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THE STRUCTURAL EVOLUTION OF THE GOLDEN LANE, TAMPICO EMBAYMENT, MEXICO

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The Golden Lane oil fields of Mexico will always hold a place of prominence in the annals of petroleum geology. The most prolific oil-well ever drilled, Cerro Azul *No. 4, was one of a string of wildcats which defined a Cretaceous carbonate ridge that lay buried below gently-dipping Neogene clastics on the Tampico coastal plain. Continued drilling showed that the buried ridge had an arcuate shape, and this led to the interpretation that the feature was a Lower Cretaceous reef. When the* Poza Rica *"giant" was discovered in detrital Cretaceous limestones west of the ridge, these were naturally considered to be forereef talus. Later drilling offshore discovered another string of Cretaceous carbonate traps which joined the onshore fields to complete the circlet that became renowned as the "Golden Lane atoll."*

An abundance of rudists in Cretaceous reservoirs of the Golden Lane and Poza Rica *gave rise to the concept of the rudist reef build-up. A presumed analogue for the rudist reef of the Golden Lane was discovered in Lower Cretaceous rudistid limestones exposed at Sierra El Abra, NW of the oil fields. The foregoing interpretation has become entrenched in geological literature, even though an integrated structural-stratigraphic synthesis of the Golden Lane is lacking*

Time-stratigraphic control of Cretaceous formations in the Tampico embayment is complicated by scarcity of documented marker fossils, and confused by the common occurrence of reworked detritus. It is assumed herein that Cretaceous volcanicity in the Tampico embayment, as in the Gulf of Mexico generally, commenced in the Late Cenomanian. From this, it is concluded that much of the Golden Lane and Poza Rica *reservoir sequences in which bentonite layers occur are of Late Cretaceous age. The El Abra outcrops, on the other hand, are undoubtedly Early Cretaceous. Structural analyses show that the Golden Lane area has an active and complex structural history. Strong faulting along NE-SW trends was active in Late Cretaceous time, giving rise to syntectonic débris flows. At the same time, a major positive feature developed to the east in the Gulf of Mexico.*

By Middle Eocene time, the Gulf of Mexico positive was stripped-down to metaphoric basement and subsequently collapsed as regional extension sundered the basement and allowed the injection of oceanic crust. A salt basin formed during the Oligocene eustatic low-stand. Cretaceous carbonates of the Golden Lane were incorporated in a westward-plunging synform in pre-Oligocene time, but thereafter were rotated by regional downwarping into the Gulf of Mexico. In Holocene time, the synform was inverted, and these latest stresses were accompanied by injection of numerous dykes and plugs that cut the Golden Lane.

From this structural and stratigraphic synthesis, it is concluded that the Golden Lane anomaly is the product of a complex sequence of post-Lower Cretaceous structural events. It is bounded on the west by a buried Middle Eocene fault, and on the east by a Neogene growth fault, and is not a Lower Cretaceous carbonate build-up.

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INTRODUCTION

The geology of the Tampico embayment, and the Golden Lane within it, is important not only because of the part that it has played in the development of concepts relating to petroleum entrapment in carbonate rocks, but also because of its bearing on the much larger problem of the geological evolution of the Gulf of Mexico Basin. This paper investigates both the petroleum geological and regional geological concepts that command popular support today. The conclusions reached are controversial (Wilson, 1984).

The Golden Lane oilfields are situated in the Tampico embayment on the east coast of Mexico (Fig. 1). The discovery well for the Golden Lane, *San Diego de la Mar* No. 1. was drilled in 1908 on a site selected because of its proximity to oil seepages (Viniegra. 1970. p. 309). *San Diego de la Mar* is situated at the northern end of what became known as the Old Golden Lane.

Follow-up drilling, guided by surface seepages and “trendology”, traced the Old Golden Lane southwards with a sequence of spectacular discoveries; for example, *Cerro Azul* No. 4, drilled in 1916, which blew wild with an estimated daily production of 260,000 brls (Viniegra, 1970, p. 311).

These early wells delineated a buried ridge of cavernous, fractured limestones, shot-through with volcanic dykes and plugs. The limestones lie unconformably below 2,000 ft (600 m) of Oligocene and Miocene clastics that dip gently toward the Gulf of Mexico, giving no clue to the buried structure. The buried Cretaceous ridge has a structural elevation of as much as 3,000 ft (914 m), and is asymmetrical with a steep western flank dipping up to 35° and a gentle eastern flank.

The Old Golden Lane trend was at first interpreted as a paleo-topographic or paleo-structural feature (Muir, 1936, p. 205). But as drilling proceeded southwards, and the buried ridge was seen to have an arcuate shape, an alternative interpretation emerged in 1923 which postulated a huge Middle Cretaceous organic reef (Owen 1975, p. 403). The reef concept quickly gained favour and was reinforced by subsequent drilling results which uncovered the fore-reef Tamabra apron on the west, and evaporites on the east, near Tuxpan, that were interpreted as lagoonal or back-reef deposits. Continued drilling revealed the New Golden Lane fields extending southwards to the coast, and then the Marine Golden Lane offshore which joined the Old and New Golden Lanes to form the now-renowned Golden Lane “atoll” (Fig. 2).

At the south end of Sierra El Abras, 85 miles (135 km) NW of the Golden Lane, Cretaceous limestones with an abundant rudist fauna dated as Middle Albian—Early Cenomanian are exposed along the Tampico to Valles railway cutting. These El Abra limestones were correlated with the limestones of the Golden Lane “atoll”, and both were interpreted as Albian-Cenomanian organic build-ups in which the rudistid molluscan fauna was envisaged as the principal constructional element. Thus was born the idea of the rudist reef build-up which has since been utilized as a conceptual model for oil exploration in Cretaceous carbonates around the world.

Although for the past 50 years there has been some controversy amongst geologists regarding the degree, if any, of structural control of the Golden Lane anomaly, the vast majority have advocated organic construction as the logical explanation for this huge sub-surface feature (Muir 1936, Bonet 1952, Viniegra 1970 and 1981, Enos 1980, Lopez Ramos 1982, and many others).

The tacit acceptance of the build-up concept is rather surprising if we consider Viniegra’s comments (1970, p. 317):

> “Little or nothing is known about the genesis of the Golden Lane reef, partly because information is scarce or incomplete, but mainly because no detailed analytic studies have been made to summarize the information from all of the wells, most of which have penetrated only a few meters into the top of the reef structures,”

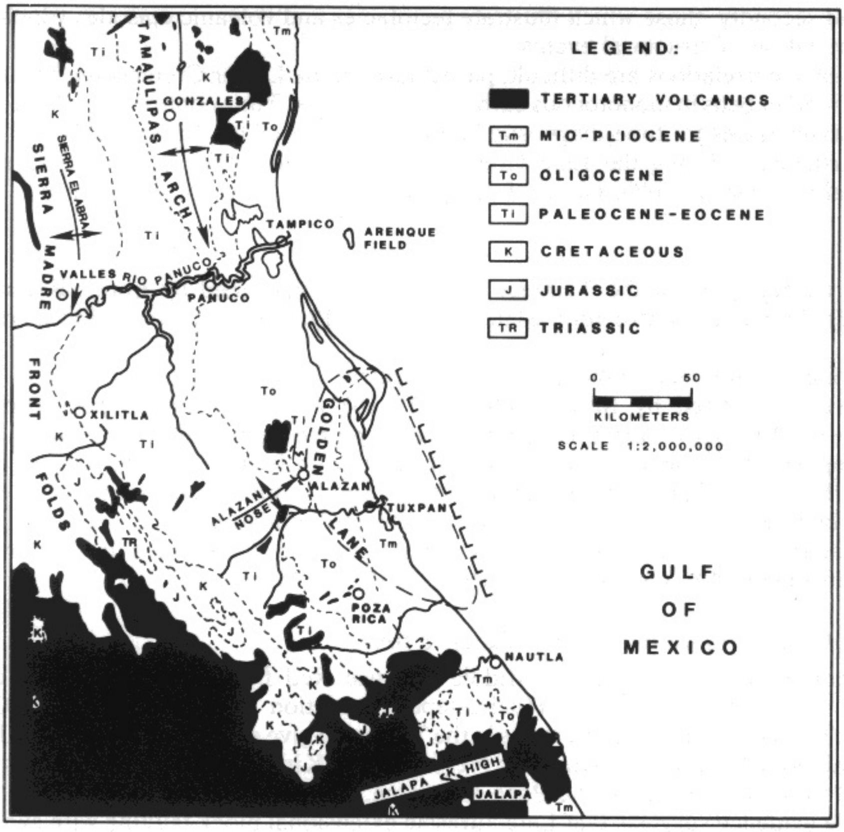


Fig. 1. Geological map of the Tampico Embayment, showing the sub-surface position of the Golden Lane fields.

and *(ibid p. 319):*

> "To date there has been no complete geologic analysis of the genesis, tectonic evolution, and geomorphology of the Golden Lane atoll."

Published interpretations of the Golden Lane, its fringing facies at Poza Rica and its supposed analogue in the Sierra El Abra have been heavily biased toward carbonate sedimentology and diagenesis (Bonet, 1952; Barnetche and Illing, 1956; Coogan *et al.,* 1972; Aguayo, 1975; Enos, 1977; Minero *et al.,* 1984). The part that successive regional tectonic disturbances or eustatic changes may have played in fashioning the Golden Lane and controlling its attendant sedimentary facies has been little discussed.

In this paper, an attempt is made to unravel the structural history of the Golden Lane and its surroundings, and to integrate this with the sequence of sedimentary facies recorded from wells and outcrops. Of crucial importance is time-stratigraphic control, without which the correct sequence of events cannot be discerned.

STRATIGRAPHY

Between the 1920's and the present, there have been many publications on the stratigraphy of the Tampico embayment. This paper relies substantially upon the published information. Emphasis is laid upon two classes of data; first, those which provide precise time-stratigraphic control; and secondly, those which illustrate tectofacies and volcanic episodes which together help interpretation of structural events.

Stratigraphic correlations are difficult, particularly in the Lower Cretaceous, because of the absence of marker beds in monotonous carbonate sequences. Time control is weakened because of unfavourable facies for time-diagnostic fauna or is confused by the occurrence of reworked faunas, particularly during the Late Cretaceous (Pessagno, 1969, p. 46). Any reports of unequivocal time stratigraphic marker fossils are, therefore, of great importance.

Jurassic

Jurassic stratigraphy for the Tampico embayment is described by Lopez Ramos (1982, p. 347-352). Ammonite control for the late Tithonian of Poza Rica is provided by Cantu Chapa (1982).

Kimmeridgian-Tithonian carbonates in the Panuco-Topila oilfield area, west of Tampico (Fig. l) were described by Muir (1936, p. 15-16) with ammonite control provided by Burckhardt (1930), but no ammonites have been reported from the Golden Lane.

The composite Jurassic succession that can be built up from descriptions given by Lopez Ramos (1982) spans Callovian to Tithonian time, and comprises several hundred meters of mainly carbonate rocks, with dark lime-mudstones predominating.

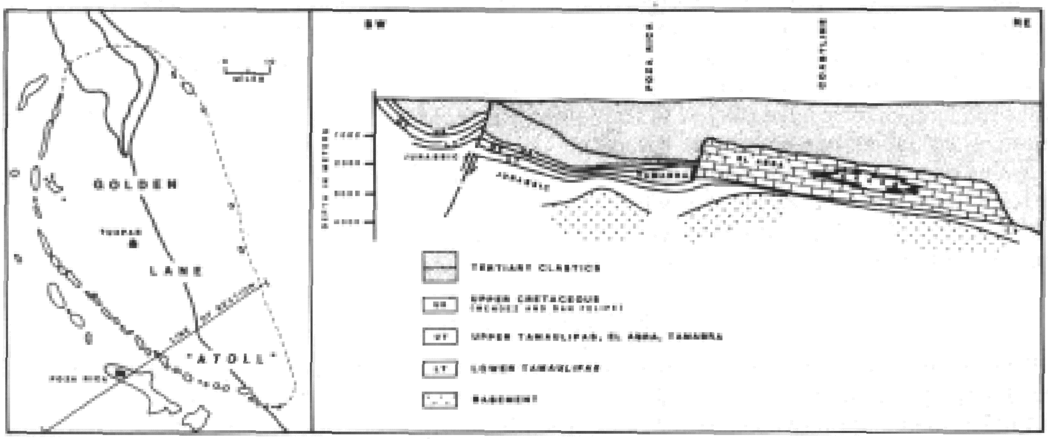
In the Panuco area, 65 m of Tithonian-Kimmeridgian carbonates were drilled and volcanic rock was encountered in the Tithonian (Muir, 1936, p. 16).

Evidence of structural activity during Jurassic time

The unconformity between the ? Middle Jurassic Red Beds (Cahuasas) and overlying limestones and evaporites of the Huehuetepec formation is indicative of pre-Callovian movement. Bentonites and eruptive rocks in the Tithonian give evidence of extensional stresses. Extensional block-faulting attributable to Nevadan (late Kimmerian) orogenic pulses has been interpreted to be present below the Poza Rica area.

Available evidence suggests that Late-Jurassic extensional block faulting with synchronous volcanic activity affected the Tampico embayment. These basement block movements were contemporaneous with similar marginal faulting along the Northern Gulf Coast. The fracturing probably was controlled by ancestral weaknesses in pre-Jurassic heterogeneous basement (Lopez Ramos 1981, p. 303, Figs. 3-1).

Fig. 2. Structural cross-section over the southern portion of the Tampico embayment, illustrating the generally-accepted interpretation of the Golden Lane atoll with central lagoonal evaporites and Tamabra forereef débris (redrawn after Enos, 1985, Fig. 28-2).



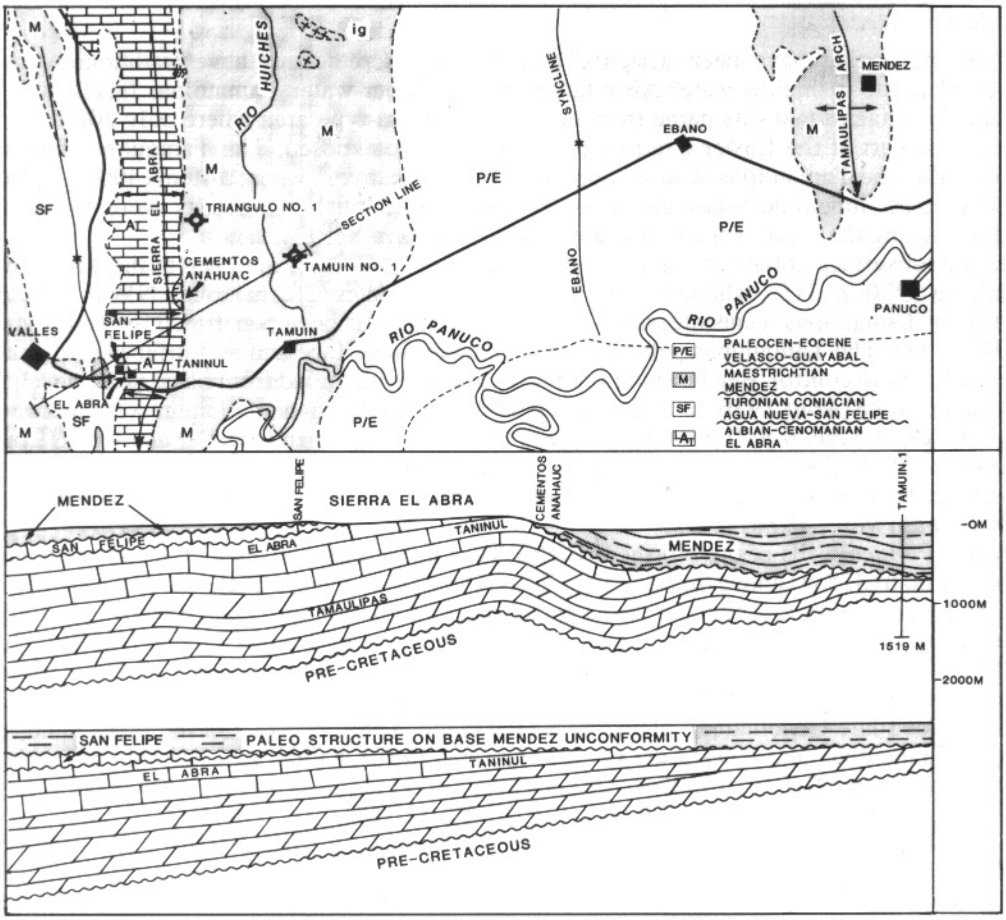


Fig. 3. Structural cross-section over the El Abra anticline between San Felipe and Cementos Anahuac, with palaeostructural restoration on base-Mendez unconformity.

