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PALEOMAGNETIC RESULTS FROM SOUTHERN MEXICO

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RESUMEN

Análisis de resultados paleomagnéticos en muestras de las Formaciones Pérmicas Inferiores de Paso Hondo y Grupera, colectadas cerca de Chicomuselo, Chiapas, indican que el área estudiada se encontraba en relación con la parte cratónica de Norteamérica, en latitudes ecuatoriales y orientada 22° en sentido contrario a las manecillas del reloj. En contraste, la paleo-posición determinada de la Formación Pensilvánica-Pérmica Yododeñe, muestreada cerca de Nochixtlán, Oaxaca, está de acuerdo con la estimada usando datos equivalentes de Norteamérica. Estos resultados implican que el Istmo de Tehuantepec representa una discontinuidad mayor y apoyan nuestra sugerencia anterior de que Mesoamérica consistió en una serie de bloques tectónicos.

ABSTRACT

The paleomagnetic analysis of samples from the lower Permian Paso Hondo y Grupera Formations, collected near Chicomuselo, Chiapas, yields an equatorial latitude and implies that the sampling area was in a position rotated 22° counterclockwise relative to cratonic North America. By contrast, the poleposition obtained from the Pennsylvanian-Permian Yododeñe Formation, collected near Nochixtlán, Oaxaca, closely agrees with equivalent North American data. This implies that the Isthmus of Tehuantepec represents a major discontinuity. The new results support our previous suggestion that Mesoamerica consisted of a series of tectonic blocks.

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INTRODUCTION

Many different paleogeographic reconstructions have been proposed for the area around the Gulf of Mexico. During the last year or two, however, some aspects have emerged on which most active investigators seem to agree. There is a general consensus that South America was closely abutted against North America in late Paleozoic-early Mesozoic time (e.g., Dickinson and Coney, 1980; Morel and Irving, 1981; Pilger, 1978; Van der Voo *et al.*, 1976; Walper, 1980), although differences do exist as to the tightness of the fit (Fig. 1). It is also agreed upon by most workers that the Gulf of Mexico formed by extension, rifting, crustal attenuation, and sea floor spreading in early to middle Mesozoic time (e.g., Buffler *et al.*, 1981; Hall *et al.*, 1981; Salvador and Green, 1980; Klitgord *et al.*, 1981).

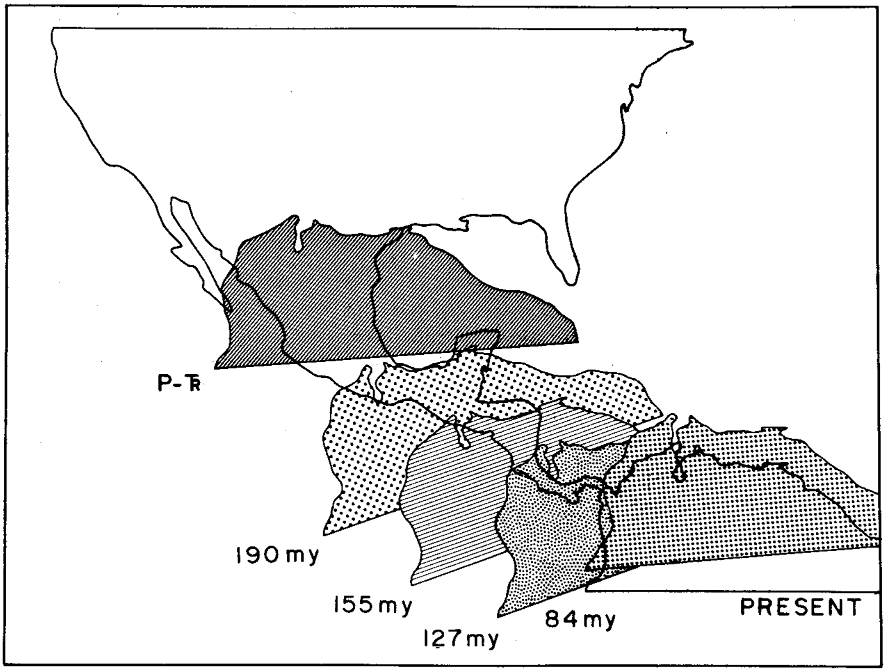

Fig. 1. Position of South America relative to North America. For ease of recognition, the continents are shown in their present outline. Based on reconstructions by Ladd (1976) and Van der Voo *et al.*, (1976).

