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Jurassic palaeomagnetic results constraining southerly motions of the Mixteca terrane, southern Mexico

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RESUMEN

Con el propósito de investigar la evolución tectónica y paleogeográfica de la porción norte del Terreno Mixteca, se llevaron a cabo estudios geológicos y paleomagnéticos de dos unidades sedimentarias continentales del Jurásico. Los resultados recientemente reportados de dos unidades de Lechos Rojos que muestran características estructurales contrastantes, permiten una revisión crítica de las interpretaciones de la evolución tectónica y del registro paleomagnético mesozoico del Terreno Mixteca. Las direcciones características respectivas de las dos unidades después de correcciones estructurales sencillas y dobles son: Unidad Piedra Hueca, Dec= 354°, Inc =4°, k=30, α_{95}= 11°; y Unidad Otlaltepec, Dec= 347°, Inc= 25°, k= 80, α_{95}=14°. Las correspondientes paleolatitudes para el Jurásico temprano y medio son, respectivamente, 12.8°± 7.9° y 2.2°± 5.6°, que restringen los movimientos desde una posición más al norte del Terreno Mixteca a magnitudes más pequeñas que aquellas sugeridas previamente. Los desplazamientos latitudinales mayores del Terreno Mixteca con respecto a América del Norte se llevaron a cabo antes de la parte final del Cretácico Temprano (Albiano).

PALABRAS CLAVE: Paleomagnetismo, paleografía, Terreno Mixteca, Lechos Rojos, Jurásico, sur de México.

ABSTRACT

Geologic and palaeomagnetic studies of the Jurassic continental sedimentary units of the northern Mixteca terrane, southern Mexico were undertaken to investigate the palaeogeographic and tectonic evolution of the area. Recent results for two previously unidentified redbed units show contrasting structural characteristics which permit a critical revision of the Mesozoic palaeomagnetic record and the tectonic interpretations for the terrane. The overall mean directions for the two units after single and two-stage tilt corrections are: Otlatlepec, Dec= 347°, Inc= 25°, k= 80, α_{95}=14°. and Piedra Hueca, Dec= 354°, Inc =4°, k=30, α_{95}= 11°. The corresponding palaeolatitudes for the Early and Middle Jurassic are 2.2°±5.6° and 12.8°±7.9°, constraining motions for northerly positions of Mixteca terrane to smaller levels (around 10 degrees) than previously suggested. Major latitudinal displacements of the Mixteca terrane with respect to North America were completed before late Early Cretaceous (Albian) and may have taken place in conjunction with active rifting in the Gulf of Mexico and left-lateral movements along the Mojave-Sonora megashear during middle Jurassic times.

KEY WORDS: Palaeomagnetism, palaeogeography, Mixteca terrane, red beds, Jurassic, southern Mexico.

INTRODUCTION

Palaeo-reconstructions of Atlantic bordering continents have long shown major areas of overlap/gap for Mexico and Central America (e.g. Figure 1). Attempts to solve the 'geometric' problem and to provide a framework for the development of the Gulf of Mexico and Caribbean Sea have invoked various models of block movements (e.g. Carey, 1958; Bullard *et al.*, 1965; Walper and Rowett, 1972; Pilger, 1978; Anderson and Schmidt, 1983; Urrutia-Fucugauchi, 1984; Dunbar and Sawyer, 1987). Southern Mexico and northern Central America are characterized by marked contrasts in crystalline basement, metamorphism, stratigraphy and petrotectonics (e.g. Fries *et al.*, 1962; Ruiz-Castellanos, 1979). Recent analyses tend to interpret the area as a collage of blocks or terranes (Figure 2), very likely of allochthonous nature (Campa-Uranga and Coney, 1983; Urrutia-Fucugauchi *et al.*, 1987). Their palaegeographic and kinematic evolution however is just beginning to be investigated.

Studies concerned with palaeo-reconstructions for the Gulf of Mexico-Caribbean Sea area have proposed the occurrence of large-scale north-south latitudinal displacements for southern Mexico, in order to avoid overlap of northern South America with southern Mexico and Central America (Carey, 1958; Bullard *et al.*, 1965). Palaeomagnetic results for Jurassic units from the Mixteca terrane do not provide conclusive evidence for major north-south latitudinal displacements; nevertheless, a northward palaeoposition has been suggested (e.g Morán-Zenteno *et al.*, 1988). On the other hand, significant rotations of the Mixteca terrane with respect to the craton have been reported during the Jurassic or Early Cretaceous (Urrutia-Fucugauchi, 1984; Böhnel, 1985; Morán-Zenteno *et al.*, 1988; Fang *et al.*, 1989; Urrutia-Fucugauchi *et al.*, 1990).

In summary, Palaeozoic and Mesozoic palaeomagnetic data for southern Mexico terranes is sparse and controversial. This is partly due to poor knowledge of the stratigraphy and the structure, which are of an extreme complexity. Palaeomagnetic studies require detailed geologic mapping, structural and stratigraphic investigations. In this paper we re-analyse the palaeomagnetic data for the Jurassic units of the northern Mixteca terrane, southern Mexico (Figure 2), and we briefly discuss the implications for the palaeogeographic and tectonic evolution of the area.

