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RECONNAISSANCE PALEOMAGNETIC INVESTIGATION OF CRETACEOUS LIMESTONES FROM SOUTHERN MEXICO

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RESUMEN

Se presentan resultados de una investigación paleomagnética de una secuencia de calizas Cretácicas aflorantes en el sur del estado de Oaxaca (~16.6°N, 97.0°W). Un total de 174 muestras orientadas fueron colectadas de una secuencia vertical de cerca de 400 m de espesor. La estabilidad magnética y la composición vectorial de la magnetización remanente natural fueron investigadas por desmagnetización por campos magnéticos alternos decrecientes y por altas temperaturas. Una selección de los resultados experimentales más confiables, con base en la estabilidad de las direcciones durante la desmagnetización y la dispersión de direcciones para cada sitio, restringe su número a un total de 115 muestras. Todas las muestras seleccionadas como estables presentan magnetización normal, lo cual es consistente con la edad geológica sugerida para la secuencia (Albiano-Cenomaniano), que la sitúa dentro del intervalo de polaridad normal del Cretácico. La dirección y posición polar obtenidas son de 348.7°, 23.0° ($k = 27$, $\alpha_{95} = 6.6°$) y 78.4°N, 149.8°E ($k = 38$, $A_{95} = 5.5°$). La posición polar difiere de las posiciones polares correspondientes para Norteamérica, lo que sugiere la posible ocurrencia de movimientos tectónicos relativos. La divergencia angular es sin embargo pequeña, por lo que es difícil establecer un posible modelo tectónico. No obstante los resultados disponibles indican movimientos tectónicos relativos entre partes de México y con respecto al cratón de Norteamérica.

ABSTRACT

Paleomagnetic data from a total of 174 oriented samples collected from a 400 m thick sequence of Cretaceous limestones from Oaxaca State, southern Mexico (~16.6°N, 97.0°W) were reported. The magnetic stability and vectorial composition were investigated by detailed alternating field and thermal demagnetization. A selection procedure based upon directional stability of demagnetized vectors and within-site dispersion restricts the data population to 115 samples. All stable samples are normally magnetized, which is consistent with the geologic age suggested for the sequence of Albian-Cenomanian, within the normal polarity interval. The direction and pole position obtained are 348.7°, 23.0° ($k = 27$, $\alpha_{95} = 6.6°$) and 78.4°N, 149.8°E ($k = 38$, $A_{95} = 5.5°$). The pole position apparently diverges from the corresponding segment of the North American apparent polar wander path, which may suggest the occurrence of relative tectonic movement between that part of Mexico and North America. The angular divergence is small, and at present, this is just considered as one of the possible tectonic events within the suggested theories for the evolution of Middle America.

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INTRODUCTION

At present the paleomagnetic record for pre-Mesozoic time of Mexico is still very poorly established. This lack of data results in a large degree of uncertainty in defining the Mexican apparent polar wander path (Urrutia-Fucugauchi, 1979), and since the direction of this path has a direct bearing on our understanding of the tectonic evolution of Middle America, paleomagnetic investigation of Mesozoic and older rocks has become a prime objective of the Laboratorio de Paleomagnetismo y Geofísica Nuclear at Mexico City.

Paleoreconstructions of the Gulf of Mexico-Caribbean-bordering lands (e.g. Carey, 1958; Dietz and Holden, 1970; Freeland and Dietz, 1971; Malfait and Dinkelman, 1972; Walper and Rowett, 1972; Uchupi, 1975; Van der Voo *et al.*, 1976) have suffered from this lack of paleomagnetic information. The timing of events in the area has also been repeatedly debated, where some authors maintain a pre-Mesozoic permanency of Middle America, and others allow large-scale movements at least up to the end of the Mesozoic.

Interpretation of the Mesozoic magnetic polarity reversal sequence has been receiving constant attention, particularly because of the possible existence of long periods of relatively constant magnetic polarity (Irving and Pullaiah, 1975; Larson and Helsley, 1975). Helsley and Steiner (1969) suggested that most of the late Cretaceous corresponded to a period of predominantly normal polarity, and subsequent works (Irving and Couillard, 1973; Shive and Fredrichs, 1974; Irving and Pullaiah, 1975; Larson and Hilde, 1975; Alvarez and Lowrie, 1978) have been supporting the existence of such normal interval. Correlation of this interval as found in studies of continental sequences and in marine magnetic anomaly surveys with a 'chronologic' time scale has been reported, however, the correlation is as yet imprecise (e.g., Mankinen and Dalrymple, 1979; Ness *et al.*, 1980). Paleomagnetic measurements on continental sequences may help in confirming further the dominant normal polarity or in detecting short reverse events, which if present, would be of great value in stratigraphic studies.

