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Microwave paleointensity analysis of historic lavas from Paricutín volcano, Mexico

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RESUMEN

Reportamos el estudio de paleointensidad de lavas históricas del volcán Paricutín por el método de microondas, las cuales fueron eruptadas durante el período entre 1943 y 1948. Muchas de las muestras se caracterizan por presentar gráficas ortogonales univectoriales. Los estudios de magnetismo de rocas y microscopía indican titanomagnetitas de dominio seudo sencillo como los portadores de la remanencia. La técnica de microondas se aplicó a muestras seleccionadas usando variantes al método de Thellier de Kono y Ueno (1977) y de Coe *et al.* (1978). Las muestras dieron resultados de paleointensidad de alta calidad técnica, no obstante mostraron alta dispersión en un mismo flujo siendo significativamente diferentes del valor esperado de 45 mT. Esto también se observó en los resultados obtenidos al aplicar el método de Thellier (Urrutia-Fucugauchi *et al.,* 2004). Se exploraron las explicaciones a este comportamiento respecto a otros estudios en lavas históricas. La alta calidad técnica de los resultados sugiere que no hay criterios que puedan distinguir entre datos de paleointensidad correctos y erróneos.

PALABRAS CLAVE: Paleomagnetismo, paleointensidad, método de microondas.

ABSTRACT

We report a microwave paleointensity study of historic lavas from Paricutin volcano, erupted during the period between 1943 and 1948. Most samples are characterized by uni-vectorial orthogonal plots. Rock-magnetic and microscopy studies indicate pseudo-single-domain titanomagnetites as the remanence carriers. The microwave paleointensity technique was applied to selected samples using both Kono and Ueno (1977) and Coe *et al.* (1978) variants of the Thellier method. The samples yielded technically high quality paleointensity results, though show high within-flow dispersion and are significantly different from the expected value of 45mT. This is also seen in results using the Thellier method (Urrutia-Fucugauchi *et al.*, 2004). Explanations for this behaviour are explored, with reference to other historic lava studies. The technically high quality of the results suggest there is no criteria that can distinguish between correct and erroneous paleointensity data.

KEY WORDS: Paleomagnetism, paleointensity, microwave technique.

INTRODUCTION

The determination of the absolute strength of the geomagnetic field is important for understanding the processes in the core that generate the field and the processes by which the field reverses polarity. Reliable absolute palaeointensities are generally much more difficult to obtain than directional data, because only certain igneous rocks which satisfy specific magnetic criteria (e.g. Kosterov and Prévot, 1998) are considered useful for paleointensity determination.

The intensity of a paleofield may be estimated by comparing the intensity of the thermoremanent magnetization (TRM) acquired by a volcanic rock at the time of cooling with the strength of a laboratory TRM produced by a known field (Koenisberger, 1938). However, heating of the magnetic remanence carriers above their maximum blocking temperatures may alter initial magnetic mineralogy and may invalidate the original TRM and laboratory TRM ratio. Thellier and Thellier (1959) devised a method to study partial TRM (pTRM), obtained from parts of the blocking/unblocking temperature spectra unaffected by magneto-mineralogical alteration. However, for the majority of natural rocks, alteration may occur at low temperatures, which can impede an accurate determination of paleointensity (Calvo *et al.*, 2002).

A 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). These 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 (e.g. Shaw *et al.*, 1996). The TRM formed by this method is almost identical to the one formed by heating (Hill *et al.*, 2002), except only the magnetic system is heated and cooled in a few seconds (and not the matrix). As this microwave TRM (T_MRM) does not involve bulk sample heating (Walton *et al.*, 1993), this technique is ideal for determining palaeointensities.

It is pertinent to study the paleomagnetic behaviour of historic lava flows, as the geomagnetic field at time of extrusion is known. In this study, we report a microscopic, rock-magnetic and microwave paleointensity investigation of the historic lava flows of Paricutín volcano, Mexico, during the period between 1943 and 1948. These lava flows are well exposed and appear fresh. Absolute intensity values obtained were compared to the data from the Teoloyucan Geomagnetic Observatory, located north of Mexico City, 320 km east of Paricutín volcano (Figure 1).

SAMPLING DETAILS

One of the best-documented cases of volcano formation is the 1943-1952 eruption of Paricutín in central Mexico (Figure 1). Paricutín volcano first erupted on February 20, 1943 near San Juan Parangaricutiro village, Michoacán State, Mexico (Ordóñez, 1943). This is in the Michoacán-Guanajuato volcanic field, characterized by numerous cinder cones and medium-sized shield volcanoes.

Both formation and growth of Paricutín volcano have been extensively discussed by Fries, (1953), Segerstrom, (1965), Luhr and Simkin, (1993) amongst others. Volcanism continued from 1943 through to 1952 (Figure 1). The composition and petrography of erupted material changed from olivine-bearing basaltic andesites in 1943 to orthopyroxene-bearing andesites at the end of 1952 (Wilcox, 1954).

102 oriented standard paleomagnetic cores from 12 flows were collected from seven different lava effusion episodes, which cover the interval between September-December 1943 and March-August 1946 (Figure 1). Samples were distributed throughout each flow both horizontally and vertically in order to minimize effects of block tilting and lightning strikes. Cores were obtained with a gasoline-powered portable drill, and oriented with both magnetic and sun compasses.

ROCK MAGNETIC EXPERIMENTS

To identify the magnetic remanence carriers and to obtain information about their paleomagnetic stability, rock-magnetic experiments were performed. These experiments include reflected light microscopy, measurements of susceptibility curves, hysteresis combined with IRM (isothermal remanent magnetization) experiments and alternating field (AF) demagnetisation of the natural remanent magnetization (NRM).

