UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Summary report on the regional geology, petroleum geology, environmental geology, and estimates of undiscovered recoverable oil and gas resources in the planning area of proposed Outer Continental Shelf oil and gas Lease No. 94, eastern Gulf of Mexico

Edited

by

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This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards and stratigraphic nomenclature.

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SUMMARY

R. Q. Foote

The first formal step in an Outer Continental Shelf (OCS) oil and gas lease sale is the preparation of a Resource Report (Summary Geology Report). The resource estimates developed for the Resource Report are then used in the preparation of the next required document, the Exploration and Development (E&D) Report. These two reports provide information needed in the selection of the Area of Geologic Potential, in the formal Call for Information (Department of the Interior, 1982).

The purpose of the Resource Report is to describe both narratively and graphically the general geology, petroleum geology, resource estimates and environmental geology of an entire planning area, such as the eastern Gulf of Mexico. The Resource Report is a synthesis of relevant publicly available data and reports; it is written in a style and format that is useful to geologists, economists, petroleum engineers, environmental scientists, and decision-makers.

This report is an updated version of the Resource Report submitted to Minerals Management Service for proposed OCS Oil and Gas Lease Sale No. 94. It summarizes our general knowledge of the geologic framework, petroleum geology, and the potential geologic problems and hazards associated with development of petroleum resources in the eastern Gulf of Mexico planning area (Fig. 1). The planning area covers 14 OCS areas and contains more than 59 million acres (Table 1). This report covers all tracts not under active lease in this area. The actual lease offering, however, has been subject to exclusion of tracts on the basis of environmental concern, military usage, low geologic potential, and other considerations.

Total estimated undiscovered recoverable resources in the planning area range from 0.22 to 3.98 billion barrels of oil (BBO) and from 0.21 to 3.23 trillion cubic feet (TCF) of gas. The mean estimate for oil is 1.53 BBO and the mean for gas is 1.58 TCF. The planning area covers 92,515 mi^2 (239,622 km^2); water depths range from less than 10 m (33 ft) to more than 3,295 m (10,810 ft).

Eight oil and gas lease sales have been held in the eastern Gulf of Mexico (Table 2). Twenty seven unsuccessful exploratory holes have been drilled and four more exploratory wells are being drilled within the planning area (see Fig. 2 for the locations of the wells and Table 3 for summaries of well information.) One planned exploratory test was not drilled. However, no offshore oil and gas fields have been found in Federal waters of the eastern Gulf (recent discoveries have been found offshore Alabama and Mississippi). In comparison, the northwestern Gulf of Mexico is the most productive offshore region in the United States. Over 94 percent of the petroleum liquids and 99 percent of the natural gas produced from the U.S. OCS in 1981 were taken from the central and western Gulf OCS off Louisiana and Texas (Havran and others, 1982). Estimates of original

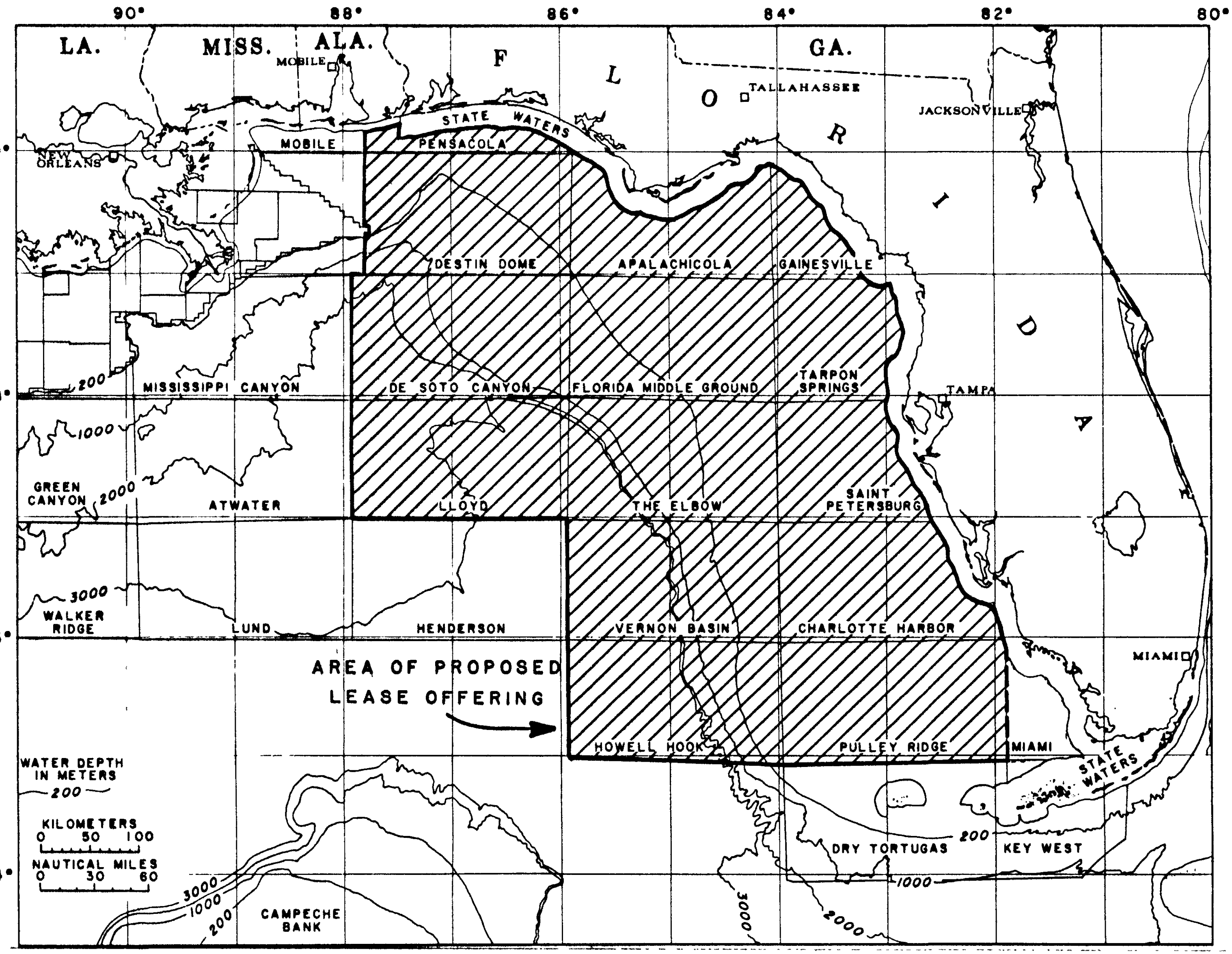

Figure 1. Map of eastern Gulf of Mexico showing the planning area of proposed Oil and Gas Lease Sale No. 94.

Table 1. Summary of OCS areas, blocks, and acreage for planning area, proposed OCS Oil and Gas Lease Sale No. 94, eastern Gulf of Mexico

OCS area	Number of blocks	Acres
Pensacola	205	1,176,335
Destin Dome	874	5,033,160
Apalachicola	625	3,528,145
Gainesville	254	1,463,040
De Soto Canyon	943	5,431,680
Florida Middle Ground	879	5,001,013
Tarpon Springs	522	3,006,720
Lloyd	861	4,959,360
The Elbow	906	5,145,729
St. Petersburg	565	3,254,400
Vernon Basin	931	5,290,530
Charlotte Harbor	832	4,792,320
Howell Hook	955	5,430,320
Pulley Ridge	989	5,696,640
TOTAL	10,341	59,209,392

Table 2. Summary of eastern Gulf of Mexico OCS oil and gas lease sales

		Tracts offered		Tracts bid on		Tracts leased	
Sale[a]	Sale date	Number	Acres[d]	Number	Acres[d]	Number	Acres[d]
5	5/26/1959	80	458,000	23	132,480	23	132,480
32	12/20/1973	147	817,297	89	496,916	87	485,396
41[b]	2/18/1976	132	687,603	41	191,717	34	161,285
65	10/31/1978	89	511,709	35	201,294	35	201,294
66[c]	10/20/1981	209	1,081,364	107	532,064	102	508,301
67[b]	2/9/1982	234	1,219,847	137	695,765	115	590,265
69 (II)	3/18/1983	125	665,478	13	68,105	11	58,120
79	1/5/84	8,868	50,631,513	186	897,786	156	897,786

a/Prior to OCS Sale 33, designators (numbered designations) were not preassigned to OCS lease sales. For ease of reference, however, a designator has been assigned to each sale. OCS Lease Sale 4, a planned Gulf of Mexico sale, was cancelled in 1956 (Lynch and Rudolph, 1984).

b/Includes central and western Gulf of Mexico OCS areas

c/Includes Sales 66, 66A, central and eastern Gulf of Mexico

d/OCS lease sales are traditionally made in terms of acres. To obtain the metric equivalent (hectares), divide the acres by 2.47.

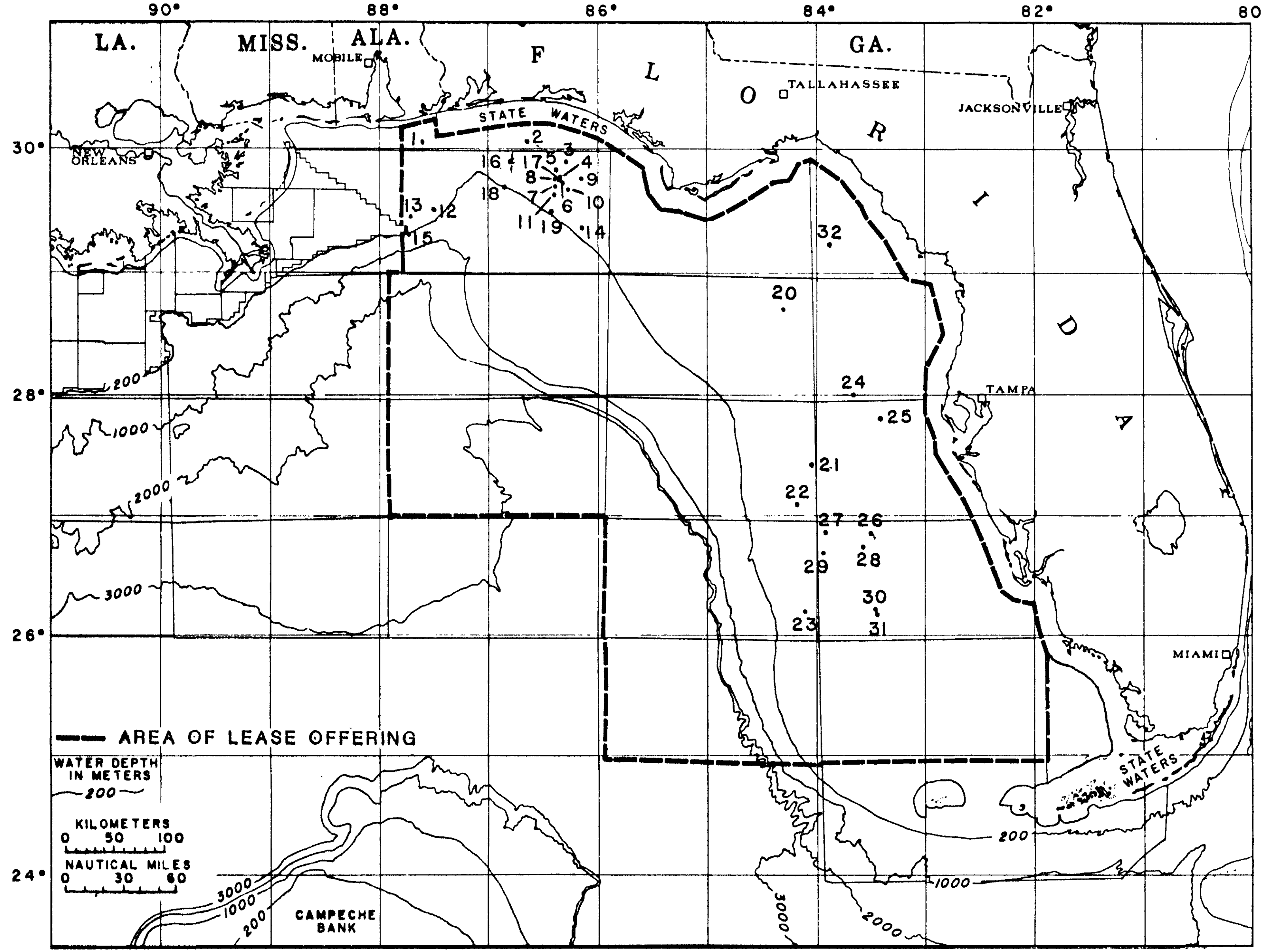

Figure 2. Map of the eastern Gulf of Mexico showing the locations of oil and gas exploratory holes in the planning area of proposed Oil and Gas Lease Sale No. 94. Table 3 contains the information on exploratory hole locations, operators, date, and depth of drilling.

Table 3. Summary of exploratory wells in planning area of proposed OCS Oil and Gas Lease Sale No. 94, eastern Gulf of Mexico. Locations of wells are shown in Figure 2.

	OCS AREA	OPERATOR	LEASE	BLOCK	WELL	API NUMBER	DATE	TRUE VERT. DEPTH (ft.)	SURFACE LOCATION (ft. block lines)	
1.	Pensacola	Mobil Oil E&P SE	G3886	73	1	608214000000	10-22-81	23,264	4,800 N	5,400 W
2.	Pensacola	Sohio Petroleum Co.	G6391	948	1	608214000010	02-18-85	drilling	7,775 N	7,825 W
3.	Destin Dome	Amoco Production Co.	G2502	31	1	608224001600	12-03-77	18,338	590 S	596 W
4.	Destin Dome	Exxon Company, USA	G2492	118	1	608224000400	09-25-74	7,075	2,006 S	8,290 W
5.	Destin Dome	Exxon Company, USA	G2492	118	2	608224001100	01-22-75	7,507	1,919 N	456 W
6.	Destin Dome	Exxon Company, USA	G2486	162	1	608224000000	08-17-74	10,930	6,014 S	5,135 E
7.	Destin Dome	Exxon Company, USA	G2486	162	2	608224000500	01-02-75	10,418	424 S	434 W
8.	Destin Dome	Exxon Company, USA	02486	162	1	608224001400	05-29-75	17,938	6,109 N	1,023 W
9.	Destin Dome	Sun Expl. & Prod.	G2490	166	1	608224000600	02-26-75	17,608	270 S	249 E
10.	Destin Dome	Exxon Company, USA	G2480	207	1	608224001300	02-27-75	4,800	5,475 N	5,554 W
11.	Destin Dome	Exxon Company, USA	G2472	250	1	608224001000	02-13-75	6,634	290 N	338 W
12.	Destin Dome	Gulf Oil Corporation	G2468	360	1	608224001200	09-22-75	20,988	836 S	937 W
13.	Destin Dome	Shell Offshore, Inc.	G3888	529	1	608224001700	06-14-80	20,450	1,217 N	5,919 E
14.	Destin Dome	Shell Offshore, Inc.	G3890	563	1	608224001800	07-18-82	21,068	1,859 S	2,116 W
15.	Destin Dome	Chevron U.S.A., Inc.	G2463	617	1	608224001500	10-15-77	10,513	543 S	5,058 W
16.	Destin Dome	Shell Offshore, Inc.	G6417	160	1	608224001900	01-01-85	17,764	7,020 S	4,302 E
17.	Destin Dome	Shell Offshore, Inc.	G6417	160	2	608224002100	05-09-85	16,953	1,539 S	7,065 W
18	Destin Dome	Exxon Company. USA	G6428	284	1	608224002200	06-28-85	drilling	5,567 N	585 E
19.	Destin Dome	Chevron U.S.A, Inc.	G6438	422	1	608224002000	07-01-85	drilling	6,521 N	4,707 W
20.	Florida Middle Ground	Texaco U.S.A.	G2516	252	1	608284000000	01-26-75	15,663	500 S	6,619 E
21.	The Elbow	Mobil Oil E&P SE	G3344	566	1	608294000000	04-14-77	15,865	4,350 S	800 E
22.	The Elbow	Mobil Oil E&P SE	G3341	915	1	608294000100	05-25-81	18,128	5,400 S	5,000 E
23.	Vernon Basin	Mobil Oil E&P SE	G3903	654	1	608304000000	04-05-81	10,768	4,600 S	5,500 E
24.	St. Petersburg	Shell Offshore, Inc.	G2527	7	1	608354000000	05-02-75	18,454	118 N	9,429 W
25.	St. Petersburg	Texaco U.S.A.	G2523	100	1	608354001000	05-19-75	17,388	5,386 S	158 E
26.	Charlotte Harbor	Gulf Oil Corporation	G3906	144	1	608364000300	06-17-81	11,366	500 N	500 E
27.	Charlotte Harbor	Gulf Oil Corporation	G3907	135	1	608364000400	12-17-80	permitted, not drilled	500 N	4,300 W
28.	Charlotte Harbor	Odeco Oil & Gas Co.	G3909	188	1	608364000600	08-25-81	11,362	502 S	644 W
29.	Charlotte Harbor	Shell Offshore, Inc.	G3912	265	1	608364000500	03-29-81	12,362	562 S	267 E
30.	Charlotte Harbor	Mobil Oil E&P SE	G3915	628	1	608364000200	04-04-81	1,270	700 S	700 E
31.	Charlotte Harbor	Tenneco Oil Co.	G3917	672	1	608364000100	02-27-81	11,302	504 N	512 E
32.	Gainesville	Sohio Petroleum Co.	G6456	707	1	608334000100	06-10-85	drilling	2,850 N	2,150 W

recoverable reserves for 531 active fields and 20 depleted fields in the northwestern Gulf of Mexico amount to 9.91 BBO and 111.6 TCF of gas; remaining recoverable reserves in the 531 active fields, as of December 31, 1984, are estimated to be 3.67 BBO and 44.5 TCF of gas (Hewitt and others, 1985).

The hydrocarbon-producing region in the northwestern Gulf is primarily a Cenozoic terrigenous basin in which the cumulative thickness of the sediments is greater than 10 km (6 mi) (Martin and Foote, 1981). The main hydrocarbon-bearing intervals offshore are of Miocene, Pliocene, and Pleistocene age (see Fig. 3 for major stratigraphic and general time divisions). The general areas of Miocene, Pliocene, and Pleistocene production in the central and western Gulf of Mexico OCS areas are also reviewed in this report.

Discussions later in this report will show that the planning area is transitional between a primarily terrigenous province in the northwestern part and a carbonate province in the southeastern part. Also, the geologic ages of prospective oil and gas horizons in the eastern Gulf are older, mainly of Cretaceous and Jurassic ages, than the producing horizons in the west. Because of these differences in the geologic characteristics and ages of the sedimentary rock regimes, usages of terms in this report, such as "more favorable areas", "favorable areas", or "less favorable areas" are relative to other parts of the eastern Gulf and are not absolute terms to be used for comparison with the western Gulf.

The main emphasis of the study was to assemble and analyze as much publicly available information as possible on the planning area. The considerable amount of geophysical and geological data collected by a variety of governmental agencies and academic institutions in the eastern Gulf provided the basis to gain a good understanding of the oil and gas potential of this broad region. Detailed descriptions of the locations and types of data analyzed in this region have been reported by Martin (1980), Martin and Foote (1981), and in this report.

Seismic data in the eastern Gulf of Mexico (Fig. 4) include approximately 17,023 nautical miles (nmi) (31,527 km) of reflection profiles ranging from shallow penetration recordings to deep penetration Common Depth Point (CDP) profiles. Approximately 3,564 nmi (6,601 km) of these data consist of high-technology CDP profiles and 12,372 nmi (22,913 km) of deep penetration single-channel sparker profiles. The balance of seismic-reflection coverage, approximately 1,087 nmi (2,013 km), is low-energy shallow penetration data. In addition, results from seismic refraction studies of the deep basin during the 1950's and 1960's provided valuable information on the thicknesses and depths of the deep crust and older stratigraphic sequences (Martin and Foote, 1981).

Geophysical data were supplemented by a limited amount of geological information obtained from drill holes within and adjacent to the planning area. Geological information relative to lithologic and stratigraphic-age aspects of the upper few thousands of feet of strata was synthesized from reports on (1) five Deep Sea Drilling Project (DSDP) sites in the eastern Gulf of Mexico and (2) fourteen shallow industry drill holes within the area of the lease offering (Fig. 5). Twenty seven exploratory wells drilled at locations within the planning area (Fig. 2; Table 3) provided valuable

Subdivisions in use by the U. S. Geological Survey (and their map symbols)					Age estimates[1] of boundaries in million years (m.y.)	
Phanerozoic Eon or Eonothem	Cenozoic Era or Erathem (Cz)	Quaternary Period or System (Q)		Holocene Epoch or Series	0.010	
				Pleistocene Epoch or Series	2	(1.7-2.2)
		Tertiary Period or System (T)	Neogene Subperiod or Subsystem (N)	Pliocene Epoch or Series	5	(4.9-5.3)
				Miocene Epoch or Series	24	(23-26)
			Paleogene Subperiod or Subsystem (Pɛ)	Oligocene Epoch or Series	38	(34-38)
				Eocene Epoch or Series	55	(54-56)
				Paleocene Epoch or Series	63	(63-66)
	Mesozoic Era or Erathem (Mz)	Cretaceous Period or System (K)		Late Cretaceous Epoch or Upper Cretaceous Series	96	(95-97)
				Early Cretaceous Epoch or Lower Cretaceous Series	138	(135-141)
		Jurassic Period or System (J)			205	(200-215)
		Triassic Period or System (TR)			~240	
	Paleozoic Era or Erathem (Pz)	Permian Period or System (P)			290	(290-305)
		Carboniferous Periods or Systems (C)	Pennsylvanian Period or System (P)		~330	
			Mississippian Period or System (M)		360	(360-365)
		Devonian Period or System (D)			410	(405-415)
		Silurian Period or System (S)			435	(435-440)
		Ordovician Period or System (O)			500	(495-510)
		Cambrian Period or System (Є)			~ 570[2]	
Proterozoic Eon or Eonothem (P)	Proterozoic Z (Z)[3]				800	
	Proterozoic Y (Y)[3]				1,600	
	Proterozoic X (X)[3]				2,500	
Archean Eon or Eonothem (A)				Oldest known rocks in U. S.	3,600	

[1] Ranges reflect uncertainties of isotopic and biostratigraphic age assignments. Age of boundaries not closely bracketed by existing data shown by ~. Decay constants and isotope ratios employed are cited in Steiger and Jager (1977).

[2] Rocks older than 570 m.y. also called Precambrian (pЄ), a time term without specific rank.

[3] Time terms without specific rank.

Geologic Names Committee, 1980 edition

Figure 3. Major stratigraphic and geological time divisions used by the U.S. Geological Survey in 1980.

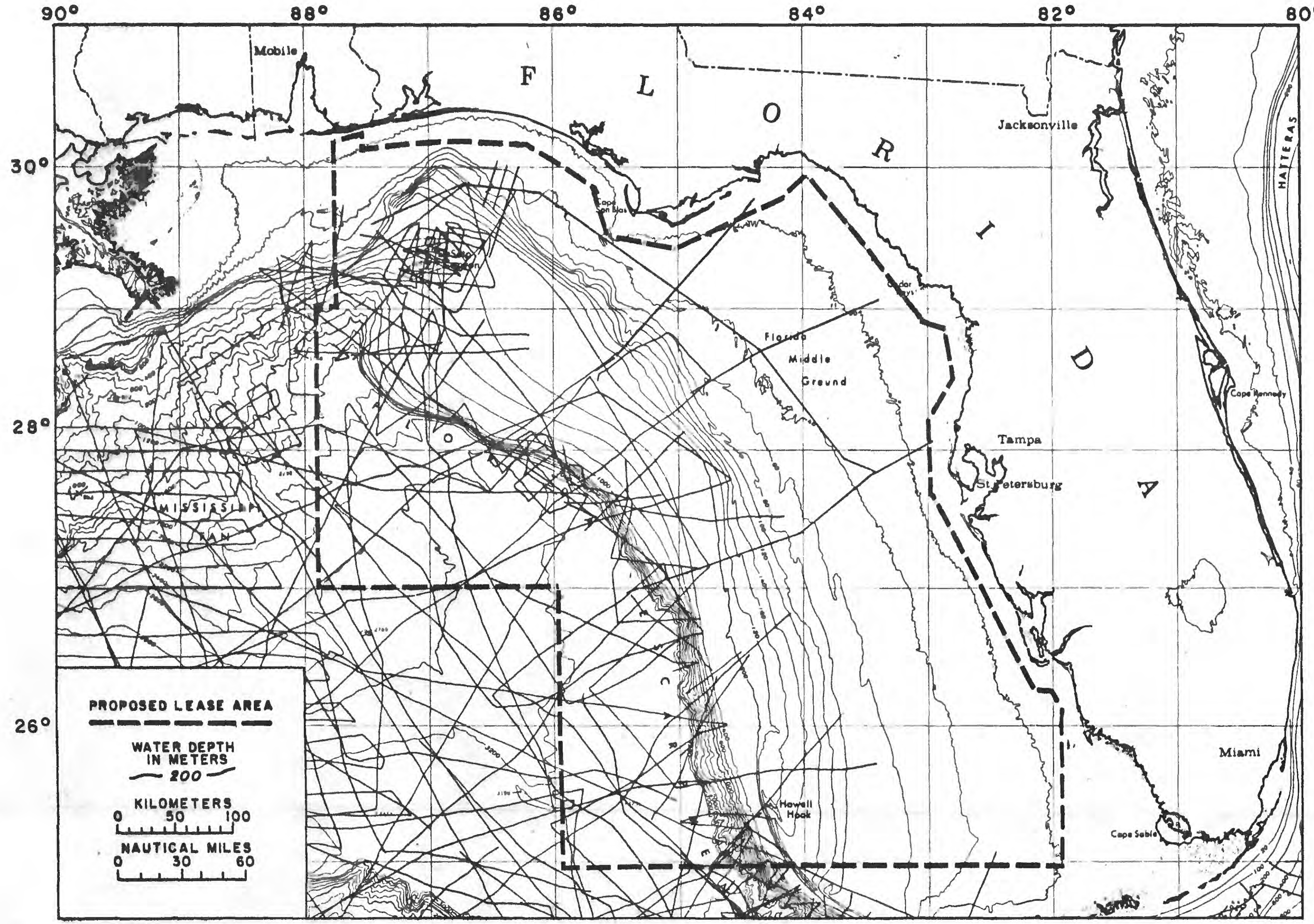

Figure 4. Map of eastern Gulf of Mexico showing seismic-reflection profile coverage within and adjacent to the planning area of proposed OCS Oil and Gas Lease Sale No. 94.

subsurface information on geologic framework and petroleum potential of the planning area.

The chapters that follow are arranged with the intent of providing general information on the Regional Geologic Framework of the eastern Gulf of Mexico (Chapter I), followed with information on Petroleum Geology (Chapter II), Oil and Gas Resources (Chapter III) and Environmental Geology (Chapter IV). References cited and illustrations have been included with individual chapters for convenience.

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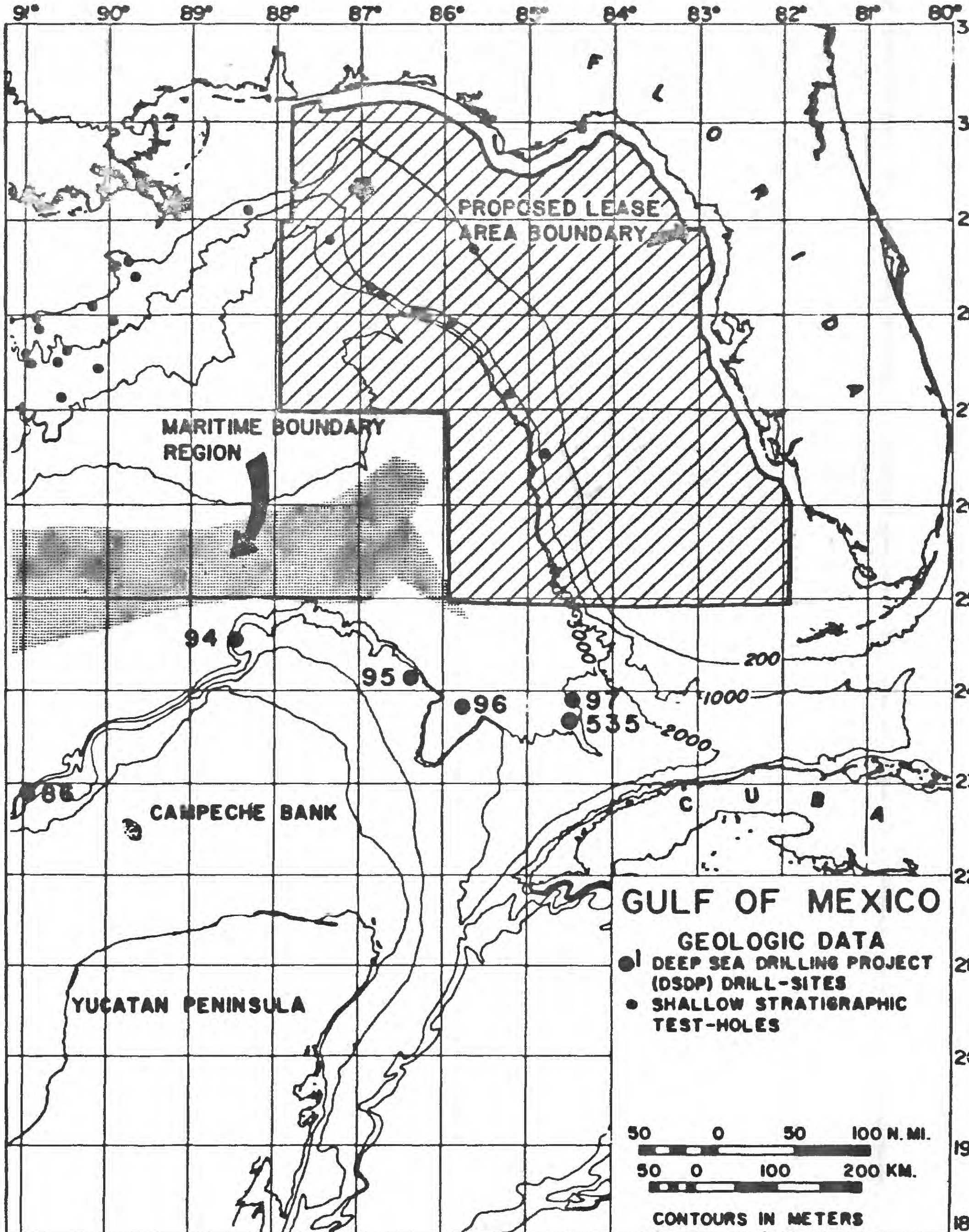

Figure 5. Map showing stratigraphic drill holes in and adjacent to the planning area of eastern Gulf of Mexico proposed OCS Oil and Gas Lease Sale No. 94 and the Maritime Boundary Region.

CHAPTER I

REGIONAL GEOLOGIC FRAMEWORK OF EASTERN GULF OF MEXICO OCS REGION

by

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GENERAL

The purpose of this chapter is to provide a regional geologic summary of the planning area for proposed OCS Oil and Gas Lease Sale No. 94, eastern Gulf of Mexico. The planning area lies in Federal waters between longitude 81°W and 88°W, and latitude 24°N and 31°N (Fig. 1) encompassing parts of the continental margin and the deep-Gulf basin.

This summary is intended as background information and is based on a synthesis of existing literature. It consists of a general discussion of the large-scale framework of the entire Gulf of Mexico Basin, followed by a more detailed discussion of the structural and stratigraphic framework of the eastern Gulf OCS lease sale planning area.

GULF OF MEXICO BASIN FRAMEWORK

Physiography

The regional physiographic characteristics of the Gulf of Mexico have been described by various workers (Uchupi, 1967; Ballard and Uchupi, 1970; Bergantino, 1971; Sorenson and others, 1975; Uchupi, 1975; Martin and Bouma, 1978), and is briefly summarized here from these sources. The Gulf of Mexico is a relatively small ocean basin that encompasses an area of approximately 1.7 million sq km (0.7 million sq mi) (Fig. 6), and which attains a maximum water depth of about 3,700 m (12,140 ft). It is a highly restricted ocean basin almost completely surrounded by landmasses.

The shallowest physiographic element of the Gulf is the continental shelf province, which extends from the coastline to a water depth generally of about 200 m (656 ft). The shelf width is highly variable, ranging from a minimum of about 10 km (6 mi) off the Mississippi Delta area to a maximum of about 280 km (174 mi) off southern Florida and the Yucatan Peninsula. Topographic relief of the shelf surface is relatively low. Local relief features have resulted mainly from erosional and accretional events associated with Pleistocene glacio-eustatic fluctuations of sea level, from reef and carbonate bank growth, shallow fault scarps, and from the near-surface movement of salt and shale diapirs.

The continental slope physiographic province extends from the shelf edge to the continental rise or abyssal plain province. The base of the slope province in the Gulf occurs at a median depth of 2,800 m (9,186 ft). The continental slope province, which encompasses over 0.5 million sq km, (0.2 million sq. mi), exhibits the greatest relief and the most diversified geomorphic features in the Gulf of Mexico. The eastern Gulf slope off the Florida Peninsula consists of an upper smooth West Florida Terrace fronted by the steep Florida Escarpment that forms the lower slope. Off south Florida, the slope consists of an upper Pourtales Terrace, which is fronted

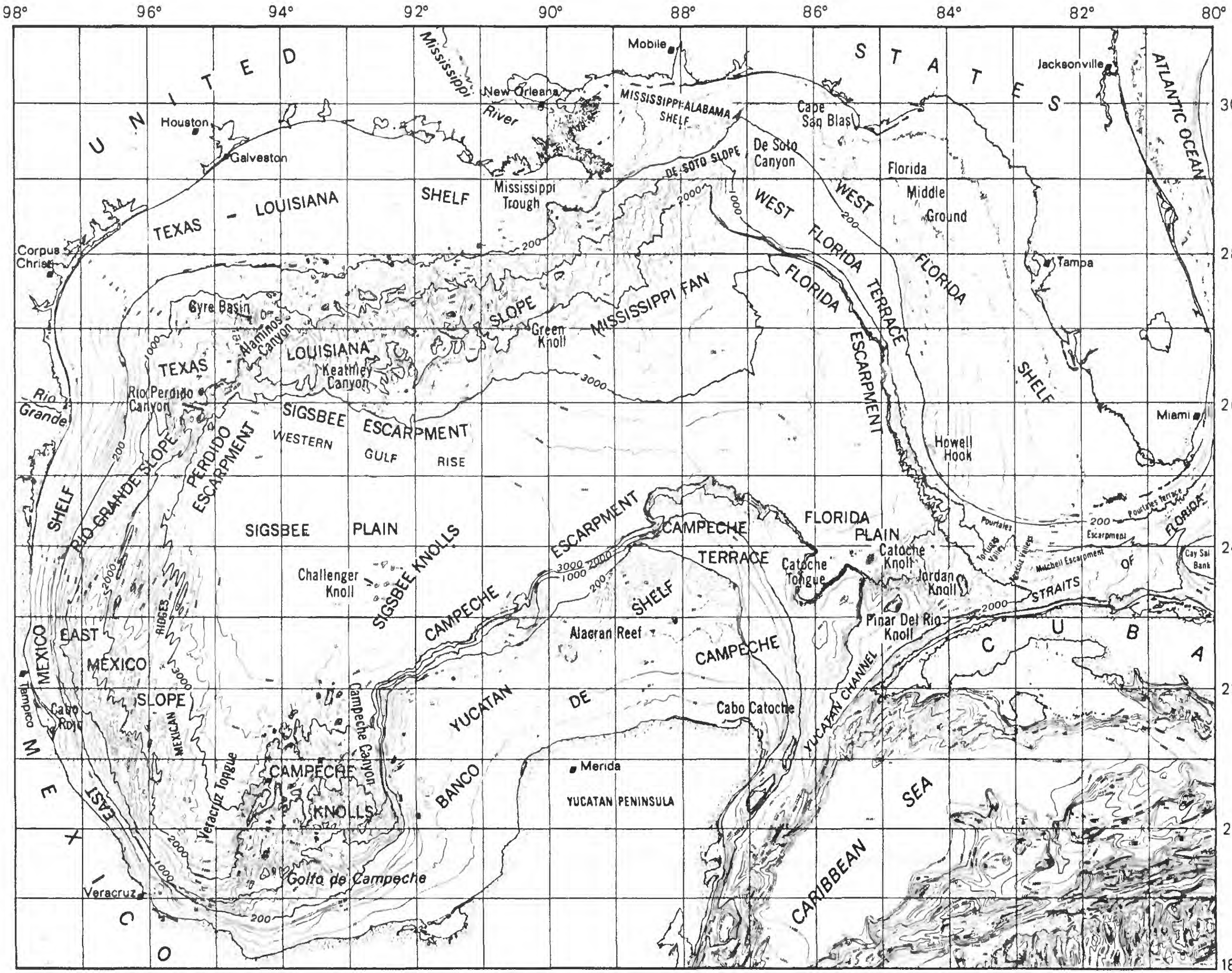

Figure 6. Bathymetric map of the Gulf of Mexico showing major physiographic features. Contour intervals: 20-m isobaths for 0-200 m depths; 200-m isobaths for depths >200 m (from Martin and Bouma, 1978).

by the Pourtales Escarpment and Mitchell Escarpment along the Straits of Florida. The southern Gulf slope off the Yucatan Peninsula is similar to the morphology of the eastern Gulf slope and consists of an upper Campeche Terrace, fronted by the steep Campeche Escarpment. The terrace/escarpment slopes of the eastern and southern Gulf are the results of accretion of thick carbonate banks and marginal reef building. Another variety of continentral slope morphology occurs in the northern Gulf (Texas-Louisiana Slope) and in the southwestern Gulf (Golfo de Campeche Slope). These slopes are largely characterized by highly irregular hummocky topography consisting of knolls and intraslope basins and submarine canyon systems. This variety of slope topography has resulted largely from salt and some shale diapirism, and sedimentation within adjacent intraslope basins.

A major physiographic element of the northern Gulf slope province is the Mississippi Fan, which occurs basinward of the modern Mississippi Delta. The fan exhibits a variety of geomorphic features, such as channels and gullies, levees, fault and slump scarps, and diapiric hills. The fan can be divided morphologically into an upper fan region characterized by a relatively high gradient surface with moderately rugged topography, and a lower fan region below a depth of 2,800 m (9,186 ft) that is characterized by a low gradient surface with very subdued topography.

The deep Gulf of Mexico seafloor where water depths exceed 2,800 m (9,186 ft) is an area of about 350,000 sq km (135,140 sq mi) and is composed of both the continental rise and abyssal plain physiographic provinces. These are very low-gradient provinces that exhibit low-relief localized features, such as isolated knolls or hills, channels and levees, and sedimentary aprons; most of the seafloor areas in these provinces are essentially featureless plains. The gently sloping continental rise province is represented by the lower portion of the Mississippi Fan. The abyssal plain province is represented by the smaller Florida Plain where water depths exceed 3,400 m (11,155 ft). The abyssal plain is underlain by thick sequences of almost horizontal strata composed of interbedded turbidites and hemipelagic oozes, and both contain isolated knolls. The Sigsbee Knolls are the surface expressions of salt diapirs, whereas the knolls of the Florida Plain (Catoche Knolls) appear to be of igneous origin (Pyle and others, 1969).

