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Paleomagnetic and isotope data from southern Mexico and the controversy over the pre-neogene position of Baja California

H. Böhnel[1], D. Morán-Zenteno[1], P. Schaaf[2] and J. Urrutia-Fucugauchi[1]
[1] *Instituto de Geofísica, UNAM*
[2] *Mineralogisch Petrologisches Institut, Ludwig-Maximilians Universität, München*

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RESUMEN

Se revisan los datos paleomagnéticos e isotópicos del suroccidente de México y de Baja California (BC), con el objeto de evaluar las propuestas de desplazamientos significativos hacia el norte de segmentos de la margen continental del occidente de México y Norteamérica. Los datos indican una relativa estabilidad tectónica del suroccidente de México desde el Cretácico medio. No existen rotaciones de los polos paleomagnéticos en sentido horario que apoyen la interpretación de fallas de desplazamiento lateral derecho; por el contrario, se reconocen algunas rotaciones en sentido antihorario que indican fallas de desplazamiento lateral izquierdo. Los datos geocronológicos de los plutones no deformados a lo largo de la margen suroccidental de México indican una clara tendencia decreciente en las edades de intrusión desde Puerto Vallarta (≈100 Ma) hasta Acapulco (≈55-33 Ma). Las edades reportadas previamente para Baja California varían de 120 Ma a 90 Ma y no muestran una tendencia discernible a lo largo de la península. La sistemática de Nd y Sr revela que el batolito de Puerto Vallarta alcanza en su porción oriental un grado de contaminación cortical alto y edades modelo (T_{DM}) superiores a 1Ga. El Batolito de Los Cabos muestra una contaminación cortical y una edad modelo relativamente altas, (T_{DM} = 0.9 Ga) con una edad de intrusión esencialmente igual a la del Batolito de Puerto Vallarta. Los datos anteriores sugieren una posición de BC para el Cretácico Tardío-Paleoceno similar a la del inicio de la apertura del Golfo de California, sólo con desplazamientos latitudinales menores.

PALABRAS CLAVE: México, Baja California, Terreno Guerrero, Terreno Xolapa, Terrenos tectonoestratigráficos, paleomagnetismo, geoquímica isotópica, geocronología, reconstrucción de tectónica de placas, contaminación cortical.

ABSTRACT

Paleomagnetic and isotope geochronology data for southwestern Mexico, including Baja California (BC), are reviewed to evaluate proposed northward displacements of continental fragments along the western margin of Mexico and North America. The data indicate a relative tectonic stability of southwestern Mexico since mid-Cretaceous. There are no clockwise rotated paleopoles which would point to right lateral shear systems; rather, some counter-clockwise rotated paleopoles indicate the activity of a left lateral shear system. Results from isotope geochronology studies give ages between 120 Ma and 90 Ma for BC, with no distinctive trend along the peninsula. In contrast, there is a clear age trend for undeformed intrusives along the Pacific coast of Mexico, from Puerto Vallarta (≈100 Ma) to Acapulco area (≈55-33 Ma). Ages previously reported for BC vary between 120 Ma and 90 Ma and do not show any trend along the peninsula. Nd-and Sr-systematics reveal high crustal contamination for the eastern part of Puerto Vallarta batholith and model age (T_{DM}) higher than 1 Ga. The Los Cabos batholith in BC also shows relatively high crustal contamination and an old model age (T_{DM} = 0.9 Ga), with an intrusion age indistinguishable from the Puerto Vallarta batholith. In combination, these data suggest that the position of BC for the Late Cretaceous - Paleocene was similar to that before the opening of the Gulf of California, with only minor latitudinal displacements.

KEY WORDS: Mexico, Baja California, Guerrero Terrane, Xolapa Terrane, tectonostratigraphic terranes, paleomagnetism, isotope geochemistry, geochronology, plate tectonic reconstruction, crustal contamination.

INTRODUCTION

The western coast of North America is composed of terranes of allochtonous origin (e.g. Coney *et al.*, 1980; Jones *et al.*, 1983; Beck, 1989). Some of them possibly were displaced several thousand of kilometers, as the Laytonville terrane (Tarduno *et al.*, 1990). Proposed transport mechanisms include travelling on oceanic plates and coastwise displacement due to oblique subduction (e. g. Beck, *et al.*, 1981, Engebretson *et al.*, 1985; Debiche *et al.*, 1987; Beck, 1991), resulting in a characteristic pattern of paleopoles reflecting the latitudinal shift and rotation of terranes. Western North America is characterized by paleopoles indicating northward translation and clockwise rotation of terranes, at least since cretaceous times.

The terrane concept was early applied to Mexico (Campa and Coney, 1983), despite of a relatively sparse knowledge of the Mexican geology (Figure 1). Here terranes were partly defined on differences of basement rocks, although in many areas they still remain poorly known (e. g. Guerrero and Xolapa terranes). Otherwise, terrane boundaries were traced on the base of lateral differences of Mesozoic sequences, deformation histories, and observed or inferred faults. Most terranes defined in that way are supposed to be of suspect origin, probably accreted to the southern portion of the North American Plate during the Late Cretaceous-Early Tertiary.

