Review of Upper Paleozoic and Lower Mesozoic stratigraphy and depositional environments of central and west Mexico: Constraints on terrane analysis and paleogeography

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ABSTRACT

Reconstructing the geological evolution of central and western Mexico during the end of the Paleozoic and the beginning of the Mesozoic is very difficult because of a lack of exposures. The few outcrops available, and indirect information obtained from geophysical and geochemical data suggests that Central and Western Mexico are made up of a mosaic of pre-Jurassic terranes, and that previously defined terranes are mostly composites of basements of different origins. Most of those terranes are allochthonous with respect to North America, but some developed not far from their present position. It has been suggested that the Coahuila and Sierra Madre terranes (Oaxaquia block), part of Gondwana during Early Paleozoic, collided with North America by Late Paleozoic time. However, their Mississippian faunas of North American affinity suggest that the collision might have occurred earlier. The nature of the basement of the Central terrane is unknown, but it is inferred to be allochthonous because there is an accretionary prism at its NE boundary. The basement of the Parral and Tahue terranes is formed by a deformed volcano-sedimentary complex of Early Paleozoic age, whose origin and paleogeographic evolution remains unknown. The Caborca and Cortes terranes are formed by Proterozoic metamorphic complexes and an accreted eugeoclinal Paleozoic sedimentary wedge. The basement of the Zihuatanejo terrane is made up of Triassic ocean-floor continental-rise assemblages accreted in Early Jurassic time.

An overview of new stratigraphic and geochronologic data indicates that a number of tectonic events occurred during Late Paleozoic to Early Mesozoic time. A continental arc with a paleo-Pacific, east-dipping subduction zone evolved from Carboniferous to Early Permian time in eastern Mexico (Oaxaquia), and it was in part contemporaneous to deformation in the Ouachita belt. This was followed by a period of volcanic quiescence during middle Permian. A more felsic arc, with a different distribution of the volcanic axis, developed along all the paleo-Pacific margin in the Permo-Triassic. Terranes in northwestern Mexico show a completely different geological evolution during the Carboniferous and Permian time. They were characterized by passive margin sedimentation and by folding and thrusting of eugeoclinal rocks in the Mississippian and Late Permian. By Late Triassic, a passive or rifting
INTRODUCTION

The region of central Mexico broadly corresponds to the southern end of the North America Craton, where a complex tectonic scenario took place at least during the Paleozoic and most of the Mesozoic. During the end of the Paleozoic and Early Mesozoic, the main tectonic processes that occurred in the Atlantic margin of the North America Craton were the assembly and breakup of Pangaea and the opening of the Gulf of Mexico. Thus, it has been proposed that parts of eastern Mexico should have been involved first in a collisional event during the end of the Paleozoic, followed by rifting and extensional tectonics beginning in Late Triassic and ending about Middle Jurassic time (e.g., Pindell, 1985; Ross and Scotese, 1988; Rowley and Pindell, 1989; Molina-Garza et al., 1992, Dickinson and Lawton, 2001).

In contrast, the Pacific margin of North America was characterized mostly by subduction related processes, strike-slip faulting and accretion of terranes. Therefore, it has been suggested that parts of western Mexico were also involved in subduction, strike-slip faulting, and/or accretion of terranes (e.g., Coney, 1983; Saleeby and Busby-Spera, 1992; Centeno-García et al., 1993b, 2003; Sedlock et al., 1993; Dickinson and Lawton, 2001).

Recorded in Mexico are the interactions between the tectonics of the Pacific and Atlantic Margins, making it an important region for understanding the tectonic evolution of North America as a whole, and for reconstructing the processes that can occur in a complex transitional zone. Campa and Coney (1983), Coney and Campa (1987), Sedlock et al. (1993), and Dickinson and Lawton (2001), among others, have proposed several models for the terrane configuration and tectonic evolution of Mexico. Most of the terranes were defined on the basis of differences in Jurassic-Cretaceous stratigraphy. However, detailed studies of the few exposures of pre-Jurassic rocks suggest a more complex terrane configuration that recorded accretions and major displacements before Late Jurassic–Cretaceous time. In other words, looking at the pre-Jurassic stratigraphy, the terranes as defined up to date are in fact composite, with pre-Jurassic, strongly deformed assemblages. This includes the Guerrero terrane, which was previously considered an allochthonous, Cretaceous intraoceanic arc (Tardy et al., 1994; Dickinson and Lawton, 2001).

Overall, lithological, geochemical, and isotopic data suggest that the basement of western Mexico is made up of more juvenile material than the east and the north (Patchett and Ruiz, 1987; Ruiz et al., 1988a, 1988b; Centeno-García et al., 1993b; Talavera-Mendoza et al., 1995; McDowell et al., 1999; Mendoza and Suástegeui, 2000; Valencia-Moreno et al., 1999, 2001). Considering this major difference in composition of the basement, the terranes of central and western Mexico can be classified in two general groups: first, terranes that have a Precambrian/Lower Paleozoic? basement and/or have old crustal signatures in the isotopic composition of their younger igneous rocks; and second, terranes whose oldest rocks are Uppermost Paleozoic to Mesozoic and/or show juvenile isotopic signatures in their igneous and metamorphic rocks. Older terranes are located in the east and northwest, and younger terranes are mostly in the central and west of Mexico, except for the Maya terrane of eastern Mexico, which is characterized by Paleozoic metamorphic rocks. Figure 1 shows the possible distribution of pre–Late Jurassic terranes, some of which are proposed in this paper.

The rocks of all these terranes are not well exposed, and most of the contacts are inferred. The only contacts that can be
observed are between the Guerrero and surrounding terranes, exposed southeast of Zacatecas City, and in Santa Maria del Oro, Durango. All other contacts are inferred on the basis of four criteria: (1) isotopic signatures of granitic intrusions, felsic volcanic rocks and xenoliths (Cameron and Cameron, 1985; Patchett and Ruiz, 1987; Ruiz et al., 1988a, 1988b; McDowell et al., 1999; Torres et al., 1999; Valencia-Moreno et al., 1999, among others); (2) geophysical data (Mickus and Montana, 1999; Moreno et al., 2000); (3) subsurface data from oil exploration drilling; and (4) structural styles and trends of the Sierra Madre Oriental fold and thrust belt, which may be reflecting major changes in crustal composition and/or previously formed major structures.

The main objective of this paper is to discuss recent data on the Upper Paleozoic Lower Mesozoic stratigraphy, depositional environments, paleontology, structural geology, and provenance of sedimentary rocks of central and western Mexico, and to review the terrane configuration of the area. Also, some of the existing tectonic models for the evolution of the western paleocontinental margin of Mexico are discussed and new models presented.

**TERRANES OF EAST AND NORTHWESTERN MEXICO**

Most of eastern and northwestern Mexico has Proterozoic basement, but only a small portion of it is considered to be part of the autochthonous Craton of North America. The rest of the Proterozoic basement is interpreted to be an assortment of allochthonous terranes (Campa and Coney, 1983; Coney and Campa, 1987; Sedlock et al., 1993), which includes the Caborca, Coahuila (Delicias, Mapimi), and Sierra Madre terranes (Fig. 1). The Coahuila (Delicias, Mapimi) and Sierra Madre terranes seem to share a common origin, thus they have been defined as the Oaxaquia block or microcontinent, which was disrupted by Late Paleozoic–Mesozoic deformational events (Ortega-Gutierrez et al., 1995). The Maya and Cortes terranes are made up of deformed Paleozoic rocks (Coney and Campa, 1987). This section contains a short discussion of the nature of the basement of these seven terranes and the North America Craton in Mexico, as well as a description of their Upper Paleozoic–Early Mesozoic stratigraphy.

**North America Craton**

The basement of northern Chihuahua and part of northeastern Sonora has been interpreted to be the southern continuation of the North America craton but is heterogeneous in composition (Cameron and Cameron, 1985; McDowell et al., 1999). It is made up of pelitic and volcanic schists that are intruded by 1.7–1.6-Ga granites (Anderson and Silver, 1977). Also, an allochthonous block of Grenvillian rocks that are exposed in Sierra del Cuervo (Los Filtros) and a small outcrop of metamorphic basement rocks at Carrizalillo, in north-central Chihuahua, have been considered part of the North America Craton (Coney and Campa, 1987; Ruiz et al., 1988b; Blount et al., 1988) (Fig. 1). Boundaries of the North America Craton in Chihuahua on Figure 1 are all inferred, and they have been traced on the basis of data by Moreno et al. (2000), Cameron and Cameron (1985), McDowell et al. (1999), and Ruíz et al. (1988b), among others.

Sedimentation during the Paleozoic in northern Chihuahua and Sonora states has been correlated to the basins that developed in Southern Texas, New Mexico, and Arizona (Bridges, 1964). Interpreting from the published stratigraphic columns (Bridges, 1964), subsidence was important throughout that time and led to the deposition of up to 3000 m in thickness of Paleozoic marine sediments. Sandstone layers contained within the calcareous succession seem to be quartz-rich arenites (Diaz and Navarro, 1964), which suggests a cratonic provenance.

Permian rocks deposited on the North America craton are mostly calcareous and occur near the U.S.-Mexico border (Sierra Las Palomas, Los Chinos and Moyotes Wells, Sierra de Teras-Bavispe) (12 and 12a in Fig. 2) (Diaz and Navarro, 1964; Tovar, 1968; Reynolds, 1972; Patterson, 1978). They are made up of thick to thin bedded limestone and dolostone that contain chert lenses and nodules. They are interbedded with variable amounts of shale, quartz-rich sandstone, and sandy limestone. Conglomerates formed of calcareous clasts and layers of evaporites (gypsum) have been reported from the base of the succession, suggesting periods of subaerial exposure (Diaz and Navarro, 1964; Tovar, 1968; Reynolds, 1972; Patterson, 1978). Horizons with abundant fossils can be found at all localities and include a wide range of corals, brachiopods, fusulinids, crinoids, and bivalves. Fossil associations, and pelletoid and oolitic limestone suggest shallow marine environments. There might have been periods of subaerial exposure, as suggested by the evaporites. The ages of the Permian rocks range from Wolfcampian to Leonardian. Their basal contact with Pennsylvanian rocks is transitional (Diaz and Navarro, 1964; Tovar, 1968; Reynolds, 1972; Patterson, 1978).