Geologic History

The geologic history of the Gulf of Mexico basin has been reviewed most recently in a symposium volume (Pilger, 1980) and by Martin (1982); these works serve as major sources for the following summary discussion.

Early Mesozoic Evolution

Many aspects regarding the early evolution of the Gulf of Mexico basin are conjectural, and several models have been proposed in the literature. In terms of its structural framework, the central Gulf is underlain by a relatively thin (5-6 km or 3-3.7 mi thick) and dense oceanic crust consisting of basaltic basement rock (Figs. 7,8). Toward the continental margins, the oceanic crust grades laterally into a thicker moderately dense transitional crust (attenuated continental crust), which forms the basement underlying the continental slopes and parts of the outer continental shelves. The transitional crust, in turn, grades landward into relatively

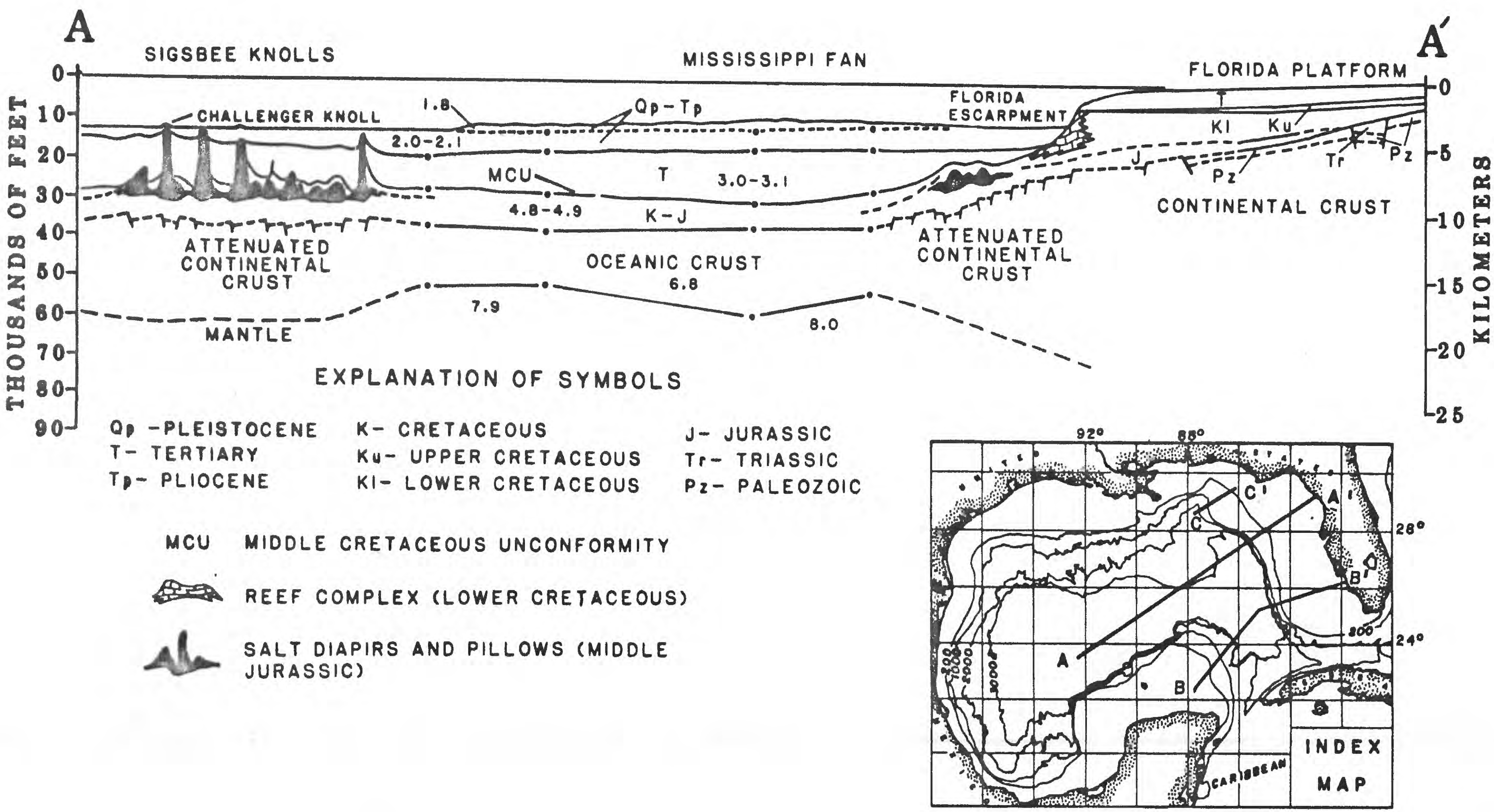

Figure 7. Diagrammatic crustal section (A-A') across eastern Gulf continental margin and adjacent deep-Gulf ocean basin; seismic velocity values in km/sec (modified from Martin, 1982). Index map also shows location of cross-sections B-B' and C-C'.

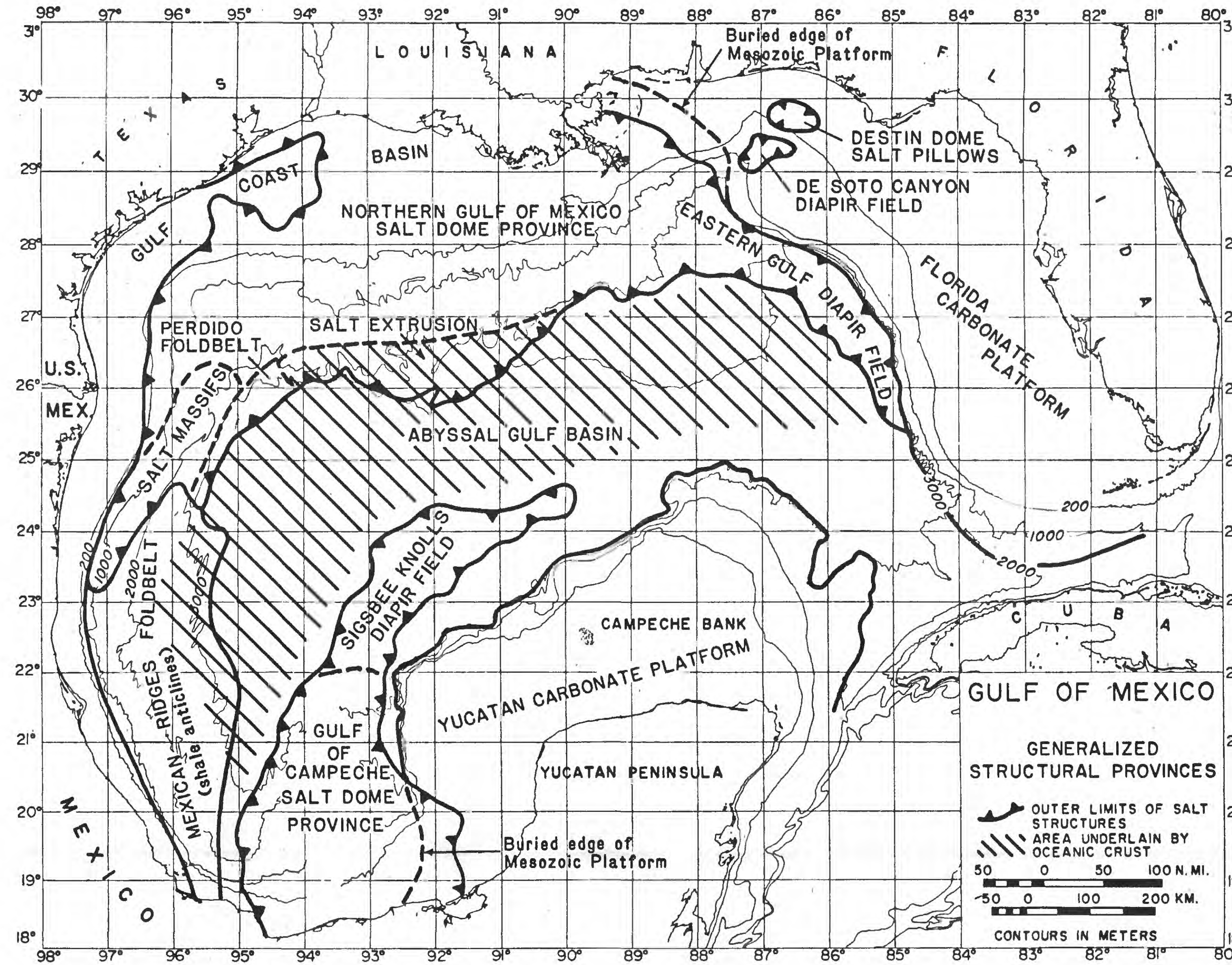

Figure 8. Map showing generalized structural provinces and distribution of salt diapiric structures in the Gulf of Mexico region (from Martin, 1982).

thick continental crust composed of lower density granitic-type basement rock.

The origin and early evolution of the Gulf basin is related to plate-tectonic processes. In a model proposed by Walper (1980), during late Paleozoic time, the area now occupied by the present Gulf of Mexico was a continental landmass that constituted the northwestern portion of the South American Plate which had converged northward with the North American Plate. The plate convergence resulted in the development of a subduction complex represented by the present Ouachita Foldbelt, which was thrusted northward onto the southern cratonic margin of the North American Plate. South of the subduction complex was an adjacent forearc basin bordered by a volcanic arc; the forearc basin remained intact and accumulated deposits throughout Late Pennsylvanian-Early Permian time. The late Paleozoic plate convergence resulted in the development of a supercontinent (Pangaea) composed of the African, South American, and North American plates.

During Triassic time, Pangaea began experiencing tensional rifting and plate separation, with the African and South American plates beginning to drift southeasterly away from the North American Plate. This period of crustal extension and plate divergence marked the beginning of Gulf basin evolution. A preliminary model proposed by Buffler and others (1980) for the early evolution of the Gulf consists of the following four distinct phases. 1. Rift Phase - A long period (Triassic-Early Jurassic) of regional uplift, doming, rifting, erosion, and the filling of rift basins with continental deposits and volcanics resulted in the formation of a thinned or attenuated continental crust (transitional crust). 2. Late Rift Phase - Medial uplift was formed due to mantle upwelling. Subsidence of adjacent basinal areas and the incursion of sea water resulted in the deposition of thick shallow-water evaporites on both sides of the medial uplift. These salt deposits are inferred to be of Middle Jurassic age and equivalent to the Louann Salt. 3. Drift Phase - A period of seafloor spreading in Late Jurassic-Early Cretaceous time resulted in the formation of oceanic crust. Rapid subsidence of the new basin due to crustal cooling resulted in deposition of deep-water sediments in the central Gulf and shallow-water sediments on adjacent margins overlying the salt deposits. Some early deformation resulted from basinward flowage of underlying salt. 4. Subsidence Phase - Seafloor spreading due to major plate reorganization ceased about 130 million years ago; subsidence continued through Early Cretaceous time as the crust continued to cool and was loaded by sediment. Deposition of deep-water sediments occurred across the central basin and shallow-water carbonate banks developed along the basin margins that were controlled by a structural hinge zone.

Many aspects regarding the early evolution of the Gulf of Mexico basin are still conjectural and controversial; however, the foregoing models by Walper (1980) and Buffler and others (1980) are certainly plausible ones. Although details of the several evolutionary models presented in the literature may vary, it does appear that divergent plate-tectonic processes were the basic formative agents, whereby the Gulf basin evolved as a trailing passive margin of the North American Plate. The basic configuration of the Gulf basin appears to have been established by Early Cretaceous time, with subsequent modifications resulting mainly from intrabasinal sedimentary and tectonic processes.

Late Mesozoic-Cenozoic Evolution

The major episode of evaporite deposition in the Gulf basin ended by Late Jurassic or Oxfordian time about 140 million years ago (Walper, 1980). The resulting salt deposits accumulated to more than 3,048 m (10,000 ft) maximum local thicknesses before flowage into the massifs, pillows, and diapiric stocks that dominate much of the structural fabric of the present Gulf basin (Martin, 1980). Following evaporite deposition, restricted circulation conditions changed to open-marine conditions, resulting in initially terrigenous clastic deposition, followed by carbonate deposition as the supply of clastic sediment diminished. By Early Cretaceous time, persistent carbonate provinces had become well established in the eastern Gulf (Florida Platform) and southern Gulf (Yucatan Platform) marginal areas, which became the sites of shallow carbonate bank development (Figs. 8,9). The seaward edges of the carbonate banks were the loci of reef-building activity. As the banks subsided, shallow-water carbonate deposition and marginal reef building kept pace with subsidence, resulting in the development of a thick sequence of limestones, dolomites, and interbedded anyhydrites. The seaward edges of the banks, which are underlain by the Early Cretaceous reef complexes, are manifested as the present Florida Escarpment in the eastern Gulf and as the Campeche Escarpment in the southern Gulf. In contrast to the shallow carbonate banks of the basin margins, the central basin was remote from sediment sources and accumulated only a relatively thin sequence of time-equivalent deep-water deposits. In mid-Cretaceous time, a period of erosion occurred, resulting in the development of a major unconformity. This unconformity has been tentatively correlated by Buffler and others (1980) with a mid-Cenomanian (97 million years ago) drop in sea level shown on the global sea level chart presented by Vail and others (1977). During Late Cretaceous time, rising sea level and continued subsidence resulted in the widespread deposition of transgressive carbonate deposits over the basin margins.

During latest Cretaceous-Early Tertiary time, Laramide tectonism, western North America, had a pronounced influence on the Gulf basin. It resulted in the eastward displacement of peninsular Mexico along a system of megashears (Walper, 1980), and provided voluminous quantities of terrigenous clastic sediment from uplifted source areas for deposition in the Gulf basin throughout the Tertiary period. Large volumes of sand and mud were rapidly deposited along the margins of the northern, western, and southwestern Gulf (Fig. 9); this resulted in the extensive gulfward progradation of the continental margin in those areas by the addition of successively younger offlapping wedges of sediment as the basin subsided. The rates of sediment influx and basinal subsidence were not synchronous, thus resulting in transgressive-regressive cyclic deposits that characterized the Tertiary sections of the northern and western Gulf margins. Thinner sequences of deep-water deposits accumulated in the central basin area. The eastern and southern Gulf carbonate platforms were remote from sources of clastic sediment and they remained as areas of shallow-water carbonate sedimentaton.

During the Pleistocene Ice Age, the voluminous influx of terrigenous clastic sediment into the Gulf basin continued, partly as the result of the advances and recessions of continental glaciers in North America. Major climatically controlled fluctuations of sea level occurred during four glacial and three interglacial stages. In addition, minor sea level fluctuations were associated with secondary glacial advances and recessions

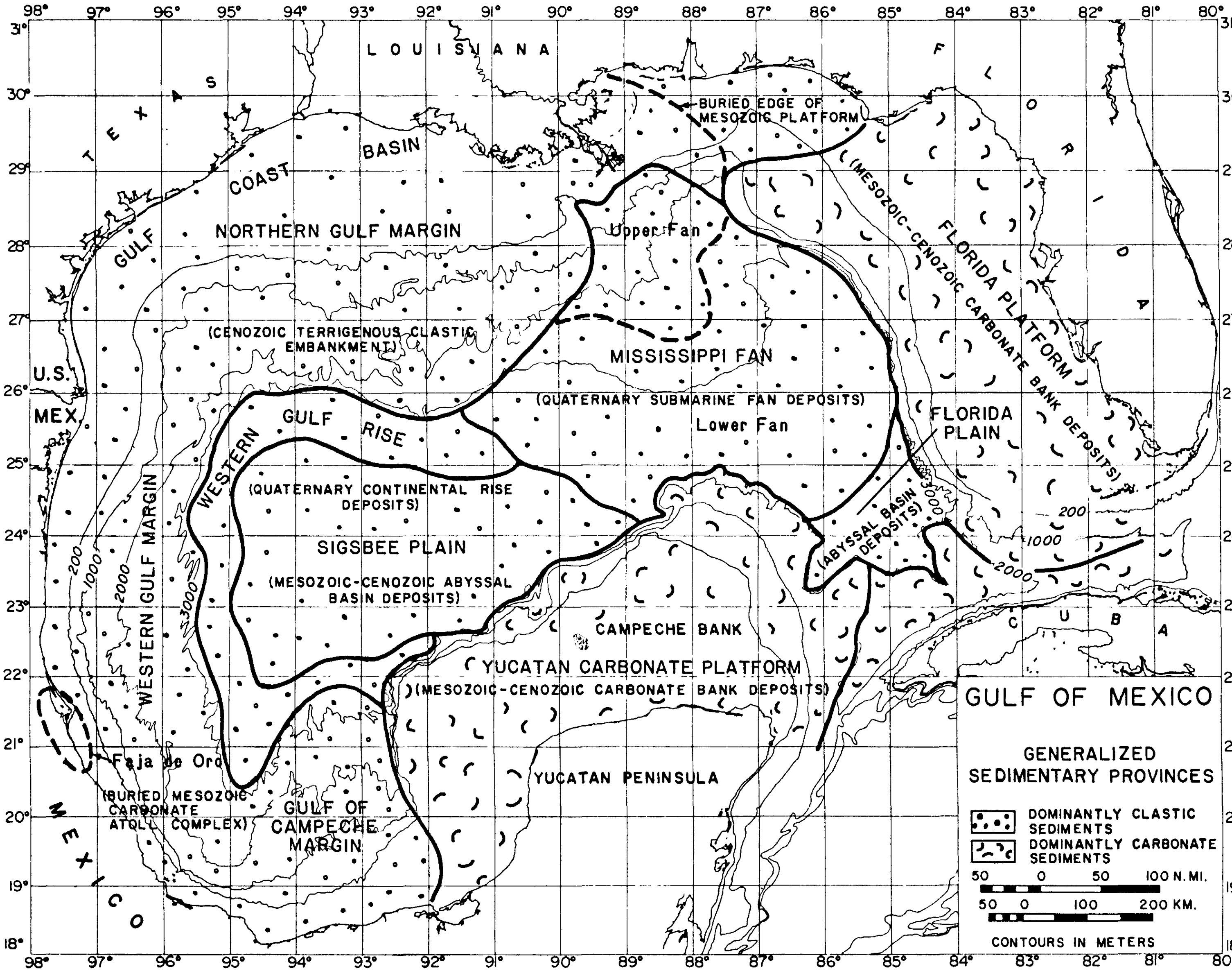

Figure 9. Map showing generalized sedimentary provinces in the Gulf of Mexico region (from Martin, 1982).

during individual glacial stages. The glacio-eustatic fluctuations resulted in multiple transgressive-regressive sequences within the Pleistocene sections of the Gulf margins. Thickest accumulations of Pleistocene deposits occurred along the outer shelf and slope areas of the northern Gulf margin, and along the north-central Gulf slope and rise where the Mississippi Fan developed. This submarine fan is a thick, apronlike wedge of mainly Pleistocene clastic deposits that were supplied to the Gulf by the ancestral Mississippi River system. The route of the ancestral Mississippi River, which served as a major source and dispersal center for the fan deposits during periods of lower sea level, may have been localized mainly in the vicinity of the presently submerged Mississippi Trough. The voluminous aggregate influx of terrigenous clastic sediments along the northern Gulf during the Cenozoic was at a rate that exceeded the rate of regional subsidence, thus resulting in progradation of the northern Gulf slope as much as 400 km (250 mi) southward since the end of the Cretaceous (Martin, 1978). The Florida Platform and the Yucatan Platform were remote from sources of terrigenous sand and mud during the Quaternary, similar to conditions that prevailed during the Tertiary, and remained areas of predominantly shallow-water carbonate deposition.

At the end of the last Pleistocene glacial stage (Wisconsinan) approximately 18,000 years ago, sea level in the Gulf of Mexico may have been about 120 m (394 ft) below its present position (Curray, 1960, 1961). With warming climatic conditions and meltwater from the waning continental glaciers entering the oceans, the last rise in sea level (Holocene transgression) resulted in submergence of the modern continental shelves. Approximately three to four thousand years ago, sea level reached its present position, thus resulting in the configuration of the modern Gulf of Mexico basin.

Structural Provinces

After Late Mesozoic time, the subsequent tectonic nature of the basin has been one of regional subsidence. Local structural deformation of Mesozoic-Cenozoic strata within the Gulf has resulted mainly from intrabasinal sedimentary processes related to sediment loading and gravity failure. Generalized structural provinces within the Gulf are illustrated in Figure 8.

As discussed in detail by Martin (1980), much of the structural deformation within the Gulf is the result of uplifting, folding, and faulting associated with the plastic flowage of Jurassic salt deposits and underconsolidated water-saturated Tertiary shale; flowage had resulted from intense sediment loading by the thick overlying Cenozoic deposits. This flowage produced widespread salt dome and diapir fields; these fields are most extensively developed along the northern Gulf margin and in the Gulf of Campeche, but also occur in the eastern Gulf and in the Sigsbee Plain.

Associated with salt and shale-flowage features along the northern and western Gulf margins are networks of down-to-the-basin growth faults, and tensional faults associated with individual piercement structures. Also present along the marginal slopes are slumps and other mass movement features resulting from gravity failure in areas of slope instability. Deformation of the Florida Carbonate Platform and the Yucatan Carbonate Platform along the eastern and southern Gulf margins has resulted mainly from broad regional warping. The deep Gulf abyssal plains and adjacent continental rises are characterized by only minor warping and normal faulting, as well as isolated salt diapirs and occasional igneous intrusions.

PROPOSED AREA FOR LEASE SALE

General Setting

Physiographically, the planning area for proposed OCS Lease Sale No. 94 (Fig. 1) is mainly underlain by the West Florida Shelf (<200 mm or 656 ft water depth), the West Florida Terrace (200 m to 1000 m or 656 ft - 3,280 ft depth) and the Florida Escarpment (1,000 m - 3,000 m or 3,280 ft - 9,843 ft depth). However, other physiographic elements encompassed by the planning area include the DeSoto Slope, the Mississippi-Alabama Shelf, the eastern portion of the Mississippi Fan, and the northern portion of the Florida Plain.

In terms of general sedimentary provinces, the West Florida Shelf, Terrace, and Escarpment constitute the Florida Carbonate Platform that is composed of a thick Mesozoic-Cenozoic sequence of predominantly carbonate bank deposits (Fig. 10); this carbonate province underlies the majority of the proposed lease area. The Florida Carbonate Platform is geologically similar to the Yucatan Carbonate Platform off southern Mexico, which lies about 150 km (93 mi) to the southwest. The two carbonate provinces are separated by the clastic provinces of the lower Mississippi Fan and the Florida Plain. In contrast to the carbonate deposits of the Florida Platform that underlie most of the planning area, the western margin of the area is underlain by terrigenous clastic provinces of the Mississippi-Alabama Shelf/DeSoto Slope, Mississippi Fan, and the Florida Plain.

Structural Framework

Florida Carbonate Platform

The dominant structural feature of the eastern Gulf of Mexico lease planning area is the Florida Carbonate Platform that underlies the Florida Shelf, Slope, and Escarpment (Figs. 8,9); this structural feature also includes the emergent Florida Peninsula. Tectonically, the Florida Platform has been an area of broad regional subsidence since Late Jurassic time, resulting in the accumulation of a thick Mesozoic-Cenozoic sequence of predominantly carbonate and evaporite deposits. The shallow-water nature of the sequence indicates that depositional rates generally kept pace with the rate of subsidence. On the offshore part of the platform, many structural details are still unknown. This is partly because of the highly competent and reflective nature of the thick carbonate sequence, thus resulting in poor quality seismic-reflection records caused by excessive multiple reflections.

Basement structures.--The pre-Middle Jurassic basement underlying the Florida Carbonate Platform consists of a metamorphic-plutonic and volcanic complex of rocks ranging in age from Precambrian to Early Jurassic. The nature of this basement complex is best known from well data along the Florida Peninsula, where basement rocks compose the northwest-southeast

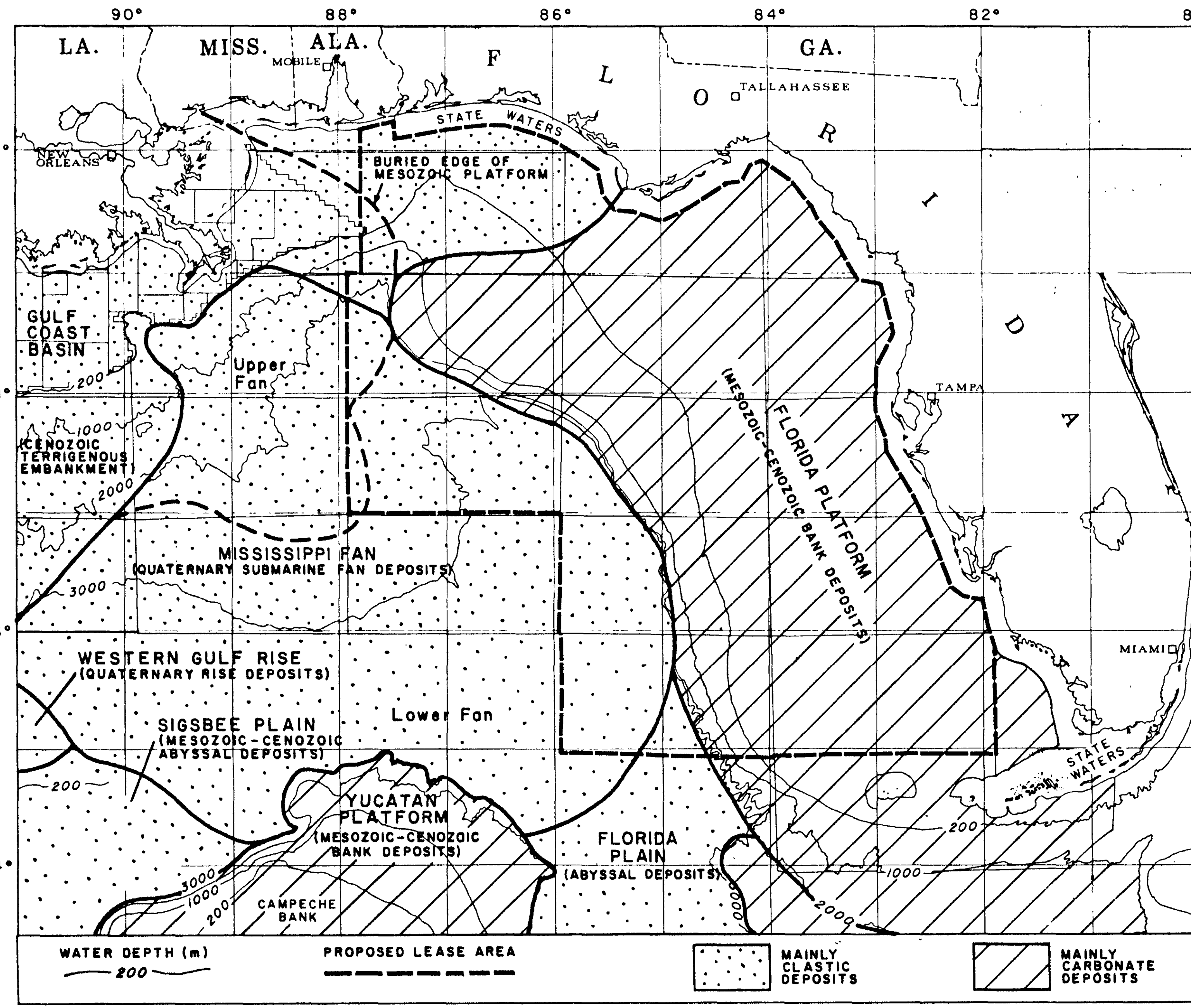

Figure 10. Map of eastern Gulf of Mexico showing general sedimentary provinces in the planning area of proposed OCS Oil and Gas Lease Sale No. 94 and adjacent areas.

trending Peninsular Arch, which represents the dominant positive element and nucleus of the Florida Platform (Figs. 11,12). The basement complex along the arch has experienced multiple episodes of uplift, block faulting, igneous intrusion, and volcanic activity. Extensive faulting, which culminated in Triassic graben development, resulted in a basement complex characterized by discordant fault trends (Fig. 12).

The magnetic heterogeneity of the basement complex has resulted in magnetic anomaly trends that reflect basement structures. A regional magnetic study of the Florida Peninsula by King (1959) indicated two distinct tectonic provinces; a northern province that is characterized by a northeast magnetic trend, and a southern province characterized by a discordant northwest magnetic trend. The magnetic anomaly trends have gravity anomaly counterparts, indicating a common source from variable density basement rocks. King (1959) suggested that the northern tectonic province may be generally related to the Appalachian structural belt, whereas the southern province may be related to the Ouachita structural belt.

The nature of the pre-Middle Jurassic basement structure in the offshore platform area is poorly known. Elongate anomaly trends oriented toward the northeast-southwest over the northern part of the offshore platform were noted by Heirtzler and others (1966) and Gough (1967); they are similar to the trends noted by King (1959) in northern peninsular Florida, and may be related to volcanic basement rocks of the Appalachian structural belt. Further southward across the central platform, recent offshore well data and magnetic data suggest the presence of a northeast-southwest trending basement high, here referred to as the Central Florida Arch. Regarding the southern Florida Platform, the faulted Triassic and Early Jurassic volcanic rocks that characterize the southern Florida Peninsula also may extend offshore to the Florida Escarpment, as suggested by the westward extension of strong magnetic anomalies (Martin, 1978). Another feature related to offshore basement structures is an anomalous oceanic crustal block beneath the Florida Platform west of the City of Tampa. This crustal block is associated with a positive Bouguer gravity anomaly (>30 mgal) salient that projects eastward across the Florida Shelf (Krivoy and Pyle, 1972). These workers hypothesized that the anomaly may reflect either reef progradation across an ancient oceanic embayment, or alternately, a transition from continental crust toward oceanic crust produced by the rotation of Florida and consequent rifting.

Late Mesozoic-Cenozoic structures.--Since Late Jurassic time, the Florida Platform has undergone slow differential regional subsidence, resulting in the development of positive and negative structural elements (Fig. 11). The Peninsula Arch on the Florida mainland remained the dominant positive element of the platform. It served as a sediment source supplying adjacent subsiding areas until it was inundated by the widespread marine transgression during Late Cretaceous time (Rainwater, 1971). In the northern part of the Florida Peninsula, a younger local uplift (Ocala Uplift) developed along the southwest flank of the Peninsular Arch, probably as the result of post-Cretaceous structural deformation (Vernon, 1951; Applin and Applin, 1965). Discordant to the Peninsular Arch is another positive element represented by the northeast-southwest trending Middle Ground Arch across the northern platform area. As noted by Martin (1972), this arch was well established by middle Early Cretaceous time, and its

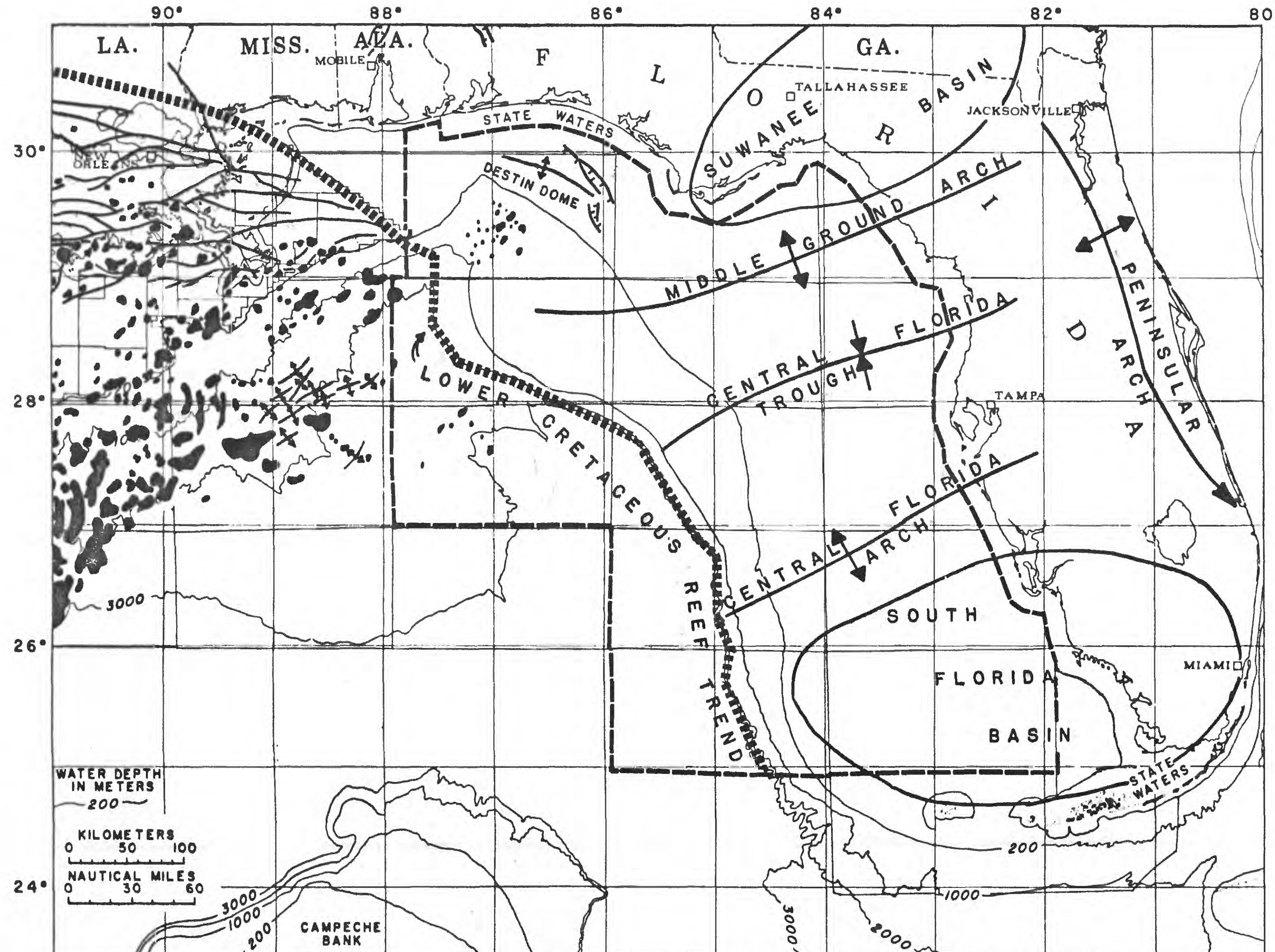

Figure 11. Map of eastern Gulf of Mexico showing major structural features of the planning area of proposed OCS Oil and Gas Lease Sale No. 94 and adjacent areas. Locations of salt diapirs and massifs (solid black pattern) and faults in western half of map taken from Martin (1978).

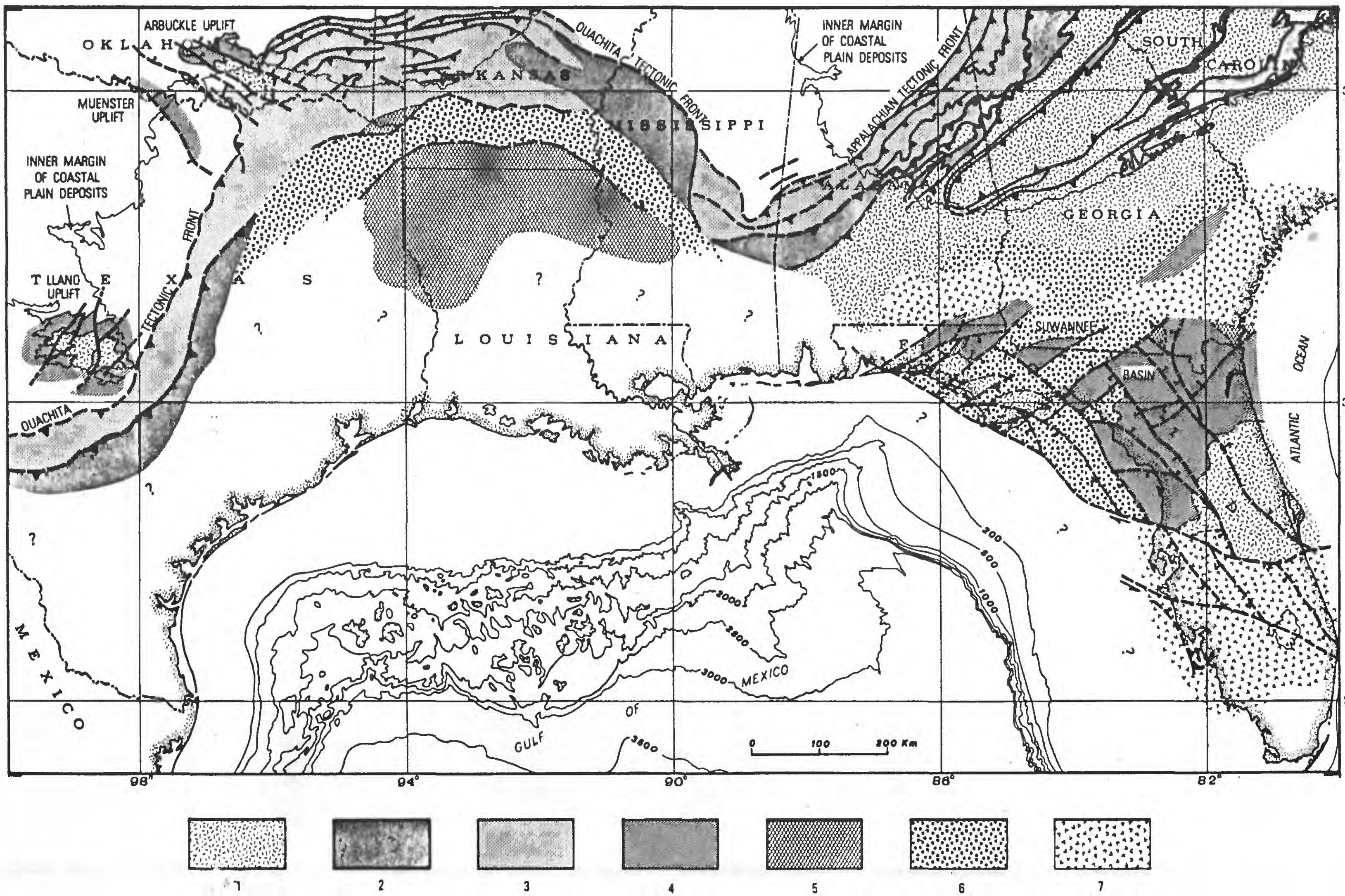

Figure 12. Map showing the distribution of pre-Middle Jurassic (Callovain) rocks in northern and eastern Gulf of Mexico regions. Adapted from Woods and Addington (1973), King (1975), and Barnett (1975). Explanations: (1) Precambrian and Paleozoic metamorphic and plutonic basement rocks; (2) Precambrian and Paleozoic metasedimentary rocks - slate, quartzite, marble, and schist; (3) Paleozoic sedimentary rocks deformed by Paleozoic orogenies: (4) Lower Paleozoic undeformed platorm deposits; (5) Upper Paleozoic undeformed platform deposits; (6) Triassic and Jurassic red bed and diabase graben deposits - Eagle Mills Formation, Newark Group, and equivalent; (7) Triassic and Lower Jurassic volcanic and plutonic complex - mainly volcanic rocks of Early Jurassic age. Bar and ball on downthrown side of normal fault; sawteeth on overthrust plate of reverse fault (from Martin, 1978).

western terminous along the platform margin provided a favorable site for reef development. The trend of the Middle Ground Arch may have been determined by pre-existing tectonic trends of the Appalachian structural belt; the arch is associated with a trend of positive gravity anomalies (Martin and Case, 1975). Further southward, recent well data and seismic reflection measurements indicate that the Central Florida Arch also may have been an active positive element during the Cretaceous. The differential uplift of both the Central Florida Arch (also called Sarasota Arch) and the Middle Ground Arch appears to have resulted in somewhat thicker deposits accumulating within an intervening subsiding area; this mildly negative element is here referred to as the Central Florida Trough (also called Tampa Embayment).

