Evolution of the Guerrero composite terrane along the Mexican margin, from extensional fringing arc to contractional continental arc

Elena Centeno-García[1,†], Cathy Busby[2], Michael Busby[2], and George Gehrels[3]

[1]*Instituto de Geología, Universidad Nacional Autónoma de México, Avenida Universidad 3000, Ciudad Universitaria, México D.F. 04510, México*

[2]*Department of Geological Sciences, University of California, Santa Barbara, California 93106-9630, USA*

[3]*Department of Geosciences, University of Arizona, Tucson, Arizona 85721, USA*

ABSTRACT

The western margin of Mexico is ideally suited for testing two opposing models for the growth of continents along convergent margins: accretion of exotic island arcs by the consumption of entire ocean basins versus accretion of fringing terranes produced by protracted extensional processes in the upper plate of a single subduction zone. We present geologic and detrital zircon evidence that the Zihuatanejo terrane of the Guerrero composite terrane originated from the latter mechanism. The evolution of the Zihuatanejo terrane can be explained by extensional and compressional processes operating entirely within the upper plate of a long-lived subduction zone that dipped east under the Mexican margin. This process controlled crustal growth by continental margin rifting and addition of new igneous and volcaniclastic material during extension, followed by accretion and thickening of the crust during contraction.

Prior to this study, all Mesozoic rocks in the western part of the Guerrero composite terrane were considered to be part of a single arc. However, we divide it into four distinctive tectonostratigraphic assemblages: (1) a Triassic–Early Jurassic accretionary complex (Arteaga complex); (2) a Jurassic to earliest Cretaceous extensional volcanic arc assemblage; (3) an Early Cretaceous extensional arc assemblage; and (4) a Santonian–Maastrichtian compressional arc assemblage. (1) The Arteaga subduction complex forms the basement to the Zihuatanejo terrane and includes Grenville, Pan-African, and Permian detrital zircon suites that match the Potosi fan of the Mexican mainland. (2) The Jurassic to earliest Cretaceous extensional volcanic arc assemblage shows a Callovian–Tithonian (ca. 163–145 Ma) peak in magmatism; extensional unroofing began in this time frame and continued into through the next. (3) The Early Cretaceous extensional arc assemblage has two magmatic peaks: one in the Barremian–Aptian (ca. 129–123 Ma), and the other in the Albian (ca. 109 Ma). In some localities, rapid subsidence produced thick, mainly shallow-marine volcano-sedimentary sections, while at other localities, extensional unroofing of all older assemblages resulted in recycling of zircon from all older units (1, 2, 3). (4) For the Santonian–Maastrichtian compressional arc assemblage, our new detrital zircon dates show for the first time that arc volcanic rocks of this age are present in the coastal Zihuatanejo terrane. The contractional arc developed atop assemblages 1–3, which were shortened between Turonian and Santonian time (ca. 93 and 84 Ma). Taken together, the western Zihuatanejo terrane records a more protracted history of arc magmatism than has yet been dated in other terranes of western Mexico, but it closely matches the history of Baja California to the northwest.

INTRODUCTION

The western margin of Mexico is ideally suited for testing two opposing models for the growth of continents along convergent margins. In the first model, the continent grows through accretion of exotic island arcs by the consumption of entire ocean basins at multiple subduction zones with varying polarities. In the second model, protracted extensional processes in the upper plate of a subduction zone produce numerous arc-related basins, some rifted off the continental margin and others formed of new oceanic lithosphere; these continent-fringing basins become filled with detritus derived from arcs or the continental margin, and later become accreted to the edge of the continent during contractional or oblique contractional phases of subduction. This process can contribute substantially to the growth of a continent (Collins, 2002; Busby, 2004; Centeno-García et al., 2008; Collins, 2009). In some cases, renewed upper-plate extension or oblique extension rifts or slivers these terranes off the continental margin once more, in a kind of "accordion" tectonics along the continental margin, referred to by Collins (2002) as tectonic switching. This "accordion" tectonics may be modified by along-strike translations.

The Cordillera of western North America records most of the global crustal growth during Phanerozoic time, and therefore it serves as a modern/young analog for genesis of the continents in Paleoproterozoic time. The Guerrero composite terrane of western Mexico and the Alisitos arc terrane of the Baja California Peninsula represent major components of this margin (Fig. 1). These terranes are significant because they constitute about a third of Mexico (Fig. 1), a portion of the continent that was tectonically assembled in relatively recent geologic time (largely late Paleozoic to Mesozoic).

Most models that have been proposed for the origin of the Guerrero composite terrane and the Alisitos terrane fall into two categories: an exotic arc model, and a fringing arc model. In the exotic arc model, oceanic/island arc terranes were accreted to nuclear Mexico via a subduction system that dipped westward, thereby closing an entire ocean basin located between the arc and the continent (Tardy et al., 1994; Lapierre, et al., 1992; Dickinson and Lawton, 2001; Wetmore et al., 2002, 2003; Umhoefer, 2003). The hypothetical ocean basin was referred to by Tardy et al. (1994) as the "Arperos basin" and by Dickinson and Lawton (2001) as the "Mezcalera basin." In this model, material derived from the Mexican continental margin would not be found within the arc, because it is

[†]E-mail: centeno@servidor.unam.mx

GSA Bulletin; doi: 10.1130/B30057.1; 12 figures; 2 tables; Data Repository item 2011132.

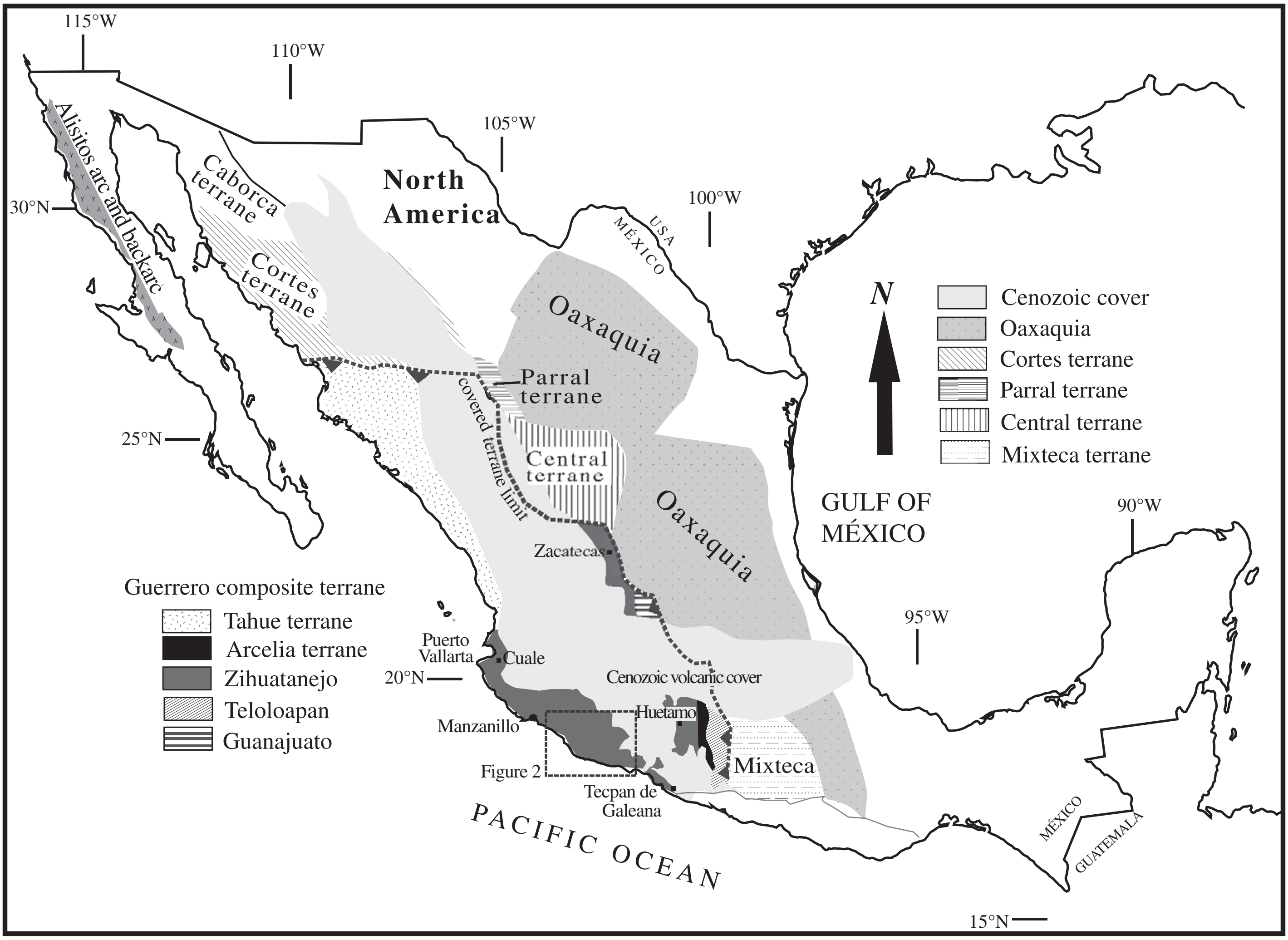


Figure 1. Terranes of Mexico discussed in the text. This paper focuses on the Guerrero composite terrane. A geologic map of part of the Zihuatanejo terrane is shown in Figure 2. The positions of all stratigraphic columns are plotted on these maps except for column A of Figure 3, the position of which is plotted here (Cuale).

postulated to have formed on the other side of a large ocean basin. In contrast, in the fringing arc model, the Guerrero and Alisitos terranes represent one or several oceanic/island arcs that evolved near the Mexican continental margin (Campa and Ramírez, 1979; Böhnel et al., 1989; Centeno-García et al., 1993, 2008; Busby et al., 1998, 2006; Busby, 2004; Keppie, 2004; Talavera-Mendoza et al., 2007; Mortensen et al., 2008; Martini et al., 2009). A third possibility, and much less frequently proposed model, that these terranes represent autochthonous continental arc rocks (De Cserna et al., 1978a; Lang et al., 1996), is inconsistent with their geochemistry and overwhelmingly marine stratigraphy. The controversy over the exotic versus fringing arc origin of the Alisitos and Guerrero terranes is important, not only for tectonic reconstructions of western North America, but also for understanding the formation of continents.

This paper presents new detrital zircon and lithostratigraphic data to show that the Zihuatanejo terrane of the Guerrero composite terrane of westernmost Mexico (Fig. 1) has a Gondwana signature that indicates an origin on or marginal to the Mexican continental margin. In other words, our new data show that the terrane is not exotic. Additionally, we present new U-Pb zircon ages that show for the first time that Cretaceous strata of the study area were deposited upon the remains of an extensionally unroofed Jurassic arc, as well as upon an accretionary complex basement (Arteaga complex) that was previously described by Centeno-García (2005) and Centeno-García et al. (2008).

Prior to this study, all Cretaceous rocks in the Zihuatanejo terrane were considered part of a single arc (Lapierre, et al., 1992; Centeno-García et al., 1993, 2003; Tardy et al., 1994; Talavera-Mendoza et al., 1995). In this paper, we divide these Cretaceous rocks into two distinct tectonostratigraphic assemblages by integrating detrital zircon data with new stratigraphic, structural, and petrographic data. These tectonostratigraphic assemblages are referred to as "assemblage 1" (an Early to mid-Cretaceous arc assemblage), and "assemblage 2" (a Santonian–Maastrichtian arc assemblage). We present new geologic maps of these tectonostratigraphic assemblages, which formed sequentially, so we discuss them by map area, from east to west. At the end of the paper, we propose a model for further testing the hypothesis that assemblage 1 records an extensional fringing oceanic arc setting, and assemblage 2 represents a contractional autochthonous continental arc setting.

GUERRERO COMPOSITE TERRANE (WESTERN MEXICO)

The main feature that characterizes the Guerrero composite terrane and separates it from neighboring terranes is its large volumes of volcanic and volcaniclastic rocks that range in age from Middle Jurassic to Late Cretaceous, deposited in mainly submarine environments. In previous publications, the Guerrero composite terrane has been divided into five terranes, based on stratigraphic, structural, geochronological, and geochemical differences (Centeno-García, 2005; Centeno-García et al., 2008) (Fig. 1). These are: Tahue, Zihuatanejo, Arcelia, Teloloapan, and Guanajuato terranes. The distinctive part about the Zihuatanejo and Tahue terranes, relative to other terranes of the Guerrero composite terrane, is that they contain exposures of the basement upon which the Jurassic–Cretaceous arc was built, whereas the others (Arcelia, Guanajuato, and Teloloapan terranes) do not (Centeno-García, 2005; Centeno-García et al., 2008). In addition, the Arcelia and Guanajuato terranes are distinctive by virtue of being formed of deep-marine sedimentary rocks and basaltic lava flows with primitive arc and ocean-island basalt (OIB)–mid-ocean-ridge basalt (MORB) geochemical signatures. The stratigraphy of the Arcelia, Teloloapan, and Guanajuato terranes has been described by several previous authors (for a summary, see Centeno-García et al., 2008, and references therein). Detrital zircon geochronology of the Arcelia and Teloloapan and part of the Zihuatanejo terranes was presented by Talavera-Mendoza et al. (2007). Also, new zircon geochronology from ore deposits within the Guerrero composite terrane and their role in the tectonic evolution are summarized in Mortensen et al. (2008) and Bissig et al. (2008).

Zihuatanejo Terrane

The Zihuatanejo terrane is the largest of all the terranes that form the Guerrero composite terrane (Fig. 1). It includes a coastal belt between Puerto Vallarta and Tecpan de Galeana, an inland belt at Huetamo, and a belt in central Mexico at Zacatecas (Fig. 1; Centeno-García et al., 2008; Mendoza and Suastegui, 2000). This paper focuses on the parts of the coastal Zihuatanejo terrane from Colima to Playa Azul (Figs. 1 and 2), where successions are thick and the rocks cover a large time span (Fig. 3). These include Triassic–Jurassic? basement rocks (Arteaga complex) and Jurassic granitoids, as well as Lower to Upper Cretaceous volcanic and sedimentary rocks (Fig. 3). The Zihuatanejo terrane extends northwestward beyond the area we have mapped (Fig. 2), to Cuale (Fig. 1), where Jurassic rocks are also exposed (Fig. 3, column 1; Bissig et al., 2008).

Much of the original work in our study area of the coastal Zihuatanejo terrane was done by PEMEX, the national oil company of Mexico, in unpublished reports. Mining and exploration companies have made local geologic maps, but again, few were published. As a result, there are many local formational names, and in places the

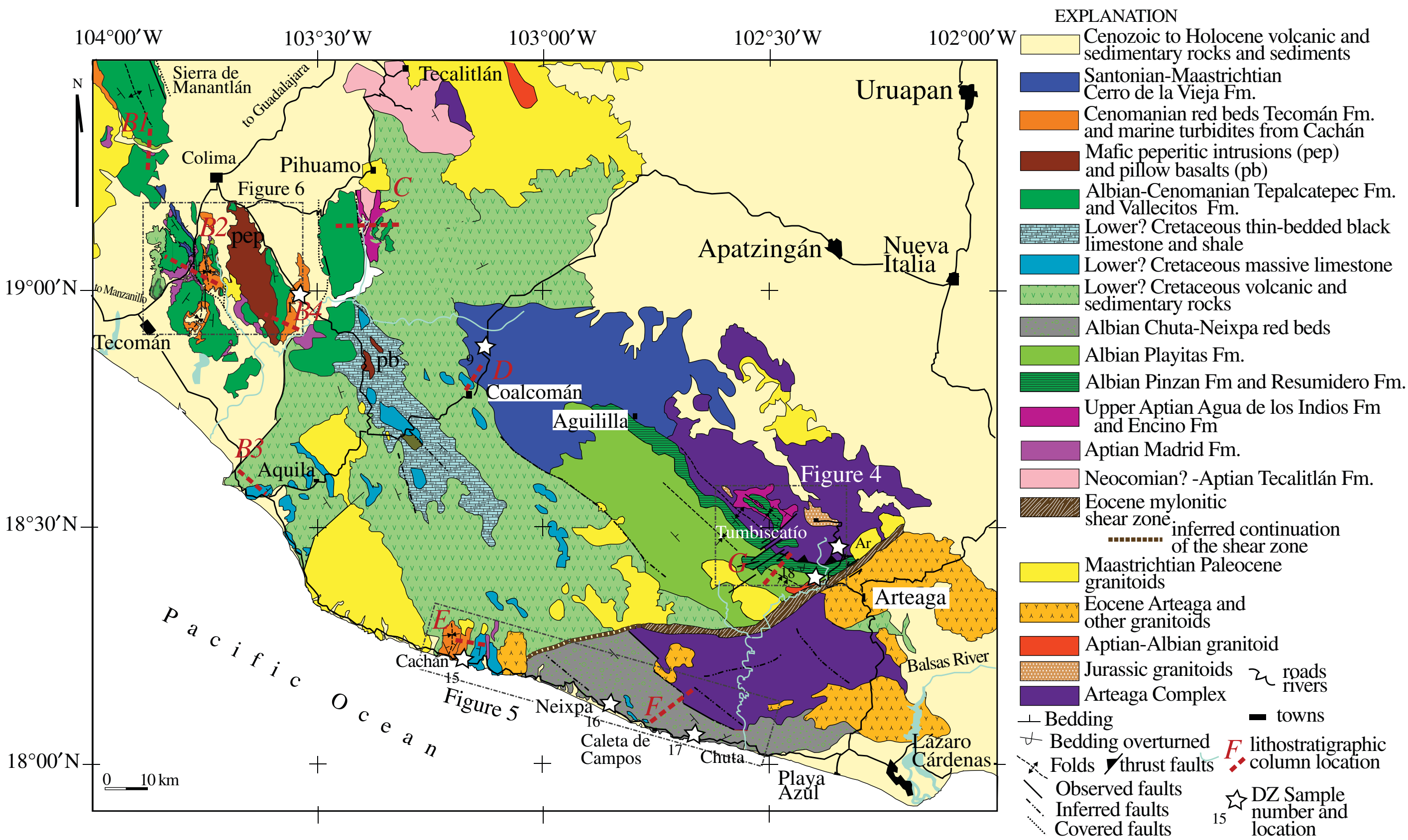


Figure 2. Geologic map of part of the Zihuatanejo terrane of the Guerrero composite terrane (Fig. 1), based on our new unpublished work and the following publications: Grajales and López (1984); Pantoja and Estrada (1986); Garduño-Monroy et al. (1999); Centeno-García et al. (2003); and Servicio Geológico Mexicano maps E13–3 (Rosas-Helguera et al., 1999) and E13–6-9 (Barrios-Rodríguez et al., 2002). Positions of detrital zircon sample localities are shown with stars and numbers, and lithostratigraphic columns (Fig. 3) are indicated by letters. DZ—detrital zircon.