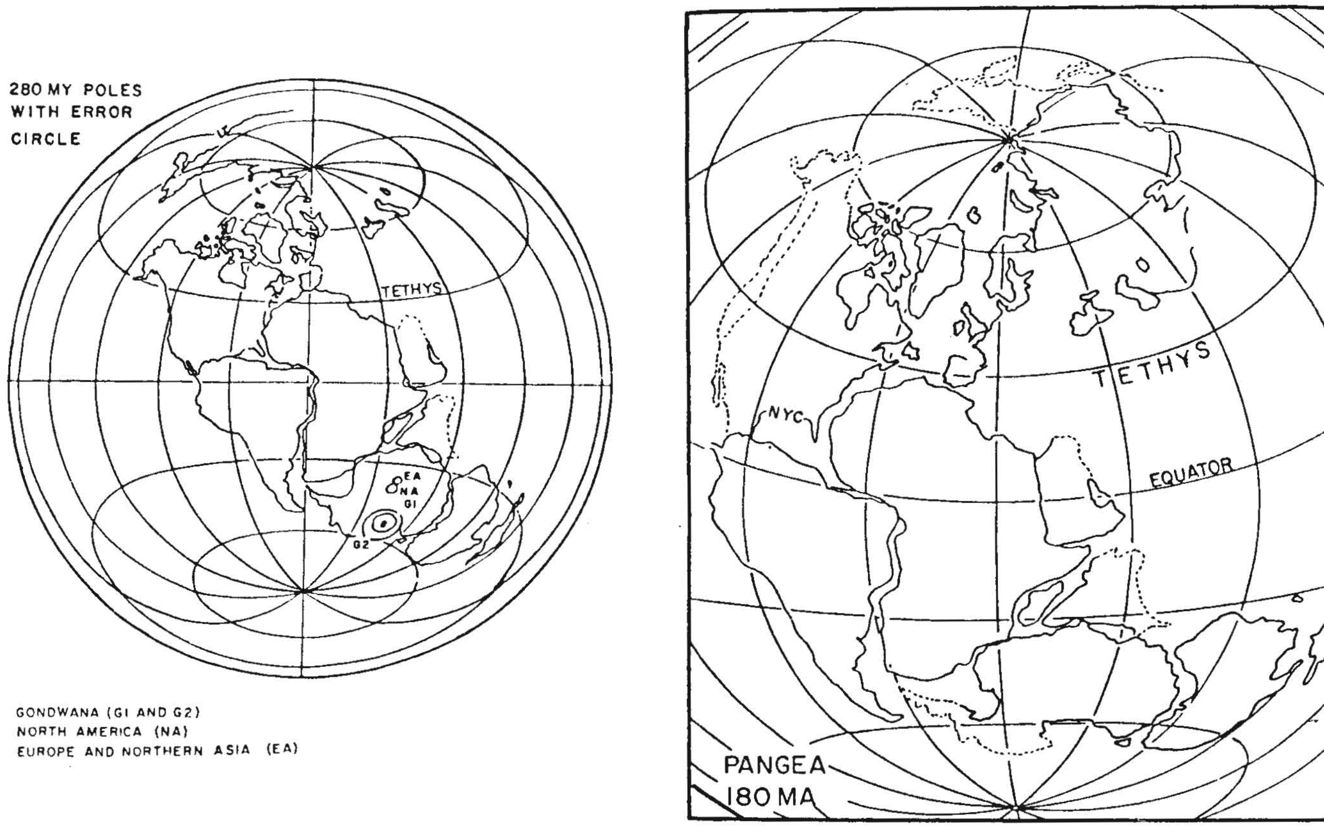

Fig. 1. Palaeoreconstruction models for western Pangea by (a) Irving and Morel (1981), and (b) Van der Voo and French (1974). Note that in the two cases, there is considerable overlap of northern South America onto the space of Mexico and Central America.

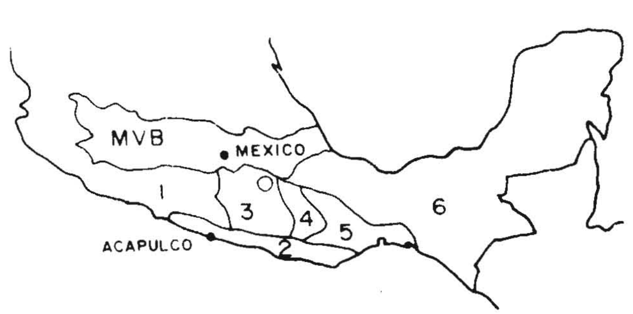

Fig. 2. Schematic tectonostratigraphic terrane map for southern Mexico (adapted from Campa and Coney, 1983). 1 Guerrero; 2 Xolapa; 3 Mixteca; 4 Oaxaca; 5 Juárez; 6 Maya. The study concentrates on the northern Mixteca terrane.

GEOLOGIC SETTING

The Mixteca terrane has been characterized from the Acatlan Complex, a tectonically juxtaposed two-assemblage metamorphic basement. Suggested terrane boundaries often feature high-angle mylonitic zones, which may be obscured by younger intrusives and the Mesozoic-Cenozoic sedimentary and volcanic cover. The Lower Palaeozoic rock units are described in the literature (e.g Ortega-Gutiérrez, 1981) and in a recent paper on the palaeomagnetics of the Totoltepec stock and Palaeozoic red beds in the Acatlan region (Fang *et al.*, 1989). Attention will be here concentrated on the Mesozoic sedimentary sequence, which in the northern Mixteca terrane presents a maximum thickness of about 2500 meters. The sequence partly covers the Lower Palaeozoic Acatlan Complex and the Early Permian Totoltepec stock (Yañez *et al.*, 1991). The lower section is conformed by detrital continental redbed units, whereas the upper section is formed by Cretaceous marine sediments.

In the area studied, to the northeast of Acatlán between Totoltepec and Ixcaquixtla (Figure 3), the redbeds feature two units separated by an angular unconformity. They have been informally named Piedra Hueca and Otlaltepec redbeds (Ortega-Guerrero, 1989). The Piedra Hueca redbeds in the reference section contain a basal conglomerate and an alternancy of sandstones, arkosic sandstones, conglomerates, siltstones and mudstones from red and brown to yellow and white, with a thickness of 880 meters. The abundance of alkaline feldspars and andesine-oligoclase suggests a nearby source of intrusive rocks of intermediate to acid composition, such as the Totoltepec stock. The lithic fragments are derived from the Acatlán Complex. Erosion was probably rapid and relief was high. The impressions and remains of plants, distrification, ripple marks and absence of marine fossils indicate a fluvial environment. The identified fossil plants recovered in our study include *Otozamites hespera* Wieland, previously reported from the Teconcoyunca Group and assigned to the Middle Jurassic (identification by Dr. A. Silva-Pineda) and *Ptillophylum*

