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# INTRAOCEANIC SETTING OF THE WESTERN MEXICO GUERRERO TERRANE—IMPLICATIONS FOR THE PACIFIC-TETHYS GEODYNAMIC RELATIONSHIPS DURING THE CRETACEOUS

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## ABSTRACT

The Guerrero terrane of western Mexico includes arc sequences, particularly the Mexican Late Jurassic-Early Cretaceous Alisitos-Teloloapan arc. It could extend to the Colombian Andes, passing through the Greater Antilles. New geological, petrological and geochemical data from central and southern Mexico led the authors to propose a new model for the building of the Alisitos-Teloloapan arc. This arc, partly built on Pacific oceanic lithosphere and partly on a continental fragment, could be related to a southwestward dipping subduction of an oceanic basin—the Arperos basin—under the paleo-Pacific plate.

At the beginning of the magmatic activity in the oceanic segment of this arc, LREE-depleted tholeiitic basalt was emitted in a submarine environment below the carbonate compensation depth. While the subduction process was going on, the arc magmatism evolved from depleted tholeiite to mature tholeiite, and then to calc-alkalic basalt and andesite. Concurrently, the arc sedimentary environment changed from deep oceanic to neritic with the deposition of Aptian-Albian reefal limestones, at the end of the arc building. In the continent-based segment, the arc magmas are exclusively high field strength elements (HFSE)-enriched calc-alkalic differentiated suites with predominantly silicic lavas and pyroclastic rocks, emitted in a subaerial or shallow marine environment.

Thus, the Cretaceous volcanic series accreted to the margins of cratonal America in Colombia, Venezuela, Greater Antilles and Mexico, could be related to the same west-southwest dipping subduction of oceanic basins, fringing the North and South American continental cratons, and connected directly with the inter-American Tethys. While the subduction was going on, this magmatic arc drifted towards the North and South American cratons and, finally, collided the continental margins at different times during the Cretaceous.

Key words: tectonics, geochemistry, arc magmas, suspect terranes, Tethys, Pacific, Mexico.

## RESUMEN

El terreno Guerrero del occidente de México incluye secuencias de arco, en particular, el arco volcánico-plutónico Alisitos-Teloloapan del Jurásico Tardío-Cretácico Temprano. Con características similares, este terreno se extiende hacia los Andes colombianos y las Antillas Mayores. Datos geológicos, petrológicos y geoquímicos recientes de las regiones central y meridional permiten proponer un modelo geodinámico nuevo para la génesis del arco Alisitos-Teloloapan y, finalmente, del terreno Guerrero. La formación de este arco, en parte edificado sobre litosfera oceánica pacífica y, en parte, sobre fragmentos continentales, está relacionada con la subducción hacia el sudoeste de una cuenca oceánica—la cuenca de Arperos—bajo la antigua placa pacífica.

Al inicio de la actividad magmática en la parte oceánica del arco, fueron emitidos basaltos toleíticos empobrecidos en tierras raras ligeras, en un ambiente submarino profundo, debajo del nivel de compensación de los carbonatos. Durante el desarrollo de la subducción, los productos magmáticos del arco evolucionaron hacia basaltos toleíticos, ligeramente enriquecidos en tierras raras ligeras y, finalmente, hacia basaltos y andesitas calcialcalinos. Al mismo tiempo, el ambiente sedimentario cambió, pasando de un ambiente oceánico profundo a condiciones neríticas con el depósito de calizas arrecifales durante el Aptiano-Albiano, al final de la edificación del arco. En la parte del arco con basamento continental, las emisiones magmáticas fueron exclusivamente secuencias calcialcalinas diferenciadas, enriquecidas en elementos con carga iónica elevada (HFSE), con lavas predominantemente silícicas y rocas piroclásticas emitidas en ambientes subaéreos o marinos someros.

Así, tomando en cuenta el modelo mencionado, las secuencias volcánicas jurásico-cretácicas acrecionadas al borde continental americano en México, las Antillas Mayores, Venezuela y Colombia, pueden ser relacionadas con la misma subducción hacia el oestesudoeste de cuencas oceánicas, a

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lo largo de América del Norte y del Sur, estando estas cuencas relacionadas con el Tethys. Durante la subducción, este arco volcánico-plutónico se acercaba al margen norte- y sudamericano, hasta chocar con él en varias etapas del Cretácico.

Palabras clave: tectónica, geoquímica, arcos magmáticos, terrenos sospechosos, Tethys, Pacífico, México.

## INTRODUCTION

The cordilleran ranges, fringing the western margin of the North American craton and the northwestern margin of the South American craton—Venezuela, Colombia and Ecuador—consist of two structural domains (Figure 1). The eastern domain comprises para-autochthonous units, built during the Mesozoic-Tertiary tectonic events that have affected the margins of cratonic Americas. The western domain includes various lithostratigraphic and lithodemic sequences, collectively known as "suspect terranes" (Coney *et al.*, 1980; Coney, 1989; Howell and Jones, 1989; Megard, 1989), which successively collided with the American cratons during the Mesozoic and Cenozoic.

One of these terranes—named Guerrero terrane in Mexico (Campa and Coney, 1983; Coney, 1989)—likely extends from Mexico to the Colombian Andes, passing through the Greater Antilles. The Guerrero and equivalent terranes include volcano-plutonic and volcano-sedimentary arc sequences that yielded a Late Jurassic-Cretaceous fauna; in Mexico, these arc sequences are collectively called the Alisitos-Teloloapan arc (Campa *et al.*, 1974; Tardy *et al.*, 1986). The collision of the Guerrero terrane with the North American borderland—with subsequent overthrusting on the latter—occurred at different times during the Cretaceous: toward the end of the Early Cretaceous in Mexico (Campa *et al.*, 1976; Tardy, 1980) and Late Cretaceous in the Colombian segment of South America and in the Greater Antilles (Stephan *et al.*, 1990). In the Greater Antilles, this collision took place when the Late Jurassic-Cretaceous arc was brought in front of the Tethys ocean during its northeastward drift (Stephan *et al.*, 1990).

The geographic outset and the genesis processes of this Late Jurassic-Cretaceous arc are still little known. Until nowadays, it was classically admitted (Figure 2) that the Mexican segment of this arc was a continental magmatic arc linked to an east-northeastward dipping subduction of the Pacific lithosphere under the western margin of the North American craton (Córdoba *et al.*, 1980; Tardy, 1980; Rangin, 1985; Stephan *et al.*, 1990). For other authors (Campa and Ramírez, 1979; Campa and Coney, 1983; Coney and Campa, 1987; Servais *et al.*, 1986), these arc sequences belonged to a complex set of back-arc basins dividing oceanic