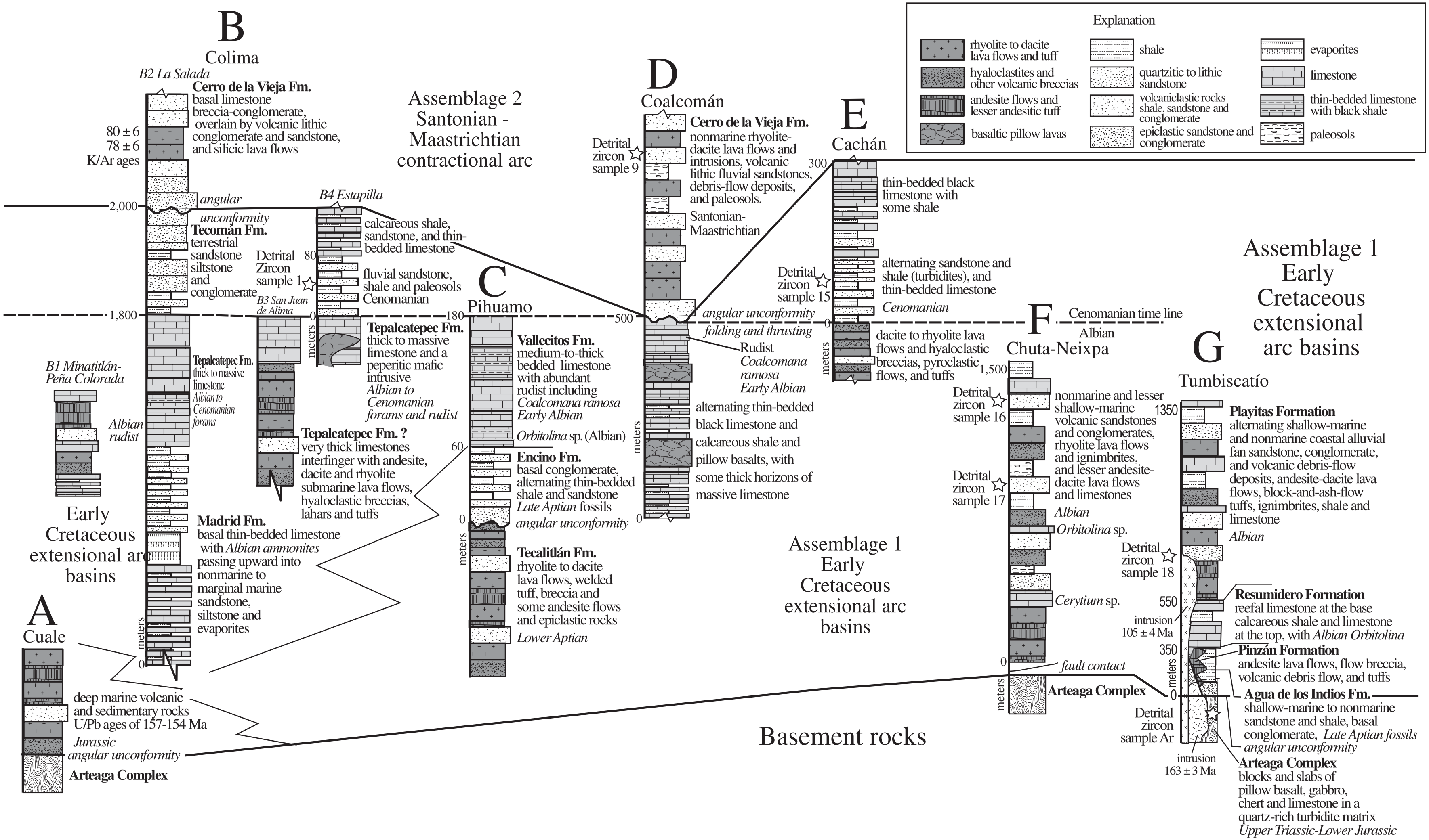


Figure 3. Lithostratigraphic columns for rocks of the western (coastal) Zihuatanejo terrane of the Guerrero composite terrane. Positions are shown on Figures 2, 4, 5, and 6. Figure was compiled from our unpublished data and the following published work: Ferrusquía et al. (1978), Grajales and López (1984); Pantoja and Estrada (1986); Centeno-García et al. (2003); and Bissig et al. (2008).

same rocks are given two different names. This has made regional compilation, correlation of units, and their interpretation difficult. Much of the unpublished information is synthesized in an IMP (Mexican Petroleum Institute) unpublished report by Grajales and López (1984). The PEMEX work was subsequently built upon by detailed mapping or paleontological and geochronological studies from small areas of the studied region of the Zihuatanejo terrane, including publications by De Cserna et al. (1978b), Allan (1986), Alencaster (1986), Ferrusquía et al. (1978), Campa et al. (1982), Buitrón (1986), Alencaster and Pantoja-Alor (1986), Pantoja and Estrada (1986), De la Campa (1991), Centeno-García et al. (1993), Buitrón-Sánchez and López-Tinajero (1995), Corona-Esquivel and Alencaster (1995), Talavera (2000), Bissig et al. (2008), Mortensen et al. (2008), and others. Field guides were published in conjunction with a Geological Society of America conference (Centeno-García et al., 2003; Pantoja-Alor and Gómez-Caballero, 2003; Schaaf et al., 2003), and geologic maps were published by the Mexican Geological Survey (Rosas-Helguera et al., 1999; Barrios-Rodríguez et al., 2002; Alvarado-Méndez et al., 2004, 2006), and the University of Michoacán (Garduño-Monroy et al., 1999). The stratigraphy proposed by PEMEX in the numerous internal reports was adopted by most of the authors of peer-reviewed papers, and in the published Mexican Geological Survey maps; thus, we continue the use of such lithostratigraphic terminology for the Colima region. However, we emphasize that the lead author of this paper only used these publications to guide her own field work, so all of the field relations describe here are her own observations and interpretations, documented in the maps and stratigraphic columns of this paper.

Prior to our study, there was very little done in the study area in terms of sedimentary-volcanic facies analysis; instead, prior publications focused on the geochemistry of the Lower Cretaceous volcanic rocks. They include calc-alkaline basalts, andesites, dacites, and rhyolites (Centeno-García et al., 1993; Tardy et al., 1994) with Th/Yb and Ta/Yb ratios that show transitional compositions between oceanic island arcs and continental margin arcs (Centeno-García et al., 1993, 2003; Freydier et al., 1997; Mendoza and Suastegui, 2000). The basaltic and andesitic lavas show rare earth element (REE) patterns that are typical of island arcs, and are enriched in light REEs, with a negative Eu anomaly (Centeno-García et al., 1993; Freydier et al., 1997). Felsic lavas are calc-alkaline and show light REE–enriched patterns, higher than those from mafic lavas (Freydier et al., 1997). The initial ε_{Nd} values range from +3.0 to +7.8 for all compositions (Centeno-García et al., 1993; Freydier et al., 1997); this is close to values observed in modern island arc volcanic rocks, and it indicates that the lavas were derived from juvenile sources. Nd model ages range from 290 to 460 Ma and suggest that Precambrian crust was not involved in the magma generation (Centeno-García et al., 1993). The high potassium content, the abundance of felsic lavas, and the trace-element abundances of the Early Cretaceous volcanic rocks of the assemblages are similar to those observed in island arcs where the crust is thick (greater than ~20 km), allowing magma differentiation (Centeno-García et al., 1993).

Most of the stratigraphic and geochronological data presented in this paper constitute our new contribution to a vast area with poorly known geology. Figure 2 is our compiled regional geologic map of the studied part of the Zihuatanejo terrane, and detailed maps are shown in Figures 4, 5, and 6. In the following sections, we provide a context for our new dating by describing the geologic relations and stratigraphy (Fig. 3) area by area.

Arteaga Tumbiscatío Area

Basement Rocks. The basement of the Zihuatanejo terrane is largely made up of an accretionary complex referred to as the Arteaga complex (Figs. 2, 3, and 4; Campa et al., 1982; Centeno-García et al., 1993). This accretionary complex is called Las Ollas complex near Zihuatanejo city (Talavera, 2000). The Arteaga accretionary complex has a quartzose turbidite matrix, with one report of Triassic (Ladinian–Carnian) fossils (Campa et al., 1982); this matrix encloses blocks and slabs of pillow basalt, diabase, banded gabbros, chert, and limestone. The Arteaga accretionary complex basement is exposed on the southeast edge of the study area (Figs. 2, 3F, 3G, and 4), and also north of the study area at Cuale (Fig. 1), where it is overlain or intruded by Jurassic arc magmatic rocks (Fig. 3, columns A and G). At Cuale (Fig. 1), the Arteaga complex is overlain by Jurassic deep-marine volcanic and sedimentary rocks with U/Pb ages of 157–154 Ma (Fig. 3, column A; Bissig et al., 2008).

Assemblage 1. All of the stratigraphic data reported here from Tumbiscatío area (Fig. 3, column G; Fig. 4) is our new work. We measured a composite section, 1350 m thick, composed of four formations; the basal three formations progressively onlap the Arteaga complex (Fig. 4). The basal formation, the Agua de los Indios Formation, is a 20–350-m-thick, volcaniclastic and lesser arkosic sandstone and shale sequence. It has a thin (1.5 m) basal conglomerate with pebbles of quartz-rich sandstone, black slate, and schist derived from the underlying Arteaga complex, as well as granite clasts. The basal two-thirds of the Agua de los Indios Formation is shallow marine, with rhythmically bedded sandstone, shale, and calcareous shale with gastropods and bivalves. These include the species Mesoglauconia (Mesoglauconia) burnsi, M. (Triglauconia) kleinpelli, and Gymmentome (Gymmentome) paluxiensis, which date the unit as Upper Aptian (F. Vega-Vera, 1994, personal commun.). The upper third of the formation is nonmarine red sandstone, siltstone with local development of pedogenic carbonate nodules, and silicic reworked tuffs and tuffs. This formation has the same lithofacies and fossil assemblages as the San Lucas and El Cajón formations of the Huetamo area of the Zihuatanejo terrane, and the Encino Formation at the Pihuamo area.

The Pinzán Formation consists of volcanic rocks that overlie the Agua de los Indios Formation and the Arteaga complex (Fig. 3, column G; Fig. 4). The Pinzán Formation is a 5–250-m-thick sequence of andesite lava flows, hyaloclastic flow breccias, monolithic block-and-ash-flow tuffs, and polylithic volcanic debris-flow deposits, with minor silicic tuffs and lapilli tuffs, and minor calcareous siltstones with bivalves of indeterminate species. Some lava flows have jigsaw textures on their tops and complexly invade the sedimentary section, suggesting subaqueous deposition.

The Resumidero Formation consists of limestones that interfinger with and overlie the Pinzán Formation (Fig. 4). It is 10–200 m thick and consists of massive to thick-bedded limestone with abundant rudists, which form banks preserving original growth positions. The Resumidero limestone is interbedded with calcareous shales at its top, where it contains middle-late Albian microfossils of *Orbitolina* (*Mesorbitolina*) *texana texana*, small bivalves, and dinosaur bone fragments up to 10 cm in size.

The Playitas Formation consists of sedimentary and volcanic rocks that conformably overlie limestones of the Resumidero Formation (Fig. 4). It is a >800-m-thick sequence of alternating shallow-marine and lesser nonmarine sedimentary and lesser volcanic rocks deposited in a coastal environment. The sedimentary rocks include cross-bedded fluvial sandstones as well as massive sandstones interstratified with limestone. Pebbly sandstones contain shell fragments, and some show trough cross-bedding typical of a nearshore high-energy environment. Sandstone matrix-supported volcanic boulder conglomerates lack shell fragments and are interstratified with fluvial sandstones, suggesting deposition on alluvial fans. Limestones or calcareous shales occur as lens-shaped bodies, 30 cm

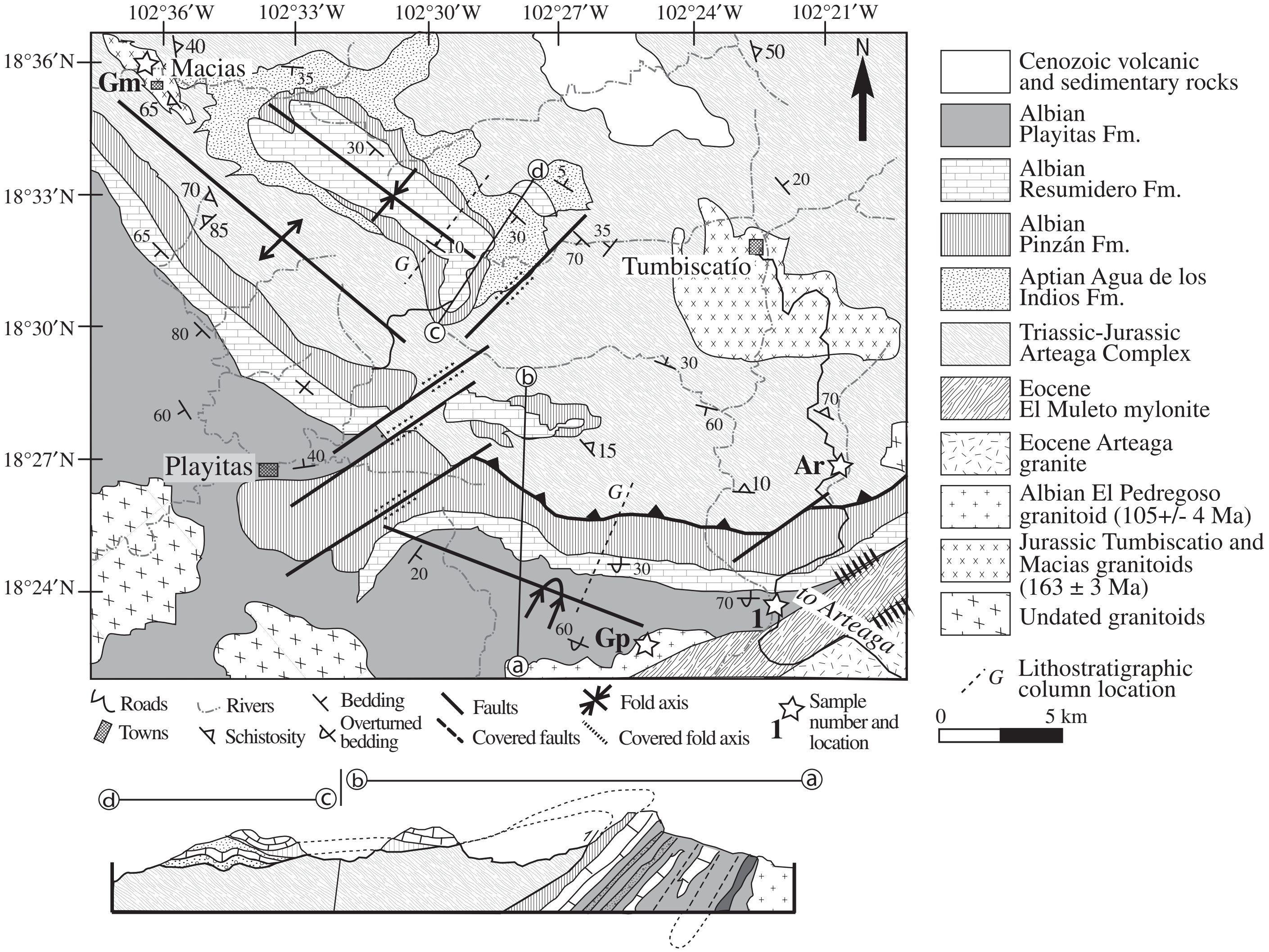


Figure 4. Geology of the Tumbiscatío area by Centeno-García, and composite cross sections a–b, c–d (not to scale). Stratigraphic column G, shown on Figure 3, was constructed from the same cross section. Stars are location of the analyzed zircon samples: Gm—Jurassic Macias granitoids; Gp—Albian Pedregoso granitoids; Ar—quartzose turbidite, matrix of the Arteaga complex; 1—detrital zircon sample from Albian Playitas Formation.

to 10 m thick, within sedimentary and volcanic sections. Volcanic rocks include andesite-dacite lava flows, block-and-ash-flow tuffs, and ignimbrites. Like the Agua de los Indios Formation, sedimentary rocks of the Playitas Formation locally contain clasts of metamorphosed quartz arenite that are identical to the sedimentary matrix of the Arteaga complex, as well as granite clasts. Because this formation conformably overlies limestone of the Resumidero Formation, it must be Albian or younger in age.

Chuta-Neixpa

Assemblage 1. The section at Chuta-Neixpa (Fig. 3, column F; Fig. 5) is dominated by nonmarine volcanic sandstones, siltstones, and conglomerates, with rhyolitic lava flows and ignimbrites, and minor andesitic and dacitic lavas flows. The nonmarine sedimentary rocks contain dinosaur footprints (Ferrusquía et al., 1978), as well as raindrop marks, desiccation polygons, and paleosols. Limestones occur at a few horizons (<20 m thick) within the section. These contain orbitolinids, *Nummoloculina heimi*, gastropods, *Cerythium* sp., and some pelecypods, which are reported from Albian strata in the area (Ferrusquía et al., 1978; our own observations). These rocks were deposited upon, or are in fault contact (left lateral) with, the Arteaga complex. The section at Chuta-Neixpa is similar to the Playitas Formation, although it has a lower proportion of marine strata relative to nonmarine strata. In Figure 2, it appears to be offset from the Playitas Formation in a right-lateral sense, but kinematic indicators and geochronologic data show that it is a Cenozoic sinistral fault (Centeno-García et al., 2003); thus, we do not extend the name "Playitas Formation" to the Chuta-Neixpa section. Our field work in this area is not detailed enough to propose lithostratigraphic divisions and correlation with other units in the region.