Pennsylvanian sedimentary rocks in central Chihuahua State are well exposed in the Carrizalillo, Placer de Guadalupe, and Sierra del Cuervo areas (location 1 and 2 in Figs. 2 and 3). They range from Proterozoic(?)-Cambrian to Permian, and are strongly deformed. No major angular unconformities within the succession have been reported, except for an unconformity described by Bridges (1964), from Placer de Guadalupe, where Permian rock unconformably overlie Early Pennsylvanian–Early Permian limestone. Permian rocks of central Chihuahua are more clastic than rocks of similar ages in northwest Chihuahua (location 1 and 2 in Fig. 2). They are made up of siltstone and sandstone, some conglomerate as channel-fill deposits, and lenses of fessiliferous, calcareous debris flows. Permian rocks overlie Early Pennsylvanian–Early Permian limestone, mostly in a parallel, slightly erosional contact in Carrizalillo. Fauna associations from Placer de Guadalupe suggest a shallow marine depositional environment, however most of the sediments are turbidites, thus they might be submarine fan deposits (Hadschy and Dyer, 1987).

Pennsylvanian-Permian rocks of the Sierra del Cuervo (location 2 in Figs. 2 and 3) are mostly thin-bedded sandstone and shale, and basinal limestone, with sparse conglomerate, bentonite, and bedded chert. Sandstone becomes more quartz-rich
arenite upward, with more abundant lithic clasts at the base (carbonate and argillite grains); feldspar grains increase upward as well (Handschy and Dyer, 1987). Sedimentary structures suggest that the succession was deposited by turbidites in a submarine fan environment (Handschy and Dyer, 1987). These rocks were strongly deformed before the deposition of Cretaceous units, but the age of deformation has not been constrained (Handschy and Dyer, 1987).

There has not been a systematic sedimentological and provenance study of the Upper Paleozoic assemblages. Likewise, with no systematic study on reconstructing depositional environments and paleowater depths, there can only be loose constraints on the tectonic setting of these sedimentary basins. However, some important information can be obtained from published data.

Rock and fossil associations in Placer de Guadalupe indicate a change from mostly calcareous shallow marine environments to deeper quartz-rich submarine fan facies. Bridges (1964) suggests that the sedimentary characteristics of the Placer de Guadalupe turbidites are more similar to foreland basins than to deep marine eugeoclinal deposits of the Marathon collisional front. More detailed studies could be done to characterize the sedimentation and provenance of these rocks. But from the evidence described in the literature, it might be possible that the Placer de Guadalupe succession evolved from calcareous platform to foreland sedimentation in Pennsylvanian-Permian time. Those rocks have also been interpreted as basins related to strike-slip motion active during late Pennsylvanian–earliest Permian time (Lawton and Giles, 2000).

Sedimentary rocks at the Sierra del Cuervo seem to be similar to the deposits of Placer de Guadalupe. They have also been interpreted as part of eugeoclinal deposits of the paleocontinental margin of North America (continental slope-rise) (Handschy and Dyer, 1987). Their relationship with coeval rocks from Caborca and Cortes terranes has not been determined. Two important
differences between these rocks and coeval units from Caborca and Cortes terranes are as follows: apparently they contain some volcaniclastics (altered ash) (Bridges, 1964); and the basement is involved in the deformation, which is not seen in accreted eugeoclinal successions throughout the Cordillera (Miller et al., 1992).

There are no outcrops of Uppermost Permian or Triassic sedimentary rocks in Chihuahua or northeast Sonora. Only a few granitic intrusions of Upper Permian age (250 ± 20 and 267 ± 21 Ma) have been reported (Torres et al., 1999). Paleozoic rocks are unconformably covered by calcareous marine deposits (La Casita Formation) that contain abundant ammonites of Late Jurassic age (Kimeridgian and Tithonian) (Bridges, 1964).

Maya Terrane

The Maya terrane (Fig. 1) was defined on the basis of the report of Paleozoic metamorphic rocks in the subsurface along the Gulf of Mexico (Campa and Coney, 1983, Coney and Campa, 1987, Murillo and Torres, 1987; Sedlock et al., 1993) Whether the Maya terrane extends further north is unknown. However, information from oil exploration boreholes in the states of Coahuila and Nuevo León, as well as gravity data from Northeastern Mexico, suggest that Paleozoic metamorphic rocks might extend north along the northern part of Tamaulipas, Nuevo León, and Coahuila states (Schurbet and Cebull, 1987; Ramirez-Ramirez, 1992; Moreno et al., 2000). The only exposure of the Maya terrane’s basement is located near the U.S.-Mexico border. These rocks are made of strongly deformed sandstone and shale that yielded one Rb/Sr age of 240 Ma (Carpenter, 1997) (location 13 in Fig. 2). Scarce information on Paleozoic rocks is found in unpublished reports of the Mexican national oil company Pemex. Core samples of schist yielded K/Ar ages between 277 and 204 Ma, and granite samples of 358–144 Ma (Ramirez-Ramirez, 1992; Torres et al., 1999). Discussion on the origin and extension of the Maya terrane is outside the scope of this paper.

Caborca Terrane

The oldest rocks of Mexico form the basement of the Caborca terrane (Fig. 1). They are orthogneisses and high-grade schist complexes intruded by meta plutonic rocks 1.8–1.7 Ga in age (Anderson and Silver, 1971). The oldest sialic basement of Mexico is exposed in the Caborca terrane (Bamori complex and Aibo granite) (Anderson and Silver, 1977, 1981). There are different opinions on the origin and correlation of its basement with respect to the metamorphic complexes of North America (Anderson and Silver, 1979; Stewart et al., 1990; McDowell et al., 1999; Iriondo et al., 2000).

The northern and eastern limits of the Caborca terrane (Fig. 1) have been placed at slightly different locations (Anderson and Silver, 1979; Coney and Campa, 1987; McDowell et al., 1999; Dickinson and Lawton, 2001). Its southern limit is considered to be placed where continental slope-rise sedimentary rocks (eugeoclinal) are thrust over shallow marine successions at the Mina La Barita, Sonora (Gastil and Miller, 1983; Stewart et al., 1990; Poole et al., 1992).

The sedimentary cover of the Caborca terrane ranges in age from Upper Proterozoic to Permian. Permian rocks are mostly calcareous (location 3 in Figs. 2 and 3). The succession is made up of fossiliferous limestone and dolostone, with abundant chert nodules, and extends from Carboniferous to Lower Permian (Cooper and Arellano, 1946). Shale and sandstone are rare. In the Sierra del Alamo, there is a succession of limestone and dolomite (Los Monos Formation) of mid-Permian age (Guadalupian), but its contact relationships with the other described units are unknown. This unit is covered disconformably by the El Antimonio Formation (Cooper and Arellano, 1946; González-León, 1996, 1997; González-León et al., this volume). The Antimonio stratigraphy is described in detail in this volume; this unit is formed by interbedded thin beds of calcareous siltstone with calcareous nodules, limestone, sandstone, and some beds of conglomerate. Clasts from the conglomerate are mostly chert, limestone, quartzite, rhyolite, quartz porphyry, and granite. It contains, at its base, fossils that are similar to those in underlying Guadalupian rocks and extends into the Triassic and Jurassic (location 3 in Figs. 2 and 3) (González-León, 1996, 1997; González-León et al., this volume). These rocks were deposited in shallow marine environments. The calcareous successions have been interpreted as the southern continuation of the Western U.S. miogeoclinal deposits (Stewart, 1988). González-León et al. (this volume) and other authors consider the Antimonio rocks to be mostly deposited in a forearc setting, but its basal part might have been deposited in a marine platform environment.

Triassic stratigraphy of the Caborca terrane is discussed in detail by González-León et al. in this volume. It is a succession of sandstone, siltstone, and limestone with some conglomerate horizons (Antimonio Group, location 3 in Figs. 2 and 3) that were deposited mostly in shallow marine, but also some in continental environments. Sediments toward the top of the succession were deposited in deeper water. Ages range from Middle to Late Triassic (Carnian) (González-León, 1997). The succession contains abundant fossils and has been interpreted as deposited in a forearc setting and changes upward to Jurassic marine rocks (González-León et al., this volume).

Cortes Terrane

The Cortes terrane (Fig. 1) was originally defined as allochthonous, Early Paleozoic, deep-marine rocks (eugeoclinal) emplaced on thinned continental crust (Poole and Madrid, 1986, Coney and Campa, 1987; Stewart et al., 1990). Pb and Nd isotopic composition from Cenozoic granitoids and volcanic rocks emplaced in the Cortes terrane suggest that its basement might be Proterozoic (McDowell et al., 1999; Valencia- Moreno et al., 1999, 2001). However, there is a difference in the isotopic signatures of the Cenozoic magmatism between the Caborca and Cortes terranes, suggesting that the basement of the Cortes terrane
could be thinned Proterozoic rocks, perhaps the same as in the Caborca terrane, or a Proterozoic basement different from that of the Caborca terrane (McDowell et al., 1999; Valencia-Moreno et al., 1999, 2001).

The northern limit of the Cortes terrane is placed where the Paleozoic deep-marine sedimentary rocks are thrust over calcareous shelf facies of the Caborca terrane (Fig. 1) (Stewart et al., 1990). The southern limit has not been well defined, and it is inferred to be north of El Fuerte, Sinaloa, on the basis of the last northern occurrence of Cretaceous marine volcanic rocks of the Guerrero terrane (Fig. 1) (Servais et al., 1982; Henry and Fredrikson, 1987; Roldán-Quintana et al., 1993; Freydier et al., 1995).

A thrusting event during the Mississippian deformed deep marine rocks of Ordovician and Devonian–Lower Mississippian age (location 4 in Figs. 2 and 3) (Poole and Madrid, 1988; Stewart et al., 1990; Poole et al., 1992). Overlying this event, the Upper Mississippian to Lower Pennsylvanian succession is characterized by submarine turbidites made up of fine-grain sandstone, shale and siltstone, and channel-fill conglomerate (Poole and Madrid, 1988; Stewart et al., 1990; Poole et al., 1992). Upper Pennsylvanian and Lower Permian rocks are a thin-bedded rhythmic succession of mudstone and siltstone that contains chert and detrital limestone beds all deposited by turbiditic flows (Poole and Madrid, 1988; Stewart et al., 1990; Poole et al., 1992). They were deposited in a deep marine environment and are interpreted to be part of the Paleozoic eugeoclinal deposits (continental slope-rise) of western North America (Poole and Madrid, 1988; Stewart et al., 1990; Poole et al., 1992). The change in sedimentation to deeper facies during Early Permian time has been interpreted as a change from a stable continental margin to an active margin (subduction or strike-slip) (Stewart et al., 1997). Apparently a second deformational event originated folding and trusting of these units by Late Permian to Early Triassic time, because continental rocks of Upper Triassic age lie unconformably over the deep-marine strata (location 4 in Figs. 2 and 3) (Stewart et al., 1990).

