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FIELD TRIP 9: APRIL 4–6

GEOLOGY AND TECTONIC EVOLUTION OF THE WESTERN GUERRERO TERRANE—A TRANSECT FROM PUERTO VALLARTA TO ZIHUATANEJO, MEXICO

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INTRODUCTION

The Guerrero terrane is a composite terrane mostly characterized by submarine and rarely subaereal volcanic and sedimentary successions that range in age from Upper Jurassic (Tithonian) to middle Upper Cretaceous (Cenomanian). Campa and Coney (1983) first subdivided the southern part of the Guerrero terrane into three subterranes: Teloloapan, Huetamo and Zihuatanejo. However, further studies have shown that Guerrero is a composite terrane with a more complex stratigraphy and evolution. Based on recent data, at this time the Guerrero is consider to be formed by at least four to five terranes.

1. The original Huetamo and Zihuatanejo subterranes have similar basements, with similar arc stratigraphy and geochemistry (Centeno-García et al., 1993a, 1993b; Centeno-García, 1994; Talavera-Mendoza et al., 1995, Mendoza and Suástegui, 2000). Therefore, they were grouped into a single terrane, the **Zihuatanejo terrane**, whose stratigraphy is described later. This terrane extends along the coast and apparently up to Zacatecas City. It is thrusted over the Arcelia, Guanajuato, Oaxaquia and Central terranes (Figures 1 and 2).

2. Ramírez-Espinosa et al. (1991) and Talavera-Mendoza et al. (1995) subdivided the Teloloapan subterrane into two different assemblages: Teloloapan and Arcelia (Figures 1 and 2). These have enough major differences to be considered as separate terranes: the Arcelia and Teloloapan terranes. The **Arcelia terrane**, located eastward of the Zihuatanejo terrane, shows deeper marine facies and less evolved magmatism than the rest of the arc sequences (Figure 2) (Talavera et al., 1990, 1995). It is made up of intensively deformed basaltic pillow lavas and ultramafic bodies, black shale and chert that thrust over the Teloloapan terrane (Figure 2) (Ramírez et al., 1991; Talavera et al., 1995). The chert layers contain radiolarians of Albian-Cenomanian age (Ramírez et al., 1991). Geochemical signatures of the Arcelia magmas are similar to recent primitive island arcs and MORB. The nature of its basement is unknown.

3. The **Teloloapan terrane** (Figures 1 and 2) is exposed in the easternmost parts of southern Guerrero composite terrane. Structurally the terrane is a complex thrust fault system with a vergence toward the east. Its rocks are severely deformed and metamorphosed in low-grade green schist facies, and overrides either Aptian Albian platform carbon-

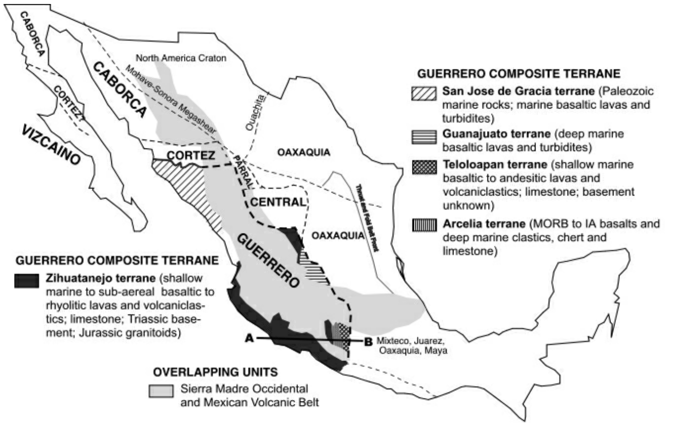

Figure 1. Location of the Guerrero composite terrane and its terranes (modified after Campa and Coney, 1984).

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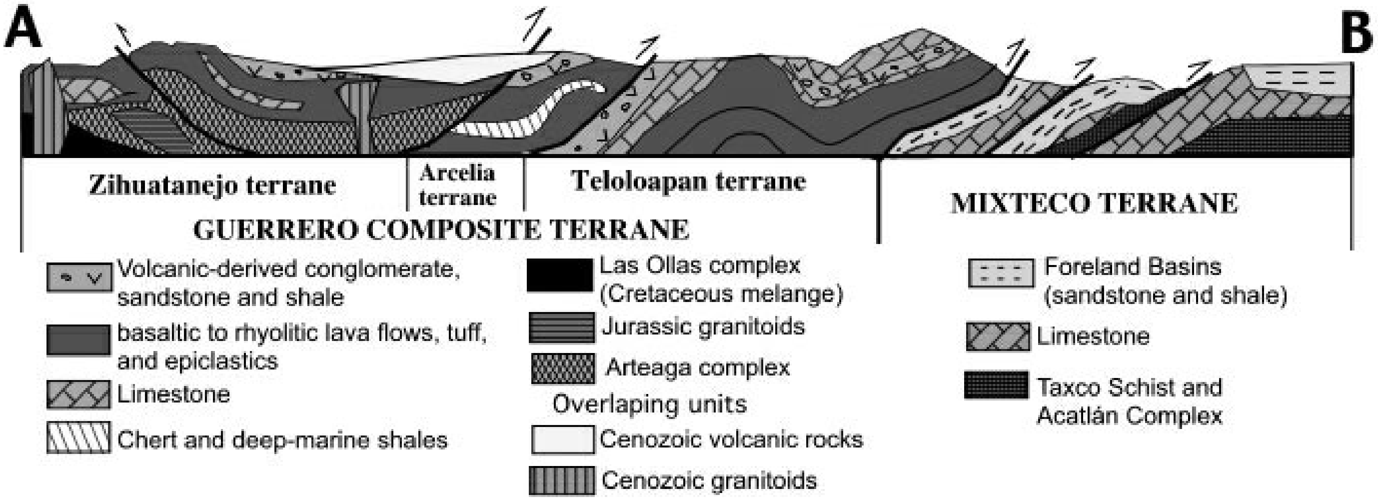

Figure 2. Geological cross section (not to scale), showing the different terranes and their relationships.

ates or Turonian clastic rocks that belong to the Mixteco Terrane (Figure 2) (de Cserna, 1978; Campa and Ramírez, 1979). It is characterized by andesitic lava flows, tuffs, epiclastics, and limestone; alternated with interbedded shale/sandstone packages at the top of the sequence. They all contain abundant shallow marine fossils, including rudists, gastropods, corals, etc. (Campa and Ramírez, 1979, Guerrero-Suástegui et al., 1991). The Teloloapan arc facies change toward the west to deeper marine deposits, including black detrital limestone and shale. The magmatism is mostly Neocomian (Hauterivian) to Albian in age (Guerrero-Suástegui et al., 1991). The nature of the basement of the Teloloapan terrane is still under debate. There is a metamorphosed volcanic-sedimentary succession (Tejupilco metamorphic complex) that has been interpreted as having formed prior to the Upper Jurassic-Cretaceous arc assemblage (Elías-Herrera and Sánchez-Zavala, 1992). However, the same metamorphosed rocks of Tejupilco have been considered part of the Cretaceous arc assemblage by other authors (Campa and Ramírez, 1979; Ramírez et al., 1991).

4. Exposures of the Guerrero terrane assemblages are more scattered to the north of the Trans Mexican Volcanic Belt, making it difficult to correlate among them, and with the southern Guerrero terrane. Exposures located close to the cities of Guanajuato, and Aguascalientes are consider as a separate terrane, the **Guanajuato terrane**. Even though the rocks of Guanajuato are in some way are similar to Arcelia terrane, they are not grouped together until more evidence of correlation is collected. The stratigraphy in Guanajuato goes from the roots of the arc (gabbros and diabases, and dike swarms) to pillow basalts, interbedded with thin bedded siltstone, shale, chert, and fine-grained volcanic sandstone (Arperos Formation) (Lapierre et al., 1992). These rocks are thrusted over the calcareous platform of Oaxaquia. The nature of their basement is unknown, but its geochemical signature is similar to present primitive island arcs and within plate volcanism (Lapierre et al., 1992).

5. To the northwest, in Sinaloa and Durango states, Paleozoic rocks seem to lie underneath the Cretaceous arc volcanic and volcaniclastic rocks. Although internal stratigraphy and contact relationships have not been determined, we consider this as a different terrane, the **San José de Gracia Terrane**. It seems to be thrusting over the Cortez terrane. However, its relationships with other terranes and other parts of the Guerrero terrane have not been studied in detail.

Unfortunately, correlation among the terranes is very difficult because large volumes of Tertiary granitoids, volcanic rocks of the Tertiary Sierra Madre Oriental, and the

Quaternary Trans Mexican Volcanic Belt cover up a substantial portion of the Mesozoic Guerrero terrane stratigraphy. This makes it difficult to construct paleogeographic models, however some of those proposed by several authors are discussed latter.

Zihuatanejo terrane

The Zihuatanejo terrane is located along the Pacific Coast and includes the Huetamo and coastal regions (Figure 1). This terrane contains the most complete stratigraphic column of the Guerrero Composite Terrane. The oldest rocks found to date are exposed in the Huetamo and Arteaga areas. They are made up of ocean-floor assemblages of Triassic age that were strongly deformed and partially metamorphosed during Early to Mid Jurassic. These rocks are cut by mid-Jurassic granitoids, and both units are unconformable covered by Cretaceous arc related successions.

Most of the stratigraphy and regional mapping of the Zihuatanejo terrane along the coast have been done by PEMEX, the national oil company of Mexico. Unfortunately the information is in unpublished reports that are not available to the public. Locally, mining and exploration companies have been done mapping, but again few were published. As a result, it is hard to have access to the information, there are many local formational names, and sometimes the same rocks are described with two names. These have made regional compilation, correlation of units, and their interpretation to be very difficult. Overall, Cretaceous arc related rocks could be separated into five following stratigraphic assemblages, they are: the Huetamo, Jalisco-Colima, Titzupa-La Unión, Aguililla-Tumbiscatío, and Zihuatanejo.

The arc assemblages at Zihuatanejo terrane are folded, but not as strongly deformed and metamorphosed as those of the Teloloapan and Arcelia terranes, during the Laramide. The area has large exposures of intrusive rocks that range in age from Upper Cretaceous to Eocene-Oligocene. Volcanic rocks of the same age are exposed to the north of Zihuatanejo City, forming a high elevation range between Huetamo and Zihuatanejo areas. Some strike slip shear zones and faults that cut the young intrusives and older rocks are exposed in the area; they trend NE-SW, E-W and NNW-SSE. However, these shear systems have not been studied in detail. The stratigraphic column ends with Pleistocene marine terraces and recent normal faults associated with active tectonism that can be observed along the coast (Grajales and López, 1984). Only the Triassic to Cretaceous stratigraphy of the area that will be visited by the field trip is described in detail.

Basement of the Zihuatanejo terrane

There has been a lot of debate about the composition and nature of the crust of the Jalisco-Zihuatanejo region. Some authors had proposed the presence of Paleozoic (Carboniferous) eugeosyncline rocks underneath the Zihuatanejo area (de Cserna et al., 1978). Based on its geochemistry, others had proposed that the arc in Zihuatanejo had been built on oceanic crust (Lapierre, et. al., 1992; Tardy et al., 1994). Others have suggested that the arc was constructed on previously accreted oceanic crust (marginal sea-back-arc assemblages), and during the Cretaceous the Zihuatanejo terrane was a micro-continental arc, similar to the Japan Arc at present (Centeno-García et al., 1993a; Centeno-García, 1994). Geochemical and isotopic studies of the rocks that were considered Paleozoic have shown them to be Cretaceous arc-related rocks (Talavera-Mendoza et al., 1995). Therefore, the oldest rocks found to date belong to the Triassic-Jurassic Arteaga Complex, which will be visited on the second day of the field trip.

The Arteaga Complex

The Arteaga complex is composed of several lithologic units (Figure 3). The most significant of those is the Varales lithofacies that constitutes approximately 60% of the mapped area, and is composed almost exclusively of silicic terrigenous sediments. The second most abundant unit is the Charapo lithofacies that are made up of basaltic pillow lavas, massive flows, and aphanitic magmatic bodies (shallow intrusives and dikes) (Figure 1.5). Minor lithofacies are green volcaniclastics of the lithofacies Jaltomate, green chert of the Bocana lithofacies, gabbros and plagiogranites of the Las Juntas lithofacies, and the erratic blocks of limestone (Figure 3).

Varales lithofacies

The Varales lithofacies (Figure 3) is mostly composed of siliciclastic sediments such as black shale, quartz-rich

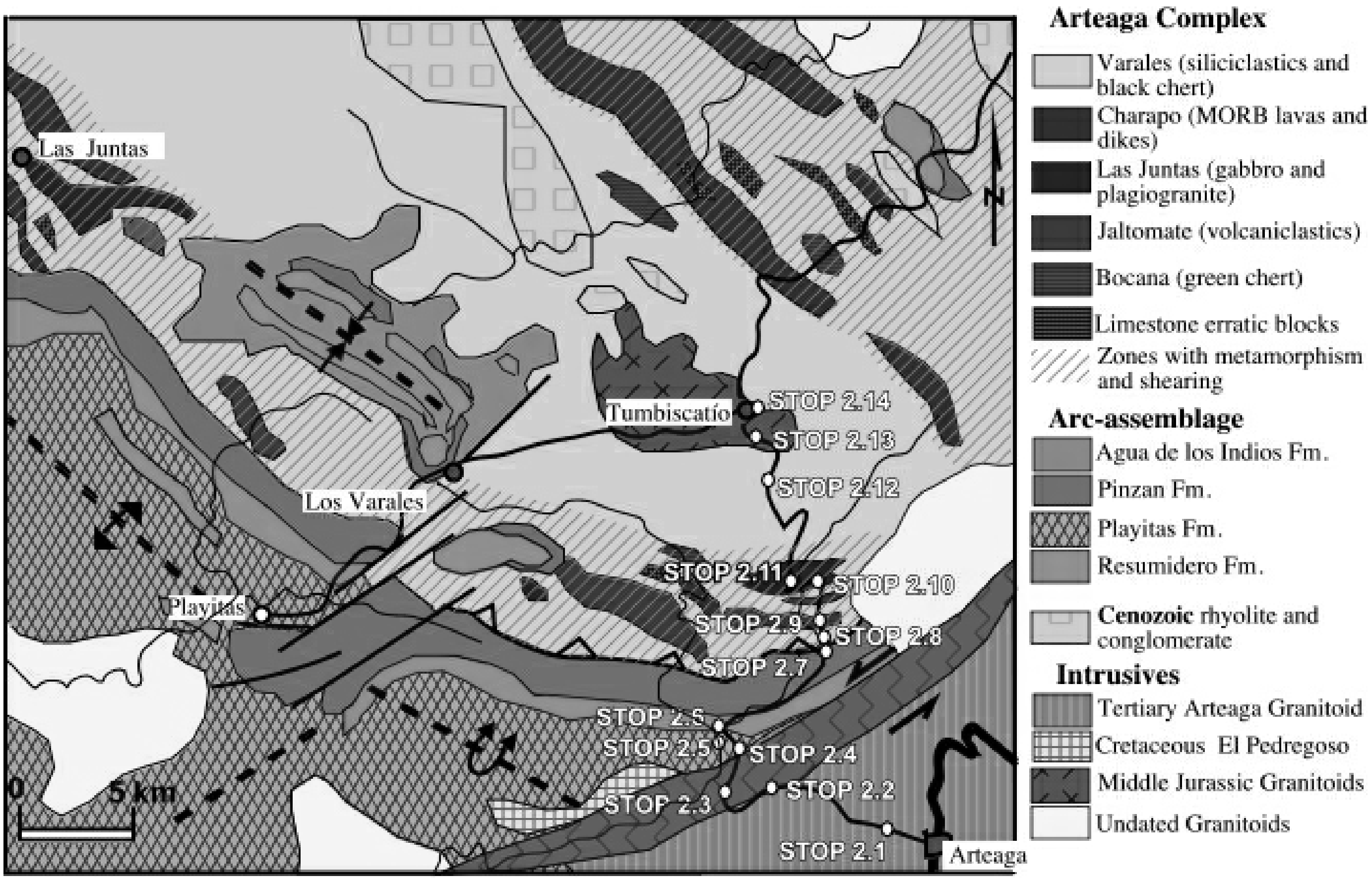

Figure 3. Geologic map of the Arteaga-Tumbiscatío region, and location of stops for day 2 (modified after Centeno-Garcia, 1994).

sandstone, and some black chert and conglomerates. It is occasionally interbedded with scarce packets (some up to 200 meters thick) of green metavolcaniclastics of the Jaltomate lithofacies, and the green chert of Bocana lithofacies (Figure 3).

