geofísica internacional

Paleomagnetism of Plio-Quaternary basalts in the Jalisco block, western Mexico

J.M. Maillol(1), W.L. Bandy(2) and J. Ortega-Ramírez(2)
(1)Dept. de Geologie et Genie, Universitè Laval, Sainte-Foy, Canada
(2)Instituto de Geofísica, UNAM, México, D.F.

Received: January 29, 1996; accepted: October 25, 1996.

RESUMEN

El interior del bloque Jalisco, al occidente de México, está formado por varios grabenes con orientaciones desde NW-SE a NE-SW y asociados con rocas volcánicas recientes que son delimitadas por lineamientos regionales con orientaciones WNW. La geometría de estas estructuras sugiere deformaciones de tipo translación diestra, consistente con el movimiento NW del bloque Jalisco con respecto a la placa de Norte América. Se realizó un estudio paleomagnético en los grabenes de Mascota y Talpa de Allende, y en el campo volcánico de San Sebastián. Resultados de 16 sitios estudiados (D=354.6ø, I=33.3ø, k= 18.1, a95= 8.9ø), concuerdan con la dirección paleomagnética esperada para Norte Am&eaute;rica. Por consiguiente, no se delinea significativamente algún desplazamiento o rotación reciente. Sin embargo, la dispersión de medias paleomagnéticas para los sitios es mayor que la esperada, sugiriendo que rotaciones diferenciales pudieron ocurrir dentro del bloque. El volcanismo dentro del graben de Talpa de Allende y el de la parte sur del graben de Mascota, es probablemente anterior a 0.78 Ma, apoyado por el descubrimiento de cuatro flujos de lava con magnetizaciones reversas.

PALABRAS CLAVE: Bloque Jalisco, paleomagnetismo.

ABSTRACT

The interior of the Jalisco block, western Mexico, is disrupted by several NW-SE to NE-SW oriented grabens and associated recent alkaline volcanics which are bounded by WNW oriented regional lineaments. The geometry of these features suggests deformation from a right-lateral shear couple, consistent with NW motion of the Jalisco block relative to the North American plate. A paleomagnetic study was carried out in the Mascota graben, the Talpa de Allende graben, and the San Sebastián volcanic field. Results from 16 sites (D=354.6ø, I=33.3ø, k= 18.1, a95= 8.9ø) agree with the expected North America directions. Therefore, no significant recent regional displacement or rotations were found. However, the dispersion of paleomagnetic site means is greater than that expected from secular variation alone, suggesting that differential block rotations may have taken place. Volcanism within the Talpa de Allende graben and the southern part of the Mascota graben is probably older than 0.78 Ma as evidenced by the discovery of four reversely magnetized lava flows.

KEY WORDS: Jalisco Block, paleomagnetism.

1. INTRODUCTION

The Jalisco block, western Mexico, lies southwest of the Tepic-Zacoalco rift and northwest of the Colima rift (Figure 1). It is disrupted by several NW-SE to NE-SW oriented grabens, including the Mascota and Talpa de Allende grabens, which contain both recent alkaline and calcalkaline volcanic rocks (Luhr et al., 1989; Lange and Carmichael, 1990, 1991; Righter and Carmichael, 1992; Wallace et al., 1992). Rifting and associated volcanism has been attributed to rifting of the Jalisco block away from the North American plate; the rifting would involve a NW movement of and NW-SE stretching of the Jalisco block relative to the North American plate (Luhr et al., 1985; Nieto-Obregón, 1985; Serpa et al., 1989; Righter and Carmichael, 1992; Wallace et al., 1992; Bandy, 1992; Maillol and Bandy, 1994b; Kostoglodov and Bandy, 1995).

Newly published Landsat images (INEGI, 1995) show structural features in the NE half of the Jalisco block that are consistent with horizontal, right-lateral, shear (Figures 2 and 3). Much work remains to be done in order to verify the existence of a shear couple corresponding to this motion and to determine the timing and details of the associated deformation. As a first step in this work, paleomagnetic data was collected within the Talpa de Allende and Mascota grabens.

2. GEOLOGICAL SETTING

The main rift systems in western Mexico are the Tepic-Zacoalco rift and the Colima rift (Figure 1). The Tepic-Zacoalco rift is a broad, NW oriented, topographically low region consisting of several grabens (Allan, 1986; Allan et al., 1991; Ferrari et al., 1994). It is bounded to the northeast by the Río Grande de Santiago and to the southeast by the Río Ameca. The Colima rift extends from its intersection with the Tepic-Zacoalco rift, south of Guadalajara, to the Middle America trench near Manzanillo (Allan, 1986; Bourgois et al., 1988). These two rifts, along with the Middle America trench, bound the area of western Mexico previously referred to as the Tepic-Colima Structural Block (Allan, 1986), but now commonly known as the Jalisco Block (e.g., Allan et al., 1991).

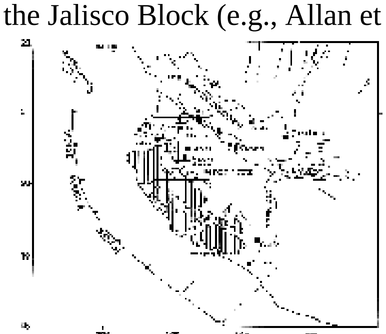


Fig. 1. Location map of study area. Hatched area represents surface exposures of Cretaceous granites. The two small boxes outline the sampling areas shown in more details in Figures 4 and 5; the larger box outlines the area covered by the Landsat image shown in Figure 2. Abbreviations are: Rgs: Río Grande de Santiago; Ra: Río Ameca.

