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PRELIMINARY RESULTS: PALEOMAGNETISM OF MESOZOIC UNITS FROM NORTHWEST SONORA AND THEIR TECTONIC IMPLICATION FOR NORTHERN MEXICO

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RESUMEN

Los resultados preliminares de una investigación paleomagnética de estratos miogeosinclinales Triásico Superior-Jurásico Inferior de la Formación Antimonio (localizados en el noroeste de Sonora) permiten determinar una posición polar paleomagnética de 74.8°N y 106.2°E (I = 33.8°, D = 350.0°, α_{95} = 12.1°, k = 104.4, dp = 7.89 y dm = 11.68). Esta posición polar concuerda con la posición polar determinada en un estudio anterior (Nairn, 1976) de la Formación Nazas (Triásico Superior-Jurásico Inferior) de la parte norte-central de México.

Las posiciones relativas de la parte norte de México y de Norteamérica antes y durante el rompimiento de Pangaea han sido motivo de especulación para numerosos investigadores. Nuestros resultados combinados con los de Nairn (1976) sugieren que, si un movimiento diferencial entre el norte de México y Norteamérica ha ocurrido desde el Mesozoico Temprano, el desplazamiento observado en el segmento de la curva de movimiento polar aparente para el norte de México es de pequeña magnitud y en sentido contrario a las manecillas del reloj; ello con respecto a la curva de Norteamérica. El movimiento del bloque tectónico del norte de México con relación al cratón de Norteamérica se limita a un máximo de varios cientos de kilómetros y su sentido debe ser lateral izquierdo.

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ABSTRACT

Preliminary results from a paleomagnetic investigation of Upper Triassic-Lower Jurassic miogeosynclinal strata (Antimonio Formation) located in northwest Sonora, Mexico yield a paleomagnetic pole position at N 74.8° E 106.2° ($I = 33.8°$, $D = 350.0°$, $\alpha_{95} = 12.1°$, $k = 104.4$, $dp = 7.89$, $dm = 11.68$). This pole position agrees well with a pole determined from an earlier study of the Upper Triassic-Lower Jurassic Nazas Formation (Nairn, 1976) of north-central Mexico.

The relative position of northern Mexico and North America prior to and during the breakup of Pangaea have been speculated on by many previous workers. Our data in combination with those of Nairn (1976) suggest that if differential movement of northern Mexico relative to North America has occurred since the early Mesozoic, displacement of a segment of the northern Mexico apparent polar wandering path is of a small order and in a counterclockwise direction with respect to the North American apparent polar wandering path. The motion of the northern Mexico tectonic block relative to cratonic North America is limited to, at most, several hundreds of kilometers displacement which must be of a sinistral sense.

GEOLOGY AND SAMPLING

The Sierra del Alamo range of northwest Sonora (Fig. 1) is comprised of mid-Permian, Upper Triassic, and Lower Jurassic miogeosynclinal strata disconformably overlain by a volcanic sequence of uncertain age (González, 1979). These units generally strike northwest and dip 10° to 60° southwest forming a simple homoclinal structure. On a regional scale, the range may comprise part of the western limb of a northtrending, doubly plunging anticline with wavelength on the order of 100's of kilometers (Damon, *et al.*, 1962; T. H. Anderson, unpublished data). The structure whose age is probably as young as Cretaceous has been cut by both high-angle and low-angle faults.

Sampling for this study was concentrated in the Upper Triassic-Lower Jurassic strata mapped as the Antimonio Formation (González, 1979). This formation is a thick package of sedimentary rocks (3400 m) comprised of beds of sandstone, siltstone, shale, and limestone. Abundant marine fossils preserved in some units of the formation show the lower part is Karnian-Norian in age with the upper part Hettangian-Sinemurian in age. Four distinct stratigraphic units were sampled in the formation (Fig. 2) and included two in the lower part and two in the upper part. The sampled lithologies are highly diverse and include beds of red siltstone, limestone, sandy limestone, sandstone, and blue-gray shale.

