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An attempt to determine the microwave paleointensity on historic Paricutín volcano lava flows, Central Mexico

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RESUMEN

Reportamos un estudio preliminar de magnetismo de rocas y paleointensidad con la técnica de microondas de los flujos de lava históricos entre 1943 y 1948 del volcán Paricutín. Esos flujos de lava muestran afloramientos frescos y bien preservados. La mayoría de las muestras estudiadas se caracterizan por diagramas ortogonales simples. Las curvas de magnetización remanente isotermal muestran saturación en campos bajos a moderados sugiriendo la serie de titanomagnetitas. De los experimentos de histéresis se determinó que los portadores magnéticos son probablemente titanomagnetitas ricas en hierro con un comportamiento de dominio sencillo a pseudosencillo. La técnica de paleointensidad por microondas se aplicó a tres muestras seleccionadas usando el método de Kono y Ueno (1977); i.e., la dirección del campo aplicado en laboratorio fue perpendicular a la dirección de la magnetización remanente. Los resultados de paleointensidad fueron de 11.38, 26.37 y 51.6 microTeslas, que son significantemente diferentes de los valores esperados. La dispersión observada puede deberse a la pequeña fracción de la magnetización remanente natural usada para la determinación de la paleointensidad, o de no haber usado una corrección por la razón de enfriamiento para muestras naturales.

PALABRAS CLAVE: Paleointensidad, técnica microondas, magnetismo de rocas, México Central, volcán Paricutín.

ABSTRACT

We report a preliminary rock-magnetic and microwave paleointensity study of historic lava flows between 1943 and 1948 of Paricutín volcano. These lava flows show well-preserved, well-exposed, fresh and extensive outcrops. Most samples are characterized by simple uni-vectorial plots. The isothermal remanent magnetization curves show saturation at low to moderate fields, suggesting titanomagnetite series. From hysteresis experiments magnetic carriers are likely iron-rich titanomagnetites with single-domain or pseudo-single-domain behavior. Microwave paleointensity technique was applied to three selected samples using Kono and Ueno's (1977) method; i.e., the direction of applied laboratory field was perpendicular to the direction of remanent magnetization. The samples yielded paleointensity values of 11.38, 26.37 and 51.6 microTesla, which are significantly different from expected values. The observed scatter is likely to be caused by the small fraction of natural remanent magnetization used for paleointensity determination, or from not using a cooling rate correction for natural samples.

KEY WORDS: Paleointensity, microwave technique, rock-magnetism, Central Mexico, Paricutín volcano.

INTRODUCTION

The intensity of the paleofield may be estimated by comparing the intensity of the thermoremanent magnetization (TRM) acquired by a volcanic rock at the time of emplacement with the strength of a laboratory TRM produced by a known field (Koenisberger, 1938). Heating of the rock above its maximum blocking temperature alters initial magnetic mineralogy and may disturb the relationship between field and TRM. Thellier and Thellier (1959) devised a method to study partial TRM (pTRM), obtained from parts of the blocking/unblocking temperature spectra not affected by magneto-mineralogical alteration. However, for most of natural rocks the alteration may occur at very low temperatures, which impedes an accurate determination of ancient geomagnetic field strength (Kosterov and Prévot, 1998).

Conventional TRM is formed when heat in the form of phonons is sufficient to generate spin waves (magnons) within the individual magnetic domains (Walton *et al.,* 1993). The spin waves allow magnetization to reverse, and during cooling the magnetization becomes fixed with a statistical bias towards the ambient magnetic field direction. Alternatively, spin waves can be generated within magnetic grains by direct microwave excitation (Shaw *et al.,* 1996). The TRM formed by this method is almost identical to the one formed by heating, except that the magnetic system is heated and cooled very quickly (a few seconds). Thus microwave TRM does not cause any noticeable alteration of the magnetic minerals (Walton *et al.,* 1993). Microwave techniques seem to be ideal for determining paleointensities.

It is extremely valuable to study historic lava flows as the geomagnetic field at time of extrusion is known. In this study, we report a preliminary rock-magnetic and microwave paleointensity investigation of historic lava flows of Paricutín volcano, from the period between 1943 and 1948. These lava flows feature well preserved, well-exposed, fresh, extensive outcrops.

PARICUTÍN VOLCANO

Paricutín volcano emerged on February 20, 1943 in a corn field near San Juan Parangaricutiro village, Michoacán, Mexico (Ordóñez, 1943). This area is in the Michoacan-Guanajuato volcanic field, which is characterized by numerous cinder cones and medium sized shield volcanoes. In this area, Jorullo volcano was born on September 29, 1759, some 72 km to the southeast (Figure 1).