The tectonic evolution of Mesoamerica assumes a key role in any paleogeographic reconstruction of the area around the Gulf of Mexico, and paleomagnetism is particularly suitable for determining past plate motions. Our analysis of rocks from northeastern Mexico, Guatemala, Honduras, Nicaragua, and Costa Rica indicate that Mesoamerica consisted of a series of tectonic blocks which aggregated from north to south (Gose and Swartz, 1977; Gose *et al.*, 1980, 1981, 1982). This paper reports results from a pilot study of late Paleozoic rocks from the states of Oaxaca and Chiapas, southern Mexico (Sánchez-Barreda, 1981). The two sampling areas (Fig. 2) are located on either side of the Isthmus of Tehuantepec and the associated Salina Cruz fault (Viniegra, 1971) and were chosen to test whether the Salina Cruz fault represents a major structural discontinuity. The pre-Mesozoic rocks west of this fault are mainly metamorphic rocks of Precambrian age, whereas to the east the intrusive rocks of the Chiapas Massif (Ordovician to late Permian) are the most abundant pre-Mesozoic rocks (López-Ramos, 1976).

SITE GEOLOGY AND EXPERIMENTAL PROCEDURES

The two sampling areas are located on either side of the Isthmus of Tehuantepec, one near Nochixtlán, Oaxaca, and the other near Chicomuselo, Chiapas (Fig. 2). In Oaxaca we sampled the Yododeñe Formation at its type locality along the Cuesta del Tiuno. This continental formation consist of reddish conglomerates interbedded with sandstones and lutites and contains no fossils. The Yododeñe Formation is conformably underlain by the Ixtaltepec Formation, a marine sandstone-shale sequence of Pennsylvanian age (Pantoja-Alor and Robinson, 1967;

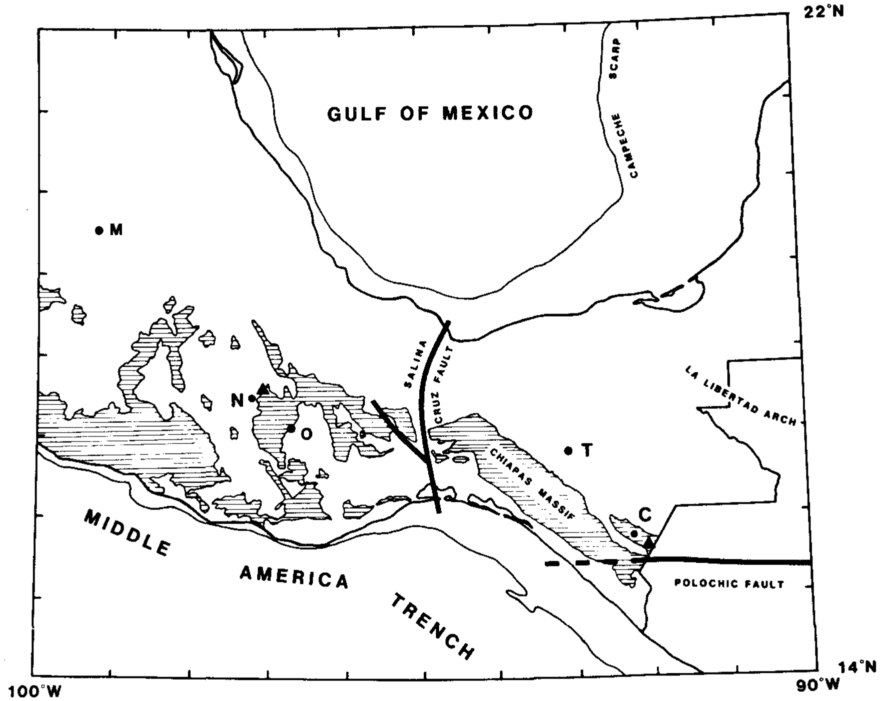

Fig. 2. Location map. ▲ sampling sites; M Mexico City; N Nochixtlán; O Oaxaca; T Tuxtla Gutiérrez; C Chicomuselo. Hatched areas represent surface exposures of pre-Mesozoic rocks. Based on the geologic map of Mexico (López-Ramos, 1976) and a paper by Viniegra (1971).

Pantoja-Alor, 1970). It is overlain with angular, erosional unconformity by Cretaceous and Tertiary rocks. Based on its lithology and stratigraphic and tectonic setting, the Yododeñe Formation has been assigned an age range from Pennsylvanian to middle Permian. We collected 26 fine-grained samples distributed over 50 meters of stratigraphic section.

