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Jurassic-Cretaceous paleogeographic evolution of the northern Mixteca terrane, southern Mexico

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RESUMEN

Con base en un análisis estratigráfico realizado en tres diferentes áreas del norte del Estado de Oaxaca y sur del de Puebla, se presenta un modelo de la evolución paleogeográfica para el Jurásico-Cretácico de la porción norte del Terreno Mixteca. Las capas más antiguas de la secuencia mesozoica (Toarciano (?)-Aaleniano), expuestas en el área de Tezoatlán-El Rosario, consisten de estratos de conglomerados, areniscas, limolitas y lutitas con algunas capas de carbón. Estas capas se acumularon después del cambio de un régimen tectónico de levantamiento, activo desde el Triásico Temprano, a un régimen tectónico tensional con hundimiento. En respuesta a este cambio se formó un grupo de cuencas tectónicas, acompañadas por el desarrollo de un sistema fluvial con pendiente general hacia el sur. La secuencia continental acumulada durante el Jurásico Medio en esta porción del Terreno Mixteca tiene un espesor máximo de 2,300 m y muestra fuertes cambios laterales que representan transiciones de abanicos aluviales a llanuras de inundación y depósitos de canal. Durante el Bajociano y Bathoniano, esta región experimentó transgresiones marinas de corta duración, provenientes del Pacífico, las cuales inundaron la parte sur del Terreno Mixteca hasta una línea situada entre Tezoatlán y Huajuapan de León.

Del Calloviano al Hauteriviano dominaron condiciones de sedimentación marinas someras con depósitos calcáreos y detríticos en la parte sur de la región estudiada, previamente ocupada por el sistema fluvial. La paleogeografía del Jurásico Tardío se caracterizó por una bahía somera (Bahía de Tlaxiaco) conectada hacia el sur con el Oceano Pacífico. En algún momento entre el Tithoniano y el Valanginiano, es posible que se haya establecido por primera vez una comunicación entre esta bahía y los cuerpos de agua conectados con el Golfo de México. No existen evidencias estratigráficas para sustentar la interpretación de una conección marina entre la Bahía de Tlaxiaco y el área correspondiente al sur de la Sierra Madre Oriental para el Calloviano y la mayor parte del Jurásico Tardío.

Para el Barremiano-Aptiano no existen indicios de sedimentación marina en la mayor parte del Terreno Mixteca, únicamente hacia el norte, en San Juan Raya, se ha reportado una secuencia marina contínua del Valanginiano al Aptiano. Para este tiempo, en la región de Santo Domingo Tonalá, ocurrieron episodios de volcanismo monogenético subaéreo. A partir del Albiano y hasta probablemente el Turoniano, se desarrolló una amplia plataforma calcárea sobre los terrenos Mixteca y Oaxaca, la cual probablemente se extendía hasta la plataforma de Actopan situada al norte de la actual Faja Volcánica Transmexicana. En los tiempos posteriores al Turoniano ocurrió un levantamiento general asociado a plegamiento, que afectó la porción norte del Terreno Mixteca. Unicamente en la parte suroeste de este terreno parece haberse desarrollado una sedimentación contínua hasta el Maestrichtiano.

PALABARAS CLAVE: Terreno Mixteca, Jurásico, Cretácico, paleogeografía, México.

ABSTRACT

A model of Jurassic-Cretaceous paleogeographic evolution for the northern portion of the Mixteca terrane is presented. The interpretation is based mainly upon stratigraphic analysis of three different areas of southern Puebla and northern Oaxaca, where Mezosoic beds are well exposed. The oldest beds of the Mesozoic sequence (Toarcian(?)-Aalenian) are exposed in the Tezoatlán-El Rosario area where they consist of conglomerate sandstone, siltstone, and shale strata with some coal layers. These beds accumulated after a change from an uplift tectonic regime, active since Early Triassic, to an extensional tectonics with subsidence. In response to this change a group of tectonic basins with a north-south orientation formed in the Mixteca terrane together with the development of a fluvial system with a general slope toward the south. The continental sequence which accumulated during the Middle Jurassic in this region has a maximum thickness of 2,300 m and shows strong lateral variations, representing transitions from alluvial fans to floodplains and channel deposits. During Bajocian and Bathonian this region experienced brief marine transgressions of Pacific origin which covered the southern part of the Mixteca terrane up to a line situated between Tezoatlán and Huajuapan de León.

From Callovian to Hauterivian times, shallow marine conditions dominated and calcareous and detrital deposits accumulated in the southern part of the studied region, which had been occupied by the fluvial system. The Late Jurassic paleogeography featured a shallow bay (Tlaxiaco Bay) connected to the south with the Pacific Ocean. A connection between this bay and the Gulf of Mexico might have initially occurred between Tithonian and Valanginian times. There is no evidence to support the existence of a direct marine connection between the northern part of the Tlaxiaco Bay and the southern portion of the Sierra Madre Oriental area during Middle Jurassic and most Upper Jurassic times.

There are no indications of Barremian-Aptian marine sedimentation in most of the Mixteca terrane. Only to the north, in the San Juan Raya area, a continuous marine Valanginian-Aptian sequence has been reported. During this time, subaerial monogenetic volcanism locally occurred near Santo Domingo Tonalá. From Albian until probably Turonian, a broad calcareous platform evolved over the Mixteca and Oaxaca terranes and may have extended to the Actopan platform, north of the present Mexican Volcanic Belt. In post-Turonian time, general uplift contemporaneous with folding affected the studied region. Only in the southwestern part of the Mixteca terrane the marine sedimentation was apparently continuous until the Maestrichtian.

KEY WORDS: Mixteca terrane, Jurassic, Cretaceous, paleogeography, Mexico.

INTRODUCTION

Strong vertical and lateral variations in sequences of the Mesozoic stratigraphic record of northern Oaxaca and southern Puebla suggest the confluence of different paleogeographic elements in this region. Major contributions on the Mesozoic stratigraphy and inferences on the paleogeography of this region were carried out by Felix and Lenk (1889), Aguilera (1906), Calderón-García (1956), Erben (1956), Pérez-Ibargüengoita and co-workers (1965), Ruiz-Castellanos (1970), Ferrusquía-Villafranca (1976), Ortega-Gutiérrez (1978b), Monroy and Sosa (1984a), López-Ticha (1985). Some paleontological studies have been also conducted on the Mesozoic marine and continental sequences of this region (Burckhardt, 1927; Alencaster, 1956; Alencaster and Buitrón, 1965; Silva-Pineda, 1978; Ferrusquía-Villafranca and Comas-Rodríguez, 1987). In spite of these contributions, some fundamental questions about configuration and evolution of paleogeography subsist.

This region constitutes the northern portion of the Mixteca terrane, for which large-scale southwestward translation relative to North America and other continental portions of Mexico has been suggested (Anderson and Schmidt, 1983; Urrutia-Fucugauchi, 1984; Morán-Zenteno *et al.*, 1988). Several paleomagnetic studies of Jurassic and Cretaceous units have been carried out in this terrane in order to investigate possible latitudinal displacements (Böhnel, 1985; McCabe *et al.*, 1983; Urrutia-Fucugauchi, 1988; Morán-Zenteno *et al.*, 1988; Ortega-Guerrero, 1989). The results are not conclusive, but most inclination values of observed paleomagnetic directions suggest southward displacements relative to North America from Middle Jurassic until Early Cretaceous times.

One possible tectonic discontinuity which may have accomodated some displacement is a megashear proposed to coincide with the Mexican Volcanic Belt (MVB) (Anderson and Schmidt, 1983). The Tertiary-Quaternary volcanic rocks of this belt cover the northern edge of the Mixteca terrane obliterating the Mesozoic paleogeographic relationships between this terrane and the region situated to the north.

We have carried out a stratigraphic study in the northern part of the Mixteca terrane, in order to find out about the paleogeographic evolution of this region during Jurassic and Cretaceous times and furthermore its relationship to the Mesozoic sequences north of the MVB. Our studies have been concentrated in three areas where the Jurassic-Cretaceous sequence is particularly well exposed. These areas are Coyotepec-Tianguistengo, Petlalcingo-Huajuapan de León and Tezoatlán de Juárez-Diquiyú (Figures 1 to 5). Detailed mapping, stratigraphic analysis and section measurements were carried out in each area. Our paleogeographic interpretation is also based on earlier petrofabric measurements and primary structure observations in Tecomazúchil Formation in the Huajuapan de León area (Figure 1) (Caballero-Miranda *et al.*, 1990).

The main uncertainties about the stratigraphic record of this region stem from the difficulties of establishing ages and correlations among Jurassic continental units, because the flora contents have wide stratigraphic ranges. This situation also introduces some degree of uncertainty in the conclusions pertaining to the paleogeographic evolution.

COYOTEPEC-TIANGUISTENGO AREA

The area located between San Vicente Coyotepec and Santo Domingo Tianguistengo villages, in southern Puebla, contains extensive outcrops of sedimentary rocks assigned to the Jurassic (Figure 2). This zone of 300 km^2 has maximum relief of 500 m. The most extensive outcrops of Cretaceous rocks in southern Puebla occur east and northeast of this area. The Mesozoic sequence has a maximum thickness of 2,500 m; it overlies the Paleozoic Acatlán Complex and the Upper Paleozoic Totoltepec stock.

The lower part is constituted by two detrital continental units assigned to the Jurassic. The upper part consists mainly of marine Cretaceous rock bodies. The units of this area were informally designated by Ortega-Guerrero (1989) as "Piedra Hueca", "Otlaltepec", "Magdalena" and "Caliza Coyotepec".

The main structure of this area is a homocline dipping to the northeast, which is well expressed in the Cretaceous sequence. The underlying Jurassic bodies show complex tectonic structures that record overprinted structural phases.

"**Piedra Hueca unit**". The lower unit of the Mesozoic consists of about 800 m sequence composed of basal conglomerate and alternating layers of arkose, siltstone and shale. Cross-stratification and ripple marks occur typically as well as fossil flora remains. This unit rests unconformably over both Totoltepec stock, to the south, and the Acatlán Complex to the east and southwest. The upper contact is an angular unconformity with both Otlaltepec and Magdalena units.