Cachán

Assemblage 1. The stratigraphic column we measured at the Cachán locality consists of dacite to rhyolite lava flows and hyaloclastic breccias, pyroclastic flow deposits, and tuffs (Fig. 3, column E). These rocks are conformably overlain by a sandstone-shale turbidite section, with interbeds of thin-bedded limestone near

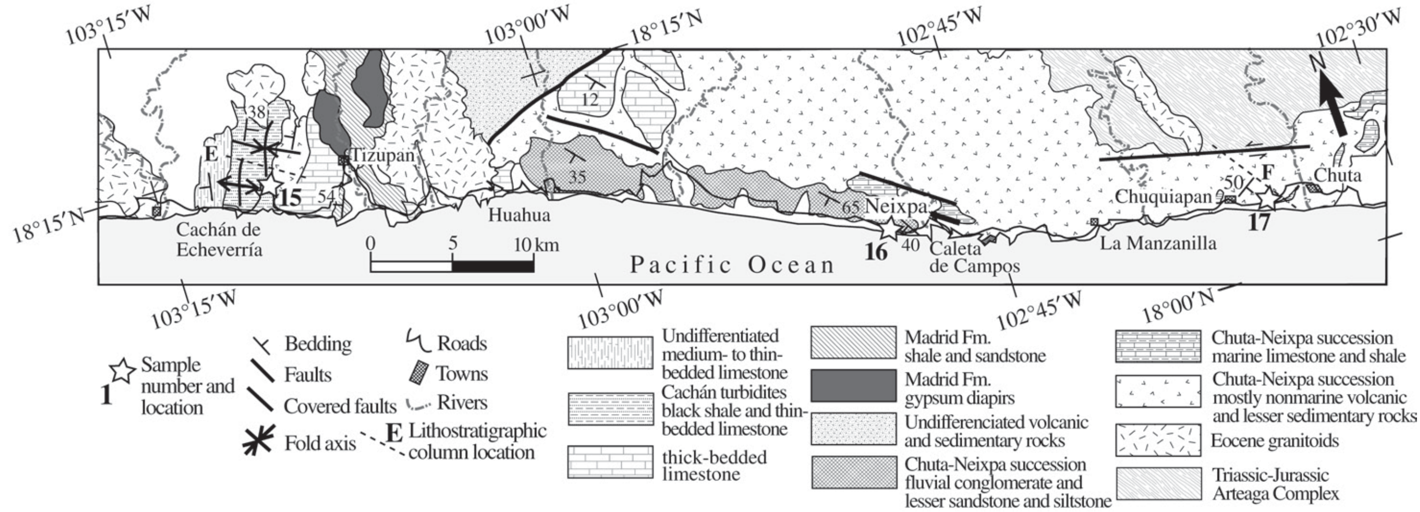


Figure 5. Geologic map of the Cachán to Chuta area, showing with stars the location of detrital zircon samples: 15—Cachán, 16—Neixpa, and 17—Chuta. Dotted gray lines show measured sections E and F shown on Figure 3. Geology is from Ferrusquía et al. (1978); Alvarado-Méndez et al. (2006); and Centeno-García (this study).

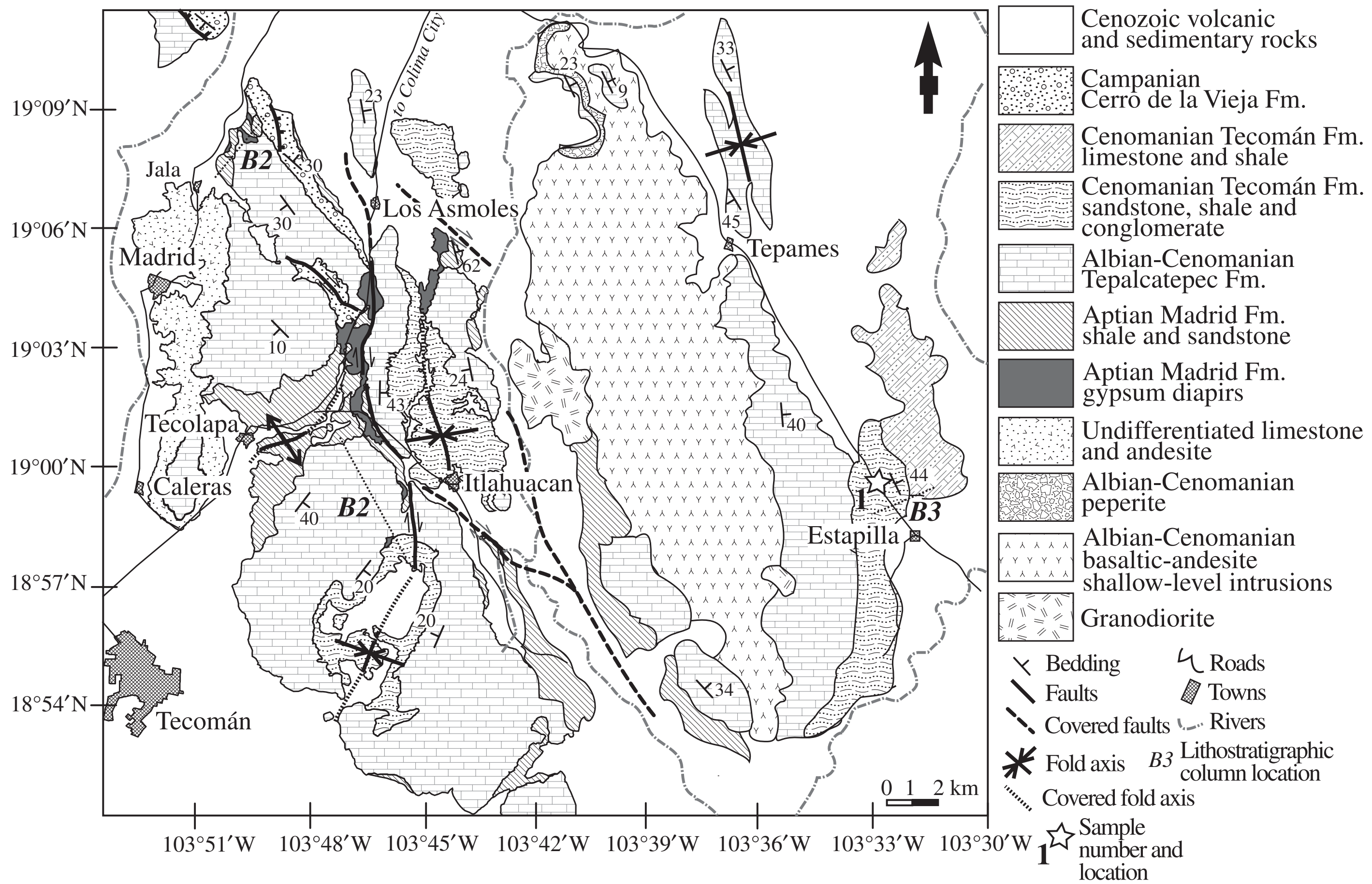


Figure 6. Geologic map of the Colima area and location of the measured stratigraphic columns B2 and B3; B2 is a composite column from two measured sections, one near Jala and the second NW of Tecomán. Star shows location of the analyzed detrital zircon sample 1 from Cenomanian fluvial sandstone.

the top (Fig. 5). The turbidite sandstones are dominantly thin-bedded, with normal grading, ripple cross-lamination, rip-up clasts, and erosive bases. The shale is very thin-laminated, and in places calcareous, or with medium-bedded calcarenites. The turbidite section is 600 m thick and passes gradationally upward into an ~100-m-thick section of thin-bedded limestone that has not yet yielded any fossils. Our field work in this area is not detailed enough to propose lithostratigraphic divisions. However, our age constraints suggest that the turbidites at Cachán are the same age as the Tecomán Formation in the Colima region (described in the following); thus, we consider the rocks at Cachán to record a lateral facies change, from red beds of the Tecomán Formation to marine strata at Cachán.

The section we measured (Fig. 5) is underlain by a thick limestone body, which in turn overlies interbedded shale and sandstone that is cut by gypsum diapirs; this part of the section is similar to the Madrid and Tepalcatepec Formations at Colima (Fig. 3, column B2).

Coalcomán

Assemblage 1. Rocks at Coalcomán (location in Fig. 2; stratigraphy in Fig. 3, column D) consist of ~500 m of alternating limestone and calcareous shale, with minor pillow lava horizons. It contains abundant fossil invertebrates, including the rudist *Coalcomana ramosa* (Boehm, 1889a and 1889b) of early Albian age. Rocks that are exposed north of Coalcomán town were originally considered as part of the Lower Cretaceous marine volcanic and clastic succession (Alvarado-Méndez et al., 2004); however, our work has shown that they are part of assemblage 2, described here.

Assemblage 2. Nonmarine arc volcanic and sedimentary rocks overlie folded Early Cretaceous marine arc volcanic and sedimentary rocks in angular unconformity at Coalcomán (Fig. 3, column D). The nonmarine section at Coalcomán (Fig. 3, column D) is >1000 m thick and consists of nonmarine rhyolitic to dacitic lava flows and tuffs, interstratified with volcanic lithic fluvial sandstones, volcanic lithic debris-flow deposits, and siltstones. The presence of silicic lava flows indicates proximity to vent regions. The red beds show abundant trough cross-lamination, planar lamination, and cut-and-fill structures typical of stream channels, and the laminated to massive siltstones show soil horizons typical of fluvial overbank environments. Paleosol horizons occur at several stratigraphic levels. Sedimentary structures and textures are similar to those of the Colima red beds of the same age, but they show a lower proportion of fluvial channel deposits relative to floodplain deposits. The red beds of Coalcomán differ from the underlying Early Cretaceous strata by having no interstratified limestones. This area is not yet mapped in detail.

Pihuamo

Assemblage 1. The stratigraphy of this area (Fig. 3, column C) was described by Pantoja and Estrada (1986). The Tecalitlán Formation is composed of rhyolitic to dacitic lava flows, volcaniclastic rocks, and tuffs that Pantoja and Estrada (1986) considered to be Neocomian in age, based on their stratigraphic position beneath rocks with late Aptian fossils. However, 35 km to the south at the La Minita locality, the Tecalitlán Formation contains early Aptian rudists (Corona-Esquivel and Alencaster, 1995). Therefore, we consider it to be Aptian (Fig. 3, column C). Strata of the Tecalitlán Formation were tilted before deposition of the Encino Formation marine clastic rocks (Pantoja and Estrada, 1986). The Encino Formation has a basal conglomerate that passes upward to alternating shale and sandstone with abundant marine fossil invertebrates, including several species of the *Nerinea* gastropods and *Orbitolina* sp. of late Aptian age (Buitrón, 1986). The Encino Formation changes transitionally upward to the Vallecitos Formation, which is made up of medium- to thick-bedded limestones that contain abundant rudists, including *Coalcomana ramosa* of early Albian age (Alencaster, 1986; Alencaster and Pantoja-Alor, 1986). We correlate the Encino and Vallecitos Formations of the Pihuamo area with the Madrid and Tepalcatepec Formations (respectively) around Colima (Fig. 3, column B1).

Colima Region

Assemblage 1. Cretaceous strata of the Colima region are mainly Albian to lowermost Cenomanian in age. Drilling by PEMEX reported over 3400 m of Albian to Cenomanian strata without reaching the bottom of the section (Grajales and López, 1984). Although folding and thrusting may have caused some repetition of the section penetrated by drill core, our outcrop studies suggest that there are at least 2000 m of unrepeated stratigraphic section.

In outcrop, the oldest strata are exposed in the La Salada-Jala section (Fig. 3, column B2) and comprise the Madrid Formation (Fig. 6). The lower part of the formation consists of thin-bedded limestone with some thin- to very thin-bedded calcareous shale; it contains middle to late Albian ammonites (R. Barragán, 2009, personal commun.). The upper part of the formation consists of nonmarine to marginal marine sandstone, red siltstone, and evaporites, with prominent diapiric structures. The thickness of the Madrid formation could not be determined because its base is not exposed, and it shows strong deformation due to salt diapirism, but we estimate a minimum of 400 m.

The Madrid Formation is gradationally overlain by the Tepalcatepec Formation (Fig. 3, column B2), which consists of very thick limestones that vary in thickness from 20 to 800 m in La Salada, and up to 1200 m in the Sierra de Manantlán (Fig. 2). In the Minatitlán–Peña Colorada area (Fig. 3, column B1), limestone of the Tepalcatepec Formation is interbedded with andesitic lava flows and lesser rhyolitic to dacitic lava flows and pyroclastic deposits (Corona-Esquivel and Alencaster, 1995; this study). The Tepalcatepec Formation reaches a thickness of at least 2400 m in PEMEX wells (Grajales and López, 1984). It contains abundant fossils, including rudists, oysters, gastropods, and some algal layers that indicate shallow-marine environments. Rudists of Albian age have been reported at the Minatitlán–Peña Colorada section (Corona-Esquivel and Alencaster, 1995). We found microfossils such as *Nummoloculina heimi* and *Orbitolina* sp. that have an Albian–Cenomanian age range at the Minatitlán–Peña Colorada and La Salada sections. Toward the northwest from La Salada, limestone of the Tepalcatepec Formation contains basaltic peperitic intrusions (Fig. 3, column B3; Fig. 6), formed by mixing of magma with wet sediment, indicating that magmatism was contemporaneous with sedimentation.

We propose the name Tecomán Formation for a previously undescribed nonmarine section in the Colima region near a town of that name. This formation is ~500–800 m thick (Fig. 3, column B2) and is exposed in the core of two synclines, one north of Tecomán, and the other west of Estapilla (Figs. 2 and 6; Fig. 3, columns B2 and B4). In the syncline north of Tecoman, at La Salada, the base of the Tecomán Formation overlies the Early Cretaceous Tepalcatepec Formation in gradational contact (Fig. 3, columns B2 and B4); there, massive marine limestones pass upward, through ~20 m of fossiliferous marine shales and limestones, into ~100 m of thin-bedded to massive red siltstones with abundant pedogenic calcite nodules, which we interpret to be fluvial floodplain deposits. This is overlain by ~400–700 m of fluvial conglomerates, pebbly sandstones, sandstones, and minor siltstones. In the syncline west of Estapilla, the section conformably overlies Early Cretaceous Tepalcatepec Formation like it does at La Salada, but it is thinner and more fine grained (Fig. 3, column B2). The basal 80 m of the Tecomán Formation at Estapilla consist of red, mostly fine-grained to medium-grained sandstones and siltstones, with trough cross-lamination and planar lamination, which we interpret as fluvial deposits. The thickness of the upper marine section is not known because it is folded and eroded, but it consists of calcareous shale, sandstone, and thin-bedded limestone with marine shell fragments.

Assemblage 2. Arc volcanic and sedimentary rocks overlie folded Early Cretaceous to Cenomanian nonmarine and marine rocks in angular unconformity (Fig. 3, column B2). These nonmarine rocks (Cerro de la Vieja Formation, Fig. 6) form a >500-m-thick (top eroded) section of sandstone, conglomerate, and siltstone, with silicic lava flows in the middle part of the section. Basal sandstones and conglomerates are dominated by angular to subrounded limestone clasts, with minor volcanic clasts; these were derived from the Early Cretaceous formations, upon which they rest in angular unconformity (Fig. 6). Most of the section, however, is dominated by volcanic clasts. The presence of silicic lava flows indicates proximity to vent regions. Although we have no geochemical data on these rocks, phenocryst assemblages indicate that these volcanic rocks are more silicic than the Early Cretaceous strata of the Colima area, which suggests that they are more evolved.

The nonmarine section of the Cerro de la Vieja Formation at Colima is lithologically similar to that at Coalcomán, and they occur in the same stratigraphic position, in angular unconformity upon folded marine Cretaceous rocks, so we correlate them. K/Ar ages on lava flows at Colima are 80 ± 6 Ma and at La Salada are 78 ± 6 Ma (Grajales and López, 1984; Fig. 3, column B2).

Huetamo Region

In this section, we describe the stratigraphy of the Huetamo area (Figs. 1 and 7) in order to compare it with that of coastal Zihuatanejo and to use it in discussions of zircon provenance and the tectonic models at the end of the paper. The strata occur in two sections, one in north-central Huetamo and the other in southern Huetamo.

Basal strata of the north-central Huetamo area consist of 1200 m of deep-marine volcaniclastic turbidite sandstones (Angao Formation; Pantoja-Alor, 1959; Guerrero-Suastegui, 1997; Martini, 2008; Martini et al., 2009) with two horizons of pillow basalt and a few beds of volcanic lithic conglomerate (Guerrero-Suastegui, 1997). The Angao Formation is mostly Valanginian in age (Guerrero-Suastegui, 1997), although Pantoja-Alor (1959) reported Kimmeridgian–Tithonian fossils. The Angao Formation passes gradationally upward to an up to 2000-m-thick section of shallow-marine clastic rocks and lesser limestone (San Lucas and Comburindio Formations; Pantoja-Alor, 1959; Guerrero-Suastegui, 1997; Martini et al., 2009). These strata contain fossils of Barremian to Aptian age (Pantoja-Alor and Gómez-Caballero, 2003; Omaña et al., 2005; Barragan et al., 2004). These strata pass gradationally upward into 400 m of reefal limestone of early Aptian age (El Cajon Formation; Guerrero-Suastegui, 1997; Omaña and Pantoja, 1998). This in turn is conformably overlain by up to 1000 m of shallow-marine clastic and calcareous rocks (Mal Paso Formation) that range in age from early Albian (clastic lower member) to early Cenomanian (calcareous member) (Pantoja-Alor, 1959; García-Barrera and Pantoja-Alor, 1991; Buitrón-Sanchez and Pantoja-Alor, 1998; Martini et al., 2009). In summary, the stratigraphic section at north-central Huetamo is up to 4600 m thick and ranges in age from Kimmeridgian(?) to Cenomanian.

The southern Huetamo section is much thinner (800 m) than the north-central Huetamo section and only contains the uppermost formation (Mal Paso Formation) resting unconformably on basement rocks (Arteaga complex). The Mal Paso Formation consists of early Albian clastic rocks that pass gradationally upward to calcareous strata of Cenomanian age.

Folding of Early to Mid-Cretaceous Arc Deposits

Cenomanian strata were folded together with the conformably underlying Early Cretaceous strata prior to deposition of the Santonian–Maastrichtian strata (see map-scale folds on Figs. 2, 4, 5, and 6). This produced an angular unconformity beneath red beds of the Cerro de la Vieja Formation, which was deposited unconformably on deformed and folded Cenomanian limestone at some localities, and on deformed and folded Early Cretaceous marine rocks at other localities. There are no similar unconformities within the Aptian to Cenomanian section, so we infer that folding occurred between Cenomanian and Santonian time. The folds are widespread, open, upright folds, with lesser overturned folds; axial planes strike N-S to NNW-SSE and verge eastward to northeastward (Figs. 2, 4, 5, and 6). Reverse and thrust faults dip 10°–70° to the S (Figs. 2, 4, 5, and 6). Areas with thin bedding show some disharmonic folding and chevron folding, and folds are tightest around the gypsum diapirs in the Colima region. Santonian to Maastrichtian strata unconformably overlie these folded rocks (Figs. 2 and 6), with basal conglomerates.

