

geofísica  
internacional

Geofísica Internacional

ISSN: 0016-7169

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Universidad Nacional Autónoma de México  
México

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Mexico  
Geofísica Internacional, vol. 37, núm. 4, october-december, 1998, pp. 283-292  
Universidad Nacional Autónoma de México  
Distrito Federal, México

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## The Late Triassic-Early Jurassic active continental margin of western North America in northeastern Mexico

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Received: November 21, 1997; accepted: June 29, 1998.

### RESUMEN

En el noreste de México se han reportado algunos afloramientos de rocas volcánicas Triásicas y Jurásicas, cuyas características petrológicas y geoquímicas demuestran una afinidad de arco que permite relacionarlas a una margen continental activa. Más elementos que apoyan este ambiente tectónico se localizan en los estados de Durango, Zacatecas, San Luis Potosí, Nuevo León y Tamaulipas, en donde una secuencia siliciclástica tipo flysch en la porción occidental y un bloque continental pre-mesozoico en la porción oriental subyacen a la secuencia volcanogénica. En el presente trabajo se propone que las rocas volcánicas Triásicas y Jurásicas, así como algunas capas rojas asociadas que se encuentran en el centro y noreste de México, están relacionadas genéticamente con una margen continental activa y solamente algunas de las secuencias de capas rojas expuestas en el extremo oriental de México estarían relacionadas a estructuras de rift, posiblemente asociadas a la partición de Pangea como se ha propuesto hasta ahora, o en nuestra opinión, relacionadas más bien a cuencas de trasarco, además de las secuencias relacionadas a procesos posteriores, como la transgresión marina del Calloviano-Oxfordiano, asociada a la evolución de la margen pasiva o la apertura del Golfo de México.

**PALABRAS CLAVE:** Triásico, Jurásico, margen activa, estratigrafía.

### ABSTRACT

Exposures of Triassic-Jurassic volcanic sequences in northeastern Mexico suggest that they developed along an active continental margin. Other sequences in support of such a tectonic environment are exposed in Durango, Zacatecas, San Luis Potosí, Nuevo León and Tamaulipas, where siliciclastic flysch sediments to the west and an older metamorphic continental block to the east underlie the volcanics. It is proposed that these Triassic to Jurassic volcanic rocks and associated redbeds from middle to northeastern Mexico are genetically related to a Jurassic active continental margin. The red beds of easternmost Mexico are either associated with rifting related to the break-up of Pangea, or preferably to a back-arc basin and to the younger transgressive Callovian to Oxfordian sequence, beginning with redbeds and associated to the basin evolution of the Gulf of Mexico and an eastern passive continental margin.

**KEY WORDS:** Triassic, Jurassic, active margin, stratigraphy.

### INTRODUCTION

According to Grajales-Nishimura *et al.* (1992) and Jones *et al.* (1995), Lower Mesozoic subaerial volcanic rocks occur at several outcrops and wells in southern Arizona, northern Sonora, Durango, Zacatecas, San Luis Potosí, Nuevo León and Tamaulipas. The absence of these rocks in parts of Chihuahua and eastern Sonora is explained as a result of left-lateral displacement along the Mojave-Sonora Megashear proposed by Silver and Anderson (1974). Our field work in the key areas of Huizachal Valley, Tamaulipas; Aramberri, Nuevo León; Real de Catorce and Charcas, San Luis Potosí; and Peñón Blanco, Arroyo Pimienta and Caopas-Pico de Teyra areas in Zacatecas, supports the proposal by Jones *et al.* (1995) that the volcanics belong to the Nazas Formation (Pantoja-Alor, 1972). Furthermore, we propose a correlation between underlying and overlying units. Our goal is to document other elements of an active continental margin, which are partially exposed in the same key areas. This is

supported by paleontological (Burckhardt and Scalia, 1906; Maldonado-Koerdell, 1948; Cantú-Chapa, 1969; Gallo-Padilla *et al.*, 1993), petrological, geochemical and geochronological data (Fries and Rincón-Orta, 1965; Pantoja-Alor 1972; López-Infanzón 1986; Grajales-Nishimura *et al.*, 1992; Jones *et al.*, 1995; Bartolini, 1997; Fastovsky *et al.*, 1997). Here we report some results from areas located in Zacatecas, San Luis Potosí, Nuevo León and Tamaulipas.