The purpose of this work is to report results of a reconnaissance paleomagnetic study of a sequence of Cretaceous limestones from Oaxaca State, southern Mexico. The sampling scheme adopted and the laboratory work allowed us to estimate a magneto-stratigraphic sequence and a pole position for the limestones. This in turn permits us to discuss briefly the possible significance of the study for the tectonic evolution of southern Mexico and for the Cretaceous polarity time scale.

GEOLOGIC SETTING

Carbonate rocks of Cretaceous age are well exposed in southern Oaxaca State along linear belts with approximate NW-SE orientations (Fig. 1). The rocks were sampled at a single locality (~16.6°N, 97.0°W) near Sola de Vega village, where the road Oaxaca-Puerto Escondido cuts a section some 400 m thick (Fig. 1). Detailed geologic study of the sequence is yet to be completed. The available information (e.g. Vila-Gómez, 1973; López-Ramos, 1974-1979) indicates an age for the limestones corresponding to the Albian-Cenomanian, based on limited paleontological evidence and regional stratigraphic correlations. The sequence consists of dolomitic limestones generally well stratified, with beds of variable thicknesses ranging from a few centimeters up to about 4 meters. The structure is fairly uniform, and a total of 21 bedding plane measurements carried out at regular intervals through the sequence gave a mean bedding plane estimate (strike and dip) of 241.4°, 22.0° ($k = 48$, $\alpha_{95} = 4.6°$). The folding of the Mesozoic strata apparently occurred during the Laramide orogeny, during the late Cretaceous-Eocene.

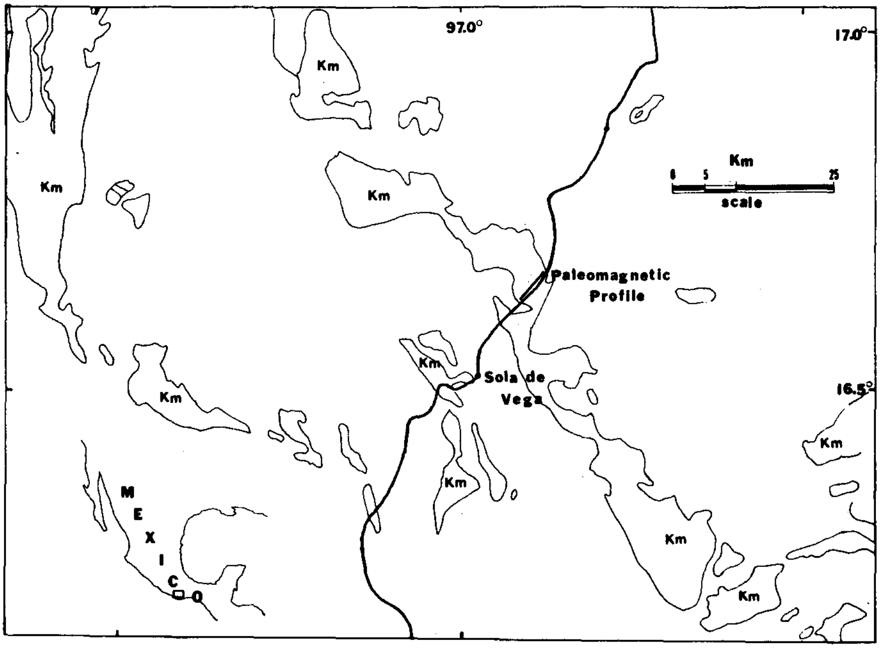


Fig. 1. Schematic map showing the location of the sampling locality (paleomagnetic profile) and the distribution of the Cretaceous limestone exposures (km) in the area (modified from López-Ramos, 1974).

For the present paleomagnetic study a total of 174 hand samples and cores were collected and oriented *in situ* with a Brunton magnetic compass. Sampling was carried out in stratigraphic order to cover some 400 m of section. For the analysis, samples collected with separation of less than 1 meter were taken as a single site (generally within thick beds), so that a total of 28 sites (all corresponding to different stratigraphic limestone beds) were finally considered.

PALEOMAGNETIC RESULTS

The intensity and direction of natural remanent magnetization (NRM) were measured with a Digico spinner magnetometer (Molyneux, 1971). Most samples presented very weak intensities, which called for extreme care and 'special' laboratory procedures in order to ensure as far as possible that the measurements were representative. By using the normal procedure of increasing the time of measurement to diminish the noise level (Molyneux, 1971), we have taken at least three replicate measurements for each sample. Thus, the internal dispersion of directions and standard deviation of intensities were used as control checks to detect unreliable measurements (Heller, 1977; Urrutia-Fucugauchi and Tarling, in preparation). Low-field susceptibility was measured with a susceptibility bridge (Collinson *et al.*, 1963).