Primary structures, fossils and lithology of the Piedra Hueca Formation suggest that it records a system of channels and flood plains, probably developed within a braided-stream environment. The recognizable fossil flora includes *Otozamites* spp. (R. Weber, personal comunication). Poor preservation precludes species identification

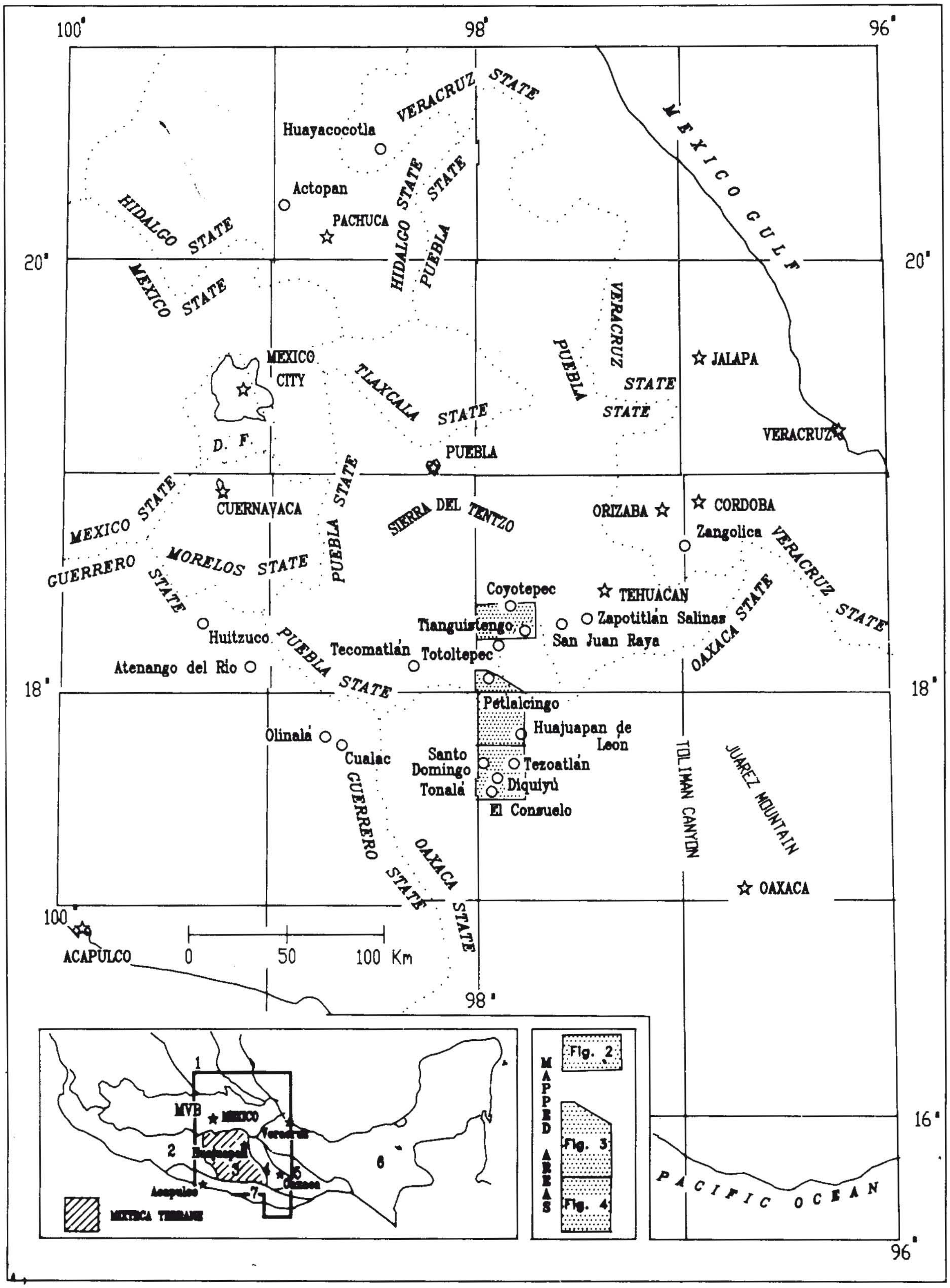

Fig. 1. (a) Location map showing studied areas and main localities referenced in the text. (b) Tectono-stratigraphic terranes of southern Mexico according to Campa and Coney (1983). 1) Sierra Madre Oriental terrane, 2) Guerrero terrane, 3) Mixteca terrane, 4) Oaxaca terrane, 5) Juárez terrane, 6) Maya terrane and 7) Xolapa terrane. MVB: Mexican Volcanic Belt.

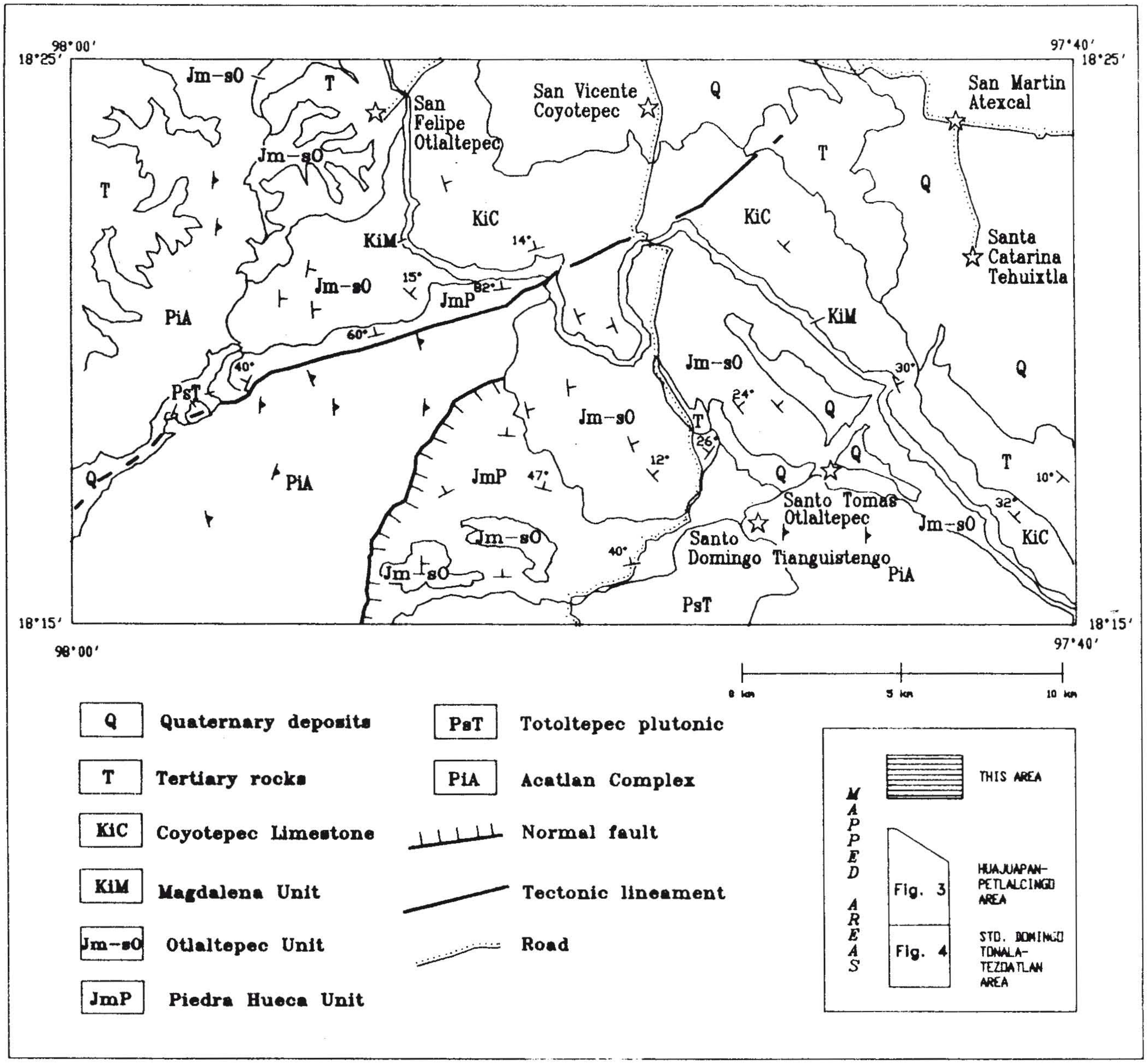

Fig. 2. Geologic map of Coyotepec-Tianguistengo area, southern Puebla (after Ortega-Guerrero, 1989).

but some specimens may belong to *Otozamites hespera* Wieland (Silva-Pineda, personal communication). Avellaneda-Córdova and coworkers (1987) reported *Ptilophyllum cuthense* Morris (Middle Jurassic) in this region, however the precise location was not indicated. In Consuelo area, near Diquiyú (Figure 1), within the upper stratigraphic section of the Rosario Formation, Wieland (1914) reported *Otozamites hespera*, which is also reported in the Middle Jurassic flora of the Tecomatlán area (Fig. 1) (Silva-Pineda, 1969). The age limits of this species are not well known; it may extend from Upper Triassic into the Jurassic. In the Tecomatlán area, *Zamites feneronius, O. reglei, P. acutifolium* and *P. cuthense*, which Silva-Pineda (1969) considers characteristic of Middle and Upper Jurassic, may be found. The presence of *O. hespera* and *P. cuthense*, as well as the petrologic affinity and geographic proximity to Tecomatlán sequence, suggest a contemporary relation, at least partially, of Piedra Hueca Unit with the Tecomatlán sequence.

"**Otlaltepec unit**". This sequence consists of alternating arkose, shale and siltstone layers of about 1500 m thick, with cross-stratification and abundant fossil flora. It overlies the Totoltepec stock and the Acatlán Complex unconformably, and the Piedra Hueca unit with an angular unconformity. It is overlain unconformably by the Magdalena unit. Its outcrops are mainly in two areas, to the west and in the central-east portion. The unit thins out toward the east and its depositional environment must be nearly the same as for the Piedra Hueca unit. Lateral variations of thickness probably indicate an irregular depositional surface, and suggest that the unit accumulated in a basin and range scenario formed during extensional tectonism.

The absence of recognizable fossil flora prevents the assignment of a precise age, but according to stratigraphical relationships it should have been deposited between the Middle Jurassic and the Early Cretaceous.

"**Magdalena unit**". This unit comprises 200 m of conglomerate, sandstone, shale and marl that overlie by angular unconformity the Jurassic units and partly the Acatlán Complex. The upper contact is transitional to Coyotepec limestone. Cross-stratification is present in the clastic beds. No fossil was found, but the upper contact relationship with Albian-Cenomanian rocks suggests an Aptian (?)-Albian age.