### BASEMENT DISTRIBUTION AND STRUCTURAL CONTROLS

Pre-Mesozoic sequences exposed in northern Mexico (Figure 1) can be divided according to their age and nature into six groups: (1) Proterozoic amphibolitic gneisses of the Bamori Complex, Sonora (Anderson and Silver, 1979; Ortega-Gutiérrez *et al.*, 1992, Sedlock *et al.*, 1993); (2) Proterozoic green-schists of northeastern Sonora and northern Chihuahua, which correlate with the Pinal Schist of southern

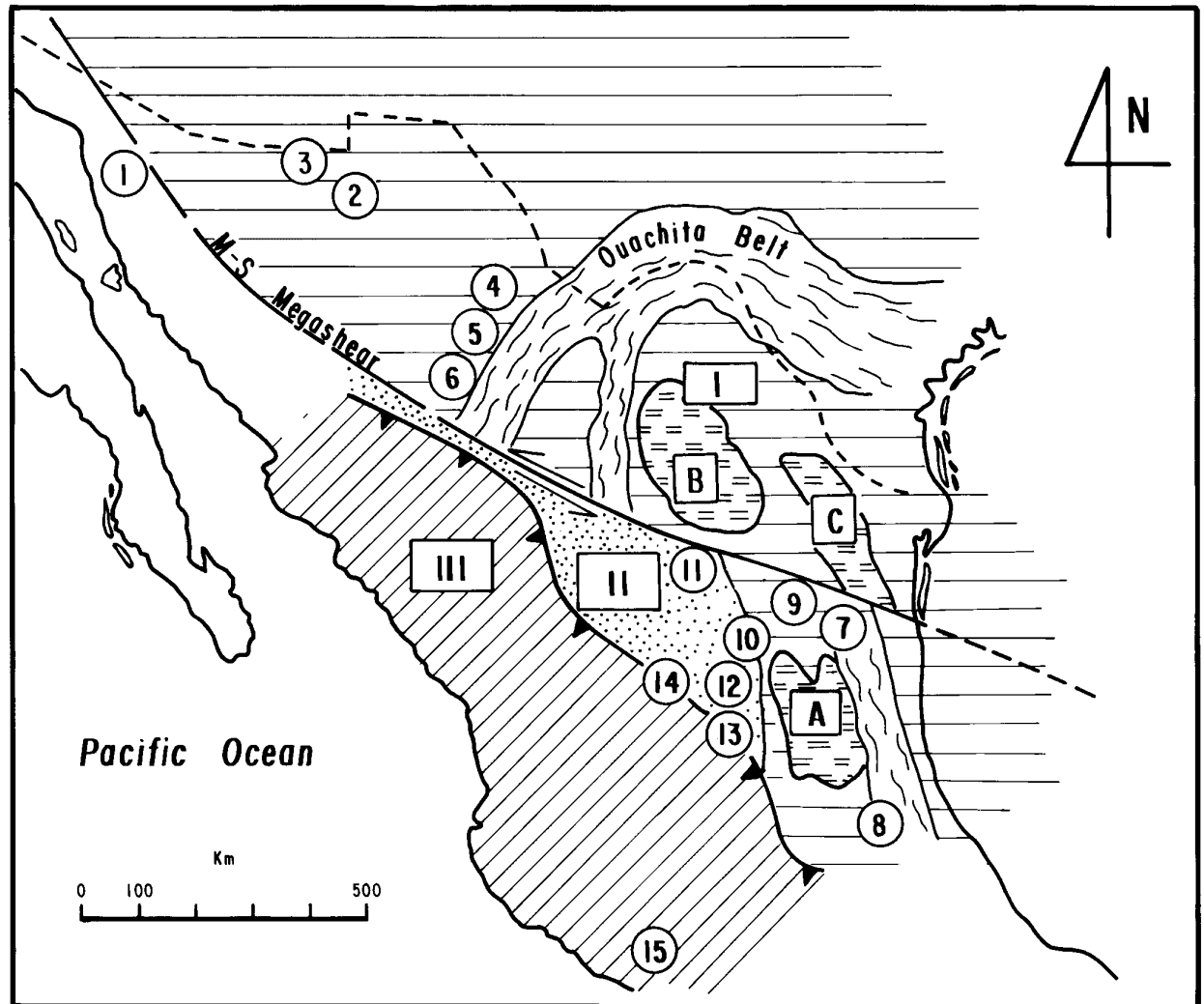


Fig. 1. Exposures of pre-Mesozoic units in northern to eastern Mexico are: 1. Caborca, 2. Nuevo Casas Grandes, 3. Janos, 4. Minas Plomos, 5. Las Delicias, 6. Boquillas, 7. Ciudad Victoria, 8. Huayacocotla, 9. Aramberri. Principal paleogeographic elements, which represent blocks of older metamorphic or magmatic rocks in the subsurface are: A. Valles San Luis Platform, B. Coahuila island, C. Tamaulipas arc. Also shown are the Ouachita orogenic belt after Moreno *et al.* (1993) and the trace of the Mojave-Sonora Megashear (Silver and Anderson, 1974). I= Northern-Northeastern continental block (horizontal lines), II= Zacatecas-block (dot pattern), III= Guerrero terrane (inclined lines). Exposures of the Triassic Marine sequence are: 10. Real de Catorce, 11. San Julián-Teyra, 12. Charcas, 13. Peñón Blanco, 14. Zacatecas, 15. Arteaga.

