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A combined paleomagnetic/dating investigation of the upper Jaramillo transition from a volcanic section at Tenerife (Canary Islands)

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ABSTRACT

A coupled paleomagnetic/dating investigation has been conducted on a sequence of 25 successive lava flows, emplaced during the upper transition of the Jaramillo subchron in Tenerife, Canary Islands. This sequence is located along the western wall of the Güímar collapse scar, in the south central part of the island. Nine flows distributed throughout this sequence were dated using unspiked K/Ar and $^{40}Ar/^{39}Ar$ methods. They bracket the section between 1009 ± 22 ka and 971 ± 21 ka (2σ). A first group of 8 flows at the bottom of the sequence is characterized by normal polarity with paleointensity values of the order of present-day field intensity in the Canary Islands. The virtual geomagnetic poles (VGP) of these 8 flows describe a short loop at high latitudes. Seven overlying flows are transitional in directions and dated between 991 ± 14 ka and 1002 ± 11 ka consistently with published ages of the upper Jaramillo reversal. This second group of flows is characterized by low paleointensity values (around 8–12 μT) that are less than 30% of the present dipole value in Tenerife. The VGPs of the first two transitional flows lie over northeastern Pacific whereas the five following transitional flows have all negative inclinations and their VGPs lie initially over East Antarctica, then describe a northward loop almost reaching New Zealand. The final group of ten flows yield intensities varying between 20 and 35 μT and VGPs close to the southern pole with two of them describing a small amplitude second loop to southeastern Pacific. Assuming a constant extrusion rate as a very first approximation, the distribution of the obtained ages suggests a duration of 7.6 ± 5.6 ka for the transitional interval. The obtained transitional positions of VGPs are consistent with the path reported for the same reversal from North Atlantic sediments but are different from the only other volcanic record from Tahiti. The intensity low characterizing the transitional interval remains the best tie point, centered at 996 ± 7 ka (2σ) relative to 28.02 Ma FC sanidine.

1. Introduction

The Jaramillo normal polarity subchron (JNS) has been first evidenced within the reverse Matuyama Chron through the study of rhyolitic domes in New Mexico (Doell and Dalrymple, 1966). Since then, the JNS has been identified in widely distributed eolian, marine, and lacustrine sedimentary sequences. The two reversals bracketing the JNS are frequently used as age markers for Pleistocene records, yet their ages have been progressively adjusted with time using improved $^{40}Ar/^{39}Ar$ ages or astronomical tuning (Berggren et al., 1985; Shackleton et al., 1990; Tauxe et al., 1992; Spell and McDougall, 1992; Spell and Harrison, 1993; Izett and Obradovich, 1994; Singer et al., 1999; Channell et al., 2009). Relative changes in paleointensity obtained from sedimentary records across the entire JNS have also been investigated with reference to long-term dynamics of the earth's magnetic field intensity changes (Valet and Meynadier, 1993; Leonhardt et al., 1999; Laj et al., 1996; Verosub et al., 1996; Dinares-Turell et al., 2002; Channell et al., 2009).

The details of the vectorial changes of the earth magnetic field during the reversals bounding the JNS and in particular the upper normal to reverse (N–R) Jaramillo/Matuyama reversal (UJR) have, on the other hand, been seldom documented, despite their relevance to decipher the behavior of the geomagnetic field during polarity transitions. A description of the UJR has been obtained from four sedimentary sequences, all of them retrieved from ODP/IODP drill cores at latitudes ranging between 53° N and 60° N in North Atlantic (Channell and Lehman, 1997; Mazaud et al., 2009). They all show the same rather simple Virtual Geomagnetic Pole (VGP)

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path, described by a first loop over the Americas down to about 30°–45° S, followed by a full N–R path over the Indian ocean sector, from along the eastern African coastline (about 40° E longitude) to over India (about 75° E longitude) depending on the core. The associated relative paleointensity profiles all show a very low value at the time of the directional changes.

Lava flows are an important archive in paleomagnetism because they provide the only way to retrieve absolute intensity values of the geomagnetic field and they can be dated using both the K–Ar and $^{40}Ar/^{39}Ar$ techniques. However, it is a challenge to locate volcanic sequences erupted during the short geological periods corresponding to geomagnetic reversals or excursions, given the sporadic nature of volcanic eruptions. Previously to this study, only one reliable volcanic record of the UJR has been obtained from a sequence of 23 flows at Tahiti, at about 18° S (Chauvin et al., 1990). Data from Tahiti are mainly directional data, only one transitional flow allowed a single paleointensity determination. On the basis of four ages from normal and transitional flows of the Punaruu valley (Singer et al., 1999), the best age estimate calculated for the termination of the JNS is 1001 ± 10 ka (Singer et al., 2004). This age is reported at 2σ uncertainty and relative to 1.194 Ma Alder Creek Rhyolite sanidine standard (ACs-2; Nomade et al., 2005) corresponding to 28.02 Ma FC (Renne et al., 1998).

Here, we report on new dating and paleomagnetic results (both directional and intensity data) from a volcanic sequence located in the NE Rift Zone of Tenerife (Canary Islands) comprising 25 successive flows, 7 of which describe the transitional field during the upper Jaramillo reversal.