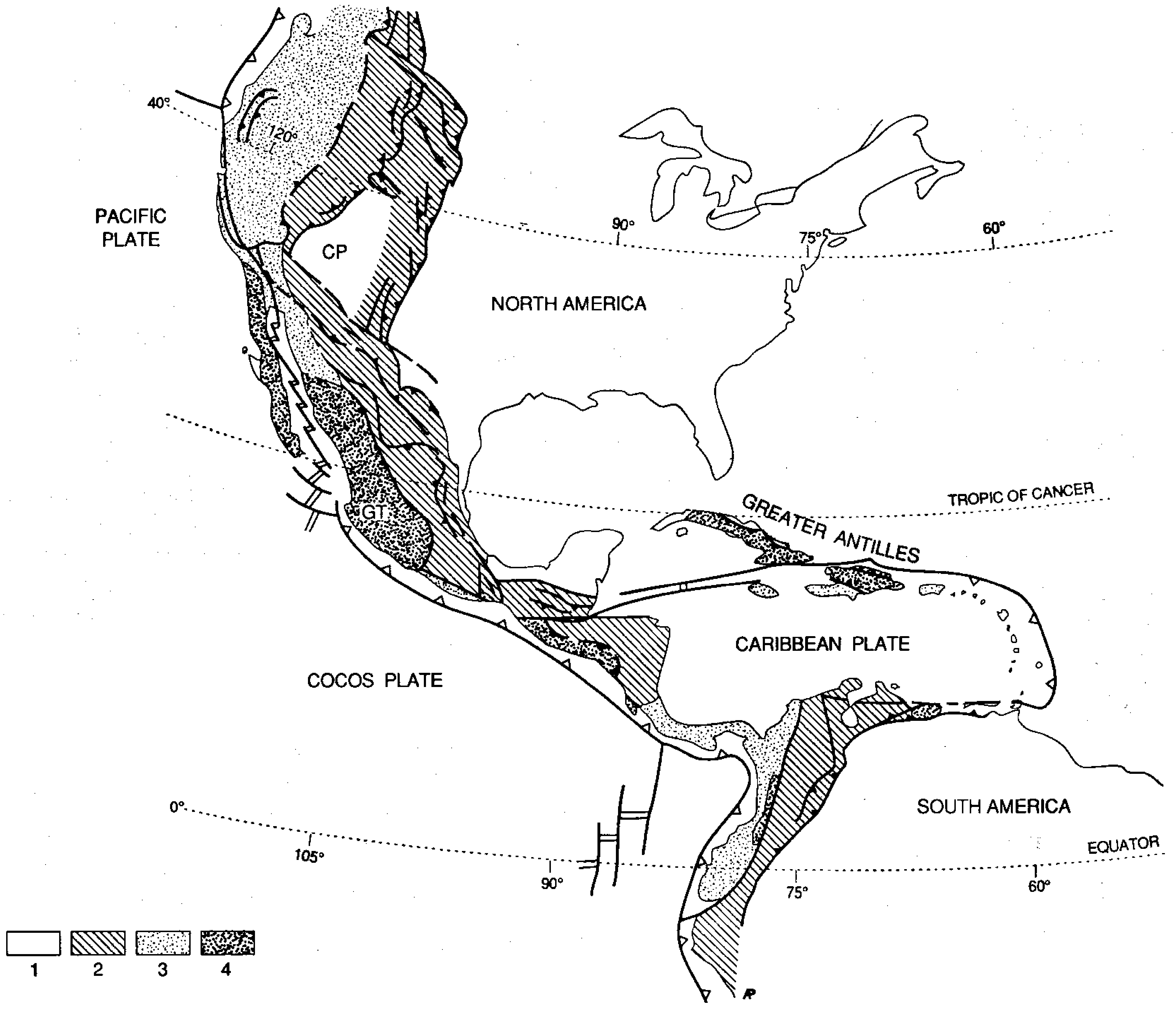

Figure 1.- Structural schematic map of the North and South American Cordilleras from both sides of the Caribbean Ranges showing the location of the suspect terranes accreted to the cratonic margins during the Mesozoic and Tertiary and, more distinctively, the Cordillera and Greater Antilles exposures of the Late Jurassic-Early Cretaceous magmatic arc. Among these terranes, the Guerrero terrane (GT) of Mexico represents a significant component. 1—North and South American cratons; 2—continental margins deformed during the Mesozoic and Tertiary; 3—undifferentiated suspect terranes; 4—Late Jurassic-Early Cretaceous magmatic arc; CP—Colorado Plateau.

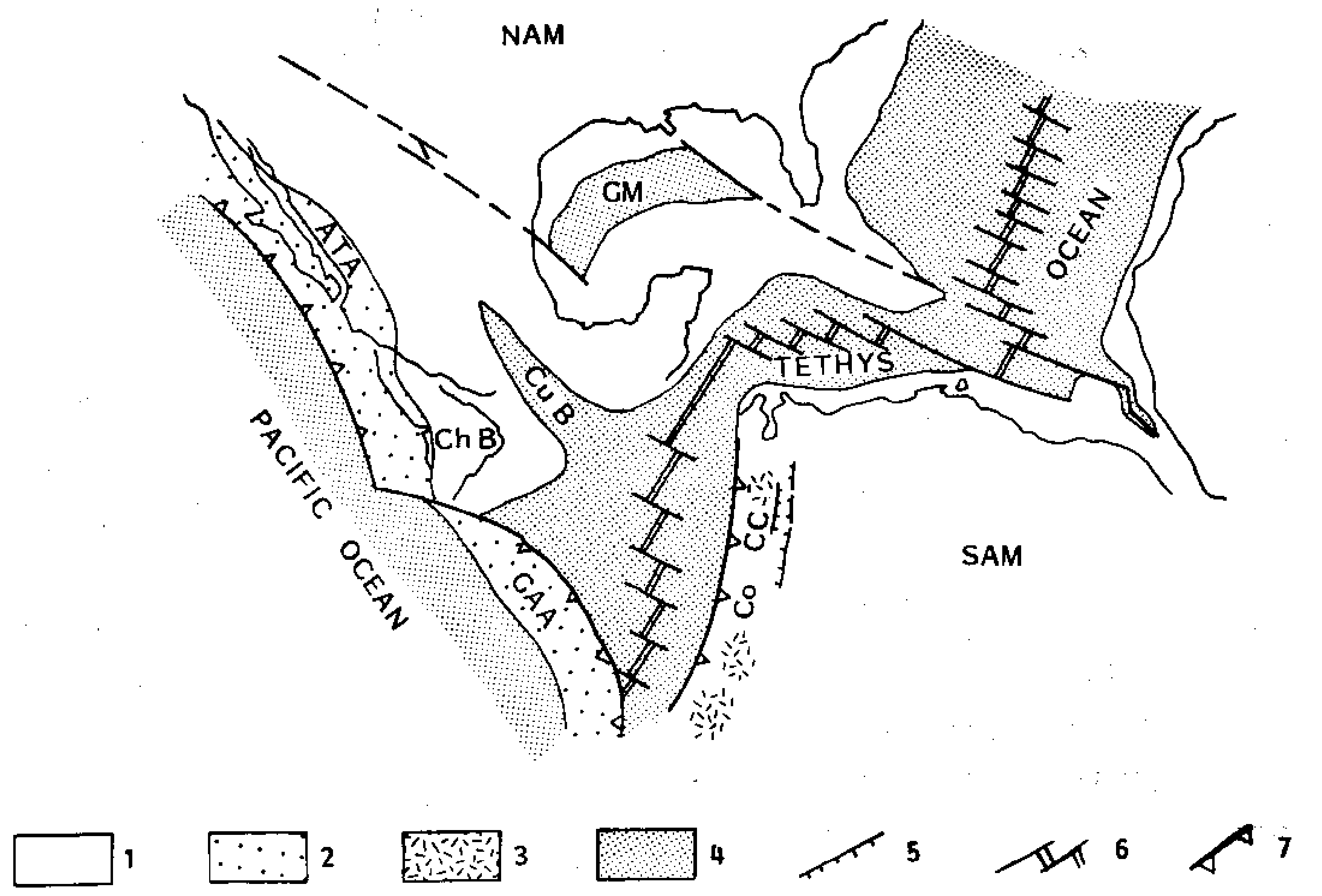

Figure 2.- Simplified palinspastic map (after Stephan *et al.*, 1990) illustrating a plausible model for the Tethyan-Pacific relationships during the Aptian. As it is currently admitted, the Alisitos-Teloloapan (ATA) magmatic arc is considered here as built on the North American margin and generated by an east-northeastward subduction of the Pacific. Its southwesternmost extension (GAA: Greater Antilles arc) is linked to the west-southwestward subduction of the Tethys under the Pacific. 1—African (AF), North American (NAM) and South American (SAM) cratons; 2—Late Jurassic-Early Cretaceous magmatic arc; 3—Central Colombia volcanism (CoCC); 4—oceanic crust; 5—normal fault; 6—spreading ridge; 7—subduction zone; Ch B—Chortis block; Co CC—Colombia Central Cordillera; Cu B—Cuicatec basin; GM—Gulf of Mexico.

arcs, fringing the North American craton, and continental arcs, built on its margin.