Paleomagnetism in the Jalisco block, western Mexico

The Jalisco block exhibits two distinct surface lithologic zones (Figure 1). Southwest of Sierra Cacoma, in the coastal region, the surface lithology is predominantly Cretaceous granitoids (Schaaf et al., 1993, 1995; Michaud et al., 1994); whereas northeast of the Sierra Cacoma Cretaceous to early Cenozoic silicic ash flows predominate (Righter et al., 1995). These two zones also exhibit structural differences. The northeast zone is disrupted by several extensional structures, including the Mascota and Talpa de Allende grabens, which contain numerous Plio-Quaternary basalts (Luhr et al., 1989; Lange and Carmichael, 1990, 1991; Righter and Carmichael, 1992; Wallace et al., 1992). In contrast, the southwest zone is relatively undisrupted and lacks significant surface exposures of recent basalts (INEGI, 1988).

Three hypotheses have been proposed to explain the presence of extensional features and associated basaltic magmatism in the northeastern Jalisco block. According to the first hypothesis they are related to a trenchward migration of subduction-related arc magmatism. Pardo and Suárez (1993, 1995) located the top of the Wadati-Benioff zone at approximately 100 km depth under the Mascota and Talpa de Allende grabens; this depth is typical for magma generation by melting of subducting slabs. The second hypothesis proposes that they are due to rifting of the Jalisco Block away from the North American plate; the rifting being caused by NW motion and NW-SE stretching of the Jalisco block relative to the North American plate (Luhr et al., 1985; Serpa et al., 1989; Righter and Carmichael, 1992; Wallace et al., 1992; Bandy, 1992; Maillol and Bandy, 1994b; Kostoglodov and Bandy, 1995). The third hypothesis also proposes that the extension is due to rifting of the Jalisco Block away from the North American plate; unlike the second proposal, however, this hypothesis proposes a SW motion of the Jalisco Block relative to the North American Plate (Johnson and Harrison, 1989, 1990; Rosas-Elguera et al., 1993; Ferrari et al., 1994).

Implicit in the second hypothesis is a right lateral shear zone which should develop between the Jalisco Block and the North American plate. Past studies have concentrated entirely within the Tepic-Zacoalco rift (Nieto-Obregón et al., 1985; Barrier et al., 1990; Michaud et al., 1991; Garduño and Tibaldi, 1991; Ferrari et al., 1994; Rosas-Elguera et al., 1993; Ferrari, 1995) where no conclusive evidence for a recently active, regional, right-lateral shear system has been found. Instead, these studies found that NE-SW directed extension predominates the recent deformation within the Tepic-Zacoalco rift. These results led to the proposal of a SW motion of the Jalisco block relative to the North American plate.

Recent Landsat images (Figure 2; see Figure 3 for interpretation) suggest that the right-lateral shear zone may not be located within the Tepic-Zacoalco graben as previously supposed, but may instead be located within the northeast zone of the Jalisco Block. Figure 3 shows at least three prominent WNW lineaments. The southern-most lineament coincides with the Sierra Cacoma (herein termed the 'Cacoma' lineament) which extends westward to the southern margin of Bahia de Banderas. The central lineament (herein termed the 'Mascota' lineament) intersects

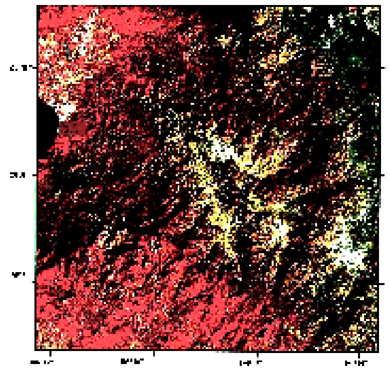


Fig. 2. False color, TM, Landsat image (after INEGI, 1995). Data was collected between January and April, 1993.

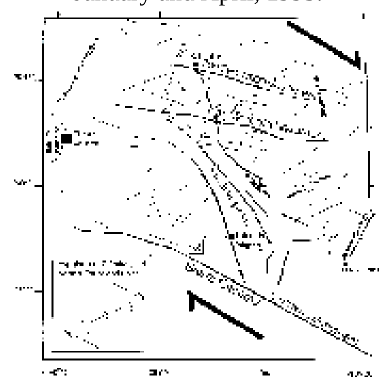


Fig. 3. Interpretation of lineaments observed on Landsat image (Figure 2). Shaded boxes indicate locations of apparent right lateral faulting. Inset illustrates the expected orientations of structural features formed within a horizontal, right-lateral shear couple (after Harding, 1974).

the northern end of the Mascota graben and extends westward towards the Puerto Vallarta graben. The northernmost lineament (herein termed the San Sebasti n lineament) is the least apparent of the three main lineaments; it appears to trend through the town of San Sebastián, towards the northern end of the Puerto Vallarta graben.

The Talpa de Allende and Mascota grabens lie between the Cacoma and Mascota lineaments. Their orientation relative to the bounding lineaments is consistent with extensional deformation within a horizontal, right-lateral shear couple (see inset, Figure 3). Northeast trending mountains (the Sierra Comalito to the east and an unnamed range to the west) are also observed between the Cacoma and Mascota lineaments. Their orientation is consistent with folding and thrusting in response to a horizontal, right-lateral shear couple.