The stability and vectorial composition of NRM were investigated by both alternating field (AF) and thermal demagnetization. AF demagnetization was carried out in 11-12 steps up to a maximum peak field of 950 Oe by using a digitally controlled three-axes demagnetizer (de Sa and Widdowson, 1974). Thermal demagnetization was carried out in 5-6 steps up to a maximum temperature of 505°-630°C by using a non-inductively-wound vertical furnace (Stephenson, 1967). At least two samples per site were subjected to detailed demagnetization. The optimum AF field or temperature was estimated from stability index (Tarling and Symons, 1967; Symons and Stupavsky, 1971) and vector subtraction (Zijderveld, 1967) analysis, by employing a Fortran IV program in use at the University of Newcastle-upon-Tyne (U.K.). Most samples were very stable to the treatments and no apparent secondary magnetizations were observed (e.g. Figs. 2, 3 and 4). The thermal treatment is more effective in investigating the vectorial composition of these limestones (Figs. 3 and 4), this because the remanences presented high coercitivity components, >950 Oe (Fig. 2). Vector diagrams for thermal pilots apparently indicate univectorial magnetizations (Fig. 4). All samples remaining were subjected to the corresponding optimum thermal treatment. Site results were calculated by successive application of Fisher's (1953) statistics, first by giving unit-weight to specimen results to compute sample means and then giving unit-weight to them to compute the site means (Irving, 1964). Intensity and low-field susceptibility results were calculated assuming a log-normal distribution (Tarling, 1966). Results are summarized in Table 1, and graphically presented in Fig. 5.

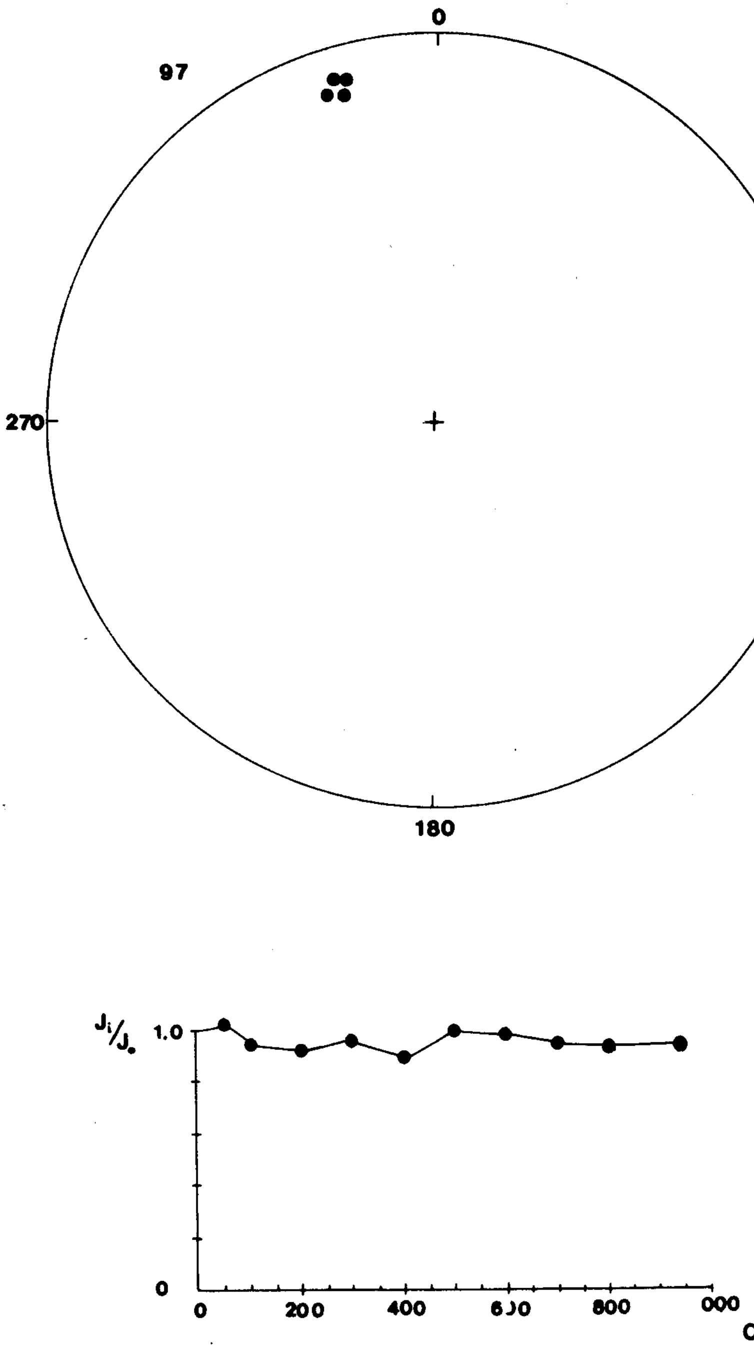


Fig. 2. Typical example of AF demagnetization results with directional changes plotted in an equal-area projection (top) and intensity changes in a normalized diagram (bottom). Open symbols represent directions up, and closed symbols represent directions down.

