The Guerrero Composite Terrane of western Mexico: Collision and subsequent rifting in a supra-subduction zone

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ABSTRACT

The Guerrero Composite Terrane of western Mexico is the second largest terrane in North America. Mostly characterized by submarine volcanism and formed by five terranes, the Guerrero records vast and complex subduction-related processes influenced by major translation and rifting. It is composed of the Teloloapan, Guanajuato, Arcelia, Tahue, and Zihuatanejo Terranes. The Teloloapan Terrane is made up of Lower Cretaceous island-arc (IA) andesitic to basaltic submarine lava flows, interbedded with limestone and shallow-marine volcanioclastic rocks. The Guanajuato and Arcelia Terranes are characterized by Lower Cretaceous supra-subduction ophiolite successions formed by deep-marine volcanic and sedimentary rocks with mid-oceanic-ridge basalt (MORB), oceanic-island basalt (OIB), and island-arc basalt (IAB) signatures. These two terranes are placed between the continent and the more evolved arc assemblages of the Zihuatanejo Terrane. The Tahue Terrane is composed of Paleozoic accreted arc and eugeoclinal sedimentary rocks, Triassic rift-related metagneous rocks, and over lain unconformably by pillow basalts, limestone, and volcanioclastic rocks. The Zihuatanejo Terrane was formed by Triassic ocean-flank to ocean-floor assemblages accreted in Early Jurassic time (subduction complexes). The subduction complexes are overlain by Middle Jurassic–evolved volcanic arc rocks, which are in turn unconformably overlain by Early and Late Cretaceous subaerial and marine arc-related volcano-sedimentary assemblages.

Mesozoic stratigraphy at the paleocontinental margin of Mexico (Oaxaquia and Mixteca Terranes) is formed by Triassic submarine fan turbidites accreted during Early Jurassic time; Middle Jurassic–evolved volcanic arc rocks are unconformably covered by a Late Jurassic to Cretaceous calcareous platform.

Six stages in the tectonic evolution are proposed on the basis of the stratigraphic and deformational events recorded in western Mexico: (1) A passive or rifting margin developed along the western margin of continental Mexico throughout the Triassic.

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thick siliciclastic turbiditic succession of the Potosi Submarine Fan was accumulated on the paleo-continental shelf-slope and extended to the west in a marginal oceanic basin. (2) Subduction began in the Early Jurassic, and the turbidites of the Potosi Fan with slivers of the oceanic crust were accreted, forming a wide subduction prism. (3) Exhumation of the accretionary prism and development of a Middle Jurassic continental arc onto the paleo-continental margin (Oaxaquia and Mixteca Terrane) took place, and also in the Zihuatanejo Terrane. (4) Intra-arc strike-slip faulting and rifting of the Middle Jurassic continental arc took place along with migration of the subduction toward the west and development of a calcareous platform in Oaxaquia and the Mixteca Terrane (continental Mexico). (5) Drifting of the previously accreted Tahue and Zihuatanejo Terranes formed a series of marginal arc-backarc systems, or one continuously drifting arc with intra-arc and backarc basins during Early to middle Cretaceous time. (6) Deformation of the arc assemblages, and development of Santonian to Maastrichtian foreland and other basins, date the final amalgamation of the Guerrero Composite Terrane with the continental margin.

Keywords: Guerrero Terrane, Mexico, tectonics, Triassic subduction complex, Cretaceous arc volcanism.

INTRODUCTION

The present configuration of continental Mexico was built after accretion of basement remnants and oceanic terranes. During most of their Mesozoic history, Proterozoic to Paleozoic accreted terranes formed a relatively narrow neck of land adjacent to the North American craton. This was bordered on its eastern side by rifting and on its western side by active subduction. Thus Mexico is probably one of the most suitable regions in North America for studying the interaction between these two differing tectonic scenarios. We suggest in this paper, based on evidence recorded in the stratigraphy of the Guerrero Composite Terrane and surrounding terranes, that the almost continuously subducting Pacific margin of Mexico was directly influenced by extensional tectonics associated with the breakup of Pangaea and the formation of the Gulf of Mexico.

The Guerrero Composite Terrane (Campa and Coney, 1983) constitutes approximately one-third of Mexico. As originally described, it is the largest of all the Mexican terranes and probably the second largest of the North America Cordillera after Wrangellia (Campa and Coney, 1983; Centeno-García et al., 1993a). The Guerrero Composite Terrane is characterized mostly by submarine and locally subaerial volcanic and sedimentary successions that range in age from Jurassic (Tithonian) to middle–Late Cretaceous (Cenomanian), and scarce exposures of older rocks. A wide variety of models has been proposed for the origin of the Guerrero Composite Terrane. Like other terranes of the North America Cordillera, it was first interpreted as an exotic terrane formed by a far-traveled Cretaceous oceanic arc. Some authors have suggested that it was an oceanic arc terrane that was accreted to nuclear Mexico in Late Cretaceous time via a westward-dipping subduction zone that closed a major ocean basin (Lapierre et al., 1992; Tardy et al., 1994; Dickinson and Lawton, 2001, etc.). Other authors have suggested that the Guerrero Composite Terrane might represent one or more complex systems of two or three peripheral arcs that developed relatively close to the continent (Campa and Ramírez, 1979; Ramírez-Espinosa et al., 1991; Mendoza and Suastegui, 2000; Centeno-García et al., 2003; Centeno-García, 2005). Some models even proposed that the arc was autochthonous and was built upon Proterozoic continental crust of nuclear Mexico (de Cserna, 1978; Elías-Herrera and Sánchez-Zavala, 1990). In other words, there is a model for each likely possibility, but each lacks strong supporting evidence.

New findings on the stratigraphy, discussed in this paper, suggest a more complex evolution, implying a series of accretions to the continent followed by rifting, and later by collision. In this paper we attempt to present our insights into the evolution of western Mexico gained from examining the stratigraphy and structure, and the geochemical and geochronological data, of such a vast area. However, we discuss in this paper only stratigraphic units and localities that are keys for reconstructing the tectonic evolution. This paper synthesizes the work done by many authors. Although there is the need for more geochronological and detailed field work, we consider that the preliminary tectonic model presented in this paper is consistent with the evidence collected to date.

OVERVIEW OF THE GUERRERO COMPOSITE AND NEIGHBORING TERRANES

The stratigraphy of western Mexico is synthesized in this paper under the framework of tectono-stratigraphic terranes, which are regions that share the same geological history and are bounded by major faults. As mentioned before, by the early Mesozoic, the Paleozoic and Proterozoic terranes were already accreted to the southern part of the North American craton.
Those that already formed part of the continental margin during the Mesozoic were Oaxaquia and the Mixteca, Parral, and Cortes Terranes (Fig. 1). Terranes accreted or displaced during the Mesozoic were those of the Guerrero Composite, the Central, as well as terranes of the western Baja California Peninsula. The latter will not be reviewed in this paper. A brief summary of the stratigraphy is described as follows; more detailed descriptions of key areas and events are discussed later.

OAXAQUIA

At the end of the Paleozoic, Proterozoic basement terranes of Gondwanan affinity were already accreted to the southern part of the North American craton. The largest of these is the Oaxaquia block (Fig. 1), a crustal fragment, subcontinent in size, of Grenville affinity (Ortega-Gutiérrez et al., 1995). This crustal block forms the backbone of eastern Mexico and is referred to herein as continental Mexico for the Mesozoic. Oaxaquia has a Precambrian (1157–900 Ma) crystalline basement (gneisses and anorthosites; Patchett and Ruíz, 1987; Ortega-Gutiérrez et al., 1995; Ramírez-Ramírez, 1992; Lawlor et al., 1999; Solari et al., 2003; Keppie et al., 2003). It is covered by Paleozoic sedimentary rocks (Fig. 2) that are capped by Permian volcanic and volcaniclastic rocks (McKee et al., 1999; Stewart et al., 1999; Rosales-Lagarde et al., 2005). Triassic (Carnian–Norian) sedimentary rocks (La Ballena Formation) are exposed at the western margin of Oaxaquia (Labarthe et al., 1982; Silva-Romo, 1993; Tristán-Gonzalez and Torres-Hernández, 1994; Centeno-García and Silva-Romo, 1997; Barboza-Gudiño et al., 1998, 1999, 2004; Bartolini et al., 2002). These rocks are made up of a thick succession of turbidites (Fig. 2) deposited in a submarine fan environment named the Potosi Fan (Centeno-García, 2005).

Triassic rocks of the Potosi Fan were deformed prior to deposition of Jurassic volcanic-volcaniclastic rocks (Centeno-García and Silva-Romo, 1997). They are interpreted as a Jurassic continental arc and rest unconformably on the Triassic Potosi Fan. Jurassic arc strata are made up of subaerial andesitic-rhyolitic lava flows, interbedded with volcaniclastic rocks (Silva-Romo, 1993). The arc sequence changes transitionally upsection to shallow-marine
volcaniclastic rocks, limestone, and some evaporites (Fig. 2; Silva-Romo, 1993; Tristán-González and Torres-Hernández, 1994; Barboza-Gudiño et al., 2004). Calcareous sedimentation in Oaxaquia ranges in age from late Oxfordian–Kimmeridgian to Turonian and is interpreted as the southern extension of the North American seaway. A major change upsection from calcareous to clastic sedimentation occurred at the uppermost part of the Cretaceous, forming a thick succession of sandstone, shale, and conglomerate (Caracol Formation; Silva-Romo, 1993). Oaxaquia is overthrust by the Guerrero Composite Terrane (Fig. 1).
MIXTECA TERRANE

The basement of the eastern Mixteca Terrane is made up of pre-Mississippian polydeformed metamorphic rocks of the Acatlán Complex (Ortega-Gutiérrez, 1981; Ruiz et al., 1988; Yañez et al., 1991). This complex is considered to be the result of complex interactions between Gondwana and Laurentia previous and during the assembling of Pangea (Ortega-Gutiérrez et al., 1999). It is unconformably overlain by Permian sedimentary rocks, which are in turn overlain unconformably by Middle Jurassic volcanic and sedimentary rocks (Fig. 2; García-Díaz et al., 2004). At the western part of the terrane, near the limit with the Guerrero Composite Terrane, partly metamorphosed volcanic and volcaniclastic rocks are exposed (Taxco Schist and Chapolapa Formation; de Cserna and Fries, 1981; Talavera-Mendoza, 1993; Campa and Iriondo, 2004). The Taxco Schist is made up of andesitic to rhyolitic lavas and volcaniclastic rocks of Early Cretaceous age (Talavera-Mendoza, 1993; Campa and Iriondo, 2004). The Taxco Schist is unconformably overlain by a thick limestone succession of Albian to Cenomanian age and by Turonian–Maastrichtian clastic rocks (Mexcala Formation; Campa and Ramírez, 1979; Talavera-Mendoza et al., 1995). Contacts between the Mixteca Terrane and Oaxaquia, as well as between the Mixteca and Guerrero Composite Terranes, are partially exposed. The Mixteca Terrane is on strike-slip fault contact with Oaxaquia, and rocks of the Guerrero Composite Terrane are thrust over the Mixteca Terrane.

PARRAL TERRANE

The Parral Terrane (Figs. 1 and 2) was first defined by Pacheco et al. (1984) and Coney and Campa (1987) and was redefined by Centeno-García (2005). The basement of the Parral Terrane is formed by Devonian to Carboniferous metamorphic rocks (Pescadito Schist; Egiluiz and Campa, 1982; Araujo and Arenas, 1986; Zaldívar and Garduño, 1984). These Paleozoic metamorphic rocks are unconformably overlain by red beds and volcanic successions (Nazas Formation; Pantoja-Alor, 1963), which change transitionally to shallow-marine limestone (Araujo and Arenas, 1986; Zaldívar and Garduño, 1984). These rocks change further transitionally to shallow-marine limestone that ranges in age from Late Jurassic to Early Cretaceous (Córdoba-Méndez, 1964). The location of the northern and eastern contact between the Central Terrane and Oaxaquia is inferred on the basis of the location of the last exposures of Paleozoic–Early Mesozoic rocks, and a contrast in deformation styles of Cretaceous rocks in both (Fig. 1). The contact between the Central and Guerrero Composite Terrane has not been studied in detail but is inferred on the basis of the distribution of the northernmost exposures of Cretaceous marine volcanic rocks that belong to the Guerrero Composite Terrane. Structural trends on both sides of the contact suggest that the Central Terrane is overthrust by the Guerrero Composite Terrane to the south (Fig. 1). The thrusting is inferred to have occurred about Late Cretaceous time.