Between the Mascota and San Sebasti n lineaments, a prominent NNW normal fault extends from the northern end of the Mascota graben to the town of San Sebastián (Figure 3). Like the Mascota and Talpa de Allende grabens, this normal fault exhibits the expected orientation for extensional features within a right-lateral shear couple.

Thus, the spatial relationships of the deformational features in this area are consistent with deformation formed in response to a horizontal, right-lateral shear couple. Yet the evidence for right-lateral motion along the lineaments is sparse, possibly because of the lack of detailed structural studies in the area. However, an apparent right lateral offset of a NE trending ridge is observed on the Landsat image at 20ø21'N, 104ø55'W, just north of the Cacoma lineament. This right-lateral offset still awaits field confirmation. Another suggestion of right-lateral motion was encountered during the collection of the paleomagnetic data used in this study. A small, N40W oriented, strike-slip fault was encountered at site MAS-5 near the town of Mascota (Figure 3). Slickensides on one of the auxiliary fault planes dip 26ø to the NNW and the roughness of the striations suggest right-lateral motion. Right-lateral motion is further suggested by the slight clockwise rotation (13±8ø) of the Puerto Vallarta batholith, just west of the study area, determined from a paleomagnetic study of 22 sites within the Cretaceous granitoids of this batholith (Böhnel et al., 1989). Lastly, a young strike-slip fault offsetting a minette lava flow in the Talpa graben has been reported (Carmichael et al., 1996), although no details were presented.

The age of the lineaments is uncertain. Radiometric dating of basalts within the Mascota graben range from 0.061 to 0.489 Ma (Carmichael et al., 1996); Lange and Carmichael (1991) report radiometric ages ranging from 0.48 to 1.52 Ma for the San Sebastián region; Righter et al. (1992) report ages from 0.64 Ma to 3.4 Ma for the Atenguillo graben, at the eastern edge of the Landsat image (Figure 2). Three reversely magnetized flows in the Talpa de Allende graben, found in the present study, indicate that the onset of volcanism there probably occurred prior to 0.78 Ma. These results suggest recent tectonic activity within this area. If it is related to the apparent right-lateral shear couple, as we propose, then the shear couple has been active for at least 3.4 Ma. More dating is needed, particularly for the basalts of the Talpa de Allende graben, but the available data suggests a WNW migration of basaltic volcanism from the Atenguillo graben to the Mascota/ Talpa de Allende/San Sebastián areas. This migration would have started roughly 1.5 Ma ago.

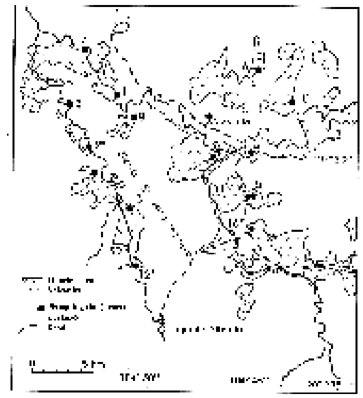
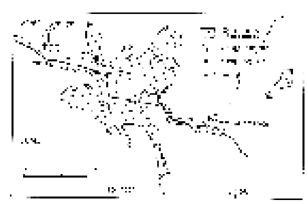
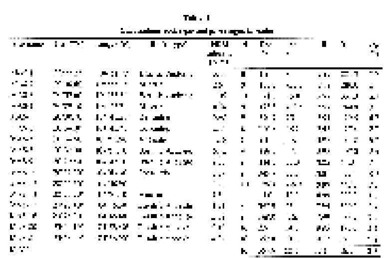


Fig. 4. Simplified geological map of the sampling area illustrating site locations in the Mascota and Talpa de Allende grabens. Asterisks by site numbers indicate reversed polarity sites.



Simplifed geological map of the sampling area ilustrating site locations within the San Sebastian volcanic field



Site locations, rock types and paleomagnetic results

3. SAMPLING

The paleomagnetic data for this study were collected from volcanic flows in the Talpa de Allende and Mascota grabens (Figure 4) and in the San Sebastián volcanic field (SSVF, Figure 5). Despite overall good volcanic outcrops, poor access and the need to find undisturbed rocks for paleomagnetic sampling limited our options to 19 sites. Three sites proved unsuitable as they yielded widely scattered paleomagnetic directions most likely due to sampling of loose blocks. The remaining 16 sites represent as many distinct flows. The results of six of these sites (MAS1 through MAS6) have been previously reported by us (Maillol and Bandy, 1994a). Nine sites are located in the Mascota graben, five in the Talpa de Allende graben and two in the SSVF. Table 1 gives the locations and rock types of the samples as determined by Lange and Carmichael (1990). Locality MAS12 posed a problem since it was mapped by Lange and Carmichael as a minette belonging possibly to the same flow as MAS13; but these sites have opposite polarities and different magnetic hysteresis loops (Figure 6). Their aspect is also different. We conclude that they may represent different flows and lithologies.

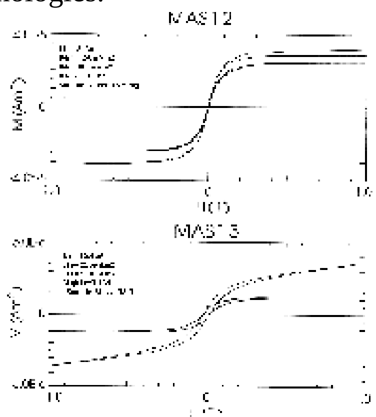


Fig. 6. Magnetic hysteresis loops for MAS12 and MAS13.

