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Chapter 3

MEXICO

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INTRODUCTION

The Mesozoic history of Mexico is consistent with a model involving the spreading Atlantic Ocean and the subducting, eastern margin of the Pacific Ocean Basin. The spreading floor of the Atlantic Ocean had a greater importance in the Triassic and produced structures that influenced distribution of sediments and organisms through the Jurassic, the Cretaceous, and the early part of the Cenozoic. The subducting, eastern margin of the Pacific Ocean Basin was more important in the later Mesozoic and produced structures and metamorphism that tend to mask previous geologic history. Mesozoic rocks of the central and north-central parts of Mexico overlie a more stable area of Precambrian and Paleozoic rocks.

Mesozoic volcanism was common in the Pacific states of Mexico, and in the Jurassic and Cretaceous included the intrusion of granitic and dioritic masses of considerable extent. Volcaniclastic rocks are particularly abundant in the Middle Cretaceous of those southern states bordering the Pacific Ocean (the states from Sinaloa to Michoacan, inclusive) and through much of the Sierra Madre del Sur, where there are also metamorphic rocks of Middle Cretaceous age. Platform and deeper, but nevertheless within the phototropic zone, pelagic limestones are common in the Late Jurassic and most of the Cretaceous, particularly in the eastern and northeastern parts of Mexico. Cretaceous reefoid limestones also occur on raised blocks between basins of volcaniclastic deposition in the Pacific coast states from Sinaloa through Jalisco, Nyarit, Colima, Michoacan, and into Guerrero. In all, a great variety of geology, representing many kinds of events, characterizes the Mesozoic of Mexico.

STRATIGRAPHY AND PALEOGEOGRAPHY

Triassic

As in many parts of the World the Triassic record in Mexico is quite restricted. There are four prominent geological activities represented in these Triassic rocks: (1) granitic intrusion in the northeast; (2) volcanism in the west-central; (3) marine basins of deposition in the northwest and west-central; and (4) deposition of red beds in the east-central and south. Marine, Triassic deposits of Mexico are restricted to the Late Triassic (Norian and Carnian) (Jaworski, 1929).

Aléncaster (1961) has shown the Upper Triassic of Sonora to have been deposited in two basins (Figs. 1, 2). The Paleobahía del Antimónio is centered around the old mining district of El Antimónio; about 150 km to the southeast is the Cuenca San Marcial, centered just south of Hermosillo, Sonora. (Fig. 3 is a map of Mexico showing the states, for the convenience of those unfamiliar with Mexican political subdivisions.) These two basins were separated by a structural sill over which some Late Triassic sediments were deposited, connecting the two basins with a continuity of sedimentary rocks (Aléncaster, 1961). The sediments are not all marine, but marine deposits are intercalated with continental sediments, mostly rather fine-grained, that contain beds of coal (Wilson and Rocha, 1946; Aléncaster, 1961). The combined basins, including the sill and all of the marine sediments, have been termed the Sonoran Embayment (Fig. 1); it opened to the Pacific Ocean.

In the vicinity of Zacatecas, Zacatecas (Figs. 1, 4), Late Triassic rocks have been described by Burckhardt (1905, 1906, 1930a), Burckhardt and Scalia (1906), Frech (1906), and Vásquez (1949). Cantu

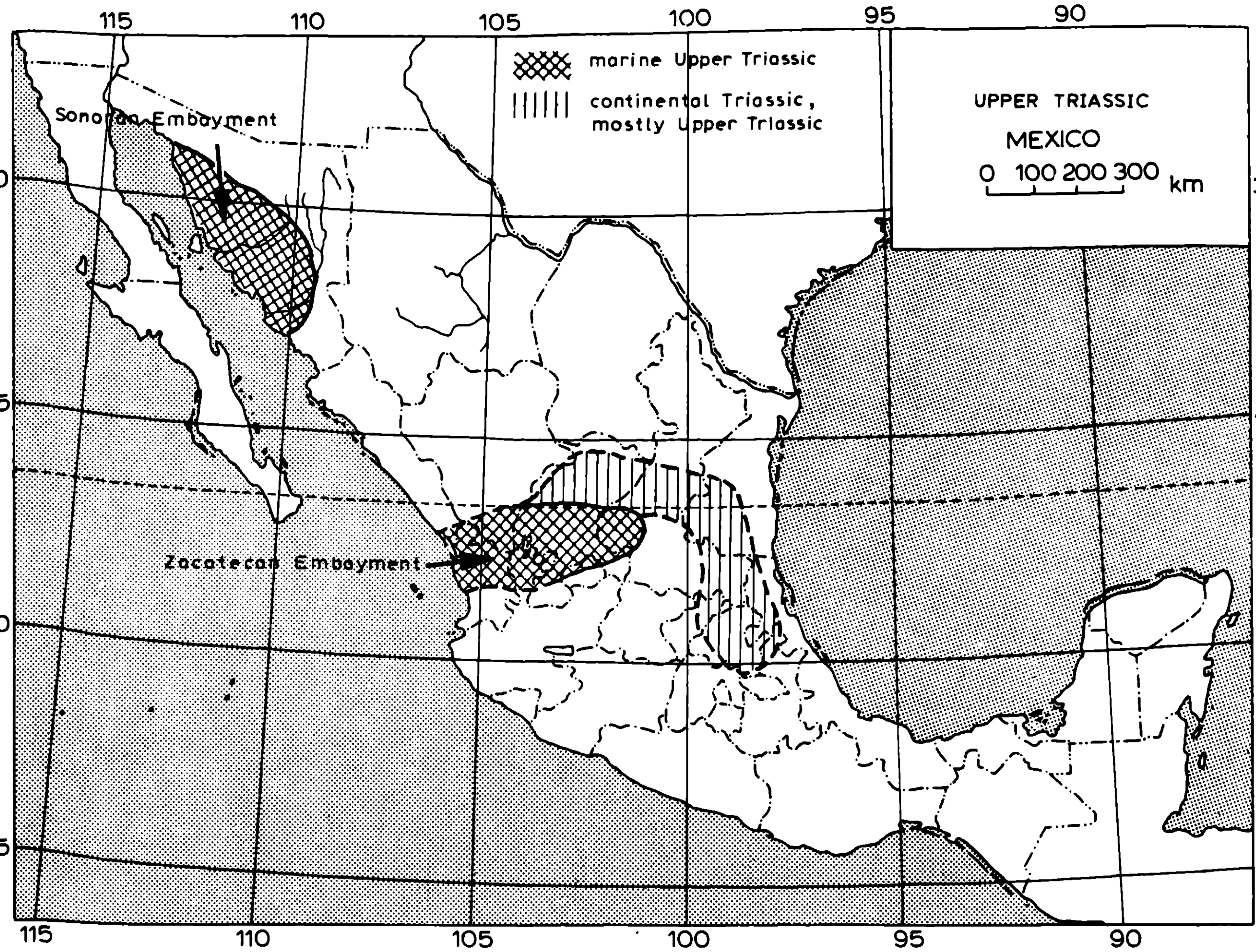

Fig. 1. Paleogeographic map of the Upper Triassic deposits of Mexico.

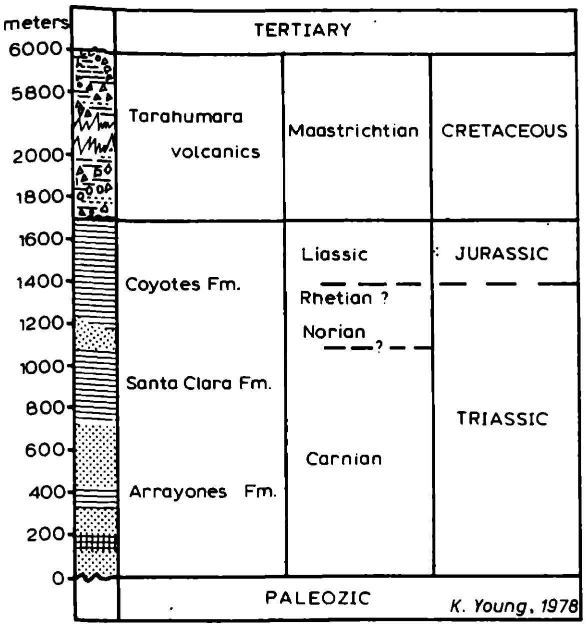

Fig. 2. Diagrammatic section of Mesozoic rocks of the Sonoran Basin, Sonora, Mexico.

Chapa (1969) has described a Late Triassic ammonite, *Juvavites* sp., from Charcas, state of San Luis Potosí, which extends the Zacatecan Basin farther southeast than it had previously been construed. This most recent discovery also emphasizes that much of the post-Triassic to pre-Late Jurassic history of Mexico is little understood, especially in the Sierra Madre Occidental, where most of the older rocks are covered by Cenozoic volcanic rocks. Although De Cserna (1969a) shows an elongated (north–south), Triassic, depositional area paralleling a Cordilleran Geosyncline, such an interpretation requires more evidence before it can be included on paleogeographic maps; even then, the concept may have to be restricted to pre-Upper Triassic rocks. In the meantime a basinal reentrant, the Zacatecan Embayment, from the Pacific Ocean, as proposed by most authors (e.g., Burckhardt, 1930a), seems to explain most simply this isolated sequence of marine Triassic rocks. This section has not been thoroughly studied, to my knowledge, since Burck-

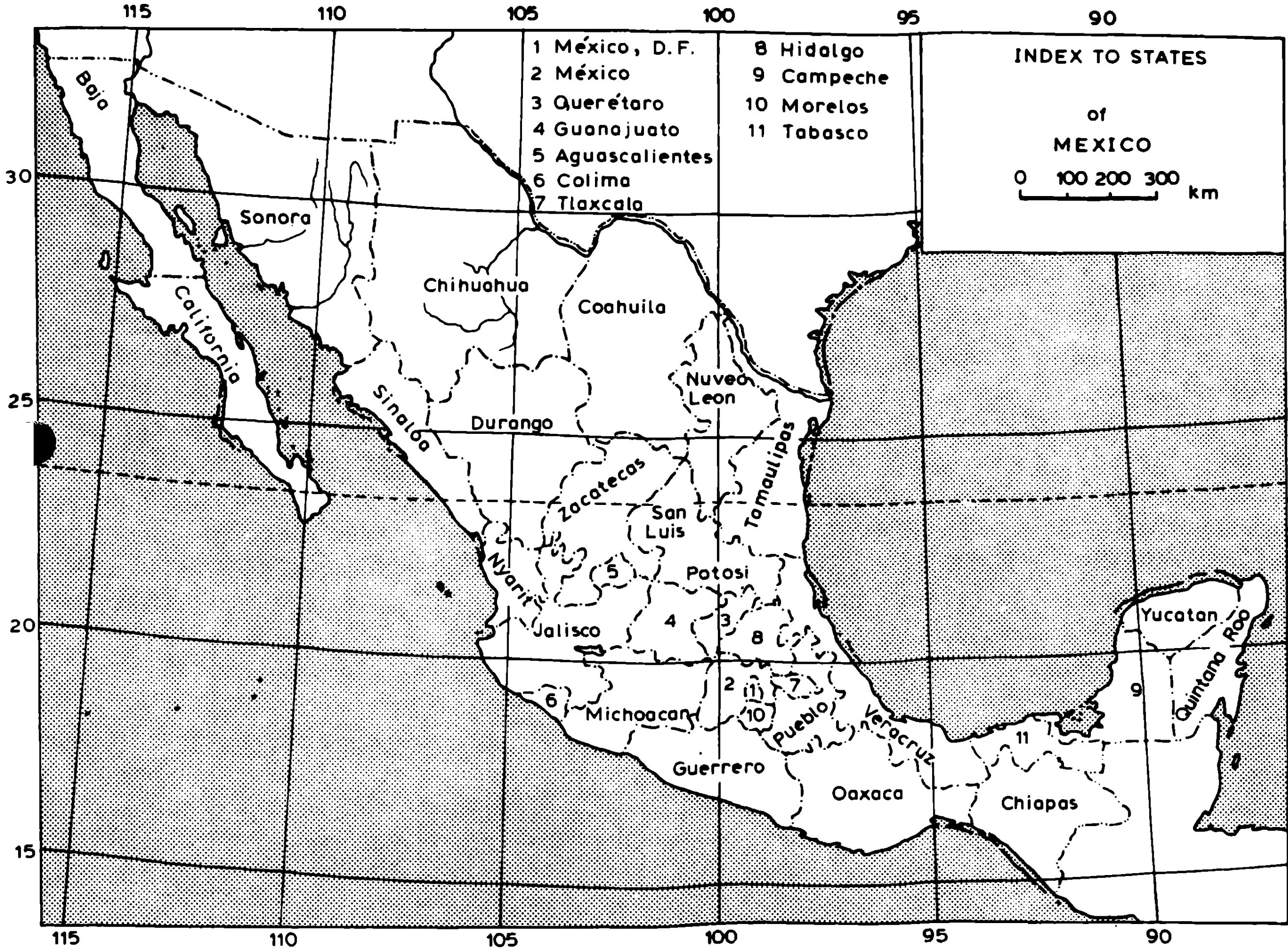

Fig. 3. Index maps to the states of Mexico.

rdt and Scalia (1906), who reported that these rocks lie between older metamorphic rocks and a younger, green, volcanic sequence (Fig. 4) which cannot be related to the green rocks farther north in Chihuahua, rocks interlayered with Permian volcanic rocks (Bridges, 1965; De Cserna et al., 1970). The relation of the Zacatecas section to metamorphic rocks of Mesozoic age (Córdoba et al., 1976) along the eastern Sinaloan boundary is still unclear.

These are the primary marine deposits of the Triassic of Mexico. Rumors of Late Triassic rocks in the Campeche Basin and underlying the Liassic in the Huayacocotlan Basin persist but are difficult to verify. Such rocks, however, should be expected, although they are not indicated by Sansores M. (1956), Gonzalez (1969), or Flores (1974).