Recently, new stratigraphic, petrological and geochemical data allowed us (1) to evince that, at least, some of the volcano-plutonic arc sequences of the Guerrero terrane belong to a single intraoceanic arc built partly on oceanic crust and partly on continental blocks; and (2) to propose a new geodynamic model for this Late Jurassic-Cretaceous arc. Additional data allow us to precise the proposed model, which sets a new insight in the Pacific and western Tethys relationship during the Early Cretaceous.

## PETROLOGY AND GEOCHEMISTRY OF THE ALISITOS-TELOLOAPAN ARC IN CENTRAL AND SOUTHERN MEXICO

Beneath the Cenozoic volcanic cover, the rocks of the Mexican arc, exposed from Baja California to Zihuatanejo (Figure 3), consist of allochthonous volcano-plutonic assemblages that underwent deformation and greenschist facies metamorphism during the late part of the Early Cretaceous, when they were thrusted eastward onto the Tethys carbonate platforms. In northern and northwestern Mexico, the arc lavas and sediments rest unconformably on a Paleozoic basement (Bonneau, 1972; Pubellier and Rangin, 1987), whereas in the southern and central areas, the arc basement rocks are unknown.

The stratigraphic succession of the Late Jurassic-Early Cretaceous Alisitos-Teloloapan arc shows significant variations from north to south. In northern Mexico (Sinaloa, Sonora and Baja California States), it consists of tuff and calc-alkalic andesite and silicic lavas (Mullan, 1978; Almazán-Vázquez, 1988a), interbedded with Aptian-Albian reefal limestones (Santillán and Barrera, 1930; Bonneau, 1972; Gastil *et al.*, 1975; Campa and Coney, 1983; Almazán-Vázquez, 1988b). In central Mexico, the lowermost levels of the arc consist of an Early Cretaceous (Guanajuato and Zacatecas States) tholeiitic volcano-plutonic submarine assemblage interbedded with radiolarian mudstone and micritic limestone (Guanajuato and Zacatecas sequences; Figure 4; Monod *et al.*, 1990; Yta *et al.*, 1990; Ortiz-Hernández *et al.*, 1991; Lapierre *et al.*, 1992, in press), while its uppermost strata (Teloloapan sequence, Guerrero State; Figure 4) are composed of predominantly calc-alkalic pillowed basalt and andesite interlayered with a thick (~1,000 m) volcaniclastic sedimentary pile that includes lenses of Aptian-Albian reefal limestone (Campa and Ramírez, 1979; Talavera-Mendoza *et al.*, 1990; Guerrero-Suástegui, 1990). Locally, calc-alkalic mafic plutons, dated as 110-100 Ma (Stein *et al.*, submitted) intrude Guanajuato tholeiitic ultramafic rocks, and likely represent the plutonic roots of the calc-alkalic extrusive rocks. The top of the arc is capped by Aptian-Albian reefal limestones. The age of the arc sequences could possibly be slightly older (Jurassic? Elías-Herrera and Sánchez-Zavala, 1990). In southern Mexico, arc lithostratigraphic succession displays differences in the lava types and their sedimentary interlayers. Near Colima (Figure 3), the arc is formed by submarine unpillowed basalt and basic tuff interbedded with limestone breccia bearing volcanic clasts, which are overlain by limestone and marl yielding upper Aptian-Albian radiolaria and foraminifera (Tecomán sequence; Figure 4; Michaud *et al.*, 1989). Between Colima and Zihuatanejo (Figure 3), the arc sequence (Playa Azul sequence; Figure 4) is made up of subaerial welded—or not—tuff, volcanic coarse-grained breccia, acidic andesite and rhyolite, interlayered with red immature phyllovolcanic sandstone and silt—yielding Early Cretaceous dinosaur footprints—and locally shallow-marine biomicrite (Ferrusquía-Villafranca *et al.*, 1978).

The arc volcanic rocks show significant differences in their petrology and geochemistry between the central and southern exposures. One hundred samples of igneous rocks, in Colima, Michoacán, Guanajuato, Zacatecas, and Guerrero States (Figure 3), were analyzed for major, trace, and rare earth elements (REE) by ICP at the Centre de Recherches Pétrographiques et Géochimiques of Nancy, and at the Laboratoire de Pétrologie Magmatique—URA-CNRS 1277—of Aix-Marseille III University (Table 1). The analytical errors are 0.5 ppm for contents < 10 ppm, and less than 5% for contents > 10 ppm. In some samples, Nb and Ce have been deleted because of the inaccuracy of the analyses. Representative rocks, including their mineralogy, are also listed in Table 1.

In central Mexico, the late Mesozoic arc assemblage shows a magmatic evolution with time. The lowermost pillow basalt and their feeder dykes, which display LREE-depleted tholeiitic affinities (Guanajuato-Zacatecas; Table 1, Figures 5 and 6; Monod *et al.*, 1990; Ortiz-Hernández *et al.*, 1991; Lapierre *et al.*, 1992) are followed first by mature tholeiitic basalt with flat REE patterns (Saucito-Arcelia; Table 1, Figures 5 and 6), and then by calc-alkalic Aptian-Albian mafic plutonic rocks, and porphyritic plagioclase-orthopyroxene-clinopyroxene pillow basalt, and andesite (Teloloapan; Table 1, Figures 5 and 6; Talavera-Mendoza *et al.*, 1990; Ortiz-Hernández *et al.*, 1991; Tardy *et al.*, submitted) characterized by (1) a depletion in high field strength elements (HFSE); (b) LREE-enriched patterns ($5.7 < [La/Yb]_N < 9.3$); and (c) Zr/Y ratios ranging between 4.17 and 7.31. Both depleted tholeiitic and calc-alkalic magmas show high and homogeneous ($+9 < \varepsilon Nd(T) < +6$; Ruiz *et al.*, 1991; Lapierre *et al.*, 1992; Stein *et al.*, submitted) which are typical of oceanic magmatic arcs (DePaolo, 1988).

In contrast, Albian-Aptian (Colima State) porphyritic olivine pseudomorph-clinopyroxene basalt exhibits shoshonitic affinities (sample 91-15; Table 1; Basaltic Volcanism Study Project, 1981; Morrison, 1980; Gill, 1981, 1987), marked by trachytic texture,