Arizona (Anderson and Silver, 1977, 1981; Ortega-Gutiérrez *et al.*, 1992); (3) Early Paleozoic, weakly metamorphosed sedimentary rocks exposed in Caborca, northern Chihuahua and Cd. Victoria (Cooper and Arellano, 1946, Stewart *et al.*, 1984, Carrillo-Bravo, 1961); (4) Late Paleozoic schists of Chihuahua and near Ciudad Victoria, Tamaulipas (Flawn *et al.*, 1961; Carpenter, 1997; Carrillo-Bravo, 1961); (5) Permo-Triassic granitoids in Chihuahua, northern Coahuila and Tamaulipas (Wilson, 1990 a, b); and (6) Late Paleozoic flysch-like sequences exposed in Nuevo Casas Grandes, Janos, Mina Plomos, Las Delicias, Carrizalillo, Cd. Victoria, Huayacocotla (Wilson, 1990 a, b; Carrillo-Bravo, 1961).

Wilson (1990 a, b) proposed a pre-Mesozoic tectonic framework for northern and eastern Mexico. Additional geophysical data (Moreno *et al.*, 1993, Sánchez and Urrutia, 1992), evidence on volcanic rocks containing lower crustal xenoliths (Ruiz *et al.*, 1988), and a morphotectonic interpretation lead us to reconstruct a continental block, which was consolidated at the end of the Permian or the beginning of the Triassic (Figure 1).

Other strongly deformed or metamorphic sequences in western Mexico, initially interpreted as Paleozoic, are recently assigned to the younger Guerrero terrane (Campa

and Coney, 1983) or to Early Mesozoic sequences. The metasedimentary rocks in the Real de Catorce area, considered by Bacon (1978), Enciso de la Vega (1992) and Franco-Rubio (1994) as Paleozoic, were recently correlated with the Carnian Zacatecas Formation by Cuevas-Pérez (1985), López-Infanzón (1986), Barboza-Gudino (1989, 1993) and Barboza-Gudino *et al.* (1997). The Taray Formation, first described by Cordova-Méndez (1964) as Paleozoic, is now interpreted as Triassic and correlated with the Zacatecas or Carnian La Ballena Formation (Silva Romo *et al.*, 1993, Sedlock *et al.*, 1993).

Jurassic-Cretaceous volcanoclastic and volcanoplutonic assemblages of the Guerrero terrane occur in western Mexico, under the Sierra Madre Occidental and Mesa Central provinces. A sequence of the Guerrero terrane overlaps marine Triassic rocks near Zacatecas and probably in the Arteaga area (Figure 1). This Triassic sequence contains tholeiitic basalts (Centeno-García *et al.*, 1993 a, b; Silva-Romo *et al.*, 1993) as possible indicators of a proximity to an oceanic crust rather than to an older metamorphic basement (García and Urrutia, 1997).

#### LATE TRIASSIC MARINE SEDIMENTATION

Early in the 20th century, marine fossiliferous rocks were discovered near Zacatecas City (Burckhardt and Scalia, 1905, 1906). Later authors have described Upper Triassic fauna from the same location (Gutiérrez-Amador, 1908; Maldonado-Koerdell, 1948) and from other siliciclastic sequences exposed near Charcas, San Luis Potosí (Cantú-Chapa, 1969; Gallo-Padilla *et al.*, 1993) and Peñón Blanco, Zacatecas (Chávez-Aguirre, 1968, Gallo-Padilla *et al.*, 1993).

We studied the areas of Sierra de Catorce, La Cardoncita northwest of Charcas, in northern San Luis Potosí and Sierra de Teyra in northern Zacatecas. In these areas we find outcrops of siliciclastic, flysch-like sequences, formed by rhythmically interbedded, gray to yellow and green sandstones and shales, with cross-bedding and ripple marks. In the Teyra area, olistolithes or wildflysch are common. In the Real de Catorce area, in the upper portion of the sequence we found probable channel deposits containing plant detritus in conglomeratic layers. In the absence of well-preserved fossils, it is difficult to determine a precise age for these deposits. Based on stratigraphy, lithological similarity, the occurrence of exotic blocks as a possible sources of Paleozoic fossils (Córdoba-Méndez, 1964; Bacon, 1978; Franco-Rubio, 1994), and the occurrence in Charcas (confirmed Carnian age from cephalopods), Real de Catorce, La Cardoncita and Teyra areas, of very similar mud molds of Pelecypoda (probable *Palaeoneilo* sp.), we conclude that all these sequences are upper Triassic and represent parts of an upper Triassic submarine fan as proposed by Silva-Romo *et al.* (1993).

