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A model for the early evolution of the Gulf of Mexico basin

Gulf of Mexico
Seismic data
Rifting phase
Subsidence
Drift
Golfe du Mexique
Données sismiques
Phase de distension
Subsidence
Déplacement

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ABSTRACT

Seismic reflection and refraction data from the deep Gulf of Mexico basin constrain the early geologic evolution of the basin. Major observations involving distribution of the crust, nature and distribution of the early sediments, and subsidence history are as follows : 1) inferred oceanic crust in the deep central Gulf (5 to 6 km thick ; 6.8 to 7.1 km/sec.) is flanked symmetrically on the north and south by inferred transitional crust (8 to 15 km thick ; 6.4 to 6.8 km/sec.) ; 2) acoustic basement seen on the reflection data in the central Gulf is an irregular reflector and probably represents the top of an oceanic volcanic (basaltic) layer (layer 2) ; 3) north of the Campeche Escarpment the top of transitional crust is represented by a strong, smooth reflector/unconformity that truncates rift basins and is onlapped by a thick salt and sedimentary section ; 4) in the southeastern Gulf transitional crust consists of tilted basement blocks probably representing a thinned and rifted continental crust ; lows between the blocks are filled with synrift sediments ; 5) thick salt symmetrically flanks the north and south sides of the oceanic crust ; 6) seismic stratigraphic analysis suggests that early sediments in the Gulf in areas of transitional crust represent an upward gradation from volcanics and nonmarine sediments including evaporites to shallow marine and then to deep marine ; only deep marine sediments occur in the central Gulf overlying oceanic crust.

These data suggest the following evolutionary sequence. The early Gulf of Mexico basin evolved as a divergent (passive) continental margin at the same time and by the same mechanisms as the North-Atlantic margin, including the formation of new oceanic crust. We speculate that a *rift phase* during the Triassic-Jurassic was accompanied by widespread doming, rifting, and filling of rift basins with volcanics and nonmarine rocks as North America began separating from Africa-South America. Formation of the thinned transitional crust occurred during this period. During the latter part of this phase (Middle-Late Jurassic) the Gulf area broke up into a series of separate subsiding basins ; in some of these basins thick salt was deposited in shallow marine environments. A *drift and subsidence phase* began in Late Jurassic time (approximately 150 my B.P.) with major rifting of the central Gulf and formation of new ocean crust. The Yucatan block probably moved away from North America along NW-SE trending flow lines parallel to the North-Atlantic fracture zones, separating the salt basin on either side of the new crust. Spreading apparently was brief, but the basin continued to subside rapidly due to thermal cooling of the lithosphere. Subsidence was accompanied by gravity flowage of salt into the basin and the extensive buildup of carbonate margins along a tectonic hinge zone near the periphery of the basin. Shallow- to deep-water sediments were deposited along the margins of the basin, while only deep-water sediments were deposited in the newly-formed ocean basin. The early evolution of the basin ended with a major middle Cretaceous event that produced a prominent Gulf-wide unconformity. Total subsidence of the basin since formation of the ocean crust has been up to 10 km, partly due to sediment loading and partly due to cooling of the lithosphere.

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RÉSUMÉ

Modèle de l'évolution initiale du bassin du Golfe du Mexique

Les données de sismique réflection et réfraction du bassin profond du Golfe du Mexique fournissent des guides pour le modèle d'évolution géologique initiale du bassin. Les principales observations, incluant la géométrie de la croûte, la nature et la répartition des sédiments initiaux sont les suivantes : 1) la croûte océanique supposée dans la partie centrale profonde du Golfe (5 à 6 km d'épaisseur ; 6,8 à 7,1 km/s) est bordée symétriquement au Nord et au Sud par une croûte supposée de transition (8 à 15 km d'épaisseur ; 6,4 à 6,8 km/s) ; 2) le substratum acoustique visible sur les données de sismique réflection dans le Golfe central est un réflecteur irrégulier représentant probablement le toit d'un niveau volcanique (basaltique) correspondant à la couche 2 ; 3) au nord de l'escarpement de Campèche, le toit de la croûte transitionnelle est représenté par un fort réflecteur/discontinuité régulier qui limite les bassins du rift et est surmonté d'une épaisse couche de sel et de sédiments ; 4) dans le Golfe méridional, la croûte de transition est constituée de blocs de substratum basculés correspondant probablement à une croûte continentale amincie et effondrée ; les creux entre les blocs sont comblés par les sédiments syn-rift ; 5) l'horizon salifère borde symétriquement les extrémités nord et sud de la croûte océanique ; 6) la stratigraphie sismique montre que les sédiments du Golfe dans les zones de croûte transitionnelle représentent une évolution verticale depuis les volcanites et les sédiments continentaux, y compris les évaporites, vers des faciès marins de faible profondeur, puis des sédiments à grande profondeur de dépôt, ces derniers reposant directement sur la croûte océanique dans le Golfe central.