Microscopy observations

A study of the opaque mineralogy was conducted with an optical microscope using polished sections and oil immersion. In general, the studied samples exhibit two generations of Fe-Ti oxides (Figure 2a). 'Skeletal' titanomagnetites are abundant in most of the studied lavas indicating fast cooling (e.g. sample P-25). However, it is hard to observe any textural characteristics. In other cases, typical titanomagnetite-ilmenite intergrowths (Haggerty, 1976) were detected (e.g. sample P-72). Theoretically, the NRM carried by these grains may be a TRM, as this paragenesis typically develops at temperatures higher than the Curie point of magnetite (~ 578°C).

Continuous susceptibility measurements

Continuous susceptibility measurements were performed on one sample per flow using a Bartington MS2 system. Samples were heated up to ~625°C at a rate 20°C/min and cooled at the same rate. Curie temperatures were determined by the Prévot *et al.* (1983) method. In general, the curves show the presence of a single magnetic/ferrimagnetic phase with Curie point 570°C compatible with relatively low-Ti titanomagnetites (Figure 2b). This agrees with the microscopic observations.

Hysteresis experiments

Room temperature hysteresis measurements were performed on all samples using the AGFM 'Micromag' apparatus at the paleomagnetic laboratory in Mexico City, with applied fields up to 1 Tesla. Saturation remanent magnetization (J_{rs}), saturation magnetization (J_s) and coercive force (H_c) were calculated after correction for paramagnetic contribution (Figure 2c). Coercivity of remanence (H_{cr}) was determined by applying a progressively increasing backfield IRM after saturation. No potbellied or wasp-waisted behavior (Tauxe *et al.*, 1996) was detected, reflecting restricted ranges of opaque mineral coercivities. From the ratios of hysteresis parameters, all samples plot in the pseudo-single domain (PSD) grain size region (Day *et al.*, 1977). Corresponding IRM acquisition curves (not shown) were found to be similar for all samples. Saturation is reached in moderate fields of the order of 150-200 mT, suggesting spinels, probably titanomagnetites, as remanence carriers.

AF demagnetization

Remanence measurements were made using a JR6 (AGICO) spinner magnetometer. Stepwise AF demagnetization used a Molspin AF demagnetizer, providing fields up to 100 mT. Most samples show single component magnetization (Figure 2d). A generally small secondary component, probably of viscous origin, is sometimes present but easily removed. The median destructive fields (MDF) range mostly from 35 to 50 mT, suggesting small pseudo-single domain grains as remanent magnetization carriers (Dunlop and Özdemir, 1996). The overall-mean direction estimated for all flows is: Dec=1.8°, Inc=37.5°, k=26, and α_{95} =8.7° (Urrutia-Fucugauchi *et al.*, 2004).

