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# Preliminary rock magnetic and paleoenvironmental studies of short sediment cores from Laguna Potrok Aike (Santa Cruz, Argentina)

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## Abstract

We report rock magnetic and magnetic mineralogy results of a preliminary study carried out for five sediment cores recovered from the maar lake laguna Potrok Aike (Patagonia, Argentina). This investigation contributes to a better understanding of the processes related to paleoclimatic and paleoenvironmental changes that occurred in the southern Patagonian steppe during the last ~700 years. In order to characterize the magnetic mineralogy, detailed magnetic measurements were made to investigate the response of the sediments to a variety of applied magnetic fields. This response is mainly determined by the mineralogy, concentration, and grain-size distribution of the magnetic phases. Rock magnetic properties document that main carriers of magnetization are ferrimagnetic minerals, predominantly pseudo-single domain (PSD) magnetite. Intervals of different magnetic content could be related to fluctuations in the lake level that can be associated with climatic variations.

## Resumen

En este trabajo se presentan los resultados de estudios de magnetismo de rocas y de mineralogía magnética de un estudio preliminar llevado a cabo en cinco testigos colectados en la laguna maar Potrok Aike (Patagonia, Argentina). Esta investigación contribuye a mejorar la compresión de los procesos vinculados con cambios paleoclimáticos y paleoambientales ocurridos en el sur de la estepa patagónica durante los últimos 700 años. Se llevaron a cabo diferentes mediciones magnéticas con la finalidad de caracterizar la mineralogía magnética. La respuesta está determinada, fundamentalmente, por la mineralogía, concentración y tamaño de grano de la fase magnética. Los resultados de los estudios de magnetismo de rocas muestran que los principales portadores magnéticos son minerales ferrimagnéticos, predominantemente magnetita dominio pseudo-simple. Intervalos con diferentes contenidos magnéticos pueden vincularse a fluctuaciones en el nivel del lago, los cuales pueden ser asociados a variaciones climáticas.

## Introduction

Environmental magnetism is a relatively new science. It essentially grew out of numerous interdisciplinary studies involving sediments in British lakes but soon expanded to include sediments in other natural archives that also retain records of past global changes (Evans and Heller, 2003). In recent decades, magnetic measurements have become a valuable and commonly applied tool in environmental studies. They have expanded rapidly to include studies of the relationship between rock magnetism and environmental processes, with an emphasis on the regional climatic response to global change (Shouyun et al. 2002). Whatever is the particular history of a given geological repository, experience shows that magnetic measurements can be of great value in our attempts to understand the environmental conditions that prevailed in the past. This is because magnetic minerals - particularly iron oxides - occur more or less universally; iron is one of the most common elements in the Earth's crust. Iron bearing minerals are present in minor amounts (usually less than 1%), but they are detected easily, rapidly, and non-destructively (Evans and Heller, 2003).

## Site Description and Sediments

Laguna Potrok Aike is a maar lake located in Southern Santa Cruz, Patagonia, Argentina. Roughly 90km west of the city of Río Gallegos, and 80km north of the Strait of Magellan, it is situated in the Pali Aike Volcanic Field (51º58´S 70º23´W) (Haberzettl et al., 2005). Forty six gravity cores with lengths up to 49cm were recovered from Laguna Potrok Aike during a field campaign in 2005 using a modified ETH-gravity corer. In this study a selection of 5 cores is analysed, four cores (PT05-16, PT05-18, PT05-29, PT05-45) were collected from the 100m deep central basin and PT05-28 from a shallower part of 90m depth (Fig. 1). In the laboratory, they were stored dark and cool at 4ºC. Sub-sampling of the cores was carried out continuously with cubic plastic boxes (20mm x 20mm x 20mm) that were pressed into the surface of the split core halves.