Ces données suggèrent le schéma d'évolution suivant : le bassin initial correspondant au Golfe du Mexique a évolué comme une marge continentale divergente (passive), à la même époque et suivant les mêmes mécanismes que la marge nord-atlantique, y compris la formation de croûte océanique. Nous supposons qu'une *phase de distension* ("rift") Triassico-Jurassique a été accompagnée d'un bombement généralisé, une distension et un comblement de bassins de rift par des volcanites et des roches d'origine terrestre lorsque l'Amérique du Nord s'est séparée de l'ensemble Afrique-Amérique du Sud. La formation de la croûte de transition amincie a eu lieu pendant cette période.

Pendant l'ultime étape de cette phase (Jurassique moyen-supérieur) le Golfe s'est morcelé en une série de bassins subsidents séparés ; dans certains d'entre eux, un épais horizon de sel s'est déposé dans un environnement marin de faible profondeur. Une *phase de subsidence et de déplacement* ("drift") a débuté au Jurassique supérieur, il y a environ 150 millions d'années avec une distension majeure du Golfe central et la formation d'une croûte océanique nouvelle. Le bloc Yucatan s'est probablement déplacé depuis l'Amérique du Nord suivant une direction NO-SE parallèle aux failles transformantes de l'Atlantique Nord, en séparant le bassin salifère de chaque côté de la nouvelle croûte océanique. L'accrétion fut apparemment brève, mais le bassin a continué à subsider rapidement du fait du refroidissement de la lithosphère. La subsidence a été accompagnée d'un fluage par gravité du sel dans le bassin et de la mise en place d'une marge carbonatée tout le long d'une zone tectonique charnière à la périphérie du bassin. Des sédiments d'eau peu profonde à profonde se sont déposés le long des marges du bassin, tandis que seuls des sédiments de grande profondeur se sont déposés dans le bassin océanique nouvellement créé. L'évolution initiale du bassin s'est terminée au Crétacé moyen, lors d'un événement d'importance majeure souligné par une forte discontinuité à l'échelle du Golfe tout entier. La subsidence totale du bassin depuis la formation de la croûte océanique a été supérieure à 10 km, en partie à cause de la charge sédimentaire et en partie à cause du refroidissement de la lithosphère.

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INTRODUCTION

The University of Texas Marine Science Institute-Galveston Geophysics Laboratory — (UTMSI-GGL) began in 1974 a long-term project to study the geologic history of the deep Gulf of Mexico basin and adjacent margins using new seismic reflection and refraction techniques. Since then, UTMSI-GGL has collected nearly 30,000 km of multifold (12-fold and 24-fold) seismic reflection data and 12 ocean bottom seismograph (OBS) reversed refraction profiles (Fig. 1). These new data allow additional insights into the deep structure and stratigraphy of the region.

Recent plate reconstructions based on paleomagnetic data suggest various Triassic-Early Jurassic overlaps of South America with central Mexico, Yucatan, and portions of the Gulf (Ladd, 1976 ; Van der Voo *et al.*, 1976 ; Pilger, 1978 ; Gose *et al.*, 1980). These reconstructions plus other structural and stratigraphic data, mainly from the periphery of the Gulf, have led various authors to propose models for the origin of the Gulf that involve movement of the Yucatan block away from North America with an associated generation of new oceanic crust sometime during the Triassic-Jurassic (Humphris, 1978 ; Buffler *et al.*, 1980 ; Dickinson, Coney, 1980 ; Salvador, 1980 ; Walper, 1980). These movements took place and were caused by the same mechanisms involved with the early rifting and opening of the North-Atlantic as Africa-South America began moving away from North America. Yucatan could have moved either independently or as part of South America.

The UTMSI-GGL seismic reflection and refraction data provide some new physical constraints that have to be considered in any model for the evolution of the Gulf. Major features include : 1) the seismic character and distribution of inferred oceanic vs. transitional crust in the central Gulf ; 2) the nature and distribution of early sediments overlying the crust, especially the symmetrical distribution of salt on either side of oceanic crust ; and 3) the inferred subsidence history of the basin. These data tend to corroborate the basic model that the present Gulf first evolved as a divergent (passive) continental margin at the same time and by the same mechanism as the early evolution of the North-Atlantic margin. In contrast to the Atlantic margin, however, formation of ocean crust in the Gulf aborted early, although the basin continued to subside as the lithosphere cooled and was loaded by sediments. Each of the three major features are discussed in more detail below. This is followed by a brief discussion of some of the details of the model as based on the new seismic data.

DISTRIBUTION OF CRUST

Previously published refraction data first suggested that part of the southern deep Gulf north of the Campeche Escarpment is underlain by a relatively thin "transitional" crust (8 to 15 km thick with velocities 6.4 to 6.8 km/sec.) which thins northward to an "oceanic" crustal layer in the northern deep Gulf 5 to 6 km thick with velocities 6.8 to 7.1 km/sec. (Ewing *et al.*, 1960 ; 1962 ; Antoine, Ewing, 1963). A similar crustal structure was later identified in the southwestern Gulf (Swolfs, 1967).