The shale and sandstone are interbedded, forming a rhythmic sequence, with beds from 2 cm to 2 m in thickness. The sandstone/shale ratio is also quite variable. Conglomerates are very rare and represent channel fill deposits. The color varies from iron blue to deep gray and black. The sparse chert layers interbedded within this clastic sequence are black, thin-bedded layers, or thick packets of green chert (Bocana).

The Varales siliciclastics are distal turbidite deposits. Fossils are very rare and poorly preserved. Only micro fossils have been found, such as radiolarian and traces of foraminifers that could not been identified. Small coal fragments are abundant. Trace fossils belong to the Cruziana facies. Original thickness is unknown, but the minimum structural thickness, observed between two packets of lavas, is 1,500 m approximately.

Sandstone of the Varales lithofacies is predominantly fine to medium-grained, and rarely larger than gravel size. A detailed description of its petrology and geochemistry is given on stop 2.8. The Varales lithofacies has modal compositions that plot in the recycled orogen provenance field on the Qt/F/L and Qm/F/Lt diagrams (Dickinson et al., 1983). Sandstones with similar composition have been considered as derived from a source analogous to an uplifted fold-thrust belt or collision suture belt that might have mixed with some continental cratonic material.

JALTOMATE LITHOFACIES

The Jaltomate lithofacies (Figure 3) consists of pelites and very fine-grained sandstone that stand out from the Varales lithofacies because of their light green color. The Jaltomate lithofacies forms packets intercalated with sediments of the Varales lithofacies. The contact between those units is transitional in places where it is still preserved without shearing, and consists of a narrow zone of interbedded black and green sediments. The thickness of the Jaltomate lithofacies is variable; because of deformation, it forms isolated blocks from a few meters up to tens of meters thick. The largest exposure of the Jaltomate lithofacies is located close to the El Jaltomate ranch, where it forms a thick unit of approximately 900 m of structural thickness. Details on its petrography and geochemistry are described on stop 2.9. This lithofacies is interpreted as volcaniclastics derived from rift basalts and/or primitive island arc sources.

CHARAPO LITHOFACIES

This is made up of basaltic pillow lava flows and massive blocks of basalt that could represent either deformed dikes or massive flows (Figure 3). Because of deformation, the basaltic rocks of the Charapo lithofacies form blocks or lenses of up to 100 m thick. In thin section they are tholeiitic basalts, composed of thin crystals of plagioclase and sparse small olivine. Metamorphic mineral associations are mostly actinolite-tremolite, but in zones with intensive shearing the basalts are serpentinized. The inter-pillow spaces are filled by red-black chert, devitrified glass, or occasionally by limestone. Most of the volcanic bodies show deformed and sheared contacts, and are always surrounded by sediments of the Varales lithofacies. There is one exposure were the lavas seem to be incorporating part of the Varales siliciclastics, which suggests that the volcanic activity might have been contemporaneous with the deposition of the sediments.

The basaltic pillow lavas of the Charapo lithofacies have low REE abundance ($\sum$REE=34.41–38.79), with patterns that show chondrite-normalized light REE (LREE) depletion, and flat heavy REE (HREE). Their REE patterns are similar to those of N-type mid-ocean ridge basalts (N-MORB). Aphanitic basaltic and diabase bodies have higher REE abundances ($\sum$REE=55.80–65.96), and relatively flat REE patterns that are similar to those of present MORB or low-K island arc tholeiites (IAV) (Hawkesworth et al., 1977; White and Patchett, 1984). They have initial ε_{Nd} values +10.9 to +8.6 that are relatively close to recent N-MORB lavas. Other trace elements suggest that all volcanic rocks of the Charapo lithofacies have a MORB affinity (Centeno-García et al., 1993b; Centeno-García, 1994).

LAS JUNTAS LITHOFACIES

The Las Juntas lithofacies includes scattered isolated bodies of foliated gabbroic, dioritic, and plagiogranitic blocks that are exposed in the northwestern region and in the southeastern part of the Arteaga-Tumbiscatío area (Figure 3). The largest of those are over 800 m in diameter and are located in Las Juntas Ranch and in the road from Arteaga to Tumbiscatío (Figure 3). The gabbros show intense deformation and well-developed foliation. Their mineralogy and geochemistry are described in detail on stop 2.10. Whether the Las Juntas lithofacies intruded the Varales Lithofacies or not is still unclear; evidence suggests that they were incorporated into the Varales sedimentary succession by thrusting and shearing.

BOCANA LITHOFACIES

Other associated lithologies found in the Arteaga complex are packets of light green chert (Bocana lithofacies), interbedded with the Varales lithofacies. This unit sometimes forms blocks because of the shearing and deformation. The chert packets of the Bocana lithofacies are distinct from the black thin-bedded chert of the Varales lithofacies because of their light green-aquamarine color. When sheared, it can form blocks of approximately 5 to 50 m in diameter. They are folded and highly fractured, and contain badly preserved radiolarians that seem to be Mesozoic forms (V.M. Dávila-Alcocer, pers. com.). One sample analyzed for REE elements shows low REE abundances, with a REE pattern parallel to Varales lithofacies sandstones, and Eu/Eu* similar to average post-Archean shale. The sample is depleted in TRE and has a pattern that indicates upper continental crust affinity. The geochemical data suggests that the green chert is not of volcanic origin.

LIMESTONE BLOCKS

Large limestone blocks (recrystallized), up to tens of meters in diameter, are sporadically found within the sediments of the Varales lithofacies (Figure 3). Considering that the clastic rocks of the Varales lithofacies do not contain interbedded limestone or calcareous fragments, the limestone blocks might be olistoliths. Some have chert nodules, and contain fragments of crinoids' stems, whose age could not be determined.

Age of the Arteaga Complex

The age span of deposition of the Varales lithofacies has not been well constrained. The fact that the youngest detrital zircons are around 260 Ma (G. Gehrels pers. com.), suggest that sedimentation was Permian or younger, which is supported by the only paleontological report from the area (Campa et al., 1982). This was of radiolarian fossils of Late Triassic (Ladinian-Carnian) age (Campa et al., 1982). Therefore, the sedimentation is considered to be Late Permian or younger, Late Triassic, and might have extended up to Early Jurassic (?).

Scarce K/Ar isotopic data are available from whole-rock and single-mineral samples of the metapelites of the Arteaga Complex (Grajales and López, 1984). The data groups into three ages: Early-Middle Jurassic, mid-Cretaceous, and Eocene, where the last two were obtained from samples collected close to granitic plutons, and are probably related to thermal effect of those intrusives (Grajales and López, 1984). The Jurassic whole-rock dates range from 194 to 168 Ma, and a sericite-age of 189 Ma has also been reported (Grajales and López, 1984; Torres, pers. comm.). Gabbros from Las Juntas lithofacies yield U/Pb age of 180± 6 Ma, and they are in tectonic contact with the sediments of the Varales Complex. The oldest postectonic granitoids are 163 and 158, and the oldest age of the arc stratigraphy is Tithonian. Thus, deformation of the Arteaga complex might have been pos Toarcian to pre Oxfordian in age.

Contact relationships, structures and regional correlation

Rocks of the arc-assemblage rest unconformably on the Arteaga complex. The contact is well exposed in the Agua de los Indios Mesa, where a Late Aptian to Early Albian basal conglomerate, with fragments of sandstone from the Varales Lithofacies and volcanic clasts, rests in angular unconformity on the Arteaga complex (Figure 3). The Arteaga complex is strongly deformed and, in some areas, metamorphosed to greenschist facies. The complex can be considered, from a structural point of view, to be a disrupted assemblage, or “broken formation”. The Varales lithofacies shows a broad variety of styles of deformation, which range from sheared, boudinaged and stratigraphicaly disrupted beds to continuous beds with little structural disruption. The less deformed rocks are commonly involved in tight chevron folding and minor reverse faulting. The boudins in sheared areas are composed of broken beds of sandstone or shale. The contacts between the Varales lithofacies and the pillow lavas, green chert, volcaniclastics and limestone blocks are usually sheared. These lithologies form large lens-shaped bodies of tens to hundreds of meters in size giving the complex a “block-in-matrix” aspect. The blocks show a wide variety of grades of deformation, sometimes higher than surrounding sediments of the Varales lithofacies, and sometimes the deformation is less intense in the block than in the sediments. Structures related to at least two phases of deformation are well recorded in the complex; the Jurassic deformational event produced major shearing and metamorphism. In contrast Late Cretaceous deformation produced wide folding and some secondary thrust faulting in the Arteaga Complex. Possible correlative units to the Arteaga complex have been reported in the state of Zacatecas (Zacatecas Formation) (Figure 1), on the northeastern edge of the Guerrero terrane, and in the Huetamo region (Placeres del Oro and Tzitzio areas), in the state of Guerrero.

Depositional environments

Sedimentary structures along with the affinity of the few fossils found in the sediments of the Varales lithofacies suggest that they were deposited in a deep ocean environment. It is possible that deposition of the sediments of the Varales lithofacies was contemporaneous with at least part of the magmatic activity of the Charapo lithofacies (MORB). This is suggested by possible assimilation of sediments into the border of a pillow lava flow, although the siliciclastic sediments have never been found filling inter-pillow spaces. In contrast, these inter-pillow spaces are sometimes filled with carbonates, suggesting that magmatism occurred above the carbonate compensation depth. In addition, dikes with similar composition to the pillowed basalts cut the sediments of the Varales lithofacies, suggesting that sedimentation might have occurred during magmatism.

The sediments of the Varales lithofacies were transported to the ocean floor by turbiditic flows, as suggested by the primary structures. It is possible that graywackes from the Jaltomate lithofacies were deposited during periods of quietude in between turbiditic flows. Since their isotopic signature does not show significant crustal contamination, the Jaltomate sediments could represent either hemipelagic deposits derived from the erosion and eruption of oceanic basalts or, alternatively, deep-sea ash layers derived from air-fall ashes erupted from some oceanic island arc.

The erratic blocks of limestone might be olistoliths carried down from a continental slope, and could be derived from platform deposits. Calcareous olistholiths containing crinoids of Paleozoic age are very common throughout the accreted ocean-floor/ocean-flank assemblages of different Mesozoic ages in the North American Cordillera (Dickinson, 1992).

Whether the Arteaga Complex originated in a marginal back-arc basin or in an open ocean environment is still uncertain. The only possible evidence of association with island arc magmatism is the volcaniclastics of the Jaltomate lithofacies.

The origin of deformation of the Arteaga Complex has not been well determined. Whether this occurred by subduction processes or by compressional telescoping is difficult to determine. Its lithological association is similar to those in accretionary prism, but high-grade metamorphic rocks, such as blueschist, have not been found in the area. However, it could be feasible that the Arteaga Complex did not experience deep erosion, and that we are actually observing superficial levels of an accretionary prism.

MIDDLE TO LATE JURASSIC MAGMATIC EVENT

Although Middle to Upper Jurassic volcanic and sedimentary rocks have not been reported from the Guerrero composite terrane. Evidence of an important magmatic event of that age has been found in the Zihuatanejo terrane. This event is represented by granitoids exposed in the Tumbiscatío area. However, it might have been widespread along the coast, since clasts of granites found in the Zihuatanejo region yielded old ages as well. (Peter Schaaf, pers. com.). The two granitoids that crop out in Tumbiscatío region are Macías and Tumbiscatío (Figure 3). They vary in composition from granodiorite, granite and quartz monzonite, and their geochemical composition is typical of calc-alkaline I-type granites (volcanic arc granites) with 66-72% SiO_2, and 4.8-6.5% Alkalies (Na_2O+K_2O).

The Macías granitoid shows intense shearing and internal deformation that seems to be related to the youngest compressional event (Late Cretaceous?). Grajales and López (1984) obtained one K/Ar date of Late Jurassic age (158±5 Ma), and one U/Pb isotopic analysis yielded 163±3 Ma (G. Gehrels pers. com.). The Tumbiscatío pluton is described in detail in stop 2.13. It is a coarse-grained granite composed of quartz, K-feldspar, oligoclase-andesine, biotite, clinopyroxene and muscovite. It intrudes the metamorphic rocks of the Arteaga Complex, and does not have structures associated to major ductile deformation neither at the borders nor within the pluton. The isotopic signature indicates that this magmatic body might have incorporated melts of the Varales sedimentary rocks. It is Oxfordian-Kimmeridgian in age and it sets some constrains on the age of deformation of the Arteaga Complex.

UPPER JURASSIC-CRETACEOUS ARC STRATIGRAPHY

The stratigraphy of the arc is characterized by frequent lateral facies changes and internal minor erosional unconformities. The geographic distribution of the facies is very irregular and it has not been determined in detail yet. As mentioned before, the rocks have been described locally using different formation names, but their lateral extension and contact relationships have not been determined. Therefore, compiling, correlating, and synthesizing the stratigraphy is very difficult, because it varies considerably from one area to the other. Thus, we decided to group the arc successions in four regional assemblages, base on general similarities/differences in their facies. The following descriptions are of regional synthetic stratigraphic columns from each assemblage. We use formational names that have more extensive use, and the rocks are described by age and/or stratigraphic position from base to top. The different formations and units were not differentiated in the geological maps because of the lack of information and the scale of the maps.

1. THE JALISCO-COLIMA ASSEMBLAGE

Most of the detailed mapping of the Jalisco-Colima region has been done by PEMEX (the national oil company of Mexico). The stratigraphy was described in Aguayo (1983), among unpublished reports. The basement of the column is neither exposed not cut by drilling. The Cretaceous succession ranges from Berriasian to Turonian in age, and it is formed by volcanic and volcaniclastic rocks interbedded with limestone, evaporites, and some redbeds. There is only one report of Jurassic rocks (Michaud et al., 1987).

Jurassic (Tithonian) limestone succession

The oldest fossils reported from the Jalisco-Colima assemblages are the ammonites *Mazapilites* sp. and *Hybonoticeras* sp. gr. *hybotum* collected from a limestone succession that is exposed in Coquimatlán, a few km southwest from Colima City. The ammonites are early Tithonian in age (Michaud et al., 1987). The limestone unit does not have interbedded volcanic or volcaniclastic rocks, and are in parallel contact with Cretaceous arc-related rocks (Michaud et al., 1987).