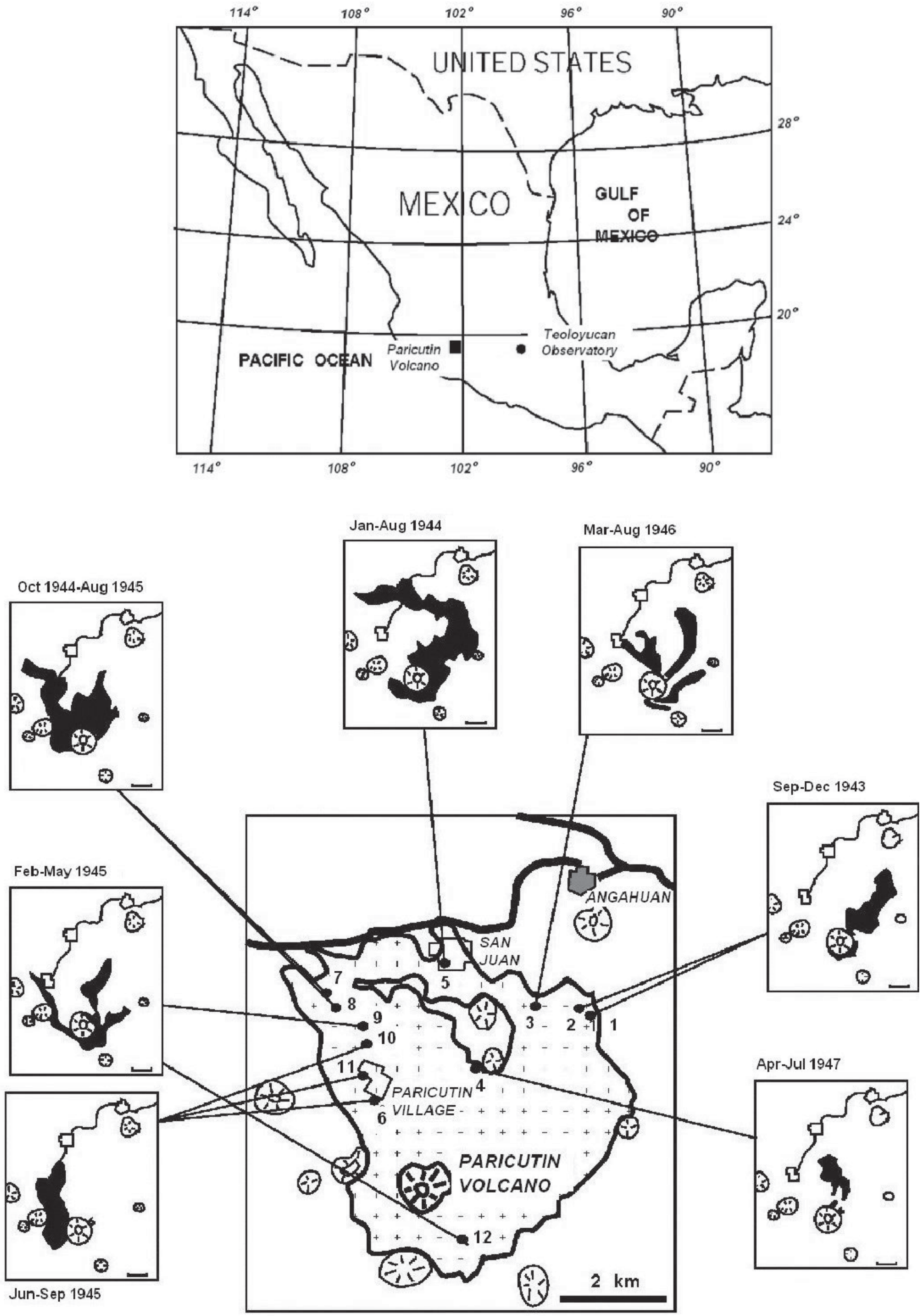

Fig. 1. Location of Paricutín volcano and Teoloyucan Geomagnetic Observatory. Schematic map of the Paricutín volcano, its lava field (shaded area) and location of paleomagnetic sampling sites (numbered dots). The distribution of sites in terms of lava eruptive episodes is shown in the small maps, with dates of the episode and the aerial extension of lavas (maps adopted from Luhr and Simkin, 1993). Each site corresponds to one individual lava flow.

Rock magnetic summary

From the results of all the above experiments, the majority of the samples exhibit a single component thermal remanence that is carried by low-Ti titanomagnetites, of a grain size in the pseudo-single domain range.

MICROWAVE PALEOINTENSITY EXPERIMENTS

Two sets of experiments were carried out at the Geomagnetism Laboratory, University of Liverpool. The first method used, detailed by Hill and Shaw (1999), is a variant of the stepwise Thellier method (Kono and Ueno, 1977), in which a microwave thermoremanence (T_MRM) is induced perpendicular to the primary NRM direction, so that only a single microwave application is required for each power step (Figure 3a). This eliminates the need for accurate reproducibility of microwave power absorbed by the sample. This method was performed on 21 samples (Figure 3a). 13 sister samples were subjected to the double 'heating' modified Thellier type (Coe, 1967) procedure (Figure 3b), with demagnetisation and remagnetisation steps performed in a zero and an arbitrarily oriented applied field, respectively. The latter method included the addition of pT_MRM checks.

RESULTS

23 out of 34 samples (68%) yielded technically good quality paleointensity determinations (Figure 3 and Table 1). The accepted minimum NRM fraction f, was 0.32 (mean value of 0.62) and the minimum quality factor, (Coe *et al.*, 1978) q was 5, with a mean of 23. Results with less than four points and a regression coefficient r^2 of less than 0.99 on the slope of the Arai plot were rejected. In total, we rejected 11 samples that did not meet these criteria. With the perpendicular field method, the sum of the angles between the total magnetization vector and the NRM and T_MRM directions was monitored during each step, and if any increase above 90º was observed, the experiment was terminated, as this implied the primary NRM direction was not isolated or unstable. With the double 'heating' method, a maximum difference between the pT_MRM and the pT_MRM check of 20% was used.

Overall, the mean paleointensity estimate is calculated as 35 ± 19μT, with results ranging from 11 to 79μT. This is significantly different from the expected intensity of ~45μT, from observatory data (Figure 4), though similar to dispersion seen from the Thellier study (Figure 5) which gives a mean of 36 ± 20μT (Urrutia-Fucugauchi *et al.*, 2004). Some samples taken from the same 25mm core, using both variants of the microwave method, yielded different results (e.g. samples P31, P34A, P78A – see Figure 3). This is different from other microwave paleointensity studies which show a high correlation between pairs of samples from the same 25mm core (Gratton *et al.*, in press in Phys. Earth Planet. Int) and between the two methods (Hill *et al.*, 2002). In the majority of cases, the double 'heating' method yields higher results than those obtained using the perpendicular field, suggesting that undetected alteration may have occurred in the latter case, resulting in a lower field estimate, due to increased TRM capacity. Alternatively, the multidomain (MD) remanence and variable angle between the laboratory field and NRM may also contribute to the difference between the double heating and perpendicular methods (Coe *et al.* 2004).

DISCUSSION

The mean values for flows 5, 7 and 12 are comparable with observatory data, though associated standard deviations for flows 5 and 7 are large (~50%). There are no significant differences in quality between results from these flows and those that give different results to the expected values. There have been several paleointensity studies of historic lavas that record problematic paleointensity results, including a previous investigation of the Paricutín flows (González *et al.*, 1997), which found similar dispersion of results using both Thellier and Shaw methods.

A through-flow study of the Holocene Xitle lava flow, Mexico by Böhnel *et al.* (1997) showed a high within-flow dispersion of paleointensity results, attributed to rock magnetic variations throughout the flow. A study of historical lava flows from Mt. Etna (Calvo *et al.*, 2002) found that acceptable results (including positive pTRM checks) overestimated the field by 25%. This was attributed to multi-domain (MD) grains carrying the majority of the remanence. The majority of acceptable Paricutín flow results (including positive pT_MRM checks) both overestimate *and* underestimate the correct value, therefore MD behaviour is not likely to be the cause of the wide-dispersion seen here.