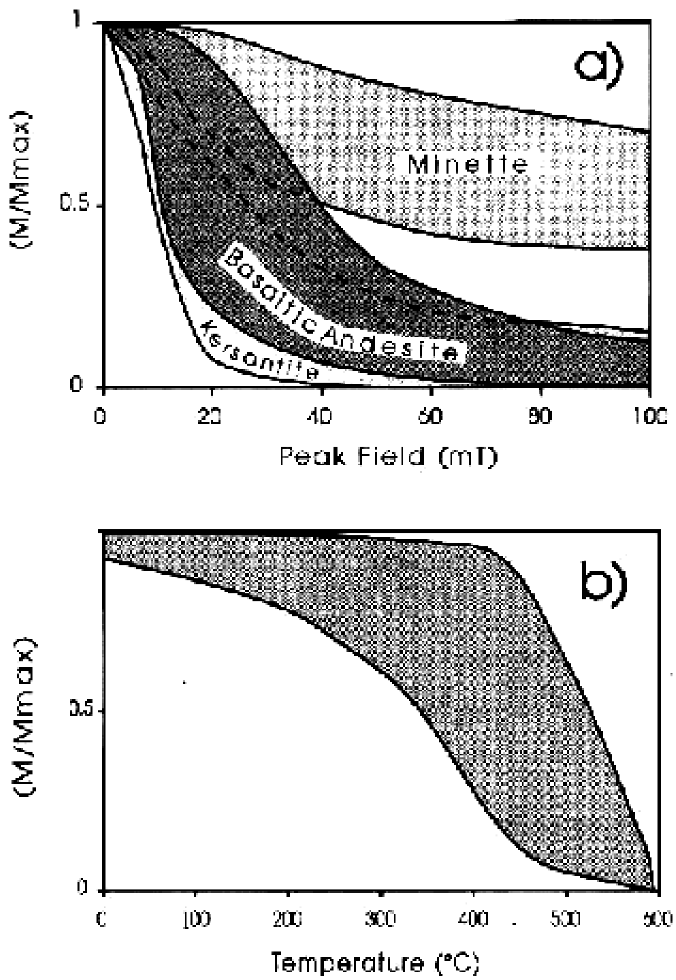


Fig. 7. (a) Envelopes of normalized AF demagnetization curves for the three main lava types. Note the higher coercivity of minettes. (b) Envelope of thermal demagnetization curves.

Standard cores, 2.5 cm in diameter and 6 to 10 cm long, were drilled using a portable gas powered corer and were oriented with an inclinometer and magnetic compass. Local magnetic declinations were measured by taking sun bearings at each site. These values were used to correct magnetic readings. The cores were subsequently cut in the laboratory into 2.5 x 2.2 cm cylindrical specimens.

4. PALEOMAGNETIC RESULTS

For each of the sixteen sites, two to four specimens were chosen for a detailed pilot experiment involving both alternating field (AF) and thermal demagnetization. AF demagnetization was carried out with a Sch"nstedt demagnetizer and thermal demagnetization with a Magnetic Measurements thermal demagnetizer. All remanent magnetizations were measured with a Geofysika JR5 spinner magnetometer.

As evidenced by the AF demagnetization curves (Figure 7a), basaltic andesites and most of the potassic lavas exhibit coercivities well below the peak field of the AF demagnetizer; the minettes on the other hand show higher coercivities relative to the other samples. Thermal demagnetization curves do not show a significant difference between different rock types (Figure 7b). The disappearance of all magnetization below 600øC along with the low coercivities suggests titanomagnetite as the dominant remanence carrier. This is also indicated by the saturation magnetizations of MAS12 and MAS13 which were 1.6 and 0.12 Am2/Kg, respectively (Figure 6). The higher coercivity of the minettes thus appears to be due to their smaller grain size.

All pilot specimens exhibit a simple behavior during demagnetization, which is characteristic of at mos

After the pilot experiment, single specimens from each of the remaining samples were routinely AF demagnetized at 4 or 5 different steps, between 30 mT and 90 mT. Characteristic directions were calculated using principal component analysis, by least squares line fitting of at least three points (Kirschvink, 1980). The site mean directions are given in Table 1 and their equal-area projections are shown in Figure 10. The decision to use one specimen from each sample was based on a comparison of the results obtained using all specimens (see Table 2, Maillol and Bandy, 1994a), versus those obtained using a single specimen (Table 1, this study) from sites MAS1 through MAS6. This comparison yielded only minor differences between the two procedures.

The most immediate result is that four sites have definitely reverse polarities (MAS2, MAS4, MAS12 and MAS16), while the remaining twelve are clearly normal. Three of the reverse sites are from the Talpa de Allende graben; the fourth one is the southernmost site from the Mascota graben. The presence of these reverse flows indicates that the age of the volcanism may extend at least back to the Matuyama chron (>0.78 Ma). The mean direction for the sixteen sites is D=354.6ø, I=33.3ø, k=18.1, a95=8.9ø. As mentioned above, the rocks are thought to be recent, and the paleomagnetic results support this idea. If no regional or local tectonic rotations were involved, one would expect the mean paleomagnetic direction to coincide with that of the geomagnetic axial dipole field. For a mean latitude of 20ø30'N, this corresponds to D=0ø and I=36.8ø, which differs by 5.4ø in declination and 3.5ø in inclination from the observed paleomagnetic direction. These differences are not statistically significant since the expected direction of the dipole field falls well within the 95% confidence cone of the mean paleomagnetic direction.

