AN ABSTRACT OF THE THESIS OF

MIGUEL ANGEL ALVARADO OMANA for the degree of MASTER OF SCIENCE in GEOPHYSICS presented on June 13, 1986.

Title: GRAVITY AND CRUSTAL STRUCTURE OF THE SOUTH-CENTRAL GULF OF MEXICO, THE YUCATAN PENINSULA, AND ADJACENT AREAS, FROM 17°30'N TO 26°N AND FROM 84°W to 93°W.

Abstract approved: Richard W. Couch

About 9600 nautical miles of marine gravity, magnetic, and bathymetric data were collected by Oregon State University during the cruise Yucatan'85 in the north and eastern margins of the Yucatan Peninsula, using a research vessel of the Mexican Navy, the Altair. A compilation of Yucatan'85 marine data and marine and terrestrial data provided by the Defense Mapping Agency produced Gravity Anomaly and Bathymetric/Topographic Maps of the south-central Gulf of Mexico, the Yucatan Peninsula, and adjacent areas from 17°30'N to 26°N and from 84°W to 93°W.

The Gulf of Mexico is a small ocean basin underlain by crustal structures that are significantly different from normal continents or ocean basins. Seismic refraction data, in addition to the marine gravity, magnetic, and bathymetric data, constrain a crustal and subcrustal model across the Campeche Escarpment in the south-central Gulf of

Mexico. The model presented here provides an overview of the transitional structure between oceanic and continental crust in the northern Yucatan Platform region.

A mantle layer of density 3.46 g/cc in the south-central Gulf of Mexico is found to be denser than expected based on the Ludwing, Nafe and Drake velocity-density curve, and a compressional wave velocity of 8.0 km/sec. The presence of material denser than 3.32 g/cc beneath the crustal structure of the Gulf of Mexico may be attributable to thermal contraction associated with the great age of the basin (Triassic or older), and to a denser than average lithosphere-asthenosphere substratum as indicated by a regional geoid "high" in southern Mexico and Central America.

The computed crustal cross-section suggests that the Campeche Escarpment has a tectonic origin due to faulting. According to the crustal model, no extent of an attenuated or rifted continental crust (transitional crust) is evident. On the contrary, the model suggests the existence of an abrupt oceanic-continental boundary.

Mapping of a pre-rift crystalline-basement high overlain by a high-density "carbonate" block (older in age than the Challenger Unit) over the north-central Yucatan Platform, makes this area a promising place for a drilling site that would recover samples of basement rocks. Direct identification of the composition and age of the crystalline-basement and the overlying "carbonate" sequence would contribute to a better understanding of the origin and evolution of the Gulf of Mexico.

Large tectonic-eustatic sea level changes occurred during the early rift phase of the Gulf of Mexico. A model for the sequence of sedimentary deposition, subsidence, and opening of the Gulf which influenced the present crustal architecture of the "carbonate" and crystalline basement suggests that the "carbonate" layer may be constituted of two materials: a) a mix of carbonate sediments and detrital sediments eroded from the continent above sea level that were deposited in shallow water on both sides of the crystalline-basement "high", and b) by carbonate sediments created once the basement block completely subsided below sea level.

Computed mass columns east and northwest of the Yucatan Platform indicate that a lighter density material (3.40 g/cc), as compared with that existing beneath the north-central Yucatan Platform, must form the mantle in these basinal areas.

Comparison of mass columns for wells located in the central and northeastern Yucatan Peninsula with the crustal model, indicates a difference in density between the basements forming the lower crust beneath the drilled sedimentary sequence. These differences suggest that the basement in the eastern and northern Yucatan Platform is formed of denser material than the basement in the central Yucatan

Peninsula. The differences also suggest that the Yucatan Block is formed of a series of "micro-continental" blocks which encircle the central Yucatan Platform.

Gravity and Crustal Structure of the South-Central Gulf of Mexico, the Yucatan Peninsula, and Adjacent Areas from 17°30'N to 26°N and from 84°W to 93°W

by

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A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

Completed on June 13, 1986

Commencement June 1987

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Date Thesis is Presented 13 June 1986

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ACKNOWLEDGEMENTS

This research was conducted under the supervision of Dr. Richard W. Couch. I am grateful for his guidance and continued support during my studies at Oregon State University. His many helpful suggestions, the discussions we had throughout this study, and his continued enthusiasm regarding my research topic are greatly appreciated.

Thanks, Dr. Couch, for pushing me when I needed to be pushed, for "talking" to me when I needed it, and for backing off when I felt that the walls were closing in. My special thanks to him for teaching me what "research" means, for making me understand the difference between "passive" and "active", and for making me realize what it takes to become a geophysicist.

I wish to express my gratitude to Dr. Paul Dauphin and Dr. Gordon Ness for their valuable support, time, and advice.

I thank Michael Kelsay, who helped me in dealing with the computer, Steve Troseth and Anne Yeaple, who drafted some of the figures and the maps, and Gloria Walker, who typed every word of this thesis.

My sincere thanks goes to all my friends for their comments, help, and encouragement -- to Pierre Doguin and Yannick Duroy for sharing with me their travel adventures, good food, good drinks, good talks, good soccer, and good work, all of them with the good French style; to Bryndis

Brandsdottir, an extraordinary classmate, friend, and neighbor, for letting me try that Icelandic seafood, pancakes, and drinks she prepares; and to all my office mates, Haraldur Audunsson, Fa Dwan, Bruce Dubendorff, Marijke van Heeswijk, and Osvaldo Sanchez, for making all the time I spent with them so enjoyable.

I am also grateful to Matthew Azevedo for being patient and helping me to review the grammatical structure of this thesis. Thanks to all CONMAR personnel for being so great with me.

Thanks are due to the Mexican Government, to Consejo Nacional de Ciencia y Tecnologia of Mexico (CONACYT) for providing support during my graduate studies at Oregon State University.

I would like to thank my family for believing in me and for being there to listen and offer support when I most needed it -- to my parents, Elias Alvarado and Yolanda Omana, who deserve love and infinite gratitude; to my brother, Hector Elias, for his cheering me on, and to my sister, Etna Yolanda, whom I love very much.

Finally, special thanks to my wife, Zoraya, for her invaluable understanding, patience, suggestions, love, and encouragement. She brings to every day so much meaning and joy to my life.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

GRAVITY AND CRUSTAL STRUCTURE OF THE SOUTH-CENTRAL GULF OF MEXICO, THE YUCATAN PENINSULA, AND ADJACENT AREAS, FROM 17°30'N TO 26°N AND FROM 84°W to 93°W.

INTRODUCTION

In figuring out the puzzle of global tectonics, fitting in the small pieces is often the hardest part. It is obvious, for example, how South America and Africa fit together, how the Middle Atlantic Ridge is the geologic zipper along which the ocean opened. It is not so obvious, however, how the small ocean basins, such as the Gulf of Mexico, developed. For that reason, the Gulf of Mexico has been subject to intensive geophysical and geological investigation for the last 30 years.

From the several proposed models for the origin of the Gulf of Mexico, the mobilist models, which maintain that the Gulf is a relatively recently formed ocean basin produced by rifting of continental crust, have won the acceptance of a growing number of investigators. Buffler (1984a), based partly on earlier proposed models and mainly using seismic reflection and refraction results, presented an updated model of the structure and evolution of the Gulf of Mexico. His model suggests that rifting and formation of the new oceanic crust occurred in the Gulf during the Late Triassic and Jurassic. Seismic techniques have been critical to most hypotheses of the formation of the Gulf of Mexico because they have provided the only, but very strong, evidence for the oceanic crust underlying the central part of the Gulf. Mapping of the present major tectonic features of the Gulf and construction of regional cross-sections across the Gulf of Mexico have indicated much about the Gulf's structural framework. Seismic data, however, do not provide enough detail to precisely map the boundary between oceanic and continental crust, or even a transitional crust. Therefore, uncertainty exists about the distribution of crustal types in critical regions such as the area located seaward of the Yucatan Platform in the south-central Gulf of Mexico. In addition, very little seismic control exists in broad areas such as the entire Yucatan Shelf, where the depth to the basement is speculative.

Because seismic investigations alone cannot resolve the structure at the transition zone between continents and oceans, it is advantageous to employ gravity and magnetic data at such places to help resolve the structure. Knowledge of the exact distribution of oceanic crust is one of the important keys to the early history of the Gulf of Mexico (Uchupi, 1980).

The research reported here focuses on the crustal structure across the Campeche Escarpment, one of the most critical structural transitions between oceanic and continental crust. By using marine gravity, bathymetric, and magnetic data combined with previous seismic refraction work, the crustal and subcrustal structure of this critical region was mapped. A two-dimensional model was developed by integrating the marine gravity and magnetic measurements made by the Continental Margins Study Group (CONMAR) at Oregon State University, published seismic stratigraphy results, geophysical data compiled by the Defense Mapping Agency (DMA), and a large background of geological and geophysical studies done in the area. Also, an updated Gravity Anomaly Map and a Bathymetric/Topographic Map have been produced for from 17°30'N to 26°N and from 84°W to 93°W, an area of almost 950,000 square kilometers, based on spatially dense and precise geophysical measurements collected during the Yucatan'85 cruise of the research vessel, the Altair, of the Secretaria de Marina, Mexico. These maps encompass the south-central Gulf of Mexico, the entire Yucatan Peninsula, and adjacent areas, thus allowing a more accurate determination of the basement structural features. Both maps and the crustal model are mainly intended as a basis for further studies of the Gulf of Mexico.

TECTONIC FRAMEWORK AND SEDIMENTARY SETTING

Buffler (1984b) and Buffler and Sawyer (1985) interpreted multifold seismic reflection and refraction data collected by the University of Texas Institute for Geophysics and with information from other studies developed a generalized model of the early evolution of the Gulf of Mexico which suggests that rifting and formation of new oceanic crust occurred in the Gulf at the time of Late Triassic through Jurassic (Figure 1). The varied basement that underlies the Gulf of Mexico (Buffler, 1984b) includes, as defined by Buffler and Sawyer (1985), all crustal rocks lying beneath a widespread unconformity that is overlain and onlapped by Middle Jurassic salt as well as younger sedimentary rocks. Included within the basement are inferred Late Triassic to Early Jurassic rift basins that Buffler (1984b) considers a part of the early evolution of the basin. There are broad areas, however, like the broad Yucatan Platform, where there is very little data and the presence of basement highs and lows is speculative (Buffler, 1984b). Buffler (1984b) and Buffler and Sawyer (1985) interpret this broad area of basement highs and lows, to be underlain by "stretched or attenuated continental crust", i.e., transitional crust between true continental and true oceanic crust that formed in Early to Middle Jurassic time during the rifting of the basin that

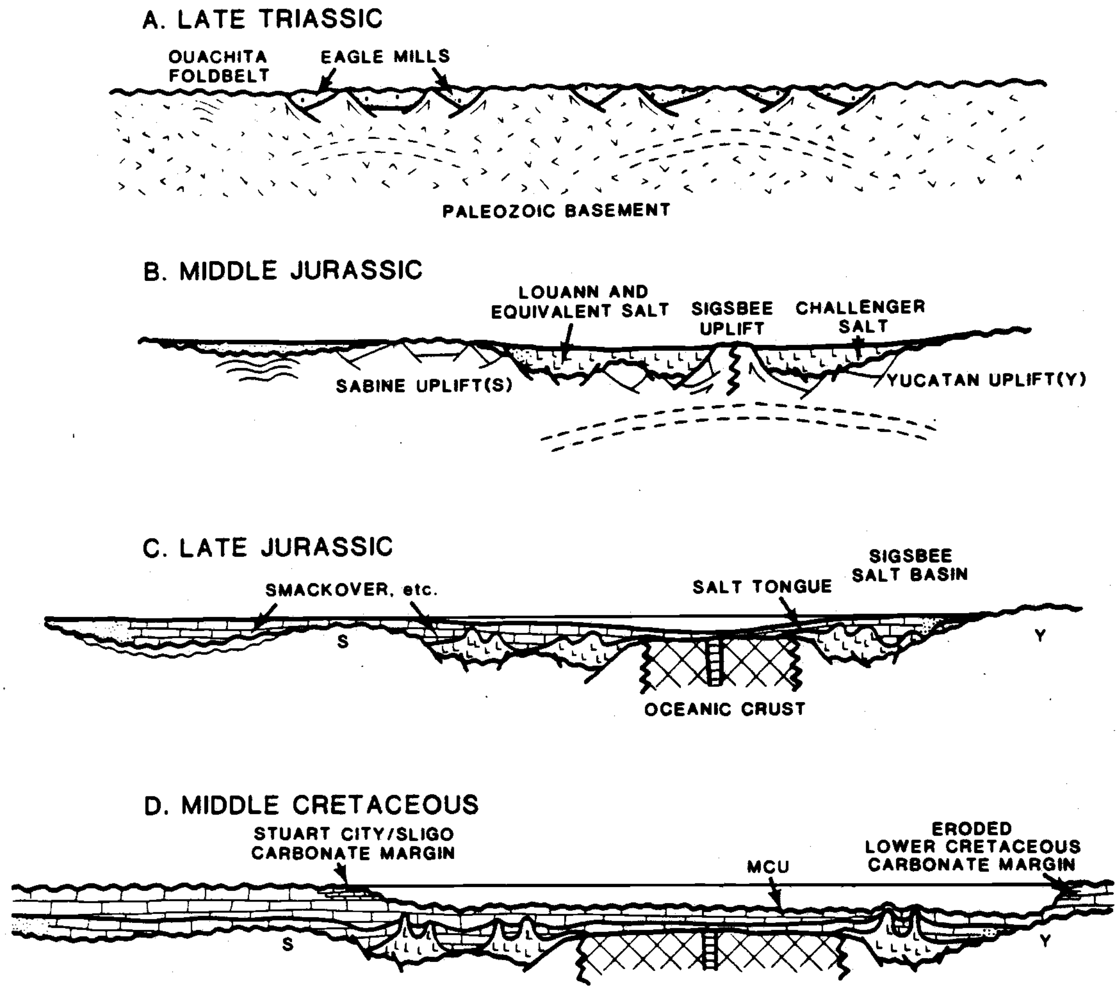


Figure 1 -- Schematic diagram showing a general model for the early (Pre-Middle Cretaceous Unconformity) evolution of the deep basin within the Gulf of Mexico (from Buffler, 1984b). The model includes: 1) a Late-to-Middle Jurassic rift stage, during which a transitional crust (rifted or attenuated continental crust) formed and widespread evaporites accumulated; 2) a brief Late Jurassic period of oceanic crust formation in the deep central Gulf; 3) a Late Jurassic-through-Early Cretaceous period of cooling and subsidence of the crust and build-up of extensive platforms surrounding the deep basin; and 4) formation of a widespread Middle Cretaceous Unconformity (MCU).

accompanied the separation of South America and North America.

Knowledge of the nature of the basement is limited to information obtained from drilled or exposed rocks around the periphery of the basin (Buffler, 1984b). True basement drilled all around the periphery of the Gulf, including the Wiggins Anticline in the central U.S. Gulf coast plain, the northern and central Florida, the southeastern Gulf, and the Yucatan Peninsula, suggests that the basement apparently consists of a complex variety of igneous, metamorphic, and sedimentary terranes (Buffler, 1984b, and Pindell, 1985). Extrapolation towards the Gulf of Mexico basin of drilled rocks or rocks that crop out around the basin suggest that most of the crust beneath the continental margin of the Gulf consists of a complex of Pre-Cambrian and Paleozoic igneous and metamorphic rocks containing a Pan-African metamorphic age of about 500 My± (Buffler, 1984b; Buffler and Sawyer, 1985). In many places these rocks have been overprinted with a Late Paleozoic metamorphic age that probably represents the widespread collision of the Florida, African, Yucatan, and South American blocks with North America (Buffler and Sawyer 1985).

Regional seismic studies and isopach maps published by Buffler (1984b) and Shaub et al. (1984) respectively, indicate a general filling of the deep Gulf of Mexico basin. They show that the deep Gulf basin is underlain by a thick section of Jurassic-to-Recent sedimentary rocks. These rocks can be conveniently subdivided into two major sequences and periods of deposition (Buffler, 1984b), the pre-Middle Cretaceous sequence and the post-Middle Cretaceous sequence. A prominent Middle Cretaceous Unconformity (MCU) which represents a major period of erosion and non-deposition, separates these two sequences. Three regional cross-sections presented by Buffler (1984a) and Buffler and Sawyer (1985) provide an overview of the sedimentary setting of the basin (Figure 2). The pre-Middle Cretaceous sequence represents a long and complex history involving the early evolution of the basin (Buffler, 1984b). The post-Middle Cretaceous history is somewhat less complicated and consists of the filling of the basin mainly with thick wedges of siliclastic sediments derived first from the west in Late Cretaceous to Early Tertiary time and then from the north in Late Tertiary through Pleistocene time (Buffler, 1984b).

