HIGH RESOLUTION 1300-1940 AD GEOMAGNETIC DATA FROM MARINE CORES OFF THE COAST OF PERU

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Abstract

Rapidly-deposited marine sediments may provide a high-resolution record of the direction and the relative paleointensity of the past geomagnetic field. We present directional, relative paleointensity and environmental magnetic data for two cores of rapidly deposited sediments (>200 cm/kyr) collected off the coast of Peru covering the past seven centuries. Except for the top of the cores, directional data present high stability and excellent correlation between neighboring samples in each core and between coeval samples from the two cores. This behavior suggests that the magnetic record in the two cores is a primary detrital remanent magnetization. Both relative intensity and directional data follow the trend of the geomagnetic models CALS3k but show some differences which can be due to either a time-lag between the magnetic lock-in in the sediments and the radiometric ages of the cores or to a bias in available models due to the lack of paleomagnetic and archeomagnetic data in the region. It is worth noticing that our dataset is the only one in a radius of 5,000 km and the closest sites (Argentinean lakes) were deposited much slower, thus smoothening the high-frequency variations gathered in the Peruvian cores. Moreover, important long-standing non-dipolar anomalies in the region may interfere significantly on model's outputs. Our preliminary data off the Pacific South American coast show that good-quality paleomagnetic data are urgently required in the region in order to improve the current geomagnetic models.

Resumo

Sedimentos marinhos depositados rapidamente podem fornecer um registro de alta resolução da direção e paleointensidade relativa do campo geomagnético no passado. Neste trabalho serão apresentados dados de direção, paleointensidade relativa e magnetismo ambiental obtidos a partir de dois testemunhos com alta taxa de sedimentação (>200 cm/ano) coletados na zona *off shore* da costa do Peru. Com exceção do topo dos testemunhos, dados direcionais apresentam alta estabilidade e excelente correlação, o que sugere que o comportamento magnético nos dois testemunhos representa a magnetização remanente detrital. Tantos os dados direcionais quanto os dados de paleointensidade relativa seguem a tendência dos modelos CALS3k, mas mostram algumas diferenças que podem ser devidas ao lapso de tempo entre o momento de fixação da magnetização e problemas de datação ou devido à baixa resolução dos modelos de campo, ocasionada pela escassez de dados na região. Nossos dados são os únicos em um raio de 5,000 km e o registro mais próximo (lagos Argentinos) podem ter tido as variações de alta freqüência mascaradas devido ao fato de terem sido depositados lentamente. Além disso, anomalias não-dipolares existentes na região podem interferir de forma significativa nos modelos. Nosso registro mostra que é urgente a obtenção de dados paleomagnéticos de boa qualidade na região na tentativa de melhorar os modelos geomagnéticos atuais.

Introduction

Marine sediments from high-deposition environments are potential recorders of the past geomagnetic field in both its direction and its relative paleointensities. They allow one to analyze magnetic features in a continuous and detailed way, thus tracking rapid variations in the Earth's magnetic field that are otherwise smoothed out in slow-deposition environments. However, many problems may arise in such a kind of deposit, related either to the magnetization acquisition process and preservation or with our ability to provide accurate dating for the remanence in the sediments. Magnetic remanence in rapidly deposited sediments may be reset by mass flows or early diagenetic events, which can erase the original magnetization and precipitate secondary phases deep in the sediment column. The dating of remanence acquisition, by its turn, is complicated by the time-delay between the moment that the magnetic grains settle at the water/sediment interface and the exact moment in which the magnetization is locked-in (e.g. Roberts and Winklholfer, 2004). This time-delay differs from core to core by orders of magnitude. Since radiometric dating provides the age of sediment and organic matter burial, many features of the geomagnetic field can be wrongly positioned in time by decades or even more than a century depending of the lock-in depth (e.g. Sagnotti *et al.*, 2001). This is particularly critical when dealing with the archeomagnetic or the historical field record (variations within 10^4-10^3 yrs).

