GEOLOGY OF THE WEST FLOWER GARDEN BANK

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ABSTRACT

The West Flower Garden Bank, located on the outer edge of the Texas-Louisiana continental shelf at longitude 93°49.0' west and latitude 27°52.6' north, was investigated with respect to the subsurface structure of the pre-reef pinnacle, the environment currently surrounding the pinnacle and the carbonate sediments being deposited on the bank.

Based on previous gravity work and on 3.5 kHz, 1 cubic inch air gun and bathymetric profiles taken during this survey, the topographic high is shown to have been formed by the intrusion of a shallow salt plug. The central section of the dome is a collapsed area, flanked on the east, west and north by banks rising to within 10.5 fms (19 m) of the surface. Based on erosional and depositional surfaces of the bank, stillstands of the Gulf of Mexico waters during the last transgression

were at 67-73 fms (121-134 m) sometime prior to 13,000 years B.P.; 40-45 fms (73-82 m) at 17,000-15,000 years B.P.; 48-50 fms (89-90 m) at 14,000-13,000 years B.P. and 28 fms (51 m) 13,000-12,000 years B.P.

The Holocene sediments of the bank are (1) a *Diploria-Montastrea-Porites* Facies from 10.5 fms (19 m) to 27 fms (50 m); (2) a Coral Detritus Facies that interfingers with the *Diploria-Montastrea-Porites* Facies at 17 fms (31 m) and the *Gypsina-Lithothamnium* Facies at 27 fms (50 m); (3) a *Gypsina-Lithothamnium* Facies from 25 fms (46 m) to 40-45 fms (73-82 m); (4) the 1st Transition Facies from 28 fms (51 m) to 50 fms (91 m); (5) an *Amphistegina* Facies from 40 fms (70 m) to 55 fms (100 m); (6) the 2nd Transition Facies between the *Amphistegina* and Quartz-Planktonic Foraminiferal Facies; and (7) a Quartz-Planktonic Foraminiferal Facies from 50 fms (91 m) to the surrounding shelf.

The scleractinian members of the West Indies coral reef community capping the pinnacle are, in order of their decreasing abundance, *Diploria strigosa*, *Montastrea annularis*, *Montastrea cavernosa*, *Porites asteroides*, *Madracis asperula*, *Mussa angulosa*, *Colpophyllia natans*, *Agaricia agaricites*, *Agaricia fragilis*, *Madracis decactis*, *Agaricia nobilis*, *Scolymia* wellsii, Oculina spp. and Siderastrea sp. The coral reef probably constructed the upper 100 feet (30 m) of the shallowest pinnacle, indicating a growth rate of 0.43 cm/year for the reef structure. The main physical parameters controlling the lower limits to which the corals can grow are the low temperatures, low levels of illumination and water turbulence (i.e., mobile substratum) found on the 28 fms (51 m) terrace during the passage of storm fronts. The lack of a more diverse scleractinian fauna on the bank is thought to be due to the length of time the planula stage takes to travel from the Veracruz and Yucatan reefs to the West Flower Garden Bank.

The main coralline algae of the Gypsina-Lithothamnium Facies are Lithothamnium, Lithophyllum and Lithoporella. Together with the encrusting foraminifer Gypsina, they develop nodules on the shallower terraces due to the large waves generated during the summer hurricanes and winter northers. They form free crusts in the less turbulent waters found at greater depths. The Amphistegina Facies is composed of up to 25% Amphistegina test. Scattered throughout this facies and the deeper facies are outcrops of Cenozoic bedrock that are the source of the terrigenous lithoclasts found in the thin sectioned samples. The Quartz-Planktonic Foraminifers Facies is the deepest facies of the bank. The quartz is derived from reworked Pleistocene beaches and sand dunes. The abundance of planktonic foraminifers indicates a lack of carbonate detritus working down-slope from the shallower facies.

Although sparce colonies of hermatypic corals are found growing on Stetson Bank, 30 nautical miles to the northwest, the East and West Flower Garden Banks represent the northern limit of flourishing coral reefs in the Gulf of Mexico.

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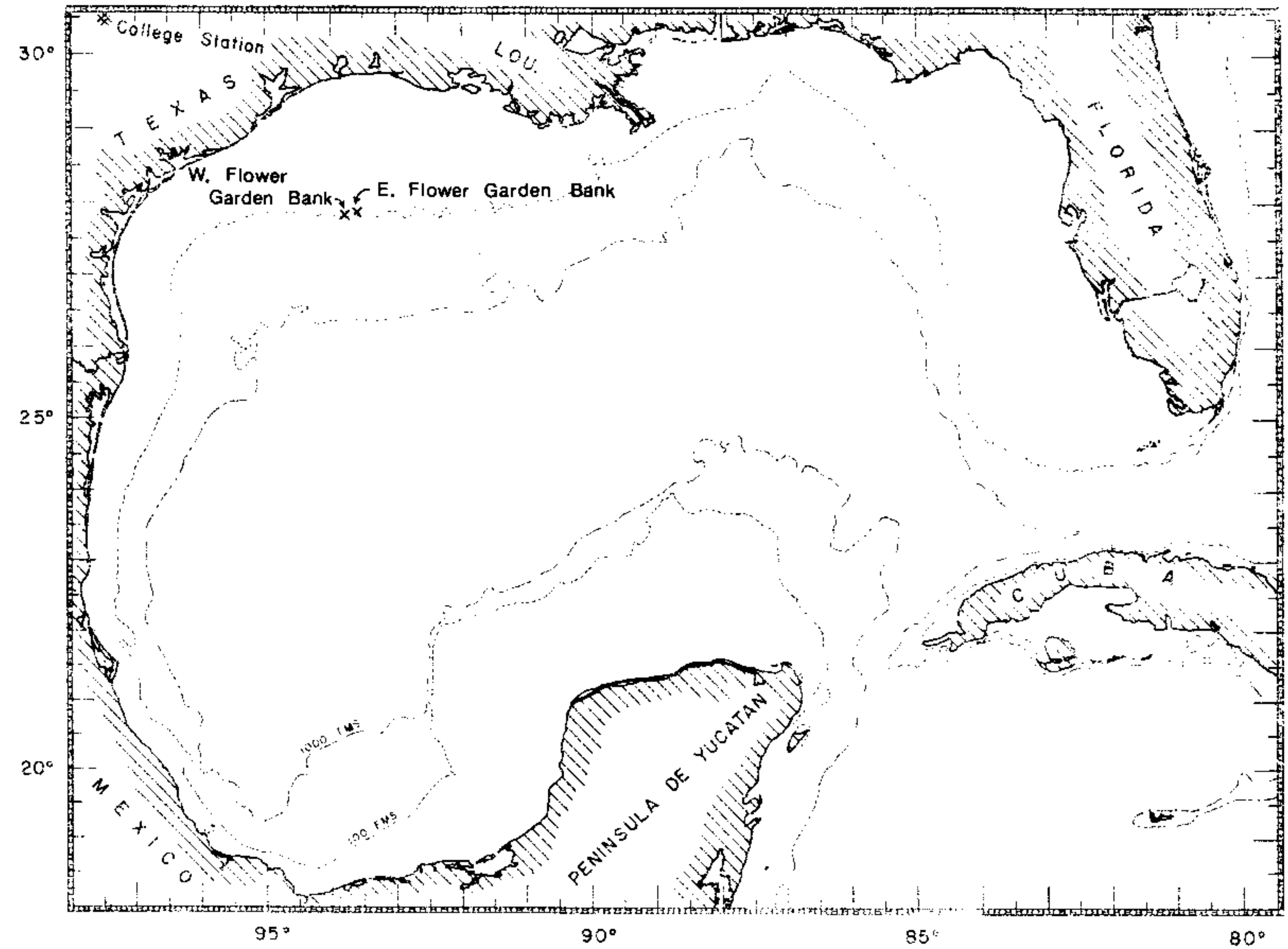
INTRODUCTION

The West Flower Garden Bank, located 107 nautical miles due south of Sabine Pass at longitude 93°49.0' west and latitude 27°52.6' north (Fig. 1), was the first bioherm along the Texas-Louisiana continental shelf to be positively identified as a coral reef (Stetson, 1953). Together with the East Flower Garden Bank, they represent the northern limit of flourishing coral reefs in the Gulf of Mexico. Their discovery helped to establish the outer margins of all the continental shelves surrounding the deeper Gulf as potential sites of carbonate deposition.

This investigation examines the section of the Texas-Louisiana continental shelf bounded by latitudes 27°49'N to 27°57'N and longitudes 93°44'W to 93°55'W. The topographic high situated in the middle of the study area, locally known as the West Flower Garden Bank, rises to within 10.5 fms (19 m) of the surface and forms a favorite fishing ground for snapper fishermen and an underwater paradise for scuba divers. To

Fig. 1. Chart of the Gulf of Mexico giving the locations of the East and West Flower Garden Banks.


College Station
TEXAS
LOU.
FLORIDA
W. Flower Garden Bank
E. Flower Garden Bank
CUBA
PENINSULA DE YUCATAN
MEXICO
1000 FMS
100 FMS
30°
25°
20°
95°
90°
85°
80°

geologists, it represents a site of active carbonate deposition situated on the outer margin of a broad, terrigenous continental shelf.

While the presence of carbonate bioherms and biostromes on the outer Gulf Coast continental shelf has been known since 1937 (Shepard, 1937), knowledge concerning the detailed distribution of living reef building organisms and associated sedimentary facies has been lacking. This publication describes the bathymetry, subsurface structures, physical oceanography and carbonate sediments of the West Flower Garden Bank. These descriptions are used to construct theories on the topography, Holocene sediment facies and origin of the bank. It is hoped that the conclusions reached in this study will be useful to geologists working with the rock column; that it will assist them in delineating ancient environments of deposition.

PREVIOUS WORK

Reefs and Carbonate Facies

In his book The Structure and Distribution of Coral Reefs, Charles Darwin (1842) presented to the scientific community the problems associated with coral reef morphology and reef growth. His personal travels failed to take him into the Gulf of Mexico, therefore his classification of the Florida, Cuba and Mexico reefs is based on ships' logs and letters from friends. His chart showing the worldwide distribution of coral reefs referred to the reefs bordering the coastlines in the southeastern Gulf of Mexico as fringing reefs. Dana (1890) described reefs growing off Florida, Cuba and Yucatan and stated that "the west shores of the Gulf of Mexico, as well as the northern, like Florida, are ... without reefs" (p. 352). Alexander Agassiz (1888, 1894) described reefs from Cuba, Mexico and Florida, but like many of the early workers, he was more interested in the origin and morphology of reef structures in the Gulf than in the sediment facies of the reef complexes. Heilprin (1890), in addition to discussing the morphology of the reefs offshore from Veracruz, Mexico, described the coral fauna and sediment distribution surrounding these patch reefs. From traverses made on Isla de Sacrificios located on the reefs at the Port of Veracruz, he identified 10 species of coral, described the effect of hurricanes on the reef structures and postulated a rate of growth of 1.5 inches (3.7 cm) per year for a few of the shallow water brain corals.

Agassiz (1894) devoted part of his Bahama Banks study to the distribution of sediments on the Bahama Platform. The Bahamas now rank as one of the most thoroughly investigated environments of carbonate deposition, with a few of the more recent works on the sediment facies and reef structures being those by Illing (1954); Newell, et al., (1957); Newell et al., (1959); Imbrie and Purdy (1962); Cloud (1962) and Storr (1964). Storr's paper, The Ecology and Oceanography of the Coral-Reef Tract, Abaco Island, Bahamas concluded that "the wide variety of reef structures (in the Bahamas) ... is due to the combined effect of geological formations, direction of exposure to wind and wave activity, tidal flow, underwater light intensity, temperature and the factors of sedimentation and salinity" (p. 88).

The accessibility of Florida Bay and Florida Reef Tract has permitted detailed analysis of their fauna, flora and sediment facies by various authors (Vaughan, 1919; Young, 1935; Thorp, 1936; Ginsburg, 1957; Taylor, 1960; Shinn, 1963, 1966; Taft and Harbaugh, 1964; Scholl, 1966; and Ball, 1967). Jordan and Stewart (1959) identified the carbonate sediment facies along the west-central Florida shelf and noted the presence of small, dead reef patches in 20-85 fms (37-155 m) on the southwestern Florida continental shelf. Gould and Stewart (1955) reported Pleistocene coralline algal reefs from the same general area. Ludwick and Walton (1957) reported reefs from the outer margins of the Alabama shelf in water depths from 40 to 55 fms (73-101 m). These reefs were reported to be in an intermediate stage between active growth and fossilization and, like the reefs off southwest Florida, had their most active growth during periods of lower sea level. Jordan (1952) reported pinnacles capped by coral reefs from the Middle Ground of the northwest Florida continental shelf. Judging from his comments on the dense fish population, these reefs are probably still alive.

Following Heilprin's article in 1890, reefs in the far western Gulf went unreported in the scientific literature for over 60 years. Recently, these reef structures and their adjacent sediment facies have been described by Emery (1963), Morelock and Koenig (1967), Rigby and McIntire (1966), Edwards (1969) and Freeland (1969, 1971). The Yucatan shelf, with its hazardous reefs and shoals, has been studied in recent years by Kornicker and Boyd (1962), Rice and Kornicker (1962), Walsh (1962), Harding (1964), Folk and Robles (1964), Davis (1964) and Logan, et al. (1969).

The most comprehensive study of any carbonate province in the Gulf of Mexico is that by Logan, et al. (1969). They described the late Quaternary carbonate sediments, coral reefs and banks of this area and related these features to the last transgression of the Gulf waters across the Campeche Platform. From a worldwide viewpoint, the most complete work on coral reefs is that by Stoddard (1969). His paper, entitled "Ecology and Morphology of Recent Coral Reefs" summarizes the current viewpoints on reef ecosystems, the relationship between Quaternary sea level and reef topography and the importance of reef organisms and reef-derived sediments in the construction of the reef framework. Rezak and Edwards (in press) reviewed the work on the distribution of carbonate sediments in the

Gulf of Mexico and presented a chart delineating the coral reefs in this basin.

Sediments of the West Flower Garden Bank

The carbonate facies associated with the Flower Garden Banks have been mentioned by numerous scientists (Shepard, 1937; Carsey, 1950; Ekman, 1953; Galtsoff, 1954; Geodicke 1955; Gealy, 1955; Greenman and LeBlanc, 1956; Parker and Curray, 1956; Forman and Schlanger, 1957; Shepard, et al., 1960; Pulley, 1963; Pierce, 1967; Levert and Ferguson, 1969; Stoddard, 1969; and Rezak and Edwards, in press). The most detailed description of the sediment facies of the Flower Garden Banks is the paper by Stetson (1953). Five of the eight dredge hauls taken on the 1947 winter cruise of the R/V Atlantis in the area of the pinnacles produced a mixture of corals, "lithothamnium" balls and shell fragments while the remaining three returned to deck empty. Two of the four long cores attempted on the flanks of the East Flower Garden Bank produced a mixture of terrigenous and carbonate sediments. Stetson failed to identify the encrusting algae and foraminifers that were building the 'lithothamnium' nodules, but did state that they were living when recovered. Dead specimens of corals, identified as Montastrea gyrosa, Diploria strigosa, Porites astreoides and Madracis mirobilis (sic), were recovered in their dredge hauls. Based on his samples, Stetson was able to divide the East Flower Garden bioherm into three facies: (1) the coral facies from 55 to 150 feet, (17-46 m); (2) the "lithothamnium" ball facies on the terraces at 138 to 160 feet, (24-49 m); and (3) the calcareous and quartz sand facies on the lower flanks of the pinnacle (Fig. 2). Parker and Curray (1956) identified 50 species of molluscs from the Flower Garden Banks plus finger-like colonies of Madracis mirabilis. Most of these coral samples were alive when collected. They concluded that the fauna is similar to, but isolated from, the main West Indian coral reef community.

Pulley (1963) was the first to report that the Flower Gardens were indeed flourishing coral reefs. In 1961, with the assistance of scuba divers, he was able to photograph and collect live corals from both the East and West Flower Garden Banks. Pierce (1967) and Levert and Ferguson (1969) further substantiated Pulley's findings by publishing photographs and short descriptions of the corals and associated organisms of the West Indian coral reef community.

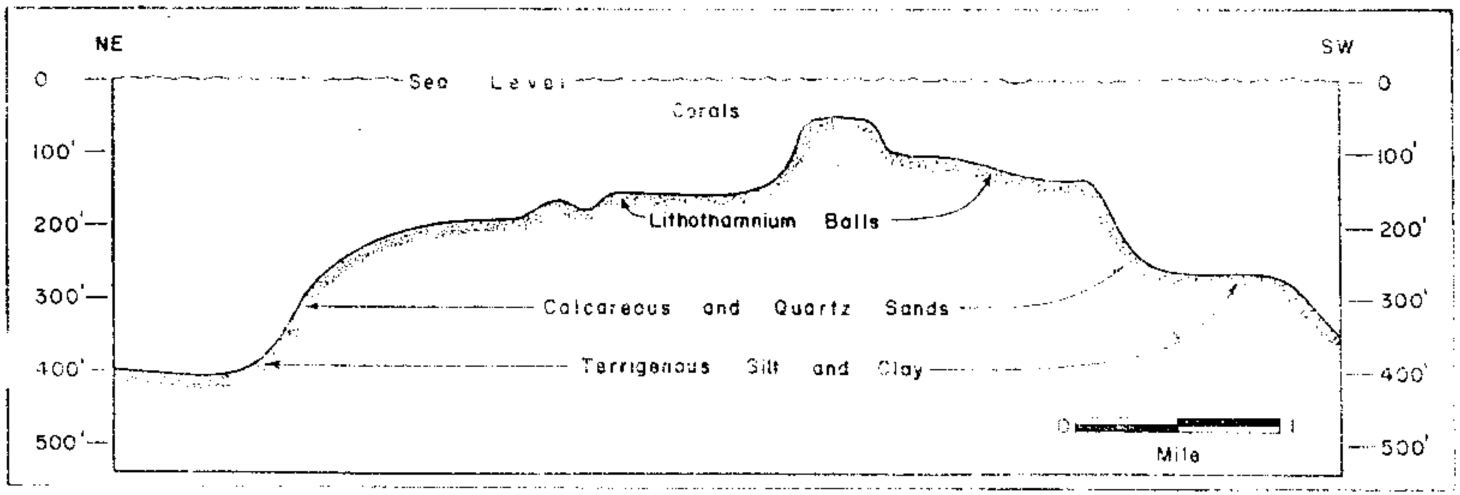


Fig. 2. Cross section of the East Flower Garden Bank showing the sediment zones and terraces described by Stetson (after Stetson, 1948).

Origin of the Pre-Reef Pinnacle

Darwin (1842) placed great emphasis on the structures upon which atoll, barrier and fringing reefs were built. His system of reef classification allowed him to divide the ocean basins into areas of regional subsidence and elevation. Besides the three main types of reefs, Darwin (1842, p. 3) states: "reefs also occur around submerged banks of sediments and worndown rocks; and others are scattered quite irregularly where the sea is very shallow: these in most respects are allied to those of the fringing class, but they are of comparatively little interest." If Darwin had known the importance of glaciers on the Pleistocene and Holocene fluctuations of sea level, it is doubtful that he would have taken this stand on the importance of small, juvenile reef structures. For in the developmental history of reef substrates and in the origin of their structure lie many facts concerning the last regression and transgression of the world's oceans.

In 1936 the U. S. Coast and Geodetic Survey conducted a detailed survey of the Louisiana and Texas continental shelf. Shepard (1937) analyzed this survey and noted the presence of at least 26 pinnacles along the outer portion of the northwest Gulf of Mexico continental shelf. Carsey (1950), using the unpublished flow sheets of the 1936 U.S.C. & G.S., contoured the two features known as the East and West Flower Garden Banks (Fig. 3). He agreed with the hypothesis originally proposed by Shepard (1937) that salt tectonics probably formed these pinnacles, but noted that the state of Veracruz, Mexico, contains similar features caused by igneous plugs. Stetson (1953), while not rejecting the salt dome hypothesis for the origin of the pinnacles, suggested that they were bioherms built during the last transgression of the sea. He presented a profile of the East Flower Garden Bank (Fig. 2) showing major terraces at 10, 30 and 62 fms (18, 55 and 113 m). Geodicke(1955) drew an analogy between the Persian and North German salt basins and the Gulf coast geosyncline near Galveston. He suggested a genetic relationship between the proposed salt tectonics and the pinnacles found along the outer Gulf shelf. Gealy (1955), in her study of the topography of the outer continental shelf, suggested that some of the pinnacles on the outer shelf might be related to salt domes, but hypothesised that erosional processes formed most of the relief observed along the edge of the shelf. Hydrographic charts published by Parker and

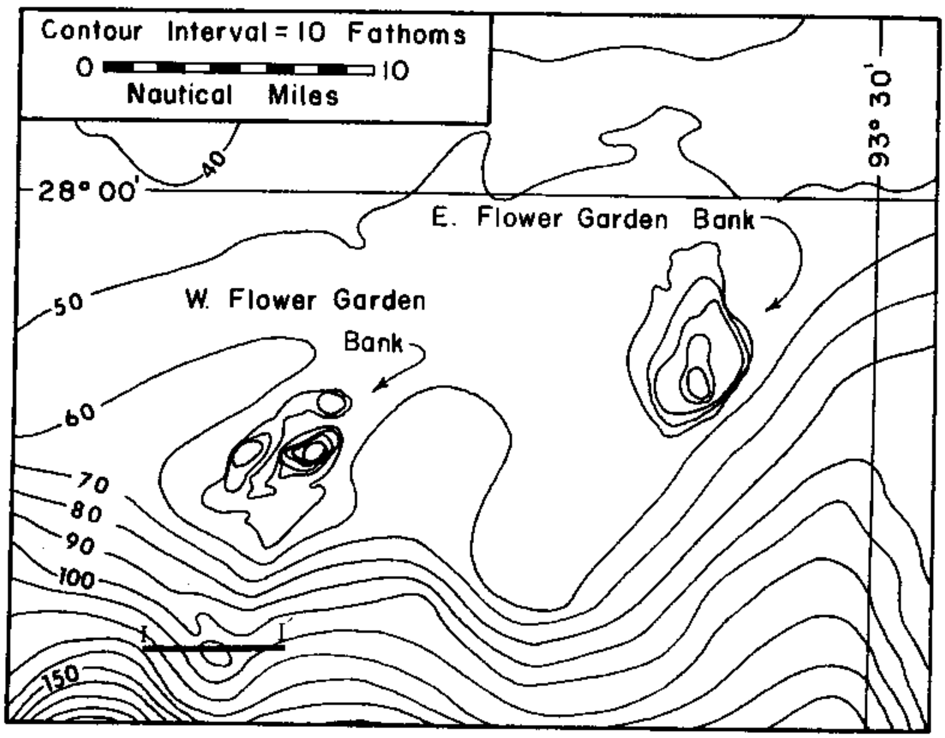


Fig. 3. Carsey's contour chart of the East and West Flower Garden Banks (after Carsey, 1950). The heavy line plots subsurface profile II'.

Curray (1956) of both the East and West Flower Garden Banks were based on the 1936 survey, the chart published by Carsey (1950), and sounding lines run by the trawler Neva J. during their own survey (Fig. 4). Their conclusions concerning sea level stands will be presented in more detail later; however, it is worth noting that they considered the flat tops of the Flower Garden Banks to be due to both erosional processes and cessation of coral growth.

In 1956 Nettleton (1957) conducted a gravity survey of the West Flower Garden Bank. Based on 50 stations situated over the mound and on the topography as published by Parker and Curray (1956), Nettleton (1957) states:

(1) The gravity anomaly is caused by a very large, shallow salt dome quite possibly, but not certainly, having a substantial overhang.

(2) The Dome is shallow with a depth probably less than 2,000 ft. deep and possibly very shallow.

(3) The dome probably is without substantial thickness of caprock.

(4) The shallow dome is genetically related to the topographic mound.

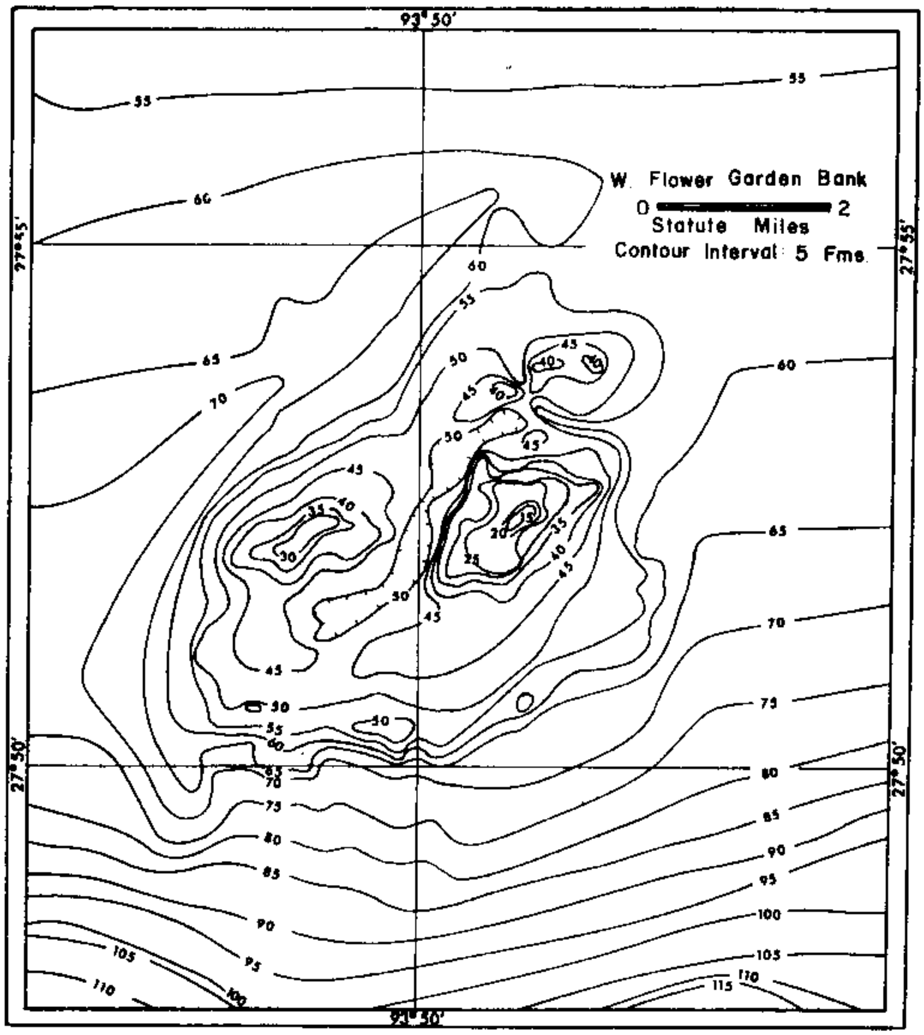


Fig. 4. Parker and Curray's contour chart of the West Flower Garden Bank (after Parker and Curray, 1956).

Figure 5 reproduces Nettleton's residual and calculated gravity profiles of an east-west line across the top of the dome and figure 6 shows his residual gravity contours of the area. In his calculations he estimated the source formation from which the salt dome originated to be in excess of 35,000 ft. below the surface. He also speculated that due to the small geographical dimensions of the central pinnacle, its relief was probably due to a combination of erosion and coral growth. Articles by Curray (1960), Phleger (1960), Parker (1960) and Shepard (1960) in Recent Sediments of the Northwest Gulf of Mexico review the literature on the fauna, topography, and sea level fluctuations on the continental shelf where the Flower Garden Banks are situated. Levert and Ferguson (1969) published a review of previous work on the origin of the Flower Garden Banks and presented several new profiles across both banks.