2

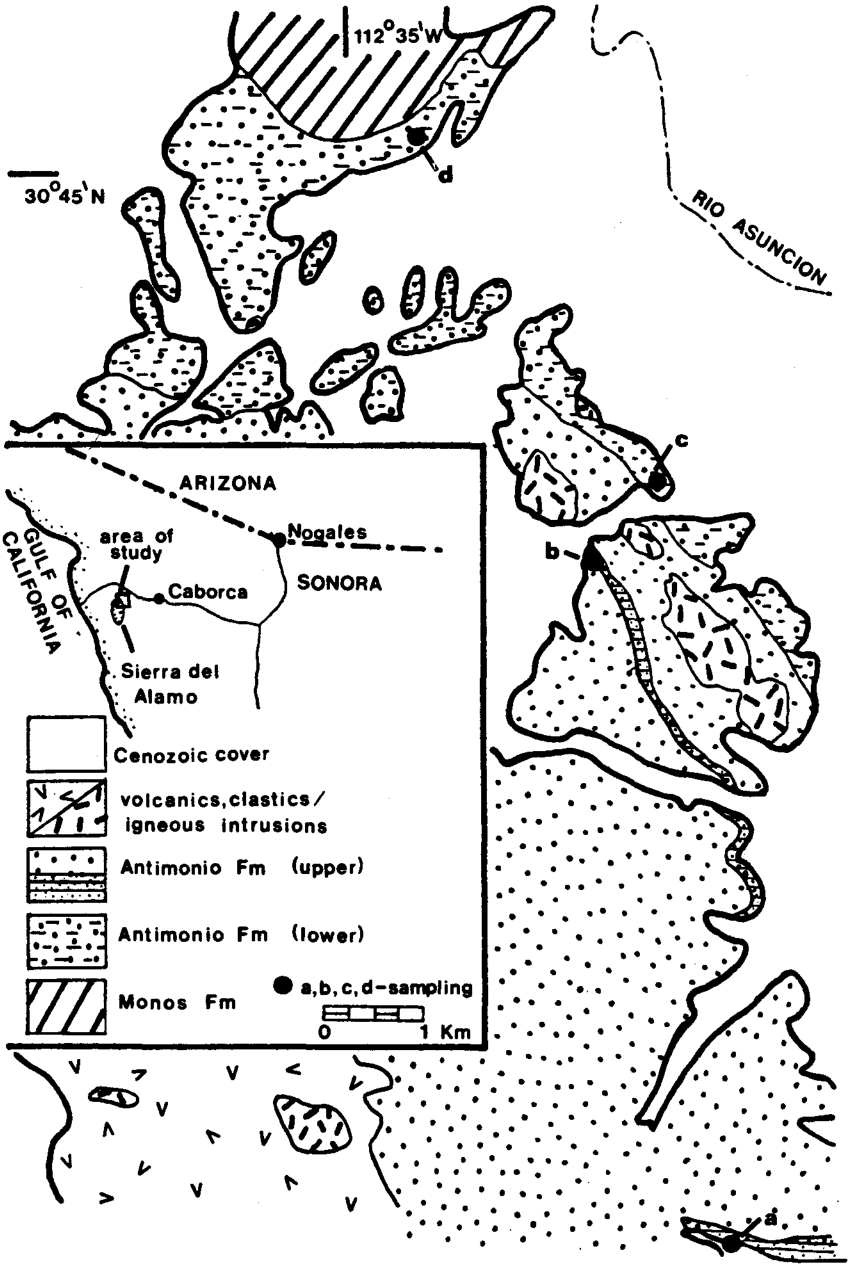

Fig. 1. Generalyzed geology of Sierra del Alamo. Generalized geology (González, 1979) and location of sampled units in the northeastern section of Sierra del Alamo.

