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

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ABSTRACT

Late Jurassic–Cretaceous arc-related volcaniclastic rocks from the southern Guerrero and western Mixteca terranes of Mexico were analyzed by U-Pb detrital zircon geochronology (laser ablation-multicollector–inductively coupled plasma–mass spectroscopy) to place constraints on the depositional history and provenance of the rocks. Pre–Middle Jurassic basement rocks and sandstone from the Upper Cretaceous Mexcala Formation were also analyzed to define the origin and provenance of the prevolcanic substratum, and the time of accretion of Guerrero composite terrane sequences.

Data from the Taxco-Taxco Viejo, Teloloapan, and Arcelia assemblages indicate that the youngest (129–141 Ma) zircon fraction in each sequence was derived from local volcanic sources, whereas older populations (ca. 247–317, 365–459, 530–617, 712–878, 947–964, 1112–1188, 1350–1420, 1842–1929, 2126–2439, and 2709–3438 Ma) show sediment influx from varied sources, most likely through grain recycling. The major zircon clusters in these sequences match the populations recorded in the nearby Acatlán Complex. In contrast, the Huetamo sample is dominated by Lower Cretaceous (ca. 126 Ma) zircons of local volcanic provenance, and the Zihuatanejo sample contains zircon clusters (ca. 259, ca. 579, and ca. 947–1162 Ma) comparable to major populations recorded in the underlying Arteaga Complex.

A sample from the Middle Triassic–Middle Jurassic Arteaga Complex at Tzitzio contains zircon clusters (ca. 202–247, ca. 424, ca. 600, ca. 971, and ca. 2877 Ma) consistent with an ultimate derivation from both North American and South American sources. The sample from the Las Ollas suite contains comparable zircon populations (ca. 376–475, ca. 575, ca. 988–1141, and ca. 2642–2724 Ma), and it is interpreted to be part of the prevolcanic basement. In contrast, the youngest zircon cluster (ca. 105 Ma) in the Mexcala Formation coincides with the major volcanic events in the Taxco-Taxco Viejo, Teloloapan, and Arcelia assemblages, whereas the older clusters (ca. 600, ca. 953, ca. 1215, ca. 1913, and ca. 2656–2859 Ma) broadly match the major populations recorded in rocks from the Acatlán Complex.

These new data combined with available geochemical and isotopic data indicate that the Taxco-Taxco Viejo arc assemblage developed on continental crust. The Acatlán Complex is the most plausible candidate. The Teloloapan and Arcelia arc assemblages were developed on oceanic crust as offshore arcs facing the Acatlán Complex. The Zihuatanejo terrane assemblages were developed on the Arteaga Complex, and evidence no influence from the Acatlán Complex. This suggests that these assemblages were formed farther away or in a restricted basin.

The Guerrero composite and Mixteca arc successions are coeval with the Alisitos arc of northern Mexico and in part with the Nevada and Klamath ranges of the southwestern United States, and with the arc series from the Greater and Lesser Antilles and northern South America. Data indicate that during late Mesozoic time, southwestern North America was a site of intensive volcanism in a complex arc-trench system similar to that of the east Pacific. Our data are consistent with a diachronic accretion of the Guerrero composite terrane sequences, beginning during late Cenomanian time with the amalgamation of the Teloloapan and probably the Arcelia assemblages, and finishing at the end of Cretaceous time with the accretion of the Zihuatanejo terrane assemblages.

Keywords: U-Pb detrital zircon, Late Jurassic–Cretaceous arc successions, Guerrero terrane, Mixteca terrane, southern Mexico, southwestern North America, Caribbean region.

INTRODUCTION

The breakup of Pangea in early Mesozoic time produced a drastic change in the tectonic regime of the western margin of the Americas, resulting in a complex convergent margin. In the peri-Caribbean region, Triassic–Middle Jurassic convergence developed in an Andean-type continental margin (e.g., Dickinson, 1981; Grajales et al., 1992; Torres et al., 1999), whereas most Late Jurassic–Cretaceous volcanism took place in an

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GSA Bulletin; September/October 2007; v. 119; no. 9/10; p. 1052–1065; doi: 10.1130/B26016.1; 7 figures; Data Repository item 2007148.

intraoceanic setting (e.g., Centeno-García et al., 1993a, 1993b; Talavera-Mendoza, 1994, Mendoza and Guerrero, 2000; Snoke et al., 2001).

The Guerrero composite and Mixteca terranes of western-central Mexico contain the largest and most complete record of Upper Jurassic–Cretaceous arc successions of southern North America (Fig. 1). Arc series from these terranes are coeval with the Alisitos arc of northern Mexico and in part with the Nevada and Klamath arc magmatism of the southwestern United States. However, the evolution of the Guerrero and Mixteca magmatic arcs is commonly linked to the evolution of the Greater and Lesser Antilles, and therefore may help us to better understand the paleogeography and the tectonomagmatic evolution of southwestern North America during late Mesozoic time. The arcs may also provide important data on the geotectonic evolution of the proto-Caribbean region at the end of Mesozoic.

Geochemical and isotopic data collected in the past decade on rocks of the Guerrero and western Mixteca terranes have revealed a great diversity of magmatic suites, including island-arc tholeiites, calc-alkaline rocks, shoshonites, backarc basin basalts, and ocean island basalts (Tardy et al., 1994; Talavera-Mendoza, 1994; Mendoza and Guerrero, 2000). Available paleontological and radiometric data indicate that much of this volcanism took place simultaneously in a variety of tectonic settings. Amalgamation of volcanic successions with mainland Mexico began during Cenomanian time (e.g., Tardy et al., 1994) and continued to the latest Cretaceous Laramide orogeny (e.g., Campa and Coney, 1983; Centeno-García et al., 1993a; Talavera-Mendoza, 1994; Mendoza and Guerrero, 2000).

Even though the nature and timing of volcanism have been broadly defined in most volcanic assemblages, many aspects of their evolution remain poorly understood, e.g., whether volcanism took place in a single arc containing oceanic- and continental-based realms, or was produced by separate arc-trench systems (e.g., Centeno-García et al., 1993b; Tardy et al., 1994; Talavera-Mendoza, 1994; Mendoza and Guerrero, 2000), or built on several unrelated basement assemblages, or a single heterogeneous basement complex. Because there are few

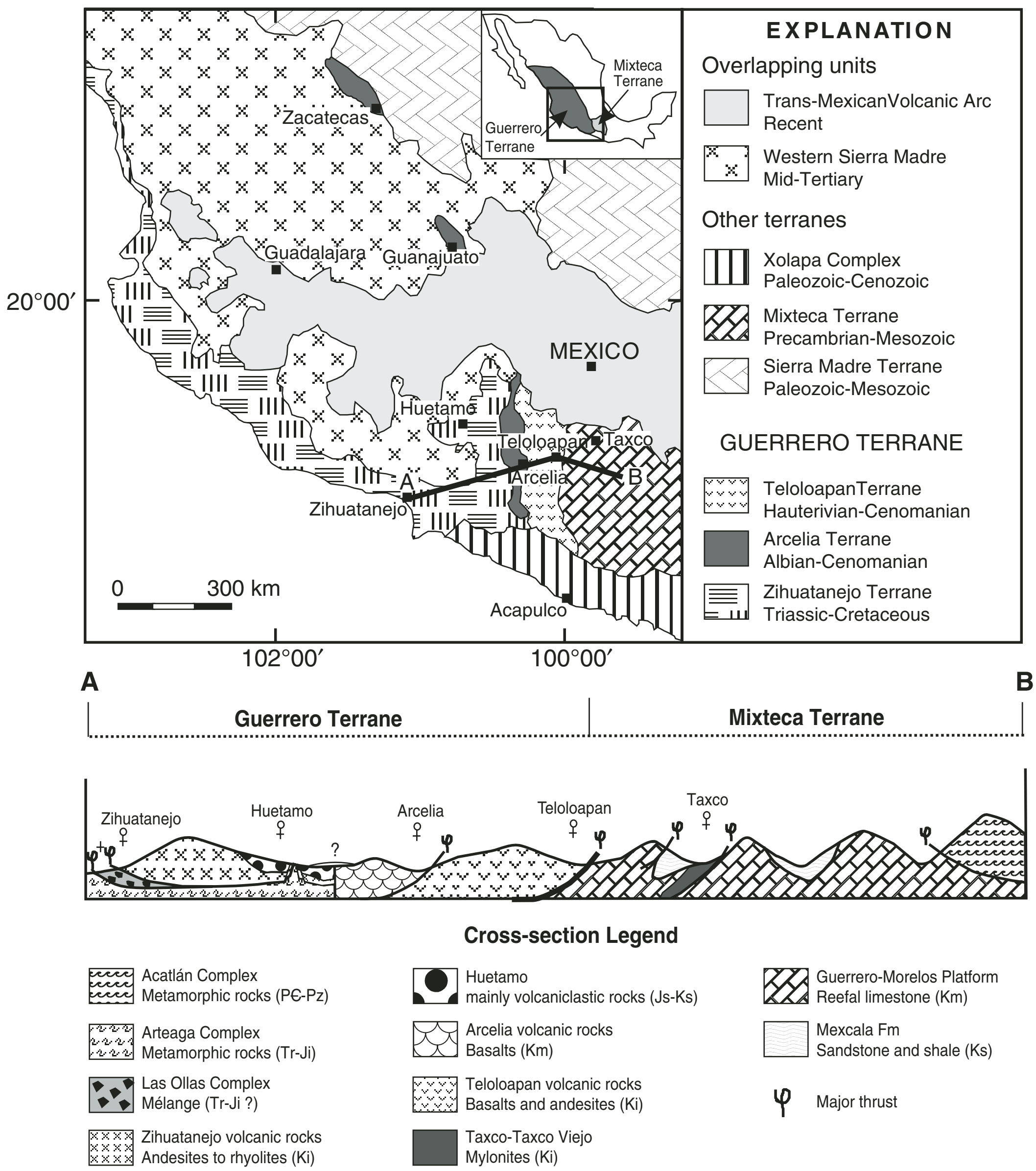

Figure 1. Terrane map of southwestern Mexico and schematic cross section showing distribution and structural relationship of Upper Jurassic–Cretaceous volcanic arc successions of southern Guerrero and western Mixteca terranes (after Mendoza and Guerrero, 2000).

constraints on the sedimentological relationships among the volcanic successions of the Guerrero composite terrane and between these successions and nuclear Mexico, it is not yet possible to determine if they evolved as offshore or far-traveled arcs.