Another explanation for the results is that the TRM is of (thermo)chemical origin (CRM or TCRM). In a study of cooling Hawaiian lava lakes, Grommé *et al.* (1969) found zones in which NRM was held by minerals formed by subsolidus reactions at temperatures below their Curie point. Like the Paricutín lavas, Ti-poor titanomagnetites with visible ilmenite lamellaes were responsible for the remanence. Rolph (1997) studying the 1169 and 1971 eruptions of Mt. Etna and Hill and Shaw (2000) studying 1960 Kilauea (Hawaii) lava flows also suggested the reason for anomalous results could be due to CRM in some samples of their collection. Presently, it is almost impossible to distinguish between TRM and CRM due to the lack of any strict criteria. McClelland (1996) suggested that grain-growth CRM carried by magnetite or hematite could be distinguished from a TRM by analyzing a Thellier paleointensity experiment. A 'slow / fast growth CRM' may show a

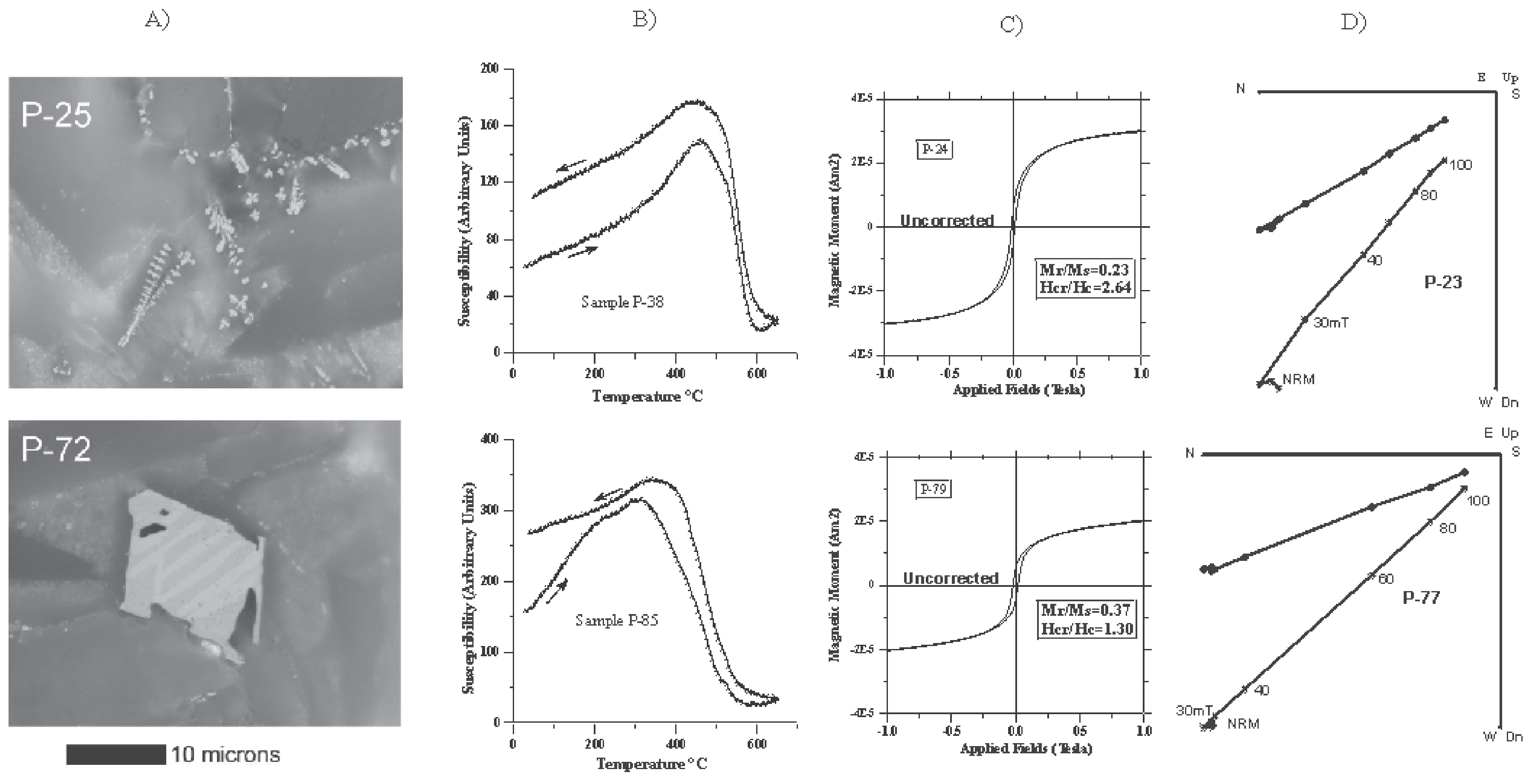

Fig. 2. A) Representative photomicrographs of the opaque minerals; B) Representative susceptibility versus temperature curves. The arrows indicate the heating and cooling curves; C) Examples of hysteresis loops (uncorrected for paramagnetic component) of sample chips; D) Orthogonal vector plots of stepwise AF demagnetization (stratigraphic coordinates). Numbers refer to peak alternating fields in mT. o – projections into the horizontal plane, x – projections into the vertical plane.