The sequence below the Middle Cretaceous Unconformity (MCU) is collectively known as the Challenger Unit (Ladd et al., 1976; Shaub et al., 1984). It consists of all Jurassic-to-Lower Cretaceous rocks between oceanic basement and the MCU. The unit is about 2 km thick over much of the basin, but it thins locally along the base of the Campeche Escarpment, and it corresponds to the upper part of a 4.5 to 5.1 km/sec velocity layer (Ibrahim et al., 1981). The

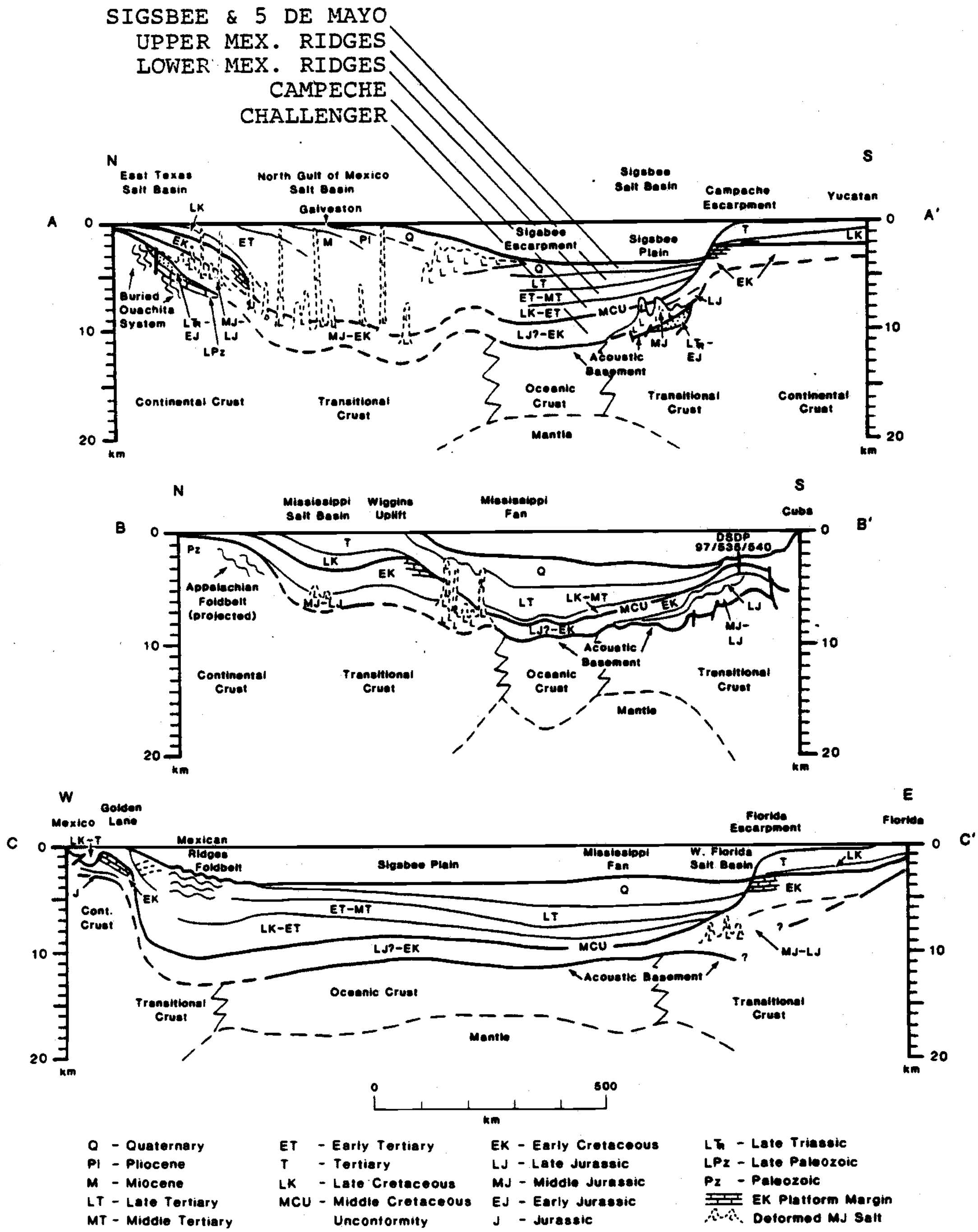


Figure 2 -- Regional cross-sections across the Gulf of Mexico based on seismic measurements (after Buffler, 1984b).

seismic reflection characteristics of the lower part of the Challenger Unit include: 1) a high seismic velocity of 4.4 to 4.8 km/sec.; 2) an undulating top reflector; and 3) a flat bottom reflector (Lin, 1984; Buffler, 1984b). These characteristics strongly suggest that the Challenger Unit contains a salt layer that feeds the domes and knolls of the Sigsbee Salt Basin (Ladd et al., 1976). Worzel and Burk (1978) obtained several sections which seem to show the roots of the salt diapirs. One in particular shows flowage from the Challenger Unit into a dome, whereas the bottom of the unit appears to continue beneath the domes largely undisturbed. This section is one of the best indications that the Challenger Unit contains the salt which forms the diapirs of the Gulf. The Middle Cretaceous Unconformity is a major Gulf-wide unconformity traceable as a seismic reflector, which separates the Lower Cretaceous and Cenozoic rocks (Buffler, 1984b). This surface is easily recognized along the flanks of the deep basin as a prominent high-amplitude reflector and unconformity that truncates beds below and is onlapped by the later fill of the basin (Buffler, 1984b). It generally rises up and merges with the sediments on the Campeche and Florida Escarpments along the southern and eastern margins of the basin (Buffler, 1984b). The MCU represents a major turning point in the sedimentation patterns and depositional history of the basin and has been tentatively correlated with a drop in sea level during Cenomian time (Buffler et al., 1980; Shaub et al., 1984). The unconformity, also recognized on the outer margins of the adjacent carbonate banks, corresponds to the terminal drowning of banks and step back of the margins (Buffler, 1984b). Faust (1984) and Buffler (1984b) suggest that the most likely cause of this major break and turning point in the Gulf sedimentation is a rapid drop of sea level followed by a rapid rise. According to Faust (1984), the drop could have terminated the outer carbonate margins and also concentrated turbidity currents and deep-sea contour currents along the base of the slope, causing erosion of the escarpment. The later rapid rise in sea level quickly drowned the outer carbonate margins causing them to "step back" to new positions further landward.

The post-MCU history of the Gulf consists essentially of filling of the deep basin with huge clastic wedges, first from the west (Mexico and Rio Grande Embayment), and then from the north (Ancestral Mississippi River Drainage) (Buffler, 1984b). During this time, carbonate deposition continued on the Yucatan and Southern Florida Platforms. The post-MCU section in the deep Gulf is up to 6 km thick along the deformed northern and western margins of the basin, and it is about 4 to 5 km thick in the central Gulf (Buffler, 1984b); Shaub et al., 1984). The Post-MCU section thins to the south and east and pinches out depositionally by onlap at the base of the Campeche and Florida Escarpments (Ladd et al., 1976; Buffler, 1984b).

Table 1 by Shaub et al. (1984) summarizes the stratigraphic units defined as seismic sequences with their boundaries being major unconformities along the margins of the basin. The ages for the seismic units are not very well constrained, especially for the lower units. The ages of the sediments between the Campeche and Lower Mexican Ridges Units and between the Lower and Upper Mexican Ridges Units are unknown and are based on extrapolation of drilling results obtained around the periphery of the Gulf (Buffler, 1984b). The upper two unit boundaries are fairly well constrained by correlations with DSDP sites 87, 90, and 91 in the deep basin and with the seismic units in the northeastern Gulf of Mexico (Addy and Buffler, 1984).

SUMMARY OF DEEP GULF OF MEXICO SEISMIC UNITS

Unit	Age	Typical Reflection Characteristics	Suggested Depositional Environment Depocenter Source
Challenger	Middle Jurassic (?) to Middle Cretaceous	Moderate amplitudes, low frequency; generally continuous, parallel and sub-horizontal in central Gulf; discontinuous and gently dipping, deformed and even chaotic along the base of the Florida and Campeche platforms.	Unit immediately overlies acoustic basement (ocean and transitional crust). Predominantly deep marine sediments in central Gulf. Evaporites, shallow then deep marine along Campeche and Florida Escarpments. Eastern depocenter may have source in Tampa Embayment; central Gulf depocenter apparent source in Campeche region.
Campeche	Upper Cretaceous to Early Tertiary (?)	Low amplitude, low frequency, continuous, parallel, horizontal or gently dipping.	Predominantly deep marine distal clastics in western of study area; pelagic in east. Western depocenter source is probably Rio Grande Embayment.
Lower Mexican Ridges	Early (?) to Middle (?) Tertiary	Moderate amplitudes and frequencies; generally continuous commonly parallel and horizontal.	Predominantly deep marine distal clastic sediments. Broad western depocenter attributable to ancestral Texas and Mexican rivers. Considered a continuation and progradation of the sedimentation pattern of the underlying Campeche unit. Clastics are distributed throughout the entire deep basin.
Upper Mexican Ridges	Middle Tertiary (?) to Late Miocene	High amplitude, high frequency; continuous, parallel, horizontal, sub-horizontal; minor channels and clinoforms near depocenters.	Predominantly deep marine distal sands, silts, muds. Western margin progradation and sedimentation continues from western margin. A northeastern depocenter is established in the study area for the first time and is attributed to the ancestral Mississipi River.
Cinco de Mayo	Late Miocene through Pliocene	Generally acoustically transparent; otherwise variable amplitude and frequency; parallel and sub-horizontal.	Abyssal terrigenous and biogenic ooze. No major depocenter in deep Gulf; sediments thicken slightly in northern and southwestern Gulf. Most of clastic supply may be trapped by sedimentary deformation along northern and western margins.
Sigsbee	Pleistocene	Mid-fan; variable but generally high amplitude and frequency; complex, even chaotic reflection; configurations interpreted as channels, levees, and channel fill, interchannel and overbank strata. Lower fan, high amplitude, high frequency; continuous, parallel and horizontal, in places wavy or distorted with channels. Western and southwestern continental rise generally acoustically transparent.	Abyssal submarine fan and other northern-source mass-transport deposits in eastern of Gulf, contributed by Pleistocene Mississippi River mostly suspension deposits in west; some fine-grained turbidites also derived from Mexican rivers in western basin.

TABLE 1 -- Summary of Deep Gulf of Mexico Seismic Units (from Shaub et al., 1984).

DATA DESCRIPTION AND LOCATION OF THE STUDY AREA

During the spring of 1985, the Continental Margins Study Group (CONMAR), of the College of Oceanography at Oregon State University, surveyed the north and east margins of the Yucatan Peninsula using a research vessel of the Mexican Navy, the Altair. Cruise Yucatan'85 collected about 9600 nautical miles (17,800 km) of marine gravity, magnetic, and bathymetric data. The survey covered the Yucatan Platform with uniformly spaced, precisely-navigated tracklines. Measurements made on the Yucatan Platform extended over the following provinces shown in Figure 3: the Campeche Escarpment, Campeche Bank, Campeche Terrace, and the Mexican Caribbean. The measurements, made along the tracklines that were spaced approximately 22 km apart and oriented mainly in a north-south direction (Figure 4), yielded a spatial density along the tracklines of approximately one station per kilometer.

The Defense Mapping Agency (DMA) provided compiled marine gravity and bathymetric data from cruises by Lamont Doherty Geological Observatory (Cruises Vema 18 and Vema 21) and from several cruises of the Naval Oceanographic Office. Yucatan'85 data merged with the data provided by the Defense Mapping Agency produced a Free-Air Gravity Anomaly Map and Bathymetric Map for the south-central Gulf of Mexico and the Mexican Caribbean area. Land gravity

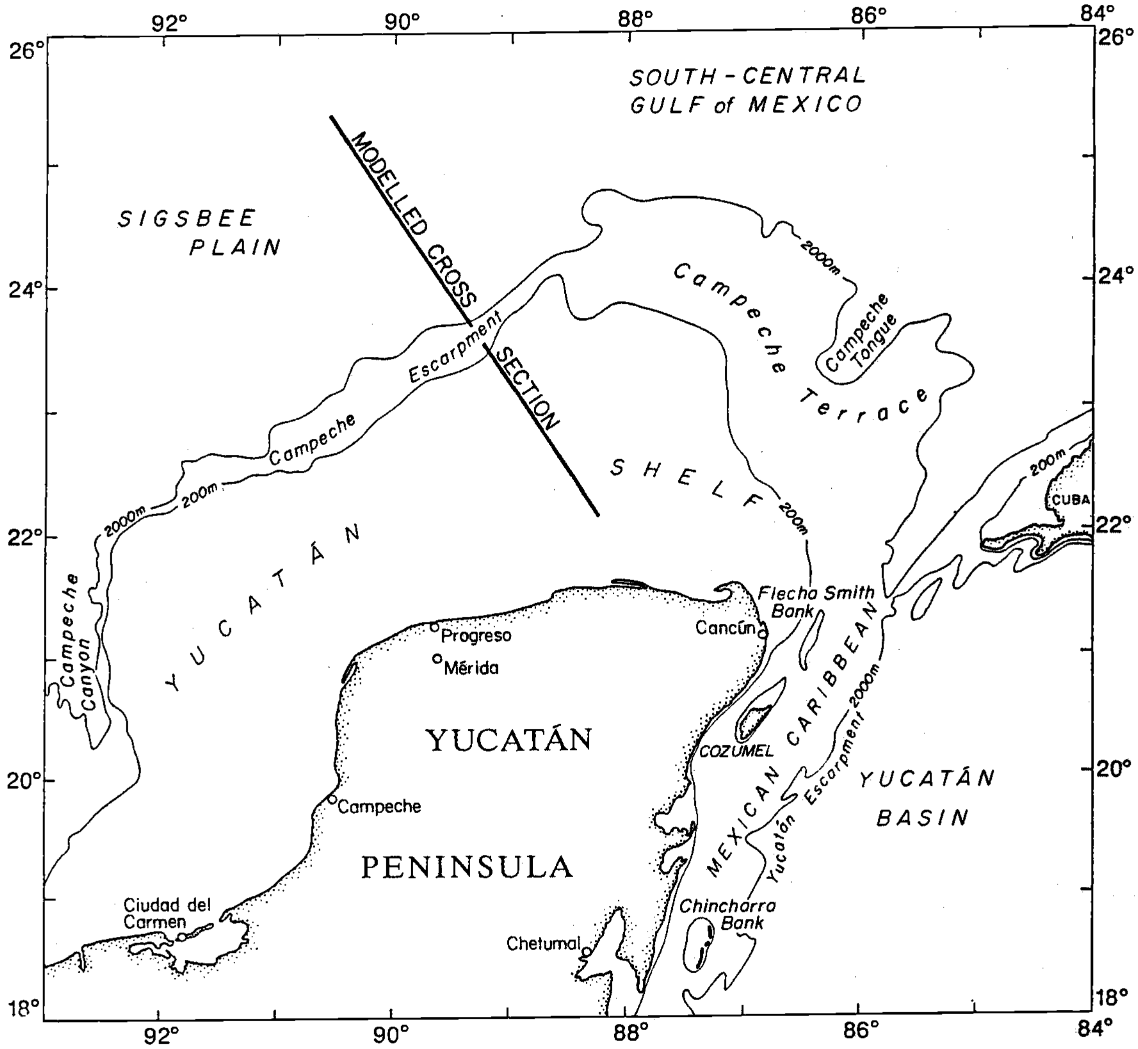


Figure 3 -- Main physiographic provinces in the study area.

