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Magnetic links among lava flows, tuffs and the underground plumbing system in a monogenetic volcano, derived from magnetics and paleomagnetic studies

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ABSTRACT

A combined study using magnetics and paleomagnetism of the Toluquilla monogenetic volcano and associated lavas and tuffs from Valsequillo basin in Central Mexico provides evidence on a 'magnetic' link between the lavas, ash tuffs and the underground volcanic conduit system. Paleomagnetic analyses show that the lava and ash tuff carry reverse polarity magnetizations, which correlate with the inversely polarized dipolar magnetic anomaly over the volcano. The magnetizations in the lava and tuff show similar southward declinations and upward inclinations, supporting petrological inferences that the tuff was emplaced while still hot and indicating a temporal correlation for lava and tuff emplacement. Modeling of the dipolar anomaly gives a reverse polarity source magnetization associated with a vertical prismatic body with southward declination and upward inclination, which correlates with the reverse polarity magnetizations in the lava and tuff. The study documents a direct correlation of the paleomagnetic records with the underground magmatic conduit system of the monogenetic volcano. Time scale for cooling of the volcanic plumbing system involves a longer period than the one for the tuff and lava, suggesting that magnetization for the source of dipolar anomaly may represent a long time average as compared to the spot readings in the lava and tuff. The reverse polarity magnetizations in lava and tuff and in the underground source body for the magnetic anomaly are interpreted in terms of eruptive activity of Toluquilla volcano at about 1.3 Ma during the Matuyama reverse polarity C1r.2r chron.

1. Introduction

Volcanic rocks have been long investigated for paleomagnetism and rock magnetism. Lava flows are characterized by relatively strong and stable remanent magnetizations acquired during eruption and emplacement (Tarling, 1983; Tauxe, 2010). The acquired thermoremanent magnetization (TRM) records the ambient geomagnetic field direction at time of cooling through the blocking temperature spectra of the magnetic minerals. Paleomagnetic studies have been carried out on a wide range of volcanic rocks, other than lavas, including ash flows, ignimbrites, and volcanic debris deposits. Studies have been conducted on composite stratovolcanoes, shield volcanoes, lava domes, calderas, and monogenetic volcanoes (e.g., Tanaka et al., 2004; Urrutia-Fucugauchi et al., 2004; Speranza et al., 2006; Ruiz-Martínez et al., 2010). The related volcanic sequences span widely different spatial and temporal ranges, from the long-lived large stratovolcanoes and calderas to the short-lived small cinder cones (Valentine and Gregg, 2008; Luhr and Simkin, 1993). Considering the widespread use of volcanic rocks in paleomagnetism, considerable research has been conducted on the nature and reliability of the paleomagnetic record of the different volcanic products and on the magnetic mineralogy and remanence acquisition mechanisms.

TRMs in volcanic rocks provide reliable spot readings of the geomagnetic field variations. Paleomagnetic data are successfully used for geomagnetic studies, correlation and dating of volcanic units and for structural and tectonic analyses (Tarling, 1983; Tauxe, 2010). There are cases in which the directional and intensity records deviate from the geomagnetic field due to post-eruption processes such as hydrothermal alterations, re-heating or structural deformation that result on remagnetization of the initial record. Different techniques have been developed to take into consideration the overprinting effects on the paleomagnetic records. There are however other more complex cases, for instance in studies of recent eruptions for which data on the ambient geomagnetic field direction and intensity are available that have documented discordant directions and intensities, which are not apparently related to remagnetization or structural deformation (e.g., Castro and Brown, 1987; Urrutia-Fucugauchi, 1996; Urrutia-Fucugauchi et al., 2004). Study of the mechanisms involved in producing discordant records has attracted considerable attention. In addition, there is interest in investigating the record of other volcanic products such as air-fall ash deposits, volcanic glasses, ignimbrite flows, surges, and spatter lavas.