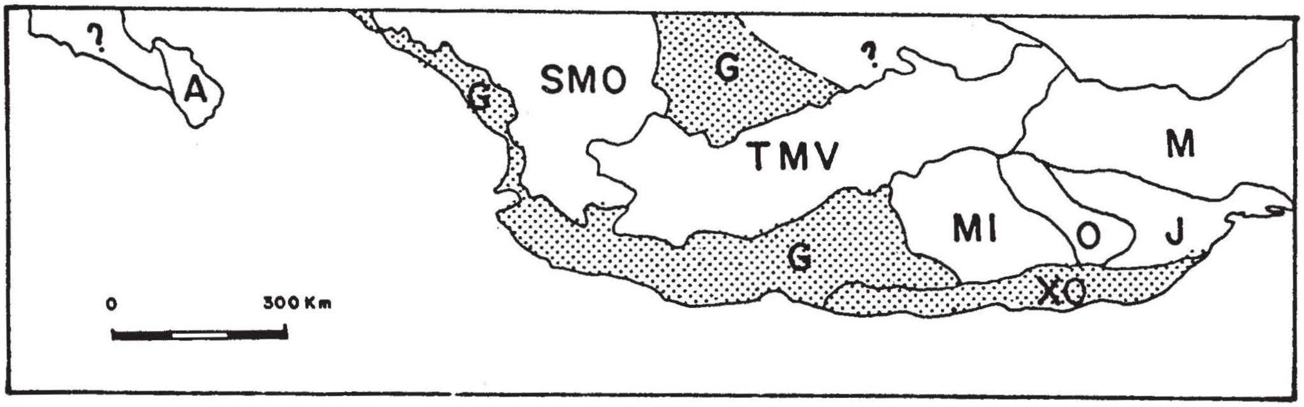

Fig. 1. Tectonostratigraphic terranes in southern Mexico according to Campa and Coney (1983).

We have conducted extensive paleomagnetic (Table 1) and isotope geochemistry studies (Table 2) on rocks along the Pacific continental margin of Mexico and in southern Mexico (Figure 2) (Böhnel *et al.*, 1989; Schaaf, 1990; Morán-Zenteno, 1992) and we discuss in this paper the results in terms of the tectonic evolution of that region and also the plate tectonic history of the Baja California Peninsula (BC). BC has been subject of numerous geological and paleomagnetic studies (e. g. Gastil *et al.*, 1975; Karig *et al*, 1978; Frizzell, 1984 ; Hagstrum *et al.*, 1985; Beck, 1991; Butler *et al.*, 1991 and references therein). Paleomagnetic data have been interpreted in terms of a northward displacement of BC of about 2500 km. Geological evidence favours only minor latitudinal shift. Gastil (1990), Beck (1990) and Butler *et al.* (1991) (for a listing of paleomagnetic data for BC, see references therein) discuss the paleomagnetic and geological data in terms of tectonic stability or northward transport, and their relationships with the tectonic history of southern Mexico. Unfortunately, they do not take into account the corresponding data gathered and already published for that region, so that their discussion remains incomplete. Here we re-adress this analysis taking into account this important data base to evaluate if the data may constrain the pre-Neogene position of Baja California and by that way contribute to resolve the apparent conflict between paleomagnetic data and other geological elements.

GEOLOGICAL FRAMEWORK OF THE PACIFIC CONTINENTAL MARGIN

The western continental margin of central Mexico is occupied by a number of batholiths that intrude different assemblages of sedimentary, volcanosedimentary and metamorphic sequences. In Sonora the batholithic belt intrudes Precambrian metamorphic basement of the southwestern portion of North America Craton and its Paleozoic cover as well as Triassic to middle Cretaceous sedimentary and volcanic assemblages (Roldan-Quintana, 1984). In Sinaloa the batholithic belt is emplaced in Upper Paleozoic sedimentary sequences that underlay Cretaceous volcanosedimentary rocks (Bonneau, 1971). In western Baja California the pre-batholithic terrane consists of a Jurassic-Cretaceous volcanosedimentary arc that overlaps to the west Mesozoic oceanic and ophiolitic sequences of the Continental Border Land. To the east the arc sequences are limited by Paleozoic to Cretaceous metasedimentary assemblages which originated by erosion of the North American craton (Gastil, 1985).

In the Guerrero and Xolapa terranes (Figure 1), the batholiths intruded Triassic to Early Cretaceous volcanosedimentary and sedimentary sequences (Figure 2). In contrast with Sonora and Sinaloa regions, there are no confirmed Precambian or Paleozoic basement outcrops. The oldest known sequences are metasedimentary rocks and basaltic flows of oceanic affinity that underlie unconformably Early Cretaceous volcanosedimentary sequences in isolated localities between Puerto Vallarta and Zihuatanejo (Campa *et al.*, 1982; Vidal-Serratos, 1991; Centeno-García *et al.*, 1991).

