PRELIMINARY RELATIVE PALAEOINTENSITY RECORD AND CHRONOLOGY ON SEDIMENTARY CORES FROM LAKE ESMERALDA (VEGA ISLAND, ANTARCTICA)

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ABSTRACT

Four cores from bottom sediments of Lake Esmeralda, Vega Island, Antarctica (60°48'S, 57°37'W) were analysed to achieve relative palaeointensity (RPI) records. Rock magnetic studies suggest that the main carriers of magnetisation are ferrimagnetic minerals, predominantly pseudo single domain (PSD) (titano) magnetite. The magnetic grain size of the samples is in the range 1-5 μm and the variation of the inter-parametric ratios is less than one order of magnitude. Demagnetization of the natural remanent magnetization (NRM) shows a stable remanent magnetization in most of the samples. Thus, the samples fulfil the necessary conditions to calculate RPI. Radiocarbon dating was conducted on three sediment samples. Then, a combined method of radiocarbon and RPI dating was applied. The RPI records obtained in this work are in good agreement with reported records from the area and Patagonia (Argentina). According to the results, the records of Lake Esmeralda span the last 15,000 cal. BP. A hiatus was found at around 10,980 cal. BP, and apparently the sedimentation ceased during 1,800 years. The mean sedimentation rate is 0.3 mm/yr reaching a maximum of 1.3 mm/yr, which is expected for the region under study.

Key words: Paleomagnetism, Radiocarbon dating, Relative palaeointensity record, Antarctic dating.

RESUMEN

Se analizaron cuatro testigos de sedimentos del fondo de la Laguna Esmeralda, Isla Vega, Antártida (60°48'S, 57°37'W) con el objeto de obtener registros de paleointensidad relativas (RPI). Los estudios de magnetismo de roca sugieren que los principales portadores de la magnetización son minerales ferrimagnéticos, fundamentalmente, (titano) magnetita de dominio pseudo simple (PSD). El tamaño de grano magnético de las muestras se encuentra entre 1-5 μm y la variación de los cocientes interparamétricos es menor a un orden de magnitud. Los experimentos de desmagnetización de la magnetización remanente natural (NRM) muestran una magnetización estable en casi la totalidad de las muestras. Por lo tanto, las muestras cumplen con las condiciones necesarias para calcular RPI. Se realizaron dataciones radiocarbónicas en tres muestras de sedimentos. Con los estos datos se aplicó un método combinado de datación radiocarbónica y por RPI para ajustar las edades. El registro de RPI obtenido en este trabajo concuerda con registros previos del área y la Patagonia (Argentina). Los resultados indican que el registro abarca los últimos 15,000 cal. BP. Se encontró un hiato alrededor de 10,980 cal. BP, aparentemente la sedimentación cesó durante un período de 1,800 años. El ritmo de sedimentación promedio es de 0.3 mm/año alcanzando valores de 1.3 mm/año, el cual es un valor esperado para la región estudiada.

Palabras clave: Paleomagnetismo, Datación radiocarbónica, Grabaciones de paleointensidades relativas, Dataciones Antárticas

Introduction

Water bodies and their sediments are containers of diverse information. In particular, lakes were widely used for palaeoclimatic and palaeomagnetic studies around the world (Stoner *et al.*, 2002; Irurzun *et al.*, 2006; Gogorza *et al.*, 2012; Lisé-Pronovost *et al.*, 2012). The last ones are very scarce in Antarctica. Most of the Antarctic studies were carried out in ice cores, sea sediments or igneous rocks (Ciesielski, Weaver, 1974; Grunow, 1995; Wilson *et al.*, 2007) and only a few in lakes (Zale, Karlén, 1989; Björck *et al.*, 1996; Brachfeld *et al.*, 2000; Willmott *et al.*, 2006). The main problem with this region is to calibrate the sediments because of the limited organic matter and in consequence low quantities of organic carbon to get a reliable radiocarbon dating, and on the other hand, the reservoir effect (Doran *et al.*, 1999). The purpose of this study focuses on obtain a high quality RPI curve, and calibrate the sediments of Lake Esmeralda using a combination of radiocarbon and RPI dating.