#### LATE TRIASSIC?-LOWER JURASSIC VOLCANIC ARC

There are exposures of pre-Oxfordian subaerial volcanic rocks and associated redbeds in the states of Durango, Zacatecas, Nuevo León, San Luis Potosí and Tamaulipas (López-Infanzón, 1986, Grajales-Nishimura *et al.*, 1992, Jones *et al.*, 1995). The volcanics are mainly andesites, rhyolites and dacites, in the form of pyroclastic flows and some lava flows, rhyolitic domes and debris flows probably from stratovolcanos. A pre-Oxfordian age for these rocks is based on their stratigraphic position below the La Joya (Callovian?-Oxfordian) and Zuloaga (Oxfordian) Formations. It is difficult to date these volcanics because of their alteration and occasional low grade- or anchimetamorphism. The most reliable isotopic data indicate an age between  $165 \pm 3$  Ma (U-Pb, zircon) reported by Jones *et al.* (1990) or 220 Ma (Pb- $\alpha$ ) reported by Fries and Rincón Orta (1965). In the localities of Charcas and Peñón Blanco, this sequence overlies unconformably the Carnian Zacatecas Formation and underlies the Callovian?-Oxfordian La Joya Formation (Figure 2).

In outcrops of northeastern Durango and northern Zacatecas, this volcanogenic sequence and related clastic deposits are known as the Nazas Formation (Pantoja-Alor, 1972). In northeastern Mexico, the volcanic rocks are in the lower part of the Huizachal Formation (Imlay, 1943; Carrillo-Bravo, 1961) or La Boca Formation (*sensu* Mixon, 1963). At the localities of Aramberri and Real de Catorce, the sequence containing Jurassic volcanic rocks has been variously identified as La Boca Formation (Mixon, 1963), Huizachal undifferentiated (Belcher, 1979), Nazas Formation (López-Infanzón, 1986) or as a volcanic basal member of the La Joya Formation (Barboza-Gudino, 1989).

López-Infanzón (1986), Grajales Nishimura *et al.* (1992), Jones *et al.* (1995), Barboza-Gudino *et al.* (1997) and McKee *et al.* (1997) noted that the Mesozoic volcanics in northern Mexico are correlative in age and tectonic significance. Grajales-Nishimura *et al.* (1992) and Jones *et al.* (1995) proposed that they represent a remnant of a Cordilleran magmatic arc, where this arc would be found south of the proposed trace of the Mojave-Sonora megashear in northeastern Mexico, and north of the same structure in northern Sonora and Arizona. This would be due to pre-Oxfordian left-lateral displacement along this zone.

We propose, based on published isotopic data (Figure 2), stratigraphic relationships and the nature of the calcalkaline, mainly pyroclastic volcanics, that all these volcanics are parts of a Triassic-Jurassic arc as described by Grajales-Nishimura *et al.* (1992) and Jones *et al.* (1995). This arc is related to the Triassic-Jurassic active continental margin of western North America and the subduction of the Kula