In this study we present U-Pb geochronological data of detrital zircons from the most representative Upper Jurassic–Cretaceous volcano-sedimentary successions from the southern Guerrero composite and western Mixteca terranes in southern Mexico. The new data provide significant new insights into the depositional history, ages of ultimate parental rocks, and sedimentological relationships among successions. Detrital zircons from pre–Middle Jurassic sedimentary and metasedimentary assemblages were also analyzed to further delimit the origin and provenance of the prevolcanic basement. We also present analyses of detrital zircons from the foreland basin fill (Mexcala Formation), the origin of which has been related to the accretion of the Guerrero terrane assemblages (Campa et al., 1976; Tardy et al., 1994).

GEOLOGICAL SETTING

North of the Trans-Mexican Volcanic Arc, volcano-sedimentary successions of the Guerrero composite terrane are largely covered by mid-Tertiary volcanic rocks of Sierra Madre Occidental (Fig. 1). South of the arc, the upper Mesozoic volcano-sedimentary sequences crop out nearly continuously over more than 300 km, and in most cases, relationships between various sequences can be clearly established (Fig. 1).

In the Taxco-Zihuatanejo sector (Fig. 1), Upper Jurassic–Cretaceous volcano-sedimentary assemblages of the Guerrero composite and Mixteca terranes form four fault-bound, north-south–trending belts. From east to west, these are the Taxco-Taxco Viejo assemblage of the Mixteca terrane, the Teloloapan terrane, the Arcelia terrane, and the Zihuatanejo terrane of the Guerrero composite terrane (Fig. 1). We briefly summarize the main stratigraphic, geochemical, and isotopic characteristics of each sequence. For a complete and detailed description of the geology of the sectors, see Centeno-García et al. (1993b, 2003), Talavera-Mendoza et al. (1995), Mendoza and Guerrero (2000), Talavera (2000), and Centeno-García (2005).

Taxco-Taxco Viejo Assemblage

This assemblage consists of two relatively small and isolated exposures (~35 km^2) representing the lowest structural level in the Taxco-Taxco Viejo area (Fig. 2). Although no physical evidence has been presented, correlations suggest that this assemblage is underlain by Paleozoic rocks of the Acatlán Complex, which is the basement of the Mixteca terrane (Campa and Coney, 1983). The succession consists of a lower, ~700-m-thick unit composed essentially of interbedded andesitic to dacitic lava flows and polymictic conglomerate with minor layers of quartzose sandstone, tuffaceous shale, and scarce limestone. There is an upper, ~300-m-thick succession composed almost entirely of acidic tuff and tuffaceous shale (Fig. 3). The volcanic rocks are high-K calc-alkaline, typical of arcs on continental crust (Centeno-García et al., 1993b; Talavera-Mendoza, 1994). The age of the sequence is Early Cretaceous (130 ± 2.6 and 131 ± 0.85 Ma; U/Pb; Campa and Iriondo, 2003). The Mesozoic cover in this region includes Albian–lower Cenomanian limestone of the Morelos Formation and Turonian–Maastrichtian sandstone and shale of the Mexcala Formation (Fig. 3).

Teloloapan Terrane

The Teloloapan terrane is an ~100-km-wide and ~300-km-long volcano-sedimentary unit that represents the easternmost volcano-sedimentary assemblage of the Guerrero composite terrane. It consists of an ~3000-m-thick succession of basic to intermediate, pillowed and massive lavas, pillow breccias, and hyaloclastites. Volcanic rocks from lower levels are interbedded with cherty shale and siltstone containing Lower Cretaceous radiolaria. The upper levels are made up of lava flows interbedded with debris-flow deposits, and discontinuous layers of Aptian limestone (Guerrero et al., 1993). The volcanic rocks are medium-K calc-alkaline in composition, typical of mature island arcs (Talavera-Mendoza et al., 1995; Mendoza and Guerrero, 2000). These volcanic rocks are overlain by a thick (~1500 m) succession of Albian–lower Cenomanian graywacke and tuffaceous shale, reefal and bioclastic limestones, and Turonian turbiditic sandstone and shale (Fig. 3; Campa and Ramírez, 1979; Talavera-Mendoza et al., 1995; Monod et al., 2000). The nature of its basement is unknown. The Teloloapan terrane is thrust over the western margin of the Mixteca terrane and it is overthrust by the Arcelia terrane (Fig. 2).

Arcelia Terrane

The Arcelia terrane is an ~15-km-wide and ~250-km-long, north-south–trending belt west of, and thrusted over, the Teloloapan terrane (Fig. 2). The Arcelia terrane consists of an ~2000-m-thick volcanic unit including pillow lavas, pillow breccias, and hyaloclastites. The unit is intruded by numerous narrow doleritic dikes. The volcanic rocks contain horizons of radiolarian-bearing chert, cherty shale, and black shale particularly in the upper stratigraphic horizons. The volcanic rocks are capped by chert, cherty shale, black shale, and infrequent strata of uncommon fine-grained volcaniclastic sandstone (Fig. 3). Small bodies of serpentinized gabbros and ultramafites are structurally associated with pillow lavas and sedimentary rocks. Radiometric dating and paleontological determinations have bracketed the age of the Arcelia assemblage between Albian and Cenomanian (Delgado et al., 1990; Ortiz et al., 1991; Dávila and Guerrero, 1990).

The magmatic succession of the Arcelia terrane is composed of basaltic rocks. Based on their geochemical and isotopic characteristics, two distinctive magmatic suites have been recognized: an island-arc tholeiitic suite and a backarc suite containing both backarc basin basalts and ocean island basalts (Mendoza and Guerrero, 2000).

Zihuatanejo Terrane

Rocks assigned to this terrane are distributed along the Pacific margin from Zihuatanejo to Puerto Vallarta, and in the Huetamo area in the central Guerrero composite terrane (Fig. 2). The Zihuatanejo terrane is west of the Arcelia terrane. The contact between both assemblages is covered by mid-Tertiary volcanic and terrestrial deposits. Four distinctive assemblages compose the terrane.

1. The Zihuatanejo assemblage consists of ~2000 m of andesitic to rhyolitic volcanic rocks intercalated with volcaniclastic conglomerate, sandstone, and lenses of limestone in the uppermost stratigraphic levels (Fig. 3). This succession is capped by Albian–Cenomanian reefal limestone and red beds containing dinosaur footprints (Ferrusquía-Villafranca et al., 1978). In the Arteaga region, this succession unconformably overlies the Arteaga Complex (Centeno-García et al., 1993b). Volcanic rocks are differentiated medium-K calc-alkaline to shoshonitic, typical of mature island arcs (Mendoza and Guerrero, 2000).

2. The Las Ollas Complex consists of a succession of fault-bounded slices of tectonic mélanges composed of blocks of limestone, quartzite, chert, tuff, pillow basalt, amphibolite, gabbro, and serpentinized ultramafites enveloped in a sheared matrix of quartz-rich turbidites and serpentine (Fig. 3). Blocks of gabbro, basalt, and amphibolite show geochemical and isotopic characteristics of island-arc tholeiitic suites (Talavera, 2000; Mendoza and Guerrero, 2000). Some mafic blocks contain relicts of high-pressure blueschist facies (Talavera,