Sea Level Fluctuation

Accurate bathymetric charts of the continental shelf have permitted recognition of wave cut terraces, ancient shorelines, depths to the tops of pinnacles

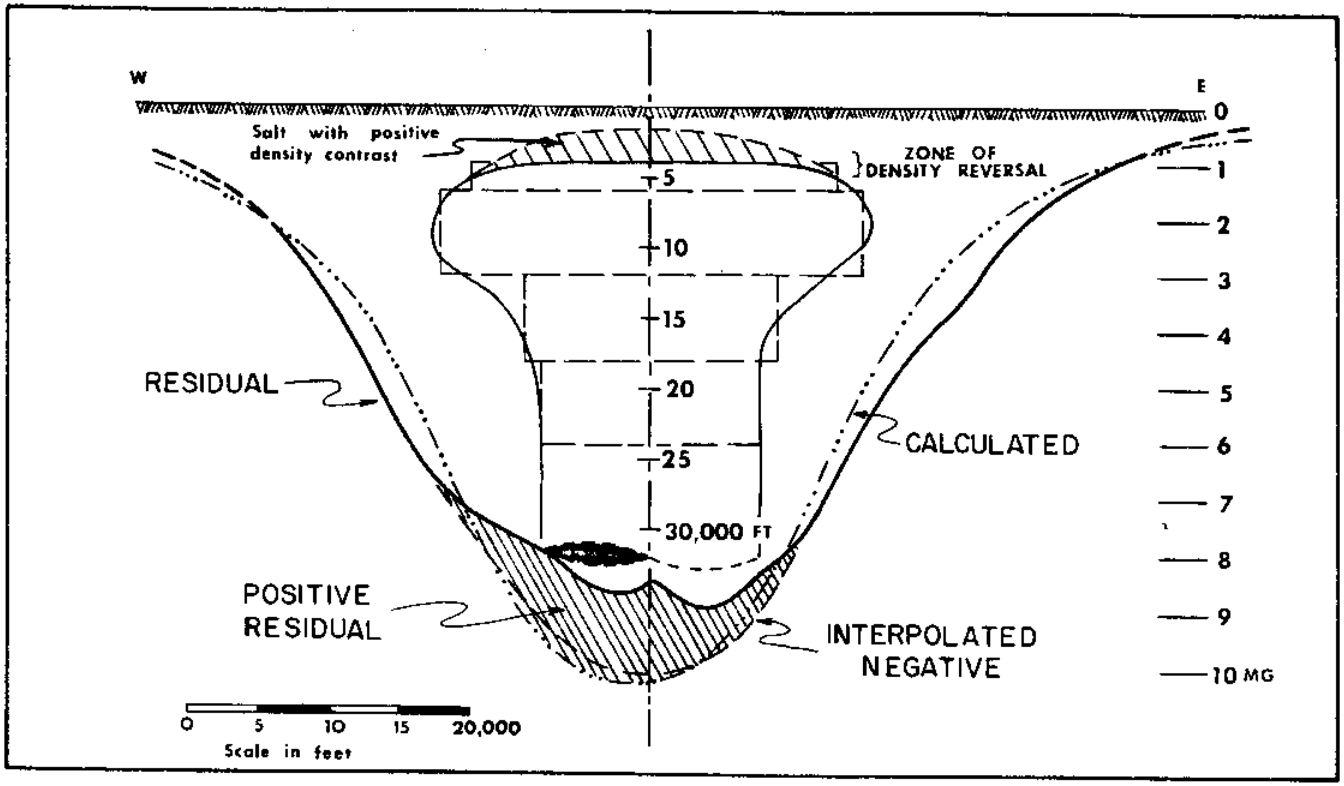


Fig. 5. Calculated and residual gravity anomalies of the West Flower Garden Bank (after Nettleton, 1957).

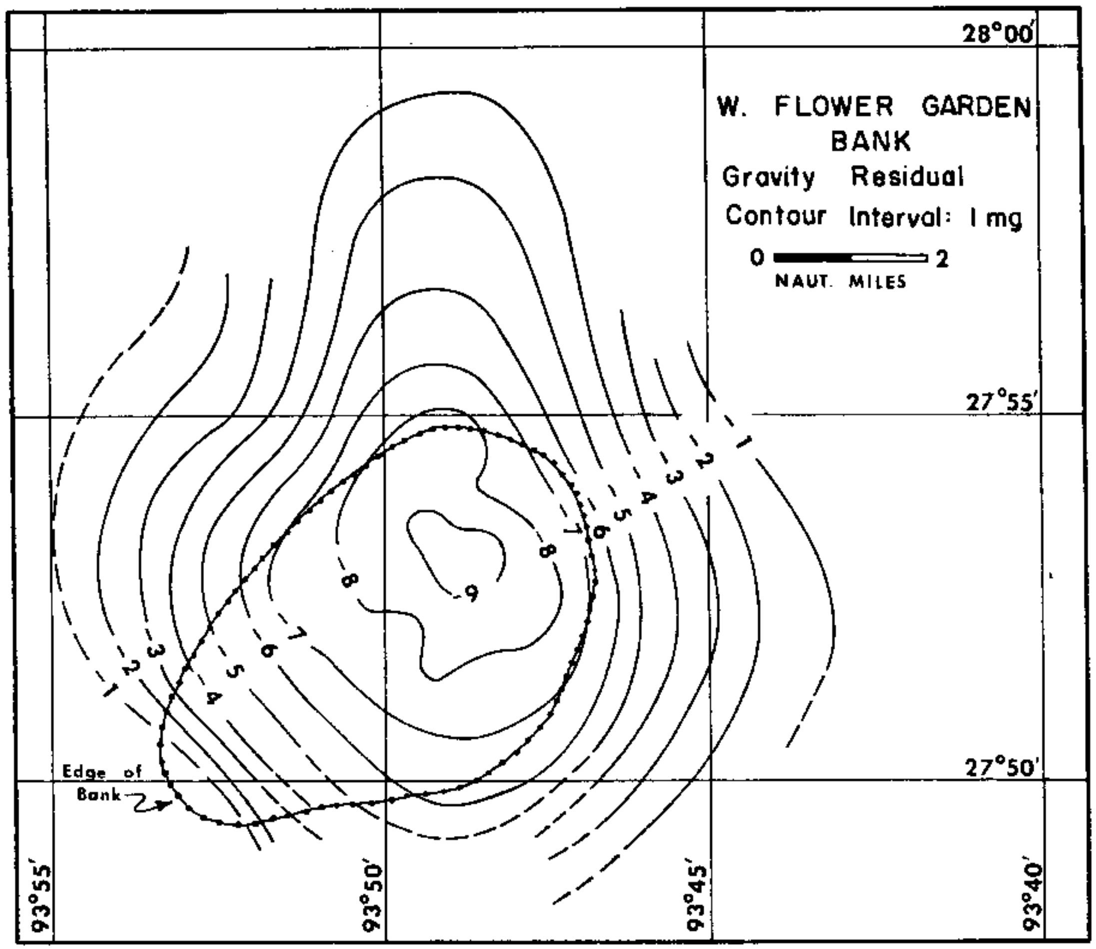


Fig. 6. Contour chart of the gravity residual of the W. Flower Garden Bank (after Nettleton, 1957).

and drowned river channels. These features have, in turn, been used to postulate the sequence of events that took place during the last transgression of the Gulf of Mexico across its shelves. With the development of the 3.5 kHz profiler system researchers acquire the ability to identify shallow subsurface structures beneath these topographic features. This allows geologists to determine whether these structures were formed by tectonic, erosional, or depositional processes.

Carsey (1950) observed that the flatness of the Gulf Coast shelf and the "break off" in slope at 65 to 70 fms (119-128 m), as shown on his chart of the Flower Garden Banks (Fig. 3), could be a product of wave planation during a Pleistocene lowering of sea level to 70 to 80 fms (128-146 m). From their contour charts of the East and West Flower Garden Banks, Parker and Curray (1956) noted that major tops of mounds overlying the west dome were found at 11, 30 and 40 fms (20, 55 and 73 m). At 45 fms (82 m) they identified a well developed terrace with a poorly developed terrace at 25 fms (46 m). Parker and Curray (1956) published a histogram (Fig. 7) showing the most frequently occurring depths to the top of domes offshore from Texas and Louisiana to be at 9, 31 and 45 fms (17, 57 and 82 m).

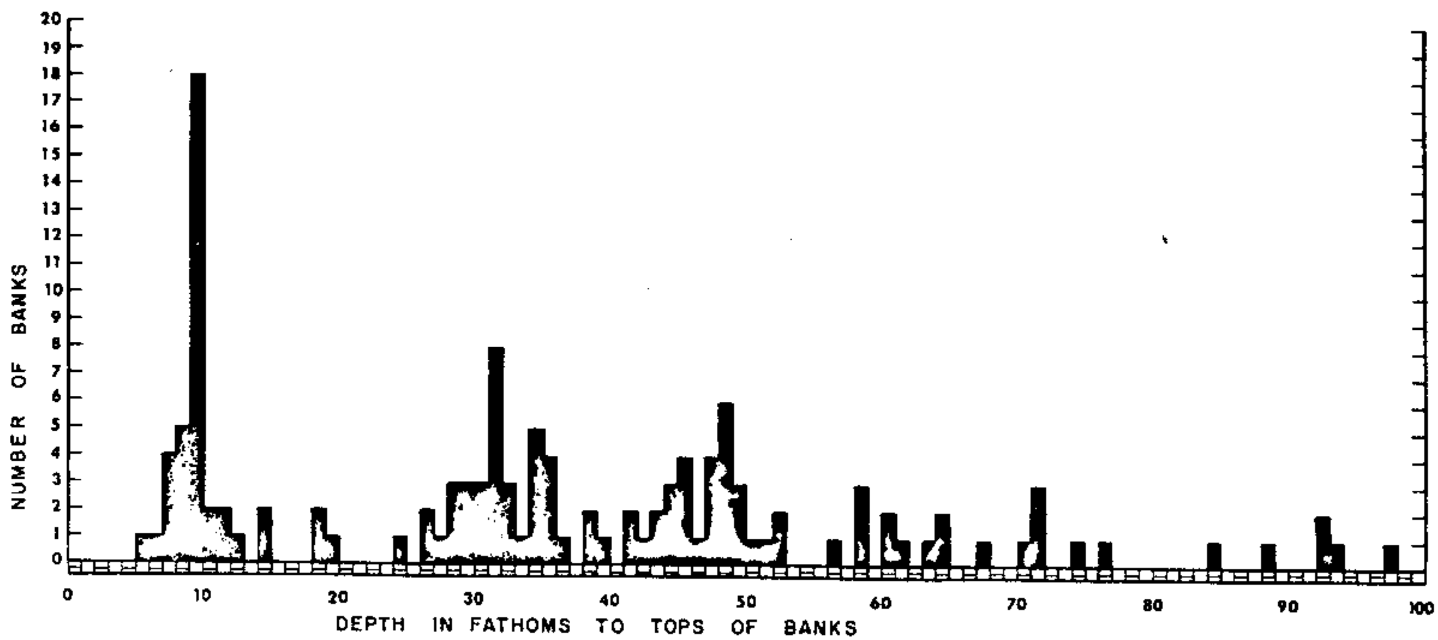


Fig. 7. Histogram of banks on the Texas and Louisiana shelf grouped according to their shallowest depths (after Parker and Curray, 1956).

They believed that these tops were formed during stillstands of the last transgression. Jordan and Stewart (1959) described Howell Hook, a 65 mile long spit and lagoonal structure situated between 75 and 100 fms (137 and 183 m) and a smaller spit at 68 fms (124 m) along the southwestern edge of the Florida continental shelf. These spits, together with a similar feature at 30 fms (55 m) (Gould and Stewart, 1955) were attributed to stillstands during the last transgression at 90-100, 70 and 30 fms (165-138, 128 and 55 m) respectively. Moore and Curray (1963) examined three low frequency continuous reflecting profiles across the continental shelf off Louisiana and Texas and concluded that the shelf terraces were built by processes of upbuilding and outbuilding with local modifications caused by salt tectonics. Because of the low resolving power of their arcer system, they were unable to delineate the shallow structures. This prevented them from correctly evaluating subareal and submarine erosional structures formed during the last low stand of sea level.

Curray, in _Recent Sediments, Northwest Gulf of Mexico_ (1960), examined bathymetric charts, reworked Pleistocene and Holocene sediments, environmental processes and carbon 14 dates from shells found on the NW Gulf shelf before deriving a sequence of events for the last transgression (Fig. 8). Briefly, his sequence of events are:

(1) Prior to 18,000 years B.P. A 65 fms (119 m) stillstand of the Gulf of Mexico based on: (a) the edge of the shelf, as defined by an increase in slope, is found at this depth and no terraces are found below 65 fms (119 m) in the northwestern Gulf; (b) the presence of basal sands at this depth; and (c) the base of high erosional escarpments at this depth.

(2) 18,000 to 16,000 years B.P. A stillstand of 45 fms (82 m).

(3) 16,000 to 12,000 years B.P. A continued stillstand at 45 fms (82 m) with a slight reversal to perhaps 50 fms (91 m). The 50 fms (91 m) stand is based on the presence of low escarpments at this depth and the pinnacle planation described by Parker and Curray (1956). Towards the end of this period the sea rose to approximately 25 to 22 fms (46 to 40 m).

(4) 12,000 to 10,000 years B.P. A high of 25 to 22 fms (46 to 40 m) at the beginning of the period based on the sediments, submerged channels and

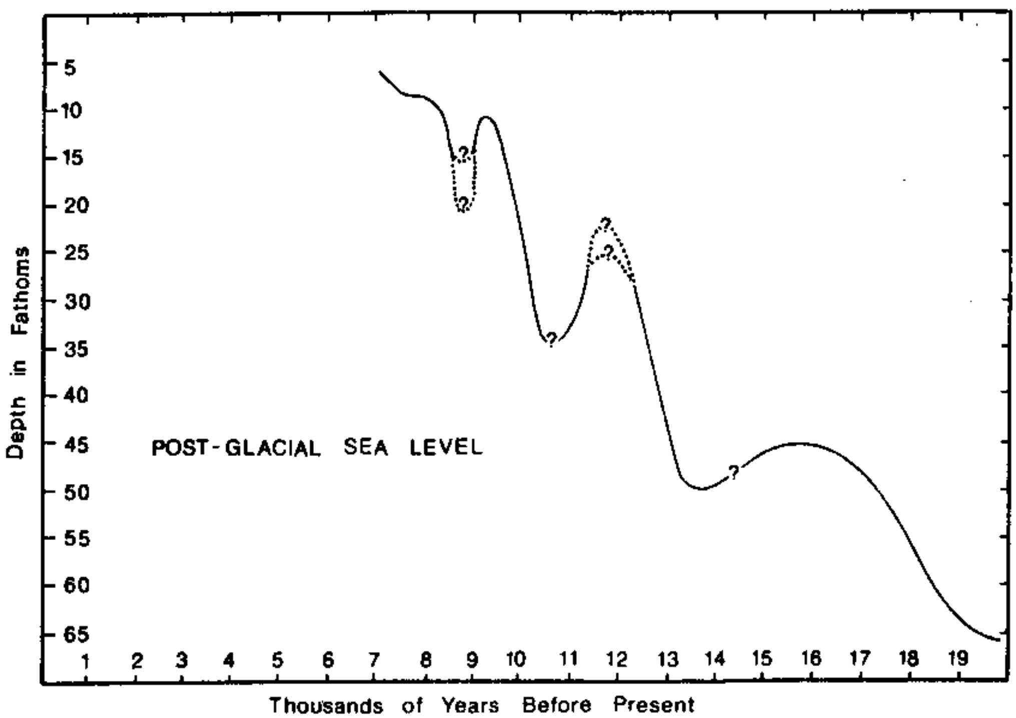


Fig. 8. Graph of the sea level rise during the last transgression (after Curray, 1960).

barrier bars at this level. Between 12,000 and 11,000 years ago the glaciers readvanced across portions of the Northern Hemisphere, lowering the seas to 35 fms (64 m) which in turn forced the rivers along the Texas and Louisiana shelf to erode new channels. At 11,000 to 10,000 years B.P. the Gulf waters warmed bringing a new suite of planktonic foraminifers into the northern Gulf.

(5) 10,000 to 7,000 years B.P. The seas readvanced to approximately 10 fms (18 m), then returned to 21 fms (38 m) for a brief stillstand, followed by a transgression to its current level 7,000 years ago. The abundance of banks with their tops at 9 fms (16 m) suggests a short stillstand at this depth during the migration of the waters across the shelf. Shepard (1960), van Andel (1960), Phleger (1960) and Parker (1960), the other authors of the volume, agree with Curray's timetable (Fig. 8).

In their detailed analysis of the carbonate sediments and bathymetry of the Campeche shelf, Logan et al. (1969), proposed the following stillstands for the last Quaternary transgression of the sea:

(1) 18,000 to 13,000 years B.P. A stillstand of the sea at 50 to 75 fms (91 to 137 m) based on radiocarbon dates from shallow water carbonate sediments, the presence of terraces along the outer shelf and the abundant lithoclasts in the unconsolidated surface sediments found at this depth.

(2) approximately 11,000 years before present. A stillstand at 28 to 35 fms (51 to 64 m) based on erosional terraces and the type of sediments associated with those terraces.

(3) 9,000 to 8,000 years B.P. A stillstand at 16 to 20 fms (29 to 37 m) based on shallow terraces, radiocarbon dates from shallow water ooids and the presence of shallow water sediments blanketing the shelf at this depth.

Ballard and Uchupi (1970) reviewed the literature on the morphology of the United States Gulf Coast shelf and found that three ancient shorelines could be described. These are located at:

(1) 87 fms (110 m). During the lowering of sea level 70,000 or 14,000 years B.P., coastal spits and lagoons, offshore submarine canyons and erosional stream valleys were formed. These were preserved in the bathymetry of the

outer shelf and upper slope as the seas transgressed 14,000 years ago.

(2) 33 fms (60 m). They postulated that the sea fluctuated around this depth 10,000 years B.P., forming a major ridge and valley complex from Cape San Blas to the Dry Tortugas, a break in slope eastward of Howell Hook, a cuspate foreland at 33 fms off Cape San Blas and a distinctive series of bulges in the 33 fms contour from Cape San Blas to the Rio Grande.

(3) 22 fms (40 m). During the transgression from the 33 fms (60 m) depth, the sea paused at the 22 fms (40 m) level. The land forms produced during this stillstand have been modified by the subsequent readvancement of the sea, producing an "intricate mixture of modern and ancient surface forms" (Ballard and Uchupi, 1970, p. 556).

They mentioned the break in slope offshore from Texas and Louisiana at 71 fms but failed to place any significance in it.

TABLE 1

Stillstands of the Gulf of Mexico
During the Last Transgression

Authors	Depth Fathoms	Meters	Time Years Before Present
1. Carsey (1950)	70-80	128-146	not given
2. Parker & Curray (1956)	45	82	not given
	31	57	not given
	9	17	not given
3. Jordan & Stewart (1959)	90-100	196-183	not given
	70	128	not given
4. Gould & Stewart (1955)	30	55	not given
5. Curray (1960)	65	119	prior to 18,000
	45	82	18,000-16,000
	50	91	16,000-12,000
	22-25	40-46	12,000
	35	64	12,000-11,000
	10	18	10,000-8,000
	21	38	10,000-8,000
	9	16	9,000-8,000
6. Logan, et al., (1969)	50-75	91-137	18,000-13,000
	28-35	51-64	11,000
	16-20	29-37	9,000-8,000
7. Ballard & Uchupi (1970)	87	110	70,000 or 14,000
	33	60	10,000
	22	40	8,000
8. this paper	over 100	over 183	unknown
	66-73	121-134	prior to 18,000
	40-45	73-82	17,000-15,000
	48-50	89-90	14,000-13,000
	28	51	13,000-12,000

PHYSICAL OCEANOGRAPHY OF THE WEST FLOWER GARDEN BANK

The value of any study dealing with an active environment of carbonate deposition lies not only in a description of the sediment facies but also in a description of the surrounding environment. By being able to identify the physical agents that control the deposition of calcareous sediments, the study will assist geologists in their interpretation of the hydrology and meteorology of ancient environments. Unfortunately, the cost and difficulties of obtaining physical oceanographic data from the West Flower Garden Bank makes this objective difficult to meet. Information from the Texas A&M Department of Oceanography, the National Oceanographic Data Center and from conversations with Texas and Louisiana sport divers and fishermen gives only a sporadic coverage of this section of the Gulf of Mexico.

Water Temperature

Water temperatures listed in table 2 are based on bathythermograph data available from the National

TABLE 2

Mean Monthly Water Temperatures for the Flower Garden Banks. Bathothermograph data from the National Oceanographic Data Center for the area between 93°30' - 94°00'W and 27°30' - 28°00'N.

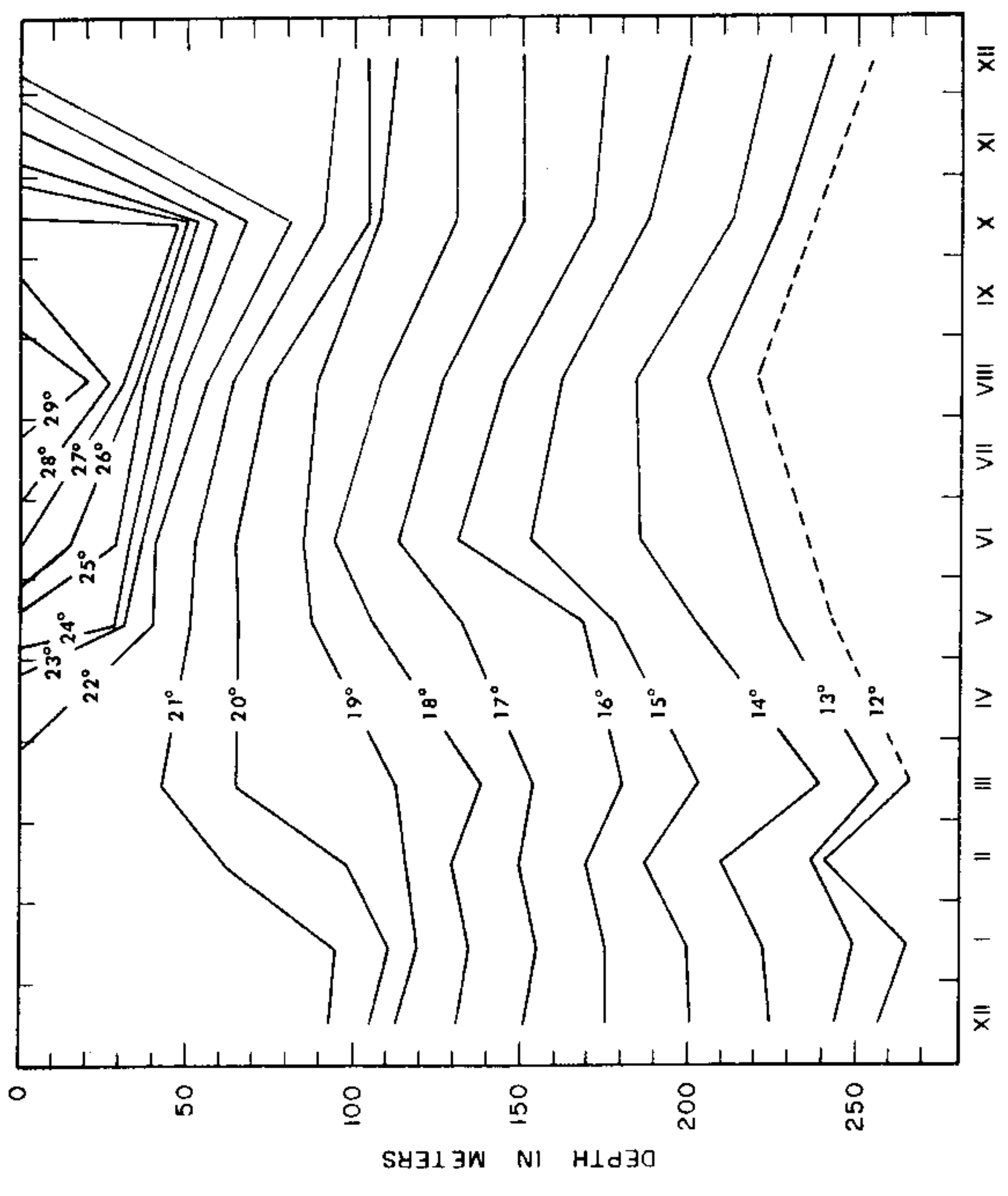
Month	Surface			20 m			50 m		
	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.
I	21.3	22.7	19.6	21.2	22.7	19.6	21.2	22.5	19.6
II	20.5	21.2	19.9	20.4	21.2	19.8	20.2	20.9	19.8
III	20.2	20.6	18.8	19.8	20.4	18.3	19.4	20.3	18.2
IV	22.7*	-	-	22.8*	-	-	24.0*	-	-
V	25.3	25.4	25.2	25.0	25.3	24.5	21.3	21.5	21.0
VI	27.1	28.0	26.6	25.6	27.9	24.7	21.2	22.7	20.3
VII	28.4*	-	-	28.1*	-	-	24.0*	-	-
VIII	29.7	30.4	29.1	29.0	29.8	28.1	23.3	24.7	21.9
IX	28.6	29.9	27.7	28.2	28.8	27.8	24.2	28.3	22.1
X	26.4	27.5	24.4	26.4	27.6	24.4	25.8	27.5	24.4
XI	23.8	24.0	23.6	23.8	24.1	23.5	23.8	24.1	23.4
XII	23.1*	-	-	23.1*	-	-	23.1*	-	-

*Averages based on one observation

Oceanographic Data Center and records from Texas A&M University for the area bounded by longitudes $93^{\circ}30'$ to $94^{\circ}00'$ W and latitudes $27^{\circ}30'$ to $28^{\circ}00'$N, an area inclusive of both the East and West Flower Garden Banks. The maximum temperature observed at depths equivalent to the reef tops (i.e., 20 m) was 29.8°C and the minimum value was 18.3°C. Averages represent the mean temperatures for the available data, but precaution should be taken in judging these averages since one cruise lasting only several days and measuring only one set of conditions might account for a majority of the data. Figure 9 from Parker (1968) shows the mean monthly temperature profile for the water mass above the upper portion of the Texas and Louisiana continental slope between longitudes 92°-96°W and latitudes $27^{\circ}30'$-27° 50'N. The sporadic data available suggest that during January and February the mixed-layer depth extends to approximately 100 m while the summer thermocline varies in depth depending on the storm activity.

Dana (1843), Vaughan (1919), and others, have noted the effect temperature has on the distribution of coral reefs. Vaughan and Wells (1943) indicate that the length of exposure time is critical to the coral polyp. Unfortunately, this type of serial data are

Fig. 9. Graph of the mean monthly water temperatures versus depth for the area adjacent to the Flower Garden Banks (after Parker, 1968).

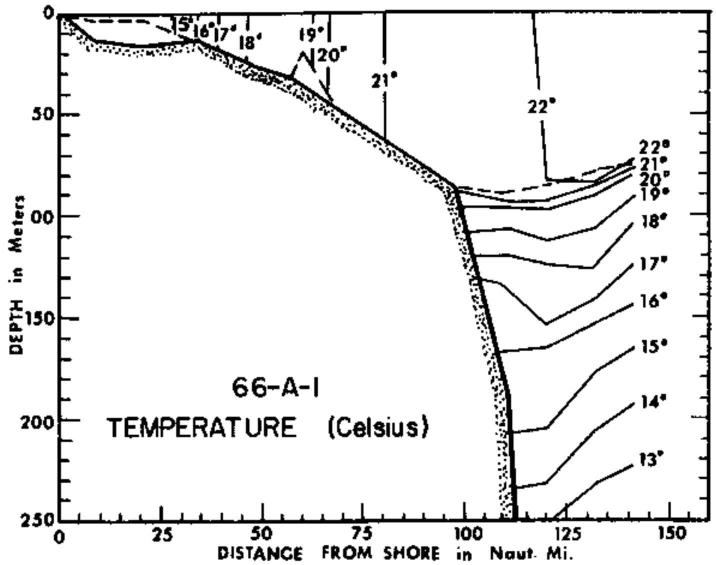

DEPTH IN METERS
0
50
100
150
200
250
MONTHS
XII
I
II
III
IV
V
VI
VII
VIII
IX
X
XI
XII
29°
28°
27°
26°
25°
24°
23°
22°
21°
20°
19°
18°
17°
16°
15°
14°
13°
12°

very difficult to obtain from a spot on the ocean located over 100 nautical miles from the nearest land. Parker (1968), in a quasi-synoptic study of the Texas and Louisiana shelf, shows the amount and rate of change of water temperature after the passage of a cold front. Figure 10A is a vertical temperature profile taken from the R/V Alaminos cruise 66-A-1 while figure 10B is based on data taken on cruise 66-A-2, 15.7 days later. Figure 17 shows the course followed on both cruises. During the 15.7 days there was a crop of over 1.5°C in the water surrounding the Flower Gardens.