Nonmarine, Triassic rocks are more widespread than the marine. Nonmarine, Triassic rocks (Fig. 1) are exposed in the Sierra Madre Oriental from Hidalgo to the north, continually, to Tamaulipas, where

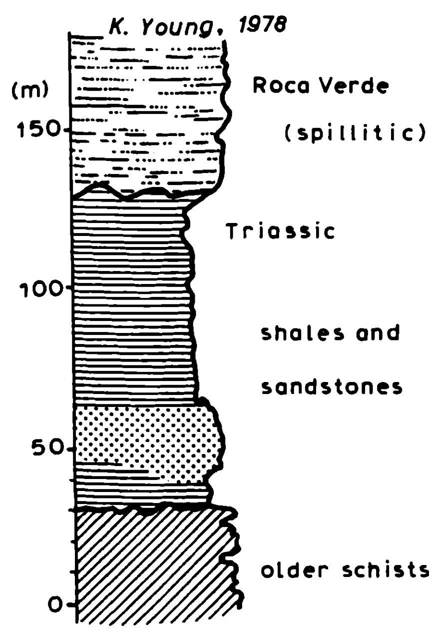

Fig. 4. Diagrammatic section of Upper Triassic rocks at Zacatecas, Zacatecas, Mexico.

they are known as the La Boca Formation of the Huizachal Group (Mixon et al., 1959). They extend through the southern third of Tamaulipas and the southern third of Nuevo Leon. There are red beds of Triassic age which also crop out in a broad belt across northern San Luis Potosí and northern Zacatecas. The overlying Jurassic red beds are spread over a much greater area. In the region of Galeana, Nuevo Leon, volcaniclastic rocks appear within the Triassic red beds. These volcanically derived rocks thicken to the west and in northeastern Zacatecas constitute over half of a section which is over 200 m thick (Belcher, 1978). Red beds to the north and west of those illustrated in Fig. 1 appear to be of Jurassic age (Belcher, 1978). To the south of Hidalgo, especially in Chiapas, Oaxaca, and the subsurface of southern Veracruz and Tabasco, are red beds usually correlated with the Todos Santos Formation of Guatemala and Honduras (Fig. 19). These extend to the west into Guerrero as the Chapolapa Formation (Klesse, 1970). In Guatemala the Todos Santos Formation is said to be latest Triassic and Jurassic (Mills et al., 1967; Finch, 1972). It extends on deeper into Guatemala and into Honduras as the Atíma Formation (Finch, 1972; Ritchie, 1975). In this report I include these with the continental Liassic (Fig. 5), since Jurassic fossils are definitely known from the Todos Santos Formation in Mexico, and Triassic fossils are unknown, except that they have been described from the Todos Santos Formation to the south of Mexico (Newberry, 1888). However, the probability that lower parts of the Chapolapa and Todos Santos Formations may be Late Triassic in southern Mexico should not be ignored. Triassic plants have been described from northeastern Hidalgo by Silva Pineda (1963), but this far north, in a different basin, these beds are

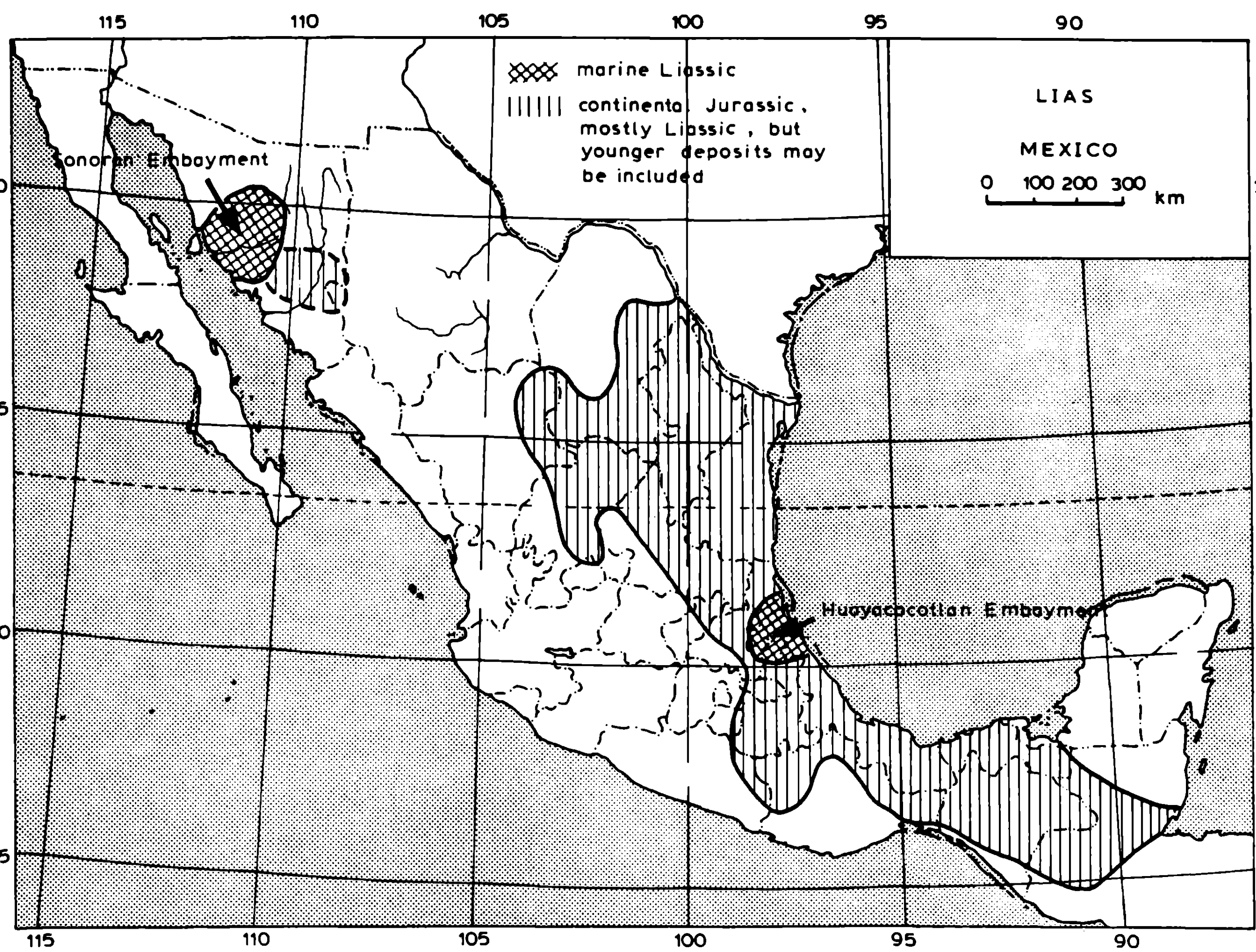

Fig. 5. Index map to the marine Liassic of Mexico. The continental rocks depicted on this map include all of the Jurassic red beds and are not restricted to the Lias.

more often referred to the Huizachal (Sansores and Navarrete, 1969) or just referred to as "los Lechos Rojos" (Ornelas, 1969).

The rocks of the La Boca Formation of the Huizachal Group in the Sierra Madre Oriental and the equivalent red beds of the Huayacocotlan Embayment and surrounding areas often change from a thickness of as much as 1000 m to only a few meters in a distance of only a few kilometers (Toledo-Toledo, 1969; Varela, 1969). That these deposits are thick locally in basins, thinning over intervening highs, seems apparent (Belcher, 1978), but the data are still incomplete.

Jurassic

Jurassic rocks occur throughout northern and eastern Mexico, but in most areas only Late Jurassic rocks are represented. Included in the Late Jurassic rocks are great thicknesses of evaporites, not only in Mexico, but all along the northern part of the Gulf of Mexico. That these evaporitic deposits extend throughout the area of the Gulf of Mexico is indicated by some (e.g., Cook and Bally, 1976), but the determination of actual age is, as yet, unsatisfactory.

Liassic

Known marine Liassic rocks of Mexico are restricted to two areas (Fig. 5). In the Sonoran Embayment the southernmost of two basins containing marine Liassic rocks – the Cuenca San Marcial – also contains marine Liassic (Fig. 2). Deposition was probably continuous from the Carnian into the Lias (Aléncaster, 1961). The Liassic seaway in this area spread farther south, to the Guaymas area, than did the Triassic, and also farther inland (Córdoba et al., 1976). However, it was still a small, marine re-entrant that must have been open to the Pacific Ocean, and it still represents the Sonoran Embayment.

The other small area of marine, Liassic rocks constitutes the Huayacocotlan Embayment of the Veracruz–Hidalgo area (Figs. 5 and 6), a small, marine re-entrant from the ancestral Gulf of Mexico (Burckhardt, 1930a; Erben, 1957b). Erben also questionably shows a small basin during the Liassic, extending from the Pacific Ocean into Guerrero, the Guerreran Embayment (Fig. 7), but there is little evidence, as yet, of its Liassic importance.

Much of the Lower Jurassic of Mexico consists of red beds. They extend from deep into Guatemala and Honduras, where they are known as the Todos Santos and Atíma Formations, northward into Chiapas, Tabasco, and Oaxaca. Liassic red beds in eastern Guerrero, Pueblo, and on to the north, may have been continuous with these, but in different areas the red beds are now interpreted to be of different ages (Sanchez Montes de Oca, 1969; Varela, 1969; Cantu Chapa, 1971).

GUERRERAN EMBAYMENT	SE PUEBLA	HUAYACOCOTLAN EMBAYMENT	
		Pimienta	MALM
Acahuizotla		Tamán	
		Tepexic	
Consuelo	Mapache (?)	Huehuetepec	DOGGER
		Huayacocotla	LIAS
		red beds	TRIASSIC

K. Young, 1981

Fig. 6. Relation of Jurassic strata from the Huayacocotlan Embayment to those of the platform in the State of Pueblo and the Guerreran Embayment. Not all of the formational names utilized by geologists are utilized on this diagram. The Huehuetepec Formation contains both red beds and lagoonal deposits.

In the states of San Luis Potosí, Tamaulipas, Coahuila, and much of the subsurface adjacent to the Gulf of Mexico, these Liassic red beds are known as the La Joya Formation. The La Joya Formation overlies the Late Triassic La Boca Formation, and together they constitute the Huizachal Group (Mixon et al., 1959). Both are red beds. But the Jurassic red beds are much more widespread than the Triassic red beds, especially to the northwest. Although these red beds are illustrated on the Liassic map (Fig. 5), they are not restricted to the Liassic; some of them are Dogger (Erben 1957a; Silva Pineda, 1969, 1970), and some of them are even Upper Jurassic (Cook and Bally, 1976). If there are similar Cretaceous red beds, as indicated to the south and east of the Campeche Embayment (= Isthmian Embayment of Ewing et al., 1970) by Sanchez Montes de Oca (1969), they have not yet been fully documented.

On the east side of the Aldama Platform in Chihuahua (Fig. 8) there is a fairly thick sequence of red sandstone, red pebbly sandstone, and red silty sandstone (Diaz and De Cserna, 1956); it lies disconformably below marine late lower-Aptian (*Cheloni-*

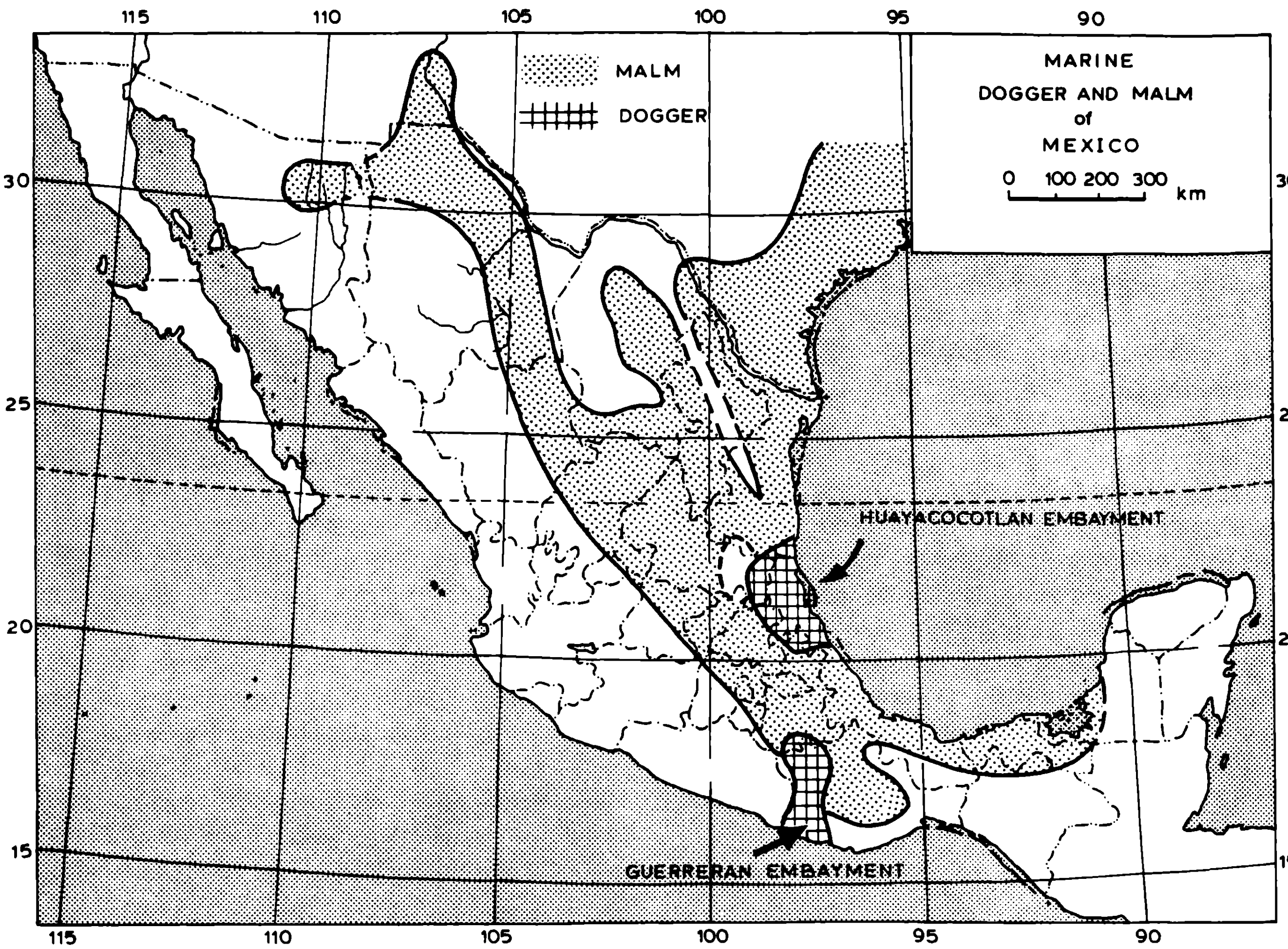

Fig. 7. Paleogeographic map depicting the maximum transgression of Dogger and Malm seaways in Mexico.

ceras sp.) and unconformably over the Permian flysch of that area. Similar beds to the west of Torreon, Durango, the Nazas Formation, underlie marine Upper Jurassic (García Calderón, 1976). Whether the strata east of the Aldama Platform are marginal to the Cretaceous Navarette and Las Vigas Formations (Neocomian and early Aptian) or marginal to the Kimmeridgian cannot be determined at this time, and any correlation with the Jurassic because of their reddish color is unsafe.