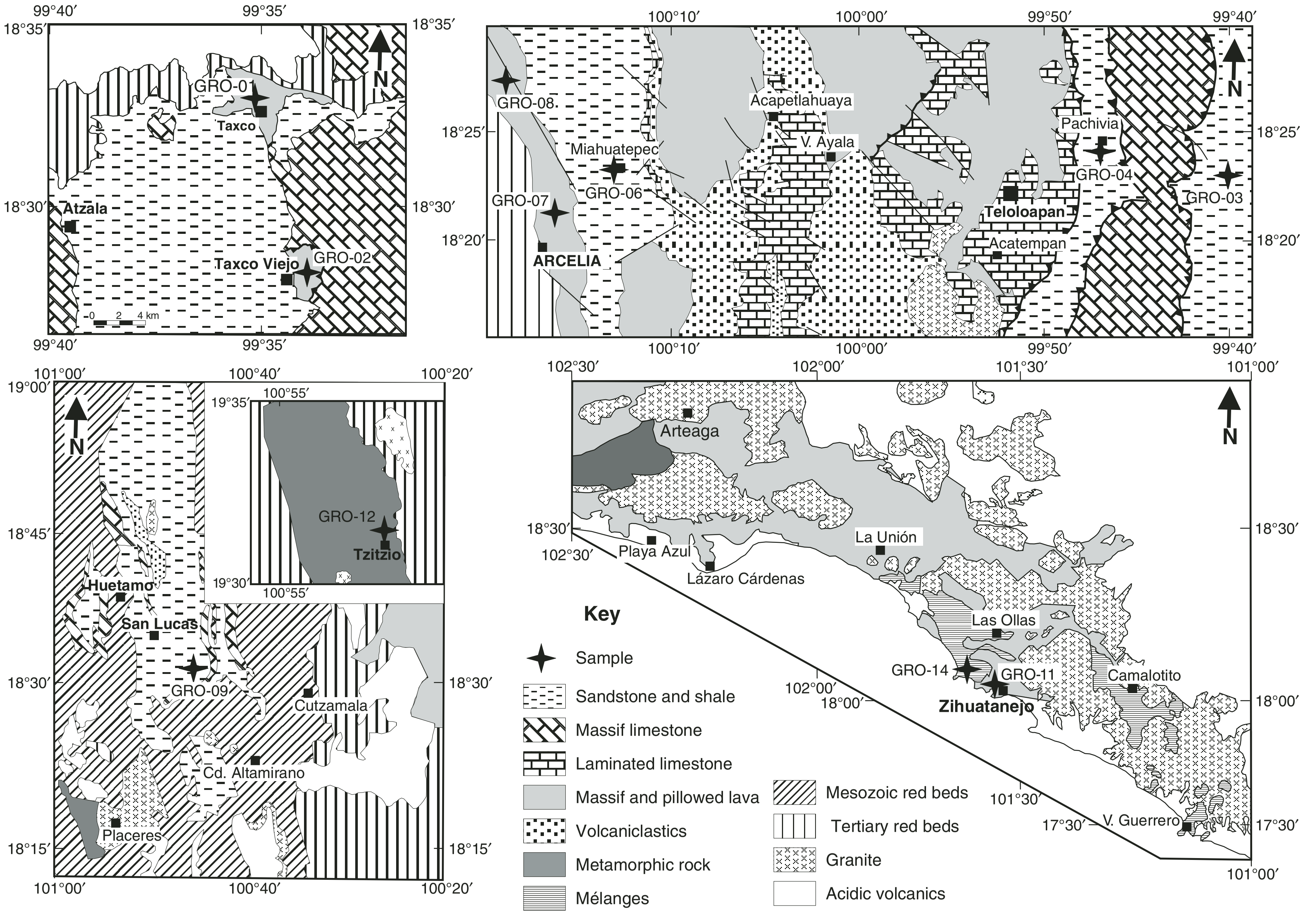

Figure 2. Geological maps of the Taxco, Teloloapan, Huetamo, and Zihuatanejo sectors showing locations of dated samples (Taxco and Huetamo maps after Campa and Ramírez, 1979; Teloloapan map after Ramírez et al., 1991; Zihuatanejo map after Vidal, 1984).

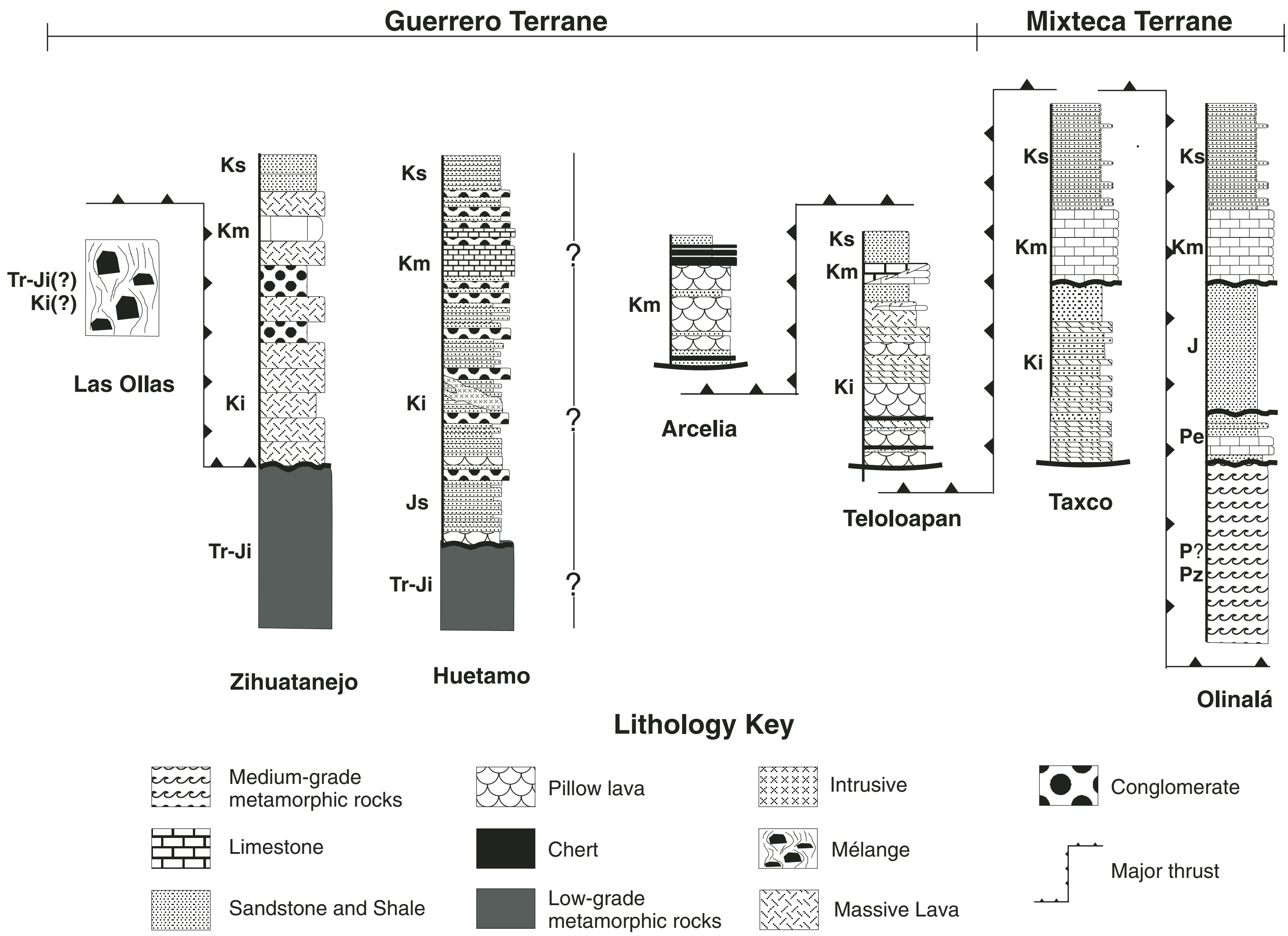

Figure 3. Stratigraphy and structural relationship of studied successions (after Talavera, 1994).

2000). Based on available cooling radiometric ages and field relationships, an Early Cretaceous age was previously assigned to the formation of this suite (Talavera, 2000).

3. The Huetamo assemblage consists of ~4500 m of mainly sedimentary rocks of Late Jurassic–Late Cretaceous age that crop out in the Huetamo region in the central Guerrero composite terrane (Fig. 2). Although the base of the lithostratigraphic succession is not exposed, it is inferred to unconformably overlie a metamorphosed basement represented by the Arteaga Complex, which crops out southwest and north of Huetamo (e.g., Campa and Ramírez, 1979; Centeno-García et al., 1993a). It is made up of Tithonian volcaniclastic deposits, cherty shale, and uncommon pillow basalt of the Angao Formation, grading upward into a succession of Neocomian volcaniclastic turbidites of the San Lucas Formation, which is the thickest sedimentary unit of the Huetamo assemblage. The top of the sedimentary pile contains Aptian–Maastrichtian(?) reefal limestone and red beds of the Cutzamala and El Cajón formations (Fig. 3).

4. The Arteaga Complex represents the lowermost structural levels of the western Guerrero terrane and is actually considered to be the prevolcanic basement over which the Zihuatanejo arc was developed (Centeno-García et al., 1993b, 2003; Centeno-García, 2005). Paleontological and radiometric data from crosscutting granites have bracketed the age of deposition as Norian–Carnian, and the age of deformation as earlier than the Middle Jurassic (Centeno-García et al., 2003; Centeno-García, 2005). This complex comprises a thick succession of quartzose sandstone, black shale, radiolarian-bearing chert, and conglomerate containing meter- to mountain-size lenses of pillow lava, massive flows, banded gabbros, green chert, and rare recrystallized limestone (Fig. 3). Pillow basalts show geochemical and isotopic characteristics of mid-ocean ridge basalts (Centeno-García et al., 1993b). Thick (~900 m) layers of green volcaniclastic sandstone and shale are intercalated in the succession. The Arteaga Complex is strongly deformed and, in some areas, metamorphosed to greenschist to amphibolite facies. It forms a block-in-matrix suite characteristic of a subduction complex (Centeno-García, 2005).

SAMPLING AND ANALYTICAL METHODS

Detrital zircons from eight representative samples from the Upper Jurassic–Cretaceous volcano-sedimentary assemblages from the southern Guerrero composite and western Mixteca terranes were analyzed. Two samples from pre–Middle Jurassic basement rocks and one sample from the Upper Cretaceous Mexcala Formation were also studied. Analyses from the Acatlán Complex, inferred to underlie the Taxco-Taxco Viejo assemblage, were presented in Talavera-Mendoza et al. (2005). Figure 2 shows the locations of the samples. Geochronological data and the geographic locations of samples are indicated in GSA Data Repository Table DR1[1]. A brief description of the samples is presented in the results section.

