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PALAEOMAGNETIC STUDY OF MESOZOIC ROCKS FROM IXTAPAN DE LA SAL, MEXICO

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RESUMEN

Se reportan datos paleomagnéticos para 25 muestras de tres localidades de una secuencia de rocas metavolcánicas expuestas en el área de Ixtapan de la Sal, México. Las muestras presentan grados variables de alteración hidrotermal y metamorfismo, con dos sitios de esquistos verdes y un sitio de andesitas alteradas. Las muestras fueron sometidas a tratamiento con campos magnéticos alternos decrecientes y con altas temperaturas. Las direcciones tienen polaridades normal y reversa, son estables con la desmagnetización y proporcionan una posición polar media de 54.1°N, 139.1°E (dp = 10°, dm = 7°). Las magnetizaciones son llevadas por minerales magnéticos de alta coercitividad, posiblemente hematita secundaria. Dataciones radiométricas de K-Ar en muestras de dos sitios dan edades de 108 ± 5 ma y 125 ± 5 ma, las cuales se relacionan con el evento de compresión y alteración regional que afectó la zona. Se sugiere que las magnetizaciones remanentes observadas fueron adquiridas durante el Jurásico Tardío o Cretácico Tardío. La posición polar derivada de las rocas metavolcánicas diverge de otros polos paleomagnéticos reportados para otras áreas de México del Mesozoico, lo que sugiere la posible ocurrencia de movimientos tectónicos de esta área.

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ABSTRACT

Palaeomagnetic data from 25 hand samples collected from three localities of a sequence of metavolcanic rocks exposed in southern Mexico are reported. The samples show variable degrees of metamorphic and hydrothermal alteration resulting in green schists (2 sites) and altered andesites (1 site). After AF and thermal demagnetization the majority of samples show stable directions of normal and reverse polarities and yield a palaeomagnetic pole at 54.1°N, 139.1°E (dp = 10°, dm = 7°). The magnetization is carried by high coercitivity minerals, possibly by secondary haematite. K-Ar dating of samples from two sites gives dates of 108 ± 5 Myr and 125 ± 5 Myr, which correlate with the event of regional compressive tectonism which affected the area. It is suggested that the stable remanences observed were acquired during the Late Jurassic to Early-Late Cretaceous. Comparison of the pole derived with Mesozoic pole positions reported for other areas in Mexico supports the possible occurrence of relative tectonic movements of the sampling area.

INTRODUCTION

A thick sedimentary-volcanic sequence affected by varying degrees of metamorphism is exposed over an extensive area in the States of Mexico and Guerrero in southern Mexico. The sequence is of predominantly green colour and it has been referred to as the Roca Verde Taxco Viejo (Fries, 1960), or simply as a metavolcanic-metasedimentary sequence (Campa-Uranga *et al.*, 1974). This paper reports on new

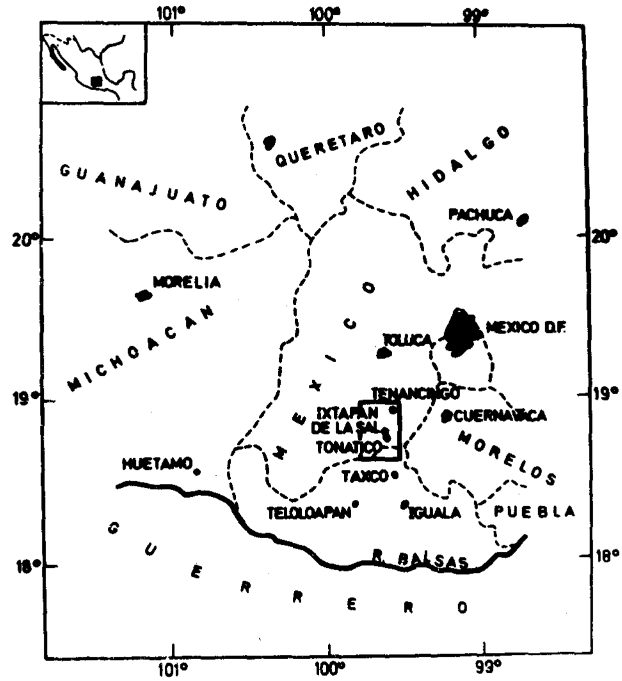

Fig. 1. Location of area studied around Ixtapan de la Sal village, Mexico State. Area enclosed in the rectangle is shown in Figs. 2 and 3.

palaeomagnetic data obtained from volcanic rocks of three localities near Ixtapan de la Sal village, Mexico State (Fig. 1).

The plate tectonics framework of Mexico during the Cretaceous has been difficult to establish. During the Middle Cretaceous, the carbonate platform deposits of the e.g. Aurora, Sierra Madre, and El Abra formations indicate an apparent tectonic stability of large areas in Mexico. The volcano-sedimentary deposits of southern Mexico in the Guerrero Alisitos terranes with magmatic arc type rocks suggests a different situation which may have involved plate subduction and closure of marginal basins, resulting in accretion of island arc terranes. There are however geometric and geologic problems with such possibility, and alternative explanations involving drastic lateral facies changes, etc. have been proposed. In this paper, we propose a preliminary plate tectonic model as a working hypothesis for further research and discussion.

