Geofísica Internacional (2001), Vol. 40, Num.3, pp. 191-205

Paleomagnetic results for the Middle-Miocene continental Suchilquitongo Formation, Valley of Oaxaca, southeastern Mexico

J. Urrutia-Fucugauchi[1] and I. Ferrusquía-Villafranca[2]
[1] *Laboratorio de Paleomagnetismo y Geofísica Nuclear, Instituto de Geofísica, UNAM, México, D.F., MEXICO*
[2] *Departamento de Paleontología, Instituto de Geología, UNAM, México, D.F., MEXICO*

Received: January 31, 1991; accepted: August 29, 2001

RESUMEN

La Formación Suchilquitongo al noroeste del Valle de Oaxaca consiste en una secuencia gruesa integrada por varios estratos delgados de colores luminosos, areniscas y limolitas. Esta secuencia contiene localmente a la fauna mamífera Hemingfordian. Contiene también lechos intercalados de calizas lacustres y tobas verdes y grises (Ignimbrita Etla). Afectan a esta formación fallas y fracturas principalmente al N45°W-S45°E y N65° W-S65°E, causando inclinación de 12° a 15° en varias direcciones. Tres nuevos datos de K-Ar se han obtenido en concentrados de biotita y plagioclasa de la Ignimbrita Etla, que dan una edad aproximada de 20 Ma. Se han recobrado direcciones de polaridad paleomagnética reversa bien definidas de 40 muestras distribuidas en 5 sitios. La dirección media de la Formación Suchilquitongo es: B=5, Dec=190.9°, Inc=-37-7°, α95=6.0°, y k=165, y la correspondiente posición del polo se encuentra a 79.0° N, 330.6° E. Esta dirección se desvía de la dirección esperada (Dec=176°, Inc=-30°) calculada en el Valle de Oaxaca, con 15° discordante en el sentido de las manecillas del reloj. La aplicación de una corrección de doble rotación para compensar la deformación estructural usando 20° de inclinación en la recumbencia del pliegue y 10° en la pendiente de la estratificación resulta en la dirección corregida (y posición del polo) de Dec=178.6°, Inc=-30.9° (88.6° N, 151.5° E). Esta dirección corregida concuerda dentro de la incertidumbre estadística con la dirección esperada. Los datos de anisotropía de susceptibilidad magnética determinados en la Ignimbrita Etla presentan una alta dispersión angular, lo que no permite inferir las direcciones de flujo y la localización de la fuente.

PALABRAS CLAVE: Paleomagnetismo, tectónica, fábrica magnética, Mioceno Medio, Formación Suchilquitongo, ignimbrita de Etla, Oaxaca.

ABSTRACT

The Suchilquitongo Formation of the northeastern Valley of Oaxaca is a thick sequence of thin-bedded tuffaceous sandstones and siltstones, which locally contain Hemingfordian mammal fauna, and interbedded lacustrine limestones and rhyolitic tuffs (Etla Ignimbrite). Three new K-Ar dates of biotite and plagioclase concentrates from the Etla Ignimbrite yield an age of about 19-20 Ma. Well-defined reverse polarity paleomagnetic directions are recovered by alternating field demagnetization from 40 samples distributed in 5 sites. The overall mean direction for the Suchilquitongo Formation is B = 5, Dec = 190.9°, Inc = -37.7°, a_{95} = 6.0°, and k = 165, and the pole position lies at 79.0° N, 330.6° E. This direction deviates from the expected direction (Dec = 176°, Inc = -30°) for the Oaxaca Valley, by a 15° clockwise discordance in declination. A double rotation correction to compensate for structural deformation using a 20° plunge and a 10° bedding dip results in a corrected direction and pole position of Dec = 178.6°, Inc = -30.9° (88.6°N, 151.5°E), which agrees within the statistical uncertainties with the expected direction. The anisotropy of magnetic susceptibility principal axes for the Etla Ignimbrite are characterized by large angular dispersion, which does not permit to infer the flow directions and possible source location.

KEY WORDS: Paleomagnetism, tectonics, magnetic fabrics, Middle Miocene, Suchilquitongo Formation, Etla ignimbrite, Oaxaca.

1. INTRODUCTION

As part of a long-term investigation of the stratigraphy and tectonics of continental sedimentary and volcanic deposits in southern Mexico (Ferrusquia-Villafranca, 1990a,b), we have initiated paleomagnetic, magnetostratigraphic and geochronological studies of selected mammal fossil-bearing formations in the states of Oaxaca and Chiapas. In this paper, initial results for the Middle Miocene Suchilquitongo Formation, central Oaxaca, are reported.

Wilson and Clabaugh (1970) studied the Cenozoic continental volcanic and sedimentary deposits in the Etla sector of Oaxaca Valley, and described and named the Suchilquitongo Formation. This formation is constituted by tuffaceous volcanoclastic deposits, accumulated in or marginal to a lake, and an ignimbrite member (Etla Ignimbrite). The strata were folded and faulted during the Neogene. Geologic information on the continental volcanic and sedimentary deposits is still scarce. Regional tectonic evolution is linked to the North American, Cocos and Caribbean plate interactions, but Neogene deformation in the continental interior and along the active Pacific margin has not been well documented. The paleomagnetic study was designed to investigate the structural and tectonic relationships of the Suchilquitongo Formation, and to document the emplacement and source location for the Etla Ignimbrite.

2. GEOLOGIC SETTING

The Suchilquitongo Formation is exposed in the northwestern sector of the Valley of Oaxaca, approximately between Oaxaca City and Telixtlahuaca village (Figure 1). The Valley of Oaxaca is a NW-SE trending intermontane graben some 20 km long and 6 km wide, which forms part of the Valles Centrales sub-province of the Oaxaca-Puebla upland morphotectonic province. The northeastern limit is the Oaxaca fault zone and the large NW-SE trending mylonitic belt, formed from a gneissic protolith. The southwestern limit is the Precambrian metamorphics and the Paleozoic granitic intrusives. The Oaxaca Valley lies at the northeastern limit of the Grenvillian Oaxaca Complex, whose regional orientation is also to the NW. The Cenozoic sequence is preserved as part of the graben floor, bounded by crystalline Precambrian and Paleozoic rocks unconformably overlain by marine calcareous sequences.

The lithostratigraphic column for the area is summarized in Figure 2 (Ferrusquia-Villafranca 1990a,b). The basement in central Oaxaca is constituted by the Precambrian Oaxaca Complex (Fries *et al.,* 1962). In the Oaxaca Valley, there are outcrops of the anorthositic massif near San Lorenzo Cacotepec, and outcrops of the sequence of schists, paragneisses and orthogneisses. The Oaxaca Complex is intruded by a granitoid stock of Paleozoic age. An unnamed metamorphic complex of probable Paleozoic age is also exposed in the northeastern horst block. The next oldest unit is a red thickly bedded arkosic phyllarenite, questionably referred to as the Jurassic Yogana Formation. Elsewhere, an 800 m thick calcareous Cretaceous sequence unconformably overlies the crystalline metamorphic basement. Its lower part consists of indurated, thickly bedded calcareous sandstones and mudstones bearing terrigenous clastics and interbedded by biomicrite; scant micro-and macrofossils suggest an Aptian age. The upper part consists of thinly-bedded, cherty biomicrite interbedded by clayey calcareous mudstones. Scarce microfossils suggest an Albian-Cenomanian age. A thickly-bedded, well-indurated, light-brown limestone cobble-to pebble-conglomerate crops out north of San Juan del Estado; it unconformably overlies the Cretaceous sequence and corresponds to the lowermost Cenozoic unit in the area. Highly-altered latiandesite lava flows make up small isolated mounds west of Etla and unconformably underlie the Suchilquitongo Formation. A brecciated, polymictic cobbly conglomerate some 70 m thick crops out near Telixtlahuaca, and unconformably overlies the Suchilquitongo Formation. Its age is not well constrained; it is probably Pliocene. Alluvium, colluvium and soil form the Quaternary deposits in the graben (Figure 2).

The Suchilquitongo Formation is a fluviolacustrine volcanoclastic sequence some 300 m thick, consisting of light-colored, thinly-bedded friable siltstones, sandstones, occasional cobble-to pebble-volcarenitic conglomerates, interstratified by thinly-bedded terrigenous detritus-bearing lacustrine biomicritic limestones. The Etla Ignimbrite is formed by pistachio-green, well-indurated, medium-to thickly-bedded, vitiric to vitric-lithic, largely-welded silicic ash falls and ash-flow tuffs. The thickness varies between some 5 m to 11 m. The deposition of the Suchilquitongo Formation was in and around a fresh-water lake, as indicated by analysis of carbonate deposits and fossil contents (Wilson and Clabaugh, 1970).