The dominant negative element of the Florida Carbonate Platform is the elongate South Florida basin, which extends in an east-west direction across southern peninsular Florida and the South Florida Shelf. The basin contains a sequence of Mesozoic-Cenozoic carbonate deposits over 4.6 km (2.9 mi) thick (Martin, 1978). The geology and oil potential of the South Florida basin has been described by Winston (1971), who noted that the basin contains several local positive and negative tectonic elements that are reflected by the structure of Comanchean Cretaceous deposits. The more prominent intrabasinal elements include the Martin High, the Largo High, and the Broward Trough. Another major negative element of the Florida Platform is the elongate Suwanee basin, which extends in a northeast-southwest direction across southern Georgia, and the northern Florida peninsula and adjacent inner shelf. The Suwanee basin occurs between the Peninsular Arch to south, and outcropping crystalline rocks of the Piedmont Plateau to the north. This synclinal feature, previously referred to as the "Suwanee Straight" and "Suwanee Saddle", has been discussed by Applin and Applin (1967) who considered it to be of post-Cretaceous age. According to their interpretation, the feature existed to Late Cretaceous (Navarro) time as an upwarped barrier that separated a shallow-water marine environment in southern Georgia from a partly restricted marine-shelf environment in northern Florida. Tectonic movement during the Tertiary resulted in relative subsidence of the barrier by differential uplift of the areas north and south of it, thus forming the present Suwanee basin.

Another structural element of the Florida Platform indicated by seismic data and seafloor samples is an intermittently developed Cretaceous reef trend that occurs along the base of the Florida Escarpment (Figs. 6,7). This reef structure has been discussed by several workers (e.g., Antoine and Ewing, 1963; Ewing and Ewing, 1966; Antoine and others, (1967); Bryant and others (1969); Garrison and Martin (1973). It apparently formed as an intermittent shelf-edge barrier reef system, which kept pace with regional subsidence of the carbonate platform during Early Cretaceous time (pre-Cenomanian).

Mississippi-Alabama Shelf/DeSoto Slope

In the northwestern part of the lease planning area, the surface of the Florida Carbonate Platform plunges northward beneath the terrigenous clastic province of the Mississippi-Alabama Shelf and DeSoto Slope (Figs. 6,10). Seismic profiles across the present DeSoto Canyon illustrate that it is located at the junction of a sediment wedge derived from eastern sources, and an overlapping prograded sediment wedge derived from western sources (Garrison and Martin, 1973).

This province occurs at the eastern limit of salt diapiric activity in the northern Gulf. The dominant structural element in the province is the west-northwest trending Destin Dome, a large salt uplift associated with growth faults. Recent seismic-reflection measurements (Ball and others, 1983) indicate that the dome is 80 km (50 mi) long, 30 km (19 mi) wide, and has 1 km (0.62 mi) of relief on Lower Cretaceous rocks; it appears to have been uplifted during Late Cretaceous and Cenozoic time.

A field of salt diapirs also occurs south of Destin Dome near the head of DeSoto Canyon (Harbison, 1968; Martin, 1980). According to Martin (1980), as many as 24 individual salt structures penetrate and uplift Cretaceous to late Miocene strata of the upper slope around DeSoto Canyon. He also notes that additional piercement domes and nondiapiric salt swells exist between the DeSoto Canyon field and the Destin Dome area.

Mississippi Fan/Florida Plain

The Mississippi-Alabama Shelf/DeSoto Slope province grades westward into the terrigenous clastic province of the Mississippi Fan, the eastern part of which is in the lease planning area (Figs. 6,10). The Mississippi Fan is a thick wedge of Quaternary deposits that extends southward across the continental slope and rise, and grades into the Florida Abyssal Plain. The internal structure of the upper fan has been characterized by Garrison and Martin (1973) as a complex of numerous cut-and-fill features, levees, diapirs, and slump structures; whereas, the lower fan is characterized mainly by uniformly stratified hemi-pelagic deposits that grade into flat-lying deposits of the abyssal plain. The dominant structural features of the Mississippi Fan are salt domes and ridges, which have been described by Martin (1980); he noted that the salt ridges are commonly associated with intervening troughs that contain stratified sedimentary sections with thicknesses of 2,000 m (6,562 ft) or more. Martin (1980) also noted that isolated diapiric plugs and nondiapiric pillowlike swells pierce and uplift Cretaceous and lower Tertiary strata in a poorly defined belt subparallel to the Florida Escarpment (Fig. 8). This southeasterly trending belt extends into the western part of the lease planning area.

Stratigraphy

Most stratigraphic information about the Eastern Gulf is known from drilling activity along peninsular Florida and the adjacent inner continental shelf of the Florida Platform. The regional stratigraphy of this area has been described in several studies. Summary reviews of these studies have been provided by Maher and Applin (1968), Rainwater (1971), Barnett (1975), and Martin (1978), which serve as major sources for the following general discussion. The regional stratigraphy of peninsular Florida is summarized in a northwest-southeast geologic cross section (Fig. 13).

Pre-Cretaceous Rocks

The nature of pre-Cretaceous basement rocks of peninsular Florida is largely summarized in Figures 12 and 13. The oldest rocks of the peninsula are a Precambrian-Early Paleozoic complex of plutonic, volcanic, and metasedimentary (slate, quartzite, marble, schist) rocks. Following a period of granitic intrusion during the Cambrian, this complex was overlain

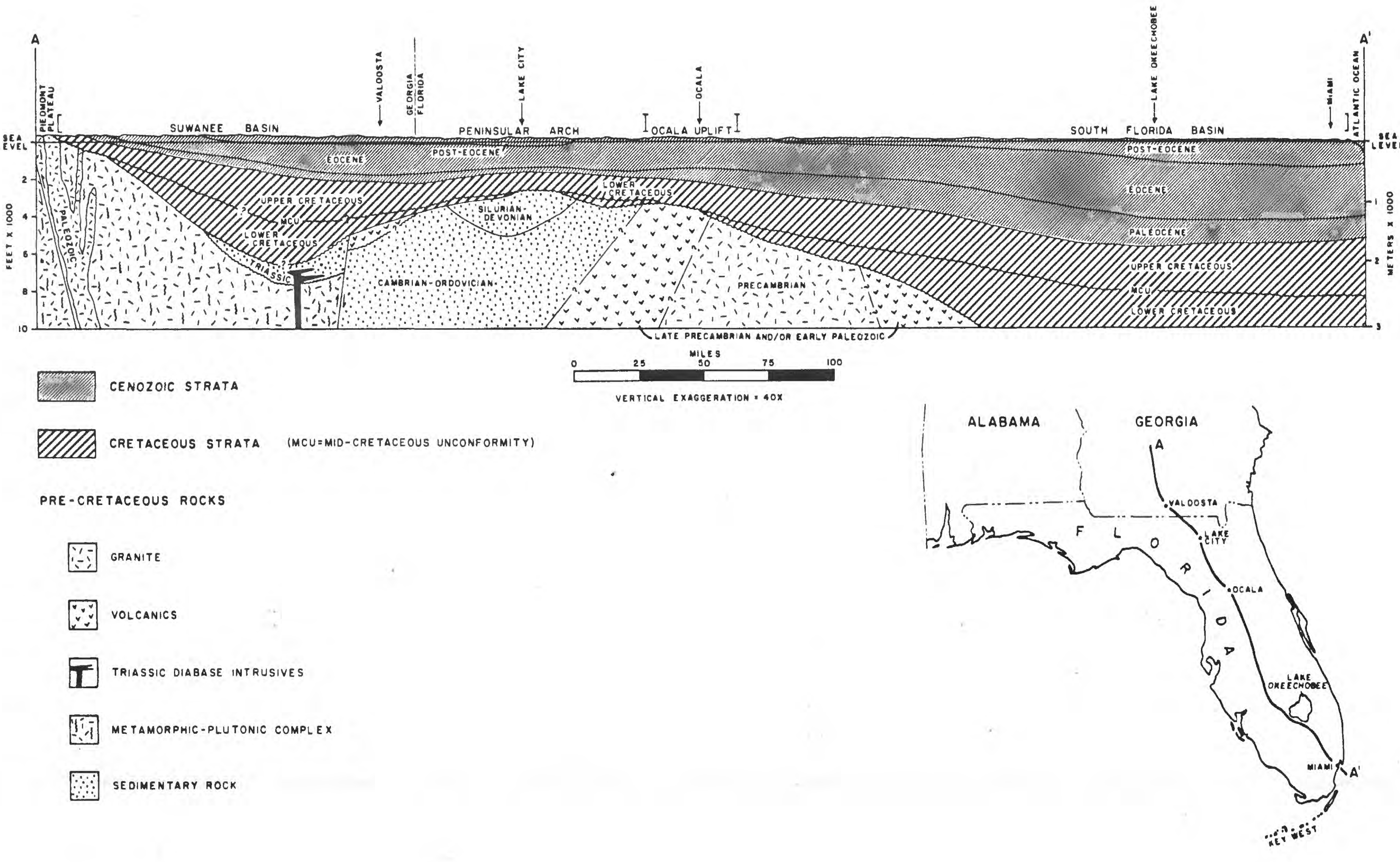

Figure 13. Generalized geologic cross section (A-AA') trending northwest-southeast along peninsular Florida (modified from AAPG, 1975).

by a Lower Paleozoic (Ordovician-Devonian) sequence of clastic sedimentary rocks consisting of quartzitic sandstones and shales in the northern half of the peninsula. The Lower Paleozoic sedimentary sequence attains a thickness of more than 2,000 ft (610 m) in northern Florida (Rainwater, 1971), and it appears to represent a miogeosynclinal assemblage (Barnett, 1975). During Late Paleozoic time, the Precambrian and Paleozoic rocks were uplifted and block-faulted, with associated volcanic activity.

During Triassic time, renewed uplift and block-faulting resulted in graben development along peninsular Florida; this was associated with volcanic activity and diabase intrusives. In northern Florida and southern Georgia, thick sections of nonmarine clastic deposits accumulated within graben structures, mainly as alluvial fans. These Triassic deposits are mainly arkosic sandstone and shale redbeds with interspersed diabase intrusives; as noted by Barnett (1975), maximum thickness of the deposits may exceed 3,750 ft (1143 m). The Florida Triassic redbeds appear to be the correlative of the Eagle Mills Formation of the Gulf Coast and the Newark Group of the eastern United States.

Igneous activity continued into Jurassic time, resulting in a Triassic-Lower Jurassic complex of volcanic and plutonic rocks that underlie the southern half of the Florida Peninsula; similar rocks may extend beneath the South Florida basin (Martin, 1978). In the northern part of the peninsula, the deposition of clastic redbeds within grabens continued into Early Jurassic time. By Middle Jurassic time, restricted marine conditions existed over parts of the present offshore platform area, resulting in evaporite deposits that are probably correlative with the Louann Salt (Rainwater, 1971). These deposits are manifested as salt diapirs and pillows along the base of the Florida Escarpment, and in the salt dome field of the DeSoto Canyon-Destin Dome area (Figs. 8,11) After salt deposition, normal open-marine conditions resulted in carbonate deposition (Smackover Formation equivalent), followed by an influx of terrigenous clastic sediment (Cotton Valley Formation equivalent) from northern and western source areas (Rainwater, 1971). The presence of basal clastic deposits overlying an extrusive igneous basement across the northern part of the South Florida basin has been determined by well data. Although the age of the clastic unit is questionable, it has been tentatively assumed to be equivalent to the Jurassic Cotton Valley Formation (Sheffield, 1978). Along the West Florida Shelf, seismic reflection profiles indicate that Jurassic strata onlap truncated Paleozoic rocks along the Middle Ground Arch, indicating that the arch was a pre-Jurassic erosional high (Ball and others, 1983). Also within the lease planning area, Jurassic deposits have been established by drilling activity on the Destin Dome structure where the Smackover Formation, Norphlet Formation, and Louann Salt were penetrated (Ball and others, 1983). Further westward on the Alabama Shelf off Lower Mobile Bay, the Jurassic Norphlet Formation has been the target of recent hydrocarbon exploratory drilling.

Cretaceous Deposits

Since Late Jurassic time, the Florida Platform has been an area of essentially continuous regional subsidence, resulting in the accumulation of a thick Cretaceous section. Along peninsular Florida, Cretaceous strata unconformably onlap the truncated pre-Cretaceous basement complex (Fig. 13). The thickest Cretaceous sections occur within the Suwanee basin and South

Florida basin, reaching a maximum thickness of over 10,000 ft (3,048 m) within the latter basin. The generalized geologic column of the South Florida basin section has been presented by Winston (1971), and is illustrated in Figure 14. The first comprehensive studies of Cretaceous deposits in Florida and southern Georgia were the reports of Applin and Applin (1965, 1967), which served as the foundation for many subsequent studies.

Lower Cretaceous.--The Lower Cretaceous deposits referred to in this report are of pre-Cenomanian age and constitute the Coahuilan and Comanchian series. These deposits represent a transgressive sequence that formed in a northward advancing sea that inundated the subsiding Florida Peninsula. Lower Cretaceous deposits are distributed throughout the Florida Platform except for an area in southern Georgia and northern Florida along the northern Peninsular Arch, which served as a positive area and sediment source during Early Cretaceous time (Rainwater, 1971). Thickest deposits occur within the South Florida basin, where the section exceeds 7,000 ft or 2,134 m (Rainwater, 1971; Winston, 1971).

Lower Cretaceous deposits exhibit north-south regional lithofacies variability. Southern Georgia and the northern half of the Florida Platform are characterized by a terrigenous clastic facies consisting of arkosic sandstones, siltstones, mudstones, and varicolored shales. The sediments were derived from southern Appalachian and Peninsular Arch sources, and were deposited in deltaic and other coastal environments. The clastic facies grades southward and seaward into a mixed transitional facies consisting of interbedded clastic rocks, argillaceous and arenaceous carbonates, and evaporites. Further southward, the mixed transitional facies grades into a carbonate-evaporite facies, which characterizes the southern half of the Florida Platform. The carbonate-evaporite facies represents a starved-basin assemblage that reflects a shallow-water shelf environment remote from any significant source of terrigenous sediments.

The Lower Cretaceous carbonate-evaporite lithofacies is thickest in the South Florida basin, where it consists of interbedded carbonates and evaporites (Fig. 14). The section reflects varying conditions of restricted and open-water circulation on the shallow shelf. Periodic water restriction was probably caused by the extensive shelf-edge barrier reef system that developed during Early Cretaceous time (Figs. 7,11); the vertical growth of the reef system apparently kept pace with platform subsidence. In addition to the shelf-edge barrier reef, patch reefs also developed on the platform interior, such as those under the Sunniland and Sunoco-Felda oil fields (Rainwater, 1971).

Stratigraphic details of the South Florida basin section have been summarized by Winston (1971). The oldest unit of the section is the Ft. Pierce Formation (Coahuilan), which consists of a locally developed basal transgressive clastic facies overlying the basement complex; the clastic facies, in turn, is overlain by anhydrite, dolomite, and limestone. The overlying Comanchian Series consists of units of Trinity age (Glades Group, Ocean Reef Group), Fredericksburg age (Big Cypress Group), and Washita age (Naples Bay Group). The entire Comanchian Series is characterized by a sequence of interbedded limestones, dolomites, and anhydrites.

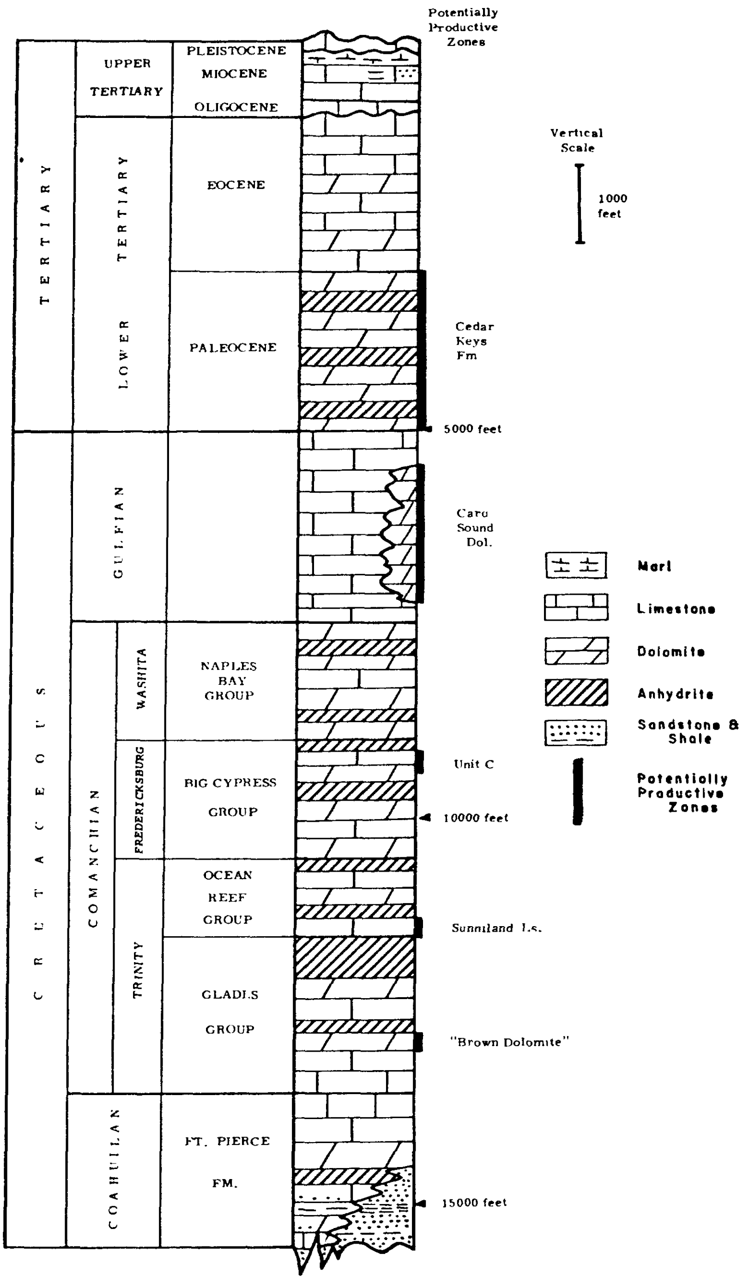

Figure 14. Generalized columnar section of major Cretaceous-Tertiary stratigraphic units in the South Florida Basin (from Winston, 1971).

Upper Cretaceous.--The Upper Cretaceous deposits constitute the Gulfian Series, and are of post-Albian (Cenomanian-Maestrichtian) age. Upper Cretaceous deposits are widely distributed throughout southern Georgia south of the Piedmont Plateau and throughout all of the Florida Platform. As noted by Rainwater (1971), Upper Cretaceous deposits are more widespread than Lower Cretaceous deposits, but they are substantially less volumetrically; this relationship is illustrated by geologic cross sections across the Florida Platform (Figs. 7,15). Upper Cretaceous deposits are thickest in the South Florida basin, reaching a maximum thickness of about 3,000 ft or 914 m (Rainwater, 1971; Winston, 1971).

The Gulfian Series unconformably overlies pre-Cretaceous basement rocks along the northern Peninsular Arch, and unconformably overlies Comanchian deposits throughout the remainder of the area. The Gulfian Series represents deposits of a widespread transgression in the eastern Gulf. The transgression resulted in the drowning of the shelf-edge barrier reef system; it also resulted in the complete inundation of the Peninsula Arch for the first time since the Paleozoic Era (Rainwater, 1971). Gulfian strata exhibit a regional lithofacies transition. In southern Georgia, the Gulfian deposits comprise a terrigenous clastic facies representing gravel, sand, and muddy sediments derived from the Appalachian Piedmont and deposited in coastal plain and marginal-marine environments. The clastic facies grades southward and seaward into a carbonate facies underlying peninsular Florida. The carbonate facies consists of chalk, limestone, and dolomite, which were deposited in an open-marine shelf environment that experienced very little influx of terrigenous sediment.

The Gulfian Series in the southern Georgia-northern Florida area consists of four major stratigraphic units, as described by Applin and Applin (1967). The oldest unit is the Atkinson Formation, which is predominantly a shale and sandstone unit with some interbedded limestones. It is a shallow-marine facies that grades northward into the nonmarine or littoral clastic facies. The overlying stratigrahic unit is of Austin age, and is composed mainly of chalky limestone; this unit is overlain by beds of Taylor age, which are predominantly clastic in the north but grade into a carbonate facies southward along the Florida Peninsula. The youngest unit is of Navarro age, and also consists of a clastic facies in the north, which grades southward into carbonates. The northern shallow-marine clastic facies may have been separated from the shallow partly-restricted marine carbonate facies to the south by an upwarped barrier that prevented the further southward dispersal of terrigenous sediment. This southward-trending barrier may have been located in the vicinity of the present axis of the Suwanee basin.

In the South Florida basin, the Gulfian Series is composed mainly of chalk. The main exception occurs along the southeastern coast of Florida, where a distinctive dolomite facies occurs; this unit has been named the Card Sound Dolomite, and attains a maximum thickness of about 1,300 to 1,400 ft or 396 to 427 m (Winston, 1971).

Tertiary Deposits

Following widespread transgression by Late Cretaceous seas, southern Georgia and the Florida Platform remained submerged by shallow seas until middle Miocene time (Rainwater, 1971). Regional subsidence continued,

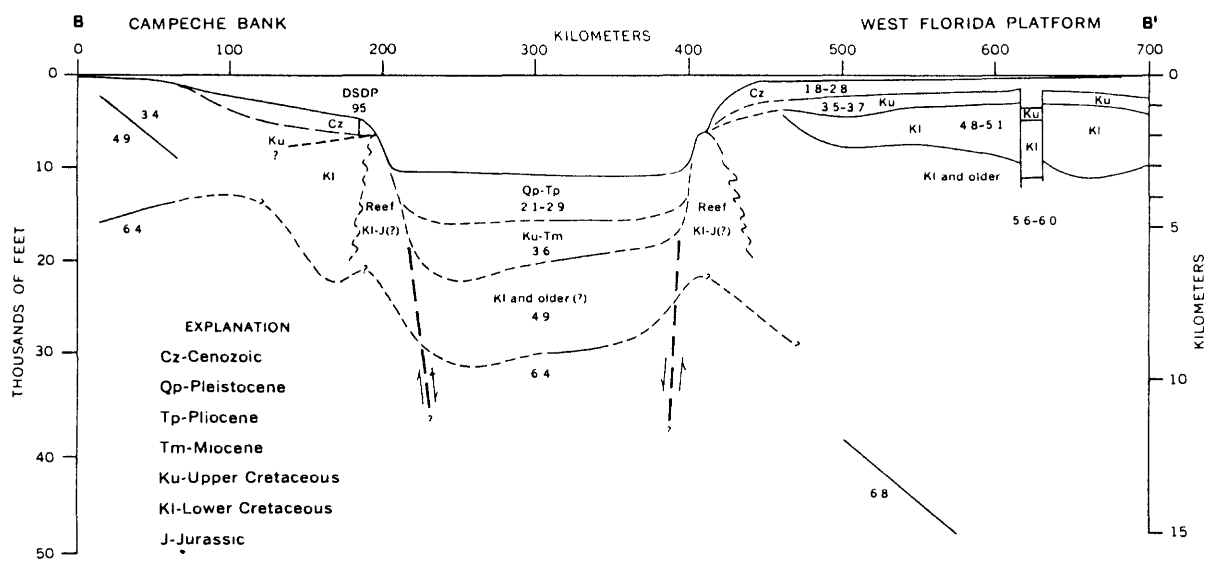

Figure 15. Geologic cross-section (B-B') from West Florida Platform to the Campeche Bank (location shown in Fig. 7); seismic velocities given in km/sec (from Martin and Case, 1975).

resulting in the accumulation of mainly shelf carbonates and evaporites on peninsular Florida and in most of southern Georgia. Terrigenous sediments were derived from the Piedmont Plateau, but clastic deposition was largely restricted to the northern part of the Suwanee basin and other areas marginal to the Piedmont. The Tertiary stratigraphy of the region has been summarized by Rainwater (1971), which is the major source for the following discussion.

Lower Tertiary.--Paleocene strata (Midway Group) are distributed throughout peninsular Florida, southern Georgia, and probably the adjacent continental shelf. Their thickness is generally less than 1,000 ft (305 m) but they attain a maximum thickness of about 2,400 ft (732 m) within the South Florida basin. A northern terrigenous clastic facies was deposited in coastal and shallow neritic environments marginal to the Piedmont sourceland, whereas the remainder of the region accumulated mainly dolomite and anhydrite. The latter facies developed in a shelf environment with restricted circulation, possibly partly attributed to barrier reef growth along the western margin of the platform. Within the South Florida basin (Fig. 14.), the Paleocene section is represented by the Cedar Keys Formation. This stratigraphic unit consists of a repetitive sequence of dolomite and anhydrite beds about 2000 ft (610 m) thick (Winston, 1971).

Eocene deposits are distributed throughout most of southern Georgia, peninsular Florida, and probably the adjacent continental shelf. The Lower Eocene (Sabine) section attains a maximum thickness of about 1,200 ft (366 m) within the South Florida basin. The Middle Eocene (Claiborne) section attains a maximum thickness of about 1,400 ft (427 m) in central peninsular Florida, and the Upper Eocene (Jackson) section attains a maximum thickness of about 800 ft near the southwestern end of the Suwanee basin. The foregoing thickness variability illustrates the varying differential subsidence of the platform that occurred throughout the Eocene Epoch. A regional lithofacies transition occurs throughout the Eocene section. Terrigenous clastic facies deposited in coastal plain, marginal-marine, and shallow neritic environments occur north of the Suwanee basin axis. The clastic facies grades southward into a carbonate facies deposited in a shallow-water shelf environment. Shelf-water circulation varied from open-ocean to partially restricted conditions, resulting in mainly limestone and dolomite deposits, with very little influx of terrigenous sediment. Within the South Florida basin (Fig. 14), the total Eocene section is about 2,000 ft (610 m) thick, and consists of an alternating limestone-dolomite sequence (Winston, 1971). In the order of decreasing age, the stratigraphic units comprising the Eocene section of Florida are the Oldsmar, Lake City, Avon Park, and Ocala formations.

Upper Tertiary.--Oligocene strata (Vicksburg Group) are absent from much of the Florida Peninsula, which is probably attributed to post-depositional erosion. The thickest Oligocene section is about 400 ft (122 m) within the South Florida basin. Lithologically, Oligocene strata are essentially carbonates formed in a shallow-shelf environment. Shelf waters were generally warm with unrestricted circulation, resulting in the deposition of a variety of limestone types. The partial restriction of some shelf areas is indicated by occasional beds of gypsiferous dolomite.

Miocene deposits are distributed throughout most of the region except in the northwestern part of peninsular Florida; they are extensively exposed in peninsular Florida. The Miocene section attains a maximum thickness of about 800 ft (244 m) in the South Florida basin. The Floridian Miocene section is represented by the Tampa Group, and the overlying Alum Bluff and Choctawhatchee groups. Lithologically, the section is composed of a basal sandy limestone, a middle unit of phosphatic sandstone and dolomite, and an upper marlstone unit; the section reflects deposition in shallow marine, littoral, and lagoonal environments. Terrigenous sediments were derived from sources to the north, and parts of the Florida Peninsula that became emergent during middle Miocene time. This was the first emergence of peninsular Florida since early Late Cretaceous time, and resulted in partial separation of the Gulf of Mexico from the Atlantic Ocean. Much of the interior of Georgia and peninsular Florida have remained landmasses since the end of Miocene time.

The Pliocene Epoch was a time of general emergence in the Georgia and peninsular Florida area, and the deposition of sediments was not significant. If present, they would probably consist of thin patches of non-marine deposits. Frequently, Pliocene sediments have not been differentiated from overlying Pleistocene deposits. Offshore, terrigenous clastic deposits of Pliocene age occur on the continental shelf off Louisiana, Mississippi, and Alabama (Foote and Martin, 1981). This trend could continue further eastward into the northwestern corner of the lease planning area. Pliocene deposits have been reported on the West Florida Slope in the vicinity of DeSoto Canyon (Mitchum, 1978). However, their presence on the adjacent West Florida Shelf has not been established. If present, they probably represent a very thin sequence.

Quaternary Deposits

The Pleistocene Ice Age consisted of four glacial stages (Nebraskan, Kansan, Illinoisan, Wisconsinan), and three interglacial stages (Aftonian, Yarmouthian, Sangamonian). The glacial stages were times of relatively cool climate and glacier advances, resulting in a worldwide lowering of sea level. In contrast, the warmer interglacial stages were times of glacier recession and a worldwide rising of sea level. Superimposed on these major eustatic cycles were some secondary fluctuations of sea level resulting from minor glacial advances and recessions. The net result was essentially a continuously migrating shoreline along the eastern Gulf during Pleistocene time. In addition, voluminous quantities of terrigenous clastic sediment were introduced into the northern Gulf from high-discharge continental drainage systems carrying sediment-ladened glacial meltwaters; the ancestral Mississippi River was the dominant source of clastic sediment in the northwestern part of the lease planning area.

The fluctuating Pleistocene sea level is reflected in the subaerial coastal plain deposits of Georgia and peninsular Florida; in these areas, several geomorphic terraces developed that represent the positions of former sea level stillstands. The southern portion of the Florida Peninsula remained an area of carbonate deposition. A shallow shelf environment is indicated by Pleistocene reefs that comprise the modern Florida Keys (Key Largo Limestone), and an associated oolitic limestone facies (Miami Oolite). Carbonate deposition in South Florida has continued to the present.

On the West Florida Shelf, the last rise of sea level that began about 18,000 years ago (Holocene transgression) resulted in the drowning of former

Pleistocene features such as reefs, terraces, coastal spits, and a karst topography. A more detailed discussion of Quaternary deposits on the West Florida Shelf and adjacent slope is presented in a subsequent chapter of this report.

Deep-Gulf Stratigraphy

The stratigraphy of the West Florida Slope/Escarpment and adjacent Mississippi Fan in the western part of the lease planning area is known mainly from seismic reflection and refraction data, and from some supplemental core data and dredge samples.

The stratigraphy of the West Florida Slope has been summarized by Mitchum (1978), which serves as the main source for the following discussion. The northern part of the slope (above 26°30'N lat.) is best known because of good quality seismic profiles and supportive core hole control. The stratigraphic section of the northern slope ranges from Early Cretaceous to Recent in age (Figs. 7,16). Lower Cretaceous rocks consist of shallow-shelf carbonate deposits, with probable marginal reef deposits along the present Florida Escarpment. Post-Early Cretaceous faulting occurs along the escarpment; however, the possible existence of deeper crustal faulting in localizing and developing the escarpment has not yet been resolved. Upper Cretaceous deposits on the outer slope average about 1,500 ft (457 m) in thickness, and consist mainly of shallow to deep-water carbonates. Lower Tertiary deposits average about 2,000 ft (610 m) in thickness, and consist mainly of nonargillaceous to slightly argillaceous bathyal carbonates; the section is represented by well-developed and frequently contorted Eocene and Oligocene-Lower Miocene sequences, possibly locally overlying very thin Paleocene beds. The middle-upper Miocene section is composed of relatively thick prograded sequences of mixed carbonates (foraminiferal-coccolith ooze) and terrigenous clays supplied from northern sources; the amount of terrigenous sediment decreases southward along the slope. The lithologically similar Pliocene-Recent sequence has prograded over earlier deposits, and decreases in thickness southward.

In contrast to the northern slope, the stratigraphy of the southern slope is not as well defined; tentatively, it is inferred to be of an age similar to the northern slope section (Early Cretaceous-Recent). The section exhibits prominent fault scarps along the upper slope, and prominent slump features in the lower slope areas. Lithologically, the southern section appears to be mainly carbonate with relatively little terrigenous clay, as contrasted with the more argillaceous northern section.

The Florida Escarpment is encroached from the west by sediments of the Mississippi Fan, and is completely buried by fan deposits west of DeSoto Canyon. The Mississippi Fan encompasses a surface area of approximately 170,000 sq km, and the eastern part of the fan occurs within the western lease planning area. The seismic stratigraphy of the Mississippi Fan has been summarized by Moore and others (1978), which serves as the main source for the following discussion. No deep wells have yet been drilled on the Mississippi Fan; consequently, its stratigraphy is not well defined. Available physical subsurface data consist of shallow piston cores within the fan itself, some deeper core holes drilled on the adjacent upper continental slope, and DSDP drilling sites on the fan and adjacent Sigsbee Plain. The oldest deposits penetrated by any core within the fan itself are

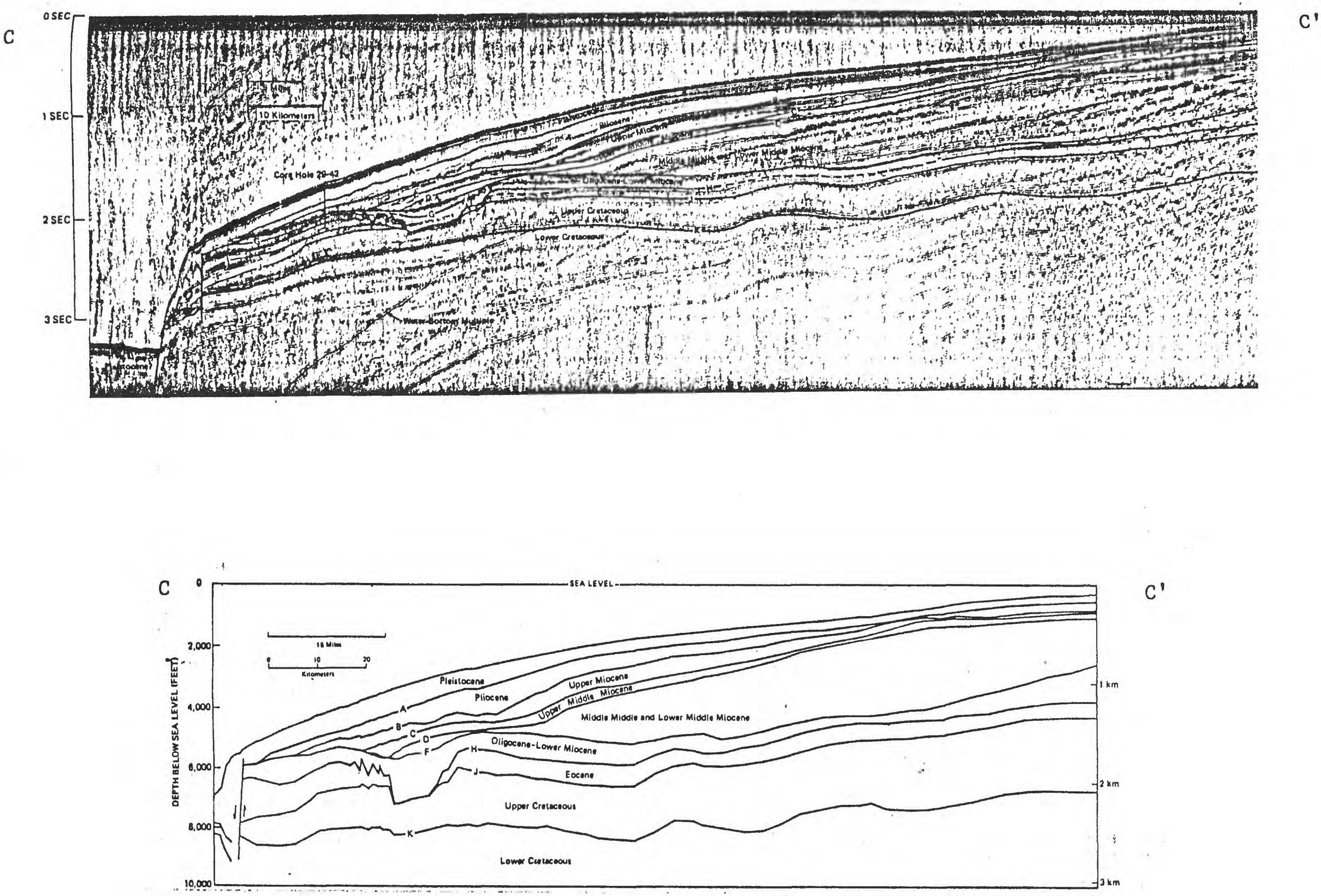

Figure 16. Seismic stratigraphic section (C-C') of the northern West Florida Slope near De Soto Canyon (location shown in Fig. 7). Upper illustration is seismic profile with supportive core hole (29-42) location, and lower illustration is converted line drawing with depth scale. Vertical exaggeration=20 (from Mitchum, 1978).

of Pliocene age. Preliminary correlations of seismic profiles across the Mississippi Fan with western Gulf seismic profiles (Ladd and others, 1976; Watkins and others, 1976) tied into DSDP drilling sites indicate the following seismic stratigraphic section for the fan: 1. Unit A - This is the youngest and thickest seismic unit; it is interpreted to be of Pleistocene age, and correlates with the "Sigsbee" seismic unit. Unit A is the thickest in the upper and middle fan areas, where it attains a maximum thickness of over 9,843 ft or 3 km (assumed seismic velocity = 2.15 km/sec). This seismic unit represents the bulk of the clastic wedge comprising the Mississippi Fan. The unit consists of a suprafan proximal facies characterized by a chaotic seismic signature. This facies is interpreted as an assemblage of mass movement deposits, turbidites, channel complexes, and interbedded hemipelagic calcareous muds. The distal facies of Unit A is characterized by parallel to slightly divergent discontinuous reflectors that probably represent a sequence of turbidites and hemipelagic calcareous muds; 2. Unit B - This underlying unit is interpreted to range in age from Pleistocene to Late Miocene, and is correlated with the "Cinco de Mayo" and "Upper Mexican Ridges" seismic units. Unit B attains a maximum thickness of about 2.4 km (7,875 ft) in the upper fan area (assumed seismic velocity = 2.9 km/sec). The seismic signature indicates bands of well-layered reflectors that gently converge down the lower fan onto the abyssal plain. This sequence is inferred to consist of interbedded turbidites and hemipelagic clays and oozes; 3. Unit C - This unit is interpreted to be of Middle Miocene age, and is correlated with the "Middle Mexican Ridges" seismic unit. Unit C is relatively thin, attaining a maximum thickness of about 0.9 km (2,953 ft) in the upper fan area (assumed seismic velocity = 2.9 km/sec). The unit is largely acoustically transparent, and is probably composed of a relatively homogenous assemblage of hemipelagic sediments.

These three seismic stratigraphic units can be traced over most of the Mississippi Fan, as well as over the adjacent continental rise and abyssal plain areas. The stratigraphic section indicates that the Mississippi Fan is a geologically youthful feature; it developed mainly during the Pleistocene Epoch, when over a 3 km (1.9 mi) thickness of clastic sediment accumulated along the northern continental margin. The clastic sediments were derived mainly from the ancestral Mississippi River, which served as the major drainage system that supplied voluminous quantities of sediment to the northern Gulf of Mexico during Pleistocene time.