Cretaceous

Cretaceous stratigraphy in the Tampico embayment is very complex, and as a consequence, interpretations are controversial. Conventional wisdom envisages the various facies changes as resulting from the interplay of organic carbonate build-ups, reefs or shelf edges and the penecontemporaneous destruction of these sedimentological edifices by storm-wave erosion and associated non-tectonic phenomena.

The part played by structural forces in the moulding of the Cretaceous paleoenvironment has received very little attention in the literature. Proper interpretation of Cretaceous time stratigraphy, which is crucial to an understanding of the Golden Lane area, has been handicapped by continued use of the tripartite subdivision, inherited from early European explorers in Mexico (Bose 1927, p. 14) instead of the standard subdivision into Early and Late Cretaceous. In this analysis, the dual Cretaceous subdivision is used with the worldwide mid-Cenomanian break as the dividing point (Tarling and Hart 1973, McFarlan 1977, p. 6). The importance of bentonite horizons is stressed. These are useful not only as time indicators, but also as evidence of volcanic activity associated with regional tectonic unrest.

Lower Cretaceous

Carbonates that have been assigned to the Lower Cretaceous have traditionally been subdivided into a shallow-water Abra facies, and a deeper-water Tamaulipas facies.

The Abra facies takes its name from the Sierra el Abra-type area where only 200 ft of the uppermost part of the Lower Cretaceous carbonates are exposed. The Tamaulipas facies is named after the Tamaulipas-type section in La Borrega canyon, where 149 m (490 ft) of thin-bedded, dark lime-mudstones and massively-bedded, whitish limestones were measured, without seeing the base of the Cretaceous (Muir 1936, p. 25, Fig. 6).

In the subsurface of the Golden Lane area, 5,108 ft (1,467 m) is assigned to the Abra facies (Viniegra 1970, p. 315), whereas in the Panuco area 50 miles (80 km) to the NW a complete section of Tamaulipas facies measuring 1,700 ft (518 m) has been penetrated by wells (Muir, 1936, p. 33). The Tamaulipas pelagic limestone facies in surface and subsurface sections has some ammonite control. Berriasian ammonites have been identified from basal beds in wells in the Panuco area (Muir 1936, p. 33), and Berriasian-to-Hauterivian ammonites were recovered from the *Bejuco No. 6* well, midway between the Golden Lane and the *Panuco* wells (Lopez Ramos, p. 353). The Tamaulipas formation is subdivided into Lower and Upper members by the Otates horizon which yielded Lower Albian ammonites in the type surface section in Sierra Tamaulipas (Muir, 1936, p. 27).

In the *Panuco* wells of the Northern Fields, the Otates horizon was tentatively recognized about 1,100ft (335 m) above the base of the Tamaulipas, thus giving a thickness of 600ft (183 m) for the Upper member. The top of the Tamaulipas formation in the Panuco wells is distinctly marked by bright-green, tufaceous beds of the Turonian basal Agua Nueva (Baker, 1928, p. 406). The precise age of the Upper Tamaulipas is in question because, in the Perigrina canyon section NW of Victoria, both the uppermost Tamaulipas and the overlying Cuesta del Cura yielded late Cenomanian planktonics (Pessagno, 1969, p. 34). On the other hand, the Upper Tamaulipas and Cuesta del Cura limestones in the Xilitla area are said to be time-equivalent (Lopez Ramos, 1982, p. 328), and the former is shown to range through the entire Albian-Cenomanian time span *(op. cit.,* Fig. VI-17, p. 348).

From these data, it seems possible that the Mid-Cenomanian break dividing Early from Late Cretaceous may lie somewhere within the Upper Tamaulipas.

The thick Abra facies which has been penetrated by deep wells in the Golden Lane and on the south plunge of Sierra el Abra has not yielded ammonites. The age assignation depends on the abundant benthonic macro and microfauna occurring in the upper part of the section. These fauna can be compared to benthonic assemblages which occur in the Lower Cretaceous (Comanchean) of Texas, where time-stratigraphic ranges are controlled by ammonites.

It should be stressed, however, that the lower part of the carbonate section in the subsurface is often so heavily dolomitized that both time-stratigraphic and facies assignations become problematic. It may well be that the lower part of the thick carbonate sequence drilled on the south plunge of Sierra El Abra belongs to the lower Tamaulipas (Fig. 3).

The main part of the El Abra formation in the Golden Lane has been assigned to the Albian-Cenomanian time-span on the basis of both microfauna, such as *Orbitolina texana,* and macrofauna including many rudistids that occur in the Comanchean of South Texas. The El Abra “reef” facies has been interpreted, almost universally, to be the time-equivalent of the Tamabra facies, which are generally accepted as shelf-slope or reef-front debris deposits.

There are some critical problems relating to the age and facies relationships of the El Abra, Tamabra and Upper Tamaulipas which affect the interpretation of the Golden Lane and are discussed subsequently.

Evidence of structural activity during the Lower Cretaceous

The lower Tamaulipas limestones appear to have been deposited in moderate water depths during a tectonically quiescent period. No unconformities within the sequence have been reported.

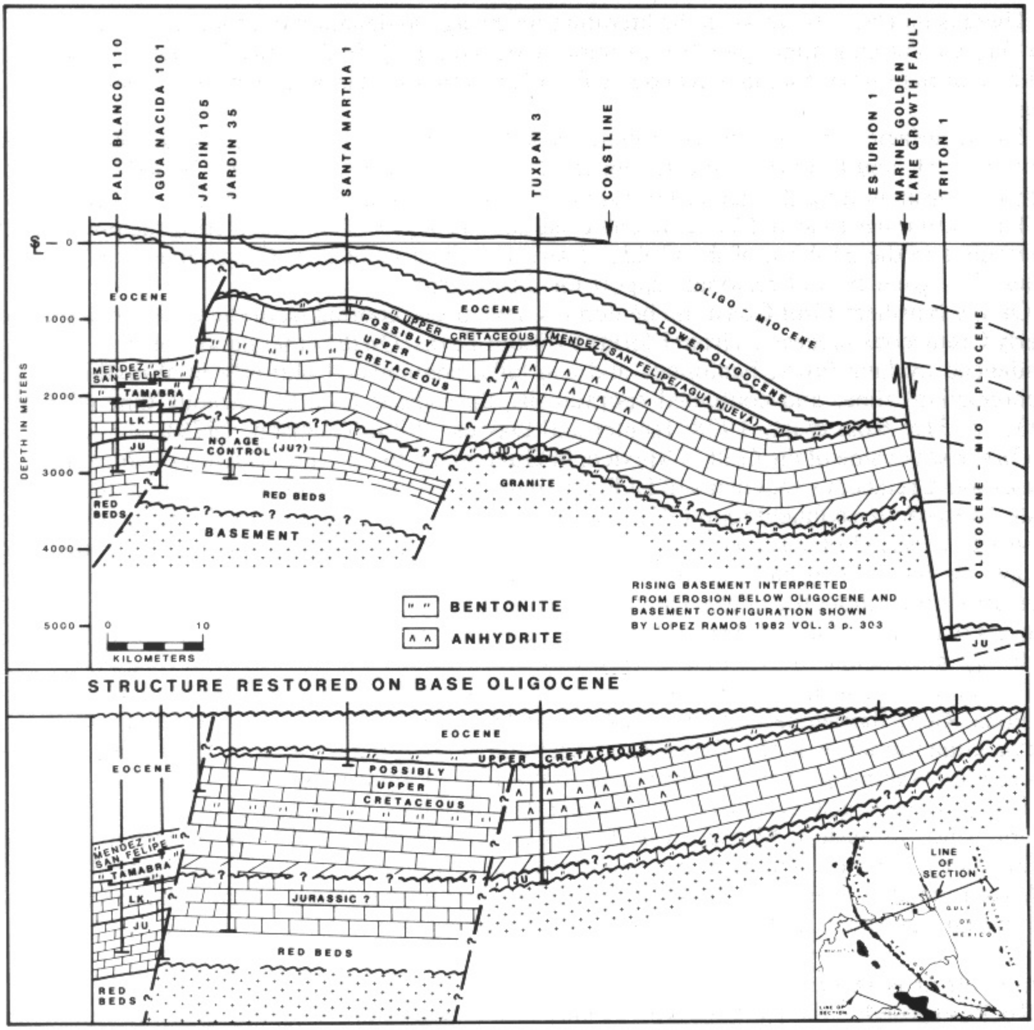


Fig. 4. East-west structural cross-section over the Golden Lane, with palaeostructural restoration on base Oligocene. (Upper panel redrawn and modified after Lopez Ramos, 1982, Fig. VI-20, and Carrillo Bravo, 1980 Fig. 6-A).

In the *Panuco* area of the northern oilfields, some slight variations in thickness of the uppermost Tamaulipas are indicative of early paleostructural growth (Muir, 1936, p. 34). It is not clear if this structural activity is attributable to latest Early Cretaceous or earliest Late Cretaceous time.

Likewise, movement at the junction between the Early and Late Cretaceous may be responsible for the basal Agua Nueva conglomerate, which has been observed SW of Victoria, 200 km NW of Tampico (Muir 1936, p. 48).

Upper Cretaceous

The allocation of formations to Upper or Lower Cretaceous depends upon precise paleontological control. Unfortunately, such control is generally confusing for just those formations which have a major bearing on the interpretation of the Golden Lane, i.e. the El Abra, Tamabra and Upper Tamaulipas formations.

There is much controversy in the literature on the age-assignation of lithological units within the Albian-Turonian time span. For example, Coogan *et al.* (1972, p. 1423) state that the Agua Nueva formation is Cenomanian and not Turonian, although it is placed in the Turonian in their Fig. 4.

The tectofacies of the various formations reflect upon the penecontemporaneous tectonic environment, and to unravel the sequence of structural events during the 20 MM* years of Albian-Turonian time the age-relationships of lithostratigraphic units must be clarified.

The Author has followed Viniegra and Castillo (1970, p. 374) in considering the presence of bentonites in the El Abra of the Golden Lane as indicative of Late Cretaceous age (Fig. 4). There is a great deal of regional support for this interpretation.

On the Northern Gulf Coast, no bentonites have been reported from the intensely explored Early Cretaceous succession from Florida to South Texas. On the other hand, volcanic activity, evidenced by lava flows, bentonites and ash falls, commenced abruptly in Woodbine (late Cenomanian) time, and continued sporadically throughout Late Cretaceous time (Adkins, 1932, p. 515; Ross *et al.,* 1928; Hunter and Davies, 1979; Thomson, 1979).

On the south side of the Gulf of Mexico, in Guatemala, there is no evidence of volcanicity in the Lower Cretaceous sediments of El Peten, but volcaniclastics appear abruptly at the start of Late Cretaceous sedimentation (Wilson, 1974). Evidence from around the Gulf of Mexico points to a period of volcanic quiescence from Valanginian to Early Cenomanian time. No doubt, for this reason and because bentonites mark the base of the Turonian Agua Nueva formation throughout the entire Tampico Tuxpan basin, Viniegra and Castillo (1970, p. 314) suggest that part of the El Abra in the Golden Lane where bentonites have been recognized on well-logs may belong to the Late Cretaceous.

For the same reason, the bentonite horizons recorded in the Tamabra and Upper Tamaulipas at Poza Rica (Barnetche and Illing, 1956), at Moralillo (Suarez, 1950, p. 671) and in the Ahuacatlan formation in the Valles-San Louis Potosi area (Suter 1984, p. 1388), raises doubt about the assignment of these formations to the Early Cretaceous.

The first geologist seriously to confront the problem of “Middle Cretaceous” facies relationships in eastern Mexico was Arnold Heim, (1940, p. 325) who proposed that the Tamaulipas, Taninul and El Abra limestones were different facies of the same Tamabra (“Mixed facies”) formation. Many geologists have been puzzled over the relationships that Heim first described, and the problem is still very controversial.

The El Abra Formation

Rocks exposed in the El Abra type locality east of Valles are of great petroleum-geological interest because they are considered equivalent to those of the oil reservoir in the Golden Lane fields (Bonet, 1956, p. 90). The limestone exposures brought to the surface by the El Abra anticline between El Abra and Taninul have been studied and described by many geologists, most notably, Baker (in Muir, 1936); Bonet, (1952); Aguayo, (1975); and Minero *et al.,* (1983).

The Taninul facies exposed on the steep east flank is considered to be rudist reef build-up, whereas the Abra facies, interpreted as a back-reef or lagoonal environment, is exposed on the gentle west flank.

Aguayo considered the two facies exposed on either flank of the anticline to be time equivalent, whereas Bonet (1952, p. 206) considered the Taninul to be slightly older than the Abra.

Determinations of many rudistids and other macrofossils from the Taninul locality led Adkins to equate the beds to Fredericksburg-Washita, not much younger than Middle Albian (Muir 1936, p. 38). Coogan (1977) published a new list of rudists from the Taninul exposures

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** Million (10 ^{6}) years.*

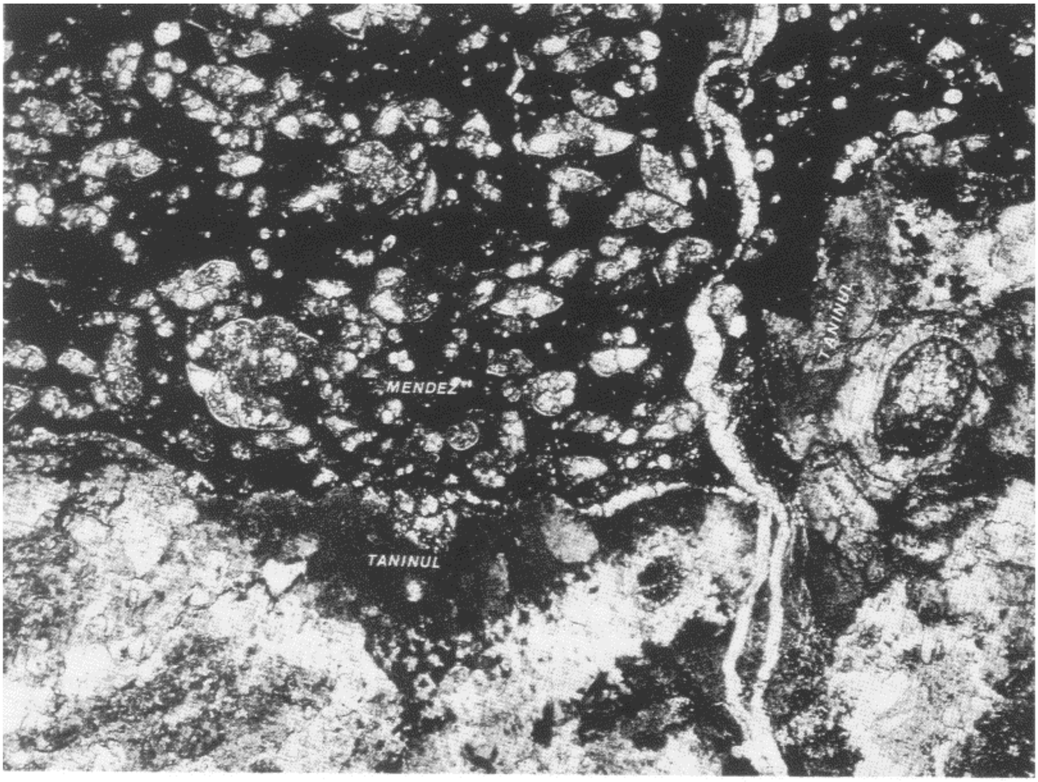


Fig. 5. Microphotograph (×20) of unconformable contact between Mendez deep-water shale crowded with Globotruncanidae (Maestrichtian), and Taninul rudistid limestones (Albian). Sample taken from south side of Cementos Anahuac quarry. (Microphoto by M.J. Queen, Standard Oil Production Co.)

which he assigned to the Cenomanian, even though identified species such as *Eoradiolites davidsoni, E. quadratus, Caprinuloidea anguis* and *C. multitubifera* are listed by Coogan (1977, p. 35) as Middle Albian fauna.