PALEOMAGNETIC RESULTS

Oriented rock samples were collected by drilling cores *in situ* using a portable gasoline powered rock drill and by cores obtained from block oriented samples. Cores approximately 2.54 cm in diameter and length were measured using a Superconducting Technology three axis cryogenic magnetometer. NRM intensities for the sampled lithologies ranged from a low of 4.0×10^{-8} to a high of 5.0×10^{-5} emu/gr. Pilot samples were stepwise alternating field demagnetized and stepwise thermally demagnetized to determine the best cleaning technique for the rock samples. Field directions were corrected for the deformation in the area by a simple bedding correction. Zijderveld diagrams (Zijderveld, 1967) were used extensively to interpret the field directions through the demagnetization procedures. Additionally, polished thin-sections were inspected to supplement the data on the magnetic mineralogy of the rock lithologies.

The lowest stratigraphic unit (d) sampled in the Antimonio Formation (Fig. 2) is believed to belong to the basal part of the formation which is comprised of red siltstone. Alternating field and thermal demagnetization techniques showed the primary carrier of remanence for these rocks is hematite. Thermal demagnetization of pilot specimens at 150°, 250°, 350°, 450°, 550°, and 625° C showed thermal treatment by 350° C was effective in removing any spurious components. All specimens were thermally treated at 350°, 450°, and 550° C. The field directions at 350° C were used in the final results, for it was at this temperature that field directions stabilized and minimum dispersion occurred. All field directions measured from this locality were reversed in polarity showing southerly declinations with negative inclinations of generally 20° to 40°.

The next stratigraphic unit (c) sampled in the Antimonio Formation (Fig. 2) is comprised of limestone and sandy limestone, and lies within uppermost units of the lower part of the Antimonio Formation. The magnetizations of the pilot samples were most commonly multicomponent. A large component of the NRM was due to magnetite (titanomagnetite) and a smaller component due to hematite or limonite. Using alternating field demagnetization and Zijderveld diagrams, it was observed that for most of these carbonate samples the medium coercitivity component (5 to 50 millitesla) carried a normal field direction not quite antipodal to those recorded by the red siltstones. This medium coercitivity component is thought to be due to detrital magnetite that recorded an Upper Triassic field direction when these carbonates formed. The field directions carried by this medium coercitivity component were used in the final results of this study.

The lowest samples of Early Jurassic strata collected (b) included beds of shale and sandy limestone (Fig. 2). Fossils from these beds indicate a Hettangian-Sinemurian age (González, 1979). Weak NRM intensities and complex multicomponent behavior during demagnetization showed most of these samples had not preserved