In 1969 paleontological studies by J.A. Wilson and I. Ferrusquia-Villafranca revealed the presence of Miocene mammals near Suchilquitongo in volcanoclastic beds seemingly positioned about 80 m above the tuff strata. The fossils are a small merycoidontid artiodactyl and the equid Merychippus sp. Some uncertainties remained concerning the stratigraphic relationships, because of faulting and erosional discontinuities. Wilson and Clabaugh (1970) tentatively proposed an age of late Miocene; they proposed that the sequence is correlatable with similar volcanoclastic sediments near Yagul, Mitla and Matatlan. In the last locality, foot bones of Merychippus were recovered, supporting a late Miocene age. Ferrusquia-Villafranca *et al.* (1974) reported K-Ar dates of 16.5 +/- 0.5 and 17.4 +/- 0.3 Ma for the Etla Ignimbrite, supporting an early age inference. More recently, Ferrusquia-Villafranca (1990a) formally described the Suchilquitongo mammal fauna and assigned to the Late Hemingfordian-Early Barstovian, noticing a slight discrepancy with a late Miocene age assignment. Further studies have recovered a larger mammal fauna better located in the local stratigraphic column, that includes typical Hemingfordian taxa such as Paratoceras sp. and Merychyus elegans (Ferrusquia-Villafranca, unpublished data). Three new K-Ar dates obtained from biotite and plagioclase mineral concentrates on samples from the Etla Ignimbrite suggest an older age of about 19-20 Ma (Table 1), which would place the Suchilquitongo Formation in the Middle Miocene.

Normal faults and fractures trending N45°W-S45°E and N65°W-S65°E subdivide the Tertiary units, particularly the Suchilquitongo strata, into several blocks tilted 12° to 15° in various directions. The NE-SW trend is marginally dominant, thus defining a NW plunging broad arcuate synclinoidal structure (Wilson and Clabaugh, 1970). The deformation occurred after deposition of the

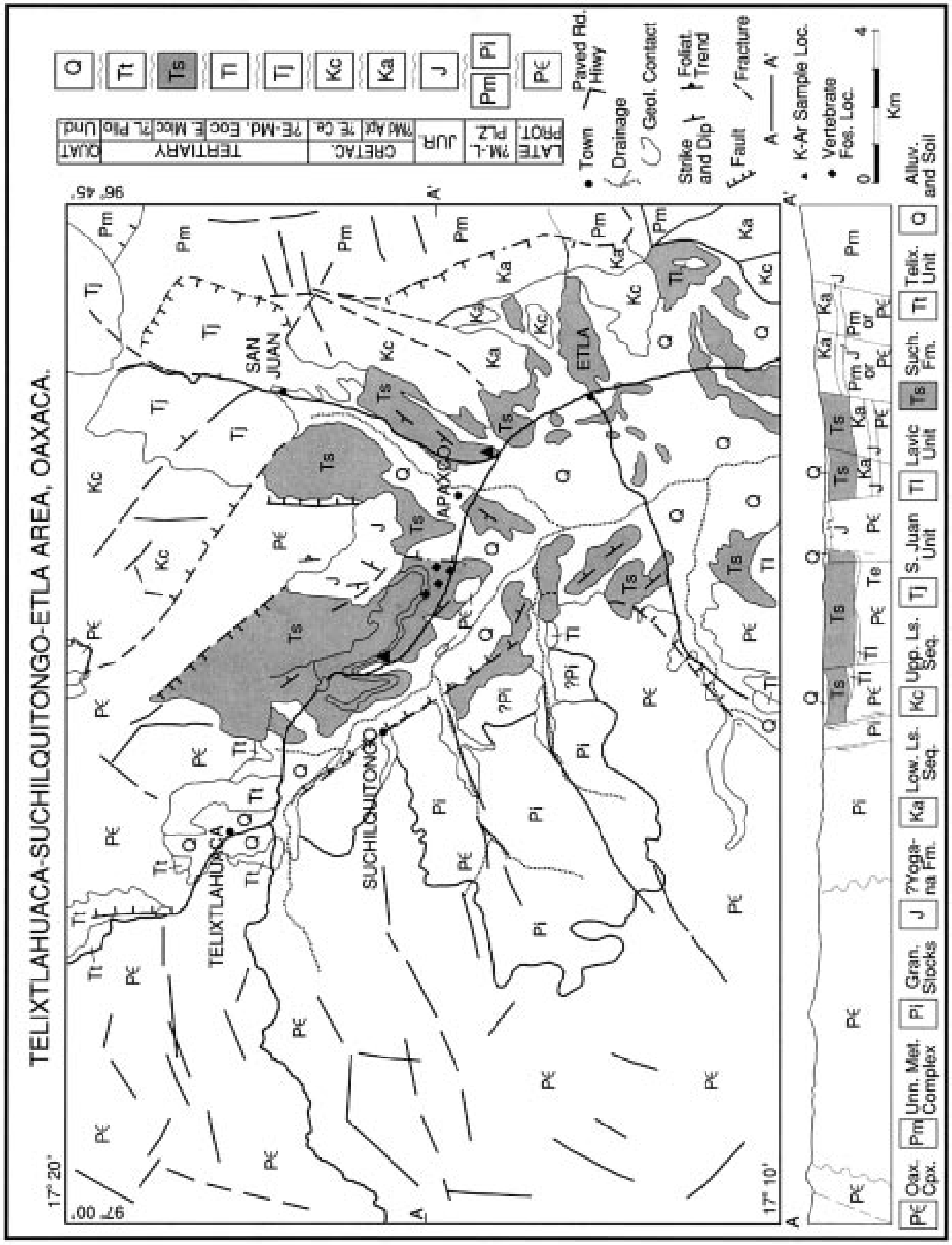

Fig. 1. The Etla sector of Oaxaca Valley, central Oaxaca, showing location of sampling sites (solid squares) and fossil locations (solid triangles). Pc, Oaxaca complex; Pzm, Paleozoic complex; Pzp, granitoid pluton; J, Yogana Formation; Ka, Middle Cretaceous sequence; Kc, Late Cretaceous sequence; Tcj, conglomerate; e, latitic lava flows; Tm, Suchilquitongo Formation; Tl, polymictic conglomerate; Q, Quaternary deposits.