From the El Abra facies, Toucasia rudists occur at the top of the sequence and the miliolid *Nummoloculina heimi is* present in profusion. The occurrence of *Nummoloculina heimi* in North America according to Conkin and Conkin (1958), is restricted to the Early Cretaceous.

The larger foraminifera *Dictyoconus* and *Orbitolina* were mentioned by Rose (1963, p. 60) from the Taninul locality, and more recently, Minero (1983, p. 37) recorded orbitolinid foraminifera from lime mudstone facies in the El Abra type locality. However, it appears that these authors, like Bonet (Douglass 1960, p. 46), have misidentified *Dicyclina schlumbergi* as *Orbitolina* .

The abundant benthonic microfauna and macrofauna that has been collected from the El Abra type locality points irresistibly to an Albian-Lower Cenomanian (Early Cretaceous) age for these rocks.

It was therefore somewhat surprising when Aguayo (1975, p. 7) reported a thin parting of biosparite in the El Abra type section quarry that yielded a pelagic microfauna of late Turonian or younger age. This led to the suggestion that the El Abra carbonates in the type locality actually ranged up into the Late Cretaceous.

However, the disparity of several millions of years in age between Aguayo's pelagics and the benthonic faunas occurring in 80 ft of overlying platform carbonates leads to the interpretation, *(pers commun.* from J.L. Wilson), that the Late Cretaceous faunas are an example of "stratigraphic leak." This possibility is further supported by the unconformable relationship between the El Abra limestones and the overlying Late Cretaceous.

At San Felipe, on the west flank of the El Abra fold, an early Campanian fauna occurs in the San Felipe type section immediately above the El Abra (Pessagno 1969, p. 37), whereas on the east flank several hundred feet of Mendez shales of Maestrichtian age are exposed at Cementos Anahuac quarry dipping east at 45°, and in unconformable contact with Taninul limestone beds which also dip at 45° (Fig. 3). This important contact is beautifully exposed, and the Author was able to sample across the actual unconformity (Fig. 5). There is no thrust contact as was previously supposed.

There is a large solution cavern on the west side of the El Abra quarry, some 50 ft below the top of the section, and solution crevices in the Taninul limestone filled with early Campanian pelagics were observed by Aguayo (1975, p. 8).

If the post-Mendez deformation which formed the Sierra El Abra asymmetric fold is removed, then it appears that pre-Upper Mendez erosion cut progressively more deeply into Lower Cretaceous carbonates towards the east (Fig. 3). This supports Bonet's view that the Taninul is slightly older than the El Abra member.

In the subsurface of the Golden Lane, the El Abra is different from the type section. In the Jardin No. 35 deep test (Fig. 4), the top of the El Abra was recorded at 690 m (2,263 ft), and a prominent bentonite horizon was recognized at 1,487 m (4,877 ft) (Bonet, 1952, p. 229). This bentonite horizon is taken to be indicative of Late Cretaceous age (Viniegra and Castillo, 1970, p. 374) and is herein shown tentatively as base Upper Cretaceous in Fig. 4. However, below this bentonite there are shell breccias with *Orbitolina* and more volcanic ash horizons (Bonet 1952, p. 229) so that even more of this drilled section than indicated may be assignable to the Late Cretaceous. Bentonite markers in the El Abra of the Golden Lane were used for correlation of logs by Pedrazzini (1979), but the positions of the markers were not reported.

If the volcanism evinced by bentonite intercalations in the Golden Lane is indeed Late Cretaceous, then the *Orbitolina* and other Early Cretaceous benthonic faunas occurring above the bentonites must be redeposited, and these carbonates, like the adjacent Tamabra, are detrital.

The problem of correct age determination of Cretaceous sediments with a large content of reworked material may be more pervasive than heretofore recognized in the Tampico embayment. For example, in Wells *Mecatepec 33* and *Poza Rica 96,* a thin interval of typical Agua Nueva limestones comes below several meters of typical "Urgonian" (El Abra) limestones. This is explained by assuming a reverse fault (Bonet, 1952, p. 223), but Nigra (1951, p. 131) suggests that the El Abra material is reworked.

South of the El Abra type locality, Nigra (1951, p. 1 56) observed the interdigitation of Agua Nueva sediments containing a *Globotruncana* assemblage and limestones of El Abra type with miliolids and rudists, which Nigra suggests may be reworked. Similar reworking of shallow water Early Cretaceous benthonics *(Orbitolina)* into Mid Cenomanian deeper-water sediments has been documented from Gulf of Mexico deep-water core holes (Cherchi and Schroeder, 1984; Silva and McNulty, 1984).

On the east side of the Golden Lane "atoll" where the El Abra has been deeply eroded (Fig. 4), Lower Cretaceous limestones are probably present. The evaporitic section drilled in Tuxpan No. 3 (Fig. 4) is probably autochthonous Albian, equivalent to the anhydrites in the Coban formation of Guatemala and the Ferry Lake anhydrite of Texas. This evaporitic section is herein interpreted to be fault-separated from probable Upper Cretaceous beds to the west. A similar fault was interpreted by Carrillo (1980, Fig. 6-A).

To sum up, the El Abra formation in the type locality is of Early Cretaceous-Albian-Cenomanian age. However, it is interpreted that limestones attributed to the El Abra in the

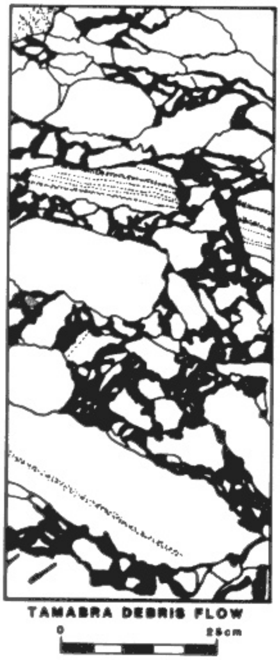


Fig. 6. Tamabra limestone débris flow. Drawing is traced from a photograph of core from the *Poza Rica* No. 217 well. (Enos, 1977, Fig. 22B).

Golden Lane, where bentonite intercalations occur, are redeposited carbonates that were laid down during early Late Cretaceous time. The observation of breccia-conglomerates from the Agua Nueva (Muir, 1936 p. 223) and the El Abra in some early Golden Lane wells is also suggestive of reworking (Muir, 1936 p. 40).

The Tamabra Formation

The name Tamabra was originally introduced by Heim (1940, p. 321) for the entire limestone complex that underlies the San Felipe or Agua Nueva (Xilitla) formations in the Sierra Madre mountain front exposures. The Tamabra, as the name implies, was interpreted to comprise a “mixed facies”, which included elements of Tamaulipas (deep water), El Abra (platform) and Taninul (reef) facies (Heim, 1940, p. 325).

Subsequent usage of the term Tamabra has been restricted to the subsurface bioclastic limestones and limestone breccias encountered west of the Golden Lane, particularly at the giant *Poza Rica* field, where they comprise the reservoir rock. Detailed subsurface studies of the Tamabra at *Poza Rica* have been published by Barnetche and Illing, (1956), Coogan *et al.*, (1972) and Enos (1977 and 1985).

At *Poza Rica*, the Tamabra comprises about 650 ft (200 m) of bioclastic limestones, often with abundant rudist fragments, and limestone breccias with angular elements of a variety of limestones, including clasts of laminated, pelagic, lime wackestone of basinal origin (Fig. 6). These coarse, clastic beds are separated by graded bioclastic limestones, often finely laminated and sometimes displaying penecontemporaneous soft-sediment deformation (Enos 1977, p. 307).

Secondary dolomitization is widespread, particularly in the Lower Tamabra (Barnetche and Illing, 1956 p. 20). The lithological character of the Tamabra is well illustrated by Enos (1977) who interprets that the detrital limestones have been deposited by successive submarine density and debris flows. The evidence presented by Enos leaves little doubt that this is the correct interpretation. Apart from rudist and other macrofossil debris, there are also displaced smaller and larger benthonic foraminifera, such *as Orbitolina* and *Dictyoconus* of Albian age (Becerra, 1970, p. 37).

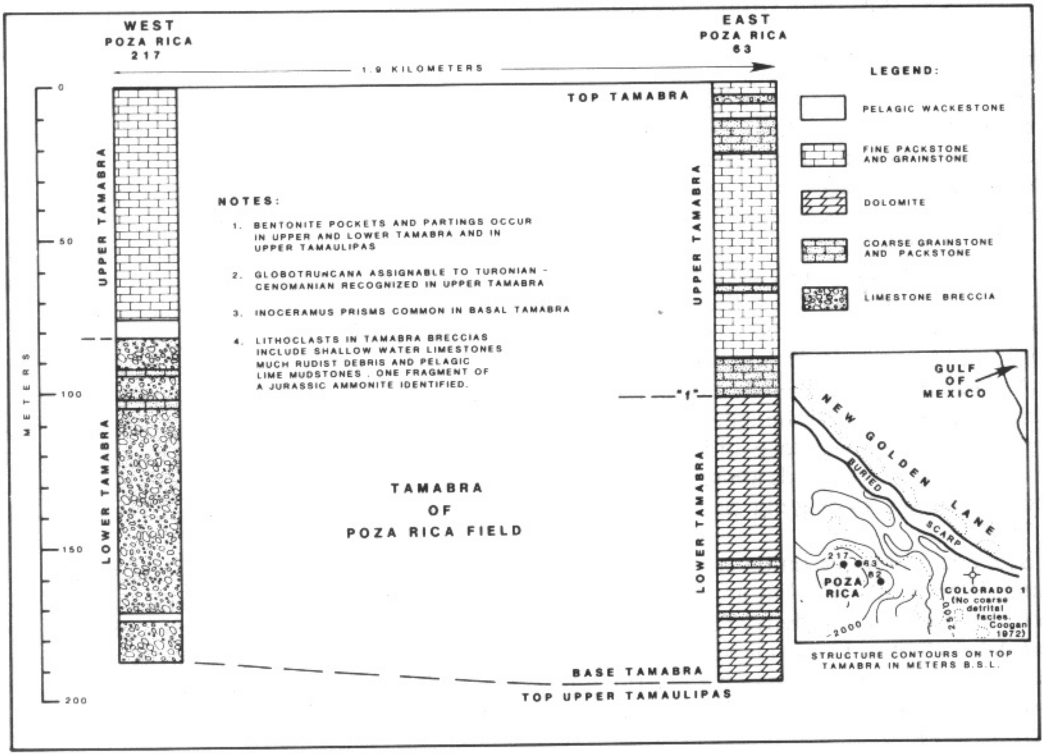
Barnetche and Illing (1956) divided the Tamabra into Upper and Lower members, which are separated by a thin compact impervious zone with blue-green bentonitic shale partings, designated horizon "f". The top of the Tamabra was picked where dense, greenish-gray calcilutites of the San Felipe or Aqua Nueva formation give way to white, skeletal debris limestone. The base of the Tamabra was picked where a sharp gamma-ray log "kick" marks the top of dense calcilutites of the Tamaulipas facies.

In the Upper part of the Tamabra, bright green-blue bentonitic shales have been cored which, in thin section, reveal volcanic shards (Barnetche and Illing, 1956, p. 14). Below horizon "f" other gamma-ray peaks are taken to be caused by bentonitic laminae *(op. cit.,* p. 17). About 66 ft (20 m) below the highest breccias of the Tamabra, *Globotruncana* sp. is reported (Barnetche and Illing, 1956, p. 3; Becerra, 1970, p. 22). Similarly, *Globotruncana(?) is* reported 177 ft below the top of the Tamabra in Tantima No. 1, 60 miles NNW of *Poza Rica* (Viniegra and Castillo, 1970, p. 319). Apart from abundant reworked Albian-Cenomanian fossil debris, a fragment of a Jurassic ammonite has also been identified from the Tamabra at *Poza Rica* (Bonet 1963, p. 46).

The age of the Tamabra at *Poza Rica* and elsewhere is unsettled, although it has been assigned to the Albian-Turonian (20 MM yrs) time-span (Becerra, 1970). The upper part carries Turonian pelagics, but reliable age determinations from the Lower Tamabra are lacking, and the dominance of reworked fauna as well as dolomitization add to the difficulties of reliable dating.

The Tamabra facies with mass flow deposits is suggestive of very rapid deposition. Consequently, a long period of sedimentation does not appear likely. The bentonitic horizons

Fig. 7. Distribution of limestone breccia (débris flows) in *Poza Rica* wells Nos. 217 and 63. This suggests an eastward decrease in débris towards the Golden Lane. (Lithofacies distribution taken from Enos, 1977, Fig. 9).



NOTES:

1. BENTONITE POCKETS AND PARTINGS OCCUR IN UPPER AND LOWER TAMABRA AND IN UPPER TAMAULIPAS
2. GLOBOTRUNCANA ASSIGNABLE TO TURONIAN - CENOMANIAN RECOGNIZED IN UPPER TAMABRA
3. INOCERAMUS PRISMS COMMON IN BASAL TAMABRA
4. LITHOCLASTS IN TAMABRA BRECCIAS INCLUDE SHALLOW WATER LIMESTONES MUCH RUDIST DEBRIS AND PELAGIC LIME MUDSTONES . ONE FRAGMENT OF A JURASSIC AMMONITE IDENTIFIED.

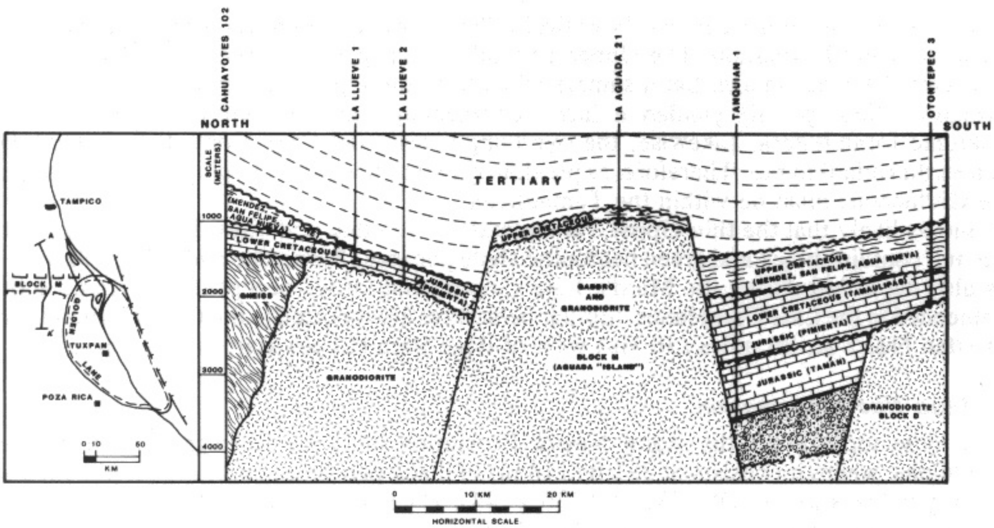


Fig. 8. North-south structural cross-section over the La Aguada (Block M) horst-block which borders the Golden Lane. (Redrawn and modified from Lopez Ramos, 1972, Fig. F-F1).

are suggestive of Late Cretaceous volcanicity for reasons previously stated. The majority view is that the Tamabra is a fore-reef deposit that accumulated at the foot of the Golden Lane El Abra reef-front, but there are several observations that cast some doubt upon this interpretation; for example, the presence of a Jurassic ammonite fragment and the common occurrence of deep-water carbonate breccia clasts, which may or may not be Jurassic, can hardly have been derived from the Golden Lane. The incidence of breccia beds within the Tamabra does not seem to increase toward the Golden Lane, as might be expected (Fig. 7).

It is known that Jurassic carbonates were exposed and being eroded on the Jalapa high south of *Poza Rica* because Jurassic elements are present in thick conglomerates of Late (Middle?) Cretaceous age (Olivas, 1953, p. 171).

The origin and timing of the west face of the Golden Lane is very controversial. There is reasonable evidence that it represents a middle Eocene paleofault scarp. Furthermore, Block M (La Aguada) is a major east-west trending horst block (Lopez Ramos, 1972 a, p. 297) from which Jurassic and Cretaceous sediments have been removed, that intersects the north end of the Golden Lane (Figs. 8 and 9).