The Ixtaltepec and Yododeñe Formations have been tentatively correlated with limestones and shales near Chicomuselo, Chiapas. The Grupera Formation of Wolfcampian age (Hernández, 1973) and the Paso Hondo Formation of Leonardian age (Buitron, 1977) are believed to have been deposited on a shallow platform under protected marine conditions (Hernández, 1973). Near Chicomuselo, we sampled two outcrops in the Grupera Formation and near Paso Hondo, two outcrops in the Paso Hondo Formation for a total of 77 limestone samples (Fig. 2).

Oriented core samples of 2.5 cm diameter and 3 to 10 cm length were collected with a portable, gasoline-powered drill. In the laboratory, the cores were cut to 2.3 cm length and stored in a magnetically shielded room (about 100 gammas residual field) in order to eliminate possible viscous magnetization. The samples remained in this room throughout the experimental procedures. A cryogenic magnetometer, interfaced with a computer, was used for the measurements. All samples were subjected to thermal demagnetization in an ambient field of less than 3 gammas. The carbonate rocks were heated to 200, 250, 300, 350, and 400°C, and the clastic rocks to 200, 250, 400, 500, and 600°C.

RESULTS

The natural remanent magnetization of most carbonate samples (Grupera and Paso Hondo Formations) had a strong component aligned with the present geomagnetic field (Fig. 3). After heating to 250°C, a reversed magnetization was generally obtained, and demagnetization to 300°C and 350°C simply improved the clustering. Most samples were further demagnetized at 400°C, which resulted in a deterioration of the data quality with exception of site 4. The intensity of magnetization was typically between 10^{-7} to 10^{-8} emu/gm for the NRM with only a slight decrease upon demagnetization.

The clastic rocks from the Yododeñe Formation were heated to higher temperatures, and the best clustering was achieved after heating to 600°C. However, no significant change in the direction of magnetization occurred during demagnetization (Fig. 4). The intensity of magnetization decreased from about 10^{-6} emu/gm to half that value during demagnetization. The remanence is carried by hematite as evidence by the small change in intensity upon exceeding the magnetite Curie point.

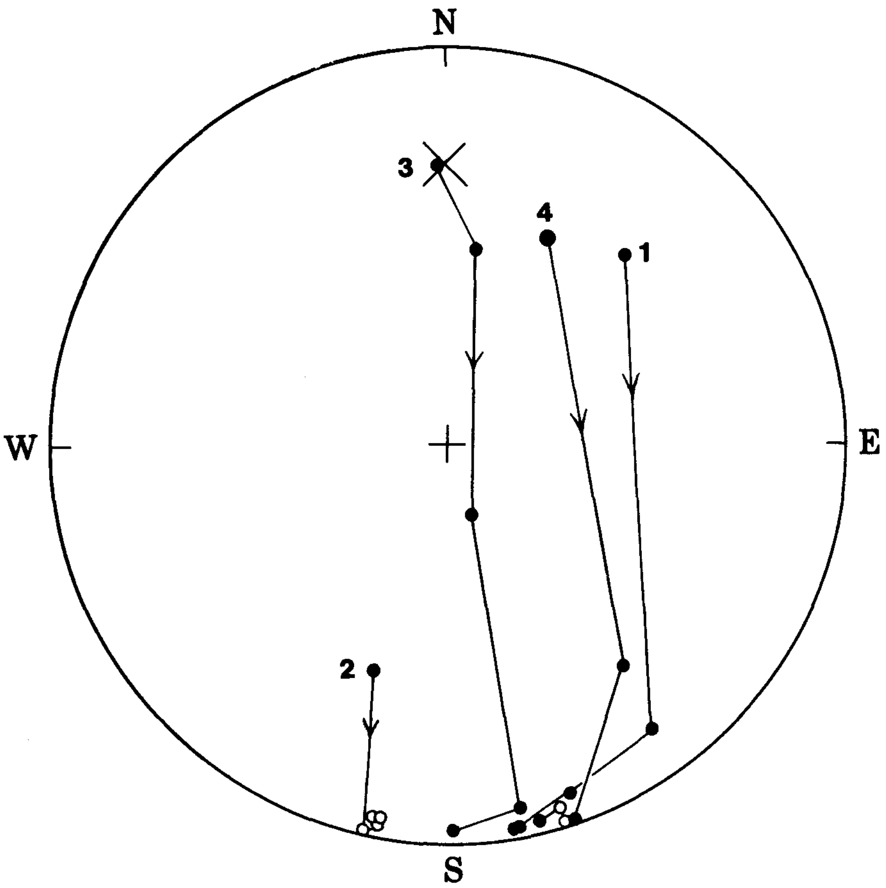

Fig. 3. Change in the site mean direction during thermal demagnetization of the outcrops in Chiapas. The steps are: NRM, TD200, TD250, TD300, TD350 and, for outcrop 4, also TD400. x = present magnetic field direction. Schmidt equal area projection.