From Acapulco to Puerto Angel, the batholiths intrude a metamorphic assemblage formed by metasedimentary sequences, migmatites, amphibolites and deformed plutons. The age of the metasedimentary sequences is unknown but U-Pb dates of inherited zircons range from 1 to 1.5 Ga (Robinson *et al.*, 1989; Herrmann *et al.*, 1991) and Rb-Sr isochrons in syntectonic plutons yield ages around 130 Ma (Morán-Zenteno, 1992; see below). Between the Xolapa and Oaxaca terranes, is Juchatengo area, there is a small block formed by a plutonic-sedimentary assemblage of Late Paleozoic age whose tectonostratigraph affinity is unknown (Grajales-Nishimura, 1989).

PALEOMAGNETIC DATA

A large number of paleomagnetic data is available for the Guerrero, Mixteca and Xolapa terranes. The data are summarized in Table 1, together with their sources. The studied rocks are of igneous and sedimentary origin and cover the time span between mid-Cretaceous and Tertiary. Their paleopoles and paleolatitudes are shown in Figures 3 and 4, together with the apparent polar wander path (APWP) for cratonic North America and the fixed paleolatitude of the study area relative to North America. Independent of the lithology of the rocks and their belonging to one of the several tectonostratigraphic terranes in

Table 1

Cretaceous and Tertiary paleomagnetic data from southern Mexico

Code	Unit and rock type	N	R	K	A95 deg	Lat/Long deg/deg E	Age Ma	λ deg	Ref
P1	Puerto Vallarta Batholith	14	13.69	41	6.2	80.7/182.7	80-100	23±6	1
P2	Turla Limestone	11*	10.83	57*	6.1*	62.0/184.2	91-113	25±5	1
P3	Autlan Igneous	14	13.32	19	9.3	68.2/169.5	40-70	20±9	1
P4	Encino Igneous+sedim	19	18.07	19	7.8	57.0/171.2	65-83	18±8	1
P5	Encino Volcanics	8	7.65	20	12.7	46.8/180.2	98-119	21±12	1
P6	Arteaga-Zihuat. Igneous	10	9.41	15	12.7	52.1/159.8	35-65	9±13	1
P7	Acapulco Batholith	12	11.14	13	12.6	81.9/199.6	43-1	21±13	1
P8	Chilpancingo Limestone	28*	27.87	215*	4.0*	62.9/197.7	91-113	28±3	2
P9	Petlalcingo Limestone	27*	26.68	82*	3.1*	75.4/192.8	91-113	23±2	3
P10	Oaxaca Limestone	19*	18.53	38*	6.0*	78.4/149.8	91-113	12±3	4
P11	Cintalapa Red beds	89*	85.53	25*	3.0*	69.8/160.0	120-150	11±2	5

Note: Code refers to Figure. 2; N = number of sites; R, K, A95 = statistical parameters for paleopole; Lat/Long coordinates of paleopole; Age in Ma; λ = paleolatitude; age data are TRM acquisition ages, estimated from intrusion and cooling ages; References: 1, Böhnel *et al.* (1989); 2, Urrutia Fucugauchi (1988); 3, Böhnel, 1985; 4, Urrutia Fucugauchi (1982); 5, Guerrero *et al.* (1990). The asterix denotes individual sites, where statistical parameters correspond to site mean directions.