If, for the sake of interpretational balance, we distrust the assumption that the Tamabra debris flows at Poza Rica were derived from a passive El Abra carbonate build-up, then what alternative interpretation might seem reasonable? It is here suggested that the Tamabra facies, rather than being indicative of a passive tectonic environment are, on the contrary, typical of sharp penecontemporaneous structural activity in which sedimentary debris was shed from active fault-blocks, some of which lay to the east of the Golden Lane and others which comprised east-west crossing trends. The same mode of origin would likewise explain the occurrence of large exotic blocks and allochthonous breccias (debris flows) that occur in the Upper Tamaulipas at Xilitla (Carrasco, 1977, p. 266) 75 miles (120 km) west of the Golden Lane (Fig. 1).

The Upper Tamaulipas Formation

The type area for the Tamaulipas Formation in the Sierra Tamaulipas is traversed by the La Borrega and Peregrina canyons (Muir, 1936, p. 31). Humphrey and Diaz (1953) redefined the Upper Tamaulipas as comprising about 305 ft (93 m) of dark grey calcarenites and interbedded black shales and siltstones coming above the La Peña Formation (Otates of Muir) and below the Cuesta del Cura Formation. The Upper Tamaulipas has generally been considered as Early Cretaceous (Albian) in age, but a sample taken from the Upper part in Peregrina canyon by Pessagno (1969, p. 34) yielded a late Cenomanian (early Eaglefordian) assemblage of planktonic foraminifera. Likewise, the overlying Cuesta del Cura Formation yielded early Eaglefordian planktonics. Therefore, as previously mentioned, the boundary between Early and Late Cretaceous must lie within the Tamaulipas.

It seems likely that the thin Upper Tamaulipas section that underlies the Tamabra at *Poza Rica* and contains black and green bentonitic shale partings (Barnetche and Illing, 1956, p. 17) was also deposited during the Middle Late Cenomanian, if we accept that volcanic activity commenced in the Late Cretaceous. Similar bentonites are reported in the Upper Tamaulipas of Amixtlan No. 2-A, 20 miles (30 km) west of Poza Rica (Lopez Ramos, 1982 p. 339).

The Agua Nueva Formation

The type locality for the Agua Nueva Formation is in La Borrega canyon in Sierra Tamaulipas where it consists of 381 ft (116 m) of black petroliferous shales interbedded with dark grey to black calcarenites (Muir, 1936, p. 44). The middle part of the type section yielded a pelagic foraminiferal assemblage of late Turonian age (Pessagno, 1969, p. 35) including *Margino-truncana sigali* (Reichel) and *M. canaliculata* (Reuss). The characteristic macrofossil for the Agua Nueva is *Inoceramus labiatus.*

In the subsurface of the *Panuco* fields, Baker (1928, p. 405) describes the highly bentonitic and tuffaceous nature of the Agua Nueva, particularly the lower part which contains bright green tuffaceous beds.

The contact between the Agua Nueva and the Upper Tamaulipas seems to be transitional, although, in one locality SW of Victoria, there is a basal conglomeratic limestone with angular elements of the underlying Tamaulipas (Muir, 1936, p. 48).

Evidence for structural activity during the early Late Cretaceous

Palaeontological evidence suggests that the Upper Tamaulipas, Tamabra, and Agua Nueva were deposited during the Mid Cenomanian to Upper Turonian time span. It seems probable that the upper part of carbonates (designated as El Abra) with bentonite horizons in the Golden Lane are also Late Cretaceous.

The occurrence of bentonite horizons in all these formations gives evidence of penecontemporaneous volcanic activity. The centres of volcanicity appear to have been to the east, in what is now the Gulf of Mexico (Baker, 1928, p. 412).

Evidence of structural activity during the Turonian is provided by isopachs of the Agua Nueva in the Panuco area (Muir, 1936,p. 49) and at Moralillo (Suarez, 1950,p. 675) where the formation thins over structures, indicating penecontemporaneous growth (Fig. 10). As already mentioned, the Tamabra and Xilitla debris flows are thought to have been triggered by penecontemporaneous fault movements. Such faulting may have been synchronous with major dislocations along the Tuscaloosa trend on the Northern Gulf Coast.

Positive structural activity at the end of the Turonian is also suggested by the basal San Felipe unconformity at Sierra El Abra and over the Golden Lane.

The San Felipe Formation

The type-locality for the San Felipe formation (Fig. 3) is west of San Felipe on the Valles-Taninul railway, on the west flank of the El Abra anticline (Muir, 1936 p. 58). The formation is poorly described as alternating limestones and shales of Coniacian and Lower Santomian age and no measured section or thickness is given. Later sampling in the type locality by Pessagno (1969 p. 37) showed that the San Felipe in the type locality is not older than early Campanian, and there is therefore a major time gap of some 10 MM yrs (Late Cenomanian to late Santomian) between the San Felipe and El Abra Limestone.

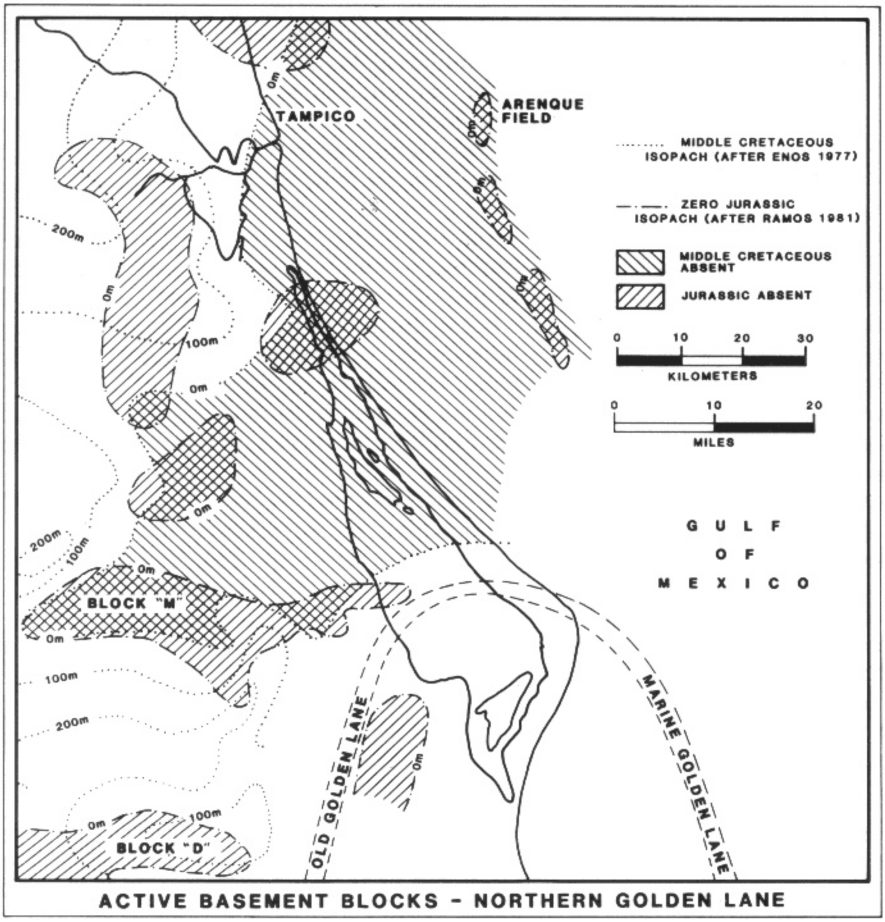


Fig. 9. Map showing the disposition of pre-Tertiary positive structural elements to the north and NW of the Golden Lane.

There is a distinct possibility that basal Mendez beds may have been mistakenly assigned to a new formation (San Felipe) and the nomenclature has remained in the literature despite the inadequacy of the original formation description. The identification of San Felipe beds in the subsurface of the Golden Lane must also be suspect in view of poor lithological and palaeontological definition of a type section, and also because of the the common occurrence of reworked faunas in succeeding Mendez beds (Pessagno, 1979 p. 46).

In the subsurface of the Northern fields (Panuco area) some 500 ft (148 m) of interbedded limestones and shales with tuffaceous interbeds have been assigned to the San Felipe (Muir 1936 p. 63). However, in some places only shale beds occur, and it is difficult to distinguish the San Felipe from Mendez lithologies (Muir, 1936 p. 67).

No micropalaeontological support is provided for subsurface intervals in the Northern fields.

The Mendez Formation

The Mendez formation also takes its name from a station on the Tampico-Valles railway line (Fig. 3). The outcrops occur where the line crosses the Tamaulipas arch near Mendez Station (Muir l936 p. 69), where only the upper part of the Mendez shales are exposed. About l,100ft (335 m) of Mendez shales have been drilled in the Northern (Panuco) fields on the south plunge of the Tamaulipas arch (Muir 1936 p. 75). The shales are red and gray, have some sandy beds near the top, and contain numerous bentonite and volcanic ash horizons. The pelagic microfauna indicate that the sediments were deposited in bathyal to shallow abyssal depths (Pessagno, 1969 p. 49) and the age of the formation is Late Campanian to Maestrichtian. Reworked pelagic microfauna occur in lower Mendez beds, and the sporadic occurrence of rudists in these deep-water sediments are also thought to be due to reworking (Pessagno, 1969 p. 49).

Mendez shales are unconformably overlain by Paleocene Tamesi (Velasco) beds (Muir, 1936 p. 70). The base of the Mendez lies unconformably on El Abra rudistid limestone on the eastern flank of the El Abra anticline at Gomez Farias in the north (Muir, 1936 p. 62) and at Cementos Anahuac in the south. The basal unconformity is well-exposed at Cementos Anahuac. There is no visible angularity between the shallow-water Taninul rudistid limestone and the overlying deep-water Mendez shales, both of which dip at 45° to the east. However, when post-Mendez (Sierra Madre) deformation is removed from the El Abra fold, a low-angle unconformity is suggested with the Mendez bevelling down section towards a paleohigh on the east (Fig. 3).

Micropalaeontological examination of basal Mendez shale samples from Cementos Anahuac yielded a rich planktonic microfauna, including *Globotruncana contusa, G. elevata, G. fornicata, Heterohelix semicostata, Pseudotextularia* sp. and *Hedbergella* sp., which indicate a Maestrichtian age. Thus, a major hiatus between the Mendez and Taninul is revealed, with the whole Late Cenomanian to Campanian interval missing (Fig. 5).

Remnants of Mendez shale have been encountered in wells on the Golden Lane below the Oligocene or Eocene unconformities. These shales indicate that the same deep-water environment prevailed over the supposed Golden Lane atoll. If a bathimetric high had existed at that time, the Mendez shales would have ponded around it before overlapping the top. This, therefore, suggests that no “atoll” was present in Mendez time.

Evidence for structural activity towards the close of Late Cretaceous time

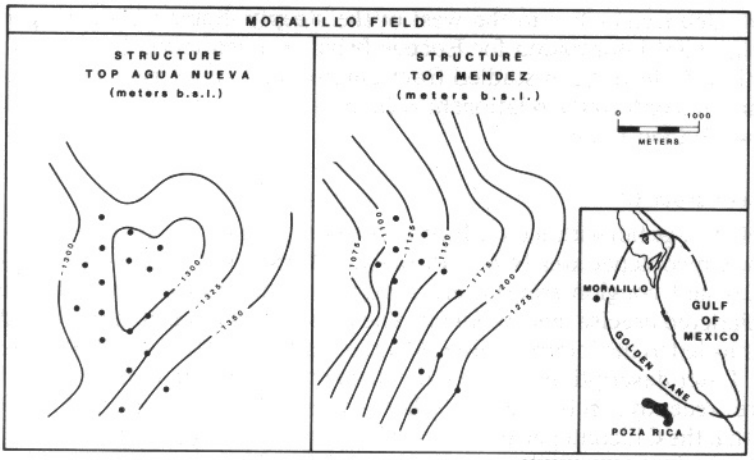
During the Santonian-Maestrichtian time-span, there is evidence of sporadic volcanic activity from intercalations of volcanic ash and bentonite in the San Felipe and Mendez formations throughout the Tampico embayment.

Pre-Maestrichtian faulting and fracturing on the south plunge of the Tamaulipas arch has been documented from drilling results in the Northern oilfields, for example in the *Cacalilao* field (Muir, 1936, p. 183). The dominant fault and fracture trend is NE-SW, as exemplified by the San Manuel fault, which displaces pre-Mendez beds (Muir, 1936, p. 175). Oil entrapment in the Northern fields is controlled by pre-Mendez fracture permeability trends and not by present-day structural closure (Muir, *ibid.*, p. 170).

Such fracturing was probably in response to major block-fault movements such as those exemplified by Block “M” situated south of the Northern (Panuco) fields (Figs. 8 and 9).

Subsurface structure in the Golden Lane area is described by Muir (1936 p. 162) as “a complex symposium of various erosion cycles and tectonic features.” Numerous faults trending ENE and NE across the Old Golden Lane were interpreted from subsurface data (Muir, 1936, Figs. 32, 33, 34). Precise dating of this faulting is prevented because of the major pre-Eocene and pre-Oligocene unconformities that cut deeply into the Golden Lane ridge. However, it seems probable that much of this fracturing is of Late Cretaceous age and resulted in the deposition of breccia conglomerates which have been recorded from many wells at the base of the San Felipe (Muir 1936 p. 205).

A summary of volcanic and structural activity in the Tampico embayment during the Cretaceous and its comparison with that on the Northern Gulf Coast is shown on Fig. 11. It must be stressed that the scarcity of unequivocal time stratigraphic control renders this interpretation tentative, but the same might be said of previous attempts to define time stratigraphic relationships. Much of the stratigraphic confusion can be blamed upon poor



CONTOURS AFTER R. SUAREZ 1950

Fig. 10. *Moralillo* **Field. Structural contours drawn at top Mendez and top Agua Nueva datums illustrate structural growth during Late Cretaceous. (Redrawn from Suarez, 1950).**

definition of formation type sections and their loose application to subsurface successions. The correlation of the El Abra type section, where only 200 ft of platform limestones are exposed, to the thick carbonate sequence of questionable age drilled in the Golden Lane, is a good example of the confusing correlations that have become accepted through repetition in geological literature.

The major hiatus between Maestrichtian Mendez shales and Albian Taninul limestone exposed on the east flank of Sierra El Abra obscures the structural activity that occurred in early Late Cretaceous time. This activity is revealed not only by evidence of volcanicity but also by structural growth, faulting and the deposition of tectonically activated mass breccia flows and olistoliths in the Tamabra, Agua Nueva and San Felipe intervals. The provenance of clastic Cretaceous sediments is relevant to the overall structural setting in the Tampico embayment. Derivation of conglomerates from the Jalapa "high" during Late (?Middle) Cretaceous time (Olivas, 1953) indicates that this "crossing trend" south of the Golden Lane was active. It is interpreted that other block-faulted positives such as Block ''M" (Fig. 10) were active during early Late Cretaceous time, and gave rise to Tamabra mass flow deposits comparable to penecontemporaneous mass flow breccias that were shed from active Kimmeridgian faults in Greenland (Surlyk, 1978) and Scotland (Bailey, 1932), and also from Eocene palaeofaults in the southern Pyrenees (Labaume *et al.,* 1986).

The north-south trending Albian-Cenomanian positive ("continent") illustrated by Lopez Ramos (1972 b, Fig. 86) is noteworthy, as is the much earlier postulation by Bosë (1927 p. 138) that a land area was emergent in Campanian (Mendez) time off the east coast in what is now the Gulf of Mexico. What we now know about the basal Mendez unconformity supports Bosë's intuitive thinking. This "continent" may also have been the source of clastic material in the Mendez formation before the Sierra Madre began to rise.

Tertiary

Tertiary sediments ranging in age from Paleocene to Miocene are exposed on the Tampico coastal plain where they overlie the Golden Lane (Fig. 1). The Tertiary sediments are dominantly clastic as opposed to the carbonate regime of the Mesozoic. Tertiary sediments dip eastwards as a result of successive uplifts of the Sierra Madre belt from mid-Eocene time, coupled with strong downwarping in the Gulf of Mexico in Neogene time. As a result of these late movements, much of the Tertiary sedimentary package has been destroyed by erosion, and this creates problems in palaeosedimentological reconstructions. For example, well control shows that the Eocene depocenter lies to the west of the steeply dipping Chicontepec outcrop belt (Fig. 12), so that vital information for Eocene basin reconstruction has been destroyed.

Tertiary sediments have been studied from outcrop and subsurface control points. Facies distributions and unconformity relationships help in the interpretation of Tertiary structural evolution of the Golden Lane.