GUEGUERO COMPOSITE TERRANE

Areas with large volumes of Lower Cretaceous volcanic and volcaniclastic rocks, located toward the west of Oaxaquia and the Mixteca Terrane, were originally grouped as the
Guerrero Terrane by Campa and Coney (1983) and were, 10 years later, divided into the Tahue, Nahuatl, and Tepehuano Terranes by Sedlock et al. (1993). Subsequent regional mapping has shown that the divisions proposed by Campa and Coney (1983) are closer to the field locations of faults delimiting the terranes than those of Sedlock et al. (1993). Therefore, more recent reviews of the terrane distribution of Mexico (e.g., Centeno-García, 2005) have been based on Campa and Coney (1983). The Guerrero is a composite terrane, formed by at least five terranes: Tahue, Zihuatanejo, Guanajuato, Arcelia, and Teloloapan (Figs. 1 and 2; Talavera-Mendoza et al., 1995; Mendoza and Suastegui, 2000; Centeno-García et al., 2003; Centeno-García, 2005). Their stratigraphy is briefly described from NNW to ESE (Fig. 1):

**Tahue Terrane**

The Tahue Terrane contains the oldest rocks found so far within the Guerrero Composite Terrane (Fig. 2; Centeno-García, 2005). These rocks comprise Ordovician marine rhyolitic-andesitic lavas and clastic and calcareous rocks, all deformed and metamorphosed to low-greenschist facies (El Fuerte Complex; Mullan, 1978; Roldán-Quintana et al., 1993; Poole and Perry, 1998). These rocks may have originated as an oceanic arc that apparently was accreted previous to the deposition of Pennsylvanian–Permian deep-marine sedimentary rocks (San José de Gracia Formation; Carrillo-Martínez, 1971; Gastil et al., 1991; Arredondo-Guerrero and Centeno-García, 2003; Centeno-García, 2005). These deep-marine turbidites are strongly deformed but do not show the metamorphism of the El Fuerte Complex; thus an unconformable contact relationship between these two units is inferred. Paleozoic rocks of the Tahue Terrane are unconformably overlain by Cretaceous marine arc volcanic rocks and are interpreted as part of the Guerrero Arc (Ortega-Coney et al., 1979; Henry and Fredrikson, 1987; Roldán-Quintana et al., 1993; Freydier et al., 1995). These rocks are also cut by mafic and ultramafic intrusions that are part of the same Cretaceous arc magmatism (Henry and Fredrikson, 1987; Gastil et al., 1999; Arredondo-Guerrero and Centeno-García, 2003). Therefore, the Paleozoic units form the basement upon which the arc was built. The Tahue Terrane also contains metamorphic rocks of Triassic age (Keppie et al., 2006). The contact relationship between the Cortes and Tahue Terranes has not been studied in detail, but it is inferred to be a thrust (Fig. 1; Roldán-Quintana et al., 1993). The contact between the Tahue and Zihuatanejo Terranes is not exposed.

**Zihuatanejo Terrane**

The Zihuatanejo Terrane is the largest of all terranes that form the Guerrero Composite Terrane (Fig. 1). It extends north of the Mexican volcanic belt and along the Pacific Coast of Mexico (Centeno-García et al., 1993a, 1993b; Talavera-Mendoza et al., 1995; Mendoza and Suastegui, 2000). Its basement is made up of large volumes of Triassic (Norian) quartz-rich turbidites (sandstone and shale) that are tectonically imbricated (Campa et al., 1982; Centeno-García et al., 1993a, 1993b). The turbidites form a matrix within which are blocks and slabs of pillow basalts, diabase, banded gabbros, chert, and limestone (Fig. 2). These rocks have received different names at different outcrops: Zacatecas Formation, Arteaga Complex, and Las Ollas Complex (Burchhardt and Scalía, 1906; Ranson et al., 1982; Cuevas-Pérez, 1983; Monod and Calvet, 1991; Centeno-García and Silva-Romo, 1997; Talavera-Mendoza, 2000; Centeno-García et al., 2003). The deformation of these rocks varies from gently folded strata to highly sheared block-in-matrix textures, and their metamorphism ranges from none to high-greenschist–amphibolite facies (Centeno-García et al., 2003). Blueschist facies have been reported only in one locality (Las Ollas Complex; Talavera-Mendoza, 2000). These lithologies are interpreted to constitute an Upper Triassic (?)–Lower Jurassic subduction-related accretionary complex.

Scattered exposures of rocks of Middle to Late Jurassic–evolved arc volcanism lie along the Pacific Coast of the Zihuatanejo Terrane. These rocks are made up of submarine rhyolitic lavas and volcaniclastic rocks, and granitoids that were emplaced in rocks of the accretionary complex (Bissig et al., 2003; Centeno-García et al., 2003). The Middle to Upper Jurassic arc rocks were in turn deformed and exhumed previous to the deposition of uppermost Jurassic–Cretaceous arc-related strata (Centeno-García et al., 2003).

The Cretaceous arc succession ranges from Berriasian to Cenomanian in age, and it includes andesitic, basaltic, and some rhyolitic volcanic and volcaniclastic rocks, interbedded with limestone, evaporites, and some red beds (Grajales and López, 1984). The arc succession contains abundant fossils such as rudists, gastropods, microfossils, fossil logs, and vertebrates.

This arc succession was deformed prior to the intrusion of large granitoids of latest Cretaceous to Paleogene age (Schaaf et al., 2000). Also, uppermost Cretaceous (Santonian to Maastrichtian) red beds and volcanic rocks rest unconformably on all previous units (Altamira Areyán, 2002; Benammi et al., 2005). The contact between the Zihuatanejo Terrane and Oaxaquia is exposed at its northern limit, where Cretaceous arc rocks of the Zihuatanejo Terrane are thrust over shallow-marine limestone of Oaxaquia. Its contact with the Arcelia and Guanajuato Terranes is inferred to be an east-verging thrust, but it is covered by uppermost Cretaceous and Cenozoic red beds and volcanic rocks.

**Guanajuato Terrane**

The Guanajuato Terrane has been interpreted as a complete crustal section through a primitive island arc that appears to lack an older basement (Ortiz-Hernandez et al., 1991; Ortiz-Hernandez, 1992). It has also been interpreted as the remains of an oceanic basin that lay between the Guerrero arc and the continental margin (Freydier et al., 2000). This terrane was formed by a series of tectonic slivers that placed lower crust rocks (gabbro,
tonalite, serpentinite, wehrlite, and dike swarms) on pillow basalts, rhyolitic tuffs, volcanic turbidites, chert, and black detrital limestone (Quintero-Legorreta, 1992; Ortiz-Hernandez et al., 1992; Lapierre et al., 1992; Monod et al., 1990; Martínez-Reyes, 1992; Ortiz-Hernandez et al., 2003). These rocks were poorly dated as Tithonian–Hauterivian in age (Ortiz-Hernandez et al., 2003; Hall and Mortensen, 2003). Previously deformed volcanic turbidites are unconformably overlain by Aptian–Albian limestone (Ortiz-Hernandez et al., 2003). This suggests that sedimentation and at least one phase of deformation occurred previous to the Aptian–Albian (Ortiz-Hernandez et al., 2003).

At present the Guanajuato Terrane is thrust over the calcareous platform of Oaxaquia (Ortiz-Hernández et al., 2002). Contact relationships between the Guanajuato and Zihuatanejo Terranes have not been constrained.

Arcelia Terrane

The Arcelia Terrane is made up of basaltic pillow lavas and ultramafic bodies, black shale and chert, and volcanic turbidites, all intensively deformed and partly metamorphosed (Ramírez-Espinosa et al., 1991; Talavera-Mendoza et al., 1995). It is characterized by Early Cretaceous deep-marine primitive arc or arc-related oceanic facies and shows the least evolved magmatism of all the arc successions of the Guerrero Composite Terrane (Talavera-Mendoza et al., 1995; Mendoza and Suastegui, 2000). The Arcelia Terrane appears to lack an older basement (Talavera-Mendoza et al., 1995; Mendoza and Suastegui, 2000). Rocks of the Arcelia Terrane apparently were thrust over the assemblages of the Teloloapan Terrane, and were in turn overthrust by rocks of the Zihuatanejo Terrane. However, these contacts are inferred because they are covered by younger red beds.

Teloloapan Terrane

The Teloloapan Terrane consists of two distinct regions: the eastern region is characterized by shallow-marine volcanic and sedimentary deposits (Fig. 2), and the western region by deeper volcanic and sedimentary facies (Guerrero-Suastegui et al., 1991; Ramírez-Espinoza et al., 1991; Talavera-Mendoza et al., 1995; Mendoza and Suastegui, 2000; Guerrero-Suastegui, 2004). Both are marine arc assemblages, which vary in composition from basalt-andesite to scarce dacite-rhyolite (Talavera-Mendoza et al., 1995). This unit contains microfossils (radiolarians and coccoliths), gastropods, and bivalves that range in age from Hauterivian to Aptian; these rocks change transitionally upsection to Aptian–Albian island-arc carbonates (Guerrero-Suastegui et al., 1991; Ramírez-Espinoza et al., 1991; Talavera-Mendoza et al., 1995). The Teloloapan Terrane (Fig. 1) is exposed in the easternmost parts of the Guerrero Composite Terrane. It is characterized structurally by a complex thrust-fault system that verges eastward. Its Lower Cretaceous rocks are severely deformed and metamorphosed in low-grade greenschist facies. The Teloloapan Terrane overrides either Lower to Middle Cretaceous platform carbonates or Upper Cretaceous clastic sediments that belong to the Mixteca Terrane (Fig. 1; Campa and Ramirez, 1979). The nature of its basement remains unknown. Metamorphic rocks that are exposed near the northwestern boundary of the Teloloapan Terrane with the Arcelia Terrane have been interpreted as a possible basement for the former (Elías-Herrera and Sánchez-Zavala, 1990; Sánchez-Zavala, 1993). The rocks in this area are of uncertain age and origin.

TECtonic MODEL

The most abundant rocks of the Guerrero Composite Terrane are marine, and rarely subaerial, arc volcanic and sedimentary successions that range in age from latest Jurassic (Tithonian) to middle Late Cretaceous (Cenomanian). The composition of the few scattered exposures of older units suggests a complex earlier tectonic evolution. These older rocks were not taken into consideration for the tectonic models proposed by previous authors (de Cserna, 1978; Campa and Ramirez, 1979; Elías-Herrera and Sánchez-Zavala, 1990; Tardy et al., 1994; Lapierre, et. al., 1992; Dickinson and Lawton, 2001, etc.). Based on the available information, we identified six main tectonic stages in the evolution of the Guerrero Composite Terrane. These stages are represented in Figure 3 and are briefly described in this section. Detailed discussion of the data that support the reconstruction of each stage is presented in the following section.

Stage I: Collision of a Paleozoic Oceanic Arc?—Basement of the Tahue Terrane

The basement of the Tahue Terrane (Fig. 3) is composed of the early Paleozoic accreted volcanic-sedimentary rocks of the El Fuerte Metamorphic Complex. There are not enough data available to constrain the origin of this complex. Preliminary interpretations considered these rocks as remnants of Gondwanan crust accreted during the formation of Pangea (Poole et al., 2005). In this model, metamorphic rocks of El Fuerte could be the western continuation of basement rocks of the Parral Terrane (Figs. 1 and 2). An alternative interpretation is that the El Fuerte Complex may be a displaced fragment of the early Paleozoic arc (Antler Arc) that collided with the western continental margin of North America during late Paleozoic time (Burchfiel et al., 1992; Sánchez-Zavala et al., 1999; Dickinson, 2004; Centeno-García, 2005). Carboniferous deep-marine turbidites (San José de Gracia Formation) that apparently cover the lower Paleozoic arc rocks unconformably may be correlative with deep-marine sedimentary rocks exposed in the eastern peninsular ranges of Baja California and the southwestern Cordillera of North America (Gastil et al., 1991; Centeno-García, 2005).

In either of the two scenarios, deformed Paleozoic rocks of the Tahue Terrane are the basement upon which Cretaceous volcanism was built, indicating an earlier history of accretion of the Guerrero Composite Terrane than was previously interpreted by other authors.
Figure 3. Tectonic models for the evolution of western Mexico, showing the alternating stages of subduction-collision and rifting.
Stage II: Late Triassic Passive Margin—Deposition of the Potosi Fan

The paleo-continental edge of Mexico lay approximately at the western boundary of the Oaxaquia and Mixteca Terranes in the early Mesozoic (Fig. 1; Centeno-García, 2005). Thus the Central and Guerrero Composite Terranes (Fig. 1) were accreted or displaced to their present position during the Mesozoic. Sedimentation along the western continental margin of Oaxaquia was dominated by large volumes of siliciclastic turbidites (quartz-rich sandstone and shale) that were deposited in the distal continental shelf or at the continental slope at least during Carnian–Norian time (Fig. 3). Accretionary complexes that form the basement of the Central Terrane and parts of the Guerrero Composite Terrane (Zihuatanejo Terrane) are formed largely (up to 60% of the total area of exposures) by similar quartz-rich sandstone and shale turbidites that made up the matrix within which blocks of variable composition are embedded. These turbidites in the accreted terranes contain fossils of the same age as those from turbidites deposited at the continental slope of Oaxaquia.

