PALEOSECULAR VARIATION FROM NORTHERN PATAGONIA RECORDED BY 0-5 MA CAVIAHUE-COPAHUE LAVA FLOWS

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ABSTRACT

A total of 41 paleomagnetic sites were sampled for secular variation analysis from lava flows emplaced in the Caviahue-Copahue volcanic field (Argentina). Previous K-Ar age determinations indicates that the volcanic activity started by ~5 Ma ago with episodic eruptions until recent periods. Site mean directions were obtained from both alternating field and thermal demagnetization resulting in 35 reliable directions of which 30 are of normal and 5 are of reversed polarity. The mean direction from normal (reverse) sites is D = 355.9°, I = -51.7°, α_{95} = 4.6°, N = 30 (D = 189.1°, I = 57.5°, α_{95} = 4.4°, N = 5) and the resulting mean virtual geomagnetic pole (VGP) from both combined polarities is located at Lat: 85.4º, Lon: 238.1º, A_{95} = 4.8º. The VGP angular dispersion (15.7° with upper and lower confidence limits of 18.2° and 12.6°) was compared with the global 0-5 Ma dataset and with the paleosecular variation model proposed by McFadden *et al.* (1988). Our new data support the hypothesis that the Geocentric Axial Dipole can account for the most paleodirections reported in South America for the studied period and only a small contribution of nondipolar components is required to model regional time-averaged field determinations.

Keywords: Paleosecular variation, Northern Patagonia, Copahue Volcanic Field.

RESUMEN

Se tomaron muestras de un total de 41 sitios paleomagnéticos para el análisis de la variación secular de los flujos de lava emplazados en el campo volcánico Caviahue-Copahue (Argentina). Las edades K-Ar informan que la actividad volcánica comenzó hace ~ 5 Ma con erupciones episódicas hasta períodos recientes. Las direcciones medias por sitio se obtuvieron mediante métodos de desmagnetización de campo alterno y de desmagnetización térmica, lo que resultó en 35 direcciones confiables, de las cuales 30 son de polaridad normal y 5 de polaridad inversa. La dirección media de los sitios con polaridad normal (inversa) es D = 355.9°, I = -51.7 °, α_{95} = 4.6 °, N = 30 (D = 189.1 °, I = 57.5 °, α_{95} = 4.4 °, N = 5) y el polo geomagnético virtual (VGP) medio resultante de ambas polaridades combinadas se encuentra en Lat: 85.4º, Lon: 238.1º, A_{95} = 4.8º. La dispersión angular VGP (15.7 ° con límites de confianza superior e inferior de 18.2 ° y 12.6 °) se comparó con el conjunto de datos global de 0-5 Ma y con el modelo de variación paleosecular propuesto por McFadden *et al*. (1988) Nuestros nuevos datos respaldan la hipótesis de que el Dipolo Axial Geocéntrico puede dar cuenta de la mayoría de las paleodirecciones reportadas en América del Sur para el período estudiado y solo se requiere una pequeña contribución de componentes no-dipolares para modelar determinaciones de campo promediadas en el tiempo.

Palabras Claves: Variación Secular, Patagonia Septentrional, Campo volcánico Copahue.

1. Introduction

Analysis of the time-averaged field (TAF) and its secular variation are key to improve our knowledge of the ancient Earth's magnetic field. The main characteristic of the TAF is that over a large time interval its geometry is similar to that of a Geocentric Axial Dipole (GAD). This idea is commonly accepted by the paleomagnetic community mainly because it allows, in a simplified approach, the reconstruction of plate tectonics over geological time. However, studies of Paleosecular Variation (PSV) derived from 0-5 Ma lavas flows suggest considerable departures from the GAD, mainly due the presence of persistent axial quadrupolar and octupolar components.

Paleodirectional data from lavas emplaced over the past 5 Ma were first compilated by McElhinny and Merrill (1975) and then updated by several authors (*e.g.,* Lee, 1983; Quidelleur *et al.,* 1994; Johnson and Constable, 1996; McElhinny and McFadden, 1997; Johnson *et al.,* 2008) with modifications regarding the selection criteria following the evolution of magnetometers and methods that improved the data quality. More recently, Cromwell *et al.* (2018) compiled a paleomagnetic database from lavas of the past 10 Ma, it includes high-quality data obtained with modern laboratory methods, which reduces sampling bias and improves TAF and PSV determinations.