"**Coyotepec Limestone**". The upper unit of the Mesozoic rocks of this area is about 400 m thick and contains partly dolomitized biomicrite with black flint nodules and lenses near the base and interbedded shale layers increasing in abundance upward. It is overlain unconformably by Tertiary and Quaternary deposits. It shows symmetrical ripple marks with polygons of cracks in which gasteropod, pelecipod and foraminifera remains are abundant. *Toucasia polygyra* and *Nummoloculina heimi* Bonet suggest an Albian-Cenomanian age. Dolomitization and ripple marks point out to interpret an inter- or supratidal depositional environment.

HUAJUAPAN-PETLALCINGO AREA

The Mesozoic record exposed in this area includes sedimentary rocks with beds of fluvial origin at the base and marine origin in most of the sequence. It ranges from Middle Jurassic to the beginning of Late Cretaceous. Cretaceous beds are tilted, forming an homoclinal. The strata strikes north-northwest and dip to the east and form elongated hills upon which an obsequent drainage pattern developed.

Tecomazúchil Formation. At the base of the Mesozoic sequence in this area there are detrital rocks of continental origin named Tecomazúchil Formation (Pérez-Ibargüengoitia *et al*, 1965). This unit has a minimum measured thickness of 600 m (Caballero-Miranda, 1990a) and may be as thick as 2000 m (Ortega-Gutiérrez, 1978b). It overlies unconformably the Acatlán Complex. Between Santiago Chilixtlahuaca and San Francisco Yosocuta, the contact with this Complex is a normal faulting system. Near Petlacingo the upper contact constitutes a transition to Oxfordian marine rocks (Chimeco Formation; Pérez-Ibargüengoitia *op. cit.*). To the south, near El Limón, the contact is an angular unconformity. Elsewhere, younger Mesozoic units lie unconformably upon the Tecomazúchil Formation.

Several discordances may be found within this formation. Units bounded by significant angular unconformities may be delineated as members or subunits, clearly distinguishable in aereal photographs. The lithology of the basal Tecomazúchil Formation consists of a non-rhythmic alternating sequence of conglomeratic lithic arkoses to arkosic lithic arenites, commonly with cross stratification and plant remains, sandy conglomerates, siltstones and sandy siltstones. The lithic debris are derived from metamorphic rocks and locally from fine-grained clastic rocks. The coarse layers form lenticular and striped bodies. In the lower portion of the Tecomazúchil Formation there is a conspicuous conglomeratic unit in the area between Texcalapa and San J. Ayuquililla. Restricted volcanic bodies crop out at the contact with the Acatlán Complex and in between the clastic rocks of the lower sequence exposed in the Santiago Chilixtlahuaca-San J. Silacayoapilla area. Other volcanic accumulations have been reported near Texcalapa (Ortega-Gutiérrez, 1978b).

Chimeco and Mapache Formations. Two lithologically distinct Jurassic marine sequences overlie Tecomazúchil Formation. One is detrital-calcareous and crops out in the northern part of the area; the other is muddy-calcareous and crops out in the southern part of the area. The northern clastic-calcareous sequence is constituted by the Chimeco and Mapache Formations (Pérez-Ibargüengoitia *et al.*, 1965). At Texcalapa, the total maximum thickness of these two units is 600 m and both disappear because of erosion to the south. The southern sequence is constituted by the muddy-calcareous "Solano unit" of Caballero-Miranda (1990a).

Chimeco Formation overlies Tecomazúchil Formation in most places. In a limited area zone near Santiago Chilixtlahuaca, the Mapache Formation lies conformably over the Chimeco Formation and unconformably over the Tecomazúchil Formation. Both units have abundant fossils, mainly pelecipods *(Griphaea mexicana, Pinna quadrifrons, Lima comatulicostosa, Pleuromya* spp., *Lucina* spp, and others), brachiopods *(Rhynconella arellanoi)*, ammonoids, gasteropods, corals and echinoids (Cidaris). This fossil assemblage supports an Oxfordian-Tithonian age for these units (Alencaster and Buitrón, 1965).

The Chimeco Formation is composed of sandy limestone, calcareous sandstone and oosparite. The Mapache Formation contains mainly muddy limestone with conspicuous biomicrudite coquina beds made up of internal casts of bivalves. At the base of the Chimeco Formation there is a thin purple sandy siltstone and a claystone bed which is very useful as a marker and enables us to detect repetitions due to faulting, which is common near Chila de las Flores (see Figure 3). The Chimeco and Mapache Formations at Chila de las Flores area contain *Purpuroidea acatlana*, which is typical of Upper Jurassic deposits such as the Mapache Formation at its type locality (Buitrón, personal communication, October 1988). The fossil assemblage of these units includes stenohaline and euryhaline organisms.

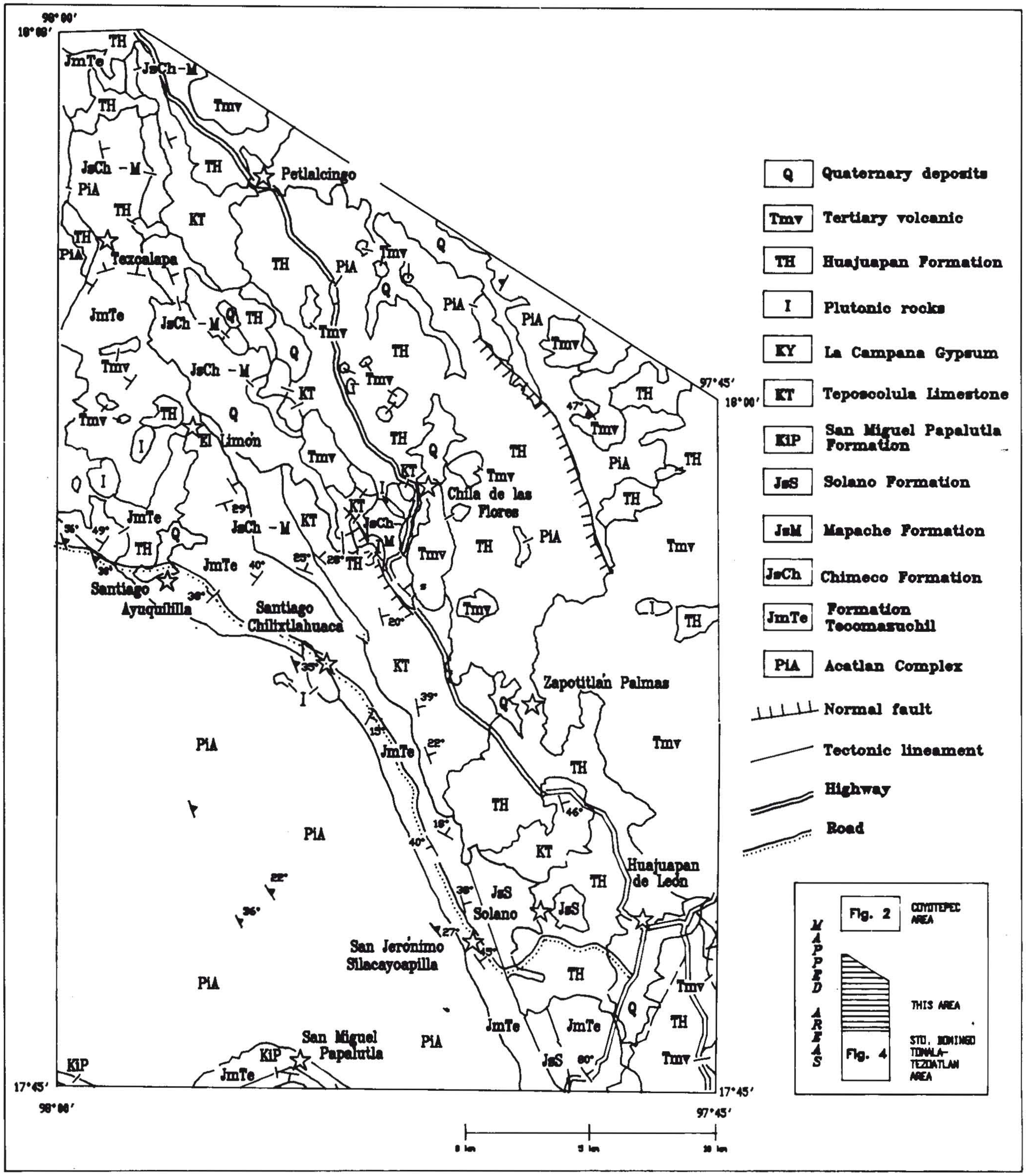

Fig. 3. Geologic map of Huajuapan-Petlalcingo area, southern Puebla and northern Oaxaca (after Caballero-Miranda, 1990; Caballero-Miranda *et al.*, 1989).

These organisms and the lithology suggest a littoral environment with fresh water inflow. The Chimeco Formation probably accumulated in a paleobay with high energy that restrained the access of planktonic organisms. These conditions must have changed to one of lower energy during deposition of the Mapache Formation.

"Solano unit". An informal unit of indeterminate thickness unconformably overlies the Tecomazúchil Formation in the southern part of this area (Caballero-Miranda, 1990a). It contains laminated mudstone-wackestone limestone, commonly muddy, locally dark and organically rich; dolomitized limestone; marlstone and calcareous shale with single pelecipod valves and iron nodules. Its stratigraphic position is constrained by ammonites found between S. J. Silacayoapilla and Solano, and identified as *Virgatites* sp., which is a Tithonian genus. This unit may have accumulated in a quiet marine environment with open sea communication. At times, events of quick sedimentation may have occurred, allowing the conservation of organic material.

"San Miguel Papalutla unit". A muddy-calcareous sequence, informally named "San Miguel Papalutla unit", crops out in the southwest corner of this area (Caballero-Miranda, 1990a). Ichtyosaurs and plesiosaurs are reported (Ferrusquía-Villafranca and Comas-Rodríguez, 1987) from this unit as well as ammonites of Valanginian-Hauterivian ages (González-Arreola and Comas-Rodríguez, 1981). The ammonite genus *Neocomites*, found by us in addition to the reported fossils, leads us to assign a Valanginian-Hauterivian age for this unit. It lies unconformably over the Tecomazúchil Formation. Late Jurassic units found at other localities, are absent in this area.

San Miguel Papalutla unit consists of muddy limestone, recrystallized limestone, marlstone and some sandy limestone and mudstone. At the base there are some beds of reddish lithic arenite and shale. All features suggest accumulation in a shallow marine environment near to a shoreline and without barriers to the open sea.