Detrital zircon ages obtained from turbidites from all the localities of the Carnian–Norian turbidites, from Oaxaquia to basal accretionary complexes of the Central and Zihuatanejo Terranes, show the same populations, which suggest that the fan turbidites spread into a marginal oceanic basin that was later accreted to the continental margin. These siliciclastic rocks are grouped as the Potosi Fan (Centeno-García, 2005) and are important because they can be traced from Oaxaquia to the present Pacific Coast of Mexico, and they tie together the Central Terrane, the westernmost part of the Guerrero Composite Terrane (Zihuatanejo Terrane), and the continental margin of southern North America (Oaxaquia) during Late Triassic time. Thus, the Potosi Submarine Fan may have been a large sedimentary feature, probably close to the dimensions of the present Bengal Fan.

There is no evidence of Triassic magmatism in continental Mexico, and detrital zircon geochronology of the fan turbidites suggest that the youngest age populations are much older than depositional ages in all the studied localities of the Potosi Fan (Fig. 3; Centeno-García et al., 2005; Centeno-García, 2005). Therefore, the Potosi Fan probably was deposited across a passive margin, or at least a margin that had no active subduction along the length of the fan at the time of deposition.

Stage III: Accretion of the Potosi Fan to the Continental Margin via Subduction—Basement of the Central and Zihuatanejo Terranes

All the Triassic units of central and western Mexico are strongly deformed and partially metamorphosed, indicating that a major compressional event occurred during latest Triassic–Early Jurassic time. This event is characterized by tight folding, shearing, and axial cleavage in the continent-slope deposits of the Potosi Fan in Oaxaquia (La Ballena Formation), and block-in-matrix texture in the Taray Formation (Central Terrane), in the Zacatecas Formation, and in the Arteaga and Las Ollas Complexes (Zihuatanejo Terrane). These last three units formed in the distal ocean-floor zone of the Potosi Fan. The presence of mélanges (Arteaga Complex and Taray Formation) as well as blueschist in the Las Ollas Complex (Zihuatanejo Terrane) indicates that deformation occurred in a subduction zone. During this deformational event the turbidites of the Potosi Submarine Fan, with slivers of the oceanic crust and its sedimentary cover, were accreted to the continent. This accretionary prism apparently was very wide, as suggested by the large areas that are floored by it. Whether the subducting slab was dipping toward the west (under an oceanic arc) or the east (under continental Mexico) has not been constrained. There are two isolated reports of dated Early Jurassic volcanic rocks in Oaxaquia (Barboza-Gudiño et al., 2004; Fastovsky et al., 2005), but whether they are part of a continental arc or not is not known. Evidence of contemporaneous oceanic-arc magmatism is exposed in the Vizcaíno Peninsula of Baja California (Kimbridge and Moore, 2003), where Triassic–Jurassic volcanic rocks have geochemical signatures of primitive arc affinity. It is possible that the rocks in the Vizcaíno Peninsula represent a displaced fragment of an oceanic arc that accreted to the Arteaga and Las Ollas Complexes of the western Guerrero Composite Terrane, which in turn accreted to the Taray, Zacatecas, and La Ballena Formations, but this model needs to be supported by more evidence.

Stage IV: Late Jurassic Continental Arc—Overlapping Assemblage for Guerrero Composite Terrane, Central Terrane, Oaxaquia, and Mixteca Terrane

Subaerial volcanic and sedimentary rocks, as well as shallow porphyritic intrusives, dikes, and sills, overlie or cut previously deformed Triassic sedimentary rocks in Oaxaquia and rocks of the accretionary prism in the Central Terrane. These rocks range in age from 174 to 158 Ma (Jones et al., 1995; Barboza-Gudiño et al., 2004). A common attribute of all the outcrops of these rocks is that they are mostly rhyolitic in composition, with minor dacitic-andesitic lava flows and tuffs, and show evolved-arc geochemical signatures (Centeno-García and Silva-Romo, 1997; Centeno-García, 2002; Centeno-García and Díaz-Salgado, 2002). Coeval volcanic rocks have been reported in the Mixteca Terrane as well, suggesting that arc volcanism was widespread in continental Mexico at that time (García-Díaz et al., 2004). Rocks of similar age range and similar evolved-arc geochemical signatures are exposed in the western Zihuatanejo Terrane of the Guerrero Composite Terrane (Bissig et al., 2003; Centeno-García et al., 2003). This suggests that the Guerrero Composite Terrane may have been incorporated into the continental margin by that time.

Summarizing the data described above: (1) Triassic basement rocks of the Zihuatanejo Terrane (Guerrero Composite Terrane) share a provenance linkage with rocks of the same age in Oaxaquia and the Central Terrane; (2) all Triassic rocks, from those deposited on the paleo-continent’s margin of Mexico to those within the accreted terranes, were deformed previous to the
development of a Late Jurassic continental arc; and (3) evolved Upper Jurassic continental-arc volcanism was widespread among continental Mexico and accreted terranes (Central and Zihuatanejo Terranes). On the basis of these facts, we propose in this paper that the first accretion of the Guerrero Terrane occurred during latest Triassic–Early Jurassic time instead of near the end of the Cretaceous, as previously proposed by other authors. Therefore, the Late Jurassic magmatic event represents an overlapping assemblage that stitches all the terranes of central and western Mexico for that period.

Stage V: Late Jurassic–Early Cretaceous Intra-Arc Strike Slip(?)—Rifting of the Continental Arc—Drifting of the Guerrero Composite Terrane

It has been proposed that major lateral displacements occurred during the activity of the Jurassic continental arc of stage IV (Anderson and Silver, 2005). Therefore, the arc was originally in a more northerly position, and it was displaced, via the Mojave-Sonora Megashear, to its present position in central Mexico prior to, or at, the early stage of development of the calcareous platform (Anderson and Silver, 2005).

Whether this major strike-slip system existed or not has been widely discussed (see GSA Special Paper 393). We consider that extensive geological evidence of major tectonism during and after arc volcanism exists (see following discussion). The cessation of magmatism in the Central Terrane and Oaxaquia suggests a change in the location of the subduction zone. Then, a major regional calcareous platform developed over the arc and other older rocks. This major transgression initiated the deposition of limestone on Oaxaquia, and on the Mixteca and Central Terranes. Calcareous sedimentation in central and eastern Mexico was characterized by high subsidence rates (Goldhammer, 1999). Arc magmatism continued only in a small area in the western Mixteca Terrane and became widespread in the Guerrero Composite Terrane. Although there is some overlap in age ranges of arc volcanism among the terranes that form the Guerrero Composite Terrane, there is a general trend from older ages in eastern Oaxaquia and the Central Terrane to younger ages in the western Guerrero Composite Terrane (Fig. 3). This suggests a possible W-SW migration of the subduction zone. We propose that during and after the continental arc activity (Late Jurassic–Early Cretaceous time), large amounts of extension and lateral translations may have occurred (see inferred faults in Fig. 1). This extensional-transstensional(?) event split the continental arc, initiating the drifting of parts of previously accreted oceanic rocks (basements of the Tahue and Zihuatanejo Terranes) and the generation of new oceanic crust (Guanajuato and Arcelia Terranes).

With the data available, it seems that volcanic activity at the northern Zihuatanejo Terrane and at the Guanajuato and Telolapan Terranes was restricted to latest Jurassic–Early Cretaceous time (Fig. 3). In contrast, in the Arcelia, Tahue, and southern Zihuatanejo Terranes, arc volcanism apparently continued up to Albian–Cenomanian time (Fig. 3). Geochemical and isotopic compositions of most of the Upper Jurassic–Cretaceous igneous rocks of the different arc assemblages of the Guerrero Composite Terrane suggest primitive sources, with little or no influence on an evolved continental crust (e.g., Ortiz-Hernandez et al., 1991; Lapierre et al., 1992; Centeno-García et al., 1993a; Freydière et al., 1995; Gastil et al., 1999; Talavera-Mendoza et al., 1995; Mendoza and Suastegui, 2000, among others). Basalts with ocean-island (OI) and mid-oceanic-ridge basalt (MORB) signatures of the Arcelia and Guanajuato terranes (Lapierre et al., 1992; Ortiz-Hernandez et al., 2003; Mendoza and Suastegui, 2000) suggest the influence of a mantle source for the magmatism.

Regional differences in the strata suggest abrupt lateral changes in the depositional environments from shallow marine to deep marine. Also, lateral differences in thickness of the successions suggest that they may have been deposited in alternate subsiding basins and basement highs where the deposits draped thinly or were absent. These major geological differences suggest that intra-arc rifting was considerable and was probably associated with a complex paleogeography of marginal arc and backarc systems in western Mexico. Whether or not the different terranes of the Guerrero Composite Terrane were formed in a single arc has not been constrained. Some authors proposed that the Guerrero Terrane formed from a complex system of two or three arcs (Ramírez-Espinosa et al., 1991; Mendoza and Suastegui, 2000). However, no Cretaceous subduction-related accretionary prisms have been identified within any of the terranes of the Guerrero Composite Terrane.

Stage VI: Final Accretion of the Guerrero Composite Terrane, and Development of a New Continental Arc

A major Late Cretaceous–early Paleogene orogenic phase is recorded throughout Mexico, coeval to the Sevier and Laramide orogenies in western North America. This event is associated with the Mexican Fold and Thrust Belt of the Sierra Madre Oriental. Apparently, final amalgamation of the Guerrero Composite Terrane occurred during this orogenic event, and volcanic and sedimentary rocks of the Telolapan, Guanajuato, Zihuatanejo, and Tahue Terranes were thrust over the calcareous platform rocks of Oaxaquia and the Central, Cortes, and Mixteca Terranes. The amount of tectonic transport apparently is significant, as xenoliths of Precambrian continental crust were found in Cenozoic volcanic rocks that erupted onto accreted rocks of the Guanajuato Terrane (Urrutia-Fucugauchi and Uribe-Cifuentes, 1999). Significant tectonic transport is also suggested by the amount of shortening that produced tight folding and major thrusting within the northern Zihuatanejo Terrane and the Arcelia and Telolapan Terranes (Salinas-Prieto et al., 2000). In contrast, deformation of Cretaceous rocks in the southern parts of the Zihuatanejo Terrane formed wide regional anticlines, and some overturned folds and minor thrust faults locally. The structures generally trend NW-SE, although locally some structures trend N-S and E-W. Santonian terrestrial sedimentation covers unconformably the previously deformed arc assemblages of the Zihuatanejo
Terrane (Benammi et al., 2005). Synorogenic sedimentary basins (Caracol Formation in Oaxaquia, and Mexcala Formation in the Mixteca Terrane) containing clasts derived from the Guerrero Composite Terrane suggest that these terranes were deformed and exhumed by that time. In addition, synorogenic sedimentation overlaps the Arcelia and Teloloapan terranes (Miahuatlan Formation), which suggests that these two terranes were also amalgamated during the same orogenic event (Mendoza and Suárez, 2000; Guerrero-Suárez, 2004). All these synorogenic basins range in age from Turonian to Maastrichtian. In addition, Paleocene granitoids along the coast cut the previously folded units of the Zihuatanejo Terrane and suggest a Late Cretaceous–early Paleogene deformation.

Therefore, final amalgamation of the Guerrero Composite Terrane occurred between Santonian and Turonian–Maastrichtian time.

**DISCUSSION**

This section summarizes the stratigraphic, structural, and geochemical data that support the proposed stages for the tectonic evolution of western Mexico.

**Stage I: Origin of the Basement of the Tahue Terrane**

Exposures of pre-Cretaceous rocks in northwest Mexico are scattered; thus contact relationships among them can only be indirectly inferred (Figs. 1 and 4). Approximate distribution of the contacts among the terranes of western Mexico (Caborca, Cortes, and Tahue; Figs. 1 and 4) was outlined on the basis of the geographic distribution of pre-Cretaceous outcrops and lateral changes in the isotopic signatures of Cretaceous–Paleogene granitoids (Valencia-Moreno et al., 2001). Thus the nature of the contacts and the amount of displacement among different basements are unknown. In this section the main stratigraphic units that define the terranes are described following a NW to SE transect throughout the Paleozoic rocks of the Caborca, Cortes, and Tahue Terranes (Guerrero Composite Terrane).