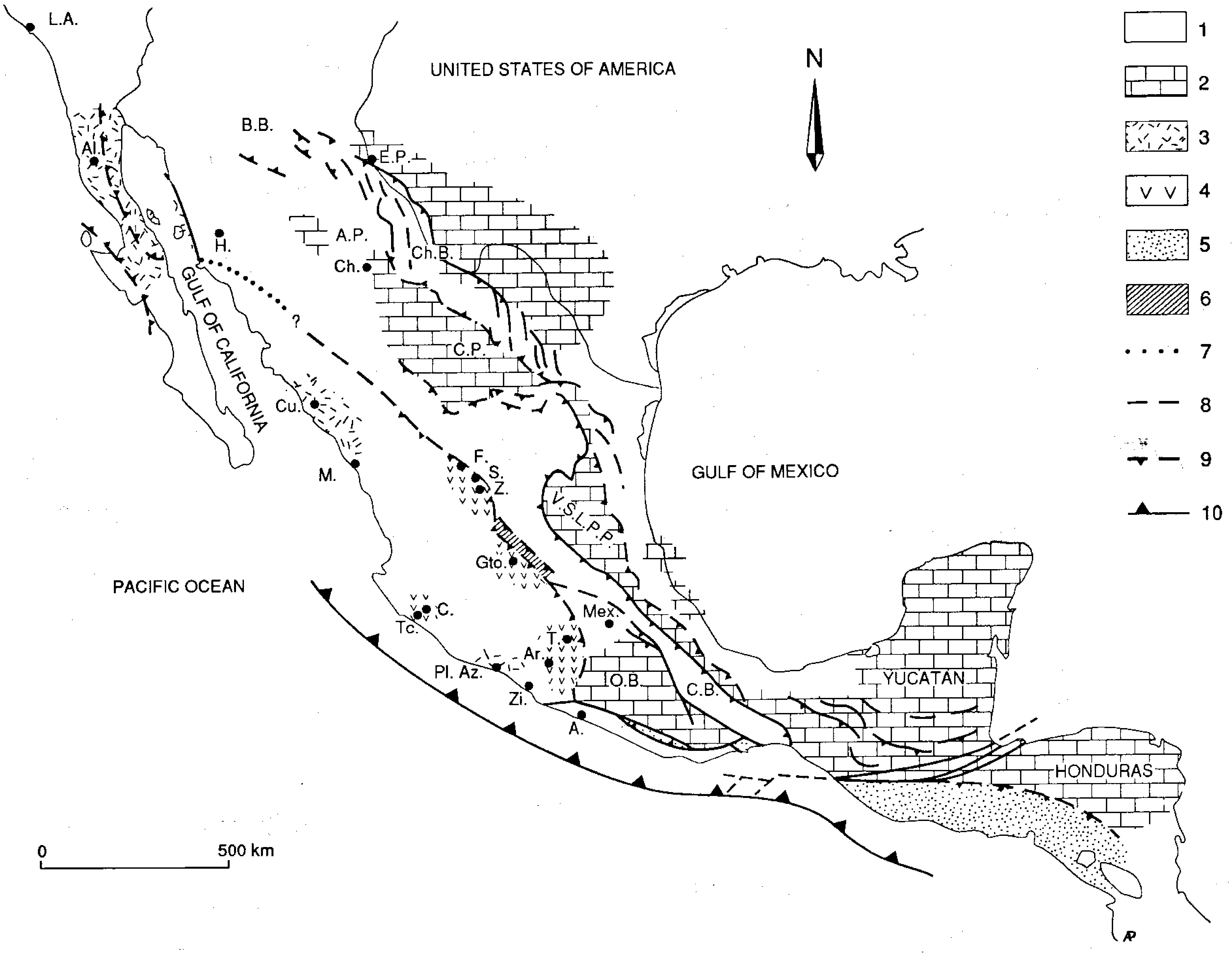

Figure 3.- Structural sketch map of Mexico showing the location of the Late Jurassic-Early Cretaceous Alisitos-Teloloapan arc. The Cenozoic volcanic cover has been omitted. 1 and 2—Eastern Tethyan domain, with (1) toward the end of the Early Cretaceous basin, (2) upper part of the Early Cretaceous carbonate platforms; 3 and 4—western domain or Alisitos-Teloloapan arc (Guerrero terrane), with (3) Late Jurassic-Early Cretaceous inferred continent-based arc volcano-plutonic assemblages; 5—Late Jurassic-Early Cretaceous arc volcano-plutonic assemblages, the basement of which is unknown, but likely built on a continental basement or intermediate type crust; 6—Early Cretaceous oceanic alkalic basalts and deep basin sedimentary rocks (Arperos Formation); 7—$^{87}Sr/^{86}Sr = 0.706$ line (after Cochemé, 1985); 8—main faults; 9—main thrusts; 10—present day subduction. A.—Acapulco; A.P.—Aldama platform; Ar.—Arcelia; B.B.—Bisbee basin; C.—Colima; C.B.—Cuicatec basin; C.P.—Coahuila platform; Ch.B.—Chihuahua basin; Cu.—Culiacán; E.P.—El Paso; F.—Fresnillo; Gto.—Guanajuato; H.—Hermosillo; L.A.—Los Ángeles; M.—Mazatlán; Mex.—Mexico City; O.B.—Oaxaca block; Pl.Az.—Playa Azul; S—Saucito; T.—Teloloapan; Tc.—Tecomán; V.S.L.P.P—Valles-San Luis Potosí platform; Z.—Zacatecas; Zi.—Zihuatanejo.

presence of K-feldspar in the groundmass, high $Al_2O_3$, $Fe_2O_3$, Zr, and Y contents (Zr/Y = 4.72; Table 1), and significant LREE enrichments ($[La/Yb]_N = 6.56$; Table 1, Figures 5 and 6). While southwest of Tecomán, clinopyroxene-phyric basalt shows medium HFSE enriched calc-alkalic affinities, with lower Nb contents and lesser LREE enrichment (sample 91-25; $[La/Yb]_N = 3.41$; Table 1, Figures 5 and 6; Basaltic Volcanism Study Project, 1981; Gill, 1981, 1987), rather similar to the Teloloapan basalt.

The Playa Azul predominantly acidic andesite (sample 91-45; Table 1) and rhyolite (samples 91-2 and 91-6; Table 1), including preserved brown hornblende and biotite phenocrysts, belong to a high-K ($2.43 < K_2O\% < 4.10$; Table 1) calc-alkalic suite with low $TiO_2$ (< 0.65%) and $Fe_2O_3$ (< 5%) contents and high Y, Zr (Table 1, Figure 5) and LREE ($14.58 < [La/Yb]_N < 26\text{-}63$; Figures 5 and 6) abundances (Table 1). Some rhyolite rocks (sample 91-6; Figure 5) differ by: (1) a marked Eu negative anomaly; (2) lower LREE contents; and (3) greater HREE enrichment ($[La/Yb]_N = 1.27$; Table 1), due to the presence of zircon, mineral known to concentrate the HREE (Nagasawa *et al.*, 1979). Locally, alkalic acidic ($SiO_2 = 66\%$; $Na_2O + K_2O = 7.72\%$; $Na_2O/K_2O = 0.75$) aegirine-augite and green to blue Na-rich amphibole-phyric lava flows are interbedded in the Playa Azul arc sequence (Table 1, Figures 5 and 6).

So, with respect to the sedimentary environment, according to the petrology and the geochemistry of its igneous rocks, the Teloloapan-Alisitos arc, during Aptian-Albian time, shows three main lithostratigraphic and magmatic successions. The first type, represented by the Teloloapan succession, follows the depleted to mature low-K tholeiitic suites exposed in central Mexico. It consists of predominantly mafic low-K calc-alkalic pillow lavas with very rare silicic tuff and lavas erupted in a submarine environment. The second type, represented by the Tecomán succession, is formed of submerged massive shoshonitic olivine basalt flows. The third type, exposed near Playa Azul, shows the predominance of $SiO_2$-saturated lavas, with abundant pyroclastic rocks in a subaerial to shallow-water environment.

## A NEW MODEL PROPOSED FOR THE DEVELOPMENT OF THE ALISITOS-TELOLOAPAN ARC

The geological, petrological and geochemical data allow us to propose a new model for the building of the Alisitos-Teloloapan magmatic arc. Its development began during the Late Jurassic. It