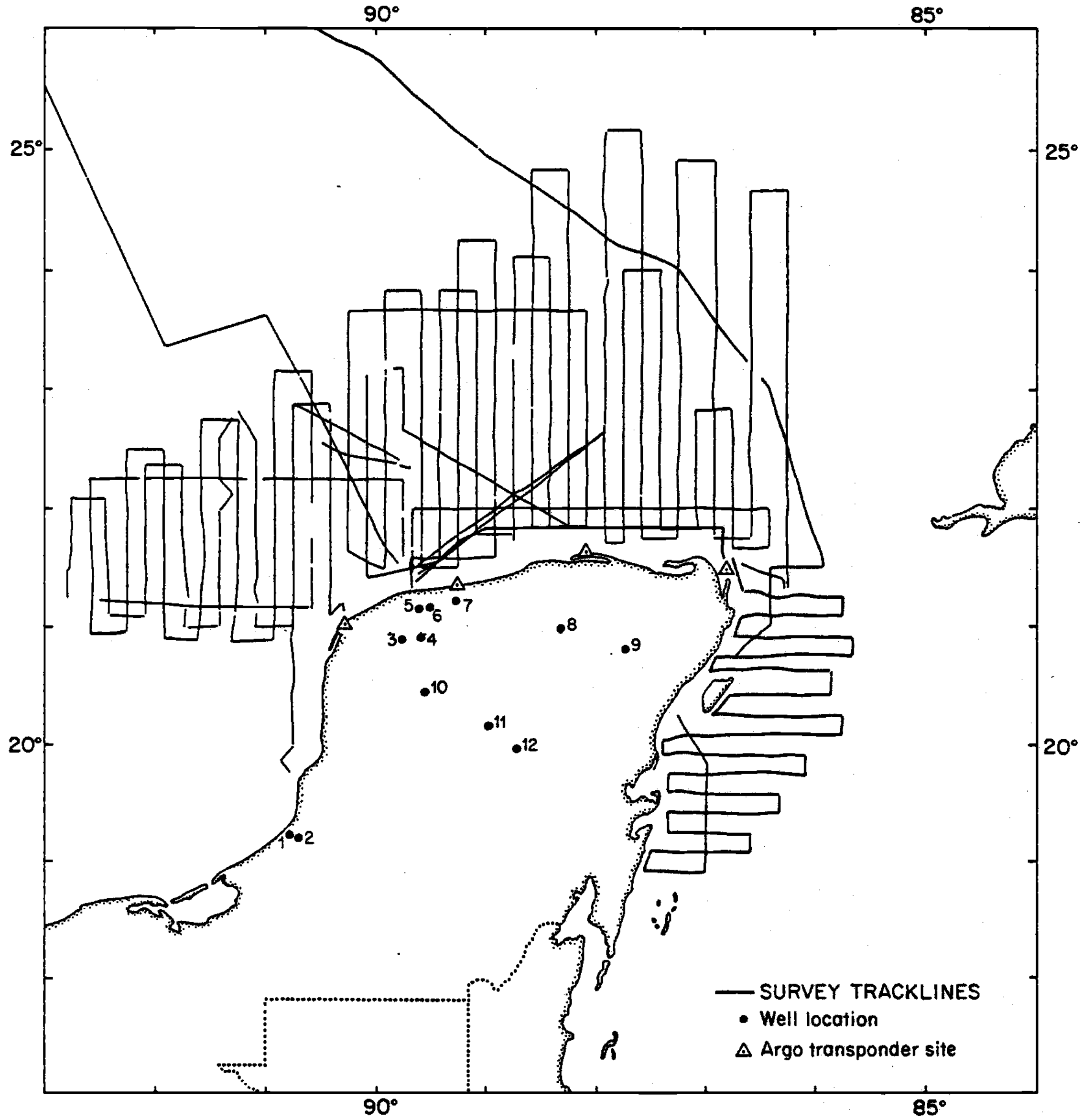


Figure 4 -- Yucatan'85 tracklines. Triangles locate ARGO navigation sites. Dots locate drilling sites, which are: 1) Champoton 2. 2) Champoton 1. 3) Yucatan 6. 4) Merida 2. 5) Progreso 1. 6) Chicxulub 1. 7) Sacapuc 1. 8) Yucatan. 5A. 9) Yucatan 4. 10) Ticul 1. 11) Yucatan 2. 12) Yucatan 1.

data as well as topographic data were also requested from the Defense Mapping Agency in order to compute Simple Bouguer Gravity Anomaly and obtain topographic values over the Yucatan Peninsula. As a result of the terrestrial and marine data, a Gravity Anomaly Map and Bathymetric/Topographic Map were produced for an area of almost 950,000 square kilometers from 17°30'N to 26°N and from 84°W to 93°W.

Figures 8 and 13 show the Gravity Anomaly Map and the Bathymetric/Topographic Map respectively at a scale of approximately 0.9 inches per degree. The pocket in the back of this thesis contains these two maps at a scale of 4 inches per degree.

Yucatan'85 magnetic measurements, made contemporary with the gravity measurements, extend over the entire Yucatan Shelf and the Campeche Escarpment. Magnetic values from a Total Intensity Magnetic Map published by Hall et al. (1982) supplied magnetic data seaward of the escarpment.

The gravity and magnetic maps served as the main constraints for the crustal and subcrustal model described below.

DATA ACQUISITION AND REDUCTION

Navigation: High quality navigation is a requirement of any marine geophysical survey and, in particular, gravity surveys. Uncertainties in position, speed or heading reduce the ability to correct the observed values of gravity for accelerations caused by movement of the ship over the surface of the earth (the Eötvös effect). Positions along the Yucatan'85 tracklines were supplied by two navigational systems, the ARGO system and the Transit Satellite system.

North of the Yucatan Peninsula, the predominant navigational system used was the ARGO system, a long-range radio navigation system, pseudo range-range with which the position of the ship was recorded every 30 seconds with a spatial uncertainty of approximately 90 meters (Kelsay, 1986, personal communication). ARGO DM-54 with NC-100 Argonav Computer produced positions (latitude and longitude) which, after being filtered, provided the main constraints for the computed Eötvös corrections. The Transit Satellite system, a Magnavox dual channel satellite navigator, MX1107RS, provided back-up for the ARGO system along the north-central region of the survey. Satellite fixes occur at non-uniform intervals ranging from a few minutes to a few hours and have a spatial accuracy of approximately 300 meters (Kelsay, 1986, personal communication). The position of the ship was determined onboard at 1 minute intervals by dead reckoning from a satellite position.

East of the Yucatan Peninsula the survey was conducted using the Transit Satellite system as the primary navigation. The ARGO system requires manned radio transponder sites on the periphery of the survey area. Due to time constraints imposed by the cruise schedule, it was not possible to install them for the survey in the Mexican Caribbean area.

Marine Gravity Measurements: S-42, a LaCoste and Romberg two-axis Air/Sea Gravity Meter, recorded the marine gravity data along the tracklines of Yucatan'85. The measurements sampled and recorded every 10 seconds and later thinned to 3 minutes, yielded a gravity measurement about each kilometer at a ship's speed of 10.8 knots.

Because the marine gravity values recorded by shipboard gravity meters such as the S-42 are relative to those on land stations where "absolute" values of gravity have been established, the sea measurements must be tied to those referenced land stations. This task was done by measuring the gravity difference with two LaCoste and Romberg land gravity meters, G-706 and G-707, between the place where the ship was docked at Progreso, Yucatan, and the adjacent International Gravity Station (IGB08LL9; ACIC CODE 1764-1), where the gravity value is 978721.32 mGal.

G-706 and G-707, read side by side, tied the International Gravity Station at Progreso to a tie point on the pier alongside the ship. Each meter was looped twice with at least five readings taken per meter at each site. The meter readings that were inside one standard deviation (always at least three) were then averaged and the result reduced to gravity units using tables supplied by LaCoste and Romberg for G-706 and G-707. These values were corrected for earth tides. A linear regression was applied to these earth-tide-corrected values in order to determine meter drift. The difference between the IGS and the tie point was also computed by using the linear regression method. The gravity value of the tie point was then corrected to the level of S-42 using the Free-Air correction (S-42 was located on the ship above water level).

The drift of the shipboard gravity meter was also monitored by comparing the differences between the S-42 gravity readings at the base-tie station between dockings. The total drift for Yucatan'85 was 0.00368 mGal/day.

All marine gravity data measured from a moving platform requires corrections (LaCoste, 1967; Dehlinger, 1978). Because gravity is an acceleration, it must be separated from accelerations introduced by the ship, such as vertical (ships undulations about sea level), horizontal (action of ocean waves, ship's fishtailing, or short term changes in ship's speed and direction), and cross-coupling accelerations (interactions between vertical and horizontal accelerations within the gravity meter). Corrections to compensate for these effects, as described by LaCoste (1967) and Dehlinger (1978) were applied to gravity data collected during Yucatan'85.

Another acceleration affecting sea gravity meters such as S-42 is the Eötvös effect. The difference in the value of gravity measured by a meter that moves with the earth and that recorded by a meter near or on the earth's surface moving relative to the earth, is called the Eötvös correction. The Eötvös effect arises from changes in centripetal acceleration experienced by an observer moving on the earth's surface. A detailed description of the Eötvös correction is given by Dehlinger (1978). The following expressions from Dehlinger (1978) summarize the computation of the Eötvös effect.

For a ship, the total vertical centripetal acceleration at speed V is: $A_a = \dfrac{V_\phi^2 + 2V_\phi v_e + v^2}{r}$ in which V_ϕ is the linear velocity due to the rotation of the earth's surface at latitude ϕ ; r is the earth's radius; v_e is the eastward component of the ship's speed; and $v^2 = v_e^2 + v_n^2$ where v_n is the northward component of v .

Gravity on the platform, which is reduced or increased by the ship's velocity, must be added or subtracted to the observed gravity. The Eötvös correction is accordingly:

$$E_{ec} = \frac{2V_\phi v_e + v^2}{r}$$

By substituting $V_{\phi} = r\omega\cos\phi$ where ω is the earth's angular velocity and $v_e = v\sin\phi$:

$$E_{ec} = 2\omega v\cos\phi\sin\alpha + \frac{v^2}{r}$$

finally:

$$E_{ec} = 7.5028v\cos\phi\sin\alpha + 0.0041566v^2 \text{ mGal}$$

where α is the ship's course measured clockwise from the north; v is the ship's speed given in knots; and ϕ is the latitude in decimal degrees.

The Eötvös correction, added algebraically to the observed gravity measurement, yielded the corrected stationary gravity measurement.

The Free-Air gravity anomaly is the difference between observed gravity values measured at sea level and the theoretical value of gravity, calculated for that latitude using the International Gravity Field of 1967 (International Association of Geodesy, 1971) or $FAA = G_{obs} - G_{theo}$. A mathematical expression for gravity on the surface of a uniform rotating oblate spheroid, a close approximation to the equilibrium sea level surface of the earth, yields the theoretical value of gravity as a function of latitude ϕ (International Association of Geodesy, 1971). This expression, known as the International Gravity Formula, or IGF, provides a reference to which gravity on the real earth can be compared. The most recent version of the IGF, adopted by the International Association of Geodesy (1971), is given by the equation:

$$g = 978.03185\ (1+0.005278895\ \sin^2\phi+0.000023462\sin^4\phi) \text{ in Gals.}$$

Marine Magnetic Measurements: A GeoMetrics G801/3 Marine/ Airborne Proton Precession Magnetometer measured the total magnetic field during Yucatan'85. The sensing element installed in a waterproof container was towed approximately 180 meters behind the ship to avoid magnetic interference produced by the vessel. The total magnetic field, recorded digitally every 10 seconds aboard the ship, was subsampled to an interval of 3 minutes. The uncertainty of the instrument is ±1 gamma (GeoMetrics operating manual for model G801/3). The total magnetic field anomaly was obtained by subtracting, in scalar form, the 1985 International Geomagnetic Reference Field values (International Association of Geomagnetism and Aeronomy, Division I, Working Group 1, 1986) from the observed total magnetic field. Although the components of the magnetic field are vector quantities, they were treated as scalars because anomaly values are about 1% of the IGRF values.

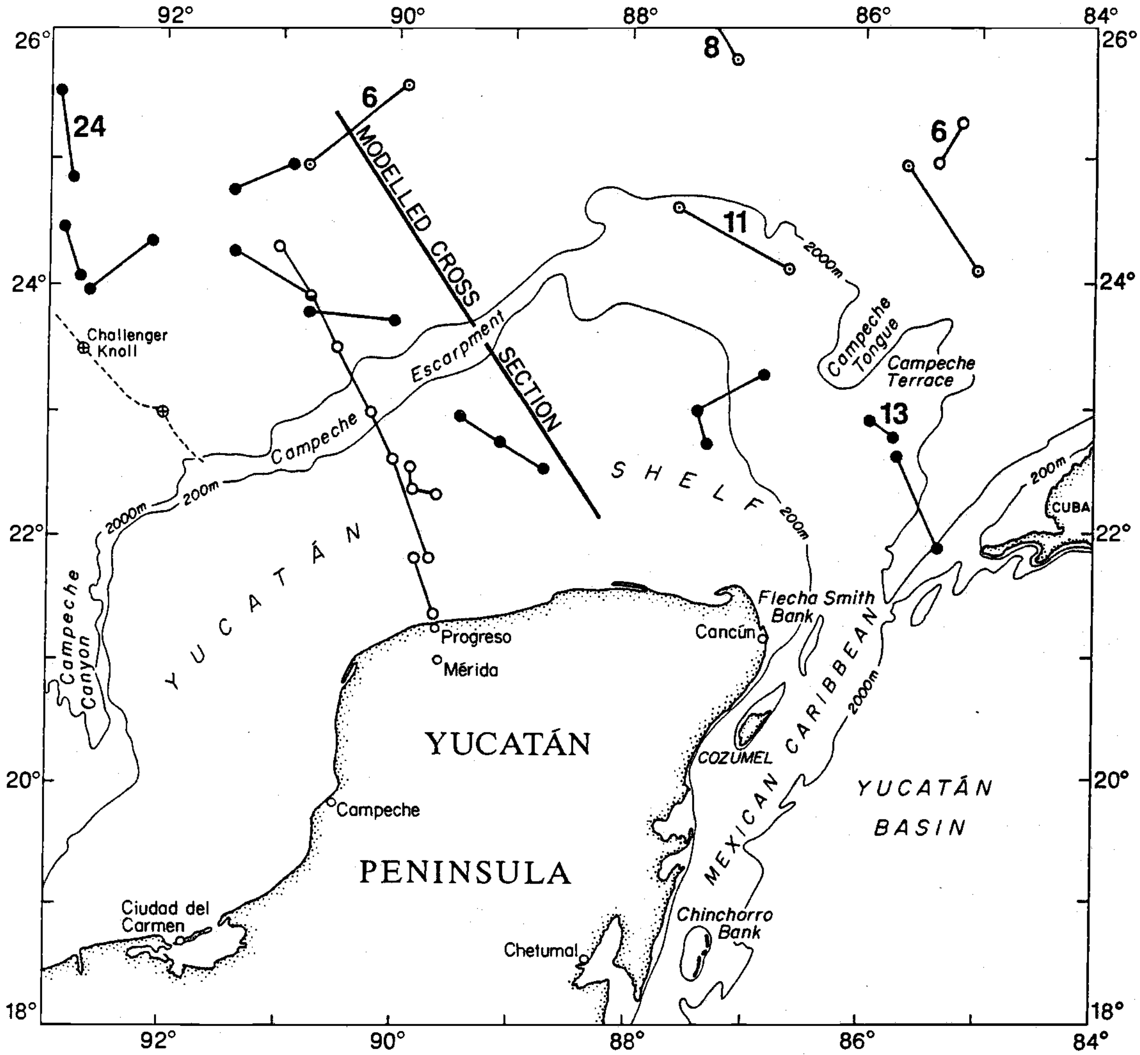
A GeoMetrics Proton Precession Magnetometer, G-856A, recorded magnetic observations at land-based stations. Data acquired digitally at a 3 minute interval rate carries an estimated instrument accuracy of ±0.5 gamma (GeoMetrics operating manual for model G-856A). The purpose of these land measurements was to detect time variations of the external magnetic field occurring during the survey. Such variations include diurnal variations and magnetic fluctuations due to electrical storms, sunspots, and other solar phenomena.

Bathymetric Measurements: An EDO Western Echo-Sounding system, with a 2 kilowatt transceiver operating at 12 kHz, recorded bathymetric data for Yucatan'85. The records, displayed on an EPC 4600 single-channel graphic recorder at a 4 second sweep rate, were later hand digitized at a 3 minute interval. The EDO system provided readings in uncorrected fathoms. Carter's tables (Carter, 1980) for the velocity of sound in sea water, provided the correction to transform uncorrected fathoms into corrected meters. The bathymetric data were then added to the gravity, magnetic, and position data for each station.

COMPUTATION OF THE MODEL CROSS-SECTION

In this study, all seismic, gravity, magnetic, and bathymetric data were used to constrain the crustal and subcrustal model cross-section of the Campeche Escarpment. Figure 5 and Figure 6 show the location of the cross-section, which was chosen to accommodate the two-dimensionality required by the modeling program developed by Talwani et al. (1959). By orienting the cross-section perpendicular to the escarpment, this assumption was in part fulfilled. However, the orientation also was selected by identifying on the Gravity Anomaly Map a two-dimensional structure whose long axis is approximately parallel to the escarpment. In addition, the location and orientation of the profile also was selected so that the model could be tied to a seismic line. As a result, the cross-section was placed so as to extend a distance of 427 km straight southeast from 25°21.8'N, 90°32.5'W in the south-central Gulf of Mexico, to 22°08.6'N, 88°15'W on the Yucatan Platform.