The paleomagnetic polepositions are shown in Fig. 5, together with the results from stable North America (after Irving, 1979), and the statistical parameters are listed in Table 1. About one fourth of the samples were deleted from this analysis. These samples displayed directions of magnetization which differed from the site mean by at least three times the angle of the 95 % confidence cone; in most cases, the divergence was considerably larger.

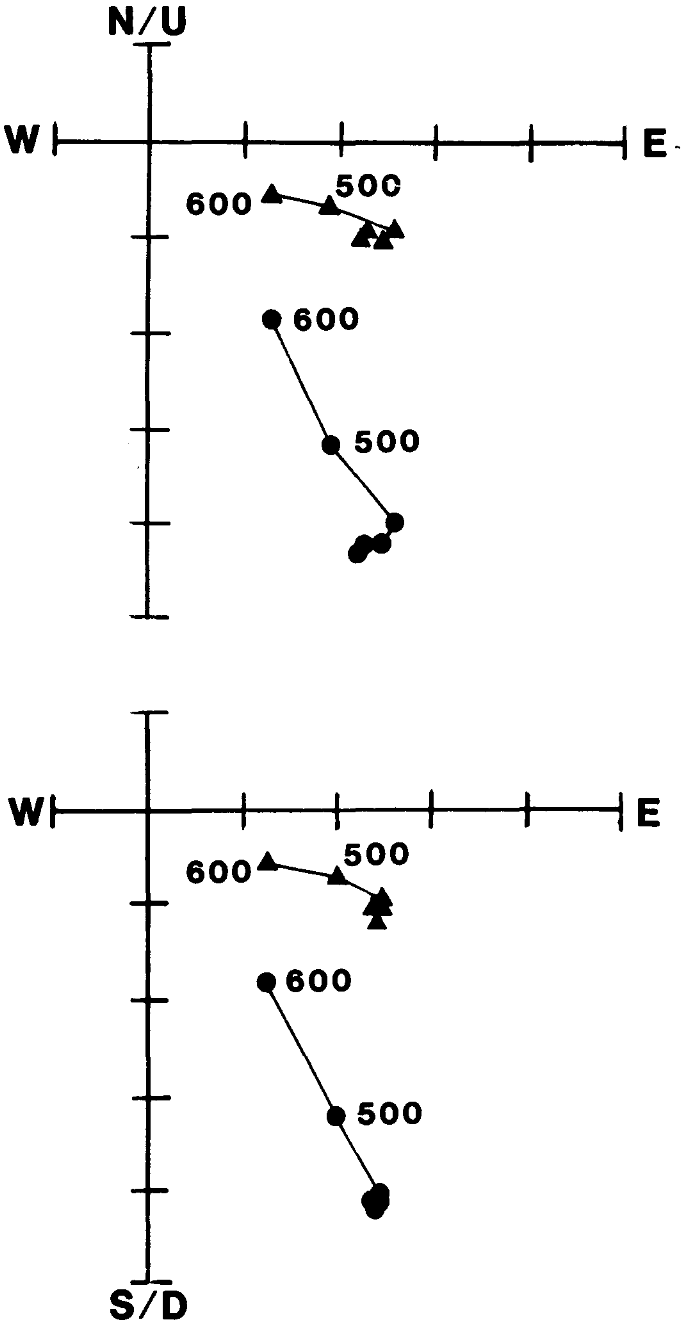

Fig. 4. Orthogonal projection of magnetic vector during thermal demagnetization for two samples from the Yododeñe Formation. ● are the projection onto the horizontal plane, ▲ on the vertical plane. The NRM intensity for both samples is 2.3 x 10^{-6}emu/gm.