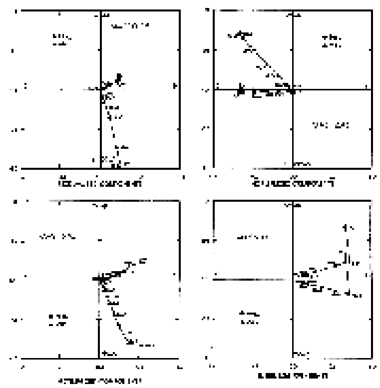


Fig. 8. Examples of normalized orthogonal component plots showing the behavior of 3 normal and 1 reverse (MAS12A3) samples during AF demagnetization.

Thus the mean direction is not significantly different from the expected direction. However, a fairly large scatter of the directions is observed (amounting to an angular standard deviation of 18.4ø). This is slightly higher than expected for secular variation at this latitude. We find a standard deviation of 14ø as determined from the paleosecular variation Model-G of McFadden et al. (1988) which could be as low as 11ø if this area exhibits lower-than-predicted paleosecular variations as in the Basin of Mexico (Urrutia-Fucugauchi, 1995). The low within-site dispersions (Table 1) shows that this scatter cannot be due to uncertainties in the determination of paleomagnetic directions at the site level. Most of the spread of the site mean directions is likely caused by secular variation, but because of its large amplitude we cannot entirely rule out dispersion associated with tectonic rotations of small fault blocks. To investigate this possibility, the sites were grouped according to location, geological composition and magnetic polarity, and paleomagnetic statistics were determined for the various groupings. The result of this analysis is shown in Table 2 and Figure 11. The first step consists in recomputing the mean after the two sites located in the SSVF were rejected because of their remoteness from the main study area. This hardly changed the mean direction, as the directions corresponding to these two sites were very close to the mean. Next, results were obtained separately for the

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
ALL Sites	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[illegible]

Mascota graben and for the Talpa de Allende graben. We found that the two means do not differ significantly and that other two sub-groups do not have lower dispersions. Comparing normal to reverse sites yielded similar results. The lower standard deviation of the reverse sites may be due to the small number of data points (4 sites) or to their shorter time span. Lastly, sites were grouped according to rock type, assuming that different lava types were erupted at different periods and might have been affected differently by local tectonics. Now a larger difference was found between the two site means, especially in inclination (7.4ø), but it is not statistically significant. None of these groupings constitutes any direct evidence for differential rotations, though the result is inconclusive because of the small number of sites in each group.

5. DISCUSSION AND CONCLUSIONS

Recent structural studies in the northwest Tepic-Zacoalco rift suggest a complex deformational history. They point to deformation associated with left-lateral strike slip motion between 14.5 and 11.5 Ma, right-lateral strike-slip motion between 12 Ma and 9 Ma, and more recently, NE-SW extension (Garduño and Tibaldi, 1991; Ferrari et al., 1994; Ferrari, 1995). The predominance of recent NE-SW extension in the rift system suggests either that the earlier assumption of NW motion of the Jalisco Block relative to the North American plate is incorrect, or that the right-lateral motion is accommodated elsewhere. For example, the Tepic-Zacoalco rift might not be the kinematic boundary between the Jalisco Block and the North American plate.

The geometry of the structural features from the Landsat image of Figure 2 suggests that the Mascota, Talpa de Allende, Puerto Vallarta, and Atenguillo grabens may well be the kinematic boundary between the Jalisco Block and the North American plate. This suggestion is appealing, though many questions remain to be answered before it can be confirmed. These questions include: (1) What is the motion along the major WNW oriented lineaments? (2) Does the deformation involve local rotation or tilting of crustal units? (3) When was the system initiated and is it still active at present? (4) Can the rate of relative motion between the Jalisco Block and the North American plate be determined from the deformational features of the apparent right-lateral shear couple?

A major objective of this study was to determine the type of motion along the boundary lineaments from the

Fig. 9. Normalized orthogonal component plots and equal area projections (insets) showing the behavior of a high coercivity specimen during successive AF and thermal demagnetization. The secondary component removed by thermal treatment is a viscous magnetization acquired after the initial AF treatment, but no significant difference can be observed between the end points reached after both treatments.

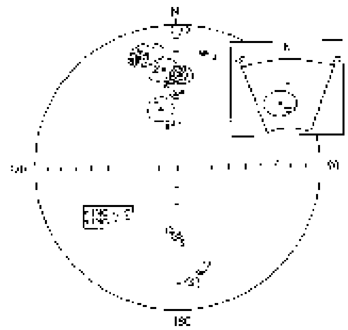


Fig. 10. Equal area projection of site mean paleomagnetic directions and their 95% confidence cones. Inset shows the general mean direction and its 95% confidence cone compared to the direction of the present axial dipole field (cross) at the average site location.

Sense of rotation of the basaltic rocks located within the shear couple, the premise being that the rocks would exhibit a clockwise rotation if the right-lateral shear couple had been recently active. We find, however, that the mean pole is located 5.4ø counterclockwise from the expected pole, which would appear to preclude a recently active right-lateral shear couple. However, the uncertainty (a95=8.9ø) in the location of the pole could still allow up to 3.5ø of clockwise rotation. Thus, our results neither confirm nor rule out a presently active right-lateral shear couple in this area.