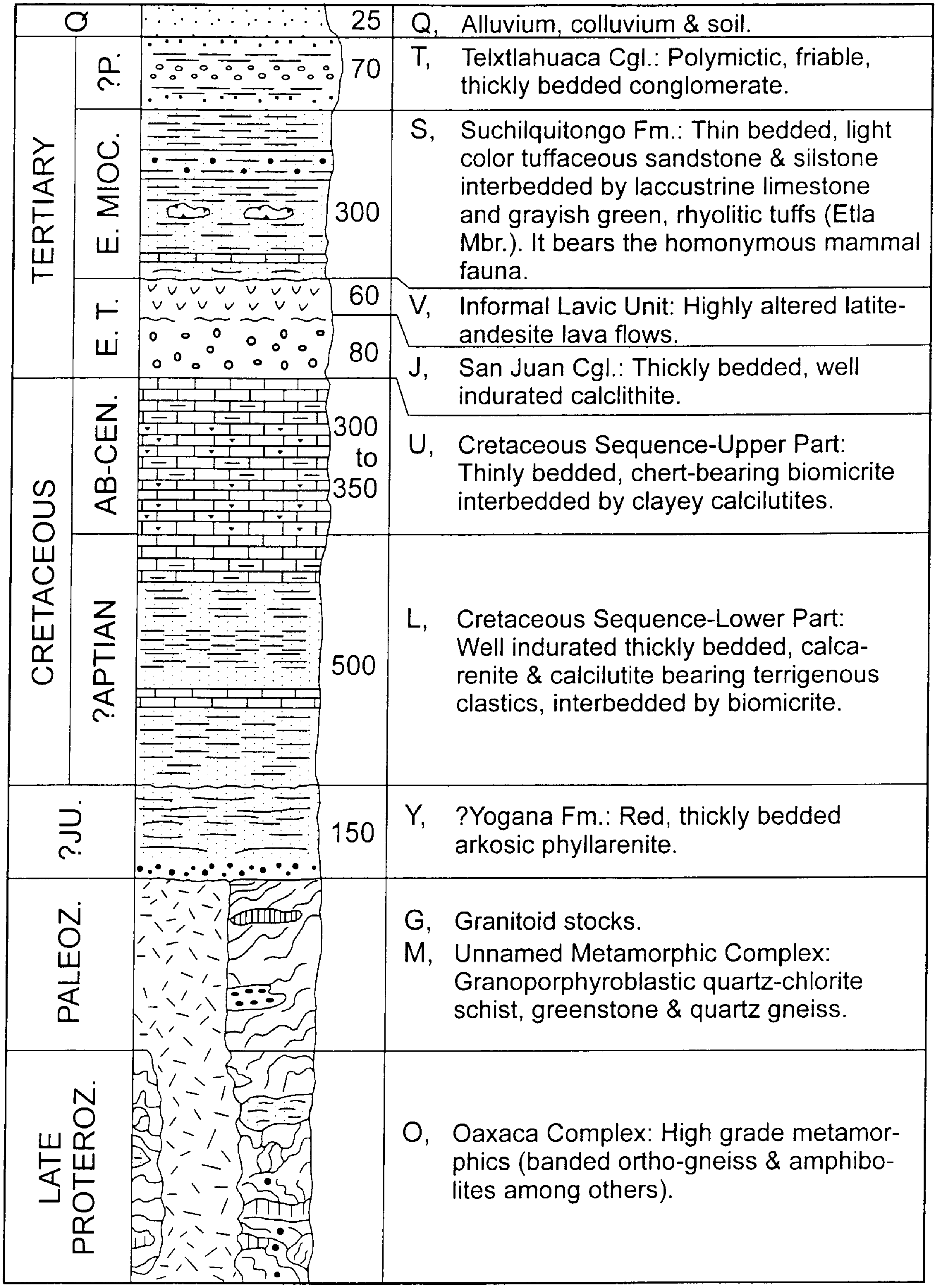

Fig. 2. Schematic lithostratigraphic column for the Oaxaca Valley, central Oaxaca.

Table 1

Radiometric and geochemical data for the Etla Ignimbrite, Suchilquitongo Formation, Oaxaca

Sample	Mineral	%K	% ^{40}Ar	x 10^{-8} acc/g	Date (Ma)
FV69-185	biotite	6.714	73	5.092	19.2 +/- 0.3
		6.765	36	5.041	
FV88-497	biotite	6.825	88	5.465	20.6 + /- 0.3
		6.747	78	5.459	
FV88-497	plagioclase	0.583	47	0.440	19.3 + /- 0.5
		0.583			

Geochemical data (major oxides)

SiO_2	68.25
TiO_2	0.58
Al_2O_3	12.44
Fe_2O_3	2.33
FeO	0.50
MnO	0.03
MgO	0.64
CaO	1.31
Na_2O	3.85
K_2O	4.87
P_2O_5	0.01
SO_3	0
CO_2	0
H_2O^+	4.93
H_2O^-	0.28
	100.02

Note: K-Ar dating has been completed at the Geochronological Laboratory of University of Texas at Austin (F.W. McDowell)

Suchilquitongo Formation and before the Quaternary deposits.

The ignimbrites have been extensively quarried because of their attractive green color, and can be found in archaeological sites like Yagul and Mitla, as well as in many colonial and modern buildings of Oaxaca City including the Cathedral, churches and public buildings. The possible source for the ignimbrites has not been located. Similar ignimbrite exposures are found near Yagul and Mitla, in the Tlacolula Valley, and southeast of Oaxaca City. Wilson and Clabaugh (1970) suggested that the Tlacolula-Mitla sequence including the ignimbrite is part of the Suchilquitongo Formation. If so, the extent of the ignimbrite is quite large and its eruption constituted a major volcanic event. However, new K-Ar dates of 14.3 +/- 0.3 to 16.0 +/- 0.4 Ma obtained for the tuffs in the Tlacolula-Mitla Valley, some 60 km from Suchilquitongo, do not seem to support this correlation (Ferrusquia-Villafranca, 1996).

3. PALEOMAGNETIC SAMPLING AND RESULTS

Forty oriented samples were collected from three sites in the Etla Ignimbrite and from two sites in the volcanoclastic tuffaceous strata of the Suchilquitongo Formation (Figure 1).

The intensity and direction of natural remanent magnetization (NRM) were measured with a Molspin fluxgate spinner magnetometer. The stability and vectorial composition of NRM were investigated by stepwise alternating field (AF) demagnetization, by using a Schonstedt AF demagnetizer. AF demagnetization was carried out in 8-12 steps up to maximum fields of 100 mT, in a three-axes non-thumbling procedure. Vectorial components of NRM are determined from vector plots, vector substraction and principal component analysis (Zijderveld, 1967; Kirschvink, 1980).

The NRM directions showed declinations between 180° and 330° and upward inclinations (Figure 3). With AF demagnetization, directions move along great circles to a reverse polarity direction (Figure 4). Analysis of the orthogonal vector plots (Figure 5) indicates the presence of two components. One is a low-coercivity component of normal polarity (B-component), and the other is a low-to intermediate coercivity component of reverse polarity (A-component). The A-component can be determined from principal component analysis and vector subtraction, or from end points in the stereograms and vector plots, and is interpreted as the characteristic remanence (ChNRM) for the Suchilquitongo strata. The B-component shows a coercivity spectrum that overlaps with the A-component, and the corresponding direction could not be estimated. Comparison of normalized intensity diagrams shows the relative proportions of the A- and B-components (Figure 6).

Site mean ChNRM directions for each site were calculated by giving unit weight to sample directions. The corresponding angular dispersion estimates are calculated by using standard Fisher statistics (Fisher, 1953). The overall mean direction for the Suchilquitongo Formation is calculated as the mean of the site mean directions. The corresponding virtual geomagnetic pole (VGP) is calculated assuming a central dipolar field configuration. Results are summarized in Table 2.

Further investigation of rock-magnetic properties was completed by giving selected samples an isothermal remanent magnetization (IRM) and by AF demagnetization of the saturation IRM. IRMs were given in steps up to 500 mT by using a pulse magnetizer. Samples show saturation in low fields (Figure 7), suggesting the presence of titanomagnetites of magnetite. Comparison of coercivity spectra for the NRM and IRM (Figure 8) suggests that the magnetic carriers show a behavior corresponding to single or pseudo-single domain (Lowrie and Fuller, 1971).

The anisotropy of magnetic susceptibility (AMS) on samples from the Etla Ignimbrite was measured by using a Molspin anisotropy delineator. Details of the experimental

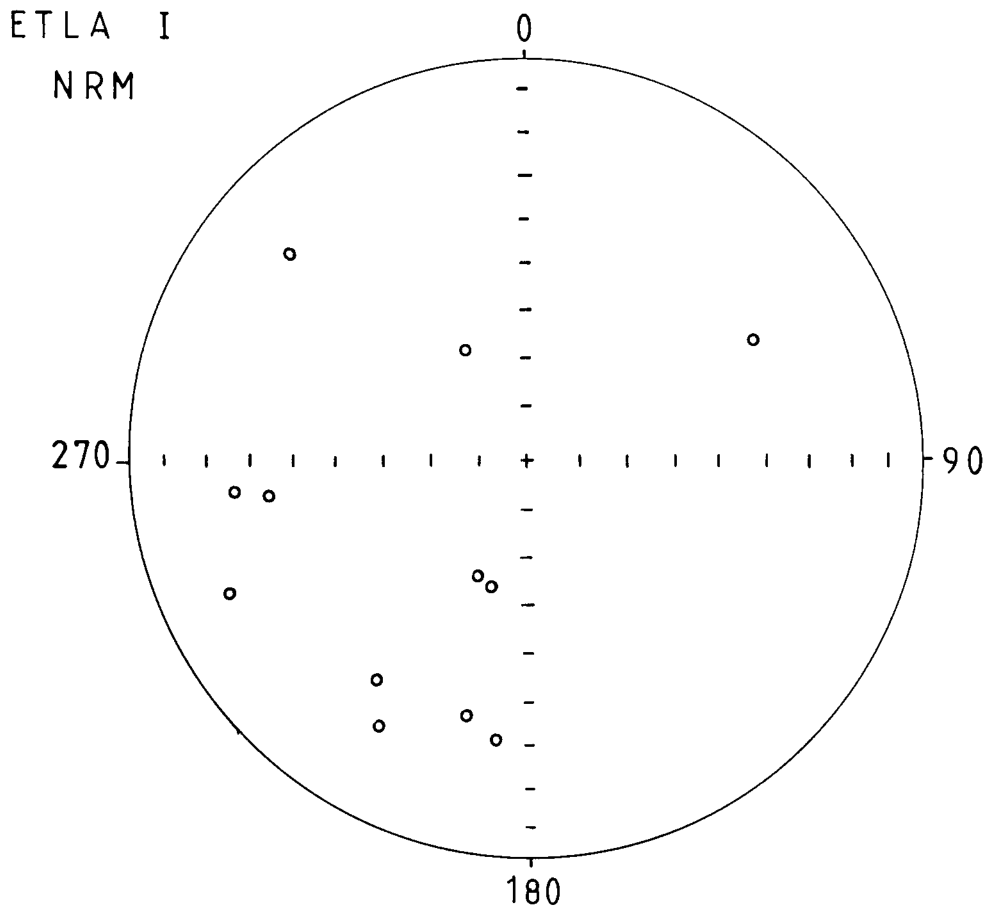

Fig. 3. NRM directions for site 1 in the Etla Ignimbrite plotted in an equal-area stereographic plot. Open symbols indicate upward negative inclinations. Note that the angular scatter is high. After demagnetization, the directions cluster in a reverse polarity direction with low scatter (Table 2).