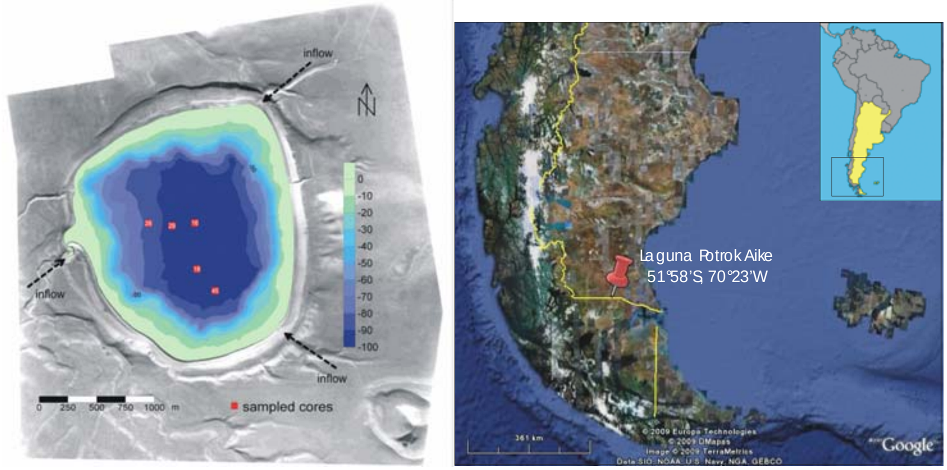

**Figure. 1**

## Sedimentology

Previous studies carried out at Laguna Potrok Aike by Haberzettl et al. (2005) reveal a continuous and high-resolution sedimentary record. The sediment sequence is characterized as minerogenic with only minor amounts of organic carbon and biogenic silica but with varying contents of calcite (Gogorza et al., 2011).

## Methods

To characterize the magnetic mineralogy, detailed magnetic measurements were made to investigate the response of the sediments to a variety of applied magnetic fields. This response is mainly determined by the mineralogy, concentration, and grain-size distribution of magnetic phases.

The procedure used for the magnetic measurements was as follows:
1. Measurements of the magnetic susceptibility at low frequency (k).

2. Acquisition of the anhysteretic remanent magnetisation ($ARM_{100mT}$), with a direct field of 0.1mT and an alternating field between 2.5 and 100mT. After acquisition, the ARM was stepwise demagnetized using nine successive steps at 5, 10, 15, 20, 25, 30, 35, 40, 50, 60, 70, 80 and 95mT
3. Acquisition of isothermal remanent magnetisation (IRM) in growing steps until 1T, reaching the saturation isothermal remanent magnetisation (SIRM); back field, in growing steps until cancelling the magnetic remanence. These measurements were used to calculate the $S_{ratio}$ ($IRM_{-300mT}$/SIRM), the “hard” IRM (HIRM= ((SIRM+$IRM_{-300mT}$)/2)/SIRM), and the remanent coercitive field ($B_{CR}$). SIRM was stepwise demagnetized using the same steps as for ARM.
Associated parameters were calculated:, SIRM/k, $ARM_{100mT}$/k, SIRM/$ARM_{100mT}$, SIRM/k vs. $B_{CR}$, anhysteretic susceptibility ($k_{anh}$) and $k_{anh}$/k.
A Minispin spinner fluxgate magnetometer (Molspin Ltd.) was used for measurements of remanent magnetisation and the magnetic susceptibility was measured using a Bartington MS2 Susceptibilimeter. A pulse magnetiser IM-10-30 AC Scientific and an alternating field demagnetizer Molspin Ltd. with and ARM device were used for IRM and ARM acquisition experiments, respectively.
4. For a set of pilot samples the following parameters were measured:

a) Hysteresis properties (such as saturation magnetisation $M_S$, saturation remanence $M_{RS}$, coercitivity $H_C$, coercitivity of remanence $H_{CR}$ and high-field susceptibility ($k_h$)) using a PMC Alternating Gradient Field Magnetometer,

b) Temperature variation of magnetic susceptibility with an AGICO susceptibilimeter (Advanced Geoscience Instruments CO., LTD. Brno, Czech Republic), MFK1-FA model. The amplitude of the applied alternating field was 200 A/m at a frequency of 997 Hz. The low and high temperature range covered was from -190ºC to 5 C and from 30 C to 700 C, respectively.