In a paper as short as this there is not sufficient space to include and discuss completely all of the stratigraphic nomenclature, but stratigraphic diagrams illustrating the nomenclature in key section are important; most of the references contain such diagrams. As the Triassic red beds, so the Jurassic red beds vary greatly in thickness over short distances, with sediment sources from many greatly divergent directions (Belcher, 1978). For example, the disposition of red beds would indicate that the extension of a Toarcian seaway over the Miquihuana Platform, as shown by Erben (1957b, fig. 4) to be impossible, since the elements of the Platform were already extant at that time (Fig. 8). But small seaways in small elongate basins aligned from 30 to 20 degrees west are not impossible. Such basins would be parallel to major features of the positive elements of the platform. Near areas of marine deposition, such as the Sonoran and Huayacocotlan Embayments, red beds are often replaced by gray shales, also continental, that may contain plants and thin seams of coal (Wilson and Rocha, 1946; Silva Pineda, 1963, 1969, 1970).

Dogger

The marine rocks representing the Dogger are as restricted as the Liassic rocks (Figs. 4, 7). These rocks are primarily Bathonian, as the Bajocian is known for

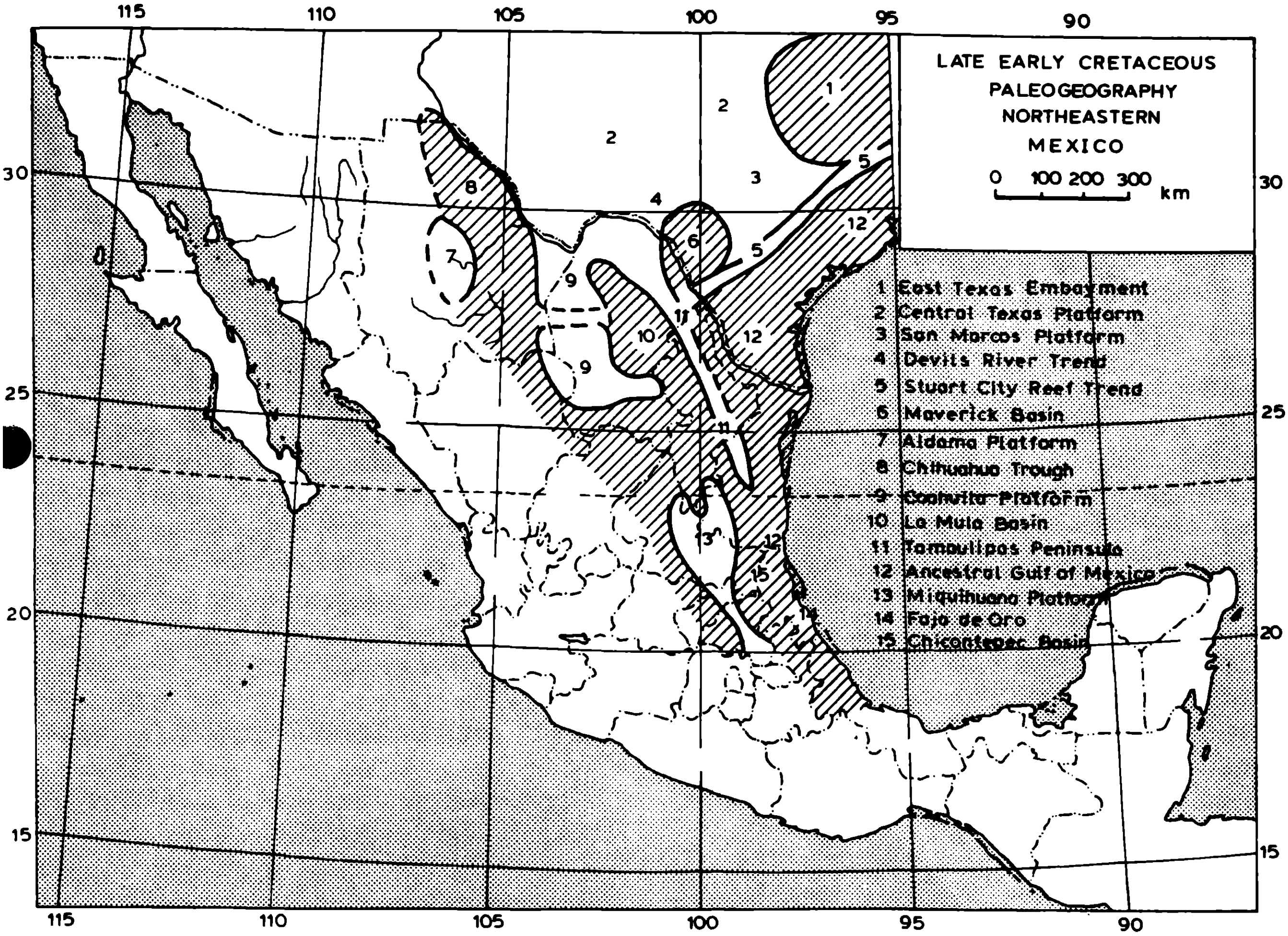

Fig. 8. Index map to the major tectonic elements of northeastern Mexico during the Jurassic and Cretaceous.

certain from only the Guerrreran Embayment in Mexico (Ochoterena, 1963), although interpreted to be present in the Huayacocotlan Embayment. Marine, Bathonian rocks lie above the Toarcian in the Huayacocotlan Embayment, occupying about the same geographic areas as the marine Pliensbachian sediments (Erben, 1957b, fig. 5; Figs. 5, 6). Marine Dogger is at times more restricted than the Liassic, and continental red beds intervene between the Liassic and the Callovian (Cantu Chapa, 1971).

The Sonoran Embayment had become inactive by Middle Jurassic, and this paleogeographic feature did not again reappear. The Guerreran Embayment, questionably suggested as appearing in the late Liassic by Erben (1957b), is, in the Middle Jurassic, a distinct, although a small, feature containing marine, Bathonian and Bajocian sediments. Erben believed that some of the Bathonian marine rocks interfinger with Jurassic red beds, and if so, deposition of red beds was continuous from the Liassic into the Dogger in some areas. Silva Pineda (1970) has described Middle Jurassic plants from north of the northern end of the Guerreran Embayment. However, the red beds usually cannot be separated paleontologically or physically and are therefore included on the map of the Lias (Fig. 5). Cook and Bally (1976) show even a wider distribution of marine, Liassic and Dogger rocks than does Erben, and they indicate that some of the evaporites of northeastern Mexico are probably Middle Jurassic.

Malm

Although the basic elements of Mesozoic paleogeography of Mexico (Fig. 8) appear to have been established before the end of the Triassic, rapid changes in facies, rapiu changes in thickness, and lack of data from the outcrop and subsurface, make the details of that paleogeography difficult to document, at least prior to the Aptian. Burckhardt's (1930ab) original interpretations dealt primarily with the western margin of various seaways of different times. Imlay (several papers, but especially 1938 and 1953) developed interpretations that since have only been modified in detail (Carillo Bravo, 1969; Carrasco, 1970; Cook and Bally, 1976; Young, 1978), except along the Pacific margin of Mexico, where much new information in the last decade is still insufficient for definite interpretations.

Perhaps the Liassic and Dogger sea invaded east-central Mexico through a series of elongate basins (grabens?) between intervening, narrow ridges (horsts?) (Toledo Toledo, 1969; Varela, 1969) of a since abandoned, Triassic, spreading rift-area, but the data are not yet clear. During the Malm there is enough evidence to indicate that paleotopography controlled the pathways of expansion of the Late Jurassic seaways. Whether this actually started in the Bajocian, Callovian, or even the Oxfordian, is more a matter of individual aesthetics than a matter of real data obtainable at the present time, but such interpretations depend on the age of most of the outcrops of limestone north of Veracruz. This Jurassic limestone usually has been identified as Zuloaga (Oxfordian), but many of the outcrops now appear to be "Cotton Valley" Limestone (Kimmeridgian), a limestone unit at the base of the La Casita (the Cotton Valley of the Texas Gulf Coast). Nevertheless, the Late Jurassic, primarily Kimmeridgian, seaway underwent a great expansion across Mexico and particularly across northern Mexico, except for the western states adjacent to the then subducting margin of the Pacific Ocean Basin, where there is no known marine invasion of Late Jurassic age. This does not, however, preclude some of the metamorphic rocks, dated as Mesozoic, from being anywhere in the pre-Albian Mesozoic, as De Cserna (1969a, 1970) so frequently indicates.

Furthermore, by late Kimmeridgian the Jurassic seaway had invaded the Chihuahua Trough (Córdoba and Guerrero, 1970) and the La Mula Basin (= Sabinas Basin of many authors) (Salinas, 1969). Cook and Bally (1976) indicate that the La Mula Basin was invaded in the Oxfordian, as is also indicated by Humphrey and Diaz (ms.). Sabinas Basin was first used to describe the intermontane coal basin (Fig. 20) in the vicinity of Nueva Rosita, Coahuila (Robeck et al., 1956), it is not the same feature as the "Sabinas" Basin used by other authors to describe the Late Jurassic–Early Cretaceous basin between the Coahuila Platform on the west and the Tamaulipas Peninsula on the east (Fig. 8); at one time E.J. Guzman termed this basin "Golfo de Mesozoica de Coahuila" (lectures at the University of Texas at Austin, 1956). This name is too long to conveniently use on maps, but Guzman was correct in differentiating that basin from the Sabinas (coal) Basin proper. In order to prevent confusion, I have, for many years, termed this other Mesozoic basin the La Mula Basin.

Whether, at some time during the Late Jurassic, the Miquihuana Platform (or archipelago) was completely covered by sediments or not remains unclear, but the presence of nerineid limestones along some of the southern part of the eastern margin of that platform indicates deposition in very shallow water, and the absence of Jurassic over parts of the platform suggests nondeposition, although its removal by erosion is not ruled out. Imlay (1937, 1943) has interpreted the Miquihuana area as an island, and Böse (letter to J.A. Udden, Univ. of Texas, Archives at Austin) interpreted this particular island as the source area for the Galeana Sandstone (lower Hauterivian).

Certainly the Jurassic seaway did not cover the Aldama Platform or the Coahuila Platform (Fig. 9), and the Tamaulipas Peninsula, although completely covered by a Kimmeridgian sea at times, was probably an archipelago of small islands on a shallow, elongate platform during much of the Tithonian and lower Neocomian, accounting for the restricted accumulation of various deposits of evaporites in basins (La Mula) to its west (Fig. 8). The top of the La Caja Formation (Tithonian?) in the Rincon de Pelillo, Sierra Gomas, west of Potrero, Nuevo Leon, appears to be lagoonal, but on the east side of the Tamaulipas Peninsula; the barrier to the east of this lagoonal facies is unknown.

In the Chihuahua Trough there are also Late Jurassic evaporites, and near Placer de Guadalupe the "green formation" between the Paleozoic and the marine Jurassic, long thought to be Jurassic, was considered to be Permian by Bridges (1965). De Cserna et al. (1970) now report interlayered Permian rhyolites, dated radiometrically, within this formation.

Jurassic rocks between Arteága Canyon, southeast Coahuila, and Valles, southeast San Luis Potosí, crop out in very isolated sections that make interpretation difficult. The limestone identified as "Zuloaga" in the Sierra de Fraile, Nuevo Leon, the Sierra Minas Viejas, Nuevo Leon, and near Galeana, southern Nuevo

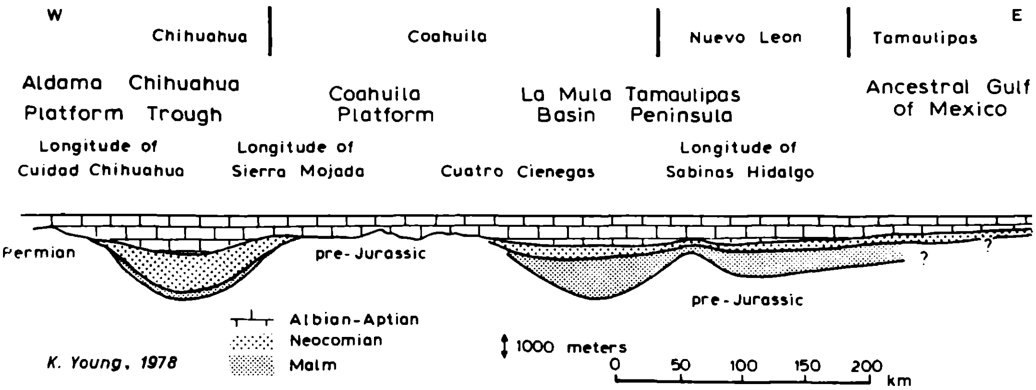

Fig. 9. East–west cross-section illustrating the general relations of Jurassic–Neocomian and Neocomian–post-Neocomian rocks in northern Mexico.

Leon, now appears to be "Cotton Valley Limestone" (Kimmeridgian) and has little to do with the real Zuloaga Limestone (Oxfordian) (Moor, 1978). Therefore, the ages of evaporites underlying this limestone need to be reinterpreted; they are more likely Kimmeridgian (Buckner equivalent in Texas) than Oxfordian.

In both the Campeche Embayment and northeastern Mexico there are thick sequences of evaporites. Those in the La Mula Basin may be Oxfordian at the oldest, and there also appear to be Oxfordian evaporites below the Zuloaga Limestone in areas south of Cuidad Victoria. A younger sequence of evaporites, at least in Nuevo Leon and Coahuila, is Kimmeridgian.

The southern part of the Rio Grande Trench, which in space, if not in time, is a continuation to the north of the Chihuahua Trough, must have been active before the end of the Late Jurassic, because the Grimm, Hunt, Brown, and American Arctic, Ltd., No. 1 Mobil 32 encountered Jurassic rocks, tentatively identified as Oxfordian (but more likely Kimmeridgian in the writer's opinion) at depths of 4210 m (Thompson, 1975). This extends the Chihuahua Trough into New Mexico somewhat north of its most northern limit on the maps of DeFord and Haenggi (1970), De Cserna (1970), Hayes (1970), and Cantu Chapa (1976).

There are metamorphosed rocks of Mesozoic age along the Sinaloa–Durango border (De Cserna, 1970; Córdoba et al., 1976). Cook and Bally (1976) show some of these as Triassic. Slightly metamorphosed flyschoid rocks in northwestern Jalisco, just south of Cabo Corrientes, were long labeled as metamorphosed Mesozoic (Salas et al., 1968), but Córdoba et al., (1976) now show these rocks to be metamorphosed Paleozoic, but the age of the rocks in Jalisco has not been firmly established. The age of most of the metamorphic rocks in the Sierra Madre del Sur has also not been completely established, although some have yielded fossils as young as Middle Cretaceous (Palmer, 1928a).

That there are Jurassic intrusive and volcaniclastic rocks in western Mexico is doubted by few, but the subduction zone along the western coast of Mexico had proceeded for only a short time by the Late Jurassic, and igneous events of the Jurassic are minor when compared to the igneous events of the Cretaceous. The Sierra Madre Occidental is composed largely of Cenozoic igneous rocks, which not only overwhelm, in volume, those of the Cretaceous and Jurassic, but also conceal most of the pre-Cenozoic rocks of that large area.

