HIGH-RESOLUTION PALEOMAGNETIC RECORDS FROM LAGUNA POTROK AIKE (PATAGONIA, ARGENTINA) FOR THE LAST 16,000 YEARS

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Abstract

Holocene and Late-glacial records documenting variations in direction and intensity of the geomagnetic field during the last 16,000 cal. BP are presented for Southern Patagonia. This continuous high-resolution terrestrial record from Laguna Potrok Aike (51°58’S, 70°23’W) was recovered within the SALSA (South Argentinean Lake Sediment Archives and modeling) project. Mineral magnetic measurements indicate that pseudo single-domain magnetite is the major carrier of the remanence allowing the reliable definition of stable natural remanent magnetization inclinations and declinations from alternating field demagnetization and principal component analysis. Paleomagnetic secular variation records reveal many of the familiar features of declination and inclination that have previously been recorded in other records from South Argentina but conspicuous centennial-scale differences are also observed. The results illustrate the potential of PSV records for dating sedimentary sequences in southern South America.

Resumen

En este trabajo se presentan los resultados de las variaciones direccionales y de intensidad del campo geomagnético durante los últimos 16000 años correspondientes al periodo holocénico y la última glaciación en el Sur de la Patagonia. Estos registros continuos y de alta resolución fueron obtenidos en el marco del proyecto SALSA (South Argentinean Lake Sediment Archives and modeling). Las mediciones de los minerales magnéticos indican la presencia de magnetita de pseudo-mono dominio como principal portador de la remanencia, lo cual permite la obtención de registros estables de inclinación y declinación a partir del análisis de componentes principales de los resultados de desmagnetización mediante campos alternos. El estudio de las variaciones seculares obtenidas muestra resultados tanto en inclinación como en declinación, previamente obtenidos en otros lagos del Sur de Argentina, aunque se observan importantes diferencias a escalas centenarias. Estos resultados ilustran el potencial de las variaciones seculares como herramienta de datación en Sur América.

Introduction

The paleomagnetic secular variation (PSV) of the Earth’s magnetic field obtained from soft lacustrine sediments during the last decades (e.g., Frank et al., 2002; Yang et al., 2009) have been essential to reconstruct the dynamic behavior of the Earth’s geomagnetic field at high-resolution beyond the range of instrumental observations. During the last decade, we therefore have made an effort to reconstruct
the behavior of the Holocene geomagnetic field by studying sediment records of lakes from southwestern Argentina (e.g. Gogorza et al., 2000; 2004, 2006, 2011; Irurzun et al., 2006, 2009) in order to fill the gaps of data distribution for the Southern Hemisphere. Here, we present a high-resolution record from Laguna Potrok Aike which provides a valuable correlation tool for this region and geomagnetic time-series data in a previously poorly represented part of the globe. The resolution of the new SALSA record is actually an order of magnitude higher than any available records in this region up to the present.

Study Area

Laguna Potrok Aike is a maar lake located in southern Santa Cruz, Patagonia, Argentina (51º58’S 70º23’W). Roughly 90 km west of the city of Río Gallegos and 80 km north of the Strait of Magellan, it is situated in the Pali Aike Volcanic Field (Fig. 1). The volcanic setting of Laguna Potrok Aike ensures a strong magnetic component in the material, and the potential to make detailed magnetic measurements.

Methodology

Two overlapping sediment cores from the 100 m deep central basin (PTA03-12/13) showing a high sedimentation rate (Haberzettl et al., 2007) and one core at 47 m water depth (PTA03-5) showing a much lower sedimentation rate (Haberzettl et al., 2009) were recovered with an UWITEC piston coring system in 2003 (Fig. 1). In the laboratory sediment cores were stored dark and cool at +4°C. All cores were cut into meter sections and split open, photographed and described lithologically.