In 1978, UTMSI-GGL shot 12 reversed refraction profiles in the Gulf using ocean bottom seismographs (OBS) and

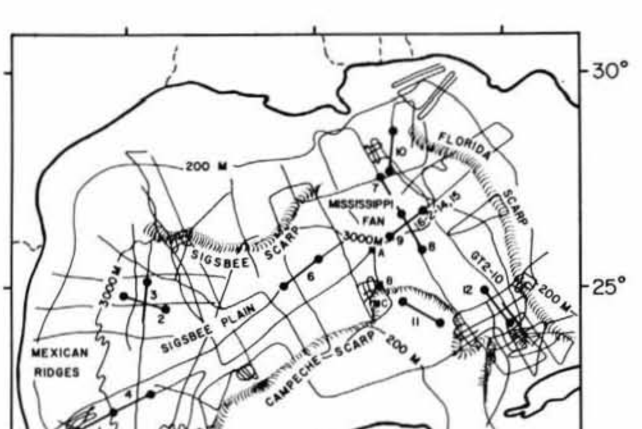

Figure 1

Map of Gulf of Mexico area showing location of UTMSI-GGL multifold seismic lines and OBS refraction profiles. Heavy line along Line GT2-10 is location of Figure 5. Letters A-D indicate control points used in Figure 7.

explosive charges to better define the deep crustal structure. The profiles were located along multifold seismic lines (Fig. 1). These data seem to corroborate the idea that two types of crust, oceanic and transitional, do underlie the deep Gulf. These terms, therefore, as defined generally above by thickness and velocity, are adopted for use in this discussion, although we realize the origin of the crust is still controversial.

The new OBS data help outline better the general distribution of the two types of crust in the deep Gulf. Two structure sections summarizing some of the data are presented in Figure 2. The long E-W section suggests that the oceanic-type crust extends the entire length of the basin from beneath the Mississippi Fan to the southwestern Gulf. The N-S section suggests that oceanic crust beneath the eastern Gulf thickens both north and south into some kind of transitional crust (Fig. 2). A more detailed summary of the new refraction data is presented by Ibrahim *et al.* (in press).

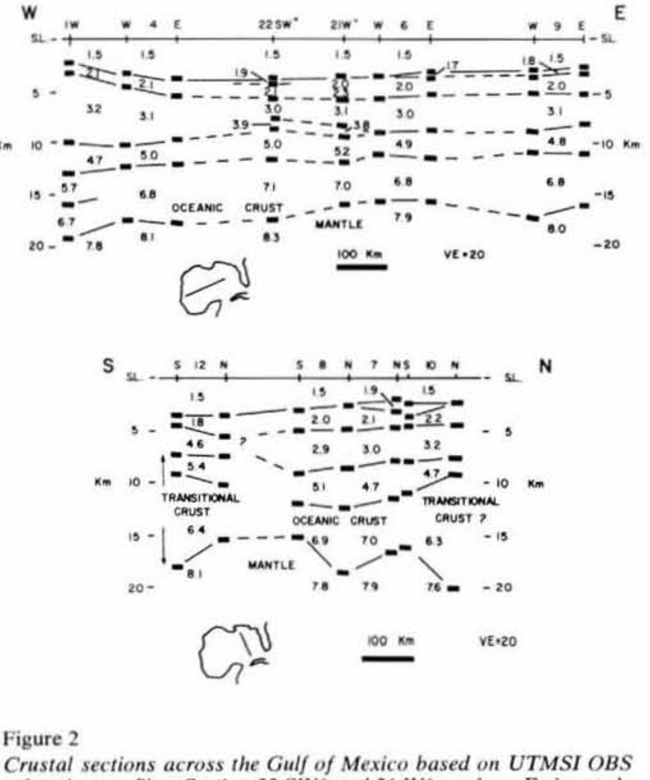

Figure 2

Crustal sections across the Gulf of Mexico based on UTMSI OBS refraction profiles. Station 22 SW and 21 W* are from Ewing* et al. *(1960, 1962). Velocities are in km/sec. See Figure 1 for location of OBS profiles.*

A map showing the generalized distribution of inferred oceanic vs. transitional crust is included as Figure 3. This map is based both on the published and OBS refraction data (bars on Fig. 3) as well as the seismic reflection data (Fig. 1). This distribution is fairly well controlled over most of the basin except in the northern part beneath the Texas-Louisiana slope. Here a thick deformed salt and sedimentary section masks any deep seismic reflection and refraction data. The presence and distribution of transitional crust, therefore, is highly tentative. It is based mainly on the assumption that the salt underlying the slope is somewhat autochthonous and was deposited on transitional crust. The former assumption is still somewhat speculative, while the latter is based on analogy with the deep southern Gulf (discussed below). If these assumptions are close to correct, there appears to be a fair degree of symmetry in the distribution of transitional crust on either side of the oceanic crust (Fig. 3).