The northernmost end of the section crosses almost perpendicularly the 110.5 km long reversed refraction profile 6E-6W reported by Ibrahim et al. (1981) about 45 km east of its westernmost extremum (Figure 5). Their refraction measurement was made using ocean bottom seismographs (OBS). Table 2 shows the results. Layer thicknesses used in the model were estimated from the seismic results by



SEISMIC REFRACTION DATA SOURCES

- ⊙ Ibrahim et al., 1981
- ● Ewing et al., 1960
- ○ Antoine and Ewing, 1963

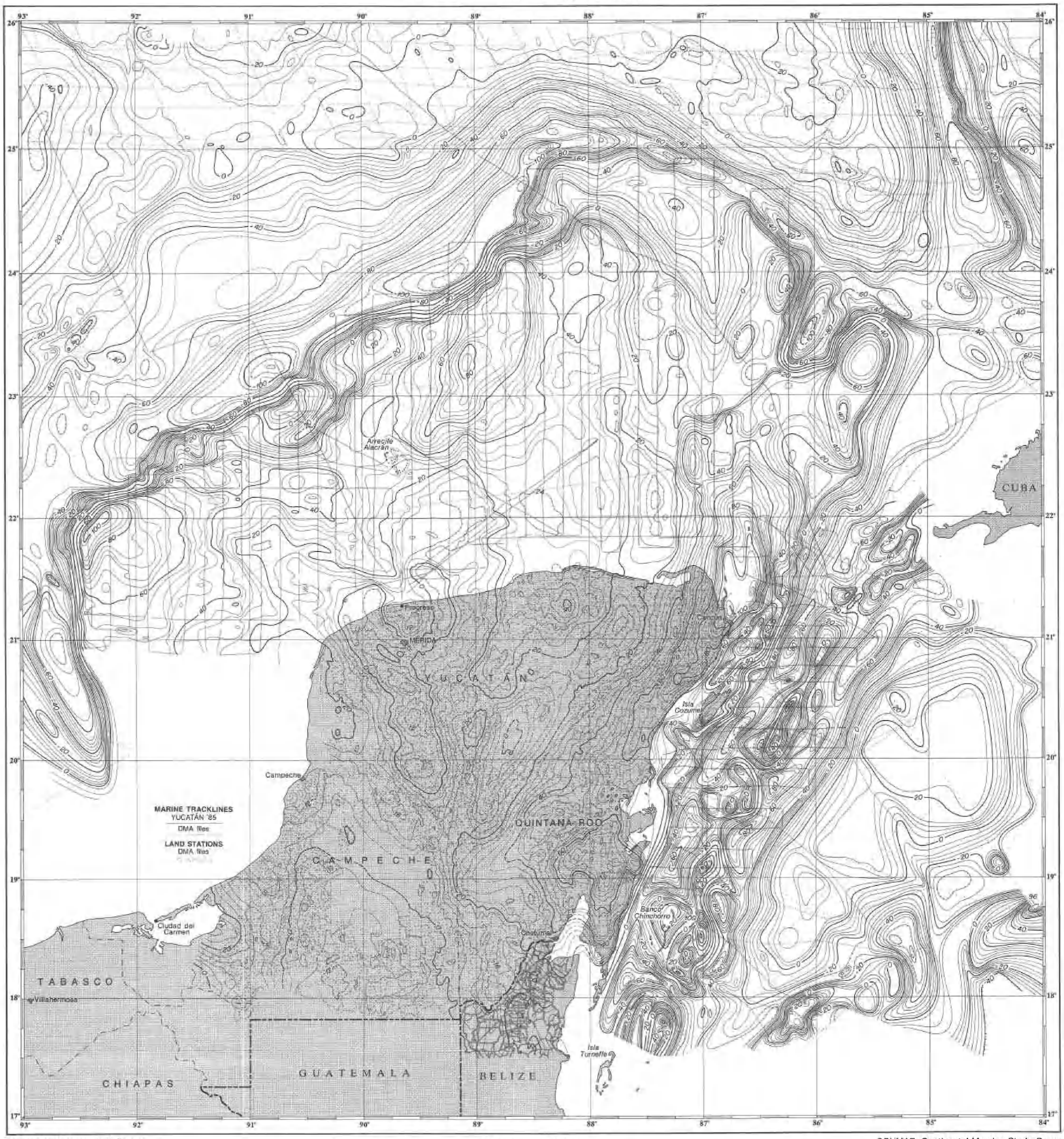
8 Refer to seismic refraction lines used to compute mass columns

⊕ DSDP sites along a 24-fold multichannel seismic line

Figure 5 -- Location of seismic refraction lines and main physiographic provinces in the study area.

Figure 6 -- Gravity Anomaly Map.

GRAVITY ANOMALY MAP
Yucatán Peninsula and Adjacent Waters



Free-air anomaly at sea, simple Bouguer anomaly on land (reduction density 2.67 g/cm^3)

Estimated RMS uncertainty 2 milligals

Theoretical gravity: IGF (1967)

Data sources: Oregon State University cruise YUCATÁN '85, and Defense Mapping Agency – Gravity Services Branch

SCALE at 21.5° 1: 4,250,000

0 50 100 nautical miles

0 50 100 150 kilometers

MERCATOR PROJECTION

Contour interval 4 milligals

CONMAR: Continental Margins Study Group
Oregon State University
and
Dirección General de Oceanografía
Secretaría de Marina
JUNE 1986

Figure 6

Profile	Position °N Long. °W Lat.	Unconsolidated Sediment		Velocity (km/sec) Consolidated Sediment, High Velocity A	B	C	D	E	F	Layer Thickness (km) Water	Unconsolidated		Consolidated High Velocity A	B	C	D	E
1W	21.92 95.26		2.1		3.2	4.7	5.7	6.7	7.8	1.94		0.88		7.86	2.01	3.38	3.59
2E	24.43 94.02	1.8		2.6	3.4	4.5	6.1		8.0	3.66		1.02	1.30	3.76	3.77	5.94	
W	24.68 94.95									3.55		1.12	0.70	5.33	3.54	5.13	
3N	25.04 94.37	1.8		2.7	3.3	4.7	6.3		8.2	3.59		0.94	1.30	4.05	5.21	4.00	
4E	22.33 94.31		2.1		3.1	5.0		6.8	8.1	3.57		1.67		4.56	3.32		3.96
W	21.92 95.26									3.06		1.53		5.88	2.27		4.09
5N	20.96 94.61		2.0	2.7	3.5	5.1		6.7	8.2	3.20		0.68	1.13	5.59	2.69		6.44
S	20.06 95.05									2.78		0.95	0.99	5.66	5.14		5.47
6E	25.57 89.92	1.7	2.0		3.0	4.9		6.8	8.0	3.24	0.28	1.84		3.44	2.94		4.02
W	24.95 90.78									3.53	0.05	1.70		3.60	2.31		4.61
7N	27.46 88.24	1.9	2.1		3.0	4.7		7.0	7.9	2.23	0.87	1.65		3.13	3.54		5.34
S	26.63 87.69									2.70	0.08	2.16	3.32	3.75			6.49
8N	26.63 87.69	1.8	2.0		2.9	5.1		6.9	7.8	2.70	0.12	1.89		3.79	2.39		7.71
S	25.77 87.10									3.21	0.12	1.56		3.94	3.40		2.55
9E	26.73 87.18	1.8	2.0		3.1	4.8		6.8	8.0	2.79	0.42	2.11		3.12	2.78		5.05
W	26.04 87.96									2.95	0.57	1.62		3.76	2.17		6.50
10N	28.71 87.88	1.8	2.2		3.2	4.8	6.3		7.6	2.17	0.16	2.25		2.68	1.81	11.94	
S	27.72 87.98									2.50	0.98	0.93		3.22	4.63	3.32	
11E	24.13 86.64		2.0		3.4	4.7	5.9	6.4		1.28	0.57			1.01	2.22	9.46	
W	24.61 87.59									1.60	0.01			0.52	1.92		
12N	24.94 85.63	1.8				4.6	5.4	6.4	8.1	3.25	1.91				1.85	2.74	5.09
S	24.11 85.02									3.36	1.05				2.56	1.48	9.94

Table 2 -- Ocean Bottom Seismograph (OBS) results (from Ibrahim et al., 1981). Profile 6E-6W provided constraints for the crustal model.

assuming the layers are horizontal along the refraction profile.

The observed seismic velocities were then converted to densities by utilizing the empirical relationships between compressional wave velocities and densities developed by Ludwing, Nafe and Drake (1970). Assuming that no lateral inhomogeneities exist in the mantle below 50 km, a model of the crust and subcrustal structure was constructed. By using the line integral method as applied by Talwani et al. (1959), the vertical component of the gravitational acceleration at points along the earth's surface due to the sum of the gravitational accelerations of the polygons of the cross-section was computed. The results yielded the gravitational attraction along the profile produced by the model.

Barday (1974) computed the gravitational attraction produced by an average oceanic section 50 km thick based on seismic refraction measurements and empiral relationships between velocity and density. Barday's section, adopted as a standard, uses a density of 1.03 g/cc for a water layer of 4.05 km thick; 2 g/cc for a 0.460 km sedimentary layer 1; 2.60 g/cc for a 1.10 km thick layer 2; 2.90 g/cc for a 4.0 km thick oceanic layer 3; and 3.32 g/cc for the mantle layer (Figure 7). The gravitational attraction of the 50 km-thick oceanic standard section is 6442 mGal. This value was then used as a reference for the Campeche cross-section

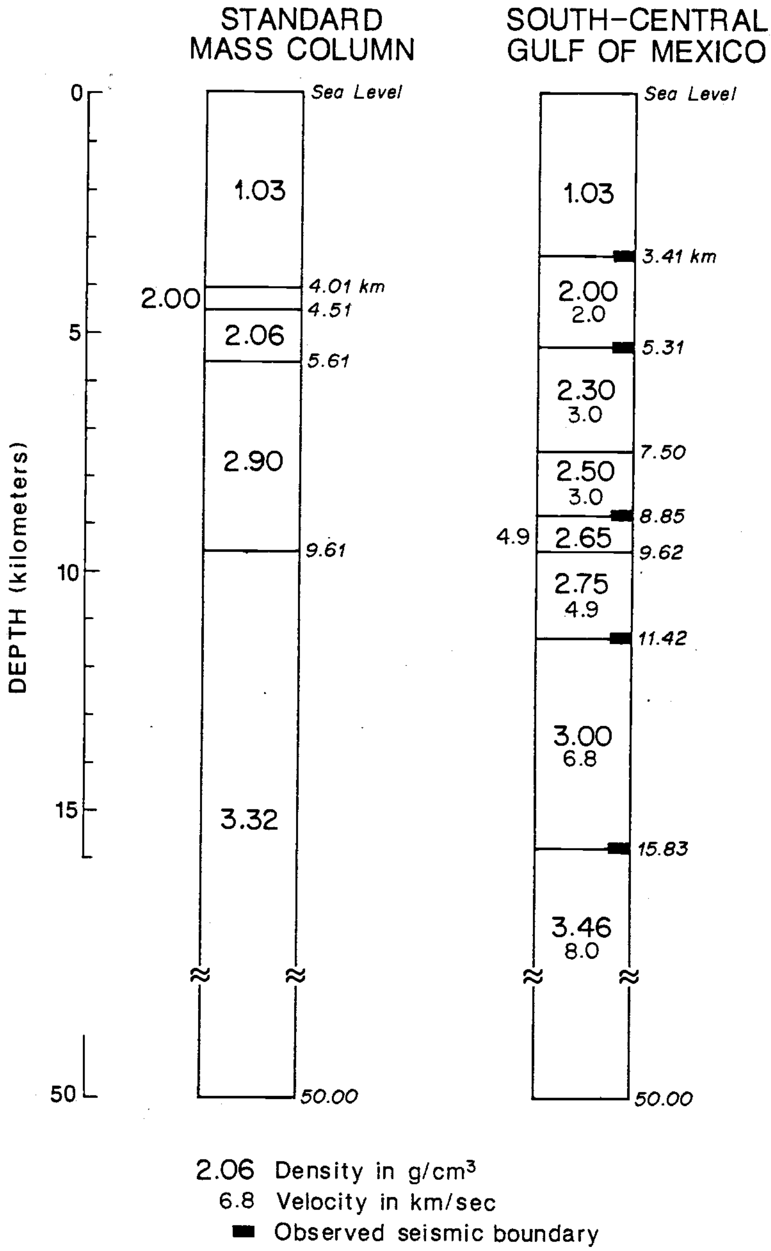


Figure 7 -- Comparison between the Standard Mass Column (from Barday, 1974) and the South-Central Gulf of Mexico Mass Column generated by using seismic refraction line 6 (reported by Ibrahim et al., 1981). Densities for the Gulf of Mexico Mass Column were computed to fit the observed gravity anomaly which lies in the region.

model. When 6442 mGals were subtracted from the computed values of the cross-section, the difference yielded the computed free-air anomaly produced by the two-dimensional model. The computed gravity was compared with the observed gravity, and iterative adjustments of the polygons were made until the observed and computed gravity values agreed.

Magnetic data observed during Yucatan'85 were used to model the magnetic structure beneath the Yucatan Platform and the Campeche Escarpment between 24°N, 89°33.8'W and 22°08.6'N, 88°15'W. Magnetic data published by Hall et al. (1982) served to extend the observed magnetic anomalies 100 km further northward of the escarpment. The extension of the magnetic anomaly profile further north of the Campeche Escarpment was intended to yield a model of the transitional crust beneath the base of the slope that had been inferred by Buffler (1984a) and Buffler and Sawyer (1985) as shown in Figure 2.

INTERPRETATION OF THE CROSS-SECTION

Figures 8 and 9 show the geophysical and geological interpretation of the crustal and subcrustal structure in the southern margin of the Gulf of Mexico respectively. Figure 8 shows the geophysical cross-section at two different scales; the upper section with a vertical exaggeration of 4:1 and the lower with no vertical exaggeration. The numbers inside the blocks indicate densities in grams per cubic centimeter and, in their respective cases, the magnetization in electromagnetic units per cubic centimeter. Normal or reverse magnetization is indicated by right and left diagonally hachures, respectively. Heavy bars and adjacent numbers indicate the observed seismic refraction horizons and velocities.

The lower solid curve above the model shows the observed free-air anomaly along the section, and the open circles indicate the computed gravity values. In the same way, the uppermost solid curve represents the observed magnetic anomaly and the open circles indicate the computed magnetic values.

Free-air gravity values in the northernmost part of the section range from -5 to 4 mGal, then decrease almost linearly from there to the base of the Campeche Escarpment where the minimum value is -108 mGal. A very steep gravity

Figure 8 -- Geophysical crustal and subcrustal model across the Campeche Escarpment.