The structures of PSV are commonly investigated by means of the angular dispersion of the virtual geomagnetic poles (VGP) and its variation with latitude (McElhinny and McFadden, 1997). The main factor observed is the increase of the angular dispersion with latitude (*e.g.,* McFadden *et al.,* 1988). Recent data compilations show that this increase is larger in the Southern Hemisphere than in the north, although this asymmetry needs a larger amount of better geographically distributed data to be corroborated. Data scarcity is mainly observed in the southern hemisphere (Johnson *et al.,* 2008; Cromwell *et al.,* 2018) where continental coverage is much lower than in the northern hemisphere. Therefore, the acquisition of directional data in the 0-5 Ma range on this part of the Earth is essential for understanding the hemispherical symmetry of the geomagnetic field (Lawrence *et al.,* 2006; Johnson and McFadden, 2007). In order to improve the data distribution, we present new high-quality paleomagnetic data recorded over the past 5 Ma in Caviahue-Copahue lava flows from northern Patagonia of Argentina.

2. Geological setting and sampling

The Southern Volcanic Zone (SVZ) of the Andes is a product of the eastward subduction of the Nazca plate under the South American plate (*e.g.,* Ramos, 1999). The SVZ is bounded to the north (33°S) by the non-magmatic Chilean flat-slab subduction of the Juan Fernández Ridge and to the south (46°S) by the Austral volcanic zone.

The Caviahue-Copahue volcanic field (CCVF) is part of the SVZ (Fig. 1a), and located at the transition between the Central and Patagonian Andes (38ºS). Its magmatism is dominated by effusive and explosive episodes, the latter related to the collapse of the Pliocene Caviahue caldera (Melnick *et al.,* 2006; Varekamp *et al.,* 2006). The effusive volcanism started at 5.6-4.0 Ma with the deposition of the basaltic to andesitic lava flows from the Cola de Zorro formation, this unit occurs regionally and forms the basement and walls of the Caviahue caldera. After the collapse of the Las Mellizas volcano, resulting on the Caviahue caldera, two lava flows (~2.6 Ma) were deposited. The first one, Lower lavas, crops out only locally inside the caldera while the second one, Upper lavas, fills most of it. Exposed in the northern part of the caldera, are andesitic lavas related to the Trolope formation (1.6-0.8 Ma) and located in the western margin is the active Copahue volcano.

The evolution of Copahue volcano is subdivided into three main stages of lava flow extrusions (Melnick *et al.,* 2006). The preglacial stage (1.2-0.7 Ma) is formed by andesitic lavas and forms the volcanic edifice. The synglacial stage (700-15 ka) is composed by andesitic to dacitic lavas and exhibit characteristics of lava-ice contact. The post-glacial stage (< 15 ka), of basaltic-andesitic composition, overlie the previous stages and have no evidence of glacial erosion.

Paleomagnetic samples were collected from the described formations during two field seasons in April 2016 and February 2017 with a portable gasoline-powered rock drill. At least ten independently oriented cores were taken from every site and each one was oriented by means of a magnetic compass and when possible using a sun compass. A total of 41 independent sites were collected for the CCVF area. Location and lava formation of all sampling sites is shown on Figure 1b.