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CHAPTER II

PETROLEUM GEOLOGY OF EASTERN GULF OF MEXICO OCS REGION

by

R. Q. Foote, L. M. Massingill, and R. H. Wells

INTRODUCTION

This chapter highlights the findings of numerous studies by government, industry, and research institutions on the petroleum geology of the lease sale planning area, eastern Gulf of Mexico.

Significant accumulations of hydrocarbons depend on many factors: 1) substantial thicknesses of sedimentary rocks deposited in a marine environment and containing large amounts of organic material; 2) a favorable regional thermal history and suitable environment for the maturation of organic material into oil and gas; 3) hydrodynamic conditions permitting migration to ensure entrapment of hydrocarbons; 5) adequate geologic traps for the accumulation of hydrocarbons; 6) an impermeable seal over the reservoir to prevent the upward escape of hydrocarbons; and 7) porous and permeable reservoir rocks.

The northwestern Gulf of Mexico has long been a major oil and gas producing region because these conditions are met. Exploration in the northwestern Gulf Coast basin has followed a natural progression from onshore, bays, and estuaries to the continental shelf and, more recently, to the upper continental slope. Recently, commercial oil and gas production was also extended into offshore Alabama and Mississippi in the eastern Gulf of Mexico. Two prospective frontier regions are present within the lease sale planning area: 1) the Mississippi-Alabama Shelf and the West Florida Shelf, and 2) the deep Gulf of Mexico, including the Mississippi Fan (Fig. 6), and the Eastern Gulf Diapir Field (Fig. 8).

SOURCE BEDS AND MATURATION

In this report, petroleum source beds are defined as sediments above basement and below depths at which minimum temperatures exist for hydrocarbon maturation. The types and amounts of organic material, depositional environments, regional thermal history, maturation environments, and pathways of migration have significant effects on what types of hydrocarbons are generated and entrapped. Dow (1978) has suggested that oil and gas are formed from disseminated sedimentary organic matter (kerogen) by a series of predominantly first-order chemical (thermogenic) reactions. The rates of these reactions depend primarily on temperature and the duration of heating. He described three basic types of organic matter which are available for incorporation into sediments: 1) terrestrial matter derived from higher order land plants; 2) amorphous material from lower order aquatic life; and 3) recycled organic material from erosion of uplifted sedimentary rocks. The first type will yield primarily gas and some condensate; the second type produces oil; and the third type generates very little gas and no oil.

Oil and gas produced on the continental shelf and upper continental slope offshore Texas and Louisiana are probably from numerous, widespread source beds ranging in age from Jurassic to Quaternary. Jurassic marine shales appear to be source beds for gaseous and liquid hydrocarbons recently discovered in Jurassic age rocks onshore and in state waters offshore Alabama (Foote and Martin, 1981). Throughout southwest Alabama, the lower Smackover Formation (Fig. 17) consists of predominantly algal mudstones and occasionally peloidal wackstone, peloidal-oncolitic packstone, or dolomite (Tolson and others, 1982). The lower mudstone facies represent low energy, shallow subtidal sediments deposited during a marine transgression which probably occurred during late Norphlet time. The algal mudstones are excellent petroleum source rocks (Mancini and Benson, 1980).

The sedimentary sequences of onshore Florida were studied by Reel and Griffin (1971) to determine the potentially petroliferous section. They reported that the favorable areas for petroleum generation are: the Jurassic trend in the western Panhandle (Fig. 18), a small area over central Florida, and the extreme southwestern part of the peninsula that includes the Sunniland Formation producing trend (Fig. 19). Prospective areas in the Jurassic Smackover Formation of Florida, Georgia and Alabama are between the 260°F and 330°F isotherms, with the lower range yielding oil, and the upper range yielding gas and condensate (Griffin and others, 1978). However, isothermal values of the Lower Cretaceous Ferry Lake Formation (Fig. 20) suggest that all of Georgia, eastern Alabama, and Florida east of the Apalachicola River have a high probability of being barren because the rocks are cooler than the 160°F minimum temperature required for oil maturation in rocks of that age. Subsurface temperatures as high as 280°F have been recorded in southwestern Alabama, which is warm enough for wet gas and oil in the cooler parts (Griffin and others, 1978).

Lower Cretaceous rocks are the most widespread and have the greatest volume of any Gulf Coast stratigraphic division. Depositional environments of Lower Cretaceous strata were favorable for the accumulation and preservation of vast amounts of hydrocarbon source material (Rainwater, 1970), including those within the lease planning area.

Analyses of core samples from oil and gas test wells in the South Florida basin (Fig. 19) by Palacas (1978) reveal carbonate rocks that contain greater than 0.4 percent organic carbon. These carbonate rocks are possible petroleum source beds in almost every subdivision of the Lower Cretaceous section (Fig. 20). Comanchean age carbonates are relatively richer in average organic carbon (0.41%) than those of Coahuilan age (0.20%) and Gulfian age (0.19%), and richer than those of Paleocene (0.20%) (Palacas, 1978).

Reconnaissance geochemical analyses were made of drill cuttings of Lower Cretaceous (pre-Punta Gorda) rocks in seven widely scattered deep wells in South Florida (Palacas and others, 1981). The results of that study suggest that the upper Pumpkin Bay Formation (upper Coahuilan) (Fig. 20) has argillaceous carbonate beds that are rated as good hydrocarbon source beds, particularly in the vicinity of the West Felda field and in the lower part of the Florida Keys (Fig. 19). The potential for oil-generating source beds in pre-upper Pumpkin Bay rocks is poor, but the potential for natural gas cannot be eliminated because of the reported gas show in the Wood River Formation at about 15,000 feet in the P-565B Phillips-Mobil 1-C Seminole well (Fig. 19) (Palacas and others, 1981).

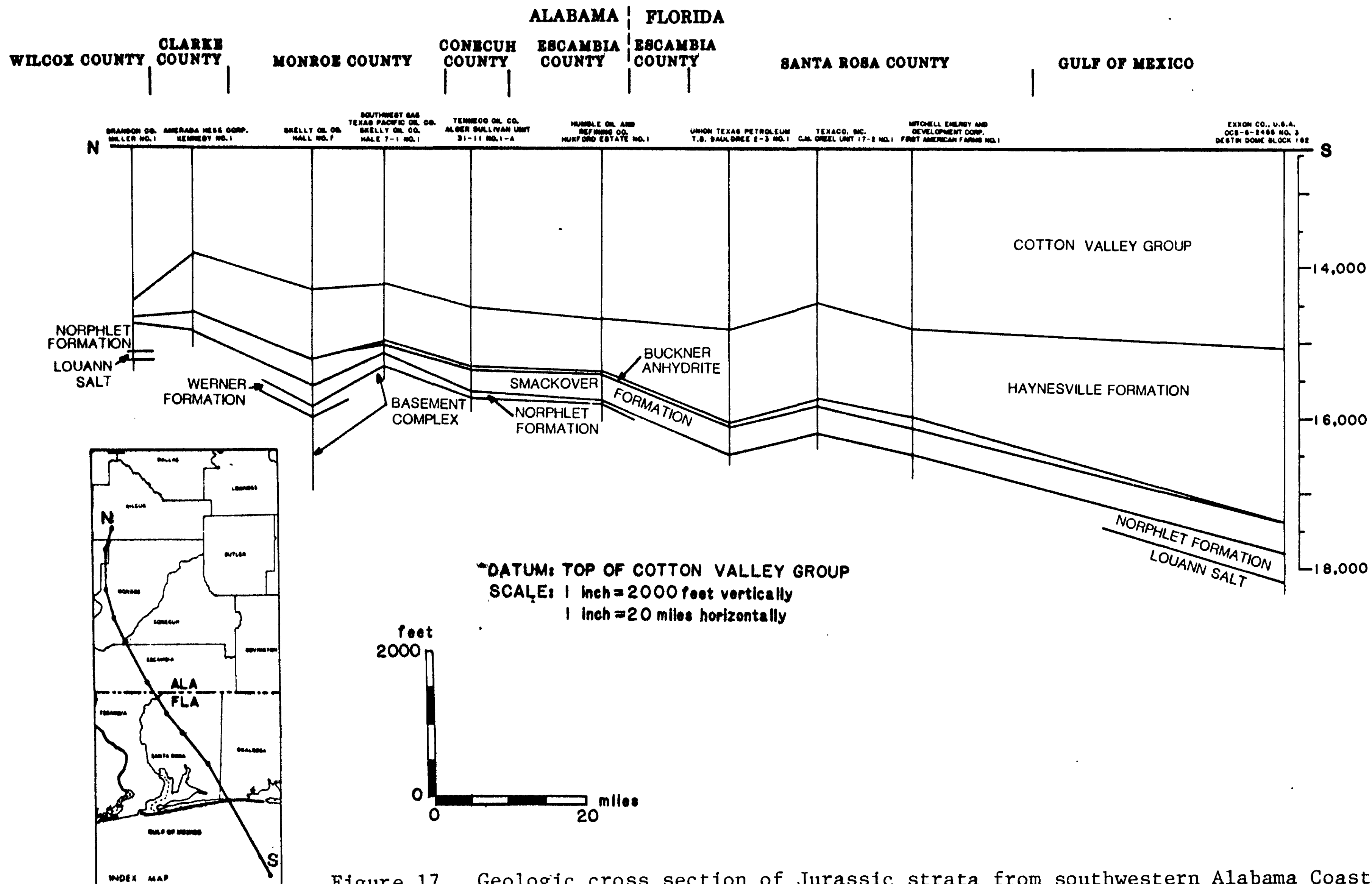

Figure 17. Geologic cross section of Jurassic strata from southwestern Alabama Coastal Plain to Destin anticline, offshore Florida (after Tolson, 1982).

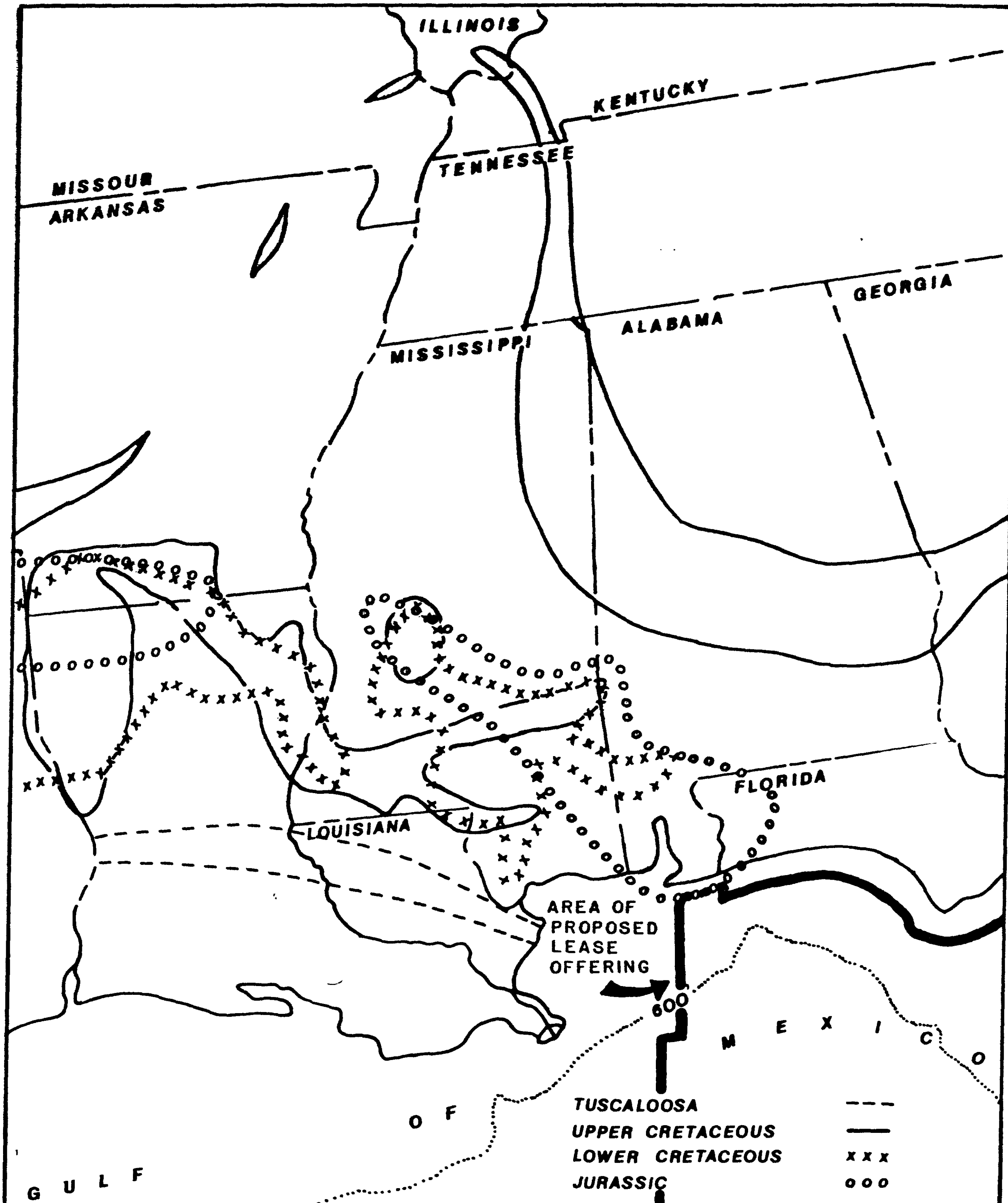

Figure 18. Map showing major oil and gas producing trends in Mesozoic strata, Texas to Florida (after Rainwater, 1968; Funkhouser and others, 1980; Foote and Martin, 1981).

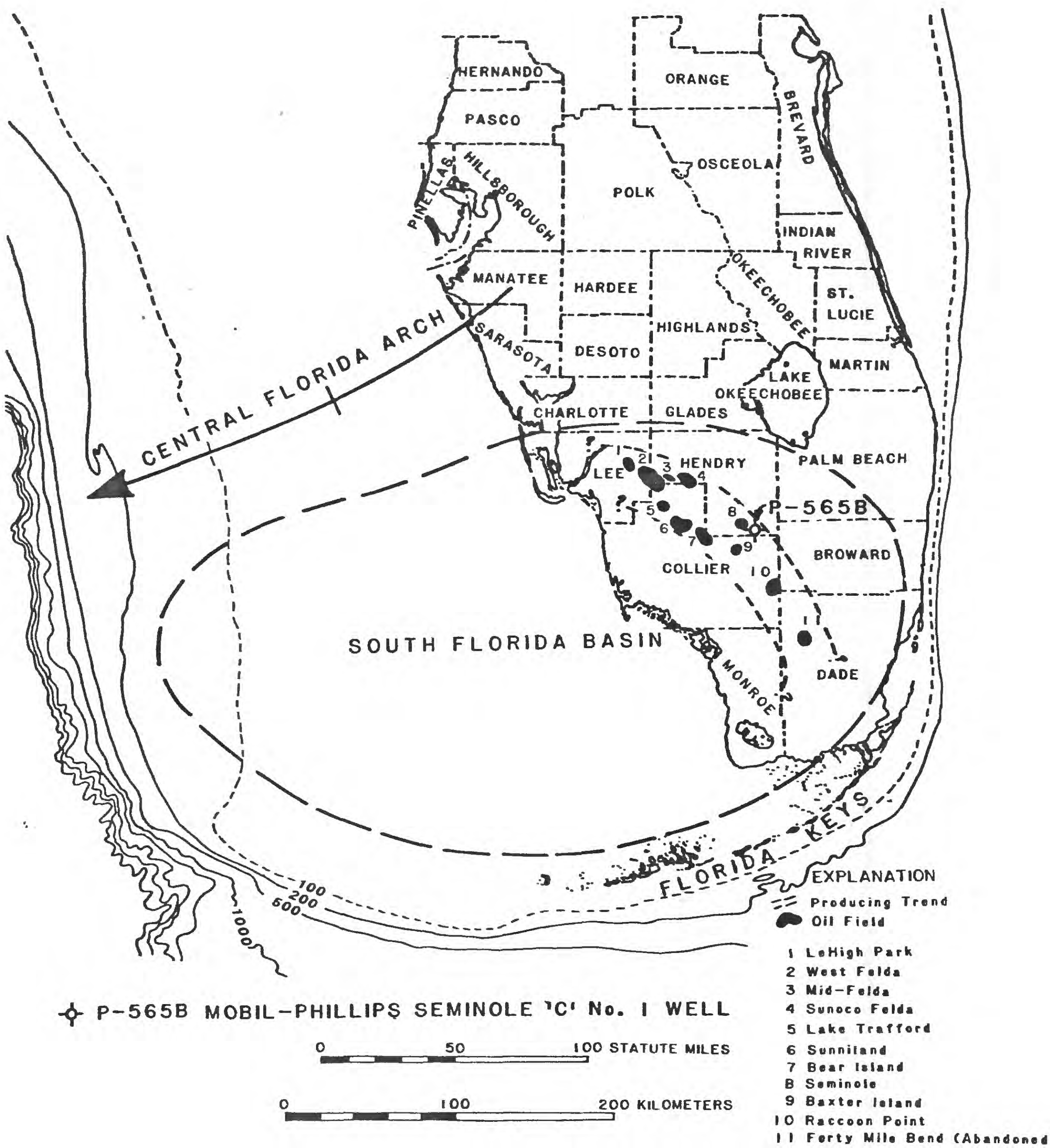

Figure 19. Map showing the oil and gas fields in Sunniland Formation trend, South Florida basin (after Palacas and others, 1981).

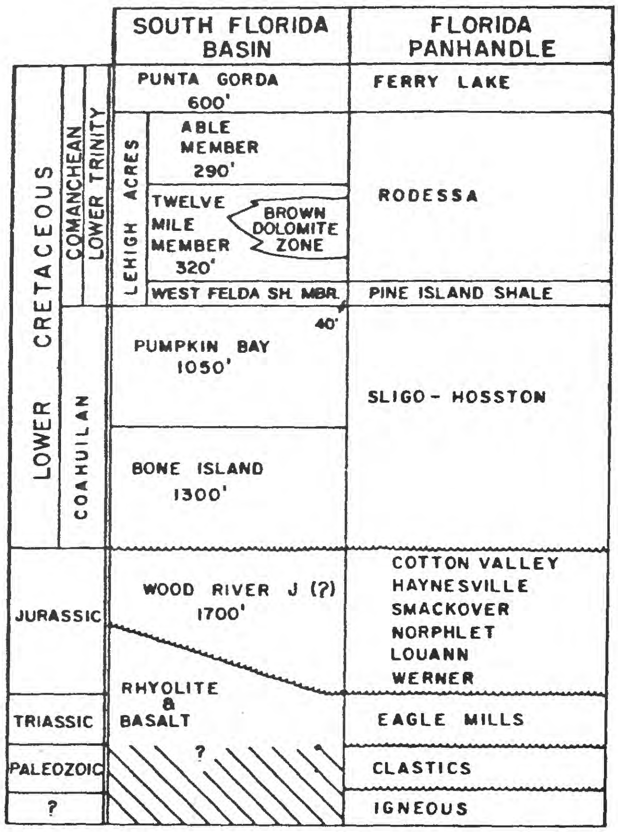

Figure 20. Stratigraphic column of pre-punta Gorda rocks of South Florida basin and stratigraphic equivalents in the Florida Panhandle (modified from Palacas and others 1981; Tolson and others, 1982).

Producing fields in the South Florida basin are associated with magnetic highs and structural arches on the northeastern rim of the basin. The potential of the central and western areas of the basin are untested and may prove more prospective. Source beds and hydrocarbon preservation may improve in the deeper portions of the basin particularly in those areas that were exposed to more frequent open marine conditions with improved preservation of source material (Sheffield, 1978).

Geochemical analyses performed by Palacas and others (1983) on selected core samples from DSDP Hole 535 (Fig. 5) show that the oil stains and associated asphalt or tarlike deposits in Lower Cretaceous limestones have a common origin and are not derived from the associated organic-rich limestones. Organic matter indigenous to the associated limestones appears to be thermally immature; the oil-stained and asphaltic material appears to be a relatively mature altered oil that has migrated up from source rocks deeper in the section or from stratigraphically equivalent, but different organic-rich source facies down dip from the drill site. Based on common biological marker compound distributions, the altered oil appears to be originally quite similar in composition to the Lower Cretaceous Sunniland crude oils produced in the South Florida basin (Palacas and others, 1983).

The Late Cretaceous (Fig. 3) was a time of world-wide transgressions when the continents sank and marine waters covered more of the earth's surface than ever before or since. Many large deltas were constructed through East Texas to Mississippi and Alabama during these transgressions. Seaward of these deltas, thick marine shales were deposited which served as source beds for many of the Gulf Coast basin Upper Cretaceous oil and gas reservoirs (Rainwater, 1968). These shales may be present in the eastern Gulf, particularly in the deep-water parts of the planning area.

Published geochemical analyses of Cenozoic-age (Fig. 3) samples from industry holes show that the organic-carbon content of sediments increases significantly from shallow to deep-water depositional environments in the Gulf of Mexico (Dow and Pearson, 1975). Therefore, the continental slopes, rises, and abyssal regions of the Gulf should be favorable sites for potential oil and gas source beds. Cenozoic strata in the Mississippi Fan and in the continental rise regions in the southwestern part of the planning area may be especially prone to biogenically generated methane gas (Foote and Martin, 1981).

Shallow Tertiary rocks of onshore and offshore Florida were deposited during minimal tectonic activity on a stable shelf and severe flushing by fresh to brackish water to depths of more than 3,000 feet (914 m) has occurred. The presence of these low salinity aquifers suggests that hydrocarbons probably were not entrapped and preserved in this zone. Minor oil shows have been encountered in Tertiary rocks and these "shows" may have been generated in deeper Cretaceous source beds (Sheffield, 1978).

Source beds to generate natural hydrocarbons are most likely present throughout most of the lease offering area. However, the thermal history of the area is not ideal and the minimum temperatures to generate hydrocarbons may not have existed in the Apalachicola, Gainesville and Tarpon Springs areas, offshore Florida.

SEALS AND TIMING

Cenozoic and Mesozoic shales and dense limestones serve as seals in producing oil and gas fields in the Gulf Coast basin. Generally, similar type shales or limestones should be present in the lease sale planning area to seal possible lower Quaternary, Tertiary, and Mesozoic reservoir rocks. Geological and geophysical evidence to support this hypothesis are presented below.

Favorable associations of reservoir rocks and seals are found in the Florida Panhandle, over the southwestern Alabama Coastal Plain and in State waters (see Figs. 21 and 22 for the locations of oil and gas fields in southwestern Alabama and Lower Mobile Bay, respectively). This reservoir/seal relationship most likely extends at least into the northwestern part of the lease sale planning area and possibly southeastward to the western entrance of the Florida Straits.

Geologic information from wells drilled on the Destin Dome Area and southeastward to the Charlotte Harbor Area suggest that dense limestones and shales are present throughout the lease offering area to serve as seals. There are serious questions, however, about timing of structural development in the Destin Dome Area relative to the generation and migration of hydrocarbons. A discussion later in this report will briefly focus on why it now appears that the Destin anticline (Fig. 11) may have developed too late in geologic time to entrap migrating hydrocarbons.

Timing does not seem to have been a major factor in the entrapment of oil and gas in the Sunniland Trend in South Florida basin because of the close proximity of source beds and reservoir rocks.

Cenozoic sedimentary units of clastic origin over the broader part of the Mississippi Fan and the eastern Gulf Diapir Field are considered to be well-layered alternating sands and shales, based upon their seismic characteristics and our geologic knowledge of depositional environments. Some of the shales in these sequences should, upon compaction, become effective seals. In addition, deep-water pelagic and hemipelagic sediments deposited in the region from Early Cretaceous through Pleistocene time should be effective seals where compacted.

Turbidite sandstones of Miocene, Pliocene, and Pleistocene age in the Mississippi Fan, should follow the normal pattern of turbidite deposits and grade laterally and vertically into marine shales consisting of very fine silts, clay minerals and other deep-water deposits. This pattern could result in a particularly favorable association of reservoirs and seals.

MESOZOIC RESERVOIR ROCKS

Jurassic

Jurassic reservoir rocks extending across the Gulf Coast Plain from southwest Alabama and the Florida Panhandle southeastward into the offshore area are lithofacies deposited in high to moderate energy environments on the flanks of structures, or over relatively deeper-seated anticlines, domes, and paleo-highs. They are primarily grain-supported textures consisting of grainstones, leached and dolomitized wackestones, packstones

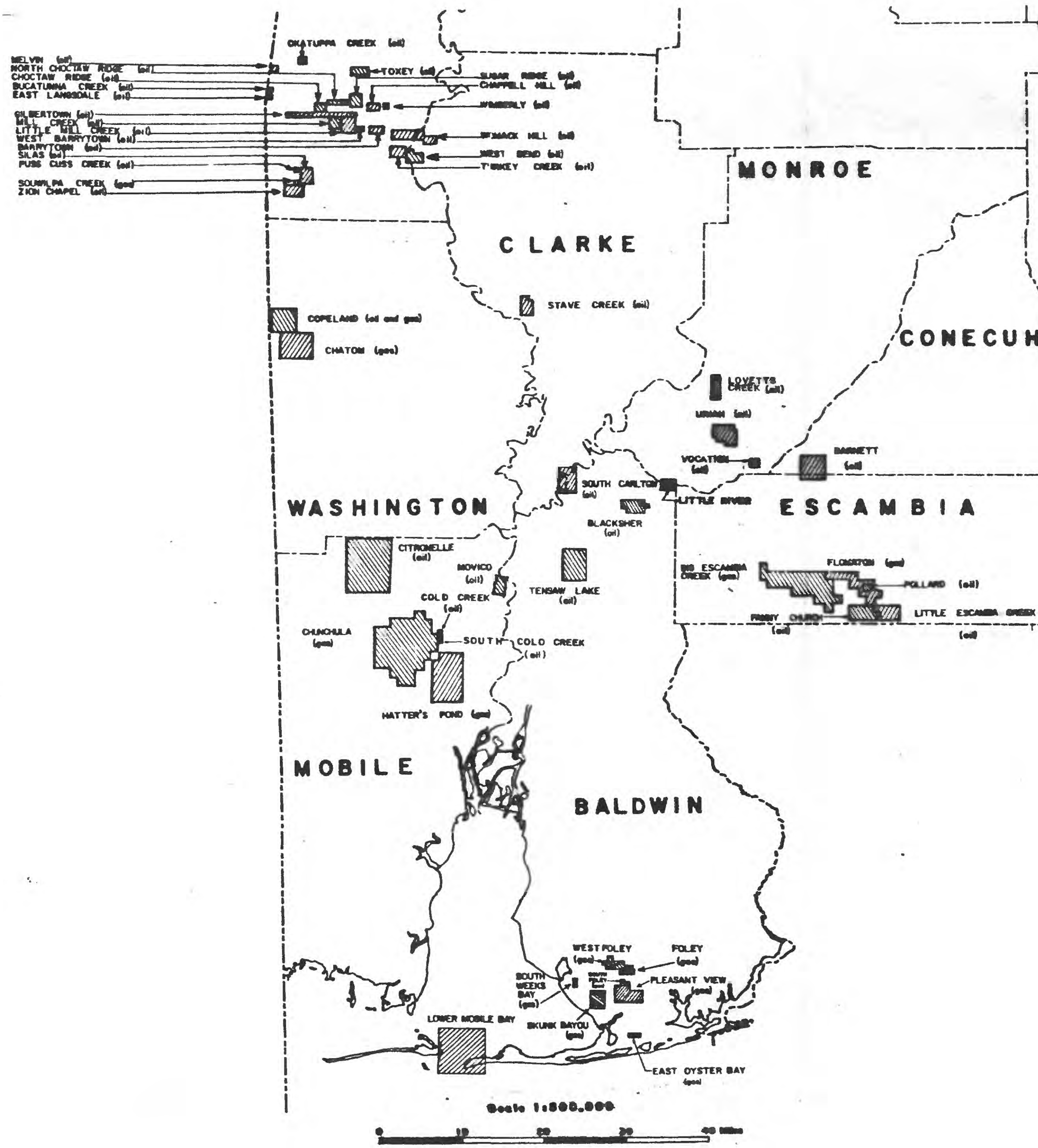

Figure 21. Map showing locations of oil and gas fields in southwestern Alabama (from Geological Survey of Alabama, 1983).

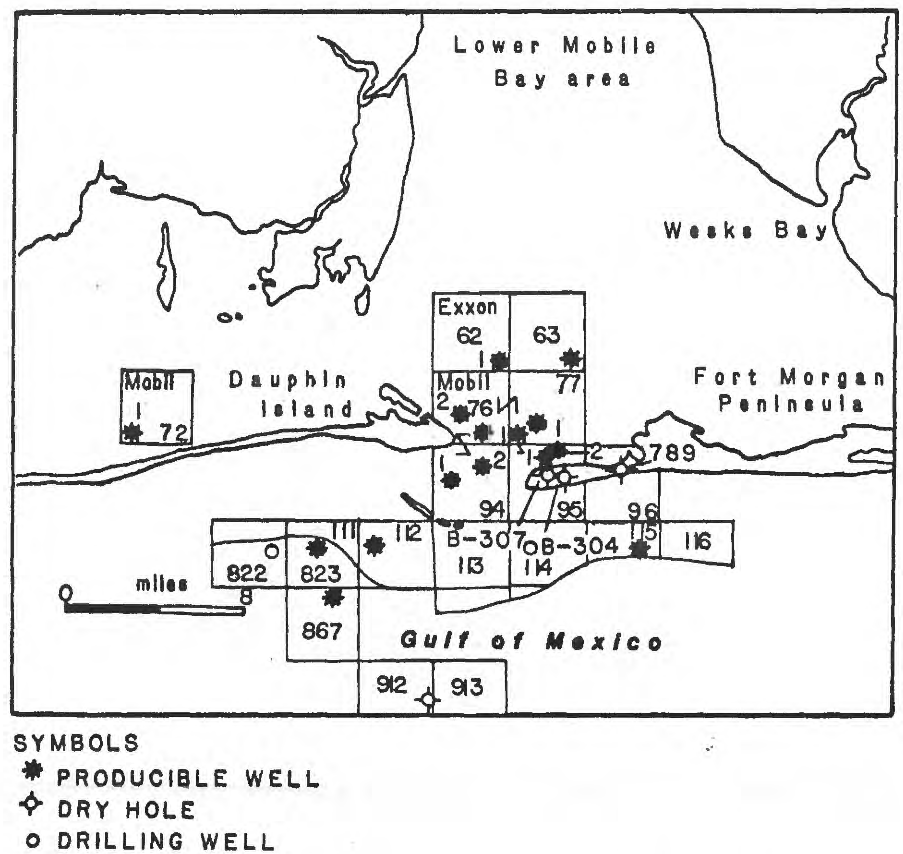

Figure 22. Map showing the locations of oil and gas wells in Lower Mobile Bay, Alabama (after Oil and Gas Journal, 1983; Geological Survey of Alabama, 1983).

and grainstones, dolomites, and occasionally mudstones. Porosity is facies selective. The primary interparticulate has been preserved or has undergone favorable diagenetic alteration. Dolomitization and leaching of reservoir rocks are critical for porosity enhancement by the development of intercrystalline dolomite or secondary grain moldic porosity; porosity can be reduced through concentration. Porosity includes primary interparticulate, secondary grain moldic, intercrystalline dolomite, vuggy, and fracture (Mancini and Benson, 1980).

Jurassic stratigraphic units in the subsurface of southwest Alabama, in ascending order, are the Werner Formation, the Louann Salt, the Norphlet, Smackover, Haynesville, and the Cotton Valley Formations (Fig. 17). These stratigraphic units range in age from Middle to Late Jurassic, with the Jurassic-Cretaceous boundary possibly occurring in the upper part of the Cotton Valley Formation (Tolson and others, 1982).

The Louann Salt is generally a termination point for oil and gas test wells. All of the Jurassic section above the salt can be considered to have potential reservoir rocks in the southwest Alabama Coastal Plain and in state waters offshore Alabama; these potential reservoir rocks probably extend across the lease offering area from the Pensacola Area to the Florida Keys.

The Norphlet Formation is overlain by the Smackover Formation with a conformable contact in some areas and it overlies the Louann Formation, Werner Anhydrite, Eagle Mills Formation, and Paleozoic basement in different areas with unconformable contacts (Pepper, 1982). The Norphlet Formation in the subsurface of southwest Alabama includes an updip conglomeratic sandstone, a discontinuous and localized basal shale, red beds, and an upper quartzose sandstone that constitutes most of the formation. Paleozoic ridges and paleo-highs, such as Conecuh Ridge and the Wiggins Arch (Fig. 23), were partially emergent and served as sediment source areas and depositional limits for the Norphlet Formation. Norphlet sediments were deposited in alluvial plain, braided stream, eolian, intertidal, and/or beach shoreface environments (Tolson and others, 1982).

The Smackover Formation extends from south Texas to western Florida and is entirely in the subsurface. Olsen (1982) describes the Smackover Formation as a lower member of carbonate mudstone facies deposited in a low-energy euxinic environment and an overlapping upper member of mostly grainstones and mudstones. Depositional environments of upper Smackover strata include updip a (1) backshelf and successively downdip, (2) shelf, (3) shelf slope, and (4) basin facies. The Smackover Formation is predominantly a lime mudstone, wackestone, or dolostone, and the upper part is generally a dolomitized limestone which accumulated in supratidal to subtidal environments (Tolson and others, 1982).

Upper Jurassic rocks on the Destin anticline overlie the Louann Salt and include the Norphlet, Smackover, Haynesville, and Cotton Valley Formations. Upper Jurassic sediments in the Jay Field (Fig. 24) are thinner than equivalent age strata over the Destin anticline indicating that Destin anticline sediments were deposited basinward from the Jay field.

Facies changes from carbonate to terrigenous clastic sedimentary deposits are commonplace in the Mesozoic-Cenozoic section of the

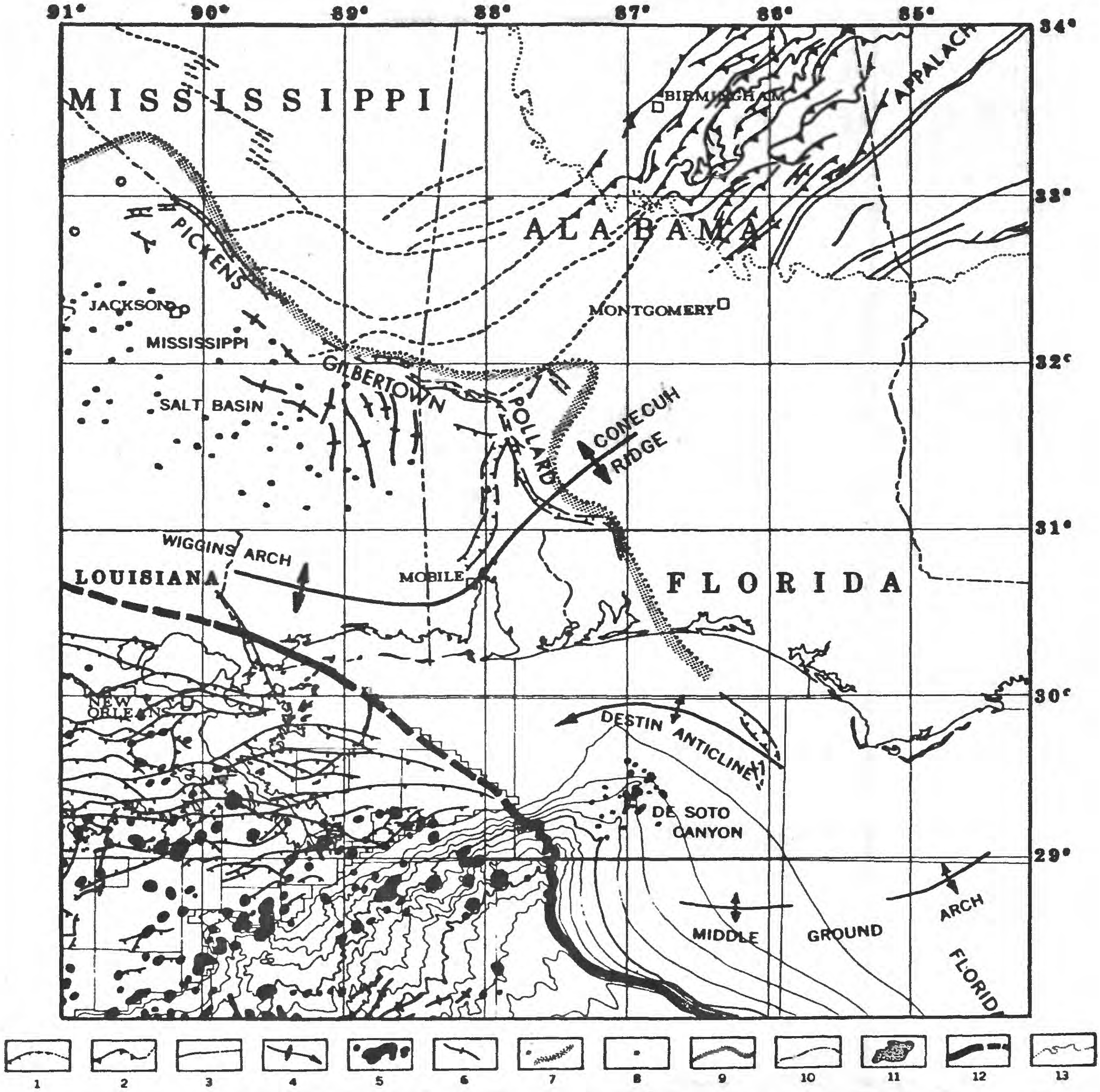

Figure 23. Tectonic map of northeastern Gulf of Mexico region. Explanation of patterns and symbols: 1) normal fault, 2) reverse fault, 3) fault of undetermined movement, 4) broad anticline or arch of regional extent, 5) salt diapirs and massifs, 6) salt anticlines and pillows, 7) shale domes and anticlines, 8) Mesozoic plutonic and volcanic rocks, 9) updip limits of Louann salt, 10) known downdip extent of buried Ouachita tectonic belt, 11) exposures of Paleozoic strata and Precambrian basement, 12) Lower Cretaceous shelf-edge reef system, and 13) inner margin of Cretaceous and Tertiary strata. Bathymetry in meters (200 m interval; scale approximately 1 cm = 120 km (modified from Martin, 1980; Tolson and others, 1982).