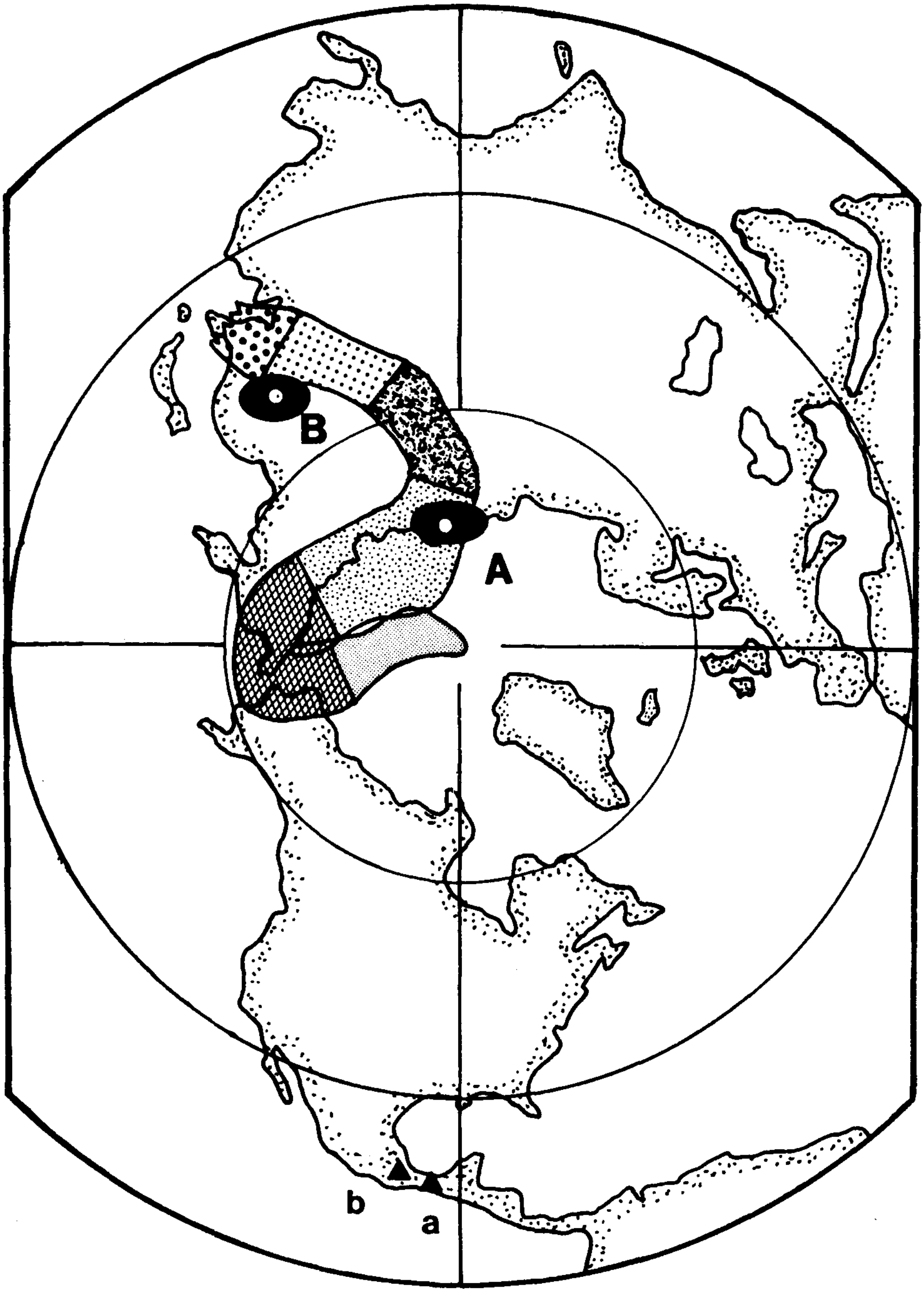

Fig. 5. Poleposition from Chiapas (A) and Oaxaca (B) together with the polar wander path for cratonic North America (after Irving, 1979). The shaded areas correspond to the geological periods from Tertiary to Pennsylvanian. ▲ = sampling sites, a = Chiapas, b = Oaxaca.