We processed ~2 kg of each sample for zircons using standard heavy liquid and magnetic separation methods. A large fraction of the recovered zircons was mounted in epoxy resin and polished; 100 zircons from each sample were analyzed. Selection of zircons for analyses was made at random from all of the zircons mounted. Cores of grains were preferred to avoid possible metamorphic overgrowth or alteration.

Analyses were performed with a Micromass Isoprobe multicollector–inductively coupled plasma–mass spectrometer (ICPMS) equipped with a New Wave DUV 193 nm Excimer laser ablation (LA) system at the University of Arizona. The analytical procedure was 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. Only grains largely exceeding the used spot size were analyzed. Isotopic fractionation was monitored by analyzing an in-house zircon standard, which has a concordant thermal ionization mass spectrometry (TIMS) age of 564 ± 4 Ma (Dickinson and Gehrels, 2003). This standard was analyzed once for every five unknowns. Uranium and Th concentrations were monitored by analyzing a standard (National Institute of Standards 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 lead isotopic ratios were corrected for common Pb using the measured ^{204}Pb, assuming an initial Pb composition according to Stacey and Kramers (1975) and uncertainties of 1.0%, 0.3%, and 2.0%, respectively, for $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$, and $^{208}Pb/^{204}Pb$.

Ages are considered reliable if five or more analyses performed in different grains yield overlapping $^{206}Pb/^{238}U$ or $^{206}Pb/^{207}Pb$ ages. This strategy is used because of the low precision of $^{206}Pb/^{207}Pb$ ages for young grains, making concordance and/or discordance poor criteria for determining reliability. Gillis et al. (2005) demonstrated that U-Pb ages of detrital zircons analyzed using both isotope dilution–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.

Modal analyses were carried out on sandstone samples collected from all assemblages to constrain interpretations from the detrital zircon geochronology; the data were plotted on ternary diagrams (Fig. 4) (Dickinson and Suczek, 1979).

RESULTS

Taxco-Taxco Viejo Assemblage

Two samples from the Lower Cretaceous Taxco-Taxco Viejo succession were analyzed. Sample GRO-01 is a fine-grained tuffaceous sandstone intercalated with sericitic schist (collected on the Federal Highway at Taxco). Sample GRO-02 is an acidic tuff from upper stratigraphic levels of the Taxco Viejo exposures, ~200 m below the contact with the Mexcala Formation. Both samples contain predominantly recrystallized volcanic material presumably of pyroclastic origin (Campa et al, 1974; Talavera-Mendoza, 1994). In both samples, zircons are small (<50 µm) and whitish to colorless; most are thin and elongated with well-developed prismatic and bipyramidal forms that resemble zircons reported in volcanic successions (Pupin, 1983; Dabard et al., 1996). A significant population of zircons in sample GRO-01 is subrounded, suggesting a detrital origin. The difference in zircon morphology is clearly reflected in recorded ages (Fig. 5). Sample GRO-01 yields Paleoproterozoic to Cretaceous ages ranging from 2115 ± 40 to 113 ± 5 Ma; one Archean grain is 2709 ± 35 Ma. In this sample, the most important cluster occurs in the range 153–113 Ma (peak ca. 131 Ma) with smaller populations ca. 459, ca. 723, ca. 1102, and ca. 1482 Ma (Fig. 6). By contrast, sample GRO-02 yields mainly Upper Jurassic–Lower Cretaceous zircons in the range 158 ± 23 to 128 ± 6 Ma (peak ca. 141 Ma), with only two older grains at 280 ± 42 and 1128 ± 181 Ma. In both samples, the U/Th ratios of zircons are <9, indicating a magmatic origin (Rubatto, 2002).

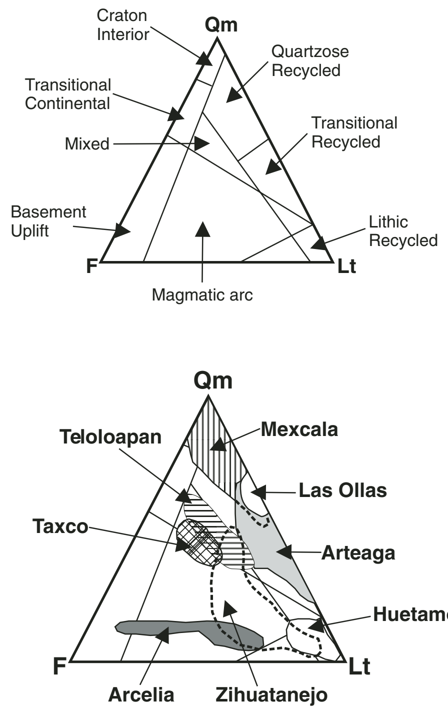

Figure 4. Ternary diagram illustrating the composition of sandstone from the southern Guerrero composite and western Mixteca terrane successions. Provenance fields are from Dickinson and Suczek (1979).

Teloloapan Terrane

Two samples from the Teloloapan terrane were analyzed. Samples GRO-04 and GRO-06 are medium-grained sandstone collected from the middle stratigraphic levels of the Turonian turbidites of the Pachivia and Miahuatepec successions, which cap the Teloloapan Lower Cretaceous volcanic rocks (Figs. 2 and 3). Modal studies indicate that sandstone from these units is composed of grains of quartz, feldspar, abundant volcanic and clastic sedimentary lithics, and scarce schist lithic grains. Teloloapan volcaniclastic rocks show a mixed provenance characteristic of sand derived from an arc mixed with sand shed from an exposed orogenic belt or crystalline basement (Fig. 4; Centeno-García et al., 1993a; Guerrero-Suastegui and Hiscott, 2004; this study). Both of the samples we collected yielded abundant medium-sized (40–80 µm), white to pinkish zircons with variable morphology. Some zircons are thin and elongated with well-developed prismatic forms, suggesting a volcanic origin (Pupin, 1983; Dabard et al., 1996) and local provenance. Others are short and prismatic with abraded edges, indicating a more extended transport. A significant zircon fraction

[1]GSA Data Repository item 2007148, Table DR1, U-Pb geochronological data of detrital zircons from the southern Guerrero composite and western Mixteca, is available at http://www.geosociety.org/pubs/ft2007.htm or by request to editing@geosociety.org.

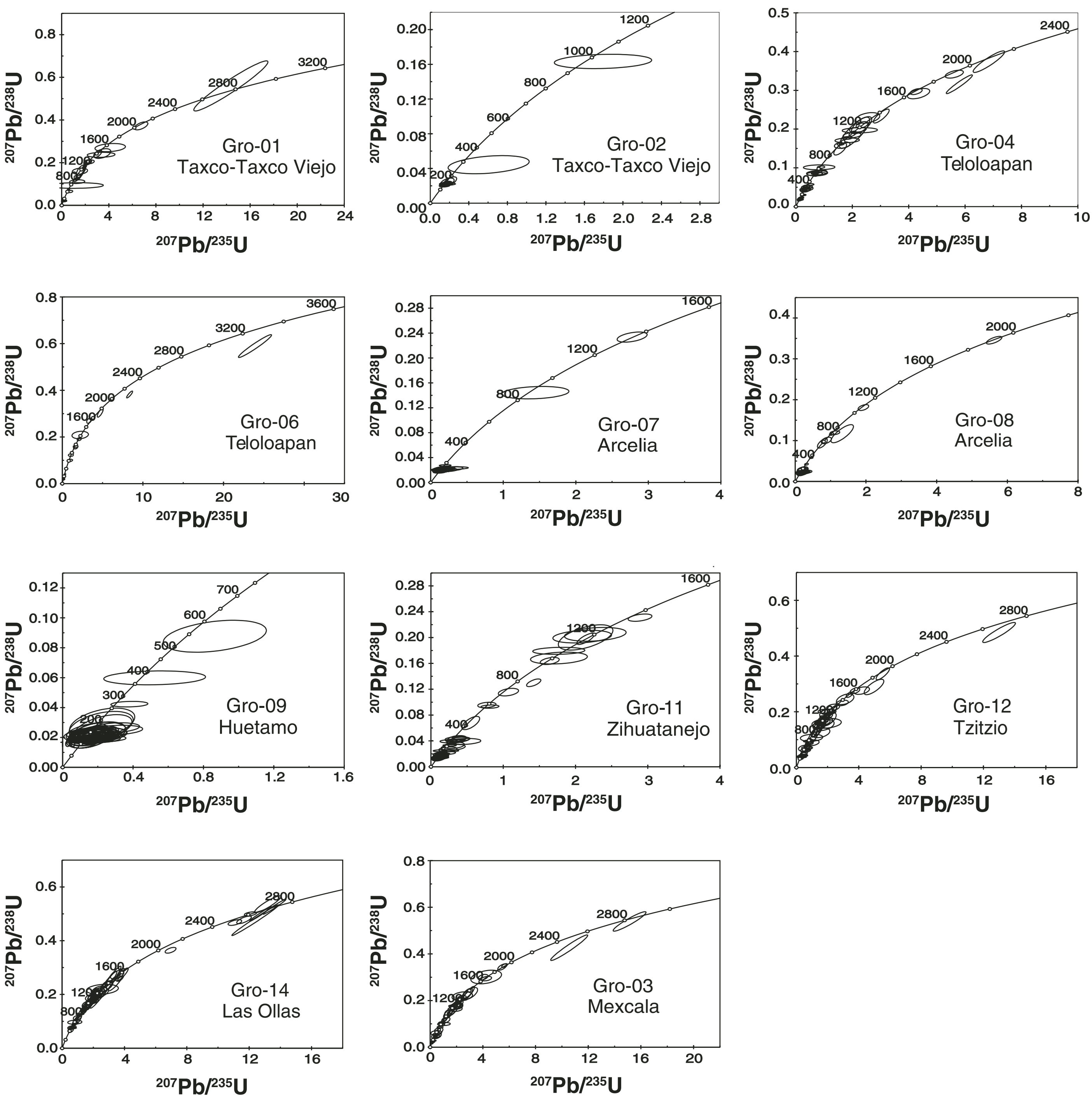

Figure 5. Concordia diagram showing U/Pb age data of detrital zircons from volcano-sedimentary sequences of the southern Guerrero composite and western Mixteca terranes. Ellipses are 1σ sigma.