GEOLOGIC SETTING

The oldest rocks recognized in the area around Taxco village (Fig. 1) are metamorphic rocks forming the Esquisto Taxco Formation (Fries, 1960). The presence of schists in the area was observed long ago (de Humboldt, 1808, p. 545), and were grouped together with slates and conglomerates, and classified as flysh deposits of Late Cretaceous age (Osborne, 1956). More recently, de Cserna *et al.* (1974) reported a Pb-α date determination using zircon concentrates of 1 020 ± 110 Myr, *i.e.*, Late Precambrian. The schists correspond to sericite schists formed mainly from rhyolitic tuffs, which generally present a dark brown colour due to oxidation, being light brown to green in fresh cuts. The rocks above these schists are metasedimentary and metavolcanic rocks of the Roca Verde Taxco Viejo Formation (Fries, 1960), which were assigned to the Late Triassic. Studies by Campa-Uranga *et al.* (1974) in the area of Ixtapan de la Sal, Mexico State (Fig. 2) assign an age of Late-Jurassic-Early Cretaceous to the metamorphic sequence. The sequence is formed by volcanic rocks of predominantly green colour with andesites, tuffs and agglomerates. The andesitic lavas show pillow structures, typical of oceanic flows; the tuffs and agglomerates are foliated following the bedding. The metasediments are composed of phyllites, sandstones, quarzites and foliated limestones. The phyllites are formed of hardly metamorphosed lutites showing fine foliation parallel to bedding. The sandstones are mainly foliated and folded greywackes. The limestone is interstratified with the phyllites, in some folded areas it is forming marble, and in some outcrops it shows hydrocarbon impregnations. In some areas, near Taxco village, the metamorphic sequence is covered by sediments of the Acahuizotla Formation, which is covered by lutites and phyllites of the Acuitlapan Formation. This Formation grades up into limestones of the Xochicalco Formation. In the area near Ixtapan de la Sal, the metamorphic sequence is covered by limestones of the Xochicalco or Morelos Formation.

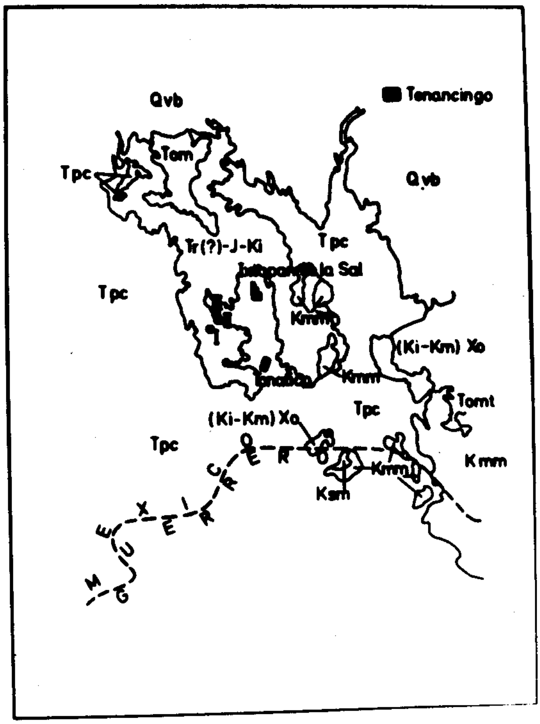

Fig. 2. Schematic geologic map of the area of Ixtapan de la Sal, and location of sampling sites I, II and III. Symbols are as follows: Qvb Quaternary (basic volcanism); Tpc Pliocene (Cuernavaca Formation); Tomt Miocene-Oligocene (Tilzapotla Formation); Ksm Late-Middle Cretaceous (Mexcala Formation); Ki-Km Early-Middle Cretaceous (Xochicalco Formation); Kmm Middle Cretaceous (Morelos Formation); and Tr (?)-J-Ki Triassic-Jurassic-Early Cretaceous (Metavolcanic-metasedimentary sequence). Adapted from Ramírez-Espinosa (1977).

The region has been affected by several tectonic events (Fig. 3). The metasedimentary metavolcanic sequence was affected by compressive tectonism during Middle Cretaceous, Palaeocene and Miocene (Ramírez-Espinoza, 1977). The stronger deformation phase may have been that of the Middle Cretaceous.

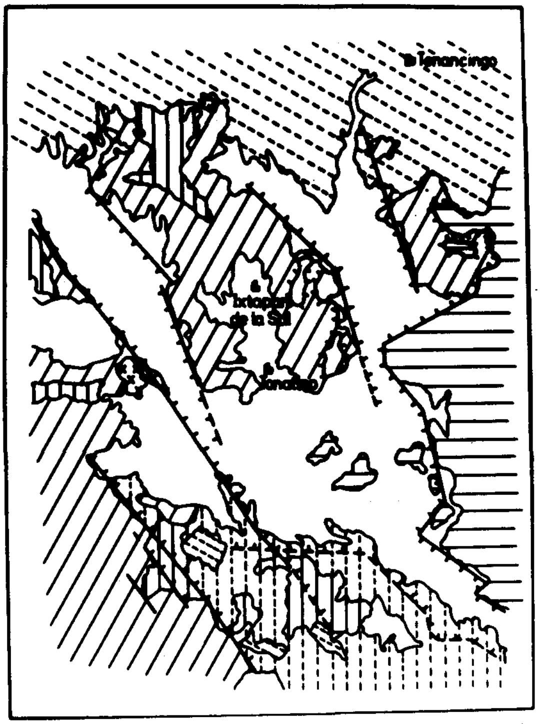

Fig. 3. Schematic tectonic map of the area of Ixtapan de la Sal. Symbols are as follows: //// first phase; ≡ second phase; |||| third phase; /// acidic volcanic activity; and xˣxˣx intrusive. Adapted from Ramírez-Espinosa (1977).

