ON THE RECURRENCE OF THE SOUTH ATLANTIC GEOMAGNETIC ANOMALY: PALEOMAGNETIC EVIDENCE FROM LATE PLEISTOCENE AND HOLOCENE CHILEAN VOLCANIC ROCKS

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ABSTRACT

The growth of the South Atlantic Magnetic Anomaly (SAMA) during the last 2 centuries has generated very large geomagnetic secular variation in Chile (Roperch *et al*., 2015). Most global geomagnetic models suggest very low secular variation in southern South America during most of the Holocene but this result may simply be due to the lack of data to constrain the models. The paleomagnetic results obtained in the present study indicate little geomagnetic secular variation in direction during the Holocene except near 750-1000AD with the steepest inclination (-71.6°) and the highest intensity (70µT±5) (Roperch *et al*., 2014).

High paleointensities in the range 50-70µT are observed in the time interval 2,000 BC - 1,500 AD in agreement with global models showing geomagnetic moments above 10 x10^{22} Am^2. The lowest paleointensities, similar to the present-day field are found in Late Pleistocene pyroclastic flows (14,000- 15,000 BC), a feature already seen in silicate glasses from a site in northern Chile (Roperch *et al.*, 2017).

Low paleointensity values similar to the present-day ones are recorded in pyroclastic deposits at the end of the Pleistocene. Although the available data are not numerous enough to describe precisely geomagnetic field variations, we suggest that features like the SAMA may have occurred in the late Pleistocene and did not trigger a geomagnetic reversal at that time, as it is often speculated for the future evolution of the geomagnetic field in the short term.

Keywords: Geomagnetism, Paleointensity, South Atlantic Magnetic Anomaly

RESUMEN

El crecimiento de la Anomalía Magnética del Atlántico del Sur (SAMA) durante los últimos 2 siglos, ha generado una gran variación geomagnética en Chile (Roperch *et al*., 2015). La mayoría de los modelos geomagnéticos globales sugieren una variación secular muy baja en la región sur de Sudamérica durante la mayor parte del Holoceno, pero este resultado puede deberse simplemente a la falta de datos para restringir los modelos. Los resultados paleomagnéticos obtenidos en el presente estudio indican poca variación secular geomagnética en cuanto a direcciones durante el Holoceno, excepto alrededor de 750-1000 dC con una inclinación mayor (-71.6°) y una intensidad más fuerte (70µT±5) (Roperch *et al*., 2014).

En el lapso 2,000 aC - 1,500 dC se observan altas paleointensidades del rango 50-70µT en concordancia con los modelos globales que muestran momentos magnéticos superiores a 10 x10^{22} Am^2. Por otro lado, las paleointensidades más bajas similares al campo actual se encuentran en los flujos piroclásticos del Pleistoceno Tardío (14,000 - 15,000 BC), una característica previamente observada en vidrios silicatados de un sitio al norte de Chile (Roperch *et al.*, 2017).

Los valores bajos de paleointensidad, similares a los actuales, están registrados en depósitos de flujos piroclásticos del final del Pleistoceno. Aunque los datos disponibles no son numéricamente suficientes para describir con precisión las variaciones del campo geomagnético, las características como el SAMA sugieren que pudieron haber ocurrido a finales del Pleistoceno y no desencadenaron una inversión magnética en ese momento, como muchas veces se especula sobre la evolución futura del campo geomagnético a corto plazo.

Palabras clave: Geomagnetismo, Paleointensidad, Anomalía Magnética del Atlántico del Sur

1. Introduction

The recent secular variation of the Earth's magnetic field is mainly characterized by the large growth of the South Atlantic Magnetic Anomaly (SAMA) during the last three centuries, first documented in the geomagnetic field model *gufm1* (Jackson *et al*., 2000). This present-day magnetic anomaly is characterized in Chile by low magnetic inclinations and low intensities of the geomagnetic field (-40° and 25.7µT at 40°S).

A recent study of historical lava flows from Chile (Roperch *et al*., 2015) confirms the high reliability of the *gufm1* models. In contrast, geomagnetic models only based on archeomagnetic, paleomagnetic and sediments (Nilsson *et al*., 2014) (Licht *et al*., 2013) present important discrepancies with the *gufm1* model and data for the historical period in Chile (Roperch *et al*., 2015).