The birth and growth of Paricutín volcano have been extensively discussed Fries, (1953), Segerstrom, (1965), Luhr and Simkin, (1993) and others. Activity extended from 1943

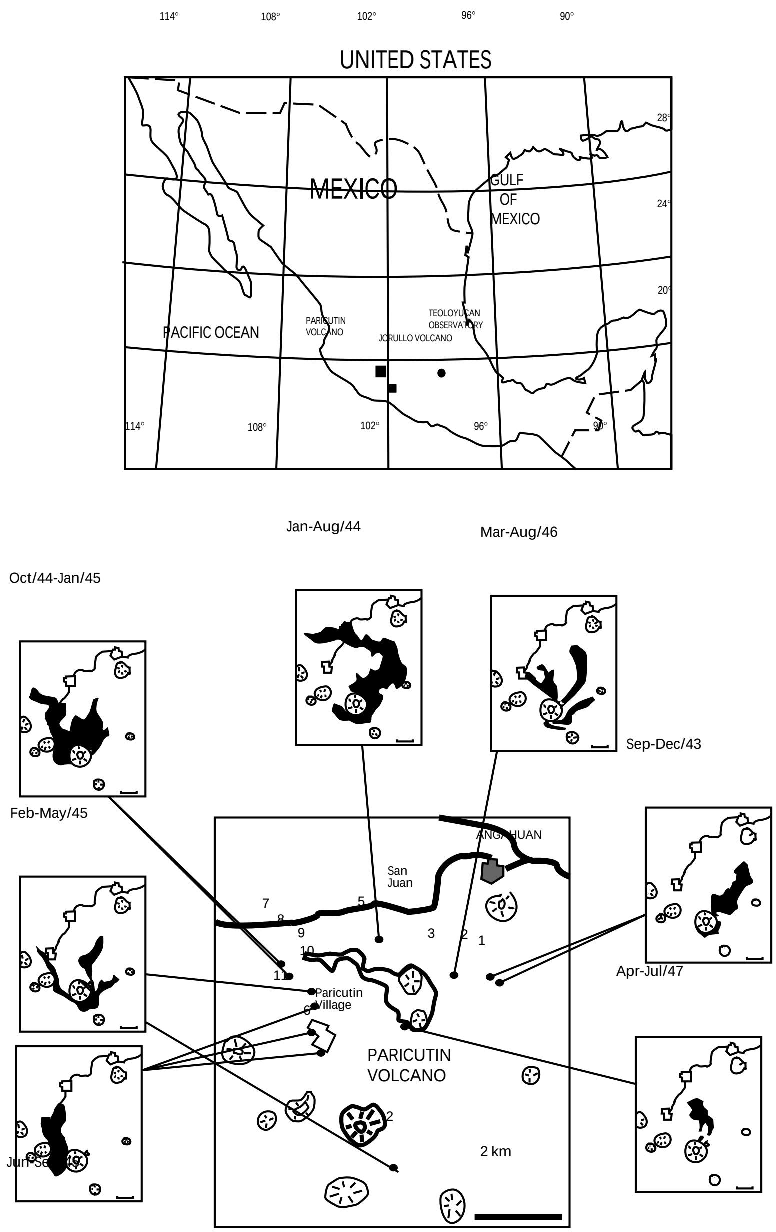

Fig. 1. Schematic map of the Paricutín volcano and its lava field (shaded area). The distribution of flows in terms of lava eruptive episodes is shown in the small maps, with the dates of the episode and the aeral extension of lavas (maps adapted from Luhr and Simkin, 1993).

trough 1952 (Figure 1). The composition and petrography of erupted material changed from olivine-bearing basaltic andesites in 1943 to orthopyroxene-bearing andesite at the end of 1952 (Wilcox, 1954).

ROCK-MAGNETIC PROPERTIES OF PARICUTÍN SAMPLES

The NRM measurements were performed by using a Molspin spinner magnetometer. The low-field susceptibility was measured with a Bartington MS2 system equipped with dual frequency laboratory sensor. Stability and vectorial composition of natural remanence were investigated by stepwise alternating field (AF) demagnetization in 9 to 11 steps up to a maximum of 100 mT, using a Schonstedt demagnetizer in the three-axes stationary mode.

The viscosity index (Thellier and Thellier, 1944; Prévot *et al.,* 1983) may estimate the capacity of a sample to acquire a viscous remanent magnetization, and its paleomagnetic stability. We placed the samples during 10 days with one axis aligned with Earth's magnetic field. After measuring the magnetization (M_d), the samples were placed for another 10 days in a field-free space, and the magnetization (M_0) was measured again. The viscosity index is $V = [(Z_d - Z_0) : M_{nrm}] \times 100$, where Z_d and Z_0 are the magnetization components of M_d and M_0 parallel to the magnetizing field, and M_{nrm} is the intensity of natural remanent magnetization. The values were lower than 2.7 %: thus, there is no evidence of significant viscous remanent magnetization in Paricutín lavas.