Upper Triassic rocks that overlie in an angular unconformity the Upper Paleozoic rocks are exposed in southern Sonora State (Barranca Group, column 4 in Fig. 3) (Stewart and Roldán-Quintana, 1991). They form a succession of continental and marine deposits and are made up of sandstone, shale and conglomerate with abundant coal beds, and some tuffaceous layers (Stewart and Roldán-Quintana, 1991). They contain abundant fossil plants and marine fossils such as ammonites, pelecypods, and brachiopods of Late Triassic (Carnian to Norian) age (Stewart et al., 1990). These rocks have been interpreted as deposited in a rift-type basin (Stewart and Roldán-Quintana, 1991). They are overlain by Upper Cretaceous continental sedimentary and volcanic rocks (Stewart and Roldán-Quintana, 1991).

Oaxaquia Block

Ortega-Gutierrez et al. (1995) proposed that the Proterozoic basements of the Sierra Madre and Coahuila terranes, together with southern Grenvillian terranes (Zapoteco terrane, parts of the Juarez and Maya terranes), might have evolved together as a large piece of continent, which they called Oaxaquia (Fig. 1). Other authors extend Grenvillian basement to areas with Paleozoic metamorphic rocks (e.g., Coahuila, Tampico, and Del Sur blocks of Dickinson and Lawton [2001]). However, regional geology indicates that large parts of those areas have metamorphic Paleozoic basements and are considered to be different
terranes (e.g., Ramirez-Ramírez, 1978; Yañez et al., 1991; Ortega-Gutierrez et al., 1999). In this paper, the subdivision of the northern Oaxaquia block into the Coahuila and Sierra Madre terranes will be used.

Paleogeographic evolution of the Oaxaquia Block (includes Coahuila and Sierra Madre terranes) seems to be quite complex. Its main metamorphic event has been related to collision between north Amazonia and northeast Laurentia in the Proterozoic (Grenville orogeny) (Keppie and Ortega-Gutierrez, 1999; Ruiz et al., 1999). Most of the models agree that Oaxaquia stay in Gondwana during the end of the Proterozoic and most of the Paleozoic. A collisional event between Oaxaquia and Laurentia seems to have occurred during the mid-Paleozoic (Restrepo-Pace et al., 1994, 1997; Keppie et al., 1996; Keppie and Ortega-Gutierrez, 1999; Ortega-Gutierrez et al., 1999). Silurian faunas from sedimentary units located in northern Oaxaquia, as well as Ordovician faunas of southern Oaxaquia, are distinctly different from fauna of comparable age in adjacent parts of North America and have Old World realm/Gondwana affinity (Robison and Pantoja-Alor, 1968; Boucot et al., 1997; Stewart et al., 1999). This suggests that Oaxaquia remained allochthonous with respect to North America and was part of Gondwana at least up to the Silurian (Stewart et al., 1999). Late Paleozoic tectonic evolution of Oaxaquia will be discussed later.

Coahuila Terrane

There are no exposures of the basement of the Coahuila terrane (Fig. 1). Moreno et al. (1993, 2000), among other authors, suggest that the Ouachita belt may extend into Mexico, between the Chihuahua and Coahuila terranes (Fig. 1). The Coahuila terrane has been subdivided into smaller terranes, such as the Mapimi terrane (Moreno et al., 1993, 2000) and the Delicias terrane (McKee et al., 1999), both apparently floored by Grenville-age crust (Cameron and Cameron, 1985; Lopez, 1997; Lopez et al., 2001). In this paper, the Delicias and Mapimi terranes are grouped with the rest of the Coahuila terrane and are referred herein only as the Coahuila terrane. Xenoliths have been collected near the inferred contact between the North America craton in Chihuahua and the Coahuila terrane; they yielded Grenville isotopic signatures (La Olivia) (Rudnick and Cameron, 1991; Ruiz et al., 1988a). These xenoliths have been interpreted as part of the North America craton (Ruiz et al., 1988b; Sedlock et al., 1993; Dickinson and Lawton, 2001) or as the basement of the Mapimi terrane (Moreno et al., 2000).

With no exposures of the north-western contact between the Coahuila terrane and the North America craton, its location and nature remain uncertain. The eastern limit of the terrane is not exposed, and it has been located at different positions by different authors (Coney and Campa, 1987; Sedlock et al., 1993; Ortega-Gutierrez et al., 1995; Dickinson and Lawton, 2001). It is located in Figure 1 on the basis of reports of Paleozoic metamorphic rocks in the subsurface that are considered part of the Maya terrane (Ramirez-Ramirez, 1992).

Paleozoic rocks are exposed only in the Delicias region (Delicias Formation) (location 10 in Figs. 2 and 3). These rocks have been described in detail by McKee et al. (1999). They are made up of an Upper Mississippian to Upper Permian (Guadalupian) succession of turbidites and debris flows that contain large blocks, from several to tens of meters, of limestone, volcanic, and volcaniclastic rocks and some conglomerate (King, 1944; Wardlaw et al., 1979; McKee et al., 1988, 1999; Lopez, 1997). A peperite intrusive with a U/Pb age of 331 Ma was emplaced in the lower parts of the unit, and two granodiorite intrusions that cut the succession have K/Ar ages of 256 and 266 (Lopez, 1997; Torres et al., 1999; Lopez et al., 2001). Most volcanic rocks range in composition from rhyolite to andesite, but there are a few basalts (Lopez, 1997). Rare conglomerates within the Paleozoic succession contain metamorphic clasts, including Precambrian gneisses, granite, quartz, schist, and clasts of limestone that suggest a mixed provenance of volcanic arc and uplifted basement (Lopez, 1997; Lopez et al., 2001). These rocks have been interpreted as deposited on the margin of a continental arc (McKee et al., 1999). They were deformed after Ouachita and apparently before Late Triassic (McKee et al., 1999), but surely before deposition of Cretaceous rocks (McKee et al., 1999), and are overlain, in a regional unconformity, by Cretaceous rocks.

Sierra Madre Terrane

Basement rocks of northern Sierra Madre terrane (part of the Oaxaquia block) are exposed in Ciudad Victoria and Molango areas (Huiznopala and Novillo Gneisses) (Fig. 1). Both have metamorphic ages between 911 and 1080 Ma, and Nd model ages from 1.4 to 1.8 Ga that are similar to the those of Grenville Belt (Patchett and Ruiz, 1987; Ruiz et al., 1988b; Lawlor et al., 1999). Upper Paleozoic rocks of northern Sierra Madre terrane are exposed east of Ciudad Victoria, Tamaulipas State (location 8 in Figs. 2 and 3) (Carrillo-Bravo, 1961). An update on the stratigraphy and paleontology of this locality was made by Stewart et al. (1999). The Lower Mississippian (Vicente Guerrero Formation) succession is made up of fine-grained sandstone, siltstone, and shale and contains a few conglomerate lenses at the base (Stewart et al., 1999). To the top, there are interbedded rhyolite flows that yielded an Early Mississippian U/Pb age (334 ± 39 Ma) (Boucot et al., 1997; Stewart et al., 1999). Shale and sandstone contain abundant brachiopods, gastropods, fusulinids, and corals (Stewart et al., 1999). Primary structures suggest that they were deposited by turbiditic and other gravity flows, maybe in a deltaic and/or submarine fan depositional environment.

In the same area, near Ciudad Victoria, where Upper Paleozoic rocks are exposed, metamorphic rocks (Granjeno Schist) of apparently similar age are also exposed (location 8 in Figs. 2 and 3). They are made up of metamorphosed shale, sandstone, volcanic, and ultramafic rocks that yielded Mississippian K/Ar and Rb/Sr ages (ca. 330 Ma) (Ramirez-Ramirez, 1978; Garrison, 1978). Those rocks are in fault contact with the rest of the Proterozoic and Early Paleozoic units (Ramirez-Ramirez, 1978).
Lower Pennsylvanian rocks (Del Monte Formation) rest unconformably on Silurian, Mississippian, and even the metamorphic rocks of the Granjeno Schist (Fig. 3) (Ortiz-Ubilla et al., 1988; Centeno-García et al., 1998; Stewart et al., 1999). They are mostly turbidites made up of alternating sandstone, shale, siltstone, and some conglomerate. The conglomerate contains clasts of sandstone, siltstone, felsic volcanic, gneiss, and schist fragments. The Lower Permian (Guacamaya Formation) is a thick turbiditic succession made up of fine-grained sandstone interbedded with shale and siltstone (location 8 in Figs. 2 and 3). It contains a few conglomerates made up of volcanic clasts. Some andesitic breccia was observed as clasts in the present river wash, but outcrops of such rocks were not found. Sandstone petrography shows a change in grain composition from quartz/metamorphic/sedimentary > volcanic arenes in the Mississippian beds to volcanic > quartz/metamorphic/sedimentary arenites in Pennsylvanian to Permian layers (Centeno-García et al., 1998). Felsic grains (ryholite, felsite) are more abundant in the Mississippian; in contrast, intermediate and mafic grains (andesite, trachyte) are more abundant in the Permian sandstone (Centeno-García et al., 1998). The Proterozoic and Paleozoic units are unconformably overlain by Mesozoic red beds (Jurassic?).