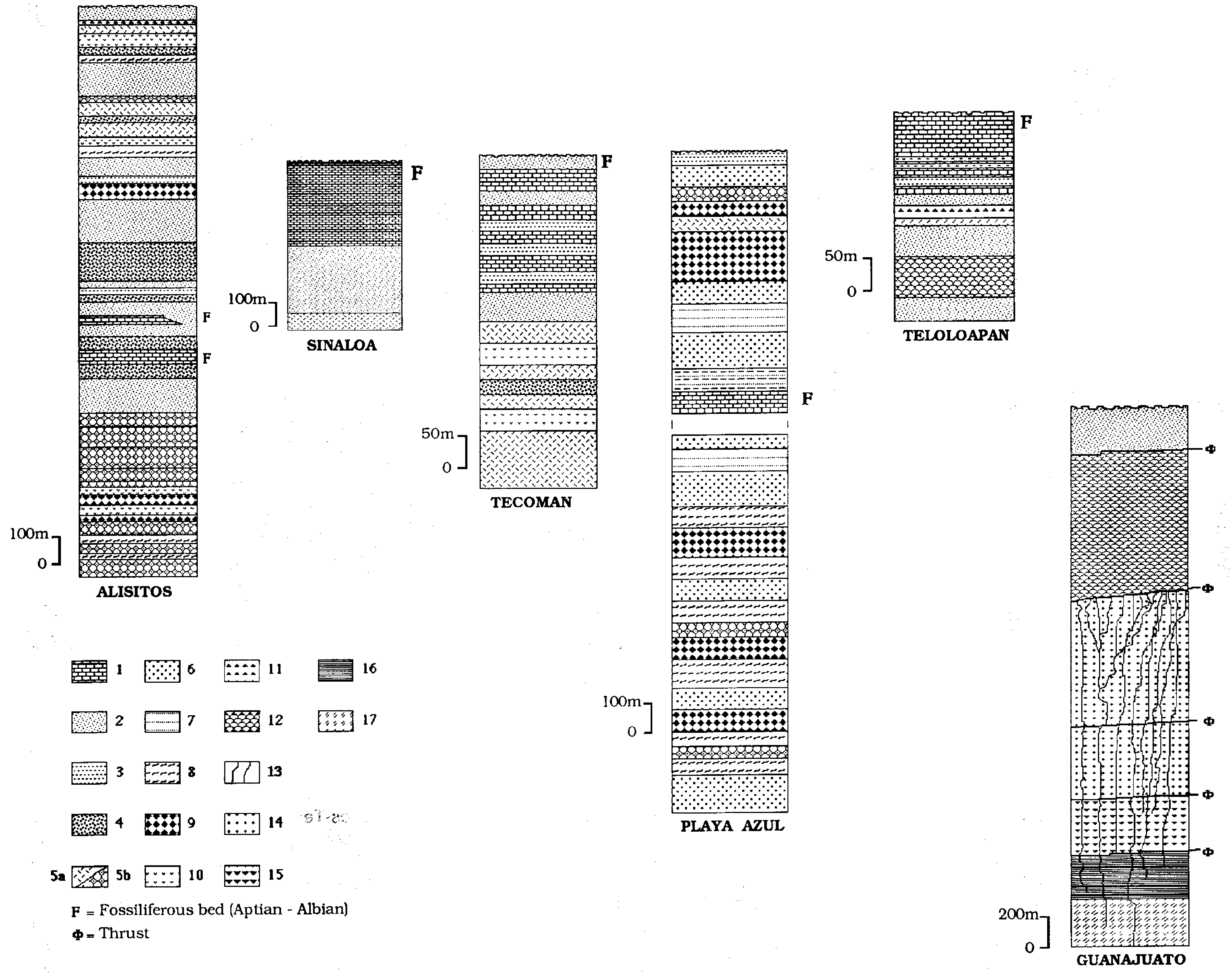

Figure 4.- Simplified lithostratigraphic sections of the Alisitos-Teloloapan arc exposed in the central and southern parts of Mexico. 1—Aptian-Albian reefal limestones; 2—volcaniclastic sandstones and mudstones; 3—marls; 4—volcaniclastic breccia; 5—mafic (a) and silicic lavas (b); 6—red sandstones; 7—red siltstones; 8—silicic welded or not tuffs; 9—silicic volcanic breccias; 10—basaltic and andesitic volcanic breccia; 12—basaltic and andesitic pillow basalts; 13—dike complex; 14—silicic plutonic rocks; 15—Mg-hornblende diorites; 16—layered cumulate gabbros; 17—cumulate ultramafic rocks.

was built partly on oceanic crust and partly on continental crust. The remnants of the oceanic segment of this arc occur now in central Mexico, between Guanajuato and Teloloapan, while the remnants of its continental segments are exposed elsewhere in Mexico—Baja California, Sonora and Sinaloa.

At the beginning of the magmatic activity of the oceanic arc segment, LREE-depleted tholeiitic basalt flows were emitted in a submarine environment under the carbonate compensation depth (CCD). Their εNd(T) ratios fall within the range found commonly for oceanic magmatic arcs (DePaolo, 1988). The lack of any continental derived sediments interbedded with the predominantly pillowed basaltic flows suggests that the arc was separated and/or far from the North American craton.

As the subduction process was going on, the arc magmatic activity evolved. The LREE and lithophile elements increased in the tholeiitic basaltic magma, because of the increasing part of the subducted sediments and oceanic crust involved in the subduction process. The arc volcanic pile was thickening. The deposition of micritic limestones, which are found interbedded within the volcanic rocks of the Saucito and Francisco I. Madero sections, suggests that, at this time, the basalt and andesite erupted above the CCD. Finally, during Aptian-Albian times, the arc magmatism became low-K calc-alkalic—Fresnillo and Teloloapan sections—predominantly with the eruption of basalt and mafic andesite, and scarce silicic lavas and pyroclastic rocks. The arc was still submerged but its sedimentary environment has changed. The presence of limestones, including an Aptian-Albian reefal fauna, shows that this environment was neritic.

In the continent-based segment of the arc, the magmatism is restricted to K-rich orogenic volcanic rocks. The latter are either shoshonitic basalt greatly enriched in LREE, Zr and Y or high-K calc-alkalic silicic andesite and rhyolite showing high contents in Zr, Y and lithophile elements. In contrast with the oceanic arc segment, andesitic and rhyolitic tuffs, silicic pyroclastic breccias and tuffs prevail on the lava flows. The associated sediments with the extrusive rocks indicate that the latter were emitted generally in a subaerial or shallow-marine environment, excepting the shoshonitic basalt, which poured under the sea.

Table 1.- Major element whole rock, trace element and REE analyses of the Alisitos-Teloloapan arc lavas.