Salinity

Salinity variation in the water surrounding the Flower Garden reefs is minimal and is characteristic of an ocean environment with the measured salinity values for depths equivalent to the coral reef ranging from 35°/oo to 36°/oo. Figure 11 (Nowlin, in press) is a vertical profile made in March, 1962, that extends along longitude 93°W from the Louisiana shoreline southward to latitude 26.5°N and figure 12 represents two vertical salinity profiles taken on cruises 66-A-1 and

A.



B.

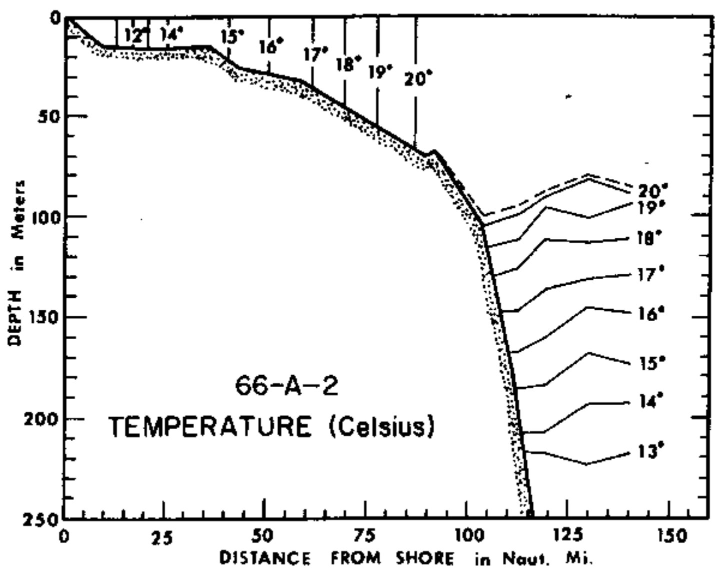


Fig. 10. Water temperature profiles extending from Galveston, Texas, to 150 nautical miles offshore, cruises 66-A-2 (after Parker, 1968).

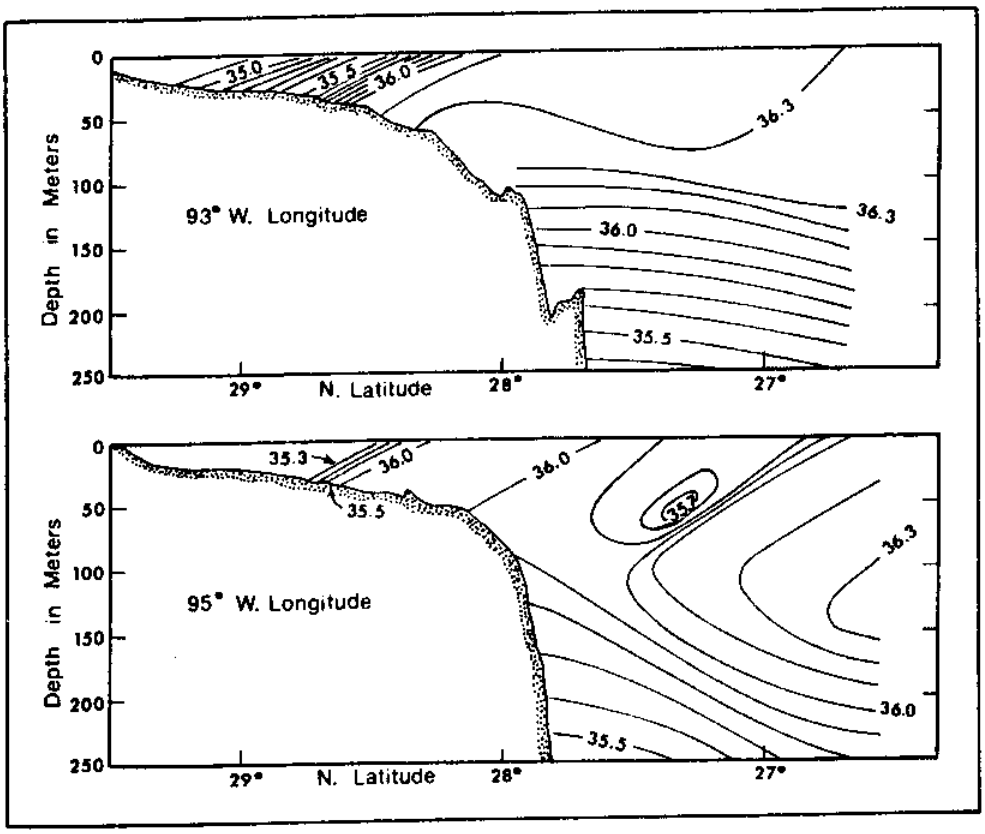


Fig. 11. Salinity profiles across the shelf and slope along longitudes 93°W and 95°W for March 1962 (after Nowlin, in press). Salinity values in parts per thousand.

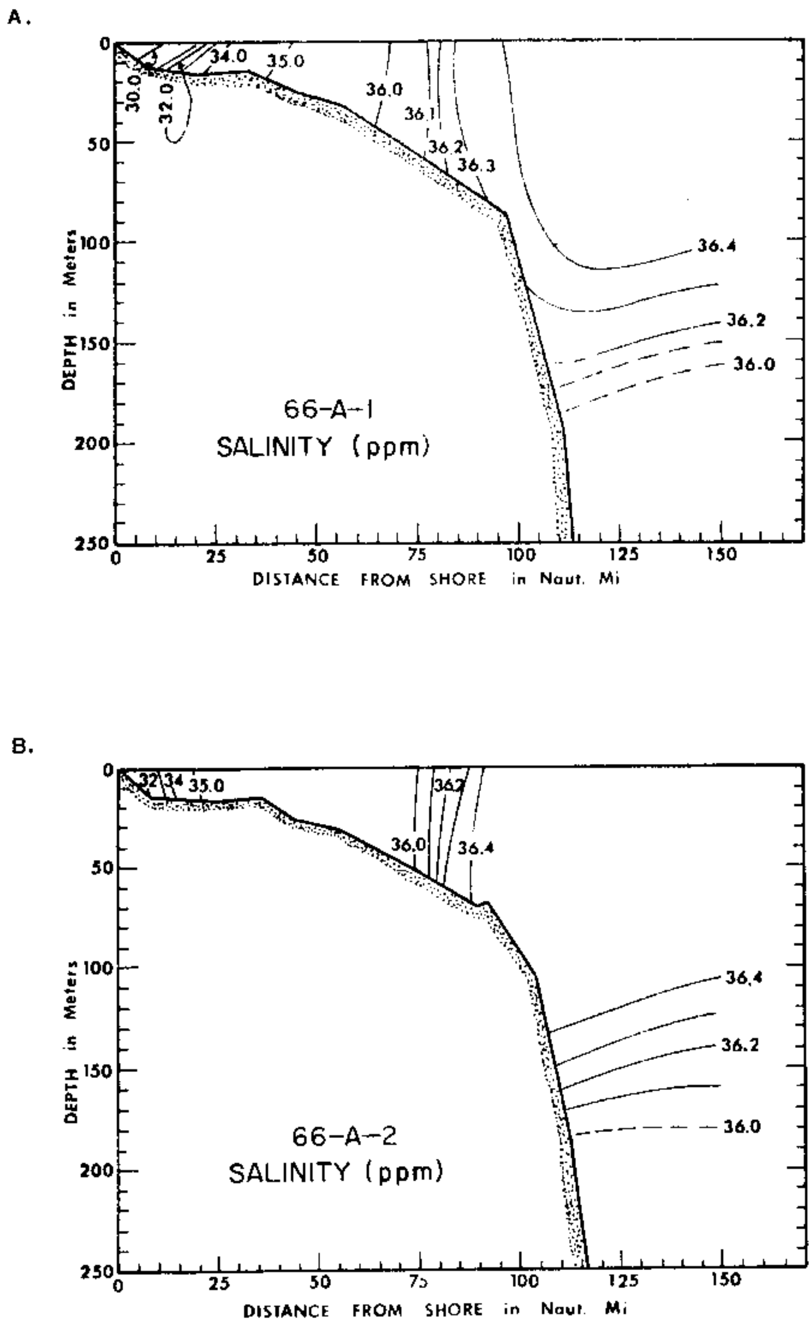


Fig. 12. Salinity profiles extending from Galveston, Texas to 150 nautical miles offshore, cruises 66-A-1 and 66-A-2 (after Parker, 1968). Salinity values in parts per thousand.

66-A-2 that extend SSE from Galveston, Texas, to $18^{O}N$, passing between the two reef pinnacles.

Light Intensity

Accurate measurements of the light absorbing properties of the water surrounding the West Flower Garden Bank have not been made. Two stations (Fig. 13) from the central Gulf of Mexico are thought to be typical of the light intensity available to the organisms living at various depths on the bank. They represent ideal conditions during periods when clear, oceanic water covers the area. Periods of high productivity will greatly reduce the transparent qualities of the water which, in turn, reduces the amount of light available to the biota living on the bank.

Other Physical Parameters

Figure 14 gives a January and August profile of the oxygen content versus depth of the near surface waters from stations close to the West Flower Garden Bank. The summer and winter phosphate values for the near surface waters located above the upper continental slope are shown in figure 14. Values for the pH range

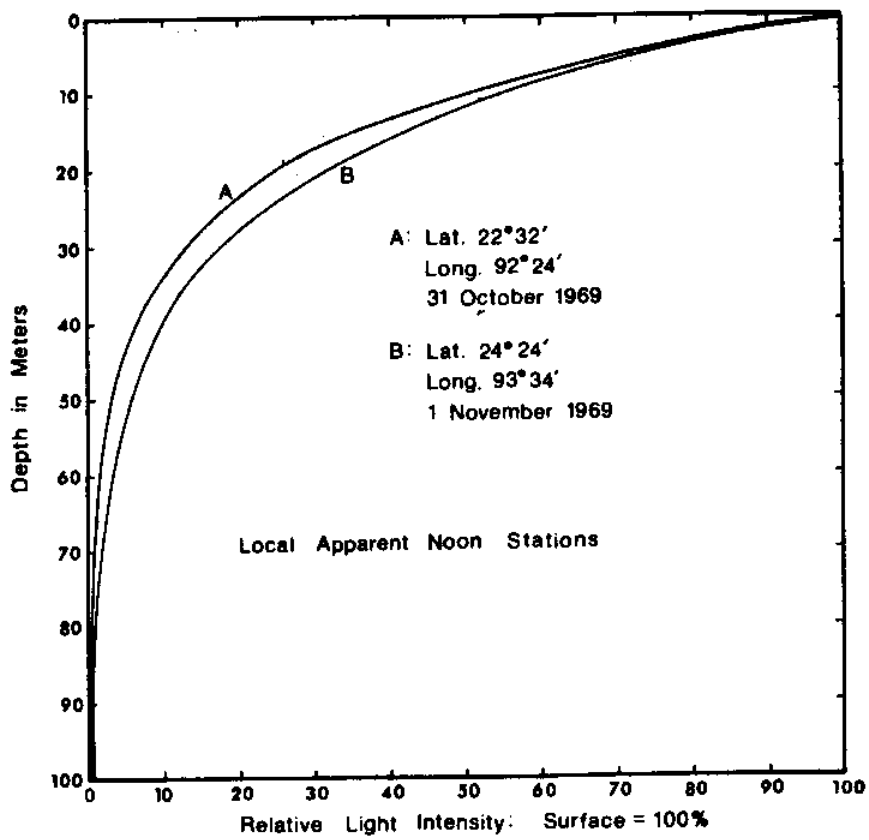


Fig. 13. Relative light intensity versus depth for the water surrounding the Flower Garden Banks.

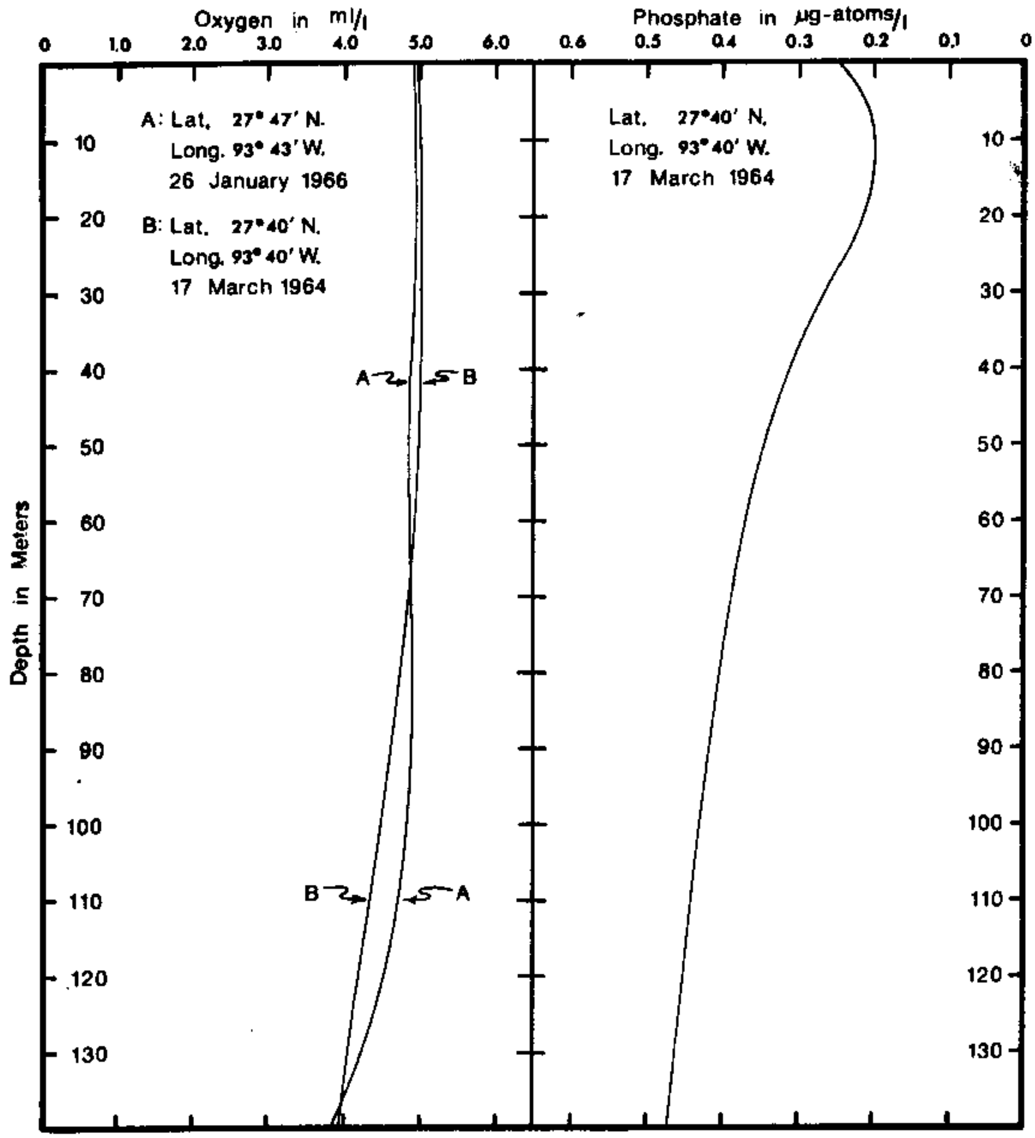


Fig. 14. Oxygen and phosphate values for the water surrounding the W. Flower Garden Bank.

from 8.22 to 8.27. Although the pH readings are of questionable accuracy, they do indicate that a normal, open ocean environment surrounds the bank.

Hurricanes

The dominant mechanical forces for the destruction of the reef and for the movement of carbonate sediments from the reef pinnacle to the flanking beds are large waves generated by the hurricanes that enter the Gulf of Mexico. On the average 3 or 4 hurricanes enter the Gulf every year and any one section of the Texas and Louisiana coastline can expect to be affected by the winds from a hurricane at least once every 5 years (Russel and Schueller, 1971). Waves generated by hurricane force winds are difficult to measure, but based on the radius of maximum wind, the barometric pressure and the forward velocity of a hurricane, Patterson (1971) was able to hindcast hurricane wave heights for storms in the Gulf. Table 3 lists the hindcast wave heights from hurricanes Carla, Betsy and Hilda as developed by Patterson. Maximum wind speeds were 84 knots for Carla, 83 knots for Betsy and 59 knots

TABLE 3

Hindcast of Hurricane Generated Waves from Hurricanes Carla, Betsy and Hilda. Water depth is 50 fms. (after Patterson, 1971)

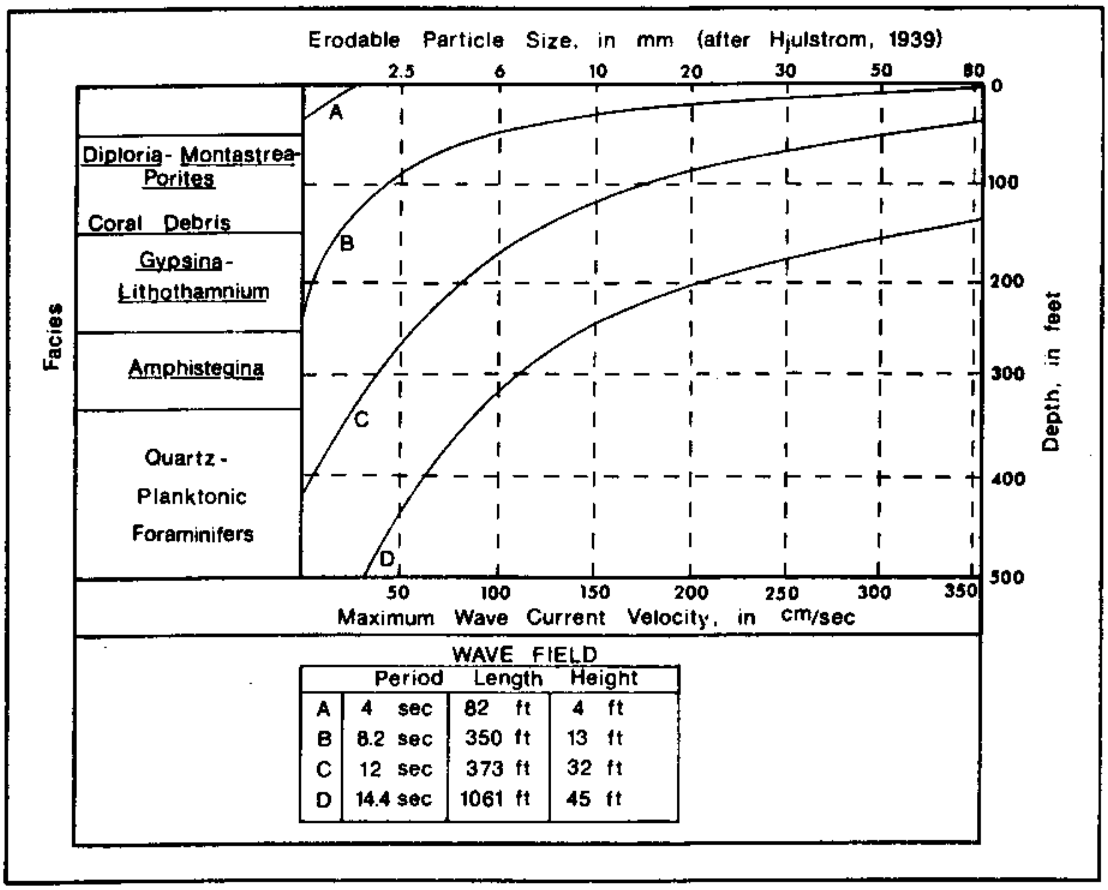
Distance from eye Naut. Miles	Wave Height Feet	Wave Period Seconds	Wave Celerity Knots	Wave Length Feet
Carla				
180	31	15.1	49	1160
120	32	15.2	50	1190
60	43	14.6	45	1098
30	35	15.2	49	1188
0	41	14.7	46	1105
30	42	13.6	41	945
60	45	14.2	43	1039
120	45	14.4	44	1043
180	43	14.3	44	1061
240	39	13.9	43	944
420	31	12.6	39	809
Betsy				
30	47	14.5	44	1076
Hilda				
30	25	11.1	34	631

for Hilda, far below the maximum recorded values of over 140 knots for hurricane Camille. In addition to the wave heights for deep water waves as listed in table 3, Patterson hindcast the maximum height of waves produced by intersecting wave sets in the area of maximum wind. For Carla the maximum wave height in a confused sea should have been 73 feet; for Betsy, 76 feet; and for Hilda, 41 feet.

The ability of large, deep water waves to erode sediments is shown in figure 15 (after Logan, et al., 1969). For deep water waves, the maximum horizontal orbital velocities at the sediment-water interface were derived from the equation $u = \pi H/T \sinh k\, h$ (Inman, 1963) where u = orbital velocity, H = wave height, T = wave period, k = wave number and h = depth. For a small, rapidly shoaling area like the West Flower Garden Bank, the theoretical orbital velocities have not been verified by direct observations.

Currents

The circulation of the water masses in the Northwest Gulf of Mexico is poorly understood. From an accurate study of the salinity and temperature distribution, Nowlin (in press) was able to identify



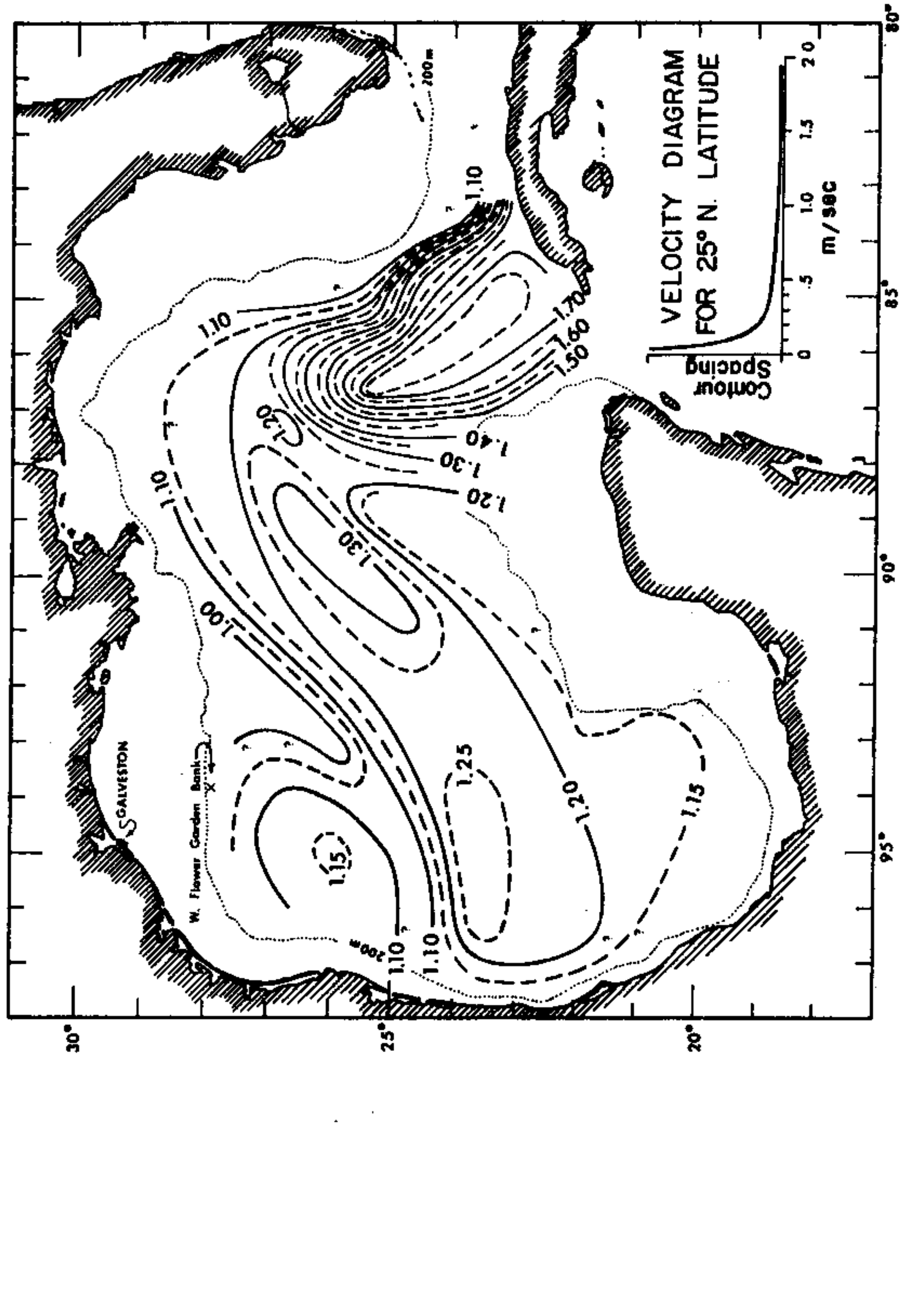
	Period	Length	Height
A	4 sec	82 ft	4 ft
B	8.2 sec	350 ft	13 ft
C	12 sec	373 ft	32 ft
D	14.4 sec	1061 ft	45 ft

Fig. 15. Maximum wave current velocities for different wave fields common to the Gulf of Mexico (after Logan, et al., 1969).

geostrophic currents for this section of the Gulf for three time spans: 23-30 March 1958, 17-26 January 1964 and 27 February - 2 March 1964. Geostrophic currents are based on the assumption that an ocean is infinitely large and deep, that it is stratified with respect to density, that somewhere below the surface there is a layer of no motion and that the only accelerations acting on the water masses are those of gravity, Coriolis and the pressure gradient. By being able to calculate the first two parameters from known constants and by assuming a layer of no motion, all one needs to measure at sea are the salinity and temperature of the water. For the Gulf of Mexico, geostrophic current calculations are of questionable value since it is a closed basin, but based on a level of no motion of 1000 decibars, the currents as shown in figure 16 are thought to be real currents. Remembering that in the Northern Hemisphere currents flow parallel to the contours, with the larger numbers on the right as you face in the direction of the flow, several Gulf of Mexico currents can be recognized. In the eastern Gulf the Loop in the Yucatan Current dominates the year round while in the western Gulf there is a westward flow along the edge of the Campeche Shelf, a northward flow offshore from the states of

Fig. 16. Dynamic topography of the sea surface relative to the 1000-db surface, winter of 1962 (after Nowlin, 1971). Contour interval, 0.05 dynamic meters.

Fig. 16. Dynamic topography of the sea surface relative to the 1000-db surface, winter of 1962 (after Nowlin, 1971). Contour interval, 0.05 dynamic meters.


VELOCITY DIAGRAM
FOR 25° N. LATITUDE
Contour Spacing
m/sec
0
.5
1.0
1.5
2.0
GALVESTON
W. Flower Garden Bank
200m
1.10
1.20
1.30
1.40
1.50
1.60
1.70
1.00
1.15
1.25
30°
25°
20°
95°
90°
85°
80°

Veracruz and Tamaulipas, Mexico, and an eastward flow above the outer portion of the Texas and Louisiana continental slope. Based on the three cruises mentioned before, Nowlin (in press) states: there is an indication of a westward component to the north of the eastward flowing flank of this generally east-west oriented ridge. This would place a westward flowing current over the Flower Garden Banks during certain periods of the winter. It is Nowlin's belief that this westward flowing current is not permanent, but is dependent upon lower salinity waters on the outer shelf. For the summer months Nowlin (1971) was unable to construct a unique pattern for the Texas and Louisiana slope and outer shelf areas due to what he believes are eddies from the eastern Loop Current drifting into the western portion of the Gulf.