To the south, in the central part of the Sierra Madre terrane, Upper Pennsylvanian to Lower Permian rocks (Tuzancoa Formation) are exposed in northern Hidalgo state (location 9 in Figs. 2 and 3; Rosales-Lagarde et al., 1997; Rosales-Lagarde, 2002). At its base, this unit is made of quartz-rich sandstone and shale. This changes upward to andesitic brecciated and massive lava flows, volcanic conglomerate and tuff interbedded with volcanioclastic turbidites (alternating shale and sandstone), and some calcareous debris flows containing abundant crinoids stems, solitary corals, and fusulimid. Volcanioclastic rocks at the top contain conglomerate lenses, deposited as channel fill, made up of volcanic, granite, gneiss, and limestone clasts (Rosales-Lagarde et al., 1997; Rosales-Lagarde, 2002). Fossil crinoids, fusulimid, and brachiopods are dated as Early Permian (Wolcampaian-Leonardian), but some taxa have ranges that go down to Virgilian (Upper Pennsylvanian) (Carrillo-Bravo, 1961; Arellano-Gil et al., 1998; Rosales-Lagarde, 2002). The chemical composition of the volcanic rocks indicates that they are mostly andesitic to basaltic-andesites and were formed in an arc setting (Rosales-Lagarde, 2002). Geochemical and isotopic signatures of the volcanic rocks of the Tuzancoa Formation are very similar to those reported by Lopez (1997) from the Mississippian-Permian rocks from the Coahuila terrane (Rosales-Lagarde, 2002). Apparently Jurassic rocks rest on the Permian succession without an evident angular unconformity, because bedding from both units are parallel (Rosales-Lagarde, 2002). A belt of Permo-Triassic granitoids cuts all previously described units of the Sierra Madre terrane and extends into the Coahuila terrane and farther north into the North America Craton (Fig. 4) and is made up of diorite to granodiorite intrusives. Their geochemical and isotopic signatures suggest a continental arc origin, and their ages range from 287 to 232 Ma (Torres et al., 1999). Torres et al. (1999) considered that this magmatic belt corresponds to the shift from Atlantic collisional to Pacific subduction-related tectonics. There are compositional differences between the Permo-Triassic granitoids and the Pennsylvanian-Permian volcanic rocks of Delicias and Tuzancoa that suggest they were derived from different magma sources (Lopez, 1997; Rosales-Lagarde, 2002). In addition, the granitoids cut the volcano-sedimentary rocks of Delicias (Lopez, 1997; McKee et al., 1999) and Tuzancoa (Ochoa-Camarillo, 1997, personal commun.) Therefore, this belt suggests that arc magmatism in eastern Mexico continued up to the Earliest Triassic time, but its axis probably migrated, since it is placed eastward from previous Pennsylvanian-Permian arc and cuts other units.

A thick Triassic sedimentary succession is exposed along the western margin of the Sierra Madre terrane. It consists almost exclusively of siliciclastic rocks deposited by turbiditic and other gravity flows in a submarine fan setting. These rocks are exposed in Peñón Blanco and Charcas (column 8 in Fig. 3; location B and C in Fig. 4) (Labarthe et al., 1982; Silva-Romo, 1993; Tristán-González and Torres-Hernández, 1994; Centeno-García and Silva-González and Torres-Hernández; 1994; Centeno-García and Silva-
Romero, 1997; Barboza-Gudiño et al., 1998; Bartolini et al., 2002). Although they have been considered part of the Zacatecas Formation, they were redefined as La Ballena Formation by Silva-Romo (1993), Centeno-García and Silva-Romo (1997), and Silva-Romo et al. (2000) on the basis of major stratigraphic differences with respect to the type locality of the Zacatecas Formation. Rocks of La Ballena Formation are made up of quartz-rich sandstone and shale, and they rarely contain channel-fill conglomerate. Clasts in conglomeratic beds are made up of quartz, chert, and a few felsic volcanics (Silva-Romo, 1993; Centeno-García and Silva-Romo, 1997). Ammonites and bivalves of Late Triassic (Carnian) age have been reported from both the Peñón Blanco and Charcas areas and are similar to those reported from the Zacatecas Formation in Zacatecas city (Cantu-Chapa, 1969; Silva-Romo, 1987; Bartolini et al., 2002). Primary structures are indicative of gravity flows (turbidites and submarine slumps) deposited probably in a high-energy environment. The lack of chert and deep marine faunas suggest that the deposition of this unit might have occurred in a distal platform or near the continental slope. Original thickness is uncertain because of its tight folding, but up to 4640 m of the unit has been cut by exploration drilling without reaching the base of the sequence (Lopez-Infanzon, 1986). The unit was deformed and locally metamorphosed before deposition of Upper Jurassic continental volcanic and elastic formations (column 8, Fig. 3) (Silva-Romo, 1993; Tristán-González and Torres-Hernández, 1994). Similar rocks are exposed in Ojo Caliente and Toliman areas (locations D and E in Fig. 4). The name of Potosi Fan is used for this thick succession of marine siliciclastics that suffered major folding and thrusting before Middle-Late Jurassic time.

A similar though undated succession of pre-Jurassic siliciclastic rocks is exposed in San Luis Potosi State (location A in Fig. 4). They have been considered part of the Upper Triassic units located to the west (La Ballena Formation, locations B–D in Fig. 4) (Bartolini et al., 2002). However, the stratigraphies of the two have some differences. The oldest part of the succession in Real de Catorce is made up of turbiditic, fine-grained, quartz-rich sandstone and shale, and thick layers of massive shale that contain abundant limestone nodules and limestone intraclasts, the last containing a few crinoid stems (Member A). Member A contains several fine-grained andesite-basaltic dikes and massive shallow intrusives. There are also layers of laminar green beds that might be strongly deformed diabase or volcaniclastic deposits. The unit shows evidence of at least two phases of deformation. The first developed closely spaced cleavage and some low-grade green schist zones; the second produced tight folding and open cleavage. To the top of the succession, there is a thick unit of interbedded sandstone and shale, deposited from turbidite currents as well, and thick channel-fill lenses of fine-grained conglomerate (Member B).

There is no evidence of a major unconformity between Member A and Member B, but their depositional environments seem to be different. Volcanic rocks within Member A were originally considered part of the volcanic rocks of Jurassic age that are exposed in the area (Maher et al., 1991; Barboza-Gudiño et al., 1998; Franco Rubio, 1999), but field relationships indicate that some of those volcanic rocks are part of the old succession and are not related to overlying Jurassic continental volcanic-sedimentary units. The age of the marine siliciclastic rocks has not been well constrained. There are reports of Pennsylvanian palynomorph grains and pieces of Calamites (Paleozoic) (Franco-Rubio, 1999; Bartolini et al., 2002). However, possible bivalve molds of Late Triassic (Carnian) age that are similar to those from the Zacatecas Formation in Zacatecas city have been reported as well (Barboza-Gudiño et al., 1998).

It might be possible that two different successions (one Upper Paleozoic and other Upper Triassic) are exposed in Real de Catorce, but further studies are needed to constrain the origin and age of these rocks. Those rocks, as well as the La Ballena Formation at Peñón Blanco and Charcas, were deformed before the deposition of Middle-Upper Jurassic continental arc successions (Bartolini et al., 2002).

**TERRANES OF CENTRAL AND WESTERN MEXICO**

There are very scarce exposures of pre-Jurassic rocks in central and western Mexico. Thus, it is difficult to reconstruct the pre-Jurassic terrane configuration and tectonic evolution of this vast area. Overall, the pre-Jurassic units of western and central Mexico are characterized by large amounts of deep-marine siliciclastic successions. Two types of assemblages can be differentiated: siliciclastic units that are associated with island arc volcanic and volcanioclastic rocks with Early Paleozoic ages (El Fuerte and Santa María del Oro) (Fig. 1, location 5 and 11 in Fig. 2), and siliciclastic rocks that are associated with mid-ocean ridge basalts (MORB) and oceanic-island basalt (OIB) volcanic rocks and scarce or no island-arc volcanioclastics (Pico de Teyra, Zacatecas, Arteaga), and contain Upper Paleozoic (?) and/or Upper Triassic fossils (Fig. 3). On the basis of this difference, and considering the diversity in composition of their overlapping units, a new terrane configuration for central and western Mexico is proposed in Figure 1. This section contains a short discussion of the nature of the basement of these terranes, as well as a description of their Upper Paleozoic–Early Mesozoic stratigraphy.

**Central Terrane**

The basement of the Central terrane (Zacatecas state) remains unknown (Fig. 1), but it is inferred to be different from the Sierra Madre and Coahuila basements because the Central contains an accretionary complex (Taray Formation) as its northeastern boundary and only surface exposure (Anderson et al., 1990, 1991, this volume; Jones et al., 1995). The Jurassic-Cretaceous succession was deposited unconformably on the Taray subduction complex of the Central terrane (column 7, Fig. 3) and is in tectonic contact (thrust by) to the south and to the west with the Guerrero Composite terrane. The subduction zone was probably constructed along the Oaxaquia continental margin sometime between Late Permian–Early Jurassic time. To the north, the contact with the Coahuila terrane is inferred to be fault, as suggested
by the contrast in the thickness of Cretaceous units and contrast in the deformation between the two terranes. The relationship of the Central terrane with the Parral terrane is unknown.

The Taray accretionary complex is described in detail by Anderson et al. in this volume. The assemblage consists of a highly disrupted rhythmic succession of quartz-rich sandstone and shale, interbedded with scarce thin layers of black chert. There are some beds of detrital limestone that contain fragments of crinoids, gastropods, corals, bivalves, and bryozoans, and some beds of conglomerates. Both detrital limestone and conglomerates are channel-fill deposits (Diaz-Salgado et al., 2003). Primary structures in undisturbed areas suggest that the sandstone and shale, as well as the limestone and conglomerate, are mostly turbidite flow deposits in a deep marine setting.

The Taray sedimentary rocks constitutes a matrix within which blocks of black and green chert, pillow basalts, serpentine, and scarce crystallized limestone can be found (Fig. 3) (Diaz-Salgado et al., 2003). The age of this unit remains undetermined. There are reports of fusulinids from a limestone block (Upper Paleozoic?) (Anderson et al., 1990), and detrital zircons do not exceed Late Permian ages (Diaz-Salgado et al., 2003). However, there is a report of molds of pelcypod that resemble those from Upper Triassic (Carnian) rocks of Zacatecas (Barboza-Gudiño et al., 1998; Bartolini et al., 2002). The complex is overlain unconformably by Oxfordian volcano-sedimentary rocks (Anderson et al., 1990; Diaz-Salgado et al., 2003), and thus deposition and deformation should have occurred sometime between latest Permian and Early-Middle Jurassic.

**Parral Terrane**

The Parral terrane was originally defined as a thick succession of Upper Mesozoic turbiditic sandstones (Pacheco et al., 1984, Coney and Campa, 1987). However, exposures of older rocks suggest that there was accretion of terranes before the deposition of the turbidites, and that those turbidites are in fact an overlapping assemblage (Fig. 1).

