coastal Research, 16, 816- 822.

Toldo Jr., E.E., Dillenburg, S.R., Corrêa, I.C.S., Almeida, L.E.S.B., Weschenfelder, J., Gruber, N.L.S., 2006. Sedimentação de longo e curto período na Lagoa do Patos, Sul do Brasol, Pesquisas em Geociências, 33(2), 79-86.

Zijderveld, J.D.A., 1967, AC demagnetization of rocks, in: Methods in Paleomagnetism (D. W. Collinson, K. M. Creer and S. K. Runcorn, eds.), p. 256-286, Elsevier, New York.