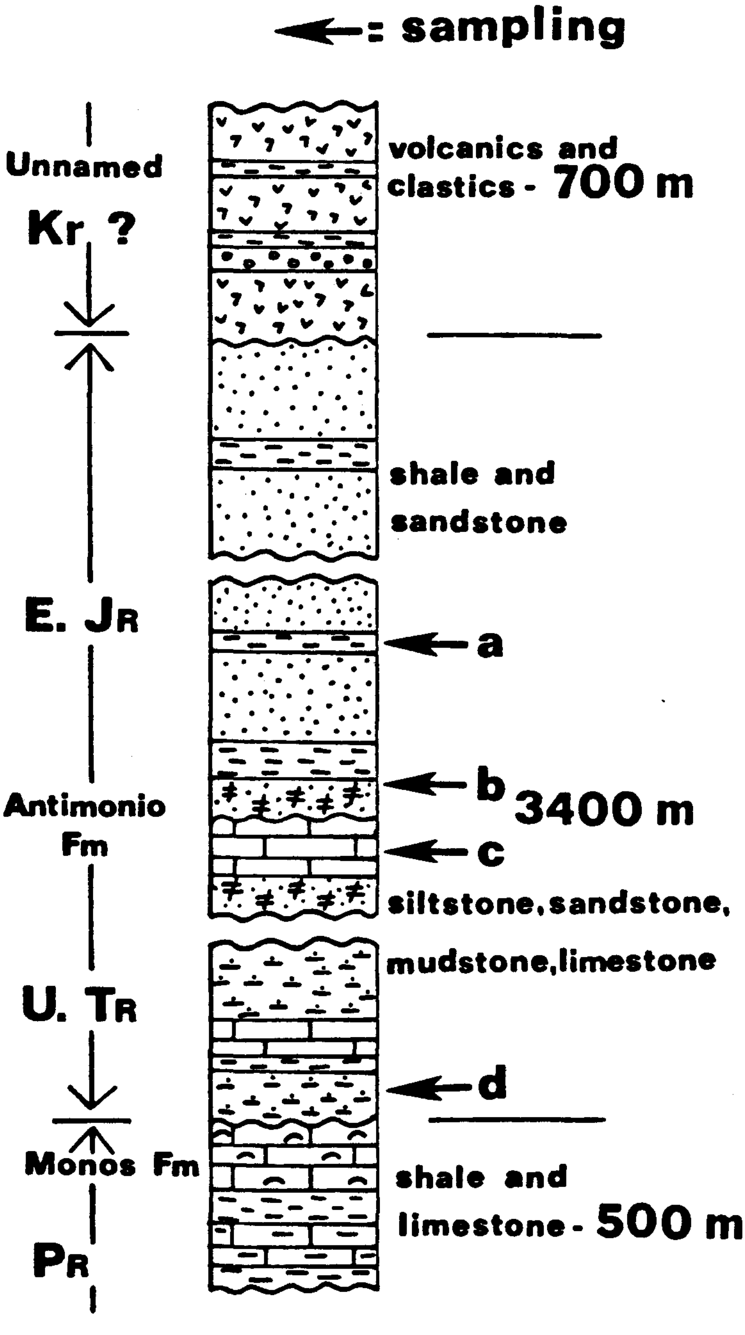

Fig. 2. Generalized stratigraphy of Sierra del Alamo. Generalized stratigraphy of Sierra del Alamo (González, 1979) indicating relationship between sampled units.

an Early Jurassic field direction. A few samples had recorded a reversed direction consistent with the field directions observed at the two other areas already discussed. These were used in the final results of this study.

The highest stratigraphic unit (a) sampled in the Antimonio Formation is blue-gray shale. Preserved ammonites from these beds (González, 1979) indicate an Early Jurassic, Hettangian-Sinemurian age for this stratum. Alternating field and thermal demagnetization procedures showed that for many of these samples, the medium coercitivity component (5 to 50 millitesla) carried a normal field direction consistent with that observed at the other Antimonio Formation sampling areas. The higher coercitivity component (> 50 millitesla) very commonly carried a field direction believed to be a weathering component due to limonite. The medium coercitivity component is believed to be due to magnetite that recorded an Early Jurassic field direction when these shales formed. The field directions carried by this medium coercitivity component were used in the final results of this study.

The field directions obtained from these Upper Triassic-Lower Jurassic lithologies in the Antimonio Formation are plotted in Fig. 3. These directions represent those selected samples, which on the basis of demagnetization procedures and Zijderveld diagrams, are believed to have preserved Upper Triassic-Early Jurassic field directions.

A paleomagnetic pole for the Antimonio Formation was determined by first calculating the mean field direction for each of the four stratigraphic units sampled. These mean field directions are plotted in Fig. 3. The four mean field directions were then given equal weight to determine the Antimonio Formation paleomagnetic pole. The pole was calculated at N 68.0^{o} E 133.1^{o} (N = 4, I = 36.0^{o}, D = 338.7^{o}, α_{95} = 23.8, k = 15.8, dp = 16.1, dm = 24.0) and is plotted in Fig. 4. Table 1 lists the statistics from each stratigraphic unit used in determining this pole. In this method used to determine the Antimonio Formation paleomagnetic pole, the vertical extent of the formation (therefore, time the unit represents) is most fairly taken into account.

Upon inspection of the mean field directions shown in Fig. 3 from the four units, it is observed that in combining results from the four stratigraphic units a Fisherian distribution criterion is not fulfilled. The limestone and sandy limestone of unit c yield a mean field direction that perturbs the Fisherian distribution because of its declination. This may be due to minor structural complexities in the area not recognized. The Antimonio Formation pole was recalculated without the results from unit c and the pole was determined at N 74.8^{o} E 106.2^{o} (N = 3, I = 33.8^{o}, D = 350.0^{o}, α_{95} = 12.1, k = 104.4, dp = 7.89, dm = 11.68). This pole is also plotted in Fig. 4 and is preferred over the first determined because of the

6

Fisherian distribution criterion. Both poles are shown in Figs. 4 and 5 for the discussion of these results.