MAGMATIC AND DETRITAL ZIRCON ANALYTICAL METHODS

Zircons separated from samples collected from the Macias and Pedregoso granitoids were analyzed by isotope dilution–thermal ionization

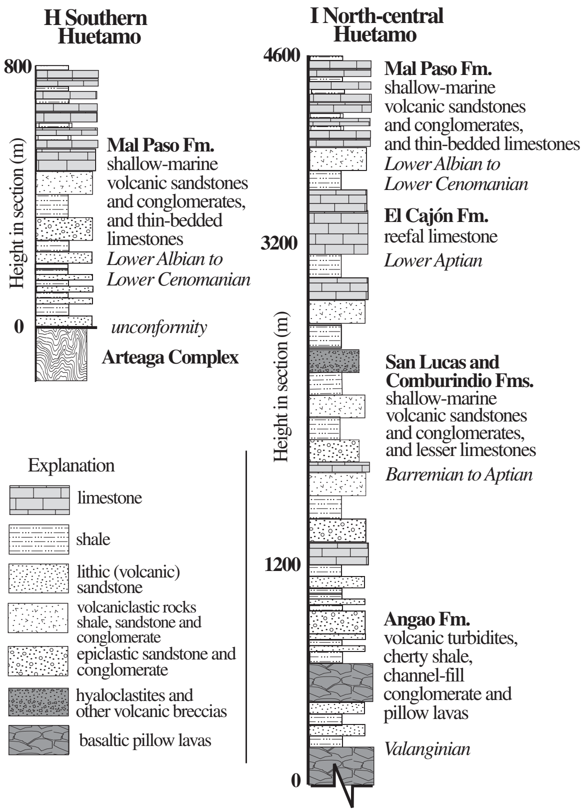


Figure 7. Stratigraphic columns for the Huetamo region; column H is our own work. Column I is based on Pantoja-Alor (1959), Guerrero-Suastegui (1997), Omaña–Pulido and Pantoja Alor (1998), Omaña–Pulido et al. (2005), Pantoja-Alor and Gómez-Caballero (2003), and others.

mass spectrometry (ID-TIMS) at the University of Arizona, following techniques described in Gehrels et al. (1991). All of the analyses were from zircon size fractions, and results are in given in the GSA Data Repository (Table DR1[1]). The data were reduced using programs of Ludwig (1991) and parameters listed in Table DR1 (see footnote 1).

For detrital zircon analyses, approximately 15 kg of each sandstone sample were processed for zircons using standard heavy liquids and magnetic separation methods. A large fraction of the recovered zircons was mounted in epoxy resin and polished. Between 47 and 100 zircons from each sample were analyzed at random from all of the zircons mounted; more grains were analyzed from samples with a greater variety of zircon ages. Cores of grains were generally analyzed in order to avoid possible metamorphic overgrowth or alteration.

Analyses were performed with a Micromass Isoprobe multicollector inductively coupled plasma–mass spectrometer (ICP-MS) equipped with a New Wave DUV 193 nm Excimer laser ablation (LA) system at the University of Arizona. The analytical procedure is described by Dickinson and Gehrels (2003) and Talavera-Mendoza et al. (2005). All analyses were conducted in static mode. The laser beam was 35 µm, with an output energy of ~32 mJ (at 22 kV) and a pulse rate of 8 Hz. Isotopic fractionation was monitored by analyzing an in-house zircon standard, which has a concordant TIMS age of 564 ± 4 Ma (Dickinson and Gehrels, 2003). This standard was analyzed once for every five unknowns. U and Th concentrations were monitored by analyzing a standard (NIST 610 Glass) with ~500 ppm Th and U. The calibration correction used for the analyses was 2%–3% for $^{206}/^{238}U$ and ~2% for $^{206}Pb/^{207}Pb$ (2σ errors). The Pb isotopic ratios were corrected for common Pb using the measured ^{204}Pb and assuming an initial Pb composition according to Stacey and Kramers (1975) and respective uncertainties of 1.0, 0.3, and 2.0 for $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$, and $^{208}Pb/^{204}Pb$.

Ages were considered reliable if five or more analyses performed in different grains yielded overlapping $^{206}Pb/^{238}U$ or $^{206}Pb/^{207}Pb$ ages. This strategy was used because of the low precision of $^{206}Pb/^{207}Pb$ ages for young grains, making concordance/discordance a poor criteria for determining reliability. Gillis et al. (2005) demonstrated that U-Pb ages of detrital zircons analyzed using both ID-TIMS and LA-ICP-MS are comparable within analytical error and that major detrital zircon populations are resolved accurately using LA-ICP-MS. Talavera-Mendoza et al. (2005) further demonstrated that igneous ages of Phanerozoic rocks are accurately determined using $^{206}Pb/^{238}U$ ratios.

The age probability plots used in this study were constructed using the $^{206}Pb/^{238}U$ age for young (<1.0 Ga) zircons and the $^{206}Pb/^{207}Pb$ age for older (>1.0 Ga) grains. In old grains, ages with >20% discordance or >10% reverse discordance are considered unreliable and were not used.

MAGMATIC ZIRCON RESULTS

The Macias granitoid (Fig. 4) plays an important role in the reconstruction of the geological evolution of the area because it provides constraints on the age of deformation of the Arteaga complex, and there have been no Middle Jurassic plutons previously recognized in the area. It varies in composition from granodiorite to quartz-monzonite. It crosscuts the metamorphic fabric in the Arteaga complex but has a penetrative mylonitic fabric that formed prior to deposition of the Cretaceous marine strata, and was in turn folded with the Cretaceous succession (Fig. 4). The Macias granite has yielded concordant ages from four size fractions, with an age of 163 ± 3 Ma (95% confidence level) (Fig. 8; Table DR1 [see footnote 1]). This constrains the age of deformation of the Arteaga complex as pre-Callovian. The Macias granitoid is slightly older than Jurassic volcanic rocks from Cuale Jalisco (Fig. 3, column A), reported by Bissig et al. (2008).

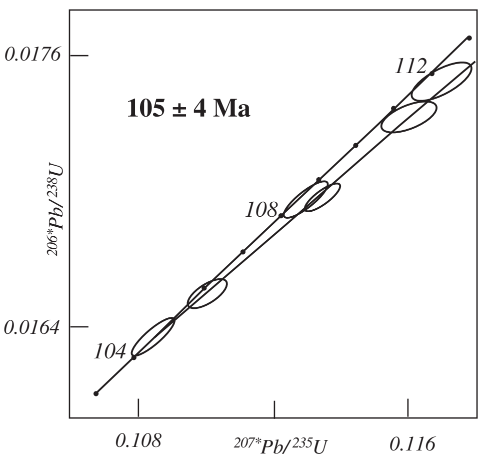
The El Pedregoso granodiorite provides a maximum age constraint on the Playitas Formation, which it intrudes (Fig. 3, column G; Fig. 4). It yielded concordant U/Pb isotopic ages on six zircon size fractions, for an age of 105 ± 4 Ma (Fig. 8; Table DR1 [see footnote 1]).

DETRITAL ZIRCON RESULTS AND PROVENANCE

We describe here detrital zircons from seven sandstone samples, one from the sedimentary matrix of the Arteaga accretionary complex, and six from Cretaceous of the western Zihuatanejo terrane. Locations are indicated on Figures 2, 4, 5, and 6, and the stratigraphic settings for the detrital zircon samples are summarized in Figure 3. Global positioning system (GPS) coordinates and rock types sampled are summarized in Table 1. All samples were studied in thin section, and point counted; between 220 and 150 counts were made from each sample, depending on the grain size of the rock (Table 2; Fig. 9). Probability plots for the detrital zircon samples are presented in Figure 10, and the full data table is in the GSA Data Repository (Table DR2 [see footnote 1]).

Basement Rocks of the Zihuatanejo Terrane: Arteaga Complex

We describe here detrital zircon data from the sedimentary matrix of basement rocks of the Zihuatanejo terrane, the Arteaga accretionary complex, for comparison with Cretaceous strata that overlie it. The sedimentary matrix of the Arteaga complex (sample Ar, location on Figs. 3 column G; Fig. 4), which has fossil ages as young as Late Triassic, has distinctive detrital zircon clusters around 260 Ma and 1.0 Ga, and



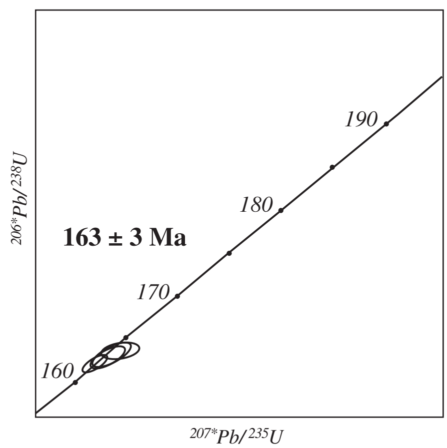


Figure 8. U-Pb zircon isochron data from: (A) Macias granite and (B) Pedregoso granite. Data are presented in GSA Data Repository Table DR1 (see text footnote 1).

[1]GSA Data Repository item 2011132, Table DR1: U/Pb geochronologic data from granitoids, Arteaga-Tumbiscatío region Zihuatanejo terrane, Guerrero Composite; and Table DR2: U/Pb geochronologic data, single-grain detrital zircon LA-ICPMS analysis from the Zihuatanejo terrane, Guerrero Composite, is available at http://www.geosociety.org/pubs/ft2011.htm or by request to editing@geosociety.org.

TABLE 1. SAMPLE LOCATIONS

Sample	Latitude (°N)	Longitude (°W)	Stratigraphic unit	Composition	Detrital zircon data
1	18°50′25.6″	103°23′59.5″	Fluvial sandstone from the Tecomán Formation outcrop near the town of Estapilla	Immature lithic-feldspathic sandstone, volcanic grains are the most abundant, contains lesser granitic clasts	Largest cluster 90–140 Ma, with a large peak at 97.1 Ma and a small peak at 129.4 Ma, small peaks 575.8, 1022.4, and 1960.6 Ma
9	18°58′09.7″	103°05′17.4″	Subaerial volcanic and sedimentary rocks north of Coalcomán on the road to Apatzingán	Immature volcanic lithic silty-sandstone	Largest cluster 60–100 Ma, with largest peak at 84.7 Ma and smaller peak 70.6 Ma, small cluster 110–160 with a peak at 131.8 Ma
15	18°14′13.5″	103°13′41.0″	Marine turbidites on the Tecomán–Playa Azul road near the town of Cachán	Immature quartz-lithic (volcanic) fine-grained sandstone, with fewer sedimentary (sandstone) and granitic clasts	Largest cluster 90–180 Ma, with main peak at 98.8 Ma, and smaller peaks at 120 and 162.4 Ma, minor peaks at 268.2, 447.6, 585.9, 1009.4, and 1171.8 Ma
16	18°05′31.0″	102°47′40.7″	Subaerial red beds on the Tecomán–Playa Azul road near the Neixpa bridge	Immature volcanic lithic-feldspathic sandstone	Narrow cluster 90–130 Ma, with a single large peak at 109.5 Ma
17	18°02′51.5″	102°34′45.7″	Subaerial red beds at the locality with dinosaur footprints near Chuta village	Immature volcanic lithic-feldspathic sandstone	Narrow cluster 90–130 Ma, with a single large peak at 109.7 Ma
18	18°23′36.0″	102°23′17.2″	Shallow-marine Playitas Formation at the Toscano River on the Arteaga-Tumbiscatío road	Conglomeratic lithic-sandstone, with mainly volcanic clasts and quartz, quartz-rich sandstone clasts and schist clasts	Main cluster 90–130 Ma, with largest peak 105.9 Ma, and smaller peak at 123.5 Ma, second largest peak at 247.1 Ma, other peaks at 158.8, 608.8, and 1173.5 Ma
Ar	18°25′56.0″	102°20′48.2″	Sedimentary matrix of the Arteaga complex, on the Arteaga-Tumbiscatío road 800 m north of Barranca Honda village	Mature quartzitic litharenite, quartz and chert grains are the most abundant, some feldspar, felsic volcanic and silt grains	Largest cluster 220–380 Ma with a large peak at 260 Ma, second cluster 900–1300 Ma with a peak at 1.0 Ga, minor clusters at 480–650 Ma, and 800 Ma

TABLE 2. COMPOSITIONS OF SANDSTONES ANALYZED FOR DETRITAL ZIRCON CHRONOLOGY

Sample	Qm	Qp	Ch	Pl	Fk	Fu	Lv	Ls	Lm	Gr	Ma/Am	Ac	Total
Ar	37	27	23	2	0	0	3	4	0	0	3	1	100
1	16	5	0	15	5	6	41	0	0	7	6	2	100
15	24	8	2	3	0	8	29	4	0	1	21	1	100
16	2	2	0	15	17	3	59	0	0	0	3	0	100
17	1	0	0	15	2	0	80	0	0	0	1	0	100
18	6	17	1	5	0	0	38	18	3	0	12	0	100

Note: Values in percentages, total counts ~220 and 150. Qm—monocrystalline quartz, Qp—polycrystalline quartz, Ch—chert, Pl—plagioclase, Fk—potassium feldspar, Fu—undifferentiated feldspar, Lv—volcanic lithic, Ls—sedimentary lithic, Lm—metamorphic lithic, Gr—granite lithic, Ma/Am—matrix and authigenic minerals, Ac—accessories.

minor clusters at 480–650 Ma and 800 Ma (Fig. 10; Centeno-García et al., 2005). A possible source area for the 1.0 Ga peak is the Grenville belt of Mexico (Oaxaquia, Fig. 1; Solari et al., 2003); Pan-African rocks of Florida and the Yucatan Peninsula are a possible source for the 480–650 Ma peak; Mexican Permian–Triassic arc rocks are a possible source for the 260 Ma peak (Oaxaquia and the Mixteca terrane, Fig. 1). Alternatively the Acatlán complex of southern Mexico could be a source for the zircons that form all three peaks in the Arteaga complex (Mixteca terrane, Fig. 1; Talavera-Mendoza et al., 2005; Keppie et al., 2006). These three peaks together are referred to herein as Gondwanan provenance. Our data set constraints on the age of deposition and deformation of the Arteaga complex as post–260 Ma (youngest detrital zircon in the matrix) and pre–163 Ma (age of Jurassic intrusions). Thus the basement for this area of the Guerrero composite terrane formed in a Late Triassic–Middle Jurassic subduction complex along the Mexican–South American continental margin. The data obtained from the matrix of the Arteaga complex are important because, as mentioned already, several previous papers have proposed that the Guerrero composite terrane originated far from Mexico, on the other side of a major ocean basin (Tardy et al., 1994; Dickinson and Lawton, 2001). The Arteaga basement and Jurassic arc both represent sources for some of the detrital zircons found within the Cretaceous rocks (described in the following).

Early to Mid-Cretaceous Assemblage 1

Playitas Formation

The Playitas Formation detrital zircon sample is from the Tumbiscatío area (detrital zircon sample 18, location on Fig. 4), and it consists of coarse-grained coastal alluvial fan and volcanic debris-flow deposits that were likely locally derived (Fig. 3, column G; Fig. 4). The sample is from a shallow-marine pebbly sandstone with volcanic, vein quartz, quartz-rich sandstone, and metamorphic and granite clasts. Volcanic clasts include devitrified tuff and fragments with trachytic and latitic textures. Sedimentary rock fragments are quartz-rich sandstones identical to those of the Arteaga complex. Polycrystalline quartz may have come from quartz veins, and those with rutile probably came from granites (e.g., nearby Jurassic granites at Tumbiscatío and Macias).

The metamorphic rock fragments are quartz–mica schist that look like the most metamorphosed parts of the Arteaga complex. In summary, the petrography shows clear evidence for mixing of first-cycle arc volcanic

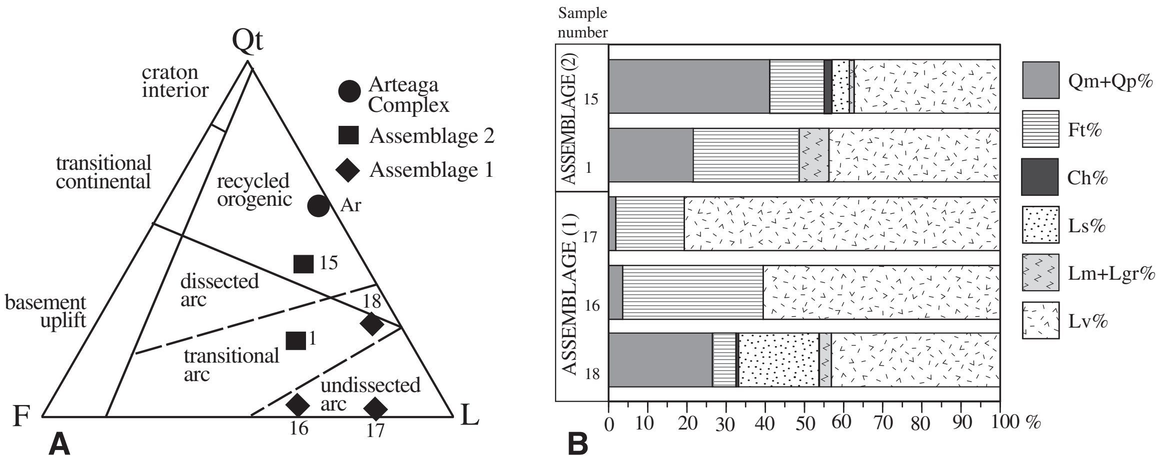


Figure 9. (A) Triangular diagram of modal analyses (fields by Dickinson, 1988), and (B) bar diagram showing percentages of main grain components of sandstones sampled for the detrital zircon analyses described here (localities shown on Figs. 2–6, global positioning system [GPS] coordinates given in Table 1, and point counts given in Table 2). Detrital zircon sample 9 from the Santonian–Maastrichtian compressional arc (Fig. 3, column D) was not point counted because it was too friable to allow preparation of a thin section.

rocks with basement rock sources (Fig. 9; Table 2). The sample falls in the transitional arc field in the QtLF provenance diagram of Dickinson (1988) (Fig. 9).

The Playitas Formation detrital zircon sample shows a wide range of ages (Fig. 10). It shows a major peak at ca. 1.1 Ga (Grenville), with a range from ca. 800 Ma to 1.3 Ga, similar to the Arteaga cluster. It also contains a cluster from ca. 450 to ca. 600 Ma (Pan-African), also similar to Arteaga. A third peak, at ca. 250 Ma, is also similar to Arteaga. The coarse-grained nature of the clasts, and petrographic evidence for an Arteaga source of the clasts, indicates that these Gondwanan zircons were derived by recycling from local basement, rather than representing far-traveled detritus originating in Acatlán or primary Pan-African–Grenville belts

The Playitas Formation also shows three distinct Mesozoic peaks (Fig. 10). The oldest has ca. 160 Ma zircons, similar to Jurassic granitoids in the area (Figs. 2 and 4; Fig. 3, columns A and G), again supporting the interpretation of erosion of local sources. This is supported by the major unconformity recorded in the Tumbiscatío area, where the Early Cretaceous Agua de los Indios Formation unconformably overlies Jurassic granitoids (Fig. 4). A second zircon peak lies at ca. 123.6 Ma, indicating that Neocomian igneous rocks were being eroded by Albian time. The youngest peak (106 Ma) is the biggest peak, so it probably represents first-cycle volcanic zircon, indicating that the age of the Playitas Formation is 106 Ma or younger. However, it can be no younger the 105 ± 4 Ma El Pedregoso granodiorite, which intrudes it. Therefore, its age is closely bracketed at 106–101 Ma, consistent with the presence of Albian fossil ages reported for the area (Fig. 3). Furthermore, a high subsidence and sedimentation rate is implied by the fact that a coarsely crystalline plutonic rock intruded the sandstones less than 5 m.y. after they were deposited (perhaps ~2000 m/m.y., if the pluton can be considered mesozonal).