Additional information on local currents around the West Flower Garden Bank comes from *in situ* measurements and observations made by divers. On cruise 70-A-13 several vertical profiles of the current were made. The current over the edge of the bank was found to be nearly uniform from the surface to the bottom at 200 feet (61 m) with an average velocity of 3/4 of a knot. From personal observations and from conversations with other scuba divers it appears that currents encountered on the bank range from zero to over 1 knot. On one known occurrence the current prevented a scuba diver from swimming back to his research vessel. Divers also report that the currents vary with depth. Sometimes they extend from the surface to the reef top at 70 feet (21 m) and at other times the surface currents die out at 20 to 30 feet (6 to 9 m). The forces driving the currents have not been isolated. They are probably due to effects of tidal flow, winds and geostrophic forces with any one force being dominant at various times of the year.

Parker (1968) in his quasi-synoptic study of the water masses on the Texas and Louisiana shelf after the passage of a cold front, found the shelf circulation controlled by a large gyre of non-shelf water. For a station 40 nautical miles SSE of Galveston, Texas, he recorded a salinity increase of $1.5^{o}/oo$ (Fig. 12) and a temperature decrease of $1.4^{o}C$ (Fig. 10) during a span of 15.7 days in January, 1966. The salinity increase was not due to river runoff, precipitation or evaporation. An increase in salinity of $1.5^{o}/oo$ due to evaporation would require evaporation of the top 50 cm of a 12 m column of sea water, producing a decrease in water temperature of $25^{\circ}C$. Therefore, this water mass must have come from another portion of the Gulf. Parker suggests that the similarity of the water 40 nautical miles from Galveston Bay with water 150 m deep and 100 miles farther offshore might indicate that this water upwelled onto the shelf. Another explanation for the origin of this water mass is that it represents surface conditions found elsewhere in the Gulf and that it advected onto the Texas and Louisiana continental shelf. Based on the surface density distribution of this gyre (Fig. 17), either possibility may be correct.

Detailed studies spread out over several years are needed before the circulation along the outer Texas and Louisiana continental shelf can be understood with any degree of confidence.

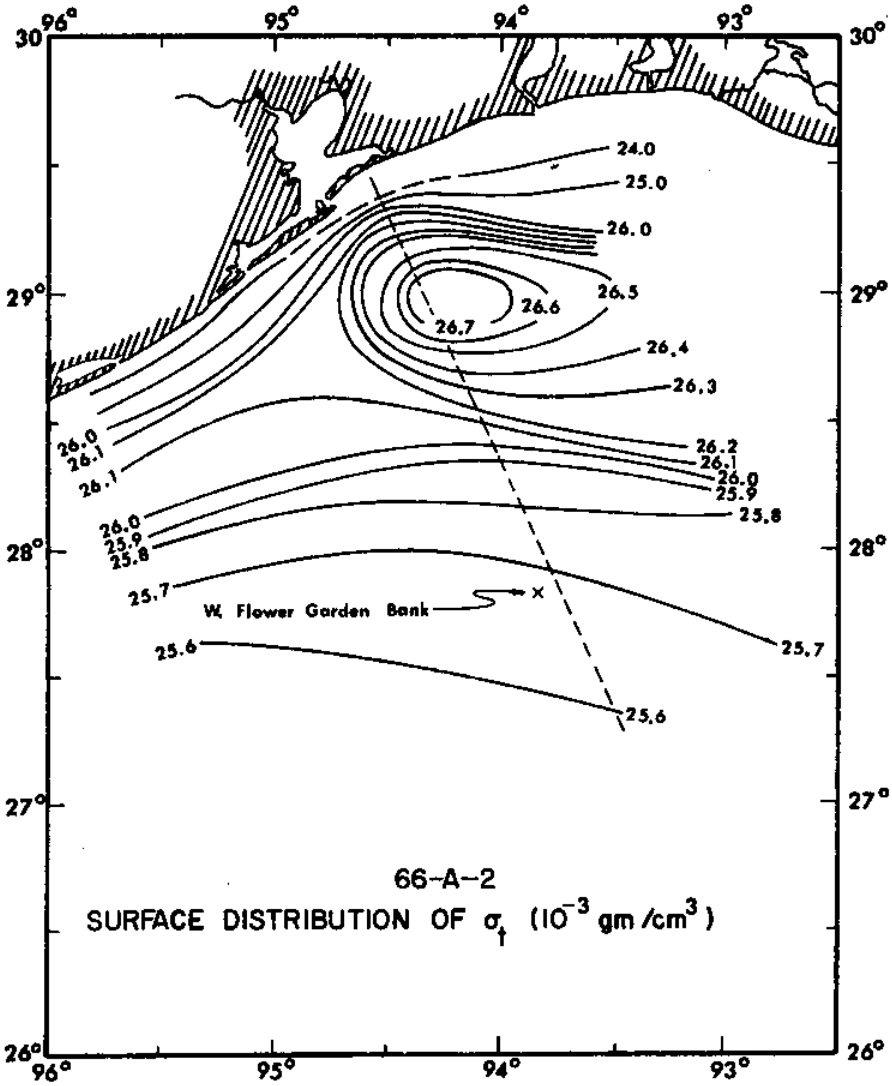


Fig. 17. Surface distribution of sea water density offshore from Galveston, Texas (after Parker, 1968). Dashed line is the cruise track for cruises 66-A-1 and 66-A-2.

BATHYMETRY AND QUATERNARY HISTORY OF THE BANK

Navigation

In order to derive detailed information from a study of the bathymetry and subbottom structures of the West Flower Garden Bank, a new bathymetric chart was prepared. Precision and accuracy of the ship's navigation was the major problem encountered while surveying the 11 nautical miles long by 8 nautical miles wide section of the outer continental shelf where the West Flower Garden Dome is situated. The prime survey was conducted during November, 1970, on cruise 70-A-13 of the Texas A&M University's R/V Alaminos. Three types of electronic navigational aids were onboard the R/V Alaminos: two Bendix loran receivers, an omega receiver and a satellite navigator.

While at anchor on the reef pinnacle, the satellite navigator gave fixes accurate to ± 150 feet. Underway, the accuracy of satellite navigation decreased since the unit could not compute the numerous course changes and varying velocities of the local currents. For these reasons it was not used as the primary navigational tool. The omega navigator was not used since its fixes are, at best, good only to ± one mile. At sunrise or sunset the ionsphere shift produces even larger degrees of error in this system. The original survey plans called for two large metal buoys with wire radar reflectors to be anchored on top of the highest mounds. These were to be used as radar targets for the ship's radar.

The buoys, unfortunately, were difficult to discern from sea scatter and the ranging ability of the radar on the larger scales was neither as accurate nor as precise as the loran A receivers.

While underway, each loran receiver was assigned a separate channel. They were kept tuned to their respective channels with readings taken every five minutes during the bottom profiling and approximately every 15 to 20 minutes during the 3.5 kHz subbottom survey. Usually the sets could be read with an accuracy of ± 1 μsec; i.e., ± 0.11 nautical mile. Accuracy decreased to ± 2 μsec. during occasional periods of high electrical background scatter, while at other times it was felt that the readings were good to ± 1/2 μsec. The precision of the loran receivers was better than 0.05 nautical mile, but an exact figure was not obtained during the survey. In addition to the operator's skill in reading the Bendix receivers and the distance between the lines of position, the American Practical Navigator (Bowditch, 1967) lists the following factors that might shift the accuracy of a loran fix:

(1) Synchronization of the master and slave stations,

(2) Uncertainty of travel time of signals,

(3) Alignment of the receivers,

(4) Incorrect location of the transmitters,

(5) Plotting error,

(6) Errors in the loran tables and chart.

Synchronization, travel time and plotting errors were thought to be negligible during cruise 70-A-13. The location of the transmitters and tuning of the R/V *Alaminos* receivers might explain why the satellite navigator placed the top of the reef approximately 300 yards (91 m) south of the loran fixes.

A loran A grid of the 3H3 and 3H2 lines of positions was constructed for the area of the Texas continental shelf bounded by latitudes 27°49'N to 27°57'N and longitudes 93°44'W to 93°55'W via techniques described in the *American Practical Navigator* (Bowditch, 1967) and *The Loran A Tables for the Gulf of Mexico*, volumes 3H2 and 3H3 (Anon., 1967). Since the study area is only 8 by 11 nautical miles, the hyperbolic loran lines were plotted as straight lines. In *The Loran A Tables for the*

Gulf of Mexico, volumes 3H2 and 3H3 (Anon., 1967) the fixes for 3H2 and 3H3 lines are rounded off to the nearest tenth of a minute latitude and tenth of a minute longitude. Therefore, the precise location of the loran lines of position on the base map may be $\pm$ 0.05 nautical mile from where they were plotted.

Bathymetry

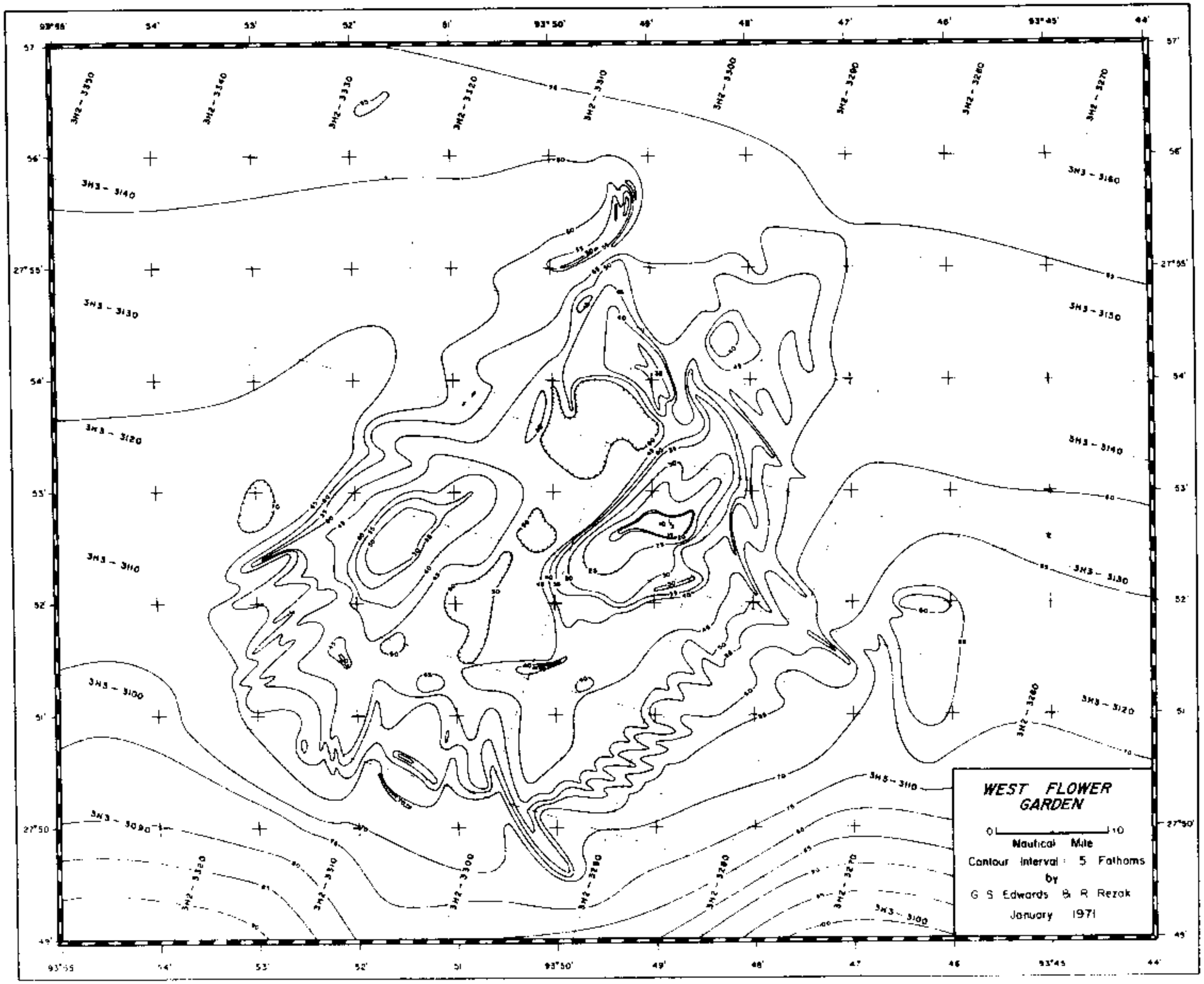
The depth recording survey was conducted over a span of three nights, included 24 hours and 50 minutes of ship time and covered 198 nautical miles at an average speed of 8 knots. In addition to their usefulness in describing subbottom structures, the 3.5 kHz profiles were used to fill in areas missed by the depth recorder. This profiler was run for three nights for a total time of 34 hours, 38 minutes and covered 190 nautical miles at an average speed of 5.5 knots.

Most of the bathymetric traverses across the West Flower Garden Bank were conducted parallel to either the 3H2 or 3H3 loran lines of position. On the resulting grid profile lines are 3 to 4 μsec apart.

The profiles following the 3H2 lines at nearly right angles to the profiles run on the 3H3 lines. Whenever the ship drifted off a desired loran line, new course headings were adopted. In addition to recording loran fixes, depth, time and ship's heading were recorded. The ship's speed varied depending on the velocities of the local currents and winds. Since loran fixes were taken every 5 minutes, it was not considered necessary to know and record the exact ship's speed during the survey.

The final chart preparation required the replotting of survey tracks based on the loran log and the course headings recorded on the depth recorder printout. On each whole minute the depth reading was transferred from the recorder profile to the chart. The speed of sound in sea water was taken as 800 fms/sec and no corrections were made on the contour chart for shifts in speed due to temperature or salinity changes. Such changes, if present, would be minimal and would account for considerably less error than that caused by the 6 to 8 foot seas encountered during the survey. On a few of the traverses it was necessary to shift the profiles slightly in order to make the intercepts match, but no traverses were shifted more than 0.05 nautical mile. A five fathom contour interval was used in the final chart (Fig. 18). Once contoured, all of the bathymetric and 3.5 kHz profiles were checked in order to

Fig. 18. Bathymetric chart of the W. Flower Garden Bank.


WEST FLOWER GARDEN
0 Nautical Mile 1.0
Contour Interval: 5 Fathoms
by
G S Edwards & R Rezak
January 1971

insure a proper and realistic fit of the records to the bathymetric chart of the West Flower Garden Bank.

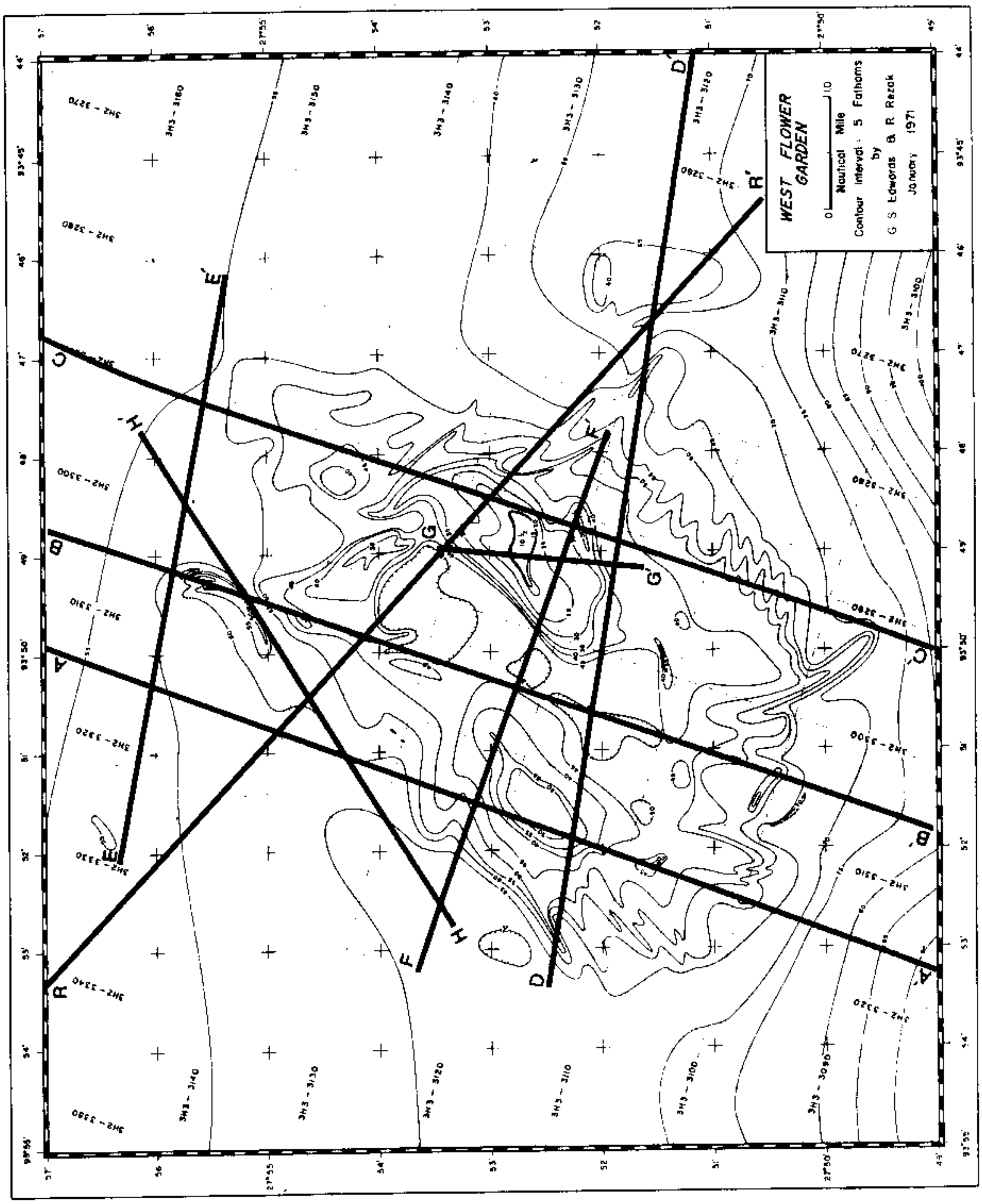
The West Flower Garden Bank is approximately seven nautical miles long by five nautical miles wide. It rises from the edge of the continental shelf with water depths of 55 fms (101 m) to the north, approximately 75 fms (137 m) to the south and 65 fms (119 m)to the east and west. The main pinnacle, with over 55 fms (101 m) of relief, rises to within 10.5 fms (19 m) of the surface. Two miles to the west lies the second highest pinnacle of the bank. It rises to within 27 fms (49 m) of the surface and is separated from the first by water depths of over 50 fms (91 m). Small pinnacles, channels, ridges and gully-like structures abound on the lower flanks of the bank, producing the irregular topography shown on the chart.

Seismic

3.5 kHz Technique

The high resolution continuous reflecting profiler system used on cruise 70-A-13 consisted of a O.R.E. transducer and transceiver linked to a Raytheon Precision Fathometer Recorder. The transducer was towed at a depth of two fms from the "A" frame located amidship. While in 100 fms each outgoing pulse covered an area extending outward 309 feet from both sides of the vessel due to a transducer configuration which produced a 55° beam width (Lowell and Dalton, 1971). The speed of sound in the sediments was assumed to be the same as the speed of sound in sea water; i.e., 4800 ft/sec (Nafe and Drake, 1963); therefore, the bedrock and subsurface sediments may have thicknesses several times that shown by the linear scale of the profiles. Maximum penetration obtained from this system was slightly in excess of 150 feet (46 m) on the flanks of the dome with little or no penetration of the coral and algal capped pinnacle. Resolution varied from extremely poor to better than one foot (0.3 m). The heavy lines on figures 3 and 19 represent the locations of the profiles shown in figures 20, 21, 22, 23 and 24. The saw tooth nature of the sediment-water interface and the subsurface reflectors is an artifact of the six to eight foot seas encountered during the survey. Both the 3.5 kHz and bathymetric profiles must have two fms added to the recorder printout in order to compensate for the depth of the transducers below the water line.

Fig. 19. Chart of the W. Flower Garden Bank showing the locations of the seismic lines.


WEST FLOWER GARDEN
0 Nautical Mile 1.0
Contour interval: 5 Fathoms
by
G S Edwards & R Rezak
January 1971

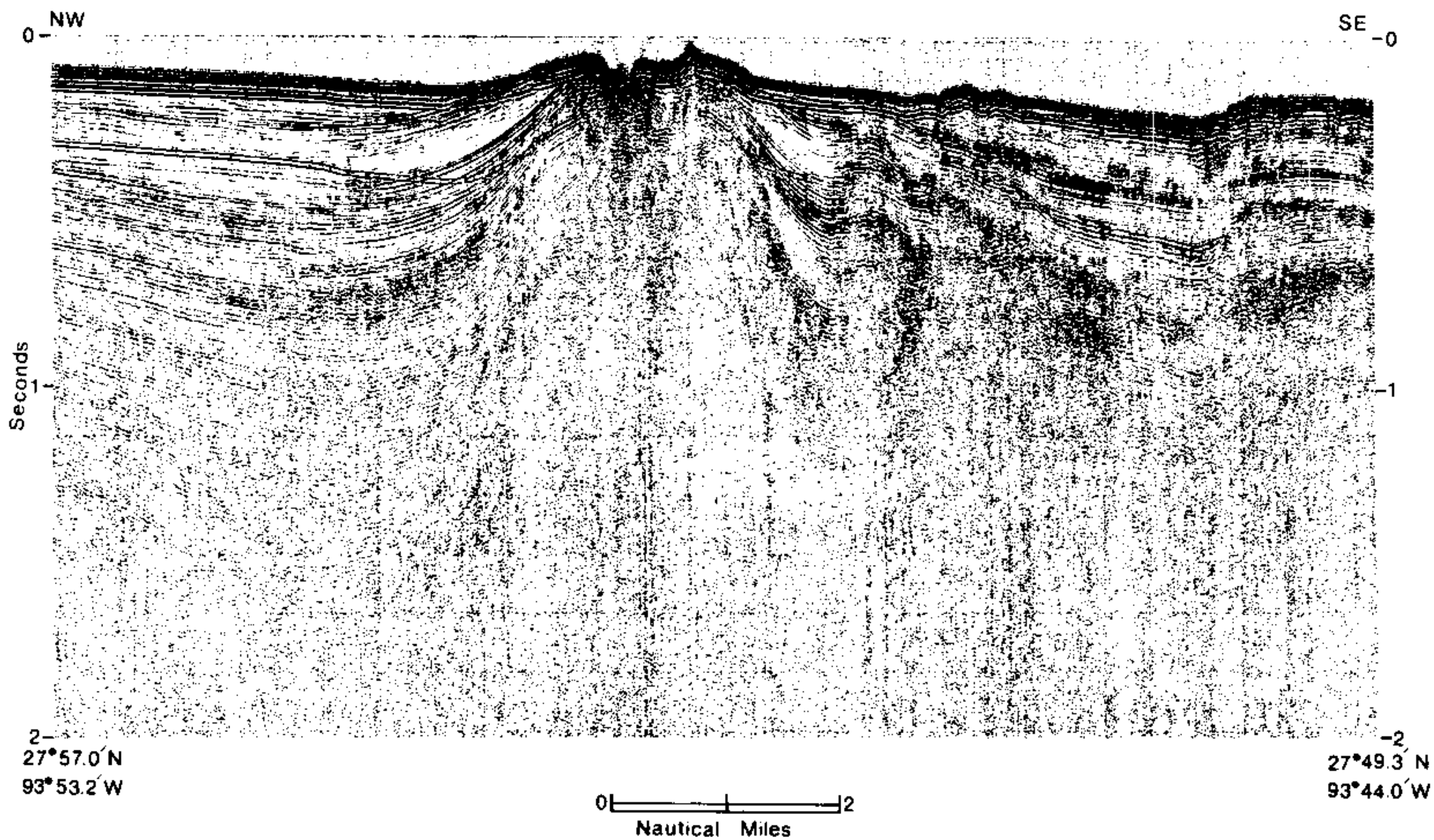
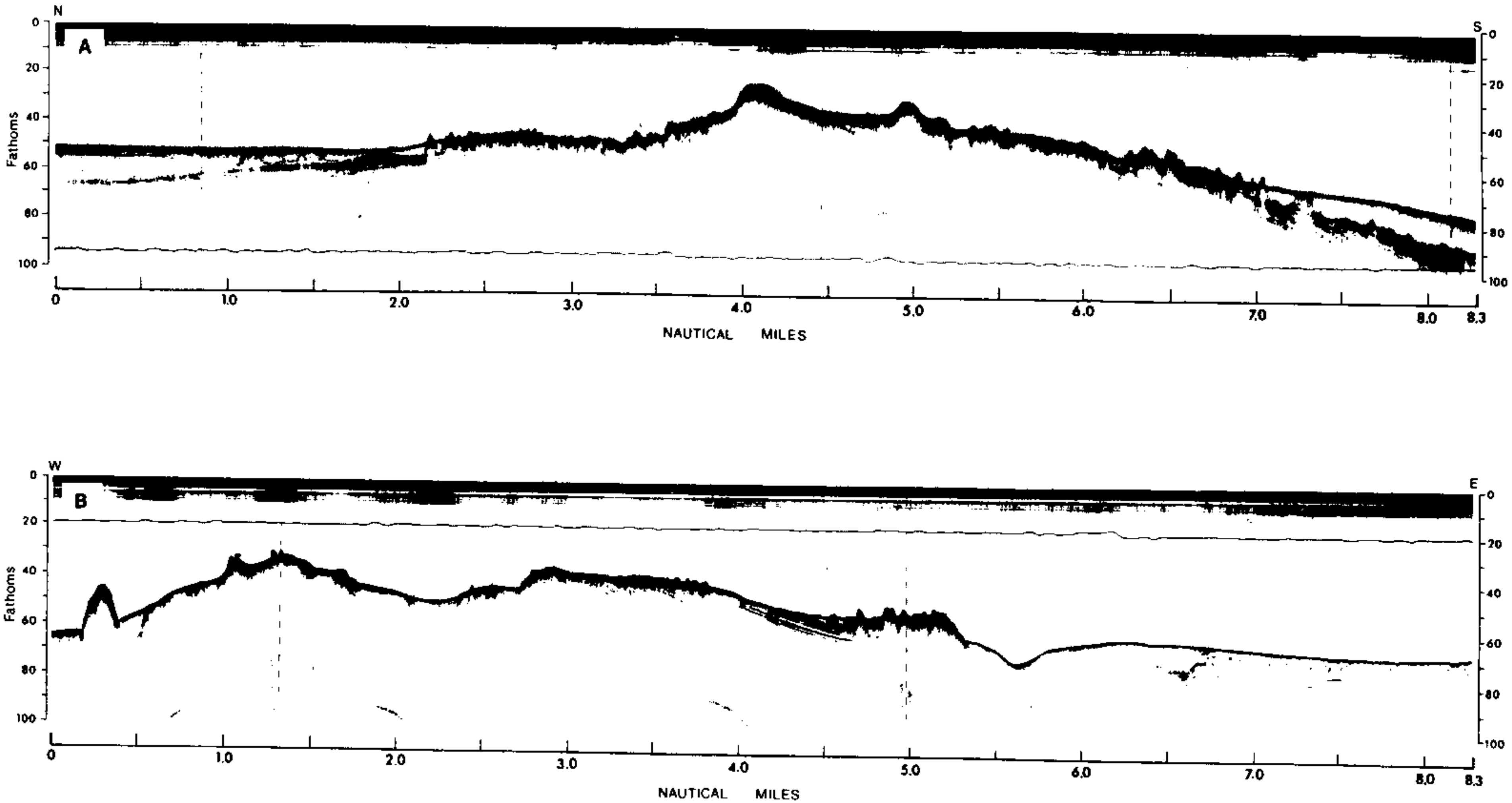

NW
SE
0
1
2
Seconds
27°57.0′N
93°53.2′W
27°49.3′N
93°44.0′W
0
2
Nautical Miles

Fig. 21. Subbottom profiles (A) AA' and (B) BB'. The dark trace running the length of each record is a printout of the ship's heading.