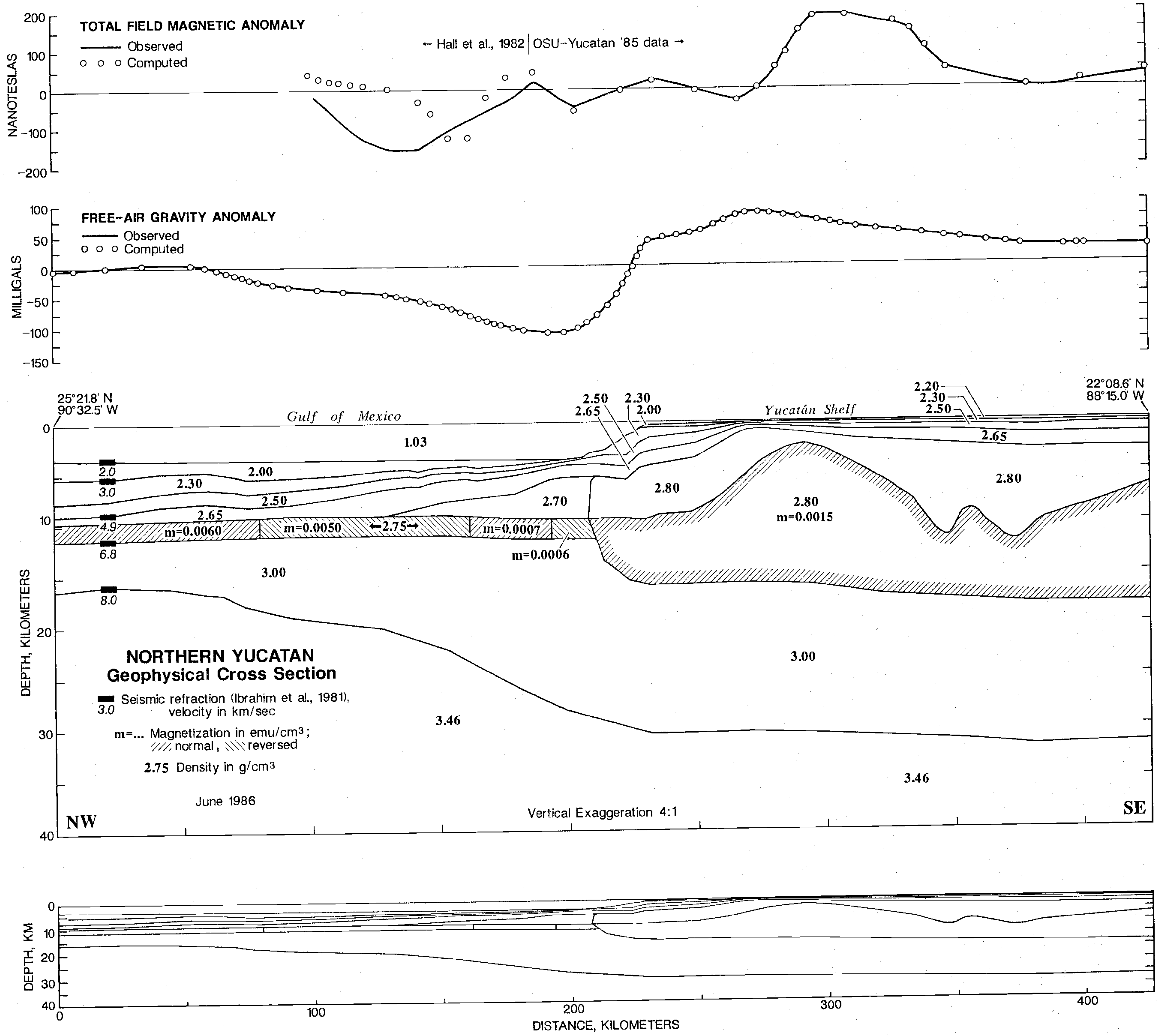

TOTAL FIELD MAGNETIC ANOMALY
Observed
Computed
NANOTESLAS
← Hall et al., 1982 | OSU-Yucatan '85 data →
FREE-AIR GRAVITY ANOMALY
Observed
Computed
MILLIGALS
25°21.8' N
90°32.5' W
22°08.6' N
88°15.0' W
Gulf of Mexico
Yucatán Shelf
NORTHERN YUCATAN
Geophysical Cross Section
Seismic refraction (Ibrahim et al., 1981), velocity in km/sec
m=... Magnetization in emu/cm³; normal, reversed
2.75 Density in g/cm³
June 1986
Vertical Exaggeration 4:1
NW
SE
DEPTH, KILOMETERS
DEPTH, KM
DISTANCE, KILOMETERS

Figure 8

gradient of 5.75 mGal/km occurs over the slope of the Campeche Escarpment. A more gentle gravity gradient of 1.12 mGal/km occurs over an area of about 40 km wide that covers the seaward edge of the continental shelf and the edge of the Yucatan Platform. The gravity anomaly reaches a maximum value of 86 mGal 42 km landward of the edge of the Campeche Escarpment, and then slowly decreases at an average rate of 0.56 mGal/km along the central part of the Yucatan Platform. The iteratively-computed free-air anomaly agrees well with the observed gravity anomaly along the profile.

A difference between the anomalies occurs over the Campeche Escarpment. However, by placing a layer of variable thickness of between 100 to 200 meters and with a higher density of about 2.80 g/cc just beneath the physiographic feature of the escarpment, the observed and computed anomalies could be fitted. This relatively thin layer could be interpreted as reef structures. Developed reefs occur in the Gulf of Mexico beyond the edge of the carbonate platforms off the Florida and Yucatan Peninsula, and are important as sediment dams (Kennett, 1982).

The refraction results to which this model was tied show five major discontinuities (Table 2). These interfaces separate unrelated units and mark the upper boundaries of the following modeled seismic sequences: 1) The first of them, represented by a thick layer containing the Sigsbee and Cinco de Mayo Units, with a seismic velocity of

2.0 km/sec, is assigned a density of 2.0 g/cc. 2) The second seismic sequence with a seismic velocity of 3.0 km/sec is assumed to contain the Mexican Ridges Unit and the acoustically transparent Campeche Unit. These units are assigned densities of 2.30 and 2.50 g/cc respectively. 3) Beneath the Campeche Unit, and truncated by the Middle Cretaceous Unconformity (MCU) lies the Challenger Unit. The Challenger Unit corresponds approximately to the upper part of the 4.9 km/sec velocity layer and is assigned a density of 2.65 g/cc. A 2 km thick Layer 2, represented by magnetic blocks of changing polarization, underlies the Challenger Unit. This layer is assigned a density of 2.75 g/cc. 4) A fourth layer with a seismic velocity of 6.8 km/sec and a density of 3.0 g/cc represents oceanic Layer 3. 5) Finally, an 8.0 km/sec velocity layer that extends to a depth of 50 km represents the upper mantle. Computation of the gravity attraction produced by the mass column of the observed units overlying the 8.0 km/sec layer helped to estimate the mass contribution due to the mantle. By assuming a depth of compensation of 50 km (a depth at which the pressure due to the overlying crustal elements is constant and below which lateral variations disappear), a mantle density of 3.46 g/cc was computed to exist beneath the crustal structure of the south-central Gulf of Mexico.

This mantle density of 3.46 g/cc, as derived from the model, is 0.14 g/cc greater than the expected "standard" mantle density of 3.32 g/cc obtained by Barday (1974). The composition of mantle rocks is unknown; and rock types postulated for the mantle, which have been measured in the laboratory under conditions believed to exist in the upper mantle, indicate that for a velocity of 8.0 km/sec densities may range from 3.0 g/cc to 3.7 g/cc (Woöllard, 1962). The empirical relation between crustal thickness, indicated by seismic measurements, and changes in surface elevation suggest that mantle densities are between approximately 3.28 g/cc and 3.46 g/cc (Woollard, 1962). Clearly the thicknesses and densities of the upper mantle material could be varied to conform with the observed gravity anomalies. However, the seismic refraction control and a small range of reasonable densities for the crust, restricted the acceptable densities of the layers for the model. Even when a greater density than normal was assigned to the sedimentary prism containing the Sigsbee, Cinco de Mayo, Mexican Ridges, Campeche, and Challenger Units, an increased density for the mantle layer was still required.

A uniform mantle is assumed below 50 km. If, however, differences in the upper mantle beneath oceans and continents extend greater than 50 km, as is possible, lateral density contrasts in the upper mantle would be reduced.

Ewing et al. (1962) calculated that the observed gravity field of the Gulf was about 200 mGal more positive than expected. They suggested that this might be due to a) a greater density of the sediments, b) a greater density of both sediments and oceanic crust, or c) a high density mantle. They preferred the idea of greater sediment and crustal density because it required the least deviation from data points on the empirical curve of Nafe and Drake. Antoine and Pyle (1970) favored a greater density than normal in the sedimentary prism alone, because the Gulf of Mexico contains a greater mass of turbidites than of pelagic deposits. Menard (1967), after examination of several "oceanic" basins, concluded that higher sediment density in small ocean basins (such as the Gulf of Mexico) cannot explain the observed gravity. He suggested, therefore, that at least part, and perhaps all, of the required high density material is in the mantle. Moore (1972) pointed to the possibility that a high-density mantle beneath the Gulf of Mexico may be attributable to the greater age of the basin (Jurassic or older), as compared with the average age for the western Atlantic (Cretaceous). Thermal contraction resulting from dissipation of initial heat after sea floor spreading causes mid-ocean rises to subside more than 3 km during the 10 MY period required to approach thermal equilibrium (Sclater et al., 1971). Considering this, Moore (1972) suggested that such thermal contraction could produce a density change in the upper mantle sufficient to balance the crust of the Gulf of Mexico, isostatically, with younger and thinner crusts of larger ocean basins.

In addition, a noticed "high" on the geoid (Couch, 1986, personal communication) is detected in the Gulf of Mexico. This geoidal high suggests that a more dense than normal (higher than 3.32 g/cc) lithospheric-asthenospheric substratum exists beneath the modeled sedimentary and crustal structure of the Gulf and surrounding area which may, in part, reflect a high density mantle.

Factors such as thermal contraction due to the age of the basin, and presence of a denser than average lithospheric-asthenospheric substratum beneath the crustal structure of the Gulf, may cause a density anomaly in the mantle. It is also thought that in addition to the high density mantle present in the Gulf of Mexico, a significantly different-than-normal load of sediments (five to ten times thicker than the normal thickness of sediments on the oceanic crust) contributes to the more positive than expected observed gravity field.

The sedimentary sequence, represented by the Sigsbee, Cinco de Mayo, Mexican Ridges, Campeche and Challenger Units (Vp= 1.7 to 4.9 km/sec) with a total thickness of as much as 6.2 km at the northern end of the section, thins towards the base of the Campeche Escarpment to less than 2 km. However, the Challenger Unit retains its average thickness further south of the escarpment. The post-MCU sedimentary section forms a sedimentary prism by thinning toward the base of the slope. The Sigsbee and Cinco de

Mayo units pinch out against the Campeche Escarpment.

Beneath the base of the escarpment, underlying the Challenger Unit, a 2.70 g/cc "carbonate" prism is located in the area where the transitional crust (rifted or attenuated continental crust) was inferred by Buffler (1984a) and Buffler and Sawyer (1985), based on seismic refraction and reflection data. This prism is believed to be composed of the same "carbonate" sequence as the block adjacent to the south with an assigned density of 2.80 g/cc (Figure 7). A difference in density of 0.10 g/cc occurring between these "carbonate" blocks suggests the prism is fractured or faulted. It is thought that the boundary between these "carbonate" units represents a major fault, caused by the relative vertical movements that occurred between the continental and oceanic crust during isostatic adjustment.

The presence of abrupt inclines in the sedimentary layers beneath the edge of the Campeche Escarpment suggests faulting. Two faults are shown in Figure 9, represented by dashed lines.

Several attempts were made to fit the magnetic anomaly north of the Campeche Escarpment. Analysis of magnetization, polarity, and extension of the crustal magnetic blocks in this area yielded an anomaly shape similar to the observed magnetic anomaly. These blocks are represented by a uniformly magnetized oceanic crustal Layer 2, formed by a

Figure 9 -- Geological interpretation of the crustal and subcrustal model.

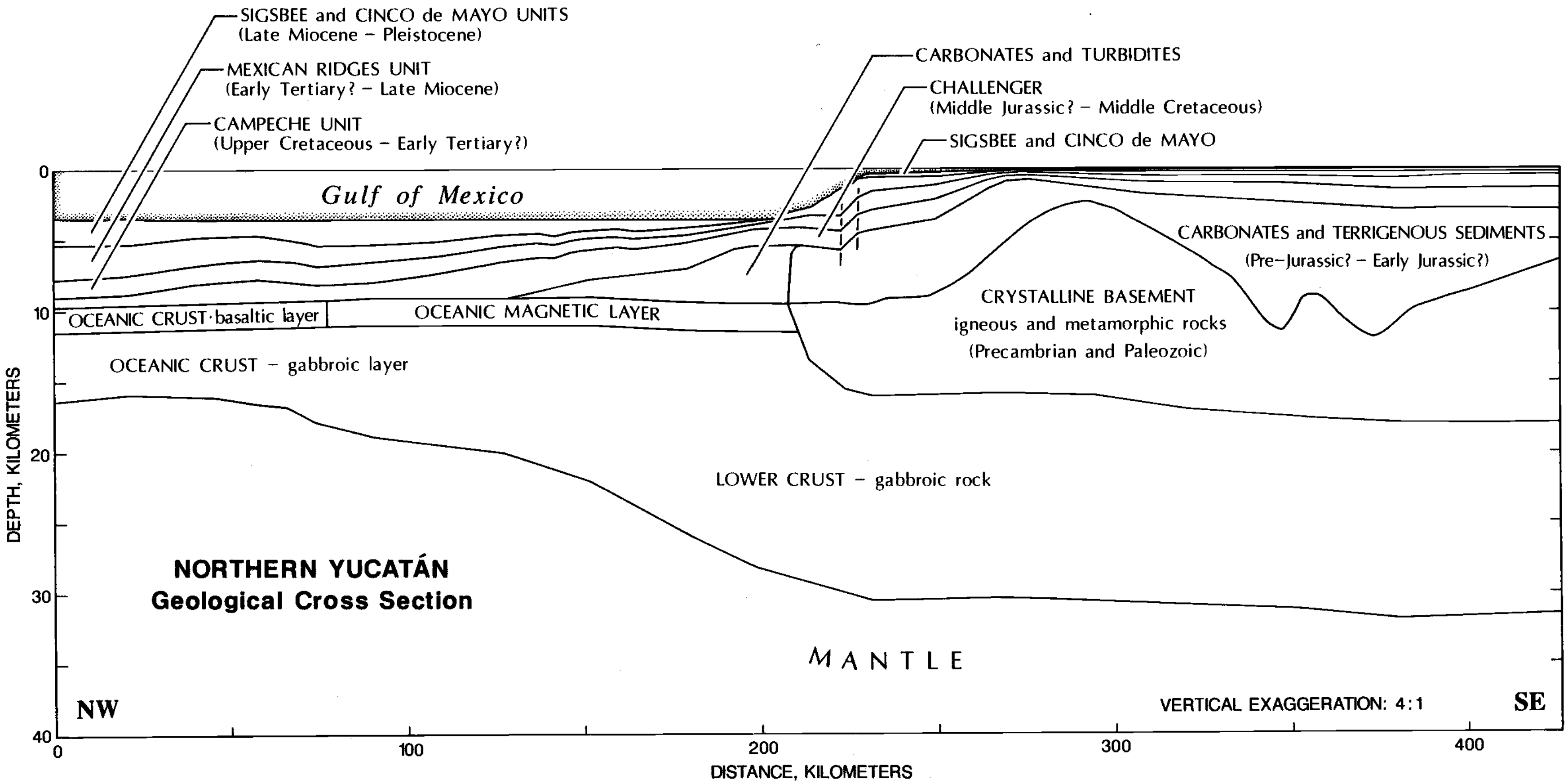

SIGSBEE and CINCO de MAYO UNITS
(Late Miocene – Pleistocene)
MEXICAN RIDGES UNIT
(Early Tertiary? – Late Miocene)
CAMPECHE UNIT
(Upper Cretaceous – Early Tertiary?)
CARBONATES and TURBIDITES
CHALLENGER
(Middle Jurassic? – Middle Cretaceous)
SIGSBEE and CINCO de MAYO
Gulf of Mexico
CARBONATES and TERRIGENOUS SEDIMENTS
(Pre–Jurassic? – Early Jurassic?)
OCEANIC CRUST·basaltic layer
OCEANIC MAGNETIC LAYER
CRYSTALLINE BASEMENT
igneous and metamorphic rocks
(Precambrian and Paleozoic)
OCEANIC CRUST – gabbroic layer
LOWER CRUST – gabbroic rock
NORTHERN YUCATÁN
Geological Cross Section
MANTLE
NW
SE
VERTICAL EXAGGERATION: 4:1
DEPTH, KILOMETERS
0
10
20
30
40
0
100
200
300
400
DISTANCE, KILOMETERS

Figure 9

series of 2 km thick blocks of alternating polarity with vertical boundaries separating them.

Stable remanent magnetization, containing the direction of the geomagnetic field at the time of initial cooling and initial magnetization, is predominant in oceanic crust, whereas viscous remanent or induced magnetization is less common (Vine and Matthews, 1963; Hall, 1976). In this study, the oceanic crust is believed to contain stable remanent magnetization, which provides the dominant magnetic response to the magnetic anomaly.

About 50 km north of the oceanic/continental crustal boundary, the magnitude of the magnetization of the oceanic crust reaches $50X10^{-4}$ emu/cc, whereas a lower magnetization of 6 to $7X10^{-4}$ emu/cc is present beneath the carbonate prism where the oceanic/continental boundary occurs. The difference in magnetization might be due to the fact that remanent magnetization at the oceanic/continental boundary has been in some way influenced by physical processes, such as high pressure and/or temperature that occurred at the time of the differential movements between the oceanic and continental crusts.

A magnetic source layer mainly constituted of serpentinized peridotite. a rock type that is believed to occur at depth in the oceanic crust, is a likely cause of the marine magnetic anomalies (Cox et al., 1964; Fox and Opdyke, 1973; Hall and Ryall, 1976). Similarly, this magnetic source layer is proposed to occur in the oceanic crust north of the Campeche Escarpment.

Deep holes drilled in the Atlantic show that the magnetic structure of the oceanic crust is much more complex than expected (Kennett, 1982). This complexity includes reversals in polarity, large systematic deviations of inclinations from expected dipole values, large variations in intensity and lateral magnetic heterogeneity in the basalts of Layer 2 (Kennett, 1982). Although an anomaly that is not very well fitted exists beyond the base of the Campeche Escarpment, similarities in shape between observed and computed anomalies can be clearly noticed. No extent of an attenuated or rifted continental crust (transitional crust) is magnetically evident.

A much better correlation between computed and observed magnetic anomalies is observed over the Yucatan Platform, where a pre-rift magnetized basement block of magnetization M = $15X10^{-4}$ emu/cc lies under a thick sequence of "carbonates" and terrigenous sediments. These sediments are thought to be older than the Challenger Unit, and may be of Early or Pre-Jurassic age.