Cretaceous

Early students of the Cretaceous of Mexico divided the System into lower, middle, and upper (Böse and Cavins, 1927); the lowermost division consisted of the initial, largely terrigenous rocks, mostly derived from local sources; the middle division consisted of the mostly carbonate part of the System, starting in the later Barremian and ending in the early Campanian, then thought to be Santonian; the upper subdivision included the final, terrigenous part of the System, consisting mostly of pre- and synorogenic deposits from the rising mountains of the Laramide Orogeny to the west; it includes rocks ranging in age from the upper 2/3 of the Campanian to, and including, the Maastrichtian. The base of the third subdivision was younger in the east and older in the west as the carbonate rocks were replaced by pre-orogenic terrigenous facies from the west (De Cserna, 1970).

Neocomian

There was some retreat of marine deposition near the end of the Jurassic, as indicated by the absence of transitional deposits over the Tamaulipas Platform and by the *Leopoldia victoriensis* Imlay zone resting on late Kimmeridgian at Samalayuca, northern Chihuahua (Webb, 1969a, b; Cantu Chapa, 1970) (Fig. 9). Many authors (e.g., DeFord and Haenggi, 1970, p. 181) seem to assume that either Young (in Webb, 1969a) or Cantu Chapa (1970) are in error on the ages of these sandstones. When the area was visited by the members of the A-13 excursion of the International Geological Congress in 1956 (Diaz and De Cserna, 1956), the late Walter Biese was certain of the Jurassic age of the outcrop visited at that time. The specimen of *Leopoldia victoriensis* Imlay, collected by Webb, cannot be doubted. Even the structure in the rocks surrounding the Sierra de Samalayuca is not all that simple (DeFord and Haenggi, 1970; Berg, 1969, 1970). Furthermore, it can never be proved that Webb collected from exactly the same beds at exactly the same locality from which the specimens described by Cantu Chapa were collected. King (1947) originally mapped the formations as Jurassic–Lower Cretaceous undifferentiated, and it seems that both Kimmeridgian and Neocomian rocks are here represented. After all, the environments of deposition and the source areas would not have been that different.

Valanginian rocks rest on marine Kimmeridgian rocks or on Jurassic red beds across the Miquihuana Platform (Imlay, 1938) and other areas of northern Mexico.

The maximum extent of the Neocomian seaway (Fig. 10) was about the same as that of the Kimmeridgian, perhaps slightly less in the Chihuahua Trough, perhaps a bit more on the Miquihuana Platform.

Wilson and Pialli (1978, fig. 4) show interfingering at the boundary of the La Casita and Taraises Forma-

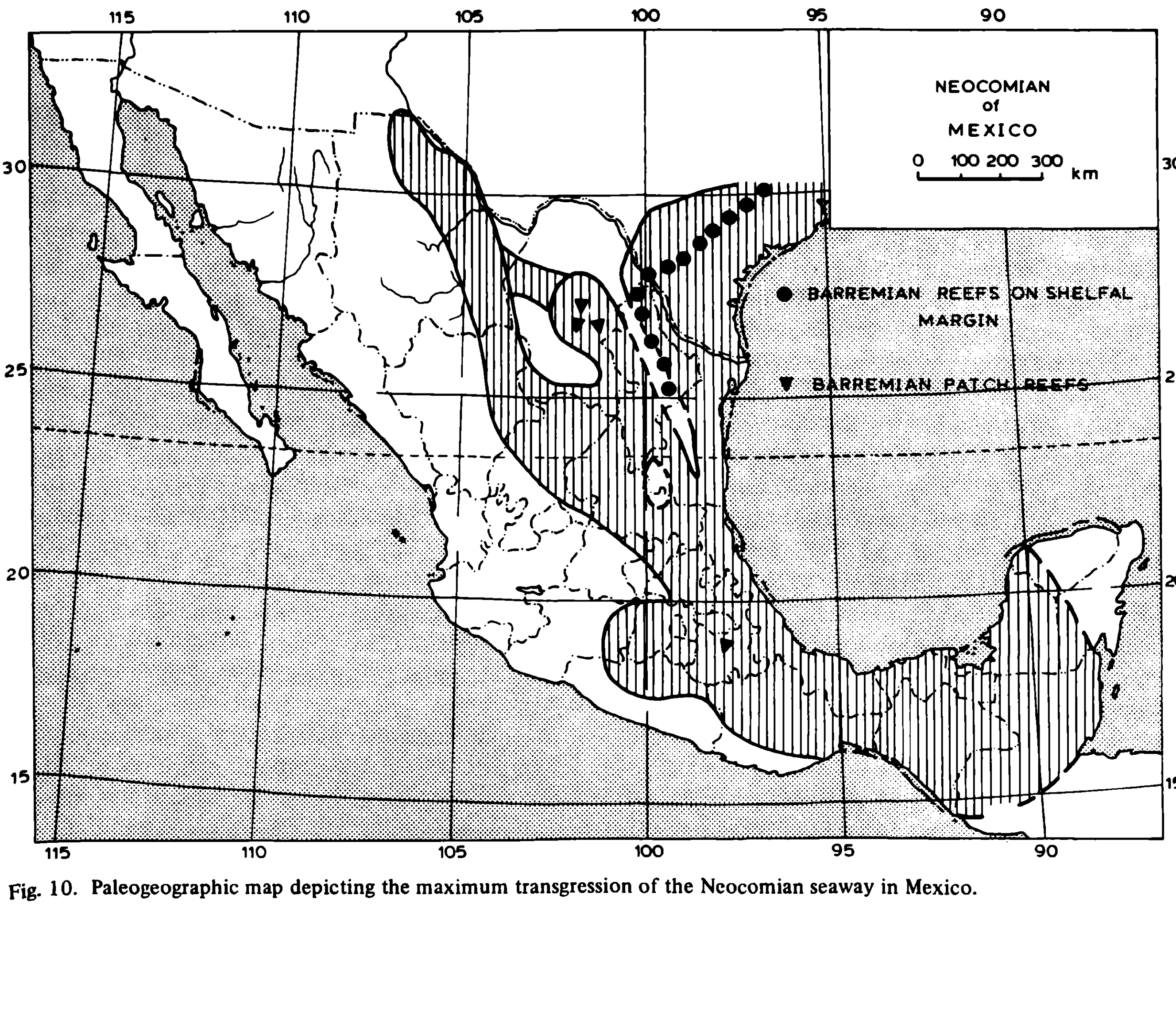

Fig. 10. Paleogeographic map depicting the maximum transgression of the Neocomian seaway in Mexico.

tions, although in the text they use paleontological indices for differentiating these boundaries; thus, there are probably changes in facies along and across the boundary of the Neocomian with the Jurassic in the La Mula Basin northeast of Saltillo, southern Coahuila. The Late Jurassic, subsequent to the Cotton Valley Limestone, is terrigenous (Böse, 1923a). The lower part of the Neocomian is also terrigenous, the terrigenous rocks gradually becoming more calcareous upward and away from the terrigenous sources as the Taraises Formation, or equivalent formations, grades upwardly and eastwardly into the Cupido Limestone. Eastward from the Tamaulipas Peninsula, into the ancestral Gulf of Mexico, the calcareous upper member of the Taraises Formation of the eastern Flank of Sierra Gomas, along the border of Coahuila and Nuevo Leon (Fuentes Fuentes, 1964), becomes more calcareous and is called Cupido Limestone when logged in wells in eastern Nuevo Leon.

It was during the Late Jurassic that the great barrier reef system (Fig. 8), surrounding much of the Gulf of Mexico, first began; it was to dominate the paleogeography of that region for about 30 million years. However, it was during the upper part of the Neocomian that this reef system began to take on the aspect that it would maintain until near the end of the Cenomanian (Young, 1972; Bebout and Loucks, 1974).

Aptian

There is a general break in the continuity of deposition of carbonate rocks during the late Aptian. This resulted in the deposition of an Aptian influx of terrigenous sediments during the *Deshayesites–Cheloniceras* zones, recognized as the La Pena Formation in the north of Mexico and the Otates Formation in the south. These beds become more calcareous to the south of Mexico into Guatemala and Honduras, where they have not been separated from the Coban or Atíma Formations (Mills et al., 1967; Finch, 1972; Ritchie, 1975), but, nevertheless, retain their distinctiveness of thinbedded limestones (7 to 10 beds per meter). Fig. 11 represents the seaway for the latest Aptian (the *Clansayes* horizon), which was the most widespread part of the Aptian seaway. Differences between my maps and those of Hayes (1970b) are largely in the selection of the horizon to be depicted than in disagreement of extent of seaways at any particular time.

Toward the northeast of the Coahuila Platform in Coahuila the La Virgen evaporites represent an Aptian, evaporitic platform-facies behind the upper part of the Cupido Limestone (Böse, 1923a; Smith et al., 1974).

Below the upper Aptian, carbonate formations have not been named according to their facies. Below the *Deshayesites–Cheloniceras*-bearing beds one can usually get by with using Cupido Limestone, or lower Tamaulipas for offshore limestone deposits, in most of the eastern Mexico or Sligo Limestone in the United States or the subsurface of northeastern Mexico. Above the *Cheloniceras* level, on the other hand, a great hodgepodge (variety) of names are used to differentiate the lateral and vertical distribution of the different facies of calcareous, sedimentary rocks. Tracts of grainstones, rudist banks, mudstones, wackestones, inner platform, outer platform, etc., each receives a different formal name.

Albian–Turonian

The Albian–Turonian history of northern and eastern Mexico is primarily centered around the different facies associated with the different platforms and basins (Fig. 8). Up until the Aptian the Coahuila Peninsula was largely exposed, shedding sediments into the Chihuahua Trough on the west to help produce the Navarette (Neocomian) and Las Vigas (Neocomian and lower Aptian) Formations. To the east, along its eastern margin, following the emplacement of late Triassic granites that crop out near Las Delicias and in the Potrero de la Mula (Denison et al., 1970) terrigenous sediments were shed into the La Mula Basin. Arkosic wedges of different ages [San Marcos (Neocomian), Menchaca (Jurassic), Patula (late Neocomian)] extend into the Basin, and some were even washed as far as the Rio Grande Embayment to produce a few red beds prior to the development of the Maverick Basin. Other unique terrigenous deposits, the La Mula Shale (a red deposit of Barremian to late Aptian age) and Barril Viejo Shale (Valanginian and Hauterivian), also have their sources in the Coahuila Platform. By the latest Aptian most of the areas that had been sources of terrigenous sediments, locally, were covered, and the deposition of carbonate rocks became the dominant depositional program of all of northern Mexico. During regressive hemicycles (Cooper, 1977; Kauffman, 1977; Matsumoto, 1977) reefoid rocks prograded away from the platforms. On the Coahuila Platform the late Albian–early Cenomanian transgression was rapid, and reefoid rocks were covered with calcareous mudstones and wackestones; reefoid rocks did not again appear on that platform (Fig. 12).

To the south, along the Miquihuana Platform (= Valles–San Luis Potosí Platform of Carillo-Bravo, 1969, the southern end of which was called the Actopan Platform by Carrasco, 1971), transgression was less rapid, and there was karstic development on some parts of the platform following the earliest Cenomanian. Just southeast of Miquihuana large specimens of *Sauvagesia* may indicate Turonian. 35 km east of San Luis Potosí, in the Sierra de Alvarez, *Radiolites* sp. cf. *mullerriedi* Bauman and *Hippurites mexicanus* Barcena (De Cserna and Bello-Barrádas, 1963; Bartlett, 1978) from the Cuautla Formation are upper Turonian or younger. Here the Cuautla Formation appears to rest unconformably on El Abra with a well-developed karstic terra rosa and red conglomerate separating the two formations.

Off, but adjacent to, the Miquihuana Platform calcispheric mudstones and wackestones, which are probably not of deep water, show little evidence of the adjacent platform (Waisley, 1978). Most of the limestones off the platform are black and highly organic. Those of Cenomanian age may represent the Cenomanian anoxic event of general occurrence throughout the Atlantic Ocean (Hays and Pitman, 1973; Ryan and Cita, 1977; Schlanger and Jenkyns, 1976; Hallam, 1977), but most of the organic, black limestones off the platform are older than Cenomanian; some of these probably represent deposition in local, anoxic basins of poor bottom circulation (Schlanger and Jenkyns, 1976). But, not all black, organic limestones are anoxic. The mudstones and wackestones in the area of Barramberri, in the re-entrant at the north end of the Miquihuana Platform, which I have drawn as extending farther north than Carrillo Bravo (1969) or Carrasco (1971), give little

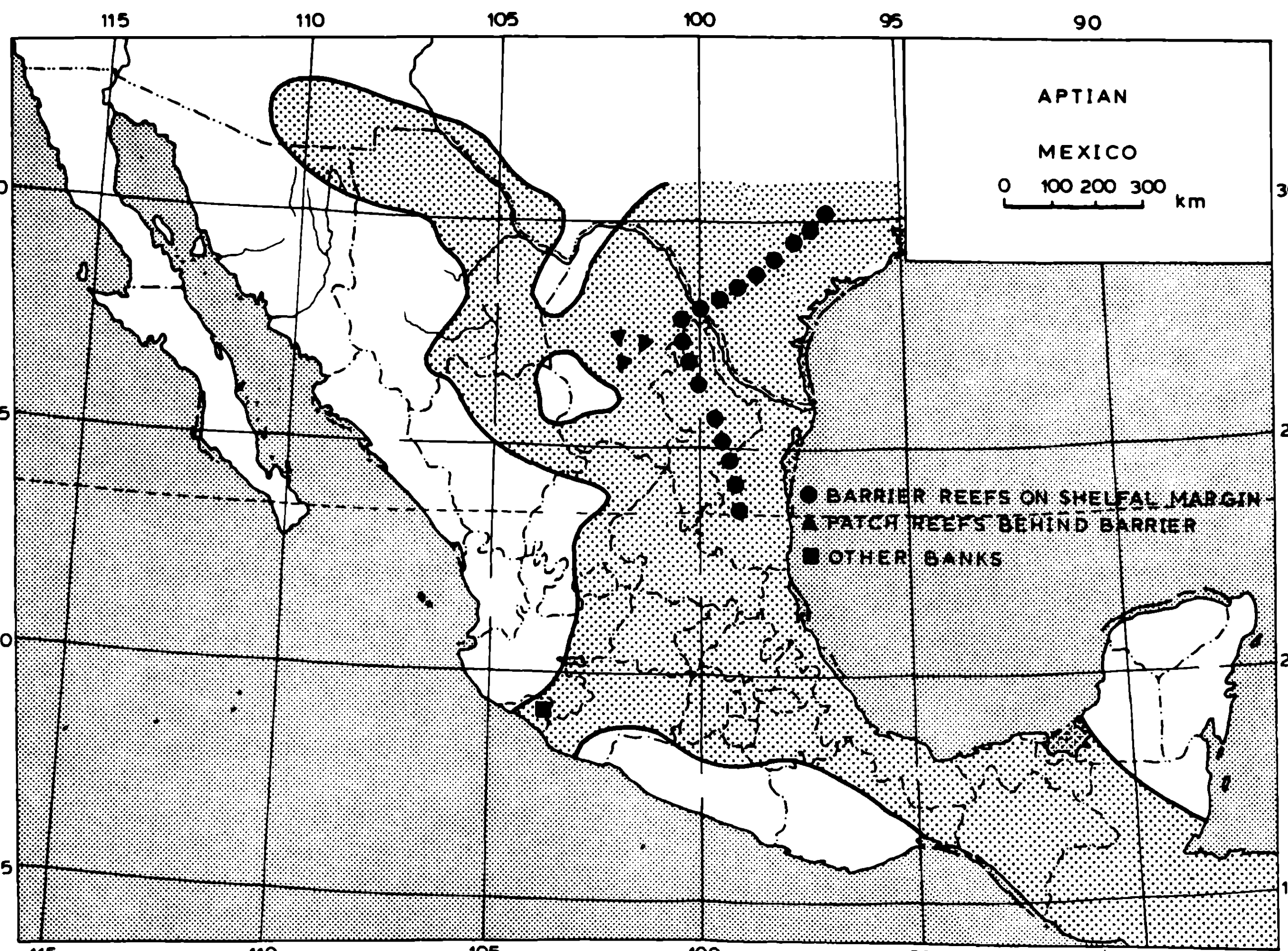

Fig. 11. Paleogeography of the maximum transgression of the Aptian seaway of Mexico. The distribution of known rudist banks are also indicated.

evidence of the adjacent platform, perhaps indicating that the relief of the platform was not great near that area (Moor, 1978; Waisley, 1978). However, soft sediment flows on the west side of the platform north of San Luis Potosí (Waisley, 1978) and on the east side of the Miquihuana Platform in Peregrina Canyon west of Cuidad Victoria, during deposition of the late Albian and early Cenomanian Cuesta del Cura Formation, indicate an effective paleoslope from the platform. The general Cenomanian transgression is not apparent in the reefoid rocks around the margin of this platform.