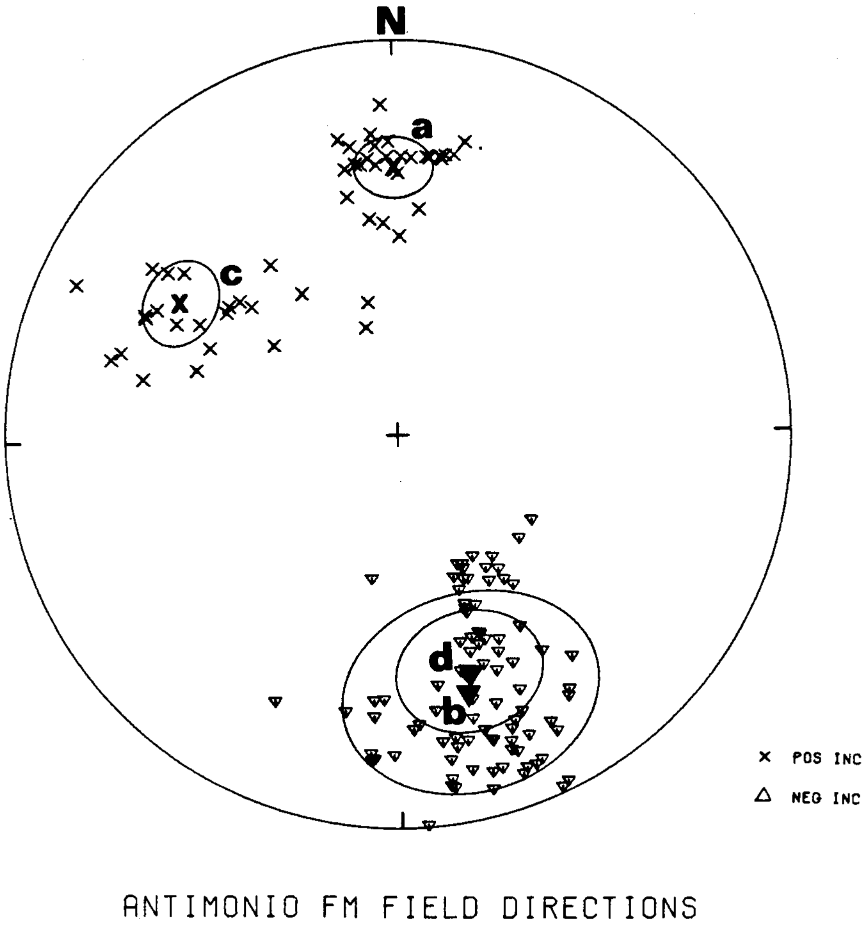

Fig. 3. Antimonio Formation field directions. Equal-area projection of field directions used in calculating pole (N = 32, n = 139). X = lower hemisphere, triangle = upper hemisphere and larger symbols indicate stratigraphic unit means with associated circles of confidence.

Table 1: Data and statistics used to determine the Antimonio Formation paleomagnetic pole.[1]

Unit (in descending stratigraphic order)	Age	Mean I	Mean D	α_{95}	k	N/n	% N repre-[2] sents of total number of samples collected from unit
a) blue-gray shale	L Jr	32.5	0.1	7.2	87.2	6/26	50 %
b) shale and sandy limestone	L Jr	–31.2	165.4	23.6	11.5	5/8	38 %
c) limestone and sandy limestone	U Tr	35.5	302.2	8.3	26.1	13/24	43 %
d) red	U Tr	–37.0	164.4	13.8	17.0	8/81	100 %

(1) I = inclination, D = declination, α_{95} = radius of circle of confidence at the 95 % level, k = precision parameter, N = no. of samples used in this Fisherian analysis, and n = no. of specimens cut from N samples. In the Fisherian analysis for each unit, each sample (N) was given equal weight in the determination of I and D.

(2) The number in this column indicates what percent N represents of the total number of samples collected and demagnetized from the unit.