Alberca Formation

The oldest Cretaceous rocks that crop out, or have been cut by drilling, are the Lower Cretaceous Alberca Formation. Its lower member is made up of interbedded black shale, sandstone and limestone, and some tuff. The upper member is composed mostly of andesitic-basaltic lava flows interbedded with limestone and shale. The Alberca Formation contains abundant fossil invertebrates, including the ammonites *Neocomites* sp. and *Subthurmannia* sp. of Berriasian-Hauterivian age (Cuevas, 1981). Its thickness is variable, and up to 1,800 m were cut by drilling without reaching the base.

Tecalitlán and Tepalcatepec Formations

The Alberca Formation changes transitionally upward to the Tecalitlán that records the main period of arc magmatism. It is made up mostly of andesitic and basaltic lava flows, with some rhyolitic flows, interbedded with pyroclastic (intermediate tuffs and ignimbrites) and epiclastic deposits. The epiclastics are mostly volcanic conglomerates and breccias (lahars), volcanic siltstone and sandstone (reworked tuff), with some calcareous siltstone and sandstone (Figure 4). The age of the Tecalitlán Formation has not been well constrained. However, the fact that the Tecalitlán Formation was deposited on top of the Alberca Formation and is covered by the Tepalcatepec Formation constrains its age range to Barremian-Aptian. Total thickness is unknown, however up to 2,400 m were measured from boreholes, without reaching the base (Grajales and López, 1984).

Apparently, the volcanic activity decreased during Early Albian time, and almost ceased by mid-late Albian. The Tepalcatepec Formation was deposited during this period of time. It is made up of thick limestone packets interbedded with scarce andesitic lava flows, and some horizons of volcaniclastic and calcareous/clastic rhythmic deposits, tuff and rhyolites, conglomerates and sandstone, red siltstone, and some evaporites (Grajales and López, 1984). It contains abundant fossils, including gastropods, bivalves, and microfossils such as *Nummoloculina heimi*, *Dicyclina Schlumbergeri*, *Orbitolina* sp., *Dictyoconus walnutensis*, and *Calcisphaerula innominata* (Ornelas, 1983). The fossil association suggests an Albian-Cenomanian age. The Tecalitlán and Tepalcatepec formations were deposited mostly in shallow marine and coastal environments, although some subaerial layers have been observed in southern Colima State. They contain abundant VMS deposits.

Madrid Formation

At the center of the state of Colima, near Colima City, the Tepalcatepec Formation changes laterally to the Madrid Formation (Grajales and López, 1984) that consists of limestone, calcareous shale, gypsum, and scarce andesitic flows and tuffs, which concentrate mostly at the base of the succession. The Madrid Formation contains abundant rudist, ostrae, gastropods and some algae layers that suggest a shallow and quiet marine environment. Fossils are Albian to Early Cenomanian in age (Grajales and López, 1984). Gypsum deposits were locally very thick, as suggested by the dimensions of gypsum diapirs found at different levels of the succession. A borehole in central Colima State measured up to 3,600 m of limestone of the Madrid Formation (Grajales and López, 1984).

Cerro de la Vieja Formation

A conglomeratic unit, formed mostly by limestone fragments, is folded together with underlying Cenomanian limestone; it contains some lava flows that were dated by K/Ar and yielded 80±6 and 78±6 Ma (Grajales and López, 1984). The conglomerates contain some sandstone and siltstone beds. Sedimentary structures and textures suggest that this formation was deposited in a con-

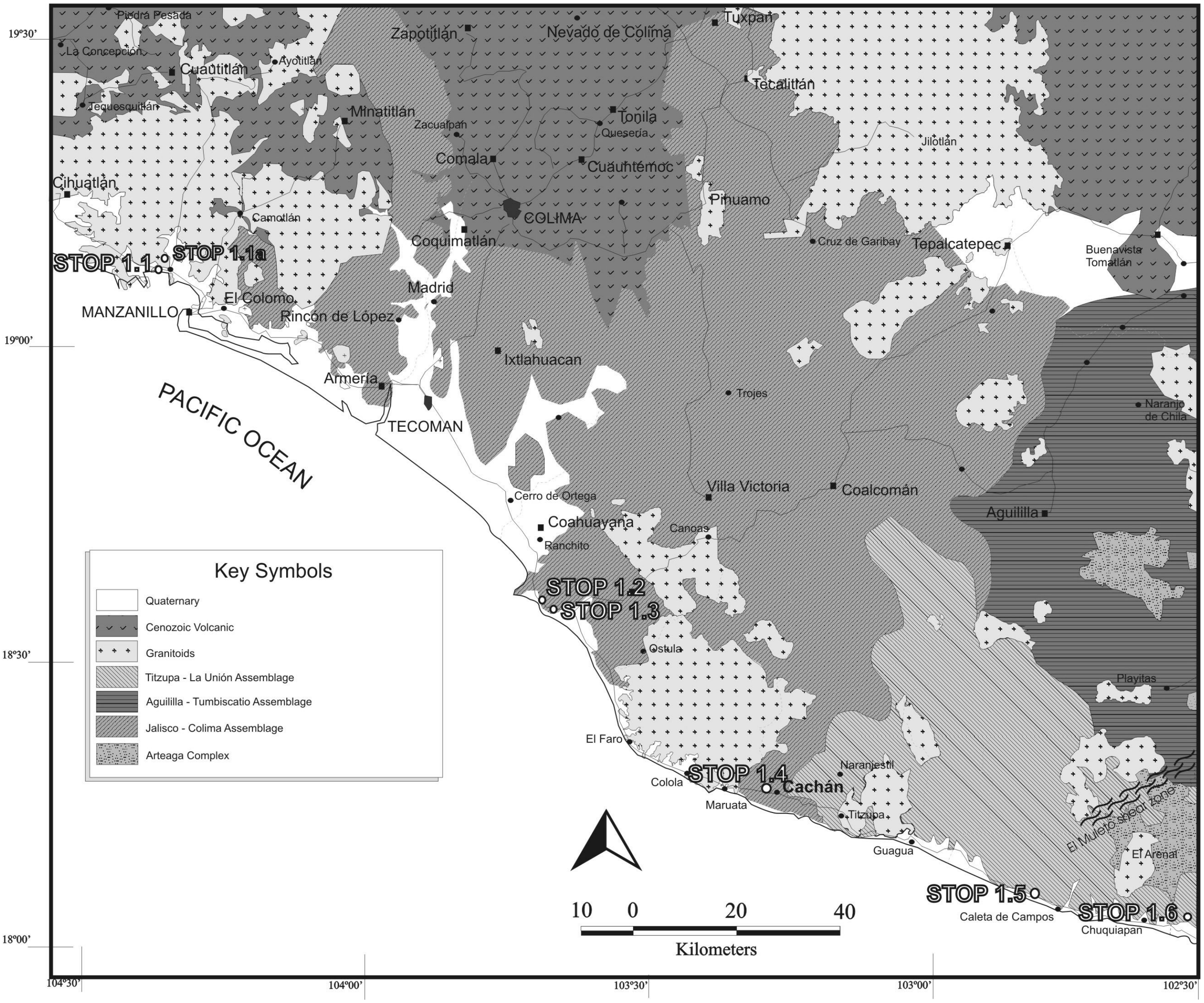

Figure 4. Geologic map of the Jalisco-Colima region, and location of stops for day 1 (compiled by P. Corona-Chávez).

tinental (fluvial) environment. The contact between the Madrid and Cerro de la Vieja Formations seems to be transitional. Base on the radiometric ages and its stratigraphic position the Cerro de la Vieja Formation has been considered Turonian in age (Grajales and López, 1984)).

2. The Titzupa-La Unión Assemblage

The stratigraphy of the Titzupa-La Unión assemblage is the least known of all the Zihuatanejo terrane successions. What is distinctive of this assemblage is that it has the largest succession of redbeds and very minor amounts of limestone compared to the other three assemblages. The assemblage is made up of rhyolitic lavas (lava flows, breccias, and ignimbrites) and minor andesitic and dacitic lavas. They are interbedded with epiclastics, such as tuff, volcanic shale and sandstone, and some conglomerate made up of clasts of volcanic, quartz and sandstone. They are interbedded with thin beds of limestone that contain orbitolinids, *Cerythium* sp. gastropods and some pelecipods (Ferrusquía et al., 1978; Grajales and López, 1984). Raindrop marks, desiccation polygons, and dinosaur footprints can be found in this succession (see stop 1.6). The age span of this succession is unknown. There is a report of the foram *Nummoloculina heimi* that is of late Albian-Cenomanian age (Grajales and López, 1984).

3. *The Tumbiscatío-Aguililla assemblage*

There are no published geological maps or reports on the geology of the Arteaga-Tumbiscatío area. Its regional stratigraphy has been approximately defined by Petróleos Mexicanos (PEMEX), in several unpublished reports (e.g., Gutiérrez, 1975). The stratigraphy described in this field guide is based on Centeno-García (1994).

Agua de los Indios Formation

The Agua de los Indios Formation is made up of a basal conglomerate that rests on top of the deformed Varales lithofacies of the Arteaga Complex. The sequence continues with a package of interbedded shale, thin-bedded calcareous shales, volcanic and arkosic sandstones and reworked tuff with abundant limestone nodules. At the top of the sequence there are some thick beds of red sandstone, rhyolitic tuff, sparse conglomerate and reworked tuffs .The basal conglomerate is formed by pebbles of quartz-rich sandstone, black slate, and schist derived from the underlying Arteaga Complex. The Agua de los Indios Formation contains fossil gastropods and bivalves that are characteristic of shallow marine facies. Gastropods belong to the species *Mesoglauconia (Mesoglauconia) burnsi*, *M. (Triglauconia) kleinpelli*, and *Gymmentome (Gymmentome) paluxiensis* that dated the unit as late Aptian to early Albian (Vega-Vera, pers. comm.). Its thickness varies from 20 m to 350 m. The unit is covered by andesitic flows of the Pinzán Formation, or by the Resumidero Limestone (Figure 3).

Pinzán Formation

The Pinzán Formation is composed of andesitic and few rhyolitic lava flows, with fewer layers of tuff and epiclastics. Lava flows are mostly massive, sometimes with a horizon of autobreccia at the top of the flow, which suggests subaqueous deposition. Some layers of heterogeneous volcanic breccias are intercalated with the lava flows. Those breccias might represent cohesive debris flows or lithic tuffs. This formation is variable in thickness, from a few meters to approximately 250 m. The age is unknown, but its close relationship with the Agua de los Indios and Resumidero Formations suggest an Aptian-Albian age. The Pinzán Formation is apparently contemporaneous, and probably correlates with the Tecalitlán and Tepalcatepec Formations of the Jalisco-Colima assemblage (Grajales and López, 1984; Pantoja and Estrada, 1986). The volcanic rocks of the Pinzán Formation lie on top of either the Arteaga Complex or the Agua de los Indios Formation, and it is in tectonic contact with the Arteaga Complex in the southeastern part of the region (Figure 3). These rocks are covered by the Playitas or Resumidero formations.

Resumidero Formation

The Resumidero Formation is made up of massive limestone with abundant rudists, which form banks and preserve original growth positions (rudist reefs). The Resumidero limestone contains microfossils of middle-late Albian age in the Agua de los Indios Mesa, where it is interbedded with calcareous shales at the top. The shales have *Orbitolina (Mesorbitolina) texana texana* of lower early Albian age, associated with small bivalves and fragments of dinosaur bones (Centeno-García, 1994). Calcareous shales that contain abundant Orbitolinas have also been found in upper levels of the Tecatitlán Formation in the Jalisco-Colima assemblage. The Resumidero limestone shows some foliation and recrystallization in the southeastern part of the area. This deformation is related to thrusting of the Arteaga Complex (Figure 3). The thickness of the limestone is variable, from 10 m to up to 200 m in some areas. It underlies the Playitas Formation.

Playitas Formation

The Playitas Formation is made up of interbedded conglomerates, sandstone, tuffaceous and calcareous shale, with some discontinuous limestone patches, and scarce lava flows (andesitic and dacitic). Bedding is sometimes discontinuous, with variable thickness (20 cm to 5 m). Conglomerates are formed by pebbles of volcanic rocks, vein quartz, quartz-rich sandstone (may be derived from the Varales lithofacies), and rarely granitic in composition. Sandstone is mostly volcanic-arenite and arkose, and shows sparse cross bedding. Those sandstone and conglomerate deposits show a red color in some areas (secondary iron-oxides matrix replacement). Some conglomeratic beds are formed by volcanic debris that contain irregularly shaped limestone clasts, as if they were deformed in a plastic state. We suggest that those volcanic conglomerates might represent debris flows or lahars that incorporated some non-lithified limestone muds originally deposited around the volcanic edifices. Ignimbrites also occur in this unit. Limestone layers (30 cm to 10 m thick), and interbedded thin-layers of calcareous shale and sandstone (packets of 10 m thick) are spread as large lenses in the Playitas Formation. These sediments contain fragments of rudists, and some microfossils of probable mid- to Late Cretaceous age. Total thickness of the sequence is unknown, although up to 800 m have been measured in the southern part of the area (Centeno-García, 1994). Depositional environments varied from shallow marine to coastal.

4. The Zihuatanejo assemblage

The Zihuatanejo region also has a well-exposed record of the arc stratigraphy. This area was mapped in detail by Vidal-Serratos (1991) who described the following units, from bottom to top.

Las Ollas Complex

This unit is made up of basalts, interbedded shale and sandstone (quartz-rich sandstone), ultramafic bodies, and blocks of metamorphic rocks that show a mélange-like structure. Blueschist facies were found by Talavera-Mendoza (1993, 2000). Geochemical compositions of the basalts are typical of oceanic arc magmas (Talavera-Mendoza, 2000). The unit is highly deformed (broken formation), and metamorphosed. The Las Ollas complex is interpreted by Vidal-Serratos (1991) and Talavera-Mendoza (2000) as a subduction complex that is composed in some areas by a sedimentary matrix and others by serpentine matrix. Talavera-Mendoza et al. (1995) suggested that the subduction complex was related to the arc assemblage and was dipping toward the east. A more detailed description is given on stop 3.1. It has been interpreted to be the subduction complex of the Cretaceous arc (Vidal-Serratos, 1991; Talavera-Mendoza, 1993).

Lagunillas Formation

This is a thick succession of shale and some volcanic sandstone of unknown age and origin. Vidal-Serratos (1991) considers that it might be part of the Las Ollas Complex. However, Centeno-García (1994) interpreted this unit as part of the stratigraphy of the arc assemblage. It contains abundant detrital mica of Jurassic age.

The Posquelite Conglomerate

This is a poorly sorted matrix-rich conglomerate that forms massive horizons of several meters in thickness with no internal gradation. Its sedimentologic features suggest that it probably was deposited by auto suspended submarine debris flows. The clasts from the Posquelite conglomerate are made up of slightly foliated granite, quartz-mica schist, metamorphosed quartz-rich sandstone, gneiss, and massive quartz fragments. Granite clasts have biotite and some muscovite. The age of the sequence is unknown, but it is stratigraphically underneath the Ixtapa limestone of Albian age. Geochemical and isotopic analysis from fragments of meta-sediments and granite are discussed in stop 3.2, as well as a discussion on the origin and importance of this member.

The Ixtapa Limestone

This is made up of massive limestone, calcareous shale, and calcareous autobreccia that contain Albian fossils (Figure 5), including abundant rudists.