An acoustic basement seen on the multifold seismic data over most of the central and eastern deep Gulf is interpreted to represent the top of the crust or basement. It has different characteristics in different areas, which provides data to better define the distribution of the crust (Fig. 3).

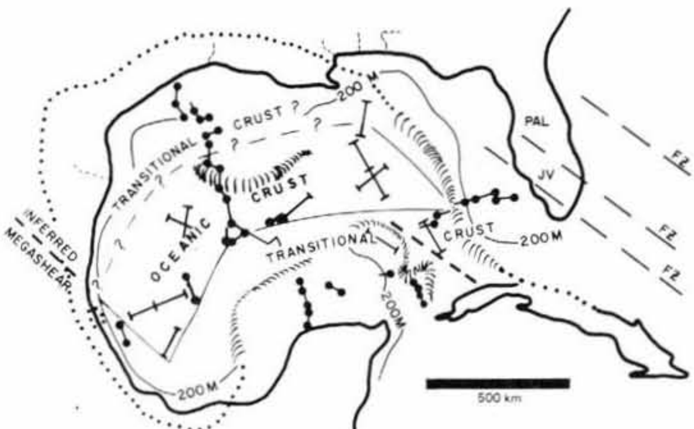

Figure 3

Map showing generalized distribution of oceanic vs. transitional crust in the central Gulf of Mexico basin based on seismic reflection data and refraction data. Bars with dark circles represent published refraction data. Heavy dashed line in southeastern Gulf represents trend of major structural boundary. Long dashed lines represent trend of North Atlantic fracture zones (FZ). JV indicates area of Jurassic volcanics in the subsurface of southern Florida lying south of Paleozoic rocks (PAL). Dotted line represents trend of middle Cretaceous carbonate margin around periphery of Gulf basin.

In areas underlain by the oceanic crustal layer defined by refraction data, acoustic basement is characterized by a very irregular, high-amplitude reflector. In the central Gulf the reflector has considerable relief (up to 1 km). An example is discussed by Buffler *et al.* (1980). In the eastern Gulf the relief is much more subdued, although local high relief features occur. An example of a seismic line in the eastern Gulf along OBS-9 is shown in Figure 4. Note that the acoustic basement occurs beneath the 4.8 km/sec. refraction layer and that the top of the oceanic crustal layer (6.8 km/sec.) occurs below the acoustic basement. Comparison of refraction data and reflection data indicates that this relationship holds true for most of the region.

The seismic characteristics of this acoustic basement in the deep Gulf are somewhat similar to the top of oceanic volcanic layer (layer 2) in other basins. We interpret the top of this acoustic basement, therefore, to be the top of a volcanic (basaltic) layer and the 6.8 km/sec. layer to represent oceanic layer 3 in typical ocean basins (e.g., Worzel, 1974). Evidently, the volcanic layer is too thin and too close in velocity to the overlying sediments to be distinguished as a separate layer on the refraction data. Also, the top of the 6.8 km/sec. layer does not appear to produce a reflector on the reflection data.

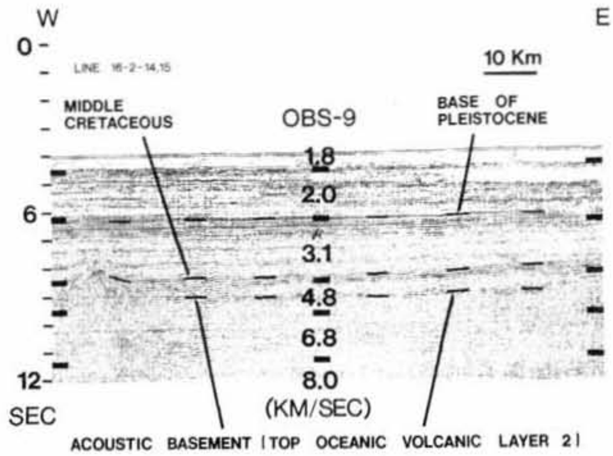

Figure 4

Portion of multifold seismic line 16-2-14, 15 along OBS-9 (see Fig. 1 for location). Top of 4,8 km/sec. layer corresponds with major middle Cretaceous reflector/unconformity. Acoustic basement occurs beneath the 4,8 km/sec. layer and is interpreted to represent the top of oceanic volcanic layer 2.

Alternatively, the irregular acoustic basement in the oceanic part of the deep Gulf could represent the top of a thin salt layer with the relief being local salt pillows. The seismic reflection characteristics are very similar to those observed for the top of salt domes and pillows in the salt provinces to the south and north. The lack of any well substantiated salt dome in the area, however, plus the absence of a smooth, sub-salt reflector seen throughout the southern salt province (discussed below and by Buffler *et al.*, 1980), suggests an interpretation that salt is absent here.