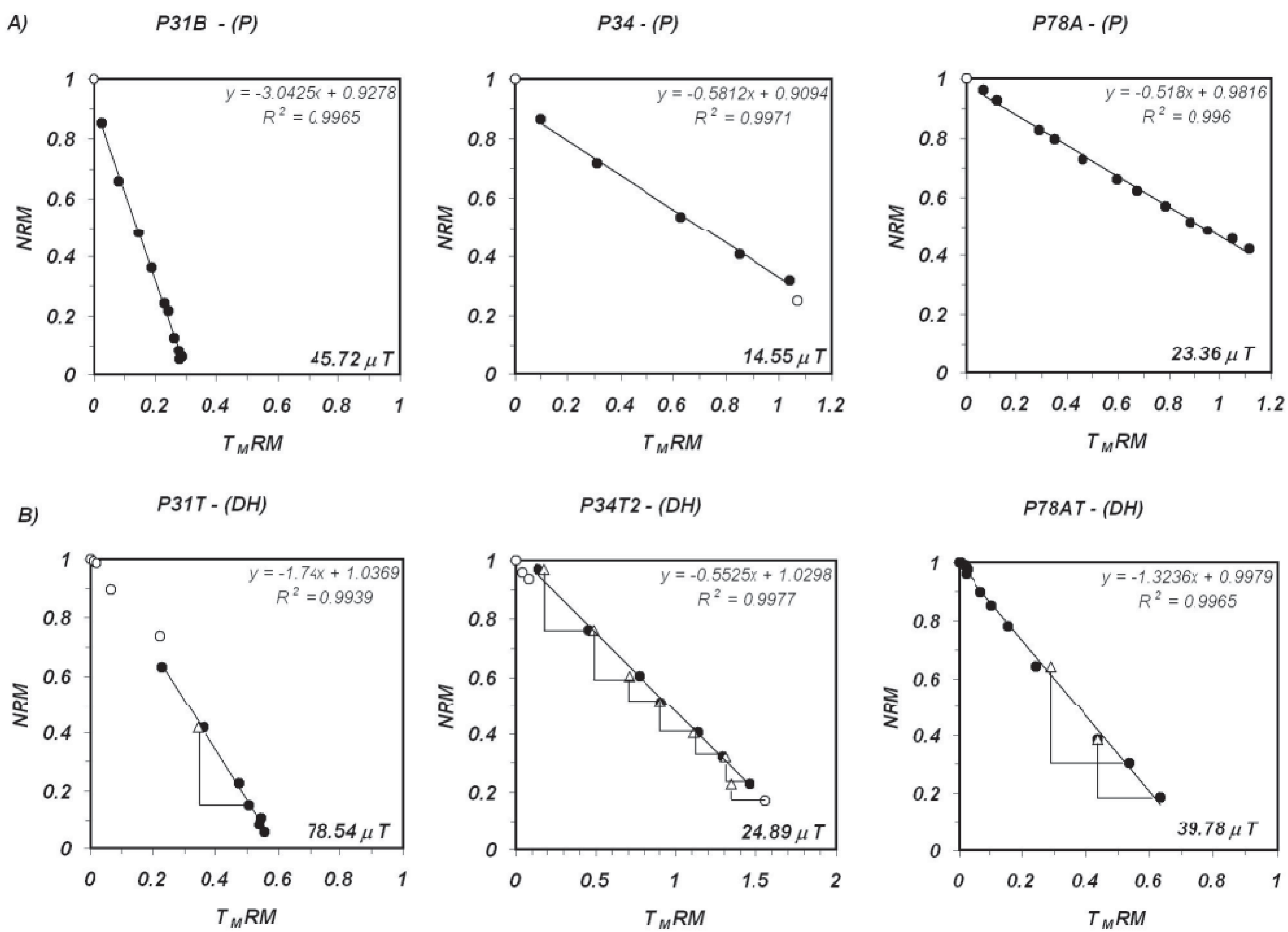

Fig. 3. Representative NRM-T_MRM plots (Arai plots) for Paricutín lavas obtained using the A) Kono and Ueno (1977) and B) Coe *et al*. (1978) methods.

Table 1

Accepted samples

Eruption	Sample	Site	F	Error	N	f	g	q	System	Method	F̲	Error̲
S5. Jan-Aug 1944	P31B	5	45.72	1.45	10	0.80	0.83	31.55	14 GHz	P	42.17	24.60
S5. Jan-Aug 1944	P31Q	5	47.13	0.75	7	0.86	0.76	63.09	14 GHz	P		
S5. Jan-Aug 1944	P31T	5	78.54	6.68	7	0.57	0.72	11.76	14 GHz	DH		
S5. Jan-Aug 1944	P34	5	14.55	1.12	5	0.55	0.73	13.00	14 GHz	P		
S5. Jan-Aug 1944	P34T2	5	24.89	0.90	7	0.74	0.81	27.72	14 GHz	DH		
S6. Jun-Sep 1945	P37B2	6	15.48	0.69	9	0.68	0.79	22.59	14 GHz	P	15.48	-
S7. Oct1944-Jan1945	P48A1	7	26.19	1.95	5	0.37	0.45	13.41	8.2 GHz	P	43.24	20.12
S7. Oct1944-Jan1945	P48A3	7	24.46	1.10	11	0.70	0.81	22.24	14 GHz	P		
S7. Oct1944-Jan1945	P53B	7	50.62	1.33	8	0.81	0.81	37.94	14 GHz	P		
S7. Oct1944-Jan1945	P55A3	7	41.37	3.68	12	0.33	0.68	11.23	14 GHz	P		
S7. Oct1944-Jan1945	P55AT2	7	73.55	2.67	12	0.85	0.86	27.58	14 GHz	DH		
S8. Oct1944-Jan1945	P61B	8	34.76	1.16	8	0.77	0.74	30.03	14 GHz	P	34.76	-
S10. Jan-Sep 1945	P71T	10	16.33	0.48	10	0.94	0.91	33.88	14 GHz	DH	23.09	9.70
S10. Jan-Sep 1946	P71U	10	17.84	0.71	10	0.90	0.86	24.95	14 GHz	DH		
S10. Jan-Sep 1945	P71Q	10	18.16	0.55	7	0.66	0.76	33.07	14 GHz	P		
S10. Jan-Sep 1945	P78A	10	23.36	0.96	12	0.54	0.89	24.25	14 GHz	P		
S10. Jan-Sep 1945	P78AT	10	39.78	1.03	14	0.81	0.82	38.60	14 GHz	DH		
S11. Jan-Sep 1945	P81A	11	12.02	1.14	10	0.40	0.87	10.58	14 GHz	P	30.53	21.99
S11. Jan-Sep 1945	P81AT	11	11.20	1.13	6	0.45	0.81	9.90	14 GHz	DH		
S11. Jan-Sep 1945	P83A	11	46.34	3.03	8	0.46	0.81	15.31	14 GHz	P		
S11. Jan-Sep 1945	P83AT	11	52.54	8.07	8	0.40	0.79	6.51	14 GHz	DH		
S12. Feb-May 1945	P87BT	12	41.48	3.50	8	0.42	0.83	11.85	14 GHz	DH	41.06	0.60
S12. Feb-May 1945	P91BT	12	40.64	7.04	4	0.32	0.61	5.78	14 GHz	DH		