Teposcolula Formation. The Mesozoic sequence culminates with a calcareous unit that covers unconformably all lower Mesozoic units. In the Petlalcingo area this unit has been described as the Petlalcingo Formation (Salas, 1949) and later as the Morelos Formation (Pérez-Ibargüengoita *et al.*, 1965). We consider that the continuous strata outcrops of this unit, everywhere in the studied area, fit the definition of the Teposcolula Formation (Ferrusquía-Villafranca, 1976) rather than the Morelos Formation. For this reason we use "Teposcolula Formation".

The upper portion of the Teposcolula Formation in the studied area is differentially eroded and is overlain by Cenozoic clastic layers. This formation is locally affected by north to northwest trending normal faults. These faults cause repetitions of some parts of the Mezosoic sequence and the Teposcolula Formation. For this reason, thickness may not be accurately measured. It is estimated to be 400 m near Petlalcingo (Pérez-Ibargüengoitia *et al.*, 1965) and 800 m near Zapotitlán Palmas (Caballero-Miranda, 1990a).

The Teposcolula Formation in the studied area may be subdivided into two parts. The lower and more exposed part is all limestone. It forms the conspicuous elongated cliffs of this area. The upper part contains muddy and sandy layers that may be seen along the highway between Chila de las Flores and Huajuapan de León. Near this area the upper part of the formation is in faulted contact with the Chimeco and Mapache Formations. The latter resembles somewhat the upper Teposcolula Formation. These similarities may lead to misidentification (cf. Erben, 1956). The lower portion contains massive wackestone and packstone limestone with chert nodules. It is locally recrystallized and, in small areas (e.g., near Solano), it contains limestone breccias with chert bands. The upper section contains muddy, silty and sandy limestone, marlstone and massive limestone. Scattered all over the formation there are pelecypods, rudists, gasteropods, echinoids and miliolid, rotalid and textularid foraminifera.

This sequence has been assigned to Albian-early Cenomanian in the Petlalcingo area (Pérez-Ibargüengoitia *et al.*, 1965), where only the lower section crops out. However, the fossils in the upper section indicates that the age of the formation in the studied area must actually range from Albian to Turonian. These fossils are *Gryphaea graysonana*, of Cenomanian age (identified by Buitrón, personal communication, October 1988) and *Hippurites resectus mexicanus*, of Turonian age (reported by Erben, 1956, from a locality here considered as within the upper section).

TEZOATLAN-DIQUIYU AREA

The Mesozoic sequence of this area has a heterogeneous lithology. There are volcanic bodies at the base and in the middle upper part; mainly continental sedimentary units in the lower portion and mainly marine in the upper. It has a total thickness of 1450 m to 2100 m. Units of the sequence range from Triassic to the beginning of Late Cretaceous. The sequence is folded in open and almost symmetrical folds with the axial surfaces trending north-south and axes plunging northward. Axial surfaces bend to the northwest near Santo Domingo Tonalá. These folds (Figure 4) constitute the structure named Diquiyú Anticlinorium (Erben, 1956).

"Diquiyú unit". A volcanic body of mainly andesitic composition (Morán-Zenteno, 1987) is exposed south of San Juan Diquiyú. It is the basal unit of the Mesozoic sequence and it crops out in the core of the Diquiyú anticlinorium. This body contains volcanic flows and pyroclastic rocks of intermediate (andesitic-basaltic) composition and also some rhyolitic flows. Most of these rocks are hydrothermally altered and, in some localities, they show some incipient cataclastic deformation.

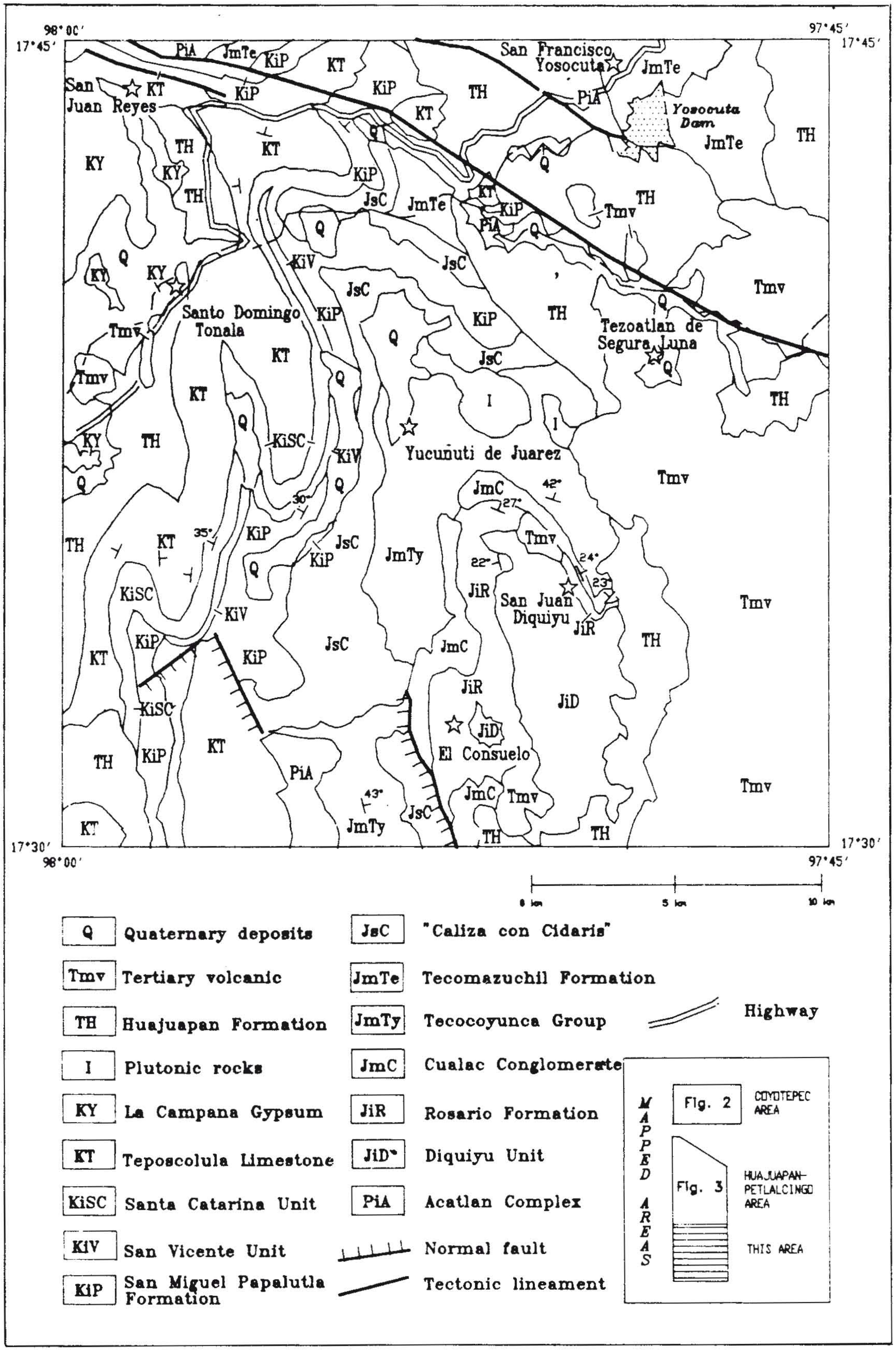

Fig. 4. Geologic map of Tezoatlán-Diquiyú area, northern Oaxaca (after Morán-Zenteno, 1987; González-Torres, 1989).

The andesitic-basaltic flows have a porphyritic texture with phenocrysts of plagioclase (andesine-oligoclase), altered pyroxenes and quartz amygdules. The pyroclastic rocks are altered tuff with a cryptocrystalline matrix that contains scattered quartz fragments and subordinate clay minerals. In some places rhyolitic rocks have flow structure (Schmitter in Ochoterena, 1981).

The bottom of this sequence is not exposed, but a thickness of 62 m has been reported in a coal exploring well (Cortez-Obregón *et al.*, 1957.). The exact age of Diquiyú unit is unknown but we suggest that it may be pre-Toarcian because it lies disconformably under the Rosario Formation, which has been considered as Toarcian-Aalenian in age (Erben, 1956).

Rosario Formation. The RosarioFormation (Erben, 1956) crops out only in this area. It contains a basal oligomictic conglomerate of andesitic clasts apparently derived from the Diquiyú unit. Over this conglomerate lies a lithic arenite with intercalations of poorly consolidated siltstone and yellowish-green shale beds, with some coal layers. Some layers contain an abundant paleoflora. There are beds containing volcanic clasts and debris of tuffaceous material. Clasts in the lithic arenite are of metamorphic and volcanic origin.

The thickness of this formation ranges from 100 to 250 m. It overlies unconformably the Diquiyú unit and underlies transitionally the Cualac Conglomerate.

Cycadophytes, typical of the Mesozoic, and ferns stand out among the paleoflora (widely studied by Wieland, 1914; Silva-Pineda, 1970, 1978; and Person, 1976). Erben (1956) estimated the age of the Rosario Formation as Toarcian-Aalenian according to its stratigraphic position. Other authors (e.g., López-Ticha, 1985) consider this unit to be of Paleozoic age, in spite of its Mesozoic paleoflora content and based only on its similarity to supposed Paleozoic green beds. According to López-Ticha (*op. cit.*) such supposed Paleozoic beds are exposed west of Petlalcingo and north of Totoltepec. However, at both places a typical Mesozoic paleoflora has been reported (Silva-Pineda, 1978, Ortega-Guerrero, 1989) and there is no evidence of Paleozoic beds. The lithology from the Rosario Formation indicates a fluvial environment with flood plain deposits.

Cualac Conglomerate. This formation contains a poorly sorted orthoquartzitic conglomerate, with rare interbedded quartz and lithic arenite, conglomeratic arenite and siltstone. Most clasts are of milky white quartz and quartzite; a few are of schist and gneiss. It contains tree trunks and other plant remains.

Lower and upper contacts are transitional. The lower contact with the Rosario Formation and the upper with the Tecocoyunca Group. The unit has a general lenticular geometry with a maximum thickness of 150 m that thins out laterally and vanishes. Its age, as in the case of the Rosario Formation, is not exactly known, but is assumed to lie in the Middle Jurassic-pre Bajocian interval.

Lithology suggests that the Cualac Conglomerate is the proximal facies of alluvial fans developed in a region of strong relief, which apparently originated during extension.