In the area underlain by inferred transitional crust north of the Campeche Escarpment (Fig. 3) acoustic basement is characterized by a high-amplitude, relatively smooth, basinward-dipping reflector that corresponds approximately to the top of the 6.4 to 6.8 km/sec. transitional crustal layer. The reflector represents a major unconformity, as the overlying salt and sedimentary section onlap and pinch out against it. Over most of the area the reflector is truly acoustic basement, but locally it truncates older sedimentary sequences interpreted to be rift basins (Ladd *et al.*, 1976 ; Watkins *et al.*, 1977 ; Buffler *et al.*, 1980). This area is discussed in more detail by Buffler *et al.* (1980).

Acoustic basement in the area underlain by transitional crust in the southeastern Gulf (Fig. 3) has an entirely different character. Here the surface has an irregular, rugged, blocky topography. The area appears to consist of tilted basement blocks suggesting rotation along listric faults, and it is interpreted to represent highly rifted and attenuated upper continental crust. Lying within the blocks are basins filled with thick syn-rift sediments. A major NW-SE trending structural boundary (heavy dashed line on Fig. 3) separates the region into two major structural provinces. Southwest of the boundary, tilted basement blocks occur almost at the seafloor and are capped with only a thin sediment cover. Northeast of the boundary the irregular basement is covered by a thick, relatively uniform sedimentary sequence. An example of the latter area is shown on an interpreted portion of seismic line (GT2-10 ; Fig. 5). Profile OBS-12 located near the seismic line shows the velocity structure of the transitional crust in the area (Fig. 5).

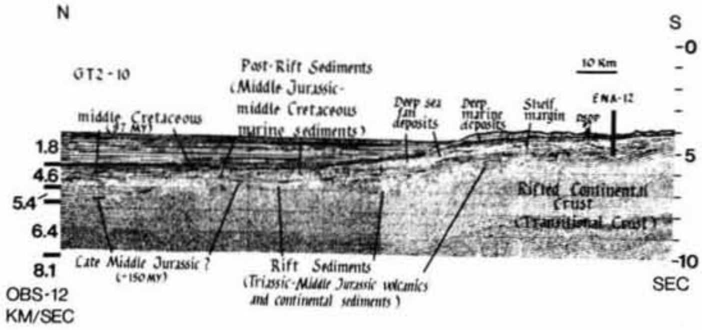

Figure 5

Portion of multifold seismic line GT2-10 in southeastern Gulf (see Fig. 1 for location) showing rifted continental crust or transitional crust containing rift basins. Prominent unconformities interpreted to be 150 my B.P. and 97 my B.P. bracket a thick post-rift sequence representing transition upward from shallow-to deep-marine sediments. Nearby DSDP 97 in projected into the section, and ENA-12 is a projected DSDP hole to be drilled in November-December 1980, OBS-12 located near the north end of the section shows the velocity structure of the transitional crust.

PRE-MIDDLE CRETACEOUS SEDIMENTARY SEQUENCES

The UTMSI-GGL seismic data show that the deep Gulf is underlain by a thick sedimentary section that, in general, 1) thins to the south and east and pinches out along the base of the Campeche and Florida Escarpments and 2) thickens to the north and west to over 10 km beneath deformed continental slopes. Some of the details of these sediments are described in previous UTMSI studies (Ladd *et al.*, 1976 ; Watkins *et al.*, 1977 ; 1978 ; Buffler *et al.*, 1980). A widespread strong reflector/unconformity tentatively dated as middle Cretaceous (97 my B.P.) divides the sedimentary section into two major sequences (Buffler *et al.*, 1980). Examples are shown on Figures 4 and 5.

The pre-middle Cretaceous sequence represents rocks deposited during the early evolution of the basin. It varies in thickness between 2 and 3 km over much of the deep basin (Buffler *et al.*, 1980). The sequence can be generally subdivided into syn-rift sediments and post-rift sediments.

In the area north and west of the Campeche Escarpment overlying transitional crust, the syn-rift sediments consist mainly of a thick salt section. The inferred age of this salt is Middle to Late Jurassic, and it is interpreted to be approximately equivalent to the Louann Salt beneath the northern Gulf coast (Kirkland, Gerhard, 1971). The seismic reflection data allow us to map the distribution of this salt in this area fairly accurately (Fig. 6). It pinches out to the south along the base of the Campeche Escarpment against the strong, smooth reflector/unconformity interpreted to represent the top of the transitional crust (discussed above and by Buffler *et al.*, 1980). It is limited on the north by an inferred basement high (Ladd *et al.*, 1976 ; Watkins *et al.*, 1977 ; 1978 ; and Buffler *et al.*, 1980).