DISCUSSION AND CONCLUSIONS

Paleomagnetic results from northern Mexico are currently sparse. A previous paleomagnetic pole for the Nazas Formation (Nairn, 1976) from north-central Mexico provides the only other data available for rocks comparable in age to the Antimonio Formation. Most workers (Clemmons and McLeroy, 1966; and Nairn, 1976) assign an Upper Triassic-Lower Jurassic age to the Nazas Formation which is largely comprised of lavas interbedded with shale and siltstone. Thus, the Nazas Formation paleomagnetic pole provides an adequate comparison to the Antimonio Formation paleomagnetic pole for northern Mexico.

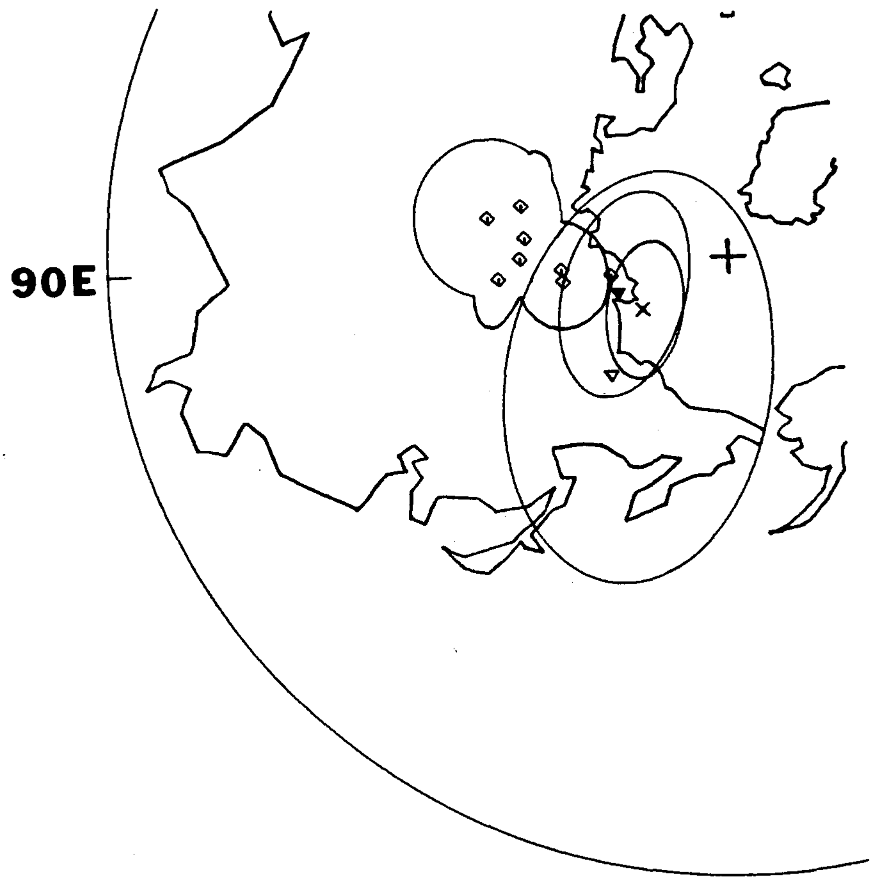

Fig. 4. Northern Mexico Upper Triassic-Lower Jurassic paleomagnetic poles. Northern Mexico Upper Triassic-Lower Jurassic pole positions for the Antimonio Formation (triangles; this study - darkened triangle is preferred pole) and the Nazas Formation (X; Nairn, 1976). Diamonds show North America cratonic Upper Triassic-Lower Jurassic pole positions (Reeve and Helsley, 1972; Steiner and Helsley, 1972 and 1974; McElhinny, 1973; Johnson, 1976; Rigotti, 1976; Irving, 1979; and Smith and Noltimier, 1979).

Fig. 4 shows the Nazas Formation paleomagnetic pole (Nairn, 1976) and the Antimonio Formation paleomagnetic pole (this study). These two poles determined from Upper Triassic-Lower Jurassic formations are in good agreement with one another. At this time, they provide the only available paleomagnetic data for northern Mexico for rocks of these ages.