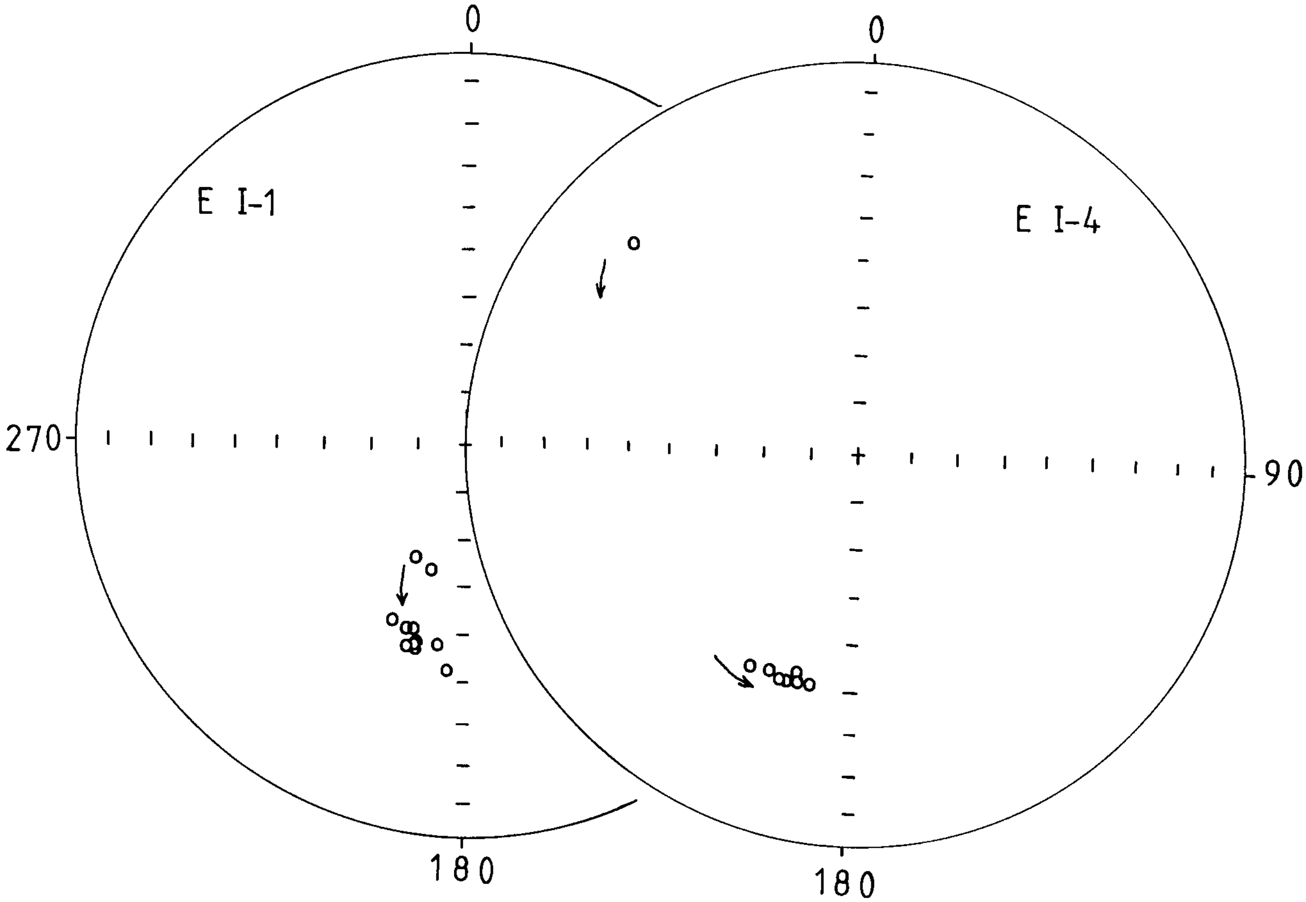

Fig. 4. Examples of alternating field demagnetization data for samples from the Etla Ignimbrite which present different proportions of the A and B remanence components, plotted in an equal-area stereographic plot. The A component is dominant and presents a stable reverse polarity direction.

procedure have been reported earlier (Urrutia-Fucugauchi, 1986). Results are given in terms of the principal susceptibility axes ($k_1 > k_2 > k_3$). The k_3 axes define the poles to the magnetic foliation planes and the flow orientation, as inferred from the lineations given by the k_1 or k_2 axes. Unfortunately, the AMS axes show a relatively large angular scatter, which do not permit to constrain the AMS mean axes. The AMS axes for two sites in the Etla Ignimbrite are shown in Figure 10.

4. DISCUSSION

The ChNRM direction for the Suchilquitongo Formation has a reverse polarity and a small angular dispersion (Table 2). Comparison of the expected direction calculated for the Oaxaca Valley from data for cratonic North America (Irving and Irving, 1982; Harrison and Lindth, 1982) or northern Mexico (Urrutia-Fucugauchi, 1979, 1984) shows that the mean declination for the Suchilquitongo Formation deviates from the expected declination by some 15°, and the mean inclination is slightly steeper. The expected direction of reverse polarity calculated from the 20 Ma VGP from Harrison and Lindth (1982) is approximately 176°/-30°, with an α_{95} of about 3.6°. The actual mean direction found for the Suchilquitongo Formation is 191° /-38°, with an α_{95} of 6° (Table 2).

The direction is referred to present geographic coordinates. Wilson and Clabaugh (1970) interpreted the tilts of the Etla Ignimbrite and the Suchilquitongo volcanoclastic deposits, which range up to 30° in terms of post-Middle Miocene tectonic deformation. They proposed that the regional structure is a northwest-plunging syncline. Therefore, the paleomagnetic direction requires a double rotation of coordinates to refer it to the original paleo-coordinates. The geometry of the plunging syncline has not been well determined, but the parameters for the double-rotation correction can be derived from the attitudes measured for the Suchilquitongo strata. Wilson and Clabaugh (1970) report data for their selected type locality, with an azimuth of N70° W and a dip of 20°. For the double-rotation correction, we have assumed that the structure plunges to the northwest (N45°W to