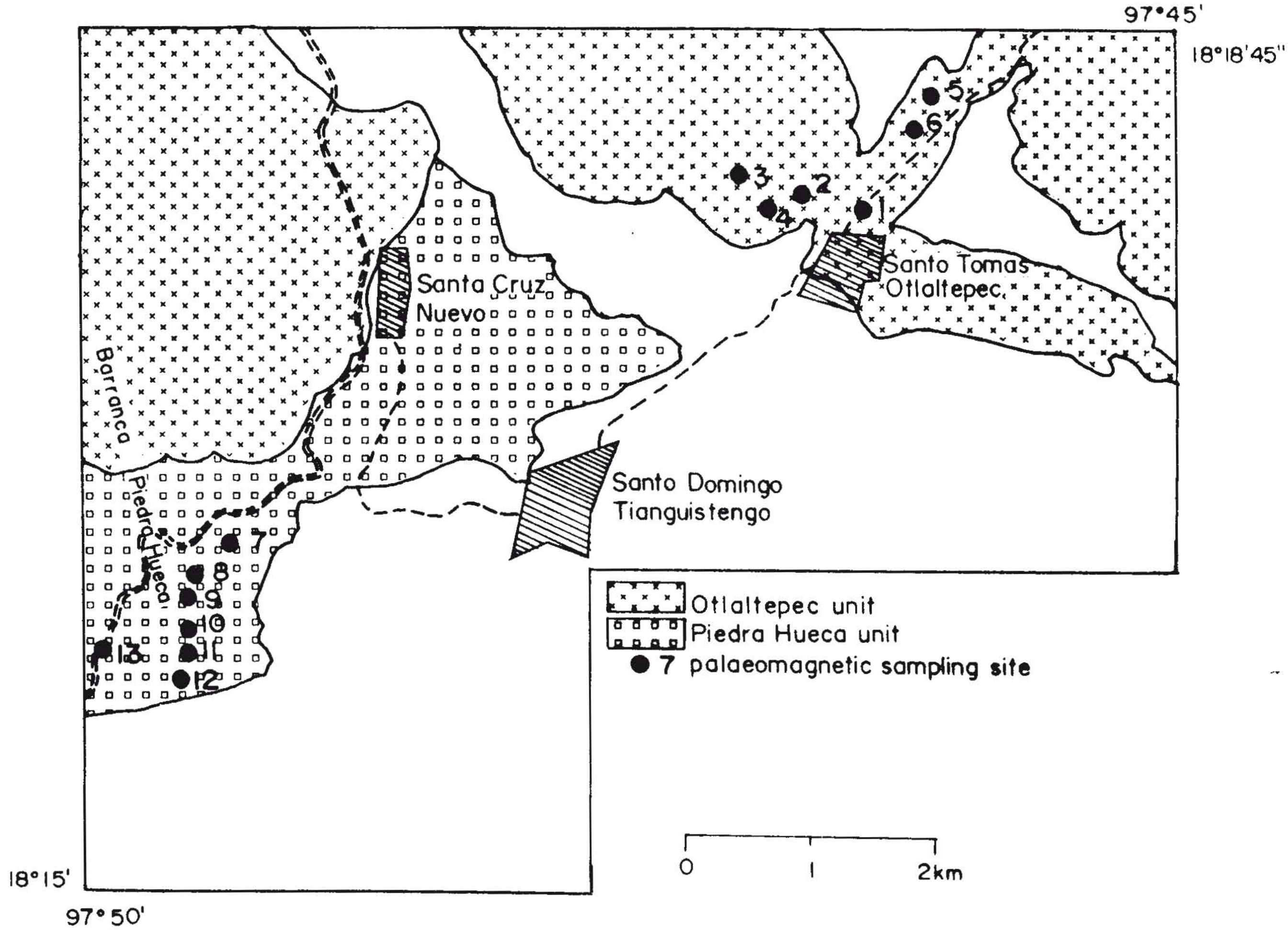

Fig. 3. Simplified geologic map for northern Mixteca terrane, showing the two Jurassic continental red bed units (Otlaltepec and Piedra Hueca) and the sampling sites for palaeomagnetic study (from Ortega-Guerrero, 1989).

acutifolium Morris (collected by Ramos Leal), previously reported in Lower and Middle Jurassic units of Puebla and Oaxaca States (Silva-Pineda, 1984; Wieland, 1914).

The Otlaltepec redbeds are some 1500 meters thick and have similar lithological characteristics as the Piedra Hueca unit. A similar depositional environment may be inferred for both sequences.

The contact between the Piedra Hueca unit and the overlying Otlaltepec and Magdalena units is an angular unconformity. The Piedra Hueca redbeds were likely deposited during a distensive tectonic regime and were subjected to regional tilting before the deposition of the Otlaltepec redbeds (Figure 3). The stratigraphic relationships between the Aptian-Albian Magdalena unit and the Otlaltepec unit provide constraints on the age of the Otlaltepec as middle Jurassic to early Cretaceous.

PALAEOMAGNETIC STUDY OF THE PIEDRA HUECA AND OTLALTEPEC

In this section we summarize the palaeomagnetic record for the Piedra Hueca and Otlaltepec redbed units.

A total of 220 oriented samples were collected from 13 sites in the two redbed sedimentary sequences: seven sites in the Piedra Hueca unit and six sites in the Otlaltepec unit (Figure 3). Samples were drilled in the field with a portable petrolpowered drill and oriented *in situ* with a magnetic compass. Measurements of bedding attitudes were taken at the sampling and at other nearby localities.

Core samples, 2.5 cm diameter, were cut into 2.2 cm height specimens. The intensity and direction of natural remanent magnetization (NRM) were measured using a Molspin fluxgate spin magnetometer. Alternating field (AF) and thermal demagnetizations were used to investigate the vectorial composition, coercivity and unblocking spectra and stability of NRMs, by using TSD-1 and GSD-5 Schonstedt instruments. Remanence components were identified from orthogonal vector plots and determined from vector subtraction and principal component analyses (Kirschvink, 1980).

AF demagnetization was less successful in isolating magnetizations for the red beds, since NRM intensities show little or no change up to fields of 100 mT. Thermal demagnetization proved more effective in resolving the vector components due to the unblocking spectrum characteristics. Thus most specimens were treated with this method. NRM intensities are reduced to near-zero at temperatures below 550°C, which indicates the absence of haematite as a major remanence carrier. Low and intermediate unblocking temperature remanence components are present in the samples. Generally a dominant higher unblocking temperature component can be isolated after removal of one or two lower unblocking temperature components. Examples of vector diagrams and normalized intensity plots for the two units are given in Figure 4.