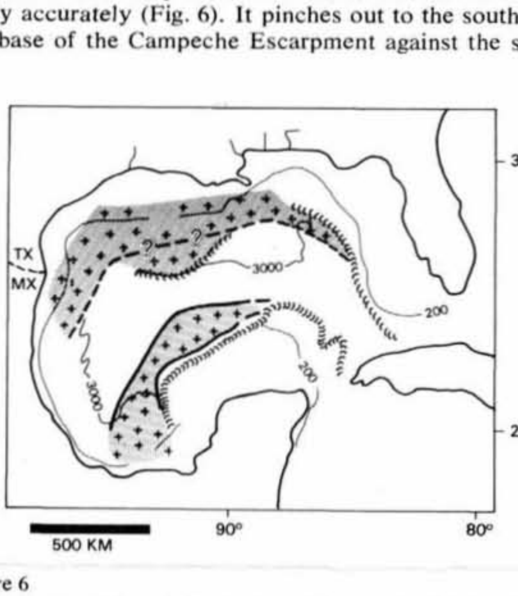

Figure 6

Map showing inferred distribution of salt (stippled) in the deep central Gulf of Mexico basin.

A thick section of salt also underlies the Texas-Louisiana slope and the area just west of the northern Florida Escarpment (Fig. 6). The exact distribution of the salt, however, is unknown. One model suggests that most of the salt beneath the slope is allochthonous and has moved out over younger sediments for distances up to several 100 km (e.g., Humphris, 1978). Seismic reflection data have penetrated only the leading edge of the salt at the Sigsbee Scarp and show salt thrust up to 10 to 20 km over young rise sediments (e.g., Buffler *et al.*, 1978). Even though the salt may be allochthonous, it still must have originated from an extensive salt basin somewhere below the shelf-slope having the same general distribution as shown on Figure 6. The original basin may be located further landward. This distribution shows a definite symmetry on either side of the area of oceanic crust, where salt is interpreted to be absent.

The syn-rift rocks in the area of the southeastern Gulf underlain by transitional crust consist of thick sedimentary sequences filling basins in the rift topography. These rocks are interpreted to represent volcanics and continental sediments based mainly on their setting (Fig. 5). Apparently, there is no salt in this area, possibly because these rift basins never were connected to the sea during the time salt was being deposited elsewhere in the Gulf. These sequences are confined to the area of rifted transitional crust and pinch out northward against a basement high at the inferred oceanic-transitional crust boundary. These sediments lie below a major unconformity estimated by correlation with global sea-level chart to be about 150 my B.P., the postulated time of formation of ocean crust in the central Gulf (Fig. 5).

A post-rift sedimentary sequence ranging in age from Late Jurassic to middle Cretaceous (150 to 97 my B.P.) occurs throughout the deep Gulf basin. In the areas of transitional crust seismic stratigraphic analysis suggests the sequence probably represents a transition upward from shallow-to deep-marine deposits, while in the area of oceanic crust the sequence probably is totally deep marine. North of the Campeche Escarpment, the lower part of the sequence is deformed by early salt flowage and is interpreted to be the southern Gulf equivalent of the shallow-water Upper Jurassic Smackover Formation and associated rocks beneath the northern Gulf coast (Buffler *et al.*, 1980). The upper undeformed part of this sequence is interpreted to represent the deep-water equivalent of the massive Lower Cretaceous carbonate banks that form the adjacent Banco de Campeche (Buffler *et al.*, 1980).

The post-rift sediments in the southeastern Gulf lying between the inferred 150 my and 97 my unconformities also may represent an upward transition from relatively shallow-marine to deep-marine deposits (Fig. 5). The gently prograding sequences are interpreted to be shallow shelf-slope deposits, which are overlain by a hummocky sequence interpreted to be deep-sea fan deposits (Fig. 5). Again, the upper part of the sequence probably represents the deep-water equivalent of the Lower Cretaceous carbonate margins forming the adjacent Florida and Campeche Escarpments. This old carbonate bank margin evidently rimmed the entire Gulf basin during Lower Cretaceous time (Neocomian-Cenomanian) (dotted line on Fig. 3).

The post-rift sediments in the central Gulf overlying oceanic crust consist of a relatively thin, uniformly layered sequence (Fig. 4) which is interpreted to represent a completely deep-water marine section deposited in the newly-formed ocean basin.

SUBSIDENCE HISTORY

One of the more convincing arguments for the formation of an ocean crust in Jurassic time can be made by analyzing the subsidence history of the basin. The top of the ocean crust and the salt in the deep basin now lie at 10 to 12 km below sea level. In the following discussion, it is assumed that 1) the salt formed at or near sea level, a model generally accepted for most large evaporite deposits, and 2) the ocean crust was at one time only 2 to 3 km below sea level, the starting point on the subsidence curves of Parsons and Sclater (1977). If these assumptions are valid, the basin has subsided up to 10 km since the postulated origin of the ocean crust (approximately 150 my B.P.). Only part of this subsidence can be due to sediment loading ; the remainder must be explained by other mechanisms such as lithospheric cooling and contraction of a newly formed ocean crust. This provides a logical mechanism similar to that proposed for the subsidence of the Atlantic margin (Steckler, Watts, 1978 ; Watts, Steckler, 1979).