Tecocoyunca Group. According to Erben (1956) this group includes five formations with variable lithology and fossil content. These five formations are not easy to recognize in the field because some of them have many lithological similarities; besides, some physical characteristics are not laterally continuous. Two clearly different se-quences can be described: the lower (equivalent to Zorri-llo, Taberna and Simón Formations of Erben, 1956) in-cludes mainly detrital sedimentary rocks with interbedded carbon layers and some calcareous horizons; the upper se-quence (equivalent to Erben's Otatera and Yucuñuti For-mations), consists also of detrital rocks but with common calcareous beds.

The lower portion of the Tecocoyunca Group is 150 m to 280 m thick (Erben, 1956; Mosquera y Meléndez, 1984). It has a basal quartz arenite layer in the contact with Cualac Conglomerate, followed by lithic arenite and sublithic arenite with interbedded siltstone, shale, coal lenses and some layers of calcareous hematitic and silty concretions. The middle part of this portion has sparitic limestone with some interbedded shale and siltstone. The uppermost part is detrital with sandstone and less siltstone and shale. Detrital fractions contain paleoflora, especially cycadophytes and ferns (*Zamites, Williamsonia, Pterophyllum* and *Otozamites;* Silva-Pineda, 1970, 1978). Calcareous horizons contain trigonids (*Myophorella formosa* and *Vaugonia v-costata;* Alencaster, 1963) and ammonoids (*Duashonoceras (Stephanoceras/Zigzagiceras* Association) and *Parastrenoceras;* Westermann *et al.*, 1984). This fossil assemblage suggests a Bathonian age. The described features lead us to infer a flood plain environment with local marsh land zones affected by marine influx across restricted channels.

The upper portion of this group contains sandstone, micritic limestone, some horizons of sparitic and sandy limestone and also coquina beds. The thickness of this portion ranges from 50 to 200 m. Its fauna content has been studied by Burckhardt (1930), Erben (1956), Alencaster (1963) and Ochoterena (1981). Imlay (1980) and Westermann *et al.* (1984) also carried out studies of the fossil content of this portion in the Olinalá area,.from which they assigned a late Bathonia-early Callovian age to these beds. Among the ammonites the genera *Neuqueniceras, Eurycephalites* and *Xenocephalites*, of clear Pacific Ocean affinity, stand out. The features of this portion suggest a littoral to shallow sea environment connected to the open sea, but with important terrigenous contributions.

"Caliza con Cidaris". This unit is rarely exposed in this area because it is covered by a thick and extensive caliche coating. However, in the southern part of the area there are some outcrops of muddy and sandy-calcareous rocks with echynoderm spicules. In the Tlaxiaco area south of the Tezoatlán-Diquiyú area, Erben (1956) reports coquina horizons and marly limestone. The thickness of this unit ranges from 180 m to 200 m (Mosquera and Meléndez, 1984).

The fossil fauna contents of this unit is benthic. There are coquinas composed of pelecipods and brachiopods *(Exogyra* cf. *ptychodes,* ostreas, *Gryphaea mexicana* Felix and *Rhynconella)* and echynoids from Cidaris genus (all reported from Tlaxiaco area by Buitrón, 1970 and Carrasco-Ramírez, 1981). The fossil contents and lithology indicate a neritic and high energy marine environment.

"San Miguel Papalutla unit". The appearance of this unit in the Tezoatlán-Diquiyú area, is in general very similar to that in the Huajuapan-Petlalcingo area. There is a basal calcareous member that is dolomitized near Sto. Domingo Tonalá Canyon (east of Sto. Domingo Tonalá village). Here the thickness of the San Miguel Papalutla unit is 150 m. The basal calcareous member conformably overlies the "Caliza con Cidaris" unit. The upper contact of this unit is discordant with the San Vicente volcanic unit. Its age is Valanginian-Hauterivian, as mentioned above.

"San Vicente unit". San Vicente is a pyroclastic unit of andesitic composition. It contains lapilli tuff, ash tuff and agglomerate of bombs and blocks. It crops out west of San Vicente del Palmar village (see Figure 4) (Morán-Zenteno *et al.*, 1988).

The lapilli tuff contains cryptocrystalline flattened fragments. Coarser fragments show a porphyritic texture with plagioclase and pyroxene phenocrysts, oxidized ferromagnesian minerals and replacements of clorite, celadonite and calcite. The matrix of these fragments is cryptocrystalline, also with celadonite and sparitic calcite fillings.

The unit has a lenticular geometry. Its maximum thickness is of 205 m in San Vicente del Palmar and it thins out until it vanishes north and south of this village. In Sto. Domingo Tonalá Canyon (east of Sto. Domingo Tonalá), its thickness is only 20 m.

Lower and upper contacts of the unit are disconformities. It overlies the Valanginian-Hauterivian Papalutla unit and is covered by a detrital rock body of pre-Albian age (Santa Catarina unit). Based upon these stratigraphic relations, this unit is assigned to the Hauterivian-upper Barremian interval.

Features of this unit suggest a strombolian volcanic activity, in a subaerial environment with low relief.

"Santa Catarina unit". This new informal designation is intended to describe a detrital-calcareous sequence that unconformably overlies the San Vicente unit. In an earlier reference (Mosquera y Meléndez, 1984) this unit was called San Isidro Formation, and it was first described in an unpublished work on the Tlaxiaco zone (López-Ticha, 1969, in Mosquera y Meléndez, 1984).

At the base there is a conglomerate of volcanic clasts overlain by a sequence of well-consolidated red lithic arenite with volcanic fragments. From bottom to top the grain size of the arenite decreases and it changes to red siltstone with intercalated calcareous sandstone. Lime content increases as well to top. The measured thickness of this unit in Sto. Domingo Tonalá Canyon is 150 m.

This unit is transitional into the Teposcolula Formation. The lower contact is an unconformity with the San Vicente unit, which in turn overlies unconformably a Valanginian-Hauterivian unit. These stratigraphic relations suggest an age within the Barremian-Aptian interval for the Santa Catarina unit. Other detrital sequences with similar stratigraphic position have been reported in the Mixteca region: the Tlaquiltepec Formation of Neocomian age, in Olinalá, Guerrero (Corona-Esquivel, 1985; Guzmán, 1950; Flores de Dios and Buitrón, 1982); red beds of Neocomian age from Sierra del Tentzo, Puebla (Monroy and Sosa, 1984); and the San Isidro Formation in Tlaxiaco, Oaxaca (López Ticha, 1985).

The lithology of this unit leads us to infer a nonmarine environment that gradually changed to marine conditions with terrigenous contributions.

Teposcolula Formation. This unit tops the Mesozoic stratigraphic column over most of this area. It is composed of medium-thick and massive bedded spary limestone with bands and nodules of flint. It contains important intraformational breccias of a calcareous, sandy or silty matrix. It also contains some beds with rudists (*Hippurites* sp.) and bands of marly limestone.

The age assigned to this unit, in localities situated to the east of this area, is Albian-Coniacian (Ferrusquía-Villafranca, 1976). The lower contact of the Teposcolula Formation is transitional with the Santa Catarina unit and is defined by a noticeable increase of calcareous material. Its thickness varies between 400 m and 500 m.

Lithology suggests shelf marine environments. The abundance of micritic limestone reflects low to medium energy conditions and the intraformational breccias may correspond to periods of retreating seashore.

"La Campana gypsum". This unit crops out in the northwest corner of this area, near San Juan Reyes village, where it takes its name from a steep bell-shaped hill called La Campana (Caballero-Miranda, 1990). It consists of white gypsum with black bands, veins and spots caused by impurities and selenite crystal aggregates. There are few beds of gray limestone; black mudstone and sandstone; light reddish siltstone and limestone. The gypsum is deformed and it is not possible to measure its thickness. Although stratigraphic relations are not clear, it seems to lie above the Teposcolula Formation and is covered by Tertiary clastic beds. Its age is uncertain.

Other evaporitic beds reported near this area are below Teposcolula Formation. They were found in two wells situated to the southeast (Teposcolula 1 and Yucudac 1 wells from PEMEX; in López-Ramos, 1979). The Anhidrita Huitzuco, located to the northwest in Guerrero State, is of Albian age and has diapiric structures.

PALEOGEOGRAPHIC INTERPRETATION

According to inferences derived from recent findings of Paleozoic sedimentary outcrops (Flores de Dios and Buitrón, 1982; Corona Esquivel, 1981 (1983); Buitrón and Flores de Dios, 1984; Enciso de la Vega, 1984; Vázquez-Echeverría, 1986), the northern Mixteca Terrane should be occupied during the late Paleozoic by a marine platform with calcareous and clastic sedimentation. During the Carboniferous this platform extended to the western part of the Oaxaca terrane, and it could have been limited to the east by an emerged land during Pennsylvanian to Permian, where the fluvial sedimentary units (Matzitzi and Yododeñe Formations) accumulated. Upper Paleozoic sediments must have been deposited over a wide region occupied on the west by the Acatlán complex and the Totoltepec stock and on the east by the Oaxacan Complex.

The conspicuous absence of Triassic-Lower Jurassic marine rocks is the consequence of a long period of emergence and slight deformation (folding or normal faulting with tilted blocks). During this time, most of the Upper Paleozoic sedimentary cover was eroded and large areas of the Acatlán and Oaxacan complexes were exposed. The andesitic volcanic unit at the base of the Mesozoic sequence in San Juan Diquiyú area is the only rock record of this time. This unit reflects subareal calc-alkaline volcanism with pyroclastic and flow activity. The lack of isotopic data precludes correlation with other units such as Las Lluvias Ignimbrite (Corona-Esquivel, 1981 (1983)) and the Chapolapa Formation (Cserna, 1965), both in Guerrero State.

The first indication of a change in the upheaval and erosional regime is the fluvial sedimentary sequence of the Rosario Formation (Figures 5, 6 and 7), assigned to the Toarcian-Aalenian(?). This unit is overlain by quartz sediments of the Cualac Conglomerate which has a lenticular geometry. The Rosario Formation is only found in the Tezoatlán-Diquiyú area; elsewhere in the region, the Cualac Conglomerate is at the base of the Mesozoic sequence. The basal conglomerate member of the Rosario Formation suggests a fluvial environment of high energy, with clastic fragments derived from the San Juan Diquiyú andesitic unit. This lower clastic unit probably accumulated simultaneously with the development of a horst-and-graben tectonics. The fine-grained upper part of the Rosario Formation suggests wide valleys with marshes, flood plains and an abundance of cycadeoidals and filicales from which coal layers were formed.