At the southern margin of the Caborca Terrane a thick shelfal limestone succession is exposed that contains Carboniferous–Permain fusulinids and other shallow-marine fossil fauna (Stewart et al., 1990). These rocks are overridden by a north-verging major thrust fault that places deeper marine sedimentary rocks of the Cortes Terrane on the shelfal rocks of the Caborca Terrane (Fig. 1; Coney and Campa, 1987; Poole and Madrid, 1988; Stewart et al., 1990).

Basal metamorphic rocks are not exposed in the Cortes Terrane, but its basement has been interpreted as thinned Proterozoic rocks, perhaps the same as in the Caborca Terrane, or else Proterozoic metamorphic rocks different from those of the Caborca Terrane (McDowell et al., 1999; Valencia-Moreno et al., 1999; Valencia-Moreno et al., 2001). The deep-marine sedimentary rocks of the Cortes Terrane are sandstone and shale turbidites, graptolitic shale, chert, and layered barite that range in age from Ordovician to Devonian–Early Mississippian and were deformed during the Mississippian (Poole and Madrid, 1988; Stewart et al., 1990). These rocks are in turn overlain by Upper Carboniferous and Permian turbidites (Fig. 5; Poole and Madrid, 1988; Stewart et al., 1990; Poole et al., 2005). They all were deposited in a deep-marine environment and are interpreted to be part of the Paleozoic continental slope-rise deposits of western North America (Poole and Madrid, 1988; Stewart et al., 1990). All these units of the Cortes Terrane were deformed and thrust over the Caborca Terrane by Late Permian to Early Triassic time, and they are unconformably covered by Upper Triassic terrestrial and marine sedimentary rocks (Stewart et al., 1990). Therefore, the Caborca and Cortes Terranes were assembled by early Mesozoic time.

The nature of the contact between the Cortes and Tahue Terranes (the latter belonging to the Guerrero Composite Terrane) has not been mapped in detail. It is inferred to be a thrust that verges toward the north, and it is probably north of El Fuerte town in Sinaloa State (Fig. 5), based on the northernmost exposures of Cretaceous marine volcanic rocks of the Guerrero Terrane (Servais et al., 1982; Henry and Fredrikson, 1987; Roldán-Quintana et al., 1993; Freydier et al., 1995).

The oldest Paleozoic rocks of the Tahue Terrane (Guerrero Composite Terrane) are exposed in the area of El Fuerte (El Fuerte Complex; Figs. 4 and 5). The El Fuerte Complex is formed by marine rhyolitic to andesitic lava flows and volcanioclastic rocks, interbedded with quartz-rich sandstone, shale, and thin-beded limestone (Mullan, 1978; Roldán-Quintana et al., 1993; Poole and Perry, 1998). All these various components are deformed and metamorphosed to greenschist facies (Mullan, 1978; Roldán-Quintana et al., 1993). Sedimentary rocks of the El Fuerte Complex contain Ordovician conodonts (Poole and Perry, 1998). Preliminary geochemical analyses indicate a calc-alkaline island-arc affinity for the volcanic rocks of the El Fuerte Complex, and are similar to those from coeval Paleozoic arc rocks in the Klamath Mountains of Northern California (Lapierre et al., 1987). However, more detailed geochemical and geochronological work needs to be done to constrain their origin and relationships.

Upper Paleozoic deep-marine sedimentary rocks are exposed south of El Fuerte, in San José de Gracia town, Mazatlán City, and other scattered localities in Sinaloa State (Figs. 4 and 5). These rocks belong to the San José de Gracia Formation (Carrillo-Martínez, 1971; Gastil et al., 1991; Arredondo-Guerrero and Centeno-García, 2003) and are made up of quartz-rich sandstone and shale turbidites, thin-beded calcareous debris flows, black shale, and chert. The turbidites contain olistoliths of limestone with chert nodules, which in turn contain Middle Pennsylvanian to Early Permian fossils at the San José de Gracia locality (Carrillo-Martínez, 1971; Gastil et al., 1991). The San José de Gracia Formation has been interpreted as deposits in a deep-marine environment (Gastil et al., 1991). The contact between the El Fuerte Complex and the San José de Gracia Formation is not exposed. However, major differences in deformation and metamorphism (turbidites of the San José de Gracia Formation
Figure 4. Geologic map of Sinaloa and the southern Sonora states, showing the geology of Caborca, Cortes, and Tahue Terranes (after Carrillo-Martínez, 1971; Mullan, 1978; Gastil et al., 1978; Henry and Fredrikson, 1987; Stewart and Roldán-Quintana, 1991; Ortega et al., 1992; and our own work).
Figure 5. Simplified stratigraphic columns for Oaxaquia and terranes north of the Transmexican Volcanic Belt. The columns are in an east-west order. They include the Tahue Terrane, which is part of the Guerrero Composite Terrane. Vertical scale shows the age range (in Ma).
are strongly deformed but not metamorphosed) indicate that the contact is probably an angular unconformity.

Both units of the Tahue Terrane (El Fuerte Complex and San José de Gracia Formation) are important because they can constrain the paleogeography of the northern Guerrero Terrane. Preliminary single-grain, detrital zircon geochronology from the quartz-rich sandstone from the turbidites of the San José de Gracia Formation shows populations that have a North American affinity (Centeno-García et al., unpublished data) and are similar to those from Paleozoic rocks in Baja California, in the Cortes Terrane, and in Nevada (Gehrels et al., 2002).

The stratigraphy, geochemistry, and provenance of the Paleozoic rocks suggest that the Tahue Terrane (Guerrero Composite Terrane) was linked to the tectonic evolution of the western continental margin of North America, probably up to Permain–Triassic time. After that, there were major differences in the composition of the Mesozoic sedimentary cover of the Caborca-Cortes Terranes with respect to that of the Tahue Terrane. Therefore, it is likely that a fragment of previously accreted island-arc and continent-margin assemblages drifted from the continental margin sometime in the early Mesozoic.

Contact relationships between the Paleozoic sedimentary rocks of the San José de Gracia Formation (Tahue Terrane) and the Triassic subduction-related complex of the Zihuatanejo Terrane are unknown because the contact is covered by younger rocks. However, the Tahue and Zihuatanejo Terranes share similar Cretaceous volcanic and sedimentary cover.

**Stages II and III: Triassic Potosi Fan and Its Accretion to the Continental Margin**

There are few exposures of Triassic rocks in Mexico, and they are limited to the Caborca and Cortes Terranes, western Oaxaquia, the Central and Zihuatanejo Terranes, and a small outcrop in the Vizcaíno Peninsula in Baja California. Triassic rocks have not been found in the Mixteca Terrane or in other terranes of Mexico. In this section we briefly describe Triassic rocks of the Cortes and Tahue Terranes (Barranca Group and Francisco Gneiss) and focus on the marine Triassic rocks of Oaxaquia (La Ballena Formation), the Central Terrane (Taray Formation), and the Guerrero Composite Terrane (Zacatecas Formation, and the Arteaga and Las Ollas Complexes).

**Barranca Group and Francisco Gneiss**

Triassic (Carnian–Norian) sedimentary rocks of the Cortes Terrane are made up of fluvial sandstone and shale that contain abundant coal layers (Barranca Group; Stewart and Roldán-Quintana, 1991). These sediments were deposited unconformably on previously deformed Paleozoic deep-marine rocks. The Triassic fluvial deposits change transitionally up the column to shallow-marine siliciclastic deposits. These rocks have no evidence of contemporaneous volcanism. In contrast, Triassic rocks of the Tahue Terrane (Guerrero Composite Terrane) are made up of metamorphosed igneous rocks of the Francisco Gneiss near Sonobari (Figs. 4 and 5; Mullan, 1978; Keppie et al., 2006). The Francisco Gneiss is made up of migmatized gneisses and amphibolites that have within-plate and continental tholeiite geochemical signatures (Keppie et al., 2006). This suggests that the Tahue and Cortes terranes may have been geographically separated at that time.

**La Ballena Formation**

Triassic rocks of Oaxaquia crop out on its western margin, near its boundary with the Guerrero Composite Terrane (Figs. 1 and 6). They are grouped as the La Ballena Formation (Silva-Romo, 1993; Silva-Romo et al., 2000), and their largest exposures are in the Peñón Blanco, Charcas, and Real de Catorce areas (Fig. 6; Silva-Romo, 1993; Tristán-González and Torres-Hernández, 1994; Barboza-Gudiño et al., 2004). The La Ballena Formation is made up of quartz-rich sandstone and shale, and scarce conglomerates deposited as small channel-fill lenses. The sedimentary structures of these Triassic rocks indicate deposition mostly by turbidity currents, although some debris flows and large slumps are present. This sequence contains abundant trace fossils and ammonites and bivalves of Late Triassic (Carnian) age at the Peñón Blanco and Charcas areas (Cantu-Chapa, 1969; Silva-Romo et al., 2000; Bartolini et al., 2002). Sedimentary structures and fossil fauna suggest that the deposition of this unit occurred in a submarine fan that developed on an external platform or continental slope setting. These rocks form part of the Potosi Submarine Fan (Centeno-García, 2005). The original thickness is unknown, but up to 4640 m was penetrated by exploration drilling without reaching the base of the succession (López-Infanzón, 1986).

**Taray Formation**

Similar marine siliciclastic rocks crop out at the Pico de Teyra region in the Central Terrane (Figs. 5 and 6). They belong to the Taray Formation, made up of highly deformed quartz-rich turbidites (sandstone and shale) interbedded with some black chert and scarce detrital limestone that contains fragments of crinoids, gastropods, corals, bivalves, and bryozoans (Díaz-Salgado et al., 2003). The Taray siliciclastic turbidites form a matrix within which blocks of black and green chert, pillow basalts, serpentinite, and crystallized limestone can be found (Figs. 5 and 6; Díaz-Salgado et al., 2003). The age of this unit remains undetermined; however, there are reports of fusulinids from one of the limestone blocks (Anderson et al., 1990). The youngest detrital zircons collected from the sedimentary matrix are Late Permian in age (Díaz-Salgado et al., 2003). There is also a report of molds of bivalves of possible Carnian age (Barboza-Gudiño et al., 1999; Bartolini et al., 2002). Thus deposition of the sedimentary matrix should have occurred between the Late Permian to the Late Triassic. The Taray Formation has a block-in-matrix structural style, formed by centimeter-size blocks to blocks of hundreds of meters in size, all in a highly sheared sedimentary matrix. This characteristic is typical of a subduction accretionary complex (Anderson et al., 1990, 2005; Díaz-Salgado et al., 2003).
**Zacatecas Formation**

The oldest rocks of the Zihuatanejo Terrane in its northernmost exposure are Triassic in age as well (Fig. 6). They make up the Zacatecas Formation, which crops out in a small tectonic window at the western margin of Zacatecas City (Fig. 6; Burckhardt and Scalia, 1906; Ranson et al., 1982; Cuevas-Pérez, 1983; Monod and Calvet, 1991). This formation is made up of quartz-rich turbidites (sandstone and shale) that contain blocks of pillow basalts that have MORB geochemical signatures (Fig. 7; Centeno-García and Silva-Romo, 1997). The Zacatecas Formation contains fossil ammonites and bivalves of Late Triassic (Carnian) age (Burckhardt and Scalia, 1906; Bartolini et al., 2002). Its contact with the La Borda Formation of Late Jurassic(?)–Cretaceous age is inferred to have been originally an unconformity, but it was sheared and detached during Late Cretaceous thrusting and folding (Fig. 3). Rocks of the Zacatecas Formation show structures associated with two distinct deformational events, one of them prior to the deformation that is recorded in the Cretaceous rocks as well. The small size of the outcrop prohibits constraints on the tectonic origin of the Zacatecas Formation, but its lava flows and siliciclastic turbidites are similar to those from the Arteaga Accretionary Complex, which is exposed in the southern part of the Zihuatanejo Terrane.