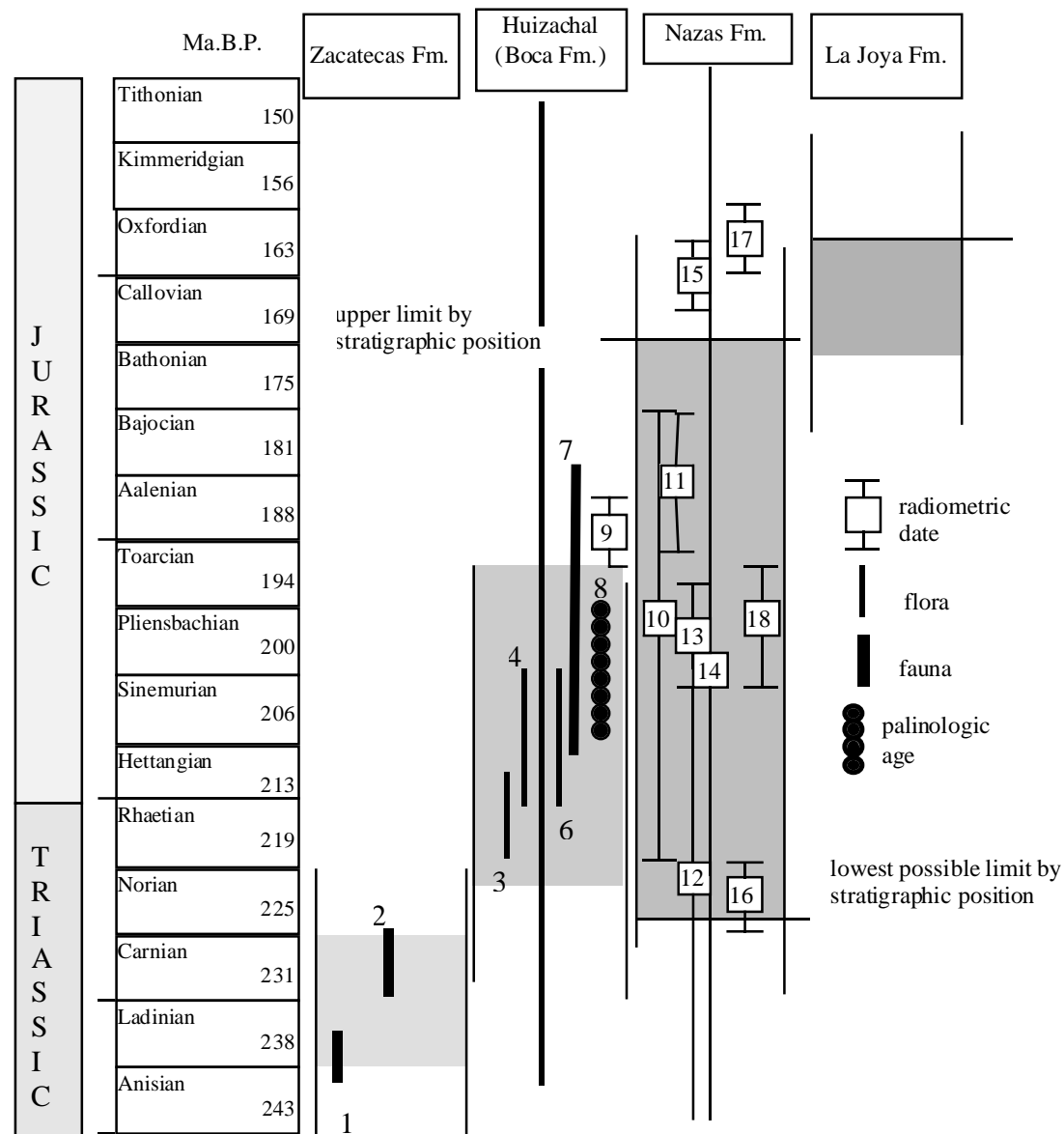


Fig. 2. Selected paleontologic, palinologic and isotopic ages of the pre-Oxfordian units of middle to northeast Mexico. 1. Cephalopoda (Gallo-Padilla *et al.*, 1993, this work); 2. Cephalopoda (Cantú-Chapa, 1969, Gallo-Padilla *et al.*, 1993); 3. Cycadeoid, conifer (Mixon, 1963); 4. Cycadeoid (Mixon, 1963); 5. Conifer (Mixon, 1963); 6. Cycadeoid (Mixon, 1963); 7. Vertebrates (Clark, J. M., 1997); 8. (Rueda-Gaxiola *et al.*, 1993); 9. Pb-Pb, zr (Fastowsky *et al.*, 1997); 10. Rb-Sr, wr (Fries and Rincón-Orta, 1965); 11. K-Ar, h (López-Infanzón, 1986); 12. Rb-Sr, wr (Fries and Rincón-Orta, 1965); 13. K-Ar, h (Damon *et al.*, 1981, in Sedlock *et al.*, 1993); 14. Rb-Sr, wr (Fries and Rincón-Orta, 1965); 15. U-Pb, zr (Jones *et al.*, 1990); 16. Rb-Sr, wr (Grajales-Nishimura *et al.*, 1992); 17. U-Pb, zr (Jones *et al.*, 1995); 18. Ar-Ar, pl (Bartolini, 1997). Shading indicates the possible age of each unit according to the stratigraphic position.

Plate (Coney, 1983). The term *Nazas Formation* is applicable to the sequence of volcanic rocks and associated redbeds of Late Triassic?-Early Jurassic age that overlies the Zacatecas Formation and likely interfingers with the Late Triassic-Early Jurassic Huizachal Formation exposed in the Huizachal-Peregrina Anticlinorium and overlain by the main sedimentary sequence of La Boca Formation or the alluvial,

fluvial and lagunar deposits of La Joya and the marine shallow water carbonates to evaporites of the Zuloaga Formation (Imlay, 1938) or Novillo Limestones (Heim, 1940). The volcanics cannot be grouped with La Boca and La Joya as *Huizachal Group* because of their genetic relation to different tectonic environments. Their present position in northern to northeastern Mexico can be explained as a result

of the left-lateral displacement along the Mojave-Sonora megashear. The volcanic sequences correlate with volcanic activity of a similar age in Sonora and Arizona (Jones *et al.*, 1995).

### **LATE TRIASSIC-EARLY JURASSIC REDBEDS**

Late Triassic-Early Jurassic (Rhaetian-Liassic) redbeds are exposed in easternmost Mexico, at Galeana-El Alamar in Nuevo León (Michalzik, 1988), Huizachal-Peregrina Anticlinorium, near Ciudad Victoria, Tamaulipas (Mixon, 1963; Rueda-Gaxiola *et al.*, 1993 a, b) and Huayacocotla Anticlinorium in Hidalgo and Veracruz (Schmidt-Effing, 1980). The pre-Oxfordian redbeds of northeastern Mexico were named Huizachal Formation by Imay (1943). Mixon *et al.* (1959) recognized two redbed units, separated by an angular unconformity; they named the older sequence La Boca Formation, with a Late Triassic-Early Jurassic age. The younger Callovian-Oxfordian sequence, was designated by the same authors as La Joya Formation.