Although some of the platform areas north of the Miquihuana Platform received rudist deposits (Figs. 12, 13) into the earliest part of the early Cenomanian (e.g., Stuart City Trend; Sierra de la Gloria near Monclova, Coahuila; northeast corner of the Coahuila Platform; Sierra de la Párra, northeast Chihuahua), all of these, unlike the Miquihuana Platform, foundered by the end of the early Cenomanian and were covered with mudstones and wackestones (Jones, 1938; Smith, 1970) deposited in the rapidly transgressing early Cenomanian seaway. As in the Albian, the Cretaceous seaway of the early Cenomanian was more widespread in Mexico than at any other time during the Mesozoic (Fig. 12). The rising mountains resulting from the Laramide Orogeny with accompanying volcanism forced retreat of the seaway during the later Cretaceous (post-early Cenomanian) (Fig. 14), even though general transgression elsewhere was more extensive into the Campanian and Maastrichtian (Cooper, 1977; Kauffman, 1977; Matsumoto, 1977).

In northeastern Chihuahua and northern Coahuila the lower part of the early Cenomanian contains the terrigenous Del Rio Claystone, whereas the upper part is represented by the Buda Limestone. In northern and eastern Mexico, during the greatest advance of the Cretaceous seaway, the early Cenomanian is

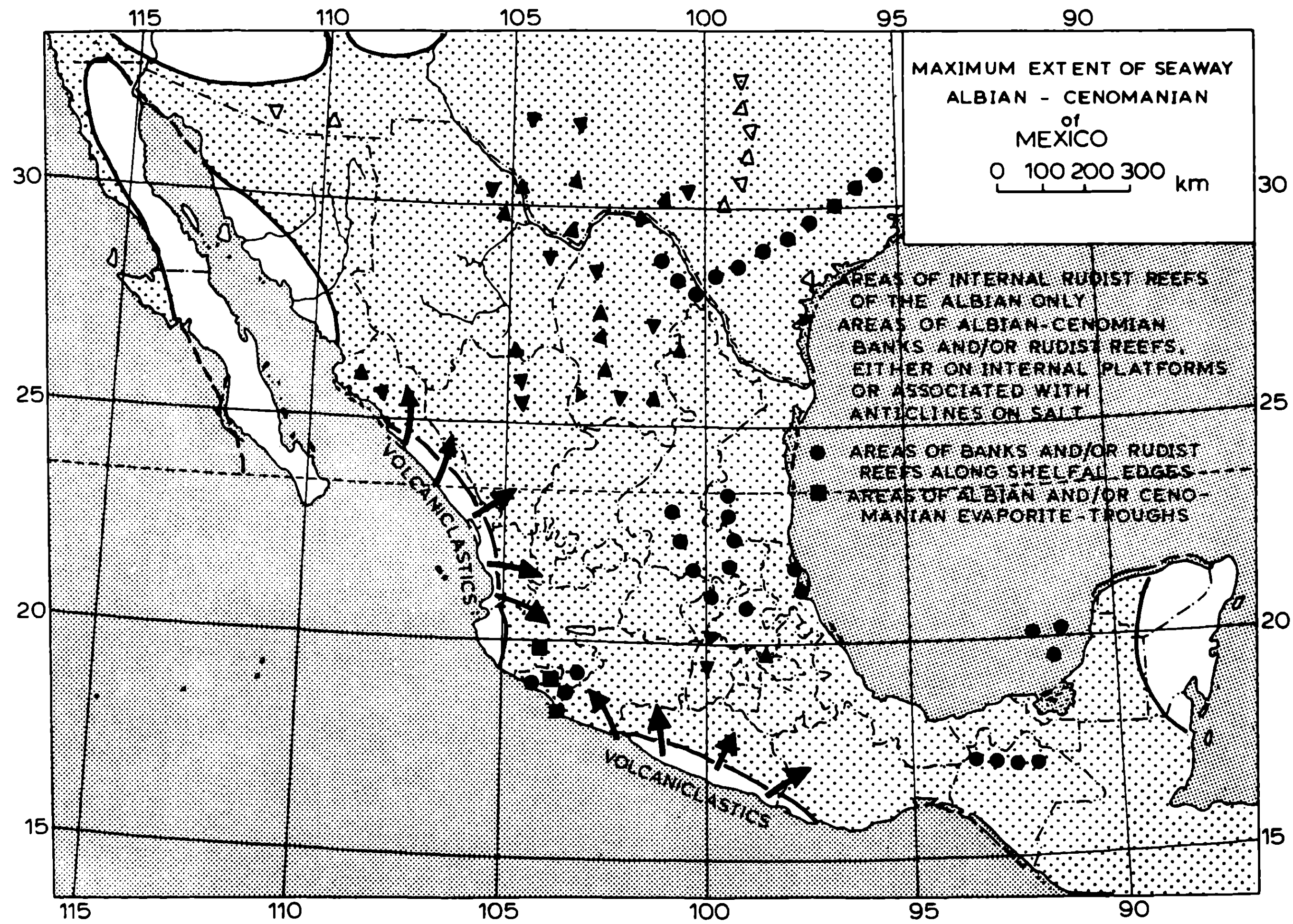

Fig. 12. Paleogeography of the maximum extent of Albian and Cenomanian seaways in Mexico. The maximum extent of the late Albian seaway is almost identical with that of the maximum extent of the early Cenomanian seaway. The seaway was less extensive during the Late Cenomanian. Known rudist banks and deposits are also indicated.

represented by the black, organic limestone of the Cuesta del Cura Formation. To the west in eastern Durango and western Zacatecas the limestone is still called Cuesta del Cura, but here there are 12 to 20 cycles per meter, in contrast to the 3 to 5 cycles per meter in eastern and northeastern Mexico. In this area the base of the Cuesta del Cura is also older than farther east, as this facies replaces the underlying, more massive limestones from east to west (De Cserna, 1976). The Cuesta del Cura Limestone then extends southward along the western side of the Miquihuana Platform, so close to the platform near Matehuala that small fragments of rudistids and other reef debris occur in some of the grainier beds.

Around the edges of the Miquihuana Platform early Cenomanian reefoid rocks replace the Cuesta del Cura Limestone. To the southwest in Colima and Jalisco thinbedded limestones, averaging 16 cycles per meter, may also be early Cenomanian (Palmer, 1928b), but may also include Albian.

Upper Cenomanian rocks are more restricted than lower Cenomanian, and the upper Cenomanian seems to be absent on the Miquihuana Platform and on the Faja de Oro (Coogan et al., 1972). Further north the upper Cenomanian is missing across parts of the Coahuila Peninsula, the zone of *Kanabiceras septemseriatim* (Cragin) being spotty at Tanque Toribio (Jones, 1938; Young, 1978), with the rest of the upper Cenomanian and the lower part of the lower Turonian being absent. Upper Cenomanian is present in the Chihuahua Trough (Wolleben, 1965, 1967; Powell, 1963, 1965) and at El Paso, across the border from northeastern Chihuahua (Powell, 1967, 1970).

Through part of northeastern Mexico the upper Cenomanian is terrigenous (Agua Nueva Formation) as is the lower-most Turonian. To the east into the Gulf of Mexico and to the south along the eastern front of the Sierra Madre Oriental, Tamaulipas, the Agua Nueva Formation is sometimes replaced by the lower part of the overlying San Felipe Limestone

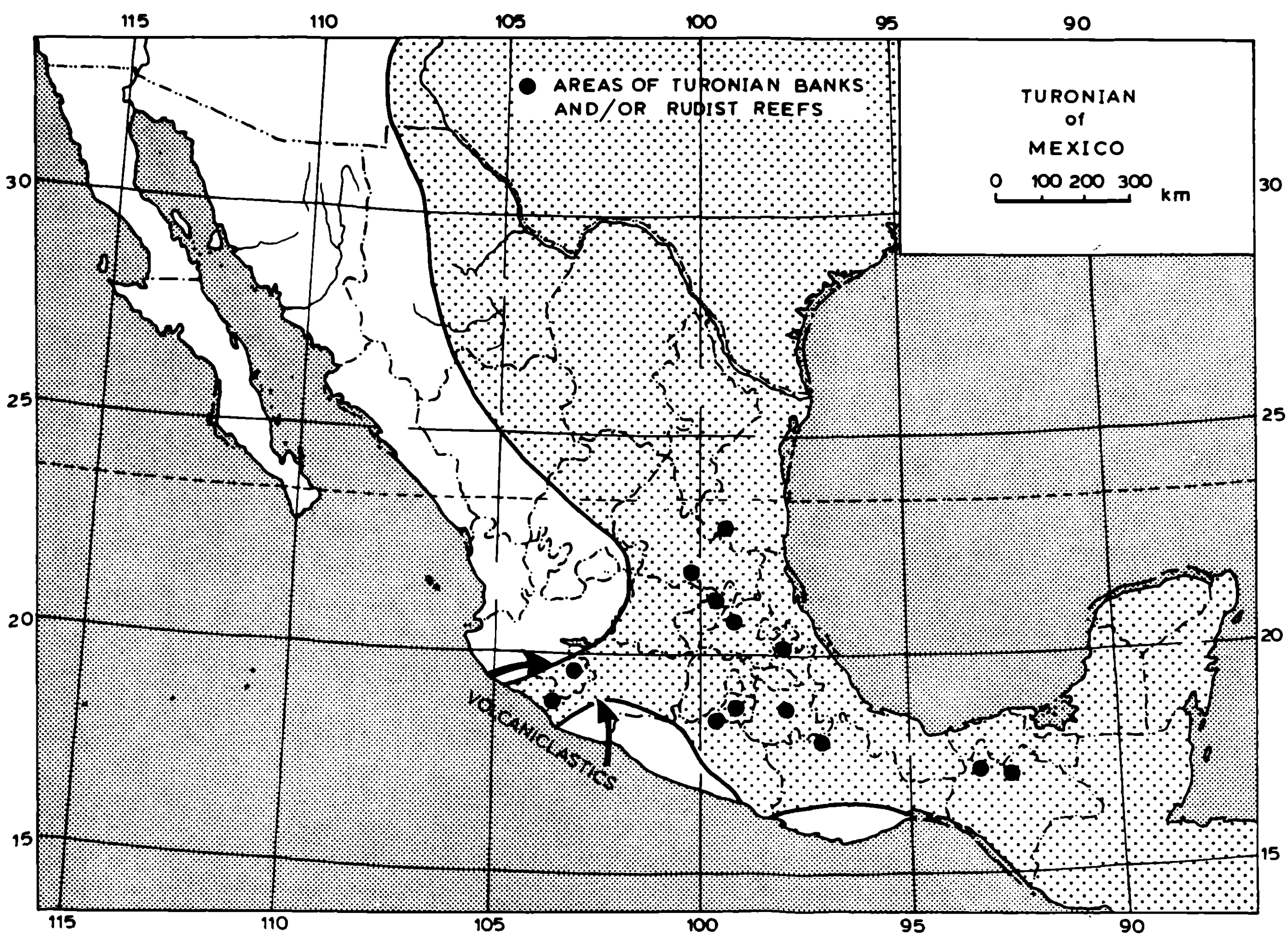

Fig. 13 Paleogeography of the Turonian of Mexico. Areas of known rudist banks and volcaniclastic deposits are also indicated.

(Fuentes Fuentes, 1964; Bishop, 1970, 1972), which also includes the upper Turonian, the Coniacian, the Santonian, and the lower part of the Campanian (e.g., *Parapuzosia boesei* Scott and Moore, species of *Submortoniceras*, and *Scaphites hippocrepis* s. l.)

Although upper Turonian rocks crop out over most of the Coahuila Peninsula in chalky beds, they are generally absent over the Miquihuana Platform, except to the south of the state of San Luis Potosí. An exception is in the Sierra de Alvarez (De Cserna and Bello Barrádas, 1963), just east of San Luis Potosí, where reefoid rocks (Cuautla Formation) contain *Radiolites, Hippurites*, and probably *Bayleoidea* (Bartlett, 1978). Similar rocks extend on south into Morelos and Oaxaca (Ferrusquía, 1976) and northern Guerrero as the Morelos Formation (Bauman, 1958; Fries, 1960; Klesse, 1970). To the west, in the western Sierra Madre del Sur (Michoacan, Jalisco, and Colima), rocks containing *Bayleoidea, Radiolites*, and caprinids are probably Turonian (Palmer, 1928b).

Senonian

At the present time erosion has proceeded until enough Albian rocks are exposed that the paleogeographic elements of eastern and northern Mexico are reasonably well established (Fig. 8).