**Arteaga Complex**

More exposures of Triassic(?) rocks are found in the southern part of the Zihuatanejo Terrane (Fig. 7). Their largest outcrops are located in the Arteaga, Placeres del Oro, and Tiquicheo areas (Arteaga Complex) and near Zihuatanejo City (Las Ollas Complex) (Fig. 8; Centeno-García et al., 1993a, 1993b; Talavera-Mendoza et al., 1995; Mendoza and Suastegui, 2000). The Arteaga Complex is made up of quartz-rich turbidites (sandstone and shale),
Figure 7. Simplified stratigraphic columns for the terranes described in the text that are south of the Transmexican Volcanic Belt, except for the Guanajuato Terrane, and include the Mixteca Terrane and the Teloloapan, Arcelia, and Zihuatanengo Terranes (Guerrero Composite Terrane). Vertical scale shows the age range (in Ma). MORB—mid-oceanic-ridge basalt; IA—Island arc.
Zihuatanajo Terrane
- Huetamo area, Cretaceous arc assemblage, mostly marine volcaniclastic rocks, limestone and some pyroclastic and lava flows
- Coastal Cretaceous arc assemblage shallow marine and terrestrial rhyolite, andesite and some basalt, limestone, volcaniclastic and basement-derived clastic rocks
- Middle to Upper Jurassic plutons
- Las Ollas Subduction Complex (age unknown)
- Arteaga Subduction Complex (Triassic)

Teloloapan Terrane
- Lower Cretaceous arc assemblages shallow marine andesitic to basaltic lava flows and volcaniclastic rocks, massive and reefal limestone (east) deep marine lava flows, calcareous debris flows and volcanic turbidites (west)

Arcelia Terrane
- Cretaceous IAB pillow lavas, fine-grained volcanic turbidites and chert (deep marine)
- Cretaceous MORB pillow lavas, fine-grained volcanic turbidites and chert (deep marine)

Mixteca Terrane
- Aptian-Albian Calcareous Platform
- Lower Cretaceous continental arc assemblages, marine and terrestrial rhyolite and andesite lava flows and epiclastic rocks, quartz-rich clastic rocks
- Paleozoic Acatlán Complex

Xolapa Terrane
- Jurassic to Cretaceous migmatises, gneisses, and plutons
- Jurassic to Cretaceous calcareous sandstones, siltstones, and limestone

Overlapping assemblages
- Miahuatepec Formation
- Upper Cretaceous clastic rocks
- Turonian-Maastrichtian clastic rocks
- Cretaceous IAB pillow lavas, fine-grained volcanic turbidites and chert (deep marine)
- Cretaceous MORB pillow lavas, fine-grained volcanic turbidites and chert (deep marine)

Figure 8. Geologic map of southwestern Mexico, showing the simplified geology of the Mixteca, Teloloapan, Arcelia, and Zihuatanajo Terranes (after Campa and Ramirez, 1979; Ortega et al., 1992; Talavera-Mendoza et al., 1995; Corona-Chávez and Israde-Alcántara, 1999; Mendoza and Suastegui, 2000; Centeno-García et al., 2003). IAB— island-arc basalt; MORB—mid-oceanic-ridge basalt.
black and green chert, and mafic tuff that form a matrix that contains blocks and slabs of pillow basalts, diabase, banded gabbros, chert, and limestone, all deformed in a block-in-matrix structural style (Centeno-García et al., 2003). Chert layers contain radio- larians of Triassic (Ladinian–Carnian) age (Campos et al., 1982). Pillow basalts and gabbros have oceanic geochemical signatures (MORB; Centeno-García et al., 1993a; Centeno-García et al., 2003). Sedimentary structures preserved in some exposures of unmetamorphosed turbidites, along with the affinity of the few fossils found in the sedimentary rocks of the matrix, suggest that the sequence was deposited in a deep-ocean environment. Apparently the quartz-rich turbidites were contemporaneous with oceanic magmatic activity, as they are interbedded with volcaniclastic rocks (Centeno-García et al., 2003). The block-in-matrix style of deformation of the Arteaga Complex, as well as its lithological associations, indicate that it was formed in a subduction accretionary prism. Metamorphism ranges from none to amphibolite facies; blueschist facies has not been found in the area.

**Las Ollas Complex**

The Las Ollas Complex forms part of the Zihuatanejo Terrane and is exposed near Zihuatanejo City (Figs. 7 and 8; Talavera-Mendoza, 2000). This complex is a tectonic mélangé formed by highly sheared blocks of metabasalt, banded and massive gabbro, metadolerite, ultramafic rocks, and shale and quartz-rich sandstone (Talavera-Mendoza, 2000). These blocks are enveloped in a highly sheared clastic (quartz-rich sandstone) or serpentinitic matrix (Talavera-Mendoza, 2000). Blueschist facies were reported by Talavera-Mendoza (1993, 2000). Geochemical compositions of the basalts are typical of MORB and primitive oceanic-arc magmas (Talavera-Mendoza, 2000). \(^{40}Ar/^{39}Ar\) and K/Ar ages obtained from amphibole from several metabasaltic blocks range from 223 Ma to 96 Ma (Permian to early Cenomanian) (Delgado, 1982; A. Iriondo, 2003, personal commun.). This has been interpreted to be the subduction complex of the Cretaceous arc (Vidal-Serratos, 1991; Talavera-Mendoza, 1993); however, its contact relationships with Cretaceous arc-related rocks, and similarities with the Arteaga Complex, suggest an earlier origin.

Quartz-rich turbidites from the La Ballena Formation of Oaxaquía (continental Mexico), the matrix of the Taray Formation of the Central Terrane, and the Arteaga and Las Ollas Complexes and the Zacatecas Formation of the Zihuatanejo Terrane (Guerrero Composite Terrane) have similar and distinctive compositions and detrital-zircon age populations (Centeno-García et al., 2005; Talavera-Mendoza et al., 2007). Therefore, Triassic sedimentation of the central and western terranes of Mexico is linked by provenance. The youngest zircon age populations from all the samples (latest Permian) are much older than the depositional ages of the turbidites (Carnian–Norian), which means that there was no active volcanism at that time. In other words, there is no evidence of Late Triassic continental arc volcanism in Mexico. Zircon age populations of the Potosi Fan are different from those of Triassic quartz-rich sandstone from the Caborca and Cortes Terranes (González-León et al., 2005) but are similar to those from Triassic fluvial sedimentary rocks of Arizona (Anderson, 2006). This suggests that at the end of the Triassic the terranes of central and western Mexico may have been to the north of their present locations.

Based on this evidence, we propose that the margin of the western paleo-continent of Mexico was passive or rifting at the end of the Triassic. This passive margin received abundant clastic sedimentation, forming the large Potosi Fan. Sediments of this fan were deposited on oceanic crust (Arteaga Basin in Fig. 3). When subduction started, slivers of the ocean floor were tectonically mixed with the already existing passive-margin quartz-rich turbidites that were forming the Taray and Zacatecas Formations as well as the Arteaga and Las Ollas Complexes. Whether the ocean basin that was covered by sediments of the Potosi Fan was an active marginal oceanic basin, a marginal backarc basin, or an open ocean–continent flank is still uncertain. The only potential evidence of association of the Potosi Fan sediments with tholeiitic oceanic volcanism is the volcaniclastic rocks interbedded with the siliciclastic turbidites in the Arteaga Complex, as the volcaniclastic rocks have geochemical signatures between primitive island arc and MORB (Centeno-García et al., 2003).

At least two phases of deformation are found in all the Triassic rocks of Oaxaquía and the Central and Zihuatanejo Terranes. The first event comprised strong shearing and tight folding, and the block-in-matrix structures. A second event was recorded only in the Arteaga Complex. This event deformed the Jurassic granitoids as well, and it is characterized by a mylonitic fabric. The third event was common to all the Triassic units and is also recorded in the Jurassic and Cretaceous cover sediments, and it is characterized by axial cleavage, open to tight folding, reverse faulting, and thrusting.

The time of accretion of the Central Terrane with Oaxaquía is assumed to have been prior to the Middle Jurassic, because the La Ballena Formation of Oaxaquía and the Taray Formation of the Central Terrane were deformed and locally metamorphosed prior to deposition of Upper Jurassic terrestrial volcanic and clastic formations (Tristán-González and Torres-Hernández, 1994; Jones et al., 1995; Silva-Romo et al., 2000). The Zihuatanejo Terrane (Guerrero Composite Terrane) was also accreted at that time, because the Arteaga Complex is cut by granitoids of Middle Jurassic age as well (Centeno-García et al., 2003).

The subduction zone that formed the Taray and Zacatecas Formations, and the Arteaga and Las Ollas Complexes, was probably constructed along the continental margin of Oaxaquía in Early Jurassic time. Whether the subducting slab was dipping to the east or to the west has not been determined.

**Stage IV: Jurassic Continental Arc of Western Mexico**

Erosion and exhumation of the accreted continental slope sediments and the accretionary complexes occurred prior to the initiation of Middle to Late Jurassic magmatism. This is indicated by the major angular unconformity that separates the Jurassic arc.
succession from the deformed Triassic rocks of Oaxaquia and the Central and Zihuatanejo Terranes. Jurassic arc magmatism has also been identified in the Mixteca Terrane. The Jurassic arc rocks have different names at different locations; they are hereby described by their occurrence in different terranes:

**Nazas, Huizachal, and La Joya Formations in Oaxaquia**

The La Ballena Formation (Oaxaquia) is unconformably overlain by the volcanic rocks and red beds of the Nazas Formation in the Peñón Blanco, Charcas, and Real de Catorce areas (Figs. 5 and 6; Silva-Romo, 1993; Tristán-González and Torres-Hernández, 1994; Barboza-Gudiño et al., 2004). The Nazas Formation is made up of dacitic and minor rhyolitic and andesitic lava flows and pyroclastic flows, dikes, and porphyritic shallow intrusives. The volcanic rocks are interbedded with conglomerate, sandstone, and scarce paleosols. Conglomerate is formed mostly by volcanic clasts and a few clasts of sandstone and shale derived from the underlying La Ballena Formation. The volcaniclastic conglomerate and sandstone form lens-shaped bedding with low-angle cross-bedding, interbedded with some debris flows, suggesting that they were deposited in a terrestrial (fluvial and alluvial fan) environment.

Although their age has not been well constrained at all the exposures, there is a report of U/Pb ages as old as 189 Ma at a subaerial volcanic-sedimentary succession in Huizachal (Huizachal Formation; Fastovsky et al., 2005), which might not belong to the same volcanic arc event (Figs. 5 and 6). Rocks of the Nazas Formation at Real de Catorce yielded U/Pb ages of 172 ± 5 Ma (Barboza-Gudiño et al., 2004). The Nazas Formation changes transitionally upward to shallow-marine volcaniclastic rocks, some evaporites, and thin-bedded limestone, which in turn become a thick limestone succession in the Peñón Blanco and Charcas areas (Fig. 6). The basal part of this limestone succession contains late Oxfordian–Kimmeridgian fossil faunas (Centeno-García and Silva-Romo, 1997). In contrast, there is an internal angular unconformity in the Real de Catorce locality (Fig. 6), which separates in two units, the terrestrial volcanic and sedimentary successions (Nazas and La Joya Formations; Barboza-Gudiño et al., 2004). The upper La Joya Formation changes transitionally upward to shallow-marine volcanic sandstone and shale interbedded with thin limestone strata. The oldest fossils reported from the base of the limestone succession in Real de Catorce are Oxfordian in age (Barboza-Gudiño et al., 2004).

**Caopas, Rodeo, and Nazas Formations of the Central Terrane**

The volcanic cover of the Taray Formation (Central Terrane; Figs. 5 and 6) belongs to the Caopas, Rodeo, and Nazas Formations (Córdoba-Méndez, 1964; López-Infanzón, 1986; Jones et al., 1995). The Rodeo and Nazas Formations are lateral equivalents of the same rocks but named differently in separate outcrops (Díaz-Salgado, 2004). Both units are made up of rhyolitic to andesitic lava flows and dikes, and pyroclastic deposits that are interbedded with fluvial sedimentary rocks, mostly sandstone and conglomerate (Anderson et al., 1990, 1991; Jones et al., 1995; Díaz-Salgado, 2004). The Caopas Formation was formed by shallow porphyritic intrusives. Felsic volcanic rocks of the Rodeo Formation yielded a K-Ar age of 183 Ma (López-Infanzón, 1986), and the Caopas Formation a U/Pb age of 158 Ma (Jones et al., 1995). Terrestrial volcaniclastic rocks of the Rodeo Formation are interpreted to have been deformed previous to the deposition of late Oxfordian limestone (Anderson et al., 1991; Bartolini et al., 2002). However, in another locality nearby the Nazas Formation changes transitionally upward to shallow-marine calcareous rocks that range in age from Late Jurassic to Late Cretaceous (Córdoba-Méndez, 1964; Díaz-Salgado, 2004).

All these volcanic–sedimentary units are interpreted in this work as the first overlapping succession that stitches the Central Terrane with Oaxaquia. The Caopas and Rodeo Formations, as well as the Nazas Formation, are interpreted as continental intra-arc assemblages (Jones et al., 1995).

**Las Lluvias Ignimbrite of the Mixteca Terrane**

Jurassic arc volcanism was also recorded in the Mixteca Terrane in which ignimbrites, interbedded with fluvial and shallow-marine siliciclastic deposits, yielded U/Pb ages of 168.2 ± 1.2 Ma, 177.3 ± 1.5 Ma, and 179.1 ± 1.5 Ma (Campá and Irondo, 2003).