The pre-rift crystalline basement block with a density of 2.80 g/cc shows the following physiographic features: A zone of about 40 km marked by a very gentle gradient (1:100) extends landward from the oceanic/continental crustal boundary. South of this area exists another zone of about 40 km where the crystalline block rises from 9 km deep to 2.3 km; and finally, the basement reaches its shallowest point in an area located about 80 km south of the edge of the Campeche Escarpment.

Because no wells have penetrated basement in the south-central Gulf of Mexico, the location of this "high" is a likely site to drill an exploratory well to sample this basement. Direct identification of the composition and age of the crystalline basement and the overlying 2.8 g/cc "carbonate" layer would contribute to a better understanding of the origin and evolution of the Gulf of Mexico.

The thick sequence of "carbonates" with a high density of 2.8 g/cc fills the basement lows in the southern area. The presence of "carbonates" seaward and landward of the crystalline-basement high outlined by the gravity high suggests that transgression of the sea, associated with subsidence of the continental block, occurred during the early evolution of the Gulf. This "carbonate" layer may be constituted of two materials: a) a mix of carbonaceous and terrigenous sediments eroded from the continent and deposited in shallow seas on both sides of the crystalline basement high, and b) carbonaceous sediments created once the basement block completely subsided below sea level. These sediments filled the topographic lows and covered the basement high with a second stratigraphic layer, formed mainly of carbonates (Figure 10). The upper part of this "carbonate" layer, characterized by an almost flat surface and gentle slope, became "basement" on which the section of Jurassic-to Recent sedimentary rocks lie.

Challenger, Campeche, and Mexican Ridges Units conform to the shape of the stratigraphic sequence above the gentle cliff of the basement high. The sequence forms a "seaward migrating escarpment" that developed during the evolution of the Gulf and culminated with the relatively recent formation and faulting of the Campeche Escarpment. On the Yucatan Shelf, each of the sedimentary units that comprise the Jurassic-Recent sedimentary sequence form approximately horizontal beds that overlie and conform to the landward part of the 2.8 g/cc "carbonate" layer.

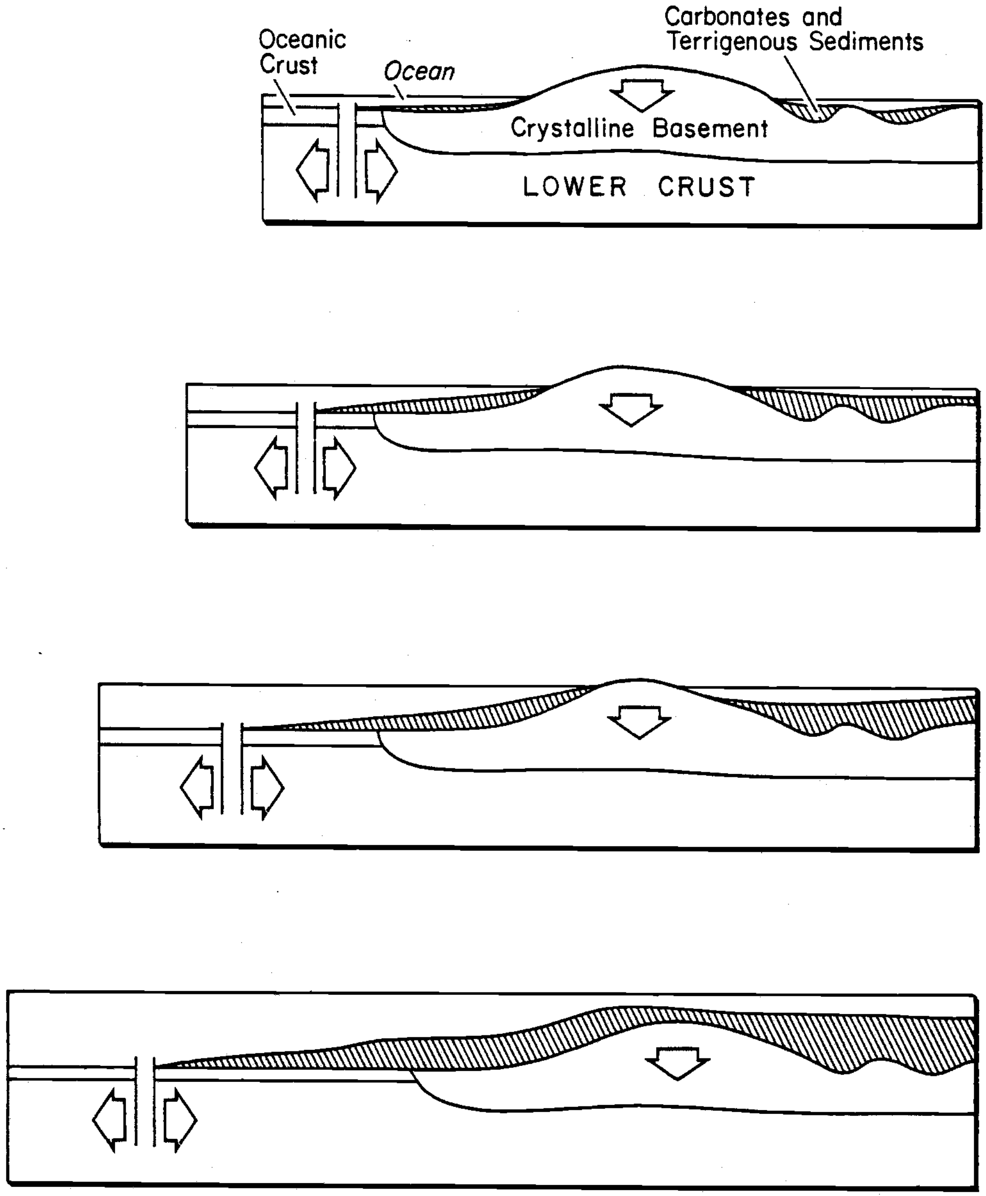


Figure 10 -- Proposed sequential model of sedimentary deposition, subsidence, and opening of the Gulf which influenced crustal architecture of the carbonate and crystalline basement beneath the Yucatan Platform.

GRAVITY ANOMALY MAP

Figure 6, presented on page 26, shows the Free-Air Gravity Anomaly Map of the south-central Gulf of Mexico and adjacent marine areas. On land, the map shows the Simple Bouguer Anomaly of the Yucatan Peninsula. With an extension of about 950,000 square kilometers, the map covers the area from 17°30'N to 26°N and from 84°W to 93°W. Marine gravity data collected along the tracklines of Yucatan'85 reveal the free-air anomalies over the Yucatan Platform, including the Bank of Campeche, the Campeche Terrace, the Campeche Escarpment, and the Mexican Caribbean. These provinces can be observed in Figure 3.

Marine gravity data, from the Defense Mapping Agency, provided additional data to extend the mapping toward those areas not covered by Yucatan'85 measurements, i.e., toward the central Gulf over the Sigsbee Plain, toward the Florida Plain, and eastward toward the Yucatan Basin. The Defense Mapping Agency provided the land gravity data used to form the Simple Bouguer Anomaly Map of the Yucatan Peninsula. Yucatan'85 included land gravity measurements for Cozumel Island and Isla Mujeres. The merging of the Yucatan'85 and Defense Mapping Agency gravity data resulted in the Gravity Anomaly Map shown in Figure 6 and included in the pocket in the back of this thesis.

The Gravity Anomaly Map is contoured at a 4 mGal interval with heavy contours every 20 mGals. Hachures on closed contours indicate lower values, and absence of hachures indicates higher values inside closed contours. For the Yucatan Platform, Campeche Escarpment, and the Mexican Caribbean where Yucatan'85 marine gravity measurements exist, analysis, based on the differences in gravity readings at 160 trackline crossings, indicates an RMS uncertainty of 1.4 mGal.

BATHYMETRIC/TOPOGRAPHIC MAP

Figure 11 shows the Bathymetric/Topographic Map for the south-central Gulf of Mexico, the Yucatan Peninsula and adjacent areas. Contouring of bathymetric readings, collected along the tracklines of Yucatan'85, show physiographic features of the Yucatan shelf and the Campeche Escarpment. Bathymetric data requested from the Defense Mapping Agency provided the information necessary to extend depth values to those areas where no Yucatan'85 bathymetric data were obtained. Eric Rosencrantz (1986, personal communication) from the University of Texas Institute for Geophysics provided bathymetric information for the eastern Yucatan Peninsula. A bathymetric map published by Schlager et al. (1984) was used to integrate the study area with their information of the southeastern Gulf of Mexico. Topographic data obtained from the Defense Mapping Agency yielded the physiographic configuration of the Yucatan Peninsula. Compilation and contouring of these data yielded the Bathymetric/Topographic Map presented in Figure 11 and the Bathymetric/Topographic Map at 4 inches per degree included in the back pocket of this thesis. Main physiographic provinces referred to below can be observed in Figure 3.

Figure 11 -- Bathymetric/Topographic Map.

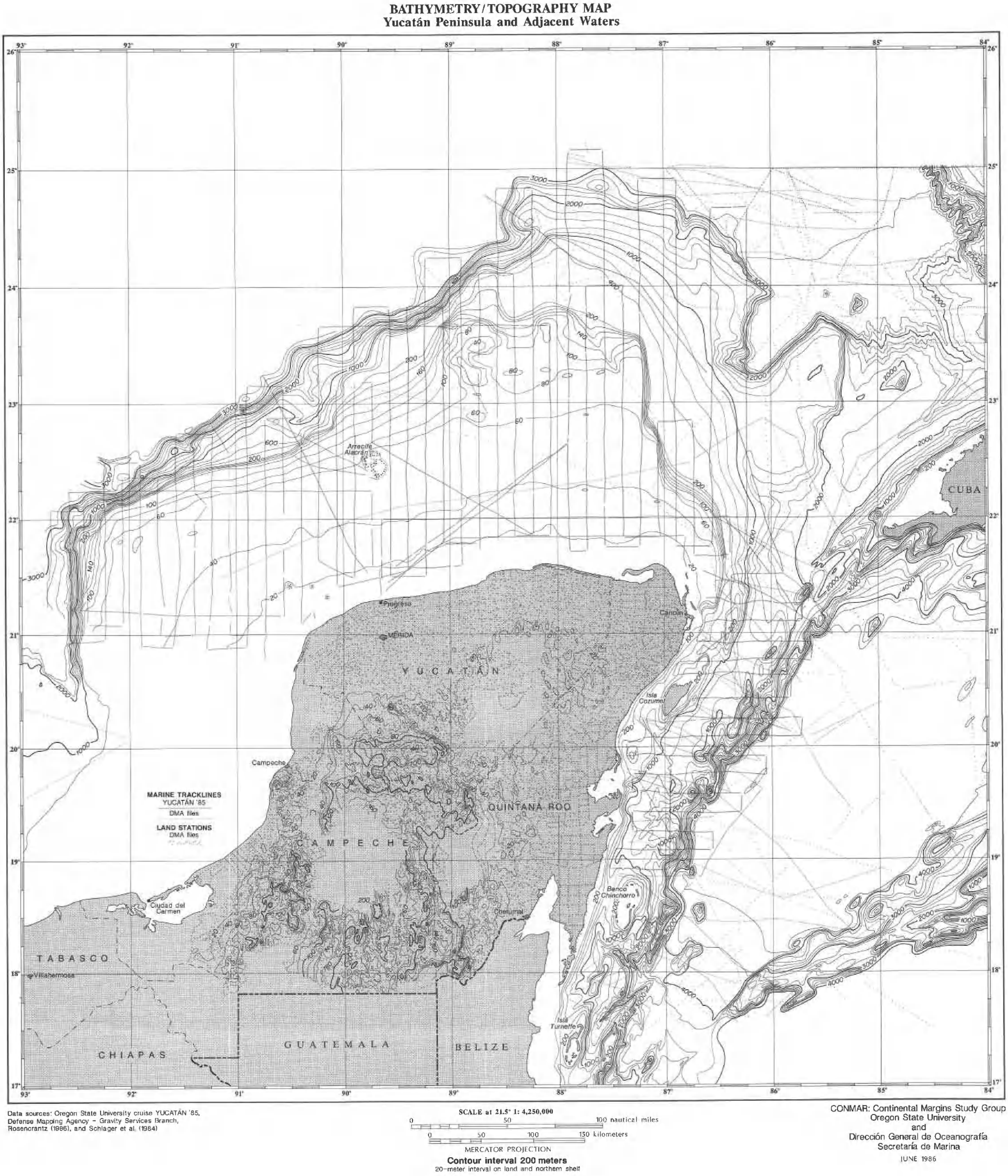

BATHYMETRY/TOPOGRAPHY MAP
Yucatán Peninsula and Adjacent Waters
YUCATÁN
CAMPECHE
QUINTANA ROO
TABASCO
CHIAPAS
GUATEMALA
BELIZE
CUBA
Progreso
MÉRIDA
Campeche
Ciudad del Carmen
Villahermosa
Chetumal
Cancún
Isla Cozumel
Banco Chinchorro
Isla Turneffe
Arrecife Alacrán
MARINE TRACKLINES
YUCATÁN '85
DMA files
LAND STATIONS
DMA files
Data sources: Oregon State University cruise YUCATÁN '85, Defense Mapping Agency - Gravity Services Branch, Rosencrantz (1986), and Schlager et al. (1984)
SCALE at 21.5° 1: 4,250,000
100 nautical miles
150 kilometers
MERCATOR PROJECTION
Contour interval 200 meters
20-meter interval on land and northern shelf
CONMAR: Continental Margins Study Group
Oregon State University
and
Dirección General de Oceanografía
Secretaría de Marina
JUNE 1986

Figure 11

INTERPRETATION OF THE GRAVITY ANOMALY MAP

The large density contrast between sea water and the underlying sediments and rocks and the varying proximity of the heavier material, cause the contours of the free-air anomalies to "follow" the bathymetric features. That is, the overlying water appears "transparent" to gravimetric measurements. The density contrast between sediments and basement rock also leads to a partial transparency of the sediment; however, the smaller density contrast between sediment and basement necessitates larger volume and/or density changes for a given gravity variation. Therefore, in areas in which the contours of the free-air gravity anomalies do not follow the bathymetric contours, large variations in sediment thickness and/or severe changes in the structure or density of the subsurface rock can be expected (Couch, 1969).

The Yucatan Shelf and the Sigsbee Plain are separated physiographically by the Campeche Escarpment, along which gravity anomalies follow a NE-SW trend parallel to the steep escarpment. Gravity anomalies along this trend conform to the bathymetric features beneath the depth of 200 meters. Similarly, a series of negative gravity lows surround the entire Yucatan Platform west, north, and eastward of the shelf, indicating a close relation between gravity and topographic change.

Seaward of the base of the Campeche Escarpment, facing the central Gulf, is a long and prominent negative gravity low which follows the NE-SW trend of the escarpment from 25°N, 88°W to 22°30'N, 92°W. This large negative anomaly exhibits its lowest values at two locations -70 to -108 mGals at 23°15'N,90°45°W, and -70 to -112 mGals at 24°N, 89°10'W. These two lows are separated by a narrow saddle low of -88 mGals. A maximum gravity change of 176 mGals (64 to -112 mGals) occurs across the Campeche Escarpment near 23°45'N, 89°W, 28 km eastward of the cross-section as shown in Figure 6. Based on the model presented here, it is clear that this gravity low is not only related to the topographic change of the escarpment, but associated with the density contrast existing beneath the escarpment where oceanic crust and continental crust are juxtaposed.