We found volcanic rocks during the present study in the lower part of the Mesozoic sequence exposed in the Huizachal-Peregrina Anticlinorium. A sedimentary environment has been demonstrated for the upper part of the same sequence (Michalzik, 1988, Rueda-Gaxiola *et al.*, 1993 a, b). Thus the Late Triassic-Early Jurassic redbeds of easternmost Mexico were deposited in a rift-like basin, which was associated either to the breakup of Pangea or, more probably, to a backarc structure related to the Pacific active continental margin located a few hundred kilometers to the west. This occurred before an approximately 800 km left-lateral displacement along the Mojave-Sonora megashear (Silver and Anderson, 1974). Our observations support the proposal by Rueda-Gaxiola *et al.* (1993) of a lower volcanic unit ("Huizachal Alloformation") and an upper sedimentary unit ("La Boca Alloformation") unconformably overlain by La Joya Formation. However, the term "alloformation" may be inadequate, because these three units are different and can be well distinguished in the field.

### **MIDDLE JURASSIC MARINE TRANSGRESSION**

The upper Triassic-Early Jurassic redbeds and volcanic rocks of central to northeastern Mexico are overlain by non-fossiliferous red to green conglomerates, sandstones and red to purple siltstones and shales of the La Joya Formation (Mixon *et al.*, 1959). The deposits are alluvial, fluvial and lagunar and contain volcanic, metamorphic, and older sedimentary rock fragments as well as hydrothermal quartz as the main reworked clastic components. The occurrence of these components change according to the source areas. The age of La Joya Formation can be determined indirectly as Callovian to early-Oxfordian because of their stratigraphic position between the Nazas or La Boca Formations and a

transitional change in the Oxfordian Zuloaga Formation.

La Joya Formation represents the basal deposits of the Oxfordian marine transgression in central to northeastern Mexico and includes alluvial and fluvial deposits, these deposits occur after the deposition of the volcanics of the Nazas and the erosion of some exposed areas of older metamorphic rocks, as well as lagunar to shallow marine deposits. La Joya Formation exhibits changes in thickness caused by several relief variations from islands or emerged areas, with no deposition (Aramberri and Miquihuana), to places with more than 200 m of alluvial and fluvial deposits (Real de Catorce).

### **STRUCTURE**

The turbiditic sequence of the Zacatecas Formation is strongly folded and generally their pelitic beds exhibit a foliation (S1) and a crenulation (S2), corresponding to a possible pre-Laramide deformation (D1) and to the Lower Cenozoic (Laramide) deformation (D2). It is probable that the pre-Laramide deformation is a result of two events which are to be set apart in the future after additional field studies: (1) related to the Triassic-Jurassic active continental margin and (2) the accretion of the Guerrero terrane in the Middle Cretaceous.

On the other hand, Triassic-Jurassic redbeds of La Boca Formation and Huizachal Formation, the volcanics from the Nazas Formation and the Callovian-Oxfordian La Joya Formation are not strongly deformed and show a regional distributed foliation resulting from Laramide events. In some places the limestones of the Zuloaga Formation are detached over the clastic sediments and marls of the upper La Joya Formation (Caopas-Rodeo-Teyra area, Charcas and Real de Catorce) or evaporitic rocks of the Minas Viejas Formation (Sierra Madre Oriental) and the stratigraphic relationship between the underlying and overlying sequences in these outcrops can only be indirectly interpreted.

The Triassic-early Jurassic redbeds in eastern Mexico were deposited in NNW-SSE elongated troughs, seen as rifts developed on a continental block (Figure 4) and the Triassic marine sedimentation to the west took place at a continental margin and presumably over oceanic crust (Centeno-García *et al.*, 1993 a, b).

### **DISCUSSION**

According to the analysis of all sedimentological and paleoenvironmental data, as well as petrological and geochemical features of the briefly described units and their ages, the following sequences can be distinguished, genetically related to the following main events or tectonic settings:

A marine turbiditic sequence deposited as part of a submarine Triassic fan at the paleopacific coast of North America (Zacatecas Formation), partly overlayed by Late Triassic?-Jurassic arc volcanics related to the subduction of the Kula plate (Nazas Formation) and to the east, a Triassic to Early Jurassic sequence which contains in the lower part volcanics from the Nazas (Huizachal Formation) and to the upper part, redbeds (La Boca Formation) (Figure 3). The Zacatecas Formation represents a marine basin at the western margin of Pangea. On the other hand, the eastern continental deposits are overlaying an older metamorphic basement and were deposited in a rift basin related to the break-up of Pangea? or possibly to the same paleopacific active continental margin, as a back-arc basin and located westward, during the Early Jurassic, before the left-lateral displacement along the Mojave-Sonora megashear.