Rejected samples

Eruption	Sample	Site	F	Error	N	f	g	q	System	Method
S1. Sep-Dec 1943	P4B	1	36.00	12.32	11	0.18	0.86	2.92	14 GHz	P
S1. Sep-Dec 1943	P4T2	1	30.10	8.93	10	0.27	0.83	3.37	14 GHz	DH
S1. Sep-Dec 1943	P4T	1	31.50	5.64	7	0.25	0.84	5.59	14 GHz	DH
S6. Jun-Sep 1945	P37B1	6	11.38	146.55	4	0.01	0.55	0.08	8.2 GHz	P
S7. Oct1944-Jan1945	P48A2	7	26.37	17.79	7	0.16	0.79	1.48	8.2 GHz	P
S7. Oct1944-Jan1945	P55A2	7	51.63	25.70	8	0.10	0.72	2.01	8.2 GHz	P
S8. Oct1944-Jan1945	P59AB	8	6.90	69.30	4	0.17	0.61	0.10	14 GHz	P
S8. Oct1944-Jan1945	P61BT	8	27.10	2.84	11	0.16	0.83	9.56	14 GHz	DH
S10. Jan-Sep 1945	P71	10	5.97	1.99	8	0.28	0.82	3.00	14 GHz	P
S12. Feb-May 1945	P87B	12	41.00	11.13	4	0.31	0.64	3.68	14 GHz	P
S12. Feb-May 1945	P91B	12	52.80	5.07	8	0.28	0.84	10.42	14 GHz	P

Microwave paleointensity results from the Paricutín volcano. F: individual paleointensity estimate with associated error (1/q); F: flow mean paleointensity with Error (standard deviation); N: number of NRM-T_MRM points used for paleointensity determination; *f*, *g* and *q* are the fraction of NRM used, the gap factor and quality factor (Coe *et al.*, 1978); System: microwave system used (8.2 or 14GHz), Method used: P – perpendicular field, DH – double 'heating'.

concave-up Arai plot, though Körner *et al*. (1998) and Goguitchaichvili *et al*. (1999) do not observe this concavity on artificially induced CRMs.

The number of determinations per flow may also be a factor in this high-dispersion. In this study, the average number of determinations per flow is less than two (counting multiple results from the same 25 mm core as one determination), and this low number will not represent the total flow. Statistical analyses by Biggin *et al*. (2003) suggest that the present norm of determinations per flow should be trebled to gain a more representative estimate of the flow mean value.

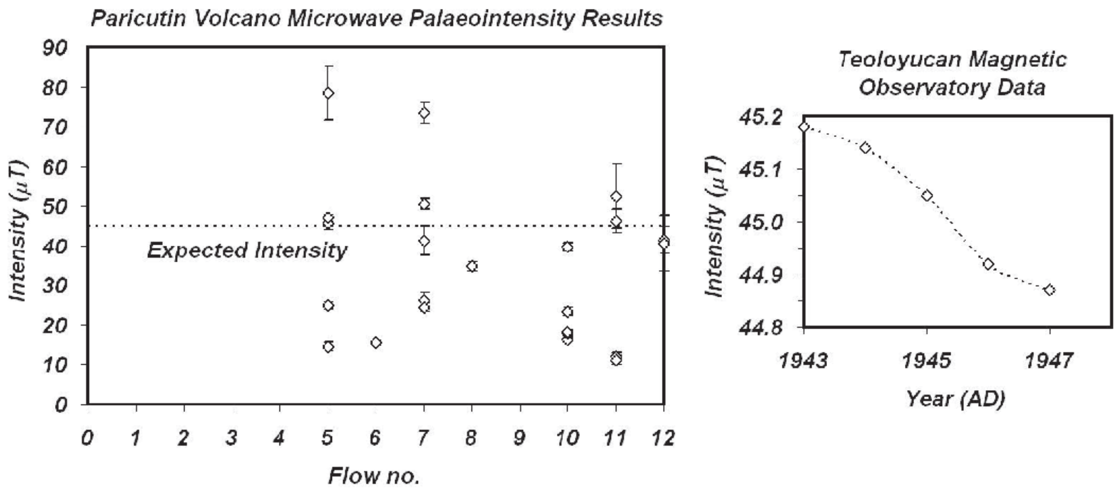

Fig. 4. Microwave paleointensity results for all studied Paricutín samples (see also Table 1) and total field intensity recorded at the Teoloyucan Geomagnetic Observatory during the study period.