Most samples, including those used for paleointensity experiments are characterized by a simple uni-vectorial component pointing towards the origin (Figure 2a). The median destructive fields (MDF) range mostly from 30 to 40 mT, suggesting 'small' pseudo-single domain grains as remanent magnetization carriers (Dunlop and Özdemir, 1997).

Hysteresis measurements at room temperature were performed on all samples using an AGFM 'Micromag' apparatus at the paleomagnetic laboratory in Mexico City, with fields up to 1 Tesla. Saturation remanent magnetization (J_{rs}), saturation magnetization (J_s) and coercitive force (H_c) were calculated after correction for paramagnetic contribution. Coercivity of remanence (H_{cr}) was determined by applying progressively increasing backfield after saturation (Figure 2b and c). A representative hysteresis curve is shown in Figure 2 (b and c). The curves are symmetrical. Near the origin, no potbellied or wasp-waisted behaviors (Tauxe *et al.,* 1996) were detected, which probably reflects restricted ranges of opaque mineral coercivities. Judging from the ratios of hysteresis parameters, all samples fall in the pseudo-single domain (PSD) grain size region (Day *et al.,* 1977), probably indicating a mixture of multidomain (MD) with a significant amount of single domain (SD) grains. Corresponding isothermal remanence (IRM) acquisition curves were found to be very similar for all samples. Saturation is reached in moderate fields of the order of 150-200 mT, which points to some spinels as remanence carriers.

RESULTS AND DISCUSSION

The paleointensity experiments were carried out at the Geomagnetic Laboratory of the University of Liverpool, using the 8.2GHz Microwave system, under scientific supervision of Dr. John Shaw. The technique used, described

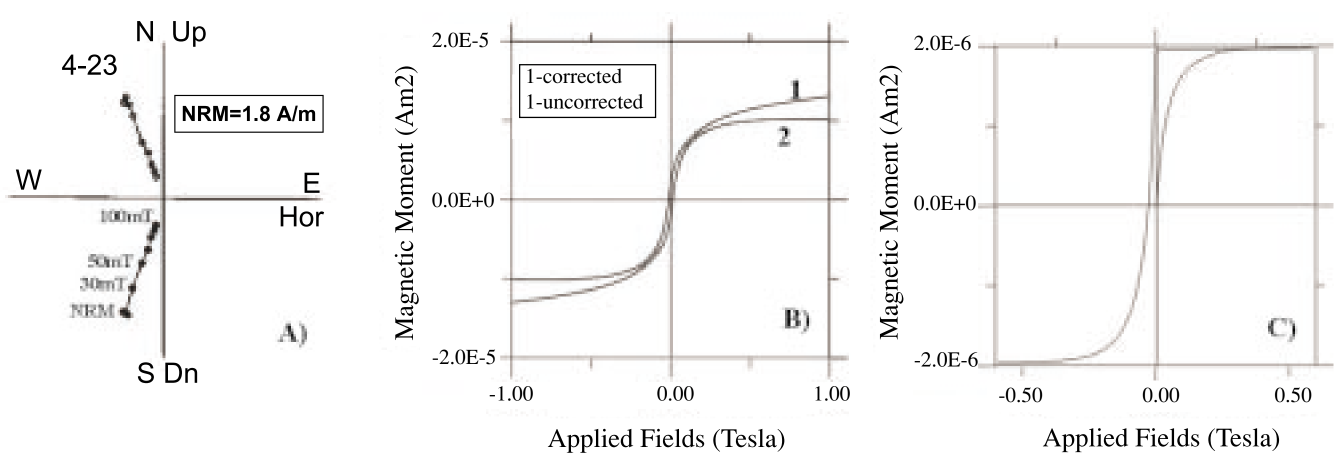

Fig. 2. A) Typical example of alternating field demagnetization vector plot for Paricutín lavas. B) Example of hysteresis curve measured with 'AGFM-Micromag' system. C) Example of direct field isothermal remanent magnetization (IRM) acquisition curve and back-field curve.