The overlying Oxfordian sequence, beginning with La Joya Formation, is related to marine transgression from the southeast or the east and to the evolution of the eastern passive continental margin of Mexico (Figure 4).

All pre-Oxfordian units and structures, also their occurrence, are compatible with the Mojave-Sonora megashear as proposed by Silver and Anderson (1974). The proposed events are intended to explain the absence of some elements of an active continental margin at the western margin of Mexico and the presence of these elements in central to northeastern Mexico.

#### ACKNOWLEDGEMENTS

We acknowledge support by Instituto de Geología,

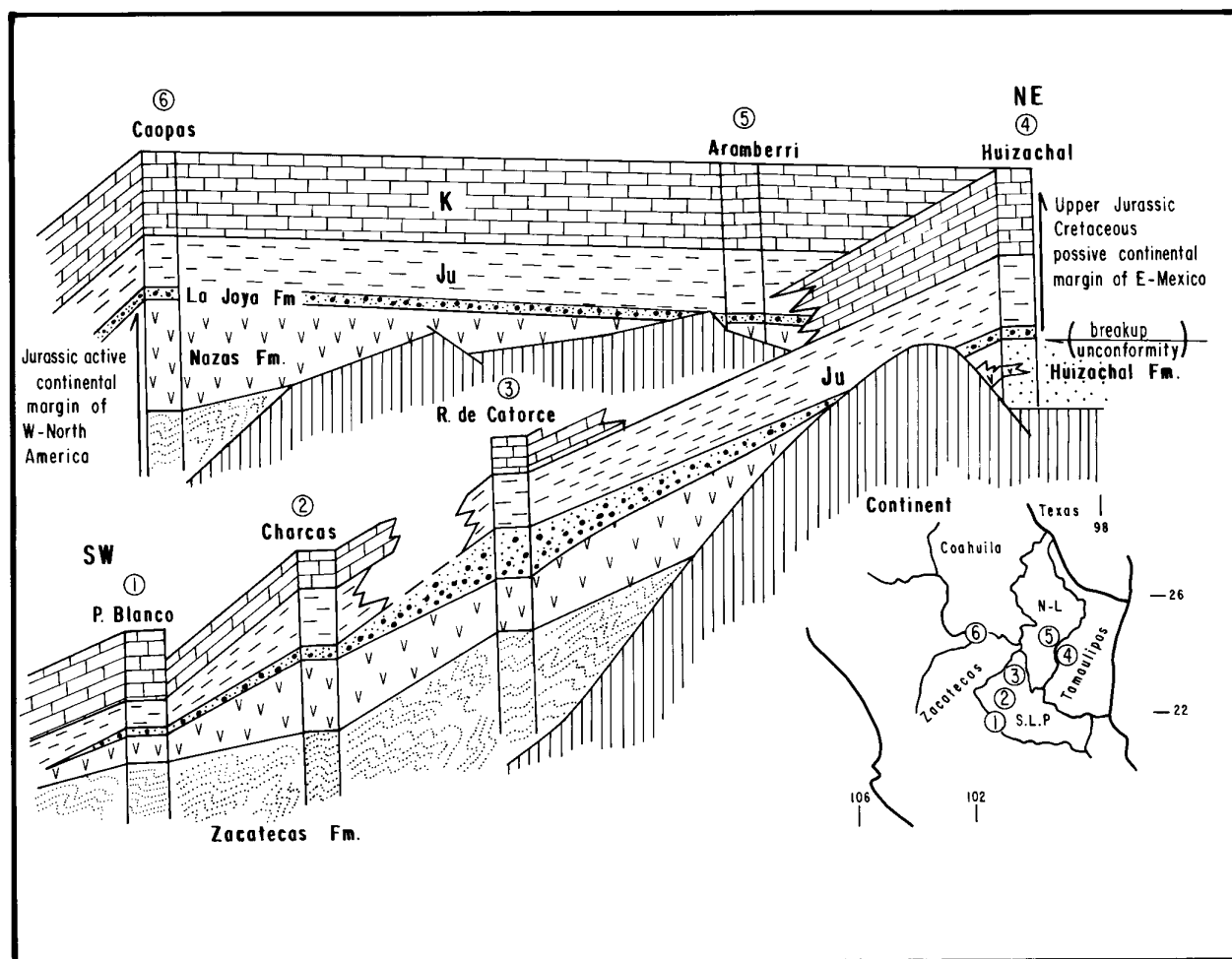


Fig. 3. Diagram of the correlation and tectonic setting of Mesozoic units from central to northeastern Mexico, based on measured sequences at the key areas (see map for location). For lithology see text.