The Mesozoic history of eastern and northern Mexico is largely one of carbonate deposition on platforms, or karstic developments on platforms' versus offshore deposition of carbonate rocks. The most widespread marine deposits in Mexico are those of the Albian and Cenomanian (Fig. 12), and the maximum extent of the seaway of these two stages is similar, and somewhat beyond the western extent of the Aptian seaway (Fig. 11). Following the Cenomanian the Late Cretaceous seaway of Mexico steadily receded to the east (Fig. 14) as a result of Laramide orogenic pulses and the resulting terrigenous deposits filling in the seaway and displacing marine water (Fig. 15). The Caracol Formation of western Zacatecas, eastern Durango, and neighboring areas, represents ter-

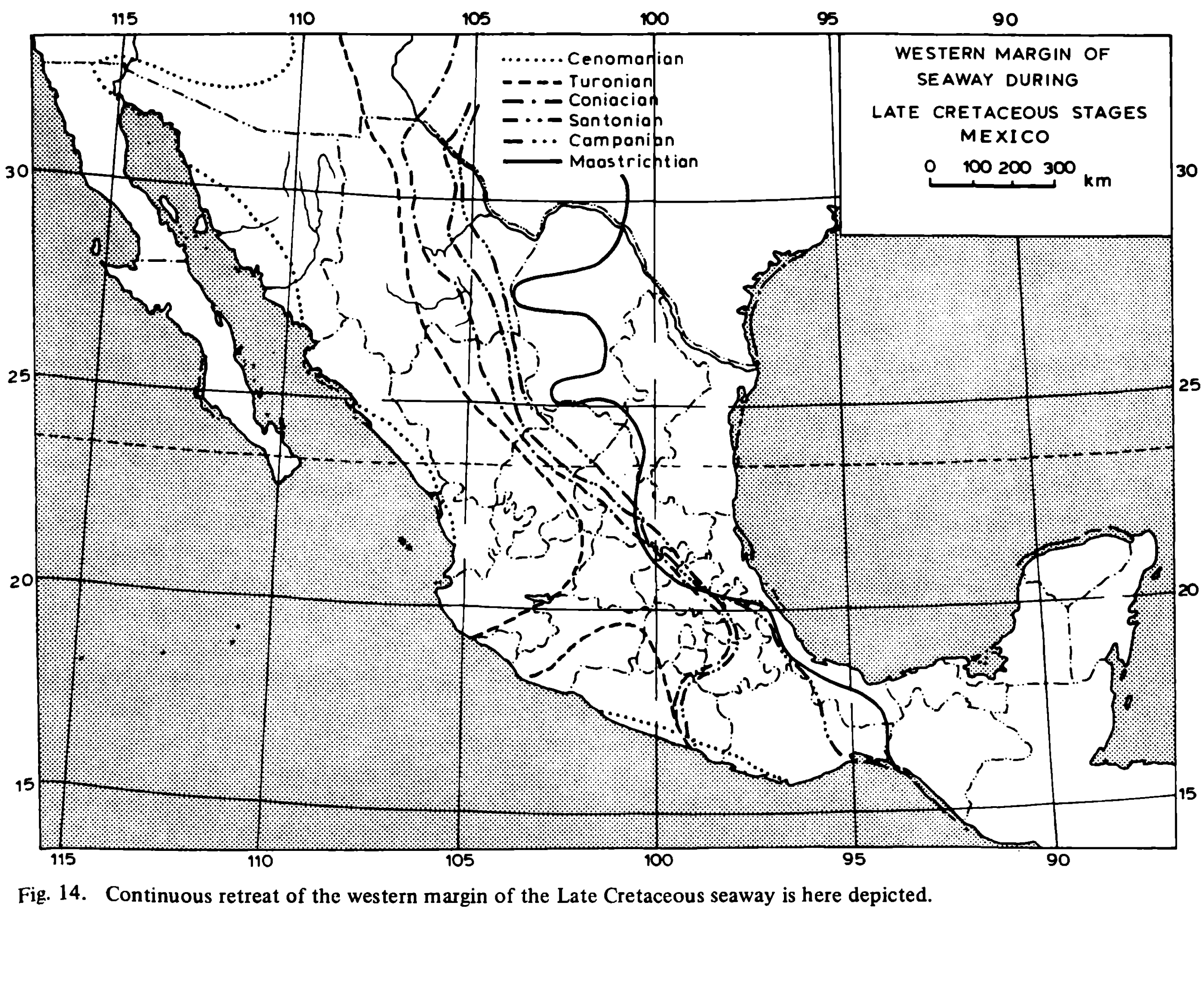

Fig. 14. Continuous retreat of the western margin of the Late Cretaceous seaway is here depicted.

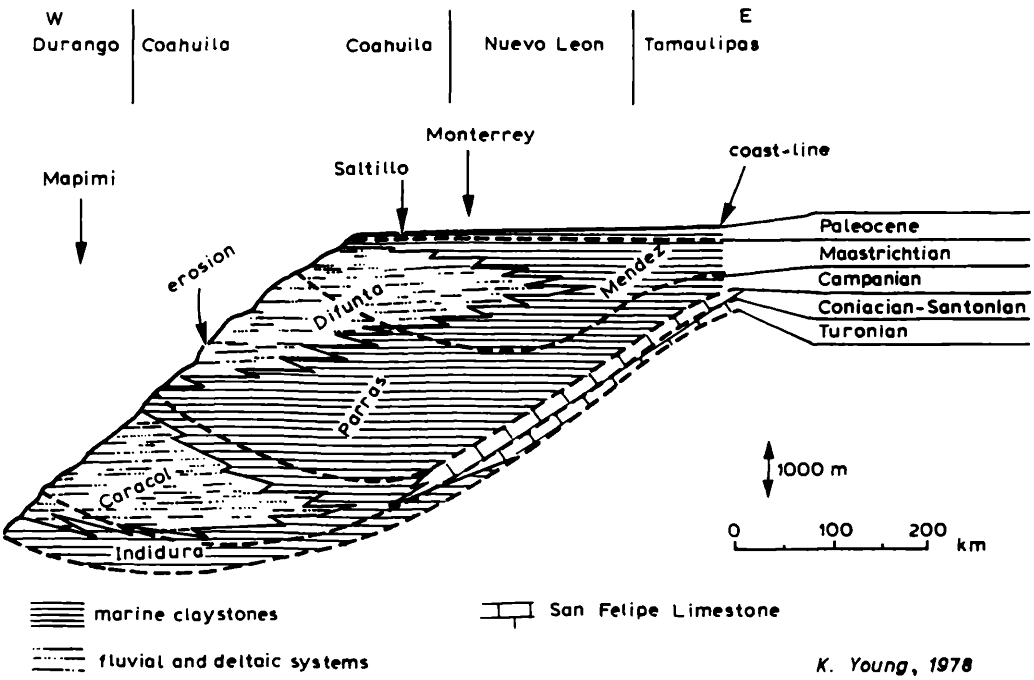

Fig. 15. Eastern migration of terrigenous depocenters through the Parras and La Popa Basins, northern Mexico.

rigenous debris from these rising mountains to the west, and these Turonian, Coniacian, and Santonian deltaic facies can be observed overlying lower Turonian *Mytiloides*-bearing strata in the Sierra de Cadeña and near Mapimí, northeastern Durango.

In northeastern Chihuahua, in the Sobaco Syncline, west of Cuchillo Parado, marine sandstones invade presumably upper Turonian strata overlying beds containing the ammonite, *Spathites*. The history of this marine regression of the Cretaceous seaway in Mexico is recorded in northeastern Chihuahua, near Ojinaga, where deltaic and fluvial systems consecutively replace younger and younger Campanian rocks to the east (Wolleben, 1965, 1966; Powell, 1967; Wilson, 1970; Weidie et al., 1972). The same story is told in the western part of the Párras Basin along the south side of the Laguna de Mayran, southern Coahuila. The upper part of the San Felipe Limestone (Santonian and lowest Campanian) of eastern Coahuila and Nuevo Leon is here represented by the Párras Shale of southwestern Coahuila, and perhaps the deltaic Caracol Formation even farther west (Fig. 15). The Méndez Formation (late Campanian of Tamaulipas) is represented to the west by the deltaic and fluvial systems of the Difunta Formation. The base of the Difunta Formation then rises from west to east, upper Campanian in southwestern Coahuila, until in Nuevo Leon it represents only the Maastrichtian. To the east, in Tamaulipas, the entire Difunta Formation (deltaic and fluvial systems) is replaced by the Méndez Shale.

To the south the more western facies (Fig. 15) have been removed by erosion, and the sequence of events is less clear, although the fluvial and deltaic systems of the Caracol Formation are recorded in northwestern Zacatecas (García-Calderón, 1976; De Cserna, 1976).

Coniacian. Coniacian rocks are of fairly wide distribution through the Caracol, Párras, and San Felipe Formations of the northeast of Mexico (Fig. 15). They extend south through Veracruz and are again widespread in the south of Mexico (Fig. 16). They are likewise present on the west side of the Miquihuana Platform as far south as Matehuala, where they occur in the San Felipe Formation in the mountains east of Sierra del Catorce. Burckhardt (1921) has described Coniacian ammonites from Zumpango del Rio, Guerrero, and Bonet (1969) considers Coniacian to be present in the Guzmantla Formation of the platform facies near Orizaba, Veracruz, and in the Necoxtla and Maltrata Formations of the offshore facies. Martínez (1972a, b) shows Coniacian to be present in a platform facies around the southern margin of the Campeche Basin, Chiapas.

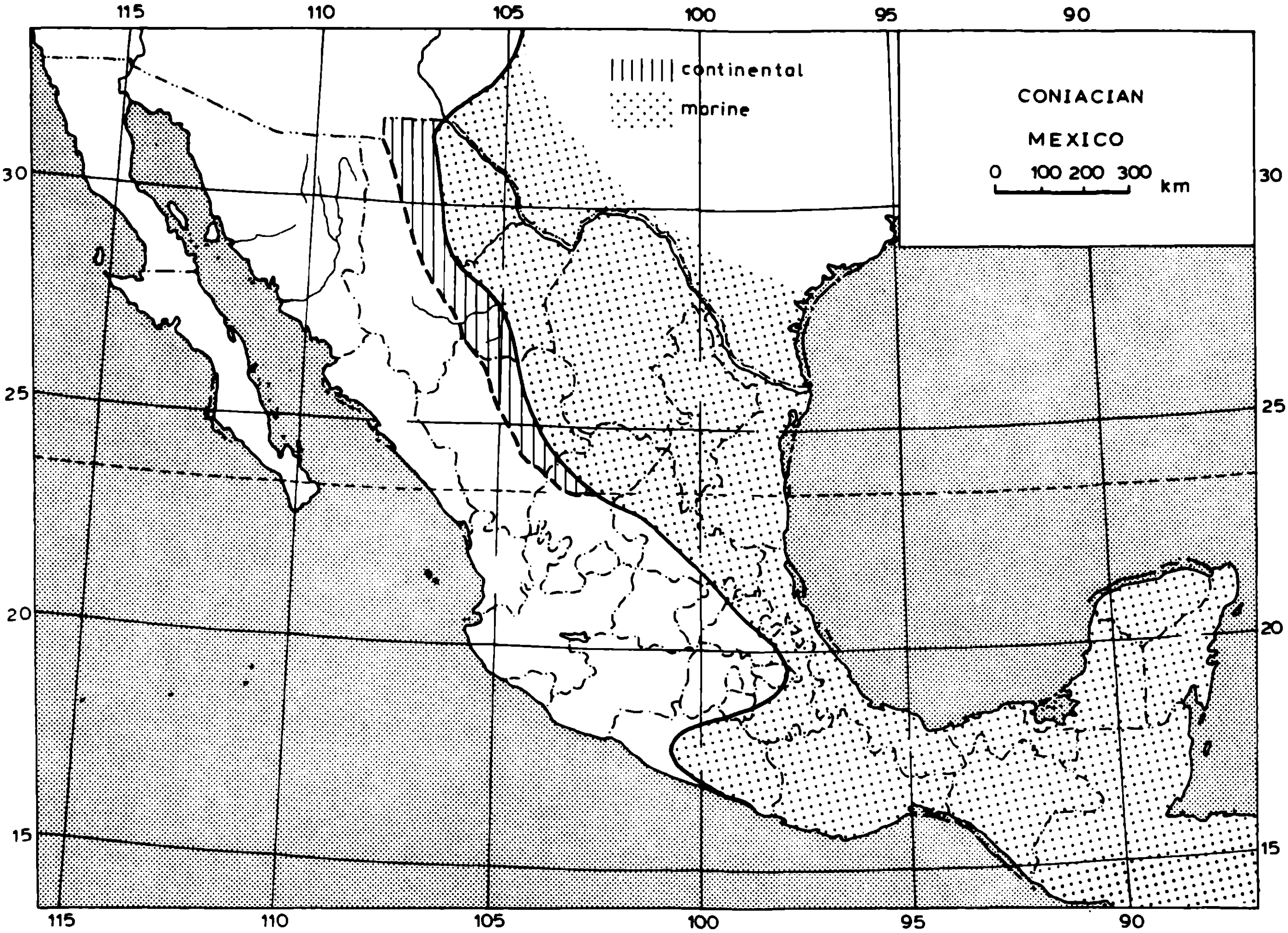

Fig. 16. Paleogeography of the Coniacian of Mexico.

Santonian. Santonian rocks have much the same distribution as Coniacian rocks (Fig. 17). In the north there are fluvial and deltaic facies in the Caracol Formation, and marine pelagic facies in the Párras Shale and San Felipe Limestone. Like the Coniacian, Santonian rocks probably occur in the San Felipe Limestone just east of Sierra del Catorce, west of Matehuala, San Luis Potosí. Santonian rocks also extend to the south on the east side of the Miquihuana Platform, where they appear to spread out over a large area of Chiapas, Oaxaca, and eastern Guerrero. Bonet (1969) considers the Santonian present in platform sections in southwestern Veracruz and adjacent Hidalgo, and Martínez (1972a) shows rocks of this age to be present in platform sections in Chiapas along the southern margin of the Campeche Embayment.

As in Colombia (Bürgl, 1956) there is a problem with the Santonian in Mexico. One of the indices for the Santonian in Colombia (Bürgl, 1956) and southern Mexico (Martínez, 1972b) is *Globotruncana fornicata* Plummer. Plummer (1931) first collected the types of this species from the Bergstrom Formation (Young, 1965), upper Campanian above the *Hoplitoplacenticeras vari* zone, at Moore and Berry's Crossing of Onion Creek, Travis County, Texas, south of Austin. McNulty (1976) records the *Globotruncana fornicata* zone from the upper part of the Austin Chalk (zones of *Submortoniceras tequesquitense* and *Delawarella delawarensis*), lower Campanian. Either *Globotruncana fornicata* Plummer is a long-ranged species that should not be used for dating, or different authors assign separate species to this taxon. A less likely possibility is that beds in Colombia and southern Mexico, considered Santonian, are really Campanian. On the other hand, Sanchez Montes de Oca (1969) indicates that the Coniacian and Santonian are both absent through much of the platform area of central Chiapas.