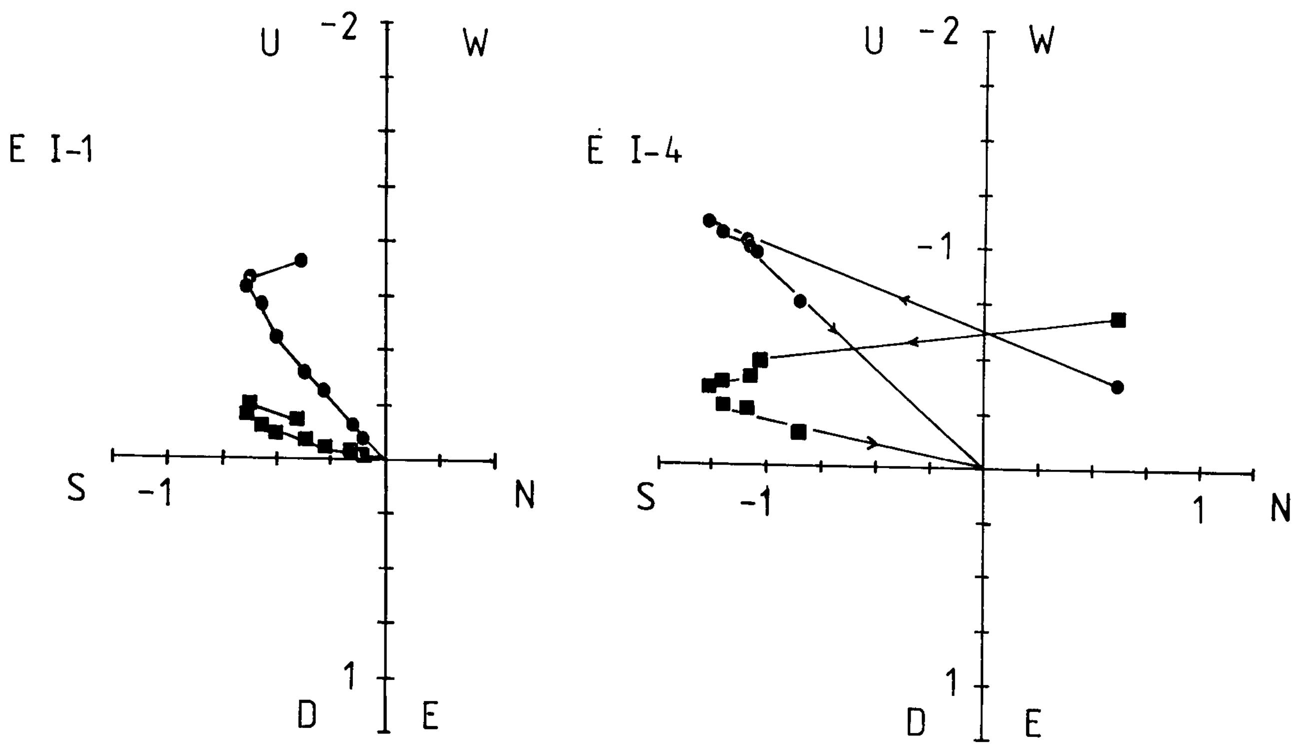

Fig. 5. Examples of orthogonal vector demagnetization plots after alternating field demagnetization for samples characterized by two remanence components of the volcanoclastic units and ignimbrite of the Suchilquitongo Formation.

Table 2

Summary of paleomagnetic data for the Suchilquitongo Formation

Site	n/m	Dec	Inc	k	α_{95}	PLat (N)	PLong (E)
E-I	10/11	191.6	-34.8	11	15.6	78.8	341.3
E-II	8/11	203.3	-42.3	112	5.3	67.1	330.8
E-III	6/6	186.6	-38.5	98	6.8	82.3	316.3
E-IV	6/6	187.8	-36.6	87	7.2	82.0	328.7
E-V	6/6	186.0	-35.6	105	6.6	83.8	328.6
Overall Mean							
B=5	5/5	190.9	-37.7	165	6.0	79.0	330.6
Corrected direction (double rotation correction)							
B=5		178.6	-30.9			88.6	151.5

Note: n/m, number of samples used for analysis/number of samples initially collected; Dec, Inc, declination and initiation of characteristic remanence after AF demagnetization (A component); k and α_{95}, Fisher statistical parameters (Fisher, 1953); PLat, PLong, latitude and longitude of the virtual geomagnetic pole.

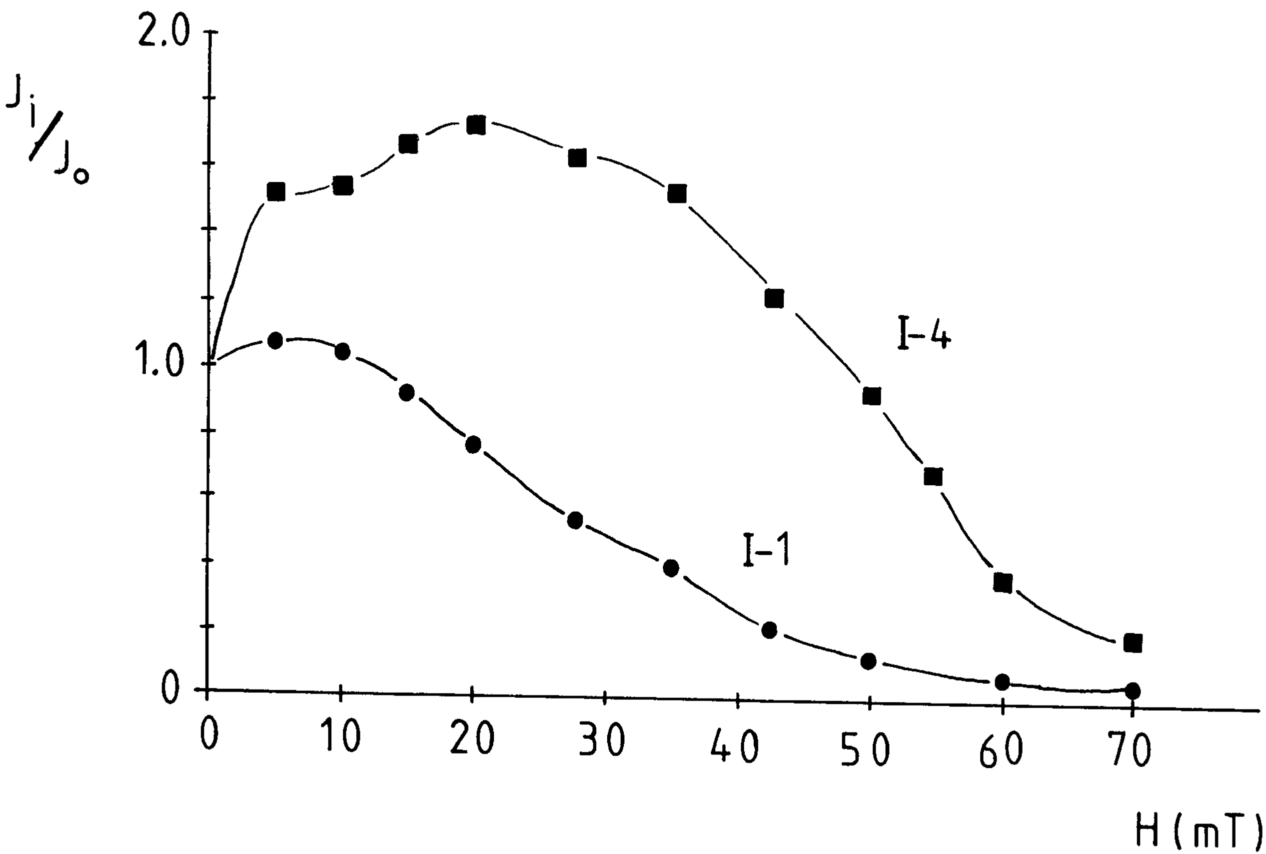

Fig. 6. Normalized intensity diagrams for the samples of Fig. 4. Note the increase in intensity in the low coercivity sector of the diagram which is due to the removal of the secondary normal polarity component (B component) and the exponential decay associated with the removal of the intermediate coercivity reverse polarity component (A component).

N50°W) and tested a range of plunge angles from 0° up to 25°. The rotated directions have been corrected by a second rotation around the bedding plane parameters, assuming a range of tilts up to 30° (following Wilson and Clabaugh, 1970). The results for the double-rotation correction are illustrated in Figure 11. The rotations for a 20° plunge structure and a 10°-15° bedding dip give a corrected direction that is close to the expected direction (Figure 11). The estimated direction for a 20° plunging synclinal structure and a bedding dip of 10° is 179° /-31°, which agrees with the expected direction within the statistical uncertainty. For comparison, the results of a single rotation without plunging of the synclinal structure is also shown in Figure 11. It can be observed that the inclination is much steeper and the angular difference increases with the angle of dip.