Methodology

The four cores (fig. 1) were extracted from the deepest zone of Lake Esmeralda (5.8 m) during the Summer Antarctic Field Work 2007 (Campaña Antártica de Verano 2007, CAV2007). The extraction was made from an inflatable raft with a manual drill which allows obtaining hemi-cylindrical cores of 7 cm in diameter and 1 m in length. The cores were described macroscopically, photographed, sub-sampled with 8 cm^3 cubic plastic boxes and stored at 4°C. A total of 357 sub-samples were obtained. Low-field volumetric magnetic susceptibility (κ) was measured with a Bartington Instruments MS2 system. NRM were demagnetized in an alternating field (AF) with a shielded demagnetizer (Molspin Ltd.) in growing peak field steps (5, 10, 15, 20, 25, 30, 40, 50, 60, 80 and 100 mT). Once ARM acquisition was done, the samples were demagnetized in the same steps as NRM. Saturation of isothermal remanent magnetization

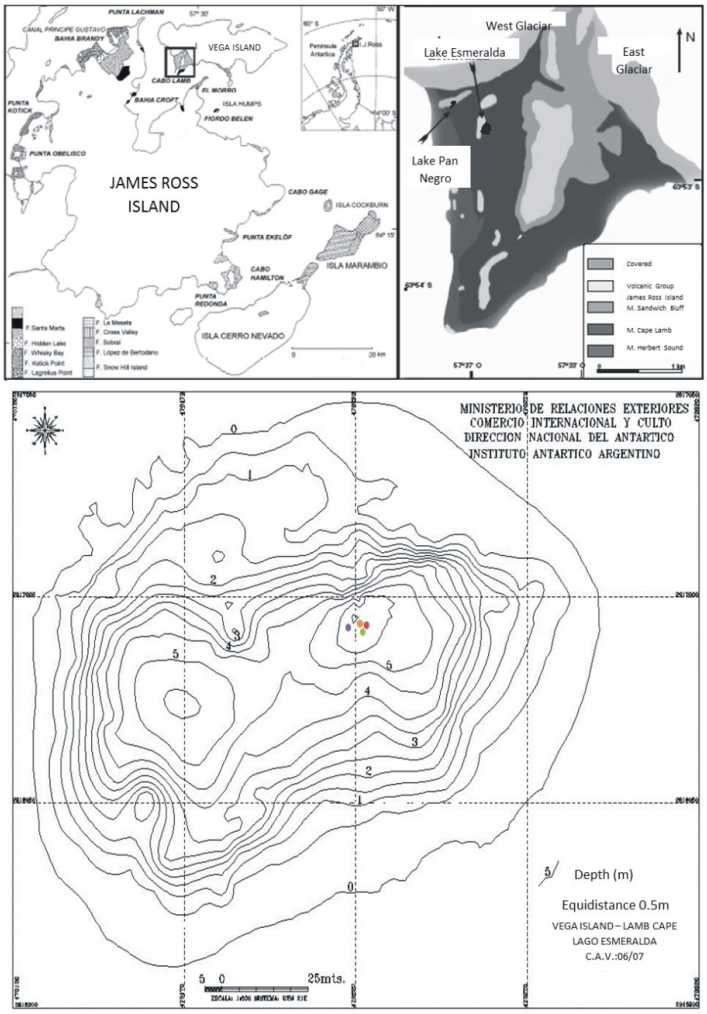

Figure 1. Study area and location of the cores: ESM2, ESM4, ESM6, and ESM7.

(SIRM) was acquired with a pulse magnetizer (model IM-10-30, ASC Scientific) with a field of 1.2 T, then demagnetized in the same steps that the NRM. Remanence magnetizations were measured with a JR6A Dual Speed Spinner Magnetometer (Agico Instruments) and a 2G-Enterprises long-core rock-magnetometer. SIRM for core ESM7 was measured on mini samples (< 50 mg) at room temperature using a Princeton Measurement Corporation Micromag 2900 AGM system equipped with a 2.2 T magnet.

Results and discussion

The cores show predominance of clay, rythmites composed by clay and fine sand of variable thickness (1-5 mm), anoxic zones and abundant organic matter. The sediments of Lake Esmeralda show at the base a dark deposit consistent of coarse gravel with basaltic sharp clusters. The sequence has horizontal thin lamination at the lower and middle zone, which becomes inclined towards the top. In some cores, a level of 5 cm thick was found, with syn-sedimentary disturbance which deforms and folds the rhythmites. There are dark layers, several centimetres thick, with microscopic algae. The cores show lateral changes, possibly due to the influence of a stream that flows into the lake. The inclined layers on the top suggest deltaic-lacustrine environment. A hiatus at 120 cm from the top was found in core ESM6.

Two results from radiocarbon dating were accepted while the other (at the surface) was rejected (Table 1). The rejected date was too old, probably because of the lack of enough carbon for the estimation. The calibration was made using Oxcal 4.1 calibration software (Bronk Ramsey, 2001; 2008).