Concerning the second question, block faulting and associated tilts and rotations are known to occur in subduction-related deformation zones (Jarrard, 1986), and complex patterns have been observed in the TMVB to the east (Nieto-Obregon et al., 1992; Soler-Arechalde and Urrutia-Fucugauchi, 1994; Urrutia-Fucugauchi and Rosas-Elguera, 1994). In our study, the higher-than-expected angular dispersion of the site means (angular standard deviation = 18.5ø) might well result from differential rotations or tilting of small blocks. The apparent lack of a geographical pattern in the dispersion further suggests that the size of the blocks must be of the order of the average distance between sampling sites (i.e. about 5 km). Such small blocks are suggested by the spacing of the lineaments observed in the Landsat image; however, further study is needed to determine if these features are the result of recent tectonic activity in the Mascota and Talpa de Allende grabens. We observed a vertical fault cutting the lava flow at site MAS5, in the Mascota graben (Figures 3 and 4) which suggests the existence of recent tectonic activity. However, a high dispersion of paleomagnetic directions could also be caused by a local, slightly anomalous behavior of the geomagnetic field, and cannot by itself be considered as proof of differential rotations or tilts. A denser distribution of sampling sites would be needed to attempt to discern a pattern in the dispersion. Unfortunately, field conditions make it unlikely that many more suitable sites can be found in the area.

Four reversely magnetized flows were found in the Talpa de Allende and Mascota grabens. This may have a direct bearing on the time of fault initiation, assuming that faulting triggered the melting of the underlying mantle providing an easy passage of the melt to the surface. The presence of basaltic magmas does not prove crustal extension, but an association between basaltic volcanism and crustal extension in convergence zones has been noted (Lange and Carmichael, 1991). If this association holds for the Jalisco area, the presence of reversed sites in the Mascota graben and Talpa de Allende grabens suggests that the onset of faulting in these grabens may have occurred prior to 0.78 Ma instead of 0.5 Ma as previously proposed (Wallace et al., 1992). The radiometric ages in the San Sebastián volcanic field and in the Atenguillo graben also suggest that the system has been active since at least 3.5 Ma and that faulting has migrated westward at about 1.5 Ma. We cannot rule out the possibility that extension may have reactivated older faults and that basaltic magmas may have risen along these faults. Thus, the apparent right-

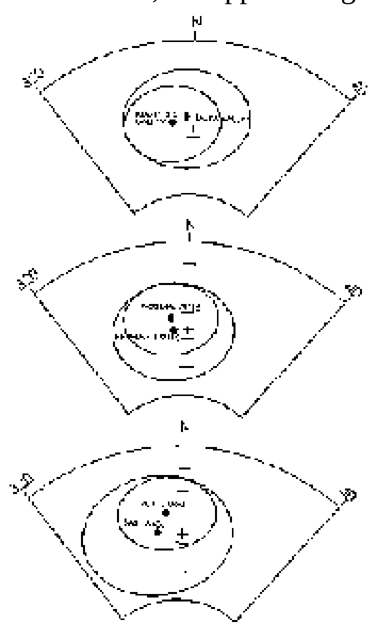


Fig. 11. Equal area projections of sub-groups mean paleomag-netic directions and their 95% confidence cones. Cross indicates the present axial dipole field direction. See text and Table 3 for explanations about the sub-groups.

Lateral deformation may have formed between 12 and 9 Ma, when right-lateral motion is proposed to have occurred in the Tepic-Zacoalco rift (Ferrari, 1995).

The basalts analyzed in the present study span the last 1.5 Ma and these rocks could have rotated only up to 3.5ø clockwise during this time. Thus we may set an upper limit to the rate of right-lateral motion between the Jalisco Block and the North American plate. A 2 km relative displacement of the blocks on either side of a 40 km wide right-lateral shear couple would produce a 3.5ø rotation about a vertical axis located in the center of the shear zone between the Cacoma and San Sebastián lineaments. The maximum allowable rate of right-lateral relative motion of the blocks to either side of the shear zone is, therefore, 1.6 mm/yr. This rate is consistent with previous proposals of the rate of relative motion between the Jalisco block and the North American plate (Nieto-Obregón et al., 1985; Allan et al., 1991; Humphreys and Weldon, 1991; Bandy and Pardo; 1994). Note that the relative motion between the Jalisco Block and the North American plate is assumed to be taken up mainly across the shear zone. Given the lack of evidence for recent right-lateral deformation in the northwest part of the Tepic-Zacoalco rift, this assumption seems reasonable.

ACKOWLEDGMENTS

This paper has benefitted from reviews by, and discussions with, Kevin Righter, Cinna Lomnitz, Jaime Urrutia-Fucugauchi, and Roberta Molina-Garza. We also thank Dominique Maillol for her assistance both in the field and in the laboratory. This work was funded by CONACYT grant #1823-T9211.

BIBLIOGRAPHY

ALLAN, J.F., 1986. Geology of the Northern Colima and Zacoalco grabens, southwest Mexico: Late Cenozoic rifting in the Mexican Volcanic Belt. Bull. Geol. Soc. Am., 97, 473-485.