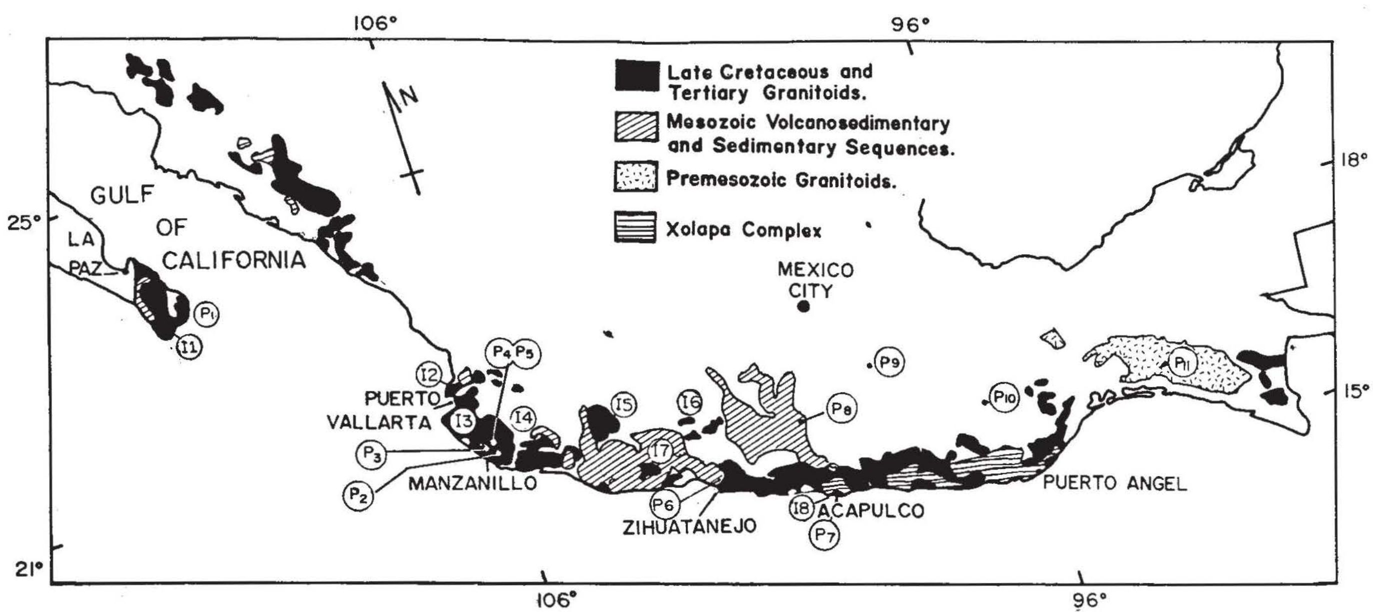

Fig. 2. Geological sketch map of southern Baja California and southwestern Mexico. I1 to I8 and P1 to P11 indicate regions where isotope geochronology and paleomagnetic data are available.

Table 2

Age and isotopic data of the plutonic rocks along the continental margin of Mexico from southern Baja California to Acapulco region. Intrusion ages were obtained from whole rock isocrons.

Locality	Unit	Age (Ma)	h εNd(T)	$^{87}Sr/^{86}Sr(i)$	Reference
BCN	northern BC Batholiths	120-90	+7.8 - + 7.9	0.70331-0.70451	5
I1	Los Cabos Batholith	94	-2.49	0.705893	1,2
I2	Punta Mita Batholith	86±9	-1.65 - +4.16	0.705202-0.704611	2
I3	Puerto Vallarta Batholith	99-91	-7.20 - +3.18	0.712632-0.703264	2
I4	Manzanillo Batholith	69±3	+5.10 - +6.37	0.703647-0.703341	2
I5	Jilotlán Batholith	68±12	+3.50 - +4.31	0.703937-0.703693	2
I6	La Huacana Batholith	42±4	+1.52 - +2.90	0.704017-0.703950	2
I7	Zihuatanejo Batholith	36±5	+3.09 - +4.66	0.704143-0.704138	2
I8	Acapulco region Intrusives	55-33	+1.50 - +3.15	0.704084-0.703648	2,3,4
I8	Acapulco region deformed plutons	144-128	-0.97 - +2.84	0.704999-0.703030	3

Note: Localities I1 to I8 according to Figure 2; BCN, northern Baja California.
$^{87}Sr/^{86}Sr$ ratios were corrected for mass discrimination by normalizing to $^{88}Sr/^{86}Sr = 0.1194$. $^{143}Nd/^{144}Nd$ were normalized to $^{146}Nd/^{144}Nd = 0.7219$.
εNd are initial values, $\varepsilon Nd = 10^4\ ((^{143}Nd/^{144}Nd(T)\ sample/^{143}Nd/^{144}Nd\ (T)CHUR)-1)$ where (T) refers to the crystallization age of the rock.
The values used for CHUR are $^{143}Nd/^{144}Nd = 0.512638$ and $^{147}Sm/^{144}Nd = 0.1936$. The relative error in $^{87}Sr/^{86}Sr$ is 0.0016% (2σ) and in $^{143}Nd/^{144}Nd$ is 0.0015% (2σ).
References: 1, Frizzell (1984); 2, Schaaf (1990); 3, Morán-Zenteno (1992); 4, Herrmann (personal comunication); 5, De Paolo (1981).

southern Mexico, all paleopoles coincide with the corresponding segment of the APWP or have the same co-latitude and consequently point to a tectonic stability at least since mid-Cretaceous. There is no significant latitudinal shift, and only occasionally rotations with counterclockwise sense have been observed, pointing to some left-lateral shear system. Until now, no clockwise rotation has been found for mid-Cretaceous or younger rocks, which is in clear contrast to results from western North America.

These data exclude major relative movements required by reconstructions as discussed by Gastil (1990) (see his Figure 3), which requires some minor northward shift of southern Mexico, and a right-lateral shear system, analoguous to the observations for terranes in western North America (e. g. Beck, 1989). Analysis of the paleomagnetic data base for southwestern Mexico enables us to conclude that there is no need for major relative movements in continental Mexico, at least since mid-Cretaceous.