The basement of the Parral terrane is considered in this paper to be represented by the metamorphic rocks (Pescadito Schist) of Santa Maria del Oro, Durango (location 11 in Figs. 2 and 3). They are made up of a muscovite schist and a chlorite schist. The protolith of the muscovite schist was quartz-rich sandstone and black shale, and of the chlorite schist deformed lava flows, dikes, and volcanics (Araujo and Arenas, 1986). The Pescadito Schist yielded K/Ar ages around 326 ± 26 Ma (Zaldivar and Garduño, 1984) and 350 Ma (Eguiluz and Campa, 1982). Ar/Ar dates from a syntectonic granitic dike yielded ages as old as Devonian (360 Ma, A. Iriondo, 2003, personal commun.). This metamorphic unit is in tectonic contact with a succession of pillow basalts interbedded with volcaniclastic rocks (Fig. 3). The volcaniclastic rocks contain large blocks of limestone and interbedded layers of limestone that contain brachiopods and abundant crinoid stems of Late Paleozoic age (Carboniferous?) (Zaldivar and Garduño, 1984).

The basaltic pillow lavas and volcaniclastic succession have been interpreted by some authors to be younger than Late Paleozoic (Cretaceous?). They have been considered part of the Guerrero terrane, based only on the observation that there are no volcanic rocks in Paleozoic units west of Santa Maria del Oro (Tahue and Cortes terranes) (Eguiluz and Campa, 1982; Pacheco et al., 1984; Aranda et al., 1988). The same authors suggest that the limestone blocks containing crinoid stems of Late Paleozoic age might be exotic. Alternatively, these volcanic, sedimentary rocks may be part of the Delicias arc assemblage, because their lava composition and fossil ages resemble rocks of volcanic origin in the Coahuila terrane (Delicias) located a few kilometers to the east, but this should be tested with further studies.

Northeast of Santa María del Oro, red beds that transitionally change to limestone rest unconformably on the metamorphic complex (Fig. 3) (Pescadito Schist) (Araujo and Arenas, 1986), but their relationship with the marine volcanic and volcanics has not been determined. The limestone beds contain Tithonian ammonites (Contreras-Montero et al., 1988). Contact relationships among the Parral, Coahuila, Cortes, and Central terranes are unknown because the contacts are covered by overlapping Jurassic-Cretaceous continental and marine successions, and Cenozoic volcanics.

**Guerrero Composite Terrane**

Some authors have interpreted the Guerrero terrane to be an allochthonous oceanic arc that developed in the paleo-Pacific and collided with Mexico by Late Cretaceous time (Lapierre et al., 1992; Tardy et al., 1994; Freydier et al., 1996; Dickinson and Lawton, 2001). However, there is strong evidence that this terrane had an older history of accretions and that its basement is made up of several strongly deformed pre-Cretaceous rocks that form a heterogeneous basement upon which the arc was built (Centeno-García et al., 1993a, 1993b; Elías-Herrera et al., 2000). Those older rocks were interpreted as part of an under thrust subduction complex by Dickinson and Lawton (2001). However, field evidence shows that deformation of those rocks occurred before the development of the arc. This evidence includes the following: Cretaceous arc-related dikes and intrusives cutting the basement; Jurassic granitoids intruding the basement rocks; regional erosion and a major regional nonconformity between arc rocks and deformed basement; and clasts of basement rocks and clasts of Jurassic granitoids in conglomerate layers at the base and within the arc succession (Vidal-Serratos, 1991; Centeno-García et al., 1993a, 1993b, 2003). This evidence indicates that the arc, at least in western Mexico, was not tectonically emplaced onto the older rocks but was built on the prearc Paleozoic–Early Mesozoic rocks that form its basement (Centeno-García et al., 1993a, 1993b; Elías-Herrera et al., 2000; Mendoza and Suastegui, 2000; Centeno-García et al., 2003). Evolution of these prearc rocks is discussed in this paper.

On the bases of variations in the arc stratigraphy and in the composition of basement rocks, the Guerrero composite
Terrane has been divided into the Tahue, Zihuatanejo, Arcelia-Guanajuato, and Teloloapan terranes (Fig. 1) (Ramírez-Espinosa et al., 1991; Centeno-García et al., 1993b, 2003; Talavera-Mendoza et al., 1995). Exposures of prearc rocks can be found in the Tahue, Zihuatanejo, and Teloloapan terranes. The basement of the Arcelia-Guanajuato terrane remains unknown.

**Tahue Terrane**

The Tahue terrane was first defined by Sedlock et al. (1993) as a different terrane from the Guerrero terrane. However, because it contains large volumes of volcanic-sedimentary rocks of the Cretaceous Guerrero arc (Roldán-Quintana et al., 1993; Freydiere et al., 1995), the Tahue terrane has been included within the Guerrero composite terrane in this paper (Fig. 1). This northernmost part of the Guerrero composite terrane is the least known, and contact relationships among its units have not been studied in detail. Its oldest known rocks are metamorphosed volcanic-sedimentary rocks of the El Fuerte Complex (location 5 in Figs. 2 and 3) (Mullan, 1978; Roldán-Quintana et al., 1993; Poole and Perry, 1998). This complex is made up of green schist, pelitic schist, quartzite, and marble. Protoliths were made up of volcanic rocks, rhyolitic to andesitic in composition, quartz-rich sandstone, and some black chert. Conglomerates are very fine-grained sandstone, interbedded with very thin layers of very fine-grained sandstone, interbedded with very thin layers of light green metamorphosed shale and limestone, and volcaniclastics that contain Ordovician conodonts (Poole and Perry, 1998).

Exposures of Upper Paleozoic rocks are located south of El Fuerte, in northern Sinaloa state (San José de Gracia town) (location 5a in Figs. 2 and 3) (Carrillo-Martínez, 1971; Gastil et al., 1991). They are made up of strongly deformed siliciclastic turbidites, thin-bedded calcareous shale (slumps), and chert. The turbidites contain blocks of limestone with chert nodules. This unit contains fossils of mid-Pennsylvanian to Early Permian age (Carrillo-Martínez, 1971; Gastil et al., 1991). They have been interpreted as deposited on a deep marine environment (Gastil et al., 1991). Deformed and partially metamorphosed turbidites of Mazatlán city, made up of interbedded shale and quartz-rich sandstone, might be the southern extension of the San José de Gracia rocks (location 5b in Fig. 2). However, those rocks do not contain chert and have only exotic blocks of recrystallized limestone (marble) (Arrendondo-Guerrero and Centeno-García, 2003). The age of this unit is unknown. It was apparently deposited on a submarine fan environment (Arrendondo and Centeno-García, 2003).

Mafic and ultramafic intrusions that are part of the Cretaceous basic magmatism of the Guerrero arc cut the El Fuerte Complex and deformed sedimentary rocks of Mazatlán (Henry and Fredrikson, 1987; Roldán-Quintana et al., 1993). Thus, these metamorphic rocks are considered to be the basement of the arc in this part of the Guerrero terrane (Valencia-Moreno, 1998). Upper Paleozoic rocks of the San José de Gracia area are overlain by Cretaceous volcanic and sedimentary rocks of Guerrero arc (Henry and Fredrikson, 1987; Roldán-Quintana et al., 1993).

Relationships between Paleozoic rocks of the Tahue terrane and other coeval rocks in surrounding terranes have not been constrained. Both Lower and Upper Paleozoic rocks of the Tahue terrane seem to have similarities with rocks of the Cortes and Parral terranes. However, direct correlation might not be feasible because the Jurassic-Cretaceous Guerrero arc, which was constructed on the Tahue Paleozoic rocks, has suffered considerable displacement during its Jurassic-Cretaceous evolution.

**Zihuatanejo Terrane**

The basement of parts of the Zihuatanejo terrane (Guerrero composite terrane) crop out in several localities (locations 6 and 6a–b in Figs. 3 and 4). The northernmost exposure of these rocks is located in the surroundings of Zacatecas city (Zacatecas Formation, location 6a in Fig. 4), where they are mostly characterized by interbedded quartz-rich sandstone, shale, and a few layers of pillow basals (Ranson et al., 1982; Cuevas-Pérez, 1983; and Monod and Calvet, 1991; Centeno-García and Silva-Romo, 1997). Pillow lavas are MORB geochemically and are different from lavas in the Cretaceous arc. Ammonoids and pelecypods from the Zacatecas Formation are Upper Triassic (Carnian) in age (Burckhardt and Scalía, 1906).

In a tectonic thrust contact, the Zacatecas Formation is overlain by a succession of unknown age. This succession, whose role in the geologic evolution of the area remains uncertain, is made up of fine-grained volcaniclastic rocks, volcanic breccias, and thin-bedded limestone. In a similar thrust contact, these undated volcaniclastic rocks are overlain by Cretaceous pillow lavas and volcaniclastic rocks of island arc affinity (Lapierre et al., 1992; Centeno-García and Silva-Romo, 1997). The Triassic rocks and undated volcaniclastic rocks were deformed before their tectonic contact with the Cretaceous rocks; they have foliation, tight folding, and some mylonitic zones that are not found in the Cretaceous rocks. The Zacatecas Formation has strong similarities with Triassic successions in southern Zihuatanejo terrane (Arteaga Complex) and has been interpreted as accreted open ocean-floor assemblages (back-arc basin?) that received sediments from a continental margin (Centeno-García and Silva-Romo, 1997).

To the south, the most complete exposure of Early Mesozoic rocks is located near the coast in Michoacán State (Arteaga complex, location 6 in Figs. 3 and 4). They are composed of several lithologic units, including siliciclastics, green volcaniclastics, pillow basalts, diabase, gabbrons, black and green chert, and exotic blocks of recrystallized limestone (Fig. 3). Approximately 60% of the exposures are of siliciclastic sediments such as black shale, quartz-rich sandstone, and some black chert. Conglomerates are rare, and their clasts are made up of quartz, black and white chert, and black siltstone; rarely, felsic and granitic clasts are found. The siliciclastics are occasionally interbedded with scarce packets (some up to 200 m thick) of light green metamorphosed shale and very fine-grained sandstone, interbedded with very thin layers of recrystallized limestone. They are interpreted as metavolcaniclastics derived from a MORB and/or primitive arc source (Centeno-García et al., 1993, 2003). Basaltic pillow lava flows and massive blocks of basalt have geochemical and isotopic composition that
are similar to those in mid-ocean ridges (MORB) (Centeno-García et al., 1993, 2003). Light green–aquamarine–color chert is interbedded with the siliciclastics, but sometimes it forms blocks originated by strong shearing and deformation. It is distinct from the black thin-bedded chert of the siliciclastics. Large limestone blocks (recrystallized), up to tens of meters in diameter, are sporadically found within the siliciclastics sediments.