Table 1. Statistical parameters of paleomagnetic analysis

Site		Treat	N	R	D	I	K	α_{95}	Lat	Long	dp	dm
Chiapas	(1)	TD350	10/6	9.8	170.9	2.5	38.6	7.9	71.1	116.5	3.9	7.9
15.5 N, 267.5 E	(2)	TD350	17/6	16.8	191.4	–5.7	91.7	3.7	73.2	44.6	1.9	3.8
	(3)	TD350	14/4	12.9	180.1	3.6	12.2	11.9	72.8	87.0	5.9	11.9
	(4)	TD400	18/2	17.4	167.0	3.4	27.6	6.7	68.6	125.5	3.4	6.7
Sample mean			59	55.9	177.8	0.6	18.8	4.4	74.2	95.4	2.2	4.4
Site mean			4	3.94	177.3	1.0	48.0	13.4	73.9	97.2	6.7	13.4
Oaxaca 17.5 N, 262.8 E		TD600	23/3	22.5	152.9	24.1	48.3	4.4	49.7	126.2	2.5	4.7

Note: Treat = thermal demagnetization at specified temperature; N = number of samples included in the statistics/number of samples rejected; R = resultant vector; D = declination; I = inclination; K = precision parameter; α_{95} = 95% circle of confidence; Lat, Long = paleomagnetic poleposition; dp, dm = semi-angles of ellipse of confidence.

DISCUSSION AND SPECULATION

Before interpreting the data, it is important to establish the age of magnetization. Unfortunately, no field test was possible. All strata are gently dipping (~20°), and no fold test could be applied. The four outcrops in Chiapas yield similar results, and all rocks carry a reversed magnetization which is the expected polarity for the Permian. We cannot rule out the possibility that these rocks may have been reheated by the late Permian intrusions of the Chiapas Massif (Carfantan, 1977), but there is no evidence to support such a thermal event.

We collected only one outcrop in the Yododeñe Formation. The gentle dip of the strata could give rise to only a very small error due to unrecognized structural complexities. The fact that 50 meters of section yielded only reversed polarities again strongly supports that the magnetization is of Permian age.

The greatest uncertainty for a regional interpretation of our results stems from the very limited data base. Due to the lack of suitable outcrops we collected at only one site in Oaxaca, and the four outcrops in Chiapas are distributed over only 14 km. Without a broader distribution of sampling sites both in space and in time, any interpretation is strongly model-dependent. We shall assume that the data reflect the motion of some larger areas and are not influenced by very local tectonics. Because the poleposition from Oaxaca is distinctively different from the poleposition of the similar-aged rocks from Chiapas, we will discuss the two areas separately.

The paleomagnetic data from the lower Permian Grupera and Paso Hondo Formations yield an equatorial latitude for Chiapas (0.3°S ±7°) and indicate that the area was rotated 22° ±8° counterclockwise relative to North America. The error estimate was obtained by combining the error estimate of our data with the error limit of the data for cratonic North America (Irving, 1979). Let us assume that Chiapas was a structural part of the Yucatan Block and that the Yucatan Block comprises the area between the Motagua-Polochic fault system and the Salina Cruz fault (Fig. 2). The equator in lower Permian time crossed North America along a line extending from northern Baja California toward the Great Lakes (Fig. 6). The closest position with respect to North America for the Yucatan Block would be off northern Baja California. A Pacific rather than a northern Gulf of Mexico position for Yucatan is also favored if South America was indeed as close to North America as suggested by Van der Voo *et al.* (1976), Pilger (1978), and Walper (1980) (see Fig. 1).

A different interpretation results if the magnetization of these rocks is not syndepositional, i.e., of lower Permian age, but rather was acquired during upper Permian to lower Triassic time. By this time the paleoequator extended across the northern Gulf of Mexico (Fig. 6). If the fit between North and South America was not

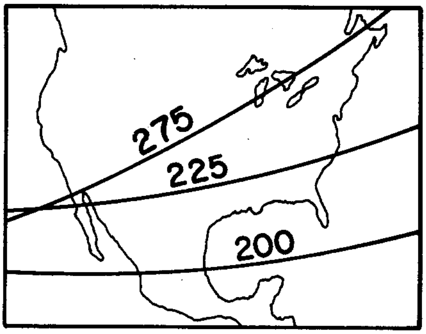

Fig. 6. Location of paleoequator at 275, 225, and 200 MYBP (after Irving, 1979).

as tight as shown in Fig. 1, or if the opening of the Gulf of Mexico basin due to rifting was preceded by crustal extension, then the Yucatan Block may have originated in the northern Gulf of Mexico.