## Results

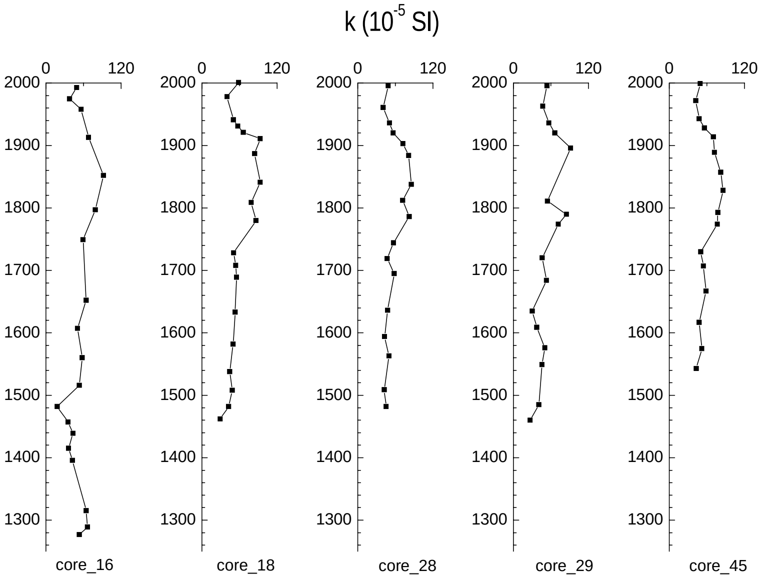

**Figure. 2**

The goal of the analysis of these rock magnetic parameters in the sediment cores is to characterize the magnetic assemblage of the sediment cores. The susceptibility logs of all cores (Fig. 2) are easily correlated and provide a rapid means of stratigraphic correlation, which is achieved without disturbing the core material. Based on variations of sedimentary parameters (Haberzettl et al., 2005) four different units (P1 to P4) have been identified in the studied cores.

Down-core profiles of mineral magnetic parameters are clearly repeatable at all core sites across the basin. Given this broad uniformity between cores, detailed results are presented for one core only, PT05-16.

### Mineral-magnetic characteristics

Plots of rock magnetic parameters of the master core (PTA05-16) are shown in Fig. 3. Down-core profiles of k, $ARM_{100mT}$ and SIRM are clearly repeatable at all core sites across the basin, although $ARM_{100mT}$ and SIRM values are slightly lower (about 10%) in PT05-16. The logs show coherence between them, with correspondence in peaks and troughs as shown in Fig. 2, except $ARM_{100mT}$ that is not so enhanced compared to the other parameters. This result suggests that, although the behaviour of these parameters is mostly influenced by changes in the concentration of the magnetic minerals, there is certain degree of grain-size dependence of these parameters. k values are between 18 and 103 x $10^{-5}$ SI, $k_{anh}$ ranges from 205 to 620 x $10^{-5}$ SI, and $ARM_{100mT}$ and SIRM oscillate between 0.1–0.4 A/m and 4-12 A/m, respectively. They remain almost constant from the bottom to app. 1400 AD, after that, they increase until 1450 AD, and finally decrease to their initial values to the top of the core. Progressive removal of this SIRM by back-field demagnetisation indicates $B_{CR}$ between 25 and 35 mT, which agrees with the characteristic average value of pure magnetite (between 8 and 60mT, Peters and Dekkers, 2003).