A. The important geological features in line AA' are: (1) southward dipping beds at the northern end of the line; (2) northward dipping faults at 3.3, 3.4, 3.6 and 3.9 miles; (3) relatively flat top of the 25 fms pinnacle; (4) northward dipping faults at 5.1 and 5.6 miles; (5) mounds or ridges from 5.3 to 6.8 miles; (6) a fault at 6.8 miles; (7) a narrow terrace at 7.3 miles and (8) a buried erosional surface from 7.3 to 8.4 miles with the seaward dip of the subsurface beds greater than the dip of the unconformity.

B. Line BB' shows: (1) horizontal to southward dipping beds at the northern end of the line; (2) a buried erosional surface at 0.8 mile; (3) a channel at 1.9 miles; (4) northward dipping subsurface beds from 1.9 to 2.6 miles that generally parallel the sediment-water interface; (5) irregular topography from 2.6 to 3.9 miles; (6) southward dipping faults at 4.2, 4.7, 4.8 and 4.9 miles; (7) irregular subsurface reflectors in the central collapsed section of the dome from 4.9 to 5.8 miles; (8) northward dipping fault at 5.8 miles; (9) southward dipping subsurface beds from 5.8 to 6.1 miles; (10) southward dipping fault at 6.3 miles; (11) small mounds from 6.7 to 6.9 miles and (12) a buried erosional surface from 7.0 to 8.3 miles with up to 120 ft (37 m) of sediment covering the unconformity.



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NAUTICAL MILES
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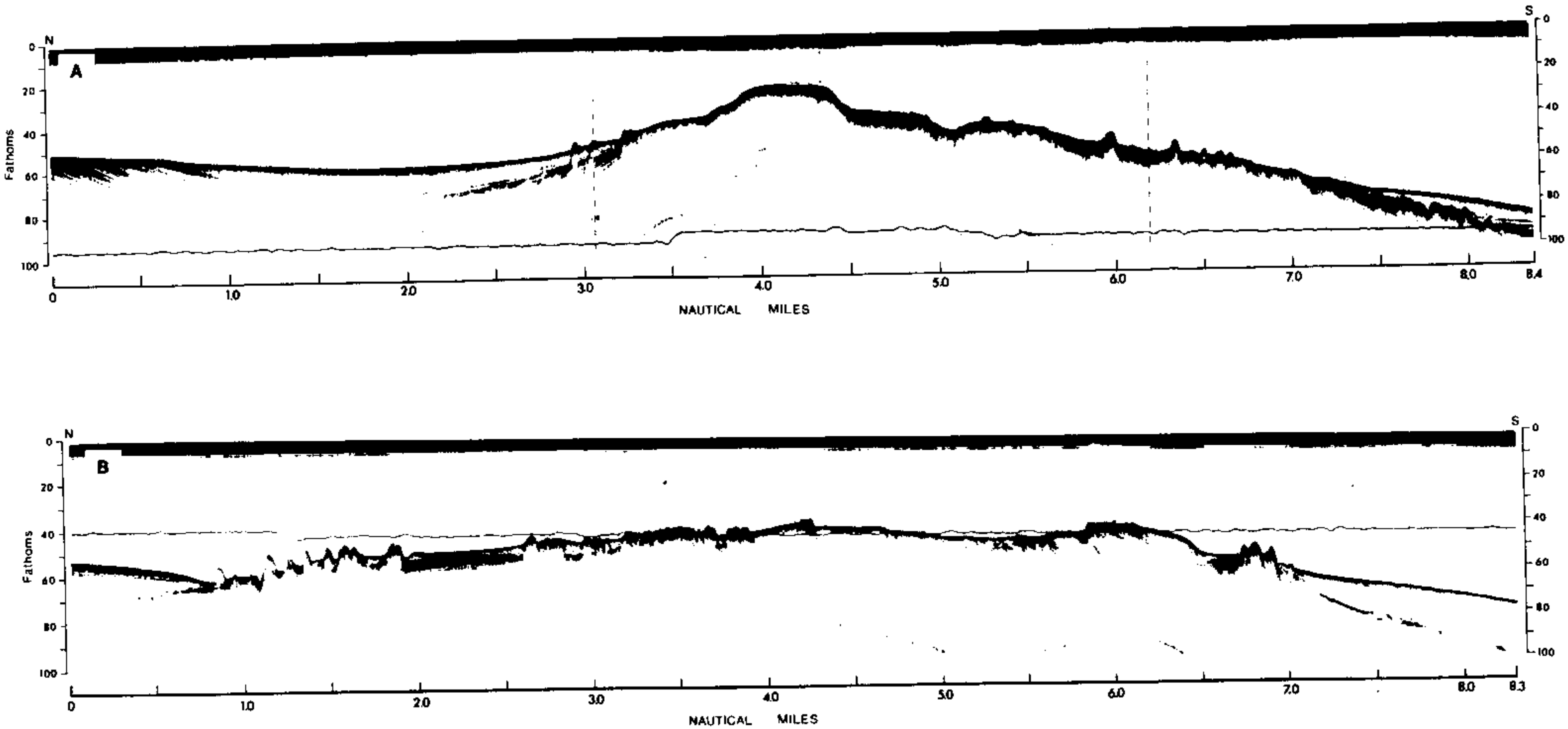
8.3
NAUTICAL MILES

Fig. 22. Subbottom profiles (A) CC' and (B) DD'. The dark trace running the length of each record is a printout of the ship's heading.

A. Prominent geological features of line CC' are: (1) bottomset beds in the subsurface for the first half mile; (2) horizontal bedding beneath a buried erosional surface from the northern end of the line to 2.2 miles; (3) an irregular bottom and no subsurface reflectors from 2.3 to 3.6 miles; (4) a northward dipping fault at 3.6 miles; (5) southward dipping beds at 3.7 miles; (6) steep northern slope of the pinnacle at 4.0 miles; (7) southward dipping subsurface beds at 4.7 miles; (8) parallel bottom and subbottom reflectors from 6.0 to 6.2 miles; (9) an irregular bottom from 6.2 to 7.1 miles and (10) a buried unconformity from 6.9 to 8.3 miles with the dip of the beds at a slightly larger than the erosional surface and that some of the strongest reflectors form the seaward slope of the small mounds.

B. Line DD' shows: (1) a 120 ft (37 m) pinnacle at 0.3 mile; (2) a buried erosional surface from 0.4 to 0.5 miles; (3) small mounds capping the 30 fms (55 m) pinnacle at 1.2 and 1.3 miles; (4) small eastward dipping scarps at 1.4 and 1.6 miles; (5) a depression from 1.6 to 2.8 miles; (6) eastward dipping subsurface beds from 3.3 to 5.3 miles; (7) small ridges from 4.5 to 4.7 miles are outcrops of the strong subsurface reflectors; (8) rough topography from 5.5 to 5.6 miles; (9) a scarp extending from 55 to 90 fms (100-165 m) at mile 5.7; (10) subsurface and surface channels centered at 5.9 miles; (11) an irregular erosional surface from 6.2 to 6.6 miles and (12) a level shelf from 6.6 miles to the eastern edge of the study area.



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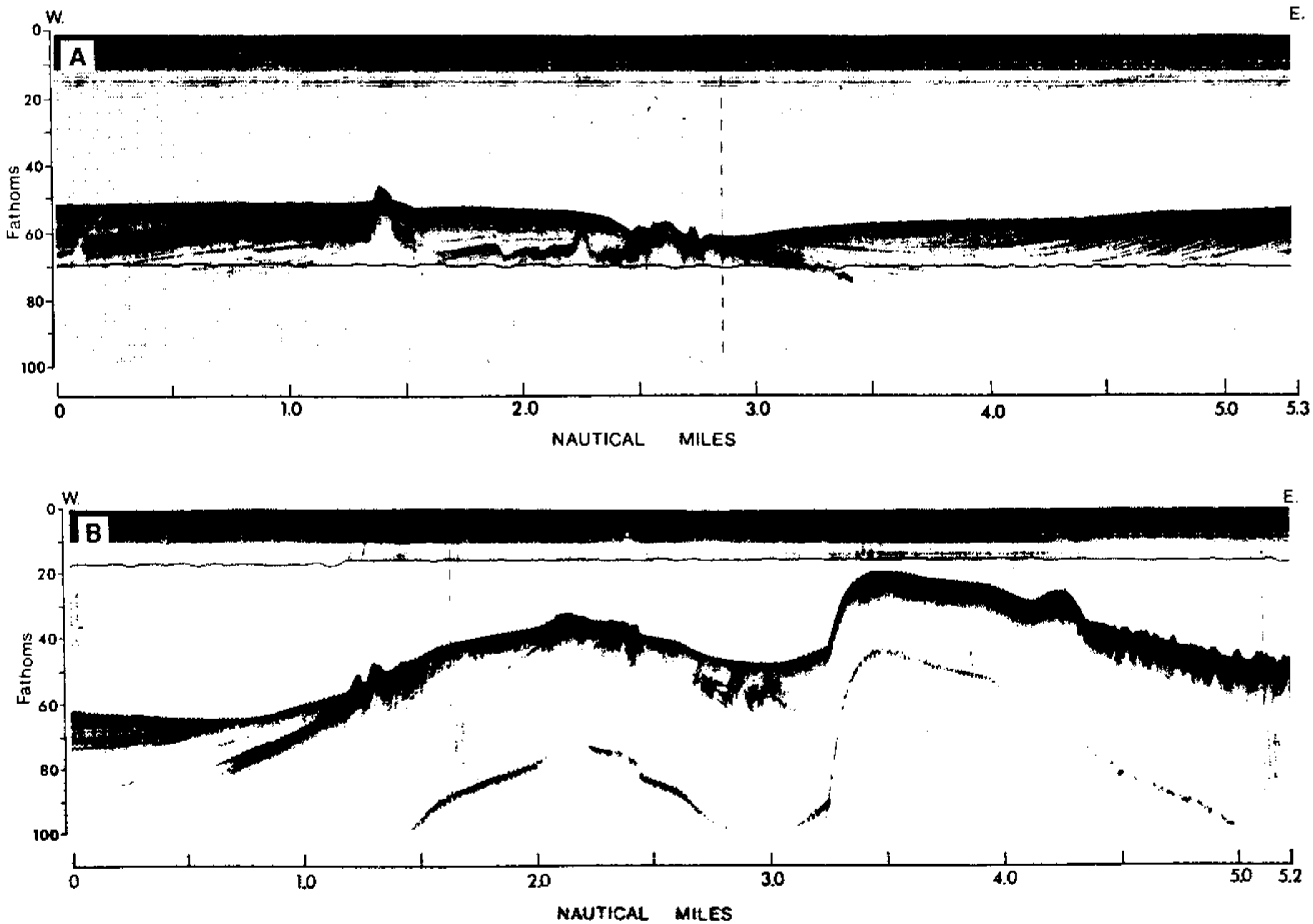
8.3
NAUTICAL MILES

Fig. 23. Subbottom profiles (A) EE' and (B) FF'. The dark trace running the length of each record is a printout of the ship's heading.

A. Profile EE' shows: (1) eastward dipping faults at 0.1, 0.9, 1.3, 1.4, 1.5 and 1.9 miles; (2) the sediments on top of the erosional surface from 1.5 to 2.3 miles are thinner than those to the east of the fault at 1.5 miles; (3) channels at 2.3 and 2.6 miles; (4) irregular topography between the channels; (5) an eastward dipping buried erosional surface starting at 2.6 miles and (6) horizontal beds at 4.0 miles. Westward these beds develop an eastward dip and thin as they approach the area of irregular topography. These same beds become foreset and topset beds from 4.0 miles to the eastern edge of the profile.

B. Profile FF' shows: (1) the top 60 feet (18 m) of sediments at the western edge of the line start to wedge out against uplifted beds at 1.0 mile; (2) a broad channel from 0.6 to 1.0 mile; (3) beds dipping to the west from the western edge of the profile to 2.2 miles; (4) a westward dipping fault at 1.2 miles; (5) an eastward dipping fault at 2.2 miles; (6) irregular subsurface reflectors from 2.2 to 3.2 miles; (7) a 120 ft (37 m) high escarpment at 3.2 miles; (8) an eastward dipping surface from 3.2 to 3.8 miles; (9) a 60 ft. (18 m) mound on the eastern slope of the main pinnacle at 4.3 miles and (10) an irregular surface from 4.3 miles to the end of the traverse.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NAUTICAL MILES
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Fathoms
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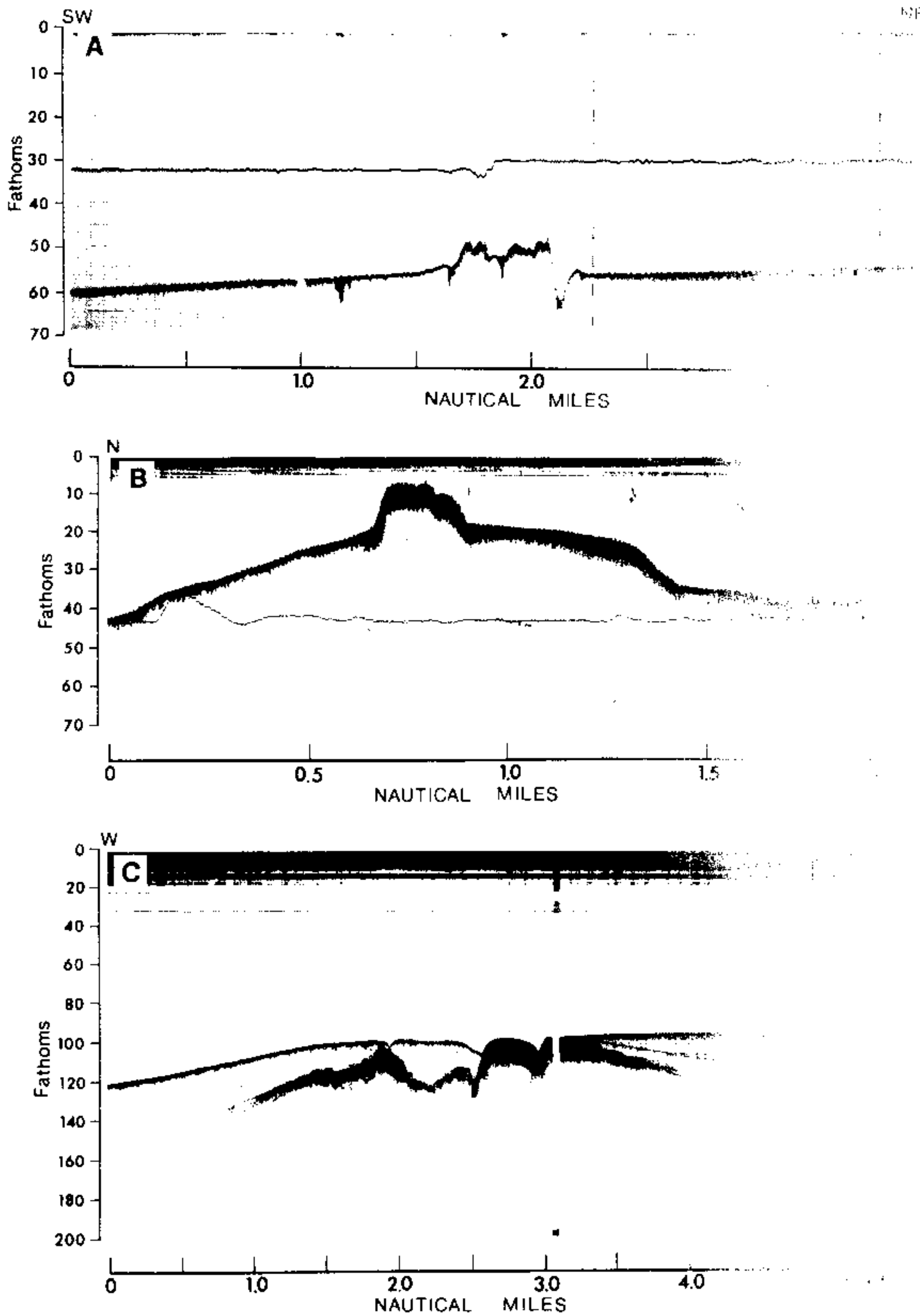
NAUTICAL MILES

Fig. 24. Subbottom profiles (A) GG', (B) HH' and (C) II'. The dark trace running the length of each record is a printout of the ship's heading.

A. Shown in line GG' are: (1) level sea bottom on both ends of the traverse; (2) small, irregular mounds from 1.7 to 2.1 miles and (3) a channel at 2.1 miles.

B. Line HH' shows: (1) a sloping surface for the first 0.7 mile; (2) the reef structure from 0.7 to 0.9 mile; (3) a terrace from 0.9 to 1.3 miles; (4) southward dipping subsurface beds from 1.6 to 1.9 miles and (5) fish schools (dark traces on the record) in depths between 10 and 20 fms, exclusive of the reef structure.

C. Line II' shows another salt dome structure approximately 3 nautical miles to the south of the W. Flower Garden Dome.



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NAUTICAL MILES
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NAUTICAL MILES

1 Cubic Inch Air Gun Profile Technique

On the November, 1969, cruise of the R/V Alaminos (cruise 69-A-15), several low frequency continuous reflection profiles were run across the top of the West Flower Garden Bank. The energy source was a one cubic inch Bolt air gun loaded to a pressure of 1600 psi and fired every three seconds. The returning signals were received and recorded by standard techniques with the final records filtered to remove ship noises. Unfortunately, failure of the ship's officers to take a sufficient number of fixes while underway considerably reduces the value of these lines. Line RR' (Fig. 20) was the single exception. Since the absolute rate of sound propagation for the sediments surrounding the West Flower Garden Bank has not been determined, 5000 ft/sec was taken as a working value (Antoine, personal communication). Sediment thicknesses interpreted from the air gun profile will, therefore, be minimum values. Besides this shift in the speed of sound due to the sediment characteristics, the record is complicated by multiples and a broad outgoing energy train that tends to mask shallow features and greatly reduces the resolving power of the system.

Results of the Air Gun Profile

The prominent structure shown by the air gun profile is the large piercement body just to the left of center on figure 19. This structure is the main salt plug described by Nettleton (Fig. 5) with the top of the salt 0.2 to 0.3 seconds below the sediment-water interface. The highly irregular nature of the beds overlying the dome is due, in part, to the collapse structures associated with dome growth. Also indicative of the intrusive nature of the salt mass is the large increase in dip of the sediments as they approach the dome. Secondary piercement structures located 1.5 and 2.5 nautical miles ESE of the shallowest part of the main dome are thought to be deep seated spines of the main salt dome. The large fault seen in the subsurface separating the two spines is reflected on the bathymetric chart as the NW edge of the small mound 2.5 nautical miles ESE of the coral pinnacle (Fig. 18).

Results of the 3.5 kHz Profiles

Halbouty (1967) describes the effect of shallow, piercement salt domes on overlying sediments. The complex faulting, graben and horst structures and steeply dipping flank beds, which he associates with salt tectonics, are all found within the study area. The complexity and number of faults prohibits the construction of a fault map of the West Flower Garden Bank. Instead, selective 3.5 kHz and fathometer profiles have been utilized to describe the general nature of the faulting and block movements associated with the emplacement of the salt dome.

Lines AA', BB', CC', DD', EE', FF', GG', and II' shown on figures 3 and 19 are tracks of the 3.5 kHz profiles. These profiles are shown unbroken in figures 21, 22, 23 and 24. By combining these profiles with the bathymetric chart of the area, a comprehensive picture of salt tectonics, erosion and deposition can be developed.

In the following discussion of the Quaternary history of the bank, several basic assumptions have been made. First, the longshore currents and wave regime of the Gulf of Mexico were basically the same during the lower stillstands of the sea. From evidence presented by Curray (1960) this appears to have been the case, except for short periods during the Pleistocene when the prevailing winds may have been from the southwest instead of the usual southeast. Secondly, if the data from the dome are to be of any value in identifying ancient sea levels, it must be assumed that the dome has not moved since the start of the last transgression. Based on all the records from the area, this appears to be a reasonable assumotion. Most of the faults do not extend into the late Pleistocene and Holocene sediments. The only observed exception is the fault seen at 1.5 nautical miles on traverse EE', but this is believed to have had its last movement while the Quaternary sediments were being deposited since the sediments overlying the erosional surface to the east of the fault are thicker than the sediments to the west of the fault. Thirdly, it is assumed that the dates given by Curray (1960), Shepard (1960) and Logan, et al., (1969) are correct and can be applied to the stillstands of the seas as observed on the West Flower Garden Bank.

Stillstand in excess of 100 fms (182 m). Prior to the stillstand at 66 to 73 fms (121-134 m) the Gulf waters stood at a depth of over 100 fms. This is indicated by the buried, seaward dipping erosional surfaces shown in figures 21 and 22. No dates are available from this study or previous Gulf studies for this lowering.

Stillstand at 66 to 73 fms (121-124 m). The first major pause of the ocean during the last transgression was at a depth of 66 to 73 fms (121-134 m). Evidence for a shoreline at this depth includes:

(1) a change in slope between 66 and 73 fms (121-134 m) on the bathymetric chart of the area. Proceeding from south to north, there is an increase in slope and possible sea cliffs on the seaward side of the dome and a decrease in slope on both the eastern and western margins of the area.

(2) a small terrace at 73 (134) fms on profile AA' (Fig. 21).

(3) a decrease in slope as the shelf begins at 70 fms (130 m) on profile CC' (Fig. 22).

(4) a sharp increase in slope and wedging out of sediments at 66 to 68 fms (121-124 m) on the western edge of the dome as shown on profiles DD' and FF' (Figs. 22B and 23B).

Curray (1960) and Logan, et al., (1969) place the 66 to 73 fms (121-134m) stillstand at sometime prior to 18,000 years B.P. During this period the Flower Garden Dome stood as a large mound along the coast with over 270 feet (82 m) of relief. To the west and northwest of the West Flower Garden Dome a lagoon probably existed, separated from the sea by a barrier bar with a tidal channel cut adjacent to the western edge of the structure. The northern extension of the dome might have separated this lagoon from a lagoon and river system east of the main pinnacle. The deep subsurface channel seen on line DD' and the present day channel outlined by the 65 fms (119 m) contour suggest that during this period a river discharged its load directly onto the upper continental slope between the main dome and the smaller mound shown on the contour chart. This might have been the "Louisiana" River described by Curray (1960). The smaller mound to the east of the main one probably was the western end of a barrier bar. Sediments from the river were carried to the west by the longshore currents (Curray, 1960) and then offshore as they approached longitude 93°52'W. The acoustically transparent sediments overlying the buried erosional surface probably were carried into the area by this drainage system and by longshore currents. Subaerial erosion formed cliffs, ridges and gullies on the flanks of the dome.

<u>Stillstand at 40 to 45 fms (73-82 m).</u> After the stillstand at 66 to 73 fms (121-134 m), the transgression continued until the sea stood 40 to 45 fms (73-82 m) below the present depth. A stillstand at 40 to 45 fms

(73-82 m) can be supported by the presence of:

(1) a wide terrace shown on the bathymetric chart (Fig. [illegible]).

(2) an erosional surface at 40 to 41 fms (73-75 m) on the main pinnacle as shown by line FF' (Fig. [illegible]).

(3) a well developed terrace at 40 fms (73 m) as shown on line AA' (Fig. 21).

(4) an erosional surface at approximately 40 fms (73 m) on the eastern edge of the main pinnacle as shown on line CC' (Fig. 22).

Curray (1960) dates this still-stand at approximately 17,000 to 15,000 years B.P. As the seas advanced they eroded the previous barriers and filled most of the lagoons with sediments. A channel developed between the two main pinnacles of the West Flower Garden Dome while the pinnacles became islands. The river channel receded up the shelf, building a delta system to the north of the study area. Except for periods of high river discharge, the water surrounding the islands was normal marine with winter water temperatures lowered to 10° to 15° C during the passage of cold fronts. Biohermal structures might have started developing on the tops of ridges and peaks previously formed by subaerial erosion.

Stillstand at 48 to 50 fms (89-90 m). The evidence for a stillstand at this level is not as strong as for the ones at 66 to 73 fms (121-134 m) and 40 to 45 fms (73 - 82 m), due, perhaps, to a shorter timespan for this event. The evidence for this stillstand includes:

(1) a large terrace on the chart. This terrace is not as level as the others and represents more of a depositional terrace than an erosional terrace. Perhaps beach and dune sands deposited during the 40 to 45 fms (73-82 m) stillstand migrated downslope and were trapped by the rough topography originally covering this horizon (Fig. 18).

(2) level, acoustically transparent sediments overlying horizontal beds at 50 to 52 fms on the northern edge of the mound (line BB', Fig. 21).

(3) ponding of sediments between peaks or ridges between 52 to 55 fms on line BB' (Fig. 21).

(4) small channels at 53, 57 and 59 fms on line BB' (Fig. 21).

(5) the development of topset, foreset and bottomset beds in the northeast sector of the study area (Figs. 22 and 23).

This slight regression and stillstand probably corresponds to the regression Shepard (1960) and Curray (1960) identified at 13,000 to 14,000 years before present. The West Flower Garden Dome was one large island with small banks around its circumference. The area between the two main peaks was probably a marsh or lagoon with restricted openings to the sea at both its northern and southern ends. Beginning with the on-set of the regression, the "Louisiana" River probably eroded its old delta and began redepositing sediments just to the northeast of the study area. It rapidly built bottomset, foreset and topset beds across the northern part of the study area. Lines BB', CC' and EE' show these delta deposits. Tidal and/or river channels developed along the northern edge of the mound.

<u>Stillstand at 28 fms (51 m)</u>. After the short regression to 48 to 50 fms (89-90 m) the sea readvanced, flooding the area to a level of approximately 28 to 25 fms (51-46 m) below the present sea surface. Terraces on both the main pinnacles as shown on the contour chart and lines AA', CC', DD' and HH' support the idea of a stillstand at this level. On line CC' subsurface beds can be seen dipping to the south with approximately the same slope as the sediment surface from depths of 35 to

27 fms (64-49 m). At 27 fms (49 m) the beds have been eroded into a level, horizontal surface. Carbonate sediments obscure most of the subsurface reflectors found beneath the pinnacle tops.

As the sea transgressed across the shelf 13,000 to 12,000 years B.P. (Curray, 1960 and Logan, et al., 1969) it eroded the tops of beds in the delta sequence in the northern sector of the study area. The two main pinnacles became either islands or an island and a shoal depending on the exact level of the seas. They were separated from the mainland by over 35 nautical miles of open shelf. The marine environment surrounding the West Flower Garden Island was presumably oceanic with lowered salinity associated with periods of high river runoff only rarely affecting the study area. Winter storms probably did not lower the water temperatures much below 15°C. Sediment influx was restricted to the carbonate sediments being produced by the organisms living on the firm substratum of the bank and the clastics eroded from the uplifted sediments.

The sediments and coral structures produced by the active West Indian reef community flourishing on the top of the pinnacle obscure the remaining record of the transgressive sequence. Evidence available from the West Flower Garden Bank neither supports nor denies stillstands at 35 and 9 fms (64-17 m) after the pause of sea level at 28 fms (51 m).