Paleocene-Lower Eocene

Sediments of this age fall within the Chicontepec group which was first described from surface exposures in the Chicontepec area NW of Poza Rica (Muir, 1936 p. 98). Over 4,000 ft (1,220 m) of sands, shales and conglomerates were assigned to the Chicontepec, although structural complexities hindered precise measurement. The presence of plant-remains together with some marine organisms led to the interpretation (Muir, *Op. cit.*, p. 100) that these were alluvial-fan or delta deposits. Later descriptions of the Chicontepec referred the facies to flysche or molasse whereas, more recently, subsurface studies by Busch and Govela (1978) led to the interpretation that the Chicontepec in the Poza Rica area was deposited in a submarine channel. This viewpoint has become popular and interpretations of submarine channels in the Mexican Tertiary have proliferated (Carrillo, 1980).

The Chicontepec is unconformable on Mesozoic rocks in the Poza Rica area, and cuts into progressively older rocks to the SE (Fig. 13). Chicontepec beds contain reworked Jurassic and Cretaceous foraminifera (Busch and Govela, 1978 p. 237) and rest directly upon the oil productive Jurassic reservoir at the *San Andres* field (Fig. 13). Busch and Govela (1978 p. 241) conclude that much of the Chicontepec detritus was furnished by the Jalapa “high” (Fig. 1), but it is also probable that the sands were derived from a basement positive lying to the east in the Gulf of Mexico. Pebbles of San Felipe and El Abra limestone have also been reworked into basal Chicontepec (Tanlajas) beds south of the plunging Sierra El Abra anticline (Muir, 1936 p. 103).

The interpretation by Busch and Govela (1978) of palaeocanyons did not consider the effect of post-Chicontepec structuring, particularly in regard to the Golden Lane west face, which may not have been present in Chicontepec time. Lower and Middle Chicontepec sediments have been recorded above the carbonates of the Golden Lane lying unconformably below Upper Eocene Tantoyuca beds (Fig. 12). If these are turbidite deposits (Busch and Govela 1978), they would not have been sedimented on top of a bathymetric high.

Middle Eocene

Middle Eocene beds which are predominantly shales with limited sands have been assigned to the Guayabal or Tempoal formation. In the *Poza Rica* field, the Guayabal thickens from 390 ft (120m) on the east, to 1,300ft (400m) on the west. According to Salas (1949, p. 1391),there is an hiatus between the Chicontepec and the Guayabal. Some 984ft (300 m) of Middle Eocene beds are present over the central segment of the Golden Lane (Muir, 1936, Fig. 15).

Upper Eocene

The main tectonic pulse of the Sierra Madre orogeny took place in late Middle Eocene time. Upper Eocene sediments reflect this tectonic activity, and occur in two facies; the conglomeratic facies of the Tantoyuca Formation and the more shaley facies of the Chapopote formation.

The Tantoyuca conglomerates in Poza Rica contain angular and sub-angular elements of Cretaceous limestone, chert and Chicontepec sandstone (Najera, 1952, p. 88). The cross-sections A-A’ and C-C’ drawn by Najera *(Op. cit)* across the *Poza Rica* field show clearly that the Tantoyuca conglomerates thicken towards the Golden Lane. This implies that the angular limestone elements were derived from an actively rising fault scarp.

On the cross-section prepared by Carillo, Rocha and Acuna of PEMEX, and reproduced by Coogan *et al.*, (1972 Fig. 7), the Tantoyuca conglomerates are shown to thicken across the

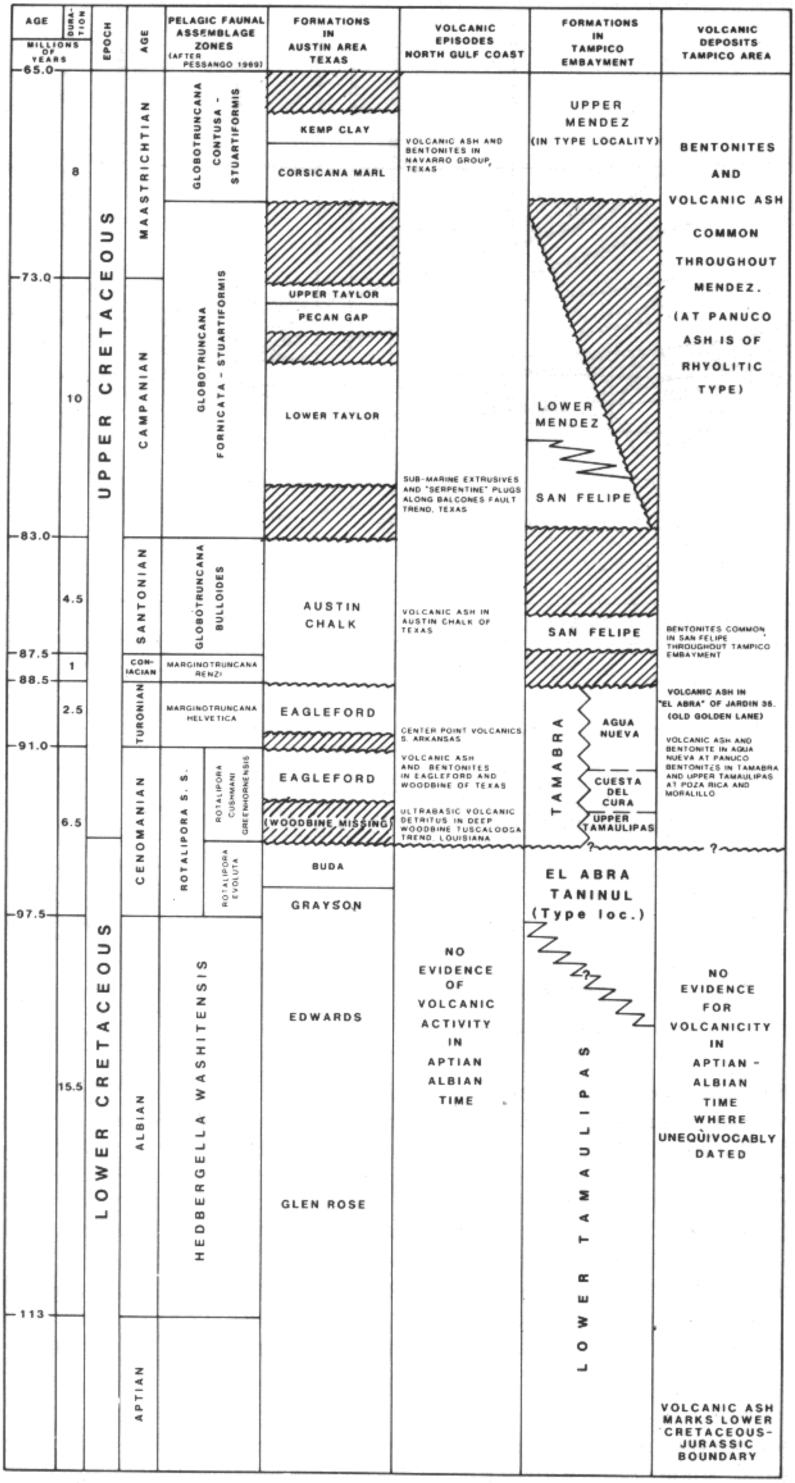


Fig. 11. Chart to show the Author's interpretations of time-stratigraphic relationships between the Cretaceous succession in Texas (Austin area), and that in the Tampico embayment.

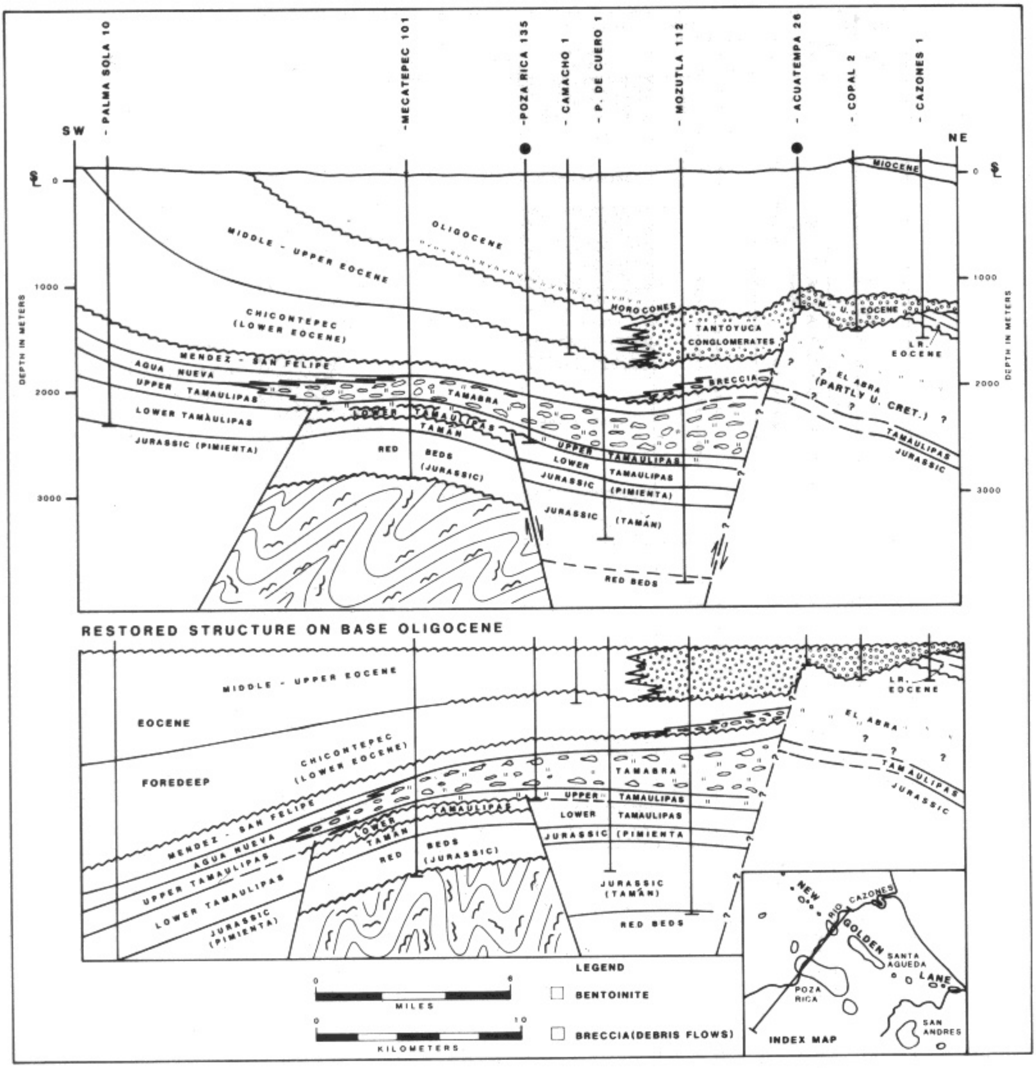


Fig. 12. NE-SW structural cross-section over the Golden Lane and *Poza Rica* fields, with palaeostructural restoration on base-Oligocene. (Upper panel redrawn from original cross-section by Carrillo, Rocha and Acuna of Pemex, reproduced by Coogan *et al.*, 1972, Fig. 7.)

Golden Lane western scarp. On the Golden Lane uplift, the Tantoyuca is shown to be unconformable on the El Abra limestone on the highest point of the scarp, and in angular unconformity with east-dipping Lower and Middle Eocene beds.

North of the Golden Lane, on the east flank of the Tamaulipas arch, a similar Tertiary conglomerate underlies Oligocene sediments and rests unconformably on Palaeozoic basement (Fig. 14). The same relationship exists also along the Arenque offshore trend (Fig. 9).

Oligocene

Lower Oligocene formations, designated Horocones, Alazan or Huasteca, outcrop west of Tuxpan above the Golden Lane Ridge (Fig. 1). Basal Oligocene beds are unconformable on the Upper Eocene at Alazan and contain many reworked fossils and derived material from Eocene formations.

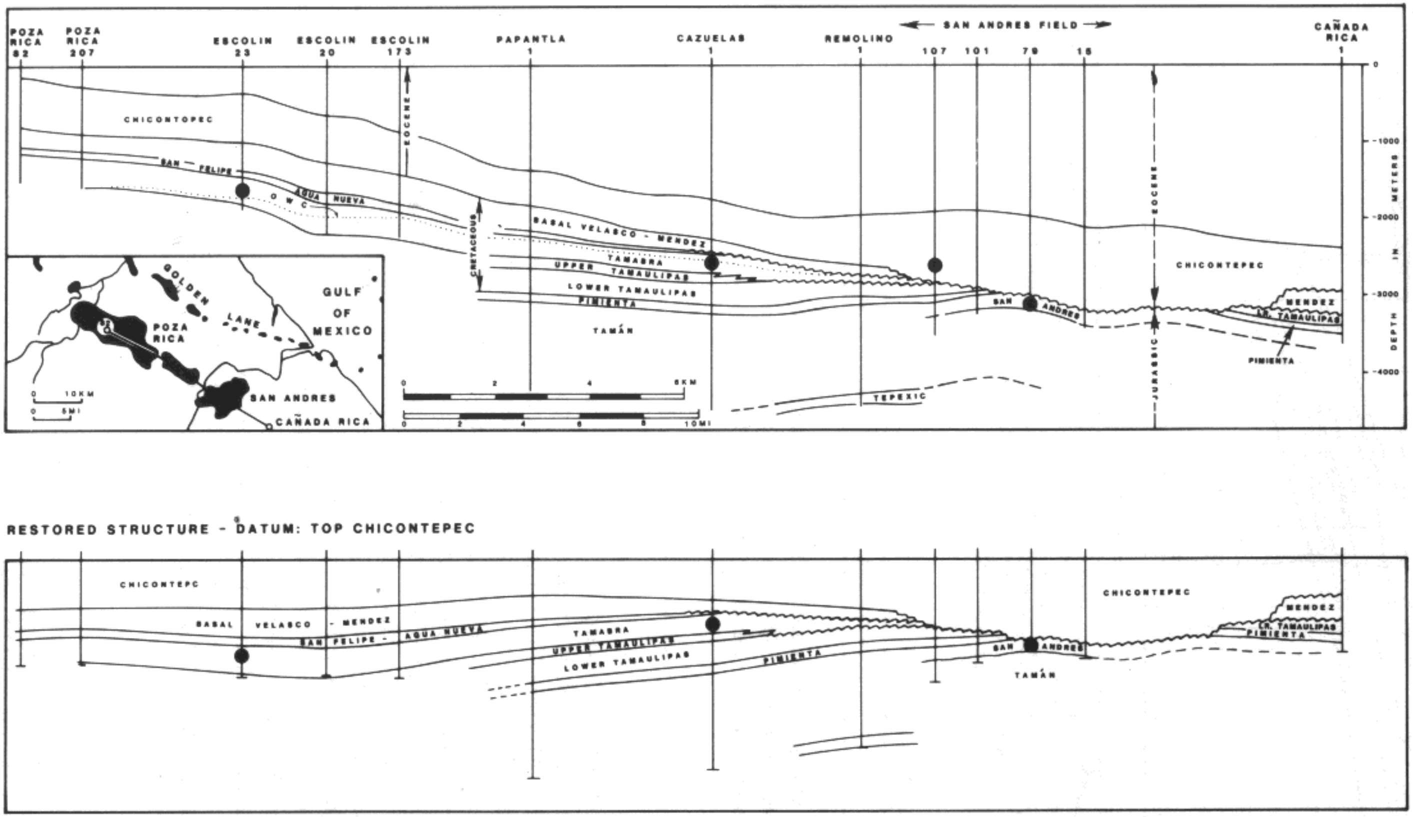


Fig. 13. NW-SE structural cross-section over the *Poza Rica* and *San Andres* fields with palaeostructural restoration on top — Chicontepec datum. This illustrates the Late-Tertiary structural inversion also seen on the Golden Lane (Fig. 16). (Upper panel redrawn from original section by A. Ramon of Pemex, reproduced by Enos, 1977. Fig. 8.)