From the demagnetization results, AF demagnetized samples and other samples that showed no consistency with apparent random behaviour were excluded from the analysis. The subsequent analysis is based on 73 samples from four sites of the Piedra Hueca unit and 71 samples from seven sites of the Otlaltepec unit. Vector means and Fisher statistics (Irving, 1964) for the characteristic remanence component (high unblocking temperature vectors) for each site of the two units are summarized in Table 1. The magnetic polarity is predominantly normal, except for one site of the Otlaltepec unit (Figures 5 and 6). Site-mean directions for the Piedra Hueca redbeds show shallower inclinations (Figure 6) than the Otlaltepec redbeds (Figure 5). In both cases, the inclinations are shallower than the dipolar and present-day field directions for the sampling sites.

The lower unit, Piedra Hueca, shows scattered site-mean directions when referred to present-horizontal or after simple tilt correction (Figure 6). The structural observations summarized in the previous section documented two major deformation events for the redbeds (Figure 3). Application of the corresponding two-stage tilt corrections (McElhinny, 1964; McFadden and Jones, 1981) result in well-clustered mean directions (Table 1 and Figure 6). The overall site-mean directions for the two redbed units after single and two-stages tilt corrections are: Otlaltepec unit, Dec = 347°, Inc = 25°, k = 80, α_{95} = 14° and Piedra Hueca unit are Dec = 354°, Inc = 4°, k = 30, α_{95}= 11° (Table 1).

DISCUSSION

Earlier palaeomagnetic studies of the Mixteca terrane for pre Mid-Cretaceous times have documented discordant directions and pole positions with respect to the segment of the apparent polar wander path (APWP) for cratonic North America. Most Mixteca pole positions are right-handed and/or near sided with respect to the APWP Jurassic segment (Figure 8). They have been interpreted in terms of predominant counterclockwise rotations and southward displacements (Urrutia-Fucugauchi, 1984; Böhnel, 1985; Morán-Zenteno *et al.*, 1988), or clockwise rotations (Fang *et al.*, 1989). The pole positions obtained for the Piedra Hueca and Otlaltepec redbeds fall closer to the Jurassic segment of the North American APWP (Figure 7). Inclusion of the Piedra Hueca and Otlaltepec redbeds and Yucuñuti Formation increase the longitudinal spread of the Mixteca Jurassic palaeopoles. The pole positions approximately lie along one or two loosely defined small circle segment (Figure 7). In terms of palaeolatitudes, the data show a simple pattern (Figure 8) which is discussed below. Mean directions and related statistical parameters for the Piedra Hueca and Otlaltepec red bed units are summarized in Table 1. Available data for other Mesozoic units of the Mixteca terrane are also included for comparison (Figure 7 and 8). Palaeomagnetic data summarized include: G, Totoltepec stock; RT, Rosario Formation; ZT, Zorrillo Formation; Y, Yucuñuti Formation; T, Tecomazuchil Formation; CC, Caliza con cidaris; O, Otlaltepec Formation; and PH, Piedra Hueca Formation.

Palaeomagnetic mean inclinations show a consistent pattern distinct from that which would be expected if the Mixteca terrane had been already keeping a latitudinal relationship similar to the present with respect to cratonic North America (reference data from Irving and Irving, 1982; May and Butler, 1986). The data cover an interval from about 200 Ma to 160 Ma, during which the palaeolatitude increased from about 2°N to 22° N. The pattern is similar to that for cratonic North America but displaced some 10 degrees. This indicates a palaeo-position for the Mixteca terrane north of its present position and suggests that the terrane was subjected to a similar palaeolatitudinal motion. This apparent similarity suggests that the Mixteca terrane was part of the palaeo-North American plate, perhaps located along its western continental margin.

The Jurassic corresponds to the episode of major rifting in the Gulf of Mexico and drifting apart between North and South America. Kinematic plate tectonic models have now solved the overlap problem, the drifting of North and South America and the aggregation of Middle America by large-scale left-lateral motions of crustal blocks or microplates (e. g. along the Mojave-Sonora and Mexican volcanic belt megashears). These new palaeomagnetic data, combined with recent palaeobiological, tectonic, stratigraphic and sedimentological studies (Imlay, 1980; Taylor *et al.*, 1984: Westermann *et al.*, 1984; Sandoval and Westermann, 1984) support a large-scale left-lateral displacement for this portion of southern Mexico to the south of the Trans-Mexican (volcanic belt) megashear.

With respect to timing and kinematics of the terrane displacement, the palaeomagnetic data do not indicate differential latitudinal movements during the studied interval (except perhaps rotations along nearby vertical axes or deformation along the margin). Palaeomagnetic results for Albian-Cenomanian limestones suggest that the movement was already completed by that time (Urrutia-Fucugauchi, 1988). This leaves an interval from about 155 Ma to 120 Ma for displacement of the Mixteca terrane. The displacement may have taken place during the Jurassic, which agrees roughly with the interval of major large scale rifting in the Gulf of Mexico and activity of the Mojave-Sonora megashear around 155 to 145 Ma