Few well-constrained archeomagnetic data are available for the South American continent. The best archeomagnetic data are from historical bricks from Brazil (Gomez-Paccard *et al*., 2019; Hartmann et al., 2011). Most of the other archeomagnetic data come from Peru and Ecuador (Bowles *et al*., 2002). These authors already pointed out that existing archaeointensity data covering the past 5000 years in northwestern South America exhibit significant scatter and contain more uncertainty than is generally recognized. Experimental inaccuracies, cooling rate effect, magnetic anisotropy, and especially dating uncertainties contribute likely to the scatter in the archeomagnetic record.

The principal data for South America used to constrain geomagnetic models come from 4 lake sediment records from Argentina (Donadini *et al*., 2009). As shown by Donadini *et al*. (2009), despite the fact that these four lakes are close from each other, it is difficult to find common features that could be used to improve the age-depth relation between records. As a consequence, the geomagnetic models constrained by these sediments have relatively little reliability over South America (Korte and Constable, 2011) (Korte *et al*., 2011).

Taking into account the few paleomagnetic results available for the Holocene in the southern hemisphere, the possible recurrence of the SAMA through time is uncertain. Shah *et al*. (2016) proposed that the

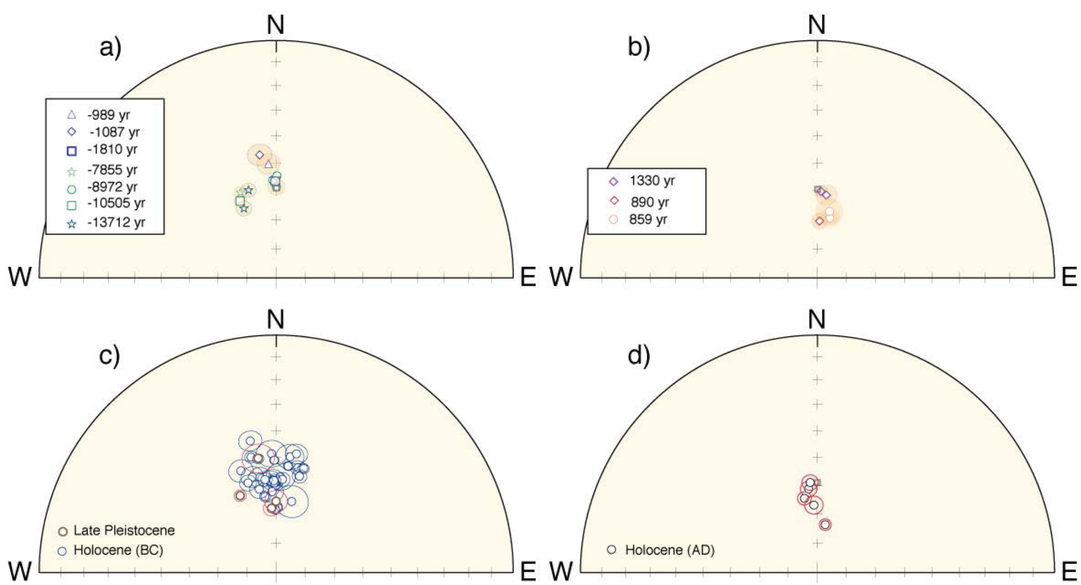

Figure 1. Stereonet of the site mean results. Results in dated sites in the BC era (a) and AD dated sites (b). Results in Holocene (BC) and late Pleistocene sites are shown in c while results in Holocene undated sites are shown in (d).

SAMA is a persistent or a recurring geomagnetic feature present between 90 and 46 ka but the very poor quality paleointensity data makes this interpretation highly questionable.

Here we report new paleomagnetic results from ^{14}C dated lava flows as well as lava flows of Holocene age but with only relative time control. In addition to lava flows, we also sampled some juvenile clasts from pyroclastic flow deposits (PFD) that also provide reliable records of the geomagnetic field (Roperch *et al*., 2014).