The assumption of structural continuity between Chiapas and the Yucatan Platform in the late Paleozoic may not be valid. Vaughan (1918) and Viniegra (1971) called attention to the very different structural styles of the areas east and west of the La Libertad Arch (see Fig. 2). In this case, our data require that only the Chiapas Massif and adjoining pre-Mesozoic rocks were located off northern Baja California. The subsequent southeasterly motion of this area could readily be accomplished along a large transverse fault. The only other pertinent paleomagnetic data are from the excellent work by Guerrero (1975) and our results from the Altos Cuchumatanes in Guatemala (Gose *et al.*, 1981) which show that this area was in its present position relative to North America by late Jurassic-early Cretaceous time. No inferences can be drawn about the position of the Yucatan Platform from paleomagnetic data. Seismic, gravity, and stratigraphic data (Buffler *et al.*, 1980, 1981; Hall *et al.*, 1981; Salvador and Green, 1980) strongly suggest that the Yucatan Platform originated in the northern Gulf of Mexico and also demonstrate its southerly drift during late Triassic to middle Jurassic time.

The poleposition from the Yododeñe Formation in Oaxaca closely matches the lower Permian poleposition for stable North America which seems to imply that Oaxaca was in the same position relative to North America as it is today. However, this inference is at variance with the Permian paleogeographic reconstruction (Fig. 1) as well as our paleomagnetic data from northeastern Mexico (Gose *et al.*, 1982). The analysis of samples from the lower Mesozoic Huizachal Group in the Sierra Madre Oriental suggests a major structural discontinuity between Mexico and cratonic North America and supports the existence of a series of WNW-trending left-lateral faults that have been proposed by de Cserna (1976). Recent paleomagnetic results from northern Mexico (Urrutia-Fucugauchi, 1981) suggest that some relative motion between cratonic North America and Mexico occurred as late as post-Oligocene. It, therefore, follows that Oaxaca was not rigidly connected with North America and a more westerly, i.e. Pacific, position is most likely (Note that paleomagnetic data cannot detect east-west translations).

The data presented here strongly support our previous interpretations of paleomagnetic data from Mesoamerica (e.g. Gose *et al.*, 1980), namely, that Mesoamerica consisted of a series of tectonic blocks. These blocks aggregated from north to south as North and South America drifted apart. The exact number of blocks and the details of their motions are still poorly known, but we believe that our model is, in principle, correct. An interesting, yet totally unresolved, question arises: where were these blocks before they became part of Mesoamerica? This problem becomes even more intriguing if one also considers that many terrains along the west coast of North America are allochthonous blocks (see Beck, 1980, for a review).

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BIBLIOGRAPHY

BECK, M. E., 1980. Paleomagnetic record of plate-margin tectonic processes along the western edge of North America. *J. Geoph. Res., 85,* 7115-7131.

BUFFLER, R. T., J. S. WATKINS, F. J. SHAUB, and J. L. WORZEL, 1980. Structure and early geologic history of the deep central Gulf of Mexico basin, *in* Pilger, R. H., ed., The origin of the Gulf of Mexico and the early opening of the central North Atlantic Ocean: Baton Rouge, Louisiana State University, p.3-16.

BUFFLER, R. T., F. J. SHAUB, R. HUERTA, A. B. K. IBRAHIM and J. S. WATKINS, 1981. A model for the early evolution of the Gulf of Mexico Basin, *Ocean. Acta, No. SP,* 129-136.

BUITRON, B. E., 1977. *Bellerophon* (Bellerophon) *Crassus meek* y *Worthen* (Mollusca, gastropoda) en el Pérmico de Chiapas, Universidad Nacional Autónoma de México, Instituto de Geología, Revista, 1, 69-73.

CSERNA, Z. de, 1976. Mexico-geotectonics and mineral deposits. *New Mex. Geol. Soc. Spec. Publ. 6* 18-25.

CARFANTAN, J. C., 1977. La cobijadura de Motozintla - un paleoarco volcánico en Chiapas. Universidad Nacional Autónoma de México, Instituto de Geología, Revista 1, 133-137.

DICKINSON, W. R., and CONEY, P. J., 1980. Plate tectonic constraints on the origin of the Gulf of Mexico, *in* Pilger, R. H., ed., The origin of the Gulf of Mexico and the early opening of the central North Atlantic Ocean. Baton Rouge, Louisiana State University, 27-36.

GOSE, W. A., and D. K. SWARTZ, 1977. Paleomagnetic results from Cretaceous sediments in Honduras: Tectonic implications. *Geology, 5,* 505-508.

