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PALEOMAGNETIC CONSTRAINTS ON THE VOLCANIC HISTORY OF IZTACCIHUATL

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RESUMEN

Las direcciones de magnetización remanente de los 24 flujos de lava del volcán Iztaccihuatl muestran polaridad magnética normal, sugiriendo que el presente cuerpo del volcán se formó durante el periodo de Brunhes Chron. Esta juventud relativa de la montaña ha sido substanciada por medio de recientes pruebas de K-Ar para comprobar la edad geológica.

Los análisis de dispersión de V. G. P. conceden una estimación de la desviación secular de 14.2°. Este valor es semejante al predicho en la latitud de Iztaccihuatl por recientes modelos de variación secular y a una media de variación paleosecular determinada por la distribución mundial de los torrentes de lava.

La concordancia de la cantidad estimada de dispersión con la esperada indica que la erupción de las lavas de este volcán ocurrió probablemente durante un intervalo de tiempo bastante grande, como para haber obtenido un ejemplo representativo de variación secular; lo que significa que el volcanismo se extendió por un periodo de tiempo más corto que el de Brunhes Chron pero más largo o comparable a la escala temporal de la variación secular. La media de V. G. P. en el volcán Iztaccíhuatl es estadísticamente indistinguible del polo geográfico.

ABSTRACT

The directions of remanent magnetization of 24 lava flows from Iztaccihuatl all show normal magnetic polarity suggesting that the present edifice of the volcano was formed during the Brunhes Chron. This relative youth of the mountain has been substantiated by recent K-Ar dating. Analysis of the dispersion of VGP positions yields an estimate of the angular standard deviation due to secular variation of 14.2°. This value is similar to that predicted at the latitude of Iztaccihuatl by recent models of secular variation and to average paleosecular variation determined from globally distributed lava flows. Agreement of the amount of dispersion with that expected indicates that extrusion of lavas from this volcano probably occurred over a time interval long enough to have obtained a representative sample of secular variation, i.e., volcanism extended over a time interval shorter than the Bruhnes Chron but longer than or comparable to the time scale of secular variation. The average Iztaccihuatl VGP is statistically indistinguishable from the geographic pole.

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INTRODUCTION

An earlier paper (Steele, 1971) presented paleomagnetic directions from the volcano Iztaccihuatl, one of the largest in the Mexican Volcanic Belt (MVB). In that paper, three K-Ar dates were reported, all within the range of 5 to 13 my B. P. Because the ages of these rocks were not consistent with their stratigraphic position, the dates were considered suspect. The paleomagnetic directions from Iztaccihuatl lavas were found to be entirely of normal polarity suggesting that they were extruded during one normal polarity chron. The possibility does exist that the flows could span an interval of reverse polarity during which no volcanism occurred and consequently no reversely magnetized lavas were produced, but this was considered unlikely. Indeed, because the present-day rate of erosion of the volcano is so high, it was tentatively concluded that the volcano was extruded entirely during the Brunhes Chron which has been dated as beginning 0.73 my B. P. by the K-Ar method (Mankinen and Dalrymple, 1979) or 0.79 my B.P. by an oxygen isotope and astronomical correlation method (Johnson, 1982). On the basis of the consistency of magnetic polarity within individual volcanic complexes of the MVB, Mooser and others (1974) concluded that the very rapid growth of individual volcanoes or volcanic units is common in the MVB. Other paleomagnetic studies in the MVB include work by Herrero and Pal (1978) and by Bohnel and Negendank (1981). A summary of paleomagnetic data from Mexico has been assembled by Pal (1978).

The conclusion that the lavas of Iztaccihuatl were extruded during the Brunhes Chron has recently been substantiated by Nixon (oral communication, 1984), who has obtained several K-Ar dates from the volcano and its vicinity, all of which are less than 1.0 my B. P. For the rocks sampled in the present study, Nixon's dates range from (580,000 ± 110,000) y B.P. to (76,000 ± 20,000) y B.P., where the uncertainty is standard deviation. These ages are stratigraphically reasonable and indicate that the three dates reported by the present author in the 1971 paper should be discarded.