ISOTOPE GEOCHRONOLOGICAL DATA

Isotope data from plutonic rocks between Puerto Vallarta and Acapulco (Figure 1) reported by Schaaf (1990) and Morán-Zenteno (1992) are given in Table 2. The ages included in this table are mainly Rb-Sr intrusion ages that range between around 100 Ma and 30 Ma, with a strong tendency to younger ages towards the southeast. This tendency seems to continue at least 400 km to the southeast of Acapulco (Figure 5). In the Puerto Vallarta-Zihuatanejo portion of the margin intensive magmatism is also indicated by the Aptian to Albian volcanic sequences that characterize the Guerrero terrane (Pantoja-Alor and Estrada Barraza, 1983; Vidal-Serratos, 1991). The initial eNd and $^{87}Sr/^{86}Sr$ values display significant variations along the continental margin. In el Cabo, Punta Mita and Puerto Vallarta batholiths (for geographical positions see Table 2 and Figure 2), where intrusion ages are similar, negative εNd values suggest a relative high degree of continental crust contamination.

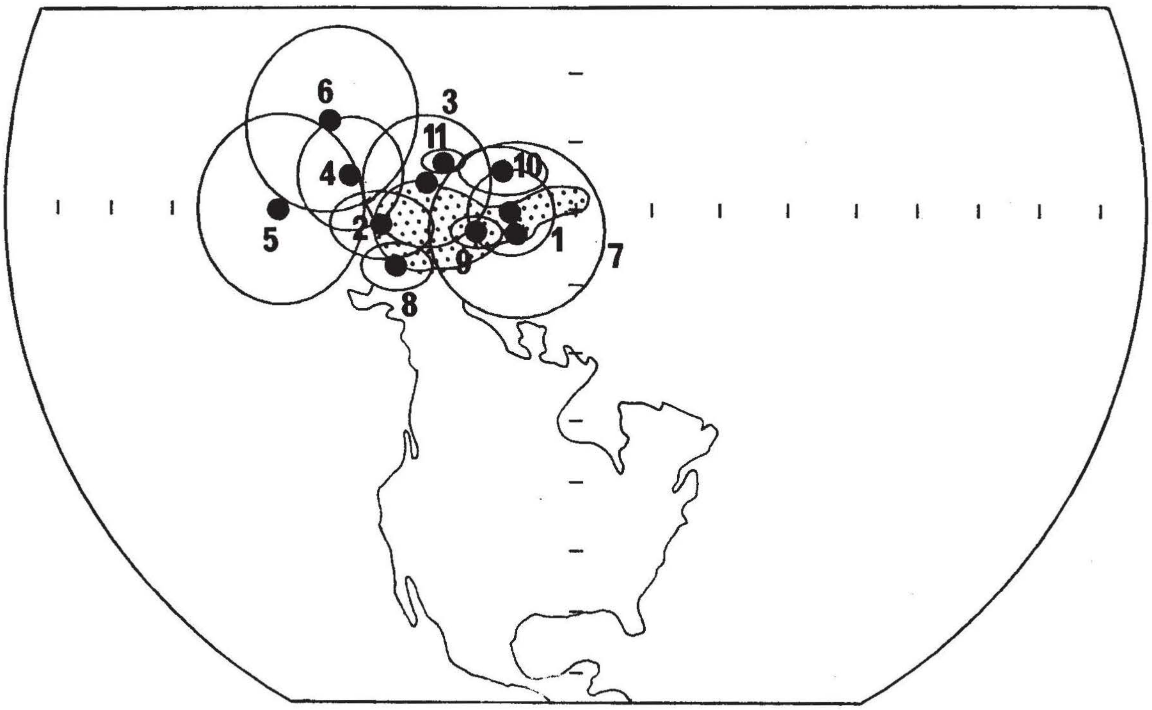

Fig. 3. Paleomagnetic paleopoles for southern Mexico. P1 to P11 refer to Table 1 and Figure 2. The shaded area corresponds to the Cretaceous and Tertiary segment of the APWP for stable North America.