RESULTS

The direction and intensity of natural remanent magnetization (NRM) were measured with two spinner magnetometers, a Digico (Molyneux, 1971) and one made in the University of Buenos Aires (Vilas, 1979). Initial remanent directions were divergent from the present Earth's magnetic field and dipolar direction. Sample means were computed giving unit weight to specimen results. Directions from sites I and II showed an apparent stringing about a northwesterly direction, with low positive and negative inclinations, whereas those from site III showed a tighter grouping of low inclination reverse direction (Fig. 4). The intensities were highly variable forming distinct groups of low values, about $0.4 - 1.5 \cdot 10^{-6}$ emu/cm^3 ($0.4 - 1.5 \cdot 10^{-3}$ A/m), intermediate values, about $50 \cdot 10^{-6}$ emu/cm^3 ($50 \cdot 10^{-3}$ A/m), and high values, about $900 - 1\,400 \cdot 10^{-6}$ emu/cm^3 ($900 - 1\,400 \cdot 10^{-3}$ A/m), without any apparent stratigraphic control. Selected pilot specimens were submitted to alternating field (AF)

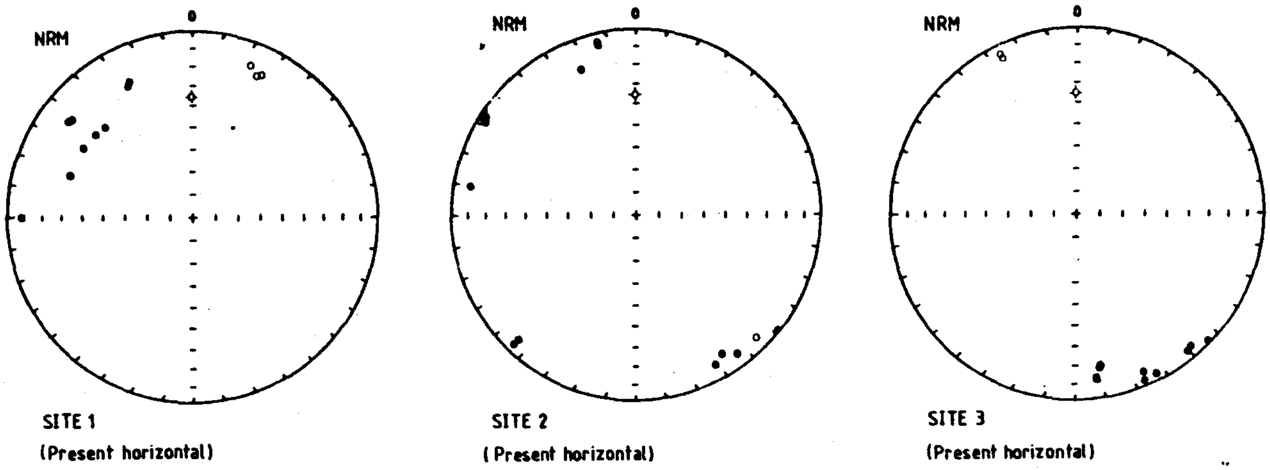

Fig. 4. Directions of natural remanent magnetization (NRM) referred to present horizontal for the three sites studied. Positive inclinations are ● and negative inclinations are ○. The dipolar field direction is given by ✧.

demagnetization in a three-axes tumbler AF demagnetizer (Vilas, 1979). This was carried out in 7 - 10 steps of 50 - 100 Oe (5 - 10 mT) up to 800 Oe (80 mT). Most specimens showed a high degree of directional stability but with only small changes in intensity (Fig. 5a); exceptions were two specimens which showed larger directional movements (these specimens correspond to samples which showed 'anomalous' initial remanence directions).

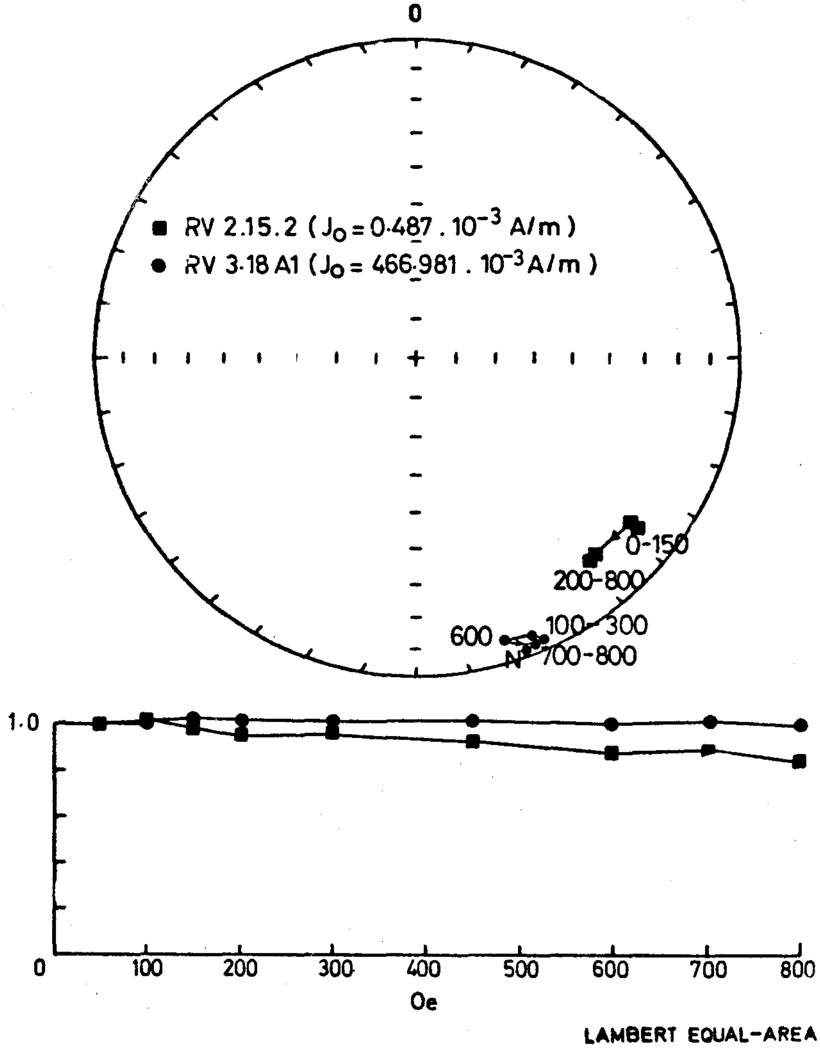

Fig. 5. Examples of alternating field (AF) and thermal demagnetization for samples from the three sites. Note the high coercitivity (fig. a) and the high blocking temperature (fig.b) components of remanence.