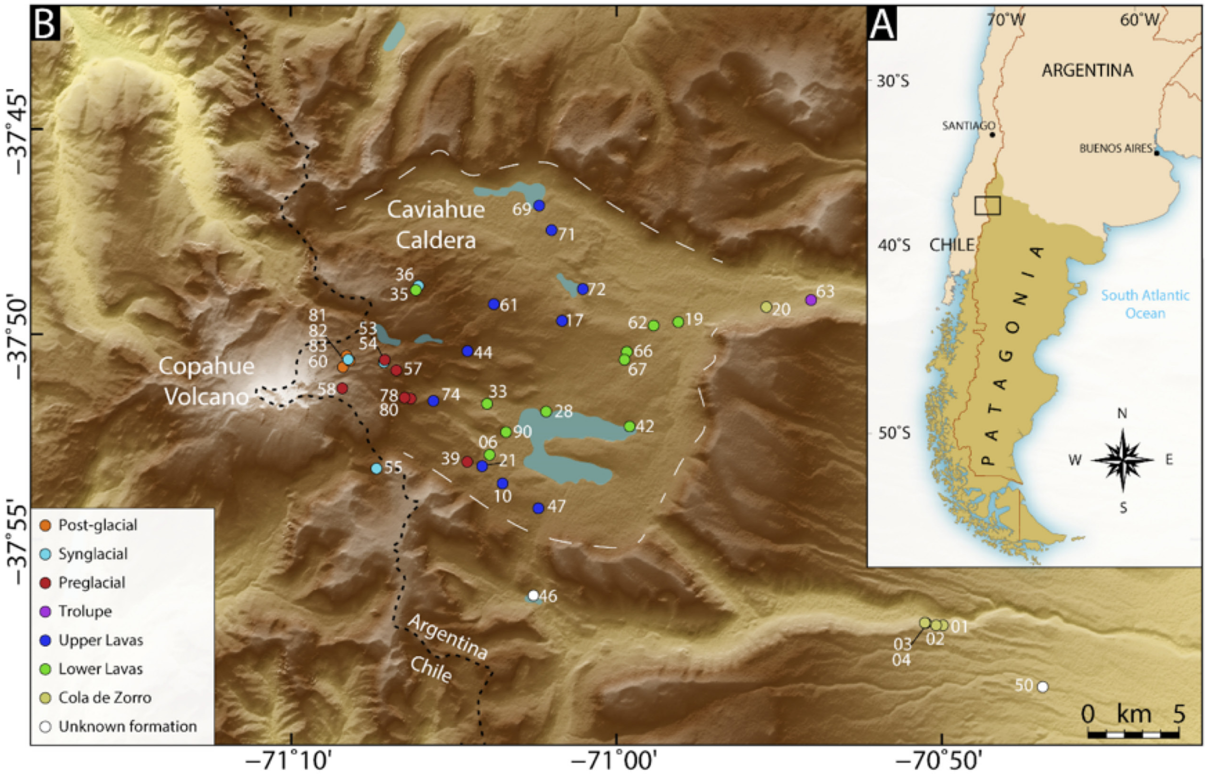

Figure 1. (a) Location map of Southern South America showing the location of study. (b) Digital elevation model (DEM) of Caviahue-Copahue Volcanic Field and location of paleomagnetic sampling sites.

3. Preliminary results and discussion

Measurements were carried out at the Laboratório de Paleomagnetismo of Universidade de São Paulo (USPmag) in a shielded room (<500 nT) using a 2G Enterprises DC SQUID magnetometer. Typically, 8–10 samples were subjected to stepwise alternating field demagnetization (AFD) comprising 15 steps up to 100 mT. In addition, three samples per site were submitted to stepwise thermal demagnetization (THD) comprising 10 steps up to 400 ºC, followed by 50 ºC steps to the maximum unblocking temperature. The characteristic remanence vectors were determined using orthogonal projection diagrams (Zijderveld, 1967). Principal component analysis (Kirschvink, 1980) was used to calculate the best-fit lines. In a few cases, great circles analyses were necessary due to the presence of secondary component that partly overlaps the primary one.

Examples of typical demagnetization diagrams are shown in Figure 2. Some samples were not fully demagnetized in the AFD but lost 95% of their initial magnetization at 550° C in the THD suggesting that high Ti titanomagnetite is the main carrier of the natural remanent magnetization (NRM). In all other samples the NRM is fully cleaned at 550° C (THD) or 100 mT (AFD) indicating that magnetite or low Ti titanomagnetite is the main carrier of the NRM. The characteristic remanent magnetization (ChRM) was easily identified in most cases from both THD and AFD demagnetizations (Fig. 2a and b). Reverse magnetization (Fig. 2b) was found in samples from Cola de Zorro formation and all other lava formations presented normal magnetization (Fig. 2a). In some cases, great circle method (Halls, 1976) were used to extract the ChRM from both THD and AFD demagnetizations (Fig. 2c).