Since the time of the previous Iztaccihuatl paleomagnetic study (Steele, 1971), much progress has been made in the understanding of geomagnetic secular variation. Several models have been proposed which predict the amount of dispersion to be expected in magnetic field directions and/or their concomitant virtual geomagnetic pole (VGP) positions from secular variation. These models provide estimates of the expected angular standard deviation in VGP position as a function of magnetic latitude.

In this paper, VGP's are presented for the flow by flow paleomagnetic study of 1971, and the dispersion of these VGP's is compared with that to be expected from the models of secular variation at the latitude of Iztaccihuatl. A value of among-flow dispersion greater than that predicted by the models would indicate undetected sources of dispersion such as unnoticed tilting or rotation of some flows relative to others, whereas an among-flow dispersion smaller than that predicted by the models would suggest that the lavas were extruded over a time interval too short to record the full range of secular variation. The possibility exists that a combination of undetected sources of dispersion and insufficient recording of secular variation could result in the expected value of dispersion due to secular variation, but such a result would be an unlikely coincidence.

THE DATA SET

Sampling technique, site locations, and specimen measurement are all described in the 1971 paper. Two pilot specimens per site were stepwise demagnetized in peak alternating fields (AF) up to 120 mT. and two other specimens from these same cores were thermally demagnetized at temperatures up to 600°C. The dissapearance of remanence in the vicinity of 550°C suggests that the magnetization resides in an essentially pure magnetite. The remaining specimens from each site were AF demagnetized in the optimum demagnetizing field as judged by study of the behavior of both direction and intensity of remanence during AF demagnetization of the two pilot cores.

The 1971 study retained all sites in the analysis including some which had obviously been affected by lightning strikes and others with a magnetization of low stability. The present study will follow the now-common practice of discarding those sites for which the half-angle of the cone of 95% confidence for the mean magnetization direction exceeds 20°. The result is that of the 35 sites used in the 1981 study. 24 will be analyzed here. Most of the discarded sites appear to have been affected by lightning. The evidence is that at least one specimen from the site had an extremely high intensity of NRM, a main criterion for discerning lightning strikes (Irving, 1964). Moreover, the pilot specimens from these sites possessed a component of remanence which was gradually removed during the serial AF demagnetization although a stable endpoint beyond which further demagnetization did not change the direction of the remanence was never reached, not even in a peak AF of 120 mT. Such lightning strikes were not expected as the rugged topography and exposed outcrops were often obvious potential lightning

Table 1. Site statistics for Iztaccihuatl paleomagnetic data.

Site number	D	I	N	α_{95}	δ	k	Lat	Long	H_0
1967-78	1.3	28.3	7	3.9	4.8	243.2	85.9	64.3	30
79	13.8	31.8	4	9.4	7.2	96.1	76.8	-2.5	60
80	354.6	33.7	7	17.4	21.0	13.0	84.9	166.6	60
82	356.1	39.8	8	4.2	5.7	178.0	84.9	-142.6	60
84	355.5	-8.0	7	7.2	8.9	70.5	66.6	93.3	8
133	10.2	25.5	6	4.7	5.1	207.5	78.7	20.2	60
1968-10	7.4	28.5	6	4.8	5.2	199.3	82.0	19.2	60
11	3.6	23.5	7	4.7	5.8	168.4	82.4	54.3	60
13	355.9	31.5	7	2.5	3.2	569.1	85.6	145.9	120
14	10.9	45.7	7	19.4	23.2	10.6	77.1	-49.1	120
16	13.4	38.6	7	11.0	13.5	31.2	77.1	-22.7	60
18	17.3	52.9	7	7.5	9.3	65.6	68.8	-54.6	60
19	20.6	51.0	7	10.9	13.4	31.7	67.5	-46.4	60
20	22.7	60.8	7	4.8	6.0	158.4	60.1	-62.7	60
21	352.4	32.1	7	5.3	6.5	131.7	82.6	160.8	60
23	0.3	24.6	7	9.2	11.4	43.8	83.9	79.3	60
24	355.3	21.3	7	6.7	8.3	82.4	80.8	112.3	30
25	27.0	61.5	6	3.7	4.1	327.6	57.2	-60.0	120
26	331.9	24.4	7	11.3	13.9	29.3	62.3	163.2	30
27	354.0	30.0	6	7.6	8.3	79.6	83.6	146.1	60
29	7.4	38.1	7	7.1	8.8	72.6	82.7	-28.4	30
30	356.6	31.9	7	6.8	8.4	79.4	86.3	144.6	120
31	3.8	35.9	7	7.6	9.4	64.3	86.3	-22.7	60
32	356.7	30.0	7	9.3	11.4	43.2	85.7	129.9	120