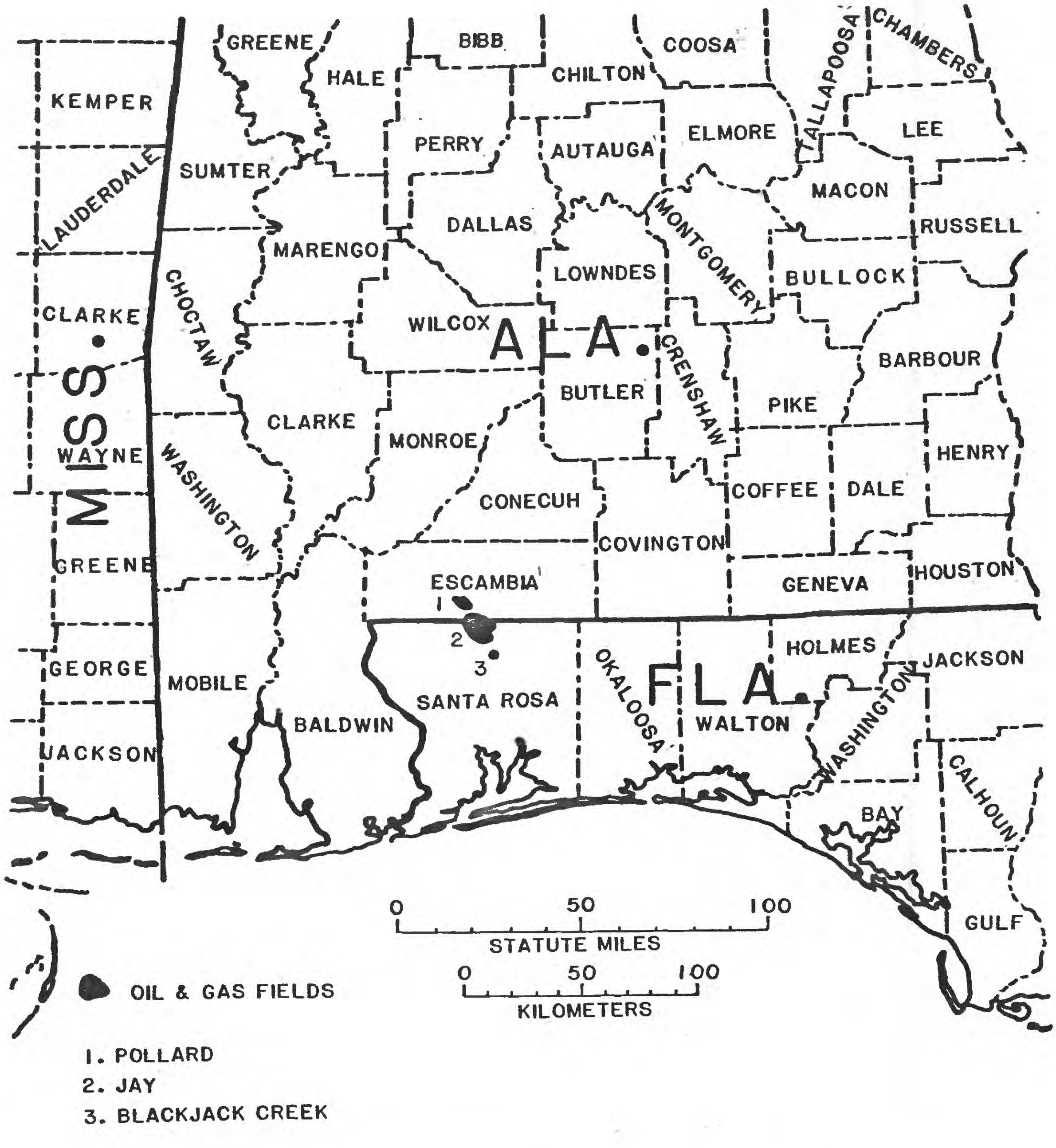

Figure 24. Map showing locations of oil and gas fields in Florida Panhandle and Escambia County, Alabama (after Geological Survey of Alabama, 1983; McCaslin, 1973).

northwestern Florida Shelf. In the Destin Dome Area, clayey shales and sands are more prevalent, interspersed with carbonates and evaporites. Toward the south, on the Middle Ground Arch, carbonate-evaporite content increases (Ball and others, 1983a).

On a local scale, transitions or terminations related to facies changes, erosion, or sediment-body geometries play a potentially important role in prediction of reservoir rock on the as yet uncondemned Destin anticline and on the untested deep structure 20 km (12 mi) south of the Destin anticline. The Exxon Block 162 No. 3 well (Fig. 2; Table 3) on the Destin anticline penetrated 20 m (66 ft) of quartz sand in the Norphlet Formation, in which porosity ranged from 20% to 30% and permeability was 1 Darcy (Ball and others, 1983a). This potentially excellent reservoir bed at a depth of about 17,140 ft (5225 m) is more than 490 ft (150 m) below the deep structural crest on the Destin Anticline. The Sun Exploration and Production Block 166 No. 1 well (Fig. 2; Table 3), east of the Exxon well, penetrated 20 ft (6 m) of oomoldic dolomite in the Smackover Formation having porosities of 13% to 15%; the test failed to find any Norphlet sandstone, as it bottomed in Louann Salt immediately below the Smackover Formation. Ball and others (1983b) speculate that the deep Destin anticline and the structure on its south flank are still viable exploration prospects.

The Buckner Anydrite Member at the base of the Haynesville Formation in southwest Alabama consists of massive anhydrite with interbedded finely crystalline dolomite deposited in supratidal environments and siliciclastics (Tolson and others, 1982).

The Haynesville Formation in southwest Alabama includes the uppermost record of evaporitic deposition and generally consists of siliciclastics and anhydrite and includes carbonate rocks. The Cotton Valley Formation at the top of the section was deposited in a paralic environment, and includes limestone, dolomitic limestone, fine to coarse-grained sandstones and shale (Tolson and others, 1982).

Lower Cretaceous

During Neocomian time, a basal sandstone unit was deposited across the entire Lower Gulf Coast region, onlapping Upper Jurassic sediments (Rainwater, 1968). A shallow epicontinental sea then advanced over the seaward parts of the eastern coastal plain and shallow-shelf carbonate rocks were deposited as the area slowly subsided. Deposition of carbonates alternated with regressive periods when the land masses to the west and north were uplifted and deposition of clastics exceeded subsidence. Lower Cretaceous sediments (mostly sand and shale) eroded from the southern Appalachians were deposited in the eastern Gulf Coast at irregular rates and are interspersed with carbonate deposits (Rainwater, 1968).

Depositional environments of Lower Cretaceous age were favorable for the formation of stratigraphic traps and for the development and preservation of many reservoir rocks (Rainwater, 1970). Oil and gas are presently being produced from Lower Cretaceous sandstones and carbonates along a trend from Texas to southwestern Alabama (Fig. 18). Each stratigraphic unit of Lower Cretaceous on the Gulf side of the producing trend has undiscovered oil and gas potential. Prospective reservoir rocks under the present-day continental shelf of Mississippi, Alabama, and Florida are deltaic and turbidite sandstones, carbonate reefs developed on the landward side of positive blocks, and shell zones. Lower Cretaceous rocks have favorable reservoir characteristics in various facies of the Sunniland limestone (Trinity age). Potential reservoir targets are also the Dollar Bay Formation (Fredericksburg age) and the "Brown Dolomite" of Trinity age (Fig. 25) in the Comanchian series (Sheffield, 1978).

In a study of the Sunniland Formation in the South Florida basin, Applegate and others (1978) noted that:
(1) Almost all of the effective porosity is on the northwest-southeast hingeline where reefal build-up in the upper Sunniland Formation has led to commercial oil accumulation.
(2) The presence of dark carbonates in the Sunniland Formation is necessary for the production of oil. All of these oil fields discovered to date lie in areas where dark carbonates make up from 30 to 60 percent of the total Sunniland section; where the dark-carbonate percentage is appreciably lower, the free-oil generating capacity is not present, and in the dark carbonates, oil is present but is trapped in impermeable non-porous micrites. (3) Total dolomite decreases rapidly both to the northeast and to the southwest from the hingeline. Dolomitization, which at least in part is believed to be secondary, appears to be important in furnishing the necessary porosity for production in some of the fields on the productive trend (Applegate and others, 1978).

Upper Cretaceous

The deep Tuscaloosa gas trend across south Louisiana (Fig. 18) is one of the most significant exploration areas in the U.S. in recent years. The trend is about 30 miles wide and over 200 miles long, extending from about the Texas line on the west, past Lake Ponchatrain and into Lake Borgne on the east. The Tuscaloosa reservoir sands are of Late Cretaceous age, and are overlain by the Eagleford Shale and the Austin-Taylor-Navarro chalk section (Fig. 25). Carbonates and shales of lower Cenomanian-Albian age underlie the Tuscaloosa section (Funkhauser and others, 1980).

The Tuscaloosa sands in the central Louisiana part of this trend are thought to have originated as clastics eroded from Lower Cretaceous sediments in North Louisiana and South Arkansas (Funkhouser and others, 1980). These eroded sediments were transported southward across the shelf and deposited as a series of deltas in an embayment formed by the Early Cretaceous bank edge. Localized sand development suggests that the deltas are of slightly different ages and reflect changing distributary systems. The deep Tuscaloosa sand trend extends southeastward across the Mississippi-Alabama Shelf and under the Continental Slope in the northeasternmost part of the planning area. In the Destin Dome Area, the Tuscaloosa section is quite variable in thickness ranging from a massive 50-foot (15 m) thick sandstone unit to a 1200 ft (366 m) thick section containing approximately 350 ft (107 m) of sand. The variation in thickness indicates depositional thinning updip along the flanks of the anticline. There are questions, however, whether these thinning beds will be present over large areas of the Florida Shelf and Slope and where the sediments grade into deep-water, non-reservoir type shales.

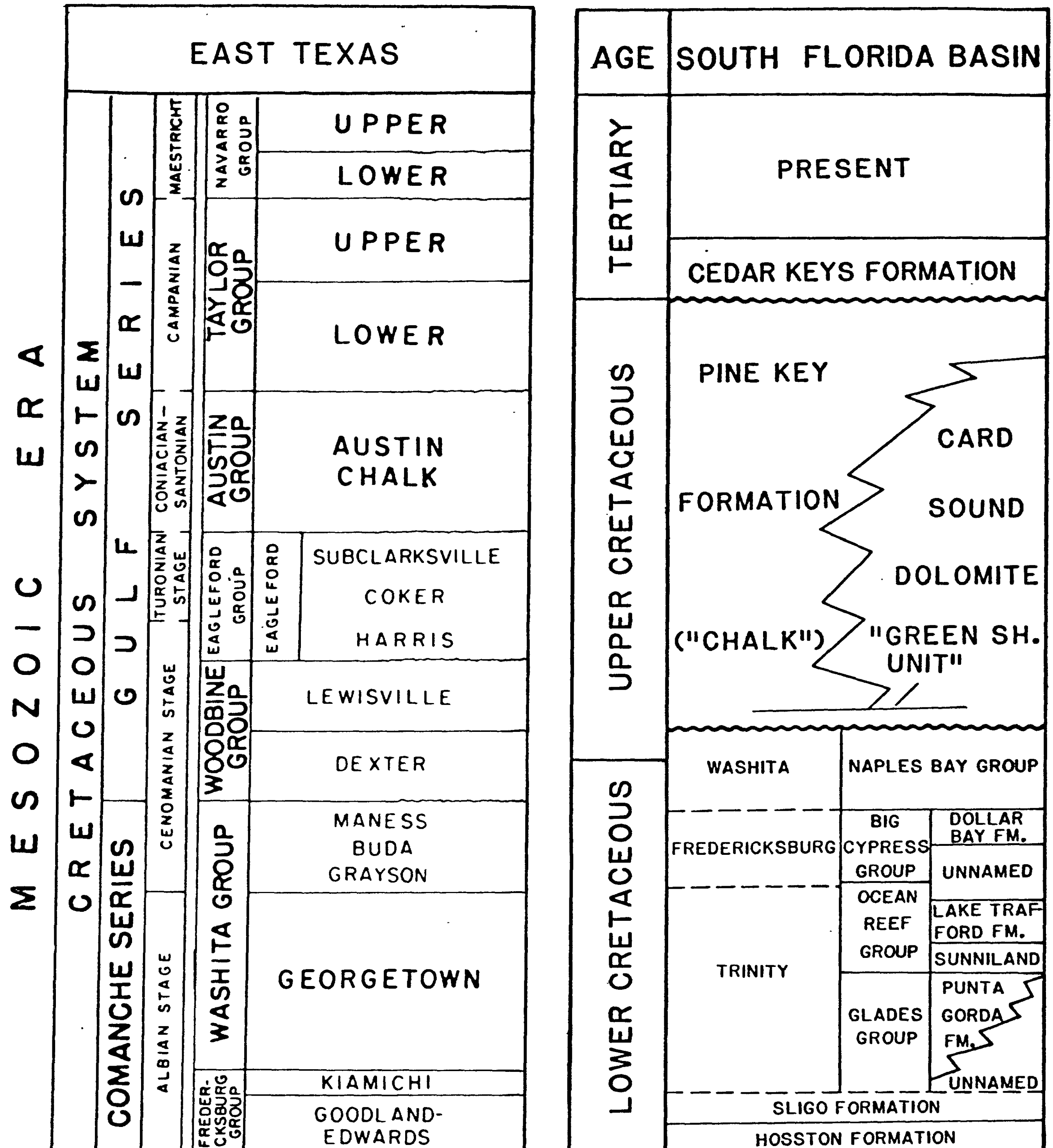

Figure 25. Stratigraphic columns of Cretaceous System rocks in East Texas and Cretaceous and Tertiary rocks in South Florida basin (from Turner and Conger, 1981).

CENOZOIC RESERVOIR ROCKS

Tertiary

Throughout Cenozoic time, the northwestern Gulf of Mexico basin received a massive influx of clastic sediments derived from northern and western sources that provide reservoir rocks on the Lower Gulf Coastal Plain of Texas and Louisiana and adjacent offshore regions. Three generalized depositional facies are recognizable in a seaward direction on the basis of sandstone percentages: continental, neritic, and deep-water bathyal (Thorsen, 1964; Norwood and Holland, 1974). Beginning at the outcrop and extending basinward, a complete sedimentary sequence consists of: (1) a continental, lagoonal, and deltaic facies of massive sandstone in which sandstones equal or exceed 40 percent of the sediment volume; (2) a neritic facies of interbedded sandstone and shale deposited in a continental shelf environment in which sandstone content ranges from 15 to 35 percent of the sediment volume; and (3) a bathyal facies, predominantly shale, deposited in continental slope and rise environments and generally containing less than 15 percent sandstone by sediment volume. The massive sandstone facies occurs along the paleo-shoreline and the age equivalent sandstone-shale and massive shale facies lie progressively seaward of it (Wallace and others, 1979). Because of progradation, this pattern of facies continued through time so that the sandstone-shale facies (reservoir rocks and seals) of one age are vertically stacked over older massive marine shales (source beds). The older and deeper sandstones can serve both as conduits for the upward passageway of oil and gas as it is expelled from the source beds and as reservoir rocks.

Oil and gas production from Cenozoic rocks in the northern Gulf basin can be related broadly to seven depocenters: Eocene, Oligocene, lower Miocene, middle Miocene, upper Miocene, Pliocene, and late Pliocene-Pleistocene (Foote and Martin, 1981). Because of changes in subsidence and salt and shale tectonics, there was a gradual northeastward shift of depocenters from south Texas to south-central Louisiana during Eocene through middle Miocene time. During this period, the continental shelf developed northeastward and prograded southward. From middle Miocene through Pleistocene time, there was a prominent shift of the depocenters to the southwest across the present shelf region.

Paleocene

At the beginning of the Cenozoic era, the north-central Gulf of Mexico was covered by a shallow sea; chalk, marl, and calcareous clays were deposited in open sea marine conditions (Rainwater, 1968). As the interior lands to the north emerged during middle Paleocene time, the fine-grained surficial sediments (Cretaceous marine shales) were eroded and deposited in the Gulf as clays and silts. The later stage of the Paleocene is represented by alternating sand and shale. These deposits were the first influx of coarse Tertiary sediments transported into the Gulf Coast basin as a result of the Laramide Orogeny in the Rocky Mountains and the uplift of the central plains. The coarser grained Paleocene sediments were deposited under the present day upper coastal plain and the fine-grained sediments toward the basin (Rainwater, 1968). The Paleocene section in the onshore portion of the South Florida basin has been reported to have oil "shows", but no commercial production has been found (Sheffield, 1978). The potential for Paleocene reservoir rocks in the planning area is, therefore, marginal.

Eocene

During the Eocene Epoch, and continuing to the present day, great quantities of coarse and fine-grained sand and clay were eroded, transported, and deposited in a generally subsiding Gulf Coast basin. There were alternating periods of transgressive and regressive seas in Eocene time giving rise to sands, silts, and clays in the central and western Gulf region and to clays, marls, and some limestones in the western part of the lease planning area (Rainwater, 1968).

Eocene and younger age rocks have favorable reservoir characteristics, but appear to lack effective seals and adequate source beds. Lower Tertiary carbonates have good permeability, porosity, and sealing cap rocks; however, adequate sources do not seem available or are not connected to these potential reservoirs (Sheffield, 1978).

Oligocene

Oligocene sediments were deposited on the western and northern flanks of the Gulf Coast basin as cyclic depositional units, which represented transgressive and regressive stages of deposition. These depositional cycles were caused by variations in sediment supply and subsidence. It has generally been accepted that the area of maximum development of Oligocene sands parallel the south Texas shoreline and represent a thick bar sand or barrier island environment which separates the Frio sandstones from thick marine shale (Halbouty, 1967). Reservoir rocks in Hackberry equivalent facies and Oligocene slope deposits and deep sea fans may be present in the Texas and Louisiana Shelf regions (Foote and Martin, 1981) but these deposits do not extend eastward into the lease sale planning area.

Miocene

At the end of Oligocene time, the depocenters shifted northeastward into Louisiana where the ancestral Mississippi River began to supply large quantities of sand, silt, and mud. In each Miocene depocenter, sediments were deposited on deltas and further distributed gulfward and laterally across broad shelf areas by marine currents (Shinn, 1971). Three major facies migrated gulfward throughout upper Miocene and Pliocene times and represent persistent and laterally uniform sedimentary environments.

In southern Louisiana depocenters, Miocene deposits exceed 20,000 ft (6,096 m) in thickness (Rainwater, 1968) and have almost ideal source beds, reservoir rocks, structural-stratigraphic traps, and reservoir seal arrangements.

The productive trend of Miocene strata extends from the Rio Grande, across Texas and Louisiana to Alabama (Fig. 26). Recently, significant gas discoveries have been made in Miocene strata in Lower Mobile Bay (Fig. 22). (Mancini and Mink, 1985).

Analyses of samples from DSDP holes and seismic data indicate that the distribution of sediments in the deep Gulf of Mexico was profoundly

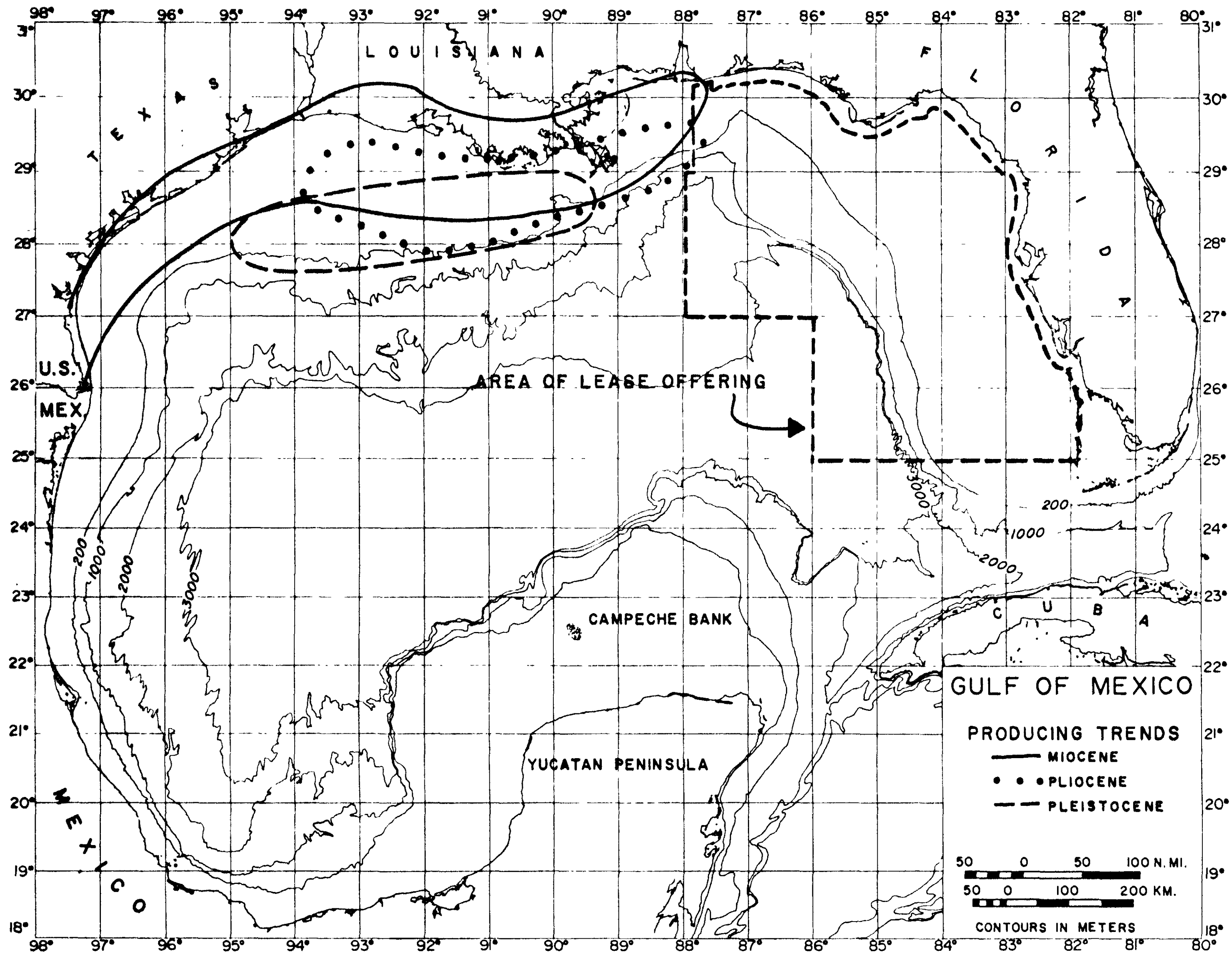

Figure 26. Map showing oil and gas producing trends in Miocene, Pliocene and Pleistocene strata, northwestern Gulf of Mexico (after Rice, 1980; Foote and Martin, 1981; Mancini and Mink, 1985).

influenced by turbidity currents and that coarse-grained turbidite sands with grain size suitable for reservoir rocks were probably deposited in the western part of the deep Gulf from middle Miocene (or older) to Pleistocene time (Foote and Martin, 1981). Most Miocene sediments in the deep Gulf are interpreted as having their source to the west, mainly the Rio Grande Embayment, based upon sediment color, grain size, thickness, and volcanic ash content. The coarser-grained proximal deposits are in deeper-water parts of the continental slope east of the Rio Grande and in the northwestern part of the abyssal Gulf. The finer grained sediments were transported eastward and may interfinger with Miocene sediments transported south and southwestward from the ancestral Mississippi River. Deposits of Miocene age appear to be especially well stratified throughout the deep basin and are presumed to consist of alternating layers of sandstone and shale. It is uncertain, however, whether reservoir quality rocks are present in Miocene strata on the eastern part of the Mississippi Fan.

Pliocene

Pliocene strata represent a continuation of the depositional regime established in the Miocene. The area of maximum sediment accumulation lies on the middle and outer shelf off central and eastern Louisiana and stretches westward from the Mississippi Canyon into the South Marsh Island Area. The productive trend of Pliocene strata extends in a wide belt from the east side of the Mississippi Delta westerly across the shelf into the East Texas OCS (Fig. 26). Downdip, Pliocene strata are productive beneath producing Pleistocene reservoirs in the Pliocene-Pleistocene trend located mainly off western and central Louisiana (Foote and Martin, 1981).

Pliocene and Pleistocene strata compose the upper sequence of the deep Gulf basin and represent a profound change in the general depositional character from Miocene sediments as a result of huge sediment volumes that were delivered to the east-central Gulf from northern glaciated regions in the continental interior (Foote and Martin, 1981).

In the east-central Gulf, the dominant physiographic feature is the Mississippi Fan, a broad sedimentary apron that transcends both bathyal and abyssal water depths. The Pliocene-Pleistocene sequence in the upper Mississippi Fan is characterized by relatively complex internal stratigraphy changing to relatively uniform bedding in the lower fan. Seismic data in the upper fan suggests numerous deep canyons and channels that were subsequently filled (possibly with sand), overbank deposits, facies proximal to sand sources, and slump and debris flow deposits. The middle fan appears to be a complex of interlocking channels dispersed over a large area. These channels are probably filled with sands and hemipelagic deposits. Reservoir rocks are most likely present in the eastern part of the deep Gulf as part of the upper and middle Mississippi Fan complex. Reflection characteristics suggest a preponderance of fine-grained silts and clays with few sands in the western sector of the lower fan, a greater likelihood of turbidite sand horizons interbedded with silts and clays in the southeast, and diffuse zones indicative of fine-grained debris flow deposits toward the west. The distal deposits from the Mississippi Fan were probably spread southwesterly over a large part of the deep Gulf, but are dominantly of fine-grained material and probably have less favorable reservoir-rock qualities (Foote and Martin, 1981).

Quaternary

Pleistocene

The Pleistocene sedimentary sequence represents a continuation of the upper Miocene-Pliocene depositional environments and, although there were numerous short transgressive and regressive sedimentary cycles, the section represents an overall regression (Powell and Woodbury, 1971). Alluvial deposits of Pleistocene age outcrop all along the rim of the northern Gulf basin.

The Pleistocene depocenter lies along the shelf edge south of Louisiana where Powell and Woodbury (1971) estimate more than 10,000 ft (3,048 m) of middle and Late Pleistocene sediments have accumulated. Offshore wells within the depocenter have penetrated as much as 15,000 ft (4,572 m) of shallow-water Pleistocene deposits underlain by an unknown thickness of deep-water clay (Lehner, 1969). The total thickness of Pleistocene deposits in the depocenter offshore Louisiana may exceed 20,000 ft (6,096 m). Uppermost Pleistocene deposits, generally within 600 m (2,000 ft) of the seafloor, are composed almost entirely of continental and deltaic facies and are not considered favorable for hydrocarbon production (Powell and Woodbury, 1971).

Potential reservoir rocks on the Upper Mississippi Fan might be expected in Pleistocene sands that may be present in sand-filled canyon and deep-sea fan deposits occurring in an otherwise very fine grained sequence.

STRUCTURAL AND STRATIGRAPHIC TRAPS

The regional structure of the area proposed to be offered for lease consists of a series of basins and ridges (Fig. 11). The lease sale planning area contains a variety of structural and stratigraphic features that could entrap oil and gas, such as: anticlines and faulted anticlines formed by deep-seated salt domes and ridges, and salt pillows; structural closures against normal faults and growth faults, and a variety of stratigraphic traps. Stratigraphic traps probably occur in sands onlapping salt domes and ridges, anticlines, in facies changes from sands to impermeable shales in updip directions, and at angular unconformities. Combination traps, such as reefs, are also possible.

Continental Shelf

In the Alabama and Florida Continental Shelf portion of the lease sale planning area, prospective oil and gas traps are primarily in extensions of Cretaceous (including the Tuscaloosa Formation) and Jurassic trends that produce onshore and Miocene sands in Lower Mobile Bay. Productive traps in the onshore trends are: the updip portion of the wedge of sediment where the sands or porous carbonates pinch out or truncate updip; anticlinal structures developed on the downthrown side of large growth faults and over deep-seated salt domes and pillows; and, very subtle fault closures. For example, in the Mississippi Interior Salt basin of southwest Alabama, petroleum traps are primarily salt anticlines or faulted salt anticlines. In the Florida Panhandle, oil and gas in the Jay Field is mainly trapped by a combination of extensional faulting and salt movement.

To the southeast, the trapping mechanisms in the Manila Embayment are domal paleo-highs. Toward Mobile Bay, a moderate relief salt anticline and a faulted salt anticline associated with salt movement along the west side a fault system are trapping mechanisms for the Chunchula and Hatter's Pond structures (Fig. 21), respectively.

Northwest Florida (Alabama/Florida) Shelf

The Destin anticline is a northwest-southeast trending anticline that is 50 mi (80 km) long, 12 mi (20 km) wide and has more than 1000 m (3,280 ft) of relief on Lower Cretaceous rocks (Ball and others, 1983a). The dome appears to be formed over a salt swell in an area that has been identified as Destin Dome Salt Pillows (Fig. 8). An extensive fault system is present on the northeast (landward) flank of the dome (Fig. 11) and it is probably an extension of the Pickens-Pollard Graben System (Fig. 23).

Most of the structural growth occurred during Late Cretaceous and Tertiary time; maximum structural closure appears to be on Late Cretaceous horizons. Lower Cretaceous and Jurassic strata do not appear to converge over the crest of the dome. The gradual thickening of Upper Jurassic sediments to the southwest across the crest of the dome also provides evidence that the structure formed after deposition of Lower Cretaceous and Jurassic sediments. Structural crests of Lower Cretaceous and Jurassic strata are about 500 ft (150 m) higher than in the previously leased area to the east. The deep Exxon test on Destin Anticline penetrated 66 ft (20 m) of quartz sand in the Norphlet Formation in which porosity ranged from 20% to 30% and permeability was 1 Darcy. The existence of this potentially excellent reservoir bed about 500 ft (150 m) below the deep structural crest on the west indicates that the Destin Anticline is still a viable exploration target (Ball and others, 1983b). Other salt swells with Jurassic and Early Cretaceous growth are present in the Apalachicola Embayment.

The Destin anticline is within an embayment that extends across the Florida Panhandle, the northwestern Florida Shelf and Slope and into the deep waters of the DeSoto Canyon. The Suwanee basin (Fig. 11) is the name applied to the more easterly portion of this feature; the westerly part of the embayment is a salt basin containing both swells and piercement structures (i.e. the Destin Dome Salt Pillows and the DeSoto Canyon Diapir Fields) that have not been drilled, but are prospective. Potential traps may be present in the anticlines developed on the downthrown side of large growth faults and in very subtle fault closures.

Middle Ground Arch

A major facies change from primarily clayey sands and shales to increased carbonate-anhydrite occurs between the Apalachicola Embayment and the Middle Ground Arch. Jurassic strata onlap Paleozoic rocks on the Middle Ground Arch, indicating that this feature is a pre-Jurassic erosional high (Ball and others, 1983b). Structural traps and stratigraphic traps in Jurassic strata onlapping Paleozoic metamorphic rocks around the western edge of the Middle Ground Arch are possible exploration targets.

The southeast side of the Middle Ground Arch dips into a structural depression, the Central Florida Trough.

Central Florida Trough

The central Florida Trough (Fig. 11) (Ball and others, 1983b) is a westward plunging basin in which sediment thickness of pre-Middle Cretaceous rocks is more than 16,400 ft (5000 m) under the edge of the Florida Scarp (Buffler and others, 1980). Prospective exploration targets are structural traps and Jurassic and Lower Cretaceous strata onlapping Paleozoic igneous and metamorphic structures.

South Florida Basin

The South Florida basin covers about 75,000 sq mi (194,235 sq km) of the larger Florida-Bahama Platform province. The geological boundaries that define the basin are: the Peninsula Arch and the Martin High to the east and northeast; the central Florida Arch to the north and northwest; the Florida Escarpment which coincides with the Lower Cretaceous Shelf Margin to the west; and the Largo High and Pine Key Arch to the south and southeast (Sheffield, 1978).

The productive trend of Lower Cretaceous Sunniland Formation extends for about 145 miles across the basin; the average width is 12 miles. Eleven oil fields have been discovered in this trend. Tables 4, 5, and 6 summarize some important oil and gas statistics of the fields. Depth of production ranges from about 11,320 to 11,890 ft (3,450 to 3,624 m). The low gravity of the oil (25° to 26° API gravity) and the low gas-oil ratio (100 cubic feet per barrel or less) are probably the result of oil being generated near the low temperature limit required for oil formation.

The producing fields are associated with magnetic highs and noses on the northeastern rim of the basin. The producing trend has the most effective priority on a northwest-northeast high-energy reef-forming hingeline. The reefal build-up separates shallow water low-energy chalky type beds to the northeast from quiet deep-water micrites to the southwest of the producing trend (Applegate and others, 1978).

The potential of the offshore areas of the basin are not fully tested and could prove prospective. Source bed and hydrocarbon preservation may improve the deeper portions of the basin particularly in those areas that were exposed to more frequent open marine conditions with improved preservation of source material (Sheffield, 1978).

Continental Slope and Rise

The West Florida Slope is characterized geomorphically by the depositionally smooth, gently sloping West Florida Terrace and the moderately inclined (35°) Florida Escarpment that extends uninterrupted from the DeSoto Canyon area in the north to the western entrance to the Straits of Florida (Martin, 1978).

The Florida Escarpment is a nontectonic constructional slope built by the vertical accumulations of shelf-margin carbonate sedimentary deposits

Table 4. Summary of Florida oil and gas fields[a]

Field	Discovery date	County	Production acres	Average formation (pay) thickness (ft)	Depth (ft)
Sunniland	9-26-43	Collier	2,080	22	11,570
Forty Mile Bend[b]	2-1-54	Dade	320	1	11,340
Sunoco Felda	7-22-64	Collier & Hendry	3,840	12	11,475
West Felda	8-2-66	Collier, Lee & Hendry	7,500	17	11,450
Lake Trafford	3-3-69	Collier	160	30	11,870
Jay (Florida only)	6-15-70	Santa Rosa	13,021	52	15,490
Mt. Carmel	11-27-71	Santa Rosa	481	39	15,120
Blackjack Creek	2-14-72	Santa Rosa	5,720	14	15,800
Bear Island	12-5-72	Collier	2,880	11	11,800
Seminole	11-14-73	Hendry	480	5	11,430
Lehigh Park	7-30-74	Lee	800	8	11,890
Sweetwater Creek	4-22-77	Santa Rosa	160	8	14,330
Baxter Island	8-11-77	Collier	160	3	11,510
Mid-Felda	10-13-77	Hendry	160	4	11,490
Raccoon Point	c/	Collier	c/	c/	c/
TOTAL PRODUCTION ACRES			37,762		

a/Data from State of Florida, State Geologist of Florida, February 1982
b/Abandoned
c/Data not available

Table 5. Crude oil statistics, State of Florida[a/] (thousands of standard stock tank barrels)

Field	Original oil in place	Gravity (°A.P.I.)	Estimated recovery factor	Original recoverable oil	Cumulative production	Remaining reserves
Sunniland	37,685.1[c/]	26	0.50	18,842.6	17,446.6	1,396.0
Forty Mile Bend	180.6	21	0.18	32.9	32.9[d/]	0.0[d/]
Sunoco Felda	32,368.4[c/]	25	0.38	12,300.0	9,868.2	2,431.8
West Felda	142,857.1[c/]	26	0.35	50,000.0	30,945.4	19,054.6
Lake Trafford	1,792.1[b/]	26	0.10	179.2	192.7	h/
Jay (Florida only)	763,129.6[e/]	51	0.42	320,514.4	276,388.1	44,126.3
Mt. Carmel	17,500.0[b/]	42	0.20	3,500.0	3,918.6	h/
Blackjack Creek	100,500.0[f/]	51	0.40	40,200.0	33,447.4	6,752.6
Bear Island	35,658.6[g/]	26	0.41	14,676.7	5,099.4	9,577.3
Seminole	1,354.1[b/]	25	0.20	270.8	84.8	186.1
Lehigh Park	23,373.8[b/]	28	0.40	9,349.5	2,836.4	6,513.1
Sweetwater Creek	624.1[b/]	45	0.10	62.4	13.7	48.7
Baxter Island	480.7[b/]	22	0.20	96.1	1.9	94.3
Mid-Felda	567.8[b/]	26	0.30	170.3	388.1	h/
Raccoon Point	h/	h/	h/	h/	5.8	h/
TOTAL	1,120,525.2			466,345.5	376,164.8	90,180.7

a/ Data from State of Florida, State Geologist of Florida, February 1982
b/ Used volumetric calculation procedure
c/ Extrapolated production decline curves
d/ Actual production; field abandoned
e/ From Hearing No. 39, December 4, 1974
f/ From Hearing No. 38, September 24, 1974
g/ From core data
h/ Data not available

Table 6. Natural gas statistics, State of Florida[a] (millions of cubic feet)[b]

Field	Gas-oil ratio[c]	Original gas in place	Original recoverable gas	Cumulative production	Remaining reserves
Sunniland	100	3,768.5	1,884.3	1,732.5	151,758
Forty Mile Bend	50	9.0	1.7	1.7	0.0
Sunoco Felda	80	2,589.5	984.0	869.1	115.0
West Felda	80	11,428.6	4,000.0	2,534.0	1,466.0
Lake Trafford	0	0.0	0.0	0.0	0.0
Jay (Florida only)	1,250	953.912.0	400,643.1	341,256.1	59,387.0
Mt. Carmel	1,000	17,500.0	3,500.0	3,885.3	d/
Blackjack Creek	910	91,455.0	36,582.0	30,010.9	6,571.1
Bear Island	80	2,852.7	1,174.1	389.0	785.2
Seminole	0	0.0	0.0	0.0	0.0
Lehigh Park	100	361.1	144.4	286.7	648.3
Sweetwater Creek	200	124.8	12.5	14.7	0.0
Baxter Island	0	0.0	0.0	0.0	0.0
Mid-Felda	53	30.1	9.0	8.2	d/
Raccoon Point	d/	d/	d/	0.0	d/
TOTAL		1,082,608.6	448,332.9	380,983.0	69,124.3

a/ Data from State of Florida, State Geologist of Florida, February 1982
b/ Standard cubic feet (SCF) of gas at 14.73 pounds per square inch and 60°F
c/ Standard cubic feet per standard tank barrel of oil
d/ Data not available

and reef growth during Early Cretaceous time. Deposition apparently was continuous, but slightly out of pace with incessant regional subsidence so that the shelf-margin environment, which the scarp represents, migrated landward to produce a moderately inclined slope rather than a vertical escarpment (Martin, 1978).

Samples of reef material from the scarp suggest that reef trends were contemporaneous in this area with those in the subsurface of Mexico, Texas, and Louisiana. It had been generally thought that rapidly increased subsidence rates along the eastern Gulf margin early in Late Cretaceous time caused reef complexes to drown and a deep water carbonate environment to be superimposed on the Lower Cretaceous outer-shelf platform. However, recent studies by Freeman-Lynde (1983) show that mid-Cretaceous limestones and dolomites sampled at five areas along the Florida Escarpment south of 27°05°N were deposited in peritidal and lagoonal environments under restricted, low energy conditions. The limestone lithologies are generally wackestone/packstone (lagoonal) and mudstone/wackestone (peritidal). Presumed mid-Cretaceous dolomites deposited in hypersaline bank interior environments were recovered from canyon walls incised from 6 to 19 mi (10 to 30 km) into the escarpment. Mid-Cretaceous samples of bioclastic rudistones and coral boundstones deposited in high energy environments were retrieved at a few sites. The lack of high-energy facies rocks indicates that the escarpment is an erosional feature, not just in the canyon reentrants, but at least south of 27°05°N (Freeman-Lynde, 1983).

Limestones of Late Cretaceous age and deep-water chalks ranging in age from Late Cretaceous through Pleistocene unconformably overlie and drape over the older shallow-water carbonates. Thus, the mid-Cretaceous platform drowned in Late Cretaceous age, resulting in the younger deep-water rocks.