Zihuatanejo Formation

This is made up of andesitic lava flows and volcaniclastic rocks apparently overlay limestone beds of the Ixtapa limestone (Vidal-Serratos, 1991; Centeno-García, 1994). A detailed description on the volcaniclastics is given at stop 3.4. Depositional environments in the Zihuatanejo Formation are mostly shallow marine.

Geochemistry of the Jurassic-Cretaceous Arc succession

The Cretaceous volcanic rocks from the Jalisco-Colima, Titzupa-La Unión and Tumbiscatío-Aguililla assemblages show the whole range of composition in the evolution of a volcanic arc (Centeno-García 1994; Talavera-Mendoza, et al., 1995; Freydier et al., 1997). The lavas range in composition from tholeiitic basalts, to calk-alkaline andesites, and abundant rhyolites and dacites. The Jalisco-Colima assemblage shows the most complete range, where even shoshonites have been reported (Centeno-García, 1994; Tardy et al., 1994). Felsic lavas

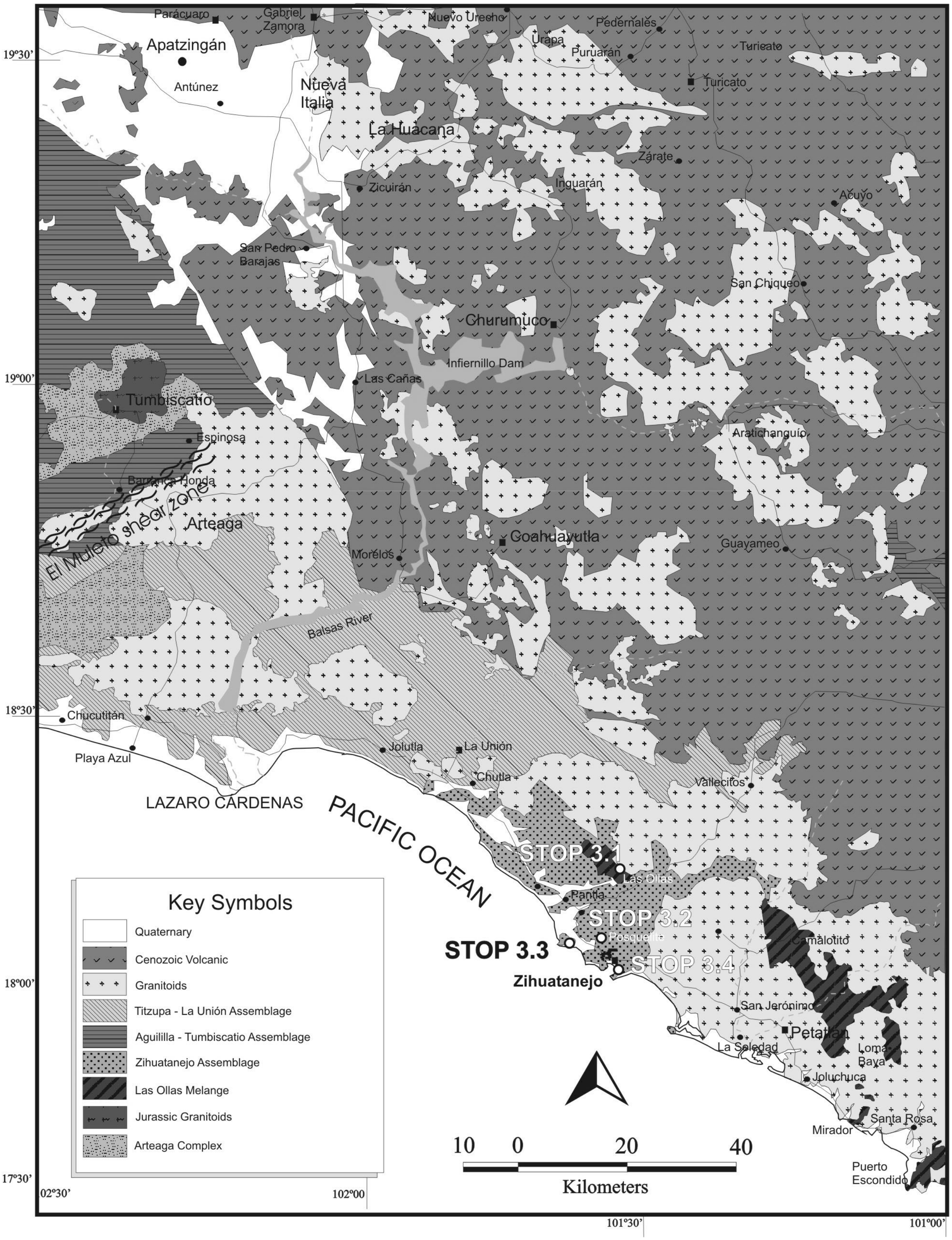

Figure 5. Geologic map of the Lázaro Cárdenas-Zihuatanejo region, and location of stops for day 3 (compiled by P. Corona-Chávez).

are more abundant in Titzupa-La Unión, whereas basaltic and andesitic lavas tend to be more abundant in the Jalisco-Colima and Tumbiscatío-Aguililla assemblages.

Overall, the Jalisco-Colima, Titzupa-La Unión and Tumbiscatío-Aguililla assemblages have Th/Yb and Ta/Yb ratios that show a transitional composition between oceanic island arcs and active continental margins (Centeno-García 1994; Freydier et al., 1997; Mendoza and Suástegui, 2000). The basaltic and andesitic lavas show REE patterns that are typical of island arcs, and are enriched in light REE with negative Eu anomaly (Centeno-García, 1994; Freydier et al., 1997). Felsic lavas are calc-alkaline and show LREE enriched patterns, higher that those from mafic lavas (Freydier et al., 1997). The initial ε_{Nd} values obtained from lavas and volcaniclastics from the three assemblages range from +3.0 to +7.8 (Centeno-García, 1994; Freydier et al., 1997). They are close to values observed in recent island arc volcanics, and indicate that both lavas and sediments were derived from juvenile sources. Model ages range from 0.29 to 0.46 Ma and suggest that Precambrian crust was not involved in the magma generation (Centeno-García, 1994). The high potassium content, the abundance of felsic lavas, and the trace-element abundance of the Cretaceous volcanic rocks of the assemblages are similar to those observed in island arcs where the crust is thick (greater than ca. 20 km) allowing magma differentiation (Centeno-García, 1994).

Cretaceous magmatism in the Zihuatanejo assemblage shows minor differences in its geochemical and isotopic composition (Freydier et al., 1997). They range from andesites to rhyolites, and have major and trace element concentrations that fall in the range of subduction-related tholeiitic and calc-alkaline lavas (Freydier et al., 1997; Mendoza and Suástegui, 2000). However, their overall composition is more homogeneous than the lavas from the other assemblages, and they are more depleted in Zr and Th, and have higher initial ε_{Nd} values (+7.5 to +8.4), compared to the other volcanic rocks (Freydier et al., 1997). This suggests that the mantle source of the magmas from the Zihuatanejo assemblage was not affected by crustal contamination (Freydier et al., 1997).

Depositional environments of the arc assemblages

The paleontological and lithological associations of the arc-related successions of the Zihuatanejo terrane mostly correspond to shallow marine environments, with periods of subaerial sedimentation. Subsidiary closed lagoons allowed the development of rudist reefs and orbitolinas. Sporadic lava flows, debris flows and ash-falls disturbed zones with carbonate precipitation and scraped off fragments of unconsolidated limestone, forming the thick sequences of volcanics and volcaniclastics with blocks of carbonate that can be observed from Tumbiscatío to Colima region.

Detailed sedimentological studies have not been done, however, the abundance of volcanic rocks, the textures and structures found in the epiclastic deposits and the large thickness of some units, such as the Tecalitlán and Tepalcatepec formations, suggest that a series of large submarine, and partially emerged, volcanic edifices (stratovolcanoes?) might have dominated the landscape during the Cretaceous. Rudist and coral reefs might have formed around the volcanoes. The composition and nature of the Madrid Formation in the Jalisco-Colima assemblage suggest that it might have been deposited in the depocenter of an intra-arc basin, which was surrounded by volcanic edifices. This basin was probably under continuing subsidence, as suggested by its thickness (up to 3,000 m). Eventually the basin was filled up, and/or the sea level dropped, allowing the erosion of previously deposited formations, and the deposition of redbeds of the Cerro de la Vieja Formation. Sandstone samples collected from the Jalisco-Colima assemblage are mostly volcanic-arenites, composed of up to 90% of volcanic fragments, and minor feldspar and quartz grains (Centeno-García, 1994). This indicates that pre-arc units were not exposed in the Jalisco-Colima area, and sediments were derived probably from local sources only. The rapid changes in thickness, and the preservation of the same depositional environments during large periods of time, suggest that the Jalisco-Colima basins might have developed under an extensional setting.

In contrast, characteristics of the sedimentary rocks from the Titzupa-La Unión assemblage suggest that this area was under subaereal conditions most of the time, with periods of sea-flooding, when shallow marine conditions prevailed. Stratigraphy of the Tumbiscatío-Aguililla assemblage suggests that the area was probably exposed during Tithonian-Neocomian time, forming a topographic high. This is based in the fact that the first unit deposited unconformably on the Arteaga Complex is uppermost Aptian-Albian in age. The Tumbiscatío-Aguililla region remained, most of the time, under sea level, with shallow marine conditions. However, short periods of subaereal exposure are evidenced in beach-type sedimentary features, and scarce, thin packets of continental redbeds. Pre Albian sedimentary rocks, related to the arc, have not been found in the Zihuatanejo assemblage. Stratigraphy in this area suggests shallow marine conditions for most of the time of the arc activity. Sandstone and conglomerate from the Titzupa-La Unión, Tumbiscatío-Aguililla, and Zihuatanejo assemblages contain, in variable percentages, clasts of granitic, metasedimentary and quartz-rich sandstone. This suggests that basal rocks were exposed during the magmatism of the arc (Centeno-García, 1994).

Structural geology and age of deformation

Most of the Cretaceous rocks in the Zihuatanejo terrane form wide regional anticlines, and locally some overturned folds and minor thrust faults can be found. Areas with thin bedding show some disharmonic deformation, and chevron folding. Deformation increases around the gypsum diapirs in the Jalisco-Colima assemblage. However, overall deformation is less tight than deformation observed in Arcelia and Teloloapan subterranes. The structures generally trend is NW-SE, although locally some structures trend N-S and E-W (Figure 5). The age of the deformation has not been constrained. However the fact that Tertiary granitoids cut the folded units suggest a Late Cretaceous/Early Paleogene deformation. Although deformation within the Cretaceous (115–90 Ma) granitoids has not been recorded, the fact that some structures change trends around them suggests that folding might be post Turonian. This age is also supported by the fact that the Turonian deposits in Colima region are folded, following the regional trends. In other parts of the Guerrero terrane, deformation is Turonian-Maastrichtian, and associated with the final amalgamation of the Guerrero terrane.

Pre-Cenozoic tectonic evolution of the Guerrero terrane

Paleogeography of the Guerrero terrane and its relationship with North America are still under debate. Whether the Guerrero terrane was a marginal or a far-traveled arc has been debated for many years. Some authors have suggested that the arc was accreted to nuclear Mexico in Late Cretaceous time via a subduction system dipping westward, closing an oceanic basin located between the arc and the continent (Tardy et al, 1994; Lapierre, et. al., 1992, etc.). However, other authors have suggested that the Guerrero terrane might represent a marginal arc (Campa and Ramírez, 1979) that developed relatively close to the continent. There are others that consider the Guerrero terrane as a complex system of two or three arcs (Ramírez-Espinosa et al., 1991; Mendoza and Suástegui, 2000), and still others have proposed that the Guerrero was a continental arc built on continental crust (de Cserna, 1978a; Elías-Herrera and Sánchez-Zavala, 1990).

We consider that the evolution of the Guerrero composite terrane was more complex than the models previously proposed (see Table 1 for a summary). The origin, as well as the role of the Paleozoic units of the San José de Gracia terrane in the evolution of the Guerrero composite terrane had not been determined. The data available suggest that the basement units of Zihuatanejo terrane was a marginal oceanic basin (back arc basin) that developed during Late Triassic, and was deformed and metamorphosed during Early to Middle Jurassic time. The place where such rocks collided remains unknown. However evidence suggests that rocks of the Arteaga oceanic basin might have collided against or near nuclear Mexico (Centeno-García and Silva-Romo, 1997). This deformation was followed by arc or post-collisional granitic intrusions during Middle to Late Jurassic, whose role in the tectonic evolution of the terrane have not been constrained yet.

The arc activity seems to have started in the Tithonian (?) in the Zihuatanejo terrane, in the Hauterivian in Teloloapan and in the Albian in Arcelia. There are different opinions on whether it was a single arc or a system of at least three arcs. Paleomagnetic data obtained from samples collected by Bönel et al. (1989) from Cretaceous arc rocks and batholiths along the coast (Zihuatanejo Terrane) show no significant latitudinal translations or rotations. The proposed timing of final amalgamation of the Guerrero terrane to the margin of older terranes that form the eastern part of Mexico is Turonian to Maastrichtian (Campa and Ramírez, 1979), as suggested by the age span of foreland basins associated to the deformation of the arc.

Table 1. Age table of units and major tectonic events in the Puerto Vallarta-Zihuatanejo area.

Age in Ma	Age	Event-Unit
0	Active	Faulting associated to the rifting of the Jalisco Block
0	Active	Uplift of the coast associated to subduction
10	Miocene	Uplifted marine rocks that form terraces
?	Unknown	Strike slip faulting systems
46–33	Eocene-Oligocene	Volcanic and volcaniclastic rocks (SMS)
32–50	Eocene-Oligocene	Granitoids (granite, granodiorite)
60–70	Paleocene-Maastrichtian	Granitoids (granite to gabros)
99–105	Albian	Granitoids (granite, granodiorite and tonalite)
?	Unknown	Folding and thrusting of the arc assamblages
151–89	Tithonian-Turonian	Sedimentation and magmatism of the Jalisco-Colima assemblage
144–99?	Neocomian-Albian?	Sedimentation and magmatism of theTizupa-La Unión assemblage
121–93	Aptian-Cenomanian	Sedimentation and magmatism of the Playitas-Tumbiscatío assemblage Sedimentation and magmatism of the Zihuatanejo assemblage Las Ollas Acretionary Complex
155–158	Callovian-Oxfordian	Tumbiscatío granitoid (K-Ar/Ar-Ar dates)
158±5/163±3	Callovian-Oxfordian	Macías granitoid (K-Ar/U/Pb dates)
194–168	Pliensbachian-Bathonian	K-Ar Ages of deformation? (schist and slate)
180±6	Toarcian-Aalenian	Las Juntas Gabro U-Pb age
287±23	Permian	Las Juntas Gabro K-Ar age
221–210	Norian	Sedimentation and magmatism of the Arteaga Complex
240–300	Permian-Triassic	Youngest detrital zircons (cluster)

Cenozoic magmatism and deformation

Widespread granitoids are mostly Eocene-Oligocene, and a few Cretaceous-Paleocene, in age. They show variations in their composition, but they are overall subduction-related calc-alkaline intrusives. Their distribution is shown on Figures 4, 5, and 6, and some of them are described in detail in the field trip log. They are related to the magmatic events of the Sierra Madre Occidental, and to its extension toward the south (Sierra Madre del Sur). Some volcanic (rhyolitic) and volcaniclastic rocks of the same age are exposed in the Zihuatanejo terrane. Origin and evolution of the magmatism are discussed in Schaaf (1990), Schaaf et al. (1994), Schaaf and Martínez (1997), and Morán et al. (1999), among others. Deformation during the Cenozoic includes shear zones trending NE-SW (El Muleto Shear Zone), N-S and E-W normal faults (Puerto Vallarta Graben), as well as uplift of the coast. Some of those features are described in the field trip log as well.