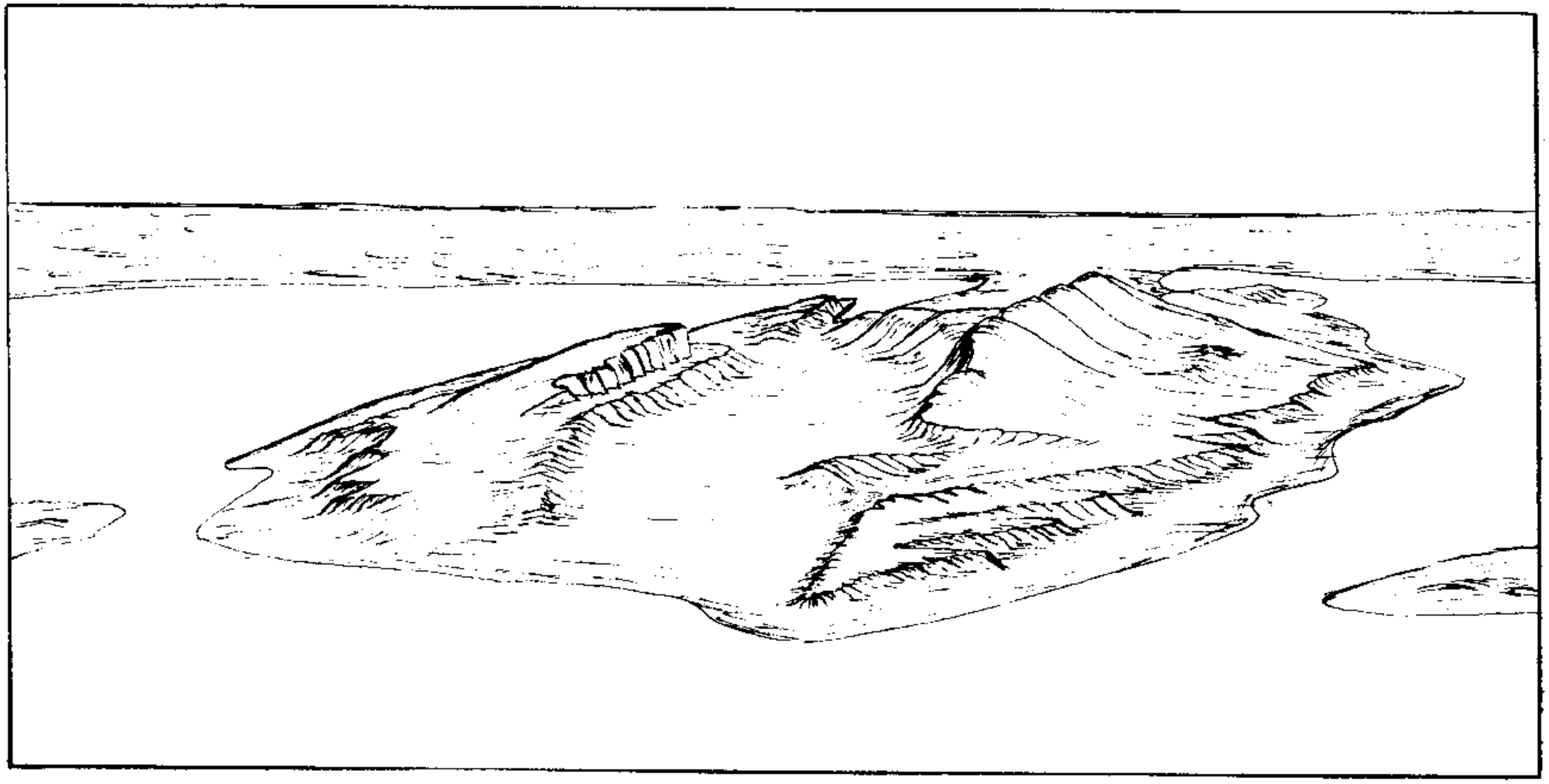


Fig. 25. Sketch of the W. Flower Garden Dome during the 66-73 fms (121-134 m) stillstand of the Gulf of Mexico.

DESCRIPTION AND CLASSIFICATION OF THE CARBONATE SECRETING ORGANISMS AND DETRITAL SEDIMENTS OF THE BANK

Scleractinia

Field and Laboratory Techniques

The main pinnacle of the West Flower Garden Bank culminates in an active West Indian coral reef community. In order to sample and photograph the corals living on the bank the author and his colleagues used self contained diving equipment. Depths obtained during scuba dives ranged from the base of coral heads at 13 fms (24 m) to the terrace at 27 fms (50 m). Since these depths limit bottom time to 40 minutes or less, the collecting and underwater photography were spread out over numerous cruises between 1969 and 1971. On cruise 71-0-6 divers using Farallon underwater scooters surveyed the top of the reef structure. This survey permitted the author to search the area for coral species absent from the Texas A&M Oceanography Department's collection. The author spent 3 hours and 35 minutes on the bottom during cruise 71-0-6 but failed to find any new species of scleractinian. If additional species are present they are rare and are only minor contributors to the total reef mass.

The first step in preparing the scleractinian samples was removal of the soft tissue. This was accomplished by hosing down the samples with high pressure water followed by a soaking in buffered bleach for several days. Identification of the different scleractinian living on the West Flower Garden Reef was based on the key by F. G. Walton Smith entitled *Atlantic Reef Corals* (1971). Publications by Vaughan and Wells (1943), Logan, *et al*. (1969), Roos (1964), Laborel (1967), and Moore (1956) were useful in unraveling the confusion presently permeating the scleractinian literature. Dr. Arnfried Antonius of the U. S. National Museum of Natural History in Washington, D. C. checked the identification and assisted J. Rannefeld and the author in comparing the corals from the West Flower Garden Reef with the specimens belonging to the Smithsonian Institution.

Classification of the Corals

A list of all known species of Scleractinia living on the bank and an account of their morphology and relative abundance is given below. No quantitative studies of the Scleractinia inhabiting the bank have been undertaken; the figures given are strictly qualitative estimates. Except for Oculina spp., depth ranges of all species are essentially the same; from the reef top at 10.5 fms (19 m) to the beginning of the nodular covered terrace at approximately 27 fms (50 m). Oculina spp. occurs down to the lower limits of the bank.

Phylum: Coelenterata

Class: Anthozoa

Subclass: Hexacorallia

Order: Scleractinia

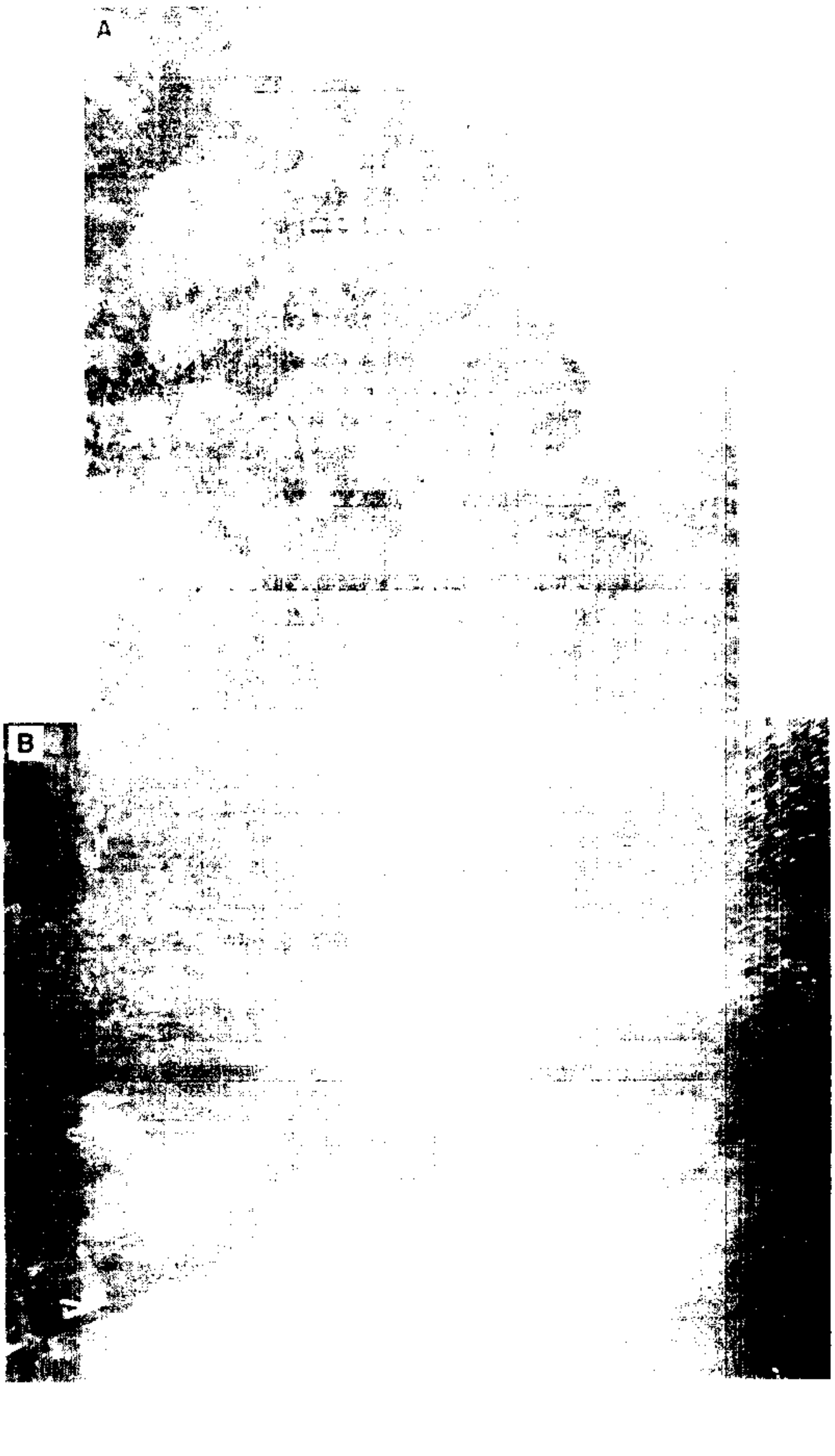
Family: Pocilloporidae Gray, 1842

Madracis asperula Milne Edwards & Haime

M. asperula grows in small clumps up to 3 feet (0.9 m) in diameter. On top of the reef its branches are short, stubby projections (Fig. 25A) while the colonies on the lower flanks of the pinnacle develop thinner branches. On long branches, only the terminal 2 or 3 cm are alive. The inner, dead sections of branches are interwoven with sponges, algae and a variety of vagrant invertebrates. Although M. asperula is not as abundant as some of the other Scleractinia, the ability of its dead branches to break loose from the

Fig. 26A. Underwater photograph of _Madracis asperula_ colonies (lower, left corner).

Fig. 26B. Underwater photograph of the author using a Farallon scooter. Photograph by W. W. Schroeder.


A
B

parent colony makes this species an important contributor to the sediments accumulating between the larger coral heads.

Madracis decactis (Lyman)

M. decactis grows as thin, irregular crusts on any solid substratum. It is a rare form with the observed colonies seldom more than 20 cm in length. Figure 27B is a close-up of several *M. decactis* corallites. The corallites of *M. decactis* and *M. asperula* are identical in form, with the only observable difference between the two species being the external morphology of their colonies. This division is open to serious question since it is possible that *M. decactis* colonies develop branches and become *M. asperula* as they age. This transformation would explain the lack of larger colonies of *M. decactis*.

Family Agariciidae Gray, 1847

Agaricia agaricites (Pallus)

The calices of *A. agaricites* are arranged in subparallel to polygonal groups separated by slightly projecting walls. The two varities found in the area are *cressa*, typically developed as encrusting or massive structures with irregular surfaces (Fig. 28A), and *purpurea*, characterized by the restriction of the cups

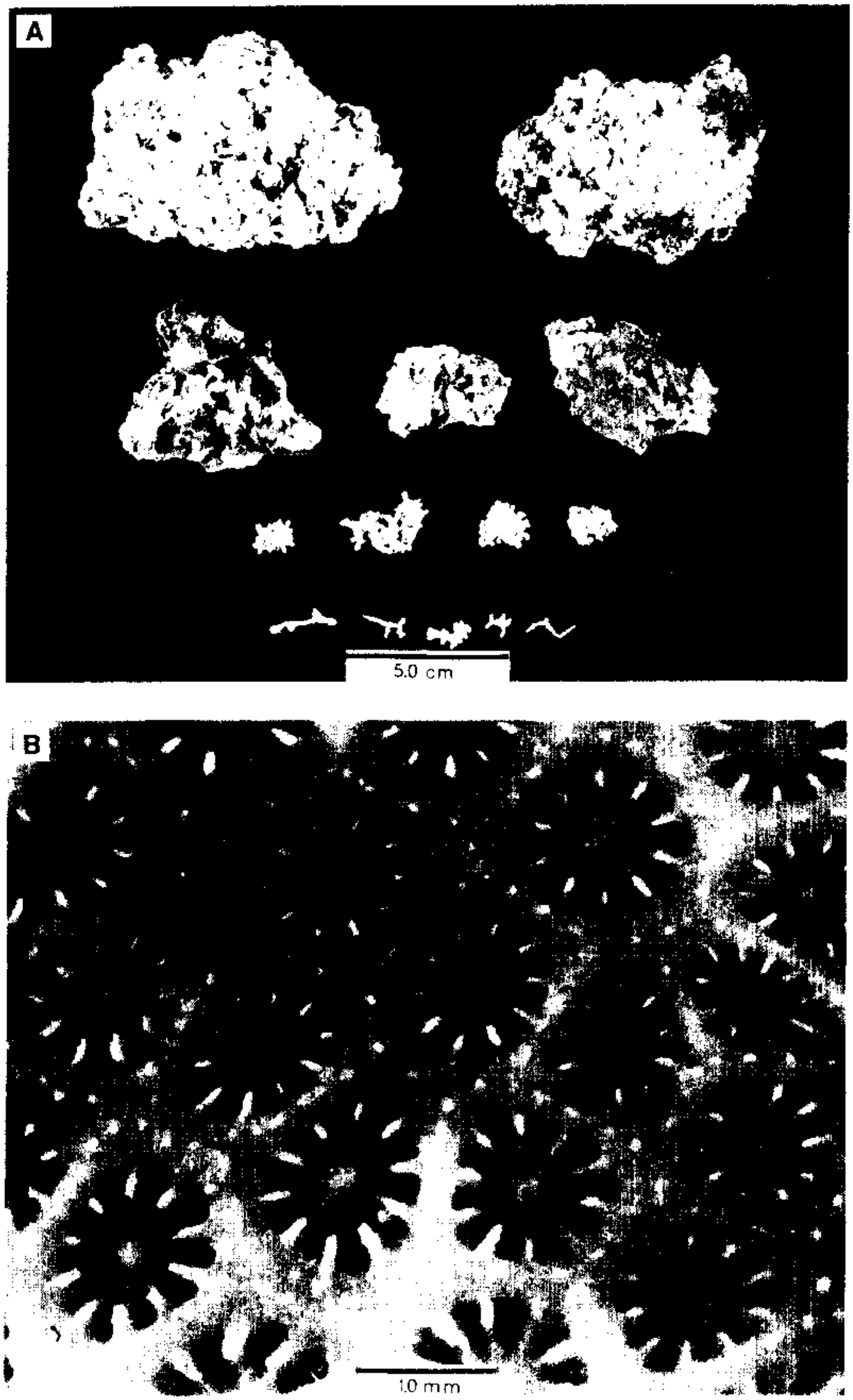
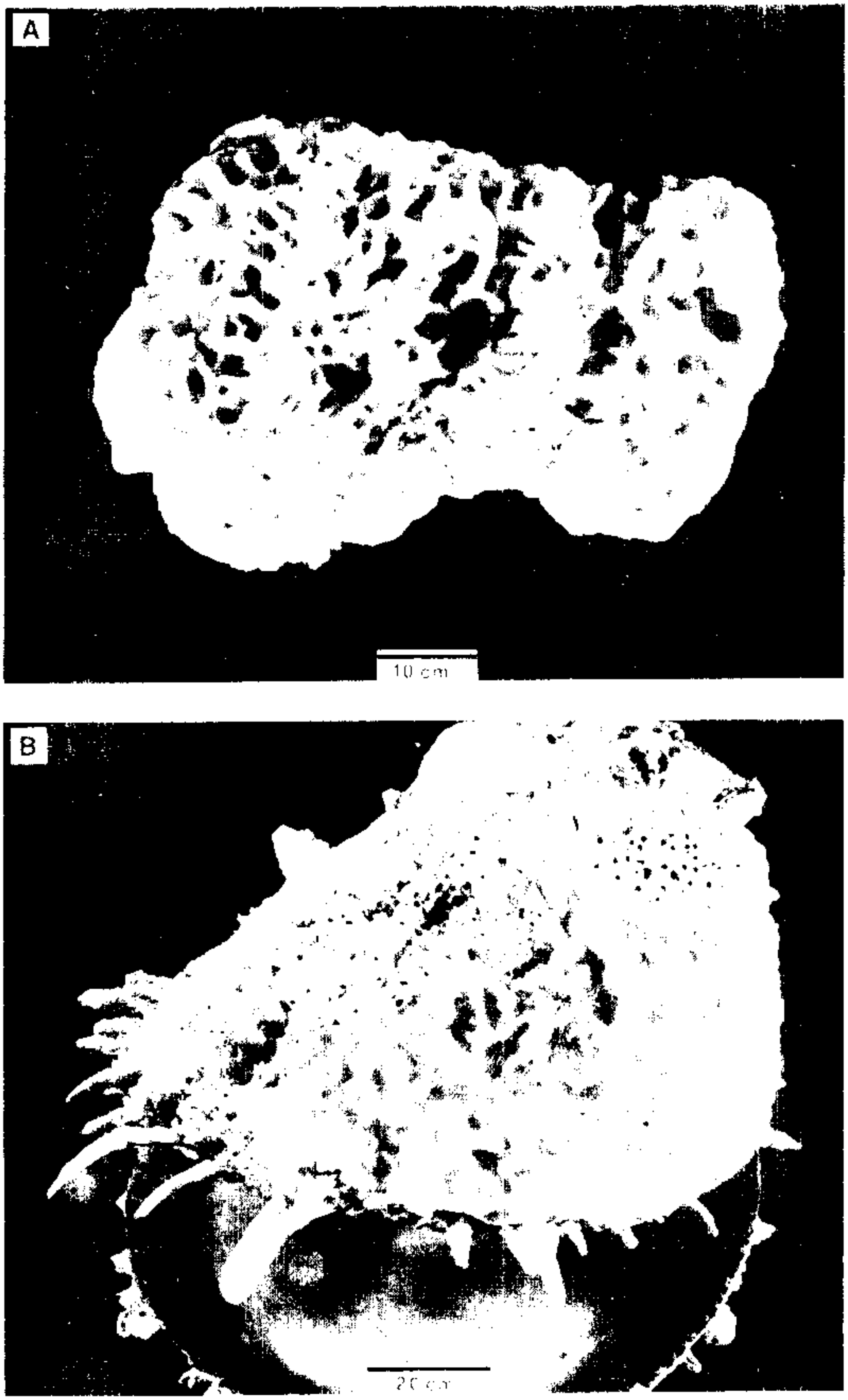

A
5.0 cm
B
1.0 mm

Fig. 28A. Photograph of *Agaricia agaricites* f. *cressa* colony.

Fig. 28B. Photograph of *Agaricia nobilis* colony on a *Spondylus* valve.


A
10 cm
B

to one face of the colony. Leaf shaped colonies of A. agaricites f. agaricites which possesses calices on both sides of the fronds were not observed. A. agaricites is a common coral of the West Flower Garden Bank, but due to its small size, it is a minor contributor to the total mass of the reef structure. A. agaricites usually grows on any firm substratum beneath or between the larger coral heads.

Agaricia fragilis Dana

A. fragilis differs from A. agaricites f. purpurea in that the walls of its calices are not as elevated and the collines are usually longer and more regular in appearance, forming concentric to slightly undulating bands. It develops small colonies seldom more than 30 cm across and usually grows beneath the larger coral heads. A. fragilis is not as common as A. agaricites.

Agaricia nobilis Verrill

A. nobilis develops as thin fronds or encrustations with cups on only one side of the corallum. As many as 7 calices are grouped together in linear rows with the exposed half of the colline protruding above the level of the coenosteum like small buckets or pulpits (Fig. 28B). It grows as rare, small colonies attached to a wide variety of surfaces. It has been proposed that this organism be reclassified Helioseris cucullata due to a close resemblance to the Indo-Pacific genus Helioseris (A. Antonius, personal communication, 1971). Due to the widespread usage of the name A. nobilis, it has been retained in this dissertation.

Family Siderastreidae

Siderastrea sp.

Siderastrea sp. has been reported colonizing the West Flower Garden Bank (Pulley, personal communication, 1971), but it has not been observed by the author growing on the bank. However, the author has observed small, isolated colonies of Siderastrea sp. growing on Stetson Bank from the top of the structure at 12 fms (22 m) down to at least 25 fms (46 m). Since this structure lies 30 nautical miles to the NW of the West Flower Garden Bank, it is reasonable to assume that Siderastrea inhabits the West Flower Garden Reef but due to its rarity and small size it has not been collected.

Family Poritidae Gray, 1842

Porites astreoides Lamarck

Based on growth form, P. astreoides is the only member of this family present on the bank. Young colonies develop as encrustations while the older ones tend to fan out around the base of their colony, occasionally bridging the open space between adjacent domes (Fig. 29A). The surfaces of the *Porites* coral heads are irregular with small, warty protuberances extending outward from the hemispheres. No branching forms of *Porites* were observed in the study area. Based on the microstructure of the calices, both *P. astreoides* (Fig. 30A) and *P. porites* (Fig. 30B) are present (Smith, 1971; plates 14 and 15). Since Smith (1971) limits *P. porites* to the branching forms with secondary emphasis placed on the type of columellae and pali, only *P. astreoides* is listed as living on the West Flower Garden Bank. Mature *P. astreoides* heads may extend 10 to 12 feet (3 to 3.6 m) above the sandy zones flooring the reef and may be 6 to 8 feet (1.8 to 2.4 m) in diameter. It is an abundant species and plays an important role in forming the reef structure.

Family Faviidae Gregory, 1900

Diploria strigosa (Dana)

D. strigosa develops at least three different varieties of wall and valley patterns (Figs. 31A, 31B and 32B). It is one of the most abundant corals, displaying heads up to 8 or 9 feet (2.4 to 2.7 m) in diameter. Heads range from nearly perfect hemispheres

Fig. 29A. Underwater photograph of _Porites astreoides_ colonies showing the corallum bridging the space between adjacent coral heads.

Fig. 29B. Underwater photograph of a _Montastrea annularis_ colony showing the shingle-like morphology of the coral head.

B

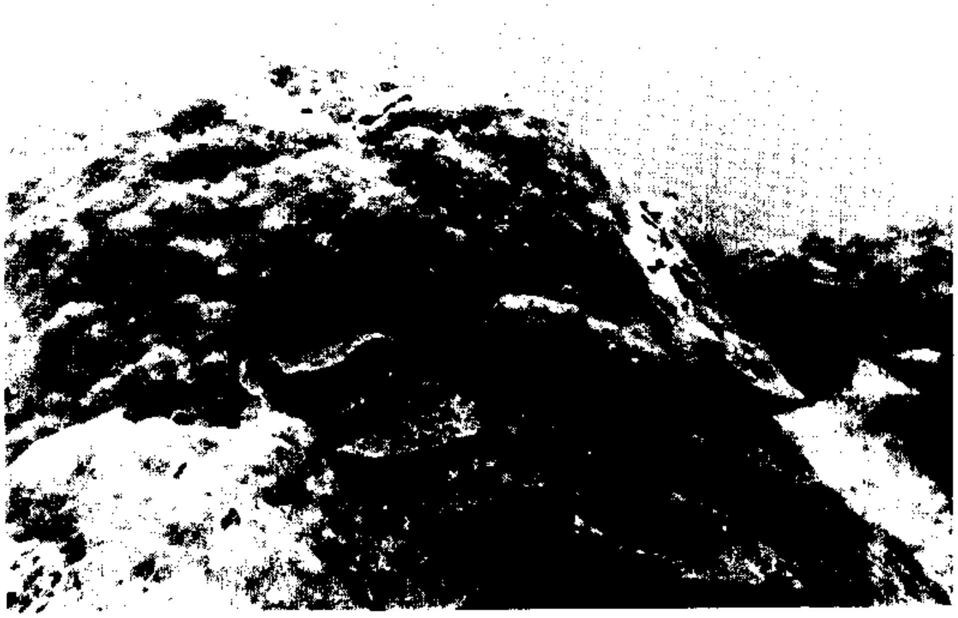


Fig. 30A. Photograph of _Porites astreoides_ calices.

Fig. 30B. Photograph of _Porites astreoides_ (_Porites porites_?) calices.

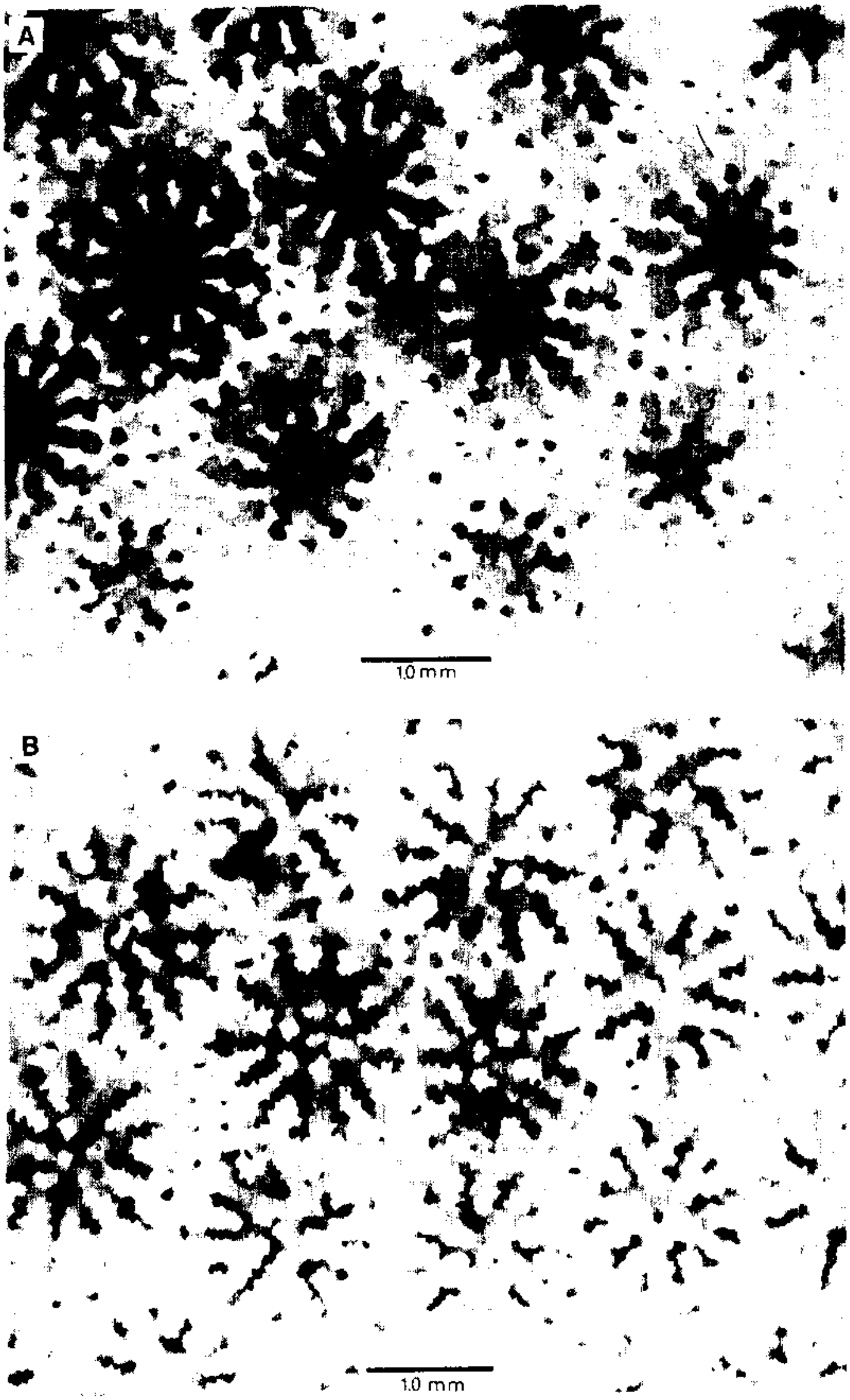

A
1.0 mm
B
1.0 mm

Fig. 31A. Photograph of *Diploria strigosa* showing the first of three valley patterns.

Fig. 31B. Photograph of *Diploria strigosa* colony showing the second of three valley patterns.