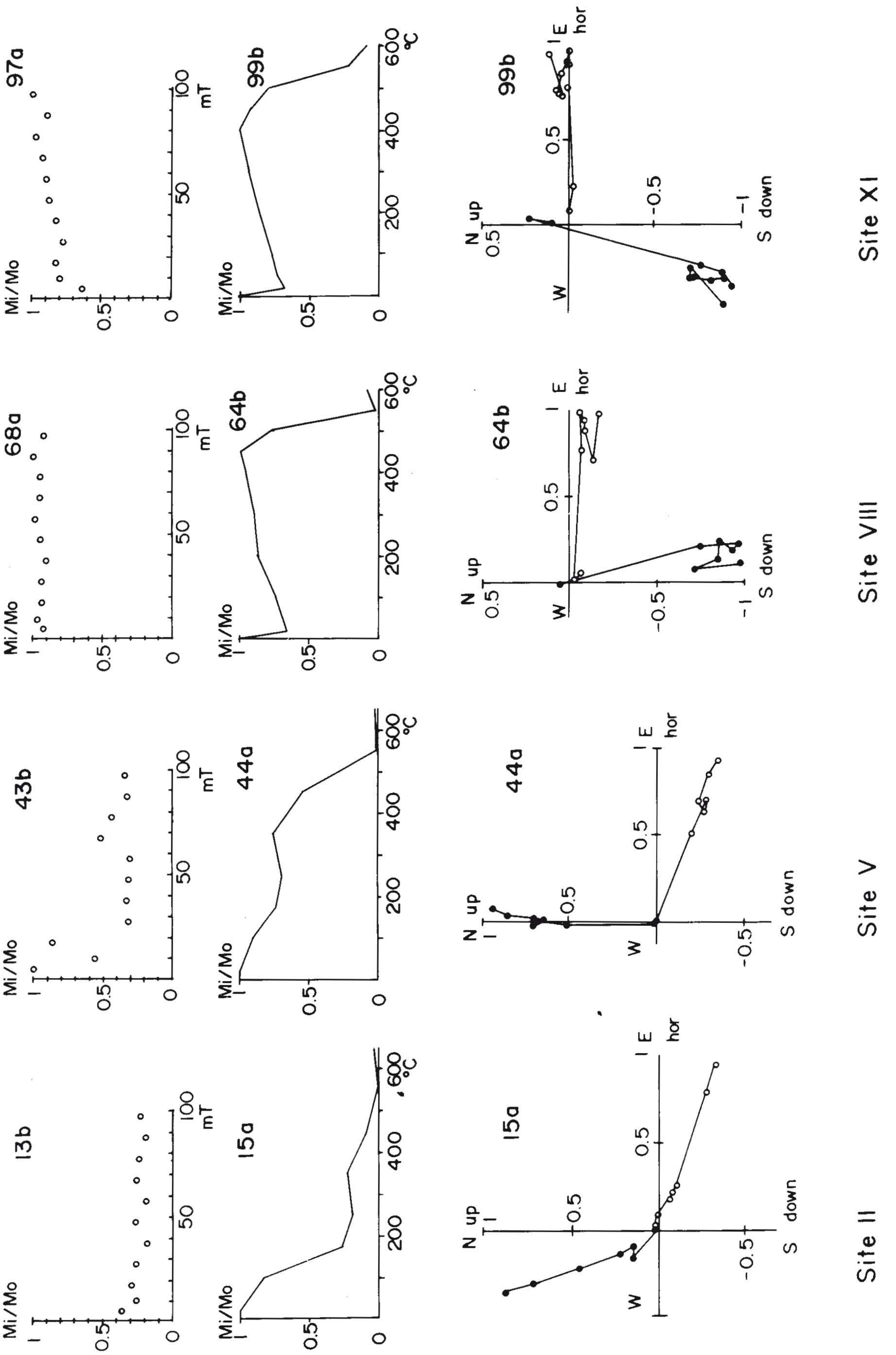

Fig. 4. Examples of demagnetization vector diagrams for samples of the Otlaltepec and Piedra Hueca red beds. Examples of normalized intensity plots for samples of the Otlalpec and Piedra Hueca red beds.

Table 1

Palaeomagnetic results of Piedra Hueca and Otlaltepec units sites

Site	n/r	Dec/Inc (tilt uncorr., °)	k	α_{95} (°)	VGP	Dec/Inc (tilt corr., °)	k	α_{95} (°)	VGP
II	16/0	347.1/ 40.6	15.1	9.8	N77°,197°E	337.5/ 21.1	15.1	9.8	N67°,157°E
IV	19/3	339.1/ 42.0	413.0	1.7	N70°,193°E	348.5/ 29.0	689.0	1.4	N79°,157°E
V	24/0	346.7/ 32.6	448.0	1.4	N77°,172°E	354.9/ 22.8	434.0	1.4	N82°,120°E
VII	7/0	32.8/ 39.8	14.3	16.5	N59°,338°E	15.1/ 5.9	7.9	22.9	N69°, 36°E
VIII-1	4/0	297.7/ 63.6	41.2	14.5	N32°,215°E	308.7/ 17.8	41.2	14.4	N40°,169°E
VIII-2	5/0	8.3/ 46.0	25.0	15.6	N78°,301°E	350.8/ 9.5	25.3	15.5	N74°,117°E
IX	15/1	349.1/ 39.3	5.7	17.5	N79°,196°E	348.6/ -1.2	5.5	18.6	N68°,114°E
X	13/1	343.5/ 51.3	11.1	13.4	N70°,218°E	337.9/ 8.5	11.1	13.6	N64°,142°E
XI	12/1	198.5/-34.1	47.0	6.7	N73°, 3°E	191.5/ -6.0	33.0	8.1	N71°, 44°E
XII	8/2	357.5/ 53.4	38.0	11.0	N69°,214°E	344.4/ 6.9	9.7	22.6	N57°,134°E
XIII	11/0	358.9/ 19.5	70.0	5.5	N81°, 90°E	3.5/-13.9	69.2	5.5	N65°,74°E
Piedra Hueca Unit						354/ 4	30.0	11.0	N73°,103°E
Otlaltepec Unit						347/ 25	80.0	14.0	N77°,152°E

n/r = numbre of samples used/rejected in the site mean calculation; k and α_{95} = statistical parameters; Dec/Inc = declination/inclination of site mean direction; VGP = virtual geomagnetic pole

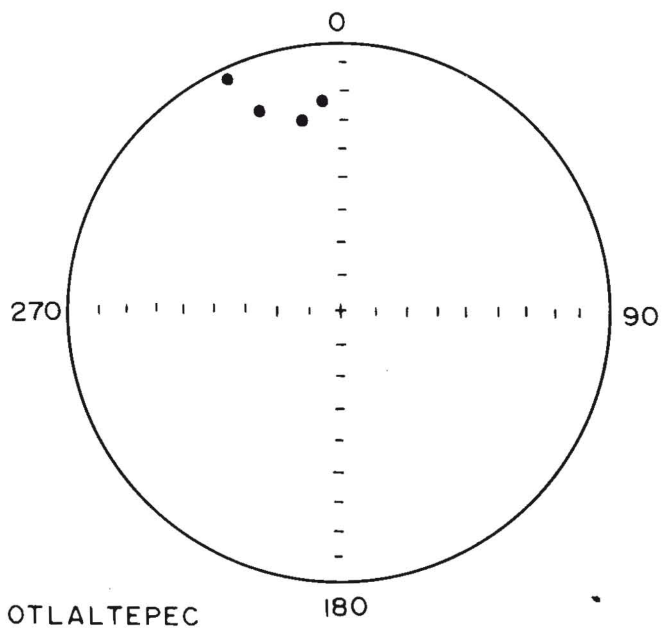

Fig. 5. Equal-area stereographic plot of site mean directions of characteristic magnetization of the Otlaltepec red beds.