We interpret two anomalously young (Cenozoic) zircon ages in the Playitas Formation to record Pb loss associated with the development of mylonites during emplacement of Eocene plutons in the region (Fig. 4; Centeno-García et al., 2003).

Chuta-Neixpa

The Chuta sample (detrital zircon sample 17; Fig. 3, column F; Fig. 5) is a red volcanic lithic pebbly massive sandstone. The sample was taken two beds (1.20 m) below the bed with dinosaur footprints. In thin section, it is poorly sorted (polymodal) and clast-supported sandstone with well-rounded to angular clasts in a siltstone matrix. It is nearly all volcanic rock fragments, with lesser plagioclase feldspar and even fewer quartz grains (Fig. 9; Table 2). The rock fragments are mainly devitrified tuff, and lesser fragments with latitic to trachytic textures. Thus, this sample represents first-cycle volcanic material. The sample plots in the undissected arc field of the QtLF provenance diagram (Fig. 9). Detrital zircon from this sample forms a strong single peak at 109.7 Ma (Fig. 10), consistent with its first-cycle volcanic petrography. The Neixpa detrital zircon sample (detrital zircon sample 16; Fig. 3, column F; Fig. 5) comes from a coarse-grained red pebbly volcanic lithic sandstone. In thin section, it is poorly sorted and clast-supported, with well-rounded to angular clasts in a siltstone matrix. The thin section is dominated by volcanic rock fragments (Fig. 9), and it has abundant sanidine and plagioclase feldspar (Table 2). Volcanic rock fragments include devitrified cryptocrystalline tuff, devitrified glass fragments, and lesser andesitic to felsic volcanic rocks fragments with trachytic, latitic, or felsitic textures. Like the Chuta sample, the Neixpa sample plots in the undissected arc field (Fig. 9), and we consider it a reworked pyroclastic rock. Detrital zircons from this sample form a strong single peak at 109.5 Ma (Fig. 10).

The detrital zircon ages for both the Chuta and Neixpa samples agree with the Albian fossil ages reported for the succession, and they form very strong peaks (109.7 Ma and 109.5 Ma), indicating that they are first-cycle volcanic zircons. This is also supported by the sandstone modal provenance. Since both samples are formed by pyroclastic debris that was remobilized as debris flows, it explains the lack of older zircons.

Estapilla

This detrital zircon sample was taken from a fine-grained fluvial sandstone in the Estapilla section at Colima region (detrital zircon sample 1, Fig. 3, column B4; Fig. 6). In thin section, the grains are subrounded to well rounded, and well sorted. Quartz overgrowths and clay minerals form a cement, and volcanic and feldspar grains are replaced by sericite and other clay

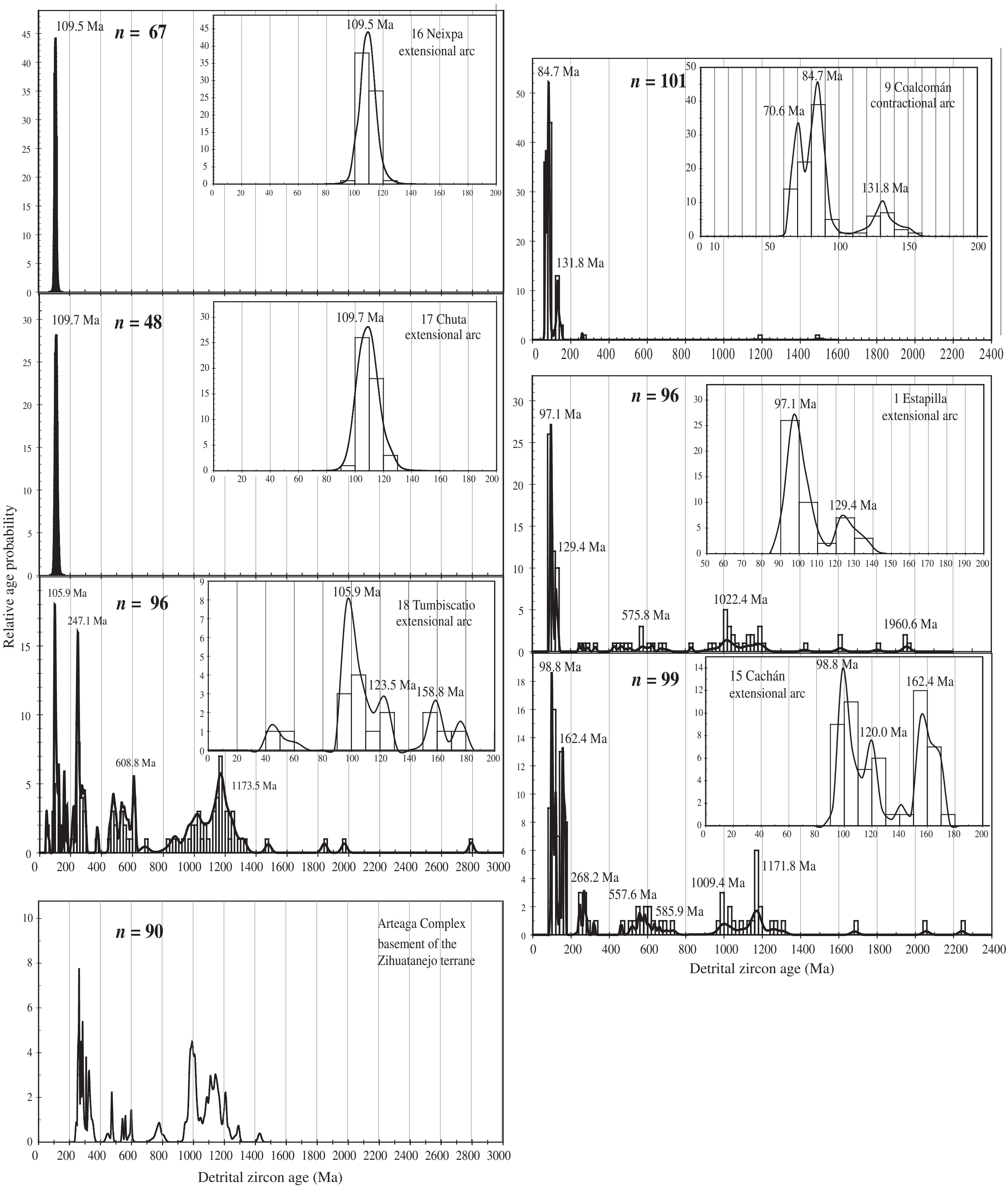


Figure 10. Relative probability plots of detrital zircon data from the Zihuatanejo terrane (see maps on Figs. 2, 4, 5, and 6 for sample location, and stratigraphic columns on Fig. 3).

minerals. The rock fragments are volcanic, with trachytic texture, mafic grains with seriate texture, altered cryptocrystalline tuff grains, and altered volcanic glass. Some quartz grains have microliths, suggesting vein quartz, and some have apatite or rutile inclusions, suggesting a granitic source. The feldspars include plagioclase and potassium feldspar, some with apatite inclusions, again suggesting a granitic source. Trace muscovite is consistent with this interpretation. This sample plots in the transitional arc field in the Dickinson's provenance ternary diagram (Fig. 9; Table 2).

The Estapilla detrital zircon sample differs from previously described detrital zircon samples by having a detrital zircon peak younger than 100 Ma; in fact the 97.1 Ma peak is the biggest peak of the sample (Fig. 10). However, the Estapilla detrital zircon sample is similar to the Playitas Formation sample by having Early Cretaceous, Permian, Pan-African, and Grenville zircon populations. It differs by lacking the Jurassic zircons. Therefore, the possible granitic source should be the roots of the Early Cretaceous or the Cenomanian arc.

Cachán

The Cachán detrital zircon sample (detrital zircon sample 15, Fig. 3, column E; Fig. 5) comes from the fine-grained sandstone turbidites. In hand sample, it has quartz and volcanic lithic fragments and rounded plagioclase feldspar. In thin section, quartz is the most abundant grain type (Table 2), mostly monocrystalline, but the sample also contains polycrystalline quartz. The volcanic rock fragments are the second most abundant sand grains; they are felsic, mafic, and intermediate with trachytic and latitic textures, plus some altered volcanic glass fragments. The sample also contains some sedimentary clasts (calcareous siltstone), and some of the polycrystalline quartz grains have feldspars, indicating that they are probably derived from granitic rocks; this is consistent with the presence of few detrital biotite grains. Most of the feldspar grains are rounded, and are mostly plagioclase; however, some sanidine clasts are present. The Cachán sandstone sample is the most quartzose sandstone of all the studied samples and plots in the recycled orogenic field on the Qt/L/P diagram (Fig. 9).

Like the Estapilla sample described previously, the Cachán detrital zircon sample has its biggest peak at 98.8 Ma (Fig. 10). It is similar to both the Estapilla and Playitas Formation samples, described already, in having Early Cretaceous, Permian, Pan-African, and Grenville populations. In addition, it shows the Jurassic zircon population that is also present in the Early Cretaceous Playitas Formation sample (Fig. 10).

Santonian–Maastrichtian Assemblage 2

Coalcomán

The Coalcomán detrital zircon sample (detrital zircon sample 9; Figs. 2 and 3, column D) comes from a volcanic lithic fluvial sandstone in a section of red beds and interstratified silicic lava flows and tuffs. It was too unconsolidated to make a thin section, so it is not described in Table 2. However, at the outcrop, it is a volcanic lithic silty sandstone.

This sample has almost no old detrital zircon populations. It shows a strong peak at 84.7 Ma (Santonian), which is almost 50% of the analyzed zircons, and a smaller peak at 70.6 Ma (Campanian-Maastrichtian boundary), suggesting they are first cycle zircons. The sample also shows a small population at 131.8 Ma, recycled from the Early Cretaceous arc, and one detrital zircon with a Paleozoic age, and two with Proterozoic ages. Santonian arc volcanic rocks have recently been identified ~150 km to the east, in the Huetamo area of eastern Zihuatanejo terrane, through U-Pb zircon dating of a 84.0 ± 2.8 Ma block-and-ash-flow tuff (Mariscal-Ramos et al., 2005; Centeno-García et al., 2008); we suspect that more Late Cretaceous volcanic rocks will be found throughout the Zihuatanejo terrane through further dating.

We interpret the Campanian–Maastrichtian zircons, with a peak at 70.6 Ma, and ages as young as 65.1 ± 1.7, as the depositional age of the sample. However, the whole volcano-sedimentary unit probably ranges in age from Santonian to Maastrichtian, as indicated by the detrital zircon populations we obtained. This is supported by ages reported from batholiths toward the west and northwest of Coalcomán. The Manzanillo Batholith, 80 km to the northwest of Coalcomán in the Zihuatanejo terrane (Fig. 1), overlaps in age, with K/Ar dates that range from 66.9 ± 1.3 to 62.3 ± 1.2 and U/Pb ages of 81 ± 2 Ma, 74 ± 1 Ma, 68 ± 1 Ma, and 63 ± 2 Ma (Schaaf et al., 1995, 2000; Tunesi et al., 2009). In addition, there are numerous K/Ar ages of 80–90 Ma, and U/Pb ages of 59 to ca. 90 Ma in the Puerto Vallarta Batholith (Schaaf and Martínez, 1997; Fletcher et al., 2007), 250 km to the north of Coalcomán in the Zihuatanejo terrane (Fig. 1). There are no granitoid fragments in the sandstone and conglomerate at the sampled outcrop, and primary volcanic rocks are abundant in the area. Thus, the ca. 84 and ca. 70 Ma zircons must have been derived from the upper (volcanic) levels of the arc.

The red beds of Coalcomán were previously undated, but our new detrital zircon data indicate that they are Santonian–Maastrichtian. Because of similarities in age and lithology, we propose to extend the name of Cerro de la Vieja Formation from Colima to Coalcomán. K/Ar ages reported from La Salada (Grajales and López, 1984; Fig. 3, column B2) are consistent with our detrital zircon ages at Coalcomán (Fig. 3, column D), supporting this correlation. Therefore, we consider the nonmarine section at Colima to be Santonian–Maastrichtian in age (Fig. 3, column B2).

We interpret the sections at Coalcomán and Colima to record Late Cretaceous nonmarine intra-arc volcanism and sedimentation; the scarcity of older detrital zircons indicates that basement sources were buried beneath Early to Late Cretaceous volcanic-volcaniclastic deposits.

DISCUSSION

In this section, we synthesize stratigraphic data (Fig. 11) with map and age data to present tectonic reconstructions of the western Guerrero composite terrane for Late Jurassic through Cretaceous time (Fig. 12). We also discuss our reasons for preferring a fringing arc model over an autochthonous arc model for Late Jurassic to mid-Cretaceous rocks of the Guerrero composite terrane, and the reasons why it cannot be exotic.

Interpretation of Assemblage I: Late Jurassic to Mid-Cretaceous Extensional Arc

We present here a model to be tested by future work that the Late Jurassic to Mid-Cretaceous succession (assemblage 1, Fig. 3) accumulated in an extensional arc setting (Fig. 12A). As described previously herein, the development of contractional structures (folds and thrust faults) postdated the deposition of Cenomanian and older strata; we suspect that this shortening reactivated older normal faults, which have not yet been recognized, with one possible exception, described here. In this section, we present direct and indirect lines of evidence to support a model for an extensional tectonic setting:

Composition of the Magmas

Published geochemical data from Cretaceous volcanic rocks indicate that they range from tholeiites to high-K basalts and andesites, with some dacites and rhyolites. Felsic and more evolved compositions are more abundant in the Neixpa-Chuta area, in contrast with the andesitic to basaltic volcanic rocks that dominate the Colima, Tumbiscatío, and Zihuatanejo areas (Centeno-García et al., 1993; Freydier et al., 1997; Mendoza and Suastegui, 2000). Overall, volcanic rocks of the Zihuatanejo terrane are dominated by mafic compositions; those show Nd isotopic and trace-element concentrations

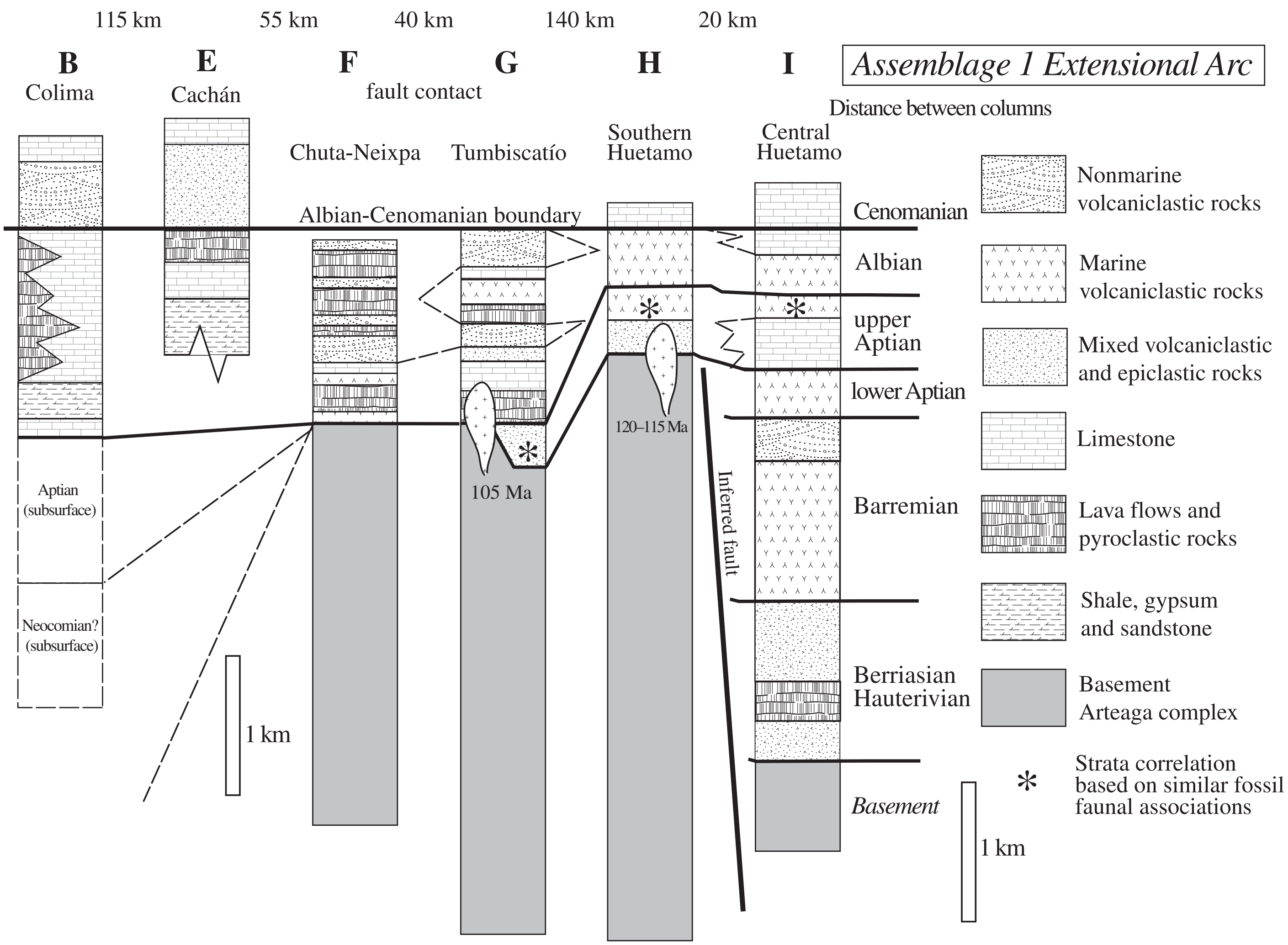


Figure 11. Summary lithofacies columns of assemblage 1 extensional arc strata from the study area (Figs. 3B, 3E, 3F, and 3G) and from the Huetamo area of the Zihuatanejo terrane (location of Huetamo area on Fig. 1), showing variations in stratigraphic thickness (to scale). Based on a rapid change in thickness of Cretaceous strata between southern Huetamo and central Huetamo, a syndepositional normal fault is inferred in southern Huetamo area (see part A).

that indicate minor or no crustal contamination, with epsilon Nd initial values that range from +5 to +7 (Centeno-García et al., 1993; Freydier et al., 1997). This is typical of extensional arcs, where magmas are allowed to ascend rapidly.

Great Thicknesses of Shallow-Marine Sediment

In the Colima area, we measure at least 2000 m of shallow-marine to coastal sediment (base of section not exposed or reached by drilling). Within this section, ~1800 m consist solely of middle to upper Albian shallow-marine limestone (Fig. 10, column 1). The Albian covers ~12 m.y., so this indicates a minimum subsidence rate of 300 m/m.y. to accumulate these photic zone sediments. In an arc setting, this rate of subsidence is typical of extensional or oblique extension basins (for subsidence rates of various basin types, see Ingersoll and Busby, 1995; Ingersoll, 2011).