D = declination of the mean direction in degrees, I = inclination of the mean direction in degrees, N = number of specimens from the site, α_{95} = half-angle of the cone of 95% confidence for the mean direction in degrees, δ = angular standard deviation of magnetization direction in degrees, k = estimate of the precision parameter of the Fisherian distribution, Lat = latitude of the VGP in degrees, Long = longitude (east positive) of the VGP in degrees, and H_0 = the peak optimum demagnetizing field.

targets. Two of the discarded sites showed highly scattered natural remanent magnetization (NRM) directions, and the scatter was not significantly reduced with AF demagnetization, no stable endpoint ever being reached in the demagnetization of the pilot specimens. Reflected light microscopic examination of specimens from these sites revealed the presence of maghemite suggesting that weathering and the concomitant acquisition of low stability remanence may have rendered these rocks useless for study of the original TRM. The sites retained in the present work and their average magnetization directions and related statistics are given in Table 1. The flow magnetization directions are plotted in Figure 1.

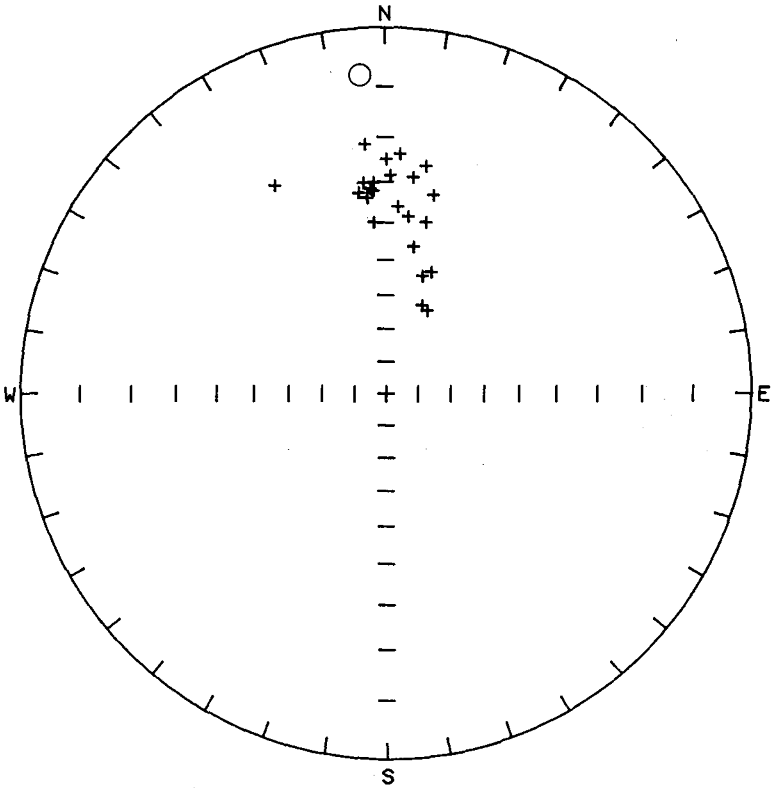

Fig. 1. Site mean magnetization directions from Iztaccihuatl in stereographic projection (Wulff net). (+) indicates lower hemisphere directions; (o) upper hemisphere.

Table 2 presents the average VGP position of the 24 flows and the statistics α_{95} and k calculated under the assumption that the flow VGP's

Table 2

Average VGP for the 24 Iztaccihuatl lavas

N	VGP Lat	VGP Long	α_{95}	δ	k
24	86.9	–26.8	5.5	14.6	29.6

All angular quantities are in degrees.
East longitude is positive.

follow a Fisherian distribution. Although no goodness of fit test was performed, the elongate nature of the data set (Fig. 1) indicates that the data might better be represented by a Bingham density function (Onstott, 1980). Nevertheless, the Fisher assumption, which is usually used in paleomagnetic studies, generally provides somewhat conservative estimates of scatter and precision (Tarling, 1983).