During the Aalenian or the early Bajocian, normal faults may have been reactivated, increasing the relief contrast and producing the coarse clasts in the Cualac Conglomerate. The general lenticular geometry of this unit suggests deposition in a piedmont setting from coalescing alluvial fans in moist and warm climate, as shown by the abundance of quartz clasts and flora debris. For the Bajocian-Bathonian interval, wide alluvial plains with marsh are inferred from the finer sediments of the Tecocoyunca Group and the coal layers, mainly in the zone between Tezoatlán and Tlaxiaco. The first marine influx is represented by the calcareous-shale Taberna Formation (from Erben nomenclature; Erben, 1956) in the middle of the Tecocoyunca Group, which must have come from the south. The marine influxes became more frequent after the upper Bathonian in the Tezoatlán, Tlaxiaco and Olinalá areas (Otatera and Yucuñuti Formations of Erben, 1956). In Coyotepec-Tianguistengo and Huajuapan-Petlalcingo areas, the Middle Jurassic stratigraphic record is wholly fluvial. This strongly suggests that the Bathonian-Callovian marine influxes reached only as far as southern Huajuapan de León (Figure 6).

The marine beds outcrops of Tecocoyunca Group, restricted to western Oaxaca and eastern Guerrero, the typical continental character of the Middle Jurassic sequence of eastern Oaxaca (Torres-Euán and Torre Alarcón, 1987), and the lack of a Jurassic record in central Guerrero and Morelos States, suggest that the active graben previously occupied by a fluvial system evolved into an estuary developed after the earliest marine transgressions from the Pacific Ocean. The existence of ammonites with Pacific affinity in Callovian layers of the Olinalá area, such as *Neuqueniceras* sp., *Xenocephalites* sp., and *Euricephalites* sp. (Imlay, 1980; Westermann *et al.*, 1984), supports the idea of a connection of this estuary with the Pacific Ocean. On the other hand, petrofabrics and magnetic fabrics in the Tecomazúchil Formation, near Huajuapan, confirm a south-southwestward general paleoslope during the time of deposition of this formation (Caballero-Miranda, 1990b).

Paleomagnetic directions in the Late Paleozoic Totoltepec Granite and other sedimentary units of the Mixteca Terrane do not support a north-south displacement (Fang *et al.*, 1989). However, paleomagnetic results of Jurassic rocks of the same terrane show a systematic group of inclinations which suggests that this region, including Mixteca and Oaxaca terranes, was originally located northwestward of its present position relative to North America (Morán-Zenteno *et al.*, 1988; Ortega Guerrero, 1989).

In Oxfordian time, the marine regime must have been established in an elongated paleobay that we call Tlaxiaco Bay, which had a nearly north-south orientation (Figure 7). It extended northward to a site between Coyotepec-Tianguistengo and Petlalcingo, as indicated by the lack of an Oxfordian-Tithonian marine record in the Coyotepec and Sierra del Tentzo areas (Figure 5). The marine Oxfordian layers north of Petlalcingo could have been

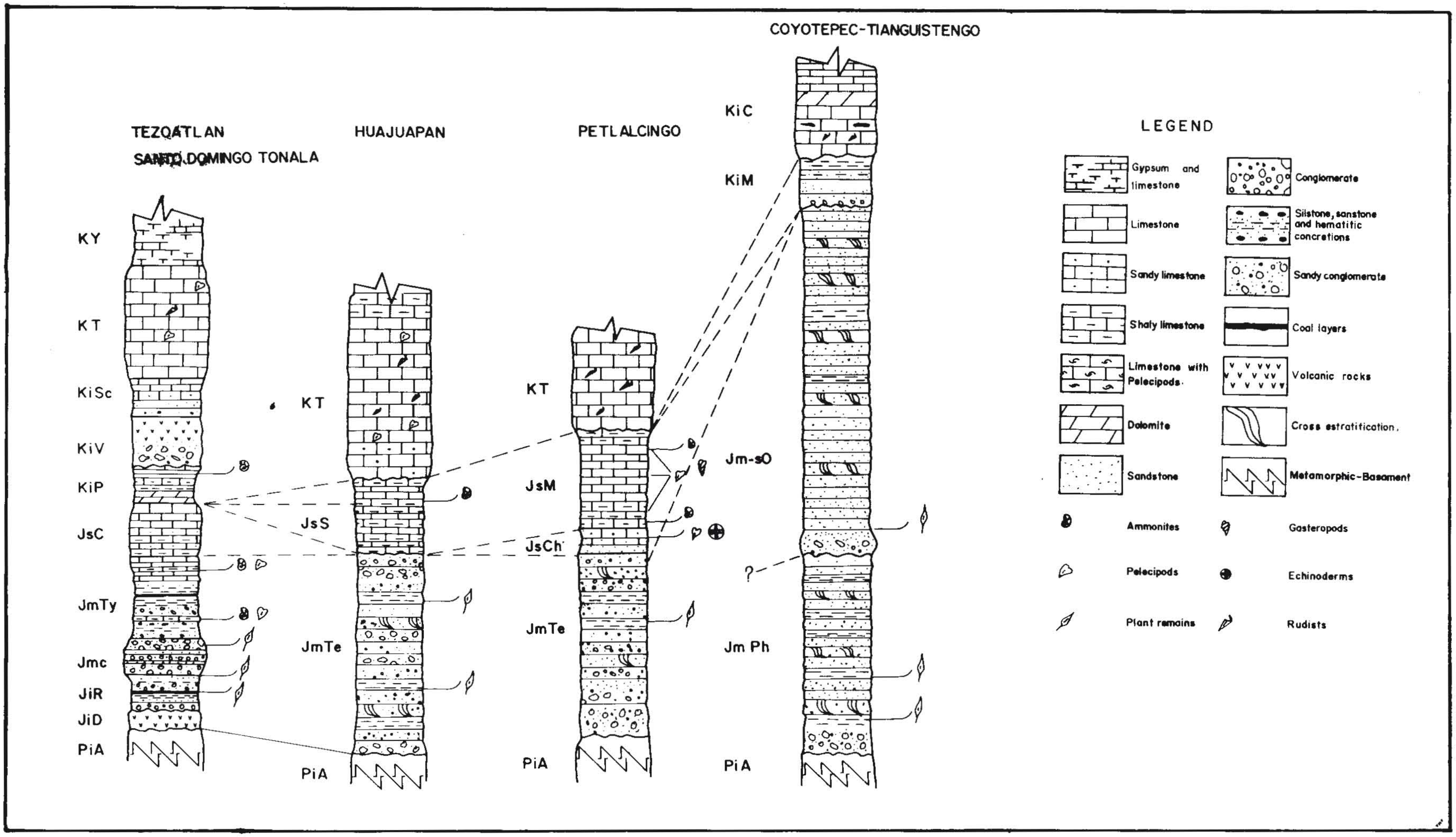

Fig. 5. Stratigraphic columns of different zones within the studied areas. The Upper Jurassic marine units thin out and disappear to the north. The preservation of a thick continental Jurassic record in Coyotepec area and the concordant contact between the Middle Jurassic continental sequence and the Upper Jurassic marine sequence of Petlalcingo, support the interpretation that the Middle Jurassic marine deposits did not reach the Coyotepec-Tianguistengo area.

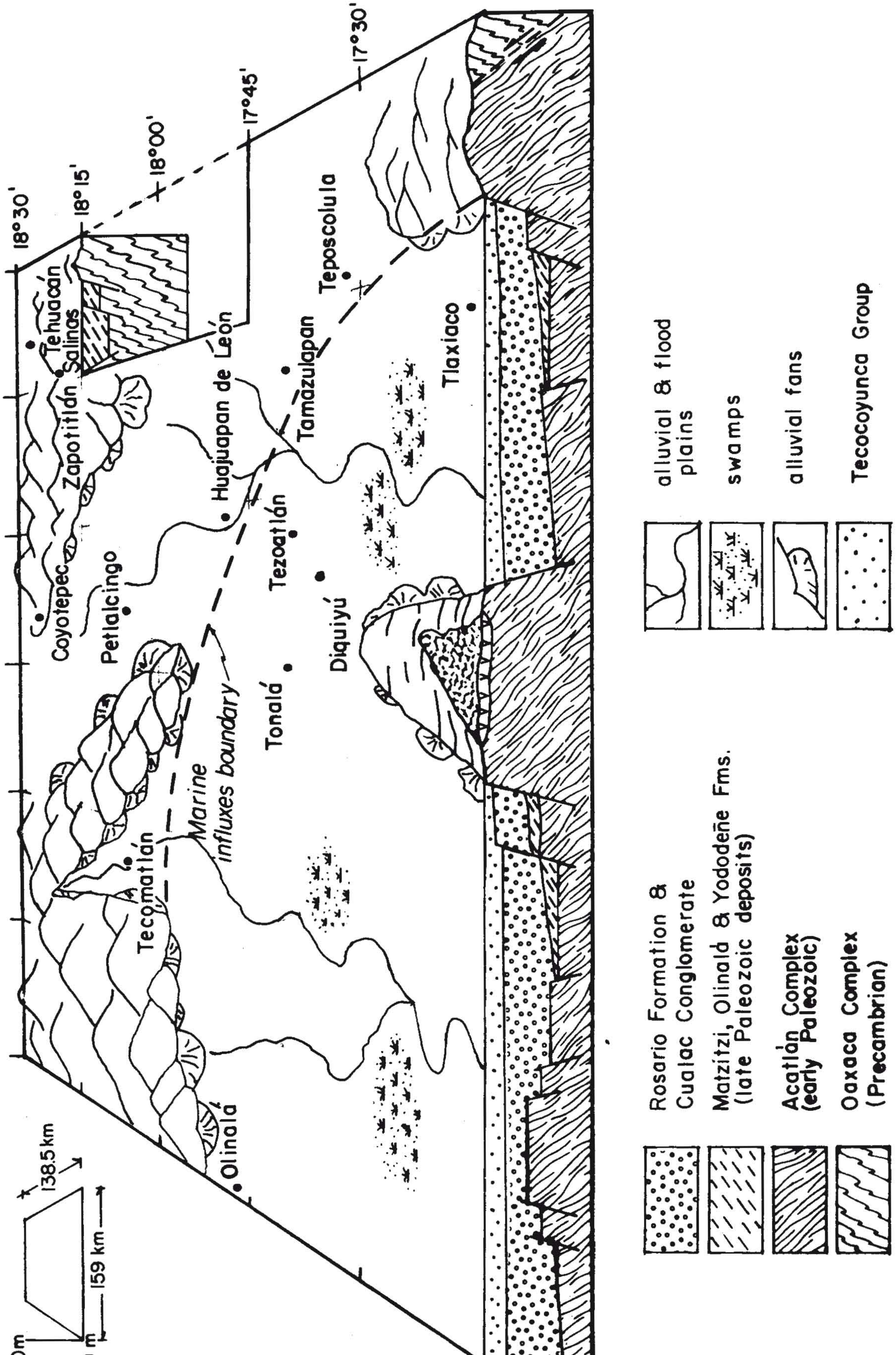

Fig. 6. Speculative paleogeographic reconstruction of the studied area for Bajocian-Bathonian time. The dotted line on the landscape surface shows the northern limit of the marine influxes which temporarily covered this region.