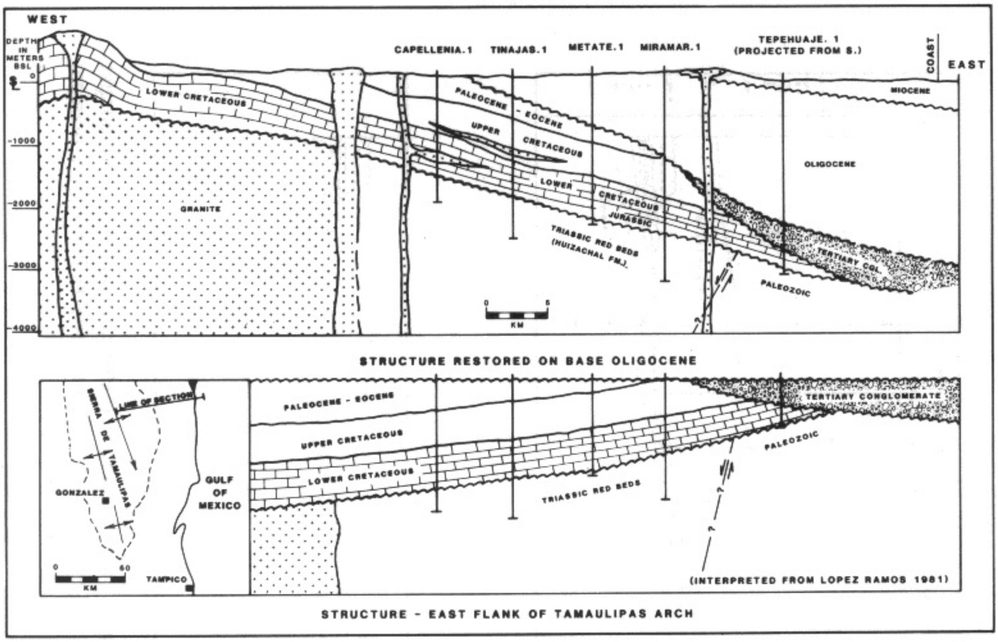


Fig. 14. East-west structural cross-section over east flank of the Tamaulipas Arch with palaeostructural restoration on base–Oligocene. This illustrates the Late Tertiary collapse of the Gulf of Mexico positive. (Upper panel redrawn from Lopez Ramos, 1982 Fig. VI-3.)

Along the Golden Lane towards the north and south ends of the buried ridge, Eocene and Upper Cretaceous sediments were eroded, and Oligocene beds rest directly upon Cretaceous limestone (Fig. 1 5). Mozutla No. 1, near the south end of the New Golden Lane, drilled into a solution cavern in the Cretaceous limestone filled with marine Oligocene sediments (Viniegra and Castillo-Tejero 1970, p. 316). Basal beds contain some volcanic material (Lopez Ramos, 1956, p. 55) and selenite is common in Huasteca shales, suggesting evaporitic conditions.

The Middle-Upper Oligocene Meson formation comprises sandy, marine clays and sandy limestones with abundant *Lepidocyclina gigas.* Very rapid facies changes are observed in outcrop with sporadic occurrence of coral reefs and channel sands. These facies suggest sedimentation during structural unrest (Muir, 1936 p. 136). Meson sediments are well developed at the north and south ends of the Golden Lane (Fig. 15), but have been eroded in the centre due to post-Miocene folding.

Oligocene sediments thicken rapidly towards the Gulf of Mexico. Beyond the eastern boundary fault of the Golden Lane, the Oligocene and post-Oligocene section thickens enormously (Fig. 4). Well *Triton-1* penetrated 17,000 ft (5,183 meters) of Oligocene and Neogene sediments.

Neogene-Recent

Younger Tertiary sediments thicken into the Gulf of Mexico, and a major expansion fault runs parallel to the coast from the southern end of the marine Golden Lane (Fig. 16) SE-wards to offshore Veracruz (Moore, 1972). Neogene sediments are overlain by Quaternary basalts which erupted through fissures and pipes, many of which cut through the El Abra reservoir of the Old Golden Lane (Fig. 15).

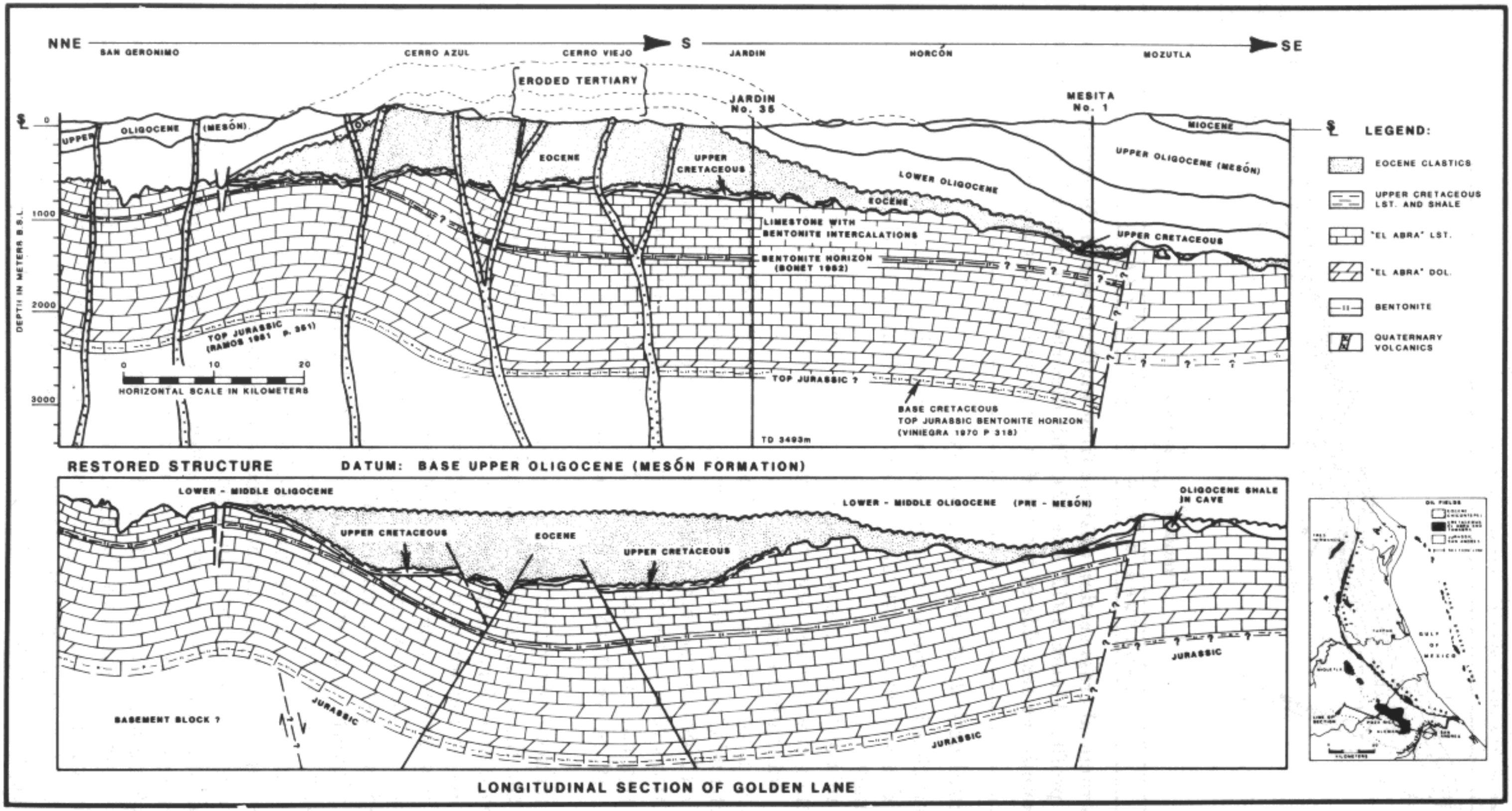


Fig. 15. Longitudinal structural cross-section along the Old and New Golden Lane fields, with palaeostructural restoration on base Upper Oligocene. This illustrates Late Tertiary structural inversion. (Upper panel redrawn and modified from Muir, 1936, Fig. 15, and Viniegra and Castillo, 1970 Fig. 8.)

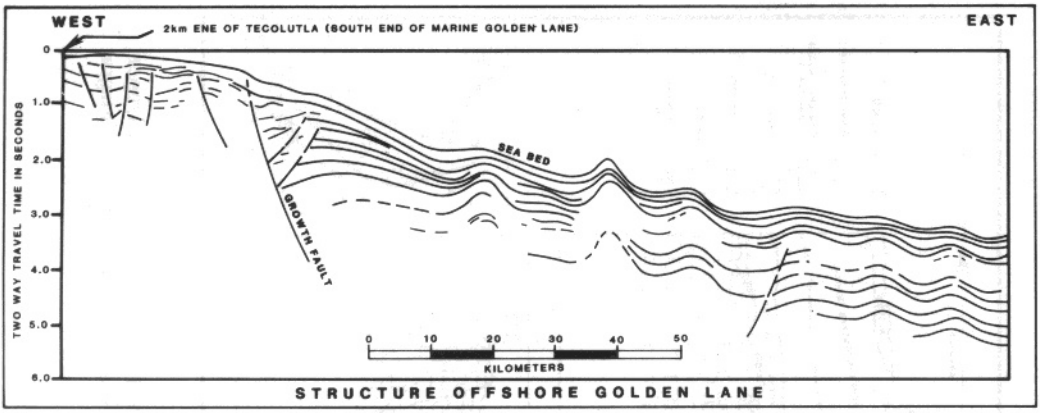


Fig. 16. East-west structural cross-section offshore from southern end of the marine Golden Lane traced from seismic profile (Moore, 1972, line 12). This illustrates the major Neogene growth fault that bounds the east side of the Golden Lane and Recent gravity folds.

Evidence of structural activity during the Tertiary

Structural unrest is clearly evidenced by the pattern of Tertiary sedimentation in the Tampico embayment. An analysis of this structural evolution bears heavily upon the interpretation of the Golden Lane anomaly.

Basal Tertiary Tanlajas beds in the outcrop belt south of Sierra El Abra contain pebbles from the San Felipe formation and many reworked foraminifera from the Mendez formation (Muir, 1936, p. 103, 140) indicating uplift and erosion.

The unconformity at the base of Chicontepec beds in the *Poza Rica* area (Fig. 14) is interpreted by Busch and Govela (1978) as submarine canyon erosion. The same mechanism is proposed by Carrillo (1980) for several palaeocanyons in the Tampico embayment. However, Carrillo's cross-sections NW of the Golden Lane, particularly that between wells *Los Cues-101 and La Laja-1 (op. cit.* Fig. 5) indicate that the basal Eocene unconformity has been folded in Miocene time. If restored to its Eocene position, the channel aspect is largely eliminated.

Published cross-sections show that the Chicontepec beds thicken westwards away from the Golden Lane, and the thickness preserved on top of the Golden Lane is comparable to that present below the west boundary scarp (Fig. 12). This suggests that the lower Eocene has been dislocated by faulting on the western margin of the Golden Lane. The full extent of Lower Eocene deposition is unknown, due to the truncation of steep-dipping beds by erosion on the west (Fig. 12). Prior to Sierra Madre folding, it seems very probable that Lower Eocene deposition extended far west of the present mountain front.

The provenance of quartz sands in the Chicontepec is also though to be from rising basement blocks to the SE and east in the Gulf of Mexico. It is in those directions that pre-Eocene positives had been cut down to expose silicate-rich basement rocks.

Following quiet sedimentation of Guayabal beds during the Middle Eocene, the main pulse of the Sierra Madre orogeny is evidenced by Upper Eocene Tantoyuca conglomerates.

The angularity of limestone elements in the Tantoyuca and the geometry of the deposit over *Poza Rica* suggests active faulting and erosion of a rising Golden Line fault-block (Fig. 12). Similar debris conglomerates present on the east side of the Tamaulipas arch provide evidence for the stripping of rising positives to the east, in the Gulf of Mexico. Late Eocene facies distribution and subcrop relationships suggest that extensional block-faulting was active on the foreland that stretched eastwards from the rising Sierra Madre fold-belt. The eastern side of the Golden Lane was deeply eroded towards the basements positive in the Gulf of Mexico (Carrillo, 1980, p. 49, Fig. 13).

In Oligocene time, this foreland area collapsed, and for the remainder of the Tertiary period sediments were dumped eastward into a rapidly subsiding Gulf of Mexico. Volcanic detritus in Oligocene sediments gives evidence of extensional rifting, presumably to the east, and at the same time there was a major eustatic drop in sea-level (Schlee, 1977). The Oligocene subcrop pattern along the Golden Lane (Fig. 15) indicates that the southern and northern ends were uplifted. Exposed Cretaceous carbonates were subjected to erosion and karstification. At the commencement of Oligocene deposition, the Mesozoic carbonates on the east (marine) side of the Golden Lane were higher than on the west, but by the end of Oligocene time this structural situation had been reversed (Fig. 4).

This structural rotation was accompanied by large-scale extensional faulting as the Gulf of Mexico depocentre developed to receive rapid Neogene sedimentation. In the Quaternary, major volcanic activity gave evidence of the latest extensional tectonic pulse. In Recent time, subsidence of the Gulf of Mexico has exceeded the rate of sedimentation, giving rise to the present deep-water offshore Tampico.

STRUCTURE

From the foregoing discussion on stratigraphy, volcanicity and unconformity relationships, it can be appreciated that the Golden Lane "atoll" is set in a very complex and structurally dynamic environment. Evidence for the sequence of tectonic pulses affecting the region is tabulated on Fig. 17.

Local structural influences in the shaping of the Golden Lane "Atoll"

Descriptions of the Golden Lane "atoll" have generally used its present-day configuration as a guide for the analysis of its evolution during Early Cretaceous time. This approach has proved to be a serious handicap to proper geological interpretation, as can be seen from the Oligocene palaeostructural restorations shown on Figs. 4, 12 and 15 . The eastern boundary of the Golden Lane "atoll" is shown to be faulted by Lopez Ramos (1982, Fig. VI- 16 and 1981, Fig. 3-1) and by Carrillo (1980, Fig. 6A). This faulting is post-Eocene, and can be seen on marine seismic lines (Moore, 1972, lines 8, 10, 12 and 14) as a typical Neogene growth fault (Fig. 16). The expanded Tertiary section on the downthrown side was proven by the *Triton No. 1* deep test (Fig 4).

The west side of the Golden Lane "atoll" also appears to be faulted and tentative faults are indicated by Carrillo (1980 Fig. 6-A). The age of faulting on the west side is interpreted to be late Middle Eocene, judging from the distribution of Tantoyuca conglomerates and eroded Chicontepec beds on the upthrown side (Figs. 4 and 12).

The longitudinal palaeostructural restoration along the Old and New Golden Lane (Fig. 15) shows that the central portion of the ridge was low to the northern and southern extremities that were uplifted and eroded during Late Eocene-Oligocene time. Late Neogene movement uplifted the central portion, and this late uplift is expressed as a structural nose (Alazan Nose, Figs. 1 and 18) in Tertiary outcrops west of the Golden Lane. From these reconstructions, it is clear that the Golden Lane anomaly is structurally diachronous and did not look like an "atoll" in Lower Tertiary time.

The situation in the Cretaceous is still more complex. The presence of Mendez shale on top of the Golden Lane anomaly, and in a comparable thickness below the west ridge, suggests that no bathymetric prominence was present at that time. This supports the Late Eocene origin of the western ridge.

The age relationship of Cretaceous limestones on the Golden Lane to the Tamabra at Poza Rica is obscured by imprecise palaeontological control. It is concluded here that bentonites in both sequences are indicative of Late Cretaceous age. It then follows that the Orbitolinas, of middle Albian age, reported from the upper part of the El Abra in Jardin 35 (Bonet, 1952,

p. 227) must be reworked. This part of the reservoir limestone is, therefore, detrital, and comparable in facies as well as age to the Tamabra at Poza Rica (Fig. 3).

It is reasonable to suppose that repetitive crustal fracturing during the early history of the Golden Lane facilitated the later injection of numerous volcanic dykes and pipes in the Quaternary tectonic pulse.

Regional structural elements that bear upon the evolution of the Golden Lane

The popular interpretation of the Golden Lane as a Lower Cretaceous carbonate build-up from which submarine screes descended, implies structural quiescence. However, from the foregoing discussion on stratigraphy, it seems very probable that the Tamabra debris flows originated from the rising Jalapa high to the SE or from the east-west trending La Aguada horst to the north of *Poza Rica* (Figs. 8 and 9) during early Late Cretaceous tectonic activity. Contemporaneous debris flows with olistostromes in the Xilita area are also interpreted here as resulting from sharp movement on faults, many of which may have been oriented NE-SW as is the case in the Northern (Panuco) fields (Muir, 1936, p. 170).