GOSE, W. A., G. R. SCOTT, and D. K. SWARTZ, 1980. The aggregation of Mesoamérica: paleomagnetic evidence, *in* Pilger, R. H., ed., The origin of the Gulf of Mexico and the early opening of the central North Atlantic Ocean. Baton Rouge, Louisiana State University, 51-54.

GOSE, W. A., R. C. BELCHER, and G. R. SCOTT, 1982. Paleomagnetic results from northeastern Mexico: evidence for large Mesozoic rotations, *Geology, 10,* 50-54.

GOSE, W. A., D. K. SWARTZ, and R. C. FINCH, 1981. Paleomagnetic studies of Mesozoic rocks in Honduras: Stratigraphic implications, *in* Informe de la V Reunión de Geólogos de America Central, Managua, 1977, I C A I T I, in press.

GUERRERO, J. C., 1975. Contributions to paleomagnetism and Rb-Sr geochronology (Ph. D. Thesis) Dallas, University of Texas at Dallas, 128 p.

HALL, D. J., T. D. CAVANAUGH, J. S. WATKINS, and K. J. McMILLEN, 1981. The rotational origin of the Gulf of Mexico based on regional free-air gravity data, *in* Hedberg Research Conference of continental margins, American Association of Petroleum Geologists, Memoir, in press.

HERNANDEZ, R., 1973. Paleografía del Paleozoico de Chiapas, Mexico. Asociación Mexicana de Geólogos Petroleros, Boletín, 25, 77-134.

IRVING, E., 1979. Paleopoles and paleolatitudes of North America and speculations about displaced terrains. *Can. J. Earth Sc., 16,* 669-694.

KLITGORD, K. D., P. POPENOE, and H. SHOUTEN, 1981. Florida: A Jurassic transform plate boundary. *J. Geoph. Res.* submitted.

LADD, J. W., 1976. Relative motion of South America with respect to North America and Caribbean tectonics, *Geol. Soc. Amer. Bull. 87,* 869-876.

LOPEZ-RAMOS, E., 1976. Carta geológica de la República Mexicana, 1:2,000,000.

MOREL, P., and E. IRVING, 1981. Paleomagnetism and the evolution of Pangea. *J. Geophys. Res., 86,* 1858-1872.

PANTOJA-ALOR, J., and R. A. ROBINSON, 1967. Paleozoic sedimentary rocks in Oaxaca, Mexico. *Science, 157.* 1033-1035.

PANTOJA-ALOR, J., 1970. Rocas sedimentarias Paleozoicas de la región centro-septentrional de Oaxaca. *Soc. Geol. Mex.,* Excursion México-Oaxaca, 67-84.

PILGER, R. H., 1978. A closed Gulf of Mexico, pre-Atlantic Ocean plate reconstruction and the early rift history of the Gulf of Mexico and North Atlantic. *Gulf Coast Assoc. Geol. Soc. Trans., 28,* 385-393.

SALVADOR, A., and A. R. GREEN, 1980. Opening of the Caribbean Tethys. Publication of the International Geological Congress 26th, Colloquium C5, Geology of the Alpine Chain born to the Tethys, Bureau de Recherches Géologiques et Minières, Paris, France, Memoir 115, p.224-229.

SANCHEZ-BARREDA, L. A., 1981. Geologic evolution of the continental margin of the Gulf of Tehuantepec in southeastern Mexico (Ph. D. Thesis), Austin, University of Texas at Austin.

URRUTIA-FUCUGAUCHI, J., 1981. Paleomagnetic evidence for tectonic rotation of northern Mexico and the continuity of the Cordilleran orogenic belt between Nevada and Chihuahua. *Geology, 9,* 178-183.

VAN DER VOO, R., F. J. MAUK, and R. B. FRENCH, 1976. Permian-Triassic continental configurations and the origin of the Gulf of Mexico. *Geology, 4.* 177-180.

VAUGHAN, T. W., 1918. Geologic history of Central America and the West Indies during Cenozoic time, *Geol. Soc. Amer. Bull. 29,* 615-630.

VINIEGRA, F., 1971. Age and evolution of salt basins of southeastern Mexico. *Am. Assoc. Petrol. Geol. Bull., 55,* 478-494.

WALPER, J. L., 1980. Tectonic evolution of the Gulf of Mexico, *in* Pilger, R. H., ed., Origin of the Gulf of Mexico and the early opening of the central North Atlantic Ocean. Baton Rouge, Louisiana State Universtiy, p.87-98.

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