To obtain high quality RPI records (Tauxe, 1998), the NRM must come from stable magnetite with magnetic grain size between 1-15 μm and the magnetic concentration should not vary more than an order of magnitude. The parameters used for RPI calculation (κ, ARM and SIRM) should be linearly related to each other and the normalization should be carried out by several methods providing consistent results.

Core ESM2 show the same behaviour as the other cores (Sinito *et al.*, 2011). Ferrimagnetic

Laboratory number	**Material**	**Depth from the top (cm)**	**Age $^{14}C \pm \sigma$ [yrs]**	$\delta^{13}C$	**Age cal. BP $\pm \sigma$ [yrs]**
N89405	Pollen and charcoal residue from surface sample (ESM7)	Surface	24,710 ± 170	-25	Rejected (too old)
AA100091	Sediment (ESM6)	121	9,636 ± 59	-25.9	10,982 ± 127
AA100092	Sediment (ESM6)	222.5	12,260 ± 110	-26.5	14,286 ± 279

Table 1. Radiocarbon dating and information derived from Lake Esmeralda: Radiocarbon laboratory number, material of the samples, depth from the top of the core, age in ^{14}C with the associated $\delta^{13}C$ and the calibrated age obtained.

minerals with PSD (titano) magnetite as main magnetic carrier of the remanent magnetization and low proportion of paramagnetic and antiferromagnetic minerals were found. The magnetic grain size is around 1-5 μm and the magnetic concentration is between 0.003 and 0.03 %. A stable remanent magnetization was isolate in 352 sub-samples. A viscous remanent magnetization was erased between 10 and 15 mT. Then, for RPI studies, the NRM and ARM after demagnetization at 20 mT were used. Because of the different equipment utilized for SIRM measurements, the values of specific SIRM were used. We conclude that the uniformity of rock magnetic results from these cores is well within the criteria proposed for relative paleointensity studies.

Figure 2 shows a linear relationship between the RPI parameters after core correlation. The Pearson's coefficient (r) between κ and ARM is 0.63, between κ and SIRM is 0.59, and between ARM and SIRM is 0.77. In all cases, r is higher than 0.5 indicating a positive statistically significant correlation.

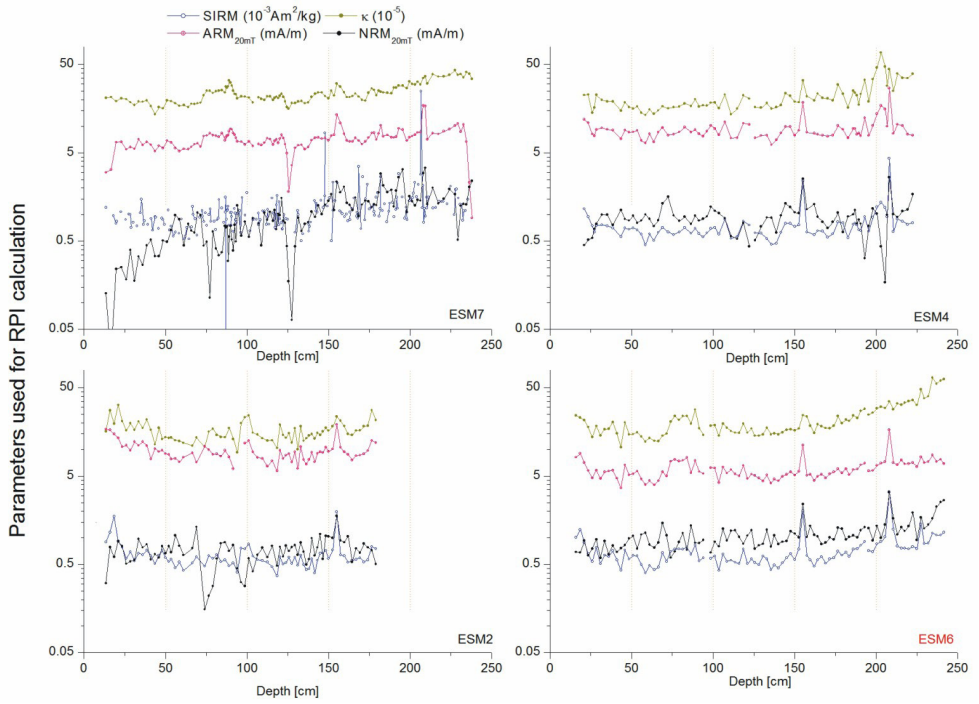

Figure 2. Parameters used for RPI calculation versus depth.

On each core, the RPI was calculated dividing NRM by ARM, κ and SIRM, respectively. The average value was calculated for each ratio and then the RPI was normalized to its mean. The obtained curves showed very similar behaviour for each core. The four cores showed most of the characteristic peaks and troughs. Because of the same trend was found in the cores ESM, a stacking process between the normalized RPI records between the cores was done.