Considering that the siliciclastic rocks of the Arteaga Complex do not contain interbedded limestone or calcareous fragments, the limestone blocks are interpreted as olistoliths (Centeno-García, 1994; Centeno-García et al., 2003). Original thickness is unknown, but the minimum structural thickness, observed between two thrust planes that contain pillow lavas at the sole, is ~1500 m. The age of deposition and deformation of the Arteaga Complex has not been well constrained. There is one report of radiolarian fossils of Late Triassic (Ladinian-Carnian) age (Campa et al., 1982). Detrital zircons are not younger than around 260 Ma (Centeno-García et al., 2003). Thus, deposition is considered to be Late Permian to Late Triassic or younger.

The Arteaga complex is strongly deformed and, in some areas, metamorphosed to greenschist facies, forming a “broken formation” type of structure. Contacts between the siliciclastics (that constitutes the matrix) and the pillow lavas, green chert, volcaniclastics, and limestone blocks are sheared, forming large lenses of tens to hundreds of meters in size, giving the complex a “block in matrix” aspect, characteristic of an accretionary complex. Jurassic granitic intrusions that cut the deformation and metamorphism of the Arteaga complex are Oxfordian-Kimmeridgian in age and set some constraints on the age of deformation of the complex (Centeno-García et al., 2003). Scarce geochronological data indicates that sedimentation and deformation of the Arteaga complex have occurred sometime between the Norian and the Oxfordian (Centeno-García et al., 2003). Volcanic and volcaniclastic rocks of the Cretaceous arc-assemblage rest unconformably on the Arteaga complex (Centeno-García et al., 1993b, 2003). Localities 6b on Figure 4 are other exposures of the Arteaga Complex (Centeno-García et al., 1993a).

Sedimentary structures, lithofacies and fossil associations suggest that the Arteaga sediments were deposited in a deep ocean environment, probably contemporaneous with part of the rift magmatic activity (Centeno-García et al., 2003). The basin received volcaniclastics that may have been either deep-marine deposits derived from the erosion and eruption of the oceanic ridge basalts or air-fall ashes erupted from some oceanic island arc. The erratic blocks of limestone might be olistoliths derived from platform deposits and carried down from the continental slope. The rocks of the complex originated in a marginal back-arc basin or in an open ocean environment (Fig. 4) (ocean-floor/continental rise setting). The structures of the complex suggest that it was deformed by subduction processes and corresponds to the upper levels of an accretionary complex (Centeno-García et al., 2003). Rocks of the Arteaga Complex are covered by Aptian-Albian marine volcanic and volcaniclastic rocks (Centeno-García et al., 2003).

DEPOSITIONAL ENVIRONMENTS, SANDSTONE PROVENANCE, AND REGIONAL CORRELATIONS

Paleozoic

The Paleozoic units previously described can be divided into four different groups or assemblages that have major differences in their stratigraphic and structural characteristics: (1) the Paleozoic assemblage of the North America craton (Chihuahua and Northeast Sonora); (2) rocks of the Sierra Madre and Coahuila terranes; (3) Paleozoic units of Caborca and Cortes terranes; and (4) Paleozoic rocks of the Parral and Tahue terranes.

The Paleozoic rocks of North America craton in Mexico (Chihuahua and northeast Sonora states) have the following distinctive features: (1) Throughout most of the Paleozoic, the sedimentation occurred in shallow marine environments, except for the Lower Permian Formations at Sierra del Cuervo and Placer de Guadalupe, which show an increment in clastic sedimentation and a deepening in the depositional environment. (2) There are no major unconformities among the succession, and thus pre–Late Permian orogenies were not apparently recorded in this area. (3) There are no reports of significant volcanic activity. (4) The crystalline basement rocks are involved in the deformation. (5) A major angular unconformity with Kimeridgian rocks that suggest at least one pre–Late Jurassic post–Early Permian phase of deformation (Bridges, 1964). Paleozoic rocks of Chihuahua and Northeastern Sonora have been correlated with the stratigraphy of Southwestern Texas and New Mexico (Flawn et al., 1961; Bridges, 1964; Pearson, 1964). Provenance studies on the Paleozoic rocks of Chihuahua have not been done.

Several publications discuss the Late Paleozoic correlation of the Caborca and Cortes terranes with other areas of the western North America margin (e.g., Stewart et al., 1990; Poole et al., 1992). Whether they were transported toward the south, and when, are still under debate, but their correlation with Cordilleran tectonics seems to be well constrained. Some of their main features are as follows: (1) shallow marine depositional environments throughout most of the Paleozoic in the Caborca terrane; (2) deep marine sedimentation during most of the Paleozoic in the Cortes terrane; (3) a Mississippian deformational event, followed by a Permo-Triassic compressive event, followed by continental sedimentation in the Triassic in the Cortes terrane; (4) a continuous sedimentation, without major angular unconformities, from Permian to the Jurassic in the Caborca terrane; and (5) no evidence of sedimentary influence from volcanic activity up to the Early Jurassic. These features are common with southern parts of the U.S. Cordilleran belt (Miller et al., 1992). Studies of zircon provenance from Paleozoic rocks from both Caborca and Cortes terranes cannot conclusively constrain the paleogeography of these terranes (Gehrels and Stewart, 1998).

The stratigraphies of the Coahuila and Sierra Madre terranes seem to have strong correlations, at least by Late Paleozoic–Early Mesozoic time. The two main common features that are not
found in the other assemblages are as follows: both terranes have recorded Mississippian to Early Permian submarine arc magmatism; and they contain a belt of Permo-Triassic granitoids. One of the differences between the Sierra Madre and Coahuila terranes is that there is an angular unconformity between Mississippian and Pennsylvanian rocks to the east of the Sierra Madre terrane (Ciudad Victoria) that was not observed in the Coahuila terrane (Delicias) (Ortiz-Ubilla et al., 1988; Centeno-García et al., 1998; McKee et al., 1999; Stewart et al., 1999). Both Coahuila and at least northern Sierra Madre show evidence of a major folding event before the deposition of Jurassic or Cretaceous marine and continental rocks.

The Parral terrane and rocks at the El Fuerte complex of the Tahue terrane recorded a pre-Devonian magmatic event that is not found elsewhere in northern Mexico. Both localities show similarities in their stratigraphy, containing Ordovician? to Devonian? arc magmatism. However, they show major differences in their Jurassic-Cretaceous cover. Magmatism of similar age has not been identified in other parts of Northern Mexico. Early Paleozoic arc magmatism has been recorded in eastern areas of the Cordilleran Belt in the USA and Canada (Burchfiel et al., 1992), suggesting a possible Cordilleran origin. Alternatively, metamorphic rocks of the Parral terrane could be the southern continuation of the Oaxaquia–North America collisional belt.

**Units with Unconstrained Ages**

The age of the succession at Real de Catorce (Sierra Madre terrane) has not been well constrained, and there is not enough information for reconstructing its tectonic and depositional environment. The rocks are mostly marine turbidites that share three characteristics in common with Pennsylvanian-Pennsylvanian rocks of the Sierra Madre terrane: they contain limestone with crinoid stems as intraclasts; they are associated with volcanic rocks of arc affinity; and they were deformed before deposition of mid-Jurassic rocks. If the Paleozoic age is confirmed, they could be correlated with the basal part of the Tuzanagan arc, which contains siliciclastic rocks and basic volcanics.

Rocks of the Central terrane (Taray Formation) were deformed by subduction processes, and it has not been determined whether they were first deposited on a passive margin or whether they represent a trench-filling succession. Similarities with Triassic sediments of the Sierra Madre terrane have led several authors to suggest that this unit is part of the Triassic submarine fan (Potosi Fan) (Silva-Romo et al., 2000; Bartolini et al., 2002) because turbidites of the Taray Formation have a Sm/Nd and U/Pb zircon provenance that is similar to those in the Potosi Fan (Centeno-García et al., 2003). If a Triassic age for sedimentation is proven, then the rocks might belong to an Early Jurassic subduction zone.

**Triassic**

The data available suggest that the continental margin during Triassic time was located west of the Potosi Fan along the limit between the Sierra Madre, Central, and Guerrero terranes (Fig. 4). Facies and fossil associations of the turbiditic siliciclastics of the Potosi Fan suggest that they were deposited on a continental shelf-slope environment. The Potosi Fan does not seem to have any correlation with rocks of the Antimonio area (Fig. 4) because the last were deposited on a forearc setting (González-León et al., this volume). Continental to shallow marine Triassic sedimentary units in Cortes terrane are interpreted as deposited on rift basins, but they contain volcanic rocks (tuffs); thus, an arc-related environment is also plausible (Stewart and Roldán-Quintana, 1991).

Lithologic assemblages of the Triassic rocks of the Zihuatanejo terrane (Guerrero composite) suggest an ocean-basin environment of deposition. Their siliciclastic sediments were derived from continental areas and transported to the ocean floor by turbiditic flows. It is possible that deposition of these sediments was contemporaneous with at least part of the rift magmatic activity (MORB signatures in the lavas). Whether the Zacatecas and Arteaga Complexes originated in an active back-arc basin or an open-ocean environment is still uncertain. The only evidence of association with island arc magmatism is the volcaniclastic sediment at the Arteaga Complex, but their geochemical signatures are not specific for discriminating between MORB-derived or primitive oceanic island arc magmatism. The abundance of cratonic-derived siliciclastic rocks indicate that rocks of the Arteaga Complex were deposited near a continent. Pb ages of detrital zircons suggest that the siliciclastics of the Arteaga Complex might have been deeper facies (ocean floor) of the Potosi Fan (Centeno-García et al., 2003). This evidence suggests that the Guerrero Composite terrane did not evolve away from the continental margin, as previously proposed, but as a marginal terrane.

**PALEOGEOGRAPHIC MODELS ANDTECTONIC EVOLUTION**

Several models have been proposed for the sedimentation and tectonic settings of the western margin of Mexico during Paleozoic-Mesozoic time (e.g., Conen, 1978, 1983; Dickinson and Conen, 1980; Damon et al., 1981; Pindell and Dewey, 1982; Cuevas-Pérez, 1983; Sedlock et al., 1993; Ortega-Gutiérrez et al., 1994; Jones et al., 1995, Dickinson and Lawton, 2001). Most of them show generalized tectonic models for large time spans. However, field evidence shows that the end of the Paleo-ozoic and the Early Mesozoic were characterized by a series of tectonic events that occurred over very short time periods. In this section, a more detailed tectonic evolution on shorter time slices is proposed.