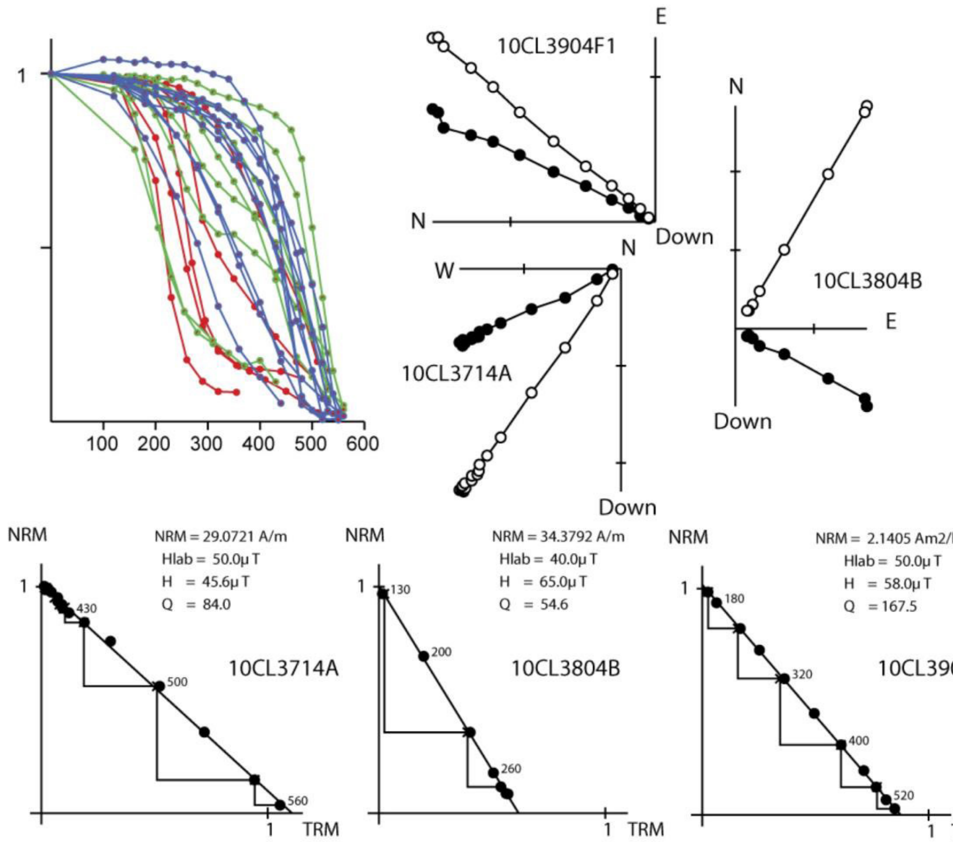

Figure 2. Examples of paleointensity determination in samples from three pyroclastic deposits, from the Choshuenco volcano. Unblocking temperatures of the NRM is variable between the studied samples. The paleointensity determination was successful independently of the blocking temperatures spectrum.

2. Paleomagnetic sampling and results

In order to better describe the poorly known secular variation during the late Pleistocene - Holocene, we sampled 21 dated lava flows or pyroclastic flows from several Chilean volcanoes located in the southern volcanic zone (~39°S-41°S). We also sampled 56 sites in Holocene lava flows with only relative ages with respect of the dated units. The largest volcanic events that can be traced at several locations within a volcanic edifice are used to constrain the relative ages of the sampled units.

The characteristic directions were determined after Alternating Field and thermal demagnetization (Figure 1). Except for the rapid changes in field direction and intensity observed during the last 2 centuries associated with the SAMA anomaly, the secular variation is not large during the Holocene. The steepest inclinations are observed around 900AD.