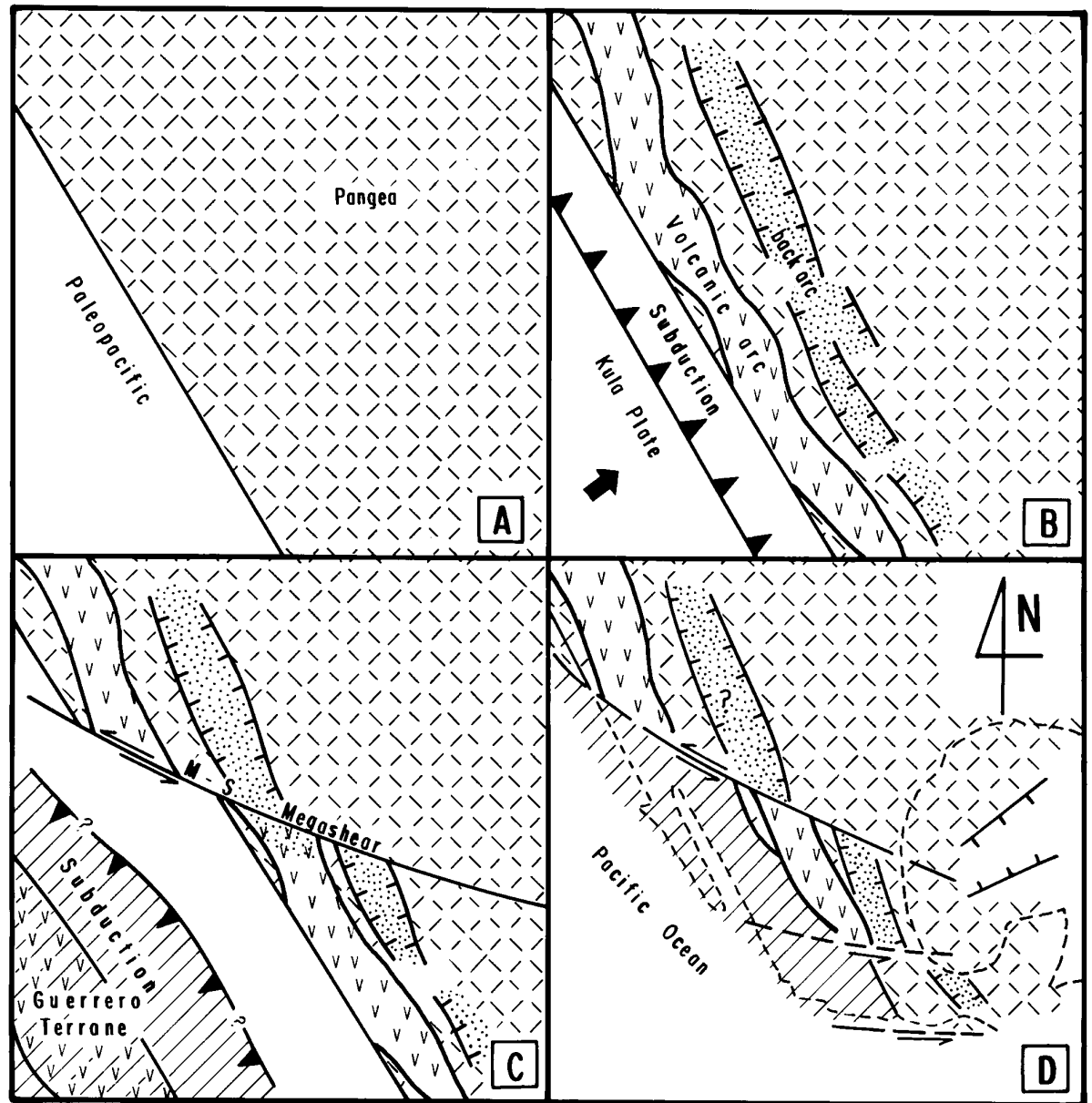


Fig. 4. Paleogeographic evolution of northern Mexico between Late Triassic and Early Cretaceous: A. Carnian (Deposition of the Zacatecas Formation at the western passive continental margin of North America, B. Early Jurassic (deposition of the volcanogenic Nazas Formation as products of the volcanic arc along the western active margin of North America and back arc basin as depocenter of the Huizachal (and La Boca?) Formation, C. Callovian-Oxfordian (left lateral displacement of Mexico along the Mojave-Sonora Megashear and probable intraoceanic arc volcanism of the Guerrero Terrane, D. Aptian-Albian (Accretion of the Guerrero Terrane and distribution of the early Mesozoic rocks under the Oxfordian transgression.

Universidad Autónoma de San Luis Potosí and Fondo de Apoyo a la Investigación (FAI, UASLP, project C97-FAI-07-3.48). The revision and comments by two reviewers and the associate editor are gratefully acknowledged, as well as comments and revision of the English text by Rudolf Held (Princeton) and Guillermo Labarthe (San Luis Potosí).

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