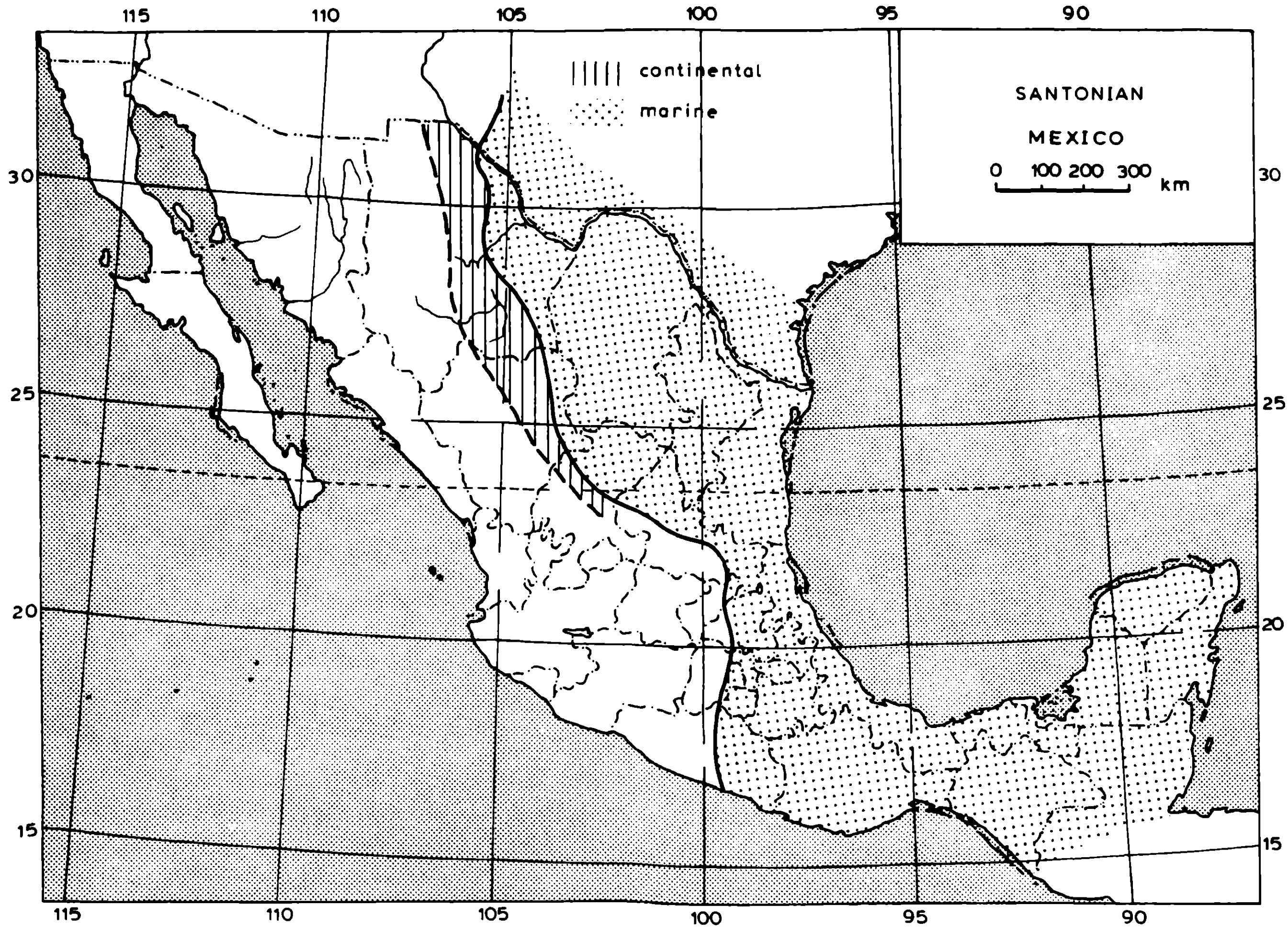

Fig. 17. Paleogeography of the Santonian of Mexico.

Campanian. Campanian rocks have much the same distribution as the Maastrichtian rocks (Fig. 18), although to the north the western margin of the seaway has not been displaced as far east (Figs. 14 and 15). There is probably Campanian in the Méndez Shale between Matehuala and Sierrra del Catorce.

A question arises as to the Maastrichtian or Campanian age of some of the deposits containing rudists. Myers (1968) interpreted the Cárdenas Formation as Maastrichtian. However, the presence of *Arctostrea aguilerae* (Böse) might indicate a Campanian age according to Sohl and Kauffman (1964), although they prefer the Maastrichtian date. Some of the earlier strata of the Cárdenas Formation in the Cárdenas area (Arroyo de la Mula at Rayon) contain a species of *Praebarrettia* closely related to *Praebarrettia sparcilirata* (Whitfield), with which species it has been identified. But the specimens of this species at Rayon contain distinct vertical grooves on the exterior of the attached valves, are more primitive, and seem to differ from those specimens of *Praebarrettia sparcilirata* from the San Luis Conglomerate in Chiapas.

The Tamazopo Limestone can be interpreted in two ways. The first interpretation is as a series of facies tracts with Tamazopo and Cárdenas being laterally equivalent (Sansores and Girard, 1969), the Tamazopo as the higher part of the bank and the Cárdenas beds as an adjacent lagoon on the west. The second interpretation considers the Tamazopo to be older than the Cárdenas (Böse, 1906). The first interpretation is aesthetically most satisfying, especially since the Tamazopo Limestone contains, generally the same fossils as the Cárdenas (Böse, 1906), except that boundstones of *Distefanella* sp. and *Biradiolites aguilerae* (Böse) are common in the Tamazopo and absent from the Cárdenas; this occurrence could be reflecting differences in depth of water.

Farther south, in the Campeche Embayment

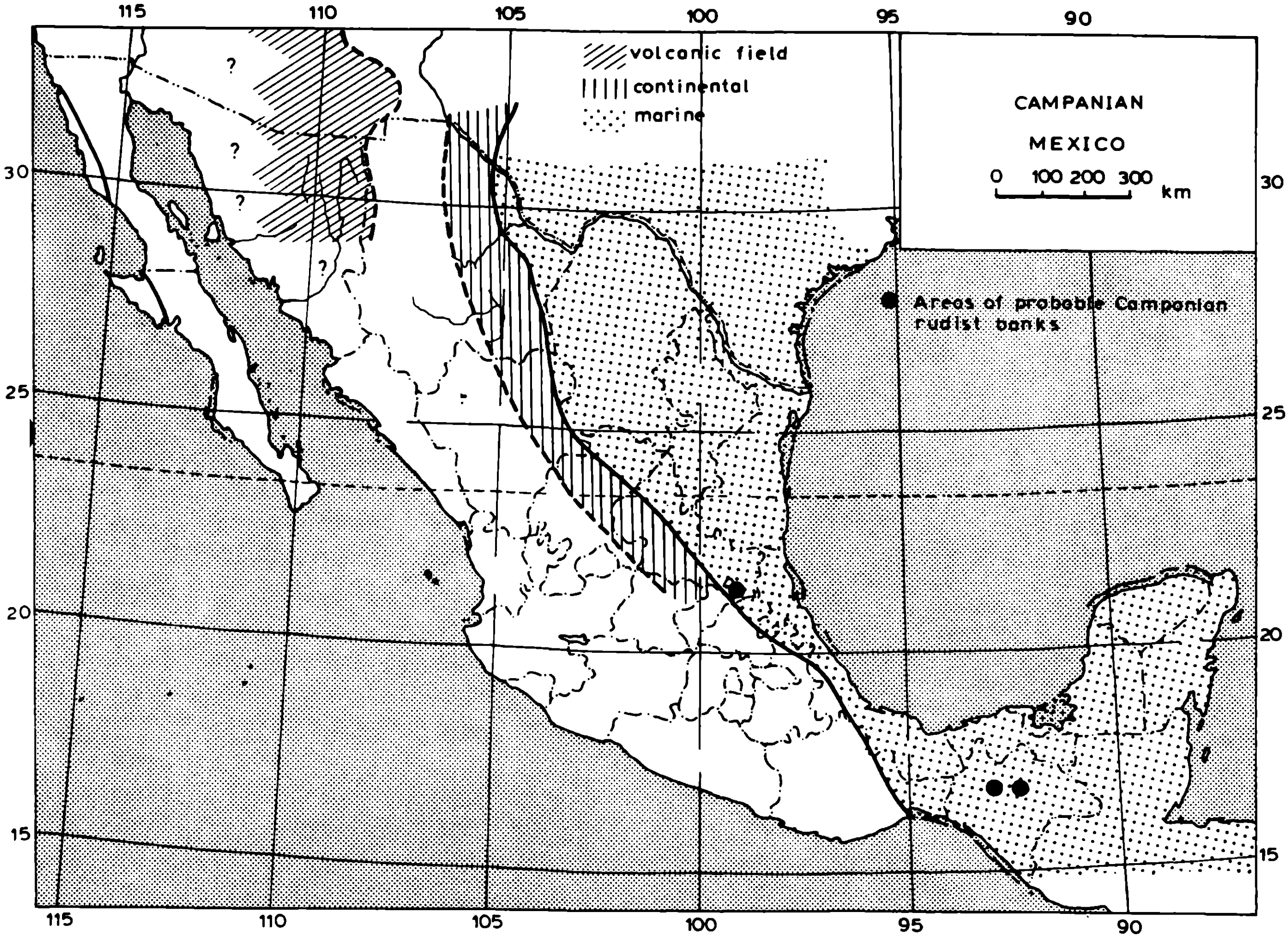

Fig. 18. Paleogeography of the Campanian of Mexico. Areas of probable rudist developments are also indicated.

Chiapas, there are strata with *Chiapasella* and *Titanosarcolites* that are undoubtedly Maastrichtian (Alencáster, 1971). Underlying these strata of the Ocozocuautla Formation (Fig. 19) are other strata of the same formation with *Praebarrettia sparcilirata* (Whitfield). The San Luis Conglomerate contains cobbles composed of *Praebarrettia sparcilirata* (Whitfield) that must have been eroded from older beds. In all, it is probable that on the platforms, at least, Campanian is thin to absent, or else it is represented in rudistaceous rocks that are now assigned to the Maastrichtian. One does gather the impression that basinal facies dated as Campanian on foraminifers are time-equivalent to Maastrichtian rocks on platforms dated by rudists.

Maastrichtian. From Rayon, southern San Luis Potosí, south of Cárdenas, to the north past Cuidad de Mais, El Doctór and Tula, large down-faulted areas contain Maastrichtian (Cárdenas Formation) terrigenous deposits that in some areas are sufficiently carbonate to represent such a low rate of deposition that such rudists as *Tampsia, Durania, Hippurites, Coralliochama, Distefanella, Bournonia,* and *Sauvagesia*, are abundant (Myers, 1968). Where the Rio Verde passes through the eastern limestone ranges of the Sierra Madre Oriental late Campanian or Maastrichtian reefoid rocks contain the genera *Praebarrettia, Biradiolites, Distefanella, Thyrastylon, Durania, Sauvagesia, Tampsia*, and many corals and large bryozoans and algae. These fossils occur in the younger rocks at Tamazopo (Böse, 1906), constituting the type locality of the Tamazopo Limestone, where it rests disconformably on a karstic surface developed on late Albian or early Cenomanian reefoid rocks (El Abra Limestone). Sansores and Girard (1969) have interpreted the Tamazopo Limestone as a Maastrichtian reefoid facies along the eastern margin of the Miquihuana Platform,

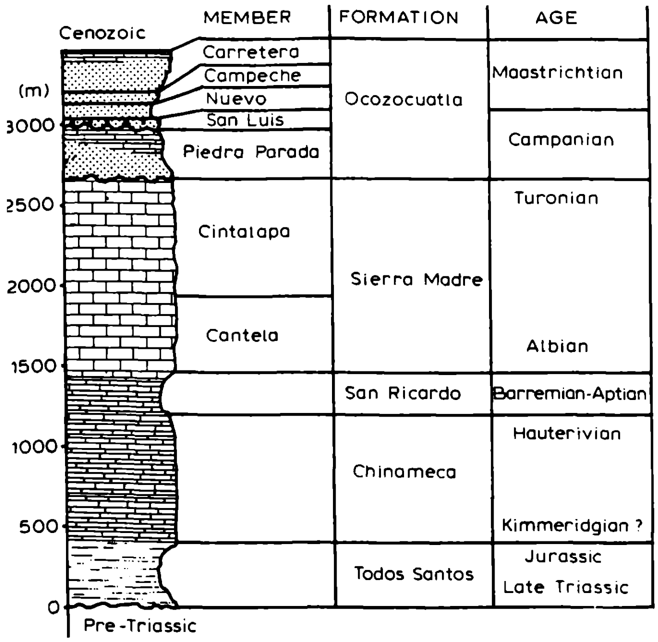

Fig. 19. Composite section from Central Chiapas along the platform south of the Campeche Basin. The problem of the presence of Coniacian and Santonian rocks in this area is discussed in the text.

with Méndez deposited to the east and Cárdenas Formation on the sagging central part of the platform to the west.

Further south in Pueblo, southern Veracruz, Chiapas, and Tabasco, Maastrichtian rocks contain many of the above rudist genera plus *Chiapasella* and *Titanosarcolites* (Chubb, 1959; Aléncaster, 1971). In the western part of this area the Maastrichtian rocks overlie red conglomerates (the San Luis Conglomerate).

The Maastrichtian rocks are mostly terrigenous, except for the grainstones and rudist banks of the Tamazopo and Ocozocuautla Formations and the larger limestone banks in the Difunta Formation of the La Popa Basin north of Monterrey, Nuevo Leon (Fig. 20) (McBride et al., 1974), which are composed largely of red algae, but contain species of *Coralliochama*, hippuritids, *Durania*, and caprinids.

Cretaceous facies: rudist

Except for areas of Pueblo, where there are Barremian monopleurids, rudistaceous deposits in most areas of Mexico appear to have developed locally in the lowest Aptian. There seems to be no such thing as a continuous rudistid reef, except for some migrating biostromes, particularly in Texas. Most rudistid developments represent patches of rudistid growth in the proper environment along platform or shelf edges. Stabler and Marquez (1978) interpret early rudistaceous deposits in the La Mula Basin as originating on highs in the middle of the Basin. They consider the highs as mud anticlines, but the underlying mud had not received much load at that time. More likely the great wedges of Cretaceous terrigenous sediments debouching off the Coahuila Platform were overloading the Jurassic evaporites, producing evaporite-anticlines at the toes of these terrigenous wedges. The anticlines resulted in shallow water over their crests, producing small, shallow water platforms (Elliott, 1978), ideal environments for rudistid growth. There is evidence that salt was flowing throughout the Cretaceous in the subsurface of the La Mula and La Popa Basins. Debris flows from such salt-anticlines (highs) occur in deposits that now reveal only the direction of the source, the anticlines probably having collapsed after salt withdrawal; they were buried by younger terrigenous wedges.