Here, we present direction, relative paleointensity and magnetic mineralogy data for two box-cores of rapidly deposited sediments (>200 cm/kyr) collected off the coast of Peru. They comprise laminated sediments accumulated in a zone presently affected by intense upwelling and preserve geochemical, sedimentary and paleontological records of significant changes in paleoclimatic and paleoceanographic conditions related to the Little Ice Age (LIA) between 1400 and 1820 AD. Directional data were obtained using Principal Component Analysis (PCA) and almost all samples present high stability and excellent correlation between neighboring samples and between coeval samples from the two cores, producing a very smooth pattern both in inclination and declination. Relative paleointensity data was obtained from classical normalization by ARM_{10mT} and IRM_{1000mT} and also present a coherent path within and between cores. The magnetic record obtained from the cores was then compared to the available models for the historical past Gufm1 (Jackson et al., 2000), Gubbins *et al.* (2006) and Finlay *et al.* (2008) and the last 3,000 yrs (CALS3k, ARCH3k, SED3k from Korte *et al.*, 2009). Our preliminary data off the Pacific South American coast show that good-quality directional and intensity results are urgently required in the region in order to improve the current geomagnetic models.

Study Area and methods

In this study we analyzed two box-cores collected from the continental slope off Peru (Fig. 1). The 92 cm long core B0506-14 (Pisco 14, 14°07'S, 76°30'W) shows a continuous sedimentation, whereas the 71 cm long core B0405-06 (Pisco 06, 14°03'S, 76°40'W) has five sedimentation gaps at depths 7, 26, 30, 40 and 46 cm (Salvatteci, 2008). Moreover, X-ray digital radiographies show a laminated sedimentation, but Pisco 06 displays a slump between 50 and 60 cm (Fig. 2). Both cores were collected from a water depth of 300 meters. These time gaps were considered in correlating the cores, whose ages were calibrated from carbon-14 and U-Th dates. Radiocarbon dating showed that the sedimentation period covers the last 700 hundred years BP and the age model display a sedimentation rate of 220 cm/ka (Sifeddine *et al.*, 2008).
Two sub-surface currents act in South America coast: Sub-Surface Peruvian Current and the south extension of Cromwell Current. The surface water is influenced by the Peruvian Current (or Humboldt Current), which flow northward carrying cold waters from Antarctic Circumpolar Current (ACC). The ACC converges with the South Equatorial Current which migrates westward in tropical latitude. Between the South and North Equatorial currents the Equatorial Counter Current flows eastward driven by trade winds and produces a difference in the surface level of the ocean, which result in a stacking of water in west Pacific. This phenomenon is known as El Niño/ La Niña Southern Oscillation (ENSO) and is the

main accountable for the upwelling in the region, which was characterized as a region of greatest productivity in the world (Carr, 2002).
Hydrodynamic characteristics in the region are driven mainly by trade winds and by intensification/ weakening of Intertropical Convergence Zone (ITCZ). According to Gutierrez *et al.* (2009) seasonal and decadal variations of ITCZ and trade winds are the key drivers of changes in the biogeochemical proxies of the Pisco 6 and Pisco 14 cores and modulate the productivity and oxygen concentration in the region. Organic and inorganic parameters were analyzed in the cores and showed a drift in the ITCZ position northward after the Little Ice Age (LIA) (Sifeddine *et al.*, 2008). This suggests that changes in the parameters are modulated by processes with long term scales.