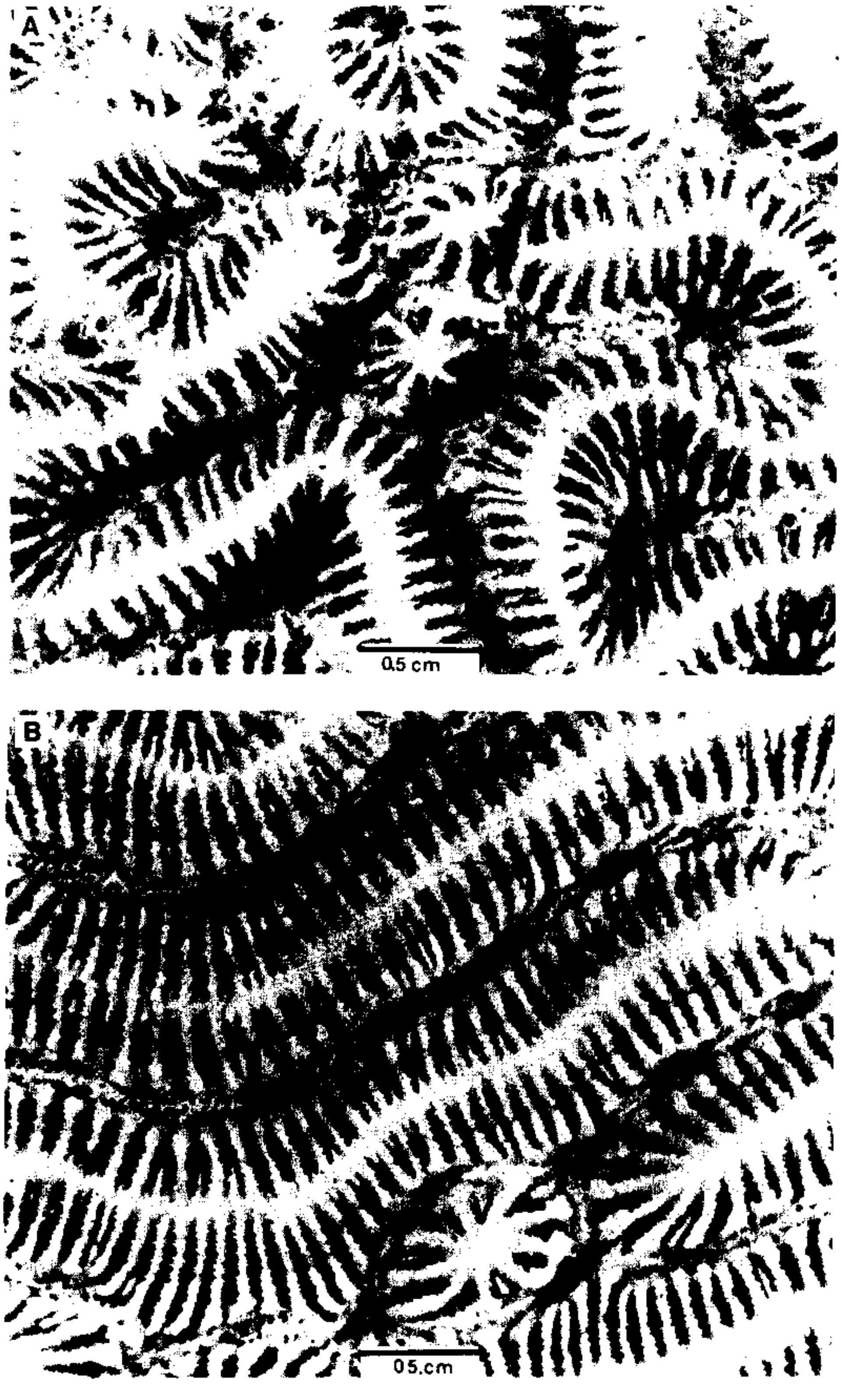
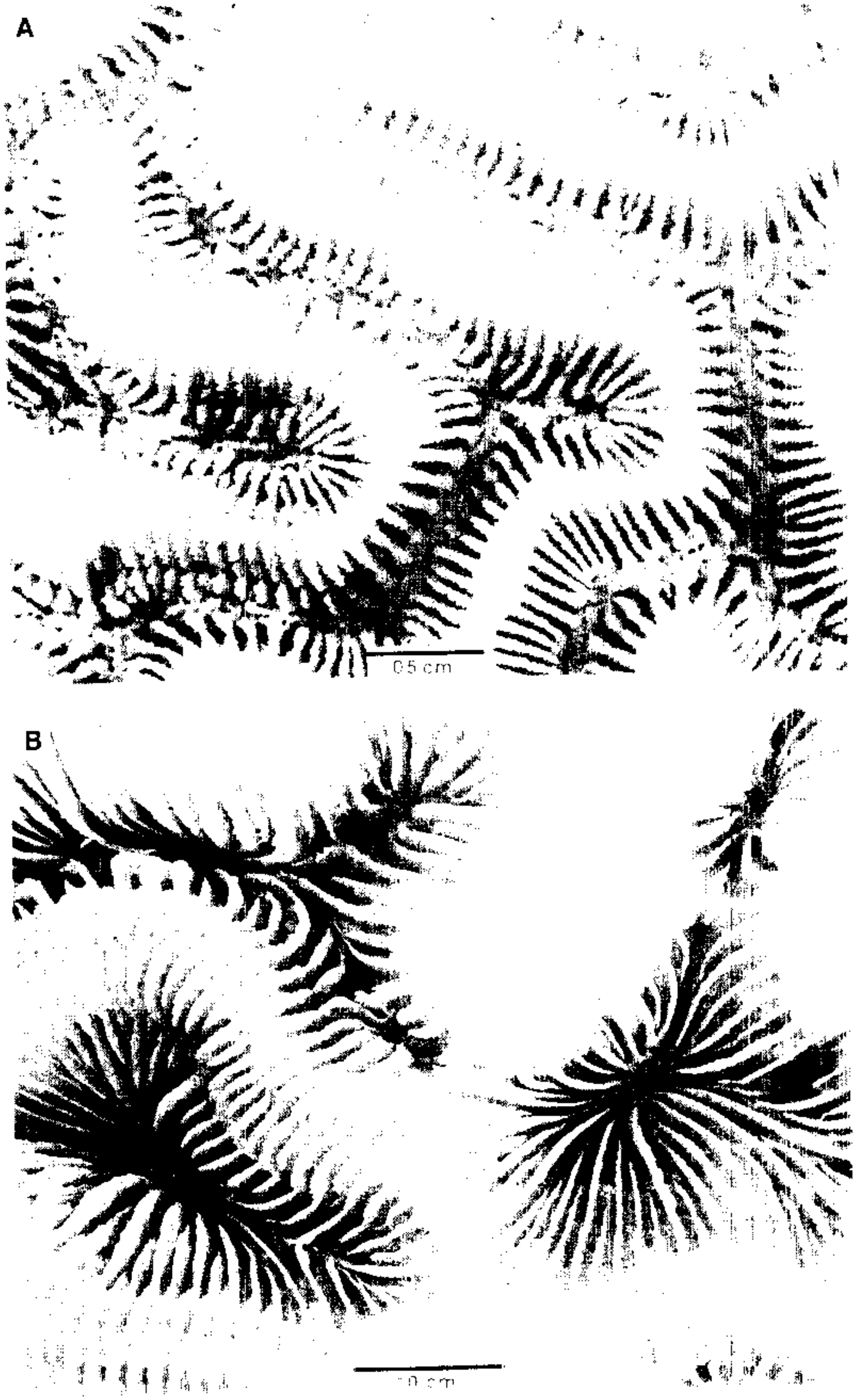

A
0.5 cm
B
05.cm

Fig. 32A. Photograph of *Diploria strigosa* showing the third of three valley patterns.

Fig. 32B. Photograph of *Colpophyllia natans* colony showing the valley pattern.


A
0.5 cm
B

to rectangles with rounded corners with any one head colonised by one or more D. strigosa colonies. Small colonies develop as flattened encrustations or small domes on various types of substrata.

Colpophyllia natans (Muller)

Massive and encrusting colonies of C. natans inhabit the reef, but they are seldom as large or as abundant as D. strigosa colonies. Underwater this brain coral can be identified by its wide valleys (Figs. 33A and 33B) while in the laboratory the criteria listed by Smith (1971) distinguish it from the other species of Faviidae (Fig. 32B).

Montastrea annularis (Ellis and Solander)

M. annularis grows as large domes up to 10 feet (3.0 m) across at their base and over 15 feet (4.6 m) tall. It is very abundant, forming one of the main reef builders on the bank. Figure 29B shows a 10 foot (3.0 m) high boulder with small, warty protuberances and shingle-like growth of the corallum. Figure 34B is a close-up of the calices showing typical septal arrangement.

Montastrea cavernosa (Linneaus)

M. cavernosa displays the same basic colony size and shape as found in M. annularis. The two can readily

Fig. 33A. Underwater photograph of Colpophyllia natans (bottom center), Diploria strigosa (center) and Montastrea cavernosa (top).

Fig. 33B. Underwater photograph of Diploria strigosa (bottom center), Colpophyllia natans (left center), Montastrea cavernosa (top center) and Porites astreoides? (top right).

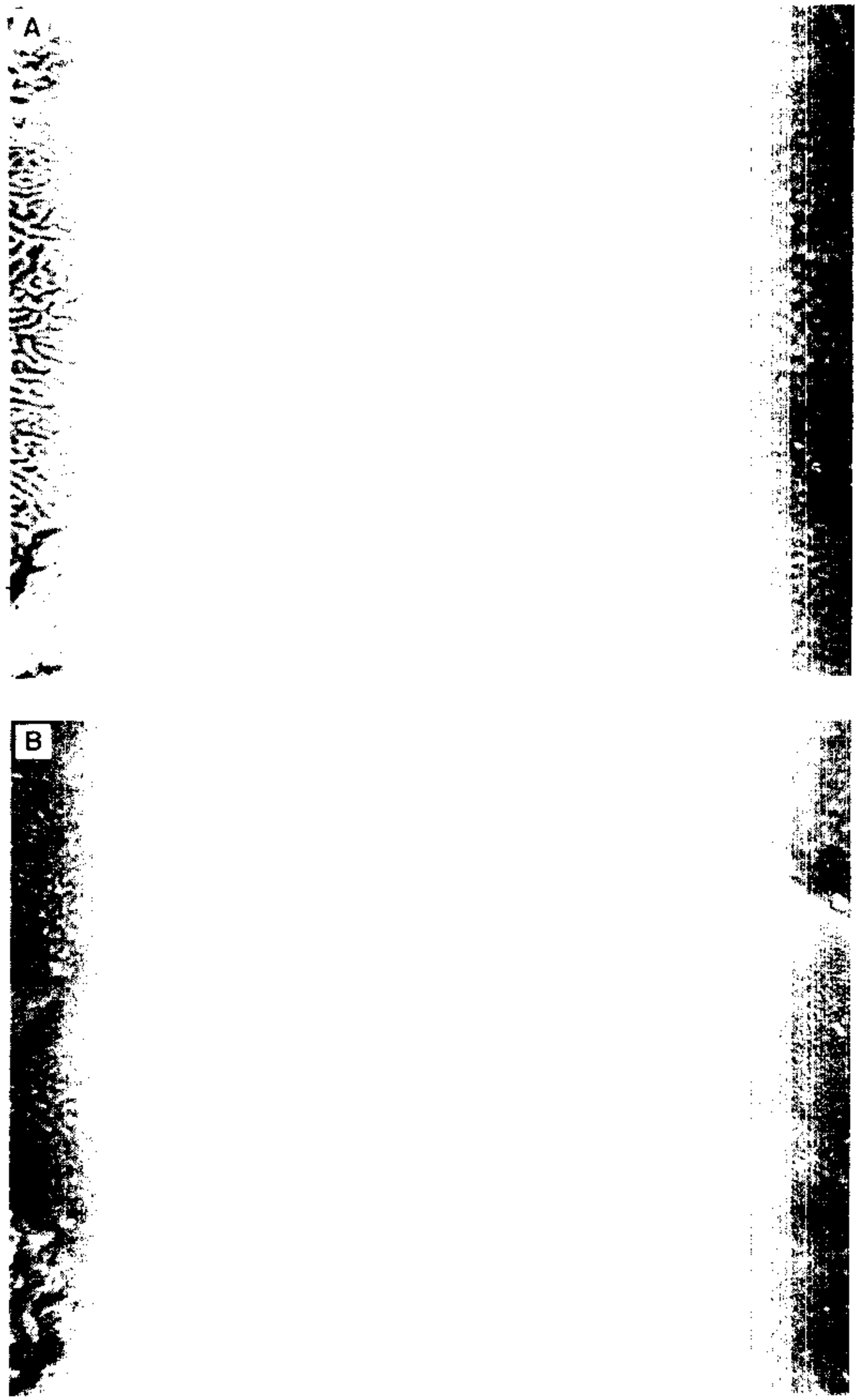
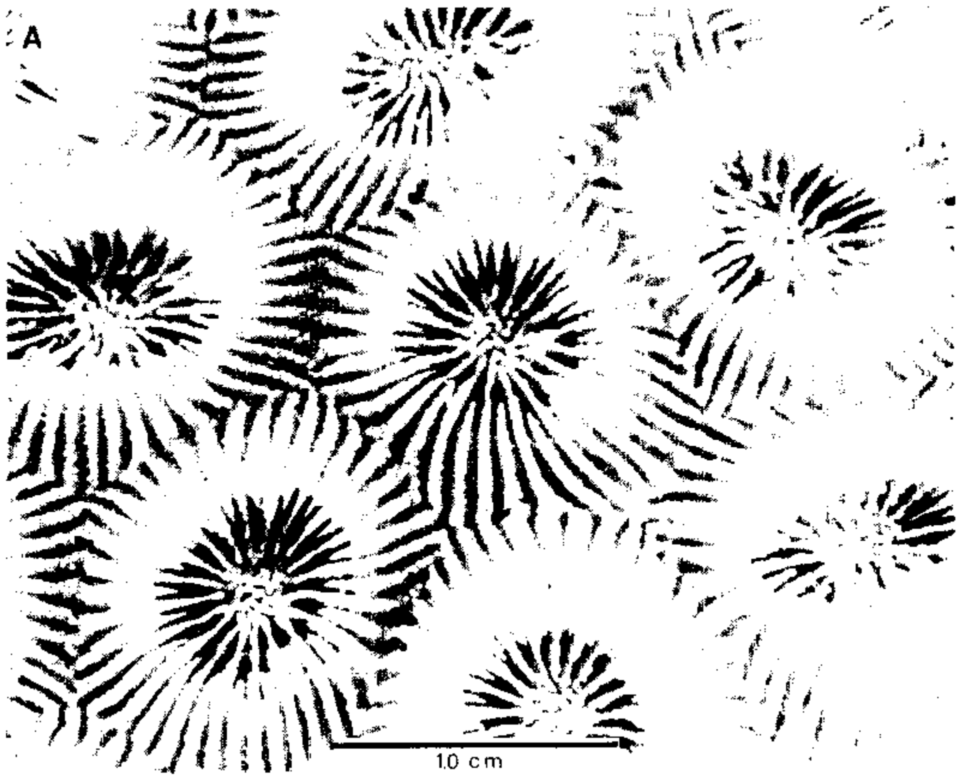
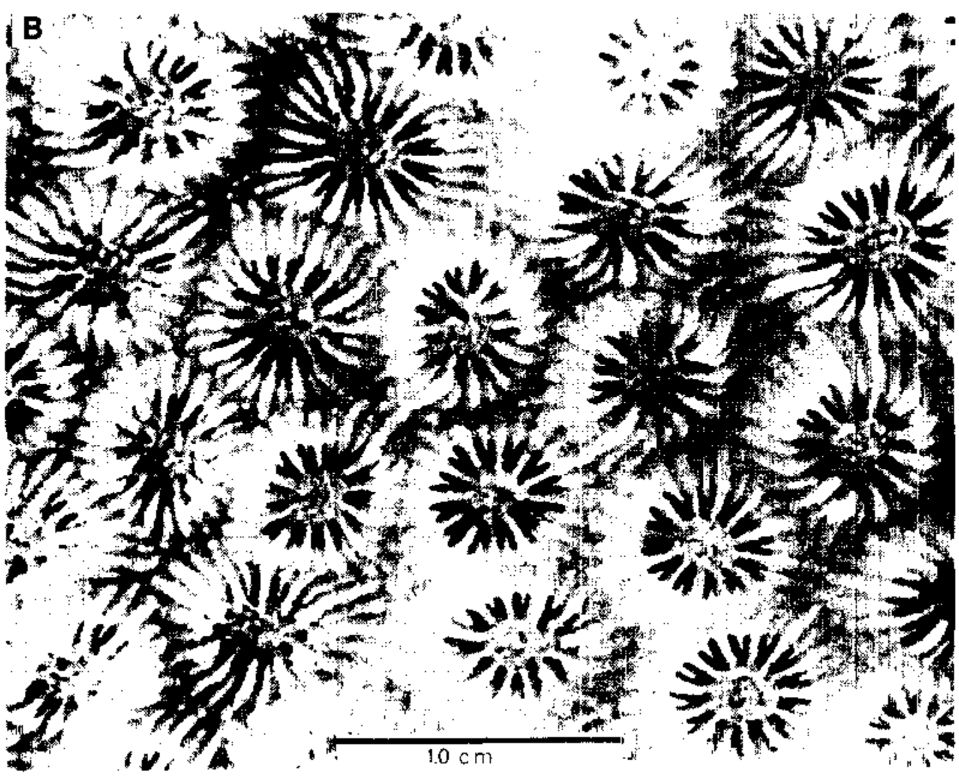

A
B

Fig. 34A. Photograph of _Montastrea cavernosa_ calices.

Fig. 34B. Photograph of _Montastrea annularis_ calices.


A
1.0 cm


B
1.0 cm

be distinguished by the large size of the M. cavernosa calices (Fig. 33A, 33B and 34A). It is one of the dominant frame builders of the reef.

Family Mussidae Ortmann, 1890

Mussa angulosa (Pallas)

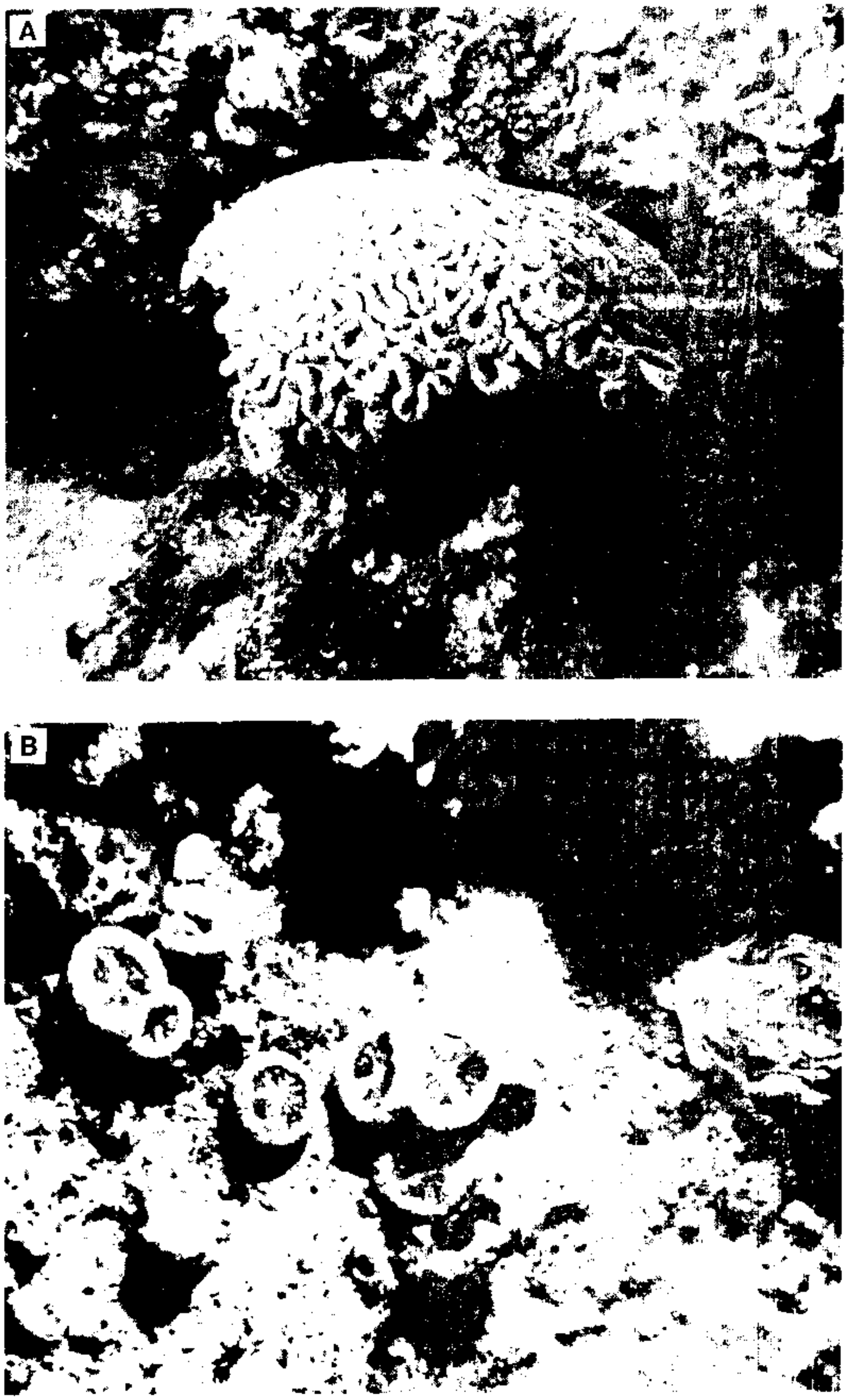
M. angulosa from the Flower Gardens closely resembles the description given by Smith (1971, p. 92). The convex upper surfaces of the calices form "bushes up to 4 feet (1.2 m) in diameter and the colonies stand approximately 1 to 1.5 feet (30 to 46 cm) off the bottom (Fig. 35A). It is a common coral and, due to its tendency to break apart after death, it is an important contributor to the loose sediment of the reef.

Scolymia wellsii Laborel

S. wellsii was erected by Laborel (1967, p. 11-12) to describe a new species of Mussidae from reefs off Brazil. The only discrepancies between the published description of the Brazil specimens and the specimens from the West Flower Garden are (1) the corallum of the samples from the Texas shelf are patellate to turbinate and (2) the color of the live individuals, as indicated by daylight balanced color photographs, is sectorally arranged with the outer margins blue-gray to greenish-gray and the inner polyp a darker green

Fig. 35A. Underwater photograph of a *Mussa angulosa* colony.

Fig. 35B. Underwater photograph of several *Scolymia wellsii* cups and a colony of *Agaricia agaricites* (right center).


A
B

to reddish-brown. The specimens in the Texas A&M collection are readily differentiated from *Mussa angulosa* as described by Smith (1971), *Mussa lacera* as described by Roos (1964), and *S. lacera* as described by Laborel (1967) on the basis of the curved, intercepting and lace-like mesh of the inner teeth on the higher order septa (Figs. 36A and 36B). Around the periphery of the corallites all of the septa are solid and the outer 1 cm of septa on some individuals is thickened. This zonation in septal structure corresponds to the two color zones of the living polyp. The solitary growth form of *S. wellsii* enables a diver to distinguish it from *Mussa angulosa*. Under crowded growth conditions, the edge zones of adjoining corallites may be distorted (Fig. 35B), but the close spacing of the two edge zones of the *S. wellsii* cups makes it possible to separate this species from colonies of *M. angulosa* (Fig. 35A). *S. wellsii* is a rare inhabitant of the West Flower Garden Reef.

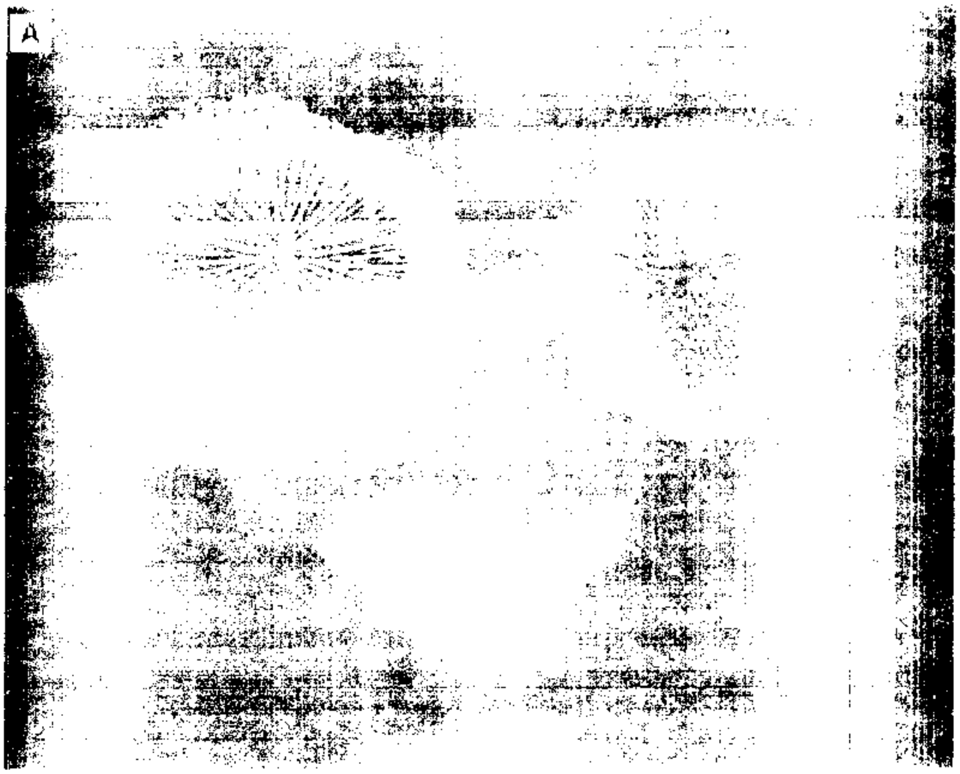
Family Oculinidae Gray, 1847

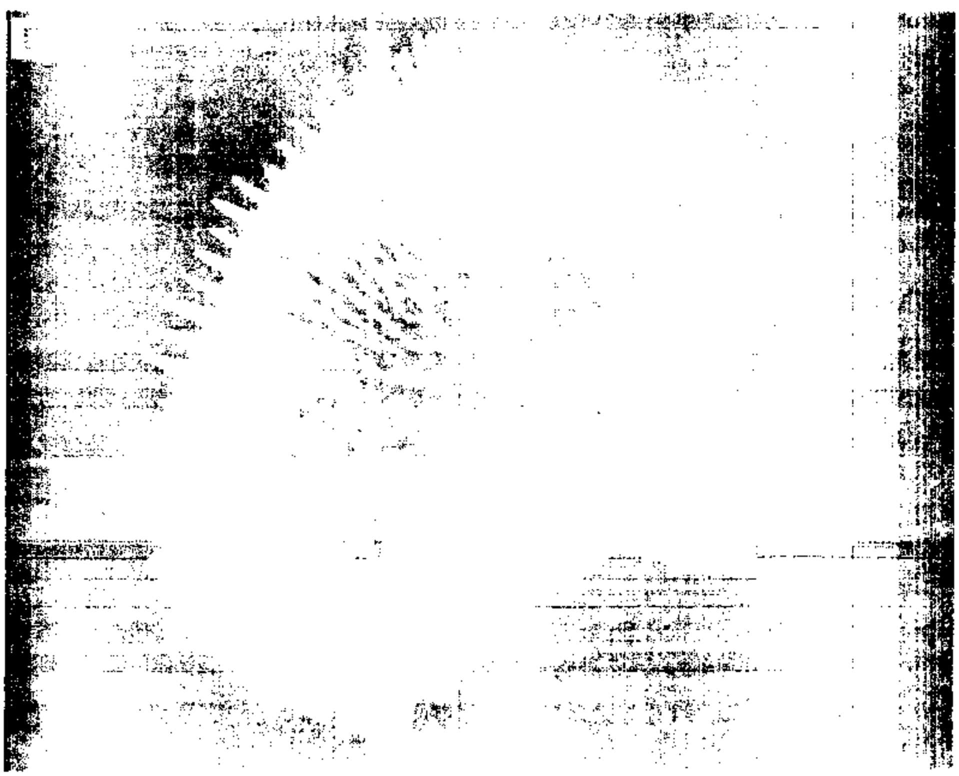
Oculina spp.