ALLAN, J. F., S. A. NELLON, J. F. LUHR, I. S. E. CARMICHAEL, M. WOPAT and P. J. WALLACE, 1991. Pliocene-Holocene riftin and associated volcanism in southwest Mexico: an exotic terrane in the making. In: The Gulf and Peninsular Province of the California's, edited by J.P. Dauphin and B.R.T. Simmoneit, pp. 425-445, American Association of Petroleum Geologists, Mem., 47, AAPG, Tulsa, OK.

DY, W. L., 1992.logical and geophysical investigation of the Rivera-Cocos plate boundary: Impli-cations for plate fragmentation. Ph.D. Dissertation, Texas A&M University, College Station, Texas, USA, 195pp.

DY, W. and M. PARDO, 1994.tistical examina-tion of the existence and relative motion of the Jalisco and Southern Mexico blocks. Tectonics, 13, 755-768.

BTMN, E., J. BOURGOIS and F. MICHAUD, 1990. The active Jalisco triple junction rift system. C.R. Acad. Sci. Paris, Serie II, 310, 1513-1520.

EL, H., L. ALVA-VALDIVIA, S. GONZALEZ-HUESCA, J. URRUTIA-FUCUGAUCHI, D. J. MORAN-ZENTENO and P. SCHAAF, 1989. Paleomagnetic data and the accretion of the Guerrero Terrain, Southern Mexico continental margin. In: Hillhouse, J.W. (ed.): Deep structure and past kinematics of accreted terranes, Monograph 50, AGU, Washington, D.C., pp. 73-92.

BOURGOIS, J., V. RENARD, J. AUBOUIN, W. BANDY, E. BARRIER, T. CALMUS, J.-C. CARFANTAN, J. GUERRERO, J. MAMMERICKX, B. MERCIER DE LEPINAY, F. MICHAUD and M. SOSSON, 1988. Active fragmentation of the North American plate: Offshore boundary of the Jalisco Block off Manzanillo. C.R. Acad. Sci. Paris, S,rie II, 307, 1121-1130.

CARMICHAEL, I.S.E., R.A. LANGE and J.F. LUHR, 1996. Quaternary minettes and associated volcanic rocks of Mascota, western Mexico: a consequence of plate extension above a subduction modified mantle wedge. Contrib. Mineral Petrol., 124, 302-333.

FERRARI, L., 1995. Miocene shearing along the northern boundary of the Jalisco block and the ope

FERRARI, L., G. PASQUAR_, S. VENEGAS, D. CASTILLO and F. ROMERO, 1994. Regional tectonics of western Mexico and its implications for the northern boundary of the Jalisco block. Geofís. Int., 33, 139-153.

GARDU¥O, V. H. and A. TIBALDI, 1991. Kinematic evolution of the continental active triple junction of the western Mexican Volcanic Belt. C.R. Acad. Sci. Paris, S‚rie II, 312, 135- 142.
NG, T. P., 1974 Petroleum traps associated with wrench faults. Am. Assoc. Petrol. Geol. Bull., 58, 1290-1304.
HUMPHREYS, E. D. and R. J. WELDON II, 1991. Kinematic Constraints on the Rifting of Baja California. In: The Gulf and Peninsular Province of the California's, edited by J.P. Dauphin and B.R.T. Simmoneit, pp. 217-229, American Association of Petroleum Geologists, Mem., 47, AAPG, Tulsa, OK.
INEGI, 1995. Espaciomapa, Puerto Vallarta Quad, scale 1:250,000, sheet F13-11, Aguascalientes, Mexico.
INEGI, 1988. Carta Geológica, Puerto Vallarta Quad, scale 1:250,000, sheet F13-11, Mexico, D.F., Mexico.
JARRARD, R. D., 1986. Relations among subduction parameters. Rev. Geophys., 24, 217-284.
JOHNSON, C.A. and C.G.A. HARRISON, 1989. Tectonics and volcanism in central Mexico: A Landsat thematic mapper perspective. Remote Sens. Environ., 28, 273-286.
JOHNSON, C.A. and C.G.A. HARRISON, 1990. Neo-tectonics in central Mexico. Phys. Earth Planet. Inter., 64, 187-210.
KIRSCHVINK, J.L., 1980. The least-squares line and plane and the analysis of paleomagnetic data. Geophys. J. R. Astr. Soc., 62, 699-718.
KOSTOGLODOV, V. and W. BANDY, 1995. Seismotec-tonic constraints on the convergence rate between the Rivera and North American plates. J. Geophys. Res., 100, 17,977-17, 989.
LANGE, R.A. and I.S.E. CARMICHAEL, 1990. Hydrous basaltic andesites associated with minette and related lavas in Western Mexico. J. Petrol., 31, 1225-1259.
LANGE, R.A. and I.S.E. CARMICHAEL, 1991. A potassic volcanic front in Western Mexico: The lam-prophyric and related lavas of San Sebastian. Geol. Soc. Am. Bull., 103, 928-940.
LUHR, J. F., S. A. NELSON, J. F. ALLAN and I. S. E. CARMICHAEL, 1985. Active rifting in Southwestern Mexico: manifestations of an incipient eastward spreading-ridge jump. Geology, 13, 54-57.
LUHR, J. F., J. F. ALLAN, I. S. E. CARMICHAEL, S. A. NELSON and T. HASENAKA, 1989. Primitive calc-alkaline and alkaline rock types from the western Mexican volcanic belt. J. Geophys. Res., 94, 4515-4530.
MAILLOL, J.M. and W.L. BANDY, 1994a. Paleomagnetism of the Talpa de Allende and Mascota grabens, western Mexico: A preliminary report. Geofís. Int., 33, 153-160.
MAILLOL, J.M. and W.L. BANDY, 1994b. Paleomagnetism and distribution of Plio-Quaternary basalts, Western Mexico: NW-SE stretching of the Jalisco Block (abstract). Geos, 14, 83.
McFADDEN, P. L., R. T. MERRILL and M. W. McELHINNY, 1988. Dipole/quadrupole family modeling of paleosecular variation. J. Geophys. Res., 93, 11583-11588.
MICHAUD, F., J. BOURGOIS, J.-F. PARROT, H. TAUD and M. KASSER, 1994. Tectonic development of the Jalisco triple junction (western Mexico) from SPOT-DEM data processing. C.R. Acad. Sci. Paris, S‚rie II, 318, 1117-1124.
MICHAUD, F., O. QUINTERO, E. BARRIER and J. BOURGOIS, 1991. The northern boundary of the Jalisco Block (Western Mexico): location and evolution from 13 Ma to present. C.R. Acad. Sci. Paris, S‚rie II, 312, 1359-1365.
NIETO-OBREGON, J., L.A. DELGADO-ARGOTE and P.E. DAMON, 1985. Geochronologic, petrologic, and structural data related to large, morphologic features between the Sierra Madre Occidental and the Mexican Volcanic Belt. Geofís. Int., 24, 623-663.
NIETO-OBREGON, J., J. URRUTIA-FUCUGAUCHI, E. CABRAL-CANO and A. GUZEMAN DE LA CAMPA, 1992. Listric faulting and continental rifting in Western Mexico-A paleomagnetic and structural study. Tectonophysics, 208, 365-376.