Folding and thrusting occurred after the deposition of Cenomanian strata and before the deposition of Santonian strata. The age of the contractional event is constrained by the regional angular unconformity between Santonian or younger strata deposited on folded and thrusted Cenomanian or older strata. In contrast, contacts among Early Cretaceous formations are gradational or show minor erosional unconformities.

Abrupt Changes in Stratal Thickness

We tentatively infer that abrupt changes in stratal thicknesses may be attributed to syndepositional normal faulting. One example occurs in the inland Zihuatanejo terrane at Huetamo (Figs. 11 and 12). In north-central Huetamo, the Berriasian through early Aptian section is 2800 m thick (Fig. 11, column 6; Pantoja-Alor, 1959; Guerrero-Suastegui, 1997; Barragán et al., 2004; Martini, 2008; Martini et al., 2009; our own observations). In contrast, only 20 km toward the SW in southern Huetamo, this section is absent (Fig. 11, column 5), so we infer that this area may have lain in the footwall of a normal fault (Fig. 12A). This area was interpreted to be an onlap sequence in Figure 4 of Martini et al. (2009), but the cross section in that figure is not drawn to scale, so the rapid nature of the southward thinning is not evident. We suggest that the dramatic thinning of strata in such a short distance is too great to be explained as a buttress unconformity; instead, we suggest that

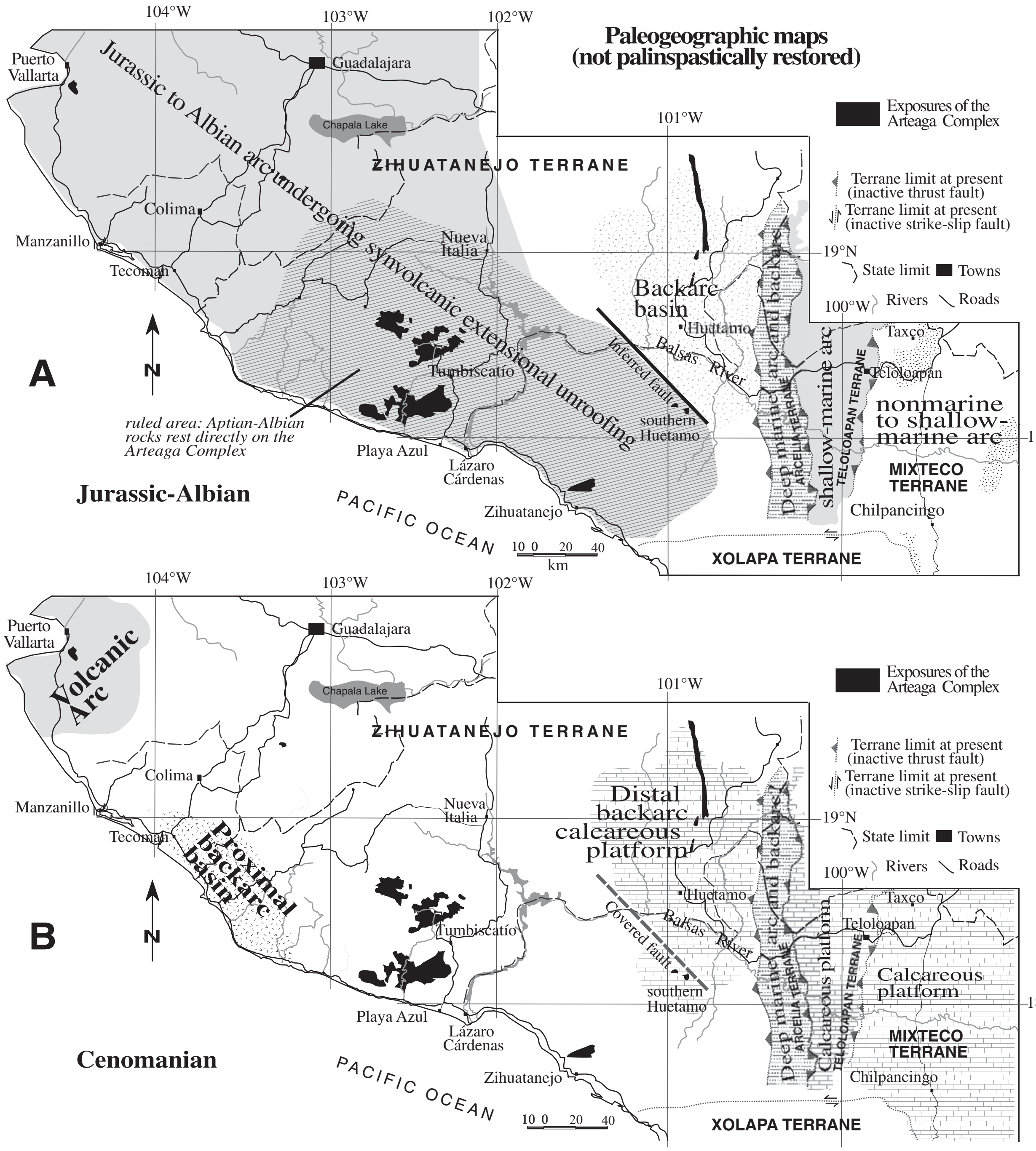


Figure 12 (*on this and following page*). Time-slice map view reconstructions of the Late Jurassic and Cretaceous evolution of the southern part of the Guerrero composite terrane of western Mexico. Primary configurations are not well known, since geologic constraints are not good enough to allow palinspastic restoration of rocks to their original positions prior to Late Cretaceous shortening. Present-day distributions of outcrops of substrate Triassic accretionary wedge rocks are shown for reference on all time slices (in black). Present-day location of thrust faults that form terrane boundaries are also shown on all time slices for reference. (A) We infer that the area shaded in gray was the site of a wide Jurassic to Albian extensional arc. The diagonally ruled part of this apparently was located in the footwall region of a major fault, because Upper Jurassic to Lower Aptian strata are missing there (Fig. 11, columns F, G, and H). We infer that the central Huetamo area was located in the hanging wall of this fault, because Early Cretaceous strata are very thick there (4000 m; Fig. 11 column I). Paleoenvironments for inboard terranes (Arcelia and Teloloapan terranes) are shown, but their original positions are not known. (B) Cenomanian paleogeography: By this time, volcanism had ceased in all but the northwestern most edge of the region ("volcanic arc"). The region labeled "backarc" lacks primary volcanic rocks but contains both first-cycle volcanic detritus and clasts derived from older assemblages. Further from the arc to the east, the distal backarc region was blanketed in carbonate and minor siliciclastic sedimentary deposits, with possible deep-water deposits in the Arcelia terrane.

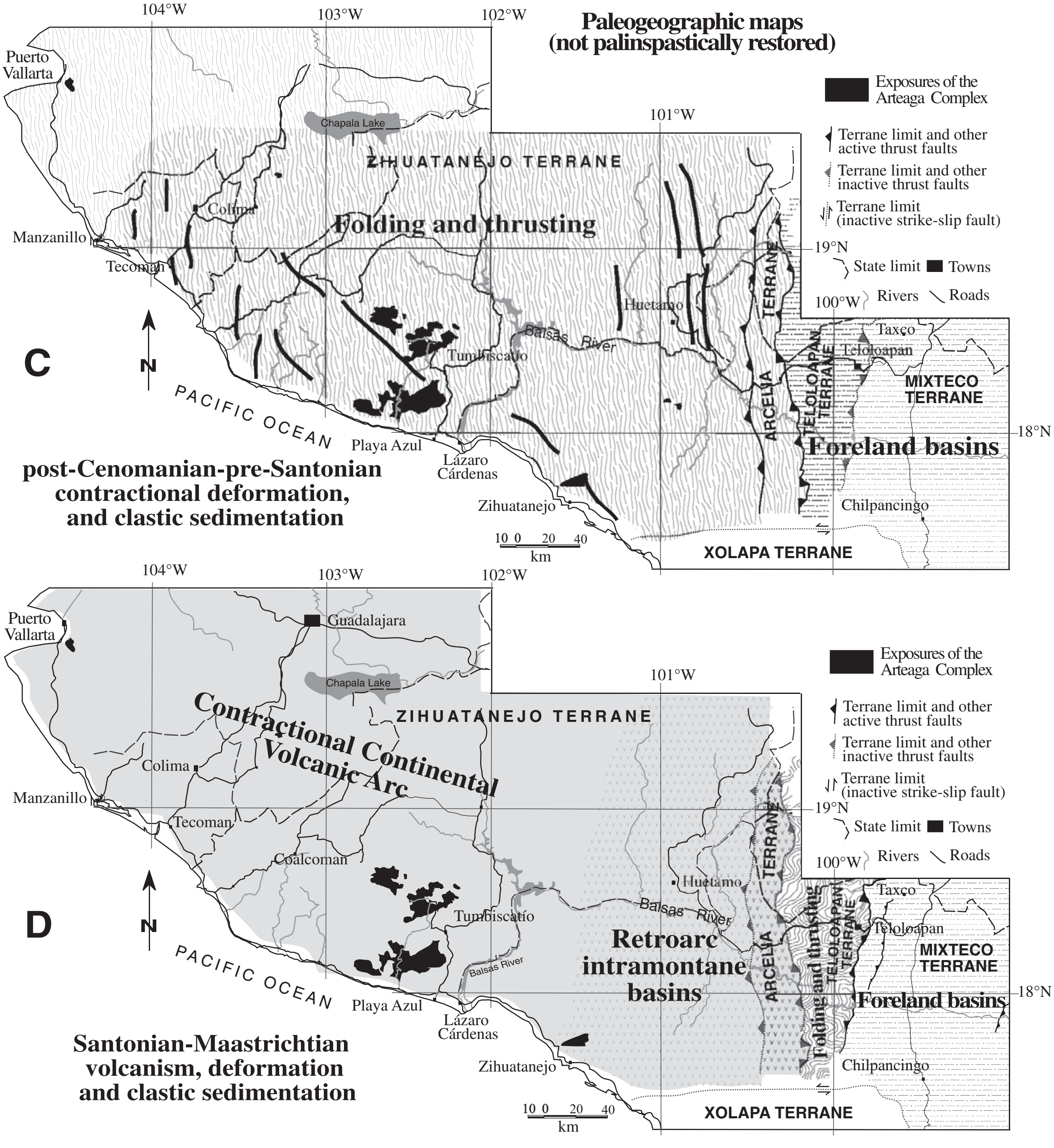


Figure 12 (*continued*). (C) Inferred area of post-Cenomanian and pre-Santonian contractile deformation, roughly time-correlative with the Sevier orogeny in the SW United States (De Celles et al., 1995). This produced folds and thrust faults in the Zihuatanejo and Arcelia terranes. This folding and thrusting resulted in erosion of Cenomanian and older rocks, and younger rocks overlie them in angular unconformity (Figs. 3B and 3D). At the same time, foreland basin sedimentary rocks were deposited atop the Teloloapan and Mixteca terranes. (D) Inferred area of Santonian to Maastrichtian contractional continental volcanic arc, shaded gray. The region immediately to the east contains fewer primary volcanic rock and more reworked volcaniclastic debris, suggesting that it may represent a retroarc intermontane basin. Inboard of that is clear evidence of folding and thrusting at this time (Arcelia, Teloloapan, and western edge of Mixteca terrane). A retroarc foreland basin formed on the Mixteca terrane. Eventually (in late Maastrichtian time), foreland basin deposits of the Mixteca terrane were deformed. Thus, contractile deformation migrated inboard throughout the Late Cretaceous (Figs. 12C–12D).

this contact formed by abrupt thinning of strata onto the footwall of a normal fault. The other alternative, that the fault is a reverse fault, seems unlikely, for reasons discussed in the previous two points of this section. The stratigraphic thickness of overlying late Aptian to Cenomanian strata is similar in both areas, so we infer that the fault became inactive by that time, and the entire region subsided at high rates. Such high rates of subsidence (discussed later herein) suggest that extension may have continued in the Albian.

Recycling of Detrital Zircon from Basement and Cannibalization of Assemblage 1 Zircon

One could argue that the Gondwanan detrital zircons in Cretaceous rocks of the study area were derived directly from the Mexican margin, as has been argued for the Teloloapan and Arcelia terranes (Fig. 1; Talavera-Mendoza et al., 2007). However, we do not consider the presence of Gondwanan detrital zircons to be proof of the autochthonous nature of the Zihuatanejo terrane in Cretaceous time, because there is no evidence that these were derived directly from the continent. On the contrary, we have clear geologic evidence for recycling of sediment from the basement.

Two lines of evidence support the interpretation of recycling of detritus from the basement: the abundance of sand, pebbles, cobbles, and boulders of Arteaga complex, and the proximal nature of the depositional systems (alluvial fan and fan delta). The abundance of conglomerate-breccia horizons with large clasts of quartzose sandstone and granite, as well as the abundant debris-flow deposits indicate proximity to Arteaga sources. Furthermore, the Cretaceous sedimentary rocks onlap the Arteaga basement (Figs. 2, 3, and 4), indicating that it was exposed.

The presence of dinosaur footprints in assemblage 1 strata of the Zihuatanejo terrane suggests that it did not develop far from a continental margin; there must have been at least one land bridge to the continent at some time during the evolution of the arc.

A further argument against a direct mainland Mexico source for Gondwanan detrital zircon in assemblage 1 Albian–Cenomanian strata of the study area is that this was a time when most of the mainland Mexico basement rocks were covered by thick calcareous sediments (Goldhammer, 1999; Fries, 1960). The same scenario applies for neighboring terranes within the Guerrero terrane, which were covered by calcareous or clastic marine rocks (Figs. 12A and 12B). Thus, none of those areas was being eroded to supply sediment at the time of deposition in the study area.

We argue that the recycling of basement zircons and older assemblage 1 (Neocomian to Aptian) zircons during deposition of younger assemblage 1 (Albian) strata could not have been accomplished by contractional deformation, because our field evidence shows that folding and thrusting did not occur until post-Cenomanian and pre-Santonian time

Regional Evidence for Extensional Arc Basins of This Age

Although this evidence is indirect for the study area, we point out that an extensional setting has been demonstrated for adjacent terranes at the time of accumulation of assemblage 1 in the study area. The Arcelia terrane is characterized by volcanism with MORB and OIB signatures and deep-marine sedimentation during the Early Cretaceous (Centeno-García et al., 2008). In addition, extension and oblique extension is well documented for Late Triassic through Early Cretaceous arc basins in Baja California (Busby et al., 1998; Busby, 2004), which restore to a position just north of Puerto Vallarta when the Gulf of California is closed (Busby, 2004). This tectonic regime may have been controlled by slab age, because the paleo-Pacific at the time of breakup of Pangea was probably composed of large, relatively old, cold plates (Busby-Spera et al., 1990; Busby et al., 1998; Busby, 2004). This extensional arc and/or arcs (?) appear to have covered a very broad region, from Baja California to the eastern Zihuatanejo terrane, and possibly the Arcelia and Teloloapan terranes to the east were also extensional arcs (Figs. 1 and 12). Arc extension ended by the Albian-Cenomanian boundary in Baja California, when the Early Cretaceous Alisitos fringing arc underthrust the Mexican continental margin and the crust was greatly thickened (see discussion in Busby, 2004).

Exotic versus Fringing versus Autochthonous Origins of the Guerrero Composite Terrane

It is clear that the basement for the Zihuatanejo terrane of the Guerrero composite terrane, the Triassic–Jurassic Arteaga subduction complex, formed along the Mexican margin. The geologic and geochemical evidence for this has been discussed in previous papers (Centeno-García et al., 1993, 2008; Centeno-García, 2005) and largely involves correlation of the sedimentary matrix of the Arteaga subduction complex with the Late Triassic Potosí submarine fan of mainland Mexico. In this paper, we presented detrital zircon data that link the Arteaga subduction complex to the Mexican margin. The combination of Permian, Pan-African, and Grenville detrital zircon populations is the signature of mainland Mexico and the northwestern margin of South America, and is referred to as Gondwanan (references cited previously). This means that the terrane is not exotic to America, and it clearly did not form by closure of a major ocean basin, because its basement has close ties with Mexico. In other words, the arc is not exotic to Mexico.

We prefer a model where the Late Jurassic to mid-Cretaceous arc fringed the Mexican continental margin, rather than forming directly on the continent. This was accomplished by an arc rifting event that separated parts of the Arteaga accretionary complex from the continental margin. This process led to formation of deep-marine basins, with primitive arc and MORB volcanic rocks (Ramírez-Espinosa et al., 1991; Ortiz-Hernández et al., 1992, 2003; Lapierre et al., 1992; Talavera-Mendoza et al., 1995, 2007; Mendoza and Suastegui, 2000), which we infer formed inboard of and coeval with the Zihuatanejo terrane (Arcelia terrane, Fig. 12A; Guanajuato terrane, Fig. 1). Also inboard of the Arcelia terrane, there are coeval shallow-marine island arc rocks of the Teloloapan terrane (Fig. 12A; Talavera-Mendoza et al., 1995; Mendoza and Suastegui, 2000); this suggests a complex paleogeographic scenario for Early Cretaceous time. Although it is not clear how those inboard terranes were translated or accreted into their present position, their existence makes us prefer a model of fringing arcs and marginal basins, similar to present arcs in the southwestern margin of the Pacific Ocean. A similar model has been proposed for Mesozoic arc terranes of Baja California (Busby, 2004).

Cenomanian Paleogeography

The only Cenomanian arc magmatic rocks that have been previously identified in the Zihuatanejo terrane are located in Puerto Vallarta (Fig. 12B). Cenomanian strata at Colima (Tecomán Formation) and Cachán are located just inboard of this, and are referred to here as "proximal backarc" because they consist of volcaniclastic sedimentary rocks that interfinger with limestone. Further east, we suggest that the Huetamo area may represent the backarc; this was too far from the arc to receive volcanic detritus and instead formed a carbonate platform (Fig. 12B). Although the position of the Zihuatanejo terrane relative to the more inboard terranes is not clear, they were also dominated by carbonate platforms (Teloloapan and Mixteca terranes), suggesting that magmatism ended previous to this time. It is not clear whether or not deep-marine strata of the Arcelia terrane continued to be deposited during this time frame, so its tectonic setting cannot be reconstructed for this time (Fig. 11B; Talavera-

Mendoza et al., 2007; Martini, 2008). In the time frame shown in Figure 12B, the term "backarc basin" is meant to describe its position relative to the arc; an extensional setting is not implied. On the contrary, we speculate that it represents a retroarc basin formed behind a contractional arc, for the following reasons (which must be tested in future studies):

(1) The westward shifting of the arc axis corresponds to the timing of accretion of the Early Cretaceous Alisitos arc terrane to the western edge of Mexico, in what is now Baja California, by underthrusting (Busby, 2004). Restoration of Baja California to its position prior to the opening of the Gulf of California places it adjacent to Puerto Vallarta, very close to the Guerrero composite terrane.