(Anderson and Schmidt, 1983). Anderson and Schmidt (1983) propose that the displacement along the Trans-Mexican megashear was completed before any motion along the Mojave-Sonora megashear: thus it took place earlier than about 160 Ma. The available results confirm the kinematic model but indicate that the terrane displacement occurred after 160 Ma, in which case movement of southern Mexico was contemporaneous with that of northern Mexico, a possibility that is also suggested by Anderson and Schmidt (1983). Further indication that movement of southern Mexico was contemporaneous with that of northern Mexico comes from the displacement sense along the megashears, because diachronous displacements would have produced right-lateral instead of left-lateral slip, as observed. This opens the possibility of a single large Mexican micro-plate existing during part of the Mesozoic, which offers a simple solution (Occam's razor) which is readily testable by palaeomagnetic studies. Pre-Jurassic palaeomagnetic data for adjacent terranes, like the Precambrian Oaxaca terrane (e.g. McCabe *et al.*, 1988), may also help in developing a coherent tectonic model.

During the Jurassic the region was subjected to a distensive tectonic phase with development of regional normal faulting and deposition of thick sedimentary sequences. Caballero-Miranda *et al.* (1990) have reported results for the Bathonian-Callovian Tecomazuchil Formation and proposed that the dominant direction of sedimentary for the fluvial system was from N-NE to S-SW with a coastline oriented SE to NW (referred to present-day coordinates). This suggests that the sedimentary sequence in the Mixteca has a palaeo-Pacific affinity, which agrees with palaeobiographic studies of the ammonite fossil record of the Mixteca terrane (Imlay, 1980; Westerman *et al.*, 1984; Taylor *et al.*, 1984).

By Albian-Cenomanian times most of southern Mexico was covered by extensive shallow sea platforms.

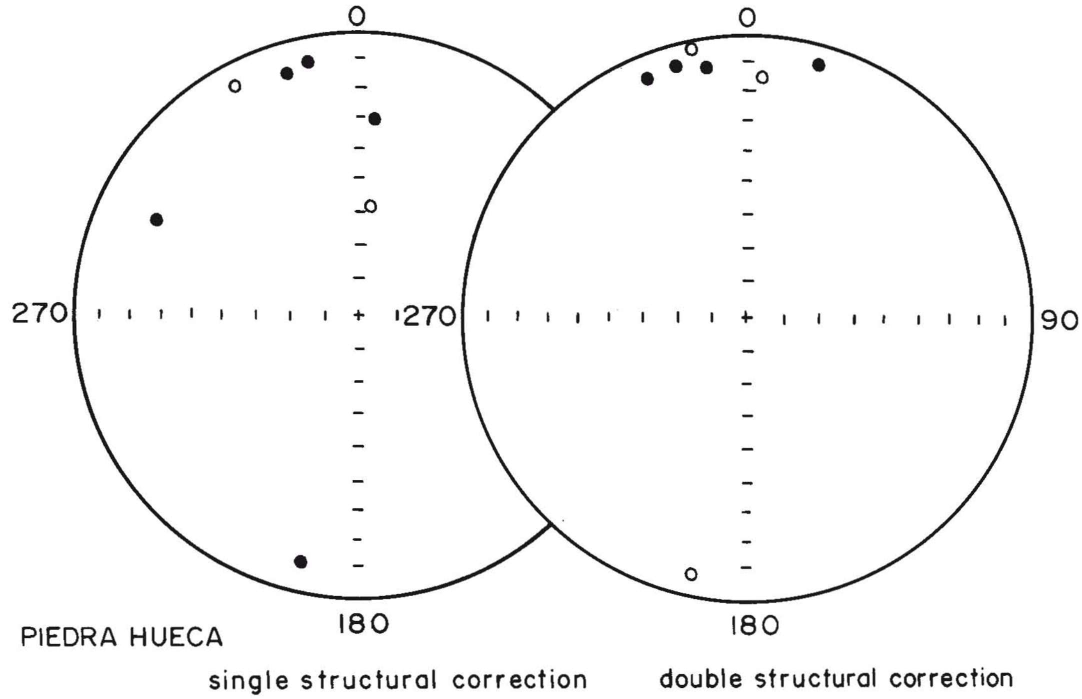

Fig. 6. Equal-area stereographic plot of site mean directions of characteristic magnetization of the Piedra Hueca red beds.