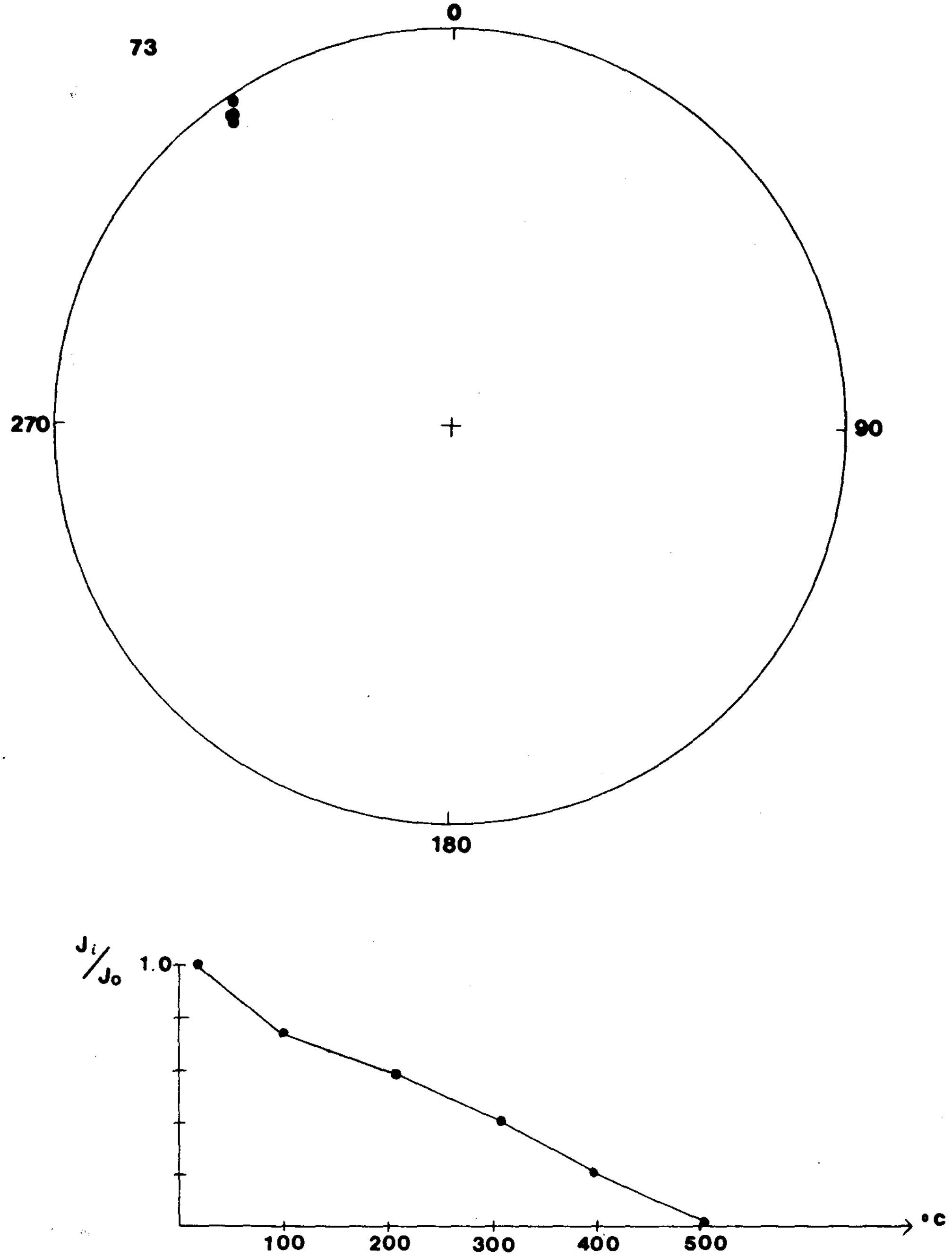


Fig. 3. Typical example of thermal demagnetization results. See figure 2 for explanation of symbols.