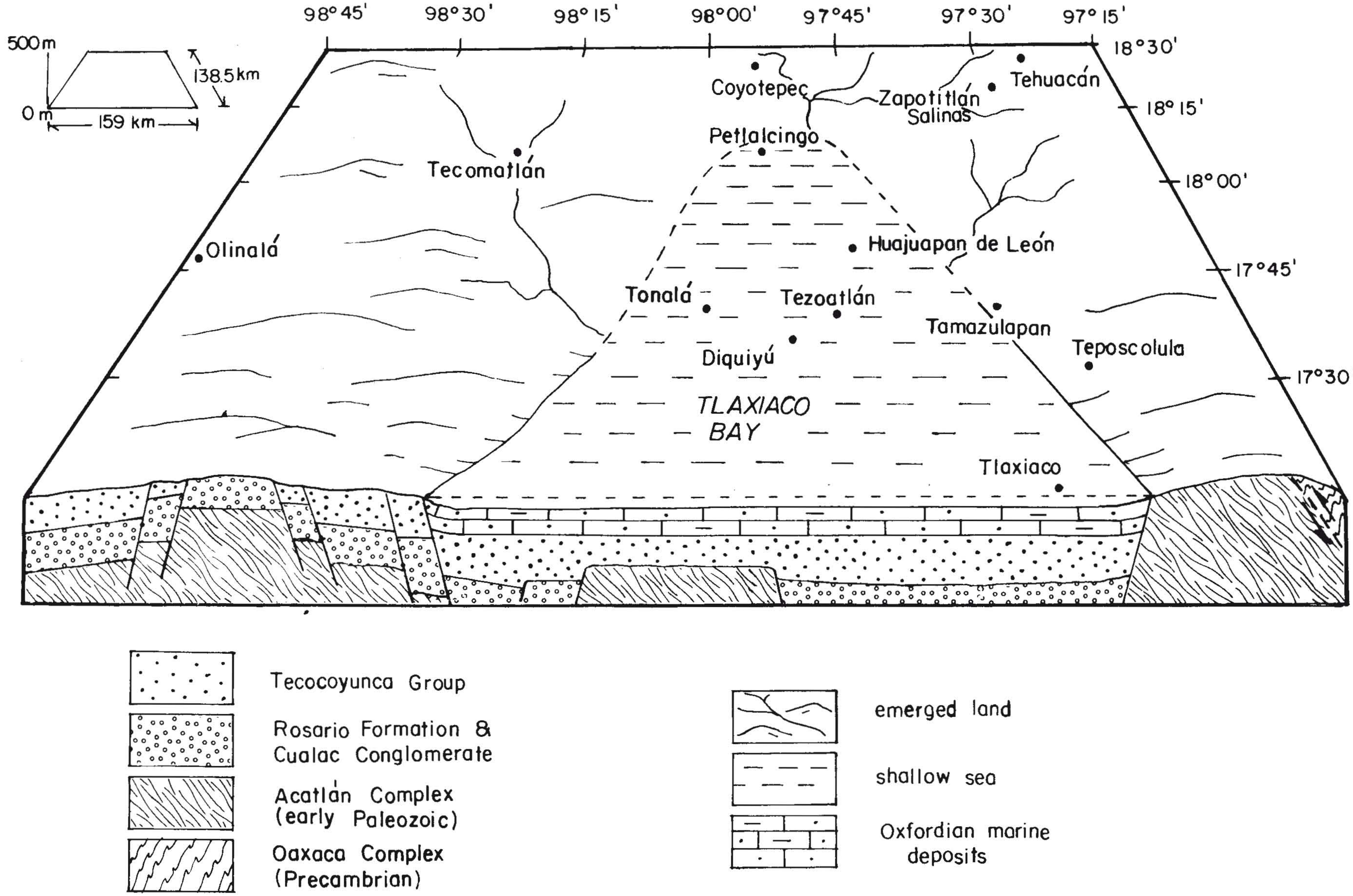

Fig. 7. Speculative diagram showing the interpreted paleogeographic situation of the studied area during Oxfordian time. The dotted line on the landscape indicates the uncertain location of the northern boundary of Tlaxiaco Bay.

eroded during the Neocomian emersion. The preservation of a thick continental Jurassic record in the Coyotepec-Tianguistengo area and its upper angular contact with the Cretaceous cover suggest that Jurassic marine layers, if they existed, should have been partially preserved. However, they are not present.

The lithologic and fossiliferous characteristics of the Oxfordian-Tithonian marine sequence indicate shallow marine conditions of deposit with abundant benthic fauna and low terrigenous contributions. High energy conditions characterized this bay during the Oxfordian and low energy during Kimmeridgian-Tithonian times. The apparent lack of ammonites during the Oxfordian may be due to high energy conditions rather than to a possible barrier that obstructed the circulation to the open sea. On the other hand, the presence of eurihaline organisms in some horizons suggests periods of salinity change due to important fresh water influx. These marine conditions persisted until the Hauterivian with variable contributions of terrigenous materials. The occurrence of marine calcareous-shale beds of Tithonian-Hauterivian age in the Cañon de Tolimán area, in the eastern part of Oaxaca terrane (Torres-Euán and Torre-Alarcón, 1987), and of Tithonian (Mena-Rojas, 1961) and Valanginian marine beds in the Sierra de Juárez area (Ortega-Gutiérrez and González-Arreola 1986) suggest that a marine connection between Tlaxiaco bay and the Gulf of Mexico might have occurred already between Tithonian and Valanginian times.

In the Petlalcingo area there is no sedimentary record from the Berriasian to the Hauterivian. Here, the calcareous Albian sequence unconformably overlies Upper Jurassic units. Nevertheless the recent finding of Valanginian fauna at the base of the Zapotitlán Formation (Castro-Mora and Pacheco-Gutiérrez, 1986) southeast of Tehuacán, suggests a possible lateral continuity of this Neocomian sequence into southern Puebla perhaps as far as Petlalcingo (Figure 8).

In the Tehuacán-San Juan Raya area the calcareous-shale marine sedimentation continued with active sinking and shallow water conditions during Barremian-Aptian times. Meanwhile, the Santo Domingo-Tonalá area underwent uplift which could have extended as far as south Tlaxiaco (Figure 9). Over the emerged portion, the andesitic volcanic activity, recorded in the San Vicente del Palmar unit, was developed. This activity generated a monogenetic volcanic field of cinder cones with mainly Strombolian activity. There is no evidence of a major deformational phase prior to the volcanism. Other Neocomian andesitic rocks are interbedded with marine layers in the Tehuacán (Carrasco, 1978) and Fortín-Zongolica areas (Carrasco, 1975).

There is not enough data to decide whether marine sedimentation in the Tehuacán area went on continuously into the Albian. Calderón-García (1956) has suggested that the sequence of the San Juan Raya and Zapotitlán Formations underlies unconformably the Cipiapa Limestone, but the contact is usually covered and the relationship between the two sequences remains obscure.

A marine transgression occurred after the Albian and generated an extensive calcareous platform that covered the area between Coyotepec and Tezoatlán, as well as the western and some other parts of Oaxaca and Guerrero States. This platform covered totally the Mixteca and Oaxaca terranes. Regionally it is continuous with the Guerrero-Morelos platform and it was surrounded by deeper zones (Cserna, *et al.*, 1978; Campa and Ramírez, 1979) and bounded by discontinuous reefal borders. At the western edge of the Guerrero-Morelos platform, one of the most important reef developments of Albian-Cenomanian times occurs (Chilacachapa Reef; Cserna *et al.*, 1978). During the early evolution of this platform local evaporitic basins formed, such as northwest of Tonalá, Oaxaca, in the Teposcolula region and near Huitzuco-Atenango del Río, Guerrero.

The reported epipelagic organisms in the Albian-Cenomanian sequence of the Teposcolula area confirm an open sea connection, at least for some time. In the Coyotepec and Tezoatlán regions, intertidal primary structures and limited rudist communities in several stratigraphic levels of the Coyotepec and Teposcolula limestones suggest sea level fluctuations from shallow to littoral with occasional emersions. The calcareous breccias of the upper Albian-Turonian sequence in the Petlalcingo-Santo Domingo area point to episodes of emersion probably linked to normal faulting that produced irregular relief. It is not possible to determine the stratigraphic range of the calcareous units developed on this platform. In the Morelos region the suggested upper limit of Cuautla Formation is Turonian (Fries, 1960), while in the Teposcolula area the range for the Teposcolula Limestone has been interpreted as Albian-Coniacian (Ferrusquía-Villafranca, 1976). In the Petlalcingo-Huajuapan area the sequence reached at least into the Turonian (Caballero-Miranda 1990a).

It seems that marine sedimentation in the Mixteca terrane was interrupted at different times. In the Guerrero-Morelos platform detrital sedimentation episodes occurred from Coniacian to Maestrichtian (Fries, 1960; Alencaster, 1981). In the Teposcolula area a clay-calcareous sedimentation persisted until Maestrichtian time (Ferrusquía-Villafranca,1976). Between Coyotepec and Tlaxiaco region no marine sequences, or fossils that could correspond to post-Turonian times, have been reported.

There is a lack of continuity between the Jurassic paleogeographic elements of the region and those of the area located to the north of the Mexican Volcanic Belt (MVB). In the southern Sierra Madre Oriental (SMO) area, the Jurassic sedimentary sequence includes Liassic marine beds (Huizachal Formation, Carrillo-Bravo, 1965; Schmidt-Effing, 1980) and Middle Jurassic continental beds (Cahuasas Formation).