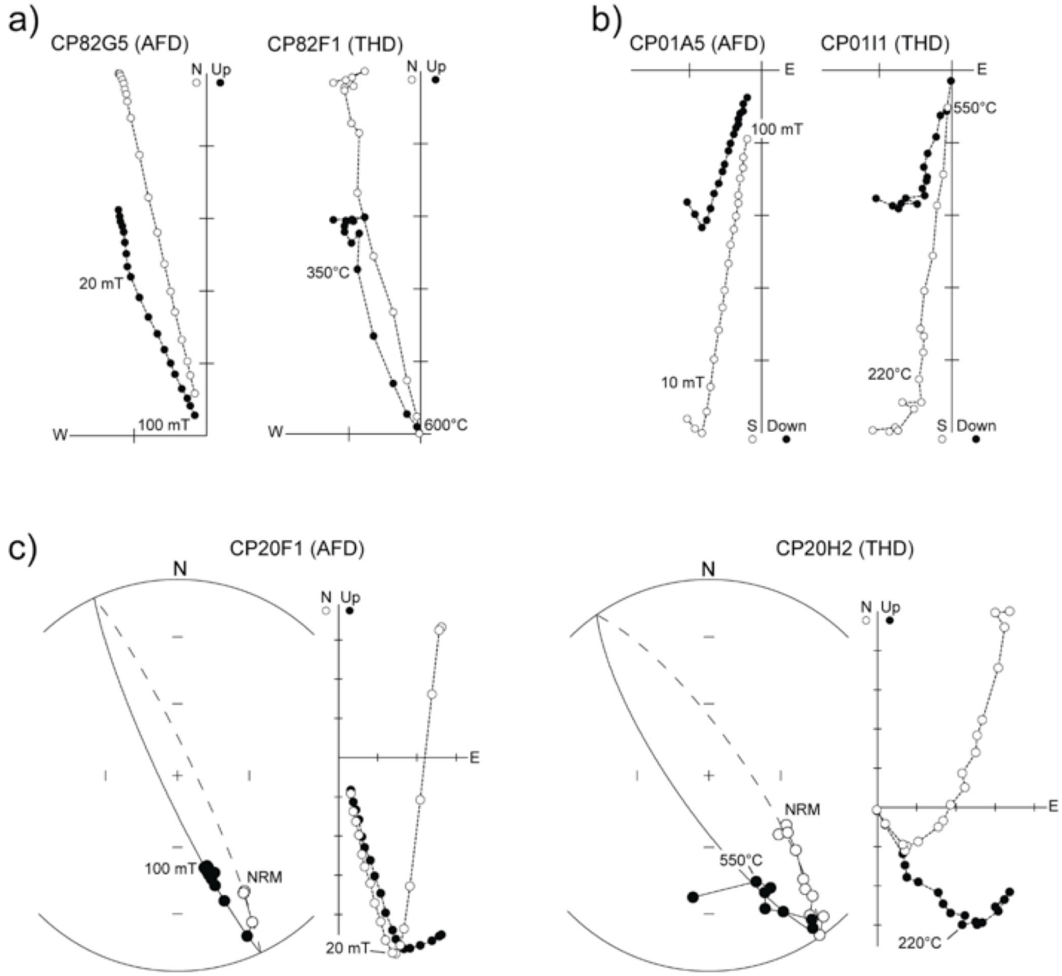

Figure 2. Examples of demagnetization diagrams. Zijderveld projections obtained with AF and thermal demagnetization for (a) normal and (b) reverse polarity. (c) Zijderveld and stereographic projections of a reverse sample with great circle fit.

A paleomagnetic direction was calculated from all collected sites. Fig. 3a shows the mean direction of the 41 sites, those in light gray presented precision parameter (Fisher, 1953) k ≥ 50 which is generally considered as an upper limit for PSV studies (Cromwell *et al.,* 2018). These sites were rejected from statistical calculations of VGP dispersion, remaining 35 high-quality directions. The mean direction (Fig. 3b) from normal (reverse) sites is D = 355.9°, I = -51.7°, α_{95} = 4.6°, N = 30 (D = 189.1°, I = 57.5°, α_{95} = 4.4°, N = 5). The reversed and normal VGP for the remaining 35 sites are combined and reported in Figure 3c. The resulting mean virtual geomagnetic pole (VGP) from both combined polarities is located at Lat: 85.4º, Lon: 238.1º, A_{95}: 4.8°.

The VGP dispersion as a function of latitude is shown in Figure 3d. Our results were compared with the global 0-5 Ma dataset (Cromwell *et al.,* 2018) and with the Model G (McFadden *et al.,* 1988). The angular dispersion was calculated with the McElhinny and McFadden (1997) approach and when averaged between the north and south hemisphere gives a value of 15.7° (with upper and lower confidence limits of 18.2° and 12.6°) which is very similar to the Model G for 38ºS (Fig. 3d). This value is also close to the global 0-5 Ma dataset in this latitude as attested by studies from nearby areas (*e.g*., Canon-Tapia *et al.,* 1994; Quidelleur *et al.,* 2009; Roperch *et al.,* 2015).