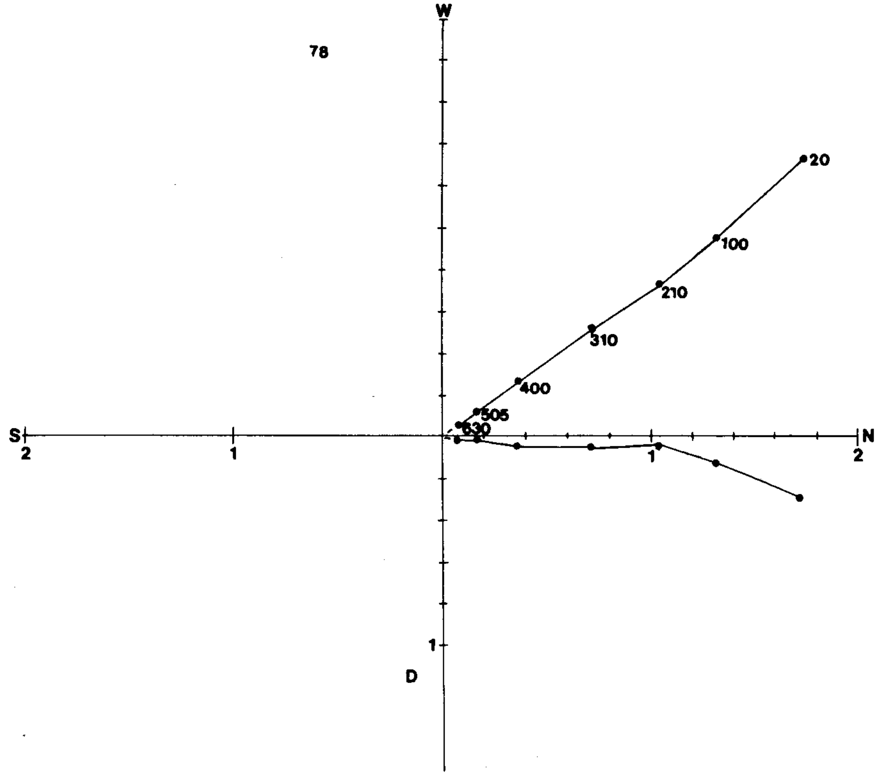


Fig. 4. Typical example of thermal demagnetization results plotted in a vectorial diagram. Open symbols are NS - Z component and closed symbols are NS-EW component. Intensities are given in 10^{-6}emu/cm^3.

The initial NRM intensity of most sites is very weak, being generally lower than 10^{-6}emu/cm^3, with only three sites with values between about 2 and $5 \cdot 10^{-6}$emu/cm^3. The susceptibility is generally negative, with only few sites with positive values. The directions of NRM after the AF and thermal treatment remained scattered, and in order to compute an overall mean direction for the limestone sequence, all site mean directions with corresponding k values lower then 10 were excluded from the calculations. The apparent dispersion of directions in these sites is believed to be partially due to difficulties in measuring the remanences, rather than to real geomagnetic field behaviour or other effects affecting those limestones. All these rejected sites except one (site 28) presented very weak site-mean intensities ($\lesssim 0.08 \cdot 10^{-6}$emu/cm^3), included specimen-results with large dispersions in replicate measurements, and in most cases, during the treatment of pilots, their intensities were weaker than the noise level (measurement without any sample in sample-holder). Results from site 28 are not in this category, since the intensities were high (highest

Table 1. Summary of palaeomagnetic data of Cretaceous limestones from Oaxaca State, Southern Mexico.

				Present horizontal		palaeohorizontal								
Site	N	Intensity	Susceptibility	Dec.	Inc	Dec.	Inc	k	α_{95}	P_{Lat}	P_{Long}	k	A_{95}	$CDS^{(Poles)}$
1	9	2.31±0.53	0.10±0.01	324.8	32.8	325.7	10.9	50	7.4	54.7	158.8	50	7.3	11.4
2	5	0.66±0.25	0.67±0.21	347.8	49.2	343.4	27.8	13	22.1	74.0	170.1	12	22.6	23.0
3	7	0.74±0.21	0.19±0.06	357.1	50.6	349.9	30.1	30	11.2	80.8	173.9	29	11.4	15.1
4	3	0.78±0.12	−0.78±0.08	349.2	42.5	345.4	21.3	42	19.2	75.1	153.9	53	17.2	11.2
5	11	0.04±0.03	−1.19±0.11	357.7	33.7	353.7	13.6	7	17.9	78.5	122.8	9	15.9	26.6
6	9	0.04±0.01	−0.94±0.10	32.4	50.3	15.6	36.7	60	6.7	74.6	334.5	90	5.5	8.5
7	5	3.84±0.78	−0.35±0.14	347.0	28.5	345.1	7.2	311	4.3	70.5	133.1	509	3.4	3.6
8	13	0.22±0.11	−1.22±0.19	2.9	48.5	354.7	28.9	160	3.3	84.8	162.7	213	2.8	5.6
9	12	0.05±0.03	−0.79±0.19	13.4	47.7	2.7	29.9	7	18.4	84.8	326.7	8	16.0	28.1
10	5	0.04±0.02	−0.92±0.06	20.8	61.0	2.1	43.9	4	45.9	72.4	291.5	3	53.1	46.5
11	5	0.10±0.06	−0.43±0.17	8.5	40.8	1.0	27.3	23	16.2	73.8	85.2	25	15.7	16.3
12	3	0.07±0.01	−1.09±0.10	23.6	32.1	16.0	17.3	5	64.5	73.9	17.6	6	58.1	34.3
13	5	0.10±0.02	−0.91±0.09	28.6	58.3	8.5	43.0	77	8.8	77.9	304.5	75	8.9	9.3
14	7	0.28±0.13	−0.67±0.11	356.3	36.4	352.0	16.0	32	10.8	78.7	127.1	76	7.0	9.3
15	5	0.21±0.07	−0.39±0.23	349.4	39.9	345.9	18.8	87	8.2	74.7	148.5	128	6.8	7.2
16	5	0.18±0.05	−0.87±0.19	353.8	43.3	348.9	22.5	28	14.7	78.6	150.7	34	13.4	14.0
17	3	0.06±0.11	−1.17±0.35	51.1	25.1	61.9	27.0	4	67.2	19.3	17.5	9	42.8	26.5