FIELD TRIP LOG

DAY 1

The fieldtrip starts in Manzanillo, Colima State (Figure 4). Along the road from Puerto Vallarta to Manzanillo, the following geological units and features can be observed:

The Puerto Vallarta Graben: The topography of the Bay of Banderas, in the surroundings of Puerto Vallarta City, seems to be controlled by recent normal faulting that forms a graben that runs SW-NE (Figures 4 and 6). Although the evolution of this graben has not been studied in detail, its morphology suggests active subsidence. This subsidence seems to be producing a local transgression of the ocean into the continent, originating remnants of the sea cliffs that form small islands of fluvial redbeds. The Vallarta Graben has been considered part of a system of normal faults that form a rift-rift-rift triple junction in western Mexico. This system is interpreted to be associated with the movement of the Jalisco Block (Bandy and Pardo, 1994). Shallow earthquakes, and active volcanism are considered evidence of the rifting of the Jalisco Block (Pacheco et al., 1999).

The Puerto Vallarta Batholith: The road runs for around 70 km across a large granitoid that is exposed from Puerto Vallarta to Tomatlán, Jalisco State (Figures 4 and 6). This is thought to be the largest plutonic body of the Mexican Cordillera. It ranges in composition from alkali feldspar granite, two-mica granite, and granodiorite, to

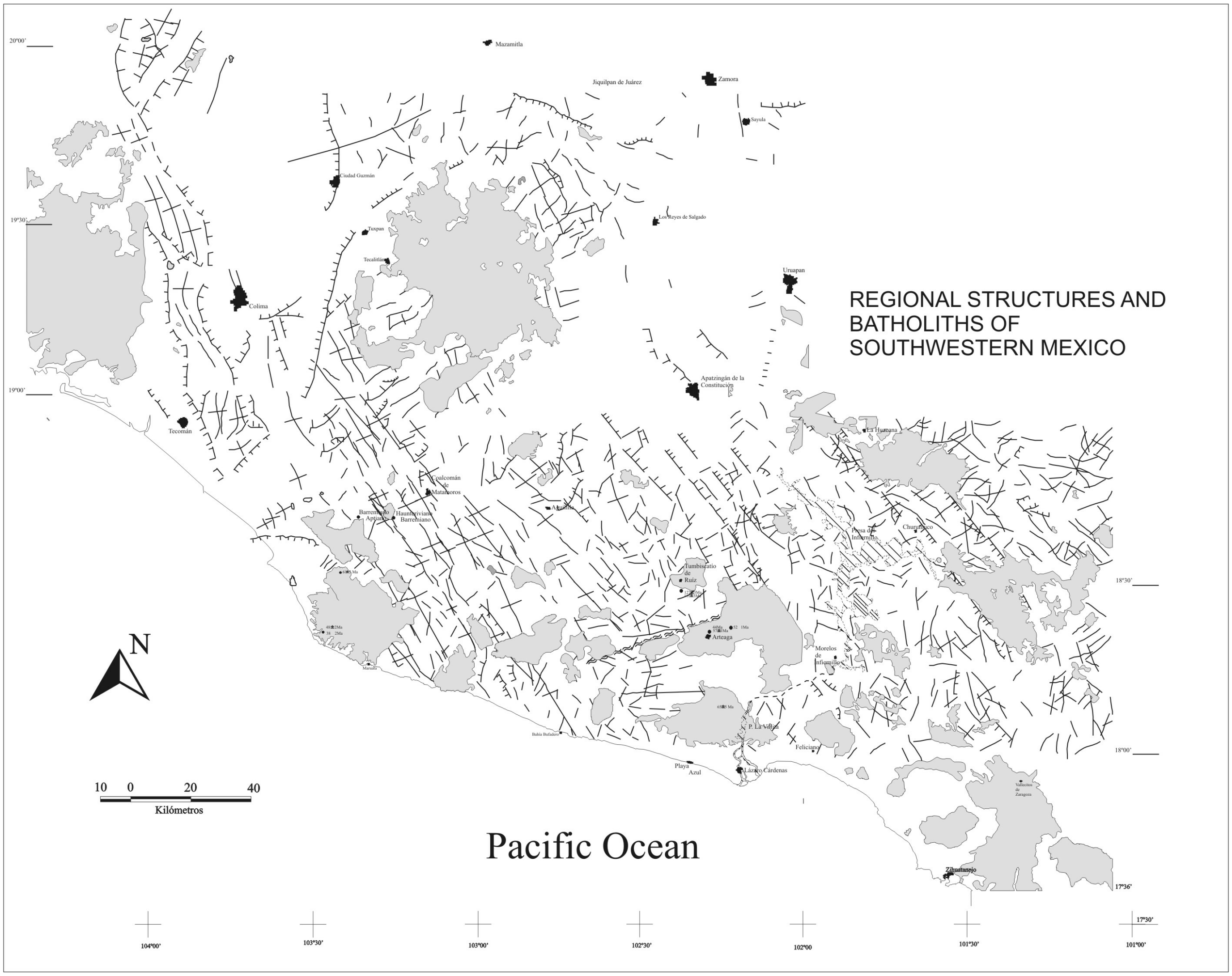

Figure 6. Regional distribution of the largest batholiths and Laramide and Cenozoic major structures (compiled by P. Corona-Chávez).

tonalite (Schaaf and Martínez-Serrano, 1997). As with other intrusives along the Mexican Pacific Coast, trace element composition and isotopic ratios of the Vallarta batholith indicates a calc-alkaline volcanic arc affinity (Schaaf, 1990). However some areas of the batholith have shown within plate and S-type affinities (Schaaf, 1990; Schaaf et al., 1995). Nd model ages range from 594 Ma to 1.5 Ga, suggesting that old crustal components were involved in the magma generation (Schaaf, 1990). These components may be the Triassic sedimentary rocks of the Varales lithofacies or some older (Paleozoic) rocks. Isochron Rb/Sr ages yield 99±4 Ma and 91±3 Ma; Mineral Rb/Sr and K/Ar ages range from 76–84 Ma, and one of 93 Ma, but younger ages have also been obtained (65 to 32 Ma) (Murillo-Muñetón and Torres-Vargas, 1987; Schaaf and Martínez-Serrano, 1997). The batholith seems not to be strongly deformed, it shows few localized fault planes with slikensides, and some mylonitic zones that seem to be related to the continental margin truncation (Schaaf et al., 1995). The relationship between the Batholith and the Laramide deformation has not been determined. It plays an important role in the reconstruction of the paleogeography of the Pacific Coast. Variations of its geochemical and isotopic composition, as well as its age and cooling history, have a good match with those of the batholith of Los Cabos Block (Schaaf et al., 2000). These data and the paleomagnetic results from both the Puerto Vallarta and Los Cabos granitoids strongly suggest that both areas were together prior the opening of the Gulf of California (Schaaf et al., 2000).

The Tomatlán Basin: Located about 79 km to the south from Puerto Vallarta, the Tomatlán Basin has a diameter of about 30 km. This basin is filled up by conglomerate, silt and clay that contain vertebrate fossil fragments of camels, horses, and giant terrestrial turtles of Pleistocene age.

The Tomatlán Granitoid: From the intersection to Tomatlán town to Miguel Hidalgo scattered outcrops of the Tomatlán intrusive can be seen along the road. This granitoid is part of the Vallarta-Tomatlán Complex, and its composition ranges from granite, hornblende-biotite granodiorite to diorite. K/Ar ages obtained from biotite are 93±7, 87+3, and 35±2 Ma along the coast, and 65±2 and 58±2 Ma more inland (Murillo-Muñetón and Torres-Vargas, 1987). This pluton seems to be the southern continuation of the Puerto Vallarta Batholith (Figures 4 and 6).

Scattered exposures of Cretaceous volcanic and volcaniclastic rocks and limestone can be observed from Miguel Hidalgo to Cihuatlán, where they are intruded by Manzanillo granitoid.

The epicenter of the biggest earthquake in Mexico registered by instruments was localized along this segment of the coast (Puerto-Vallarta-Manzanillo). It occurred on June 3, 1932, and it was 8.2 (Richter), and caused massive destruction (Schaaf, 2001).

Stop 1.1 Manzanillo gabbros and plagiogranites (19°07'07.3"; 104°21'48.0").

At the eastern end of Playa Miramar, Bahía de Santiago, in the City of Manzanillo, Colima, 4 km from the intersection of the highway with the road to Manzanillo. The outcrop is located at the beach (Figure 4).

The only Upper Cretaceous-Lower Paleocene mafic intrusions that have been found along the coast are those at Manzanillo, Colima. They are gabbros and plagiogranites that are formed by anorthite, clinopyroxene and brown amphibole. They have a broad variety of textures from fine to coarse grained, and sometimes with magmatic foliation. Pyroxene cumulates are common. The Manzanillo gabbros have a calc-alkaline arc affinity. It shows initial ε_{Nd} values of +6.4 to +5.2 and Nd model ages around 250 Ma. It yielded whole rock and mineral Rb/Sr and K/Ar ages that range between 70 and 59 Ma, and it does not show major deformation.

Stop 1.1(a) Optional: *4 km from the intersection of the road to Manzanillo with the Highway, on the road cut (Figure 4)*

Fresh exposures of the Manzanillo gabbroic intrusive can be seen at the road cut. It shows coarser textures and large pyroxene cumulates.

The Tecomán-Colima topographic low: From Manzanillo to Cerro de Ortega, located about 100 km from Manzanillo, the road runs along an area with lower elevation that forms a group of valleys from Colima City to the coast. These morphological features have been interpreted as the eastern end of the Jalisco Block. They were inferred in Allan (1986), and Harrison and Johnson (1988) as one active extensional basin or series of basins, running from Guadalajara City to Tecomán-Manzanillo (Figures 4 and 6). Alternative interpretation is discussed by Serpa et al. (1992); what they found suggested that the morphological features are associated with older compressional and transpressional deformation of N-S trending, and did not find evidence of Pliocene-Pleistocene deformation along the system.

Tecomán City (Figure 4) was partially destroyed during the January 21, 2003 earthquake. This quake had a magnitude of 7.6 (Richter) and the epicenter was located in the ocean, 10 km off coast, in front of San Juan de Lima town. It was 10 km deep, with a thrust fault focal mechanism, and was produced by the subduction zone.

Stop 1.2 San Juan de Lima andesites and volcaniclastics, Jalisco-Colima assemblage (18° 34' 02.8"; 103° 39' 22.0")

Exposure at the northern road cut, 124.9 km from Manzanillo, Colima, south from San Juan de Lima town (Figure 4). Along the road there are exposures of volcaniclastic rocks (epiclastic sandstone and conglomerate, tuff, and epiclastic mass-flows) interbedded with felsic lavas, volcanic autobreccias, massive lava flows and pyroclastic flows (ignimbrites). At the outcrop, volcanic autobreccias and ignimbrites are interbedded with fine-grained sandstone and siltstone, red in color, which might have originally been ash-fall tuffs and fine-grained ignimbrites. The succession dips 76°; 36° SE, and changes upward to limestone. It is considered part of the Tecalitlán or Tepalcatepec Formations, of the Jalisco-

Colima assemblage. The unit does not contain fossils but it underlies a thick limestone succession that contains Aptian-Albian (Cenomanian?) fossil fragments (stop 3).

Stop 1.3 Limestone Jalisco-Colima assemblage (18° 33' 45.7"; 103° 38' 50.3")

The outcrop is on the northern road cut, at the viewing area along the road (mirador), located 126.5 km from Manzanillo (Figure 4). This is part of a limestone unit, 300–400 in thickness that lies conformably over the volcanic and volcaniclastic succession of stop 2. It is a thick to medium bedded gray limestone that contains abundant fossil fragments (rudite). The fragments are not big enough to be identified, but they seem to be from rudist, ostrae, gastropods, such as Neritidae, corals, and other gastropods and bivalves. They might have been derived from rudist reefs located at present in the surroundings of Coalcomán, Michoacán, about 40 km to the northeast.

The marine invertebrate fossil fauna of the Jalisco-Colima assemblage is very abundant and diverse. It suggests warm waters and a low latitude position for the Guerrero terrane during the Cretaceous. Most of the invertebrate species have affinity with the Cretaceous Tethys Realm, and are mostly similar to the Mediterranean Tethys and Texas, although some taxa have been reported from Venezuela, Cuba and Trinidad (Alencaster and Pantoja, 1993; Buitrón, 1993). The most significant are the rudists. Some of the species have a regional distribution from Texas to southern Mexico, and some, such as *Coalcomana ramosa*, have been found in Guerrero composite Terrane, in the calcareous platform of eastern Mexico, and in Cuba. However, some endemic species have also been found (Alencaster, 1986). The age of the fauna described from several localities in the Jalisco-Colima assemblage range from early Aptian to late Albian-early Cenomanian (Grajales and López, 1984; Corona and Alencaster, 1993). The nature of the faunas suggests that Guerrero was located in latitude somewhere between the Cretaceous latitude of Texas and South America, and that it had some connection with the Caribbean Cretaceous arcs.

Alternating exposures of volcanic-volcaniclastic rocks and thick limestone units can be observed along the road between stop 3 (Km 126.5) to Km 170 (kilometers measured from Manzanillo, Colima).

The Aquila (San Telmo) Batholith: Exposures of a large batholith can be observed along the road from Km 170 to Km 186 (Figures 4 and 6). This is the Aquila or San Telmo Batholith. It is a granodiorite to tonalite, and locally it has a gabrodioritic composition. The batholith yielded 43–38 K/Ar ages and a 56.5±1 Rb/Sr age (Grajales and López, 1984; Schaaf, 1990). Geochemical and isotopic analyses of this batholith suggest a calc-alkaline arc affinity, with positive initial ε_{Nd} (+5.3 to +5.8), and Nd model ages around 320–290 (Schaaf, 1990; Centeno-García 1994).

Alternating thick patches of limestone, with successions of volcanic and volcaniclastic rocks can be observed along the road from Km 186 to Km 195. From Km 195 a succession of thin-bedded limestone, shale and sandstone (Chocola-Cachán unit) is exposed along the road (Figure 4). This is cut by a granitoid at Km 203. There is no published information about this succession.

Stop 1.4 The Chocola-Cachán rhythmic succession (18°14'03.0"; 103°13'42.7")

This stop is located 205 km from Manzanillo. After a curve there is an open area for parking, with excellent scenery of the bay and the coastal cliffs (Figure 4). Along the road cut a rhythmic succession of alternating thin-bedded to laminar fine-grained sandstone and shale, with some medium to thick limestone strata. The sandstone has abundant volcanic and plagioclase fragments. Primary structures, such as intraclasts, erosive base of the beds, cross bedding, and normal gradation suggest they are mostly turbidites. There are no studies of this specific succession. It is considered to be part of the Jalisco-Colima assemblage. The base of the rhythmic succession is exposed 2 km from stop 4 (at Km 207.3), where it lies conformably on volcanic breccias and volcaniclastics.

Alternating exposures of the Chocola-Cachán turbidites, volcanic and volcaniclastics rocks, and massive limestone can be observed along the road from Km 205 to Km 232. Another batholith is exposed from Km 232 to Km 246. After the batholith, the first exposures of the Titzupa-La Unión assemblage can be seen along the road.