**Paleozoic Paleogeographic Models**

There are a number of models interpreting the assembling of Pangea, but they basically fall into three groups (only samples referenced included):

1. Models in which the Coahuila and Sierra Madre terranes (part of the Oaxaquia Block) remain attached to Gondwana until both collide with North America during Carboniferous-Permian time (Fig. 5A). The collision with North America is via consump-
tion of an oceanic basin, via a subduction zone placed on the northeastern Gondwana margin, that existed along the Marathon-Ouachita-Chihuahua belt (e.g., Lopez, 1997; Dickinson and Lawton, 2001). In this model, Carboniferous-Permian volcanism of the Coahuila and Sierra Madre terranes is associated to the consumption of this oceanic basin placed between the continents.

2. Models with a collisional front between Coahuila-Sierra Madre terranes and North America at the Ouachita-Marathon-Chihuahua belt, changing toward the south into a continental arc (Fig. 5b). In this model, Carboniferous-Permian volcanism of the Coahuila and Sierra Madre terranes is related to a subduction zone along the Pacific margin of those terranes (e.g., Sedlock et al., 1993; Ortega-Gutierrez et al., 1994).

3. Models with the Coahuila-Sierra Madre-North America collisional zone to the east of Coahuila-Sierra Madre terranes, where Permian rocks of the Sierra Madre terrane are interpreted as orogenic flysch (e.g., Pindell, 1985).

There is not enough data to strongly support any one of these three groups of models over the other two.

The model in Figure 5A (group 1) illustrates a Carboniferous-Permian collision of the Coahuila-Sierra Madre terranes (Oaxaquia block) with North America. It seems to explain the difference in stratigraphy of the Coahuila-Sierra Madre terranes with that of the south-central part of the North America craton (northern Chihuahua state). However, it has several shortcomings. It does not explain why the Paleozoic rocks at Place de Guadalupe did not experience deformation during Mississippian to Early Permian time. This model does not explain the strong affinities of Mississippian faunas of the sedimentary cover of Coahuila and Sierra Madre terranes with the midcontinent province in North America (Stewart et al., 1999; Navarro-Santillan et al., 2002). This model also does not give an explanation to the occurrence of Mississippian metamorphic rocks at the subsurface on the Maya terrane, and the eastern margin of Sierra Madre terrane in Ciudad Victoria (Granjeno Schist) (Ramirez-Ramirez, 1978, 1992).

Tectonic models of group 2 (Fig. 5B) can better explain the time overlapping between the magmatism of the Coahuila and Sierra Madre terranes and deformation on the Ouachita-Marathon belt. However, they do not explain the Mississippian faunal affinities between Coahuila and Sierra Madre terranes and North America.

The model in Figure 5C (modified from Pindell, 1985) (group 3) seems to fit all the evidence available up to date. The main difference between this model and those in Figures 5A and 5B (groups 1 and 2) is that the Coahuila and Sierra Madre terranes (part of the Oaxaquia Block) detached from Gondwana before Gondwana collided with North America and was accreted to North America between the Silurian and the Carboniferous. In this model, the belt of metamorphic rocks located to the east of Coahuila and Sierra Madre terranes (Maya terrane) is in a position that strongly suggests it might be the continuation of deep marine successions of the collisional front between Gondwana and North America. Faunal affinities suggest that collision of Coahuila, Sierra Madre, terranes (and other southern terranes that form Oaxaquia) is more likely to have occurred between Silurian and Mississippian time. Gravity and magnetic anomalies recorded along Chihuahua state, which have been considered to be the prolongation of the Ouachita belt, might be the pre-Mississippian accretor belt between the Coahuila-Sierra Madre terranes and North America or a belt of structures perhaps related to the evolution of the Ouachita Marathon belt but developed into the continent, originating foreland basins toward the west (Chihuahua).

**Mississippian-Permian Paleogeography**

After the collision, a Mississippian to Early-Late Permian (Leonardian-Guadalupian) arc developed along the Coahuila-Sierra Madre terranes (Oaxaquia) (Delicias and Tuzancoa) (Fig. 5C). It is inferred that this arc was related to an east-dipping Pacific subduction zone, placed on the western side of these terranes (Fig. 5). However, field evidence of subduction complexes of this age has not been found. In this scenario, rocks at central Sierra Madre terrane (Tuzancoa) would have been formed in an intra-arc setting, with nearby volcanic centers of mafic composition. Thus, deposition at Delicias (Coahuila terrane) seems to have occurred in a back-arc basin because it contains less amount of volcanic rocks, more felsic magmatism, and more influence from a cratonic source in the sedimentation. Clast derived from Pan-African and Grenville complexes contained in conglomerates of the Delicias successions might have been derived from uplifted zones in east-southern Mexico and South America (Fig. 5) (Lopez et al., 2001).

No evidence of subduction-related facies has been found in the Carboniferous-Lower Permian sedimentary units of Chihuahua (Rara Formation in Sierra del Cuervo, and Plomosas) (Fig. 3), except for a slight increment in feldspar in sandstones in the Rara Formation toward the top (reported in Handchy and Dyer, 1987). There is one report of a possible rhyolitic flow within Plomosas formation (Grajales-Nishimura et al., 1992), but no abundant volcanism or volcanic detritus within the sediments has been found. Also, there is no evidence of arc activity in the Carboniferous to Permian sedimentation in the Caborca, Cortes, and Tahue successions. Instead, thick successions of siliciclastic rocks were deposited, probably in a passive and/or trailing margin environment. The Cortes terrane experienced deformation during the Early Mississippian, but such a deformation event was not recorded in Chihuahua. The deepening of the sedimentation during the Early Permian in the Cortes terrane has been interpreted as related to a change from a stable continental margin to an active margin (subduction or strike-slip) (Stewart et al., 1997).

Lower Permian volcanic rocks of the Mojave Desert (Walker, 1988) suggest that subduction might have extended toward the north along the paleo-Pacific margin. Contemporaneous strike slip occurred in the Mojave Desert (Stone and Stevens, 1988; Walker, 1988). Whether this Permian strike-slip system extends to Chihuahua or Northeastern Sonora remains unknown. Dickinson and Lawton (2001) suggested that this strike-slip system originated the translation of the Caborca and Cortes terranes to
their present position in the Carboniferous–Early Permian. However, there is presently no field evidence to support this aspect of their model. Translation of the Caborca and Cortes terranes will be discussed latter.

Permo-Triassic Paleogeography

Apparently there was a gap in the magmatic activity between Leonardian and Ochoan in eastern Mexico. Then arc magmatism was reestablished by Latest Permian–Early Triassic time (Fig. 6). There was not only a gap in the volcanism, but also a change in the composition and distribution of the magmatic centers. Upper volcanic-sedimentary levels of this arc were not preserved in Mexico, only a belt of granitoids along eastern and northern Mexico. These granitoids cut and tie together the Pennsylvanian–Lower Permian units of the North America Craton (Chihuahua and Sonora) to the Coahuila, Maya, and Sierra Madre terranes and suggest that a subduction zone extended along the paleo-Pacific continental margin of Mexico. If the accretionary prism of Central terrane (Taray accretionary complex in Figs. 4 and 6) is demonstrated to be Permo-Triassic in age, it would be an important piece of evidence for the location of the continental margin for that time. Permo-Triassic granitoids have been reported from the Mojave Desert, as well as in other parts of the western United States (Miller et al., 1992, 1995); thus, this continental arc had extended all along the southwestern margin of the North American Craton.

Paleozoic Paleogeography of the Caborca and Cortes Terranes

The Caborca and Cortes terranes seem to have a different Paleozoic tectonic evolution compared with eastern and central terranes of Mexico (Fig. 5). First, there is no evidence of magmatic activity in the Caborca or Cortes terranes during this time. Second, the Cortes terrane has recorded at least two deformational events with thrusting and folding that have not been identified in either the western Sierra Madre and Coahuila terranes, or in the Craton in Chihuahua. The first event occurred in the Mississippian and is younger than the Antler Orogeny (Poole and Madrid, 1988; Stewart et al., 1990; Burchfiel et al., 1992). The second event occurred in Late Permian to Early Triassic time and has been considered the main deformatinal event that placed deep-marine continental slope-rise sediments (eugeoclinal) onto the shallow marine platform facies (Sonoran Orogeny) (Fig. 5) (Poole and Madrid, 1988; Stewart et al., 1990; Poole et al., 1995). This second event of deformation has been related to the Sonoma Orogeny and was not recorded in the Caborca terrane (Stewart et al., 1990; Poole et al., 1992).

Whether Late Permian to Early Triassic deformation had affected other parts of Mexico is still uncertain. Upper Paleozoic sedimentary rocks of Chihuahua, as well as those of Coahuila and northern Sierra Madre terranes, were deformed at least before the deposition of the Upper Jurassic–Cretaceous units. The contact between Paleozoic and Triassic sedimentary rocks of Sierra Madre terrane is not exposed. Thus, the age of deformation of the Paleozoic rocks remains unknown. The only evidence of pre-Triassic deformation in eastern-central Mexico is a post-deformation pluton that cuts folded rocks of the Delicias arc in the Coahuila terrane. This intrusive yielded a Late Triassic age (Lopez, 1997; McKee et al., 1999).

Middle-Late Triassic Paleogeographic Reconstruction

Magmatic activity along eastern Mexico seem to be not younger than ca. 232 Ma (Torres et al., 1999), except for the one granitoid at Delicias, Coahuila, dated at 218 ± 4 Ma (Lopez, 1997). Also, no detrital zircons younger than 232 Ma have been found in Upper Triassic units of central and southwestern Mexico (Centeno-Garcia et al., 2003). Apparently, magmatism did not restart until Early(?) to Middle Jurassic time in all Mexico (Jones et al., 1995; Grajales et al., 1992; Centeno-Garcia et al., 2003; Fastovsky, et al., this volume). Thus, there is no evidence of continuous magmatism along the paleo-Pacific coast from Permian to Jurassic, as proposed by Dickinson and Lawton (2001). Instead, the Permo-Triassic volcanic arc was followed by a period of rifting? or passive margin from Ladinian(?) to Norian time, as evidenced by the stratigraphic record of central and western Mexico.