Figures 3a and 3b show the correlation between the mean RPI curves and other records from the Southern Hemisphere. The Esmeralda record was split into two, divided by the hiatus. The purple arrow indicates one of the calibrated ages obtained by ^{14}C dating. The other age is indicated as a purple point at the beginning of Figure 5b because is the first sample after the hiatus. From 0 to 90 cm, the record shows a well agreement with the 1000 yrs averaged records from Laguna Potrok Aike. From 90 to 250 cm, the agreement is better with the 100 yrs averaged record from Potrok Aike. The different agreement between the RPI of Lake Esmeralda and the 100 and 1,000 yrs averaged record from Potrok Aike, are probably due to the different sedimentation rates caused by environmental changes.

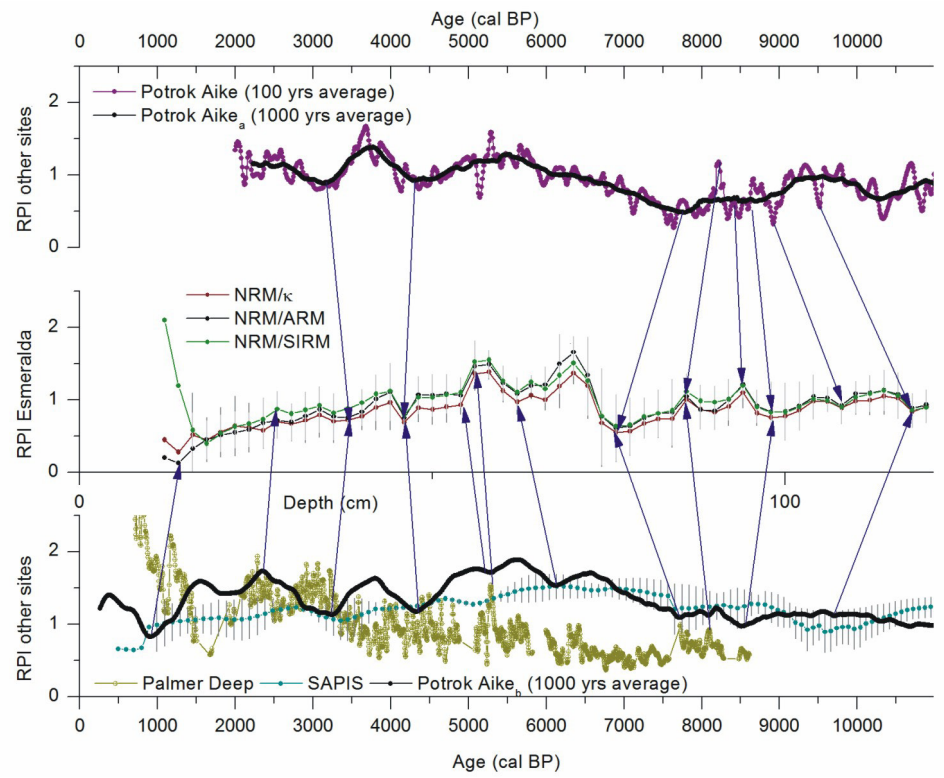

Figure 3. Correlation lines between RPI from Lake Esmeralda and other sites: Potrok Aike 100 yrs average and Potrok Aike$_a$ 1,000 yrs average (Gogorza *et al.*, 2012), Palmer Deep (Brachfeld *et al.*, 2000), SAPIS (South Atlantic geomagnetic paleointensity Stack, Stoner *et al.*, 2002), Potrok Aike$_b$ (1,000 yrs average, Lisé-Pronovost *et al.*, 2012). a) After the hiatus. b) Before the hiatus.