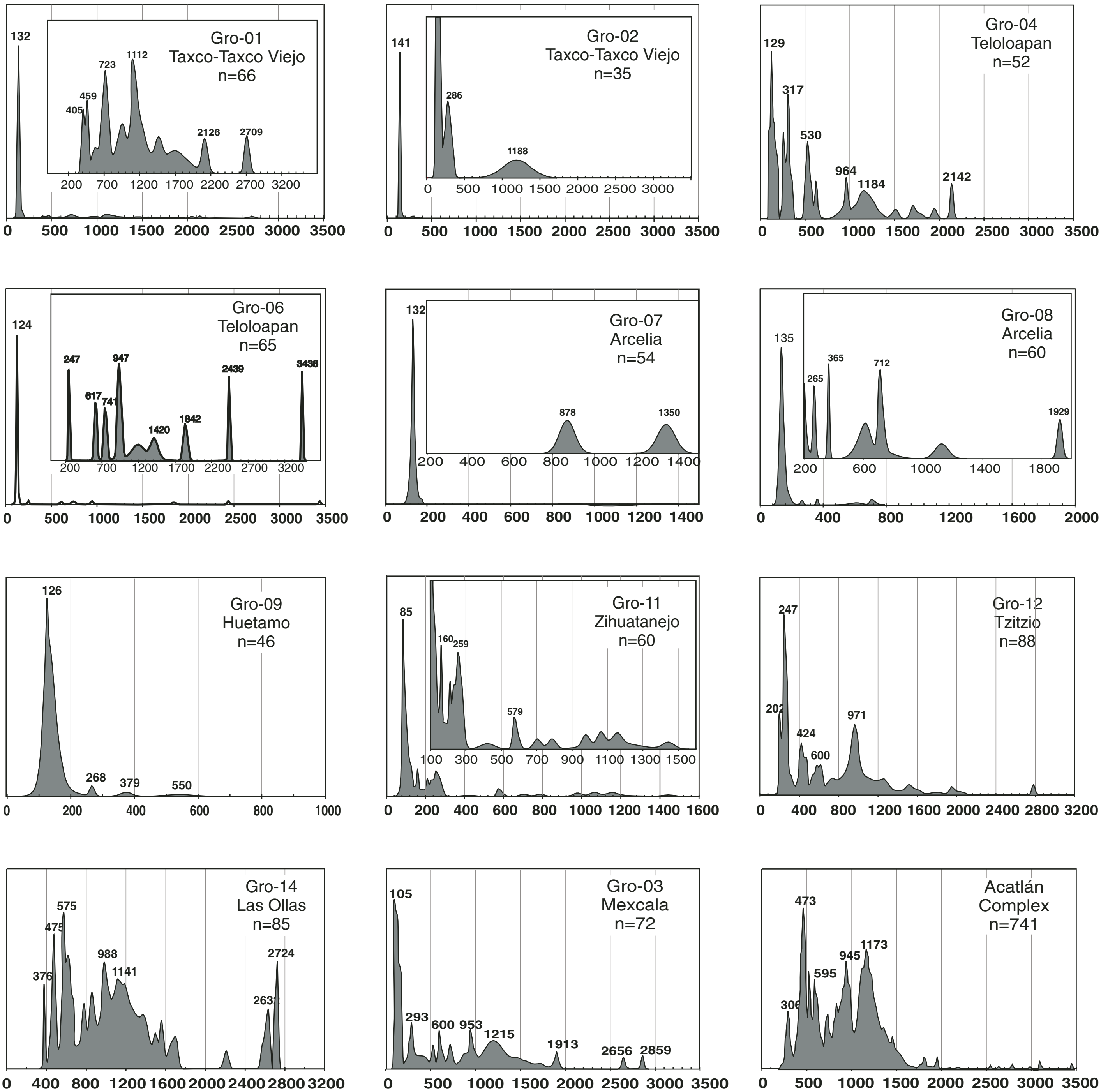

Figure 6. Cumulative-age plots of volcano-sedimentary successions of the southern Guerrero composite and western Mixteca terranes. Vertical axis is relative age probability.

has rounded shapes, which indicates extended transport or grain recycling. With minor differences, zircons from both samples yield Paleoproterozoic to Cretaceous ages ranging from 2440 ± 12 to 95 ± 4 Ma; a single Archean grain is 3439 ± 12 Ma (Fig. 5). In both samples, zircons have low U/Th ratios (<5.7), with the exception of one grain having U/Th = 13.9, indicating that almost all zircons were derived from magmatic rocks (Rubatto, 2002). Zircons from both samples form major populations between 189 and 95 Ma with age probability peaks ca. 129 and ca. 124 Ma (Fig. 6). Minor but distinctive populations occur at 358–251 Ma (peaks ca. 317 and ca. 258 Ma), 625–504 Ma (peak ca. 530 Ma), 1281–744 Ma (peaks ca. 1178 and ca. 964 Ma), and 2440–1413 Ma (peak ca. 2142 Ma).

Arcelia Terrane

Two samples from the Arcelia terrane were analyzed. Sample GRO-07 is a fine-grained volcaniclastic sandstone interbedded with back-arc pillow basalts (~10 km north of the city of Arcelia). Sample GRO-08 is also a fine-grained volcaniclastic sandstone interbedded with pillow basalts (showing island-arc basalt geochemical affinities) (collected near the town of Palmar Grande; Fig. 2). Both samples are dominated by lithic fragments mainly of volcanic (basalt) or sedimentary (shale and chert) origin. Minor detrital clinopyroxene, feldspar, and quartz are present in the samples (Fig. 4). These samples yielded a few small (<50 µm) zircons, the vast majority of which are colorless or whitish, thin, and elongated, suggesting derivation from volcanic sources (Pupin, 1983; Dabard et al., 1996). A few zircon grains have abraded forms, suggesting a somewhat extended transport. Arcelia samples are largely dominated by Jurassic–Cretaceous zircons with ages from 187 ± 19 to 109 ± 9 Ma (peaks ca. 135 and ca. 132 Ma). Only two older grains, 869 ± 37 and 1343 ± 42 Ma, were found in sample GRO-07, whereas sample GRO-08 contains ~15% older grains (Fig. 5). In this sample, the older grains have Paleoproterozoic–Permian ages ranging from 1927 ± 17 to 266 ± 9 Ma (Fig. 6). In both samples, the U/Th ratios are <8.6, indicating a magmatic origin (Rubatto, 2002).

Zihuatanejo Terrane

Two samples from the volcano-sedimentary successions were analyzed. Sample GRO-09 is from the Huetamo area and is a medium-grained sandstone from the upper stratigraphic levels of the Lower Cretaceous San Lucas Formation, ~800 m below the contact with the Aptian El Cajon limestone (Fig. 2). Sandstone from this formation contains quartz, feldspar, and a great variety of lithic fragments, mostly volcanic; however, sedimentary (quartzose sandstone and shale), metamorphic (schists), and plutonic (granitic) grains are also present. This sandstone had a mixed provenance of uplifted orogen and dissected arc (Fig. 4; Guerrero-Suastegui, 1996; this study). The Huetamo sample yields abundant small (<50 µm), whitish to colorless zircons, mostly with well-developed prismatic and bipyramidal shapes, suggesting derivation from local sources. Zircon ages are essentially Jurassic–Early Cretaceous, ranging from 187 ± 42 to 118 ± 12 Ma (peak ca. 126 Ma). Only three Paleozoic grains, 542 ± 42, 375 ± 19, and 267 ± 8 Ma (Fig. 6), were found. The low U/Th ratios in all zircons (<5) indicate that they are magmatic (Rubatto, 2002).

Sample GRO-11 is from the Zihuatanejo succession and is a medium-grained lithic sandstone interbedded with volcanic conglomerate and fallout deposits that was collected from La Madera beach at Zihuatanejo City (Fig. 2). The sandstone contains a great variety of lithic grains, including foliated metamorphic rocks, quartzite, and granite. However, volcanic grains are more abundant. The modal analyses show a mixed provenance of recycled orogen and undissected volcanic arc sources (Fig. 4). The Zihuatanejo sample yielded abundant medium-sized (30–80 µm) zircons of varied colors and morphologies. The most abundant zircons are colorless to milky with elongated prismatic forms similar to those found in volcanic rocks (Pupin, 1983; Dabard et al., 1996), suggesting local provenance. Some zircons are pinkish, and although they have prismatic shapes, show significant abrasion, suggesting moderate transport. A significant zircon fraction is pink to reddish and has elliptical or rounded shapes, suggesting a more extended transport or grain recycling.

The Zihuatanejo sample yields Mesoproterozoic–Late Cretaceous ages ranging from 1445 ± 33 to 82 ± 5 Ma (Fig. 5). The low U/Th (<7.7) ratios in nearly all zircons suggest that they are magmatic. Only two zircons with U/Th ratios near 14 may be metamorphic (Rubatto, 2002). The major population of zircons occurs between 192 and 82 Ma (peak ca. 84 Ma). Minor age populations cluster between 279 and 209 Ma (peak ca. 258 Ma), 788–574 Ma (peak ca. 578 Ma), and 1209–971 Ma (peaks ca. 1167 and ca. 983 Ma) (Fig. 6).