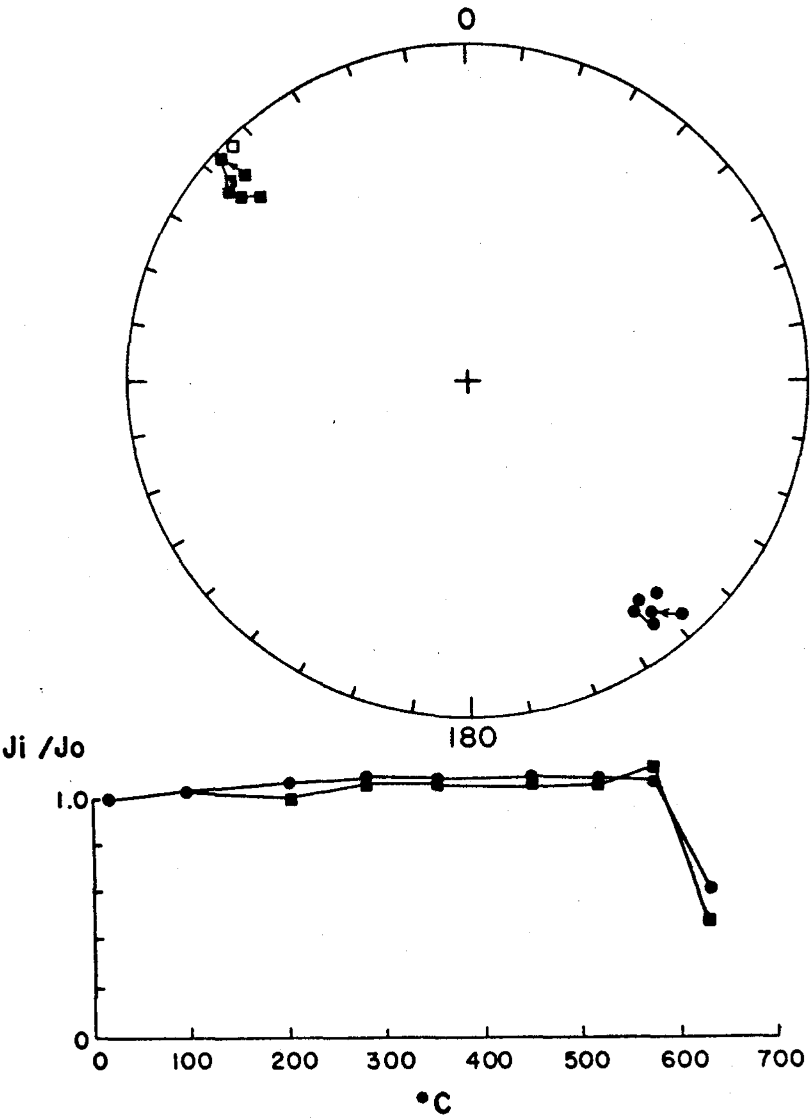

Fig. 5b.

The relatively small decrease in NRM intensity during AF demagnetization (Fig. 5a) indicates the presence of high coercitivity minerals as remanence carriers, possibly secondary haematite formed during the alteration event. This implies that the apparently stable remanent directions observed are of secondary origin. Thermal demagnetization was carried out in 8 - 10 steps up to 650°C in a vertical electric furnace. The specimens showed a high degree of directional stability with a discrete unblocking temperature range above 600°C in agreement with the presence of haematite as the main remanence carrier (Fig. 5b).

The AF and thermal demagnetization results suggest that the NRM is formed by small soft components (removed below 200 Oe or 200°C) and stable components with high coercitivity and high unblocking temperature. These magnetization components are likely carried by haematite, and are of secondary origin. AF demagnetization in fields of 200 - 300 Oe was applied to all remaining specimens and later, some of them were also thermally demagnetized at 200 or 300°C. The treatment reduced the within-site scatter in sites I and III and increased it at site II (Table 1 and Fig. 6). Comparison of results referred to the present horizontal and to the

Table 1

Summary of palaeomagnetic results (after demagnetization) for the Roca Verde Taxco Viejo

Site	N	E	present horizontal DEC	present horizontal INC	palaeohorizontal DEC	palaeohorizontal INC	α_{95}	k	pole position P_{lat}	pole position P_{long}	A_{95}	K
RV1	6	12	328.7	18.0	323.4	23.4	24.2	4.	57.5	158.3	22.4	5.
RV2	8	16	325.1	–13.7	324.6	–26.6	19.1	5.	45.7	137.1	18.3	5.
RV3	6	12	336.0	– 7.5	336.0	– 7.5	6.5	46.	57.3	128.9	5.9	56.
											(dp, dm)	
Mean	20	40	329.9	– 2.9	–	–	10.6	6.	54.1	139.1	(10.0,	7.0)
	20	40	–	–	325.6	– 6.9	11.8	5.	49.5	140.4	(11.2,	7.7)

Note: N = number of samples; E = number of specimens; DEC, INC = mean declination and inclination; α_{95}, A_{95} = semi-angle of 95% confidence about mean direction and pole position, respectively; k, K = concentration parameters; P_{lat}, P_{long} = latitud (°N) and longitud (°E) of mean poles; and dp, dm = semi-axes of 95% confidence about mean pole position.

palaeohorizontal shows that the between-site scatter is slightly lower in the first case, which also suggests that the remanence was acquired post or during folding (Fig. 7). Overall mean directions and pole positions were calculated giving unit weight to sample results (Table 1).