DeSoto Slope

The DeSoto Slope lies between the eastern limits of the upper Mississippi Fan and the West Florida Terrace. The slope is underlain by a thick sequence of conformably bedded sediments that is arched by monoclinal folds and by numerous, isolated salt domes and pillows (Fig. 27) (Martin, 1980. Potential traps exist over and around these structural features.

Regional systems of growth faults which generally parallel the shelf edge have resulted from load imbalances caused by rapid sedimentation along Tertiary hinge lines (Sheffield, 1978). Anticlinal closures may be present on the downthrown side of many such growth faults (Fig. 23) and may be sites of hydrocarbon accumulations. Peripheral and radial systems of growth faults associated with salt pillows and anticlinal closures against these fault systems (Martin, 1980) would be prospective traps.

Mississippi Fan

Stratigraphic traps are most likely present in complexly bedded strata of Pliocene to Holocene age that overlie the Miocene and older Tertiary section in the Mississippi Fan and continental rise areas of the Abyssal Gulf basin. The Quaternary and uppermost Tertiary section is composed of (1) coalesced sedimentary aprons that were built seaward from the mouths of submarine canyons in the continental rise and complex channel-fill, slump, and apron deposits that form the Mississippi Fan in the eastern Gulf; and

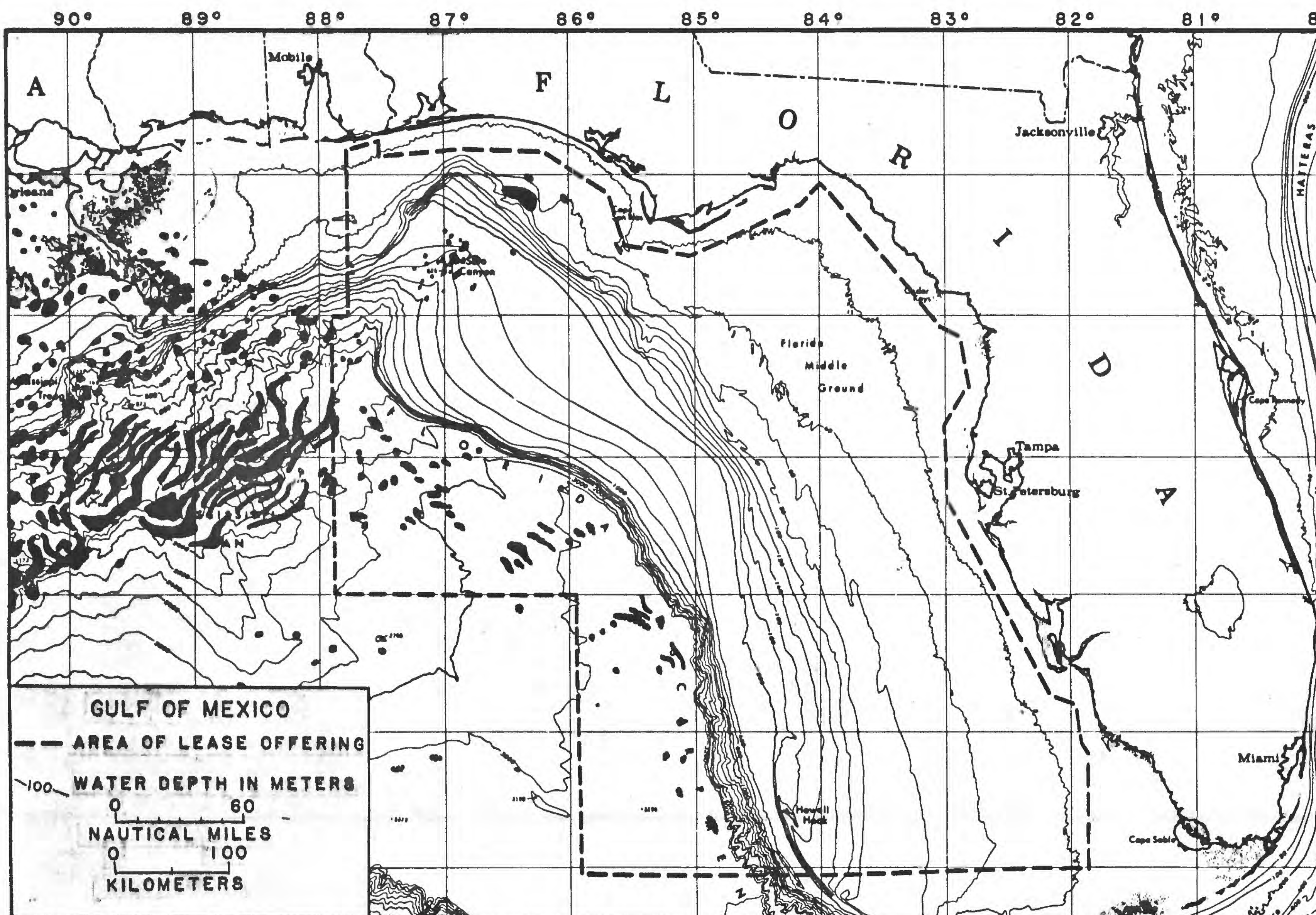

Figure 27. Map showing locations of salt structures in the eastern Gulf of Mexico. Salt structures include salt diapirs and massifs, salt anticlines and pillows. Some presumed salt structures in offshore Louisiana may be shale domes and anticlines and in the deep water of the eastern Gulf of Mexico, they may be paleo-highs of Mesozoic or Paleozoic metamorphic or igneous rocks (from Martin, 1980).

(2) near-horizontally bedded turbidite deposits that cover the Sigsbee Plain in the central Gulf basin. Cenozoic strata in the Mississippi Fan and in the continental rise regions of this area may be especially prone to biogenically generated methane gas (Foote and Martin, 1981).

The Gulf Coast Salt Dome Province extends into the western part of the lease offering area as the Eastern Gulf Diapir Field (Figs. 8,27). The salt domes and pillow structures in this field pierce or arch the sediments (Martin, 1980), resulting in generally circular and elongate anticlinal structures favorable for petroleum accumulation.

DISTRIBUTION OF OIL AND GAS ACCUMULATIONS

From the foregoing discussions, it is readily apparent that the producing trend of a particular age tends to coincide with the location of structural/stratigraphic traps and certain kinds of depositional environments. These associations of traps and depositional environments permit the classification of the planning area for the oil and gas lease offering into areas of geologic potential.

Areas of Geologic Potential

More favorable, favorable, and less favorable areas for the generation, accumulation, and preservation of crude oil and natural gas resources within the planning area were determined from synthesis of available subsurface geological information, oil and gas production figures, engineering data, seismic-reflection profile data, and data contained in published reports and articles. Consideration was given to the principal factors favorable or detrimental to the occurrence of oil and gas resources, and to the knowledge of the history of exploration and production in this region. Constraints that might impede exploration and development of offshore oil and gas resources, such as environmental, technological and economic factors, were not considered in this analysis.

The more favorable area is the region known to have a relatively high coincidence of structural features and stratigraphic conditions that favor the occurrence of petroleum resources in commercial quantities. The favorable area is the region where structural and stratigraphic factors generally favor the occurrence of oil and gas resources. The less favorable area of covers the offshore region where geologic conditions are generally unfavorable for the occurrence of petroleum resources, but where isolated, local accumulations are possible.

The more favorable area includes the continental shelf, except for Apalachicola, Gainesville, Tarpon Springs, and the eastern three-quarters of Florida Middle Ground Areas, and the continental slope portions of the planning area (Fig. 28).

The more favorable area on the inner shelf south of the Alabama-Florida coast and the mid/outer shelf to the center of the planning area is indicated on the basis of knowledge of the regional geologic setting of this area from geophysical and subsurface geologic data, and on the basis of recent petroleum discoveries in Upper Jurassic strata in the Lower Mobile Bay. Prospective targets in this area include stratigraphic traps in the Upper Jurassic section, particularly the Norphlet and Smackover Formations,

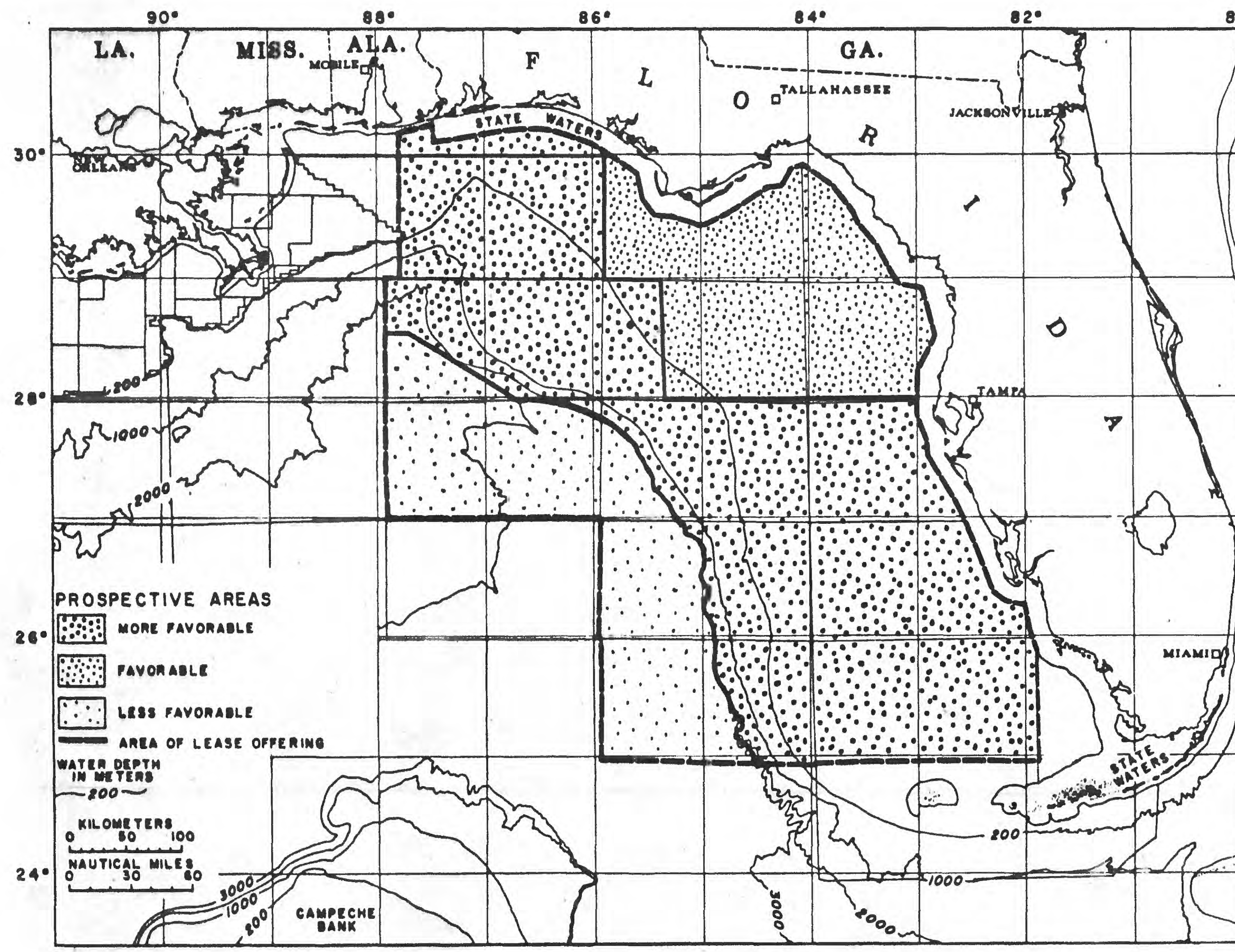

Figure 28. Map of planning area for proposed OCS Oil and Gas Lease Sale No. 94 showing areas of relative geologic potential for accumulations of hydrocarbons.

that onlap basement (igneous or metamorphic) rocks; in reefs and fore-reef talus zones of Lower Cretaceous Shelf Margin; in sands, such as the Tuscaloosa Trend, deposited on the upper slope of the Upper Cretaceous Shelf Margin; and facies changes (turbidite sands interfingering with bathyal shales) in the upper part of the east side of the Mississippi Fan. The northwestern part of the planning area may have substantial potential for the accumulation of major quantities of hydrocarbons in traps on numerous salt structures, and in structural closures in sedimentary anticlines associated with local and regional growth faults. Some of the larger structures on the shelf have been drilled with one or more wells, but smaller, untested structures remain to be explored. Future exploration objectives in the planning area may evolve toward these untested structures, as well as toward structural and combination traps in deeper waters.

In the southern-southeastern part of the more favorable area, combination traps, such as reefs and stratigraphic traps, appear to offer favorable targets. Reefs in Lower Cretaceous strata could be present on the inner and mid-shelf areas as offshore extensions of the Sunniland Trend. As noted earlier, it appears that the western edge of the mid-Cretaceous Shelf Margin has been eroded extensively south of latitude 27°N. The Lower Cretaceous Shelf Margin reefs in this area would also have been eroded, but prospective reef targets may be present to the northwest.

Stratigraphic traps may be present on the shelf in the southern part of the planning area, particularly in Upper Jurassic strata that onlap basement structures.

The area of favorable potential covers the Apalachicola, Gainesville, Tarpon Springs, and the eastern three-fourths of the Florida Middle Ground. The thermal gradients in this area do not appear to have been high enough to generate large quantities of hydrocarbons. Also, there are some structures present in the area but they are not sufficient in numbers and size to justify high resource potential classifications. There is limited oil and gas resource potential in stratigraphic traps of Upper Jurassic sediments in the western part of the area of favorable potential.

The area of less favorable potential covers the deep-water parts of the planning area. The primary reason for this classification is the lack of geologic, geophysical, and engineering data on the presence and characteristics of reservoir rocks, the possible lack of conduits for petroleum migration and structural/stratigraphic trap development after hydrocarbon migration. There are a number of major structural features in the deep waters of Lloyd, The Elbow, Vernon Basin, and Howell Hooks Areas. Other structural features appear to have only a minor degree of trapping potential.

The Cenozoic stratigraphic section consists principally of distal turbidite deposits and deepwater fine-grained muds that generally are not likely to contain widespread, suitable reservoir rocks. Suitable reservoir rocks are locally possible, however, especially in the northeastern part of this area where large quantities of sediments may have been delivered by massive turbidite flows.

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CHAPTER III

ESTIMATES OF UNDISCOVERED RECOVERABLE CRUDE OIL AND NATURAL GAS RESOURCES IN PLANNING AREA OF PROPOSED OCS OIL AND GAS LEASE SALE NO. 94

by

R. Q. Foote, R. H. Wells, and L. M. Massingill

INTRODUCTION

Undiscovered recoverable resources are those quantities of crude oil and natural gas which are estimated to exist in subsurface geologic settings in commercial amounts. Resource estimates for the northern Gulf of Mexico were assessed as a part of the study of the Nation's undiscovered recoverable conventional oil and gas resources (Dolton and others, 1981). In the Dolton resource assessment, the Gulf of Mexico was divided into two sub-regions: 1) the western Gulf which includes the Texas-Louisiana continental margin from shoreline to 2500 m (8202 ft) water depth, and 2) the eastern Gulf which includes MAFLA (Mississippi, Alabama, and Florida) continental margin to 2500 m water depth. Each sub-region was appraised in two water depth increments: 1) 0 - 200 m (656 ft), the continental shelf province, and 2) 200 m - 2500 m (656-8202 ft), the continental slope province. Lack of sufficient geological and other information was the main reason for not appraising the undiscovered recoverable oil and gas resources of the continental rise and abyssal plain regions beyond the 2500 m (8202 ft) water depth.

The planning area for proposed Lease Sale No. 94 includes the continental shelf and slope and deep water areas seaward from Alabama and west Florida boundaries. The deep water areas planned for inclusion in the lease offering extend from the 2500 m isobath to the western limits of Howell Hook, Vernon Basin, DeSoto Canyon, and Lloyd OCS areas (Fig. 1). The southwestern part of the planning area encompasses the easternmost tip of the Maritime Boundary region (Fig. 5).

ASSESSMENT PROCEDURE

Estimates of undiscovered recoverable oil and gas resources for the lease offering area were made by using direct subjective probability methods as described in detail by Miller and others (1975), Dolton and others (1981), and Crovelli (1981). Volumetric yields from known producing basins, such as Salinas basin and the Palo Duro basin, were used in the analysis as analogs to determine scaling factors for the eastern Gulf of Mexico. Arbitrary volumetric yields from the total United States (an average, a high, and a low value) were also used as scaling factors in the analysis. Extrapolations of more maturely explored parts of the basin into less explored parts and of onshore finding rates were also employed in these areas.

Each province is first assessed separately for its potential as to whether it contains: 1) any recoverable quantity of oil, and 2) any recoverable quantity of non-associated natural gas. These events are expressed in terms of probability on a scale of 0 to 1.0, and are called the marginal probability (MP). In a frontier area, such as the eastern Gulf of

Mexico where oil and gas production has not yet been established, the marginal probability (MP) for both oil and gas is less than 1.0. On the condition that commercial hydrocarbons exist, the volumes of undiscovered hydrocarbons were expressed at two probability levels; a low probability at the 95th fractile (F_{95}) and a high probability at the 5th fractile (F_5). In addition, a modal or most likely value was estimated. These conditional estimates of volumes of undiscovered oil and non-associated gas were expressed as individual subjective judgments. The associated-dissolved gas was calculated from the initial estimate of crude oil by using the gas/oil ratio (GOR) for each province (Dolton and others, 1981).

A lognormal distribution was fitted using initial low, high, and modal estimates to determine the conditional probability distribution for each province. By applying the marginal probability to the conditional probability distribution, the unconditional (risked) probability distribution of the quantity of undiscovered resource was estimated.

The mean estimates of undiscovered oil and total gas (non-associated and associated-dissolved) resources for the eastern Gulf sub-region were allocated on a percentage basis to each province in the lease planning area. The allocation percentage was calculated from the oil and total gas resource distribution for three zones of favorability (Fig. 28) - 1) area of more favorable potential, 2) favorable potential, and 3) less favorable potential - based on geologic conditions and hydrocarbon richness factors. The allocation percentage was applied to each province conditional estimates at the F_{95} and F_5 probability and a new lognormal distribution fit was established for the shelf (seaward from the state boundary to 200 m) part, and for the slope (200 m - 2500 m) part of proposed offering. Aggregations for the total area (shelf and slope to 2500 m) were made by a Monte Carlo technique.

The Gulf Coast basin has accumulated more than 60,000 ft (18,200 m) of sediments offshore Louisiana; however, estimates of resource potential in the Gulf Coast basin are restricted to 30,000 ft (9 km) depth (Dolton and others, 1981).

RESOURCE ESTIMATES

Estimates of undiscovered recoverable crude oil and natural gas for the continental shelf and slope in the area of lease offering are shown on Table 7. Total estimated undiscovered recoverable resources in the planning area range from 0.22 to 3.98 billion barrels of oil (BBO) and from 0.21 to 3.23 trillion cubic feet (TCF) of gas. The mean estimate for oil is 1.53 BBO and the mean for gas is 1.58 TCF. The planning area covers 92,515 mi^2 (239,622 km^2); water depths range from less than 10 m (33 ft) to more than 3,295 m (10,810 ft).

As noted previously, estimates were not made, however, for deep-water (more than 2,500 m, 8,202 ft) portion of the planning area. A variety of evidence, such as large structures, favorable source beds, and thermal maturation, suggests that conditions exist for the occurrence of crude oil and natural gas in the deep-water areas. An evaluation of the petroleum potential and estimates of undiscovered in-place oil and gas resources were made in a special study of the Maritime Boundary region in the Gulf of Mexico by Powers (1981). Estimates of undiscovered recoverable petroleum

Table 7. Summary of estimates of undiscovered recoverable oil and gas resources in the planning area of proposed OCS Oil and Gas Lease Sale No. 94, eastern Gulf of Mexico

	Unconditional estimates 1/			Marginal probability	Conditional estimates 5/		
	Low 2/ F_{95}	High 3/ F_5	Mean 4/		Low 2/ F_{95}	High 3/ F_5	Mean 4/
Crude oil (billions of barrels)							
Shelf (to 200 m)	0.00	3.28	0.93	0.58	0.51	3.89	1.60
Slope (200-2500 m)	0.00	0.65	0.14	0.29	0.11	1.08	0.50
TOTAL - - - - -	0.00	3.52	1.07	0.70	0.22	3.98	1.53 6/
Natural gas (trillion cubic feet)							
Shelf (to 200 m)	0.00	2.72	0.91	0.77	0.24	3.00	1.18
Slope (200-2500 m)	0.00	0.95	0.45	0.44	0.08	1.39	1.03
TOTAL - - - - -	0.00	3.07	1.36	0.87	0.21	3.23	1.58 6/

1/ The resource estimates are unconditional, that is, the marginal probability, or risk, has been applied to the estimates shown.
2/ The estimate associated with a 95% probability that more than the amount shown is present.
3/ The estimate associated with a 5% probability that more than the amount shown is present.
4/ The estimate associated with the mean of the range of resources present.
5/ Conditioned on hydrocarbons being present within the area assessed; for aggregations, (such as total shelf) conditioned on hydrocarbons being present in at least one of the areas making up the aggregation.
6/ The conditional aggregate (such as total shelf) means are calculated from the unconditional aggregate means. They are therefore not necessarily the sum of the individual conditional means.

resources were not made by Powers because not enough was known about petroleum-reservoir properties, economics, and the technology needed to develop these deep water areas. There has not been enough information gained since that report to be able to apply recovery factors needed to convert deep-water in-place resources to recoverable resources.

The Minerals Management Service (MMS) estimates of undiscovered economically recoverable oil and gas resources for OCS areas of the United States were reported by Cooke (1985). For the eastern Gulf of Mexico, the MMS estimates are: risked mean oil - 0.41 BBO; and, risked mean gas - 2.19 TCF. These estimates are generally consistent with the conditional estimates in this report for crude oil of 1.53 BBO and for natural gas of 1.50 TCF. It should be noted, however, that the MMS estimates cover a somewhat different geographic area and were assessed using a different resource appraisal method. The MMS method uses a computer model called PRESTO (Probabilistic Resource Estimates - Offshore) that provides economically recoverable resources (Cooke, 1985).

EXPLORATION HISTORY

The first OCS lease sale (No. 5) in the eastern Gulf was held on May 26, 1959; seven more lease sales have been held since then, either solely in the eastern Gulf or jointly with the central and western Gulf areas (see Table 2).

The continental shelf of Alabama and western Florida has been explored intermittently since the 1950's. The pace of offshore leasing and exploration has been slow compared to Louisiana and Texas OCS areas because, among other reasons, the resource potential appeared to be less than in the western Gulf and the geologic structures are more difficult to delineate.

With the development of the common depth point (CDP) seismic technique, long seismic streamer cables and digital computer processing in the late 1960's, the ability to map deeper geologic structures was greatly enhanced. These activities led to the development of industry interest for oil and gas lease sales in the eastern Gulf, and OCS Lease Sale 32 in 1973 followed. The primary interest in OCS Lease Sale 32, December 20, 1973, was the Destin anticline, even though the apex of the anticline is in a military zone and was unavailable for leasing.

Prospective reservoirs on the Destin Dome Area were thought to be Lower Cretaceous and Jurassic strata. The Destin Anticline is on a trend with the Jay field and the Blackjack Creek field in the Florida Panhandle (Fig. 24). The Jay field is a giant field discovered in 1970; the oil and gas statistics are shown in Tables 4, 5, and 6. The discovery well had initial potential flowing of 1,712 barrels of oil per day (BOPD) and 2,145 thousand cubic feet of gas per day (MCFD) from the Jurassic Smackover zone at 15,470 feet. Sulfur-removal facilities and production lines are required on all wells (McCaslin, 1973).

The Blackjack Creek field discovery well flowed 317 BOPD from Norphelt at 16,120 and 1,379 BOPD from Smackover at 15,790. The natural gas produced from this well analyzed 14.3 percent hydrogen sulfide and 2.5 percent carbon dioxide (McCaslin, 1972).

There was reduced bidding (in terms of number of bidders and the amount of bonus) for tracts in the eastern Gulf in OCS Lease Sales 67 and 69, Part II. The Mobile and Main Pass Areas, immediately to the west of the November 1985 area of offering, were the centers of considerable competition in bidding because of the possible extension of onshore producing trends (the Tuscaloosa and Jurassic) into these offshore areas.

Mobil Oil Exploration & Production Southeast (Mobil) has drilled deep Norphelt (Jurassic) tests in Lower Mobile Bay to delineate a significant new field discovery. These test wells are 76-1, 76-2, 94-1, 94-2, and 95-1 (Fig. 22); appraisal wells have also been drilled in Blocks 76 and 77. Mobil gauged 4 million cubic feet (MMCF) of gas from a 23 foot Miocene zone at 2,750 feet depth in well 95-2, Lower Mobile Bay field offshore Alabama (Fig. 22) (Oil and Gas Journal, 1982). Exxon drilled well 62-1 in State Lease 534 (Oil and Gas Journal, 1983).

Nine dry holes were drilled on the flanks of the Destin Dome and the immediate area between 1973 and 1977 (Fig. 2, Table 3) Although the untested crest of the Destin Dome is still an attractive exploration target, the flanks of the structure do not appear promising. All leases awarded in the Destin Dome area during the 1970's have expired or have been dropped. However, additional leases were acquired in the most recent lease sales, and drilling is currently underway.

Industry interest focused on the area off south central Florida in the 1978 lease sale (No. 65, Table 2). The targets in the Charlotte Harbor area were Cretaceous carbonates in the Sunniland, productive in the onshore South Florida basin and the Jurassic section.

The productive trend of Lower Cretaceous Sunniland Formation across the onshore portion of the South Florida basin (Fig. 19) is estimated to have original oil in place of 238,767,000 barrels; recoverable oil is estimated to be 90,485,000 barrels, at a recovery factor of 38 percent (see other statistics in Tables 4,5, and 6).

Based upon projections of producing trends and analysis of geological and geophysical data, the planning area has potential for oil and gas discoveries.

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CHAPTER IV

ENVIRONMENTAL GEOLOGY OF EASTERN GULF OF MEXICO OCS REGION

by

Charles W. Holmes and Larry Doyle*

INTRODUCTION

Knowledge of the geology and geologic processes relating to surficial sediments and near-surface strata in the eastern Gulf of Mexico region is very limited. Prior to 1972, only two areas had been studied; the Mississippi-Alabama shelf (Ludwick, 1964) and the central part of the continental shelf between Tampa and Charlotte Harbor (Gould and Stewart, 1955). A shelf-wide geologic sampling program of about 300 bottom samples was summarized by Grady (1971) and Holmes (1973). All of these studies were concerned with the distribution and composition of the surficial sediment cover.

In 1973, with increasing industry interest in the area, more environmental geology studies were initiated to obtain basic information. One such study was sponsored by the Bureau of Land Management to obtain information in the MAFLA (Missisippi-Alabama-Florida) region, which is the shelf area extending from the Mississippi-Louisiana border to latitude 26° on the Florida Shelf. This baseline study produced sedimentological, geochemical and biological data between the State-Federal boundary and the 340 ft (100 m) isobath from approximately 76 sites (the numbers varied with the season and year of the program). In addition to these data, 2300 mi (3600 km) of geophysical information was obtained along the sampling transects (Pyle and others, 1976). An additional 1500 mi (2500 km) of geophysical data, between 340 ft and 3400 ft (100 m and 1000 m), were collected in 1975 (Doyle, 1983). South of latitude 26°, 1100 mi (684 km) of high resolution data were collected in 1980 and 1981 by Holmes (1981) and Woodward Clyde (1983). In addition to these data, lease blocks that previously were nominated or sold were studied extensively by various contractors. These, however, cover about that 5 percent of the total eastern Gulf region and contribute little to the regional knowledge of the geology or geologic processes in the area.

This chapter summarizes in general terms what has been learned from these surficial sediment cover studies and the potential geohazards that may be encountered in exploring and producing petroleum in the eastern Gulf region. The subjects are discussed under four headings:

1) carbonate buildups
2) karst and channelization
3) sediment texture and composition
4) sea floor instability.

Information sources are from the literature and open file government data. Although some aspects of the geologic processes are included, this is not a complete treatise on the subject matter.

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GEOLOGY AND GEOLOGIC PROCESSES

Carbonate Buildups

Carbonate buildup, or reefs, is of considerable importance not only to those concerned with biologic resources, but to the engineer who must design structures that may sit on uneven and high diverse substrates that characterize such features. Based on internal structures and morphology, these features are of three general classes:

1) large skeletal buildup - result of inplace growth
2) large skeletal buildup - result of hydrodynamic processes
3) small skeletal buildup - inplace growth (Heckle, 1974)

The classification is employed because it allows some degree of genetic interpretation to be made based only on observed structural fabric and morphology, and does not require knowledge of the skeletal constituents. This classification also provides important foundation information. Most of the large buildups on the central shelf are dominantly of the Class 1 type with some minor construction of the Class 2 type. Complicating the classification is the relationship of reef growth to karst morphology. Karstification has been proposed as a process controlling the placement of carbonate reefs (Purdy, 1974). On the Florida shelf, this relationship is apparent with the middle ground reef in the north (Fig. 29) and the reef which composes Pulley Ridge in the south.

Six north-south trending spur-like ridges, whose morphology are analogous to geomorphic spits, lie seaward and south of the Middle Ground reef at a depth of 170 ft (50 m) to 240 ft (70 m). Ballard and Uchupi (1970) and Jordan and Stewart (1959) have suggested that these are relict spits formed at some time during a lower sea level. Although the planimetric aspect suggests that these are southward prograding class 2 skeletal buildups, seismic profiles across some of them exhibit poorly developed irregular-lenticular internal fabric suggestive of some reef growth founded on a spit deposit. The largest of these spurs on the central shelf, located due west of Tampa, and is commonly referred to as The Elbow. The internal structure of this feature clearly shows a foundation of clinoform sediments overlain by an organic reef deposit. In the south, another feature, although deeper (~500 ft, 150 m) exhibits similar characteristics. The feature, called Howell Hook (Jordan and Stewart, 1959) clearly demonstrates a foundation on sediments originating as a result of hydrodynamic processes overlain by a reef (Fig. 30). In this case, however, the process was erosional and not constructional as in The Elbow and related features.

There is another series of ridges at the shelf edge (600 ft, 200 m) whose internal structures suggest a Class I organic proliferation. The majority of these features are commonly covered by 30 ft to 60 ft (9 to 18 m) of sediment (Fig. 31) and form a seaward facing scarp marking the present shelf edge.

Class 3 type carbonate buildups are represented by pinnacle reefs on the outer shelf and individual coral heads on the inner shelf. The occurrence of coral-algal pinnacles on the west Florida Shelf has been previously noted by Jordan and Stewart (1959) and published details of similar features from the northeastern Gulf of Mexico can be found in an article by Ludwick (1964). Coral-algal features are common near the shelf

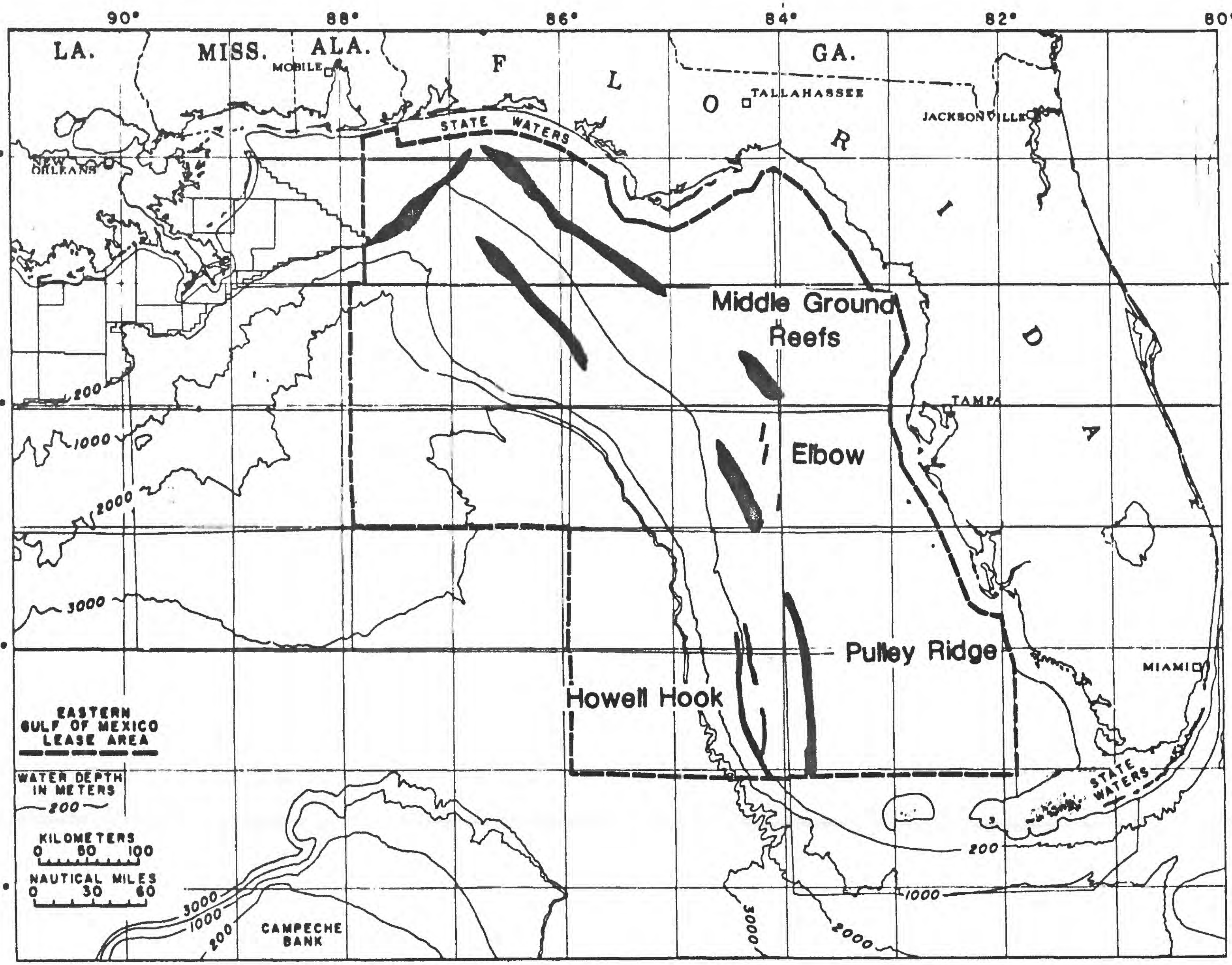

Figure 29. Map showing distribution of carbonate buildup in the eastern Gulf of Mexico.

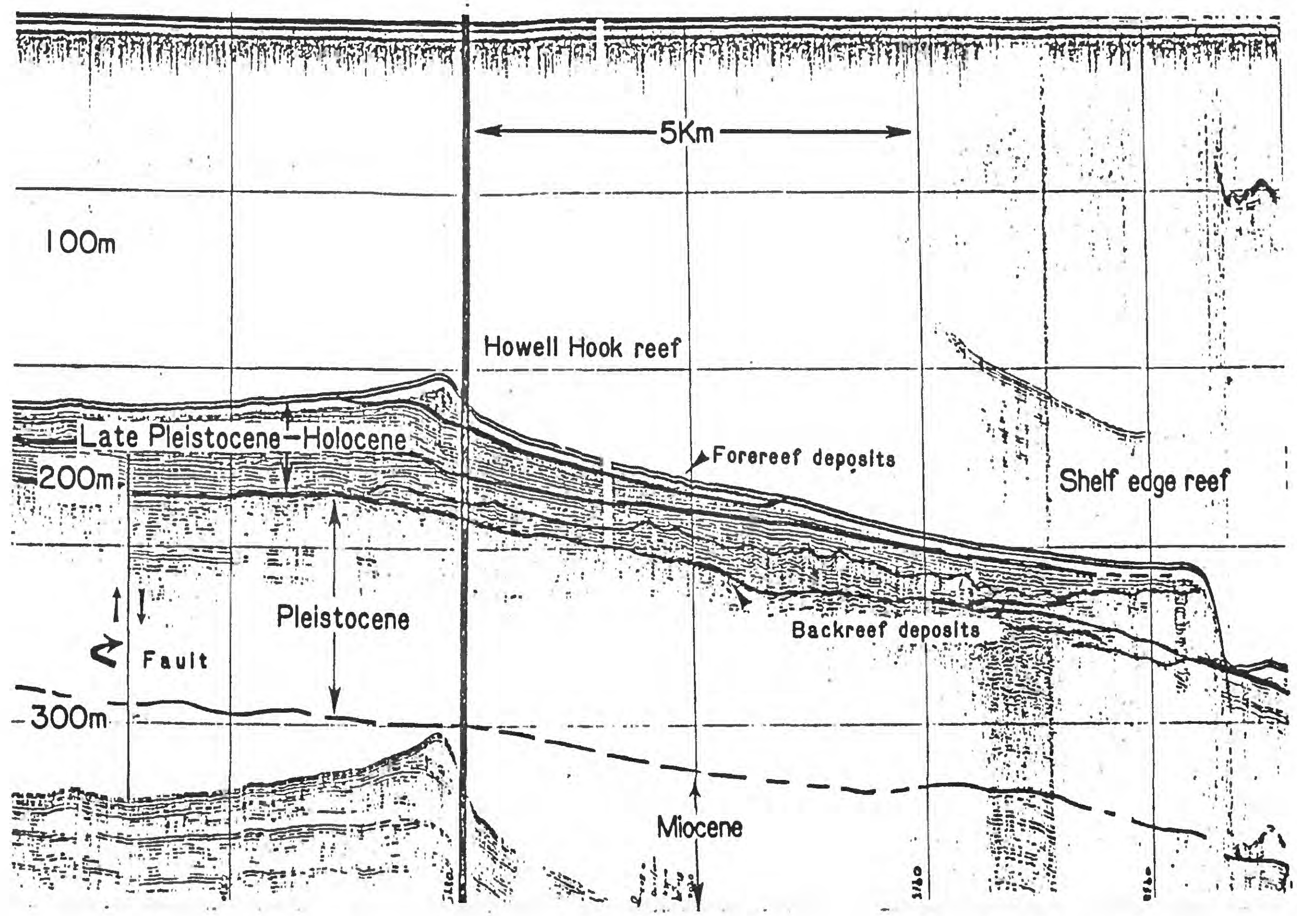

Figure 30. Interpreted seismic profile across the Howell Hook reef and shelf edge reef, eastern Gulf of Mexico. The profile (800 J sparker) shows Howell Hook and associated forereef material, and back reef material associated with the shelf edge reef. This profile details the relationship between the Miocene, basal Pleistocene, and deposits directly associated with the last transgression. A fault is present in the subsurface landward of the Howell Hook.