Sample GRO-12 is from possible basement rocks of the Huetamo area (collected on the Federal Highway in the town of Tzitzio; Fig. 2). It is a biotite schist (metamorphosed fine-grained sandstone) and is petrologically similar to rocks of the Arteaga Complex. This sample yielded abundant pink to reddish zircons ~40–100 µm in the longest dimension. Zircon morphology varies from elongated with abraded edges to elliptical and well rounded, indicating extensive transport or grain recycling. The Tzitzio sample yielded Archean–Early Jurassic ages from 2781 ± 17 to 200 ± 8 Ma (Fig. 5). Most zircons have U/Th ratios <9, consistent with a magmatic origin, although 10 grains have U/Th ratios >10 and are of probable metamorphic origin (Rubatto, 2002). Major age populations occur between 321 and 236 Ma (peak ca. 247 Ma) and 1295 and 863 Ma (peak ca. 971 Ma). Minor clusters range from 476 to 388 Ma (peak ca. 423 Ma) and from 788 to 536 Ma (peak ca. 608 Ma) (Fig. 6).

Sample GRO-14 is from the Las Ollas Complex, which is the basement of the arc succession in the Zihuatanejo area. It is a medium-grained, detrital muscovite–rich sandstone (collected at Playa Linda at Ixtapa; Fig. 2). In this unit, sandstone is dominated by quartz and lithic (mainly metamorphic and granitic) grains in addition to detrital muscovite. Sandstone from Las Ollas has a quartzose to transitional recycled provenance, and suggests that the source area probably was an eroded orogenic belt and/or crystalline basement (Fig. 4). This sample yielded abundant light pink to deep red zircons, most of which are ~60 µm in the longest dimension. Zircon morphology varies from near euhedral, short prismatic crystals to well-rounded grains, indicating contrasting extent of detritus transport. The Las Ollas sample yields zircons of Archean–Devonian age, ranging from 2730 ± 10 to 377 ± 5 Ma (Fig. 5). All zircons are characterized by U/Th of <9.3, which indicates a magmatic source (Rubatto, 2002). Age probability patterns (Fig. 6) yield three major zircon populations: 692–377 Ma (peaks ca. 574, ca. 475, and ca. 375 Ma), 1752–758 Ma (peak ca. 987 Ma), and 2730–2208 Ma (peak ca. 2723 Ma).

Mexcala Formation

Zircons from one sample of the Mexcala Formation (GRO-03) were analyzed. The sample is a medium-grained sandstone interbedded with shale (collected on the Federal Highway near the town of Ahuehuepan in the western edge of the Mixteca terrane; Fig. 2). Sandstone from the Mexcala Formation contains quartz, feldspar, and lithic fragments of mainly sedimentary and volcanic origin, along with some granitic and metamorphic fragments. This shows a mixed provenance of dissected arc and quartzose-recycled orogen (Fig. 4). The Mexcala sample yielded abundant pink to red zircons ~30–100 µm in longest dimension; morphologies vary from elongated crystals with abraded edges to rounded grains, indicating extended transport or grain recycling. The

Mexcala sample yields Paleoproterozoic–Cretaceous ages ranging from 1910 ± 18 to 103 ± 9 Ma; two Archean grains are 2856 ± 16 and 2648 ± 19 Ma (Fig. 5). Low U/Th ratios (<6.1) in nearly all analyzed grains indicate a magmatic rock origin (Rubatto, 2002), although two grains with U/Th of 10–12 may be metamorphic in origin. The biggest zircon population is in the range 175–103 Ma (peak ca. 105 Ma). Minor clusters occur in the ranges 383–229 Ma (peak ca. 293 Ma), 727–431 Ma (peak ca. 600 Ma), 1466–845 Ma (peaks ca. 1215 and ca. 953 Ma), and ca. 1913 Ma (Fig. 6).

DISCUSSION

Zircon Provenance

Although the range of ages of detrital zircons from all the Upper Jurassic–Cretaceous volcano-sedimentary sequences of Guerrero and Mixteca terranes is similar, their age probability patterns reveal significant differences, which we interpret to record different depositional histories and zircon provenance from varied sources.

The Taxco-Taxco Viejo volcano-sedimentary suite yielded an Early Cretaceous age (130 ± 2.6 and 131 ± 0.85 Ma; Campa and Iriondo, 2003). In our samples, the major and youngest zircon clusters yield a similar age of ca. 132 Ma in the Taxco sample and ca. 141 Ma in the Taxco Viejo sample. The pyroclastic nature of samples together with the morphology of zircons strongly suggest that these ages represent the age of volcanism in Taxco-Taxco Viejo. The age of ca. 141 Ma is significantly older than the ca. 131–130 Ma age, and may represent the maximum age of protolith. Ages of older zircons vary from Mesoproterozoic to Permian, with one Paleoproterozoic and one Archean grain. Although a few of these ages were obtained in cores of zircons, most are from rounded grains, suggesting a detrital origin.

The most representative populations are Ordovician–earliest Devonian (ca. 459 and ca. 405 Ma), Neoproterozoic (ca. 723 Ma), and Mesoproterozoic (ca. 1112 Ma). Mesoproterozoic and Paleozoic magmatic rocks have been reported in the nearby Oaxacan and Acatlán Complexes and their sedimentary covers (Gillis et al., 2005; Talavera-Mendoza et al., 2005), and represent potential sources. By contrast, the nearest Neoproterozoic magmatic rocks surround cratonal North America (e.g., Cawood and Nemchin, 2001), and the presence of zircons of that age in the Taxco-Taxco Viejo samples suggests grain recycling. A recent study of detrital and magmatic zircons from most units of the neighboring Acatlán Complex (Talavera-Mendoza et al., 2005) reveals the presence of Archean–late Paleozoic zircon grains with major peak ages coinciding with major populations recorded in Taxco-Taxco Viejo samples (Fig. 4), thus the most plausible source of detritus.

The age of the Teloloapan volcano-sedimentary assemblage has been bracketed between the Hauterivian and the Cenomanian (ca. 137–93 Ma) based on radiometric and paleontological data (Talavera-Mendoza et al., 1995; Monod et al., 2000). Major zircon populations in the two studied samples are Hauterivian and Barremian (ca. 129 and ca. 124 Ma) with minor populations of Carboniferous (ca. 317 Ma), Early Cambrian (ca. 530 Ma), Neoproterozoic (ca. 741–617 Ma), and Mesoproterozoic (1420–947 Ma) age. Early Cretaceous populations are similar in age to the volcanic rocks of Teloloapan and Taxco-Taxco Viejo and represent the most plausible sources. Like the older zircon populations in the Taxco-Taxco Viejo suite, the presence of Archean–Paleozoic zircons in the Teloloapan samples indicates grain recycling. As shown in Figure 6, major populations in the Teloloapan samples coincide with populations recorded in rocks from the Acatlán Complex and point to this complex as the most plausible source for these zircons.

The age of the Arcelia assemblage is Albian–lower Cenomanian (ca. 112–93 Ma) (Dávila and Guerrero, 1990; Delgado et al., 1990; Ortiz et al., 1991). The major detrital zircon populations in Arcelia samples are Valanginian (ca. 135–132 Ma) and are consistent with such an age. Zircon typology indicates that zircons of this age are probably of volcanic origin and that they underwent little transport, suggesting derivation from local sources. These ages are broadly similar to ages of volcanic rocks from the Teloloapan and Taxco-Taxco Viejo assemblages, and they represent the most plausible sources for the sediments. Older zircons are scarce and show evidence of a more extended transport. These zircons are of Paleozoic (365–265 Ma) and Proterozoic (1929–712 Ma) age, and indicate that the Arcelia assemblage had access to sources containing old zircons, perhaps through grain recycling. Old ages of Arcelia zircons match ages recorded in the Acatlán Complex, and thus it is the most plausible source.

The Zihuatanejo terrane contains Upper Jurassic–Cretaceous volcanic and related sedimentary rocks that unconformably overlie the pre–Middle Jurassic Arteaga Complex. The sample analyzed from the Huetamo succession is from Barremian strata of the San Lucas Formation. This sample contains almost exclusively detrital zircons peaking ca. 126 Ma, indicating a maximum depositional age of early Barremian for this stratigraphic level. This fact together with the zircon typology, which suggests that most zircons were derived from volcanic rocks and did not undergo extended transport, indicate that volcanism in the source region was nearly coeval with sedimentation. Only three zircons yielded Paleozoic ages (542 ± 42, 375 ± 19, and 267 ± 8 Ma), indicating that during Barremian time, sedimentological access to old sources was restricted.

The major zircon population in the Zihuatanejo sample peaks ca. 85 Ma and indicates that the stratigraphic levels at La Madera beach have a maximum Santonian age of deposition. Many zircons of this age are euhedral with morphology typical of volcanic zircons. The presence of interbedded pyroclastic fallout deposits in the sampled strata strongly suggests that volcanism was still active during Santonian time, contrary to previous studies that suggested that volcanism ended during the Cenomanian when carbonate rocks were deposited (Centeno-García et al., 1993b; Talavera-Mendoza, 1994). Unlike the Huetamo sample, the Zihuatanejo sample contains many Mesoproterozoic–Middle Jurassic zircons, implying access to areas containing older rocks. Major clusters in these zircons are Middle Jurassic (ca. 160 Ma), Late Permian (ca. 259 Ma), and Neoproterozoic (ca. 579 Ma), with some Mesoproterozoic grains (1445–977 Ma). Middle Jurassic granites intruding the Arteaga Complex represent the most plausible source for Middle Jurassic zircons. Late Permian and Proterozoic zircons match the major detrital zircon populations of the underlying Arteaga Complex, which is the most plausible source for these zircons.