North of this negative gravity low, over the Sigsbee Plain, no direct correlation exists between gravity anomalies and bathymetry. A flat sea floor, about 3600 ±100 meters deep, covers most of the Sigsbee Plain and central Gulf of Mexico. Gravity anomalies in this area are directly related to changes in density, shape, and thickness of the strata forming the crustal structure beneath the smooth surface of the sea floor. Although remaining negative, these anomalies become more positive north of the Yucatan Platform, suggesting the south-central region of the Gulf basin is isostatically compensated. Three north-south oriented gravity anomalies are located on the westernmost edge of the map. The first, a gravity low of -40 mGals lies between 24°45'N and 25°15'N and between 92°30'W and 93°W in the area of the seismic refraction line 24 reported by Ewing et al. (1960). Figure 5 shows the location of this line. By using the empirical relation between seismic velocities and densities according to the Ludwing, Nafe and Drake (1970) curve, and the thicknesses of the observed units at receiving point 24-south, the gravitational attraction of the "crust" (sediments, basaltic, and gabbroic layers) can be computed, thereby helping to estimate the contribution to the gravity anomaly of the mantle layer. A denser than average mantle with a density of 3.40 g/cc must occur beneath the sedimentary layers and crustal rock of the central Gulf to account for the observed gravity anomaly. This density is 0.06 g/cc lighter than the mantle density existing in the northern Yucatan Platform, as computed for the mantle in the model. This density difference suggests a lateral change in density occurs between the northwest and north-central Yucatan Platform. Figure 12 shows the mass column for seismic profile 24. Second, a series of well-defined negative lows overlie the location of salt knolls, salt diapirs, and salt pillows mapped by Lin (1984). Figure 13 shows the location of these seismically-observed salt structures situated between 23°N and 24°N and 92°W and 93°W. Third, a very marked negative

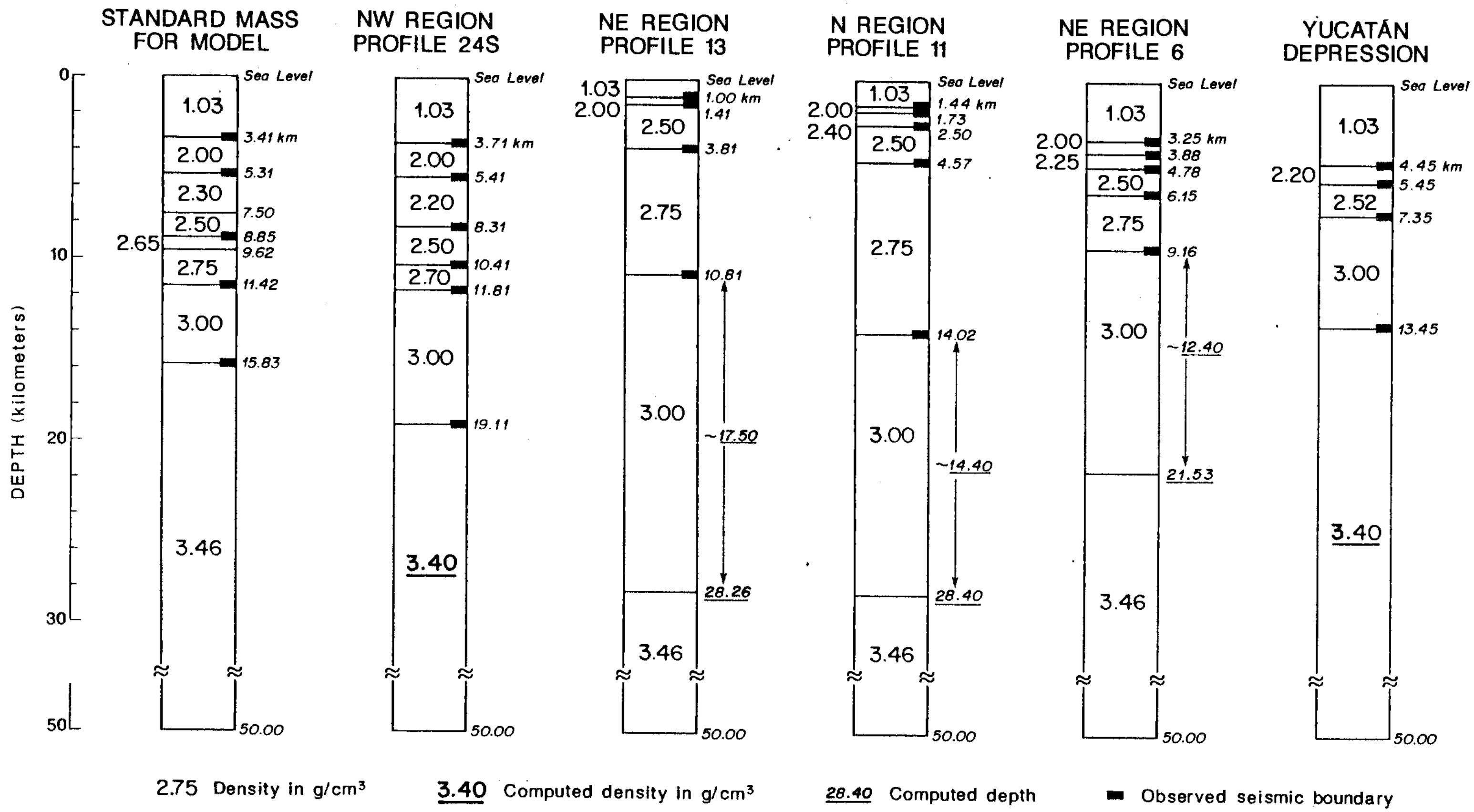


Figure 12 -- Mass Columns for different regions in the study area.

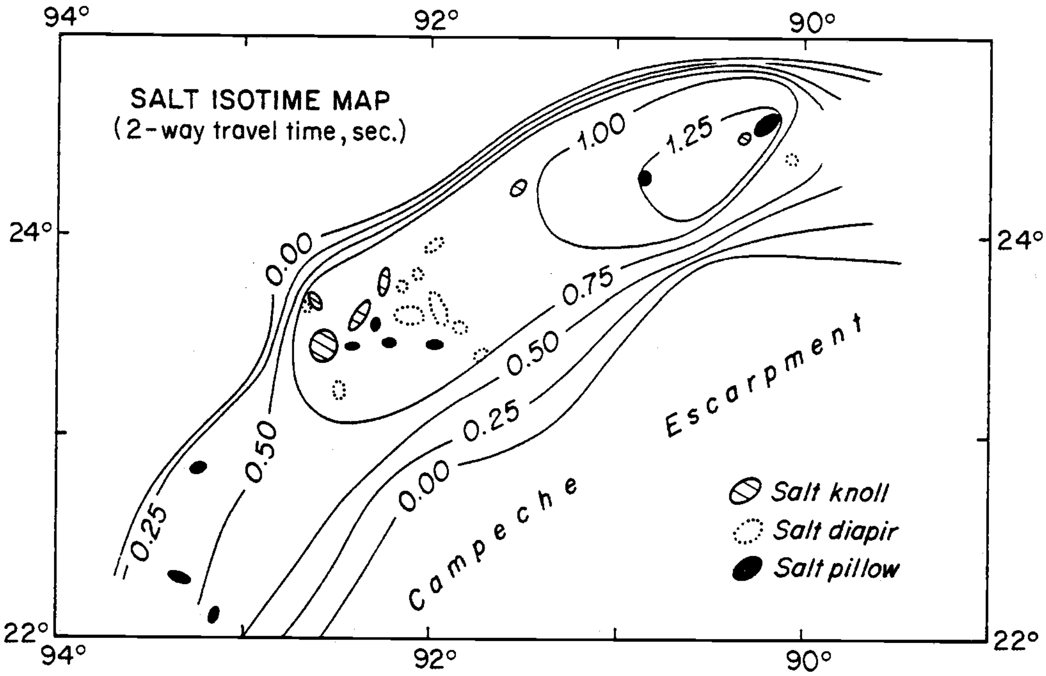


Figure 13 -- Location of salt structures in the western edge of the study area (after Lin, 1984).

gravity low of about -60 mGals conforms to the Campeche Canyon on the western edge of the Campeche Escarpment.

From north to south, the eastern edge of the Yucatan Platform contains several gravimetrically and bathymetrically related features. Adjacent to the Yucatan Peninsula, where the water is shallow (approximately 400 meters deep), two positive anomalies of about 65 mGals mirror the physiography of Cozumel Island and Bank Flecha Smith. By assuming the basement beneath the carbonate sequence of Cozumel, Bank Flecha Smith, and the 400 m deep seafloor of the adjacent waters lies horizontal, the contribution to the gravity anomalies over each of these areas due to either a 400 m thick sedimentary sequence or a water column is computed.

The presence of a 400 m thick carbonate sequence of average density 2.40 g/cc (as observed in the well Yucatan #4, located 100 km west on the Yucatan Peninsula) yields a contribution of 40 mGals to the 65 mGal observed anomaly. On the other hand, a 400 m thick water layer with density of 1.03 g/cc contributes 17 mGals to the 45 mGal observed gravity anomaly existing in the surrounding waters of Cozumel and Bank Flecha Smith. These results show that a difference of 23 mGals occurs between the 400 m deep adjacent waters and the island (or the bank), due to the presence of a 400 m thick carbonate layer, while a difference of 20 mGals is observed between these areas. This suggests that the gravity anomaly highs of Cozumel and Bank Flecha Smith are basically related to the topographic change which reflects the existence of a layer of carbonates that rises 400 m above the surrounding waters.

Southeast of the Campeche Tongue, at the northeastern part of the Yucatan Platform, a positive gravity anomaly of 40 mGals lies over an almost flat, 1 km-deep area. Analysis of seismic refraction profile #13 (Ewing et al., 1960), located as shown in Figure 5, demonstrates the presence of sedimentary and basement layers that together are approximately 10.8 km thick (Figure 12). The seismically-observed stratigraphic sequence and basement layer in this region and their respective gravitational attraction, suggest that a layer about 17.5 km thick with an average density of 3.0 g/cc lies beneath the upper crust. An estimated total thickness of 28.2 km for the crust exists in this area.

A negative gravity anomaly low of -32 mGals lies north of the Campeche Terrace, where the water is 1.4 km deep. Seismic refraction line #11, reported by Ibrahim et al. (1981), is located in the area. The presence of a 14.4 km thick layer with a density of 3.0 g/cc, provided the best fit to the gravity anomaly value. Therefore, the crust in this region reaches an estimated thickness of 28.4 km. Figure 12 shows the mass column for profile #11.

Aligned negative gravity lows exist midway between the Yucatan Peninsula shoreline and the seaward edge of the Yucatan Escarpment where the water is approximately 1200 km deep, and midway between the northernmost part of the Bank of Chinchorro and the shoreline of the Yucatan Peninsula. Along the base of the Yucatan Escarpment, east of these gravity lows and separated by a set of positive gravity anomalies, lies another alignment of negative gravity lows. These easternmost lows are related to the escarpment and to the boundary between continental and oceanic crust.

The positive gravity highs between the negative anomalies generally lay over areas 1200 m to 1400 m deep. These gravity highs are interpreted to be mainly related to the presence of an elongated basement high under the sediments, and perhaps to the existence of an elongated basement block of higher average density than the parallel basement blocks relfected by the negative anomalies at each side of the alignment of positive gravity highs.

On the northeasternmost edge of the map, negative gravity lows connect with the expression of the West Florida Escarpment. A large negative anomaly, that reaches a minimum of -88 mGals at 24°45'N and 84°40'W, suggests that, as in the case of the Campeche Escarpment, this negative anomaly relates not only to the steep escarpment, but also reflects the density contrast between oceanic and continental crust. Comparison of this negative anomaly with the similar negative anomalies seaward of the Campeche Escarpment and with the results obtained from the model, suggests that the Florida Platform is a counterpart of the

Yucatan Platform in the sense that a high density contrast occurs along the escarpment, which indicates the presence of an ocean-continent boundary. Seismic refraction results show that the sediment layers of the West Florida Salt Basin and Florida Escarpment are similar to the Sigsbee Salt Basin and Campeche Escarpment. Refraction work, and correlation of refraction horizons along with the stratigraphy of onshore wells, indicates the basic similarity in depth, velocities, thickness, and ages of the layers in the West Florida and Campeche Carbonate Platforms.

Seismic refraction line #6 (Antoine and Ewing, 1963), situated about 100 km east of the base of the West Florida Escarpment, lies on a positive gravity anomaly of 10 mGals at 25°N and 85°20'W. By computing the contribution to the gravity anomaly due to the load of sediments and the basaltic Layer 2, and subtracting it from the total anomaly, a thickness of 12.4 km is found for the layer of density 3.0 g/cc. This layer corresponds to oceanic Layer 3. A total thickness of 21.5 km is computed for the crust in this area. Figure 12 shows the mass column.

Seaward of the base of the Yucatan Escarpment, and located near 20°N and 85°W in the deepest part of the Yucatan Basin, is a positive anomaly of 24 mGals of large areal extent. No seismic refraction studies have been reported in this area. However, by projecting the closest seismic line shot about 120 km east of the depression (Line 10-11 reported by Ewing et al., 1960), and assuming continuity of the crustal thicknesses and velocities over the Yucatan Basin, computations using a mass column indicated a density of 3.40 g/cc. This density is 0.06 gm/cm^3 lighter than the mantle density in the northern Yucatan shelf, as was computed for the model. Figure 12 shows the mass column.

Positive gravity anomalies over the Yucatan Shelf suggest that beneath the thin, flat, and "transparent" Middle Jurassic-to-Recent sedimentary section exists a thick basement with a density of about 2.8 g/cc. This basement consists of crystalline rocks of Pre-Cambrian-Paleozoic age and "carbonate" rocks of Pre-Jurassic and Early Jurassic age.

Three main positive gravity anomalies of over 60 mGals occur on the Yucatan Shelf. These highs appear, a) on the northwest edge of the Campeche Escarpment, b) on the north-central part of the Yucatan Shelf, and c) on the northeasternmost end of the Yucatan Peninsula. The model previously presented fits the anomaly located in the north-central shelf. The model crosses almost perpendicular to this elongated gravity feature. Correlation of the gravity anomalies observed west and east of the Yucatan Shelf with those observed in the central Yucatan Platform and the crustal model, indicates that "shallow" basement highs are mainly responsible for these high gravity values. According to the model, the basement with a density of 2.8 g/cc can be reached as shallow as 800 meters.

On the edge of the Campeche Escarpment, two interesting features represented by negative gravity values conform to small physiographic canyons. These features lie within the areas 22°30'N to 23°30'N and 90°W to 90°40'W, and 23°30'N to 24°20'N and 86°30'W to 87°W.

Around the Yucatan Peninsula, Simple Bouguer Anomalies adjoin free-air anomaly values at sea. Gravity anomalies on the Yucatan Peninsula range between -12 and 104 mGals. In general, the Yucatan Peninsula may be divided into three physiographical regions: 1) the north, northeast and eastern part of the peninsula contain broad coastal plains approximately 150, 300, and 100 kilometers wide respectively. These plains are characterized by very low relief and a low topographic gradient (Figure 11); 2) sixty kilometers south of Merida, a second province, called the Sierrita de Ticul, rises 50 to 100 meters above the northern plain. The Sierrita de Ticul trends northwest-southeast and extends for a distance of 110 km; 3) the third province lies south of the Sierrita de Ticul and is composed of the central plains of the peninsula. This large province shows a steep topographic gradient that increases towards the southwest border of Mexico and Guatemala.

Of the only twelve wells drilled in a land area of approximately 104,000 square kilometers, only two reached basement. Figure 4 shows the location of the wells drilled in Yucatan, and Table 3 lists the depths of the stratigraphic units.

Yucatan #4 encountered basement after drilling 2390 meters below sea level beneath the red beds of the Todos los Santos formation, in an area where a positive gravity high of 40 mGals exists. The drilled basement rocks consisted of light gray, very hard, yellowish-brown, weathered, slightly metamorphosed quartzite (Lopez Ramos, 1975). Because the quartzite has been somewhat weathered, it suggests a significant period of exposure to the atmosphere before the deposition of the Todos los Santos red beds.

Considerably further southwest, the Yucatan #1, drilled in the central Yucatan Peninsula, encountered rhyolite at a depth of 3173 meters. The well lies in an area where gravity anomalies are of the order of 0 to +2 mGals. Comparison was made between the age and thickness of the layers reached in the wells (as shown in Table 3) with those of the stratigraphic units detected by refraction measurements and included in the crustal model. The depth to the top of evaporites, as reported by Lopez Ramos (1975) in addition to the above comparison, yielded the identification of the stratigraphic units and the estimation of their respective densities. The sedimentary mass contribution to the gravity anomaly in both well locations helped to estimate the contribution to the anomaly due to the basement layer.

		YUCATAN					TICUL	CHICXULUB SACAPUC	CHICXULUB	CHAMPOTON	
		1	2	4	5-A	6	1	1	1	1	2
Pliocene-Miocene (F. Carrillo Puerto)	*MR	OC	OC	OC	OC	OC	OC	OC	OC	OC	OC
Oligocene	*MR	--	--	--	--	76	--	375	298	--	--
Eocene (Upper-Middle) (M. Piste, F. Chichen Itza)	*MR	20	1	13	53	426	--	619	483	OC	OC
Eocene (Middle-Lower) Paleocene (Icaiche)	*MR	195	208	193	214	736	195	714	666	304	435
Upper Cretaceous											
Maestrich (ks)	*MR/CA	276	322	249	292	986	525	932	901	564	--
Without a formation name Turonian	*CA	1476	1381	1176	1809	--	1745	1240(?)	--	1684	1650
Middle Cretaceous (km)	*CA/CH	2258	2153	1891	2587	--	1900	--	--	1879	1805
Cenomanian-Albian	*CH	2914									
Triassic-Jurassic	*CH/RB	3058	3298	2349							
Todos los Santos (red beds)	*RB										
Basement	*RB/BS	3173		2390							
Igneous rocks (extrusive)		(Breccia and andesites)				1245		1415	1258		
Total depth		3202	3474	2398	2983	1631	3145	1516	1569	2413	2146

Depths is meters below sea level.
OC= outcrop; F= formation; M= member.
*MR/CA = Boundary between *MR and *CA.