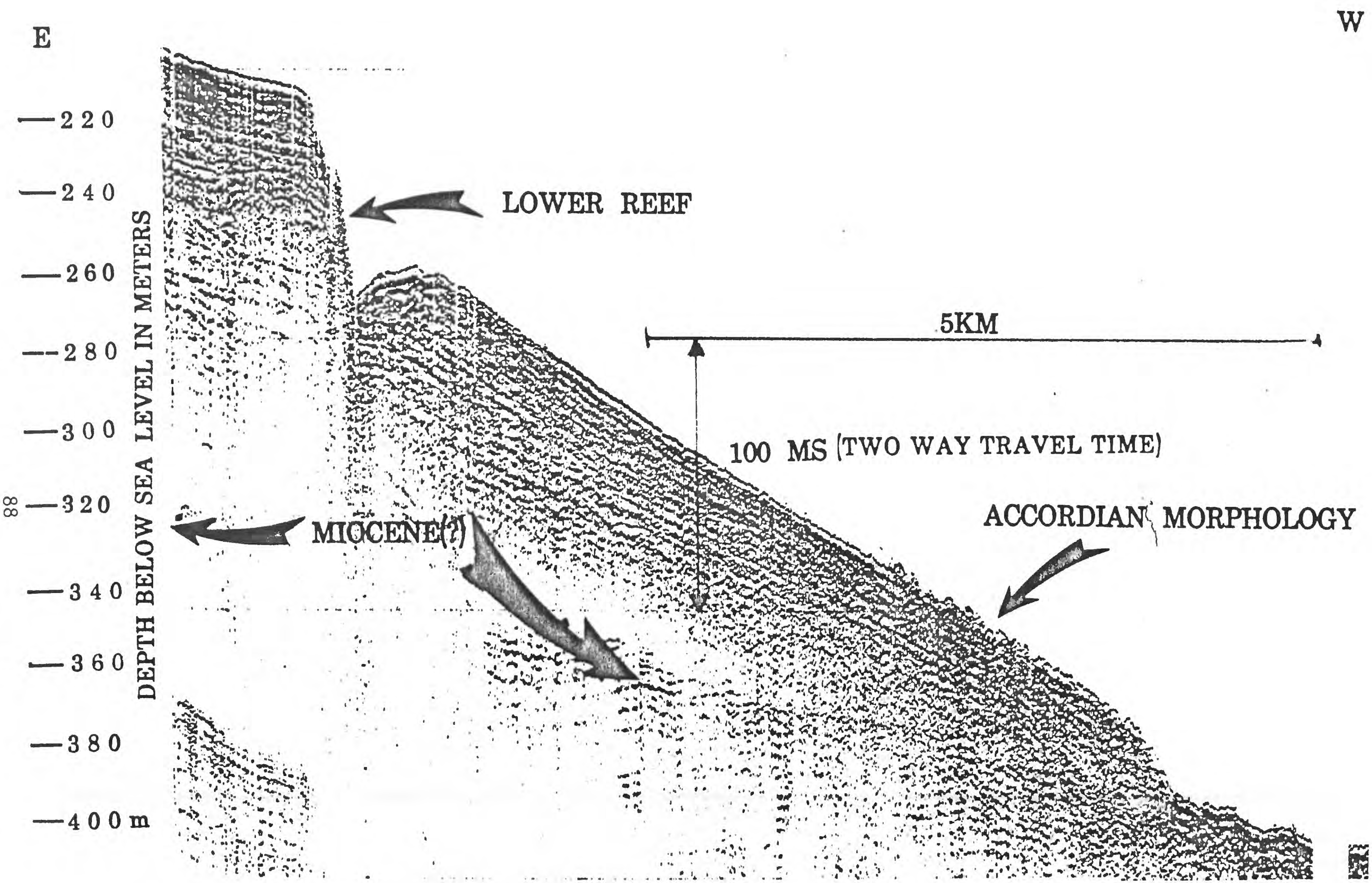

Figure 31. Seismic profile showing shelf edge reef, eastern Gulf of Mexico. The reef is buried by approximately 50-70 ft (15-21 m) of sediment. This section also shows the results of slumping in the detachment depression below the reef and the compression ridges at the base of the figure.

break bordering the DeSoto Canyon and seem to be related to bathymetric highs, such as relict cuspate deltas south of Cape San Blase, which are relict features of the drowned portion of the Apalachicola River delta. Those features at the shelf edge rest atop highs which in some cases are constructed by salt domes.

Karst Development and Channelization

The development of karst features is inherent in a carbonate terrain that has been or is exposed to subareal weathering. Concurrently, the probability exists for the development of erosional features such as river channels. Such a feature presently coexists on the exposed portion of the Florida peninsula and it is not unexpected to find similar features on that portion of the platform that is presently submerged. Available data (seismic-reflection profiles) offer few unequivocal clues for assigning a specific genesis to a particular feature. In the case of a structural depression developed on a reflecting horizon that occurs in an isolated profile, one cannot readily differentiate between channel, doline, simple basin, or in the case of a small feature, velocity anomalies. Consideration of the dimensional characteristics and bedding subtleties of sediment fill, in the context of the regional geologic setting, however, often allows subjective assignment of a process-oriented interpretation with a reasonable level of confidence. A closely spaced grid of profiles would be required to better determine the three dimensional characters, thereby confirming such inferences.

Pyle and others (1976), differentiated karst features on the basis of size (breadth) to depth. As a result, three population modes were defined at 250 ft (70 m), 1700 ft (500 m), and 10,000 ft (3000 m) diameters. Analysis of available data indicates that the majority of the small (dimensionally) groups are dolines (Fig. 32). These structures occur in two trends on the inner shelf in the north between Apalachee Bay and Tampa and in the south between Charlotte Harbor and Florida Bay. The northernmost structural features occur in two belts. The inner belt of structures is coincident with undocumented reports of sinks and springs in adjacent areas. The outer belt (Fig. 33) is better defined, is approximately 5 miles wide, and extends north-south for approximately 50 miles. The lack of data in the southern areas restrict the definition of any trends, if any are present. In both areas, however, with few exceptions near land, the doline-like features are covered with a thin veneer of sediment.

The apparent absence of karst features further north may be the result of geologic differences in Tertiary limestones. North of latitude 29°N the surficial limestone units grade into more terrigenous strata (Yon, 1966; Vause, 1959, Yon and Henry, 1972). Such strata produces better surface drainage and inhibits the karstification process.

Extremely dissected solution features are present in a 12-mile wide band on the central shelf on the other major shallow trends (Fig. 34). In the north-central portion of the shelf, these features are coincident with the Middle Ground reefs. Similarly, in the southern portion, karst features are adjacent to Pulley Ridge, a discontinuous series of reefs. Large, isolated karst features have also been identified under the outer shelf (Fig. 35). Seismic evidence indicates that most of these are not presently active but were active during early periods of sediment accumulation.

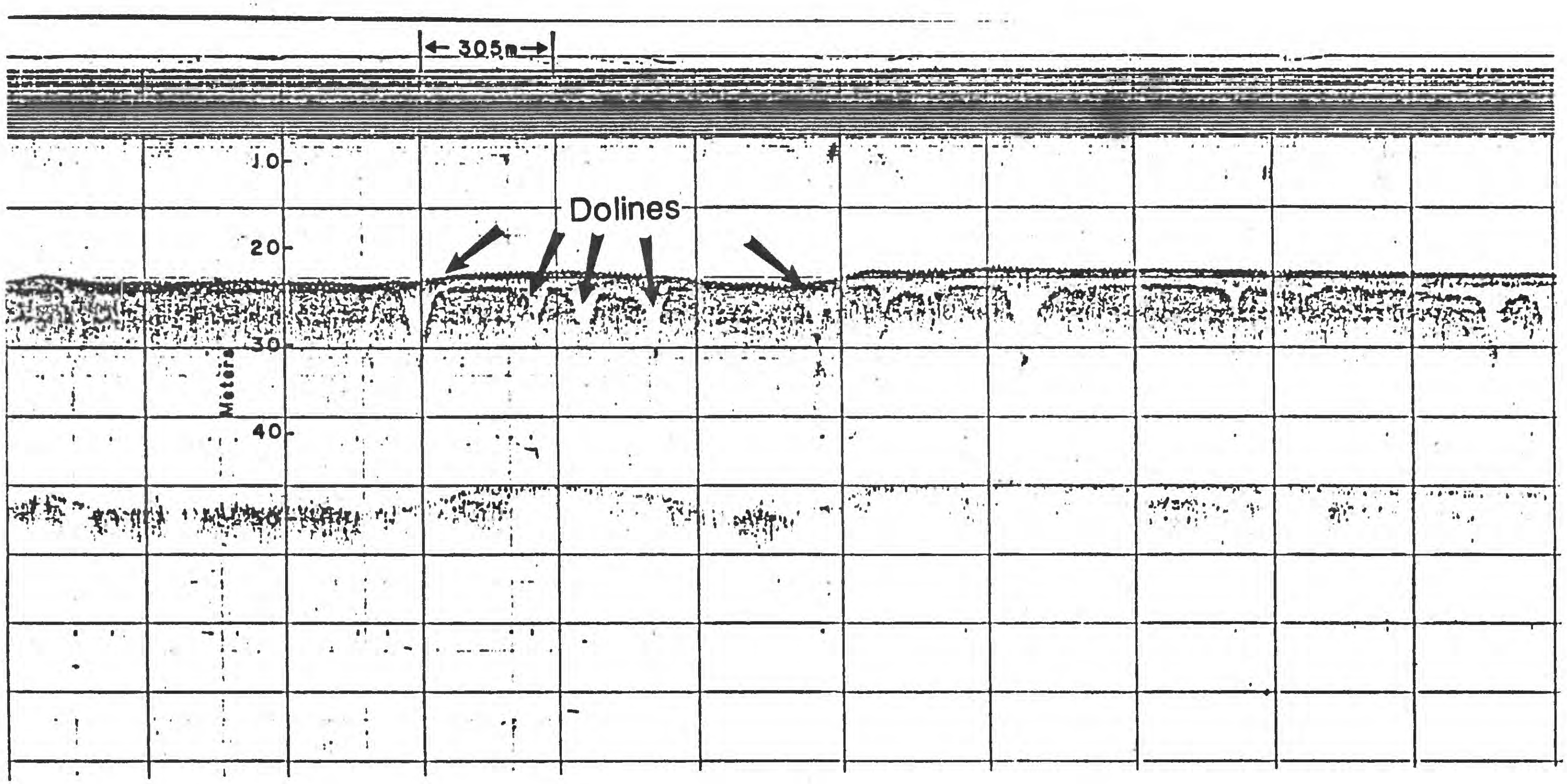

Figure 32. Seismic profile across doline features in the northeastern part of the western Florida Continental Shelf.

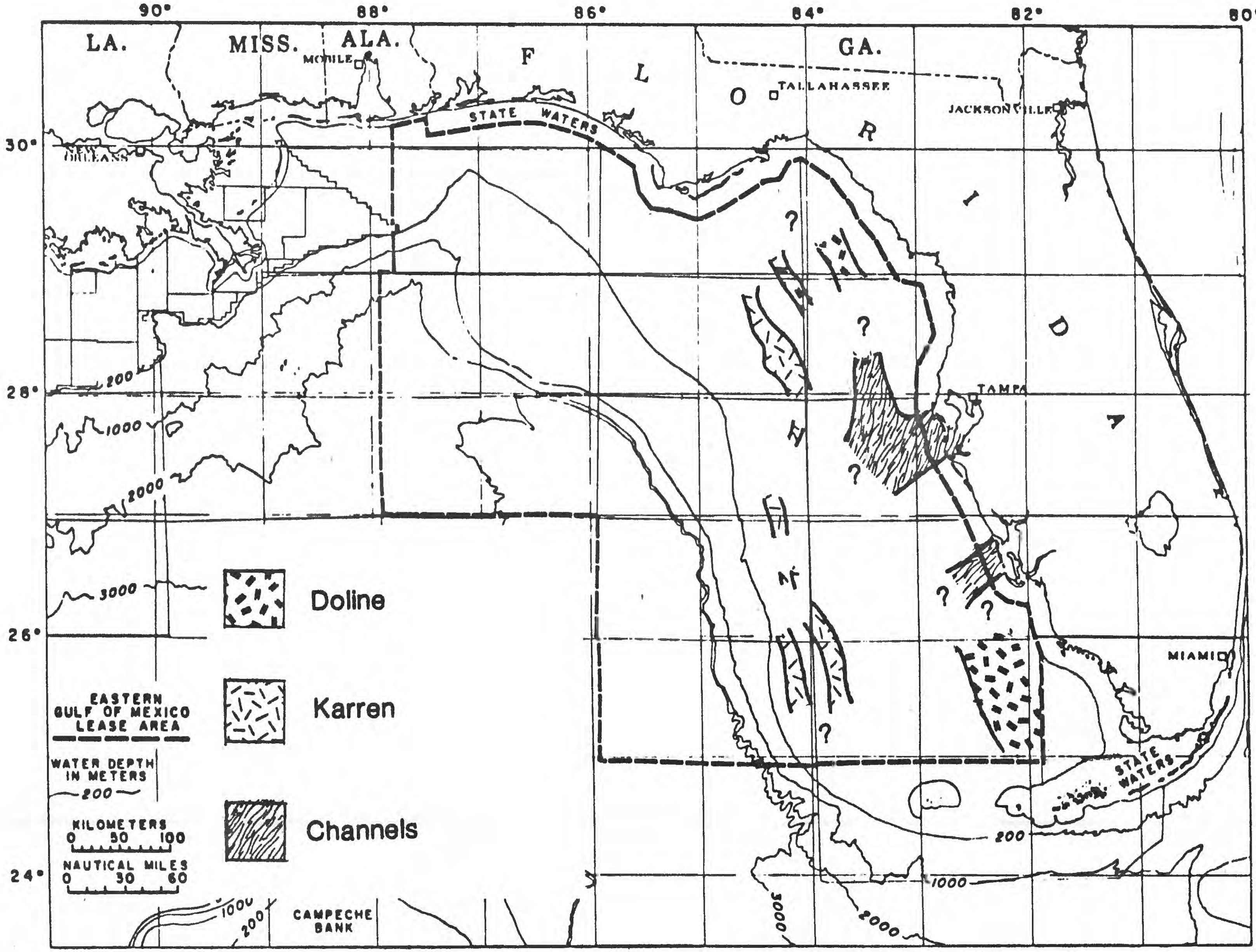

Figure 33. Map showing distribution of known areas of karst features and channels in the eastern Gulf of Mexico.

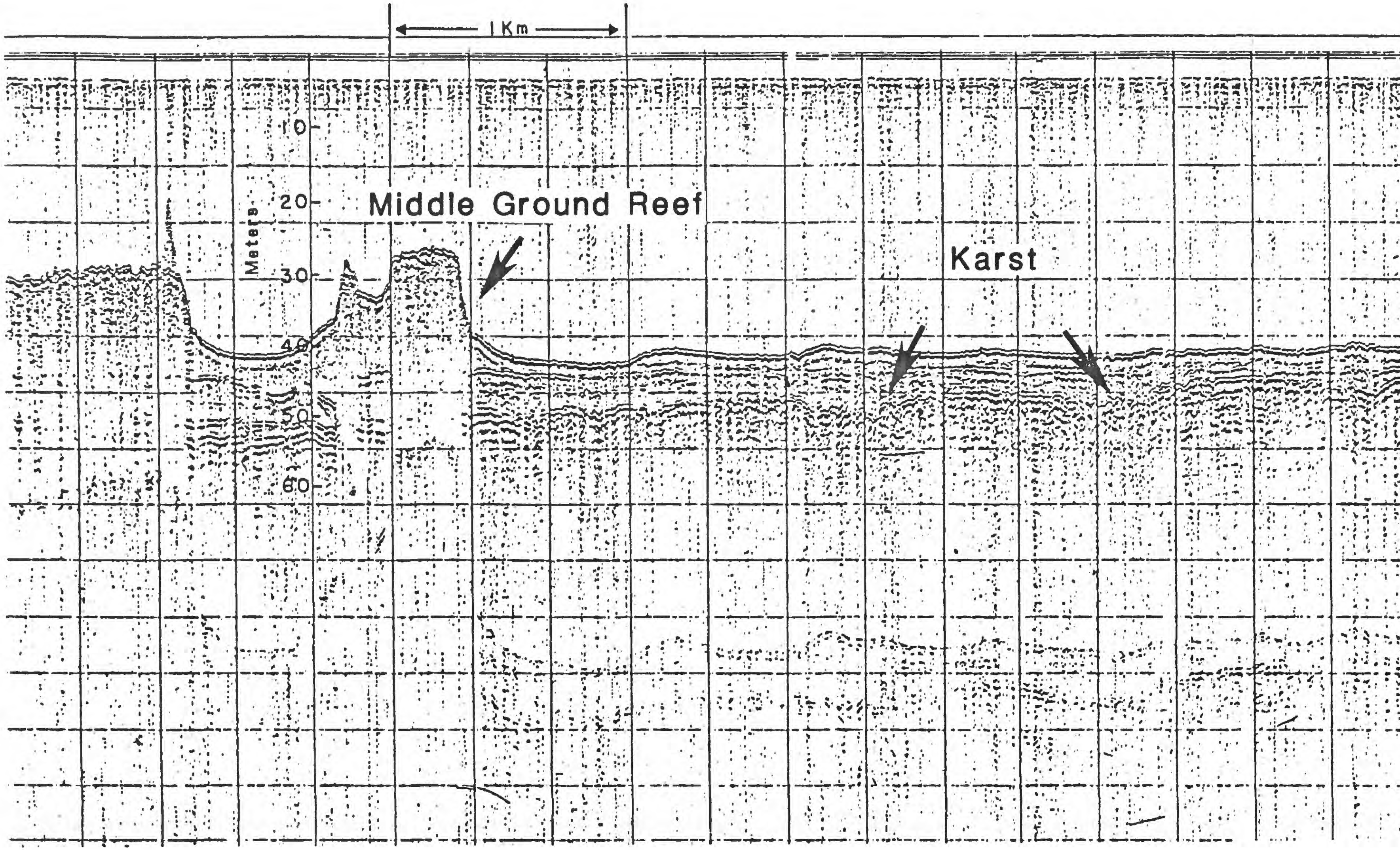

Figure 34. Seismic profile showing examples of karst features in the vicinity of Middle Ground reef, eastern Gulf of Mexico.

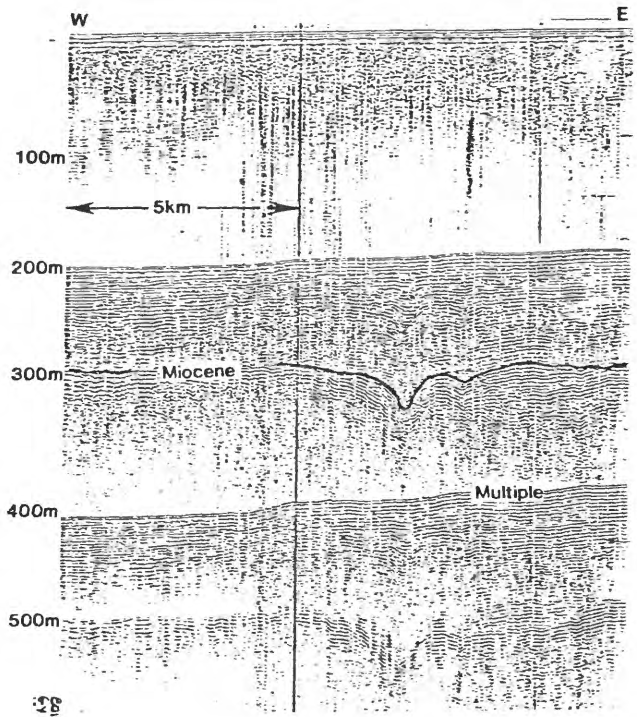

Figure 35. Seismic profile showing outer continental shelf karst feature developed on a Miocene surface in the eastern Gulf of Mexico.

On the central shelf, from Tampa to south of Charlotte Harbor, large, well developed channel complexes are present. These features seem to coincide with ancient drainage that discharged through Tampa Bay area and the Charlotte Harbor area. Seismic profiles indicate that an active fluvial system developed significant clinoform deposits (Fig. 36). The age of this system is assumed to coincide with the last regression, but attempts to follow the trends across the shelf have thus far been unsuccessful, therefore, the extent of the regression of channels is unknown. The presence of hardgrounds and/or ledges on the banks of these features also indicates that part of the process of formation was solution.

Sediment Composition

Two parameters are most diagnostic of the surficial sediment on the shelf, the percentage of sand and percentage of carbonate. Texture is defined as the description and shape aspects of a sedimentary material. Sands dominate the eastern Gulf area except for a large patch of sediments with an elevated content of fine-grained sediments that lie to the west of Tampa Bay in the central shelf region. Highest values in the center of the patch exceed 60 percent fines (Fig. 37). In general, the 20 percent fine fraction contour lies well out on the shelf edge. Even upper slope sediments of the region contain up to 50 percent sand, and are composed almost entirely of the tests of planktonic foraminifera. The fine fraction increases rapidly west of Mobile Bay as the Mississippi Delta is approached, and fine sediments also lie in the head of DeSoto Canyon.

Deeper water, finer grained sediments in the study area are generally poorly sorted while those sands and muds lying on the shelf are generally very poorly sorted. While the shelf sand sheets on both sides of Cape San Blas display textural similarities, there is a major compositional break trending slightly east of south from the Cape. The low carbonate contour, which corresponds to high quartz content, forms a bulge out onto the shelf which marks the transition between western and eastern facies (sedimentary units with distinctive characteristics). The eastern portion is dominated by up to 90 percent carbonate components while the western portion is predominantly quartz sand. A band of quartz sand also lies inshore to the east of Cape San Blas and makes up the western beaches of the Florida peninsula. The gradational transition between the nearshore quartz band and open shelf carbonate sediments, and the abrupt pinching of the quartz band at the southern limit of the study area are illustrated in Figure 38.

Clay minerals are important in their relationship to the scavenging of trace metals and in their relative proportions which may indicate general water motions and sedimentary source areas. Due to their source in Mississippi River waters, clays are most prominent in the eastern Gulf area in the northwest section, and in the deeper outer shelf and slope stations.

Clay minerals tend to concentrate or strongly influence the distribution of trace metals. There are two reasons for this; (1) clay minerals are usually of terrigenous origin, as compared to water-column derived particles, and (2) are commonly exposed to sources of metals on land. Clay minerals also carry trace metals within their crystal structures, although these are not necessarily biologically active. Of primary ecological importance in trace metal cycling is the high surface-to-volume ratio of the clay platelettes. These particles absorb

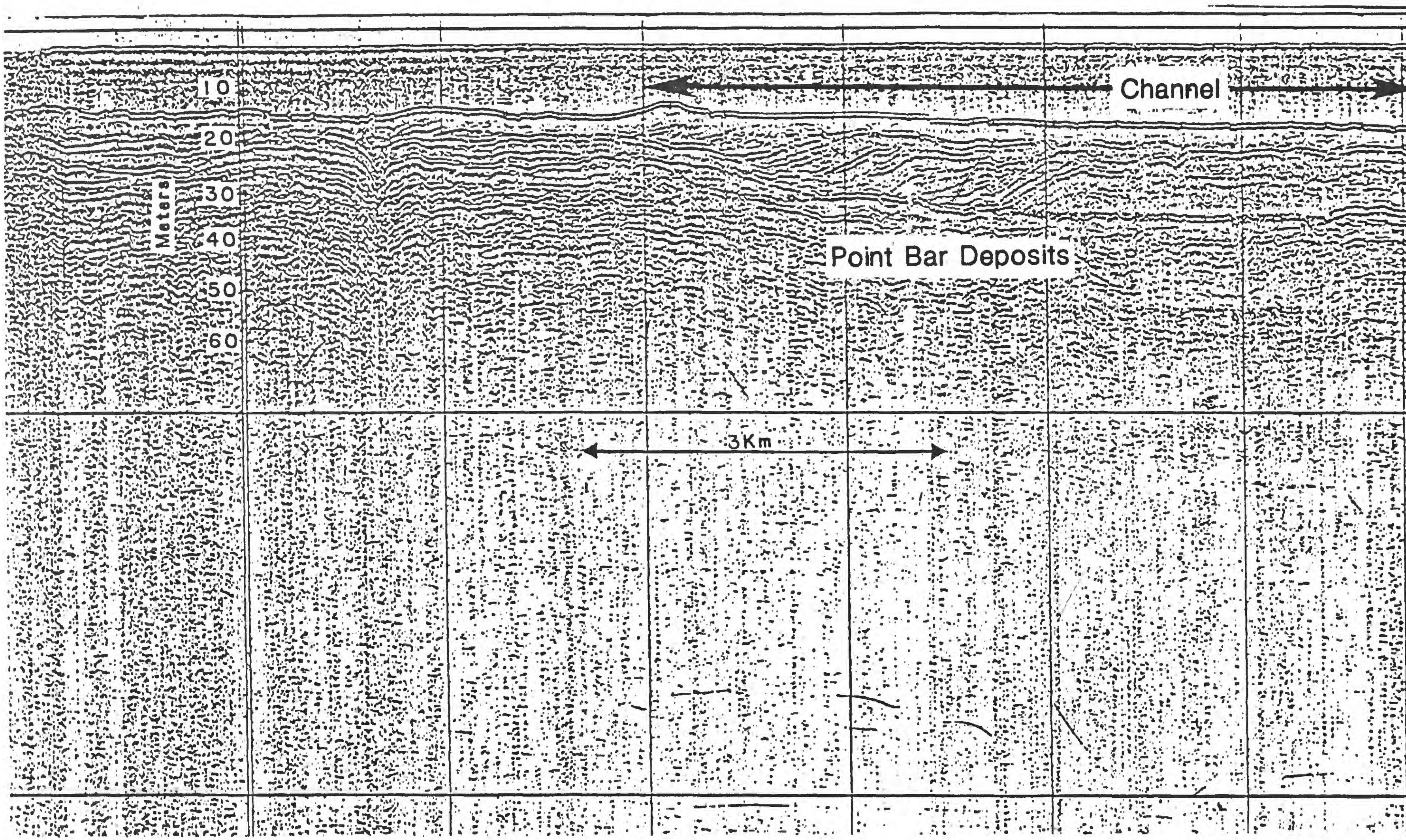

Figure 36. Seismic profile on the inner shelf across a portion of a channel near Tampa, Florida, showing significant clinoform deposits developed by an active fluvial system.

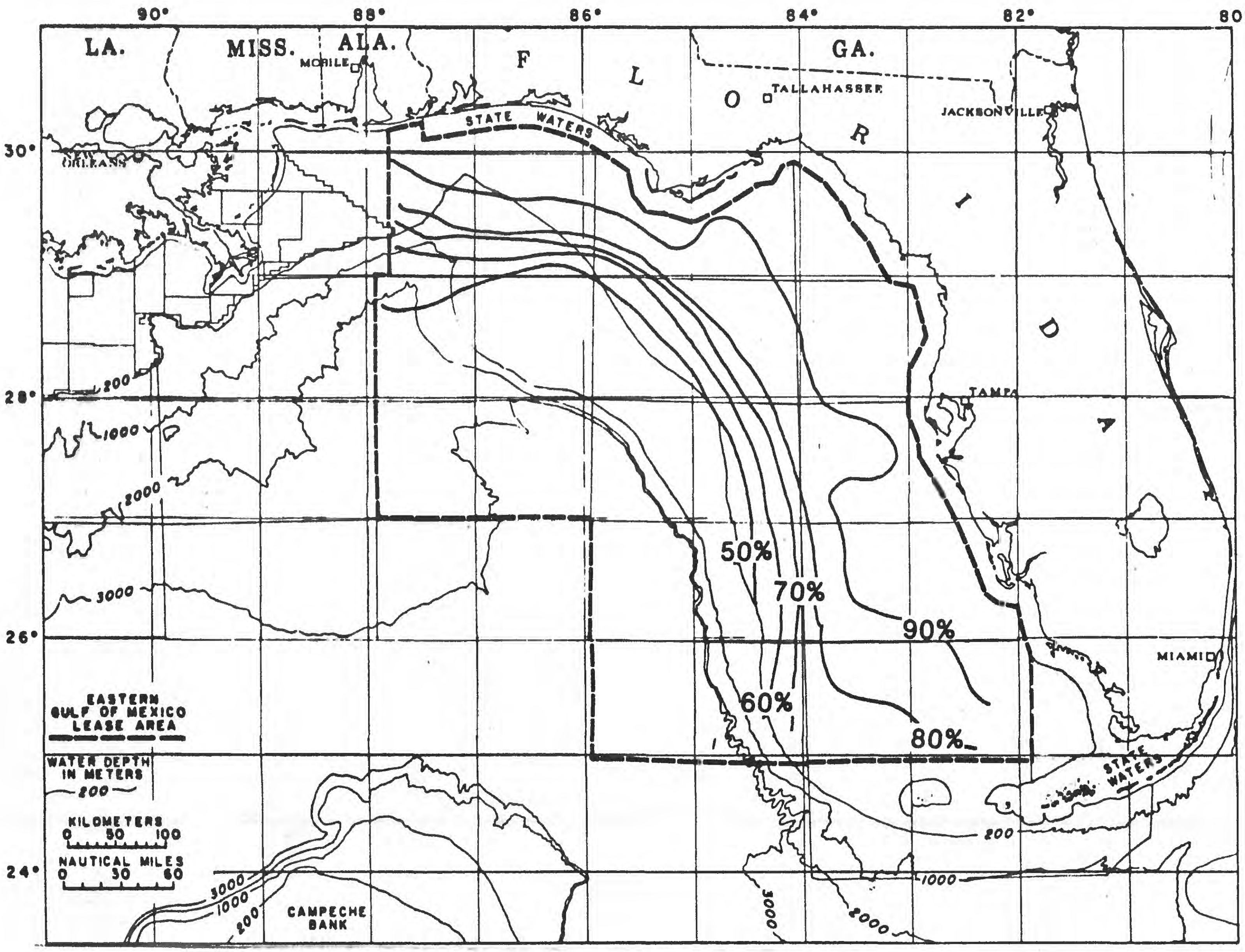

Figure 37. Map showing percent of sand distribution on the continental shelf and slope, eastern Gulf of Mexico.

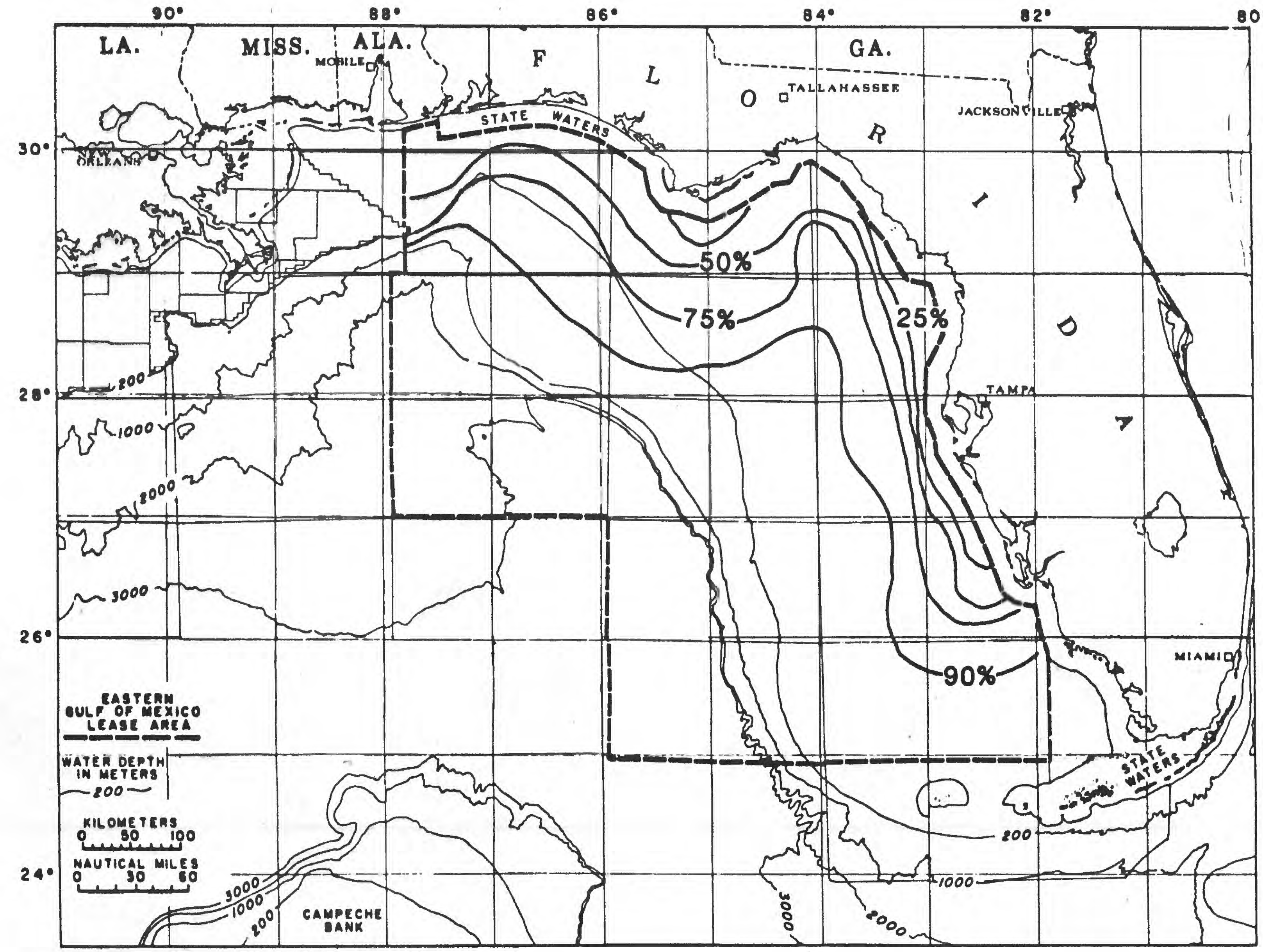

Figure 38. Map showing percent of carbonate distribution of continental shelf and slope, eastern Gulf of Mexico.

trace metals onto their surfaces where they remain available to benthic deposit or filter-feeders. Since many organisms are capable of stripping metals from the surfaces of particles, there is concern for a bio-accumulation, or amplification, of the concentrations as various trophic levels become involved in a given food chain.

Smectite and kaolinite are the predominant clay minerals in eastern Gulf margin sediments. Illite is present in most samples ranging from trace amounts to about 16 percent and shows a random pattern of distribution within the study area. Mixed layer clays and chlorite are rare and scattered in benthic samples.

Distributions of the dominant clay mineral smectite are shown in Figure 39. Smectite, characteristic of the Mississippi drainage system, dominates the clay fraction west of Cape San Blas. From the delta, relative percentages of kaolinite increase eastward toward the cape. East of Cape San Blas, kaolinite becomes more important, and over large portions of the eastern area is dominant in the clay minerals.

Several source areas feed sediments to the eastern Gulf margin. The Mississippi drainage basin is characterized by a clay mineral suite dominated by smectite (Griffin, 1962). Like the coastal plain of the southeastern United States to the north, smectite also dominates the clay mineralogy of those rivers which rise in the Tertiary rocks of peninsular Florida (Huang and others, 1975). These rivers contribute little to the Florida shelf sediments with the possible exception of the Caloosahatchee River, which empties into Port Charlotte Harbor, and where a rise in smectite values is noticeable. Kaolinite dominates the Appalachicola River system, while the Mobile River system has a mixed smectite/kaolinite suite. According to Doyle (1983) who examined the crystalinity of the clay minerals of the eastern Gulf, these latter two river systems must be the ultimate source of kaolinite in the eastern Gulf margin.

Surficial sediments of the eastern Gulf shelf and slope reflect the immediately underlying geology, that is, they may be divided at Cape San Blas into a western region of clastics and an eastern region dominated by carbonates. Facies distributions of surficial sediments in the study area are illustrated in Figure 40 (Doyle and Sparks, 1980).

Most of the sediment load of the Missisippi River is delivered directly to the shelf edge or is carried west due to the orientation of major distributaries and coastal boundary currents acting on the plume. Hence, sediments on the eastern margin of the delta change rapidly from the St. Bernard Prodelta Facies (Ludwick, 1964) which is dominated by mud, to an open shelf clastic facies, here identified as the MAFLA sand sheet. Sediments within this sheet are quartz sands with carbonate percentages of generally less than 25 percent. The heavy mineral suite of the area encompassed by the MAFLA sand sheet are characterized by van Andel and Poole (1960) and Fairbank (1962) as reflecting a southern Appalachian provenance.

Within the MAFLA sand sheet and adjacent to the eastern margin of DeSoto Canyon lies the insular Destin carbonate facies which has a carbonate content greater than 75 percent. Wanless (1977) shows this zone to be a combination of shell hash, lithothamnion algae, and foraminifera. Since the Loop Current turns to the east and then south at the DeSoto Canyon, the

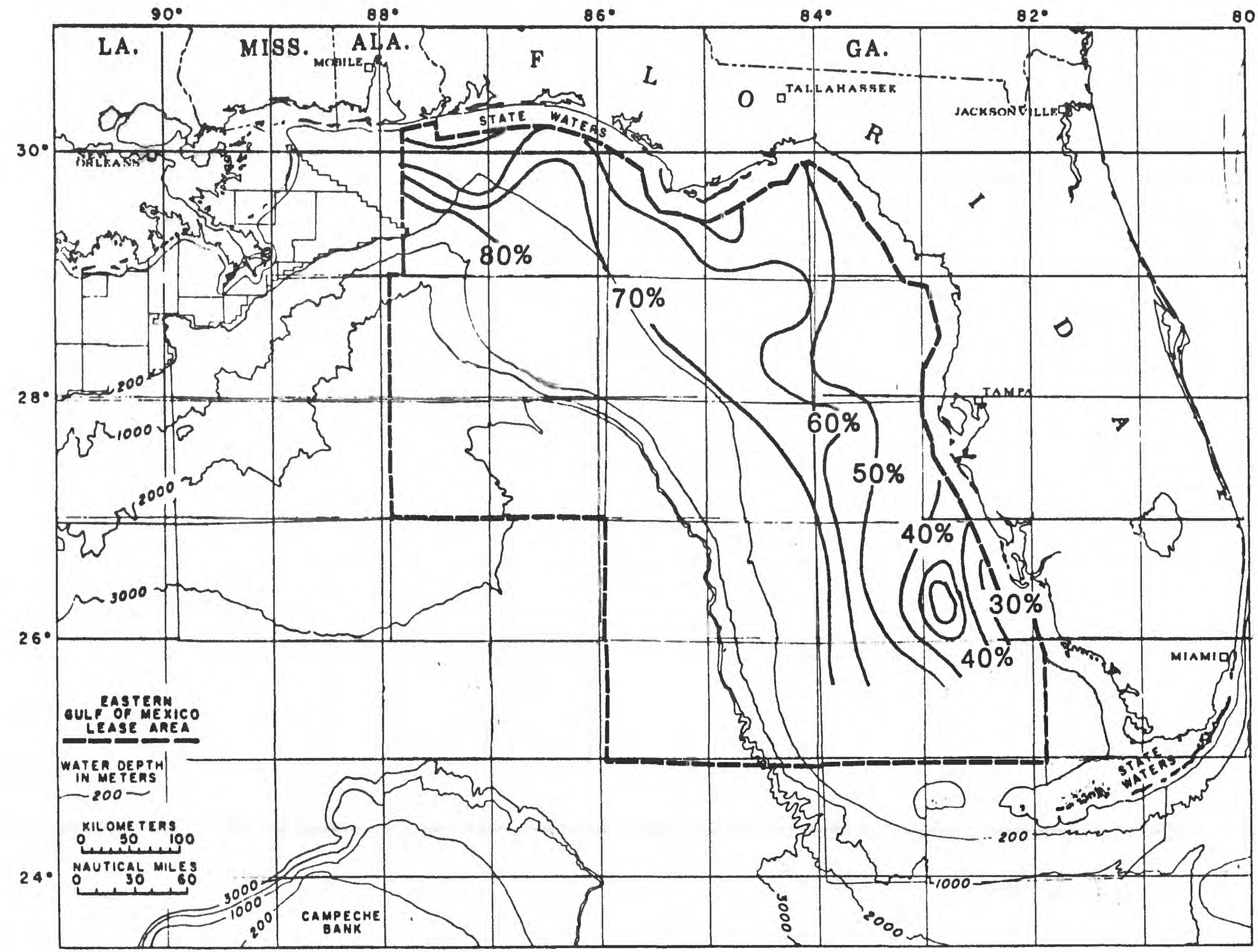

Figure 39. Map showing percent of smectite distribution on continental shelf and slope, eastern Gulf of Mexico.