Stop 1.5 Ignimbrites and conglomerates of the Titzupa-La Unión assemblage (18°05'32.9"; 102°47'34.1")

This outcrop is located at the road cut in Km 280 from Manzanillo (Figure 4). The rocks are part of the Titzupa-La Unión assemblage that is made up of mostly felsic ignimbrites and volcanic breccias, interbedded with clastic rocks that contain clasts of volcanic rocks and few metamorphic clasts.

At this stop, ignimbrites interbedded with siltstone, sandstone and conglomerate can be observed. The rocks are red in color; the ignimbrites preserve primary structures, such as devitrified shards and flat vesicles. Conglomerates are made up of small pebbles of volcanic composition, and few clasts of sandstone and white quartz. It is matrix-supported and badly sorted (gravity flow). They are interbedded with clast-supported breccia, and thick, massive layers of fine-grained sandstone and siltstone that contain disperse pebbles. The lithological associations suggest a continental, fluvial environment of deposition. The age of the rocks at the stop is unknown, but fossils found in other areas of the Titzupa-La Unión suggest an age in between Aptian to Cenomanian.

Stop 1.6 Dinosaur footprints, Titzupa-La Unión assemblage (18°02'44.0"; 102°34'55.3")

The outcrop is located at the northern road cut at 307.6 km from Manzanillo, at the small village of Boca Seca, between Chuta and Chuquiapan (Figure 4). The stratigraphic column around the Boca Seca village is made up of rhyolitic to dacitic tuff, ignimbrite, lahars and scarce lava flows. Some andesitic and basaltic flows have been reported from the area (Ferrusquía et al., 1978; Freydier et al., 1997). The volcanic rocks are interbedded with fine-grained sandstone and siltstone, and few layers of conglomerate and coarse sandstone. Bedding of siltstone and sandstone are medium to laminar, they show cross bedding, ripples and some are strongly bioturbated. Some of the siltstone beds have small geodes with chalcedony. Some beds with abundant roots and bioturbation indicate the formation of paleosols. Raindrop marks have been preserved in beds with dinosaur footprints (Ferrusquía et al., 1978). The column contains some layers of limestone and calcareous shale with gastropods (*Ceritium*?), pelecipods and *Orbitolina,* whose age has not been determined. One report of *Nummoloculina heimi* near Neixpa suggests an Upper Albian-Cenomanian age for these rocks. The possible species of dinosaurs identified from the footprints (Saurischia and Ornitischia) range from mid-Jurassic to mid-Cretaceous time. The depositional environment is transitional, with alternating periods of shallow marine and subaereal deposition. The findings of dinosaur footprints suggest that the Zihuatanejo terrane might have been relatively closed to areas of the continent that were emerged at the time. Geochemical and isotopic compositions were already described in the introduction.

At 29 km from this last stop is the town of Caleta de Campos, epicenter of the September 19, 1985 earthquake that produced major damage in Mexico City and in the area. It had a magnitude of 8.1 (Richter); a focal mechanism of thrust fault and its origin was at the subduction zone. At the moment of the earthquake, approximately 32 km of the coast was uplifted by as much as 0.60 m, causing massive destruction of the organisms that lived in the intertidal-wave splash zone (Corona-Esquivel et al., 1988).

DAY 2

The field trip runs from Playa Azul to Tumbiscatío, and back to Playa Azul (Figures 3, 4 and 5). This day is an overview of the most complete stratigraphic column of the Zihuatanejo Terrane.

Marine Terraces of La Mira Basin: From Playa Azul to La Mira (4 km from Playa Azul), the road cuts uplifted marine deposits that form terraces along the coast. The terraces extend over 50 km along the coast, and are located over 8 km inland from the present coastline, and 100 m above sea level. They are made up of sandstone, shale and conglomerate, and contain abundant invertebrate fossils. There is a report of a camel bone found in the terraces (Grajales and López, 1984). The fossil content indicates Late Miocene to Pleistocene time for sedimentation. They indicate that the coast has been under active uplift since 10 Ma ago.

The road from La Mira to Arteaga cuts the Playa Azul batholith (Figures 3, 4 and 5), which ranges in composition from granodiorite to tonalite. K/Ar analysis from biotite and plagioclase yielded 61±5 and 60±5 Ma ages, and hornblende dates are 84±5 and 129±10 (Grajales and López, 1984). North of the batholith, the road runs for several kilometers along one of the largest successions of massive and brecciated andesitic flows of the area. After the flows are scattered exposures of the Arteaga Complex and the arc succession. At 50 km from La Mira, the contact between the Arteaga Batholith and older units (Arteaga Complex?) can be observed at the road cut (18°02’44.0”; 102°34’55.3”). Minerals related to contact metamorphism, such as andalusite, can be observed at this outcrop, they show no evidence of deformation. At Km 59, Arteaga Town, Michoacán State.

The starting point for the following distances is the circular traffic connector (roundabout) at the northern end of Arteaga town, which connects the road to Nueva Italia with the road to Tumbiscatío and the main street of Arteaga. All the stops are located along the road from Arteaga to Tumbiscatío.

Stop 2.1 Arteaga Batholith (18°21’43.7”; 102°18’00”)

The town of Arteaga is settled in a large batholith. Some of the best exposures are about 1.1 km from the roundabout (Figure 3). The Arteaga batholith varies in composition from granodiorite to tonalite, and some granite. It intrudes the Cretaceous arc succession and the Arteaga Complex (?). At its northwest contact with the arc succession, the Arteaga batholith shows progressive deformation from fracturing to ultramylonites (from Km 5.3 to Km 6.5). Samples collected from the surroundings of Arteaga yielded K/Ar biotite 44±3 Ma, and whole rock 52±3 Ma ages (Grajales and López, 1984). Ar/Ar dating from a sample collected at the stop 2.1 yielded a 47.9±0.2 Ma hornblende plateau age, 47.9 ± 1.5 isochron age, and 46.7±0.03 biotite fusion age. The batholith is calk-alkaline and shows present ε_{Nd} +3.2 to 2.4, $^{87}Sr/^{86}Sr$ 0.704558 to 0.704995 and model ages of 662–514 (Schaaf, 1990).

Locally, the age of the batholith sets some constrains on the age of folding and thrusting of the Cretaceous arc succession (Laramide? deformation), since it cuts across the axes of the structures (pre-Eocene). It also constrains the age of the El Muleto Shear zone (see next stop).

Toward the southwest of the area, on the footwall of the El Muleto shear zone (Figure 3), exposures of a granodioritic batholith have been considered to be part of the Arteaga batholith. However, the sample collected from El Pedregoso ranch yielded U/Pb age of 105±4 Ma (G. Gehrels, pers. com.). It has a calk-alkaline affinity, and shows initial ε_{Nd} +6.3, and initial $^{87}Sr/^{86}Sr$ 0.704707 and 270 Ma model ages (Centeno-García, 1994). It shows incipient foliation and some deformation fabrics.

Stop 2.2 El Muleto Shear Zone (mylonitic granitoid) (18°22’45.2”; 102°20’05.6”)

This stop is to observe the mylonitic textures at the border of the Arteaga Batholith; the outcrop is located at the northern road cut in a curve, 6.2 km from Arteaga (Figure 3). The Muleto Shear Zone is a regional structure that trends N60° to 70°E and dips 60-80º NW, locally it is vertical or dips toward the SE. It has been mapped for 45 km, but in satellite images it seems to continue for over 120 km. Its thickness has not been well constrained, but over 1 km with well develop mylonitic textures has been estimated at the Arteaga region. At the Arteaga-Tumbiscatío road it is deforming the Arteaga Batholith, the aureole of contact metamorphism and volcanic and volcaniclastic rocks of the arc assemblage. At the outcrop, the mylonite shows foliation with 50°; 65°SE orientation. The mylonite is cut by felsic dike that shows foliation and lineation as well. The foliation within the dike dips 60°; 40°NW, and lineation trends N56°E. This suggests that intrusion of the dike might have been contemporaneous to deformation.

Stop 2.3 El Muleto Shear Zone (mylonitic volcaniclastic and granitic rocks) (18°22’55.9”; 102°21’18”)

This stop is located 8.5 km from Arteaga at the southern road cut (Figure 3). The best outcrop is located in a small wash. The protolith at this locality was probably volcanic, volcaniclastics (Playitas Formation) and granodiorite (Arteaga Batholith), as suggested by the petrology and geochemistry. One sample analyzed from this locality shows a calc-alkaline affinity with REE typical of present primitive island arc magmatism (Centeno-García, 1994). It has present ε_{Nd} +3.7 and $^{87}Sr/^{86}Sr$ 0.707073, and model age of 540 Ma. At the outcrop, kinematic indicators, such as domino normal faults, micro folds, δ and σ porphyroclasts suggest a left-lateral shear sense. The foliation’s strike and dip are 50°, 60°SE with lineation plunging 38°NE, suggesting a strike-slip movement with the southern block as hangingwall. However, the mylonite has right lateral indicators at other localities. Thin sections from this outcrop show thin foliated fabric (ultramylonite to mylonitic gneiss), with oriented layers of biotite, muscovite and quartz; some oriented crystals of hornblende, and crystallization of feldspars suggest that deformation occurred under high temperature conditions (450° to 500° C). It contains porphyroclast of epidote aggregates and other minerals that suggest that contact metamorphism occurred previous to deformation. Ar/Ar analysis of a sample collected at this locality yielded white mica plateau age of 45.97±0.76 Ma.

The close ages obtained from the mylonites and the intrusive, plus the high temperature of deformation, suggest that shearing might have been relatively contemporaneous to the intrusion of the granitoid.

From stop 2.3 to stop 2.4 the mylonitic deformation degreases, and a succession of volcanic and volcaniclastic rocks can be seen along the road. They belong to the Tumbiscatío arc assemblage and form part of the nucleus of an overturned syncline that trends NW-SE and dips to the NE (Figure 3).

Stop 2.4 Shale and sandstone of the Tumbiscatío arc assemblage (18° 22' 52.3"; 102° 22' 33.2")

At the quarry, 11.7 km from Arteaga a thick unit of shale that shows slate cleavage. Its bedding is 120°; 40 NE, with cleavage almost parallel to bedding. The rock is composed of interbedded gray shales with few volcanic sandstone beds, 10 cm or less in thickness. They are part of the shallow marine volcaniclastic succession of the Tumbiscatío assemblage (Playitas Formation) (Centeno-García, 1994) (Figure 3).

From Km 11.7 to Km 13.9 (measured from Arteaga town), there are scattered exposures of interbedded shale, calcareous shale, lava flows and limestone of the Tumbiscatío assemblage.

Stop 2.5 Conglomerate, Tumbiscatío arc assemblage (18°23'42.6"; 102°22'22.5")

The best exposures of the stratigraphy of the Tumbiscatío arc assemblage are along the Toscano River. The outcrops at stop 2.5 are located 13.9 km from Arteaga (Figure 3), at the river and in the road cut. The rocks are mostly sandstone and conglomeratic sandstone with some calcareous shale (Playitas Formation). Conglomeratic sandstone is matrix supported, medium to badly sorted, and is made up of volcanic clasts, and few sandstone and white quartz pebbles; it also contains limestone intraclasts. Bedding is >10 cm to 1-m thick, and have erosive bases (channel deposits), and some show cross bedding. They are interbedded with some calcareous limestone beds. Some of the conglomerates seem to be epiclastic reworking deposits, epiclastic mass-flow and reworked and air-fall tuff, deposited in a shallow marine environment. Continental and beach deposits are exposed at the northeastern part of the area (Centeno-García, 1994).

Bedding is overturned and dips 80; 50° NW, the clasts show strong flattening and there is closed cleavage with some lineation (80°; 60° NW; 50° E). At this outcrop it is hard to differentiate the deformation associated with folding from deformation related to the El Muleto shear zone.

Stop 2.6 Limestone and lava flows, Tumbiscatío arc assemblage (18°23'42.6"; 102°22'22.5")

Located at Los Olivos Ranch, 14.5 km from Arteaga, the rocks are exposed at the Toscano River (Figure 3). The amount of massive and autobrecciated lava flows increase toward the base of the volcaniclastic and volcanic succession (Playitas Formation). At this stop are andesitic lava flows with some deformed limestone fragments (marble) that might have been calcareous mud incorporated into the lava flow. Some autobrecciated lavas have been observed downstream from this stop. The lavas were deposited on a thick succession of limestone that contains fragments of rudists and other fossil invertebrates. The limestone is strongly deformed and recrystalized. Karstic features, such as breccias and caves have altered the original bedding of the rock. The age of the rock at this stop has not been determined, however it seems to correlate with limestone located at the northwest part of the area that contains Albian rudist.

From this stop to next the road cuts the thick limestone succession, and a thick volcanic unit made up of lava flows and few volcaniclastics that contain scarce patches of limestone. The contact between limestone and volcanic rocks is located around 18.6 km from Arteaga. The volcanic unit is mostly andesitic, and is in tectonic contact (overturned fold and thrust) with the Arteaga Complex.

Stop 2.7 Contact between Arteaga Complex and the Tumbiscatío-Aguililla arc assemblage (18°25'23.0"; 102°20'46.5")

This stop is along the road, 19.5 km from Arteaga, and the contact zone is located at the curve. Interbedded shale and sandstone of the Arteaga Complex (at the north road cut) are thrust over the arc assemblage (at the south road cut) at this stop (Figure 3). The structure is an overturned fold, with axial plane broken by a thrust fault. The Varales lithofacies (Arteaga Complex) shows high deformation and locally and overprint of a second schistose fabric associated to this deformation. The volcanic rocks show, in some fresh areas, cleavage parallel to the structure. The thrust plane can be follow easily because it has a good morphologic expression in the topography. This contact is an unconformity a few km to the NW along the strike of the structure. There have been some efforts to date the deformation of the arc assemblage, but they were not successful. K/Ar ages of samples from the Varales lithofacies near the contact yielded two ages, 104±3 Ma and 67±2 Ma. The second age (Maastrichtian) is more suitable to be related to deformation. Ar/Ar dating of the rocks did not yielded good results. Thus it was not possible to differentiate the Early Jurassic deformation from the Late Cretaceous-Paleogene? compressional event.

Stop 2.8 Interbedded sandstone and shale of the Varales lithofacies (Arteaga Complex) (18°25'23.0"; 102°20'46.5")

Good outcrops of the Triassic (Ladinian-Carnian) Varales lithofacies are exposed at the road cuts in the village of Barranca Honda, 20.4 km from Arteaga (Figure 3). These sedimentary rocks are made up of fine-grained, well-sorted, quartz-rich sandstone, interbedded with black shale, and scarce black chert. At the outcrop the rocks are strongly deformed and partially metamorphosed up to greenschist facies, and are cut by andesitic dikes that show no evidence of ductile deformation. Primary structures were not preserved. However, in other areas with less deformation, the rhythmic succession shows sedimentary structures that are characteristic of distal turbidite deposits (facies B, C and E of Bouma series). Lithologic associations and sedimentary structures of the Varales lithofacies suggest a deep marine depositional environment. Scarce K/Ar dates obtained from whole-rock metapelites analyses range from 194 Ma to 168 Ma (Grajales and López, 1984). Thus it seems that the complex was deformed and metamorphosed during mid-Jurassic time.