(Table 1 - continued)

				Present horizontal		palaeohorizontal								
Site	N	Intensity	Susceptibility	Dec.	Inc.	Dec.	Inc.	k	α_{95}	P_{Lat}	P_{Long}	k	A_{95}	$CDS^{(Poles)}$
18	8	0.51±0.17	−1.05±0.12	359.1	44.4	352.8	24.4	168	4.3	82.1	146.3	392	2.8	4.1
19	8	0.25±0.09	−0.95±0.17	4.4	37.7	358.4	18.6	88	5.9	83.0	96.1	157	4.4	6.5
20	10	0.42±0.25	−1.37±0.14	358.3	39.4	353.1	19.3	63	6.1	80.7	130.0	109	4.6	7.8
21	4	0.08±0.04	−1.28±0.06	3.5	−7.8	7.3	26.1	8	34.2	56.7	68.8	15	24.3	20.7
22	4	0.19±0.04	−1.11±0.01	330.0	34.2	330.2	12.2	106	9.0	59.1	157.0	265	5.7	5.0
23	7	0.01±0.01	−1.61±0.21	323.6	44.1	325.4	22.3	4	32.7	54.5	170.2	5	29.9	36.2
24	4	0.04±0.02	−1.70±0.29	335.8	36.2	335.0	14.3	14	25.1	63.6	155.7	15	24.2	20.6
25	9	0.08±0.10	−1.60±0.22	19.5	50.1	6.3	33.4	4	28.9	78.7	311.2	4	32.0	43.0
26	5	0.08±0.05	−1.13±0.04	343.0	46.8	340.1	25.1	20	17.6	70.3	168.9	41	12.1	12.6
27	6	0.33±0.14	−0.66±0.21	359.1	45.8	352.5	25.6	320	3.8	82.2	151.8	554	2.6	3.2
28	5	5.13±1.25	2.88±0.33	342.1	40.1	340.0	18.4	5	38.0	68.0	158.9	6	33.3	32.4
Mean B = 28 (N=174)			---	358.5	41.0	353.0	18.9	10	9.0	81.9	168.7	15	7.3	---
B = 19 (N=115)			---	353.8	43.5	348.7	23.0	27	6.6	78.4	149.8	38	5.5	---

values in the sequence) and the directions very stable during treatment. No explanation is at present offered for them. The exclusion of these results from the final computations attempts to restrict the sample population to data that show stable magnetic properties, measured with a minimum accuracy level. This is important if one seeks to derive a paleomagnetic pole position for a given time. Although the samples selected show no apparent effects of remagnetization events, and the pole positions are not displaced towards younger poles and are far-sided, it should be mentioned that the possibility of a complete overprint, or a younger remanence acquisition age still remains. Because of the uniform dip in the section sampled, no fold test was possible. The overall mean results are based on 19 sites (115 samples) (Table 1). Using the overall mean pole position, the angular distance relative to this pole for each individual site pole position was calculated (Fig. 5). This parameter is considered a useful means for distinguishing the polarity of the sequence (Valencio *et al.*, 1977), as opposed to the use of co-latitude variations only. Pole positions with angular distances between 0° and 45°, 45° and 135°, and 135° and 180° are considered to represent normal, intermediate, and reverse polarities, respectively.