In a wider regional sense, Late Cretaceous stratigraphic evidence points to the existence of a large positive area in the Gulf of Mexico during Albian time (Lopez Ramos, 1972, Fig. 86) that started to break up by extensional block-faulting and the shedding of carbonate debris during the early Late Cretaceous. This block-faulting became increasingly active during the Early Tertiary, when basement rocks became exposed in the Arenque area and probably far to the east of this control point.

To the west of the Golden Lane, the strong Sierra Madre structural overprint has obscured pre-Upper Eocene structural elements. Nonetheless, the presence of fundamental basement fracture trends is suggested by the trans-Mexico volcanic belt which extends SW-wards from the Jalapa “high” and the major NE-SW trans-isthmus fault-trend that intersects the south coast of Mexico east of Acapulco.

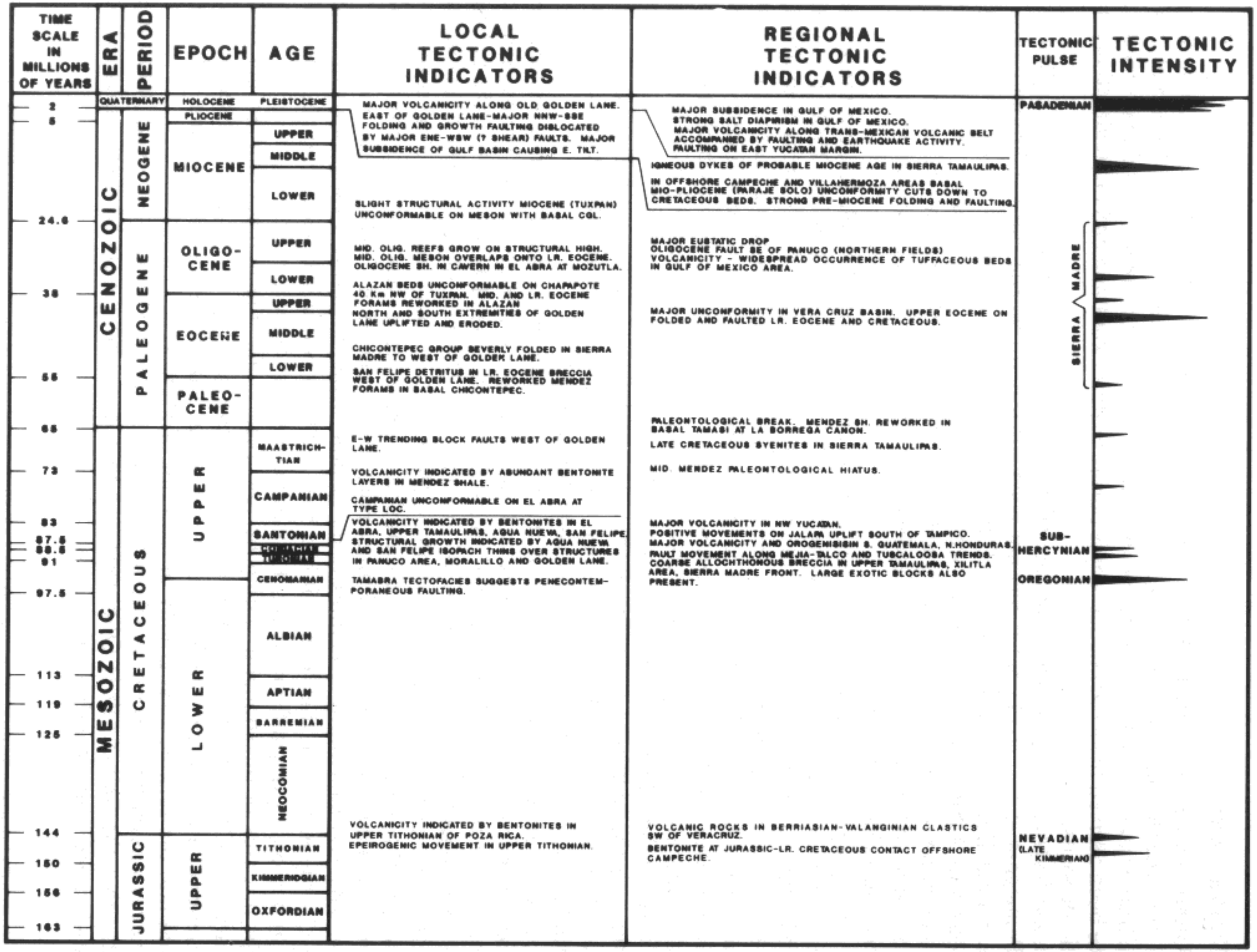
Following the collapse of the Gulf of Mexico positive in Oligocene time, the Late Tertiary sedimentation was accommodated by down-to-the-east extensional faulting. Rapid subsidence in Pleistocene to Recent time caused the development of gravity folds which may be underlain by a décollement plane on Oligocene evaporites or by listric faults.

The strong Pleistocene-to-Recent folding and faulting parallel to the Tampico coast was also accompanied by major NE-SW cross-faulting. One such prominent fracture, here designated the East Tampico Submarine Ridge (Fig. 18), has a bathymetric elevation of 5,800 ft (1,768 m) (Price, 1954, p. 45; Lynch, 1954, p. 75). Similar large Recent cross-faults have also been identified further offshore (Bryant *et al.*, 1968, p. 1215).

The Holocene movements, volcanic activity and earthquakes (Rezak, 1984, Fig. 1) are indicative of current tectonic activity (Fig. 17) which must be taken into account when interpreting the present morphology of the Gulf of Mexico.

The bearing of the Golden Lane structure on the evolution of the Gulf of Mexico

The evolution of the Gulf of Mexico has been discussed in many papers that have utilized seismic stratigraphy as the interpretive tool (e.g. Buffler *et al.* 1980). One of the problems attending seismic stratigraphic interpretation in the southern Gulf of Mexico has been the scarcity of well control on which to anchor the stratigraphy, and this has led to some uncontrolled assumptions. Ever since Jurassic palynomorphs were obtained from the cap rock of Challenger Knoll (Kirkland and Gerhard, 1971), it has been assumed that the salt in the Sigsbee Deep is Jurassic and equivalent to the Louann salt onshore northern Gulf Coast. Because the Sigsbee salt overlies what is interpreted to be oceanic crust (Ibrahim and Uchupi, 1983), it has been concluded that the age of the oceanic crust is pre-Louann and that the sediments that overlie the Sigsbee salt are of Jurassic to Early Cretaceous age (Buffler, 1984).



LOCAL TECTONIC INDICATORS

MAJOR VOLCANICITY ALONG OLD GOLDEN LANE. EAST OF GOLDEN LANE-MAJOR NNW-SSE FOLDING AND GROWTH FAULTING DISLOCATED BY MAJOR ENE-WSW (? SHEAR) FAULTS. MAJOR SUBSIDENCE OF GULF BASIN CAUSING E. TILT.

SLIGHT STRUCTURAL ACTIVITY MIOCENE (TUXPAN) UNCONFORMABLE ON MESON WITH BASAL CGL.

MID. OLIG. REEFS GROW ON STRUCTURAL HIGH. MID. OLIG. MESON OVERLAPS ONTO LR. EOCENE. OLIGOCENE SH. IN CAVERN IN EL ABRA AT MOZUTLA.

ALAZAN BEDS UNCONFORMABLE ON CHAPAPOTE 40 Km NW OF TUXPAN. MID. AND LR. EOCENE FORAMS REWORKED IN ALAZAN

NORTH AND SOUTH EXTREMITIES OF GOLDEN LANE UPLIFTED AND ERODED.

CHICONTEPEC GROUP SEVERLY FOLDED IN SIERRA MADRE TO WEST OF GOLDEK LANE.

SAN FELIPE DETRITUS IN LR. EOCENE BRECCIA WEST OF GOLDEN LANE. REWORKED MENDEZ FORAMS IN BASAL CHICONTEPEC.

E-W TRENDING BLOCK FAULTS WEST OF GOLDEN LANE.

VOLCANICITY INDICATED BY ABUNDANT BENTONITE LAYERS IN MENDEZ SHALE.

CAMPANIAN UNCONFORMABLE ON EL ABRA AT TYPE LOC.

VOLCANICITY INDICATED BY BENTONITES IN EL ABRA, UPPER TAMAULIPAS, AGUA NUEVA, SAN FELIPE. STRUCTURAL GROWTH INDICATED BY AGUA NUEVA AND SAN FELIPE ISOPACH THINS OVER STRUCTURES IN PANUCO AREA, MORALILLO AND GOLDEN LANE.

TAMABRA TECTOFACIES SUGGESTS PENECONTEMPORANEOUS FAULTING.

VOLCANICITY INDICATED BY BENTONITES IN UPPER TITHONIAN OF POZA RICA.
EPEIROGENIC MOVEMENT IN UPPER TITHONIAN.

REGIONAL TECTONIC INDICATORS

MAJOR SUBSIDENCE IN GULF OF MEXICO.
STRONG SALT DIAPIRISM IN GULF OF MEXICO.
MAJOR VOLCANICITY ALONG TRANS-MEXICAN VOLCANIC BELT ACCOMPANIED BY FAULTING AND EARTHQUAKE ACTIVITY.
FAULTING ON EAST YUCATAN MARGIN.

IGNEOUS DYKES OF PROBABLE MIOCENE AGE IN SIERRA TAMAULIPAS.

IN OFFSHORE CAMPECHE AND VILLAHERMOZA AREAS BASAL MIO-PLIOCENE (PARAJE SOLO) UNCONFORMITY CUTS DOWN TO CRETACEOUS BEDS. STRONG PRE-MIOCENE FOLDING AND FAULTING.

MAJOR EUSTATIC DROP
OLIGOCENE FAULT SE OF PANUCO (NORTHERN FIELDS)
VOLCANICITY - WIDESPREAD OCCURRENCE OF TUFFACEOUS BEDS IN GULF OF MEXICO AREA.

MAJOR UNCONFORMITY IN VERA CRUZ BASIN. UPPER EOCENE ON FOLDED AND FAULTED LR. EOCENE AND CRETACEOUS.

PALEONTOLOGICAL BREAK. MENDEZ SH. REWORKED IN BASAL TAMASI AT LA BORREGA CANON.

LATE CRETACEOUS SYENITES IN SIERRA TAMAULIPAS.

MID. MENDEZ PALEONTOLOGICAL HIATUS.

MAJOR VOLCANICITY IN NW YUCATAN.
POSITIVE MOVEMENTS ON JALAPA UPLIFT SOUTH OF TAMPICO.
MAJOR VOLCANICITY AND OROGENISISIN S. GUATEMALA, N.HONDURAS.
FAULT MOVEMENT ALONG MEJIA-TALCO AND TUSCALOOSA TRENDS.
COARSE ALLOCHTHONOUS BRECCIA IN UPPER TAMAULIPAS, XILITLA AREA, SIERRA MADRE FRONT. LARGE EXOTIC BLOCKS ALSO PRESENT.

VOLCANIC ROCKS IN BERRIASIAN-VALANGINIAN CLASTICS SW OF VERACRUZ.

BENTONITE AT JURASSIC-LR. CRETACEOUS CONTACT OFFSHORE CAMPECHE.

Fig. 17. Chart tabulating evidence for tectonic pulses in the Tampico embayment and surrounding region from Jurassic to Recent time.

There are two points for discussion that relate to this interpretation: first—how reliable is the dating of salt in the Sigsbee and Campeche-Salina salt provinces? and second — what does the structural interpretation of the Golden Lane area suggest in regard to the evolution of the Gulf of Mexico?

Age of Sigsbee Salt

The Author-pointed out earlier (Wilson, 1975) that age determinations from salt-dome caprock are not reliable indicators of the age of the salt. The insoluble residue in cap rock can originate from material plucked from below the salt or from resedimented detrital material that may have been derived from basin-edge wadis during eustatic lowstand and intercalated in the evaporitic deposits.

An exotic fragment of Carboniferous age siltstone was dredged from another Challenger Knoll (Pequegnat *et al.*, 1971) but it has not been suggested that the salt is Carboniferous.

In the Salina Basin of the Isthmus of Tehuantepec, palynomorphs of Jurassic to Early Cretaceous and Albian-Cenomanian age were extracted from cores taken in the salt. Late Cretaceous foraminifera have been obtained from shales within the salt (Contreras and Castillon, 1968). Also, shales yielding a Tertiary fauna have been found intercalated in the salt (Castillon and Larios 1963, p. 276).

Strata overlying the salt have yielded Late Cretaceous fauna in a few places, but these are commonly mixed with Eocene and Oligocene forms (Contreras and Castillon, 1968, p. 248). Such mixed faunas are a clear indication of reworking, and the age of containing sediments, therefore, cannot be older than Oligocene. The data that support an Oligocene age for the salt in the Salina Basin (Wilson, 1975 and 1977) have been disregarded in subsequent interpretations of the Gulf of Mexico. A more recent interpretation of the Salina salt-basin which integrates gravity and magnetic data with subsurface control shows enormous extensions of relatively flat-lying salt within the Oligocene (Fig. 19). Two wells, *Gurumal No. 1* and *Rabasa No. 1,* have drilled through the salt near Coatzacoalcos and provide stratigraphic control (Correa and Gutierrez, 1983). The huge blankets of salt within the Oligocene are shown to be fed by hypothetical vents from a hypothetical Jurassic “mother-salt”.

The basis for Jurassic dating of the salt in the Salina Basin is based upon questionable correlation of barren red-beds within the salt with barren red-beds of the Todos Santos formation outside the basin. Expectation of an enormous expanse of Jurassic salt in the Salina Basin is questionable, not only in view of the apparent absence of all Lower Cretaceous sediments in the basin (Contreras and Castillon, 1968, p. 259), but also because the severely-broken nature of Mesozoic carbonates in surrounding areas argues against the preservation of an extensive blanket of Jurassic salt. Futhermore, the attenuation of Oligocene and Lower Miocene beds over salt-pillow structures in the Salina Basin (Acevedo, 1980) shows that the salt was already in place at that time. If it had been fed from below in Oligocene time, it would have extruded onto the sea-floor where it could not have avoided dissolution.

Except in cases of questionable dating by reworked fauna, the non-piercing Salina salt-masses are overlain by Oligocene—Lowermost Miocene age Deposito or Encanto sediments. The presence of a widespread blanket of salt in the Oligocene of the Salina Basin has not been integrated into the seismic stratigraphy of the Gulf of Mexico.

For the reasons outlined above, and from previous publications (Wilson 1975 and 1977), it is concluded that the Salina salt is Oligocene and that it can be correlated northwards to the offshore Campeche and Sigsbee salt-basins.

