Physics of the Earth and Planetary Interiors 242 (2015) 65–78

Contents lists available at ScienceDirect

Physics of the Earth and Planetary Interiors

journal homepage: www.elsevier.com/locate/pepi

Secular variation of the Earth's magnetic field and application to paleomagnetic dating of historical lava flows in Chile

Pierrick Roperch [a,*], Annick Chauvin [a], Luis E. Lara [b], Hugo Moreno [c]

[a] Geosciences Rennes, UMR 6118, CNRS & University of Rennes1, 35042 Rennes , France
[b] Servicio Nacional de Geología y Minería, Santiago, Chile
[c] Servicio Nacional de Geología y Minería, OVDAS, Temuco, Chile

ARTICLE INFO

Article history:
Received 15 September 2014
Received in revised form 13 February 2015
Accepted 4 March 2015
Available online 23 March 2015

Keywords:
Paleomagnetism
Geomagnetic secular variation
South Atlantic Geomagnetic Anomaly
Volcanism
Chile

ABSTRACT

The recent geomagnetic secular variation is mainly characterized by the large growth of the South Atlantic Magnetic Anomaly during the last three centuries, first documented by the geomagnetic model *gufm1* (Jackson et al., 2000). We report new paleomagnetic results (directions and paleointensities) from several sites in two well dated lava flows in Chile, the 1835 AD eruption of the Osorno volcano and the 1751 AD eruption of the Llaima volcano. In addition, paleointensities were obtained on 14 samples from bricks of shelters built along the main road across the Andes from Santiago (Chile) to Mendoza (Argentina) in 1770 ± 5 AD. The results confirm the high reliability of the global geomagnetic model *gufm1* for the last three centuries with a large amplitude of the secular variation in inclination (~20°) and intensity (~25 μT). Results from three ^{14}C dated volcanic units in the time interval 1400–1750 AD indicate that more paleomagnetic results in well dated lava flows are necessary to improve the robustness of existing global geomagnetic models. At this stage, precise paleomagnetic or archeomagnetic dating in South America using global models should be restricted to the last 3 centuries.

To illustrate the potential of paleomagnetic dating in region and time interval with very large geomagnetic secular variation, we report paleomagnetic data from several sites in historical lava flows (1700–1900 AD) from the Antuco, Llaima and Villarrica volcanoes that permit to refine the ages of the major historical effusive volcanic events.

1. Introduction

The secular variation of the Earth Magnetic Field is relatively well determined for the last four centuries. From an impressive compilation of magnetic records made by navigators and direct measurements, Jackson et al. (2000) proposed a global field model (*gufm1*) providing our most complete picture of the evolution of the geomagnetic field at Earth's surface from 1590 to 1990. However, no measurement of intensity data was available prior to 1840 and the axial dipole component was linearly extrapolated back before this date in the original model. Gubbins et al. (2006) and later Finlay (2008) found that this extrapolation in the fall of the dipole was not justified and the *gufm1* model was adjusted with paleointensities determined from archeomagnetic data prior to 1840.

Most recent geomagnetic models extended to the last 3 millennia (Korte et al., 2009; Korte and Constable, 2011) are constrained by the *gufm1* model especially for the last 3 centuries.

The growth of the South Atlantic Geomagnetic Anomaly during the last three centuries induces a large decrease in the magnetic field inclination and intensity of the Earth magnetic field over South America. This large geomagnetic secular variation is likely to provide an accurate paleomagnetic dating tool for archeologic or volcanic material for the last three centuries.

In the present study, new paleomagnetic results from dated material from the Chilean Andes permit to verify and consolidate current geomagnetic models.

Numerous active volcanoes mark the western border of the Andes in south central Chile between 37°S and 42°S (Fig. 1). This part of Chile is the Araucania inhabited by the Mapuche people who resisted the Spanish conquest until the 18th century. The chronology of the historical volcanic activity of several of the active volcanoes has been studied in detail by Petit-Breuilh (2004). However, though the ages of the eruptions of some volcanoes are usually well defined, it is much more difficult to assess the exact location and extent of the lava flows possibly associated with an historic eruption. Informations related to volcanic eruptions prior to the 19th century are often scarce (Supplementary Fig. 1).

* Corresponding author.

http://dx.doi.org/10.1016/j.pepi.2015.03.005
0031-9201/

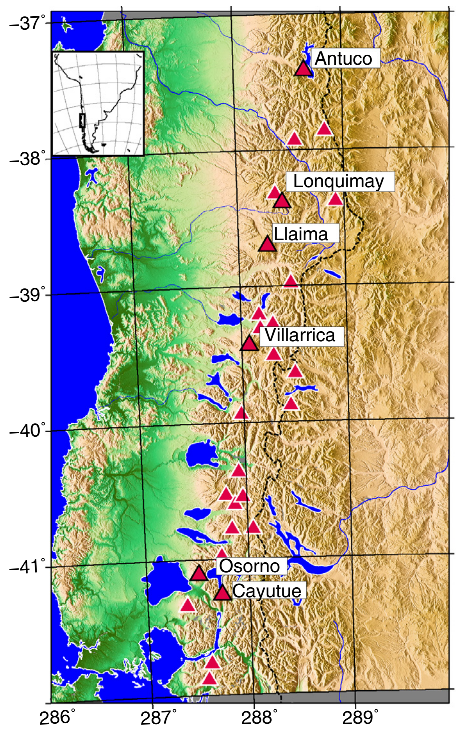

Fig. 1. Maps of south central Chile and locations of the main active volcanoes (red triangles). The largest triangles correspond to the locations of the present paleomagnetic sampling. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

We report paleomagnetic results from the two best-documented volcanic events with well-defined lava flows, the 1835 AD Osorno and the 1751 AD Llaima eruptions. Paleointensity results from bricks of two shelters built in the time interval 1766–1774 AD along the road from Chile to Argentina (Casuchas del Virey) provide an additional control on the intensity of the geomagnetic field in the 18th century. To further constrain the geomagnetic models in South America prior to the 18th century, we sampled ^{14}C dated lavas from the Villarrica, Lonquimay and Cayutue volcanoes.