DISCUSSION

The results show that the sequence is of predominant normal polarity (Fig. 5). No sample studied showed a truly reverse polarity, and only a few samples showed intermediate directions with negative inclinations. These intermediate polarity samples belong to the sites showing large apparent dispersions and with weak intensities of magnetization, and as stated above, there is doubt whether the results reflect more than the difficulties of accurately measuring the remanences. Because of this uncertainty the deviating results are not discussed any further, although we cannot definitively exclude the possibility that they represent incompletely measured events or polarity excursions. A more detailed sampling of the sequence is being planned, as well as a geologic - paleontologic study. In general, the results are consistent with the existence of a long normal polarity interval during the middle part of the Cretaceous (Irving and Pullaiah, 1975), and (although in a sense introducing a circular reasoning) are consistent with the suggested geologic age of Albian-Cenomanian (López-Ramos, 1979).

The overall mean pole position for the limestone sequence was compared with the published pole positions for the Cretaceous of Mexico (Fig. 6). The pole position is not statistically different from the pole position obtained for the Méndez shale (Keating *et al.*, 1975) of northern Mexico. The other pole position is for the Difunta Group (Nairn, 1976) also of northern Mexico.The apparent agreement of the pole positions (Méndez shale and Oaxaca limestones) may suggest the absence of relative movements between the sampling sites. Also, we note that the pole positions of northern Mexico are assigned to the Maestrichtian (Late-Cretaceous).

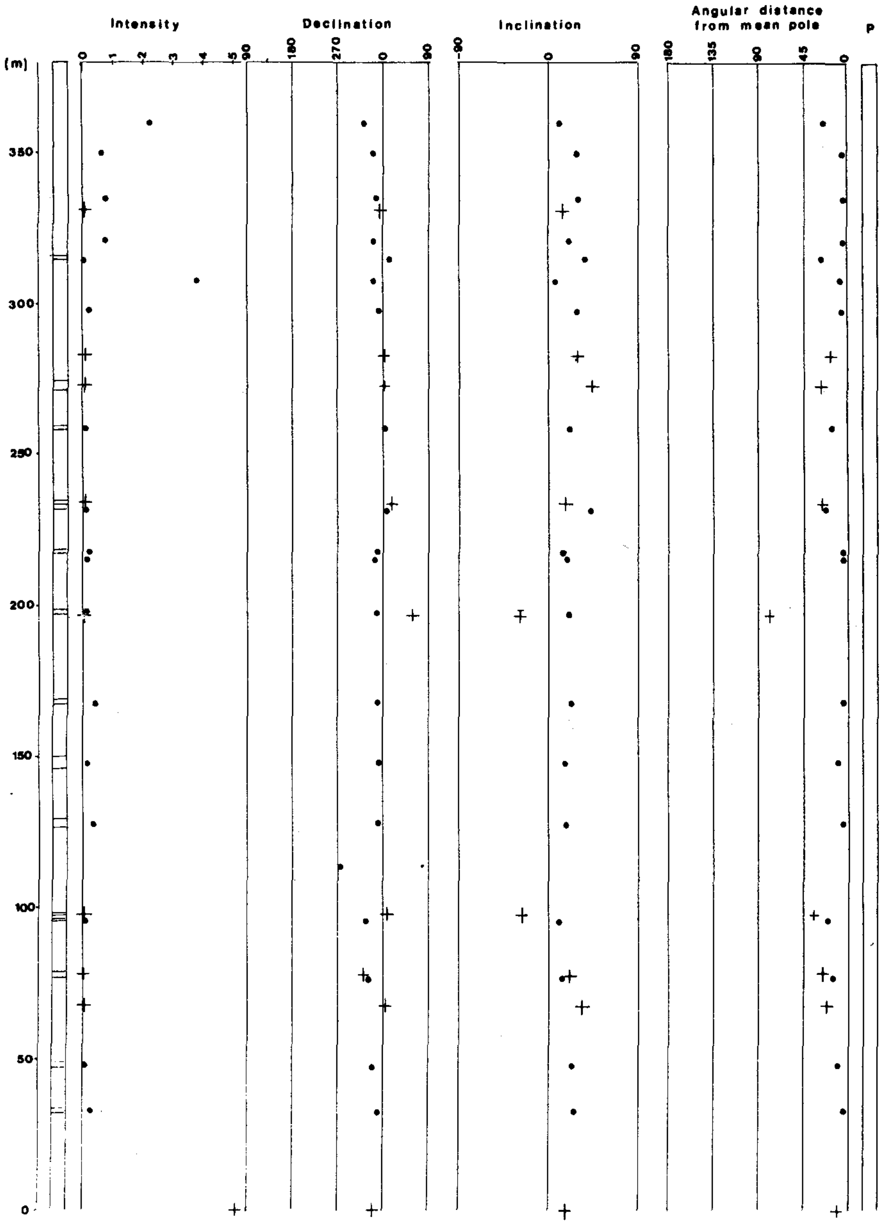
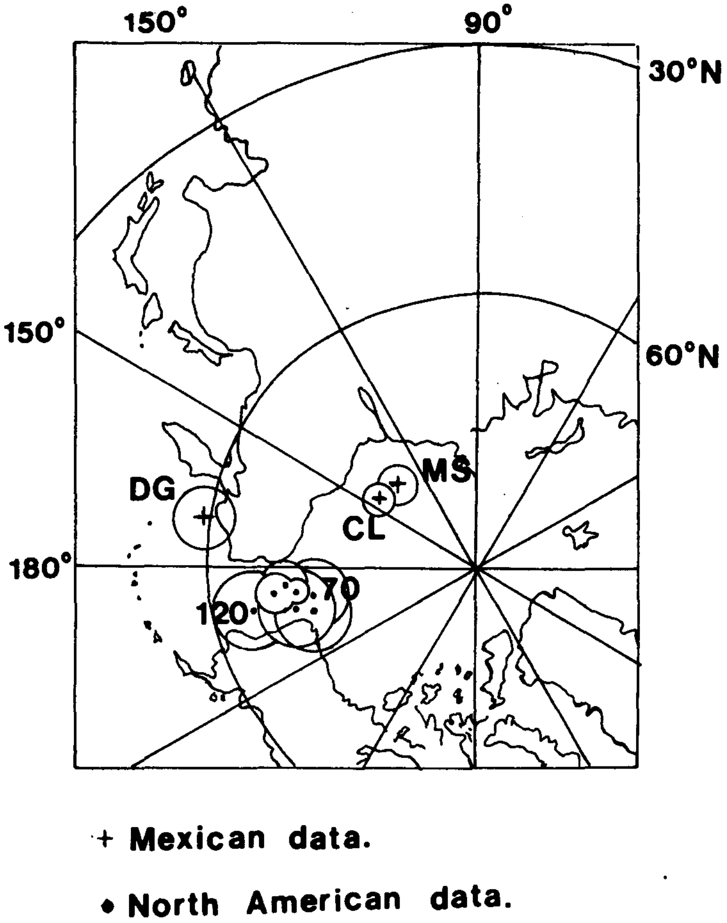