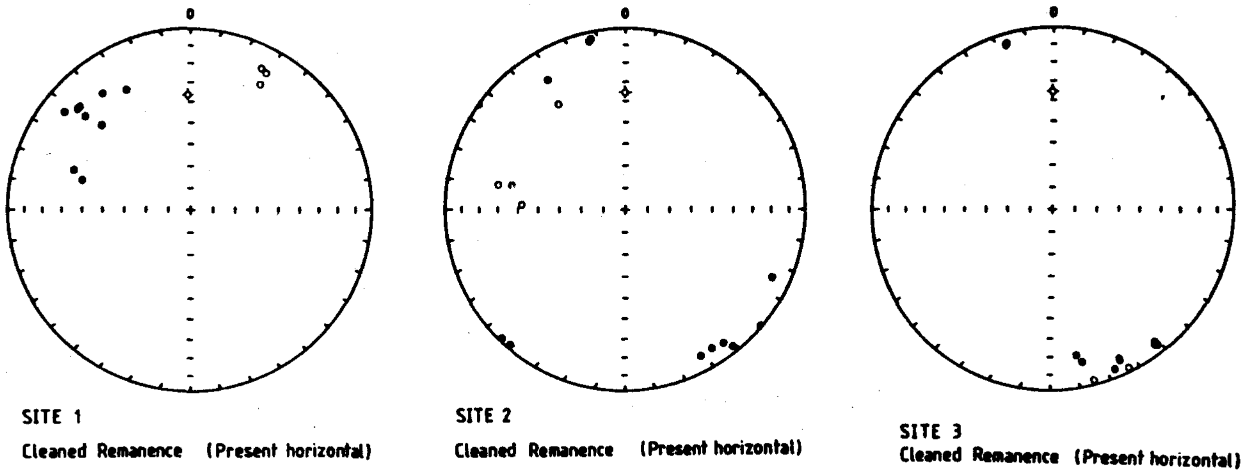

Fig. 6. Summary of cleaned NRM directions for the three sites. Symbols as in Fig. 4. Note the presence of normal and reverse polarities.

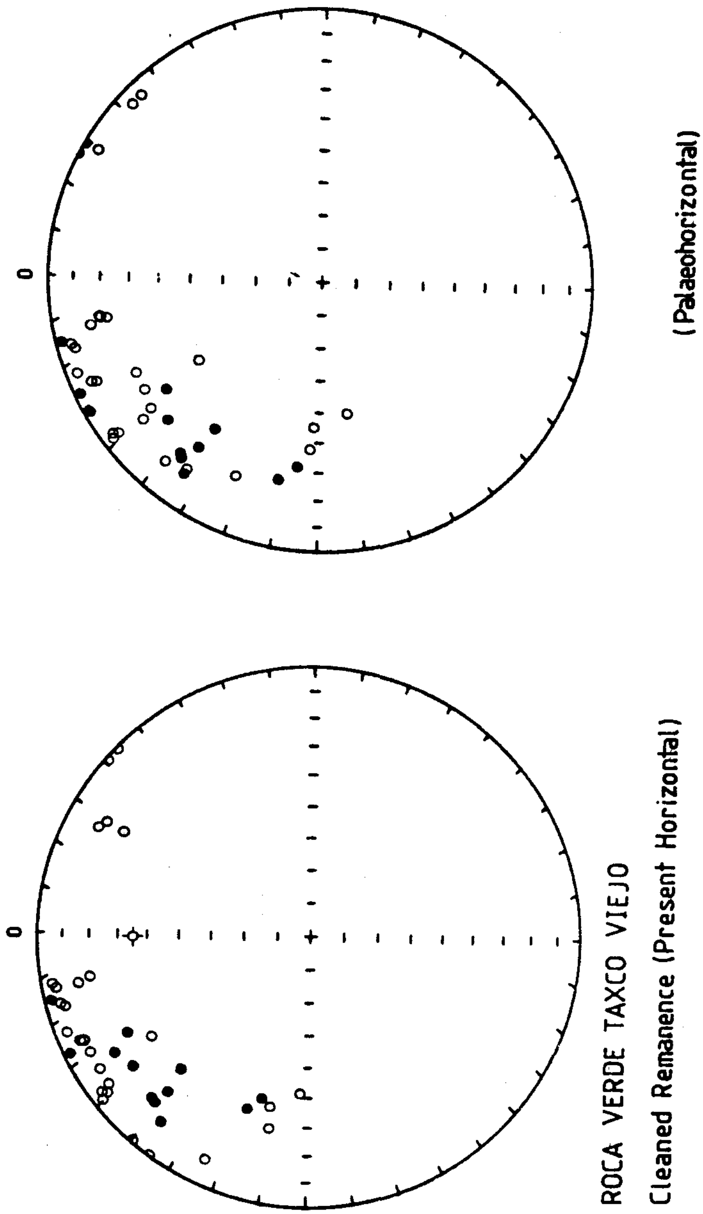

Fig. 7. Cleaned NRM directions for the three sites referred to present horizontal (left) and palaeohorizontal (right). Symbols as in Fig. 4. Note that reverse directions have been plotted in the fourth quadrant.

Directions are well grouped only for site III (k = 46 and α_{95} = 6.5) which corresponds to the less metamorphosed site (altered andesites). At this site the structure is almost horizontal, and the corresponding pole position is 57.3°N, 128.9°E (A_{95} = 5.9 and K = 56). The overall mean pole position for the three sites is 54.1°N, 139.1°E (before structural correction) which is not too different from that of site III. The two poles differ from corresponding pole positions for the Triassic to Cretaceous of Mexico (Urrutia-Fucugauchi, 1979, 1984) which does not permit to define the age of the characteristic magnetization (or magnetizations if acquired at different times). Tentatively, the magnetization is considered secondary, associated with a period of alteration or deformation. This event of magnetization may have occurred before the deposition of the Acuitlapan Formation (*i.e.* pre-Late Jurassic), or during the late Early Cretaceous (resetting of the K-Ar isotopic system).

PRELIMINARY TECTONIC MODEL

The area (Figs. 1, 2 and 3) has been affected by several tectonic events. Those before the formation of metasedimentary-metavolcanic sequence affected the Esquisto Taxco during the Late Palaeozoic. The area has been divided into two main regions: an internal zone of eugeosynclinal sedimentation to the west, and an external zone of miogeosynclinal sedimentation to the east. The metasedimentary sequence was affected by compresive tectonism during the Albian, Paleocene and Miocene (?).