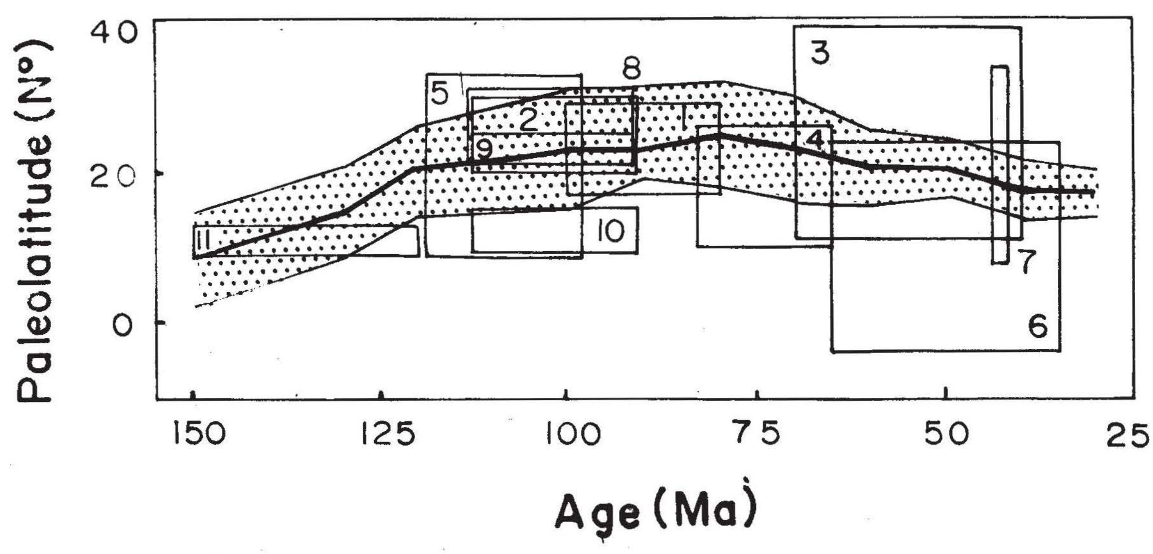

Fig. 4. Paleolatitude of regions in southern Mexico vs. time. Error margins of paleolatitude and age are given by the size of the corrresponding rectangle. The continuous line corresponds to the expected paleolatitude for Zihuatanejo, if it were part of stable North America, with the shaded area indicating the error limits. P1 to P11 refer to Table 1 and Figure 2.

This contamination reaches its maximum (εNd=-7.20) in the eastern portion of Puerto Vallarta batholith where S-type granites have been recognized (Schaaf, 1990). In this area model ages (T_{DM}) around 1.5 Ga have been obtained from granites and metasedimentary rocks. For Manzanillo to Acapulco intrusives the εNd values are positive and show a decreasing trend to the southeast. Positive εNd values (+4...+9) have been also reported for Aptian-Albian volcanic rocks in other localities of Guerrero terrane (Ortiz *et al.*, 1990; Ruiz *et al.*, 1991). Deformed plutons of Xolapa terrane in Acapulco region display some negative εNd values that suggest a greater crustal contamination. Model ages of 1.3 Ga and 1.6 Ga have been obtained from aplitic intrusives and metasedimentary rocks near the boundary with Mixteca terrane (Morán-Zenteno, 1992).

DISCUSSION AND CONCLUSION

The paleomagnetic data for southern Mexico described above in general terms indicate a relative tectonic stability since mid-Cretaceous. There is no evidence of latitudinal displacements. Such displacements would be required in most scenarios discussed by Gastil (1991), where BC is displaced along alternative positions of a Oaxaca-California megashear, necessarily situated inside the Mexican continental crust. Such megashears would have been of dextral sense, resulting in clockwise rotation of crustal blocks within the shear system, in a similar way as found for the North American Cordillera. Paleomagnetic data from southern Mexico show counterclockwise rotation which would favour a dominant sinistral shear system.

According to isotope geochronological data, southern Mexico is characterized by intrusive bodies with ages approximately between 100 Ma and 30 Ma. There is a clear decreasing age trend in undeformed plutons from Puerto Vallarta towards the southeast, through the limits between the Guerrero and Xolapa terranes. In the area of Acapulco and particularly of Puerto Vallarta eNd values and model ages indicate significant crustal contamination. Between these localities there is less contamination, possibly due to crustal thinning or younger basement rocks. The Nd model ages (TDM) and the ages of inherited zircons in the metamorphic rocks of the Xolapa terrane suggest an origin along the border of the Mixteca and Oaxaca Terranes.

Recently, the pre-Neogene position of BC has been a matter of discussion. Gastil (1991) and Beck (1991) review the contrasting geological and paleomagnetic data and discuss alternatives to bring them into agreement. Beck (1990) argues that the consistency of the paleomagnetic data requires a northward shift of BC by 10° to 12°, with possibly 40° clockwise vertical axis rotation. Gastil (1991) proposes different traces of a Oaxaca-California megashear (Figure 6), which could serve for such a displacement, but does not find arguments to support them by comparing the geology of BC and western continental Mexico. In fact, Gastil (1985, 1991) points out that the San Felipe Terrane sequence in the eastern part of northern BC may be correlated with Upper Precambrian/Lower Cambrian sections of Sonora. The Cretaceous "volcanic arc terrane" (Gastil, 1985) in BC shows similar geochronological and lithological characteristics as the Aptian-Albian volcanosedimentary sequences in Guerrero Terrane. However, no remnants of rocks similar to the "Peninsular Flysch Terrane"of eastern BC are found here, making difficult to correlate these two areas.

Butler *et al.* (1991) argue that the paleomagnetic data might alternatively be explained in terms of (1) tilting of plutonic rocks, (2) overestimation of northward transport by using unprecisely determined and therefore inadequate reference poles, and (3) data biased towards low latitudes because of compaction-related shallowing of inclination in marine sedimentary rocks. The existence of several concordant paleomagnetic data for northern BC and the observed declination dispersion of discordant data lead Butler et al. (1991) to the conclusion, that tilting of batholiths has resulted in the discordant data rather than large scale displacement of BC.