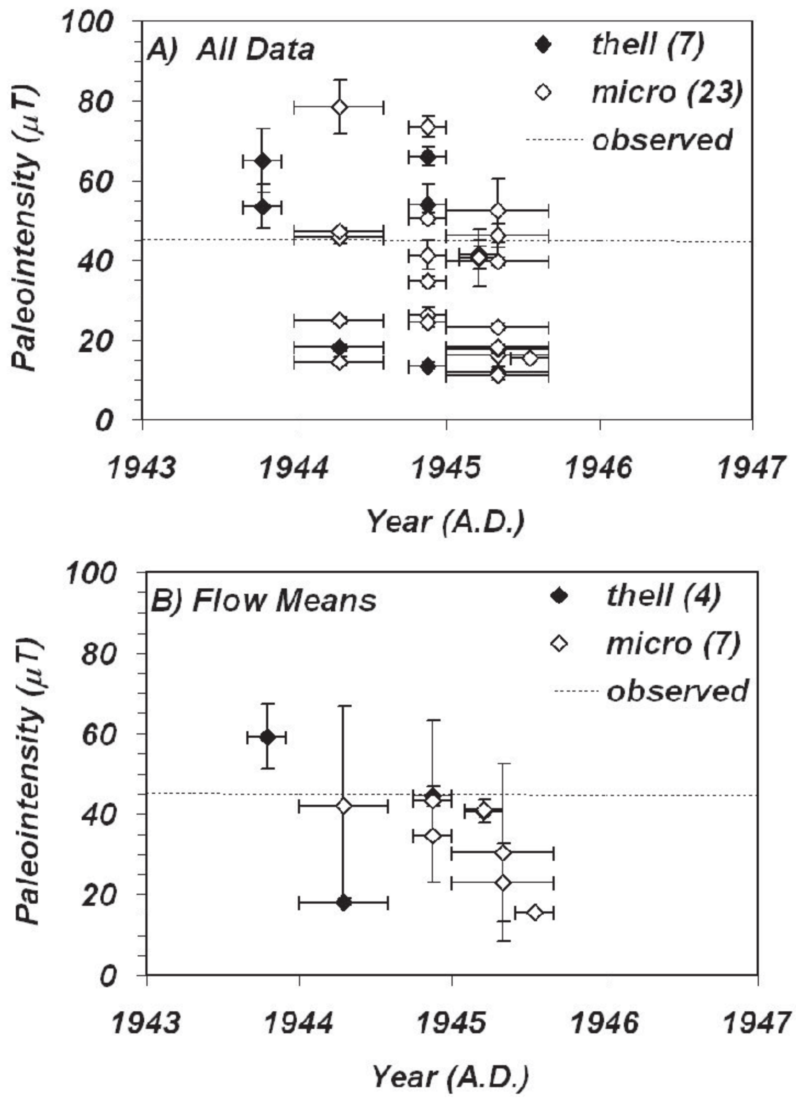

Fig. 5. Comparison of microwave and Thellier paleointensity results. A) Individual data, B) Flow mean values.

CONCLUSIONS

Both microwave methods used in this study, and also the Thellier paleointensity methods have yielded widely dispersed paleointensity values from the historically observed geomagnetic intensity. This study demonstrates that even with the knowledge of the rock magnetic characteristics of the samples and the strength of the geomagnetic field during cooling of the lava, technically accurate paleointensity results using a variety of methods, may yield incorrect results. The simplest explanation for this discrepancy is that the NRM is not a pure TRM, though there is no hard evidence to support this. The study demonstrates that when both high within-flow dispersion and non-reproducibility within a 25 mm core are observed, a reliable paleointensity determination is not possible. The technically high quality of the results suggest that there is no set criteria that can discriminate between accurate and inaccurate paleointensity data.

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BIBLIOGRAPHY

AITKEN, M. J., L. J. PESONEN and M. LEINO, 1991. The Thellier paleointensity technique: Minisamples versus standard size. *J. Geomag. Geoelctr., 43,* 325-331.

BÖHNEL, H., J. MORALES, C. CABALLERO, L. ALVA, G. MCINTOSH, S. GONZÁLEZ and C. SHERWOOD, 1997. Variation of rock magnetic parameters and paleointensities over a single Holocene lava flow. *J. Geomag. Geoelectr., 49*, 523-542.

BIGGIN, A. J., H. N. BÖHNEL and F. R. ZÚÑIGA, 2003. How many paleointensity determinations are required from a single lava flow to constitute a reliable average?, *Geophys. Res. Lett., 30,* DOI 10.1029/2003GL017146.

CALVO, M., M. PRÉVOT, M. PERRIN and J. RIISAGER, 2002. Investigating the reasons for the failure of paleointensity experiments: A study on historical lava flows from Mt. Etna (Italy). *Geophys. J. Int., 149,* 44-63.

COE, R. S., 1967. The Determination of Paleo-Intensities of the Earth's Magnetic Field with Emphasis on Mechanisms which Could Cause Non-ideal Behaviour in Thellier's Method. *J. Geomag. Geoelectr., 19,* 157-179.

COE, R., S. GROMMÉ and E. A. MANKINEN, 1978. Geomagnetic paleointensity from radiocarbon-dated flows on Hawaii and the question of the Pacific nondipole low. *J. Geophys. Res., 83,* 1740-1756.

COE, R. S., J. RIISAGER, G. PLENIER, R. LEONHARDT and D. KRÁSA, 2004. Multidomain behavior during Thellier paleointensity experiments: results from the 1915 Mt. Lassen flow. *Phys. Earth Plan. Int., 147,* 141-153.

DAY, R., M. FULLER and V. A. SCHMIDT, 1977. Hysteresis properties of titanomagnetites: Grain-size and compositional dependence. *Phys. Earth Plan. Int., 13,* 260-267.