**Cuale Assemblage and Tumbiscatio Granitoids of the Zihuatanejo Terrane**

Evidence of coeval Jurassic magmatism has been found in two localities in the Zihuatanejo Terrane (Guerrero Composite Terrane). One of the exposures is NE of Puerto Vallarta City, in the Cuale mining district, and the other locality is in the Tumbiscatio region, both along the Pacific Coast (Figs. 7 and 8). Rocks at Cuale contain volcanogenic massive sulfide (VMS) deposits and are composed of submarine rhyolitic lavas and tuffs, volcanic sandstone with evolved-arc geochemical affinity (Bissig et al., 2003), and shale that yielded U/Pb ages of 162.4 and 155.9 Ma (Bissig et al., 2003). These rocks are strongly deformed and partially metamorphosed, and their contact with Cretaceous unmetamorphosed marine volcanic and sedimentary successions has not been determined.

Two Jurassic granitoids crop out in the Tumbiscatio region. They were emplaced in previously deformed sedimentary rocks of the Arteaga Complex, and vary in composition from granodiorite to granite to quartz monzonite. Their geochemical compositions are typical of calc-alkaline subduction-related granites, which are more evolved than granitoids of Cretaceous and Cenozoic ages from the same area. Both granitoids show intense shearing and internal deformation. Grajales and López (1984) obtained one K/Ar date of Late Jurassic age (158 Ma). U/Pb isotopic analysis yielded a 163 Ma age, and Ar/Ar ages are 158 and 152.4 Ma (Centeno-García et al., 2003). The igneous rocks of the Cuale and Tumbiscatio regions have strong similarities in geochemical composition and age with volcanic rocks of the Central Terrane (Caopas, Rodeo, and Nazas); thus we suggest that they probably originated in the same volcanic arc. Therefore,
the Arteaga Complex was probably accreted to the continental margin, either near or along the strike from central Mexico.

The Jurassic volcanic event did not produce a thick stratigraphic column and apparently did not have large volumes of volcanic products. The column changes transitionally upward to shallow-marine calcareous rocks. Therefore, the lithologic associations and vertical facies changes of this volcanic-sedimentary event are similar to those of a continental rift. However, the scarce geochemical analyses from its volcanic rocks suggest an arc setting (Jones et al., 1995). These rocks have been interpreted as the southern continuation of the Jurassic continental arc that developed along the southwestern margin of North America (Jones et al., 1995).

It has been proposed that major strike-slip faults were probably active during the arc activity (Mojave–Sonora Megashear; Jones et al., 1995). This could explain the fact that the Potosi Fan is south of its possible continental fluvial correlative in Arizona, as well as the southward displacement of the Tahue Terrane.

Whether or not the Jurassic volcanic event was coeval with a major transform fault has not been well documented. The evidence in favor of an important synsedimentary deformation involving major extension is as follows: (1) Minor synsedimentary normal faults and local angular unconformities are present within the Jurassic arc volcanic and sedimentary successions, and pre-Cretaceous mylonitic shearing is recorded in the Jurassic granitoids of the Tumbiscatio region (Zihuatanejo Terrane). (2) Arc magmatism suddenly ceased in the Central Terrane and Oaxaquia, followed by a rapid transgression recorded in a few meters of transitional sedimentation. (3) Subsidence rates apparently were significant during the early stages of the Oxfordian–Kimmeridgian marine sedimentation, because the calcareous rocks show evidence of deeper sedimentation at higher stratigraphic levels as well as overall rapid sedimentation. (4) Although fault planes have been obliterated by younger deformational events, they have been inferred by the rapid lateral changes in thickness and facies of the calcareous succession through the interval from the end of the Jurassic to the Early Cretaceous. (5) In addition, major regional lineaments have been identified in central and eastern Oaxaquia, including the San Marcos and La Babia Faults (Fig. 1) (Goldhammer, 1999; Chávez-Cabello et al., 2005).

Stage V: Rifting of the Guerrero Terranes and Formation of a Complex Arc System

In this section we list the main stratigraphic features of the volcanic-sedimentary successions of the Guerrero Composite Terrane and the Mixteca Terrane. Arc volcanism was absent in Oaxaquia and the Central Terrane through the end of the Jurassic and the Cretaceous. During this period, oceanic crust was emplaced toward the east of Oaxaquia in the Gulf of Mexico, and continuous subsidence prevailed throughout the Early Cretaceous, resulting in a thick calcareous platform that covered all the Central Terrane and Oaxaquia.

Although much detailed work needs to be done in order to reconstruct the paleogeography of western Mexico during the Cretaceous, the available evidence indicates three important features:

1. Magmatism prograded generally east to west through time, from the oldest ages in the Oaxaquia and Mixteca Terranes to the youngest ages in the coastal Zihuatanejo Terrane. There is some overlap of age ranges for the volcanism among the different terranes, e.g., volcanism of the Mixteca Terrane overlaps in age with part of the volcanism of the Teloloapan Terrane (Guerrero Composite Terrane). However, on a large scale, Albian–Cenomanian volcanism is absent in the Mixteca and the Teloloapan Terranes, and it is widespread in the coastal region of the Zihuatanejo and Arcelia Terranes.

2. Magma chemistry changed through time toward a more primitive melt. The Middle Jurassic volcanic and intrusive rocks in all the terranes show mostly felsic-evolved continental-arc geochemical signatures, including the Mixteca Terrane and Oaxaquia. In contrast the Cretaceous volcanic rocks of the Guerrero Composite Terrane range from tholeiitic basalts to andesites, with few rhyolites. They show more primitive island-arc (IA) geochemical signatures overall, and some even have MORB to oceanic-island basalt (OIB) signatures. The Mixteca Terrane is the exception to this trend; its magmatism remained evolved, with continental arc signatures, into the Cretaceous.

3. Within different assemblages of the Guerrero Composite Terrane there are major differences in the stratigraphy, sediment composition, and depositional environments. And the Guerrero Composite Terrane overall is different from the volcanic-sedimentary rocks of the Mixteca Terrane to the east. In their present distribution, areas with shallow-marine and terrestrial volcanic-sedimentary successions alternate with areas with deep-marine volcanic-sedimentary successions, and suggest a complex paleogeography for that time.

These three features are hereby interpreted as evidence of intra-arc rifting-translation. We propose, as a hypothesis to be tested, that the subduction zone might have migrated to the west. This would have produced thinning of the crust, which in turn would have originated more primitive IA geochemical signatures of the magmas and promoted the development of deep basins. Whether the amount of extension was large enough to develop oceanic basins and several parallel subduction zones has not been determined.

The stratigraphy, depositional environments, age, and geochemical affinities of the main units are summarized by terrane. First, those of southern Mexico are described, following a section from east to west. Next, Cretaceous rocks of the northern terranes are described from east to west as well.

Mixteca Terrane

Three localities with Early Cretaceous volcanism have been identified in the western Mixteca Terrane near the contact with
the Guerrero Composite Terrane: the Taxco Schist and the Chapo-
lapa and Zicapa Formations (Fries, 1960; de Cserna and Fries,
1981; Talavera-Mendoza, 1993; Campa and Iriondo, 2003; Fitz
et al., 2002). The Taxco Schist is made up of submarine andesite
to rhyolitic lava flows and tuffs interbedded with epiclastic rocks
and quartz-rich sandstone and shale (de Cserna and Fries, 1981;
Talavera-Mendoza, 1993). Its volcanic rocks have a continental-
arc geochemical affinity, more evolved than contemporaneous
magmatism from the Guerrero Composite Terrane (Talavera-
Mendoza; 1993; Centeno-García et al., 1993a). The Zicapa For-
matiotn is made up of dacitic to rhyolitic lava flows interbedded
with fluvial deposits (Fitz et al., 2002). The Chapulapa Formation
is composed mostly of marine lava flows and epiclastic rocks.
The abundance of quartzites within the volcanic-sedimentary
successions of the Taxco Schist and Zicapa Formation suggests
that a crystalline basement was exposed during the arc activity.

U/Pb dating of lavas from the Taxco Schist by sensitive
high-resolution ion microprobe (SHRIMP) methods yielded
130–131 Ma ages (Campa and Iriondo, 2004), and from the
volcanic-volcaniclastic rocks of the Zicapa Formation, 127 Ma
(Fitz et al., 2002). Lava flows from the Chapulapa Formation
have 129–133 Ma SHRIMP U/Pb ages. The Taxco Schist shows
one phase of deformation and metamorphism prior to the deposi-
tion of Aptian–Albian carbonates. Thus, Early Cretaceous vol-
canic rocks of the Mixteca Terrane are unconformably covered
by a carbonate platform that ranges in age from Early to Middle
Cretaceous (Fries, 1960).

The limestone succession in the western Mixteca Terrane
changes upward to a thick clastic succession (Mexcala For-
matioon) of Turonian to Maastrichtian age (Guerrero-Suastegui,
2004). The Mexcala Formation is made up of alternating sand-
stone, shale, and conglomerate, deposited in deltaic and subma-
rine-fan environments (Figs. 7 and 8). It is a synorogenic deposit
(foreland basin-fill) associated with regional thrusting and fold-
ing of both the Guerrero Composite and Mixteca Terranes at the
end of the Cretaceous. Therefore, the Mexcala Formation is the
first overlapping assemblage that stitches the Guerrero Composite
Terrane and the Mixteca Terrane, and marks the final amalgama-
tion of the Guerrero Composite Terrane to continental Mexico.

Teloloapan Terrane

The Teloloapan Terrane (Figs. 1 and 8) is exposed in the east-
ernmost parts of the Guerrero Composite Terrane. This terrane is
characterized structurally by a complex east-vergent thrust-fault
system. Its rocks are severely deformed and metamorphosed to
low-grade greenschist facies. The Teloloapan Terrane overrides
either Cretaceous platform carbonates or Upper Cretaceous silic-
iclastic rocks that belong to the Mixteca Terrane (Figs. 7 and 8;
Talavera-Mendoza et al., 1995).

The nature of the basement of the Teloloapan Terrane
remains unknown. Metamorphic rocks of the Tejupilco area
(Fig. 8) were interpreted as a possible basement for the Telo-
loapan Terrane by Elías-Herrera and Sánchez-Zavala (1990),
and Sanchez-Zavala (1993). These authors suggested that the
Tejupilco volcanic-sedimentary sequence might represent an arc
assemblage older than the rest of the Guerrero Terrane magma-
tism. They based this conclusion on U-Pb dates from associ-
ated sulfide deposits. The ages they obtained vary broadly from
Carnian (227 Ma) to Oxfordian (156 Ma). However, the same
volcanic-sedimentary rocks were considered a part of the Cre-
taceous arc assemblage by other authors (Campa and Ramírez,
1979; Talavera-Mendoza et al., 1995).

The arc assemblage of the Teloloapan Terrane consists of
two distinct regions with different volcanic and sedimentary
rocks. The eastern region is characterized by shallow-marine
deposits, and the western region is composed of deeper facies
(Guerrero-Suastegui et al., 1991; Ramírez-Espinoza et al., 1991;
Talavera-Mendoza et al., 1995; Mendoza and Suastegui, 2000;
Guerrero-Suastegui, 2004). The stratigraphy of the eastern region,
from base to top, is made up of basaltic to andesitic pillow
and massive lava flows, volcanic breccias, and pyroclastic flow depos-
its (Villa de Ayala Formation; Talavera-Mendoza et al., 1995).
These deposits are interbedded with epiclastic sandstone and
conglomerate. Primary structures in the volcanioclastic rocks sug-
gest a marine depositional environment (Guerrero-Suastegui et
al., 1991; Guerrero-Suastegui, 2004). Storm deposits, coral frag-
ments, and other fossils suggest shallow and warm waters. This
unit contains fossil gastropods and bivalves that range in age from
Hauterivian to Aiptian (Guerrero-Suastegui et al., 1991; Ramírez-
Espinosa et al., 1991; Talavera-Mendoza et al., 1995).