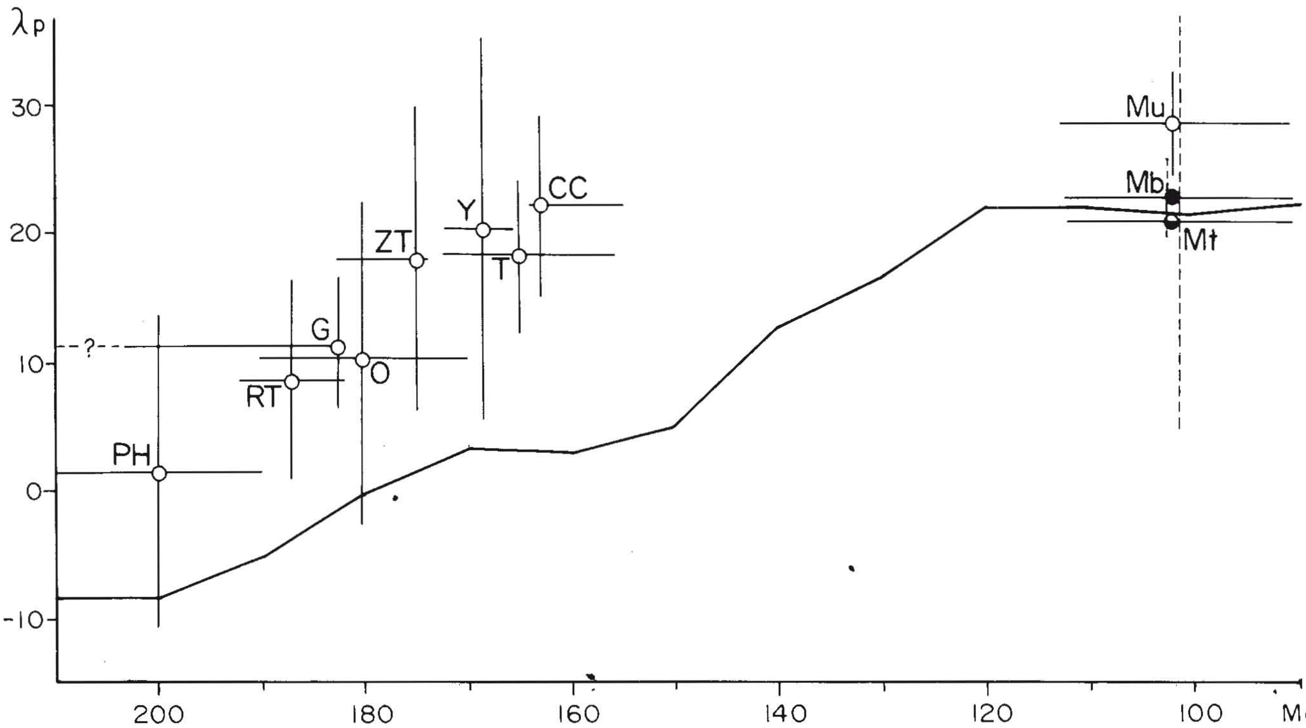

Fig. 7. Summary of palaeomagnetic pole positions for Jurassic units of the Mixteca terrane plotted in an equal-area stereographic projection. α95 circles of confidence are also included. The apparent polar wander path (APWP) for cratonic North America is plotted for reference. Note that pole positions distribute along two segments of great-circles. Pole positions for the Otlaltepec and Piedra Hueca red beds fall within the corresponding Jurassic APWP segment.

The Morelos Formation and equivalent units with thick carbonate flat-lying beds are widespread in the Mixteca terrane and across terrane boundaries. Palaeo-environmental reconstructions for Albian time around Tepeji de Rodríguez, to the north of the study area, in the northern Mixteca Alta (Pantoja-Alor, 1992), feature a wide shallow platform characterized by moderate to low energy, and the presence of emerged sites with coastal and lagoon environments.

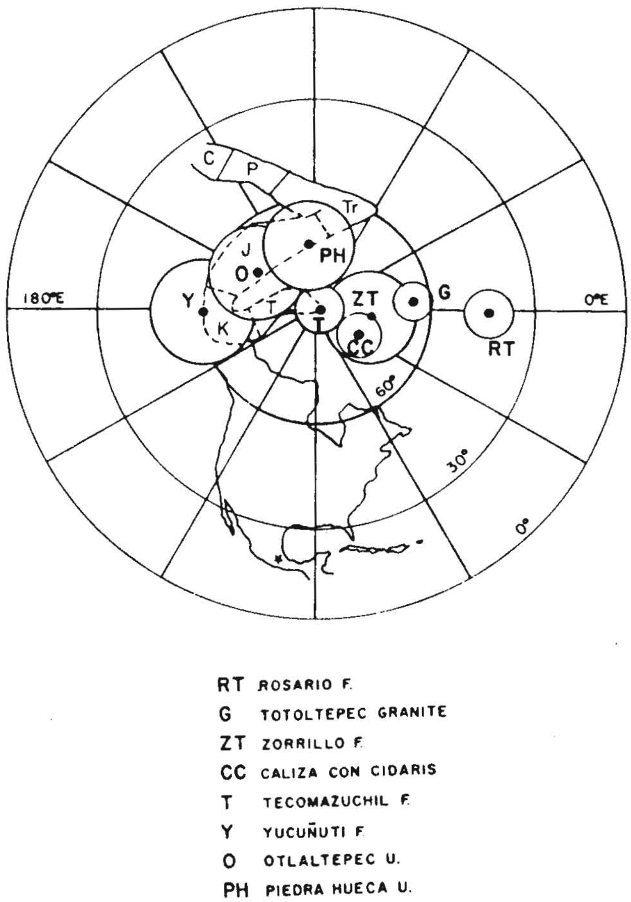

Fig. 8. Plot of palaeolatitude determinations for the Mixteca terrane as a function of time, from about 200 Ma to 100 Ma. Statistical uncertainties for the palaeomagnetic estimations and age ranges are also given. Explanation for identification of palaeomagnetic data is given in Figure 7. The continuous curve represents the average expected palaeolatitude variation for the Mixteca terrane assuming it was part of the North American paleoplate (reference data from Irving, 1982). Note that the two data sets follow similar variation trends but separated some 10 degrees from 200 Ma to 140 Ma. By late Early Cretaceous time the observed palaeolatitudes coincide with the expected curve.

Palaeomagnetic data for the Albian-Cenomanian of southern Mexico support a relative stability with no significant latitudinal motions (Urrutia-Fucugauchi, 1988; Böhnel *et al.*, 1992).

In Figure 9, we show schematic simplified palaeoreconstructions (adapted from Wilson *et al.*, 1988) for two extreme time intervals, at about 200 Ma in the Jurassic and at about 120 Ma during the late Early Cretaceous. The figures also display the complexities of terrane motions during the Mesozoic, particularly along the western palaeomargin of Mexico, with some terranes moving in opposite directions and with slow and fast latitudinal velocities (Urrutia-Fucugauchi *et al.*, 1988).

The palaeomagnetic data imply that at least part of southern Mexico (Mixteca terrane) during the interval 200 Ma to 160 Ma had a latitudinal movement similar to that of North America and was probably part of the same plate. A possible solution already advocated in earlier papers is that it was located along the western palaeo-margin of North America. The Mixteca terrane was then displaced after about 160 Ma and before 120 Ma, and most likely during 155 to 145 Ma (interval of major rifting in the Gulf of Mexico and activity of the Mojave-Sonora megashear).