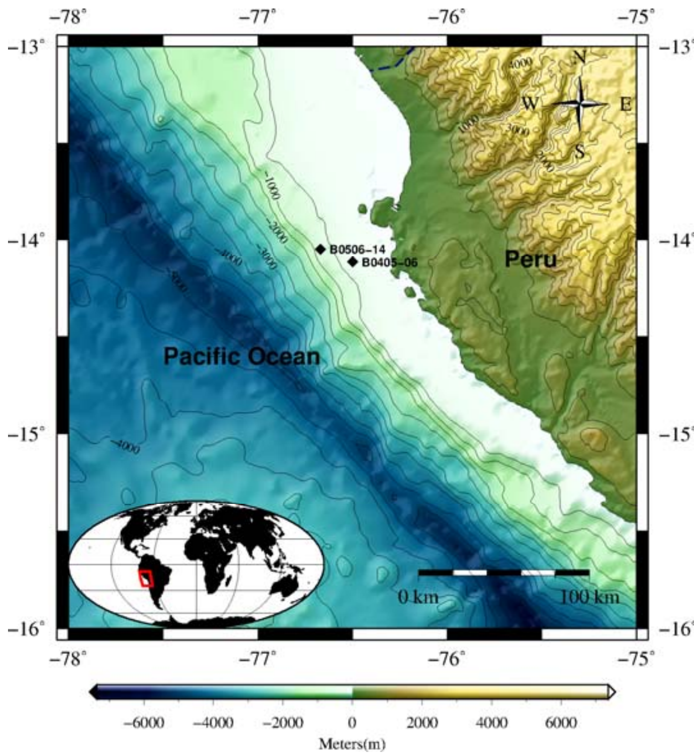

Figure 1: Location of the studied cores off the coast of Peru

Results

The magnetic mineralogy assembly throughout cores Pisco 06 (Fig. 2a) and Pisco 14 (Fig. 2b) was investigated through First Order Reversal Curves diagrams (FORC) and Zero Field Cooling curves (ZFC). FORC diagrams show an important contribution of superparamagnetic (SP) grains at depths below 40 cm in both cores. From the top of the cores down to 10 cm the coercivity is moderate to low. It increases significantly between 10 and 35 cm and slightly decreases again at the bottom of the cores. The moderate to low coercivity found in most samples suggests the presence of SD-MD magnetite as the main carrier in our samples. The presence of this mineral is confirmed by the ZFC curves which display Verwey transition in all samples throughout the cores (Figs. 2a and 2b). The insets in these figures display a more remarkable transition after the second derivative. In the top samples (10 and 17 cm in Fig. 2a; 0 and 20 cm in Fig. 2b) the Verwey transition is more abrupt whereas in the bottom samples they show a less marked fall.