A position of Baja California along the truncated margin of southwestern Mexico, as suggested by Beck *et al.* (1981) is inconsistent with isotope geochronological data. Batholiths in BC have ages between 120 Ma and 90 Ma, with no discernible trend along the peninsula. Along the Pacific coast of southern Mexico, in contrast, batholiths are younger and they present a clear age trend for undeformed intrusives at least for the relevant time interval between 100 Ma (Puerto Vallarta) and 50 Ma (Acapulco area). According to their Nd-systematics, these batholiths show significant crustal contamination, which is largest for the Puerto Vallarta batholith. In BC only the Los Cabos intrusive complex indicates a significant degree of crustal contamination, and the model age T_{DM}=0.9 Ga is larger than for intrusives south of Puerto Vallarta. Intrusion ages of these two batholiths are practically indiscernible. No other undeformed intrusive complex in BC and along the Pacific margin of southern Mexico has similar isotope geochronology characteristics like these two batholiths. If any paleogeographic reconstruction would require that adjacent rock units should have similar isotope geochronology signature, this condition would be reasonably met by the Los Cabos and Puerto Vallarta batholiths. In northern BC, initial values of εNd reported so far are larger than 7 (De Paolo, 1981) and significantly larger than values obtained for intrusives southeast of Puerto Vallarta.

The isotope geochronology data suggest a position of BC with the Los Cabos batholith close to Puerto Vallarta. This would result in a continuous plutonic belt from BC to southern Mexico. A northward displacement of this plutonic belt as a whole may be discarded because of the apparent latitudinal stability of southern Mexico Pacific margin. Furthermore, there are no paleomagnetic data from southern Mexico indicating a right lateral shear system, which would support a northward coastwise displacement of BC or the Pacific margin of Mexico. Whenever local rotations are indicated by the data, they are found near the continental margin and of counter clockwise sense, which would indicate a left lateral shear system. Ratschbacher *et al.* (1991) report structural data from mylonitic zones in the northeastern limit of the Xolapa terrane supporting displacements with left lateral components, active in Late Cretaceous to Early Tertiary time. Additional support for a left lateral shear system is given by the decreasing age of the extinction of magmatism towards the southeast, which could be related to the migration of a triple junction (e. g. the boundary between Kula and Farallon plates?) and the gradual termination of an ancient subduction zone.

Paleomagnetic and isotopic data together point to a tectonic stability of southern Mexico since mid-Cretaceous. There are no arguments for latitudinal displacements and accretion processes, as would be expected for allochtonous terranes. Rather, the Guerrero and Xolapa terranes probably