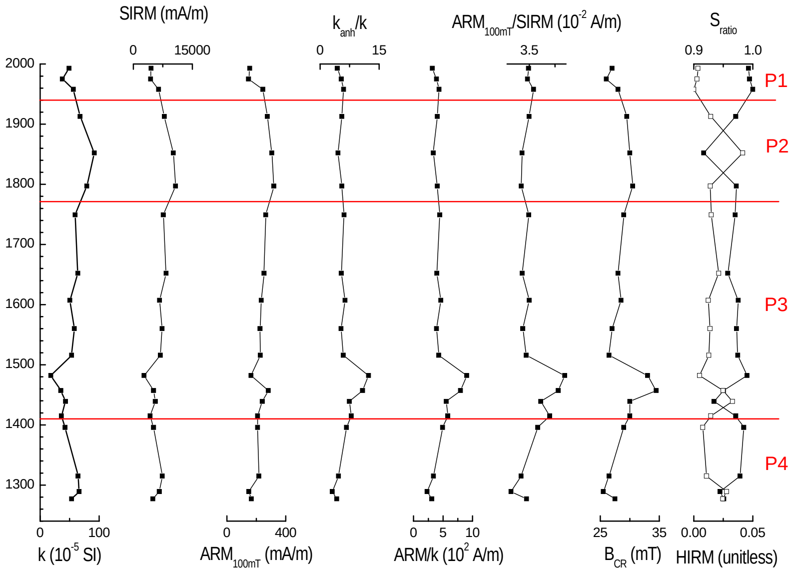

**Figure 3**

The $S_{ratio}$ and HIRM are interpreted to reflect the dominant magnetic minerals present and, in particular, to differentiate between magnetite (soft) and hematite (hard) type minerals (Anderson and Rippey, 1988). The $S_{ratio}$ and HIRM range from 0.9 to 1 and from 0 to 0.05 (Fig. 3), respectively, which suggest that magnetic mineralogy is dominated by ferrimagnetic minerals and, the contribution of anti-ferromagnetic minerals (hematite-type) is not significant (Oldfield, 1991). Another way for assessing mineralogy is the analyses of the ratio SIRM/k vs. $B_{CR}$ (Peters and Dekkers, 2003). Fig. 4.a shows the plot of these parameters for all samples, supporting that magnetite is the magnetic mineral contained in these samples.

$ARM_{100mT}/k$, $k/k_{anh}$ and $ARM_{100mT}$/SIRM imply changes in grain size, higher ratios indicating smaller grain size and a higher proportion of single-domain (SD) grains. The latter concerns only remanent magnetisation and is thus independent from paramagnetic and diamagnetic components. This assumption has been questioned for multiphase assemblages (Anderson and Rippey, 1988). Therefore, interpretation of mixed sedimentary mineral assemblages can be difficult. The presence of one dominant magnetic mineral – but in varying concentration – in our sediment cores is suggested by the plot of k vs. SIRM, which result in a straight line plot (Gogorza et al., 2011). All those ratios show the same pattern in these core sediments: rather constant values (suggesting reasonable uniformity of magnetic grain size along the whole cores) or slight increase (i.e. decrease in magnetic grain size) between 1420 and 1520 AD (Fig. 3). The topmost sediments of all cores show similar values to those observed in the bottom part.

Hysteresis parameters are useful for determining grain size and domain state of magnetite particles (Day et *al*., 1977). The hysteresis ratios are consistent with a dominant low-coercivity ferrimagnetic component (most likely magnetite) that is of PSD magnetic grain size (Fig. 4.b).

Acquisition of temperature-dependent susceptibility cooling and heating curves helps to identify the magnetic minerals in a sample (Hrouda et al., 2003). The curve in Fig. 4.c show a broad peak between 250 and 400 ºC, which can be attributed to maghemite and/or titano-magnetite (with low content of titanium), followed by a linear decrease with a break point at about 580ºC. The Hopkinson peak, which usually indicates multi-domain magnetite, is not observed. These curves are not reversible, which indicates transformation of ferrimagnetic minerals. Curves plotted in Fig. 4.d show a different behavior. Although a wide peak is also observed between 250 and 400 ºC, a broadened Hopkinson peak becomes apparent, possibly due to the mixing of SD titano-magnetite with a low proportion of titanium and multi-domain magnetite, which is characterized by a Curie temperature of 580ºC.