| Location<br>sample No.<br>Rock type<br>Magmatic affinity | Guanajuato**<br>HM 90<br>Pillow basalt<br>Depleted LKT | Zacatecas**<br>ZY 90<br>Pillow basalt<br>Depleted LKT | Zacatecas**<br>ZY08<br>Diabase dyke<br>Depleted LKT | Arcelia **<br>TX92<br>Pillow basalt<br>Mature LKT | Saucito**<br>MYS-85<br>Pillow basalt<br>Mature LKT | Fresnillo**<br>ZY-26<br>Pillow basalt<br>Calc-alkalic | Guanajuato**<br>SS5<br>Plutons<br>Calc-alkalic | Teloloapan**<br>T-206<br>Pillow basalt<br>Calc-alkalic | Teloloapan**<br>TX-36<br>Andesite<br>Calc-alkalic | Tecomán***<br>91-15<br>Basalt<br>Shoshonite | Juan/Lima***<br>91-25<br>Basalt<br>Calc-alkalic | Playa Azul***<br>91-36<br>Andesite<br>Calc-alkalic | Playa Azul***<br>91-45<br>Acid andesite<br>Calc-alkalic | Playa Azul***<br>91-2<br>Rhyolite<br>Calc-alkalic | Playa Azul***<br>91-40<br>Rhyolite<br>Alkalic |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 42.56 | 50.57 | 48.02 | 51.30 | 44.92 | 46.71 | 50.67 | 47.87 | 57.65 | 50.89 | 50.97 | 52.54 | 61.23 | 75.90 | 68.98 |
| $TiO_2$ | 0.45 | 0.68 | 0.66 | 0.44 | 1.41 | 1.37 | 0.64 | 1.25 | 0.81 | 0.95 | 1.30 | 0.49 | 0.62 | 0.10 | 0.38 |
| $Al_2O_3$ | 12.49 | 13.73 | 15.25 | 13.26 | 13.38 | 13.61 | 11.85 | 17.48 | 17.03 | 17.62 | 16.06 | 21.92 | 16.91 | 12.97 | 13.60 |
| $Fe_2O_3$ | 8.54 | 9.30 | 8.23 | 8.92 | 7.33 | 7.44 | 9.25 | 8.55 | 6.75 | 10.99 | 8.36 | 6.12 | 4.75 | 0.75 | 2.93 |
| MnO | 0.14 | 0.16 | 0.13 | 0.14 | 0.15 | 0.08 | 0.17 | 0.13 | 0.08 | 0.07 | 0.15 | 0.06 | 0.06 | 0.01 | 0.04 |
| MgO | 12.96 | 7.98 | 8.44 | 9.13 | 4.25 | 4.74 | 10.07 | 6.24 | 1.75 | 5.30 | 6.36 | 4.73 | 1.55 | 0.20 | 0.65 |
| CaO | 8.42 | 11.78 | 11.91 | 8.38 | 11.91 | 10.75 | 11.16 | 8.85 | 5.98 | 2.91 | 5.80 | 4.08 | 5.32 | 0.58 | 2.54 |
| $Na_2O$ | 2.66 | 1.82 | 2.22 | 2.34 | 4.25 | 3.82 | 2.29 | 1.98 | 3.00 | 5.93 | 5.29 | 4.90 | 5.12 | 4.48 | 3.32 |
| $K_2O$ | 0.13 | 0.22 | 0.73 | 0.96 | 0.50 | 0.96 | 1.45 | 1.81 | 3.16 | 1.05 | 0.53 | 1.23 | 1.02 | 4.10 | 4.40 |
| $P_2O_5$ | 0.12 | 0.20 | 0.24 | 0.20 | 0.29 | 0.41 | 0.43 | 0.56 | 0.34 | 0.37 | 0.19 | 0.19 | 0.21 | 0.02 | 0.12 |
| LOI | 11.70 | 3.29 | 3.24 | 3.70 | 11.94 | 9.82 | 1.69 | 5.12 | 2.68 | 4.32 | 5.47 | 4.47 | 4.13 | 1.22 | 2.19 |
| Total | 100.17 | 99.73 | 99.07 | 98.77 | 100.33 | 99.71 | 99.67 | 99.57 | 99.23 | 100.05 | 100.34 | 100.37 | 100.77 | 100.31 | 99.11 |
| Ni ppm | 1110 | 214 | 102 | 93 | 77 | 161 |  | 95 | 6.00 | 45.00 | 64.00 | 38 | 6.00 | 8.00 | 19 |
| Cr | 431 | 437 | 317 | 429 | 76 | 463 |  | 233 | 9.00 | 78.00 | 65.00 | 14 | 6.00 | 5.00 | 9 |
| V | 194 | 282 | 208 | 241 | 214 | 168 |  | 179 | 122.00 | 158.00 | 190.00 | 68 | 127.00 | 4.00 | 48 |
| Y | 11.5 | 14.13 | 16.29 | 12.55 | 30.78 | 14.2 | 19.32 | 24.89 | 23.78 | 19.00 | 23.00 | 7 | 10.00 | 7.00 | 8 |
| Zr | 36.4 | 16 | 121 | 28 | 118 | 124 | 74 | 104 | 174.00 | 110.00 | 110.00 | 72 | 98.00 | 68.00 | 145 |
| Nb | 4.6 | nd | nd | nd | nd | nd | nd | nd | nd | 8.00 | 2.00 | 4 | 3.00 | 7.00 | 5 |
| Ba | 89 | 44 | 121 | 203 | 390 | 183 | 501 | 746.00 | 358.00 | 218.00 | 68.00 | 274 | 551.00 | 217.00 | 1009 |
| Sr | 84.7* | >2000 | 297 | 299 | 286 | 124 | 632 | 665.00 | 620.00 | 639.00 | 424.00 | 529 | 520.00 | 989.00 | 379 |
| Rb | 1.767* | 10 | 15 | 15 | 14 | 20 | 26 | 29.00 | 108.00 | 12.00 | 7.00 | 10 | 15.00 | 24.00 | nd |
| Ti/Zr | 130.02 | 255.00 | 165.00 | 94.28 | 71.69 | 66.29 |  | 69.20 | 45.00 | 57.00 | 70.90 | 40.8 | 37.95 | – | – |
| Zr/Y | 3.17 | 1.13 | 1.47 | 2.23 | 3.83 | 8.72 |  | 4.17 | 7.31 | 5.78 | 4.72 | 10.28 | 9.80 | – | – |
| La | 2.31* | 0.56 | 2.36 | 3.48 | 6.33 | 12.63 | 12.01 | 28.00 | 28.70 | 10.00 | 7.37 | 5.27 | 11.00 | 13.00 | 22.10 |
| Ce | 6.17 | nd | nd | nd | nd | nd | nd | nd | nd | 23.20 | 18.8 | 9.90 | 23.50 | 23.10 | 38.30 |
| Nd | 5.00 | 3.77 | 7.42 | 5.61 | 11.88 | 14.50 | 16.67 | 27.97 | 24.90 | 12.6 | 12.7 | 4.73 | 11.80 | 7.73 | 14.90 |
| Sm | 1.51 | 1.69 | 2.51 | 1.94 | 6.00 | 3.62 | 4.20 | 6.13 | 5.20 | 2.90 | 3.38 | 1.88 | 2.75 | 1.32 | 1.89 |
| Eu | 0.59 | 0.58 | 0.86 | 0.52 | 1.40 | 1.15 | 1.17 | 1.73 | 1.45 | 0.86 | 1.22 | 1.06 | 0.83 | 0.32 | 0.97 |
| Gd | 1.87 | 2.13 | 2.73 | 2.11 | 4.94 | 3.35 | 3.47 | 5.28 | 4.31 | 2.69 | 3.60 | 1.72 | 1.96 | 0.74 | 1.51 |
| Dy | 2.09 | 2.26 | 2.77 | 1.92 | 4.43 | 2.67 | 2.81 | 4.13 | 3.81 | 3.67 | 3.67 | 1.58 | 1.60 | 0.68 | 1.81 |
| Er | 1.31 | 1.44 | 1.62 | 1.25 | 2.50 | 1.40 | 1.48 | 2.29 | 2.29 | nd | nd | nd | nd | nd | nd |
| Yb | 1.27 | 1.34 | 1.40 | 1.13 | 2.42 | 1.21 | 1.43 | 1.94 | 2.10 | 1.03 | 1.46 | 0.43 | 0.51 | 0.33 | 1.03 |
| Lu | nd | 0.21 | 0.16 | 0.16 | 0.47 | 0.17 | 0.36 | 0.25 | 0.26 | 0.19 | 0.22 |  | 0.10 | 0.07 | 0.38 |
| $(La/Yb)_N$ | 0.83 | 0.28 | 1.13 | 2.07 | 1.76 | 7.05 |  | 9.76 | 9.225 | 6.56 | 3.41 |  | 14.58 | 26.63 |  |
| La/Nb | 0.50 | – | – | – | – | – |  | – | – | 1.25 | 3.60 |  | 3.66 | – |  |
| Texture | Intersertal | Intersertal | Ophitic | Ophitic | Intersertal | Porphyritic | Oriented | Porphyritic | Porphyritic | Porphyritic | Porphyritic | Porphyritic | Porphyritic | Porphyritic | Porphyritic |
| Mineralogy | Ol, Cpx, Cr-Spl | Ca-rich Cpx, Ep-Chl | Aug-Di, Ep | Di, Lab | Aug, Ti-Mag Cal | Ol ps., Cr-Spl, Cal | Mg-Bt, Mg-Hbl, Pl, Or | Ol-Opx ps., Aug, Ca-Pl | Opx ps., Ed-Hbl, Na-rich Pl | Ol ps., Aug-Sal, Sa, Ab | Ca-rich Cpx, Ca-Pl | Ca-rich Cpx, Lab | Mg-Hbl, Bt, Ab | Mg-Hbl, Bt, K-Nafs | Agr, Na-Fe Amph, K-Nafs |

Ol: olivine; Cpx: clinopyroxene; Spl: spinel; Ep: epidote; Chl: chlorite; Aug: augite; Di: diopside; Mag: magnetite; Lab: labradorite; Cal: calcite; Bt: biotite; Hbl: hornblende; Pl: plagioclase; Or: orthoclase; Opx: orthopyroxene; Ed: edenite; Sal: salite; Sa: sanidine; Ab: albite; K-Nafs: K-Na feldspar; Agr: aegirine; Amph: amphibole; ps.: pseudomorphs. Cr, Ca, Ti, Mg, K, Na and Fe are the conventional chemical symbols.

The geochemical analyses were carried out by isotopic dilution*, and by ICP in the Centre de Recherche Pétrographique et Géochimique-Vandoeuvre les Nancy**, and in the Laboratoire de Pétrologie magmatique d'Aix Marseille III***. Mn, Na, K and Rb were analysed by atomic absorption.

The analytical conditions for ICP are 1-3% for major elements, and 1.5-2.8% for trace elements and REE.