A schematic cross-section across the southern margin of the basin from Yucatan to the central Gulf is used to illustrate further the subsidence history (Fig. 7). The diagram is very generalized and is based on four vertical sections. Sections A and B are controlled strictly by seismic data ; C is controlled in part by DSDP 94 and seismic data ; and D is controlled by a well (Yucatan 4) on the Yucatan Peninsula. Section A lies on inferred oceanic crust. If all the sediments are stripped off the crust at A using methods outlined by Steckler and Watts (1978), the crust rebounds approximately 3.4 km (section A' ; Fig. 7). This represents the amount of subsidence due to sediment loading.

If it is assumed that the oceanic crust was at about 2.5 km water depth at the time of formation or shortly thereafter (section A'' ; Fig. 7), then the difference between A' and A'' (4 km) represents the amount of subsidence due to other than sediment loading, i.e., lithospheric cooling. The total subsidence at this point is 7.4 km. This is only a simple, first order approximation, and it does not account for compaction and sea-level changes. The 4 km calculated here, however, does fit well with the subsidence expected along a passive continental margin due to thermal cooling and contraction of the lithosphere. For example, approximately 3.7 km of subsidence is predicted for time 150 my from the curves of Parsons and Sclater (1977).

We do not know exactly when most of the subsidence took place, since we do not know the paleowater depth for the sedimentary section, particularly at the 97 my unconformity (MCU). It is assumed, however, that most of the subsidence due to cooling took place during the first 50 my as predicted by the subsidence curves. This is supported by 1) the early basinward gravity flowage of salt northeast of the Campeche Escarpment (Buffler et al., 1980) and 2) the buildup of

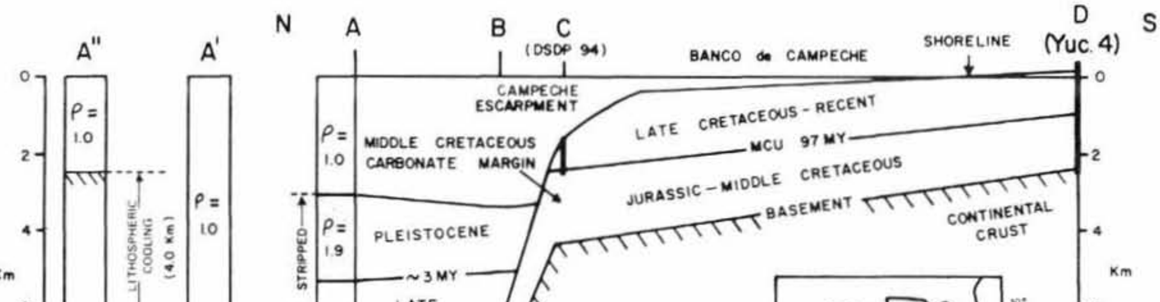

Figure 7

Schematic cross-section across southern margin of the deep Gulf basin (see Fig. 1 for location of sections). A' represents restoration of top of ocean crust after stripping entire sediment column. A'' represents inferred depth of oceanic crust just after formation (approximately 150 MY B.P.). Crust has subsided a total of 7,4 km (3,4 km by sediment loading and 4,0 km by cooling of the lithosphere).

massive carbonate bank margins around the periphery of the Gulf in Late Jurassic-Early Cretaceous time (Fig. 3). Most of the subsidence due to sediment loading probably took place since 97 my B.P., as this is the time represented by the thickest sedimentary section in the deep basin (Fig. 7).

The schematic diagram (Fig. 7) also suggests that the entire Banco de Campeche subsided somewhat uniformly, while the area of transitional crust and oceanic crust north of the bank subsided much more rapidly. The bank margin at the Campeche Escarpment seems to be controlled by some sort of major hinge zone in the basement surface. A similar hinge zone has been observed along the Atlantic margin (Watts, Steckler, 1979 ; Austin *et al.*, 1980) and may represent the boundary between continental and a thinner transitional crust.

DISCUSSION. A MODEL FOR THE EARLY EVOLUTION OF THE GULF OF MEXICO BASIN

Interpretation of new UTMSI-GGL seismic reflection and refraction data along with all previous data allow us to suggest a model or scenario for the early geologic evolution of the Gulf of Mexico basin. The model is basically similar to earlier proposed models, which suggests that new ocean crust formed in the Gulf at the same time (Triassic-Jurassic) and by the same mechanisms involved in the evolution of the early North Atlantic margin as North American separated from Africa-South America (e.g., Humphris, 1978 ; Dickinson, Coney, 1980 ; Salvador, 1980 ; Walper, 1980). Our model, however, is supported by new seismic refraction and reflection data, which constrain the model. Major features include : 1) the seismic character and symmetrical distribution of inferred oceanic vs. transitional crust ; 2) the distribution of salt on either side of oceanic crust ; and 3) the inferred subsidence history of the basin. These data are presented here or some have been presented earlier (Buffler *et al.*, 1980).