The paleomagnetic direction estimated for the Suchilquitongo units (Table 2) may be interpreted in terms of post-Middle Miocene tectonic deformation. If the attitude of the Etla Ignimbrite and the volcanoclastic deposits is a primary feature resulting from the emplacement of the ignimbrite and small-scale tilting since the sampled volcanoclastics and ignimbrite show tilts of some 10°-15° or less, the 15° declination discrepancy between the expected and observed declination is due to secular variation and/or incomplete removal of the secondary overprint. In support of this interpretation, it can be argued that the number of sites is small and secular variation effects may not have been completely averaged out. However, the volcanoclastic sediments may extend the time span recorded by the ignimbrites. The removal of the secondary component in some ignimbrite samples (Figure 3) results in great circles, which, if extended, will intersect the expected direction. But there is good agreement among the directions obtained from end-point and vector plots and the principal component analysis in the sediments and the ignimbrite, suggesting that secondary components do not affect the mean directions. The alternative interpretation is in terms of the post-Middle Miocene tectonic deformation, in particular the folding and faulting interpreted by Wilson and Clabaugh (1970). Thus the Suchilquitongo units would have been affected by deformation resulting in a regional NW plunging syncline. This interpretation is supported by the results of the double-rotation correction, using average parameters with a 20° of plunge for the structure

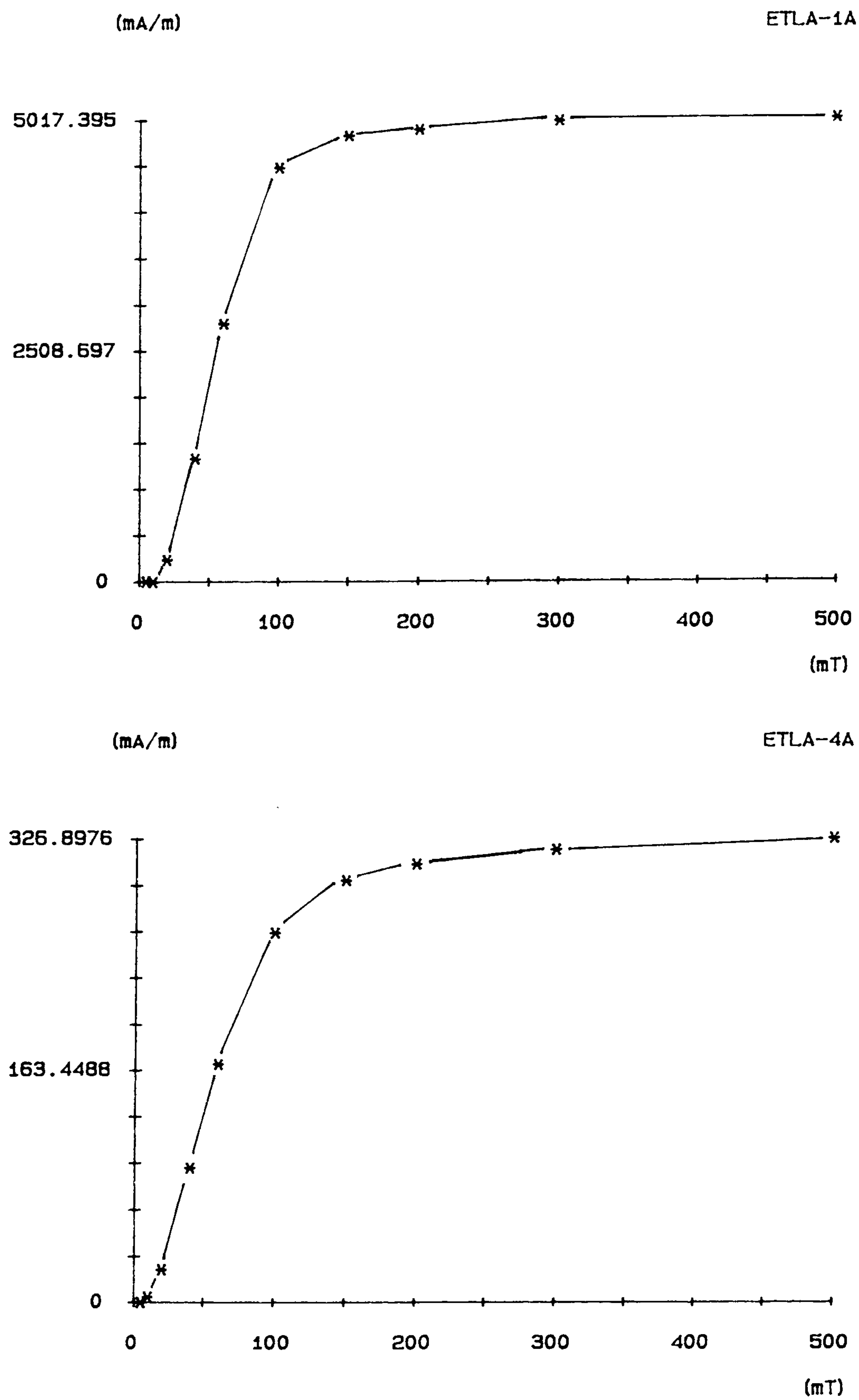

Fig. 7. Examples of isothermal remanent magnetization acquisition curves for two samples of the Etla Ignimbrite. Note that the curves saturate in fields of less than 200 mT, indicating the presence of low coercivity minerals (possibly titanomagnetites or magnetite).

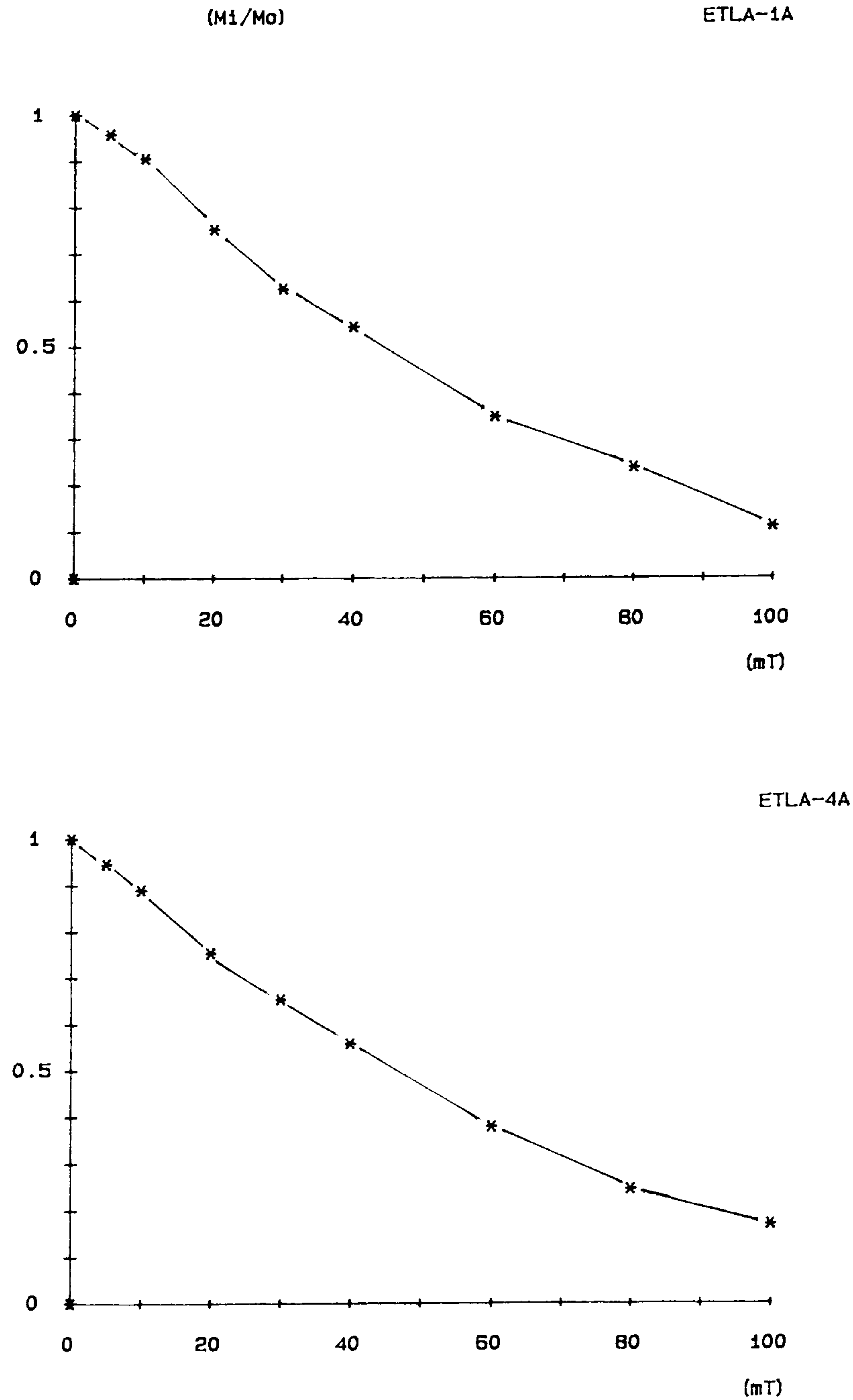

Fig. 8. Corresponding AF demagnetization data for the saturation IRM of the two samples shown in Fig. 6, plotted in normalized intensity diagrams.