The sandstone of the Varales lithofacies is composed almost totally of quartz grains (Qt=89, F=2, L=9). Polycrystalline quartz is more dominant than monocrystalline quartz ($38^{Qm}<51^{Qpt}$) and is composed of equivalent amount of crystal aggregates and microcrystalline (chert) grains ($Qpt= 28^{Qpa}+23^{Ch}$). The latter seem to be both igneous and sedimentary in origin, since some of them have radiolarian ghosts. Igneous and feldspathic fragments are less abundant, as are other grains (2^{Ft}, 3^{Lm}, 4^{Ls}), and they are mostly granite and felsic (rhyolitic?) in composition, with fewer devitrified glass clasts. Metamorphic clasts have schistose texture. Sandstones plot in the recycled orogen provenance field on Dickinson et al. (1983) diagrams. Sandstone and shale of the Varales Formation have light rare earth element (REE) enrichments and a marked Eu anomaly similar to the North American Shale Composite pattern (NASC). Initial $^{87}Sr/^{86}Sr$ ratios are very radiogenic at 0.7163 and 0.7244; Initial ε_{Nd} are negative, -6.2 and -7.2, and depleted mantle Nd model ages are 1.3 and 1.4 Ga (Centeno-García et al., 1993; Centeno-García, 1994). The Nd results indicate that the clastic sediments of the Varales lithofacies were derived from an evolved continental source, and confirm the inference from the petrological analysis of sandstones (Centeno-García et al., 1994).

Detrital single zircon provenance analysis made from a sample collected at this stop shows two distinctive clusters around 260 Ma and 1.0 Ga, and less abundant grains that yielded around 480–650 Ma, and 800 Ma ages (George Gehrels pers.com.). The closest rocks of such age are found in eastern Mexico and the southwestern Atlantic margin of the US (Grenvillian rocks and Permo-Triassic arc related volcanic and granitic rocks of the Oaxaquia and the Mixteco terrane, Pan-African rocks at the Florida Peninsula?). Zircon ages also set some constraints regarding the maximum age of sedimentation of the Varales lithofacies (Permian or younger).

The data obtained from the sediments of the Arteaga complex are very important because they place new constraints on the origin and paleogeography of the terrane. Early models proposed that Guerrero could have been a displaced fragment of Wrangellia or Stikine terranes. However, those terranes show almost no influence of continent-derived material, and they evolved in intraoceanic environments, sedimentologically isolated from continental sources until their accretion to North America in mid-Cretaceous time (Samson et al., 1990). Therefore, Guerrero composite terrane seems not to have any relationship with northernmost accreted terranes of the Cordillera. Other models suggest that the Guerrero terrane was an intraoceanic arc, which traveled far from the ocean, and approached the continent in Late Cretaceous time (Tardy et al, 1994; Lapierre, et. al., 1992). Such models have failed in explaining the origin of the Arteaga continent-derived sediments.

Stop 2.9 Green shales and sandstone of the Jaltomate lithofacies (Arteaga Complex) (18°26'11.3"; 102°21'00.7")

Exposure is located at the east side of the road, 22.1 km from Arteaga (Figure 3). This is a good exposure of the Jaltomate lithofacies, which is made up of light green color metamorphosed shale and very fine grained sandstone, interbedded with very thin layers of recrystallized limestone. They are composed primarily of microcrystalline clay-minerals, K-feldspar, plagioclase, calcite and quartz, plus sericite, chlorite, epidote, actinolite and clinozoisite related to the regional metamorphism. Their metamorphism varies regionally from low greenschist to lowest amphibolite facies. The Jaltomate Lithofacies has a primary sedimentary relationship with the Varales lithofacies, since they are intercalated forming alternated thick packets of tens of meters in thickness. At some areas, the Jaltomate lithofacies forms large tectonic blocks within the Varales lithofacies. At the outcrop of this stop, it is cut by a swarm of thin andesitic intrusives. The Jaltomate lithofacies shows geochemical and isotopic similarities with present MORB, but some primitive island arc signatures have been obtained as well. The latter might indicate the proximity of an island arc, or might be originated by the admixture of continent-derived materials (Varales shales) and sediments derived from the rift. Initial $\varepsilon_{Nd}{}^{i}$ values are +6.9 to +5.7, and Nd model ages of 0.36 Ma and 0.41 Ma, which clearly indicates a component of either young undifferentiated mid-ocean ridge basalts (MORB) or island arc in the provenance.

Between stops 2.9 and 2.10, exposures of alternated Varales and Jaltomate lithofacies can be observed at the road cuts. At Km 24.3, the basal contact (tectonic) between the Las Juntas Gabbros and Varales lithofacies is exposed (Figure 3).

Stop 2.10 Blocks of gabbro, Las Juntas lithofacies (Arteaga Complex) (18° 26' 44.5"; 102° 20' 30.4")

This stop is located at a curve, 24.7 km from Arteaga (Figure 3). At this outcrop the upper contact (tectonic) between the gabbros and Varales lithofacies can be observed. The gabbroic body forms a large sigmoidal block within the sedimentary rocks of the Varales lithofacies, which suggest that major shearing and tectonic transport have mixed the different lithologies that form the Arteaga complex. A group of these blocks are exposed at this locality along the road up to the northwest corner of the area, at Las Juntas Ranch (Figure 3). The gabbros do not have relicts of primary composition and structures. It is strongly foliated, and its mineralogy is made up of amphibole, plagioclase, quartz, titanite and oxides, which have substituted for the primary association of clinopyroxene, hyperstene, plagioclase and oxides. The percentage of pyroxene is variable, forming local cumulates with up to 85% of the mineral composition.

Metamorphism of the gabbros and surrounding sediments is much higher at the northwest part of the area (Las Juntas) (Figure 3), where some of the gabbroic blocks have been serpentinized to up to 80% of the whole rock. The metasediments at Las Juntas show low-temperature barrovian mineralogical associations of garnet, plagioclase, staurolite, quartz, muscovite and cloritoid. At the Las Juntas locality, the metagabbro has very low REE abundances; it is depleted in LREE and has a flat HREE pattern. Initial ε_{Nd} values are +7.2 and +7.3, and initial $^{87}Sr/^{86}Sr$ ratios are 0.704352 and 0.704414. Its REE concentrations and isotopic ratios suggest that the gabbros could have been associated with the magmatic activity of the Charapo lithofacies (MORB affinity) (Centeno-García et al., 1993; Centeno-García, 1994). One U/Pb dating analysis from Las Juntas locality yielded 180±6 Ma in age (G. Gehrels, pers. com.).

Stop 2.11 Cumulate gabbro, Las Juntas lithofacies (Arteaga Complex) (18°27'13.3"; 102°20'32.4")

This stop is located at the San Antonio wash, 25.5 km from Arteaga. At this locality big boulders of cumulate gabbros and plagiogranite can be observed along the wash. They vary in texture from coarse-grained equigranular to medium grained. It is formed by feldspar, pyroxene and some brown amphibole. This rock is considered to be part of the Las Juntas gabbroic block observed at the last stop. The gabbroic body extends along the road, up to Km 26.5 where it is in tectonic contact with shale and sandstone of the Varales lithofacies.

Stop 2.12 Sandstone and shale of the Varales lithofacies (Arteaga Complex) (18°27'53.6"; 102°21'18.9")

Along the road from Km 25.5 to this stop, at Km 29.1, there are exposures of the Varales lithofacies (Figure 3). Overall, the metamorphism grade decreases from south to north, and at the surroundings of the town of Tumbiscatío the Varales lithofacies shows only wide-open chevron folds, but no metamorphism. At this last locality trace fossils, carbonized plant fragments and primary structures can be observed. The stop 2.12 is at an exposure of the Varales lithofacies with intermediate deformation, where sheath folds and slate cleavage can be observed (1st phase of deformation). General bedding is 60°, 48° SE. Open folds, kink bands and crenulation cleavage (140°, 32° SE) have similar orientation to those observed at the Tumbiscatío arc assemblage (2nd phase of deformation). At Km 34.5, the contact between the Varales lithofacies and the Tumbiscatío Granite is exposed at the road cut.

Stop 2.13 Tumbiscatío Granitoid (18° 30' 39.4"; 102° 21' 38.9").

The stop is at a curve on the road to Tumbiscatío; this is a fresh outcrop located 36.1 km from Arteaga (Figure 3). The Tumbiscatío pluton is a coarse-grained granite composed of quartz, K-feldspar, oligoclase-andesine, biotite, and clinopyroxene, with some apatite, zircon, titanite and oxides. Biotite shows lamellae interlayering with muscovite and quartz. Mafic inclusions with garnet can be observed in samples collected from this locality. Although primary muscovite was not observed in the granite at this outcrop, it has been reported in other areas of the intrusive (Grajales and López, 1984; Centeno-García, 1994). The Tumbiscatío granitoid intrudes the metamorphic rocks of the Arteaga Complex, which show a zone of contact metamorphism (see stop 2.14). The borders of the pluton do not show foliation or lineation, suggesting that stress conditions were not present during emplacement. Internally it shows narrow brittle shear zones that might be related to Late Cretaceous deformation. Contact relationships with the arc-assemblage are unknown because of the lack of exposures of those rocks around the batholith. However granite clasts have been found within Cretaceous conglomerates. K/Ar dating from biotite shows three different ages: two are Early Cretaceous (127±3 and 133±11), and one is Late Jurassic (155±12) (Grajales and López (1984). Ar/Ar geochronological analysis from white mica shows a plateau of 158.8±0.7 Ma, and a biotite total fusion age of 152.4±0.07 Ma. The ages and contact relationships indicate that the emplacement occurred after deformation of the Arteaga Complex.

The Tumbiscatío granite has the most negative ε_{Nd} values among the igneous rocks of the Guerrero terrane, with initial ε_{Nd} -4.9 and Nd model ages (TDM) of 1.27 Ga. The isotopic composition suggests that partial melts of old crust, or continent-derived sedimentary rocks, were involved in the magma generation. Because of the similarity between isotopic ratios from the Tumbiscatío granite with those obtained from siliciclastics of the Varales lithofacies, the latter is most likely to be the source of melts. Overall geochemical composition suggests a subduction-related I-type granite affinity.

This granitoid is very important for reconstructing the evolution of the area, since it puts constrains on the minimum age of sedimentation and collision of the Arteaga Complex. It also indicates that there was a mid-Jurassic felsic arc in the Guerrero terrane. The nearest contemporaneous felsic arc magmatism has been described from several localities in central Mexico (Nazas, Caopas and Rodeo Formations) (Jones et al., 1995), but its relationship with the magmatic event in Zihuatanejo terrane has not been constrained.

Stop 2.14 Contact relationships Tumbiscatío Granite/Arteaga Complex (18°31'09.2"; 102°21'38.9")

This stop is located at the Tumbiscatío River, after the bridge at the entrance to Tumbiscatío town, 39.5 km from Arteaga (Figure 3). The contact shows a wide aureole of metamorphism, with andalusite (chiastolite)+quartz+plagioclase+biotite and oxides. Large andalusite crystals are undeformed, which indicate that the intrusion is post deformation of the Arteaga Complex. Minor brittle shear zones have been found in the batholith, but no major ductile deformation.

DAY 3

The road from Playa Azul to Zihuatanejo runs across the Playa Azul Batholith, Holocene sediments of the Balsas River delta (one of the largest rivers of Mexico), and the Cretaceous volcanic and sedimentary rocks of the Zihuatanejo assemblage, including lava flows, limestone and volcaniclastics (Figure 5).

Stop 3.1 Las Ollas Accretionary Complex (17° 45' 56.3"; 101° 31' 20.4")

The Las Ollas Complex is a distinctive assemblage that underlies the Cretaceous Zihuatanejo arc assemblage. Four localities of these rocks have been described (Figure 5). Stop 3.1 will be at the best exposure of those rocks (Talavera, 2000), and it is located at La Laja River near Las Ollas village (NE of Zihuatanejo), on the road from Zihuatanejo to the town of Ciudad Altamirano, 12 km north of its intersection with Zihuatanejo-Lázaro Cárdenas road (Figure 5).

Las Ollas Complex is composed of a pile of variable-sized, fault-bounded tectonic nappes and blocks with a rather variable overriding angle and constant W-SW vergence. Within nappes, two main lithological associations can be recognized: (a) an association containing blocks of metabasalt, metadiabase, metagabbro, and volcaniclastics surrounded by a clastic matrix; and (b) an association containing blocks of partially or completely serpentinized ultramafites with minor metagabbros within a matrix of serpentine. Blocks are elongated, irregularly shaped or rounded, and range in size from 10 cm to more than 250 m in the longest dimension. The matrix is highly sheared and folded, developing a sub-horizontal, anastomosing schistosity. Bedding in the clastic matrix is continuous, but locally it is disrupted, pulled apart, or boudinaged. The serpentinite-rich matrix shows folds and is characterized by the presence of numerous sheared, undulated surfaces.

Since no paleontological data are available, the age of the complex is poorly constrained. Some scarce, but consistent radiometric ages have been published from blocks, which led to establish a partially relative timing of events during Las Ollas evolution: (a) $^{40}Ar/^{39}Ar$ and K/Ar ages obtained from brown amphibole from several metagabbro blocks range from 112 ± 3 to 96.3 ± 2.5 Ma (Albian-lower Cenomanian). These ages have been considered as (or near to) crystallization ages and coincide in time with volcanism of the Zihuatanejo massif arc sequence (Delgado, 1982); and, (b) K/Ar ages obtained from green (metamorphic) amphibole and Rb/Sr on whole rock range from 33.1 ± 1.5 to 40 ± 1.5 Ma (Talavera, 1993). These ages are consistent with radiometric K/Ar ages obtained in undeformed plutons (34 to 44 Ma, Damon *in* Vidal, 1991), and thus they might reflect re-equilibration during thermal metamorphism.

Igneous and igneous-derived metamorphic blocks show geochemical and isotopic features typical of island arc tholeiitic suites: (a) low TiO_2 (0.13 to 0.91%) and Zr (5 to 57 ppm) contents; (b) high $(LFSE/HFSE)_N$ ratios; (c) low La_N/Yb_N (0.5 to 4) values; and, (d) high ε_{Nd} (+7.9 to +8.0) ratios. Petrographical and mineral chemistry indicates that some blocks underwent early recrystallization under high P/low T, blueschist facies conditions during subduction. Typical assemblages include blue (sodic through calcic-sodic to Na-rich calcic) amphibole + lawsonite ± tremolite ± Mg-chlorite ± white mica ± albite ± quartz. Phase relations and chlorite thermometry suggest temperatures of about 200-330 C and pressures of 5 to 7 Kb (Talavera, 2000; Mendoza and Suástegui, 2000).

Stop 3.2 El Posquelite Conglomerate, Zihuatanejo Assemblage (18°30'39.4"; 102°21'38.9")

The best exposure is located at the small waterfalls of El Salto, 1.5 km from the town of El Posquelite walking upstream the wash that runs parallel to the town (Figure 5). The unit is a poorly sorted matrix-rich conglomerate that forms massive horizons of several meters in thickness with no internal gradation. Its sedimentologic features suggest that it probably was deposited by auto suspended submarine debris flows. The El Posquelite conglomerate is made up of slightly foliated granite, quartz-mica schist, metamorphosed quartz-rich sandstone, gneiss, and massive quartz fragments (Vidal-Serratos, 1991). Granite clasts have biotite and some muscovite. Boulders of meta-quartzarenite have negative ε_{Ndi} of -4.2 and model ages of 1.14 Ga. Moreover, the granite clasts have negative ε_{Ndi} (-2.7) and an old model age of 1.24 that suggests it was derived from granitoids that have had old differentiated crustal material involved in the magma generation, and are similar to those obtained from the Tumbiscatío granite. The sources might be exposures of granites similar to Tumbiscatío and more deformed areas of the Varales lithofacies. The age of the sequence is unknown, but it is covered by limestone of Albian in age.