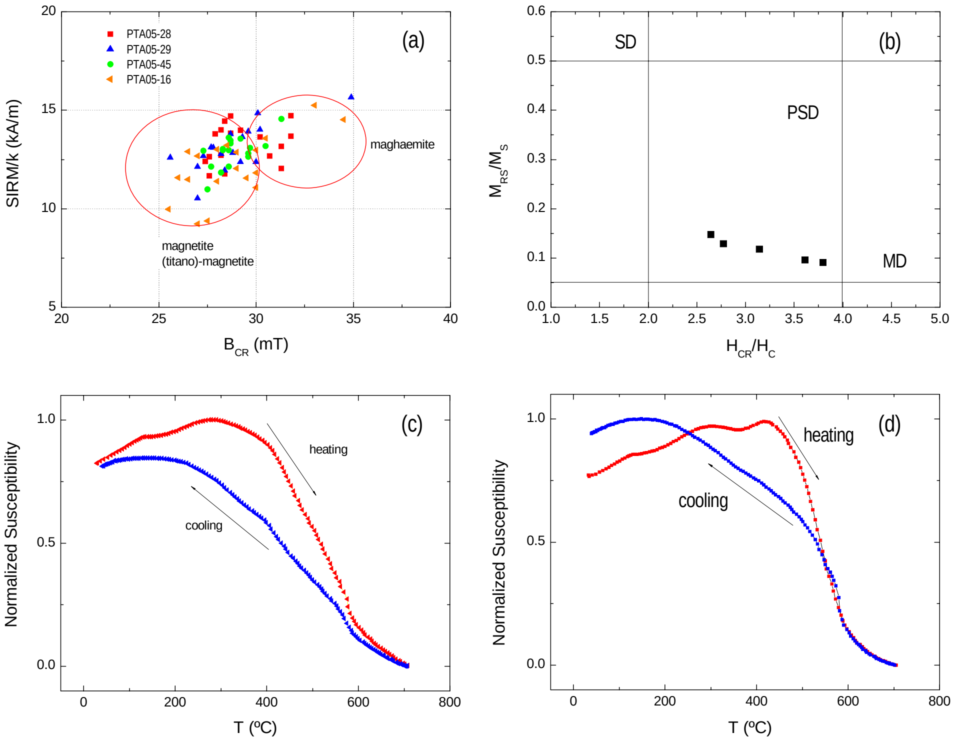

**Figure 4**

## Paleoenvironmental Reconstruction

SHD AD 1260-1410 (P-4)

Concentration-dependent parameters (k and SIRM) show a minor decrease in this period after a small peak at about 1290 AD. Grain size-dependent parameters ($ARM_{100mT}/k$, $ARM_{100mT}/SIRM$, $k_{anh}/k$) and $B_{cr}$ progressively increase. These findings agree with the results of Haberzettl et al. (2005) who report low lake levels and warm and dry climate conditions from the mid 13th century until the early 15th century.

### SHD AD 1410-1770 (P-3)

A slight increasing behaviour of concentration-dependent parameters (k and SIRM) from about 1550 AD may reflect primarily the terrigenous input variations. This result agrees with the findings of Haberzettl et al. (2005) who suggest intensified soil erosion most likely caused by the increased precipitation as expected from the high level lake. From about 1550 AD to 1770 AD, the grain size-dependent parameters ($ARM_{100mT}/k$, $ARM_{100mT}/SIRM$, $k_{anh}/k$) show small variations, which coincide with the constant level lake in this period. No significant changes in $S_{ratio}$ are observed. High peaks of $ARM_{100mT}/k$, $ARM_{100mT}/SIRM$, $k_{anh}/k$ and $B_{cr}$ and a slight decrease (increase) of $S_{ratio}$ (HIRM) at the bottom of this unit could be related to a very short lasting lake level drop (Haberzettl et al., 2005) and more arid and cold climatic conditions. Erosion of soils and lake sediments, exposed during low lake levels, can readily explain changes in concentration and grain size of the magnetic minerals (Geiss et al., 2003).

### SHD AD 1770-1940 (P-2)

This period is characterized by higher concentration of magnetic minerals, which lead to higher values of magnetic minerals of k and SIRM, coinciding with a significant terrigenous input (Haberzettl et al., 2005), which is supported by high Fe and Ti. On the other hand, Haberzettl et al., (2006) reported the increase of Fe/Mn ratio, Total Nitrogen (TN) and Total Organic Carbon (TOC) during the late 18th and early 19th century as well as the increase of biogenic silica and the subsequent rapid decrease of the F/Mn ratio during the early 19th century indicating a change in the lake ecology. These changes might have been triggered by increasingly warmer conditions at the end of the Little Ice Age also leading to enhanced lacustrine production. Coinciding with a shift in magnetic concentration there is a shift towards finer PSD grains, expressed in slight higher ratios of $ARM_{100mT}/SIRM$ and $B_{CR}$ values. $S_{ratio}$ (HIRM) shows uniform behaviour, only a low (high) value at about 1850 AD is observed, suggesting the presence of hematite-type minerals.

### SHC AD 1940-1995 (P-1)

According to the results of Haberzettl et al. (2005) a change to subsequently lower lake levels under drier conditions is recorded for Laguna Potrok Aike. k and SIRM exhibit a continuous decrease from the early to the mid of the 20th century, followed by a distinct peak in the end of this century. The concentration-independent ratios ($ARM_{100mT}/SIRM$, $ARM_{100mT}/k$) still rise and stay in a high level showing decrease towards the end of the 20th century. The $B_{CR}$ values suggest a softening in the dominant magnetic minerals present, while $S_{ratio}$ firstly declines and after increases at the last data (AD 1995); which reflect grain size shifts as much as mineralogical changes. A coincident peak in AD 1995 is reported by Haberzettl et al. (2006) in the records of total pollen concentration and pollen slide charcoal.

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