PARDO, M. and G. SUAREZ, 1993. Steep subduction geometry of the Rivera plate beneath the Jalisco Block in Western Mexico. Geophys. Res. Lett., 20, 2391-2394.
PARDO, M. and G. SUAREZ, 1995. Shape of the subducted Rivera and Cocos plates in southern Mexico: Seismic and tectonic implications. J. Geophys. Res., 100, 12, 357-12, 373.
RIGHTER, K. and I. S. E. CARMICHAEL, 1992. Hawaiites and related lavas in the Atenguillo graben, western Mexican volcanic belt. Geol. Soc. Am. Bull., 104, 1592-1607.
RIGHTER, K., I.S.E. CARMICHAEL, T.A. BECKER and P.R. RENNE, 1995. Pliocene-Quaternary volcanism and faulting at the intersection of the Gulf of California and the Mexican Volcanic Belt. Geol. Soc. Am. Bull., 107, 612-626.
ROSAS-ELGUERA, J., J. NIETO-OBREGON and J. URRUTIA-FUCUGAUCHI, 1993. Ambiente estructural en la frontera norte del bloque Jalisco. In: L.A. Delgado-Argote and A. Martin-Barajas (Editors), Con-tribuciones a la Tectónica del Occidente de México. Unión Geofís. Mex. Monogr., 1: 175-192.
SERPA, L., C. KATZ and C. SKIDMORE, 1989. The southeastern boundary of the Jalisco block in west-central Mexico. EOS, Trans. Am. Geophys. Union, 43, 1319.
SCHAAF, P., D. MORAN-ZENTENO, M. HERNANDEZ-BERNAL, G. SOLIS-PICHARDO, G. TOLSON and H. K(tm)HLER, 1995. Paleogene continental margin truncation in southwest Mexico: Geochronological evidence. Tectonics, 14, 1339-1350.
SCHAAF, P., H. K(tm)HLER, D. MULLER-SOHNIUS and V. Von DRACH, 1993. In: Proceedings of the First Circum-Pacific and Circum-Atlantic Terrane Conference, edited by F. Ortega-Guti,rrez, P.J. Coney, E. Centeno-García and A. Gómez-Caballero, Instituto De Geología, Universidad Nacional Autónoma de México, November, 1993, Guanajuato, México, pp.133-135.
SOLER-ARECHALDE, A. M. and J. URRUTIA-FUCUGAUCHI, 1994. Regional rigid/block rotation, small domain rotations and distributed deformation within the Acambay graben, central Trans-Mexican volcanic belt-Paleomagnetic implications. Geofís. Int., 33, 565-574.
URRUTIA-FUCUGAUCHI, J., 1995. Constraints on Brunhes low-latitude paleosecular variation-Iztaccíhuatl stratovolcano, basin of Mexico. Geofís. Int., 34, 253-262.
URRUTIA-FUCUGAUCHI, J. and J. ROSAS-ELGUERA, 1994, Paleomagnetic study of the eastern sector of Chapala Lake and implications for the tectonics of west-central Mexico. Tectonophysics, 239, 61-71.
WALLACE, P., I.S.E. CARMICHAEL, K. RIGHTER and T. A. BECKER, 1992. Volcanism and tectonism in Western Mexico: A contrast of style and substance. Geology, 20, 625-628.

J.M. Maillol(1), W.L. Bandy(2) and J. Ortega-Ramírez(2)
(1)Dept. de Geologieet GenieGeologique, Universitè Laval, Sainte-Foy, QC, G1K 7P4, Canada maillol@ggl.ulaval.ca
(2) Instituto de Geofísica, Universidad Nacional Autonóma de México, Cd. Universitaria, Del. Coyoacán 04510, México, D.F.

Back