The 35 new, high quality, paleodirections from northern Patagonia reported in this study will increase the available 0-5 Ma southern hemisphere dataset. As in previous studies from South America (*e.g.,* Quidelleur *et al.,* 2009; Opdyke *et al.,* 2006; Mejia *et al.,* 2004; Brown *et al.,* 2004) our VGP position (Lat: 85.4º, Lon: 238.1º, : 4.8) is not statistically different from the geographic North Pole (Fig. 3c) which supports that the GAD can account for the most paleodirections reported in this region and only a small contribution (less than 5%; Cromwell *et al.,* 2018) of non dipolar components is required to model regional TAF determinations.

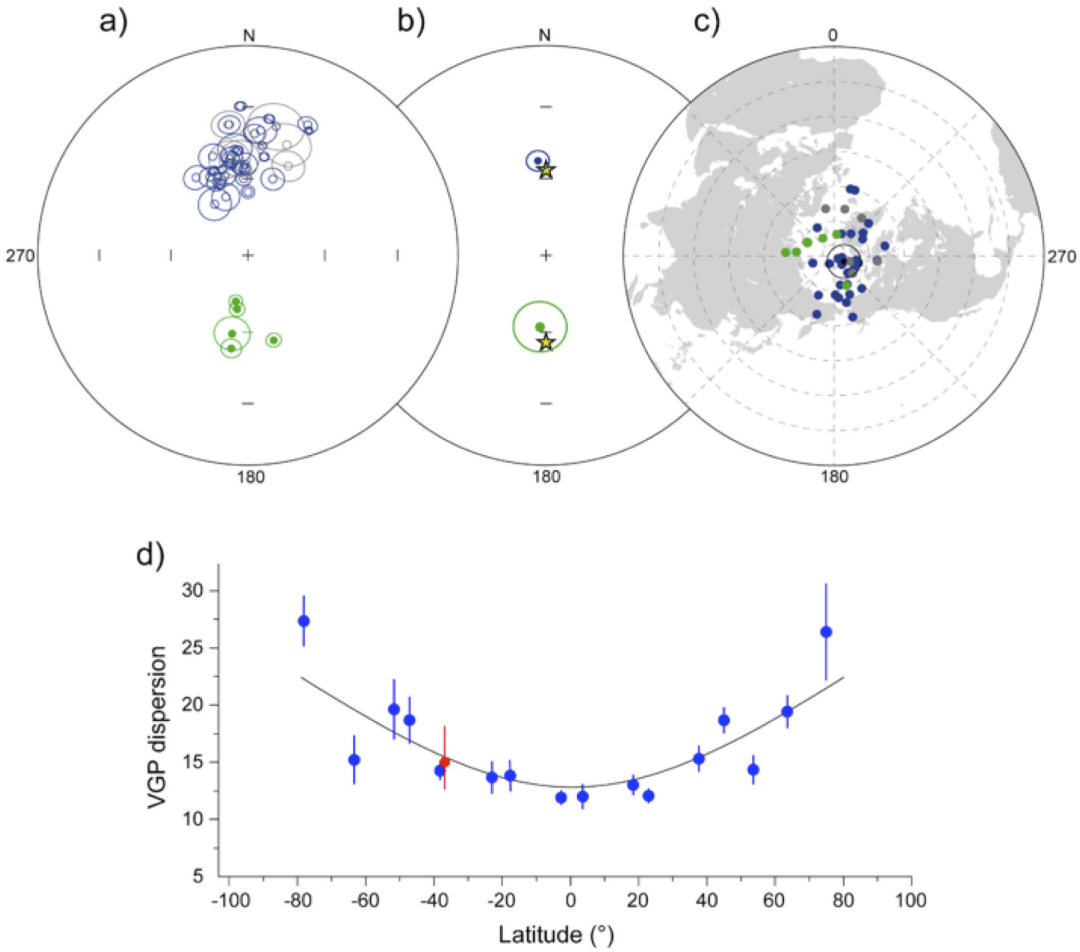

Figure 3. (a) Stereographic projection of normal (blue) and reverse (green) polarity for all sampling sites, rejected directions (k ≥ 50) are shown in grey. (b) Mean direction for normal and reverse polarity, yellow star shows the expected geocentric axial dipole (GAD) for our studied latitude. (c) Virtual geomagnetic poles (VGP), colors as in (a). (d) VGP dispersion of this study (red circle) plotted as a function of latitude and compared with the global dataset (blue circles) and with Model G (black curve).

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