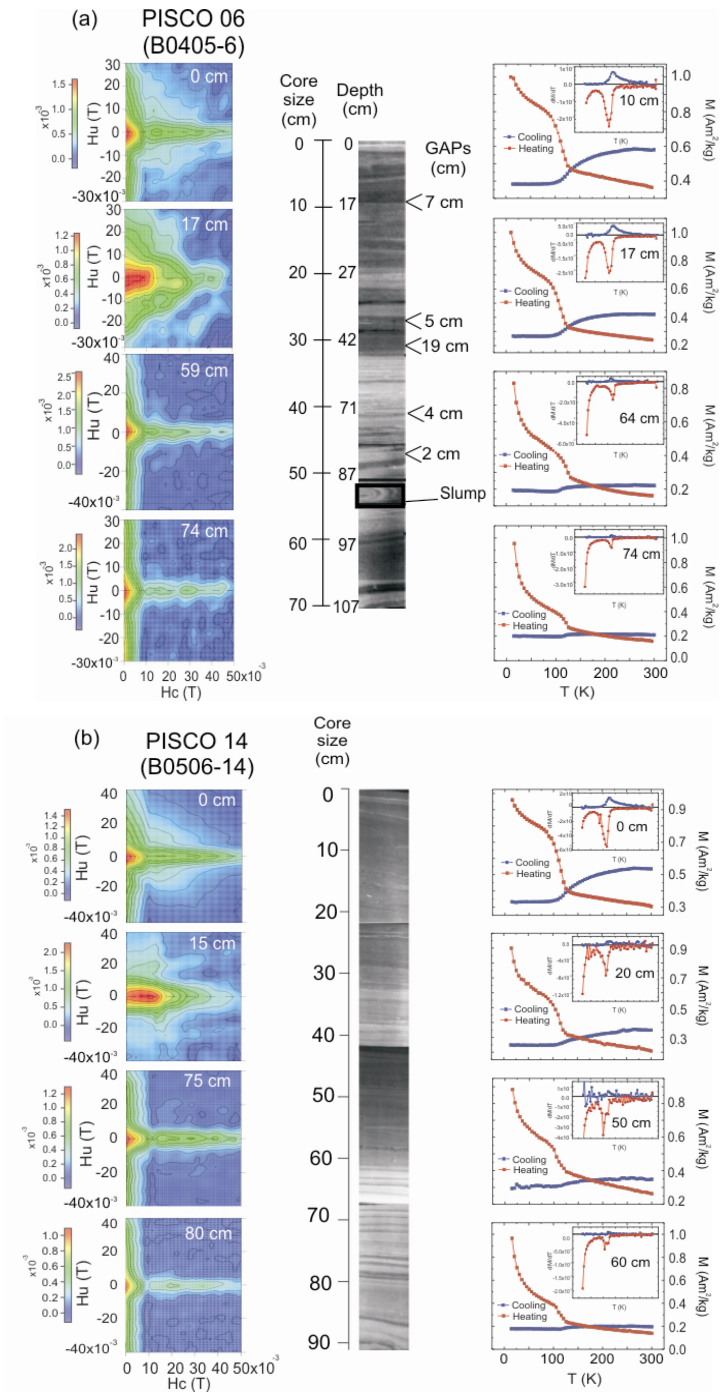

Figure 2: X-ray image of the cores (center) and magnetic mineralogy analysis (left: FORC diagrams, right: ZFC curves). (a) Pisco 06 and (b) Pisco 14.

Magnetic vectors present high stability (Fig. 3a). We excluded all samples with maximum angular deviation (MAD) greater than 12°, which amounted ten samples from the Pisco 06 and four samples from the Pisco 14. Excellent correlation was verified between neighboring samples in both cores, producing a very smooth pattern for inclinations and relative declinations (Figs. 3b and 3c). Directions show a good agreement with the geomagnetic models between around 1740-1900 AD, with two to three decades of delay-time, which may arise from the difference between settling time (dated by 14-carbon) and remanence lock-in time in the sediments. For older periods the directional data deviate significantly from the models.

(a)

(b)

(c)

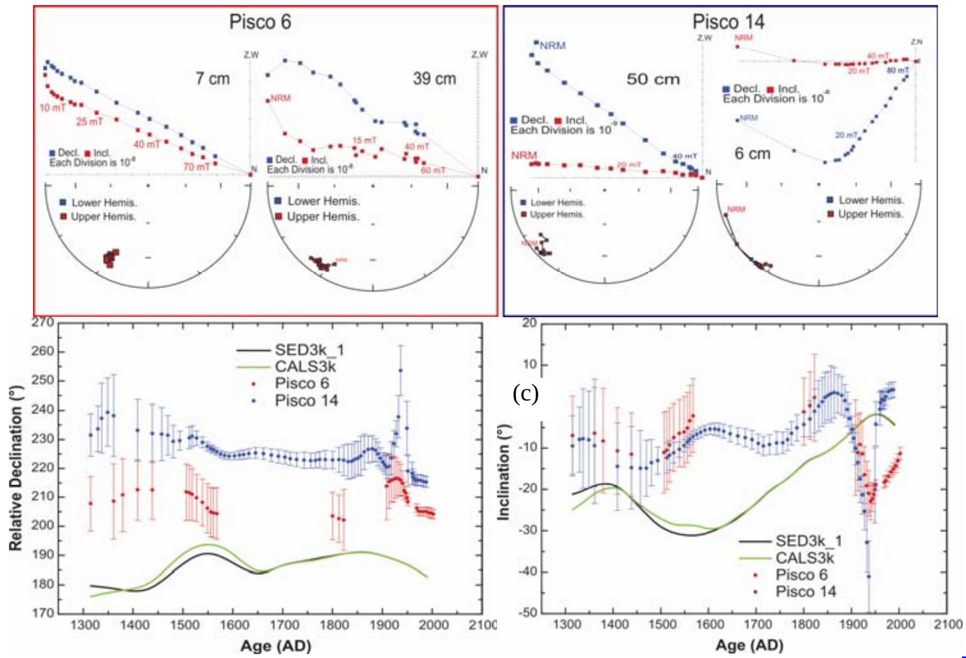

Figure 3: (a) Zijidervelds and estereograms representative of the directions stability along the cores, (b) relative declination and (c) inclination.