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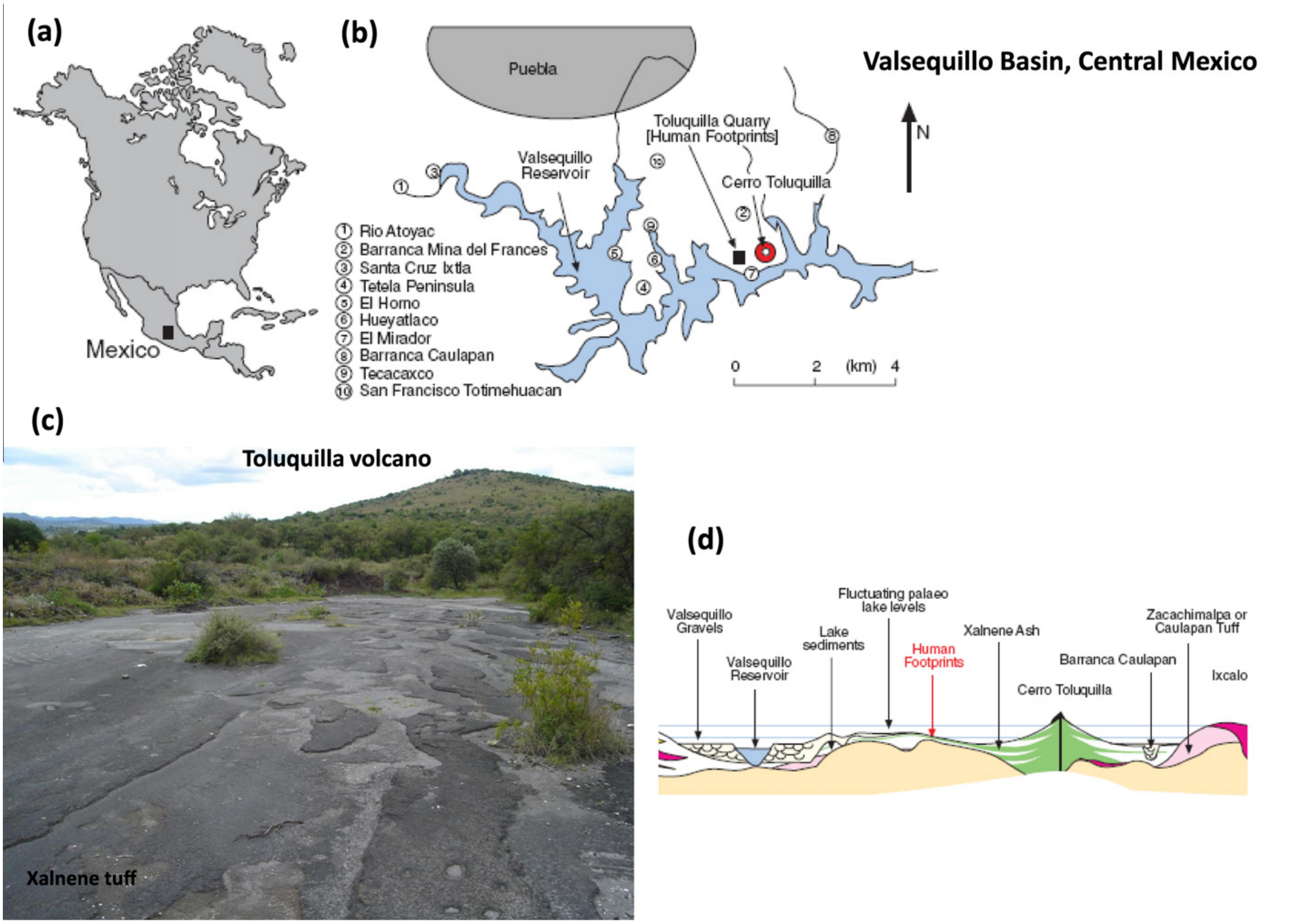

Fig. 1. Study area of Valsequillo basin, central Mexico. (a) Schematic map of Mexico showing location of study area, indicated by the square. (b) Simplified map of Valsequillo basin showing location of studied sites for stratigraphy and paleontology (Gonzalez et al., 2006). (c) View of Toluquilla volcano and quarry outcrop of Xalnene tuff. (d) Schematic cross-section of Valsequillo basin, showing the Toluquilla volcano and Xalnene tuff outcrop with the proposed human footprint tracks (Gonzalez et al., 2006).

Table 1
Summary of paleomagnetic results for Valsequillo basin.

Site	*n*	Dec (°)	Inc (°)	*k*	α_{95}	Polarity	Reference
Xalnene tuff							
Bulk samples	5	194*	−32.1	146.4	6.4	Reverse	1
Individual lapilli	20	205.1	−48.0	5.8	14.9	Reverse	2
Xalnene ash	10	280.8	17.8	52	6.8	Intermediate	3
Blackish ash	6	264.6	13.1	99	6.7	Intermediate	3
VXT-IV	5/8	196.3	−24.9	81.7	8.5	Reverse	4
VXT-V	8/9	206.3	−31.3	27.0	10.9	Reverse	4
Toluquilla lavas							
High-coercivity	12	176.3	−33.1	100.9	4.3	Reverse	2
Low-coercivity	10	354.0	−11.1	112.5	4.6	Intermediate	2
Toluquilla basalt	8	169.8	−29.7	93	5.8	Reverse	3

Notes: *Declinations have been rotated to a reference value of 194°, to allow comparison with data for the Toluquilla lavas and Xalnene tuff samples (Refs. 1 and 2). References: (1) Renne et al. (2005); (2) Feinberg et al. (2009); (3) Goguitchaichvili et al. (2009); (4) this study.

In this note we report on a study of the Toluquilla monogenetic volcano in the Valsequillo basin of central Mexico (Fig. 1). Studies have documented distinct paleomagnetic records for the lava flows, tuff and volcanic lapilli (Table 1), which have been interpreted in terms of reverse polarity magnetizations acquired during the Matuyama C1r.2r chron or as a transitional record acquired during the Laschamp geomagnetic excursion (Renne et al., 2005; Goguitchaichvili et al., 2009; Feinberg et al., 2009). Understanding the nature of the paleomagnetic record and dating the volcanic lavas and tuff presented major implications, mainly due to a report on human footprint tracks recorded in the Xalnene tuff (Gonzalez et al., 2006). Resolving the eruption date for the tuff and lavas prompted several studies, with contrasting results. Part of the controversy has recently being settled, with new Ar/Ar dating of the lavas and tuff with an age of ~1.3 Ma (Feinberg et al., 2009), ruling out an origin as human footprints (see also Mark et al., 2010). In addition to our paleomagnetic and rock magnetic studies of the lavas and tuff we conducted a magnetic survey over the Toluquilla