As seen in Fig. 4, when these poles are compared to North American poles of the same Upper Triassic-Lower Jurassic ages (Reeve and Helsley, 1972; Steiner and Helsley, 1972 and 1974; McElhinny, 1973; Johnson, 1976; Rigotti, 1976; Smith and Noltimier, 1979; and Irving, 1979), they are observed to be slightly displaced to the north from them. It has been suggested by several workers (de Cserna, 1969; Silver and Anderson, 1974; Anderson and Schmidt, 1978 and 1982; Gose and Scott, 1979; Scotese, Bambach, Burton, Van der Voo, and Ziegler, 1979; and Urrutia-Fucugauchi, 1981) that during the existence of Pangaea, northern Mexico once comprised a separate tectonic block. The boundaries of the block were plate margins and delineated northern Mexico from North America and Middle America. During the breakup of Pangaea the northern Mexico block moved differentially with respect to North America. It is not agreed upon by workers exactly what the orientation of the plate boundaries were that delineated the northern Mexico tectonic block, nor is the timing of the differential movement and the cessation of it agreed upon.

The Upper Triassic-Lower Jurassic data provided by Nairn (1976) and this study do not give conclusive support for differential movement of northern Mexico with respect to North America since Upper Triassic-Lower Jurassic time. The data suggests differential movement that is of a small order and in a counterclockwise direction with respect to the apparent polar wandering path of North America. This effect is pronounced by the influence of unit c. If unit c is discarded, it is not clear that any displacement is required. The magnetic results from this unit were judged to be as valid as those from any of the others, however. In any case, the α_{95} circles overlap sufficiently so that they are not statistically different at the 95% confidence level.

A model suggested by Anderson and Schmidt (1982) based upon Silver and Anderson (1974) and Anderson and Silver (1979) reconstructs northern Mexico's position relative to North America during the early Mesozoic (Fig 5). The model proposes 15° of clockwise rotation of northern Mexico relative to North America about the pole of rotation N 52° W 79° to obtain this reconstruction. Therefore the model implies that if North America is kept stationary, the current sites of the Nazas and Antimonio Formations must be rotated 15° clockwise about the pole of rotation N 57° W 79° to be brought into juxtaposition with sites where North

American equivalent units were accumulated. This translates into 700 - 800 km of sinistral offset of the Nazas and Antimonio Formations relative to their North American equivalent units which were originally accumulated juxtaposed to one another.

If the Nazas and Antimonio Formations paleomagnetic poles are rotated the same sense and amount used to obtain the reconstruction of northern Mexico shown in Fig. 5a (15^{o} clockwise about the pole of rotation N 52^{o} W 79^{o}), the resulting paleomagnetic poles have longitudes that are in better agreement with North American poles of comparable ages (Fig. 5b) but with no improvement in latitude. Again, the interpretation depends critically on whether or not unit c is included in the overall pole. However, the paleomagnetic data is suggestive that the present positions of the early Mesozoic rocks of Sierra del Alamo and north-central Mexico are the result of 700 - 800 km sinistral displacement from equivalent rocks of North America that originally accumulated juxtaposed to one another. Models which give similar displacements in the correct sense should also be investigated. Additionally, more geologic and paleomagnetic data need to be compiled before a final model for the tectonic displacement of northern Mexico since the breakup of Pangaea is confirmed and agreed upon.