Relative paleointensity results were obtained from classical normalization by ARM_{10mT} and IRM_{1000mT} and also present a coherent path within and between cores. We compared our results with the models from Jackson *et al.* (2000) (Gufm1), Gubbins *et al.* (2006), Finlay *et al.* (2008) and Korte *et al.* (2009) (ARCH3k, CALS3k and SED3k). Our data show a similar decrease in intensity after 1700 AD but the strong fluctuations observed in the cores for older ages are not matched by models predictions. The sudden increase in intensity from 1540 to 1650 AD accompanies a dramatic change in magnetic mineralogy and also a change in biogeochemical proxies (e.g., Siffedine et al., 2008; Gutierrez et al., 2009). So, we take the data older than 1650 AD with caution. Between 1650 and 1940 AD we consider that our paleointensity can be used as a proxy of the magnetic field intensity. They vary smoothly and present the same trend of the models.

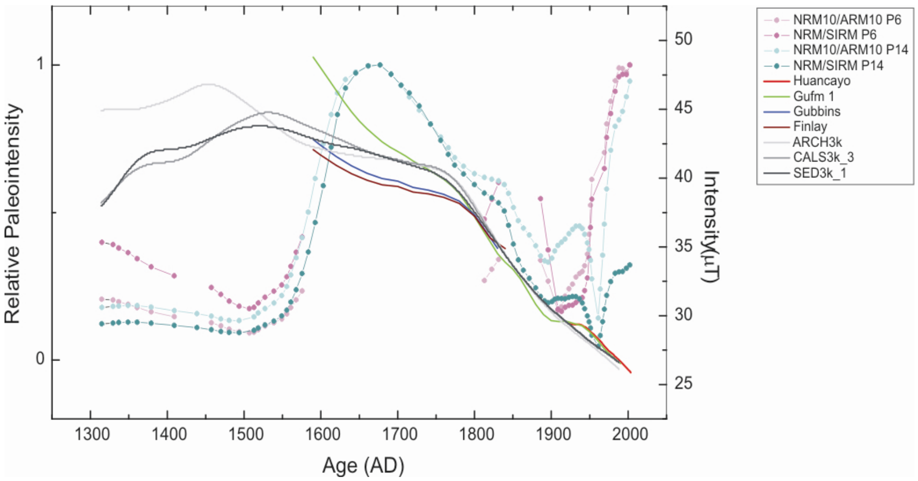

Figure 4: Comparison of the relative paleointensity with the existing models and with the Huancayo observatory.

Conclusions

Our data show a good agreement with geomagnetic models after 1750 AD for directions and after 1700 AD for relative paleointensity, but for older period relative intensity and directional data deviate significantly from the models. This indicates that either below the corresponding depth we had a significant disturbance of the primary directional signal or that the models are affected by some bias in the region towards higher inclination between 1300-1840 AD. The disturbance can result from inaccuracies in the sediment's record, but can be related also to the scarcity of data in a region where the magnetic field is particularly complex; the closest sites used in models being Argentinean lakes 5,000 km away (e.g. Gogorza *et al.*, 2006). The first hypothesis seems to be contradicted by the well-defined magnetic directions observed throughout the cores (Fig. 3a) and the coherent patterns of directions (Figs. 3b and 3c) and relative intensities (Fig. 4) observed between the two cores. Our dataset is the only one in a radius of 5,000 km and the closest sites (Argentinean lakes) correspond to sediments deposited much slower (~20 cm/kyr). Moreover, important non-dipolar anomalies present in the region along the last two centuries may interfere significantly on model's outputs. Therefore, we advocate that our results can adequately describe the ancient field in the period from 1650 AD up to 1900 AD. The differences between the relative paleointensity and the models are related to the lack of data in a region where the field is particularly complicated. Our data show good agreement with geomagnetic models after 1750 AD for directions and after 1700 AD for relative paleointensity, but strongly depart from them before that time. Our preliminary data off the Pacific South American coast shows that good-quality directional and intensity results are urgently required in the region in order to improve the current geomagnetic models.

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