(2) In Baja California, there is abundant evidence for arc shortening, uplift, and dissection during ongoing subduction in Cenomanian time (Busby, 2004). This evidence includes dated reverse faults within the arc, and a sudden influx of coarse-grained sediment with a dissected arc source in the forearc basins. Isotopic ages of detrital K-feldspar and zircons from the forearc basins show that the Peninsular Ranges Batholith was exhumed at that time (see numerous references cited in discussion by Busby, 2004). The batholith apparently extends as far south as Los Cabos at the south tip of Baja California (Grove et al., 2006). The Puerto Vallarta Batholith is clearly part of this belt, once the Gulf of California is restored to its closed position (Schaaf et al., 2000; Fletcher et al., 2007).

The Los Cabos–Puerto Vallarta area not only represents a suitable source for the 98 and 97 Ma detrital zircon peaks in our Cenomanian samples, but also for the older detrital zircon clusters in them (Fletcher et al., 2007; Kimbrough and Ledesma-Vasquez, 2008). Schists in the Cabo San Lucas block are intruded by Jurassic and Cretaceous plutons, and have the Permian, Pan-African, and Grenville zircon peaks we see in our Cenomanian samples (Fletcher et al., 2007; Kimbrough and Ledesma-Vasquez, 2008). Thus, in this tectonic scenario, the Cenomanian rocks would represent the initiation of the transition from an extensional to contractional setting in the studied area. In the next two time frames (Figs. 12C and 12D, discussed later), contractional deformation swept eastward through the study area.

Evidence for Contractional Arc Setting of Santonian–Maastrichtian Rocks

The Santonian–Maastrichtian rocks newly recognized in this study are important for constraining the timing of shortening in coastal Zihuatanejo terrane (Figs. 2 and 12C). Strata as young as late Cenomanian were folded, thrusted, and eroded prior to the deposition of the Santonian–Maastrichtian strata (i.e., during the Turonian–Santonian, between ca. 93 and 84 Ma). Pre-Santonian folding of Cenomanian and older Cretaceous strata is not only mapped in the studied area (Figs. 2 and 12C), but also to the east, in inland exposures of the Zihuatanejo terrane (Huetamo region), and in the Arcelia terrane (Figs. 1 and 12C; Campa and Ramírez, 1979; Altamira-Areyán, 2002; Morales Morales-Gámez, 2005; Martini et al., 2009). Vent-proximal volcanic rocks were deposited upon this unconformity in coastal Zihuatanejo terrane at the same time that marine clastic sediment was being deposited in foreland basins on the Teloloapan and Mixteca terranes (Fig. 12C). Thus, deformation clearly migrated from west to east (inboard) with time.

By Santonian–Maastrichtian time, the fold-and-thrust belt had migrated even further east, into the Teloloapan and Mixteca terranes (Fig. 12D; Salinas-Prieto et al., 2000; Guerrero-Suastegui, 2004; Cerca et al., 2007), and by the end of Maastrichtian time, proximal foreland basin fill of the Mixteca terrane was involved in the thrusting (Fig. 12D; Guerrero-Suastegui, 2004; Cerca et al., 2007). Thus, the Santonian–Maastrichtian contractional arc developed in the wake of this inboard-migrating deformation. We infer that Santonian–Maastrichtian strata in the study area represent the fill of an intra-arc basin within a compressional arc.

In a more regional perspective, it is widely agreed that the early Late Cretaceous continental arc of the Baja California Peninsula migrated eastward into western mainland Mexico during the same time frame. Upper Cretaceous rocks include both batholithic and volcanic rocks in northwest mainland Mexico at the latitudes of Sonora and Sinaloa States (see references in Ramos-Velázquez et al., 2008; Valencia-Moreno et al., 2001), and batholithic rocks farther south at the latitude of the Trans-Mexican volcanic belt in Jalisco State (Puerto Vallarta Batholith; Fletcher et al., 2007). Our new detrital zircon dates show that arc volcanic rocks of late Late Cretaceous age also exist in the study area, in the coastal Zihuatanejo terrane (Fig. 12D).

One of the major conclusions that can be drawn from our study is that the western Zihuatanejo terrane records a more protracted history of arc magmatism than has yet been dated in other terranes of western Mexico, except for Baja California. Another major conclusion is that pulses of magmatism in our study area closely match those dated in Baja California to the west, except for the Cenomanian magmatic event, which dominates the Peninsular Ranges of Baja California, but is only recorded in the detrital zircons of the Zihuatanejo terrane (Fig. 10), consistent with the preliminary interpretation that the Cenomanian strata represent retroarc foreland basin fill. In contrast, existing detrital and magmatic zircon ages from other, more inboard terranes of the Guerrero composite terrane (Arcelia, Teloloapan, and Guanajuato terranes) are restricted to pre-Albian time.

CONCLUSIONS

In this paper, we have integrated stratigraphic, volcanologic, sedimentologic, structural, and geochronological data to define two lithostratigraphic assemblages within Cretaceous rocks of the western Zihuatanejo terrane (Guerrero composite terrane): a Jurassic–Early Cretaceous extensional arc assemblage, and a Late Cretaceous compressional arc assemblage. In addition, we speculate that an early Late Cretaceous retroarc foreland assemblage intervenes between the two assemblages, but further work is needed to test this model.

Field evidence together with new detrital zircon data indicate the following:

(1) The basement to the Zihuatanejo terrane (Triassic to Jurassic [?] Arteaga complex) has prominent Grenville, Pan-African, and Permian zircon populations, considered to be "Gondwanan/eastern Mexico" signatures. This suggests that the Guerrero composite terrane was located close to the continental margin during its earliest history.

(2) The Arteaga accretionary complex, Jurassic arc detritus, and Neocomian arc detritus were locally recycled into intra-arc basins through Aptian–Albian time due to extensional unroofing within the arc.

(3) We identify previously unrecognized Santonian–Maastrichtian nonmarine arc volcanic and volcaniclastic rocks. These strata are important for constraining the timing of shortening in the coastal Zihuatanejo terrane because they overlie the folded strata; we interpret them to record deposition in intramontane basins within a compressional arc.

To summarize, the evolution of the Zihuatanejo terrane can be described by earlier extensional and later contractional processes operating entirely within the upper plate of a long-lived subduction zone that dipped east under the Mexican margin. Continental margin rifting and addition of new igneous and volcaniclastic material during extension created new crust, which was then accreted to the Mexican margin during a contractional phase. This led to substantial growth of the Mexican margin and supports models for significant growth of continents in this manner (Collins, 2002, 2009; Busby, 2004).

ACKNOWLEDGMENTS

This work was supported by a UC (University of California) Mexus grant to Elena Centeno-García and Cathy Busby, and by UNAM-PAPIIT (Universidad Nacional Autónoma de México, Programa de Apoyo a Proyectos de Investigación e Innovación Tecnológica) grants IN109605-3 and IN115208 to Elena Centeno-García, and National Science Foundation EAR-0732436 grant to Gehrels for support of the Arizona Laser Chron Center. The third author, Michael Busby (not related to Cathy Busby), was a University of California–Santa Barbara undergraduate student who was supported on the UC Mexus grant, and was trained to gather detrital zircon data in the fourth author's laboratory. We thank José Luis Sanchez Zavala for assistance in the field and discussions of the results, and Rodrigo Hernández Ordoñez for help with field work and mapping. We are thankful to Martin Guerrero, Oscar Talavera, Luca Ferrari, Michelangelo Martini, David Kimbrough, and Marty Grove for their comments and discussions. Special thanks are due to Jim Mortensen and an anonymous reviewer, and editors John Fletcher and Brendan Murphy for their comments, which greatly improved the manuscript.

REFERENCES CITED

Alencaster, G., 1986, Nuevo rudist (Bivalvia-Hippuritacea) del Cretácico Inferior de Pihuamo, Jalisco: Boletín de la Sociedad Geológica Mexicana, v. XLVII, no. 1, p. 47–60.

Alencaster, G., and Pantoja-Alor, J., 1986, *Coalcomana ramosa* (Bohem) (Bivalvia-Hippuritacea) del Albiano temprano del Cerro de Tuxpan, Jalisco: Boletín Sociedad Geológica Mexicana, v. XLVII, no. 1, p. 33–46.

Allan, J.F., 1986, Geology of the northern Colima and Zacoalco grabens, southwest Mexico: late Cenozoic rifting in the Mexican volcanic belt: Geological Society of America Bulletin, v. 97, p. 473–485.

Altamira Areyán, A., 2002, Las Litofacies y sus Implicaciones de la Cuenca Sedimentaria Cutzamala-Tiquicheo, Estado de Guerrero y Michoacán, México [M.S. thesis]: México, Universidad Nacional Autónoma de México, Instituto de Geología, 79 p.

Alvarado-Méndez, H., Bastida-Jiménez, R., and Vázquez-Tortoledo, R., 2004, Carta Geológico-Minera Coalcomán: Servicio Geológico Mexicano, carta E13–B56, scale 1:50,000, 1 sheet.

Alvarado-Méndez, H., Bastida-Jiménez, R., and Vázquez-Tortoledo, R., 2006, Carta Geológico-Minera Playa Azul: Servicio Geológico Mexicano, carta E13–B88, scale 1:50,000, 1 sheet.

Barragán, R., González-Arreola, C., and Villaseñor, A.B., 2004, Palaeoecological significance of Barremian ammonite assemblages and facies variations from southwest Mexico: Lethaia, v. 37, no. 3, p. 223–234.

Barrios-Rodríguez, F., Bastida-Jiménez, R., and Rosales-Franco, E., 2002, Carta Geológico-Minera Lázaro Cárdenas E13–6-9, Michoacán, Colima, Guerrero y Jalisco: Servicio Geológico Mexicano, carta E13–6-9, scale 1:250,000, 1 sheet.

Bissig, T., Mortensen, J.K., Tosdal, R.M., and Hall, B.V., 2008, The rhyolite-hosted volcanogenic massive sulfide district of Cuale, Guerrero terrane, west-central Mexico: Silver-rich base metal mineralization emplaced in a shallow marine continental margin setting: Economic Geology and the Bulletin of the Society of Economic Geologists, v. 103, p. 141–159.

Boehm, D., 1889a, Beiträge zur Kenntniss mexicanischer Caprinidenkalkes, *in* Felix, J., and Lenk, H., eds., Beiträge zur Geologie und Paläontologie der Republik Mexico, Pt. 11, no. IV: Leipzig and Stuttgart, E. Nägele, p. 143–154.

Boehm, G., 1889b, Über Capriniden kalke aus Mexico: Palaeontographica, v. 50, p. 323–332.

Böhnel, H., Alva-Valdivia, L., Gonzalez-Huesca, S., Urrutia-Fucugauchi, J., Moran-Zenteno, D.J., and Schaaf, P., 1989, Paleomagnetic data and the accretion of the Guerrero terrane, southwestern Mexico continental margin, *in* Hillhouse, J.W., ed., Deep Structure and Past Kinematics of Accreted Terranes: American Geophysical Union Geophysical Monograph 50, p. 73–92.

Buitrón, B.E., 1986, Gasterópodos del Cretácico (Aptiano Tardío-Albiano Temprano) del Cerro de Tuxpan, Jalisco: Sociedad Geológica Mexicana Boletin (Instituto de Estudios de Poblacion y Desarrollo [Dominican Republic]), v. XLVII, no. 1, p. 17–32.

Buitrón-Sánchez, B.E., and López-Tinajero, Y., 1995, Mollusk gastropods in Lower Cretaceous rudist-bearing formation of Jalisco, west central Mexico: Revista Mexicana de Ciencias Geológicas, v. 12, no. 2, p. 157–168.

Buitrón-Sánchez, B.E., and Pantoja-Alór, J., 1998, Albian gastropods of the rudist-bearing Mal Paso Formation, Chumbítaro region, Guerrero, Mexico: Revista Mexicana de Ciencias Geológicas, v. 15, no. 1, p. 14–20.

Busby, C.J., 2004, Continental growth at convergent margins facing large ocean basins: A case study from Mesozoic Baja California, Mexico: Tectonophysics, v. 392, p. 241–277.

Busby-Spera, C.J., Mattinson, J.M., Riggs, N.R., and Schermer, E.R., 1990, The Triassic-Jurassic magmatic arc in the Mojave-Sonoran deserts and the Sierran-Klamath region; similarities and differences in paleogeographic evolution, *in* Harwood, D., and Miller, M.M., eds., Paleozoic and Early Mesozoic Paleogeographic Relations; Sierra Nevada, Klamath Mountains, and related terranes: Geological Society of America Special Paper 255, p. 325–338.

Busby, C.J., Smith, D.P., Morris, W.R., and Adams, B., 1998, Evolutionary model for convergent margins facing large ocean basins: Mesozoic Baja California (Mexico): Geology, v. 26, no. 3, p. 227–230.

Busby, C.J., Fackler Adams, B., Mattinson, J., and De Oreo, S., 2006, View of an intact oceanic arc, from surficial to mesozonal levels: Cretaceous Alisitos Arc, Baja California, Mexico: Journal of Volcanology and Geothermal Research, v. 149, p. 1–46.

Campa, M.F., and Ramírez, J., 1979, La Evolución Geológica y la Metalogénesis de Guerrero: Universidad Autónoma de Guerrero, Serie Técnico-Científica, Volume 1: Chilpancingo, Guerrero, 84 p.

Campa, M.F., Ramírez, J., and Bloome, C., 1982, La secuencia volcanico-sedimentaria metamorfizada del Triasico (Ladiniano-Carnico) de la region de Tumbiscatio, Michoacan, *in* Sociedad Geológica Mexicana VI Convención Geológica Nacional, 6 Resúmenes: México D.F., Sociedad Geológica Mexicana, 48 p.

Centeno-García, E., 2005, Review of Upper Paleozoic and Lower Mesozoic stratigraphy and depositional environments of central and west Mexico: Constraints on terrane analysis and paleogeography, *in* Anderson, T.H., Nourse, J.A., McKee, J.W., and Steiner, M.B., eds., The Mojave-Sonora Megashear Hypothesis: Development, Assessment, and Alternatives: Geological Society of America Special Paper 393, p. 233–258.

Centeno-García, E., Ruíz, J., Coney, P.J., Patchett, P.J., and Ortega-Gutiérrez, F., 1993, Geology of the Guerrero terrane and its role in the tectonic evolution of the southern North America Cordillera from new geochemical data: Geology, v. 21, p. 419–422.

Centeno-García, E., Corona-Chavez, P., Talavera-Mendoza, O., and Iriondo, A., 2003, Geology and tectonic evolution of the Western Guerrero terrane—A transect from Puerto Vallarta to Zihuatanejo, México, *in* Alcayde, M., and Gómez-Caballero, A., eds., Geologic Transects across Cordilleran México: Guidebook for Field Trips of the 99th GSA Cordilleran Section Meeting: Universidad Nacional Autónoma de México, Instituto de Geología Publicación Especial 1, p. 201–228.

Centeno-Garcia, E., Gehrels, G., Diaz-Salgado, C., and Talavera-Mendoza, O., 2005, Zircon provenance of Triassic (Paleozoic?) turbidites from central and western Mexico: Implications for the early evolution of the Guerrero Arc, Geological Society of America, 101st Cordilleran Section Annual Meeting, Abstracts with Programs, v. 37, no. 4, p. 12.

Centeno-García, E., Guerrero-Suastegui, M., and Talavera-Mendoza, O., 2008, The Guerrero composite terrane of western Mexico: Collision and subsequent rifting in a supra-subduction zone, *in* Draut, A., Clift, P.D., and Scholl, D.W., eds., Formation and Applications of the Sedimentary Record in Arc Collision Zones: Geological Society of America Special Paper 436, p. 279–308.

Cerca, M., Ferrari, L., López-Martínez, M., Martiny, B., and Iriondo, A., 2007, Late Cretaceous shortening and early Tertiary shearing in the central Sierra Madre del Sur, southern Mexico: Insights into the evolution of the Caribbean–North American plate interaction: Tectonics, v. 26, p. TC3007, doi: 10.1029/2006TC001981.

Collins, W.J., 2002, Hot orogens, tectonic switching, and creation of continental crust: Geology, v. 30, p. 535–538, doi: 10.1130/0091-7613(2002)030<0535:HOTSAC>2.0.CO;2.

Collins, W.J., 2009, Growth and stabilization of continental crust by back-arc opening and closing in the Paleozoic Tasmanides of Eastern Australia: Geological Society of America Abstracts with Programs, v. 41, no. 7, p. 224.

Corona-Esquivel, R., and Alencaster, G., 1995, Rudists from the Peña Colorada Iron Mine and La Minita Sulfide Deposit, Colima and Michoacán States, SW Mexico: Revista Mexicana de Ciencias Geológicas, v. 12, no. 2, p. 185–190.

DeCelles, P.G., Timothy, F., Lawton, T.F., and Mitra, G., 1995, Thrust timing, growth of structural culminations, and synorogenic sedimentation in the type Sevier orogenic belt, western United States: Geology, v. 23, p. 699–702, doi: 10.1130/0091-7613(1995)023<0699:TTGOSC>2.3.CO;2.

De Cserna, Z., Palacios-Nieto, M., and Pantoja-Alor, J., 1978a, Relaciones de facies de las rocas Cretácicas en el noroeste de Guerrero y en áreas colindantes de México y Michoacán: Universidad Nacional Autónoma de México Instituto de Geología, Revista Mexicana de Ciencias Geológicas, v. 2, no. 1, p. 8–18.

De Cserna, Z., Armstrong, R., Yañez, C., and Solorio, J., 1978b, Rocas metavolcánicas y intrusivos relacionados paleozoicos de la región de Petatlán, Estado de Guerrero: Universidad Nacional Autónoma de México, Instituto de Geología, Revista Mexicana de Ciencias Geológicas, v. 2, no. 1, p. 1–7.

De la Campa, J., G., 1991, Geology and genesis of the La Minita barite deposit, Michoacán, *in* Salas, G.P., ed., Economic Geology, Mexico: Boulder, Colorado, Geological Society of America, The Geology of North America, v. P-3, p. 333–337.

Dickinson, W.R., 1988, Provenance and sediment dispersal in relation to paleotectonics and paleogeography of sedimentary basins, *in* Kleinspehn, K.L., and Paola, C., eds., New Perspectives in Basin Analysis: Berlin, Springer-Verlag, p. 3–25.

Dickinson, W.R., and Gehrels, G.E., 2003, U-Pb ages of detrital zircons from Permian and Jurassic eolian sandstones of the Colorado Plateau, USA: Paleogeographic implications: Sedimentary Geology, v. 163, p. 29–66, doi: 10.1016/S0037-0738(03)00158-1.

Dickinson, W.R., and Lawton, T.F., 2001, Carboniferous to Cretaceous assembly and fragmentation of Mexico: Geological Society of America Bulletin, v. 113, no. 9, p. 1142–1160.