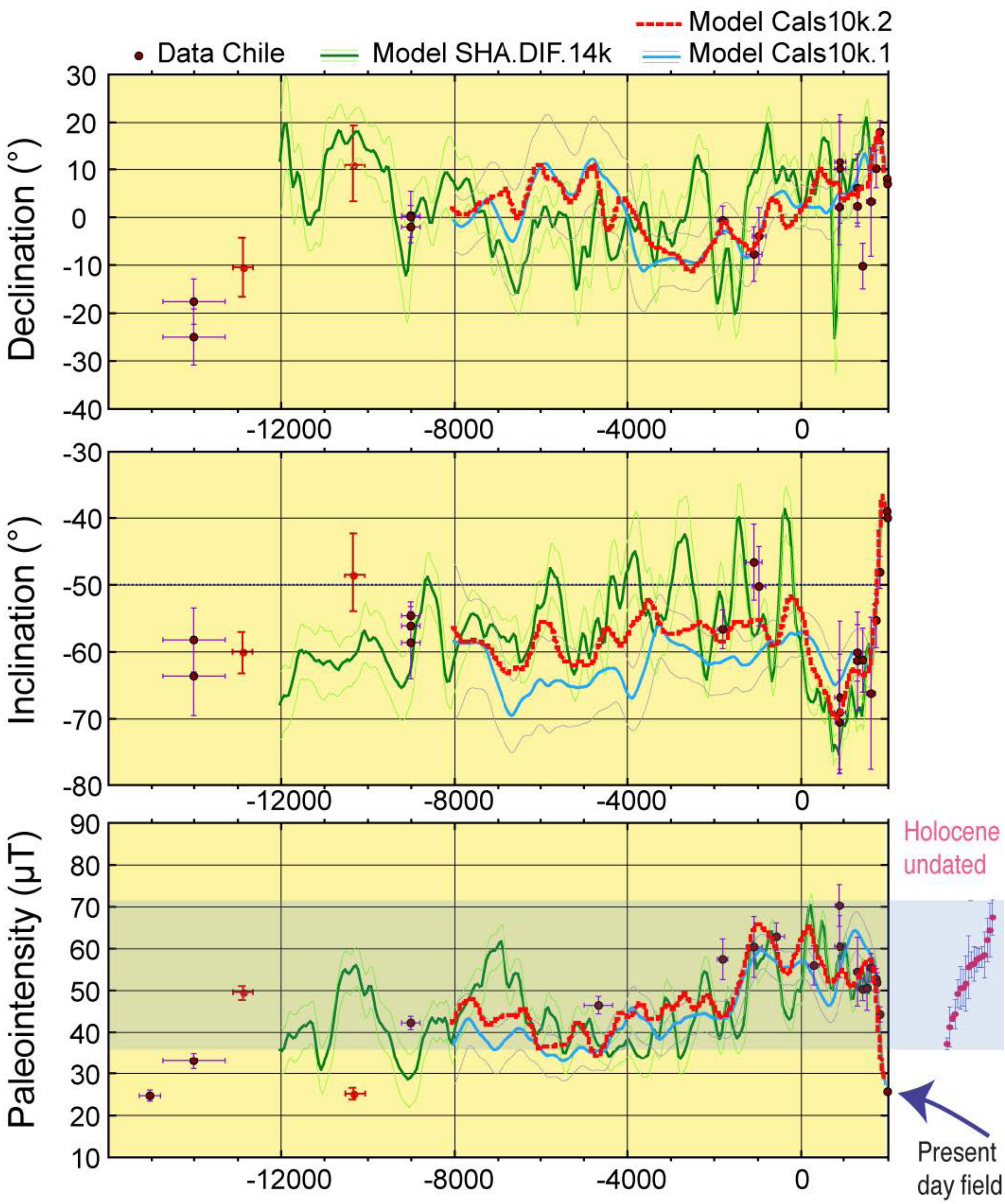

Figure 3. Comparison of the Chilean data with expected geomagnetic fields from three models. The red dots correspond to paleomagnetic field obtained from surface glasses in northern Chile that have been relocated to the Villarica volcano location, as the other data.

Paleointensity experiments were performed with the Thellier method in vacuum. 174 determinations were obtained. The best criterion for paleointensity determinations is often a high Koenigsberger ratio. Indeed the intensity of the NRM is often higher when the grain size of the magnetic particle is low. As already pointed out by Roperch *et al*., (2014, 2015), accurate paleointensities were determined in lava flows with low Curie points as well as with pyroclastic deposits. Examples of successful experiments are shown in Figure 2.

The paleomagnetic results obtained in the present study indicate little geomagnetic secular variation in direction during the Holocene except near 750-1,000AD with the steepest inclination (-71.6°) and the highest intensity (70μT ±5) found at two sites (Roperch *et al*., 2014).

High paleointensities in the range 50-70µT are observed in the time interval 2,000 BC - 1,500 AD in agreement with global models showing geomagnetic moments above 10.0 10^{22} Am^2. The lowest paleointensities, similar to the present-day field are found in Late Pleistocene pyroclastic flows (14,000 - 15,000 BC), a feature already seen in silicate glasses from a site in northern Chile (Roperch *et al*., 2017).

Almost all the paleomagnetic data from volcanic rocks come from the northern hemisphere and no other data is available for South America in the time interval (16,000 - 10,000 BC). Using the data available in the Geomagia database, the virtual axial dipole moment in the time interval (16,000 - 10,000 BC) was about 30% lower than the mean value observed in the time interval (2000-0 BC). The Chilean results are also compatible with the global data. It is not certain that the late Pleistocene secular variation is associated with the same geomagnetic feature as the SAMA. If it was the case, the SAMA is thus probably not the speculated precursor of a geomagnetic reversal.

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