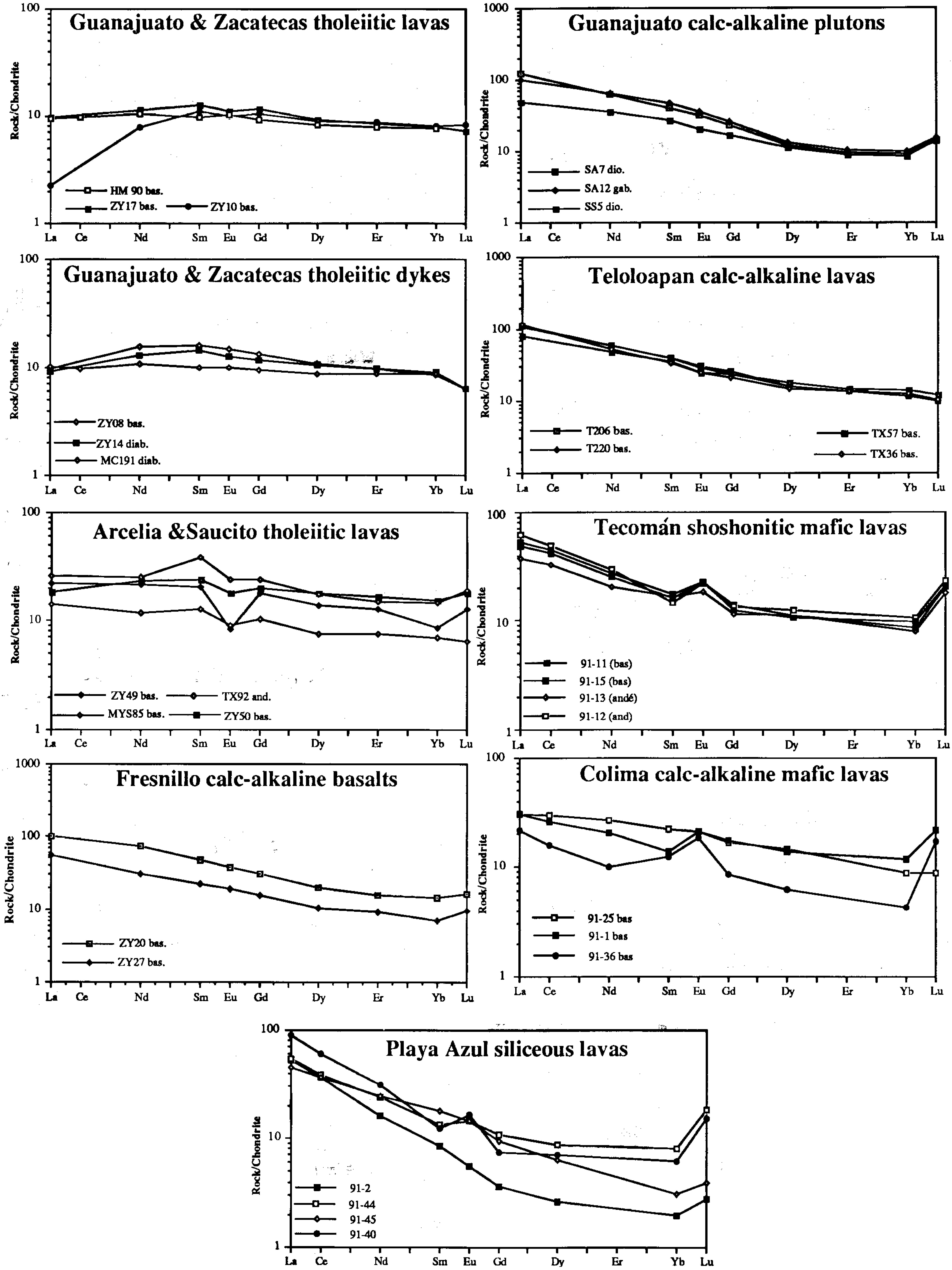

Figure 5.- REE patterns normalized to chondrites (after Evensen *et al.*, 1978) of the Alisitos-Teloloapan arc volcanic rocks.

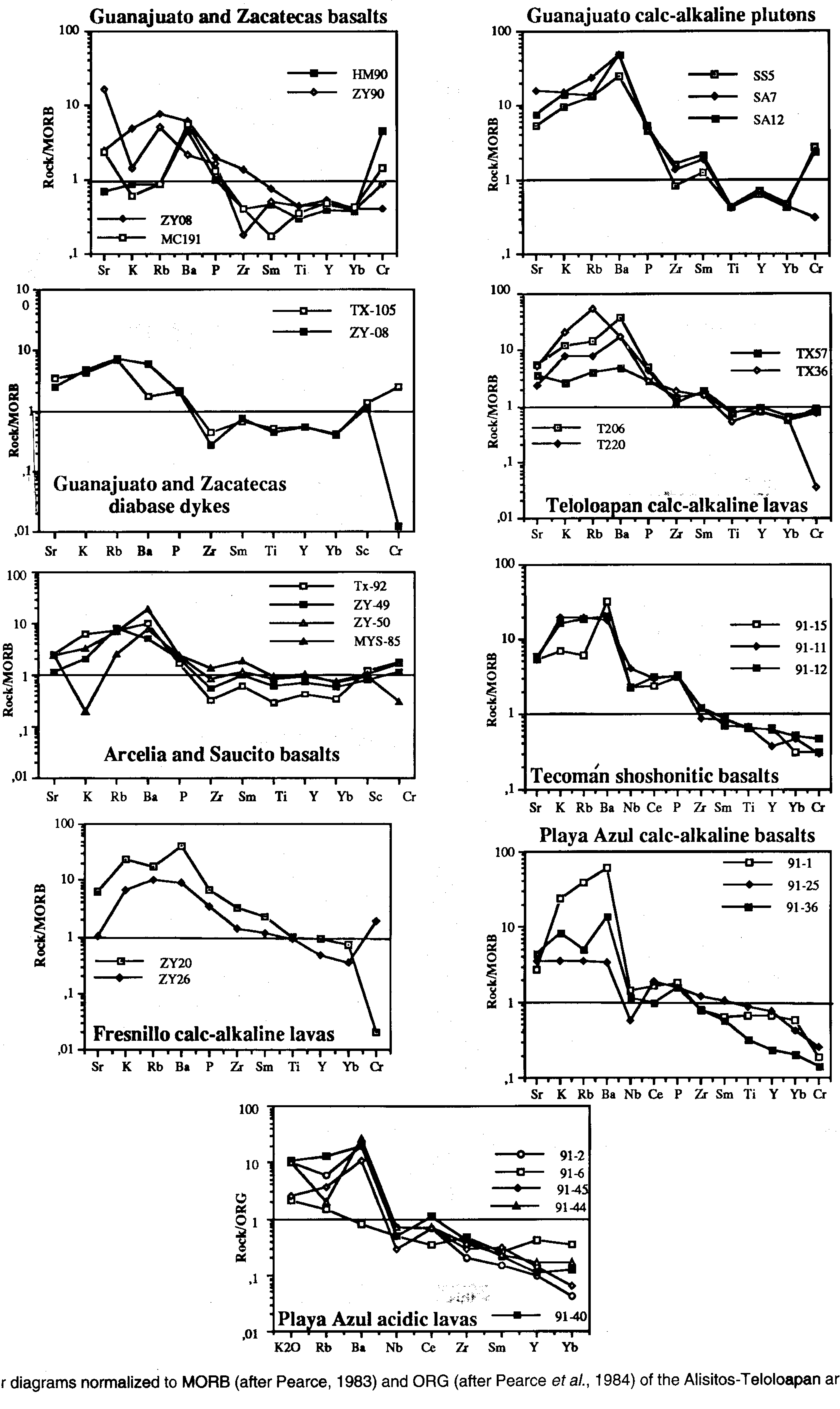

Figure 6.- Spider diagrams normalized to MORB (after Pearce, 1983) and ORG (after Pearce *et al.*, 1984) of the Alisitos-Teloloapan arc volcanic rocks.