The finding of this conglomerate, in addition to the finding of the Arteaga Complex, was very important because in the past, some geologists considered that the arc at the Zihuatanejo region was built on undeformed oceanic crust (Tardy et al., 1994). In contrast, others considered that the arc was built on Paleozoic continental crust (de Cserna et al., 1978). Thus, the characteristics of these clasts found within the arc stratigraphy have lead to a completely different interpretation.

Stop 3.3 Shale Lagunillas Formation (17°40'00.8"; 101°37'58.8")

The Lagunilla Formation is a thick unit of shale and some volcanic sandstone that contains abundant detrital micas, and crops out in the surroundings of Ixtapa. Best exposures are located at the cuts along the main street that goes to Playa Linda, 4.4 km from the northwestern exit to the road to Ixtapa (Figure 5). This unit is sheared and shows some incipient foliation. Detrital mica has been dated, and yielded Jurassic ages. This unit is considered to be part of the subduction complex by Vidal-Serratos (1991). However, others suggest, based on the composition and similar regional bedding, that it might be part of the arc stratigraphy (Centeno-García, 1994). Its age is unknown.

The detrital micas found in the Lagunillas Formation are important for regional interpretation, because they evidence that Jurassic rocks have had a wide distribution, and were exposed during magmatism of the arc. This does not support the model of a single oceanic arc, and provides more data for regional correlation.

Stop 3.4 Zihuatanejo Formation La Madera Beach, Zihuatanejo City

Along La Madera Beach, at the southern end of Bahía de Zihuatanejo (Figure 5), the cliffs show good exposures of the volcaniclastics of the Zihuatanejo Formation. It is made up of interbedded volcanic sandstone and shale, and tuff (air-fall and welded tuff). Epiclastics are coarse-grained sandstone, with scattered larger clasts that probably were deposited by turbiditic currents since they show intraclasts and erosive base. Overall sandstone content increases toward the top of the column. Sedimentary structures suggest that the sandstones are marine deposits, but their paleo-depth and age are unknown. This unit overlies limestone with rudists of Albian age.

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BIBLIOGRAPHICAL REFERENCES

Aguayo-Camargo, J.E., 1983, Integración y análisis de la información geológica-geofísica de la Cuenca Jalisco-Colima: Mexico, D.F., Instituto Mexicano del Petróleo, technical report (unpublished).

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

Alencaster and Pantoja, 1986, *Coalcomana ramosa* (Boehm) (Bivalvia-Hippuritacea) del Albiano Temprano del Cerro de Tuxpan, Jalisco: Boletín de la Sociedad Geológica Mexicana, v. 47, no. 1, p. 33–46.

Alencaster and Pantoja, 1993, Early Aptian rudists from the Huetamo region, southwestern Mexico: *in* Alencaster and Buitrón, eds., Proceedings of the Third International Conference on Rudists: Universidad Nacional Autónoma de México, Instituto de Geología, p. 4 (abstract).

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.

Bandy, W., and Pardo, M., 1994, Statistical examination of the existence and relative motion of the Jalisco and Southern Mexico blocks: Tectonics, n. 13, p. 755–768.

Böhnel, H.; Alva-Valdivia, L.; González-Huesca, S.; Urrutia-Fucugauchi, J.; Morán-Zenteno, D.J.; and Schaaf, P., 1989, Paleomagnetic data and the accretion of the Guerrero terrane, southwestern Mexico continental margin, *in* Deep structure and past kinematics of accreted terranes: American Geophysical Union, Geophysical Monograph, no. 50, p. 73–92.

Buitrón, B.E., 1993, Mollusk gastropods in an Early Cretaceous rudist-bearing Formation of Jalisco, SW Mexico, *in* Alencaster and Buitrón, eds., Proceedings of the Third International Conference on Rudists: Universidad Nacional Autónoma de México, Instituto de Geología, p. 10–11.

Campa, M.F., and Ramírez, J., 1979, La evolución geológica y la metalogénesis de Guerrero: Universidad Autónoma de Guerrero, Serie Técnico-Científica, v. 1, 84 p.

Campa, M.F., and Coney, P.J., 1983, Tectono-stratigraphic terranes and mineral resource distributions in Mexico: Canadian Journal of Earth Sciences, v. 20, p. 1040–1051.

Campa, M.F.; Ramírez, J.; and Bloome, C., 1982, La secuencia volcánico-sedimentaria metamorfizada del Triásico (Ladiniano-

Cárnico) de la region de Tumbiscatío, Michoacán: Sociedad Geológica Mexicana, Convención Geológica Nacional, 6a, Resúmenes, 48 p.

Centeno-García, Elena, 1994, Tectonic evolution of the Guerrero Terrane, western Mexico: Tucson, University of Arizona, Ph. D. dissertation, 220 p. (unpublished).

Centeno-García, Elena, and Silva-Romo, Gilberto, 1997, Petrogenesis and tectonic evolution of central México during Triassic-Jurassic time: Revista Mexicana de Ciencias Geológicas, v. 14, no. 2, p. 244–260.

Centeno-García, Elena; Ruiz, Joaquín; Coney, P.; Patchett J.P.; and Ortega-Gutiérrez, Fernando, 1993a, Guerrero terrane of Mexico—its role in the southern Cordillera from new geochemical data: Geology, v. 21, no. 5, p. 419–422.

Centeno-García, Elena; García, J.L.; Guerrero, S.M.; Ramírez, E.J.; Salinas, P.J.C.; and Talavera, O., 1993b, Geology of the southern part of the Guerrero terrane, Ciudad Altamirano-Teloloapan Area, *in* Ortega-Gutiérrez, Fernando, et al., eds., Terrane geology of southern México: Universidad Nacional Autónoma de México, Instituto de Geología, First Circum-Pacific and Circum-Atlantic Terrane Conference, Gto. Mexico, Guidebook of Field Trip B, p. 22–33.

Corona-Esquivel, Rodolfo, and Alencaster, Gloria, 1993, Rudists from the Peña Colorada iron mine and La Minita sulfide deposit, Colima and Michoacán states, SW Mexico: *in* Alencaster and Buitrón, eds., Proceedings of the Third International Conference on Rudists: Universidad Nacional Autónoma de México, Instituto de Geología, p. 21 (abstract).

Corona-Esquivel, Rodolfo; Ortega-Gutiérrez, Fernando; Martínez-Reyes, Juventino; and Centeno-García, Elena, 1988, Levantamiento tectónico asociado con el sismo del 19 de septiembre de 1985, de la región de Caleta de Campos, Michoacán: Universidad Nacional Autónoma de México, Instituto de Geología, Revista, v. 7, no. 1, p. 8–15.

Cuevas, S.F. 1981, Prospecto Tepalcatepec: México, D.F., Petróleos Mexicanos, IGPR-164, Internal report (unpublished).

De Cserna, Zoltan, 1978, Notas sobre la geología de la región comprendida entre Iguala, Ciudad Altamirano y Temascaltepec, Estados de Guerrero y México: Sociedad Geológica Mexicana, Libro Guía de la Excursión geológica a Tierra Caliente, p. 1–25.

De Cserna, Zoltan; Armstrong, R.; Yañez, C.; and Solorio, J., 1978, Rocas metavolcánicas y intrusivos relacionados paleozoicos de la región de Petatlán, Estado de Guerrero: Revista Mexicana de Ciencias Geológicas v. 2, no. 1, p.1-7.

De Cserna, Zoltan; Palacios-Nieto,Miguel; and Pantoja-Alor, Jerjes, 1978a, Relaciones de facies de las rocas cretácicas en el noroeste de Guerrero y en areas colindantes de México y Michoacán: Universidad Nacional Autónoma de México, Instituto de Geología, Revista, v. 2, no. 1, p. 8–18.

Delgado, L.A., 1982, Descripción preliminar de la geología y mecánica de emplazamiento del complejo ultrabásico de Loma Baya, Guerrero, México: Geofísica Internacional, v. 25, p. 537–558.

Dickinson, W.R., 1992, Cordilleran sedimentary assemblages, *in* Burchfield, B.C.; Lipman, P.W.; and Zoback, M.L., eds., The Cordilleran Orogen: Conterminous U.S., Geological Society of America, The Geology of North America, v. G-3.

Dickinson, W.R.; Beard, L.S.; Brakenridge, G.R.; Erjavec, J.L.; Ferguson, R.C.; Inman, K.F.; Knepp, R.A.; Lindberg, F.A.; and Ryberg, P.T., 1983, Provenance of North American Phanerozoic sandstones in relation to tectonic setting: Geological Society of American Bulletin, v. 94, p. 22–235.

Elías-Herrera, Mariano, and Sánchez-Zavala, J.L., 1990 (1992), Tectonic implications of a mylonitic granite in the lower structural levels of the Tierra Caliente Complex (Guerrero Terrane), Southern Mexico: Revista Mexicana de Ciencias Geológicas, v. 9, no. 2, p. 113–125.

Ferrusquía-Villafranca, Ismael; Applegate, S.P.; and Espinosa-Arrubarrena, Luis, 1978, Rocas volcanosedimentarias mesozoicas y huellas de dinosaurios en la región suroccidental pacífica de México: Revista Mexicana de Ciencias Geológicas, v. 2, no. 2, p. 150–162.

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

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

Guerrero-Suástegui, Martín; Ramírez-Espinosa, Joel; Talavera-Mendoza, Óscar; and Campa-Uranga, M.F., 1991, El desarrollo carbonatado del Cretácico Inferior asociado al arco de Teloloapan, noroccidente del estado de Guerrero: Convención sobre la evolución geológica mexicana, and 1er Congreso Mexicano de Mineralogía, Pachuca, Memoria, p. 67–70.

Gutiérrez, H.J., 1975, Informe geológico final, Prospecto Arteaga-Balsas: Poza Rica, Ver., Petróleos Mexicanos, Superintendencia General de Exploración Geológica, IGPR-183, Internal report (unpublished).

Harrison, C.G., and Johnson, C.A., 1988, Neotectonics in central Mexico from Landsat data: Miami, Florida, Final Report, RSMAS, University of Miami, 127 p.

Hawkesworth, C. J., O'nions, R. K., Pankhurst, R. J., Hamilton, P. J., and Evensen, N. M., 1977, A geochemical study of island-arc and back-arc tholeiites from the Scotia sea: Earth and Planetary Science Letters, v. 36, p. 253–262.

Jones, N.W., Mc Kee, J.W., Anderson, T.H., and Silver, L.T., 1995, Jurassic volcanic rocks in northeastern Mexico: A possible remnant of a Codilleran magmatic arc, *in* Jaques-Ayala, C., González-León, C.M., and Roldán-Quintana, J. (eds), Studies on the Mesozoic of Sonora and adjacent areas: Geological Society of America Special Paper 301, p. 179–190.

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

Michaud, F.; Barrier, E.; Geyssant, J.F.; Mendoza, O.T., and Suástegui, 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.

Michaud, F., Barrier, E., Geyssant, J. F., and Bourgois, J., 1987, Una serie de plataforma Mesozoica (Tithoniano-Cretácico Superior) en el Estado de Colima, oeste de México: Universidad Autónoma de Nuevo León, Actas Facultad Ciencias Tierra, Linares, 2, p. 63-65.

Morán-Zenteno, D.J., Tolson, G., Martínez-Serrano, R. G., Martiny, B., Schaaf, P., Siva-Romo, G., Macías-Romo C., Alba-Aldave, L., Hernández-Bernal, M.S., Solís-Pichardo, G., 1999, Tertiary arc-magmatism of the Sierra Madre del Sur, Mexico, and its transition to volcanic activity of the Trans-Mexican Volcanic Belt: Journal of South American Earth Sciences, v.12, n. 6, p. 513–536.

Murillo Muñetón, G., and Torres Vargas, R., 1987, Mapa Petrogenético y Radiométrico de la República Mexicana: Instituto Mexicano del Petroleo, Subdirección de Tecnología de Exploración, Informe Inédito, Proyecto c-2010, 78 pp.

Ornelas, S.M., 1984, Estudio bioestratigráfico del Cretácico. Prospecto Aguililla-Cd.Guzmán Jalisco: Instituto Mexicano del Petróleo, Informe inédito.

Pacheco, J.F., Mortera-Gutiérrez, C.A., Delgado, H., Singh, S.K., Valenzuela, R.W., Shapiro, N.M., Santoyo, M.A., Domínguez, J., and Barrón, R., 1999, Tectonic significance of an earthquake sequence in the Zacoalco half-graben, Jalisco, Mexico: Journal of South American Earth Sciences, v.12, n. 6, p. 557–566.

Pantoja, A.J., and Estrada, B.S., 1986, Estratigrafía de los alrededores de la mina de fierro de El Encino, Jalisco: Sociedad Geológica Mexicana, Boletín, v. 47, no. 1, p. 1–15.

Ramírez, 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, 1er Congreso Mexicano de Mineralogía, Pachuca, Memoir, p. 163–166.

Samson, S.D., Patchett, P. J., Gehrels, G. E., and Anderson, R. G., 1990, Nd and Sr isotopic characterization of the Wrangellia terrane and implications for crustal growth of the Canadian Cordillera: Journal of Geology, v. 98, p. 749–762.

Schaaf, P, 2001, Geología y Geofísica de la costa de Jalisco, Historia Natural de Chamela., in press.

Schaaf, P., 1990, Isotopengeochemische Untersuchungen an Granitoiden Gesteinen eines aktiven Kontinentalrandes. Alter und Herkunft der Tiefengesteinskomplexe an der Pazifikküste Mexikos zwischen Puerto Vallarta und Acapulco: Dissertation, Ludwig-Maximilians Universität, München, 202 pp.

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

Schaaf, P., and Martínez, S.R, 1997, The Puerto Vallarta Batholith, an example for multicomponent parenthood of continental arc magmas: IAVCEI, General assembly, Puerto Vallarta, 1997. Field Trip Guide, Excursion No.8 24 p.

Schaaf, P., Morán, 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.

Serpa, L., Smith, S., Katz, C., Skidmore, Ch., Sloan, R., and Pavlis, T., 1992, A geophysical investigation of the southern Jalisco block in the State of Colima, México: Geofísica Internacional, v. 31, no. 4, p. 475–492.

Talavera-Mendoza, O., 1993, Les formations orogéniques mésozoïques du Guerrero (Mexique méridional). Contribution a la connaissance de l'évolution géodynamique des cordilléres mexicaines, Ph. D. dissertation, Univ. Joseph Fourier-Grenoble I, France, 462 p.

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

Tardy, M.; Lapierre, H.; Freydier, C.; Coulon, C.; Gill, J.B.; Mercier de Lepinay, B.; Beck C.; Martínez, 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 Creteaceous: Tectonophysics, v. 234, no. 4, p. 49–73.

Vidal, S.R., 1991, Estratigrafía y tectónica de la región de Zihuatanejo, Estado de Guerrero, Sierra Madre del Sur, Convención sobre la evolución Geológica Mexicana, 1er Congreso Mexicano de Mineralogía, Pachuca, Memoria, p. 231–233.

White, W.M., and Patchett, P.J., 1984, Hf-Nd-Sr and incompatible-element abundances in island arcs—implications for magma origins and crust-mantle evolution: Earth and Planetary Science Letters, v. 67, p. 167–185.