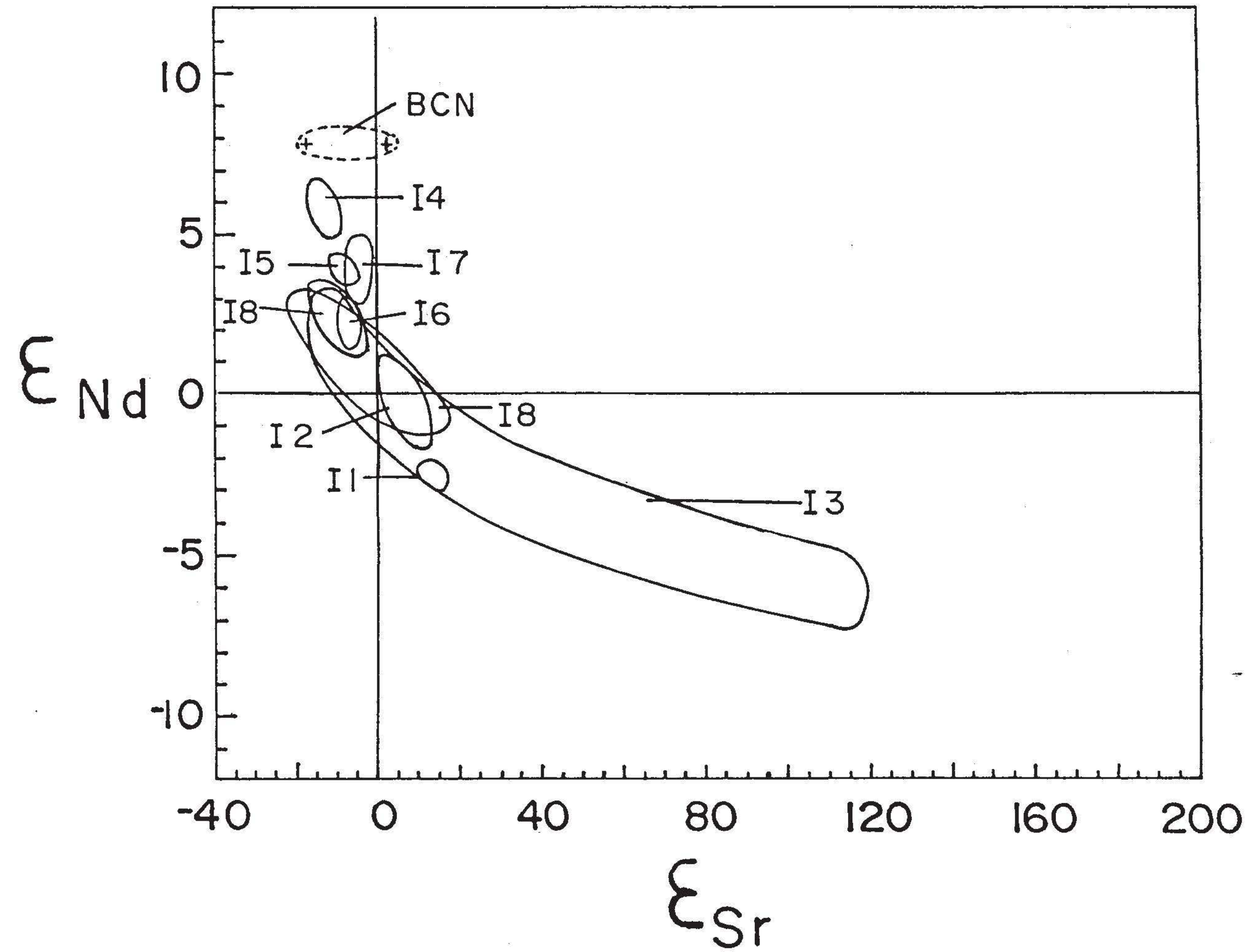

Fig. 5. Diagram of initial εNd vs εSr values for plutonic rocks from southwestern Mexico and Baja California. Distribution of data points is shown by domains for the different sampling regions I1 to I8, and for northern Baja California (BCN). For calculation of the εNd and εSr values, an εSr value of 0.7045 was used for the present CHUR.

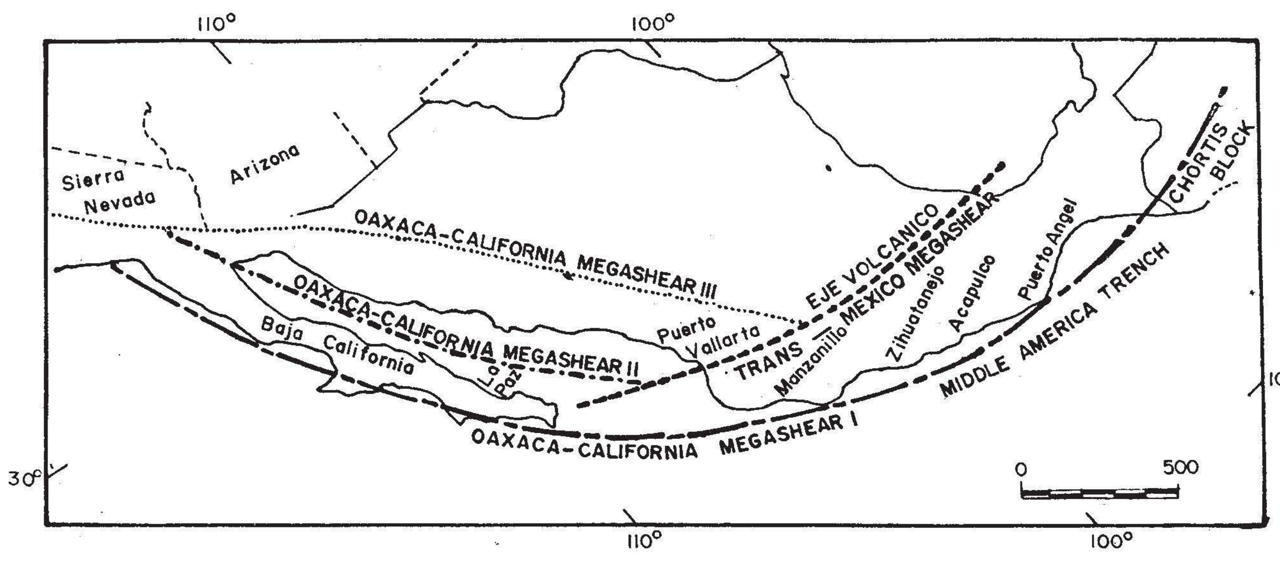

Fig. 6. Alternative traces for Oaxaca-California megashear, according to Gastil (1991).

originated in a position to North America which was very similar to the present one. Paleomagnetic data from southern Mexico together with the isotope geochronology signature of the intrusive rocks of BC and southwestern Mexico suggest a position of BC similar to that before the opening of the Gulf of California, with the Los Cabos batholith near Puerto Vallarta.

We demonstrated that the paleomagnetic and isotopic data from southern Mexico are of importance for the analysis of the tectonic evolution of Baja California. Even if they do not definitely resolve the apparently contradicting paleomagnetic data and the other elements of geology, they constrain the proposed evolutionary models and argue against the existence of a dextral Oaxaca-California megashear as a solution for this conflict.

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H. Böhnel[1], D. Morán-Zenteno[1], P. Schaaf[2] and J. Urrutia-Fucugauchi[1]

[1] *Instituto de Geofísica, Universidad Nacional Autónoma de México, 04510, México, D.F., México.*

[2] *Mineralogisch Petrologisches Institut, Ludwig-Maximilians Universität, Theresienstr. 41, D-8000 München, Germany.*