Integration of the structural interpretation of the Golden Lane with the evolution of the Gulf of Mexico

Although many uncertainties still surround any interpretation of the structural evolution of the Golden Lane and its surroundings, there remains little doubt that repetitive tectonic forces

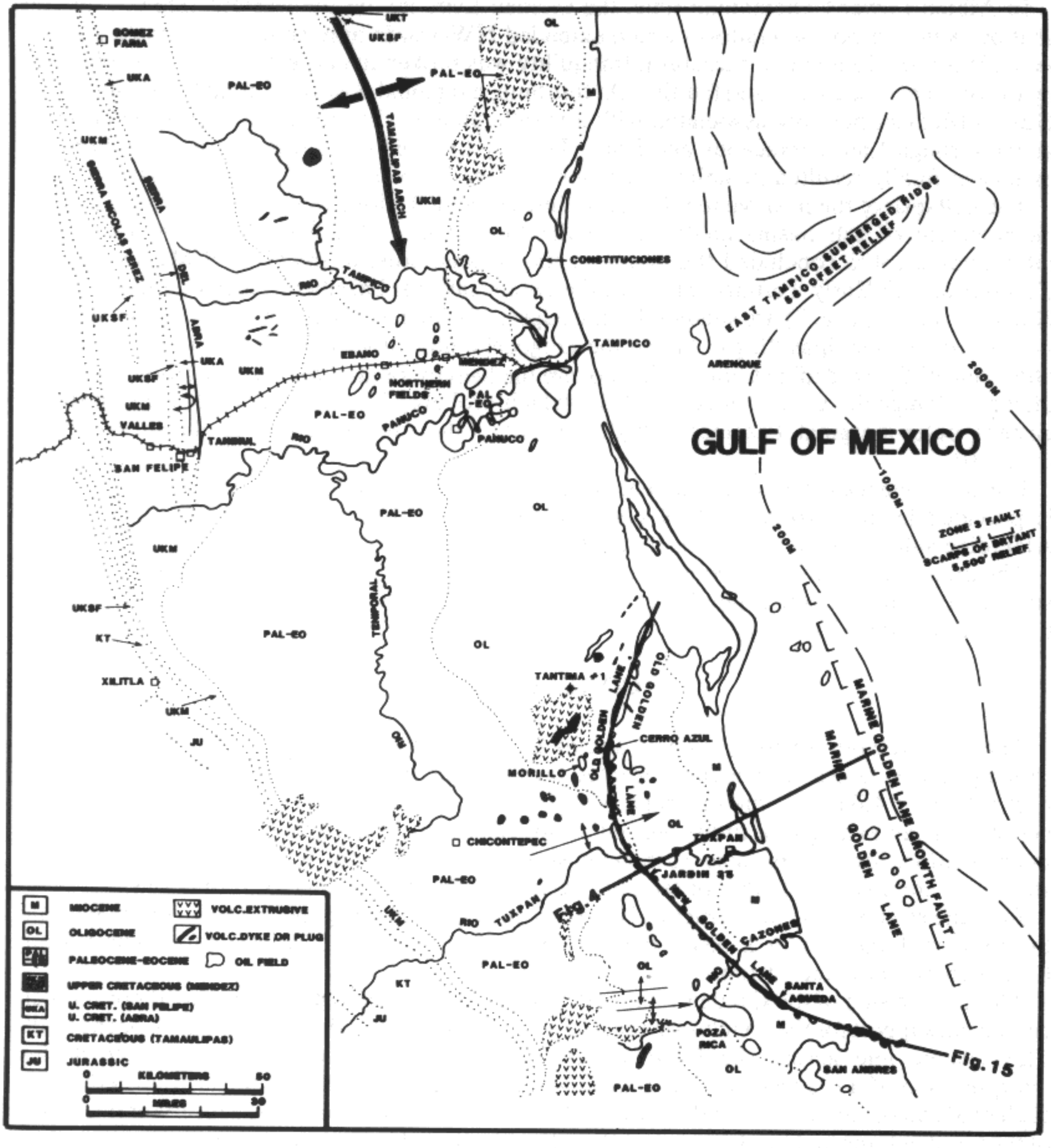


Fig. 18. Geological map of the Tampico embayment showing major structural features and the location of Golden Lane and Northern (Panuco) oilfields. Bathymetric contours show the position of the East Tampico Submarine Ridge.

were a dominant factor in the moulding of this anomaly. The evidence presented herein suggests the following evolutionary relationship of the Golden Lane to the bordering Gulf of Mexico.

In Albian-Lower Cenomanian time, the Golden Lane lay on the western side of a broad, shallow water carbonate platform which extended NW-wards from southern Yucatan and the Peten Basin of Guatemala. Structural tranquillity was broken in earliest Late Cretaceous time by the onset of volcanicity and faulting. At this time, a regional positive started to develop in the Gulf of Mexico, possibly associated with a mantle plume. This positive became increasingly active through Late Cretaceous and Early Tertiary time. Block-faulting, erosion and crustal extension finally resulted in sialic separation and the introduction of oceanic crust.

The collapse of the positive in Oligocene time coincided with a major eustatic drop, and the development of salt basins analogous to the Messinian of the Mediterranean. From this interpretation, it is concluded that much of the oceanic crust in the Gulf of Mexico is Late Cretaceous and Early Tertiary, and that the outer marginal basement "highs" interpreted by Hall *et al.* (1983, Fig. 3) are sundered sialic edges, of which we catch a glimpse in the Arenque —offshore Tamaulipas "high" below the Oligocene unconformity (Figs. 9 and 14). On the other side of the spreading Gulf of Mexico, are the heavily-faulted Mesozoic carbonates of the offshore Campeche area (Viniegra, 1981), which probably bear a similar relationship to the eastern outer-marginal basement "high", as does the Golden Lane to the western one (Fig. 20).

Further evidence for the development of Late Cretaceous oceanic crust in the Gulf of Mexico is provided by the exotic block of Campanian age basalt recovered from the cap-rock of Alderdice salt dome on the Louisiana continental shelf (Rezak and Tieh, 1984).

The presence of transform faults as suggested by Hall *et al.,* (1983) is also supported by the structural evolution of the Jalapa "high", the trans-Mexican volcanic belt and the East Tampico bathymetric ridge (Fig. 18).

CONCLUSIONS

The interpretation of the Golden Lane as a great Lower Cretaceous atoll with attendant fringing detrital facies has become accepted through repetition in geological literature over the past 60 years. Likewise, the outcrops of rudistid limestone at Sierra El Abra have become accepted as an example of rudist reef build-up, analogous to the Golden Lane. These earlier interpretations over-emphasize carbonate stratigraphy, and fail to consider the effects of structural architecture, timing of tectonic events and the precise age of formations.

Both the stratigraphic and structural evidence discussed in this paper leave no doubt but that the Golden Lane lies in a basin that was repetitively affected by structural pulses from Cenomanian until Recent time.

The eastern side of the Golden Lane is defined by a major Neogene fault, and there is much geological support for the conclusion that the western side is bounded by a Middle Eocene fault. The seismic line across the Golden Lane (Fig. 21) certainly does not contradict this interpretation. If it is accepted that volcanicity in the Tampico embayment, as elsewhere in the Gulf of Mexico, commenced in the Late Cretaceous, then at least part of the reservoir limestone of the Golden Lane and the Tamabra of Poza Rica are Late Cretaceous detrital carbonates. The El Abra and Taninul limestones are older (Albian-Lower Cenomanian). The origin of these detrital carbonates may have been from active structural positives in the Gulf of Mexico, or from crossing uplifts such as the La Aguada (Fig. 8) or Jalapa highs (Fig. 1).

In Oligocene time, the north and south ends of the Golden Lane were structurally high, whereas the center was only elevated in Neogene time.

Despite the contrary view of some geologists (Mitchell-Tapping, 1984), the rudist reef carbonate build-up concept has spread from its conceptional cradle in the Golden Lane and Sierra El Abra to Cretaceous carbonate provinces around the world. In almost all instances, interpretations of build-ups are made without consideration of paleostructural effects.

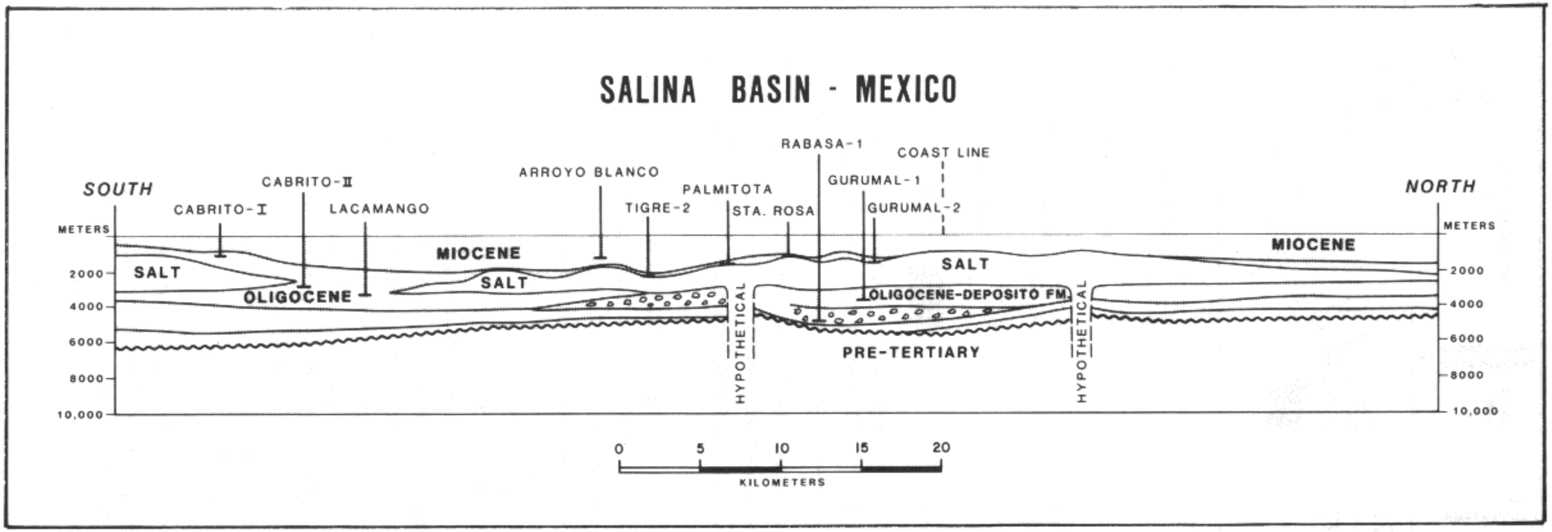


Fig. 19. North-south structural cross-section of the Salina Basin onshore and offshore showing the configuration of the salt within Oligocene sediments and the position of two wells that penetrated the salt blanket. (Redrawn and modified for Correa and Gutierriz y Acosta, 1983, Fig. 10.) Section location on Fig. 21.

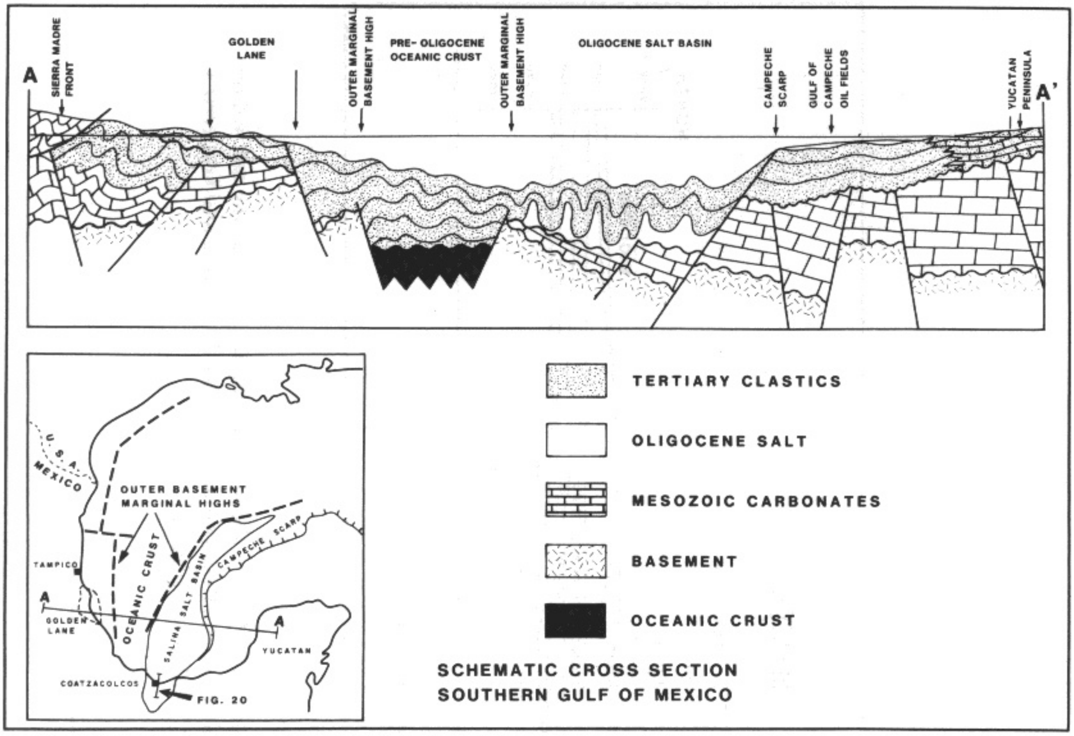


Fig. 20. East-west regional structural cross-section from the Golden Lane to Yucatan. This illustrates the Author's interpretation of the Late Cretaceous-Tertiary extensional evolution of the Southern Gulf of Mexico. (Position of Outer Marginal Basement "highs" from Hall *et al.*, 1983 Fig. 3).

Carbonate margins from the Gulf of Mexico to the Atlantic offshore have been interpreted as build-ups, and the element of extensional palaeofaulting downplayed or disregarded (Schlee and Grow, 1980). On passive continental margins that are undisturbed by extensional block-faulting, there are no spectacular carbonate "build-ups", a point that is well-exemplified in the Lower Cretaceous of Northern Mexico (Wilson and Pialli, 1977, p. 292).

Despite demonstrable Holocene tectonic activity and spectacular submarine scarps in clastic sediments, such as that east of Tampico (Fig. 18), the Carbonate margins of Florida and Campeche are generally regarded as build-ups rather than fault-scarps, although the latter possibility is grudgingly admitted (Mitchum 1978 p. 202; Mullins *et al.*, 1986 p. 170).

It is concluded that the Golden Lane is a severely-weathered diachronous block-faulted feature, and that its structural prominence has nothing to do with carbonate sedimentary construction. The carbonate reservoir is probably Upper Cretaceous in age along the western side of the uplift, and Lower Cretaceous on the eastern side.

The Albian-Cenomanian limestones exposed at Sierra El Abra display no marked sedimentological anomaly when Laramide folding is removed, and the structure restored on the basal Mendez unconformity (Fig. 3).

The source of hydrocarbons in the Golden Lane is considered to be the richly petroliferous Eocene-Oligocene sequence that overlies and abuts the leached carbonates (Wilson, 1975 p. 72), in analogy with the *Casablanca* field offshore Spain (Watson, 1982, Fig. 15). The same source-reservoir relationships probably apply also to the prolific *Campeche* offshore fields.

The structural evolution of the Golden Lane is intimately bound-up with Late Cretaceous-Early Tertiary regional extensional tectonics, through which the southern Gulf of Mexico was formed.

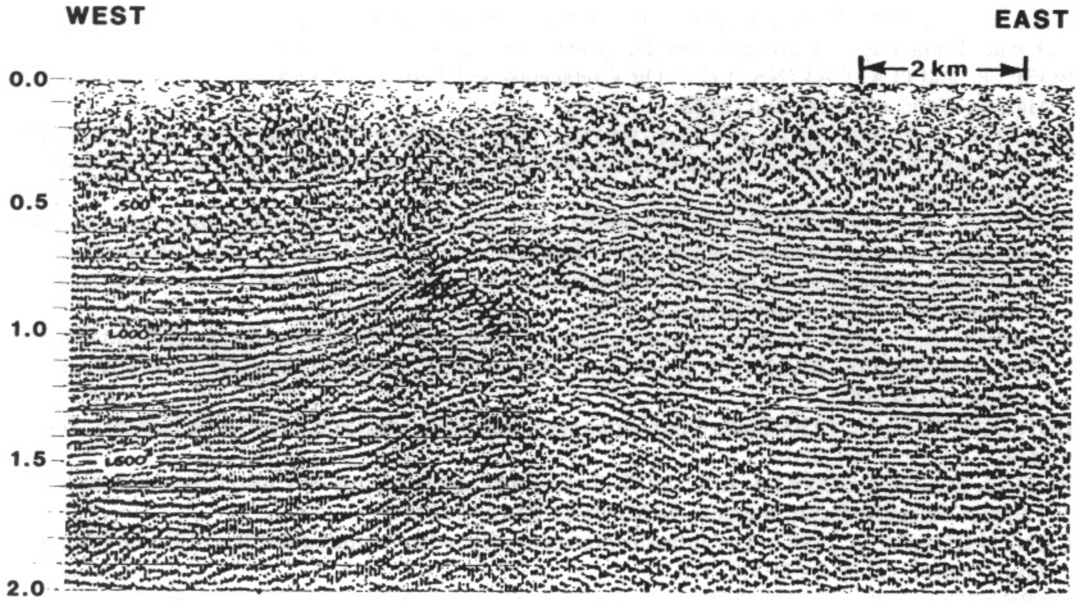


Fig. 21. Seismic profile over the west side of the Golden Lane (exact location unknown). Dark outline of supposed El Abra reef between 0.65 and 1.0 sec. has been superimposed (Sheriff, 1980, Fig. 5.12).
Reproduced by kind permission of R.E. Sheriff.

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