Regional synthesis of the western margin of North America (*e.g.* Atwater, 1970; Pal and Urrutia-Fucugauchi, 1977; Menard, 1978; Urrutia-Fucugauchi, 1978, 1984) have indicated that a consuming plate boundary was active during Mesozoic and Cenozoic times. Campa-Uranga (1978) has pointed out that the stratigraphic and structural features of the area around Ixtapan de la Sal-Taxco are similar to those of areas along several portions of western Mexico, currently associated with the evolution of marginal trenches. A problem with this scheme is the apparently anomalous location of the area between the 'Michoacan' and 'Morelos-Guerrero' platforms which show possible pre-Mesozoic continental basements. The 'Morelos-Guerrero' platform does not show evidence of related-volcanic activity and the metamorphic processes are difficult to relate to an island arc between the platforms, instead of west of the Michoacan platform (Campa-Uranga, 1978). However, these arguments are not against the hypothesis but in favour if a proper geometry is used as a working model for the area. Such a model is schematically summarized in Figs. 8 and 9.

During the Mesozoic a consuming plate boundary was active between the 'Guerrero-Morelos' block (east) and the 'Michoacan' block (west) with tectonic polarity to

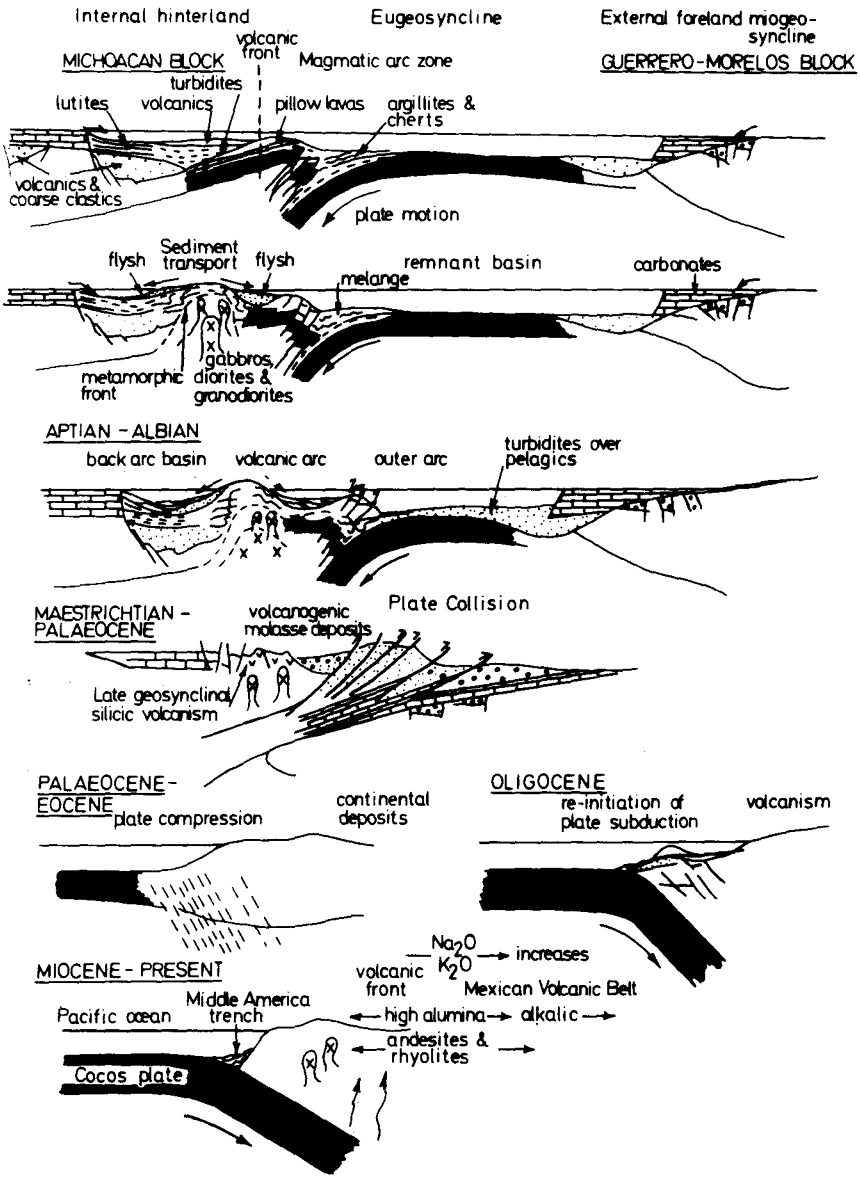

Fig. 8. Schematic plate tectonic evolution of the area of southern Mexico (see text for details and Fig. 9.). Note that the subduction polarity of the subduction zone is to the SW.