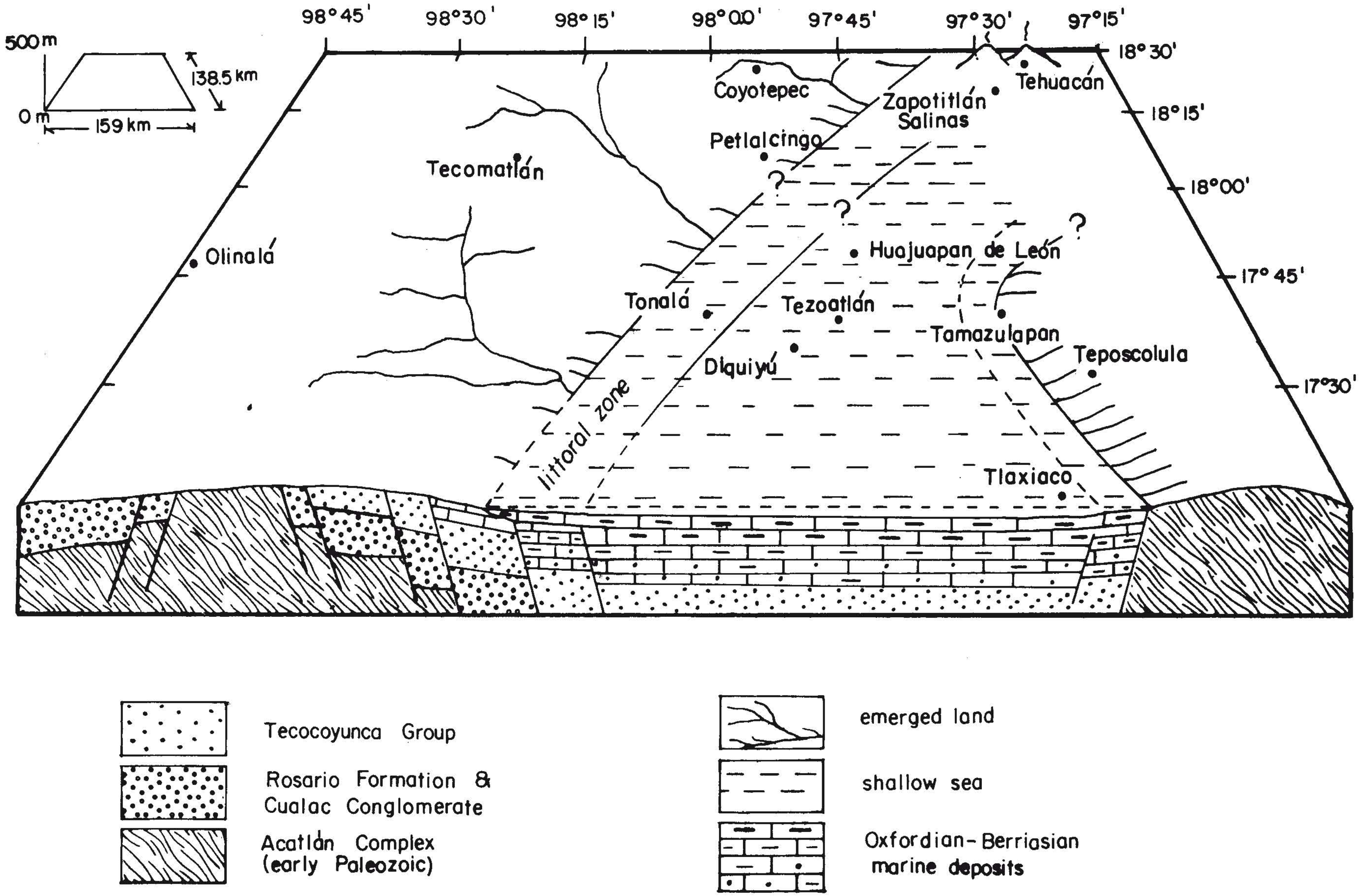

Fig. 8. Idealized paleogeographic reconstruction of the studied area for Valanginian-Hauterivian. First connection between marine bodies of this region and those from Gulf of Mexico might have taken place during this time.

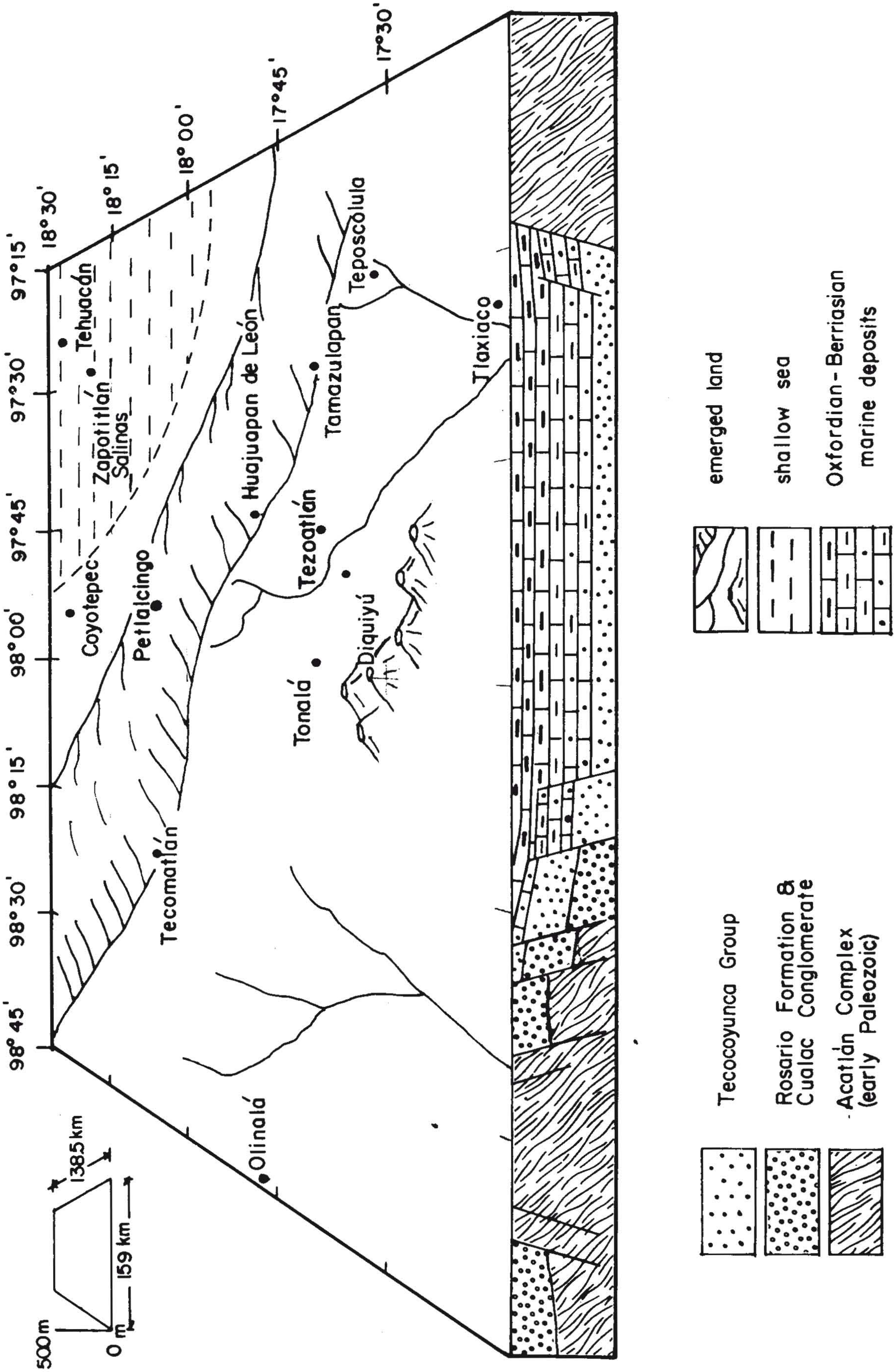

Fig. 9. Speculative diagram showing the paleogeographic reconstruction of the studied area during Barremian-Aptian time. Near Diquiyú area, a monogenetic subaereal volcanic field was developed while in the Tehuacán area shallow marine conditions prevailed.

The Cahuasas Formation is covered by a Middle Callovian-Albian transgressive marine sequence (Trancas, Tepexic, Tamán, Pimienta, Tamaulipas Inferior and Abra Formations, Carrillo-Bravo, 1965; Cantú-Chapa, 1971). This transgression gradually invaded greater portions of the SMO area until Albian time when the sea covered all of northeastern Mexico. In this time the paleogeography was characterized by several calcareous platforms bordered by deeper zones.

There is no evidence to support the existence of a direct marine connection between the northern part of Tlaxiaco Bay and the southern part of the SMO area during Callovian-Tithonian time. The Bathonian-Callovian marine beds thin out and disappear between Tezoatlán and Huajuapan de León. The northernmost outcrops of Tithonian marine units are found in the Petlalcingo area and there is no evidence of marine beds in the Jurassic folded sequence of the Coyotepec-Tianguistengo area. While the presence of Callovian *Neuqueniceras* assemblage in the southern SMO also suggests a marine connection towards the Pacific, the paleogeographic link between both regions remains unknown.

From Kimmeridgian to Aptian, the connection to the north might have occurred via the Tehuacán-Orizaba area, according to reports of continuous sequences from Kimmeridgian to Aptian (Mena-Rojas, 1960; 1961).

In Albian-Cenomanian time, a paleogeographic connection between the two regions seems to be more plausible, because there is an apparent continuity between the Actopan calcareous platform north of the MVB, and the Morelos-Guerrero Platform which extended to our study area.

CONCLUSIONS

Initial continental sedimentation during the late Early Jurassic (?) and the Middle Jurassic in the eastern part of the Mixteca terrane records the existence of a tensional tectonic phase with sinking, after a long uplift episode with intense erosion.

Since Toarcian (?)-Aalenian times the tectonic depression was occupied by a fluvial system flowing southward to southwestward. The depression was gradually occupied by shallow marine waters. Subsidence and sedimentation of this region were active into the Late Cretaceous and were only interrupted by short diachronic episodes of emergence.

The broad stratigraphic range of the fossil flora in the Jurassic continental units precludes the assignment of precise stratigraphic correlations. Only tentative chronologic relations may be inferred on the basis of stratigraphic relationships with well dated marine units.

The clear affinity of some Callovian ammonite species to the Pacific faunal realm in the Mixteca terrane is in good agreement with our interpretation that the Jurassic bay in the eastern part of this terrane was connected with the Pacific Ocean.

The age of the first communication between the Gulf of Mexico and the Pacific Ocean at this latitude cannot be well established on the basis of available geological information. It seems likely that such a connection existed in Tithonian-Valanginian times.

A Jurassic paleogeographic continuity between Tlaxiaco Bay and the southern SMO region is not supported by known stratigraphic information. A paleogeographic continuity or correspondence is more plausible in Albian-Cenomanian time. The available data suggest that a lateral displacement between these areas, if any, might have occurred during pre-Albian times.

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