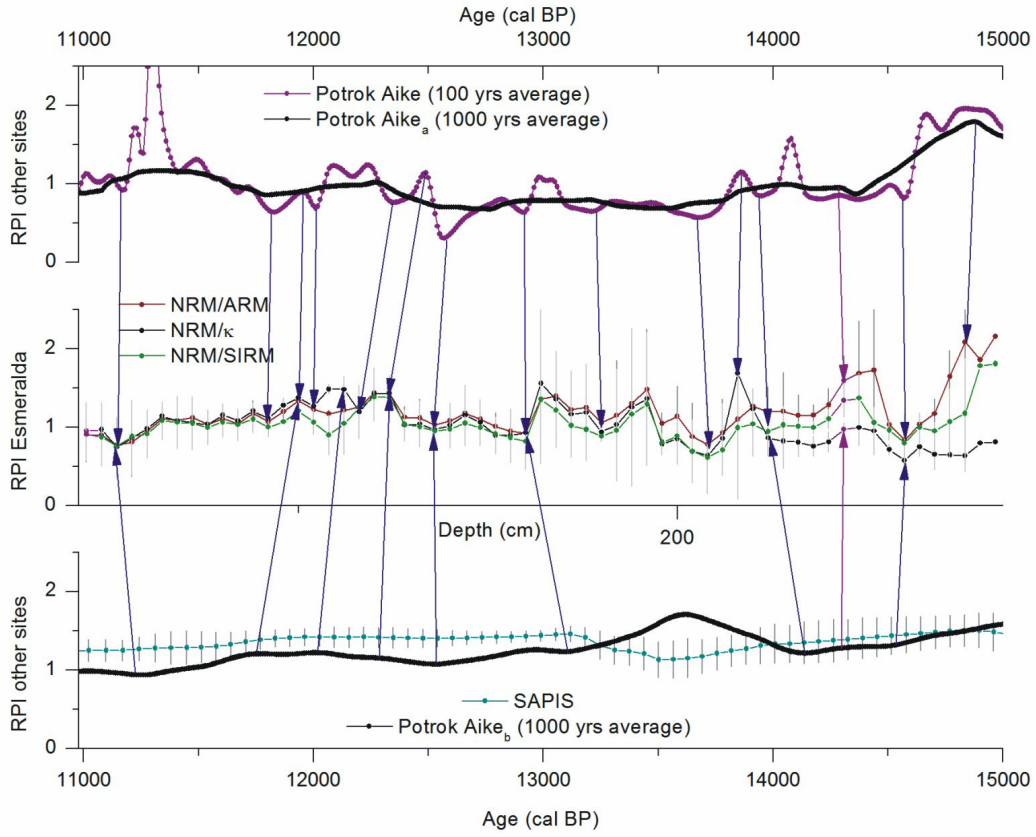

Figure 4. RPI from Lake Esmeralda after correlation with other RPI records from the area. Palmer Deep (Brachfeld *et al.*, 2000), Potrok Aikeb (1,000 yrs average, Lisé-Pronovost *et al.*, 2012) and Potrok Aike (100 yrs average, Gogorza *et al.*, 2012).

The results after RPI correlation are shown in Figure 4. NRM/ARM and NRM/SIRM show high values at about 15,000 cal. BP similar to Potrok Aike records. From 13,770 to 12,000 cal. BP, the Esmeralda RPI is similar to the Potrok Aike RPI (100 yrs average). Low values at 11,210 cal. BP are only found in Potrok Aike (1,000 yrs average). Between 9,100 and 8,000 cal. BP, the record is very similar to the Potrok Aike (100 yrs average) again. For the period 15,000 - 8,270 cal. BP, the sedimentation rate was 0.38 mm/yr with higher values (>0.5 mm/yr) around 14,170; 12,370; 11,840 and 8,960 cal. BP. High sedimentation rates were found in the period 8,700 - 7,300 cal. BP for Laguna Potrok Aike (Haberzetl *et al*., 2007) and attributed to extremely dry environments which allow allochthonous material reach the lake.
From 8,000 to 1,200 cal. BP, the NRM/κ, NRM/ARM and NRM/SIRM from Lake Esmeralda have an analogous behaviour to Potrok Aike (1,000 yrs average). Finally, for the last 1,200 cal. BP, the NRM/κ and NRM/ARM show a decreasing trend as the other sites while the NRM/SIRM shows an increasing trend only found in Palmer Deep record. The sedimentation rate from 8,200 cal. BP to the present is 0.11 mm/yr.

Conclusion

A high quality RPI curve was achieved for Lake Esmeralda (Vega Island, Antarctica), this important dating tool and only two radiocarbon dates allow us to date 250 cm of Antarctic lake sediment. The RPIs were calculated by three normalizations methods and the results have a very good agreement; however, the NRM/ARM ratio shows the best correlation with other reported records from the area. Before 8,200 cal. BP, the Esmeralda RPI shows a good agreement with high resolution record from Patagonia, Argentina. Meanwhile, from 8,200 cal. BP to the present, the Esmeralda RPI agrees better with low resolution records. NRM/SIRM shows a similar trend for the last 1,200 cal. BP with another Antarctic marine record. The differences are probably due to the different sedimentation rates. Although other radiocarbon dates are needed to tune (refine) the chronological scale, the Esmeralda RPI itself constitutes an alternative and useful dating tool for Antarctic lacustrine sediment.

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