Ferrusquía, I., Applegate, S.P., and Espinosa, L., 1978, Rocas volcanosedimentarias mesozoicas y huellas de dinosaurios en la región suroccidental pacífica de México: Universidad Nacional Autónoma de México, Instituto de Geología, Revista Mexicana de Ciencias Geológicas, v. 2, no. 2, p. 150–162.

Fletcher, J.M., Grove, M., Kimbrough, D.L., Lovera, O.M., and Gehrels, G.E., 2007, Ridge-trench interactions and the Neogene tectonic evolution of the Magdalena shelf and southern Gulf of California: Insights from detrital zircon U-Pb ages from the Magdalena fan and adjacent areas: Geological Society of America Bulletin, v. 119, p. 1313–1336.

Freydier, C., Lapierre, H., Briqueu, L., Tardy, M., Coulon, C., and Martínez, J., 1997, Volcaniclastic sequences with continental affinities within the Late Jurassic–Early Cretaceous intraoceanic arc terrane (western Mexico): The Journal of Geology, v. 105, p. 483–502.

Fries, C., Jr., 1960, Geología del Estado de Morelos y de Partes Adyacentes de México y Guerrero, Región Central Meridional de México: Universidad Nacional Autónoma de México, Instituto de Geología, Boletín 60, 236 p.

García-Barrera, P., and Pantoja-Alor, J., 1991, Equinoides del Albiano tardío de la Formación Mal Paso, de la región de Chumbítaro, estados de Guerrero y Michoacán, México: Revista de la Sociedad Mexicana de Paleontología, v. 4, p. 23–41.

Garduño-Monroy, V.H., Corona-Chavez, P., Israde-Alcantara, I., Mennella, L., Arreygue, E., Bigioggero, B., and Chiesa, S., 1999, Carta Geológica de Michoacán: Morelia, Michoacán, Universidad Michoacana de San Nicolás de Hidalgo, scale 1:250,000.

Gehrels, G.E., McClelland, W.C., Samson, S.D., and Patchett, P.J., 1991, U-Pb geochronology of detrital zircons from a continental margin assemblage in the northern Coast Mountains, southeastern Alaska: Canadian Journal of Earth Sciences, v. 28, p. 1285–1300.

Gillis, R.J., Gehrels, G.E., Ruiz, J., and Flores de Dios, L., 2005, Detrital zircon provenance of Cambrian–Ordovician and Carboniferous strata of the Oaxaca terrane, southern Mexico: Sedimentary Geology, v. 182, p. 87–100, doi: 10.1016/j.sedgeo.2005.07.013.

Goldhammer, R.K., 1999, Mesozoic sequence stratigraphy and paleogeographic evolution of northeast Mexico, *in* Bartolini, C., Wilson, J.L., and Lawton, T.F., eds., Mesozoic Sedimentary and Tectonic History of North-Central Mexico: Geological Society of America Special Paper 340, p. 197–210.

Grajales, M., and López, M., 1984, Estudio petrogenético de las rocas ígneas y metamorficas en el Prospecto Tomatlan-Guerrero-Jalisco: Instituto Mexicano del Petróleo, Subdirección de Tecnología y Exploración, Proyecto C-1160: Mexico, D.F., 76 p. (unpublished).

Grove, M., Kimbrough, D.L., Fletcher, J.M., and Lovera, O.M., 2006, Truncated lithotectonic belts and initial rupture within the southern Gulf of California: EOS, Transactions, American Geophysical Union, v. 87, no. 52, p. T41D–1615.

Guerrero-Suastegui, M., 1997, Depositional History and Sedimentary Petrology of the Huetamo Sequence, Southwestern Mexico [M.S. thesis]: El Paso, University of Texas, 95 p.

Guerrero-Suastegui, M., 2004, Depositional and Tectonic History of the Guerrero Terrane, Sierra Madre de Sur; with Emphasis on Sedimentary Successions of the Teloloapan Area, Southwestern Mexico [Ph.D. thesis]: St. John's, Newfoundland, Memorial University, 600 p.

Ingersoll, R.V., 2011, Tectonics of sedimentary basins, with revised nomenclature, *in* Busby, C.J., and Azor, A., eds., Recent Advances in Tectonics of Sedimentary Basins: Oxford, UK, Wiley-Blackwell (in press).

Ingersoll, R.V., and Busby, C.J., 1995, Tectonics of sedimentary basins, *in* Busby, C.J., and Ingersoll, R.V., eds., Tectonics of Sedimentary Basins: Blackwell Science: Oxford, UK, p. 1–52.

Keppie, J.D., 2004, Terranes of Mexico revisited: A 1.3 billion year odyssey: International Geology Review, v. 46, p. 765–794.

Keppie, J.D., Nance, R.D., Fernández-Suárez, J., Storey, C.D., Jeffries, T.E., and Murphy, J.B., 2006, Detrital zircon data from the Eastern Mixteca terrane, southern Mexico: Evidence for an Ordovician–Mississippian continental rise and a Permo-Triassic clastic wedge adjacent to Oaxaquia: International Geology Review, v. 48, p. 97–111.

Kimbrough, D.L., and Ledesma-Vasquez, J., 2008, Late Triassic paleo-oceanic basement framework of the Peninsular Ranges Batholith of Baja California: New evidence from the El Arco–Calmalli District: Geological Society of America Abstracts with Programs, v. 40, no. 6, p. 199.

Lang, H.R., Barros, J.A., Cabral-Cano, E., Draper, G., Harrison, C.G.A., Jansma, P.E., and Johnson, C.A., 1996, Terrane deletion in northern Guerrero State: Geofísica Internacional, v. 35, p. 349–359.

Lapierre, H., Ortiz, L.E., Abouchami, W., Monod, O., Coulon, C., and Zimmermann, J.L., 1992, A crustal section of an intra-oceanic island arc: The Late Jurassic–Early Cretaceous Guanajuato magmatic sequence, central Mexico: Earth and Planetary Science Letters, v. 108, p. 61–77.

Ludwig, K.R., 1991, A Computer Program for Processing Pb-U-Th Isotopic Data: U.S. Geological Survey Open-File Report 88–452, 34 p.

Mariscal-Ramos, C., Talavera-Mendoza, O., Centeno-García, E., Morales-Gámez, M., and Benammi, M., 2005, Preliminary magnetostratigraphic study of the Upper Cretaceous dinosaur site from La Barranca Los Bonites, Tiquicheo (Michoacán State, southern Mexico): Reunión Anual de la Unión Geofísica Mexicana, v. 25, no. 1, p. 57–58.

Martini, M., 2008, Estratigrafia, Deformación y Magmatismo de la Region Comprendida entre Huetamo y Zihuatanejo (Michoacán, Guerrero): Implicaciones para la Evolución Tectónica del Sur de México durante el Cretácico y Terciario Temprano [Ph.D. dissertation]: Juriquilla, Querétaro, México, Universidad Nacional Autónoma de México, Centro de Geociencias, 230 p.

Martini, M., Ferrari, L., López-Martínez, M., Cerca-Martínez, M., Valencia, V., and Serrano-Duran, L., 2009, Cretaceous-Eocene magmatism and Laramide deformation in south-western Mexico: No role for terrane accretion, *in* Kay, S.M., Ramos, V.A., and Dickinson, W.R., eds., Backbone of the Americas: Shallow Subduction, Plateau Uplift, and Ridge and Terrane Collision: Geological Society of America Memoir 204, p. 151–182, doi: 10.1130/2009.1204(07)

Mendoza, O.T., and Suastegui, M.G., 2000, Geochemistry and isotopic composition of the Guerrero terrane (western México): Implications for the tectonomagmatic evolution of southwestern North America during the late Mesozoic: Journal of South American Earth Sciences, v. 13, no. 4, p. 297–324.

Morales-Gámez, M., 2005, Geología Estructural del Sistema de Fallas Transcurrentes Pos-Cretácico de la Región de Tiquicheo, Michoacán, Sur de México [M.S. thesis]: México D.F., Universidad Nacional Autónoma de México, Instituto de Geología, 67 p.

Mortensen, J.K., Hall, B.V., Bissig, T., Friedman, R.M., Danielson, T., Oliver, J., Rhys, D.A., Ross, K.V., and Gabites, J.E., 2008, Age and paleotectonic setting of volcanogenic massive sulfide deposits in the Guerrero terrane of central Mexico: Constraints from U-Pb age and Pb isotope studies: Economic Geology and the Bulletin of the Society of Economic Geologists, v. 103, p. 117–140.

Omaña-Pulido, L., and Pantoja-Alor, J., 1998, Early Aptian benthic foraminifera from the El Cajón Formation, Huetamo, Michoacán, SW Mexico: Revista Mexicana de Ciencias Geológicas, v. 15, no. 1, p. 64–72.

Omaña-Pulido, L., González-Arreola, C., and Ramírez-Garza, B.M., 2005, Barremian planktonic foraminiferal events correlated with the ammonite zones from the San Lucas Formation, Michoacán (SW Mexico): Revista Mexicana de Ciencias Geológicas, v. 22, no. 1, p. 88–96.

Ortiz-Hernandez, E.L., Chiodi, M., Lapierre, H., Monod, O., and Calvet, P., 1992, El arco intraoceánico alóctono (Cretácico Inferior) de Guanajuato-características petrográficas, geoquímicas, estructurales e isotópicas del complejo filonianao y de las lavas basálticas asociadas, implicaciones geodinámicas: Universidad Nacional Autónoma de México, Instituto de Geología, Revista Mexicana de Ciencias Geológicas, v. 9, no. 2, p. 126–145.

Ortiz-Hernández, E.L., Acevedo-Sandoval, O.A., and Flores-Castro, K., 2003, Early Cretaceous intraplate seamounts from Guanajuato, central México, geochemical and mineralogical data: Universidad Nacional Autónoma de México, Instituto de Geología, Revista Mexicana de Ciencias Geológicas, v. 20, no. 1, p. 27–40.

Pantoja-Alor, J., 1959, Estudio geológico de reconocimiento de la región de Huetamo, Estado de Michoacán: Consejo de Recursos Naturales no Renovables Boletin (Instituto de Estudios de Poblacion y Desarrollo [Dominican Republic]), v. 50, p. 3–33.

Pantoja, A.J., and Estrada, B.S., 1986, Estratigrafía de los alrededores de la mina de fierro de El Encino, Jalisco: Sociedad Geológica Mexicana Boletin (Instituto de Estudios de Poblacion y Desarrollo [Dominican Republic]), v. 47, no. 1, p. 1–15.

Pantoja-Alor, J., and Gómez-Caballero, J.A., 2003, Geologic features and biostratigraphy of the Cretaceous of southwestern México (Guerrero terrane), *in* Alcayde, M., and Gómez-Caballero, A., eds., Geologic Transects across Cordilleran Mexico, Guidebook for the Field Trips of the 99th Geological Society of America Cordilleran Section Annual Meeting, Puerto Vallarta, Jalisco, Mexico, 4–7 April 2003: Universidad Nacional Autónoma de México, Instituto de Geología, Special Publication 1, p. 229–260.

Ramírez-Espinosa, J., Campa, M.F., Talavera, O., and Guerrero, M., 1991, Caracterización de los arcos insulares de la Sierra Madre del Sur y sus implicaciones tectónicas: Convención sobre la evolución Geológica Mexicana, *in* 1st Congreso Mexicano de Mineralogía Memoir: Pachuca, Hidalgo State, Sociedad Mexicana de Mineralogía and Instituto de Geología, Universidad Nacional Autónoma de México, p. 163–166.

Ramos-Velázquez, E., Calmus, T., Valencia, V., Iriondo, A., Valencia-Moreno, M., and Bellon, H., 2008, U-Pb and $^{40}Ar/^{39}Ar$ geochronology of the coastal Sonora Batholith: New insights on Laramide continental arc magmatism (Geocronología U-Pb y $^{40}Ar/^{39}Ar$ del batolito costero de Sonora: Nuevas aportaciones al magmatismo laramídico de arco continental): Universidad Nacional Autónoma de México, Instituto de Geología, Revista Mexicana de Ciencias Geológicas, v. 25, no. 2, p. 314–333.

Rosas-Helguera, J., Barrera-Hernández, D., Pérez-Rodríguez, G., Valladolid-Cacho, R., Vázquez-Tortoledo, R., and Romo-Ramírez, J., 1999, Carta Geológico-Minera Colima E13–3, Colima, Jalisco y Michoacán: Universidad de Guadalajara and Servicio Geológico Mexicano, carta E13–3, scale 1:250,000, 1 sheet.

Salinas-Prieto, J.C., Monod, O., and Faure, M., 2000, Ductile deformations of opposite vergence in the eastern part of the Guerrero terrane (SW Mexico): Journal of South American Earth Sciences, v. 13, p. 389–402.

Schaaf, P., and Martínez, S.R., 1997, The Puerto Vallarta Batholith, an example for multicomponent parenthood of continental arc magmas, *in* International Association of Volcanology and Chemistry on the Earth's Interior (IAVCEI), General Assembly, Puerto Vallarta, 1997, Field Trip Guide, Excursion 8: México, D.F., Instituto de Geofísica Universidad Nacional Autónoma de México, 24 p.

Schaaf, P., Moran, Z.D., Hernandez, B.M.S., Pichardo, S.G., Tolson, G., and Köhler, H., 1995, Paleogene continental margin truncation in southwestern Mexico: Geochronological evidence: Tectonics, v. 14, p. 1339–1350.

Schaaf, P., Böhnel, H., and Pérez-Venzor, P.A., 2000, Pre-Miocene palaeogeography of the Los Cabos block, Baja California sur: Geochronological and palaeomagnetic constraints: Tectonophysics, v. 318, p. 53–69.

Schaaf, P., Hall, B.V., and Bissig, T., 2003, The Puerto Vallarta Batholith and Cuale Mining District, Jalisco, Mexico—High diversity parenthood of continental arc magmas and Kuroko-type volcanogenic massive sulphide deposits, *in* Morán-Zenteno, D.J., ed., Geologic Transects across Cordilleran Mexico, Guidebook for Field-Trips of the 99th Annual Meeting of the Cordilleran Section of the Geological Society of America, Volume: Universidad Nacional Autónoma de México, Instituto de Geología, Publicación Especial 1, p. 183–199.

Solari, L.A., Keppie, J.D., Ortega-Gutierrez, F., Cameron, K.L., López, R., and Hames, W.E., 2003, 990 and 1100 Ma Grenvillian tectonothermal events in the northern Oaxacan complex, southern Mexico: Roots of an orogen: Tectonophysics, v. 365, no. 1, p. 257–282.

Stacey, J.S., and Kramers, J.D., 1975, Approximation of terrestrial lead isotope evolution by a two-stage model: Earth and Planetary Science Letters, v. 26, p. 207–221, doi: 10.1016/0012-821X(75)90088-6.

Talavera, M.O., 2000, Mélanges in southern México: Geochemistry and metamorphism of Las Ollas complex (Guerrero terrane): Canadian Journal of Earth Sciences, v. 37, p. 1309–1320.

Talavera-Mendoza, O., Ramírez-Espinosa, J., and Guerrero-Suástegui, M., 1995, Petrology and geochemistry of the Teloloapan subterrane, a Lower Cretaceous evolved intra-oceanic island-arc: Geofísica Internacional, v. 34, p. 3–22.

Talavera-Mendoza, O., Ruiz, J., Gehrels, G.E., Meza-Figueroa, D.M., Vega-Granillo, R., and Campa-Uranga, M.F., 2005, U-Pb geochronology of the Acatlán complex and implications for the Paleozoic paleogeography and tectonic evolution of southern Mexico: Earth and Planetary Science Letters, v. 235, p. 682–699, doi: 10.1016/j.epsl.2005.04.013.

Talavera-Mendoza, O., Ruiz, J., Gehrels, G., Valencia, V., and Centeno-García, E., 2007, Detrital zircon U/Pb geochronology of southern Guerrero and western Mixteca arc successions (southern Mexico): New insights for the tectonic evolution of southwestern North America during the late Mesozoic: Geological Society of America Bulletin, v. 119, p. 1052–1065.

Tardy, M., Lapierre, H., Freydier, C., Coulon, C., Gill, J.B., Mercier de Lepinay, B., Beck, C., Martinez, J., Talavera, M., Ortiz, E., Stein, G., Bourdier, J.L., and Yta, M., 1994, The Guerrero suspect terrane (western Mexico) and coeval arc terranes (the Greater Antilles and the Western Cordillera of Colombia): A late Mesozoic intra-oceanic arc accreted to cratonal America during the Cretaceous: Tectonophysics, v. 234, no. 4, p. 49–73.

Tunesi, A., Bergomi, M.A., Panseri, M., and Corona-Chavez, P., 2009, The Manzanillo Complex: New geochemical and SHRIMP geochronological study, *in* Marina Manea, M., Silva-Corona, J.J., Orozco-Esquivel, M.T., eds., GeoGuerrero, Simposio: El origen, naturaleza y evolución geológica del Terreno Guerro y sus conexiones regionales: Unidad Académica de Ciencias de la Tierra, Universidad Nacional Autónoma de México, p. 23. Abstracts online at http://www.geociencias.unam.mx/geosimposios/geos/2009/geoguerrero/poster/geoguerrero_resumenes.pdf.

Umhoefer, P., 2003, A speculative model on the North America Cordillera in the Early Cretaceous: Tectonic escape related to arc collision of the Guerrero terrane and a change in North America plate motion, *in* Johnson, S., Paterson, S., Kimbrough, D., Martin-Barajas, A. and Girty, G., eds., The Tectonic Evolution of Northwestern Mexico and the Southwestern USA: Geological Society of America Special Paper 374, p. 117–134.

Valencia-Moreno, M., Ruíz, J., Barton, M.D., Patchett, P.J., Zürcher, L., Hodkinson, D., and Roldán-Quintana, J., 2001, A chemical and isotopic study of the Laramide granitic belt of northwestern Mexico: Identification of the southern edge of the North American Precambrian basement: Geological Society of America Bulletin, v. 113, p. 1409–1422, doi: 10.1130/0016-7606(2001)113<1409:ACAISO>2.0.CO;2.

Wetmore, P.H., Schmidt, K.L., Paterson, S.R., and Herzig, C., 2002, Tectonic implications for the along-strike variation of the Peninsular Ranges Batholith, southern and Baja California: Geology, v. 30, p. 247–250.

Wetmore, P.H., Herzig, C., Alsleben, H., Sutherland, M., Schmidt, K.L., Schultz, P.W., and Paterson, S.R., 2003, Mesozoic tectonic evolution of the Peninsular Ranges of Southern and Baja California, *in* Johnson, S.E., Paterson, S.R., Fletcher, J.M., Girty, G.H., Kimbrough, D.L., Martin-Barajas, A., eds., Tectonic Evolution of Northwestern Mexico and the Southwestern United States: Geological Society of America Special Paper 374, p. 93–116.

Manuscript Received 12 February 2009
Revised Manuscript Received 18 May 2010
Manuscript Accepted 24 June 2010

Printed in the USA