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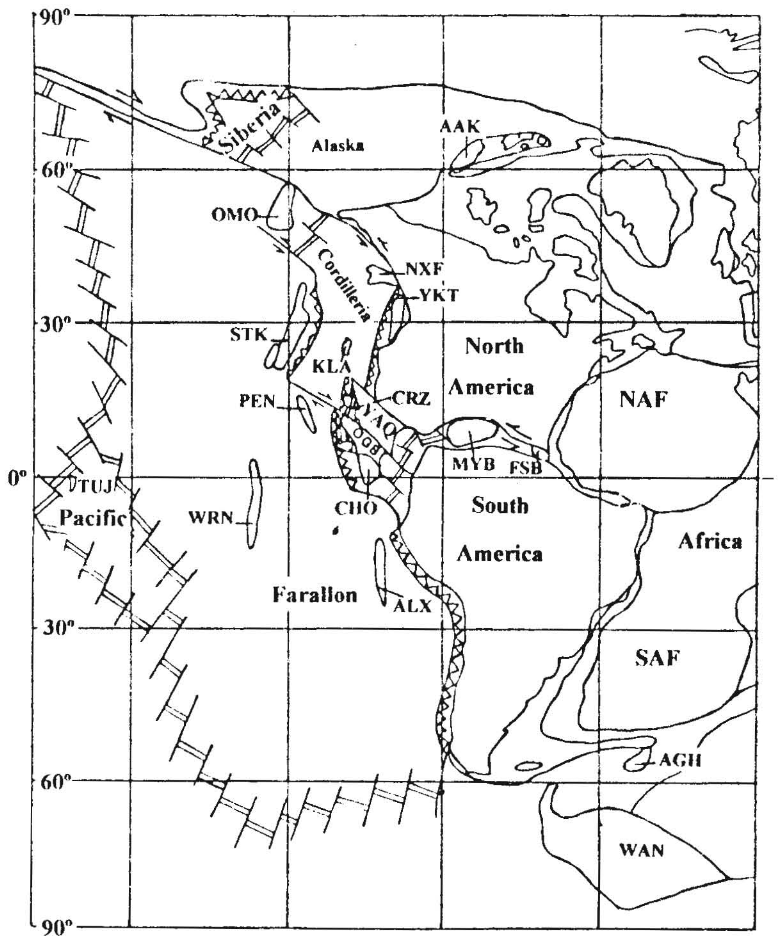
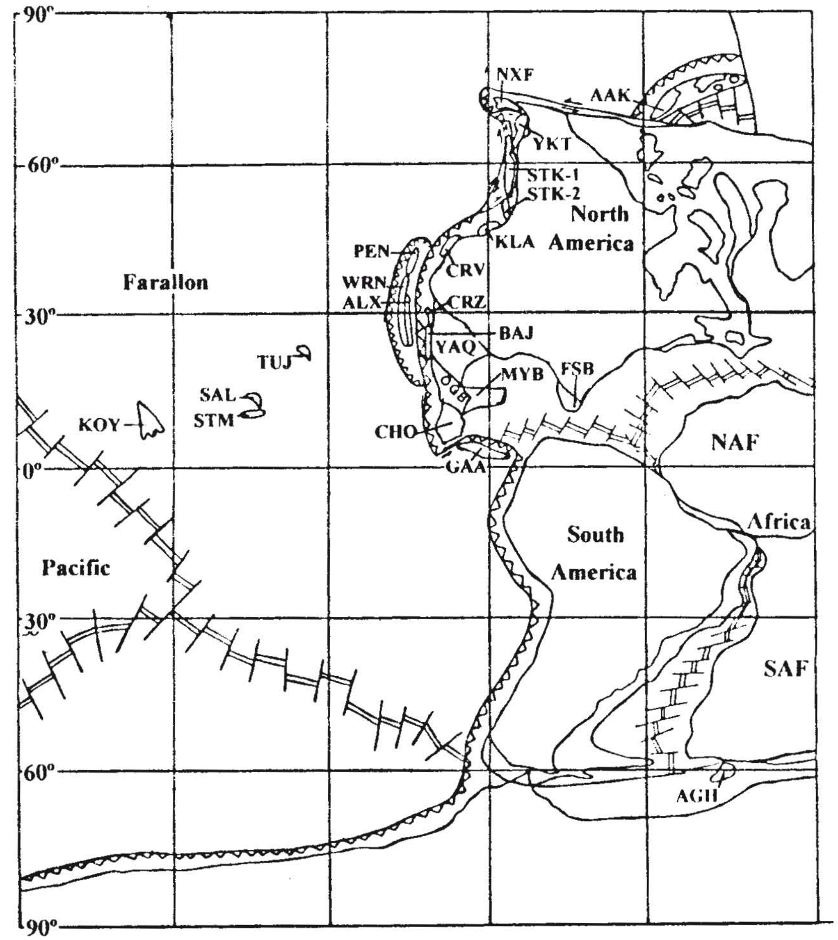


Early Jurassic (Sinemurian) 200 Ma reconstruction



Early Cretaceous (Hauterivian) 120 Ma reconstruction

Fig. 9. Palaeo-reconstructions for major continental plates and terranes along the eastern palaeo-Pacific ocean for two time windows: (a) 200 Ma, and (b) 120 Ma. Note that most terranes along the western margin of South and North America move northwards, whereas the micro-plates or terranes of northern and southern Mexico and nuclear Central America are being displaced southwards along regional left-lateral megashears Mojave-Sonora and Trans-Mexican Volcanic Belt. (From Wilson *et al.*, 1989). AAK Arctic Alaska-Chukotsk Block; AGH Agulhas Plateau; ALX Alexander Terrane; BAJ Baja Terrane; CHO Chortis Block; CRV Coast Ra-Gr. Valley Block; CRZ Cortez Block; FSB Florida Straits Block; GAA Greater Antilles Arc; KLA Klamaths West Terrane; KOY Koryak Terrane; MYB Mayan Block; NFB Nixon Fork Block; OGB Oaxaca-Guerrero Block; OMO Omolon Massif; PEN Peninsular Terrane; SAL Salinian Block; STK Stikinia Block; STM Stanley Mtn. Block; TUJ Tujunga Block; WAN Wrangellia Antarctic Block; WRN WrangelliaTerrane; YAQ Yaqui Block; YKT Yukon-Tanana Block; NAF North Africa; SAF South Africa).

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