In northern and eastern Mexico most of the rudistid reefs are distributed around and over the Coahuila and Miquihuana Platforms and the Faja de Oro during the Albian and early Cenomanian, and around the Miquihuana Platform during the later Cretaceous. In southern Mexico they occur on platforms south and west of the Campeche Embayment.

In the Sierra Madre del Sur, from Jalisco through Michoacan into Guerrero and Morelos, Albian through Turonian reefoid limestones or bank deposits are on narrow, submarine, topographic highs between narrow basins that contain volcaniclastic and/or fine-grained terrigenous sediments. But the rudistaceous reefs in the western Sierra Madre del Sur are only part of the story. The mountains east of Tecopan, on the shore of Colima, which constitute the coast ranges in this area, are composed of gypsum; the gypsum is in fault contact with fine-grained terrigenous rocks and with thinly bedded, cyclic limestone of about 16 cycles per meter. All of these rocks were considered Cenomanian by Palmer (1928b), but that age has not been verified, and similar deposits represent different ages of the Middle Cretaceous in different basins. They probably represent basinal deposits in long grabens separated by horsts upon which the rudistaceous banks developed simultaneously, and collectively probably represent all of the time from Middle Albian through the Turonian, according to the determina-

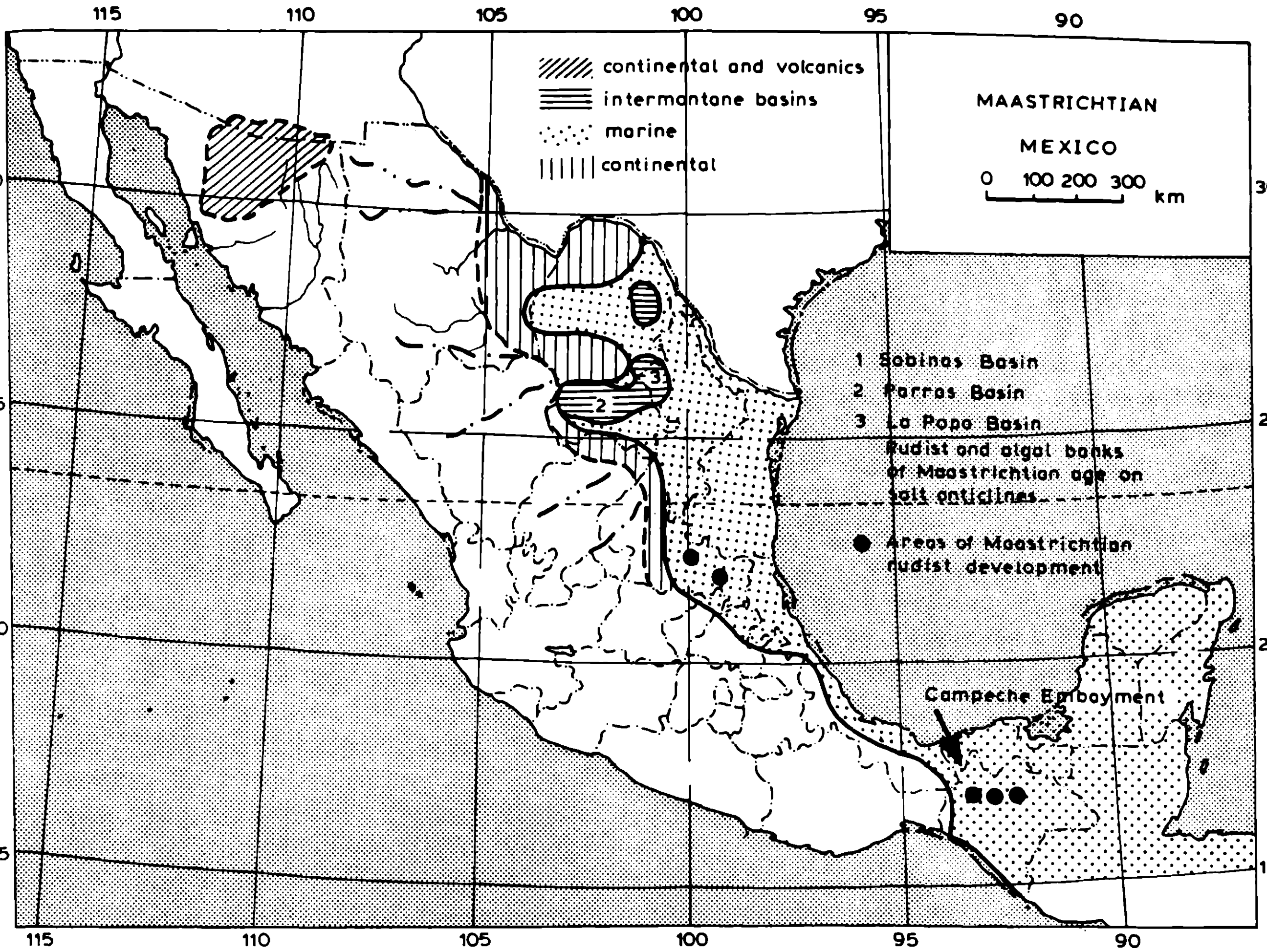

Fig. 20. Paleogeography of the Maastrichtian of Mexico. Areas of rudist development and intermontane basins are also indicated.

tions of the ranges of genera of rudists (Chubb, 1971; Coogan, 1973; 1978). Middle Cretaceous limestones and volcanic rocks continue to the eastward in the Sierra Madre del Sur into Guerrero and Morelos (Bonet, 1971).

Cretaceous facies: rocks of ill-defined age, the Pacific Slope and the Sierra Madre del Sur

Those isolated outcrops of Cretaceous rocks along the Pacific slopes of Mexico, north of Cabo Corrientes, Jalisco, are labeled Lower Cretaceous, Upper Cretaceous, or Cretaceous undifferentiated (Córdoba et al., 1976). Most of these appear to be late Albian, early Cenomanian, or both, and are here so indicated on Fig. 15. The Albian and Cenomanian are shown on the same map, largely because there is little difference in the maximum extent of seaways in Mexico during these two stages, but also because differentiation of these stages in these western states is not yet possible. Most of the Albian deposits are limestone and marl, but shales begin to appear in east-central Chihuahua, and west of Cuidad Chihuahua a large wedge of shale replaces middle Albian limestone (Guerrero, 1969), even though equivalent beds at Arivechi, northeastern Sonora, are calcareous mudstones. Along the Pacific slope, and even as far east as Durango, in the Sierra de Cadeña, the late Albian and early Cenomanian deposits are mostly thin-bedded limestone, in beds of from 12 to 20 cycles per meter, usually resting on Albian, rudistaceous, reefoid rocks. They are usually mudstones, although some graded beds of siltstone to mudstone may be observed.

Along the Pacific slope and eastward through much of the Sierra Madre del Sur Middle Cretaceous outcrops occur in four ways: (1) as horsts in Cenozoic volcanics; (2) as grabens in metamorphics older than Cretaceous; (3) as ranges of mountains that are probably horsts exposed through Cenozoic volcaniclastics; and (4) as horsts that do not represent mountains but are enclosed by Cenozoic volcanic rocks.

The ages of some of these rocks are not completely settled. Palmer (1928a,b) has considered those of Michoacan (Coalcoman), Colima (Paso del Rio and the mountains east of Tecopan), and Jalisco (Soyatlan de Adentro) as Cenomanian. Redescription of some of the rudists (Chubb, 1971; Coogan, 1973, 1978) indicates that the rocks at Coalcoman and Soyatlan de Adentro are probably Albian, although the upper ranges of such rudist genera as *Caprinuloidea, Texicaprina*, and *Kimbleia* are not well established. Certainly, the latter two genera seem to range into the Cenomanian. In addition, the fossiliferous strata at Soyatlan de Adentro are downslope debris flows intermingled with volcaniclastic strata.

Turonian deposits in this area, such as those east of Barra de Navidad, Colima, and at Huescalapa, Jalisco, contain *Bayleoidea clivei* Palmer, *Radiolites* sp. cf. *mulleriedi* Bauman, and *Discocyclina* sp., plus caprinids.

VOLCANISM

It is not usually possible to refer to volcanism within the time scale used for the paleogeographic maps of this paper. The Triassic and Jurassic volcanism for southern Arizona has been documented (Hayes, 1970a; Cooper, 1970). Undoubtedly some of these volcanic fields extend from the Sierrita and other mountains of southernmost Arizona southward into northern Sonora (Salas, 1970). Triassic volcanic rocks of western Mexico extend into western Zacatecas (Belcher, 1978), where they make up as much as a third of the total Triassic section. Their eastern attenuation extends to the east into southeastern Coahuila.

The exact age of the "Rocas Verdes", green spilitic volcanics that overlie the Upper Triassic at Zacatecas, has been debated, in that rocks of similar lithology and stratigraphic position in other areas, except that the underlying Upper Triassic is absent, have been interpreted as older than Jurassic, probably because "Rocas Verdes" at Placer de Guadalupae, northeastern Chihuahua, contain interlayered rhyolites of Permian age (De Cserna et al., 1970). These differences in interpretation still need to be resolved.

No one will deny that during the Jurassic western Mexico suffered extensive igneous activity. But, the extent and effect of such activity, above and beyond "local" regional metamorphism, has not been defined.

Cretaceous igneous events are much more widespread than Triassic or Jurassic events, but even they are subdued by the overwhelming cover of Cenozoic igneous rocks.

There is extensive igneous activity during the Late Cretaceous and into the Cenozoic through southern Sonora and Sinaloa and Nyarit (McDowell and Clabaugh, 1978). As Nyarit joins Jalisco the Sierra Madre Occidental joins the Sierra Madre del Sur. But in the Sierra Madre del Sur (one of the major volcanic transforms of Middle America) the Neogene, including the Quaternary, volcanic system has dampened, and even concealed major Cretaceous igneous and metamorphic events.

At Paso del Rio, Colima, the single reefoid cycle with *Immanitas*, a unique rudistid, is intruded by diorite of unknown origin, as are the conformably overlying fine-grained volcaniclastics, which are supposedly Cenomanian (Palmer, 1928b). At Coalcoman, Michoacan, and Soyatlan de Adentro, Jalisco, particularly the latter, rudists are preserved in debris flows down Middle Cretaceous submarine paleoslopes, interbedded with volcaniclastics, very similar to the rubble beds with Maastrichtian rudists that have rolled down an ancient paleoslope north of Hacienda Flor de Alba, Puerto Rico.

At Huescalapa, near Cuidad Guzman, Jalisco, Turonian cycles in carbonate rocks with *Bayleoidea clivi* Palmer, *Radiolites*, and caprinids, grade upward into volcaniclastics (Palmer, 1928b). Eastward from Michoacan into Guerrero and Morelos there are volcaniclastic sediments of Middle Cretaceous age, and areas in which Middle Cretaceous rocks (zone of *Plesioturrilites brazoensis*), basal early Cenomanian (Palmer, 1928a) have been metamorphosed. This is the same faunal zone as that of the silicified fauna described by Böse (1923b) from the middle of the Cuesta del Cura formation of northern Zacatecas; it also occurs at Sierra del Catorce. The unique silicification of small ammonites may be associated with silica in the rock resulting from the deposition of volcaniclastic rocks. Siliceous sponge spicules are also abundant in the fine-grained Middle Cretaceous rocks of the states of Colima and Jalisco.

Much more is to be learned of metamorphism and igneous activity of the Mesozoic in western and southern Mexico.

TECTONISM

Mesozoic tectonism of Mexico, so far as known, is generally apparent in the preceding discussion because it is reflected in all of the sedimentary rocks. The Coahuila Platform is essentially a massif, at least the eastern edge of which is held up in part by Late Triassic granites (Denison, 1970; King et al., 1944).

Eastern Mexico, including the Miquihuana Platform, as best interpreted at present on insufficient evidence, probably is associated with an ancient, later aborted, Triassic spreading system (Belcher, 1978).

The western coast, and adjacent areas, is associated with a subducting margin of the Pacific Ocean, but much of the entire region is covered by Cenozoic volcanics, and the exposures of Mesozoic rocks are few.

Central Mexico and north-central Mexico, as far south as southern San Luis Potosí, at least, is associated with a Paleozoic and Precambrian terrane that has resulted in greater tectonic stability (De Cserna, 1969a, 1970).

Salt tectonics are a field of their own, and in part produce the ridge and valley province (Humphrey, 1956) of the northeast, and they are especially developed through part of the Sierra Madre Oriental (Heim, 1940; De Cserna, 1956). The northeastern part of the Chihuahua Trough demonstrates unusual salt tectonics (Haenggi and Gries, 1970; Gries and Haenggi, 1970).

The Sierra Madre del Sur and the Isthmus of Tehuantepec are associated with and owe their peculiar configurations to their nearness to the northern margin of the Caribbean Plate. From the Sierra Madre del Sur to the south there are dominant, Mesozoic and Cenozoic, transforms that need further study.

Perhaps resulting from the more rapid movement of the American Plate to the west during the Late Cretaceous, the Laramide Orogeny began to affect rocks in the west of Mexico earlier than in the east. Thus the base of preorogenic terrigenous rocks occurs in younger and younger rocks to the east (De Cserna, 1970), rising from the late Turonian in the west into the Maastrichtian to the east.

SUMMARY

To summarize this paper, which in itself is only a summary, requires emphasizing only the briefest highlights. The Mesozoic history of eastern Mexico is dominated by a Triassic spreading system, subsequently aborted, but the tectonics of which influence deposition into the Cenozoic.

The Pacific regions of Mexico are dominated by geologic events associated with a subducting continental margin; in the particular margin in Mexico younger and younger volcanism tends to conceal earlier geologic events.

The Central Plateau area of northern Mexico, including the altiplano to at least as far south as northeastern Jalisco and southern San Luis Potosí, is made more stable by an underlying Paleozoic terrane that was largely unaffected by either subduction to the west or rifting to the east.

The Siera Madre del Sur is unique, with its interlayering of volcaniclastics and marine sedimentary rocks, in some areas dating at least from the Aptian. The thousands of meters of Middle and Late Cretaceous volcaniclastics testify to the tremendous volcanic energies released here in the Mesozoic, a volcanism that is yet continuing.

The accompanying paleogeographic maps, as imperfect as they are, tell a story of intermittent but general transgression from the Middle Jurassic to the middle of the Cretaceous, followed by continual regression to the end of the Cretaceous as a result of Laramide orogenies and progradation of the deltaic and fluvial systems from west to east across Mexico.

In western Mexico volcaniclastic rocks are known from the Triassic to the Pleistocene, and through the Mesozoic represent increasing activity from Triassic to Cretaceous. In the Sierra Madre del Sur Cretaceous volcaniclastic rocks are several thousands of meters thick. Mesozoic intrusives include the late Triassic granites along the eastern margin of the Coahuila Peninsula, and diorite and other intrusives through the Pacific states of Sinaloa, Nyarit, Jalisco, and Colima.

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