It is important to notice that the eastern part of the arc, which nowadays is thrusted onto the margin of Cretaceous North America, was completely built on oceanic crust. This implies that, during the arc magmatic activity, an oceanic domain was present between Cretaceous North America and the Alisitos-Teloloapan arc. The remnants of this arc domain, named Arperos basin (Tardy *et al.*, 1991, submitted), consist of intraoceanic, within-plate alkalic pillow basalt and dolerite (Monod *et al.*, 1990) overlain by Lower Cretaceous siliceous sediments (Arperos Formation; Dávila-Alcocer and Martínez-Reyes, 1987). They are exposed now as tectonic slices under the Guanajuato magmatic sequence, which represents the nascent stage of the Alisitos-Teloloapan arc (Lapierre *et al.*, 1992, in press).

Two assumptions can be proposed for the vergence of the subduction related to the arc development:

1—The subduction had an eastward vergence and the island arc development was linked to the subduction of the Pacific plate. In this case, the Arperos basin would represent the back-arc basin.

2—The subduction had a westward vergence; the arc development was related to the subduction of the Arperos basin under the Pacific plate. In this second case (Figure 7), this subduction led to the closure of the Arperos oceanic basin while the arc was drifting towards the margin of North America, before its collision with this continent.

The second assumption is preferred, because of the northeast vergence of the thrust sheets, folds and cleavages observed in the arc rocks (Tardy, 1980; Elías-Herrera and Sánchez-Zavala, 1990). These tectonic markers are linked to the mid-Cretaceous compressive event that occurred when the Guerrero terrane collided with North America.

According to this model, the Alisitos-Teloloapan volcano-plutonic arc, built partly on Pacific oceanic lithosphere and partly on continental blocks, is exotic with respect to North America. Its drifting towards North America is related to the destruction of the Arperos basin oceanic crust while it subducted under the Pacific plate. Thus, this intraoceanic arc, responding to the terrane definition (Guerrero terrane), collided the western margin of the North American continent at the end of the Early Cretaceous (Tardy, 1980; Rangin, 1985; Pubellier and Rangin, 1987).

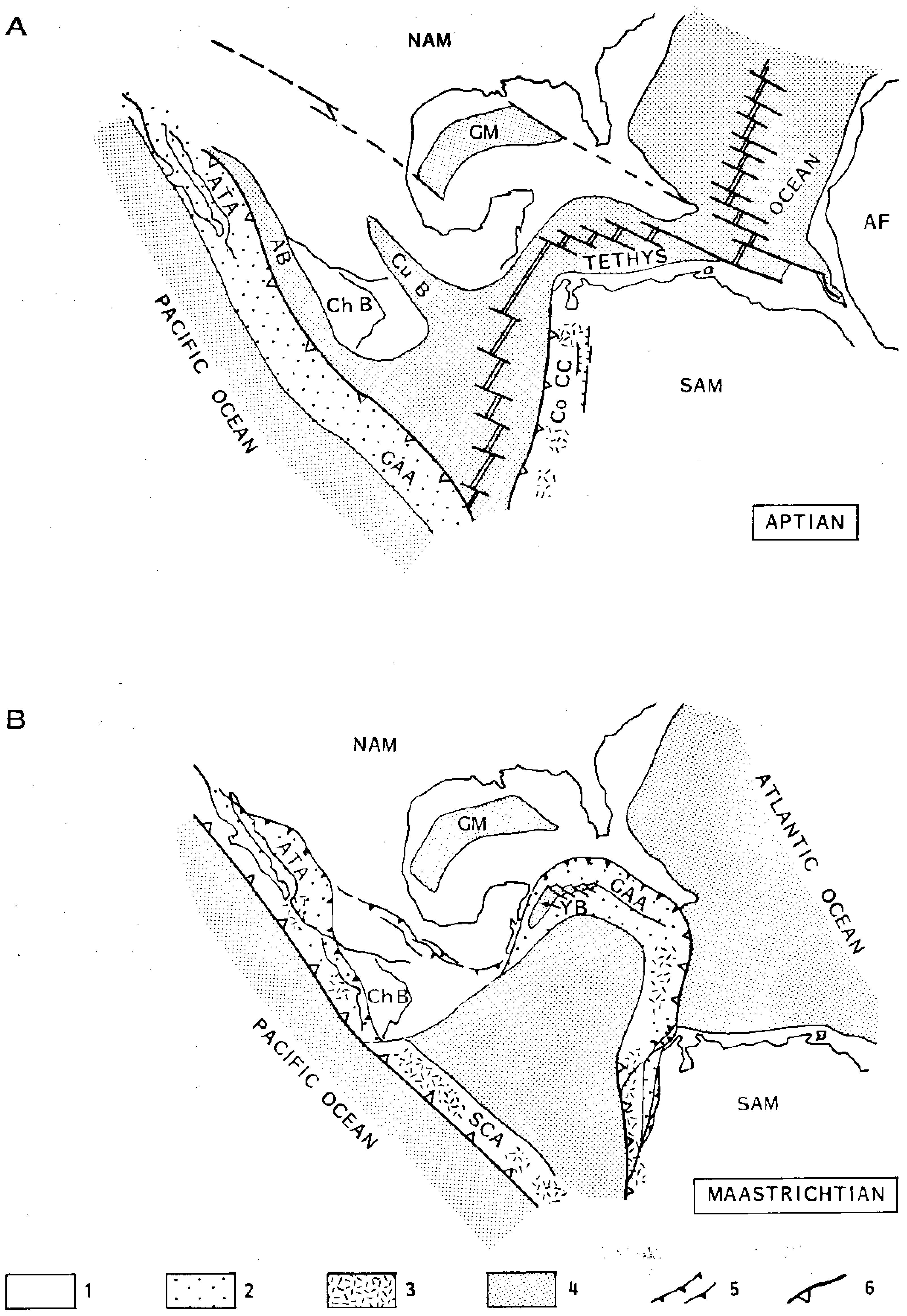

Figure 7.- Simplified palinspastic maps (modified after Stephan *et al.*, 1990), showing (*A*) the intra-Pacific environment for the Late Jurassic-Early Cretaceous magmatic arc during the Aptian, and (*B*) its remnants along the North and South American margins after its collision with the cratons (Arc Alisitos-Teloloapan at the end of the Early Cretaceous = Guerrero terrane; other arc exposures during the Late Cretaceous in Colombia and in the Greater Antilles). 1—North American and South American cratons; 2—Late Jurassic-Early Cretaceous magmatic arc; 3—active continental margin volcanism; 4—accreted segments of the Late Jurassic-Early Cretaceous arc along the American continental margins; 5—thrust; 6—subduction zone; AB—Arperos basin; SCA—South Central American arc; YB—Yucatán basin.

## CONCLUSIONS

This geodynamic model, which illustrates the origin and the development of the Guerrero terrane and its related Late Jurassic-Cretaceous magmatic arc, can be easily extended to the eastern circum-Pacific and peri-Caribbean terranes, including contemporaneous arc volcano-plutonic sequences that were thrusted onto the margins of the North and South American cratons during the Cretaceous.

The palinspastic maps, illustrated in Figure 7, give an alternative model to those proposed for the evolution of the far western Tethys and its neighboring Pacific (Calais *et al.*, 1989; Stephan *et al.*, 1990). The Cretaceous volcanic series, accreted to the margins of cratonic America, in Colombia, Venezuela, Greater Antilles and Mexico, belong to the same intra-Pacific arc. The development of these Cretaceous arc suites is linked to a west-southwestward subduction of the oceanic basins—Arperos basin—fringing the North and South American continental margins and connecting directly with the inter-American Tethys. While this subduction was going on, the magmatic arc drifted and was getting closer to the North and South American cratons and then, finally, collided their continental margins at different times. The northern arc segment—Alisitos-Teloloapan arc—collided against the Mexican during the late part of the Early Cretaceous, while the collision of the southern segment with the Colombian margin began since the Albian and lasted until the Coniacian-early Campanian. As for the central segment of this arc, it migrated towards the Caribbean-Tethys ocean, before its collision with the Greater Antilles-Florida margin during the Campanian.

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