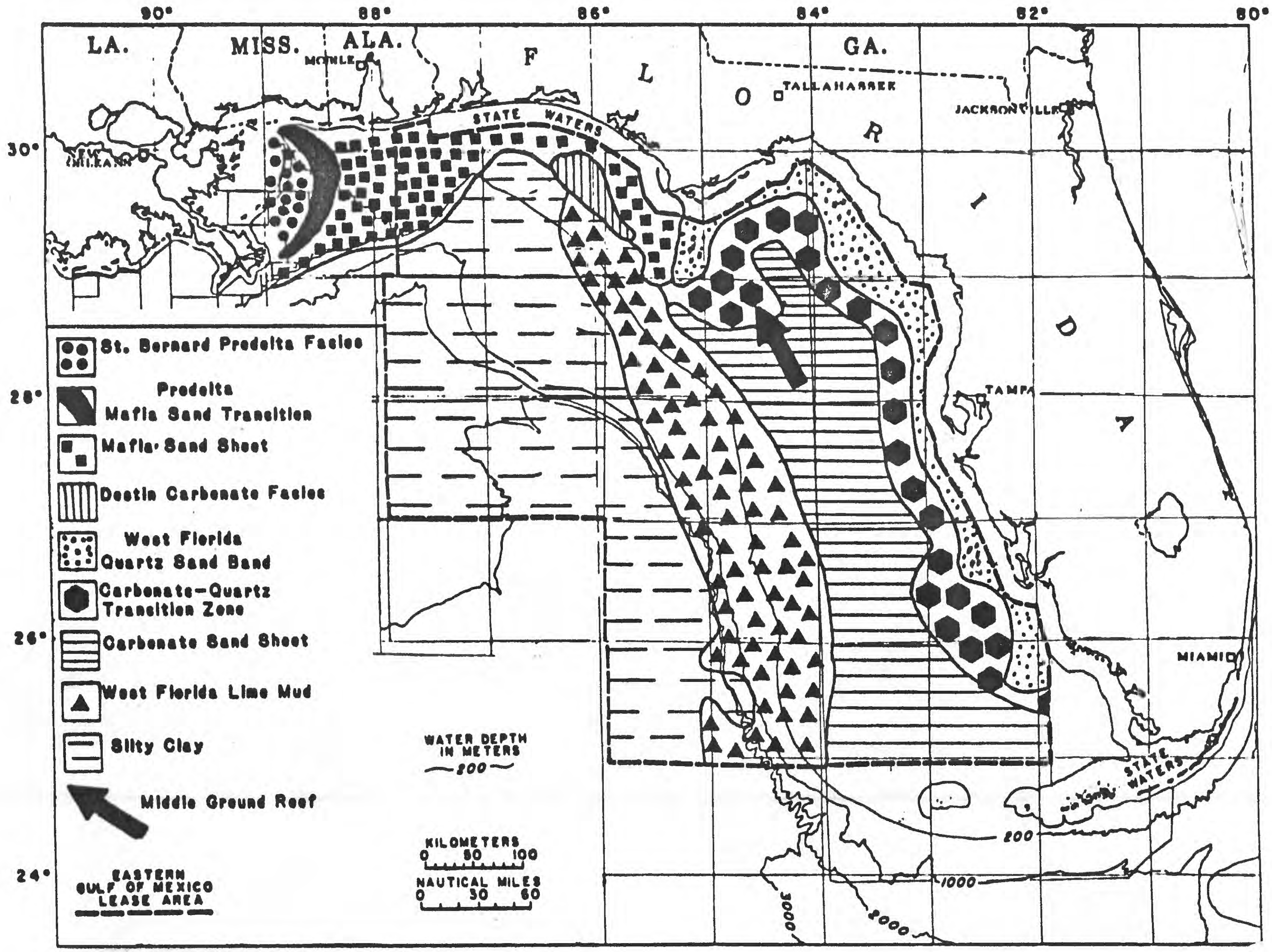

Figure 40. Map showing surface sediment facies on continental shelf and slope, eastern Gulf of Mexico (modified from Doyle and Sparks, 1980).

current may serve to block transport of detrital sediments into this zone, resulting in the accumulation of carbonate sediments similar to those of the West Florida carbonate sand sheet. This facies is so well sorted and coarse that if such currents do account for the facies presence, the currents may be quite strong and regular.

East of Cape San Blas lies the West Florida Shelf which is divided mineralogically into two facies separated by a rather broad transition zone. A carbonate sand facies dominates the outer and middle shelf. Rather than being banded with regard to texture and carbonate constituents as described by Gould and Stewart (1955), sediments within it are of patchy distribution in both texture and composition (Wanless, 1977). This facies is identified by a carbonate content arbitrarily placed at over 75 percent. Patches of shell hash, foraminifera, lithothamnion algae, and even oolites (egg-shaped $CaCO_3$ concretions) locally dominate the sediment (Gould and Stewart, 1955; Wanless, 1977). As expected, detrital heavy minerals are essentially absent in the carbonate facies. Outcrops containing phosphorite (a chemical precipitate rich in phosphorous) of suspected Miocene age are known to be present in some areas.

One transition zone shoreward of the carbonate facies includes increasing amounts of quartz toward shore (eastward). The transition is gradual and the shoreward boundary is arbitarily placed at the 25 percent carbonate isopleth. Shoreward of this transition zone lies a quartz sand facies consisting of very fine to fine sand. Due to its heavy mineral suite, characterized by the resistant minerals zircon, tourmaline, garnet, and staurolite (Fairbank, 1962), it is considered a "mature" sediment; that is, its components have passed through several sedimentary cycles of erosion and deposition. It is significant to note that this inshore quartz band also makes up West Florida's beaches.

The rivers of Florida carry little suspended load and even less bed load. Thus, the quartz band does not contain significant amounts of land-derived sediment, and it is bordered on the west and south by carbonates. Heavy mineral and clay mineral suites within this band are distinct from those contained in the detrital sediments to the west of Cape San Blas, suggesting that there is little sediment exchange between the two. These observations pose the question that without a constant source for replenishment, why does this band persist? Why hasn't longshore drift removed the quartz with subsequent replacement by carbonate sand?

The answer lies in the seasonal wind regime which prevails in the eastern Gulf of Mexico. Northerly winds dominate this coast during late fall and winter, while southerly winds predominate the rest of the year (Jordan, 1973). This alternating wind pattern leads to a southerly longshore drift in late fall and winter and a northerly drift during the remainder of the year. These two patterns offset so that there is very small annual net drift, and sediments tend to migrate back and forth. The result is an exceedingly mature sediment which has lost the original diagnostic character of its heavy mineral suite.

Since quartz is not being fed to the system at present, this band must be "relict" (a deposit remaining from an earlier time of deposition). It may result from quartz sands being brought down from the Tertiary clastic terraces of peninsular Florida during lowered stands of sea level, or it may represent the surface of a partially drowned terrace. Since clay mineralogy of the West Florida shelf is dominated by kaolinite and the coastal plain sediments of peninsular Florida by smectite, the northern Appalachicola and Suwanee Rivers may have been the most significant source area, with original smectite being partially masked or winnowed.

The West Florida lime muds (Ludwick, 1964) occupy the continental slope seaward of the carbonate sand facies. Clay minerals forming these muds are dominated by smectite (probably the result of Loop Current transport), but fine-grained carbonates (primarily coccoliths) are also important. In many places these sediments may contain large amounts of sand-sized planktonic foraminifera.

The sediment on the slope and adjacent abyssal plain in the northeastern portion of the eastern Gulf is dominated by clastic sediment from the Mississippi River system. However, the Mississippi River system exerts less influence on clastic sedimentation farther from its source, with a corresponding increase in hemipelagic sedimentation. Thus, the abyssal sediment west of Tampa consists of a thin veneer of pelagic muds over Mississippi River detrial sediment. In the extreme southern portion of the abyssal region, the carbonate sediments are much thicker. The sources of these sediments are the canyons in the extreme southeastern corner of the Florida Platform.

POTENTIAL GEOLOGIC HAZARDS

Seafloor Instability

Slumping

A large mass of sediment is present at the base of the continental slope at approximately latitude 26°N, as shown in the GLORIA (Geologic Long Range Inclined Asdic) sonograph record in Figure 41. This deposit is the apparent result of a massive landslide that created a large reentrant in the escarpment. The triggering mechanism appears to be overloading of sediment on the upper slope. The origin of this sediment is the result of high biologic productivity created by the impingement and upwelling of nutrient-rich water on the shelf.

Austin (1971) investigated the relationship between the Loop Current and various indicator organisms and was able to define the areas of high biologic productivity (Fig. 42). Much of the elevated productivity occurred along the eastern margin of the current. As entrant water is derived from the Caribbean, the production and deposition on the shelf of Caribbean fauna is expected. Analysis of the shelf sediment indicates a dominance of Caribbean species. Recent studies (Chin, 1983) have demonstrated that such activity (upwelling is not limited to the shelf edge but may extend onto the central shelf. Such processes would result in: 1) increased sedimentation rates and, 2) produce a strong north-to-south current.

While most of the sediment on the shelf may be considered relict or at least palimpsest, one area of the shelf appears to be the major depocenter for recent material. This appears to occur near the locale where the Loop Current reportedly has the greatest effect. As a result of this deposition, located near the shelf edge, conditions exist for the occurrence of mass

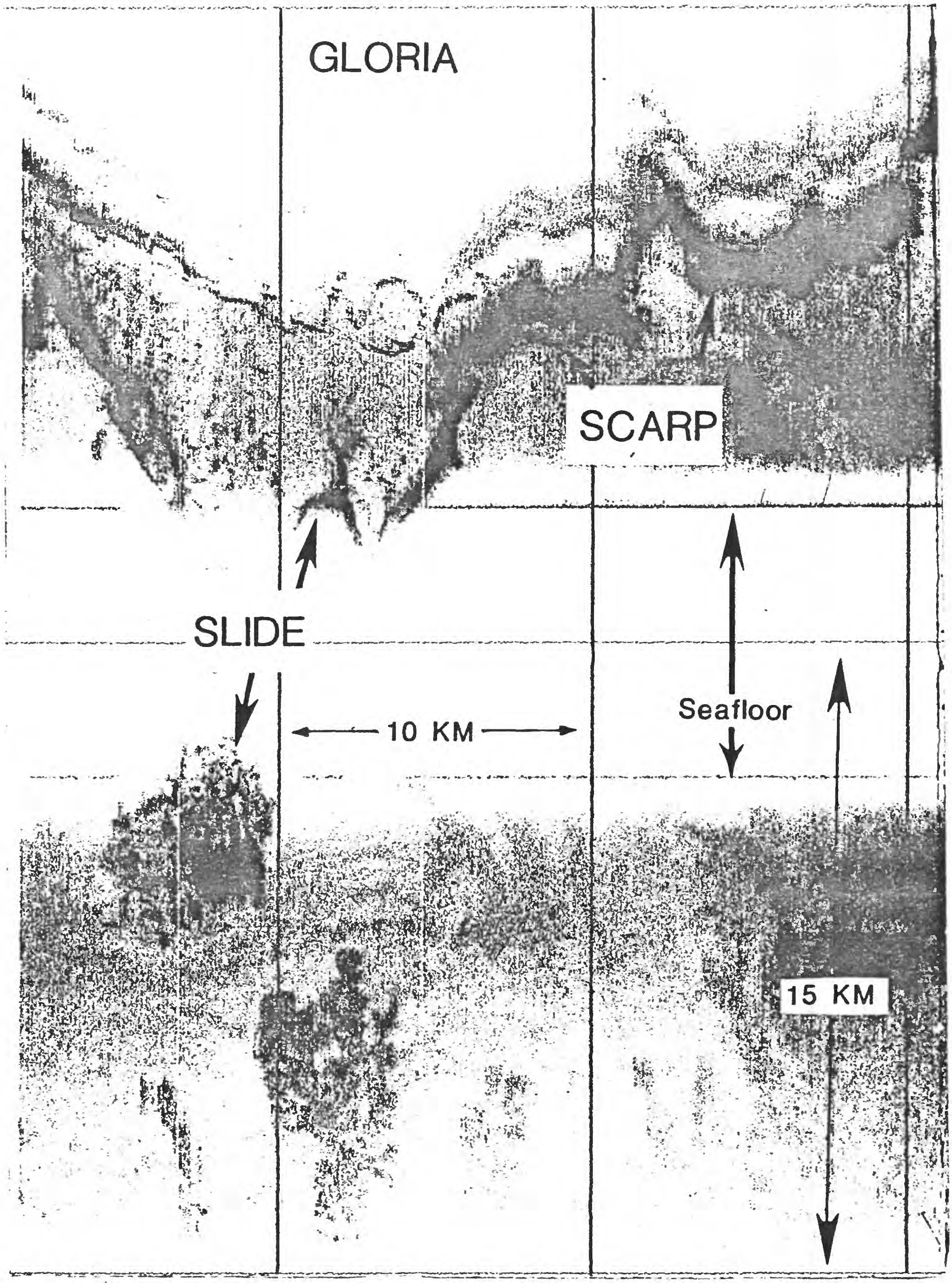

Figure 41. GLORIA sonograph record of base of Florida escarpment showing large mass of sediment derived from mass wasting on the continental slope, eastern Gulf of Mexico.

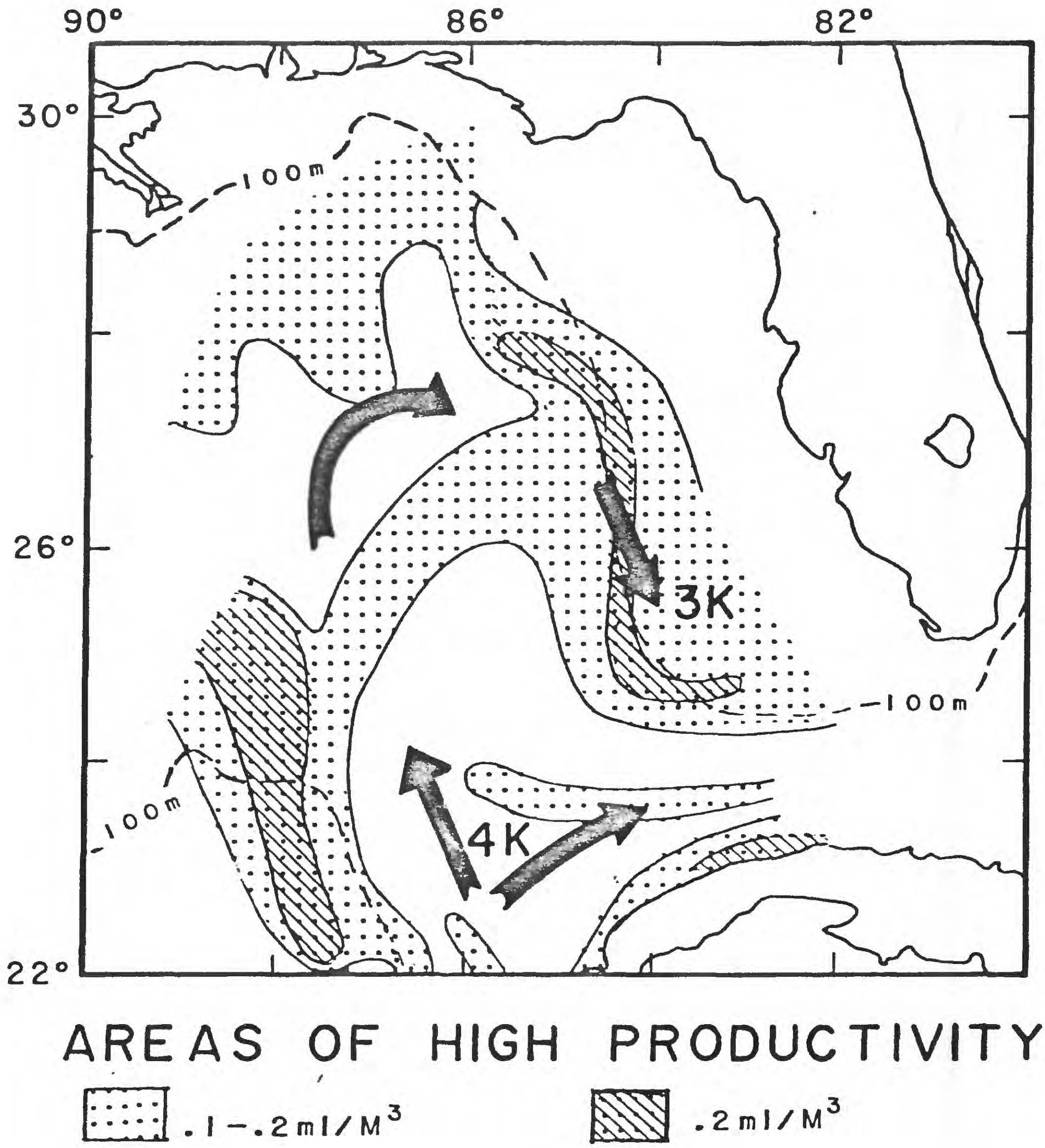

Figure 42. Map showing areas of currents and levels of high biologic productivity produced by the Loop Current, eastern Gulf of Mexico (after Austin, 1971).

wasting. Holmes (1973) has shown that mass wasting in the form of block slides has occurred on the central slope south of latitude 26°N (Fig. 43). In addition, sediment slumping is presently occurring on the upper slope from latitude 25°40' to latitude 25°N (Fig. 44). Both of these features and the large slide at 26°N are believed to be the direct result of sediment overload.

Sand Movement

A side-scan sonar investigation on the west Florida shelf revealed a multitude of bed form types. A nongenetic classification based on wavelength and ripple index (wavelength/wave height) divides the types into three groups; giant, small-scale ripples and sand wave. The last term is defined here as sediment hills of extremely long wavelength (usually >100 ft) (300 m) with comparatively low relief, which are often strongly asymmetric.

Six major zones are delineated according to the distribution of bed form types. These zones roughly parallel the coast line and extend seaward to approximately 650 ft (200 m) depths (Fig. 45).

Zone A, which parallels the west Florida peninsula out to approximately 60 ft (20 m), is characterized by giant to large-scale bed forms. These features are oriented nearly normal to the coast line and are believed to be longitudinal bed forms generated by major storms.

Zone B encompasses the shallow regions of the Big Bend area and extends down the mid-shelf parallel to the coast. Low-relief swells and scattered patches of giant to large-scale bed forms characterize this zone. The later type appears to be "current lineation," a type of longitudinal bed form probably owing its origin to a strong wind and/or wave generated currents created during a hurricane.

Zone C is subdivided into two zones extending north and south of the Middle Ground. Zone C_1 includes the Middle Ground and the area to the north while C_2 extends south into water depths of 60 m (197 ft). Both zones are characterized by small-scale features formed either by internal waves or currents set up on the summer thermocline, or by intrusion of Loop Current water onto the shelf.

Zone D is in the vicinity of Cape San Blas, Florida. Giant sand waves characterize Zone D_1 out to depths of 130 ft (40 m). Zone D_2, in depths of 130 ft (40 m) to 270 ft (80 m), has an abundance of small-scale bed forms. Storms and possibly a strong contour current help shape the bottom morphology in this area.

Zone E covers the outer shelf and exhibits a generally smooth, gently sloping sea floor. A few locations of low-relief swells and giant to large-scale bed forms suggest occasional strong hydrodynamic conditions.

Most of the giant, giant to large, and large-scale features of Zones A, B, C, and D are believed to be storm related bed forms. The small-scale features in Zone C are possibly the result of internal waves and/or tides which may be wholly, or in part, the result of Loop Current intrusion. The bed forms of Zone D and E are the result of contour parallel currents which are probably due to Loop Current circulation. These forces, combined with

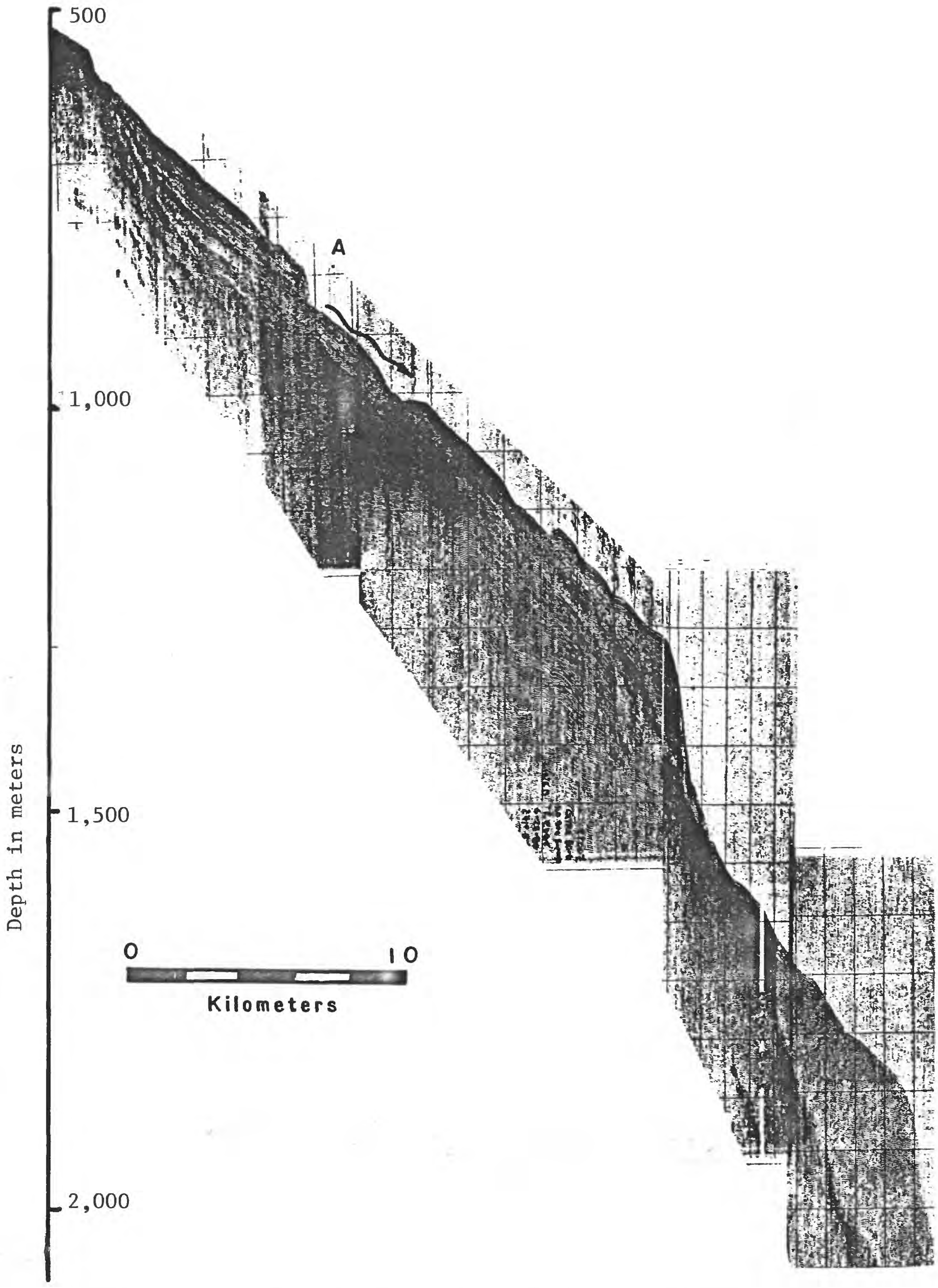

Figure 43. Seismic profile (Line 13 800J) showing block slides on central continental slope, eastern Gulf of Mexico.

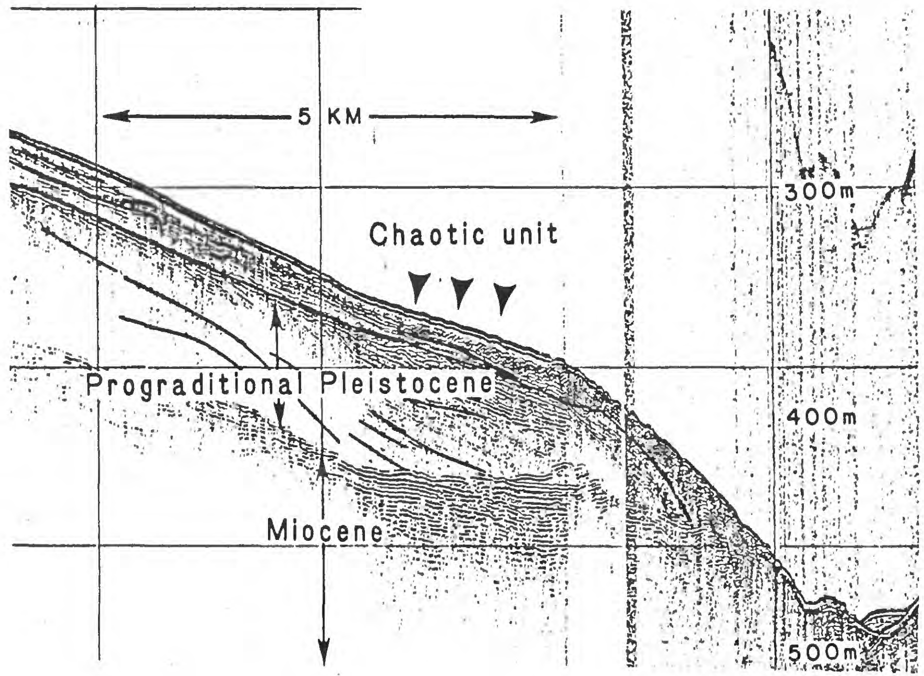

Figure 44. Seismic profile of lower portion of the upper slope from lat. 25°40'N to lat. 25°N, eastern Gulf of Mexico, exhibiting the compression ridges at the toe of a surficial sliding layer.

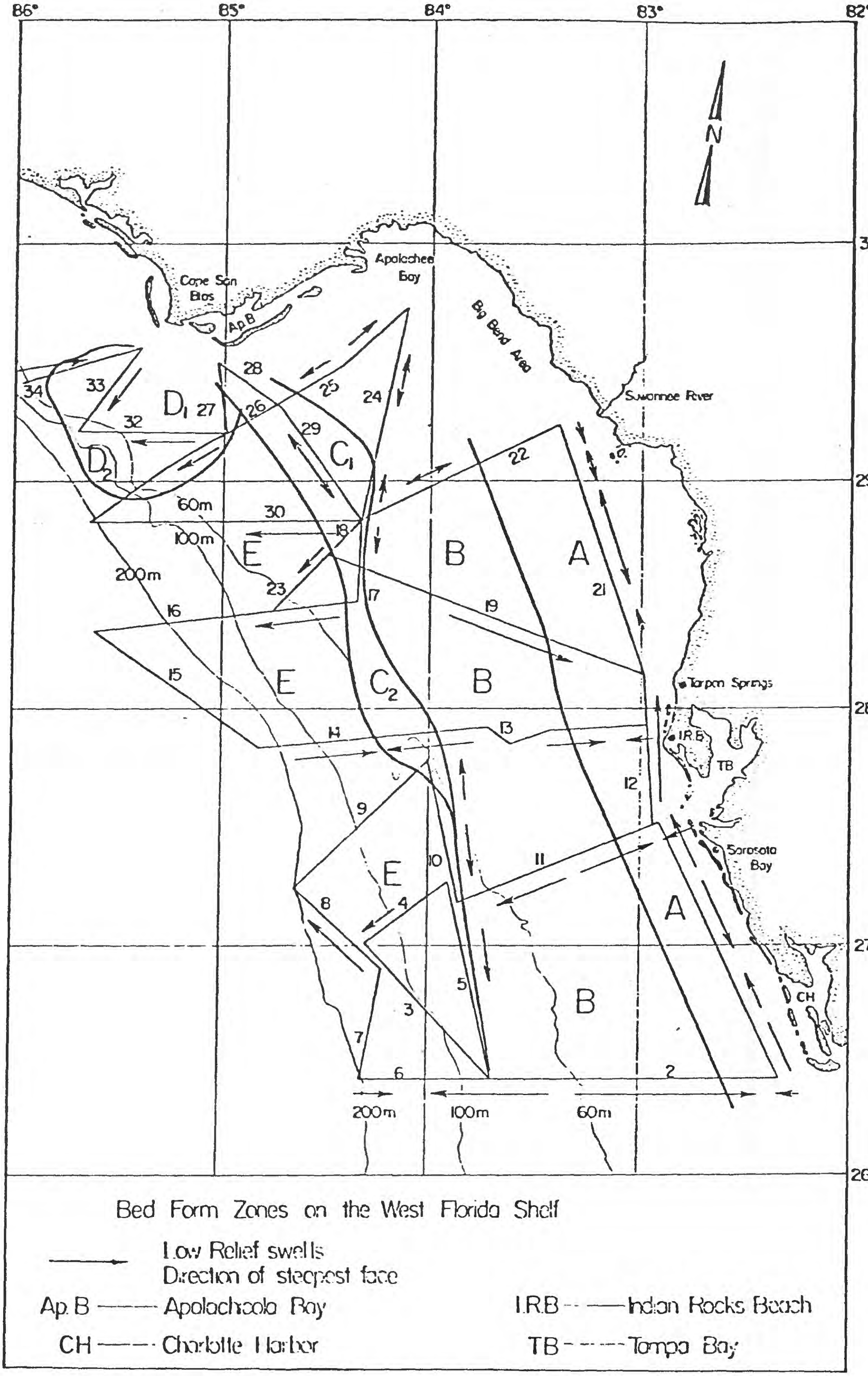

Figure 45. Map showing distribution of bedforms in the MAFLA study area, eastern Gulf of Mexico (from Pyle et al., 1976).

varying sediment supplies, water depths, and changing bottom morphology, cause the formation of bed form distribution on the west Florida shelf.

A series of sand waves is present south of 26° latitude N on the outer shelf between Howell Hook and the shelf break (650 ft, 200 m) (Fig. 46). These features are different from those described above in that they are strongly asymmetrical and occur in sets of four to five with wave heights of 15 ft (5 m), and wave lengths 0.1 mi O 1.2 mi (0.25 to 2 km) (Fig. 47). The existence of such features suggest very strong unidirection bottom currents in a southerly direction. Progradation bedding beneath the surface cover indicates that the forces that created these features have been active for some time. The source of these sediments as indicated by the biologic composition is the same source responsible for the accumulations at the shelf edge, namely the Loop Current.

Faulting

The limited amount of publicly available seismic reflection data in the eastern Gulf area does not allow for a comprehensive analysis of tectonic movement. Analysis of most seismic profiles in which faulting is reported shows that the apparent structural feature described as faulting may in reality be due to velocity anomalies. Faulting can be expected to be present on the outer shelf and on the continental slope. Such features probably would not penetrate the veneer of surface sediments; these faults would have been active only in early Holocene time.

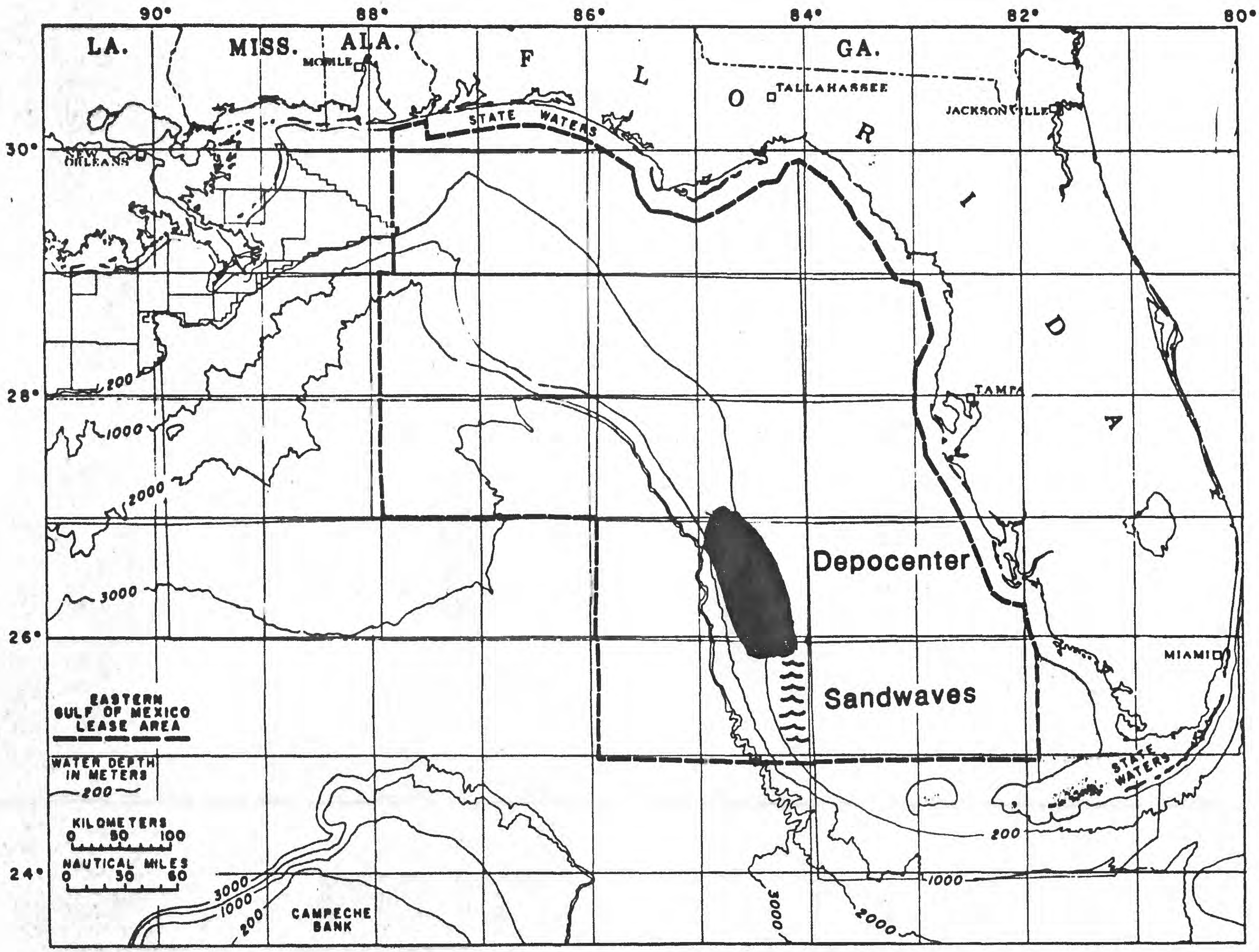

Figure 46. Map showing distribution of sand waves and sediment depocenter formed by pelagic sedimentation caused by impingement of the Loop Current on the continental shelf, eastern Gulf of Mexico.

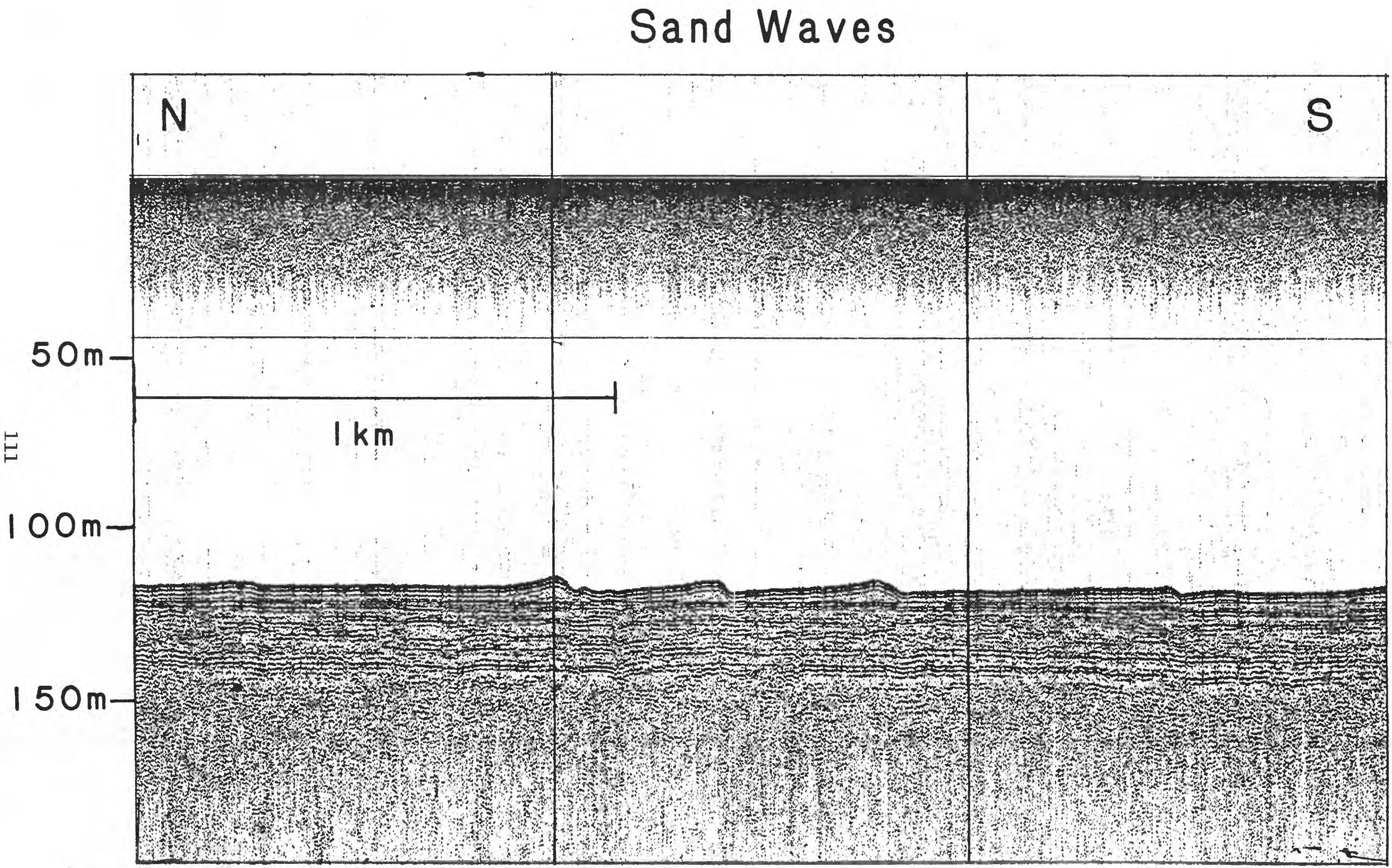

Figure 47. Seismic profile showing a sand wave train on the outer continental shelf south of lat. 26°N, eastern Gulf of Mexico.

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