ANALISIS OF DISPERSION

The total angular standard deviation, S_T, of all 24 VGP's is 14.6°. This value results not only from secular variation of the geomagnetic field but also from within-site dispersion S_W due to such factors as specimen orientation errors, minor rotations of one part of the lava flow relative to another, and other variability of the paleomagnetic recorder. If S_F is the dispersion due to secular variation, the sources of dispersion contribute to the total dispersion according to

$$S_T^2 = S_F^2 + (S_W^2/\bar{n}) \quad , \qquad (1)$$

where $\bar{n}$ is the average number of samples per site (McElhinny and Merrill, 1975).

An estimate of S_F can be obtained from S_T if the within-site variability can be determined. An estimate of this dispersion, S_W, can be obtained from the average angular standard deviation δ_M of the magnetic field directions of individual flows:

$$\delta_M = \sum_{i=1}^{24} \delta_i/24 \cdot \qquad (2)$$

To convert the dispersion in field directions due to within-site variability to dispersion in pole positions, the transformation between field angular variances and pole variances derived by Cox (1970) is used:

$$S_W^2 = \delta_M^2(5 + 18\sin^2\lambda + 9\sin^4\lambda)/8 \quad , \qquad (3)$$

where λ is the paleolatitude of the sites. For the value 9.3° for δ_M and paleolatitude 20.1° calculated from the mean pole position (86.9°N, 26.8°W) and the location of Iztaccihuatl (19.17°N, 98.63°W), S_W is found to be 8.85°. This value for the average within-site dispersion of pole positions and the average sample size 6.8 when substituted in equation (1) yield a dispersion of the pole due to secular variation, S_F, of 14.2°. The upper and lower 95% confidence limits for S_F were found from Cox (1969) to be 17.7° and 11.9°, respectively.

DISCUSSION

The amount of VGP dispersion found from the Iztaccihuatl lavas, 14.2°, is consistent with what would be expected at the latitude of the volcano. Table 3 lists values of angular standard deviation at paleolatitude 20° predicted by five different models of secular variation. The last two columns of this table list values of angular standard deviation obtained by averaging published data for the Brunhes Chron (column 7) and for the last 5 m.y. (column 8) from sites in the latitude range 16° to 30° (McElhinny and Merrill, 1975). The Iztaccihuatl VGP dispersion is consistent with the averaged paleomagnetic data and with the values predicted by the models except B (Creer and others, 1959) which describes secular variation entirely in terms of dipole wobble.

Table 3

Angular standard deviations of VGP at geomagnetic latitude 20°

Geomagnetic Secular Variation Model						Average Data	
A	B	C	D	E_L	E_U	Brunhes	5 m.y.
15.12	11.0	14.31	14.19	14.31	20.15	13.8	14.0

All values are in degrees. The summary of model values at 20° is from Baag and Helsley (1974). E_L and E_U are the lower and upper limits, respectively, of model E due to Baag and Helsley (1974). The values listed in the last two columns are averaged VGP dispersions obtained from world-wide data from sites in the latitude range 16°- 30° for the Brunhes Chron and for the last 5 m.y. by McElhinny and Merrill (1975).

In geological terms, the VGP dispersion from the Iztaccihuatl lavas indicates that they were extruded over a time span long enough to sample secular variation and to average to a pole location not significantly different from the present geographic pole, unless of course the VGP dispersion observed results from unseen tectonic rotation of one lava relative to another instead of having a geomagnetic origin. Paleomagnetic investigators have commonly assumed that a 10 000- to 25 000-year interval was necessary for secular variation to average out so that the average of VGP's from rocks formed over such an interval could be used to represent an axial geocentric dipole. Recent evidence, however, suggests the presence of longer periods of asymmetry of the field (McElhinny and Merrill, 1975; Verosub, 1983). Thus the Iztaccihuatl paleomagnetic data indicate that the present volcano formed over an interval of at least 10 000 years and probably substantially longer.

CONCLUSION

Study of paleomagnetic data from Iztaccihuatl indicates that the volcano formed during the Brunhes Chron and that its lavas were extruded during a period long compared with that of secular variation. Such a result is consistent with recent K-Ar age determinations by Nixon (personal communication).

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