Stratigraphic Units: *MR= Mexican Ridges; *CA= Campeche; *CH= Challenger; *RB= Red beds; *BS= Basement.

Densities: *MR= 2.30 g/cc; *CA= 2.50 g/cc; *CH= 2.65 g/cc; *RB= 2.65 g/cc

Table 3 -- Results of wells drilled in the Yucatan Peninsula (after Lopez Ramos, 1975). Identification of stratigraphic units and density of the units was obtained by comparison between the age and thickness of the layers reached in these wells and those of the stratigraphic units seismically observed and included in the crustal model.

For the case of Yucatan #4, drilled on the northeast Yucatan Peninsula, computations indicate the quartzitic basement reaches a total thickness of 15.75 km with a density of 2.80 g/cc. Estimating the sedimentary mass contribution to the 0 mGal gravity anomaly observed in the central Yucatan Peninsula, where Yucatan #1 was drilled, computation suggests the rhyolitic basement reaches a thickness of 14.96 km with a density of 2.75 g/cc. Figure 14 shows the mass columns for wells Yucatan #1 and #4. The above estimations assume that the depths to the top of the 3.46 g/cc mantle layer and the top of the 3.0 g/cc layer are constant at 31.4 and 18 km respectively. Computations yield these depths to the upper boundaries of the top of the mantle and gabbroic layer when a density of 2.80 g/cc is assigned to the basement beneath the Yucatan Platform and the observed gravity anomalies are fitted as is shown in the crustal model.

The difference in thickness of the basement layer between Yucatan #4 and #1 is 15.75 km - 14.96 km = 0.79 km, and the difference in depth to the basement between Yucatan #1 and #4 is 3.17 km - 2.39 km = 0.78 km. This suggests that differences in the gravity anomalies between the central and eastern part of the Yucatan Peninsula are not just due to differences in depth to the basement, but also to the differences in the densities between the two different basement blocks (Figure 14).

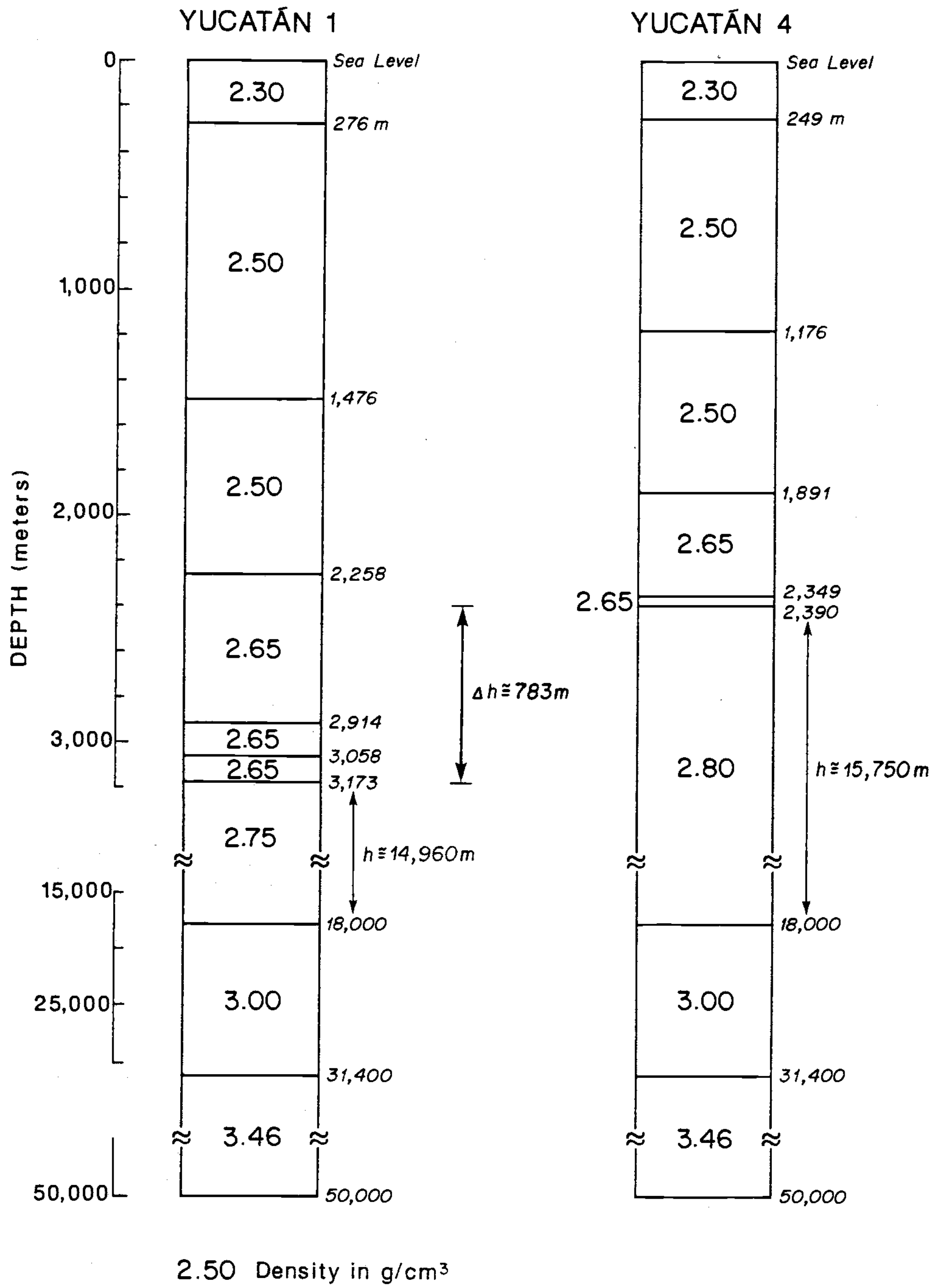


Figure 14 -- Mass columns for Yucatan #1 and Yucatan #4, located in the central and northeast Yucatan Peninsula respectively.

Because quartzite and rhyolite have densities lower than 2.80 g/cc and 2.75 g/cc respectively, it is thought that the basement blocks in Yucatan #4 and Yucatan #1 are composed of at least 2 layers, which together reach the above average densities. This implies the existence of a missing horizon which must exist beneath the "upper basement" formed of quartzite in the eastern Yucatan and rhyolite in the central Yucatan Peninsula. Therefore, the "lower basement" is expected to have a higher density than 2.80 g/cc and 2.75 g/cc.

Since the eastern block contains a basement of density 2.80 g/cc, equal to the density assumed in the model for the basement of the north-central Yucatan Platform, it suggests the "Yucatan Block" is formed of a series of "micro-continental blocks" which encircle the central Yucatan Platform. The assumption that a density of 2.76 g/cc occurs for the basement layer in the north-central Yucatan Platform instead of a density of 2.80 g/cc as was used in the crustal model causes the computed gravity anomaly to deviate from the observed gravity anomaly. Adjustments to compensate the effect of this density difference yielded a thinning of the crust. Computed thicknesses for the mantle above the depth of compensation and gabbroic layer became 19.9 km and 12.1 km respectively. Therefore, the depths to the top of the 3.46 g/cc mantle layer and the top of the 3.0 g/cc layer are 30.1 and 18.0 km respectively. By using these depths for computing the mass contribution of the mantle above 50 km depth and the 3.0 g/cc layer, estimates of the density of the basement for wells Yucatan #1 and Yucatan #4 are of 2.71 g/cc and 2.76 g/cc respectively. These results support the argument that the eastern and northern Yucatan Platform basement are formed of a denser material than the basement in the central Yucatan Peninsula.

Yucatan #4 lies within a broad, 40 mGal gravity high (Figure 6). This gravity anomaly extends from 18° 30'N to 23° 30'N, and corresponds to the western boundary of an elongated and prominent basement high. This boundary may indicate the presence of an intracontinental transform-fault zone, which probably formed the eastern margin of the Yucatan Block and may represent the eastern limits of the Pre-Mesozoic continental crust before rifting of the Gulf of Mexico occurred.

A 100 mGal gravity anomaly, the highest positive anomaly in the study area, lies at the northeastern end of the Yucatan Peninsula. A magnetic anomaly high of about 600 gammas also lies in the area (Figure 15). These anomalies suggest a high density and highly magnetic basement block exists beneath the sediments at shallow depth. The potential discovery of the nature (age and composition) of the basement makes this area a promising place for a drilling site.

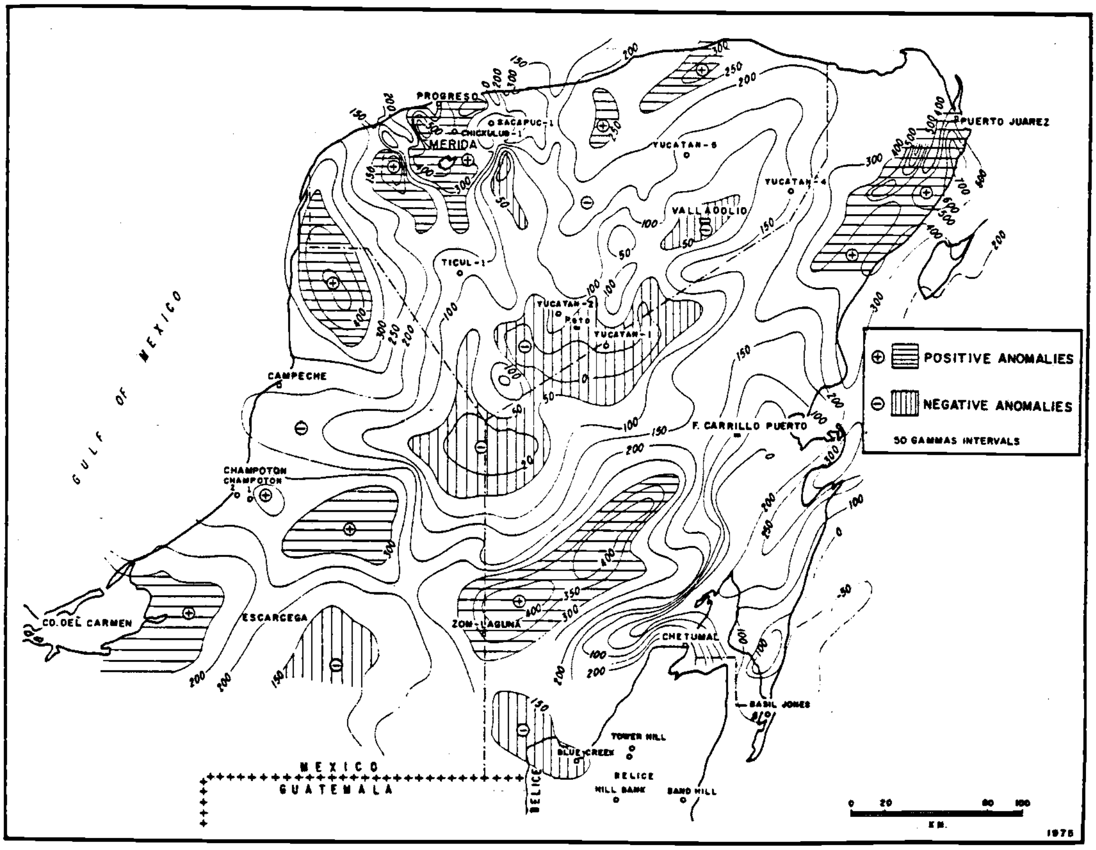


Figure 15 -- Magnetic Map of the Yucatan Peninsula showing principal regions of positive and negative anomalies (from Lopez Ramos, 1975).

A "Y" shaped gravity low, ranging from 0 to -16 Mgals, extends from the center of the peninsula towards the north. A gravity high of 8 mGals and a magnetic high of over 300 gammas occurs near Merida-Progreso. This anomaly and three wells which reached breccia and andesite sills at an average depth of 1360 meters (Table 3) suggests igneous rocks extend throughout the anomaly area.

South of the "Y" shaped gravity anomaly, and separated by an elongated northwest-southeast-oriented gravity high of 12 mGals, is a large negative gravity anomaly that covers the south-central plains of the Yucatan Peninsula north of the geographic border of Mexico and Guatemala. The topographic expression of the south-central Yucatan rises 100 to 200 meters above the broad coastal plains, and no significant contribution to the gravity anomaly is recognized that is due to this topographic gradient. Assuming the entire Yucatan Peninsula is formed by an extensive horizontal plain, the density contrast between the sedimentary layers and the basement leads to a partial transparency of the sediments. Therefore, the presence of negative gravity anomalies on the Yucatan Peninsula, like those observed in the south-central Yucatan, are mainly related to basement lows.

The free-air gravity anomalies of the abyssal plain in the south-central Gulf of Mexico indicate that, regionally, the area is in isostatic equilibrium. Anomalies generally ranging between ±25 mGals suggest the overlying crust and subcrustal material are mostly hydrostatically compensated. The mapped highs and lows of the gravity anomalies described above, the crustal and subcrustal model presented, and previous geophysical results such as magnetic anomalies, drilling results, and seismic refraction measurements, provide a better understanding of the nature of the basement in the Yucatan Platform.

SUMMARY

Seismic refraction, marine gravity, marine magnetic and bathymetric data all constrain a crustal and subcrustal model across the Campeche Escarpment that indicates a high density mantle underlies the escarpment. The mantle layer of density 3.46 g/cc in the south-central Gulf of Mexico is found to be denser than expected based on the Ludwing, Nafe and Drake (1970) velocity-density curve, and a velocity of 8.0 km/sec. The presence of material denser than 3.32 g/cc beneath the crustal structure of the Gulf of Mexico may be attributable to thermal contraction due to the greater age of the basin (Triassic or older), as compared with the average age of the Western Atlantic (Cretaceous); and/or a denser than average lithospheric-asthenospheric substratum beneath the crustal structure of the basin indicated by a geoid "high". The computed crustal cross-section suggests that the Campeche Escarpment is fault generated, and hence has a tectonic origin.

Uniformly magnetized oceanic crustal layer 2, represented by a series of 2 km thick blocks of alternating magnetic polarity, separated by vertical boundaries, seem to be responsible for the magnetic anomaly seaward of the Campeche Escarpment. No extent of an attenuated or rifted continental crust (transitional crust) is magnetically evident. Therefore, the crustal model suggests the

existence of an abrupt oceanic/continental boundary. The fitting of the observed magnetic anomaly south of the Campeche Escarpment provided a "profile" of the thickness, position, and shape of the pre-rift crystalline basement block. A high density "carbonate" block older in age than the Challenger Unit, perhaps of Early or Pre-Jurassic age, overlies the magnetic basement block.

Because no wells have penetrated basement in the south-central Gulf of Mexico, the location of a basement high beneath the sediments of the north-central Yucatan Platform is a likely site to drill an exploratory well to identify the composition and age of the basement and the overlying high-density "carbonates", and thereby contribute to a better understanding of the origin and evolution of the Gulf of Mexico.

Large tectonic-eustatic sea level changes occurred during the early rift phase of the Gulf of Mexico. A proposed model for the sequence of sedimentary deposition, subsidence, and opening of the Gulf which influenced the present crustal architecture of the "carbonate" and crystalline basement beneath the Yucatan Platform is presented. The model suggests the "carbonate" layer may be constituted of two materials: a) a mix of carbonate and detrital (terrigenous) sediments deposited on both sides of the crystalline basement in shallow water and sediments eroded from the continent, and b) by carbonaceous sediments formed after the basement block completely subsided below sea level.

Computed mass columns seaward of the base of the Yucatan Escarpment (east of the Yucatan Peninsula), and northwest of the Yucatan Platform, indicate that material (3.40 g/cc) lighter than that existing beneath the north-central Yucatan Platform (3.46 g/cc), must form the mantle in these deep-water areas.

A comparison of the age and thickness of the layers reached in wells located in the central and northeast Yucatan Peninsula with those of the stratigraphic units detected by refraction measurements, suggested the identity of the stratigraphic units and yielded estimates of their respective densities. The sedimentary mass contribution to the gravity anomaly in both well locations helped to estimate the contribution to the anomaly due to the basement layer. The results show that differences between gravity anomalies for the central and eastern part of the Yucatan Peninsula are not just due to differences in depth to the basement, but also to lateral differences in density (~0.05 g/cc) occurring between the basement blocks. These differences suggest that the basement in the eastern and northern Yucatan Platform is formed of denser material than the basement in the center of the Yucatan Peninsula. The differences also suggest that the Yucatan Block is formed of a series of "micro-continental" blocks which encircle the central Yucatan Platform.

The gravity anomalies, together with the crustal model, mass column analysis, and several geophysical lines of evidence provide a better knowledge of the nature of the basement in the south-central Gulf and the entire Yucatan area.

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