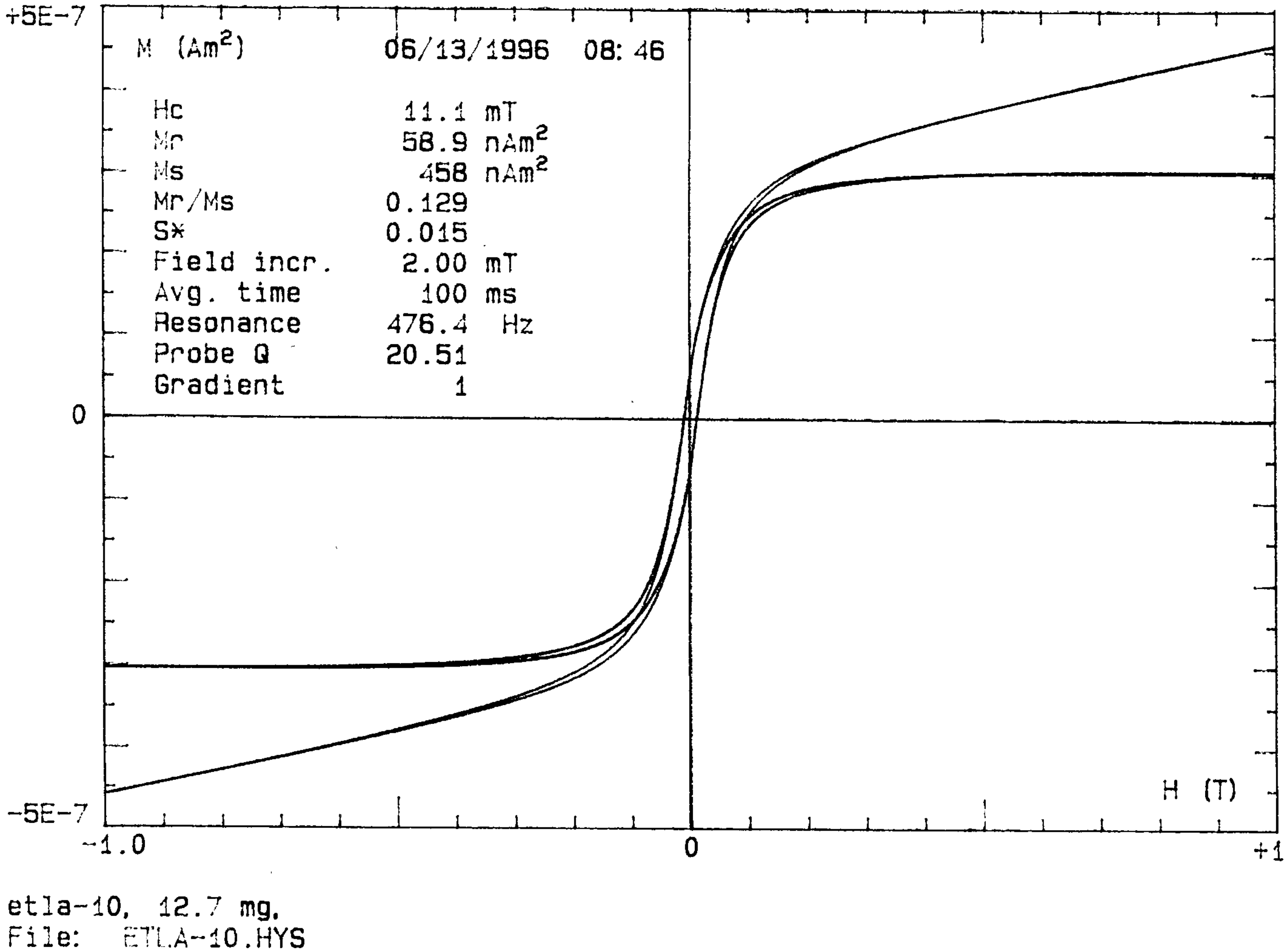

Fig. 9. Example of a hysteresis loop for a sample from the Etla Ignimbrite.

and a 10° of bedding dip, bringing the observed mean direction into agreement with the expected direction for the Oaxaca Valley. Furthermore, the AF demagnetization results indicate that the reverse polarity ChNRM directions have been well isolated, and the distribution of site mean directions for the ignimbrite and the volcanoclastic units is well clustered. Of course, it is difficult to estimate the time interval of the Suchilquitongo strata, in comparison with characteristic Middle Miocene secular variation periods.

An interpretation in terms of Neogene tectonic deformation in the Oaxaca Valley has implications for paleomagnetic studies of older units in the area. Ballard *et al.* (1989) conducted paleomagnetic studies in the Precambrian Oaxaca Complex, and proposed a tectonic and paleogeographic interpretation based on results from the anorthosites and paragneisses. Our results on the Suchilquitongo Formation suggest that the paleomagnetic directions may need to be corrected for Neogene tectonic deformation of the area.

The three new K-Ar dates determined for the Etla Ignimbrite give an age of around 19-20 Ma (Table 1). The geomagnetic polarity time scales (GPTS) indicate several reverse-polarity chrons between about 18.8 and 20.9 Ma (Harland *et al.*, 1990; Cande and Kent, 1992, 1995; Wei, 1995). For instance, Cande and Kent (1995) list three reverse-polarity chrons between 18.781 and 19.048 Ma, 20.131 and 20.518 Ma, and 20.725 and 20.996 Ma. Wei (1995) lists two reverse-polarity chrons between 18.955 and 19.603 Ma and 20.074 and 20.321 Ma. With the present data, a fine correlation with the GPTS will depend on the K-Ar date accepted and the GPTS used as reference. Dates for biotite and plagioclase (Table 1) yield 19.2 and 19.3 Ma, which lie within the reverse chron of the Wei (1995) GPTS. Magnetostratigraphic studies have been successfully used in investigations of continental volcano-sedimentary sequences