Finally, we also report paleomagnetic results (direction and paleointensity) obtained from several lava flows with ages assigned to the historical period from three volcanoes (Villarrica, Llaima and Antuco) and we use the paleomagnetic results to discuss and refine the ages assigned to these flows.

2. Paleomagnetic sampling

2.1. Dated units

2.1.1. The Osorno 1835 AD eruption

Osorno volcano (Fig. 2) is a high (2652 masl) stratovolcano that lies in a transversal NE-trending volcanic chain. The last historical eruptions were reported in 1778–1779 AD and 1835 AD (Petit-Breuilh, 2004). The area around the Llanquihue Lake was an isolated place until the second half of the 19th century and no local inhabitants served as direct eyewitnesses of the 1835 AD eruption of Osorno volcano. Charles Darwin was on board of the HV Beagle at that time and described the onset of the eruption from the Ancud bay in Chiloé Island (Darwin, 1840). Lara et al. (2012) provide a detailed cartography of the products of the 1835 AD volcanic eruption. Two main stages with lava flows emplacement and pyroclastic cones are recognized. The first stage occurred in January 1835 and the second stage occurred in December 1835. Two sites (81, 82) were drilled in a thick lava flow belonging to the January eruption. Site 87 was drilled on the limit between the 1835 and the pre-historical lava sequence. Three sites (28, 32, 78) were drilled in flows attributed to the December 1835 volcanic eruption. Three sites (29, 30, 31) were drilled along the road to the ski resort. At these sites, the volcanic flows were correlated to a pre-historical event on the base of ^{14}C ages of 240 BP to 350 BP (Lara et al., 2012) but new field evidences and the large uncertainties in the calibrated ages suggest that the sampled unit is part of the 1835 volcanic eruption.

2.1.2. Bricks of the "Casuchas del Virrey"

Ambrosio O'Higgins proposed in 1765 to build houses to provide shelters to people transporting mail between Buenos Aires and Santiago de Chile while crossing the Andes. The shelters were built mainly with bricks and brick arches formed the roof. In Chile, the only shelter that is not destroyed is the one located in Juncalillo. At the Las Calaveras site a few kilometers to the east, the refuge is entirely destroyed. We collected pieces of broken bricks littered on the ground at both Juncalillo and Las Calaveras sites. The Juncalillo shelter was one of the first to be built and the Las Calaveras shelter was built a few years later in 1774 AD. We assign an age of 1770 ± 5 AD for these structures.

The bricks were not fired at the locations of the shelters. However, the shelters were not made with ornamental bricks likely to be transported over large distances. In contrast, the artisanal bricks were probably made at short distances of the shelters either near Mendoza at about 100 km to the east or near Los Andes at about 50 km to the west, the two closest towns on both sides of the Andes.

Two cores were drilled in the bricks. One was drilled orthogonal to the brick plane and the other within the brick plane. This procedure was chosen to better detect the importance of the magnetic anisotropy in the paleointensity determinations since the laboratory thermoremanent magnetization was given along the Z axis of the core.

2.1.3. The Llaima 1751 AD lava flow

Llaima is one of the most historically active volcanoes in Chile with more than 50 eruptions since 1640 AD (Naranjo and Moreno, 2005).

Holocene volcanic activity at Llaima began with caldera collapse and eruption of the basaltic to andesitic Curacautin Ignimbrite (~13.5 ka). Historical volcanic activity of Llaima consists predominantly of Strombolian events. Six major effusive eruptions occurred between 1640 and 1957 (Petit-Breuilh, 2004). Prior to the 20th century, the 1751 event is the most well established event with a large lava flow filling the Trufultruful river. This flow was sampled at several sites. Site 18 corresponds to the bottom part of the flow while nearby site 14 was drilled in the brecciated flow top above site 18. Site 15 was taken near the Trufultruful waterfall and sites 16 and 17 were taken on small outcrops of the upper part of the flow. Site 19, 24 and 58 correspond to the lower part of the 1751 flow where the brecciated upper part of the 1751 AD lava was eroded.

2.1.4. ^{14}C dated volcanic units

Lonquimay is a stratovolcano of late-Pleistocene to dominantly Holocene age. A prominent NE-SW fissure cuts across the entire volcano and extends 10 km to the NE with a series of NE-flank vents and cinder cones, some of which have been the source of voluminous lava flows like the major andesitic lava flow erupted in 1988–90 from crater Navidad. Two kilometers to the E-NE of the crater Navidad, we sampled one of two nearby volcanic vents. These vents are likely the source of a lava flow for which a ^{14}C age of 200 ± 40 year. BP (Sernageomin, unpublished data) was obtained