The Las Ollas unit has been classically described as part of the Lower Cretaceous arc suites and contains Archean to mid-Paleozoic detrital zircons. The youngest zircon cluster of ca. 375 Ma indicates a maximum Late Devonian depositional age and would be consistent with the assigned age. However, the absence of Cretaceous zircons is surprising if one considers that current sedimentological models for forearc suites point to the arc massif as a major source of detritus (e.g., Dickinson, 1982). Accordingly, one might expect to find a significant population of zircons derived from the arc, particularly if volcanism includes acidic products, as did the Zihuatanejo arc. A biased sampling during analysis seems an unlikely reason for this because zircons were selected at random and because 100 grains were analyzed. However, the Tzitzio sample from the prevolcanic basement contains broadly the same range of ages, although in different proportions. These facts suggest that either the Las Ollas unit is part of the Cretaceous arc, as previously inferred (Vidal, 1984; Talavera, 2000), but deposited in a region with limited or no access to the coeval arc sources, or, more likely, the Las Ollas unit forms part of the prevolcanic basement.

Major populations of zircon ages in the Las Ollas sample are Middle Devonian (ca. 375 Ma), Early Ordovician (ca. 475 Ma), Late Neoproterozoic (ca. 574 Ma), Early Neoproterozoic–Mesoproterozoic (ca. 1141 and ca. 988 Ma), and Archean (ca. 2724 Ma). Devonian and Ordovician magmatic rocks are widespread in eastern North America (e.g., Cawood and Nemchin, 2001; McLennan et al., 2001); there are scarce equivalents in South America. This suggests ultimate derivation of these zircons from Laurentian sources. However, magmatic rocks of Late Neoproterozoic age, the biggest age population in the sample, are widely distributed in South America (e.g., Bernasconi, 1987; Barr et al., 2003), with restricted equivalents in North America. This suggests that this population of zircons was most likely derived from South American rocks. Potential Grenvillian and Archean sources for the oldest zircons are widespread in both North America and South America (e.g., Bernasconi, 1987; Rivers, 1997). Although the combination of major zircon populations in the Las Ollas sample has also been recorded in suites from the Acatlán Complex, which would lead to the possibility of grain recycling, the abundance of Archean grains makes first cycle provenance more likely. Thus, the Las Ollas sample is interpreted to contain zircon populations derived from both North American and South American sources.

In the Tzitzio sample, the biggest and youngest zircon cluster is Early Triassic (ca. 247 Ma), which is consistent with the Middle Triassic–Middle Jurassic age reported for the prevolcanic basement in the Arteaga area (Campa et al., 1982). The major zircon populations are Early Triassic (ca. 247 Ma), Silurian (ca. 424 Ma), and Neoproterozoic (ca. 971 and ca. 600 Ma); there are some Paleoproterozoic and Mesoproterozoic grains. Permian–Triassic magmatic rocks are widely distributed in both southern North America and northern South America and represent the most plausible ultimate sources (e.g., Dickinson, 1981; Torres et al., 1999). Silurian magmatic rocks have been extensively reported in eastern North America (Cawood and Nemchin, 2001), though they are also present in South America to a more limited extend. Late Neoproterozoic magmatic rocks are widespread in the Brasiliano orogen in South America (Bernasconi, 1987), and represent the most plausible source for the older zircons of the Tzitzio sample. Grenvillian magmatic rocks are common to North America and South America (e.g., Bernasconi, 1987; Rivers, 1997). Thus, as in the Las Ollas sample, major age populations in the Tzitzio sample point to derivation from a combination of North American and South American sources.

Mexcala Formation

Major zircon populations in the sample from the Mexcala Formation are Albian (ca. 105 Ma), latest Pennsylvanian (ca. 293 Ma), Neoproterozoic (ca. 953 and ca. 600 Ma), Mesoproterozoic (ca. 1215 Ma), and Paleoproterozoic (ca. 1913 Ma). The Albian age is older than the depositional age (Turonian–Maastrichtian), and coincides with the main stage of volcanism in the Arcelia assemblage, although its predominantly basic nature makes it an unlikely source of zircons. The Albian age also matches the late volcanism in the Teloloapan assemblage, which contains more acidic products and makes it a plausible source. Even though the Albian peak age in the Mexcala sample is ~30 m.y. younger than volcanism in the Taxco-Taxco Viejo suite, a great proportion of zircons in this population have similar ages, and thus may be also a plausible source for the Albian zircons.

The Paleozoic and Proterozoic zircons in the Mexcala sample may be present due to grain recycling. Peak ages in this sample coincide with major ages recorded in the nearby Acatlán Complex and point to this complex as the most probable source.

Nature and Origin of Prevolcanic Basement

The nature and origin of basement beneath the volcano-sedimentary sequences of Guerrero and Mixteca terranes have been subject of controversy for many years. Some consider that all are floored by continental crust of early Mesozoic, Paleozoic, or even Grenville age (e.g., DeCserna et al., 1978). Others argue that the basement is heterogeneous and includes both oceanic and continental crust (Tardy et al., 1994; Centeno-García et al., 1993b; Talavera-Mendoza, 1994; Mendoza and Guerrero, 2000; Elías-Herrera et al., 2000).

Geochemical and isotopic evidence indicates that the Taxco-Taxco Viejo volcanic-arc assemblage probably formed in a continent-based island arc or an active continental margin (Talavera-Mendoza, 1994). Our U-Pb ages indicate that most zircon grains are of local provenance, but that many come from older rocks. Ages of old zircons match ages found in the nearby Acatlán Complex (Talavera-Mendoza et al., 2005), and suggest that it may be the source of the detritus. This is consistent with the presence of abundant conglomerate strata containing boulders of mica schist and granitic rocks inferred to have been derived from the Acatlán Complex (Campa and Ramírez, 1979).

There is no evidence of prevolcanic rocks in Teloloapan and Arcelia, although it has been suggested that early Mesozoic granitic rocks reported in the northern area of the Teloloapan assemblage could represent a pre-arc basement (Elías-Herrera et al., 2000). However, the relationship of the pre-arc rocks with the Teloloapan volcanic rocks is unclear. Although our U-Pb data from Teloloapan and Arcelia clearly indicate sediment influx from old continental sources, probably through grain recycling, they do not provide any additional evidence about the type of basement. Nevertheless, the Teloloapan volcanic rocks show geochemical and isotopic features of mature intraoceanic island arcs, even though isotope and trace element evidence suggest that sediments from a continental source were involved in the magma genesis (Talavera, 1994). The Arcelia volcanic rocks show geochemical and isotopic signatures of island-arc tholeiites and oceanic basalts (both backarc basin basalts and ocean island basalts), implying the existence of an oceanic basement.

The Zihuatanejo arc is on a previously deformed Middle Triassic–Middle Jurassic basement represented by the Arteaga Complex. The Las Ollas Complex contains a comparable zircon age pattern and may be part of the prevolcanic basement. In the Arteaga area, the Zihuatanejo volcanic rocks and limestones unconformably overlie Arteaga rocks, whereas in the Zihuatanejo region, the volcanic rocks tectonically overlie rocks assigned to the Las Ollas suite. The Arteaga Complex is a modified oceanic substratum comprising a thick succession of quartzose sandstone, shale, and chert enclosing slices of oceanic pillow basalts and plutonic rocks that were deposited in an ocean floor–continent slope environment, but deformed as a subduction complex (Centeno-García et al., 1993b, 2003; Centeno-García, 2005). The Las Ollas assemblage is a block-in-matrix suite with lithological, structural, and metamorphic characteristics of a subduction complex (Talavera, 2000).

Reported $\varepsilon_{Nd}(T)$ values in volcanic rocks from Zihuatanejo and Huetamo suites range from +7.0 to + 8.3 and are in the range typical of intraoceanic island arcs in spite of field evidence, which indicates that the Zihuatanejo arc formed on the Arteaga Complex. In contrast, initial $^{87}Sr/^{86}Sr$ ratios are systematically higher than mantle values and indicate the influence of a continental component in magma evolution (Mendoza and Guerrero, 2000).

Detrital zircons in the Las Ollas and Tzitzio samples indicate derivation from North American and South American crustal sources. Sandstone petrography suggests that they were derived from mature sources formed by uplifted basement and minor felsic volcanic grains.