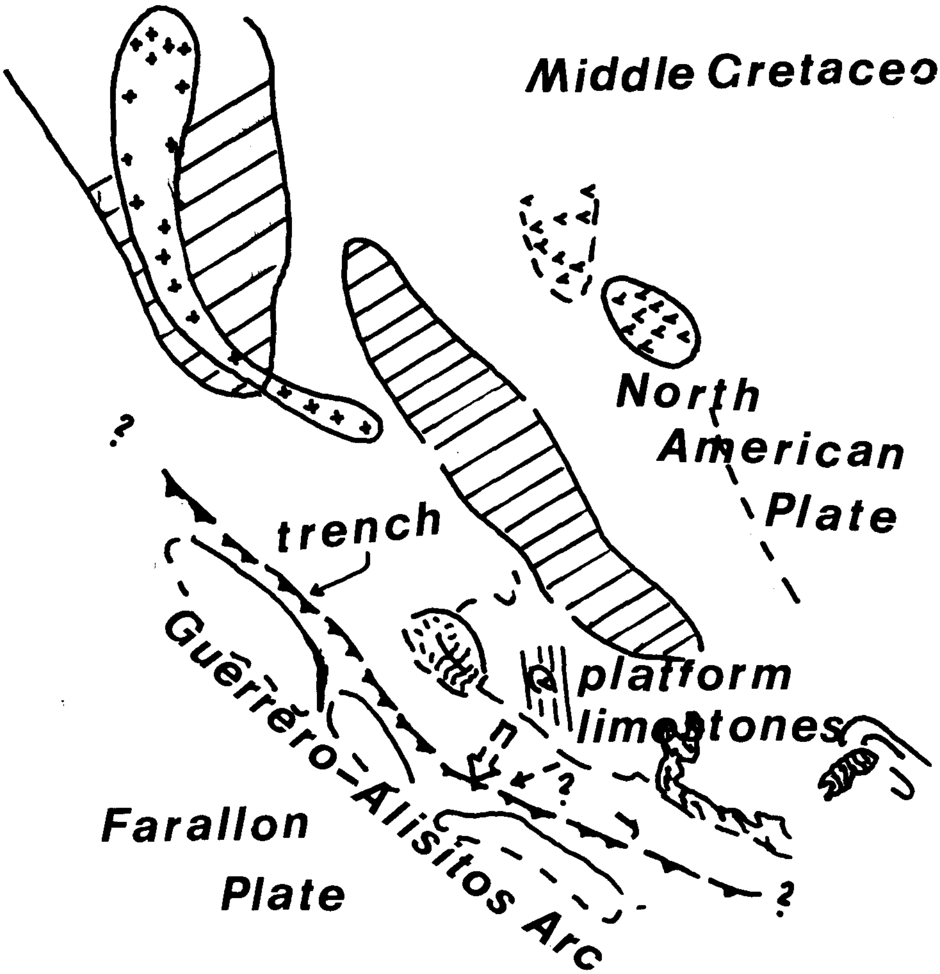

Fig. 9. Simplified palaeoreconstruction of southwestern Mexico for Middle Cretaceous time (see Fig. 8 for details). Note that polarity of subduction zone is to the SW, beneath the island arc system of Guerrero-Alisitos arc.

the west. The underthrusting of oceanic lithosphere beneath the western block gave rise to the generation of cordilleran-type tectonics. Continent-ward from the oceanic plate there was an outer arc with high pressure/temperature (P/T) metamorphism. Within this zone, there is an area of overthrusted oceanic crust with pillow basalts, affected by regional subsidence and sedimentation. Sediments are transported towards the trench, constituting a flysh wedge along the continental shelf. Continent-ward from the volcanic front, which constitutes the limit of the inner belt, a sequence of sediments and (andesitic) volcanics was generated. Farther from this volcanic front, the sediments constituted lutites and carbonates. Evolution of the plate consuming process produced metamorphism of the volcanic-sedimentary sequence and sediment transport, continentward and oceanward, where gravity sliding tectonics predates hard thrusting tectonics. A major period of metamorphism occurred during the Aptian-Albian. Along the continental shelf of the eastern block, sediments accumulated without the occurrence of volcanism and metamorphism. The carbonate deposits are represented by the Xochicalco and Morelos Formations. Further evolution of the subduction process leads to the approach and collision of the eastern and western blocks with the deformation and metamorphism of the deposits of lutites and cherts from the intervening oceanic basin. This produced a sequence of flysh deposits which form the Mexcala Formation. The Mesozoic cover is folded and thrusted in converging directions (de Cserna and Fries, 1981). This second phase of deformation may have occurred at the end of the Maestrichtian and beginning of the Palaeocene. Following this main sequence of events, the region was emerged and there was a period of deformation where the continental crust buoyancy prevented further destruction. The oceanic plate may have broken off and sunk; possibly followed by oceanic plate compression of the western side of the western block. Eventually the new tectonic process lead to the generation of a new trench with tectonic polarity to the east and the eventual occurrence of cordilleran-type tectonics of the region with the production of calc-alkaline magmatism and volcanism with alkalic polarity to the east-northeast. This period of volcanism is represented by the Tilzapotla and Buenavista Groups and the recent calc-alkaline activity. The sedimentary cover is represented by continental deposits of the Balsas Formation and includes conglomerates of limestone and volcanic material, sandstones, tuffs, breccias and lavas, which present red colouration nowadays. The age is considered Eocene-Oligocene. The other major sedimentary unit which was deposited after a period of tectonic activity associated with the present subduction zone is the Cuernavaca Formation, which consists mainly of conglomerates of andesitic material, tuffs and small deposits of travertine. This Formation lies on top of the extensive and voluminous Oligocene-Miocene rhyolitic and andesitic volcanic activity. The calc-alkaline activity continued in the Mexican volcanic belt immediately to the north-northeast of this area without major interruptions. Finally, the area was covered by the present renewed volcanic activity which continues up to now.