Cores PTA03-12/13

Magnetic susceptibility (k) measurements were performed on split cores with a Bartington MS2F point sensor at 1 cm intervals (Haberzettl et al., 2007). The top of the deep basin record was already studied sedimentologically in gravity core PTA02/4 (95 cm) (Haberzettl et al., 2005) and paleomagnetically in gravity cores PTA05/11, 12, 16 and 17 (Gogorza et al., 2011). After a detailed correlation of short and piston cores using macroscopic sedimentological features and physical properties, the total length of the composite record PTA03/12+13 was established to 1892 cm. After the core was split lengthwise, cubic plastic boxes were pushed into the split core faces, and the resulting sample was removed with a plastic spatula. In harder sediments, samples were cut from the core with a sharpened, thin-walled 2x2-cm stainless steel tube. Magnetic susceptibility was measured at low and high frequencies using a Bartington MS2 magnetic susceptibility meter at 0.47 kHz (k\text{low}) and 4.7 kHz (k\text{high}), respectively. The F\text{factor}(\%) was calculated from the difference between measurements at high and low frequencies, i.e., F\text{factor}(\%) = (k\text{low}-k\text{high}) * 100/k\text{low}. 
For the determination of intensity and directions of the natural remanent magnetization (NRM, D and I), samples were measured using a JR6A Dual Speed Spinner Magnetometer. Alternating Field (AF) demagnetization and principal component analysis (*Kirschvink*, 1980) have been applied to determine the characteristic stable inclinations and declinations of the natural remanent magnetization (NRM). About 20% of the samples were completely demagnetized as pilot samples in steps of 5-10 mT (11 steps to a maximum alternating field of 100 mT). These results were used to determine the best procedure for demagnetizing the rest of the samples, which were demagnetized in five stages (5-40 mT). The Anhysteretic Remanent Magnetization (ARM) was acquired in a peak alternating field of 100 mT with a steady bias field of 0.1 mT (ARM$_{100mT}$). The Isothermal Remanent Magnetization (IRM) was acquired at room temperature in increasing steps up to 1.2 T reaching saturation (SIRM) and in growing steps back until canceling the magnetic remanence using the Pulse Magnetizer IM-10-30 (ASC Scientific). Subsequently, AF demagnetization of the ARM$_{100mT}$ and SIRM were measured using the same steps as for the NRM demagnetization. Finally, a group of pilot samples was subjected to thermal demagnetization after applying a direct field of 1.2 T, followed by thermal demagnetization in 15 steps from 75°C to 700°C. All magnetizations have been measured on a JR6A Dual Speed Spinner Magnetometer.

Core PTA03-5
Continuous u-channel samples were taken from the core half in 2008 comprising 168 cm which due to the lower sedimentation rate is equivalent to the time period covered by PTA03/12+13 (*Haberzettl et al.*, 2009; Fig. 1). Magnetic susceptibility was measured at 4 mm intervals using a Bartington MS2E point sensor at the University of Bremen (Geopolar), whereas k of the u-channel was measured at 1 cm intervals using a Bartington MS2C magnetic susceptibility loop sensor at the Institut des sciences de la mer de Rimouski (ISMER). Declination, inclination and NRM as well as the induced remanences ARM (using a 0.05 mT DC biasing field), IRM$_{300mT}$ and IRM$_{950mT}$ were measured in progressive AF demagnetization steps from 0 to 70 mT at 5 mT increments using a 2G u-channel cryogenic magnetometer and IRM pulse magnetizer.

**Magnetic Results**

Magnetic carrier mineral
The rock magnetic data for the cores are summarized in Fig. 2. Thermal demagnetization of SIRM demonstrates the predominance of magnetite with a Curie temperature of 580°C as the carrier of magnetization in these sediments. A change in the slope of the heating curves between 200 and 350°C would confirm the presence of titanomagnetite and maghemite (*Dankers*, 1978).