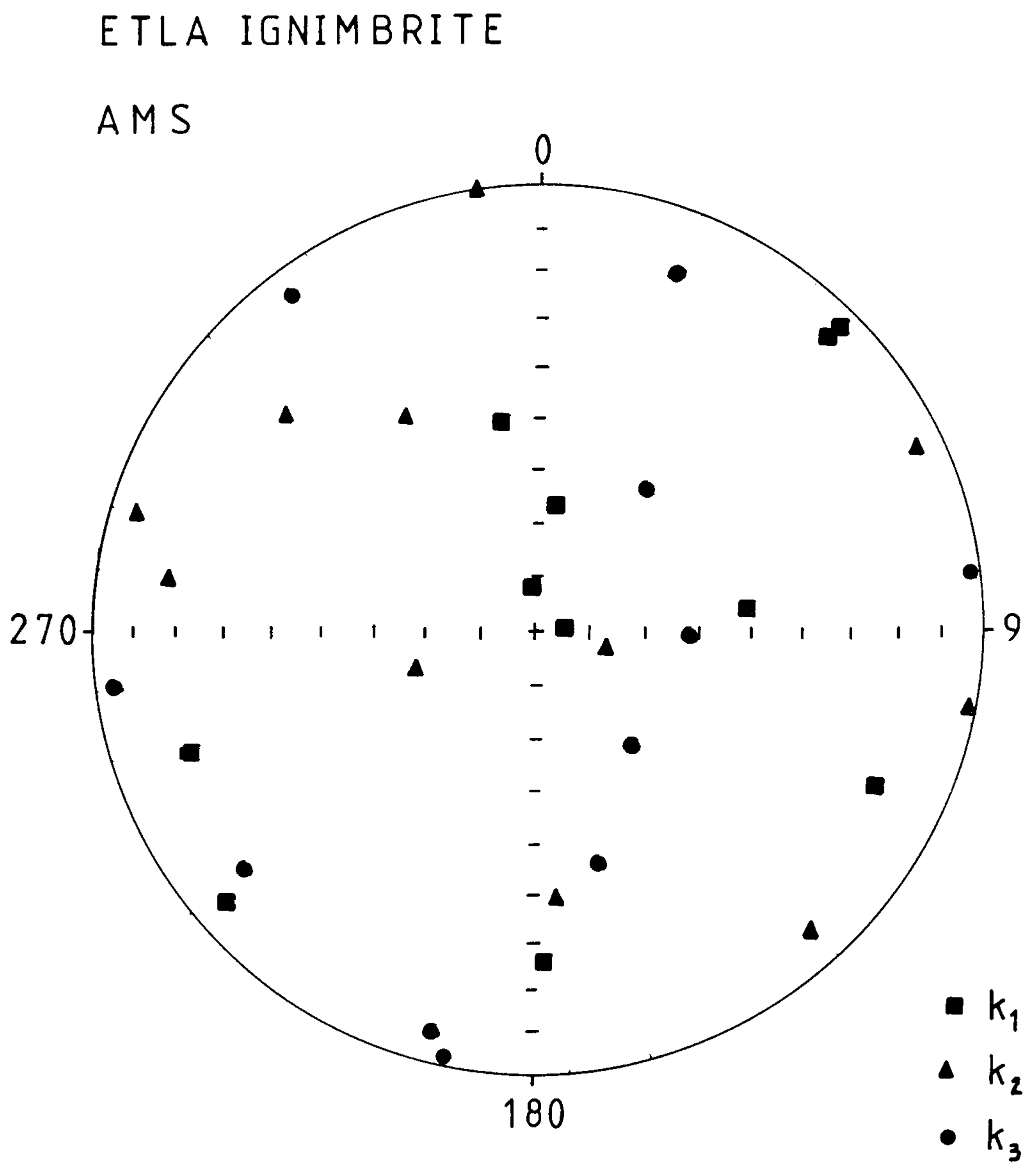

Fig. 10. Anisotropy of magnetic susceptibility principal axes for a site in the Etla Ignimbrite plotted in an equal-area stereographic projection (upper hemisphere). Note that the axes are characterized by large angular dispersion.

(e.g., Opdyke and Channell, 1996; Benammi *et al.*, 1996; Goguitchaichvili *et al.*, 2001). A detailed magneto-stratigraphic and paleontologic study involving sampling of a section of the Suchiquiltongo Formation ignimbrite and volcanoclastic deposits may provide further temporal constraints.

The emplacement characteristics, flow direction and possible source for the Etla Ignimbrite have not been documented. Outcrops in the Etla sector of Oaxaca Valley cover an area some 20 km long and 4-6 km wide; if outcrops along the Tlacolula Valley are added, as suggested by Wilson and Clabaugh (1970), then the ignimbrite extends over a larger area. Measured thicknesses in the Oaxaca Valley range from some 5 to 11 m, with no apparent consistent lateral variation indicative of proximity to source. Magnetic fabric studies have been successfully applied to investigate flow direction and emplacement temperatures in ignimbrites, lava flows and tuffs (e.g., Urrutia-Fucugauchi, 1986; MacDonald and Palmer, 1990; Palmer *et al.*, 1991). Therefore, a study of magnetic fabric was undertaken to document the flow direction and possible source for the Etla Ignimbrite. Unfortunately, the high scatter in AMS axes (Figure 10) does not permit to estimate the flow direction. The 14.3-16.0 Ma K-Ar dates obtained for the ignimbrites in the Tlacolula-Mitla Valley are younger than the 20 Ma dates for the Etla Ignimbrite, which does not support the correlation previously proposed for the volcanic units.

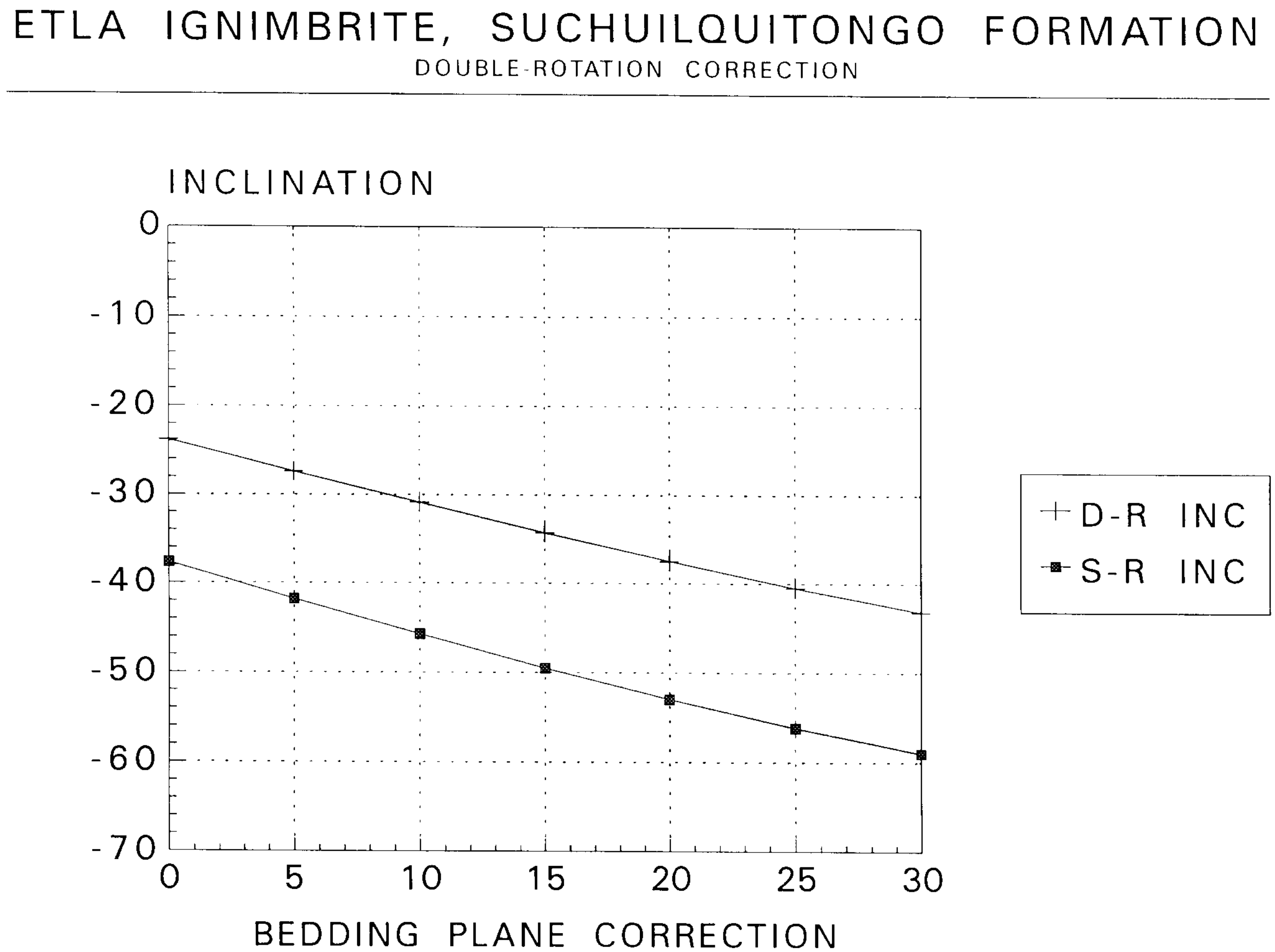

Fig. 11. Unfolding plots for the overall mean direction of the Suchilquitongo Formation, corresponding to the double-rotation correction (lower curve) and the single rotation correction (upper curve). The upper curve has first been rotated 20º to restore the plunge of the structure and then the direction has been partly unfolded assuming dips up to 30º. The lower curve is obtained assuming no plunge of the syncline structure and the direction is corrected only for the bedding attitude, up to 30º. The expected inclination for the locality is shown for comparison. Note that the best agreement is obtained after the two rotation corrections, with a 10º-15º of bedding tilt.

ACKNOWLEDGMENTS

Prof. Fred W. McDowell has made the K-Ar studies. We greatly appreciate his long lasting and important cooperation in the Cenozoic continental-sequence project. Martin Espinosa and A.M. Soler provided assistance in the laboratory study. We are indebted for comments on this study by C. Lomnitz, M. Benammi and the journal reviewers. We thank Laura Huerta for assistance with the paper. Partial financial support for the project has been provided by DGAPA, CONACYT and the European Community, Project CI1-CT94-0114.

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J. Urrutia-Fucugauchi[1] and I. Ferrusquía-Villafranca[2]

[1] *Laboratorio de Paleomagnetismo y Geofísica Nuclear, Instituto de Geofísica, Universidad Nacional Autónoma de México, Del. Coyoacán 04510 México, D.F., MÉXICO*

[2] *Departamento de Paleontología, Instituto de Geología, Universidad Nacional Autónoma de México, Del. Coyoacán 04510 México, D.F., MÉXICO*