2. Geological setting and sampling

The NE Rift Zone of Tenerife (NERZT) evolved very rapidly with high eruptive rates during the last cycle of eruptive growth between 1 Ma and 830 ka (Carracedo et al., 2011). This cycle was followed by major landslide collapses occurring at ca. 830 ka (Micheque and Güímar landslides on the northern and southern flank of the rift respectively) and between 690 and 566 ka (La Orotava landslide adjoining the Micheque landslide) (Carracedo et al., 2011).

In the valley of Güímar, a sequence of lava flows were emplaced on a slightly southward tilting slope and are now exposed on the southern wall of the Güímar landslide (Guillou et al., 2013). The sampled section is located along this “Pared de Güímar” (28°18′ N; 16°28′ W) (Fig. 1). Preliminary K/Ar dating indicated that this wall, formed by a 500 m thick sequence of basaltic flows, erupted between 1008±22 and 963±21 ka (Carracedo et al., 2011). This high eruptive rate during the activity of the NERZT therefore allows to retrieve a detailed record of changes in the geomagnetic field. In fact, the K/Ar ages indicate that this section covers the upper part of the normal polarity Jaramillo subchron, including the entire upper Jaramillo transition to the reversed polarity of the Matuyama Chron. Preliminary fluxgate measurements in the field confirmed the presence of a reversal in this sequence (Guillou et al., 2013).

Sampling of 25 successive flows was conducted over a two years period along the track of the valley of the Güímar, starting with flow TT16 in the normal polarity zone of the Jaramillo Chron and ending with flow TT55 in the reverse polarity zone of the Matuyama Chron. All the flows are accessible along the track except for the youngest flow, TT55, which is located just above it (Fig. 1). Two flows have double numbers (TT33-34 and TT31-32) because they were sampled twice along the path.

Samples were collected using a gasoline powered drill with a 25 millimeter diamond barrel. Four to 14 cores were sampled in each flow and spread out as much as possible over the outcrop, both laterally and across the flows depending on the thickness and the brittle nature of the flows, for a total of 173 cores. A Schoenstedt magnetic locator proved very useful in selecting precise drilling location devoid of very local magnetic disturbances such as lightning strikes. 80% of the 173 cores have both magnetic and sun orientation and the difference between the two ranges between 0 and 12° with an average value around 7°. The bottom chip (thin slice cut at the bottom of the core to make it flat before cutting it into specimens) was used for rock magnetic experiments. Then, between 3 and 8 specimens half the standard size of paleomagnetic samples (11 mm thick) were obtained from each core and the deepest ones were used for stepwise demagnetization and for paleointensity experiments because they did not suffer from any surface weathering.

For K–Ar and $^{40}Ar/^{39}Ar$ dating, large diameter cores (5 cm in diameter and up to 20–25 cm long) were collected in order to attain the freshest part of the most massive portion of the rock.

3. Dating methods and results

K/Ar dating was performed on nine samples. The isotopic composition and abundance of Ar were determined using an unspiked technique described in Charbit et al. (1998). The analytical procedure is described in the supplementary material. For each sample, three independent determinations of concentrations in K were carried out by atomic absorption (flame photometry) at the Centre de Recherche Pétrographique et Géochimique (CRPG, Nancy, France). These repeated measurements have relative precisions of 1% and were combined to yield a mean value for each sample. Age determinations of each sample were made using this mean K concentration value and the weighted mean of the two independent measurements of radiogenic argon ($^{40}Ar^*$). Uncertainties for the Ar data are of an analytical nature only, consisting of propagated and quadratically averaged experimental uncertainties arising from the ^{40}Ar (total) and $^{40}Ar^*$ determinations. Uncertainty on each age is given at 2σ and the details of the method are given in the supplementary material. K/Ar ages (Table 1) range from 1009 ± 22 ka to 971 ± 21 ka, consistently with the local stratigraphy except for TT26 (see below). This time interval is consistent with the upper limit of the JNS.

On the basis of both the unspiked K–Ar ages and first paleomagnetic results, aliquotes from the same groundmass separate than for K–Ar experiments were selected from five of the flows to be analyzed at the $^{40}Ar/^{39}Ar$ facility of the Laboratoire des Sciences du Climat et de l'Environnement (LSCE). The analytical procedure is also described in the supplementary material.

Two step-heating experiments were conducted on two splits for each of the 5 samples (the details are reported in the supplementary table). Plateau ages, isochron regressions and probability of fit estimates were calculated using ArArCALC (Koppers, 2002). Uncertainty of individual plateau age as well as inverse isochron is given at 2σ (full external error). In the following all ages are given with uncertainties at 2σ and relative to 28.02 FC sanidine.

Two step-heating experiments yielded concordant spectra with 100% of the gas defining the age plateaus. The eight other plateau ages comprise between 72% and 94% of the gas released (Table 2). The $^{40}Ar^*$ contents range from 10% to 60%, with typical values of 30% to 40% for the plateau steps. The $^{40}Ar/^{36}Ar$ intercept values defined for the associated isochrons are atmospheric and the total fusion ages are similar within errors to plateau or isochron ages, with the exception of the second experiment on sample TT-22 (Table 2 and Fig. 2). This indicates that for most samples the effect of argon loss or excess argon is almost negligible. This is also a powerful check of the assumptions required to validate the K–Ar ages as reliable crystallization ages, because the isochron approach makes no assumption regarding the trapped component and combines estimates of analytical precision and internal disturbance of the sample (scatter around the isochron). Therefore the isochron