Finally, a small magnetization component remaining while heating above 600°C suggests contribution of hematite to the magnetic properties of a few samples (Fig. 2a). Stepwise acquisition of isothermal remanent magnetization (IRM) in the field up to 1.2 T documents that more than 90% of SIRM were
acquired in the field of 200 mT (Fig. 2b). Progressive removal of SIRM by applying reversed fields indicates that the remanent coercive field of the SIRM ($B_{CR}$) varies approximately between 29 and 64 mT suggesting that a low coercive magnetic mineral, such as magnetite of pseudo-single domain size (PSD) might be predominant within the sediments. The $S_{\text{ratio}}$ ($IRM_{300mT}/SIRM$) varies between 0.8 and 1, with a mean value of 0.969±0.001, indicating magnetite as the dominant magnetic mineral (Thompson, 1986). The SIRM-susceptibility plot (Fig. 2c) implies that the magnetic concentration is mainly between 0.01% and 0.1% magnetite by volume and the SIRM/$k$ ratio is consistent with a magnetic grain size of 4-10 μm. The linearity of sample points on the SIRM vs. susceptibility plot (Fig. 2c) implies that the grain size does not change much within the sediments. Frequency-dependent susceptibility ($F_{\text{factor}}$) is very low and practically uniform, indicating the dominance of non-super-paramagnetic ferrimagnetic minerals (Fig. 2d).

**PSV records**

![Diagram](image)

The NRM median destructive field ($MDF_{NRM}$) ranges from 6 to 26 mT, and NRM intensities are almost completely demagnetized in fields of 60 mT. The orthogonal demagnetization diagrams show that a viscous remanent magnetization - if present at all - is progressively removed between 5 and 10 mT. A stacking process, consisting of the arithmetic average, with previous interpolation every 30 years was performed. The agreement between inclination and declination curves is good and comparable from core to core (Fig. 3a). After stacking (3b), it is necessary to diminish the amplitude of high-frequency changes in the PSV records originating either from random error (noise) during coring, sampling, palaeomagnetic measurements and/or remanence acquisition. It was carried out by smoothing the directional data using a five-point adjacent-averaging window using the OriginPro 7.0 software (3c). Stable inclinations and declinations after this processing are evident from Fig. 3c. Inclinations vary mostly between -40° and -80°. The average inclination ($\sim-62.2^\circ±0.4$) is lower than the predicted inclination of a geocentric axial dipole field (GAD) of $\sim-69^\circ$ at the latitude of the site (52°S). Despite this difference, the relative changes are good and comparable from core to core.
Relative Paleointensity Records

Rock magnetic characteristics, including the well-defined magnetization component carried by pseudo-single domain (PSD) magnetite, and variation of less than a factor of 10 in the magnetic concentration satisfy the standard criteria for paleointensity studies (Tauxe, 1993). According to the AF demagnetization characteristics of NRM directions, relative paleointensities (RPI) are generated using values of NRM, ARM and SIRM after AF demagnetization at 20 mT (\(NRM_{20mT}\), \(ARM_{20mT}\) and \(SIRM_{20mT}\)).

Comparison with other records

Comparison with local records

In order to improve the rough chronology previously obtained by using two tephra by Haberzettl et al. (2009) Mt. Hudson: 8100 cal. BP and Mt. Burney: 8680 cal. BP; see table 1 shown by Haberzettl et al. (2009), the PSV of core PTA03-5 were compared with the high-resolution records obtained in this work (Fig. 4).
Comparison with regional records of SW Argentina

In order to improve the understanding of Holocene to Late Pleistocene PSV in Southern Argentina, a regional comparison of directional records was performed with the inclination and declination records from Laguna Potrok Aike (this work), with lakes Escondido (41° S, 71° 30’ W) (Gogorza et al., 2004), El Trébol (41° 04’ S 71° 29’ W) (Irurzun et al., 2006) and Moreno (41° 5’ S, 71° 33’ W) (Gogorza et al., 2000), all of which are located more than 1000 km north of Laguna Potrok Aike (Fig. 5).

References