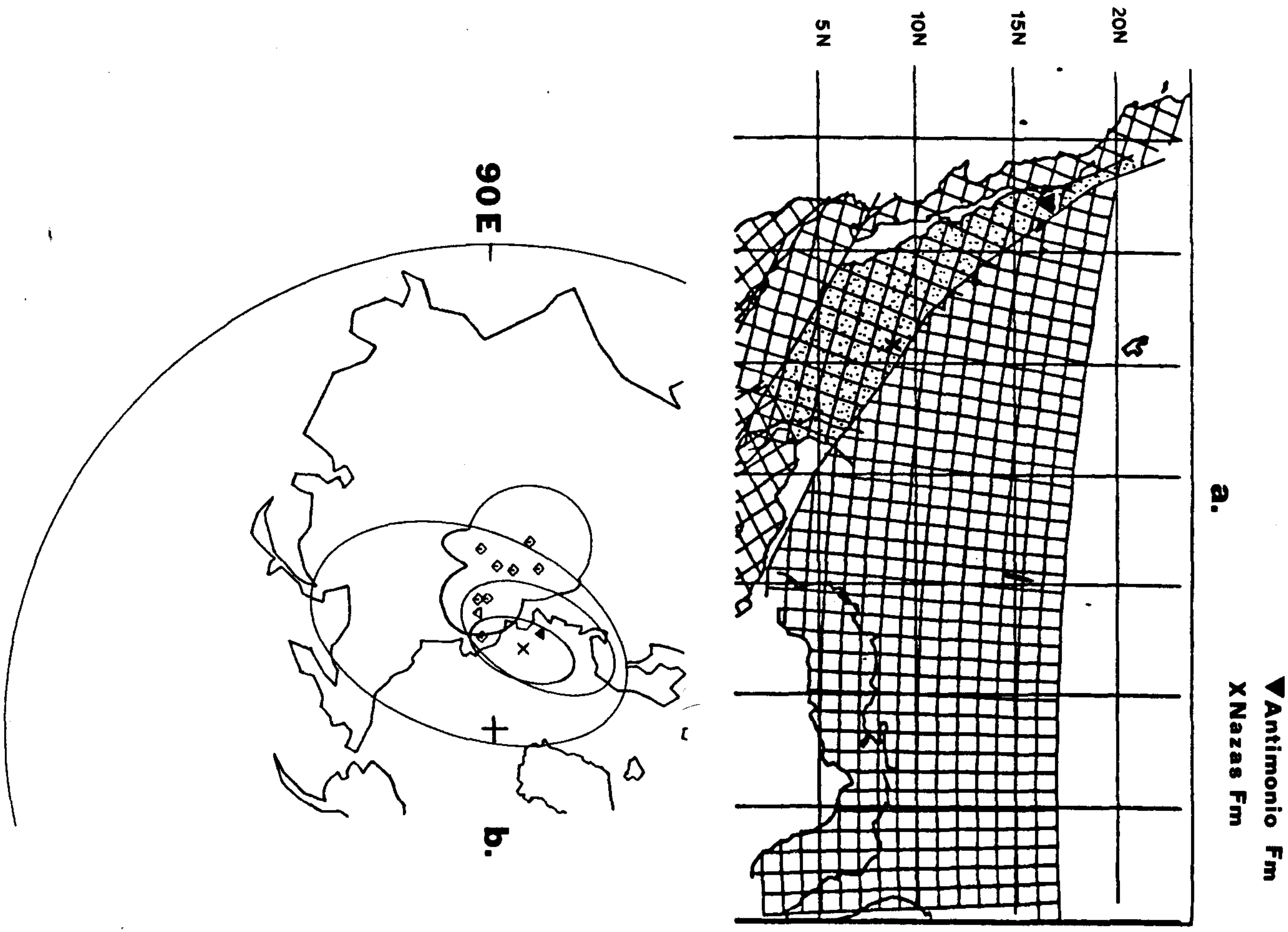

Fig. 5. Northern Mexico Early Mesozoic reconstruction and corresponding paleomagnetic poles. Upper Triassic-Lower Jurassic reconstruction (a) modified from Anderson and Schmidt (1978 and 1982) of northern Mexico (stippled) and its paleoposition relative to North America. Oblique mercator projection with projection pole Irving's (1979) Upper Triassic North American pole, N 68° E 93°. Northern Mexico's rotation is described in the text. Sampling areas for the two formations are indicated on the figure by a triangle and an X. Figure 5b is the same as Figure 4 except the Antimonio Formation paleomagnetic pole (triangles - preferred pole darkened triangle) and the Nazas Formation paleomagnetic pole (X) have been rotated the same sense and amount as the northern Mexico tectonic block (stippled, Figure 5a).

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14

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