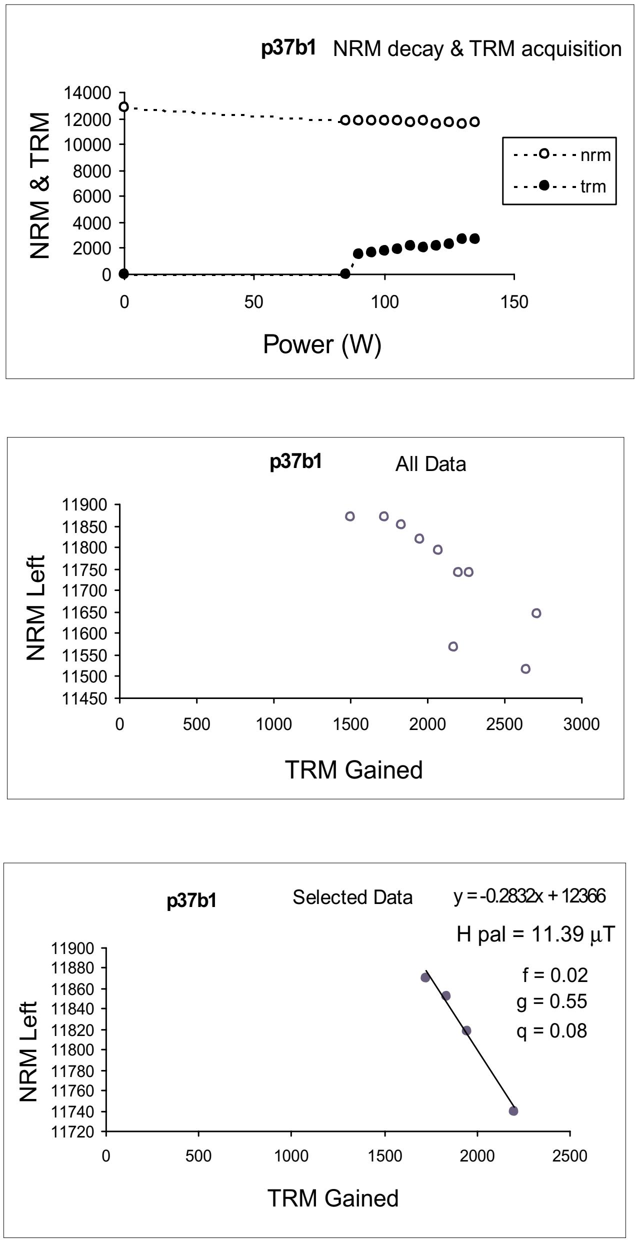

Fig. 3 and 4. Results from the microwave intensity analyses: *f*, *g* and *q* are the fraction of extrapolated NRM used, the gap factor and quality factor (Coe *et al.,* 1978) respectively. Open/close symbols devote to the points rejected/used for paleointensity determination.

in detail in Hill and Shaw (1999), is a variant of the stepwise Thellier method (Kono and Ueno, 1977). A microwave thermoremanence is induced perpendicular to the directions of NRM, so that a single microwave application is required for each power step (Figure 3 and 4). This eliminates the need for accurate reproducibility of microwave power (up to 140 W) absorbed by the sample. Control heatings (so-called pTRM checks) are normally used with the conventional Thellier type technique (Prévot *et al.,* 1985) to monitor alteration during the experiment. In the case of microwave paleointensity it is difficult to repeat a previous step because the power absorbed by a rock sample is the one that needs to be reproduced. Another way to check for alteration is to monitor hysteresis parameters (Hill and Shaw, 2000). However, Goguitchaichvili *et al.* (2001) showed that room temperature hysteresis parameters, in terms of the plot of magnetization ratio vs. coercivity ratio, lack resolution for most of natural rocks. No alteration test was performed in this study.

Three magnetically stable representative samples were selected for pilot microwave paleointensity experiments. Paleointensity data are reported on the Arai-Nagata (Nagata *et al.,* 1963) plot on Figure 3 and 4. The samples yielded paleointensity values of 11.38, 26.37 and 51.63 microTesla, which are significantly different than the expected intensity of around 45 microTesla, from Teoloyucan Observatory data (Urrutia and Campos, 1993). The scatter in paleointensity data suggest that internal effects in the lava flows may be responsible. The failure of microwave paleointensity measurements on Paricutín samples is probably due to the fact that only a small fraction of natural remanent magnetization was used for paleointensity determination. Additional measurements, using 14GHz system are strongly needed. Another explanation may be the impossibility to use the cooling rate correction for natural samples. The samples are 'cooled' down in a few seconds during the microwave paleointensity experiment. Based on experimental studies (Fox and Aitken, 1980; McClellend, 1984; Goulpeau *et al.,* 1989; Chauvin, 1989; Aitken *et al.,* 1991; Biquand, 1994), Garcia (1996) showed that there is no clear relation between the cooling rate and TRM acquisition. The differences between TRM produced with low and high cooling rates may vary between 5 and 600%. Bowles *et al.* (2002), studying some archeomagnetic material from Ecuador, demonstrated that the differences between cooling rates in the past and in the laboratory may produce a large scatter of paleointensity data. However, microwave paleointensity analysis of the 1960 Kilauea flow (Hill & Shaw, 2000), and the experimental study of Hill *et al.* (2002) show that the field intensity can be correctly estimated without using cooling corrections. Additional historic lava flows need to be studied in order to ascertain whether the failure of paleointensity experiments is due to internal characteristic of Paricutín volcano lava flows.