Geochemical analyses of volcanic rocks of the Villa de Ayala
Formation of the Teloloapan Terrane indicate that the magma-
tism is calc-alkaline and similar to that of active intraoceanic arcs
(Talavera-Mendoza, 1993; Talavera-Mendoza et al., 1995; Lapi-
erre et al., 1992; Mendoza and Suastegui, 2000; Centeno-García
et al., 1993a). The base of the Villa de Ayala Formation is not
exposed. The maximum thickness is considered to be ~3000 m
(Guerrero-Suastegui, 2004). The volcanic succession of this for-
matioon changes transitionally upward to thick, massive reeefal
limestone of the Teloloapan Formation. At the base the Teloloa-
pan Formation is composed of intertidal limestone interbedded
with volcanioclastic rocks containing rudists and nereids of late
Aptian–early Albian age (Guerrero-Suastegui et al., 1991, 1993;
Guerrero-Suastegui, 2004). Thus magmatism ceased prior to the
late Aptian (Guerrero-Suastegui et al., 1991; Mendoza and Suas-
tegui, 2000; Guerrero-Suastegui, 2004). The Teloloapan Forma-
tion grades upward into the Pachivia Formation of Turonian age,
which is made up of shale and fine-grained sandstone and shale.
The Pachivia Formation is the western equivalent of the Mexcala
Formation of the Mixteca Terrane and indicates that the Telo-
loapan and Mixteca Terranes were already in close proximity
(Guerrero-Suastegui et al., 1991; Talavera-Mendoza et al., 1995;
Guerrero-Suastegui, 2004).

The stratigraphy of the western part of the Teloloapan Ter-
rane comprises submarine basaltic, andesitic, and felsic lava
flows and volcanioclastic rocks (Villa de Ayala Formation) depos-
ited in deeper water conditions than the sediments of the eastern
Teloloapan Terrane. It is in transitional contact upsection with
the Acapetlahuaya Formation, composed of thin-bedded volcanic shale and sandstone at the base, at some localities interbedded with dark, thinly laminated limestone. It changes transitionally upward to shale, with little or no volcanic material at the top (Campa and Ramírez, 1979; Guerrero-Suastegui, 2004). This unit has been highly tectonized, making it difficult to calculate its original thickness and contact relationships. Apparently, the Acapetlahuaya Formation changes laterally toward the west and overlies transitionally the volcanoclastic deposits of the Villa de Ayala Formation. Its upper contact with the Amatepec Formation is highly tectonized. The Acapetlahuaya Formation contains ammonites, and radiolarians that are late Aptian in age (Campa et al., 1974; Guerrero-Suastegui et al., 1993; Talavera-Mendoza et al., 1995; Guerrero-Suastegui, 2004).

The Amatepec Formation is made up of thin-bedded black detrital limestone and is devoid of volcanic material. It is interpreted as deep-basin–slope deposits. This formation is tightly folded and overlies either the Villa de Ayala or the Acapetlahuaya Formation. It is late Albian to early Cenomanian in age, based on calcispherulids, planktonic foraminifers, and radiolarians (Campa and Ramírez, 1979, Guerrero-Suastegui et al., 1991, 1993; Talavera-Mendoza, 1993; Talavera-Mendoza et al., 1995). The deep-marine limestone is overlain by turbiditic sandstone–shale successions of the Miahuatepec Formation (Talavera-Mendoza et al., 1995). Fossils have not been found, but it is at least post–early Cenomanian because of its stratigraphic position. The Miahuatepec Formation was deposited, during the amalgamation of the Zihuatanejo Arcelia, and Teloloapan Terranes, in a thrust-related basin (Guerrero-Suastegui et al., 1991; Ramírez-Espinoza et al., 1991; Talavera-Mendoza et al., 1995; Mendoza and Suastegui, 2000; Guerrero-Suastegui, 2004).

The ages of magmatism of the Teloloapan Terrane have been poorly constrained by the limited fossils found in the volcanoclastic levels. A few U/Pb isotopic ages from felsic lavas at the base of the succession range in age from 137.4 to 145.9 Ma (Tithonian–Hauterivian; Mortensen et al., 2003). Thus, magmatism of the Teloloapan Terrane is in part contemporaneous with that of the Mixteca, Guanajuato, and Zihuatanejo Terranes.

There are three distinctive differences in the Cretaceous stratigraphy between the Mixteca and Teloloapan Terranes: (1) Volcanism of the Mixteca Terrane is more evolved, and its isotopic signatures show influence of old continental crust in the magma generation. In contrast, volcanism of the Teloloapan Terrane is more primitive and has no traces of contamination by old continental crust (Centeno-García et al., 1993a; Talavera-Mendoza et al., 1995; Mendoza and Suastegui, 2000). (2) Metamorphic and quartz clasts are abundant (up to 70%) in the sandstones that are interbedded with volcanic rocks in the Mixteca Terrane but are absent throughout the stratigraphic column of the Teloloapan Terrane. (3) Magmatism ceased in the Mixteca Terrane before the Aptian, and part of the volcanic-sedimentary succession was deformed and metamorphosed (Taxco Schist). In contrast, volcanism continued in the Teloloapan Terrane until Aptian–Albian time, and no internal deformation has been identified.

The arc volcanism of the Mixteca and Teloloapan Terranes has been interpreted as part of a single arc-backarc system in which volcanism of the Mixteca Terrane would be the backarc basin (Cabral-Cano et al., 2000; Monod et al., 1994). An alternative interpretation is that these two terranes belong to different arcs, separated by a double-dipping subduction of an oceanic basin (Guerrero-Suastegui, 2004).

**Arcelia Terrane**

Thrust over the Teloloapan Terrane is the Arcelia Terrane (Guerrero Composite Terrane), which shows deeper marine facies and less evolved magmatism than the rest of the arc successions of the Guerrero Composite Terrane (Talavera-Mendoza et al., 1995; Mendoza and Suastegui, 2000). This terrane is made up of basaltic pillow lavas and ultramafic bodies, black shale and chert, and fine-grained volcanic turbidites (Fig. 7), all intensively deformed and partly metamorphosed (Ramírez-Espinoza et al., 1991; Talavera-Mendoza et al., 1995). The chert layers contain radiolarians reported as Albian–Cenomanian in age (Dávila and Guerrero, 1990; Ramírez-Espinoza et al., 2007). Geochemical signatures of the Arcelia magmas are similar to those in recent primitive IAs and oceanic basins (MORB) (Talavera-Mendoza, 1993; Talavera-Mendoza et al., 1995; Mendoza and Suastegui, 2000). There are no exposures of older rocks in the Arcelia Terrane, and no clasts of older metamorphic or sedimentary rocks have been found in its sedimentary strata. Mendoza and Suastegui (2000) suggest that this terrane is entirely oceanic, that it may have originated as an independent oceanic arc and backarc basin, and that it represents partly developed oceanic crust. An alternative interpretation is that the Arcelia Terrane could also be a backarc basin of the Zihuatanejo Terrane (Centeno-García et al., 2003a).

**Southern Part of the Zihuatanejo Terrane**

Uppermost Jurassic–Cretaceous volcanic-sedimentary assemblages of the Zihuatanejo Terrane can be grouped in three main regions: northern Zihuatanejo Terrane (Zacatecas area), Huatamo area, and coastal Zihuatanejo-Colima region (Figs. 7 and 8). The uppermost Jurassic to Cretaceous strata of the southern Zihuatanejo Terrane are not as strongly deformed as those in other terranes, and original contact relationships and complete stratigraphic columns are well preserved. The strata are characterized by numerous lateral facies changes and internal erosional and angular unconformities. The geographic distribution of the facies is highly irregular, and it has not yet been determined in detail. Therefore, compiling, correlating, and synthesizing the stratigraphy of the area is difficult because it varies considerably from one locality to another. The stratigraphy of the northern Zihuatanejo Terrane (Zacatecas area) is described later.

The stratigraphic column of the southern Zihuatanejo Terrane in the Huatamo area is made up of Triassic basement rocks.
of the Arteaga Complex, overlain by uppermost Jurassic to Cretaceous volcanic and sedimentary cover. These rocks are thrust over the Arcelia Terrane (Figs. 7 and 8). Arc-related rocks of the Huetamo region (Figs. 7 and 8) overall have been formed by a thick succession of alternating shale, sandstone, and conglomerate, with scattered basaltic pillow lavas, submarine ignimbrite flows, and other intermediate pyroclastic and epiclastic flows in the lower parts of the succession (Angao and San Lucas Formations; Pantoja, 1959; Guerrero-Suastegui, 1997). These arc-related rocks lie unconformably on the Arteaga Complex (Figs. 7 and 8). Fossils of Late Jurassic age have been reported from the Angao Formation (Pantoja, 1959), although the major exposures of volcaniclastic sedimentary rocks are Berriasian to upper Aptian (Guerrero-Suastegui, 1997). Their depositional environment changes upsection from deep to shallow marine.

The volcaniclastic rocks of the San Lucas Formation change toward the top to thick limestone zones with fossil ammonites, orbitolinitids, and rudists of late Aptian–early Albian age (El Cajon and Mal Paso Formations; Guerrero-Suastegui, 1997; Pantoja-Alor and Caballero, 2003). This sequence alternates with or changes laterally into marine and terrestrial volcanic sandstone and conglomerate (Comburindio Formation; Guerrero-Suastegui, 1997; Pantoja-Alor and Caballero, 2003). The conglomerate is covered by massive, thick packets of limestone (Huetamo Formation) that contain fossils of late Albian–Cenomanian age. This unit is found only in the central parts of the Huetamo region (Pantoja, 1990).

The arc succession of the Zihuatanejo Terrane in the Huetamo area was deformed prior to the deposition of a thick, subaerial red-bed succession that is interbedded with volcanic rocks (Cutzamala Formation of Campa and Ramirez, 1979) and is related to a continental arc of Santonian–Maastrichtian age (Altamirano-Areyán, 2002; Benammi et al., 2005).

The oldest Cretaceous rocks of the Zihuatanejo Terrane in the Zihuatanejo-Colima region of coastal Mexico that have been penetrated by drilling are Berriasian–Hauterivian in age (Alberca Formation; Cuevas, 1981). The lower member of the Alberca Formation is made up of interbedded black shale, sandstone, and limestone, and some tuff. The upper member is composed mostly of andesitic-basaltic lava flows interbedded with limestone and shale. The Alberca Formation changes transitionally upward to andesitic and basaltic lava flows, with some rhyolitic flows, interbedded with pyroclastic (intermediate tuffs and ignimbrites) and epiclastic deposits. It contains limestone packets interbedded with subaerial conglomerate and sandstone, red siltstone, and some evaporites, and continues into limestone with scarce basaltic pillow lavas at the top (Tecatlitlán, Tepalcatepec, and Madrid Formations). The age range of these units, based on their fossil content, is Barremian to Cenomanian (Grajales and López, 1984).

Along the west coast between the cities of Colima and Zihuatanejo are exposures of an important succession of red beds, alternating with lesser amounts of limestone in comparison with other areas of the Guerrero Composite Terrane. The assemblage is made up of rhyolitic lavas (lava flows, breccias, and ignimbrites) and minor andesitic and dacitic lavas (Tecatlitlán Formation, Tizupu-La Unión assemblage, Playitas Formation, etc.; Ferrusquía et al., 1978; Grajales and López, 1984; Pantoja and Estrada, 1986; Centeno-García et al., 2003). These units are interbedded with epiclastic deposits such as tuff, volcanic shale, and sandstone, and some conglomerate. The assemblage also contains thin beds of limestone containing orbitolinitids, gastropods, and some pelecypods of late Albian–Cenomanian age (Ferrusquía et al., 1978; Grajales and López, 1984). Raindrop marks, desiccation polygons, and dinosaur footprints can be found in this succession (Ferrusquía et al., 1978). The lower parts of the Cretaceous succession are missing in the Arteaga region, where non-marine and shallow-marine volcanic and volcaniclastic rocks of Aptian–Albian age rest unconformably on the Arteaga Complex.

Overall, Cretaceous volcanic rocks of the southern Zihuatanejo Terrane show geochemical and isotopic signatures that suggest a transitional composition between oceanic island arcs and active continental margins (Centeno-García, 1994; Freydier et al., 1997; Mendoza and Suastegui, 2000). The high potassium content, abundance of felsic lavas, and trace element abundances of these volcanic rocks are similar to those observed in IAs where the crust is thick (~20 km), allowing magmatic differentiation (Centeno-García, 1994).

Rocks of the southern Zihuatanejo Terrane are distinctive from the rest of the terranes because they were deposited in shallow-marine and fluvial environments, contain fossil vertebrates, and show calc-alkaline volcanism more evolved than that of the Teloloapan and Arcelia Terranes. Sedimentary rocks interbedded with the volcanic flows contain clasts of their basement rocks, made up of sandstone, quartz, and mylonitic granite. Thus its stratigraphy is similar to that of arcs constructed on intermediate crust with a previous history of accretions. The presence of fossil vertebrates suggests proximity to the continent.