DODSON, M. H. and E. MCCLELLEND-BROWN, 1980. Magnetic blocking temperature of single-domain grains during slow cooling. *J. Geophys. Res., 103*, 30561-30574.

DUNLOP, D. and O. OZDEMIR, 1997. Rock-Magnetism, fundamentals and frontiers, Cambrige University Press, 573pp.

FOX, J. M. W. and M. J. AITKEN, 1980. Cooling rate dependence of thermoremanent magnetization. *Nature, 283,* 462-463.

FRIES, C., Jr., 1953. Volumes and weights of pyroclastic material, lava and water erupted by Paricutín volcano, Mexico. *Trans. Am. Geophys. Union, 34*, 603-616.

GOGUITCHAICHVILI, A., M. PRÉVOT, J. M. DAUTRIA and M. BACIA, 1999. Thermo-detrital and crystallo-detrital magnetizations in an Icelandic hyaloclastite. *J. Geophys. Res., 104,* 29219-29239.

GONZÁLEZ, S., G. SHERWOOD, H. BÖHNEL and E. SCHNEPP, 1997. Palaeosecular variation in central Mexico over the last 30 000 years. *Geophys. J. Int., 130,* 201-219.

GRATTON, M. N., E. HERRERO-BERVERA and J. SHAW, 2003. An absolute palaeointensity record from SOH1 lava core, Hawaii using the microwave technique, in prep.

GROMMÉ, C. S., T. L. WRIGHT and D. L. PECK, 1969. Magnetic properties and oxidation of Iron-Titanium oxide minerals in Alae and Makaopuhi lava lakes, Hawaii. *J. Geophys. Res., 74,* 5277-5293.

HAGGERTY, S. E., 1976. Oxidation of opaque mineral oxides in basalts. *In:* Oxides Minerals, (Ed. D. Rumble) Mineral. Soc. Amer., Reviews in Mineralogy, 3, 300 pp.

HILL, M. J. and J. SHAW, 1999. Paleointensity results for historic lavas from Mt. Etna using microwave demagnetization/remagnetization in a modified Thellier type experiment. *Geophys. J. Int., 139*, 583-590.

HILL, M. J. and J. SHAW, 2000. Magnetic field intensity study of the 1960 Kilauea lava flow, Hawaii, using the microwave paleointensity technique. *Geophys. J. Int., 142,* 487-504.

HILL, M. J., M. N. GRATTON and J. SHAW, 2002. A comparison of thermal and microwave palaeomagnetic techniques using lava containing laboratory induced remanence. *Geophys. J. Int., 151*, 157-163.

KOENISBERGER, J. G., 1938. Natural residual magnetism of eruptive rocks. *Terr. Magn. Atmos. Electr., 43,* 299-320.

KONO, M. and N. UENO, 1977. Paleointensity determination by a modified Thellier method. *Phys. Earth Planet. Int., 13*, 305-315.

KÖRNER, U., M. PRÉVOT and T. POIDRAS, 1998. CRM experiments and pseudo-paleointensity measurements on basaltic rocks with initially low Curie temperatures, Annales Geophysicae, Suppl. 1 to 16, C210. (Abstract)

KOSTEROV, A. and M. PRÉVOT, 1998. Possible mechanism causing failure of Thellier paleointensity experiments in some basalts. *Geophys. J. Int., 134,* 554-572.

LUHR, J. F. and T. SIMKIN, (Eds), 1993. Paricutin. The volcano born in a Mexican cornfield. Geoscience Press, Inc., Arizona, USA, 427 pp.

MCCLELLAND, E., 1996. Theory of CRM acquired by grain growth and its implication for TRM discrimination and paleointensity determination in igneous rocks. *Geophys. J. Inter., 126*, 271-280.

ORDÓÑEZ, E., 1943. El volcan de Paricutín, Com. Imp. Coord. Inv. Científ. Anuario, Mexico City, 241-300.

PRÉVOT, M., R. S. MAINKINEN, S. GROMMÉ and A. LECAILLE, 1983. High paleointensity of the geomagnetic field from thermomagnetic studies on rift valley pillow basalts from the middle Atlantic ridge. *J. Geoph. Res., 88,* 2316-2326.

ROLPH, T. C., 1997. An investigation of magnetic variation within two recent lava flows. *Geophys. J. Int., 130,* 125-136.

SHAW, J., D. WALTON, S. YANG, T. C. ROLPH and J. A. SHARE, 1996. Microwave archeointensities on Peruvian ceramics. *Geophys. J. Int., 124*, 241-244.

SEGERSTROM, K., 1965. Paricutin, 1965 – aftermath of eruption. US Geological Survey Prof. Paper, 550-C, 93-101.

TAUXE, L., T. A. T. MULLENDER and T. PICK, 1996. Potbellies, wasp-waists and superparamagnetism in magnetic hysteresis. *J. Geophys. Res., 95,* 12337-12350.

THELLIER, E. and O. THELLIER, 1959. Sur l'intensité du champ magnétique terrestre dans le passé historique et géologique. *Ann. Géophysique. 15*, 285-376.

WALTON, D., J. SHAW, J. SHARE and J. HAKES, 1993. Microwave magnetization. *Geophys. Res. Lett., 20,* 109-111.

WILCOX, R. E., 1954. Petrology of Paricutín volcano, Mexico. *U.S. Geol. Surv. Bull., 965C*, 281-353.

URRUTIA-FUCUGAUCHI, J., L. ALVA-VALDIVIA, A. GOGUITCHAICHVILI, M. RIVAS and J. MORALES, 2004. Paleomagnetic, rock-magnetic and microscopy studies of historic lava flows from Paricutín volcano. *J. Geophys. Int., 156,* 431-442.

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