Figure 7 shows a possible tectonic scenario for Ladinian(?) to Norian time. As mentioned before, evidence of well-spread arc-related magmatic activity during this period of time has not been found in Mexico. Although there is no direct evidence, it seems likely that this period of time was characterized by continuous uplift of the eastern and north-central parts of Mexico. This uplift might have been related to the first rifting stages of Pangea, and it seems to have produced massive erosion of the Paleozoic-Precambrian rocks. This erosional event originated the large volumes of siliciclastic turbidites that formed the submarine Potosi Fan, deposited in the western continental platform and slope/rise of the Sierra Madre terrane.

Geochemical and isotopic signatures of younger volcanic rocks, as well as the regional distribution of the siliciclastic rocks of the Triassic Potosi Fan, suggest that the continent margin of
eastern and northern Mexico extended along the western boundary of the Sierra Madre terrane before thrusting of the Zihuatanejo terrane (pre-latest Triassic–Early Jurassic). This margin was located approximately along the present limit between Sierra Madre and Guerrero terrane (Fig. 7) (e.g., Ruiz et al., 1988b; Anderson et al., 1990; Yañez et al., 1991; Torres et al., 1999; Centeno-García and Silva-Romo, 1997; Bartolini et al., 2002). If the accretionary complex of the Central terrane is post-Triassic, the continental margin would have extend along the limit between the Central and Sierra Madre and Coahuila terranes (Figs. 4 and 7).

An oceanic basin located to the west of this paleocontinental margin received sediments derived from the Potosi submarine fan, as indicated by their provenance (Fig. 7) (Centeno-García et al., 2003). Evidence of contemporaneous rift-related volcanism is found in the Arteaga Complex (Zihuatanejo terrane). This basin may have evolved as a back arc basin, as suggested by the primitive geochemical signatures of its volcaniclastic rocks, or as an open ocean-floor basin, where the mid-ocean ridge received sediments from the continent (Centeno-García et al., 1993; Centeno-García et al., 2003).

**Early Jurassic**

The exact age and number of compressional events that deformed the Triassic rocks in the Zihuatanejo and the Sierra Madre terranes (and maybe the Central terrane?) are still uncertain. However, evidence suggests that rocks of Taray, Zacatecas, and Arteaga were deformed in a subduction complex. Preliminary isotopic data suggest that the Arteaga oceanic basin might have collided against nuclear Mexico sometime between the Rhaetian and the Callovian (Fig. 8A) (Centeno-García, 1994; Centeno-García and Silva-Romo, 1997; Centeno-García et al., 2003). During this deformational event, the thick siliciclastic succession of the Potosi Fan was thrust eastward, over the Sierra Madre terrane.
The regional angular unconformity that places Oxfordian-Kimmeridgian volcanic and sedimentary rocks on the deformed Triassic rocks of the Sierra Madre and Central terranes, and the granitic intrusions of the same age that cut the Arteaga Complex in the Zihuatanejo terrane (Centeno-García et al., 2003), are evidence of the regional extension of this orogenic event. This deformation was followed by widespread continental arc magmatism along all western Mexico by Middle-Late Jurassic (Fig. 8B), and by the rifting of the Zihuatanejo terrane during the Late Jurassic–Early Cretaceous time, to form the Early Cretaceous Arperos Basin.

**Early Mesozoic Paleogeography of the Caborca and Cortes Terranes**

Early Mesozoic evolution of the Caborca terrane has major differences with the evolution of terranes of central and eastern Mexico. In Caborca, sedimentation was continuous from Triassic to Early Jurassic (González-León et al., this volume), whereas a passive margin followed by a subduction-related deformational event was occurring in the Sierra Madre, Central(?), and Zihuatanejo terranes (Figs. 7 and 8). The sedimentation in Caborca was related to an active arc during Early Jurassic time, as evidenced by the detrital zircons collected from the Antimonio Group (González-León et al., this volume). Early Jurassic magmatism has been documented in Nevada (Riggs et al., 1993), but it seems to be absent from the Mojave Desert to the Sierra Madre terrane. Thus, provenance supports a northern location of the Caborca terrane for Early Jurassic time. Triassic sedimentary rocks of the Cortes terrane are interpreted as deposited in rift-related basins (Stewart and Roldán-Quintana, 1991). Discussion on the relationships between Triassic rocks of the Caborca and Cortes terranes is presented by González-León et al. (this volume).
Paleogeography of the Tahue and Parral Terranes

The metamorphic rocks of the Tahue and Parral terranes are similar. Both are made up of metavolcanic rocks (lava flows and volcaniclastics) interlayered with metamorphosed quartz-rich sandstone and shale. Their origin remains uncertain. The rocks at Tahue terrane (El Fuerte) contain Ordovician conodonts (Poole and Perry, 1998), but the age of deformation is unknown. Basement rocks of the Parral terrane (Pescadito Schist) were deformed and metamorphosed in the Late Devonian, but the age of deposition is unknown. Whether both metamorphic units had originally been one unit or not has not been determined. They are considered in this paper as different complexes because their overlapping units are different.

Volcanic-sedimentary successions of the Cretaceous Guerrero arc are deposited on the El Fuerte metamorphic rocks. In contrast, pre-Titonian continental red beds and volcanic rocks, as well as Titonian-Cenomanian marine calcareous rocks, were deposited on the metamorphic units of Parral Terrane.

Understanding the origin of these metamorphic units will set constraints on regional displacements and paleogeography. Preliminarily, there are two plausible options. One is that metamorphic rocks of the Parral terrane could be the southern continuation of the accretionary zone between North America and
Oaxaquia (southern continuation of the Ouachita) (P1 in Fig. 5). An alternative origin for the metamorphic rocks of Parral terrane is that they were displaced from a northwestern latitude in the Cordillera (P2 on Fig. 5), because metamorphic volcanic-sedimentary rocks of similar age have been reported from Nevada and California (Miller et al., 1992).

CONCLUDING REMARKS

One of the main problems reconstructing the Late Paleozoic–Early Mesozoic paleogeographic position of the northwestern terranes with respect to central and eastern terranes is that differences in the stratigraphy and structure can be explained by either lateral changes in the tectonic settings, or major translations associated to strike-slip faulting. There is not enough evidence collected to date to strongly favor any of the models proposed in this paper or by other authors; however, any model should take into consideration the following field evidence.

1. The Coahuila and Sierra Madre terranes must have been attached to North America (Chihuahua) by Late Permian–Early Triassic time because they are both intruded by the Permo-Triassic granitic belt. Looking at the present distribution of those granitoids, a minimum sinistral strike-slip displacement between the Coahuila and Sierra Madre terranes of ~200 can be calculated (Fig. 2). Age of this displacement remains unknown.

2. Whether the Caborca and Cortes terranes were displaced southward in the Late Paleozoic is still uncertain. The evidence favoring this displacement is the possible Late Paleozoic truncation of the continental margin in the Mojave Desert region. The evidence against this early movement is that Lower Jurassic arc-related zircons were shed into the Caborca terrane Antimonio Group, because volcanism of this age has not been documented south of the Mojave Desert region.

3. There is no evidence of subduction-related magmatism in central and eastern Mexico from Middle Triassic to Early(?)-Middle Jurassic time. Composition and thickness of the Upper Triassic turbidites of the Potosi Fan suggest that the western margin of the Sierra Madre terrane was a passive margin or rifting margin during the Late Triassic. The continental edge was located approximately along the limit of the Sierra Madre terrane with the Central and Guerrero Composite terranes (Fig. 4).

4. Field evidence suggest that a major regional compressional event occurred sometime in between Latest Triassic and Early Jurassic time in the Sierra Madre and Zihuatanejo terranes. During this event, the basement of the Zihuatanejo terrane (Arteaga Complex and Zacatecas Formation) probably collided in a subduction zone with the western margin of Sierra Madre terrane (Oaxaquia). Then it probably was rifted apart during Late Jurassic–Cretaceous time.

5. Whether the Taray subduction complex was part of the deformational event described in (4) is still uncertain, but field relationships suggest that it was accreted before the development of the Middle-Late Jurassic continental arc.

6. The present position of the Early Mesozoic continental edge is evidence of strike-slip displacements in central Mexico. This edge is defined by the Taray accretionary prism, which has no continuation to the north in the Coahuila terrane. All the rocks exposed in Coahuila and Parral terranes are much older than Taray (Figs. 3 and 4). The margin might have been transported toward the east, with a minimum sinistral displacement of 300 km. Age of this displacement is unknown, but it should be post–Late Permian on the basis of the maximum age of the Taray Formation.

7. The Parral, Central, and Sierra Madre terranes must have been together before latest Middle to early Late Jurassic time, because they have a common overlapping volcano-sedimentary cover of Middle-Late Jurassic age. Volcanic xenoliths of the same age found in La Popa (NW Monterey City), located in the Coahuila terrane, open the possibility that those three terranes might not have been far from the Coahuila terrane. Middle-Upper Jurassic granitoids that cut the Arteaga complex suggest that the subduction zone of the Middle-Late Jurassic continental arc might not be the Taray Formation, as proposed by Anderson et al. (1990), but might have been much farther toward the west of the Arteaga complex (Fig. 8B).

8. The Paleozoic basement of the Tahue terrane (El Fuerte, San José de Gracia) and the Triassic basement of the Zihuatanejo terrane (Arteaga Complex and Zacatecas Formation) should have been together before Late Jurassic, because the Jurassic-Cretaceous volcanic arc that defines the Guerrero terrane was built on both units. Thus, if the El Fuerte and San José de Gracia rocks were displaced from a northern position, they should have been in a southern latitude before the Late Jurassic.

9. So far, direct stratigraphic or provenance correlation between Paleozoic–Early Mesozoic rocks in west (Caborca, Cortes and Tahue terranes) and east-central (Central and Zihuatanejo, Coahuila and Sierra Madre terranes, and the craton in Chihuahua) Mexico has not been done. In contrast, much evidence has been collected on the stratigraphic similarities between western Mexico and the southeastern United States (Stanley and González-León, 1995; Marzolf, 2000, among others). Until the correlation studies within Mexico are done, tectonic modeling will be based on only one body of evidence.

Looking at the overall present distribution of the Permo-Triassic units, as well as at the stratigraphy and tectonic evolution of their overlapping units, major lateral displacements could have happened (1) before the Late Jurassic volcanic arc (contemporaneous to the Early Jurassic orogeny?), (2) during the development of this volcanic arc and the rifting of the basements of the Guerrero composite terrane, and/or (3) during the collision of the Guerrero arc and formation of the Sierra Madre fold and thrust belt (Late Cretaceous–Early Cenozoic) of eastern Mexico.

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