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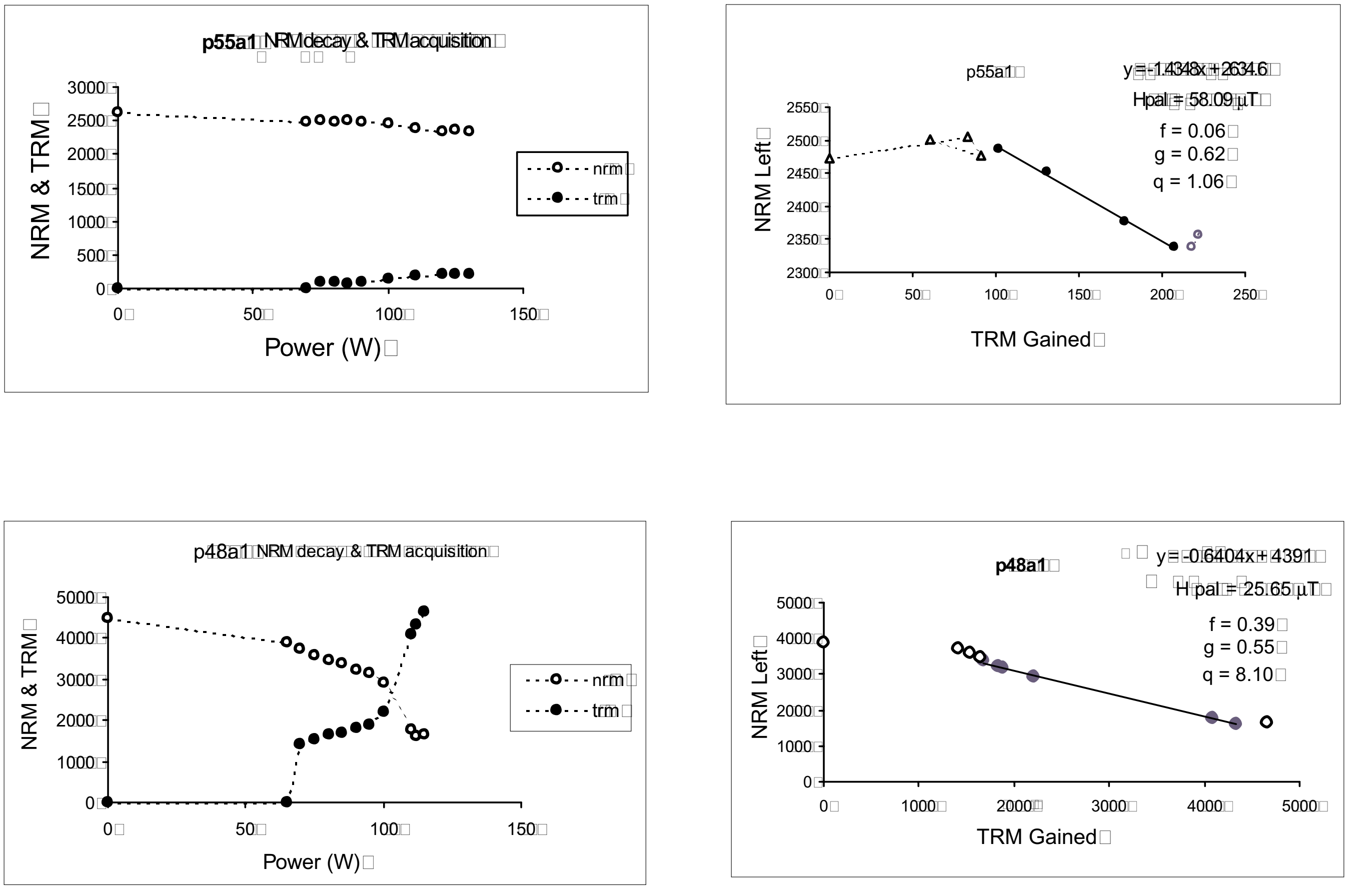

Fig. 4.

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