Fig. 5. Stratigraphic plot of initial NRM intensity (10^{-6}emu/cm^3), declination and inclination of cleaned remanence, angular distance between the site-mean pole positions and the overall mean paleomagnetic pole, and magnetic polarity (open is for normal polarity). Arbitrary thickness values are measured up from the lowest exposure sampled (total thickness, ~400 m). Results excluded from the final calculation are given by the crosses (see text for discussion of these results).

Keating *et al.* (1975) have reported the occurrence of some 14 polarity intervals which is in marked contrast with the results here obtained. The apparent agreement found, indicates that during the Cretaceous only minor apparent polar wander or continental movement took place. This is consistent with the results obtained for North America (Irving, 1979), which also indicate little apparent polar movement during the Middle-Late Cretaceous.

To proceed further, in Fig. 6, the Mexican pole positions are compared with the Middle-Late Cretaceous segment of the North American apparent polar wander path (Irving, 1979). The pole positions apparently diverge, which may be indicative of relative tectonic movements between Mexico and North America. Alternatively, they may indicate a post-Cretaceous remagnetization event of the rocks from which all or some of these pole positions were determined, or any other unknown disturbing event. The magnetization hypothesis here seems unlikely since the poles are



far-sided, and not displaced towards younger poles. In this respect, it is interesting to note that Gose *et al.* (1980) have proposed, based upon paleomagnetic evidence, that most of Mexico was not a part of North America during the Early Mesozoic. These authors have suggested a large-scale counterclockwise rotation of Mexico relative to North America occurring in Middle and Late Jurassic time and possibly continuing into the Cretaceous. The paleolatitude derived from the results of the limestone sequence is about 12°, which is lower than the actual latitude of the area (~16.6°) as well as the paleolatitude predicted for the site assuming that no relative movement between cratonic North America and Oaxaca occurred. In an attempt to characterize the possible tectonic movement, the geometric parameters proposed by Yole and Irving (1980) were calculated. Assuming that the polarity of the remanences is indeed normal (in agreement with the normal polarity interval), then the relative paleolatitudinal displacement is about 18.9° (with an error of about 6.8°), and the relative rotation is about 53.6° counterclockwise (with an error of about 7.3°). The reference paleopole used for the calculations was taken from Irving (1979) and corresponds to that for the mid-Cretaceous. One should also consider that there are three poles given for the Cretaceous of Mexico and that the two for the Late Cretaceous (northern Mexico) diverge. The pole position derived for the limestone sequence of Oaxaca (southern Mexico), as well as those for northern Mexico, require further support. Therefore, before a conclusion about the Late Mesozoic tectonic evolution of southern and northern Mexico could be drawn, it seems evident that more studies are required.

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