**Northern Guerrero Terrane**

Following a section from east to west in the northern part of the Guerrero Terrane, the main stratigraphic characteristic is an absence of rocks similar to those of the Mixteca or Teloloapan Terrane. Instead, deep-marine volcanic-sedimentary successions of the Guanajuato Terrane were thrust directly over limestone of the Arteaga Complex. Sedimentary rocks interbedded with volcanic flows contain clasts of their basement rocks, made up of sandstone, quartz, and mylonitic granite. Contact relationships between the Guanajuato Terrane and northern Zihuatanejo Terrane are unconstrained because the contact is covered by younger units. It is inferred that the Guanajuato Terrane is overthrust by the Zihuatanejo Terrane on the basis of regional vergence of the structures. Contact relationships between the Tahue and Zihuatanejo Terranes are unknown because the contact is covered by overlapping Cenozoic assemblages.

**Guanajuato Terrane**

The succession at the Guanajuato Terrane has been described as a complete stratigraphic column of an accreted volcanic arc, as its assemblages vary from the roots of the arc (gabbros and
diabases, and dike swarms) to pillow basalts, interbedded with thin-bedded siltstone, shale, chert, and fine-grained volcanic sandstone (Figs. 6 and 7; Ortiz-Hernandez et al., 1991; Ortiz-Hernandez, 1992). However, all the different stratigraphic levels are in the form of tectonic slivers (Fig. 7), with the deepest mafic levels (gabbro, tonalite, serpentinite, wehrlite, dike swarms) thrust over the upper stratigraphic levels (pillow basalt and volcanic turbidites).

The uppermost thrust sheet is made up of ultramafic-mafic rocks of the Cerro Pelón tonalite and the Tuna Mansa diorite. These ultramafic rocks are thrust over a succession incorporating a diabasic feeder dike swarm, basaltic pillow lavas (La Luz basalts), rhylolitic tuffs (Cubilete Tuff), and a deep-marine volcaniclastic succession made up of sandstone and shale turbidites, chert, and black detrital limestone (Esperanza Formation; Quintero-Legorreta, 1992; Ortiz-Hernandez et al., 1992; Ortiz-Hernandez et al., 2003). Basalts of this assemblage show geochemical signatures similar to present primitive volcanic island arcs (Ortiz-Hernandez, 1992).

The third and lowermost structural level (Fig. 7) is composed of a thick turbidite succession of volcanic graywackes, quartzites, micritic limestone, radiolarian chert, black shale, and rare conglomerate resting on basaltic pillow lavas (Arperos Formation; Ortiz-Hernandez et al., 1992; Lapierre et al., 1992; Quintero-Legorreta, 1992; Monod et al., 1990; Martínez-Reyes, 1992; Ortiz-Hernandez et al., 2003). Pillow basalts at the base of the Arperos Formation are more alkaline than the La Luz basalts and show OI geochemical signatures (Ortiz-Hernandez et al., 2003). The Arperos Formation is unconformably overlain by the Aptian–Albian La Perlita Limestone (Ortiz-Hernandez et al., 2003).

It is difficult to reconstruct the role of the Guanajuato Terrane in the tectonic evolution of western Mexico because of the lack of enough geochronological data. The only U/Pb zircon age reported from the area comes from the El Gordo volcanogenic massive sulfide ore deposit (Hall and Mortensen, 2003), which is considered part of the lowermost succession by Hall and Mortensen, (2003), but it is at the stratigraphic level of the second thrust sheet (Cubilete tuff!) in the stratigraphy proposed by Ortiz-Hernandez et al. (1992). The age of a rhylolite from El Gordo volcanogenic massive sulfide ore deposit reported by Hall and Mortensen (2003) yielded a 146.1 Ma U/Pb age. There are also reports of badly preserved radiolarians from the Arperos Formation that are in good enough condition to be age indicators (possibly Valanginian–Turonian in age), but a report of nannofossils suggests a Tithonian–Hauterivian age (Ortiz-Hernandez et al., 2003). Other ages reported from the Guanajuato area are from K/Ar analyses and seem to have been reset by later thermal events (Ortiz-Hernandez et al., 1992, 2003). The sedimentary rocks of the La Luz and Arperos Formations seem to be distal volcanic turbidite deposits, but the abundance of limestone associated with the pillow lavas suggests that deposition occurred above the carbonate compensation depth (Ortiz-Hernandez et al., 2003). Aptian–Albian limestone of the La Perlita Formation rests unconformably on the Arperos Formation and suggests that sedimentation and at least one phase of deformation occurred prior to the Aptian–Albian (Ortiz-Hernandez et al., 2003). Whether or not this deformation is related to the accretion of the Guanajuato Terrane to the continental margin has not been determined. At present the Guanajuato Terrane is thrust over the calcareous platform of Oaxaquia in the San Miguel de Allende area (Ortiz-Hernandez et al., 2002).

Rocks of the Guanajuato Terrane have been correlated with the Arcelia Terrane, and both were interpreted as having formed part of an oceanic arc independent of the Zihuatanejo and other arc terranes (Ortiz-Hernandez et al., 1992). Also, these rocks are considered relics of an oceanic basin consumed by subduction related to the arc of the Zihuatanejo Terrane (Lapierre et al., 1992; Tardy et al., 1994). An alternative preliminary interpretation, based on provenance and stratigraphy, is that the Guanajuato Terrane may have been the backarc basin of the Zihuatanejo Terrane (Centeno-García et al., 2003).

### Zihuatanejo Terrane

The Upper Jurassic–Cretaceous stratigraphy of the Zacatecas area in the northern Zihuatanejo Terrane is very different than the stratigraphy of the neighboring Central Terrane and Oaxaquia (Figs. 5–7). Whereas the strata in the northern Zihuatanejo Terrane are mostly composed of volcanic and volcaniclastic rocks, northern Oaxaquia and the Central Terrane were covered by a thick, shallow-marine calcareous platform during the Late Jurassic–Cretaceous (Centeno-García and Silva-Romo, 1997). This suggests that the Zihuatanejo Terrane was probably undergoing dislocation from the continental margin during that time.

The arc stratigraphy of the Zacatecas area is formed by the La Borda, Chilitos, and El Saucito Formations (de Cserna, 1976; Yta et al., 1990; Olvera-Carranza et al., 2001; Olvera-Carranza, 2002). These three formations are made up of pillow basalts and volcanic breccias, interbedded with thin-bedded siltstone, shale, chert, and volcanic sandstone and conglomerate, with scarce felsic tuff beds and detrital limestone (Centeno-García and Silva-Romo, 1997; Olvera-Carranza, 2002). The chert layers contain radiolarian fossils of Neocomian(?) to Aptian–Albian(?) age (Yta et al., 1990; Olvera-Carranza, 2002). However, older U/Pb ages have been reported (150–148 Ma) from the base of the succession (Danielson, 2000; Mortensen et al., 2003). Lapierre et al. (1992) and Freydier et al. (1995) characterized this magmatism as primitive IA and OI basalts. Sedimentary structures and fossil content suggest that the La Borda, El Saucito, and Chilitos Formations were deposited as distal turbidites and grain flows in a volcaniclastic submarine apron (Centeno-García et al., 2003). These Jurassic–Cretaceous arc successions contain important volcanogenic, massive sulfide ore deposits (Yta et al., 1990; Danielson, 2000; Mortensen et al., 2003).

### Tahue Terrane

Cretaceous successions of the Tahue Terrane are exposed mostly in the Sinaloa de Leyva–Porohui region (Fig. 4). They
The stratigraphy of the Guerrero Composite Terrane of western Mexico is characterized by a series of terranes whose basements were formed by Paleozoic to Triassic fragments of oceanic arcs, continental slope sediments, and ocean floor assemblages that were accreted to the continent and consecutively rifted and translated.

- Metamorphosed Ordovician volcanic and marine sedimentary rocks and a thick succession of deep-marine turbidites of the NW Guerrero Composite Terrane (Tahue Terrane) make up the record of a middle Paleozoic collision and development of a Carboniferous to Permian passive margin. These rocks might be equivalent to the early Paleozoic Antler Arc and eugeoclinal sedimentation in the SW Cordillera of North America.

- The continental margin during the early Mesozoic was located in the middle of Mexico, approximately along the boundary between Oaxaquia and the Central–Guerrero Composite Terranes. This continental margin was active during the Permian–Carboniferous, when a continental arc developed in Oaxaquia.

- Permian–Carboniferous arc-related magmatism ceased, and a passive or rifted margin developed along the western continental margin of Mexico, extending throughout the Triassic. This development is suggested by the thick submarine siliciclastic turbidite succession that accumulated on the western paleo-continental shelf–slope region (Potosi Submarine Fan). The siliciclastic fan turbidites are mostly continent-derived, quartz-rich sandstone, siltstone, and shale, containing fossils of Carnian–Norian age.

- The Potosi Fan is interpreted as passive-margin deposits, as there is no evidence of contemporaneous magmatism either in the stratigraphy or in the provenance.

- The siliciclastic rocks of the Potosi Fan extended to the west in a marginal oceanic basin (Arteaga Basin) that at present forms the basement of the Zihuatanejo Terrane of the Guerrero Composite Terrane.

- The first compressional event that deformed the Triassic rocks originated tight folding, shearing, and axial cleavage in the La Ballena Formation, and block-in-matrix texture in the Taray and Zacatecas Formations and the Arteaga Complex. This deformation was related to subduction along the early Mesozoic continental margin. It may have started sometime between the Late Triassic and Early Jurassic, accreting the turbidites of the Potosi Submarine Fan, with slivers of the oceanic crust, to the continent.

- Whether the subducting slab was dipping toward the west or the east is not well constrained, but the accretionary prism apparently was very wide. Evidence of contemporaneous oceanic arc magmatism is found in the Vizcaíno Peninsula, where a volcanic sequence of primitive arc affinity is exposed. It is possible that the rocks in the Vizcaíno Peninsula represent a displaced fragment of an oceanic arc that accreted to the Arteaga Complex of the Guerrero Composite Terrane, but this model needs more evidence.

- Arc-related volcanic and sedimentary rocks unconformably overlie the deformed Triassic rocks of Oaxaquia and the Central and Guerrero Composite Terranes. They are characterized by continental rhyolitic to andesitic lava flows, interbedded with fluvial and alluvial deposits. The succession shows minor angular unconformities, probably related to tilting. These rocks have been interpreted as the southern continuation of the Jurassic continental arc that developed along the southwestern margin of the United States. Magmatism was active from ca. 163 to 155 Ma (Callovian–Oxfordian), although older volcanic rocks have been reported for eastern Mexico (189 Ma). The Jurassic arc shows more evolved geochemical signatures than the subsequent volcanic events.

- During and after the continental arc activity (Late Jurassic–Early Cretaceous), large amounts of extension and lateral translations probably occurred, as suggested by the changes in the stratigraphy. It has been proposed that major strike-slip faults were probably active during the arc activity (Mojave-Sonora Megashear). Arc magmatism ceased in central Mexico, and considerable subsidence and extension is evidenced by the fast deepening of the calcareous platform that developed over the arc rocks.

- Major stratigraphic, geochemical, and isotopic differences are evident in the different Cretaceous stratigraphic assemblages among the Guerrero terranes. They are, from east to west: Andesitic-basaltic submarine lava flows and tuff (IA geochemical signatures), interbedded with limestone and shallow-marine volcanioclastics (Telolopaian Terrane) that were thrust over contemporaneous but more evolved arc successions and the calcareous platform of southern continental Mexico (Mixteca Terrane). Ophiolite successions,
with deep-marine volcanic and sedimentary rocks with MORB, OIB, and IA signatures (Guanaajauto and Arcelia Terranes), are placed between the continent and the more evolved arc in the north (Zihuatanejo Terrane) and between the two shallow-marine arcs (Teloloapan and Zihuatanejo Terranes) in the south.

- These major geological differences suggest that intra-arc rifting was considerable and originated a series of marginal arc-backarc systems in western Mexico, with complex paleogeography. Two possible scenarios can be proposed for the Cretaceous paleogeography of western Mexico: (1) that there was one single rifting arc, with westward migration of the magmatism and development of deep-marine intra-arc and backarc basins (Guanaajauto and Arcelia Terranes); and (2) that rifting during the end of the Jurassic was large enough to allow the formation of multiple marginal island arcs, separated by oceanic backarc basins.

- The proposed timing of the final amalgamation of the Guerrero terranes to the margin of older terranes that form the eastern part of Mexico is Turonian to Maastrichtian, as suggested by the age span of foreland basins associated with the deformation of the arc. Overlapping the previously deformed Arcelia and Zihuatanejo Terranes, a new arc developed along the coast by Santonian time.

ACKNOWLEDGMENTS

This paper is a contribution to PAPIIT projects IN109605–3 and IN116599, funded by the Universidad Nacional Autónoma de México (UNAM), and to projects UC-MEXUS Exotic versus Fringing Arc Models: Implications for the Growth of Continents, and SEP/2003 C02 42642. Special thanks are due J. Stock, C. Busby, C. Vita-Finzi, and A.E. Draut for their reviews and comments, which greatly improved the paper.

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