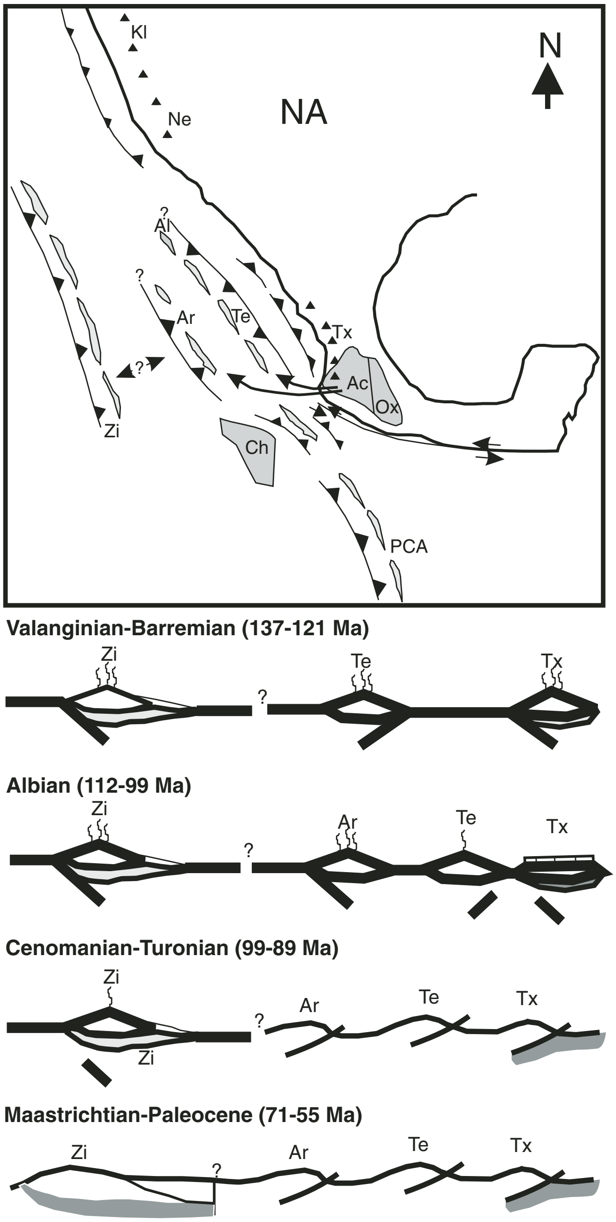

Figure 7. Paleogeography of western Mexico during Early Cretaceous time and tectonic evolution of the Guerrero and western Mixteca arc successions. NA—North America; Ne—Nevada; Kl—Klamaths; Al—Alisitos; Tx—Taxco-Taxco Viejo; Te—Teloloapan; Ar—Arcelia; Zi—Zihuatanejo; Ac—Acatlán; Ox—Oaxaca; Ch—Chortis block; PCA—proto-Caribbean arc. Gray pattern indicates crustal substratum.

Zircon ages together with their sedimentological characteristics are consistent with sedimentation in a forearc environment during the Middle Triassic–Middle Jurassic.

Sedimentological and Tectonic Implications

The variation in ages in Upper Jurassic–Cretaceous volcano-sedimentary sequences of the Guerrero and Mixteca terranes suggests different depositional histories and varied provenance. The peak ages combined with grain morphology suggest that zircons forming the youngest populations in these sequences underwent reduced transport and were likely shed from local volcanic sources. Zircons forming the other major populations show evidence of a more extended transport and deposition, very likely through grain recycling. In the Taxco-Taxco Viejo, Teloloapan, and Arcelia sequences, the combination of peak ages points to the nearby Acatlán Complex as the most plausible source of detritus and suggests evolution in close proximity. This is consistent with geochemical and isotopic data of volcaniclastic samples reported by Freydier et al. (1997) for some sequences of the Guerrero terrane, which indicated mixed provenance with volcanic arc and crustal components. In contrast, in the Zihuatanejo sequence, peak ages point to the underlying Arteaga Complex as the most plausible source of detritus.

Our data, combined with previously reported geochemical and isotopic data (Centeno-García et al., 1993b; Talavera-Mendoza et al., 1995; Freydier et al., 1997; Mendoza and Guerrero, 2000), allow us to refine the paleogeography and tectonic evolution of western Mexico and southwestern North America during late Mesozoic time. Data indicate that during the Cretaceous, southwestern North America was a site of intensive volcanic activity, and volcanism took place in distinctive arc-trench systems. The existence of coeval volcanic and plutonic arc series in the Nevada and Klamath ranges in the southwestern United States (e.g., Anderson, 1990; Ducea and Saleeby, 1998, and references therein), Alisitos in northern Mexico (e.g., Almazán-Vázquez, 1988), the Greater and Lesser Antilles (e.g., Iturralde-Vinent, 1998; Snoke et al., 2001), and northern South America (e.g., Kerr et al., 1997) attests to an orogenic volcanism of continental scale. During Early Cretaceous time (ca. 130 Ma), volcanism developed in three separate arc-trench systems (Fig. 7). Taxco-Taxco Viejo volcanism developed directly on the Acatlán Complex as a continental-based island arc or an active continental margin with an east-directed subduction, whereas Teloloapan volcanism developed as an offshore mature intraoceanic arc. Although there is not direct evidence for the polarity of subduction in the Teloloapan terrane, a west-directed subduction is preferred because it provides a suitable mechanism for moving the Teloloapan arc to nuclear Mexico and because of the northeast-east vergence of major structures (Campa and Ramírez, 1979). The Zihuatanejo terrane formed on a previously deformed oceanic assemblage containing zircon populations derived from both Laurentian and Gondwanan crustal rocks. Our data suggest little or no sedimentological connection with the Taxco-Taxco Viejo, Teloloapan, and Arcelia volcano-sedimentary successions. However, it is unclear if this sedimentological disconnection is because the Zihuatanejo arc developed far away, or simply due to a sedimentological isolation. Based on the actual position of the Huetamo basin, interpreted to have been formed in backarc position (Mendoza and Guerrero, 2000), an east-directed subduction for the Zihuatanejo arc is suggested.

At the end of Albian time (ca. 100 Ma), volcanism in the Taxco-Taxco Viejo and Teloloapan ceased, giving rise to clastic and calcareous sedimentation. By this time, the volcanism of Arcelia began in both intraoceanic arc and backarc basin settings (Fig. 7). The actual distribution of backarc (backarc basin basalts and ocean island basalts) rocks suggests an east-directed subduction, although this subduction polarity is not appropriate to explain the east vergence of major structures in the Arcelia terrane. Volcanism in Arcelia ended by early Cenomanian time.

According to our data, the Zihuatanejo arc was still active during Late Cretaceous time (ca. 80 Ma; Fig. 7), although volcanism was largely more intensive during Early Cretaceous time. During Albian–early Cenomanian time, volcanism was accompanied by volcaniclastic and calcareous sedimentation in some sectors of the arc.

Our data are consistent with accretion of the volcano-sedimentary assemblages during Laramide (Late Cretaceous) time (Fig. 7). The accretion was probably diachronic and could have initiated during late Cenomanian time with amalgamation of the Teloloapan, and probably the Arcelia assemblages (as previously suggested by Tardy et al., 1994). In contrast, the Zihuatanejo terrane assemblage, which was still active during Santonian time, must have accreted near the end of Cretaceous time. Although field data support the inferred subduction polarity in some studied arc terranes, the exact mechanism of accretion remains poorly understood.

CONCLUSIONS

The U/Pb geochronology of detrital zircons from the Upper Jurassic–Cretaceous volcano-sedimentary sequences of the southern Guerrero and western Mixteca terrane indicates provenance from varied sources. In all the studied sequences, the youngest zircon population was derived from local coeval volcanic sources. Older populations in the Taxco-Taxco Viejo, Teloloapan, and Arcelia assemblages are compatible with a derivation from the Acatlán Complex. In contrast, in the Zihuatanejo terrane assemblages, older populations of zircons have ages matching zircon populations of the underlying Arteaga Complex. Our data show no evidence of a sedimentological connection between the Zihuatanejo terrane and the volcanic sequences of Taxco-Taxco Viejo, Teloloapan, and Arcelia. This observation is consistent with petrological, geochemical, isotopic, and structural evidence indicating an independent evolution for the Zihuatanejo terrane and the volcanic sequences of Taxco-Taxco Viejo, Teloloapan, and Arcelia.

The Arteaga Complex at Tzitzio has a detrital zircon population consistent with an ultimate derivation from both North American and South American sources. The Las Ollas suite has a comparable combination of zircons and it is interpreted as part of the prevolcanic basement. This interpretation is not consistent with the previous interpretations that tied its origin to the evolution of the Early Cretaceous arc.

The Mexcala Formation contains zircon populations consistent with derivation from both the volcanic assemblages and the Acatlán Complex. This agrees with classic interpretations that link the deposition of the Mexcala formation to the exhumation of the Guerrero terrane sequences.

Thus, detrital zircon U/Pb geochronology together with petrological, geochemical, and isotopic data indicate that during Early Cretaceous time, the southwestern realm of North America was a region of intensive volcanic activity, and that volcanism took place in a multi-arc-trench system. The Taxco-Taxco Viejo arc developed on the Acatlán Complex in the western edge of the Mixteca terrane. The Teloloapan terrane represents a mature intraoceanic arc, whereas the Arcelia terrane is a primitive arc associated with a backarc basin. The Zihuatanejo terrane represents a mature arc developed on the Arteaga Complex. Arc volcanism extended northward to northern Mexico and the southwestern United States, and southward to form the arc series cropping out in the Greater and Lesser Antilles and northern South America, implying an orogenic volcanism of continental scale.

Accretion of oceanic offshore arcs was diachronic, beginning with the accretion of the Alisitos arc of northern Mexico during Albian time (ca. 105 Ma) and continuing with the accretion of the Teloloapan and probably the Arcelia arc during late Cenomanian time (ca. 90 Ma). The Zihuatanejo arc, still active during Santonian time, collided with nuclear Mexico at the end of Cretaceous (Laramide) time. The Caribbean arcs continued to be active during the Late Cretaceous and were displaced eastward, forming the Greater and Lesser Antilles islands and giving rise to the formation of the Caribbean plate.

ACKNOWLEDGMENTS

We thank Alex and Jennifer Pullen for assistance during zircon processing and cathodoluminescence imaging. The manuscript benefited from careful and constructive criticisms of Yildirim Dilek, Cathy Busby, and an anonymous reviewer. This research was supported by National Science Foundation grants EAR-9708361 and EAR-9628150.

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Manuscript Received 9 April 2006
Revised Manuscript Received 12 February 2007
Manuscript Accepted 26 February 2007

Printed in the USA