Discussion of the early geologic evolution of the basin is divided into two main periods ; a *rift phase* and a *drift and subsidence phase*. Each phase is discussed in more detail below.

The *rift phase* consists of a long period (Triassic through Middle Jurassic) of widespread doming, uplift, rifting, and filling of basins with volcanics and nonmarine sediments. Evidence for this occurs all along the margins of the North Atlantic, the northern Gulf coast, and in Mexico and Guatemala. The Jurassic volcanics in the subsurface of southern Florida (JV in Fig. 3) may have formed during the latter part of this period. The seismic data in the Gulf indicate that similar rifting also occurred benearth parts of the deep southern Gulf, as evidenced by tilted blocks and rift basins filled with synrift sediments. This evidently was part of a period of great crustal stretching, attenuation, and formation of thinned "transitional" crust along the entire Atlantic-Gulf margin accompanying the early separation of North America from Africa-South America. The mechanism in the mantle for forming this transitional crust is not well understood but probably involves some combination of subcrustal erosion, injection of igneous material, and attenuation of the upper crust.

During the latter part of the rift phase, the Gulf area separated into individual subsiding basins. Early transgression of the sea in the Middle Jurassic, probably from the southwest (Pacific Ocean), allowed deposition of great thicknesses of evaporites in some of the basins as they continued to subside, particularly in the central Gulf. Deposition of the evaporites probably occurred in relatively shallow-water environments. Some areas such as the rifted southeastern Gulf did not have early access to the sea. Here thick, nonmarine syn-rift sediments continued to fill the rift basins.

The *drift and subsidence phase* began during the early Late Jurassic (about 150 my B.P.) when a major rift opened in the central Gulf and new ocean crust began to form as the rift widened. It is not known how long the period of ocean crust formation or seafloor spreading lasted. It probably was fairly brief and on the order of several millions of years, since the amount of separation is only several hundred kilometers. This period is interpreted to correspond approximately with the major unconformity (150 my) in the southeastern Gulf separating syn-rift from post-rift sediments (Fig. 5). The opening separated the salt basins on either side of the newly-formed ocean crust.

The symmetry of crust and salt (Fig. 3 and 6) suggest that the Gulf opened in a NW-SE direction. The most logical direction would be along flow lines parallel to the North Atlantic fracture zones (FZ-Fig. 3). Similar trends have been mapped into the eastern Gulf as magnetic lineations (Klitgord, US Geological Survey, pers. comm.). This trend is also parallel to the major structural boundary mapped in the southeastern Gulf (Fig. 3) and other structural trends in the deep Gulf. Reconstruction of the basin along these lines allows for a fairly good fit between the salt basins. A slightly better fit is obtained, however, by reconstructing the Gulf along a more N-S direction. Perhaps there were several periods of movement in different directions. No magnetic lineations or stripes have yet been indentified in the central Gulf to indicate direction of opening.

A logical plate boundary at the time of opening of the Gulf would be across northern Mexico, through the central Gulf, and then out through the Straits of Florida north of Cuba. This would involve movement of Mexico and Yucatan away from North America as one block. Transverse motion would be taken up across northern Mexico by an inferred megashear (Fig. 3). Such a feature has been postulated by several authors (e.g., Pilger, 1976 ; Dickinson, Coney, 1980), particularly to explain early (Triassic-Jurassic) rotations of northern Mexico independent of North America as evidenced by recent paleomagnetic data (Gose *et al.*, 1980). An alternative plate boundary would be south across the Isthmus of Tehuantepec, which would allow movement of Yucatan south as a block independent of the rest of Mexico.

After seafloor spreading in the Gulf aborted, possibly due to plate reorganization, the basin began to subside as the lithosphere cooled and contracted. Evidence for subsidence is supported by interpreting the sedimentary history of the deep basin from the seismic data. Early deformation of salt and overlying sediments by gravity flowage was probably triggered by subsidence of the basin. Shallow-to deep-water sediments were deposited along the margins of the basin in areas overlain by subsiding transitional crust. The upper sediments were the deep-water equivalents of the massive carbonate platforms that built up on the adjacent, more stable continental blocks. The Lower Cretaceous carbonate margins were controlled, in part, by a tectonic hinge zone separating the continental blocks from the thinner transitional crust. A relatively thin deep-water section was deposited in the newly-formed ocean basin.

The early (pre-middle Cretaceous) history of the basin ended with the formation of a major unconformity, which is characterized by truncation of beds below and onlap of beds above. The unconformity is correlated with a middle Cretaceous (97 my) drop in sea level, which may have caused bottom currents to scour the seafloor. This unconformity represents a basinwide change in sedimentation including the drowning of the outer middle Cretaceous carbonate bank margins.

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