DISCUSSION

It is interesting to observe that the within-site scatter in directions correlates with the degree of alteration. The two sites of schists (I and II) showed higher dispersion than that of altered andesites (III). Results from site I show predominantly normally polarized directions with an apparent stringing about a northwesterly direction (Fig. 6a). Results from site II show both normal and reverse directions, with an elongated distribution of low inclination directions (Fig. 6b). Results from site III show a group of reverse directions, with low inclinations (Fig. 6b). These rocks were affected by compressional stress during the late Early Cretaceous-Middle Cretaceous (Campa-Uranga *et al.*, 1974; Ramírez-Espinoza, 1977; Campa-Uranga, 1978). Samples from sites II (schists) and III (altered andesites) were dated by K-Ar, giving dates of 108 ± 5 Myr and 125 ± 5 Myr, respectively (Urrutia-Fucugauchi and Linares, 1981). The results very likely are dating the compressional event. The palaeomagnetic record observed may have been acquired at that time. The carriers of the remanences may be some of the original magnetic minerals of the andesitic rocks (or secondary minerals formed before the period of alteration associated with the K-Ar dates), or magnetic minerals formed during the period of hydrothermal alteration, or both. In the first case the remanence could be a secondary thermoremanent magnetization (TRM) acquired during the cooling process at the end of the period of alterarion. In the second case the remanence could be a secondary chemical remanent magnetization (CRM) acquired during the period of alteration. In the third case, it could be a secondary C-TRM associated with chemical changes and cooling towards the end of the period of alteration. The remanence is carried by haematite and is very likely of secondary origin, being a CRM or a C-TRM. The presence of normal and reverse polarities implies a relatively long interval of remanence acquisition, and the apparent scatter, within and between sites, may suggest that the time involved in the remanence acquisition was different for the different sites. One possibility is that the remanence was acquired during the Early Cretaceous, in association with the deformation event (Campa-Uranga *et al.*, 1974; Ramírez-Espinoza, 1977) which reset the K-Ar isotopic system (*i.e.* 108-125 Myr). The other possibility is that the remanence was acquired before the deposition of the Acuitlapan Formation which is a Neocomian-Aptian age. De Cserna and Fries (1981) have indicated that clasts of the Roca Verde Taxco Viejo in the basal parts of the Acuitlapan Formation are propylitizated and slightly foliated. The propylitization event occurred before the Late Jurassic. The Acuitlapan and Mexcala Formations are folded and to a lesser extent thrusted in converging directions. Therefore, in this last case, the remanence was acquired mainly during the folding and deformation, with perhaps some components (*e.g.* in sites I and II) being acquired earlier; whereas in the second case, the remanence was acquired during foliation and propylitization sometime during the mid-Late Jurassic. Direct evidence in favour of one of the possible cases is lacking, and a combination of these cases may also be possible, with the remanence acquired then during the Late Jurassic to Late Cretaceous.

Comparison of the results for the area of Ixtapan de la Sal with those reported for the Mesozoic of Mexico (Urrutia-Fucugauchi, 1979, 1984) shows that the results diverge, which may be caused by *(i)* incomplete isolation of the remanent magnetization, or *(ii)* tectonic relative movements between the sampling site and other parts of Mexico. In this context, it is interesting to note that De Cserna and Fries (1981) have suggested that the Roca Verde Taxco Viejo may be an allochtonous unit emplaced into the region from the west at the end of the Jurassic. A tectonic alternative is in agreement with geologic-tectonic studies (Campa-Uranga *et al.*, 1974; Ramírez-Espinoza, 1977, de Cserna and Fries, 1981) which indicate the effects of regional tectonism in the area. The apparent dispersion of the remanent directions (Fig. 7) may suggest that relative tectonic movement took place during the period of remanent acquisition. The tectonic model summarized in Figs. 8 and 9 is considered preliminary, and is proposed as a working model for the evolution of the area subjected to revision, even in its major details.

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BIBLIOGRAPHY

ATWATER, T., 1970. Implications of plate tectonics for the Cenozoic tectonic evolution of western North America. *Geol. Soc. Am. Bull., 81,* 1513-1536.

CAMPA-URANGA, M. F., 1978. La evolución tectónica de Tierra Caliente, Guerrero. *Bol. Soc. Geol. Mex., 39,* 52-64.

CAMPA-URANGA, M. F., M. CAMPOS, R. FLORES and R. OVIEDO, 1974. La secuencia mesozoica volcano-sedimentaria metamorfizada de Ixtapan de la Sal Méx.-Teloloapan, Gro., *Bol. Soc. Geol. Mex., 35,* 7-28.

CSERNA, Z. DE and C. FRIES, Jr., 1981. Resumen de la geología de la hoja Taxco, Estados de Guerrero, México y Morelos. *Publ. 14Q-h (7), Inst. Geol. UNAM,* 1-47.

CSERNA, Z. DE, C. FRIES, Jr., C. RINCON-ORTA, H. WESTLEY, J. SOLORIO-MUNGUIA and E. SCHMITTER-VILLADA, 1974. Edad precámbrica tardía del Esquisto Taxco, Estado de Guerrero. *Bol. Asoc. Mex. Geol. Petrol., 26,* 183-193.

FRIES, C., Jr., 1960. Geología del Estado de Morelos y de partes adyacentes de México y Guerrero, región central meridional de México. *Bol. Inst. Geol., UNAM, 60,* 1-236.

HUMBOLDT, A. DE, 1808. Essai politique sur le royaume de la Nouvelle Espagne. Ed. F. Schoell, Paris, Francia, 904 pp.

MENARD, H. W., 1978. Fragmentation of the Farallon plate by pivoting subduction. *J. Geol. 86,* 99-110.

MOLYNEUX, L., 1971. A complete result magnetometer for measuring the remanent magnetization of rocks. *Geophys. J. R. Astr. Soc., 24,* 429-433.

OSBORNE, T. C., 1956. Geología y depósitos minerales del distrito minero de Taxco. Libro-guía Exc. A-4 y C-2, Congr. Geol. Intern., *20,* 75-89.

PAL, S. and J. URRUTIA-FUCUGAUCHI, 1977. Paleomagnetism, geochronology and geochemistry of some igneous rocks from Mexico and their tectonic implications. Proc. IV Intern. Gondwana Symp. Calcutta, India, *1,* 814-831.

RAMIREZ-ESPINOZA, J., 1977. Geología del valle de Ixtapan de la Sal, Estado de México y Guerrero. Tesis Ing. Geol., ESIA, IPN, 55 pp.

URRUTIA-FUCUGAUCHI, J., 1978. Cordilleran Benioff zones, *Nature, 275,* 464.

URRUTIA-FUCUGAUCHI, J., 1979. Preliminary apparent polar wander path for Mexico. *Geophys. J. R. Astr. Soc., 56,* 227-235.

URRUTIA-FUCUGAUCHI, J., 1984. On the tectonic evolution of Mexico: Paleomagnetic constraints. *Geodynamics Series, 12,* 29-47.

URRUTIA-FUCUGAUCHI, J. and E. LINARES, 1981. Dating of hydrothermal alteration, Ixtapan de la Sal, Mexico State, Mexico., *Isochron West., 31,* 15.

VILAS, J. F. A., 1979. Tesis Doctoral, Universidad de Buenos Aires, Argentina.

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