Fragments of several different species of *Oculina* have been recovered by scuba divers and van Veen grab samplers from the Flower Garden Bank. They are rarely

Fig. 36A. Photograph of three Scolymia wellsii specimens.

Fig. 36B. Photograph of a Scolymia wellsii corallite showing the intercepting and lace-like mesh of the inner teeth on the higher order septa.


A



encountered in the shallower portions of the reef. No attempt was made to identify the different species of *Oculina* since the fragments available do not contain a sufficient amount of any one colony to permit an accurate determination of the type of branching.

Class: Hydrozoa

Order: Milleporina

Family: Milleporidae Fleming, 1842

Millepori sp.

Millepora grows as encrustations on any solid, pre-existing surface. Mature colonies develop knobby to arborescent fronds. Its abundance makes it an important element in the reef framework. Underwater, *Millepora* is readily identified by its smooth surface, brown to greenish-brown color, and, most noticeably, by its ability to sting.

Detrital Sediments

Field and Laboratory Techniques

Except for sample number 44, all of the sediment samples used in the construction of the sediment facies map of the West Flower Garden Bank were collected by a van Veen grab sampler. Sample 44 came from the 27 fms (50 m) terrace adjacent to the coral reef and was collected by scuba divers. Most of the van Veen samples represent a single lowering of the grab; however, at several stations it was necessary to lower the grab 2 or 3 times before an adequate sample was obtained. Station locations were determined by loran fixes and the water depths were measured either by the length of wire played out during the van Veen lowerings or from the depth recorder.

Once on deck the grab sampler was emptied into a large bucket and subsamples were removed and sealed in plastic bags. In the laboratory the samples were placed in glass bottles and dried in an oven at 40°C for at least 24 hours. The samples were then removed from the glass containers and disaggregated. Sandy samples could usually be broken up with only slight pressure while the silty samples required a moderate amount of tapping.

Aluminum beer cans were opened at one end, coated internally with an alcohol base mold release compound and used as disposable containers for the sediments during impregnation by the plastic. The samples were placed in cans and then placed under a vacuum in an impregnating desiccator. The impregnating mixture consisted of 500 ml of Plaskon 951, 25 ml styrene, 5 drops of cobalt napthanate and 5 ml MEK peroxide. The procedure is as follows:

(1) to a 1000 ml beaker containing 500 ml Plaskon add 25 ml liquid styrene and mix thoroughly,

(2) add 5 drops of cobalt napthanate and mix thoroughly,

(3) add 5 ml of MEK peroxide and mix thoroughly.

Caution must be exercised in handling the chemicals since mixing of undiluted cobalt napthanate with MEK peroxide produces a violent explosion. The vacuum inside the desiccator forced the liquid plastic into the sediment filled cans through an opening in the desiccator lid. Once the containers were filled, the vacuum was released and the cans were moved into a pressure vessel. There they were kept under 120 psi of nitrogen for two hours or until the plastic has set. If they were removed before the plastic was completely cured, bubbles or strain cracks developed, depending on the degree of hardness. Impregnated samples were removed from the pressure bomb, the cans around the sediments discarded and the plastic cylinders placed in a 30°C oven for several days. Thin sections were then made by National Petrographic Services in Houston, Texas via standard techniques.

Thin section analyses were performed with a Zeiss GFL polarizing microscope equipped with a J. Swift and

Son automatic point counter. The point counting stage automatically moved 300μ between counts. If the cross hairs of the microscope failed to intercept a particle on the thin section being analysed, the stage was moved another 300μ. The crustose varieties of algae and foraminifers and some of the larger sediment particles exceeded 300μ in length; therefore, the point count does not represent the number of individuals present in a sample. Instead, the count indicates the probability of finding any one type of sedimentary particle relative to finding one of the other classes of particles.

Classification

The work by Majewske (1969) on the internal structures of invertebrate skeletal material has made it possible to assign most sand size carbonate grains to the phylum or class to which the organisms belonged.

In the case of encrusting calcareous algae, identification to the generic level requires thin sectioning of the detrital material. Since the West Flower Garden Bank is capped by an active coral reef and covered on its flanks by various types of calcareous sediments, a facies map was prepared based on the most frequently occurring sediment type as indicated by point count of thin sections.

After a cursory examination of the sediments from 44 stations occupied on cruise 70-A-13, 17 mutually exclusive categories of particles were erected. Based on their genetic origin, the carbonate particles were divided into Lithothamnium, Lithophyllum, Lithoporella, Amphiroa, Halimeda, Gypsina, Amphistegina, agglutinated foraminifers, other benthonic foraminifers, planktonic foraminifer, coral, echinoids, worm tubes, molluscs and bryozoans. The terrigenous fraction was divided into lithoclasts and quartz grains.

Carbonate Secreting Organisms

Phylum: Rhodophycophyta

Class: Rhodophyceae

Order: Cryptonemiales

Family: Corallinaceae

Lithothamnium Philippi

The most abundant coralline alga of the study area is Lithothamnium. Macroscopically it develops the four growth habits Johnson (1964) described: simple crusts, free crusts, crusts with branches or mammillae and strongly branching forms (Fig. 27A). Microscopically it can usually be identified by its calcified hypothallic and perithallic structures (Johnson, 1961). The hypothallus normally is either simple, with curved threads of cells that bend from horizontal to vertical (Fig. 37A) or plumose with cell rows that bend both inward and outward from the center (Fig. 38A). Rarely, the hypothallus will appear to be co-axial with regularly curved or arched layers of cells (Fig. 38C) (Johnson, 1964). The perithallus contains vertical rows of cells that are smaller than the perthillus cells of Lithophyllum. Conceptacles with numerous apertures are present on many Lithothamnium crusts (Fig. 38D).

Lithophyllum Philippi

Like Lithothamnium, Lithophyllum grows as simple crusts, free or nearly free crusts, crusts with warty protuberances and as branching individuals. In thin section it is recognized by its co-axial hypothallus and by the horizontal rows of perithallus cells (Fig. 38F) (Johnson, 1961 and 1964). Conceptacles are rare and when present the plane of the thin section seldom intercepts the aperture. Branching forms have a well developed co-axial hypothallus covered by a thin perithallus.

Fig. 37A. Photomicrograph of a Lithothamnium sp. crust showing both simple and plumose hypothallus and perithallus cell structures.

Fig. 37B. Photomicrograph of alternating Lithothamnium sp. and Gypsina sp. crusts.

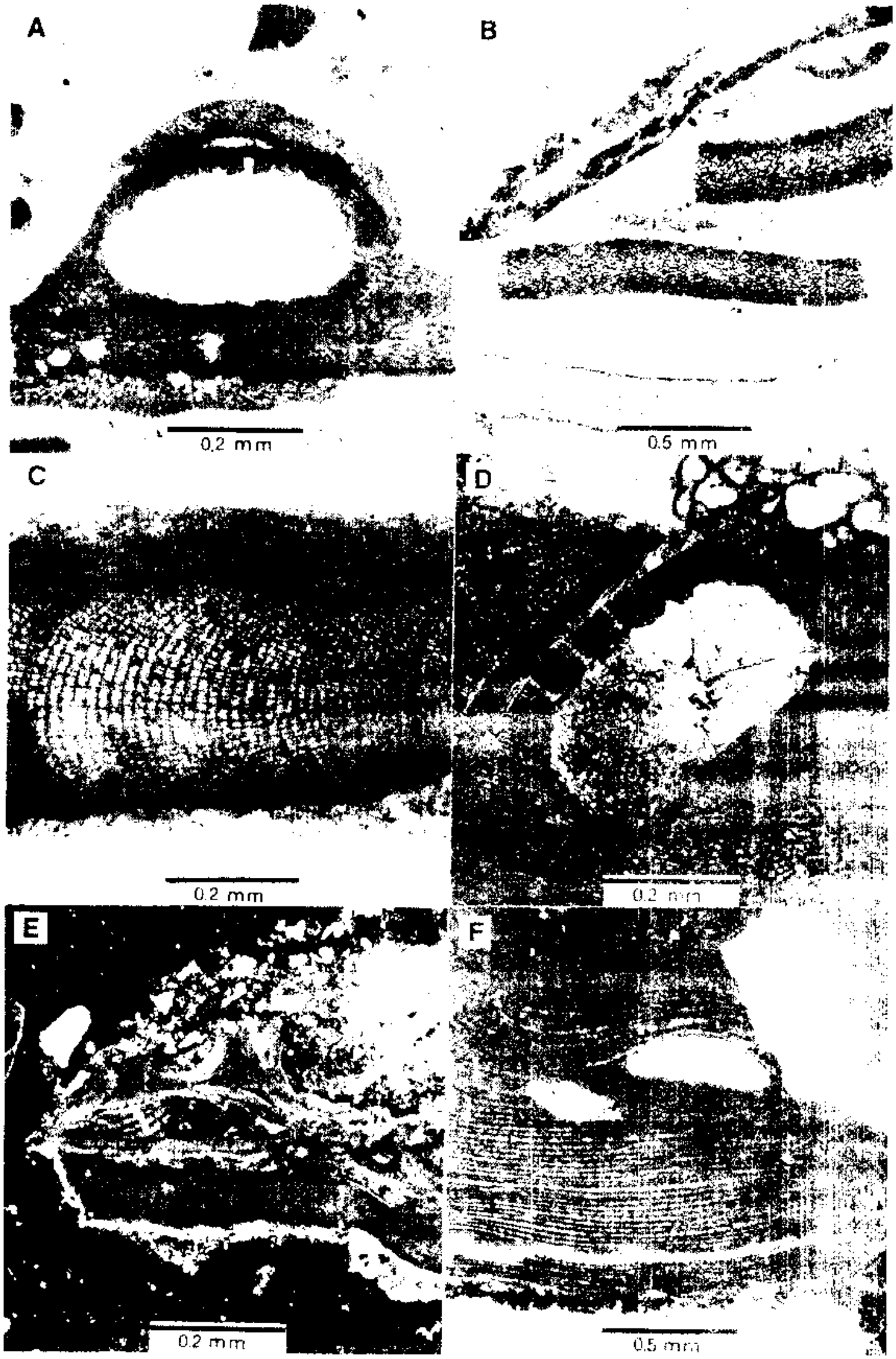
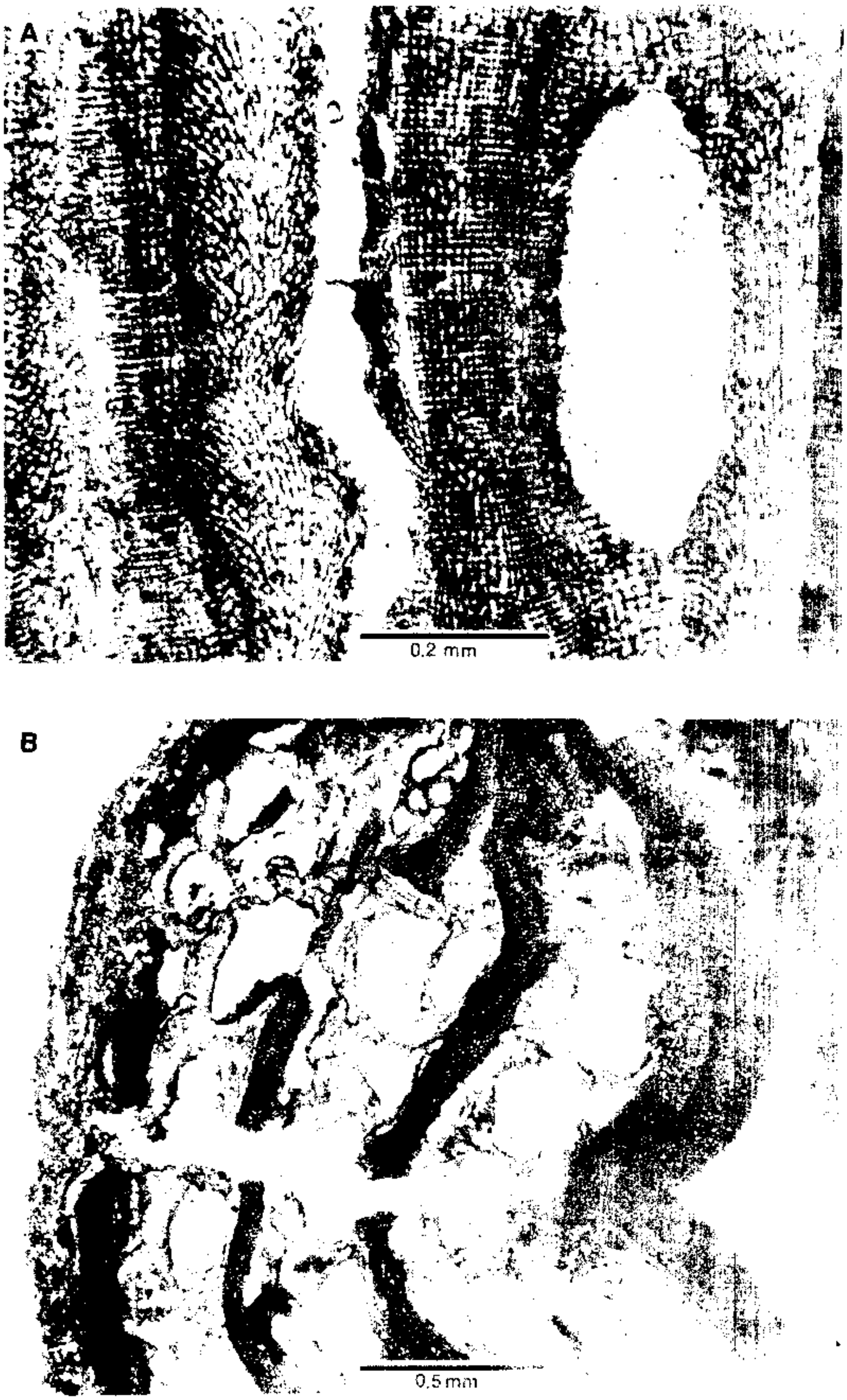

A
0.2 mm
B
0.5 mm
C
0.2 mm
D
0.2 mm
E
0.2 mm
F
0.5 mm

Fig. 38. Photomicrographs of thin sections of coralline algae showing: (A) *Lithothamnium* sp. conceptacle and plumose hypothallus; (B) branches of *Lithothamnium* sp.; (C) *Lithothamnium* sp. branch showing co-axial hypothallus and vertical rows of perithallus cells; (D) multiaperture conceptacle, *Lithothamnium* sp.; (E) *Lithoporella* sp. and (F) horizontal perithallus cells, *Lithophyllum* sp.


A
0.2 mm
B
0.5 mm

Lithoporella Fosslie

In the study area, *Lithoporella* sp. grows only as thin crusts on algal nodules. It can usually be identified by its thallus, which is formed from a single layer of elongated cells (Fig. 38E and 39B). No conceptacles were observed on these crusts. Unlike *Lithothamnium* and *Lithophyllum*, *Lithoporella* was not found fragmented and scattered about as loose sedimentary particles. Both single and stacked layers of elongated thallus cells are found in the algal nodules.

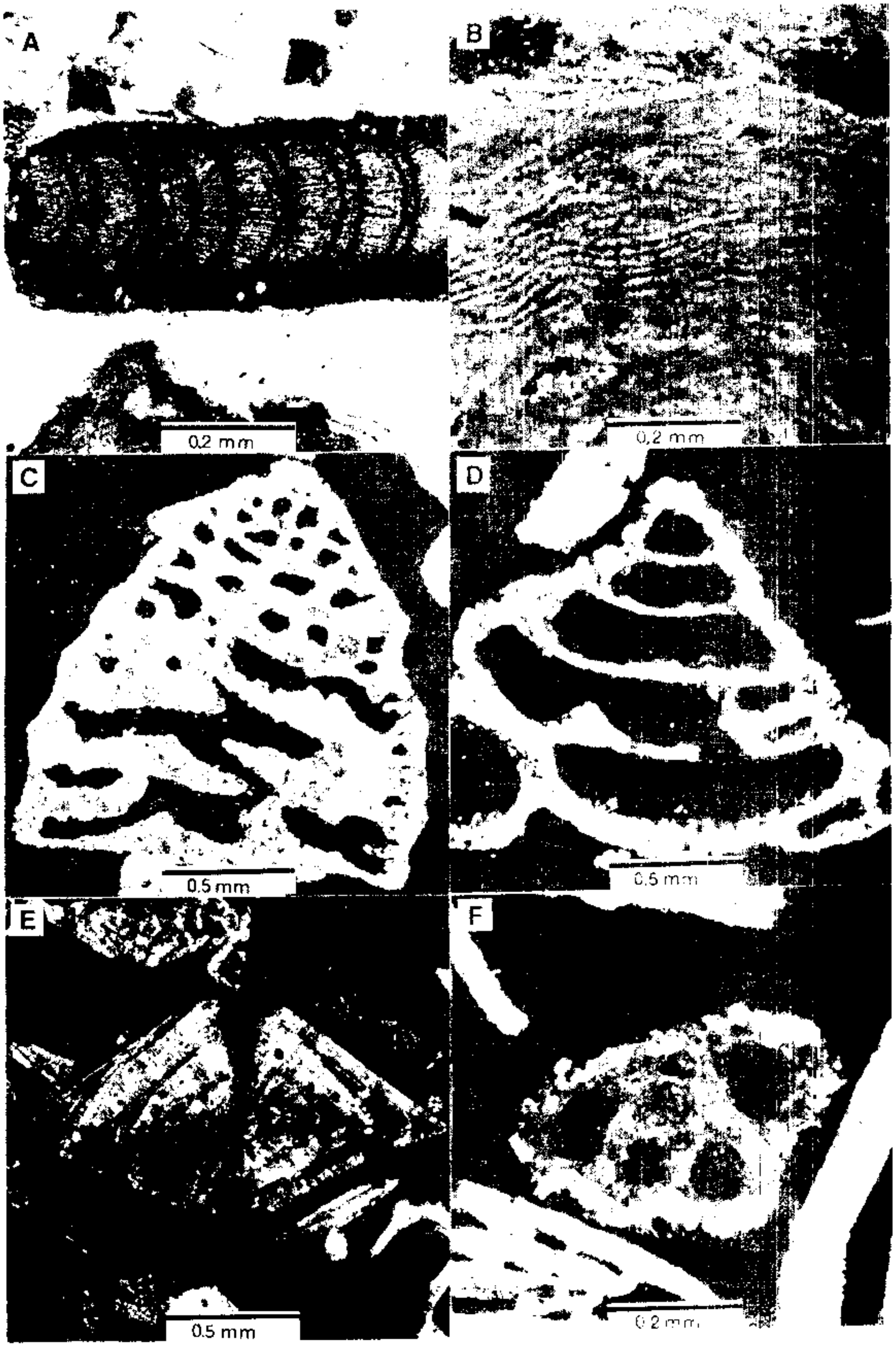
Amphiroa Lamareoux

This Corallineae is easily identified in thin section by its coaxial medullary hypothallus which is composed of arched layers of alternating large and small cells (Fig. 39A). The perithallus is usually very thin and generally lacks conceptacles. The sedimentary particles indicate that the plant is composed of slender, branching fronds. No living *Amphiroa* were collected, but this probably reflects the need for better sampling rather than its absence from the present biota of the bank.

Phylum: Chlorophycophyta

Family: Codiaceae

Fig. 39. Photomicrograph of thin sections of (A) Amphiroa sp.; (B) Lithoporella sp.; (C) Textulariella sp.; (D) Textularia sp.; (E) Amphistegina sp. and (F) agglutinated miliolid.


A
0.2 mm
B
0.2 mm
C
0.5 mm
D
0.5 mm
E
0.5 mm
F
0.2 mm

<u>Halimeda</u> Lamouroux

The unique characteristic of the Flower Garden Coral Reef is the nearly total lack of <u>Halimeda</u> in the reef and off-reef sediments. Of the 8600 point counts, only 5 poorly calcified <u>Halimeda</u> plates were observed (Fig. 40C). While diving on the reef, the author and the other divers were instructed to collect samples of all Codiaceae algae encountered, yet none have been found. The only living specimen came from a van Veen grab sample taken in deep water on the shelf near the study area. <u>Halimeda</u> plates were recognized in thin section by their light-brown, cryptocrystalline aragonite (Logan, <u>et al</u>., 1969) and by their rough, poorly calcified outer surface. None of the inner tubular structures were preserved. The four samples containing <u>Halimeda</u> plates ranged in depth from 43 fms (77 m) to 55 fms (101 m).

Phylum: Protista

Order: Foraminiferida

<u>Gypsina</u> <u>plana</u> Carter

Megascopically, the foraminifer <u>Gypsina</u> <u>plana</u> form a smooth, white to grayish white crust on pre-existing solid substrata. In thin section the subrectangular to polygonal chambers are separated by imperforate walls

Fig. 40. Photomicrograph of thin sections of (A) coral fragment showing sclerodermites; (B) mollusc shell showing crossed-lamellar microstructure; (C) Halimeda plate; (D) lithoclast with its top half made up of a echinoid plate; (E) cross section of two worm tubes showing gunsight structures and (F) oblique section of a worm tube.


A
C
E

of fibrous crystalline calcite (Barker, 1964). A few individuals exhibit walls that are perforate (Logan, et al., 1969). Gypsina plana may develop as single layers of polygonal cells, it may be several layers thick and alternate with crusts of calcareous algae (Fig. 37B), or it may form a thick encrusting mass over the entire surface of a particle. Gypsina plana particles range in depth from 10.5 fms (19 m) to 63 fms (113 m).

Amphistegina d'Orbigny

Amphistegina ranges in size from less than 40μ long to over 1780μ by 885μ. This genus is easily recognized in thin section by its lenticular shape, its thick walls and by its smooth surface traversed by numerous openings (Fig. 39E). In axial section the chambers form a complex spiral separated by thick, finely perforated walls. They were recovered in samples from the reef top at 10.5 fms (19 m) to the lower flanks of the bank at 64 fms (115 m). Living specimens have been gathered from the sand flats on top of the pinnacle. While no attempts have been made to determine the maximum depth at which Amphistegina is living on the bank, attached tests of this foraminifer have been observed on the outer surface of living algal nodules and algal crusts at depths from 27 fms (50 m) to 48 fms (88 m).

Agglutinated Benthonic Foraminifera

Several species of agglutinated foraminifers were observed in the thin sections. Two abundant families living on the bank are Textulariidae and Miliolidae (Fig. 39). They were easily recognized by their quartz grains, their tests and by the arrangement of their chambers. They were recovered from depths of 23 fms (40 m) to 64 fms (115 m).

Other Benthonic Foraminifera

The most outstanding encrusting foraminifers are Sporadotrema and Homotrema. Their red color and massive, projecting tests make them readily apparent on the outer surfaces of gravel size nodules and on the undersides of coral colonies. None, however, were observed in thin section. Numerous other free living, benthonic foraminifers are present in the sediments but no attempt was made to classify them. All bottom living foraminifers except Gypsina plana, Amphistegina and the agglutinated species were counted in this column. The classification of these organisms and their relative abundance is presently being studied by Dr. C. Wylie Poag. Benthonic foraminifers are found at all stations occupied on cruise 70-A-13.

Planktonic Foraminifers

Whole tests and fragments of tests of planktonic foraminifers are found at all depths on the West Flower Garden Bank. Their relative abundance in the sediments depends primarily on the dilution rate of skeletal material from the other calcium carbonate secreting organisms. Specimens range in size from fragments less than 40μ long to over 1000μ . The species present in the sediments from this bank have not been identified.

Phylum: Coelentrata

Class: Anthozoa

Order: Scleractinia

Corals

The hermatypic corals have been described in another section of this dissertation. It is sufficient to note that in thin section one genus can not be distinguished from another genus. Scleractinia fragments can be identified by the minute needles of aragonite that tend to fan outward from "centers of calcification" towards adjoining centers (Wells, 1956). These fiber fascicles or sclerodermites are shown in figure 40A. Depth ranges for the different species have already been given. Coral fragments are found from the top of the reef down to the lower flanks of the bank.

Phylum: Echinodermata

Class: Echinoidea

Echinoids

Majewske (1969, p. 43) distinguishes echinoids from other classes of echinoderms and from other phyla by "the occurrence of spines and sometimes by plates which show a considerable range of texture" (Fig. 40D). Like all echinoderms, the plates and spines of echinoids extinguish as single crystals when viewed in axial section under crossed nicols. The large pores in the plates also serve as a diagnostic characteristic. On the West Flower Garden Bank, they are found living on top of the reef at 10.5 fms (19 m) down to depths greater than 64 fms (115 m).

Phylum: Annelida

Worm tubes

Annelid worm tubes are composed of chitin, phosphate and calcium carbonate (Majewske, 1969). They are found at all depths and develop as encrustations on form substrate or as free tubes (Fig. 40F). In thin section they appear as circular to rectangular structures, depending on the plane of the thin section and may or may not contain a "gunsight" structure in the center of the tube (Fig. 40E). The tubes are built of foliated calcite crystals and usually encrust other carbonate sediments (Majewske, 1969).

Phylum: Mollusca

Mollusca

Originally an attempt was made to count these particles on a class level, but the fragmented nature of the grains and the destruction of the original microstructure by boring sponges and algae (Fig. 40B) forced the lumping of the classes into a phylum category. Majewske's book, Recognition of Invertebrate Fossil Fragments in Rocks and Thin Section (1969) describes in detail the different microstructures found in the shells of the different classes. A partial listing of the molluscs from the Flower Garden Banks has been published by Parker and Curray (1956). Molluscan remains range in depth from 10.5 fms (19 m) to over 64 fms (115 m).

Phylum: Bryozoa

Bryozoans

Bryozoans are rarely seen in the thin sections of the sediments from the bank. They are, however, commonly found growing on the under sides of coral colonies and encrusting mollusc shells. Majewske (1969) lists several criteria for distinguishing bryozoans from corals and coralline algae. In the samples studied, bryozoans were recognized by their small chambers and the "compass-needle" type of extension produced by the cone-in-cone calcite plate structure of their walls (Majewske, 1969). They range in depth from the top of the reef, where they have been observed growing on corals, to the lower limits of the bank at 64 fms (115 m).

Inorganic Particles

Lithoclasts

In thin section lithoclasts range in size from medium sand to fine gravel and in roundness from angular to poorly rounded. They are dark in color and usually contain numerous silt size shell fragments surrounded by a muddy matrix. Lithoclasts are found in depths from 27 fms (50 m) to 63 fms (113 m).

Quartz

Quartz grains range in depth from 27 fms (50 m) to at least 64 fms (117 m), the deepest station of this study. They are thought to be the dominant sediment of the shelf surrounding the West Flower Garden Bank. Quartz grains vary in size from fine silt to coarse sand and in roundness from very angular to well rounded. They are easily recognized in thin section by their first order gray color under crossed nicols.

Items Not Categorized or Counted

Both encrusting and branching forms of the calcareous alga Mesophyllum are present in trace amounts in several thin sections. Encrusting forms contain co-axial hypothallus and layered rows of perithallus cells containing multi-aperture conceptacles. In short branching forms the hypothallus is poorly developed and the perithallus shows irregular growth zones. Due to the plane of the thin sections, apertures were seldom seen. This makes it impossible to distinguish encrusting Mesophyllum from Lithophyllum. This, combined with the lack of well developed perithallus layers, prevents reliable segregation of this form from Lithothamnium. Since it is impossible to segregate fragments of infertile crusts of Mesophyllum, these crusts have been counted as either

Lithothamnium or *Lithophyllum*, depending on the cell arrangement.

If a particle was unidentifiable due to its small size or poor preservation it was not counted. Some identifiable items that were observed but not counted due to their small size and rarity were sponge spicules, holothurian spicules and octocoral spicules. Ooids and pellets were not observed.

Point Count Results

The relative frequency of occurrence of the 17 classes of sediment particles as indicated by point counts for the stations shown in figure 41 are given in table 4. In table 4 the stations are grouped into 7 suites based on the frequency of occurrence of the dominant sediments. The Coral Detritus Facies contains a sediment suite composed of at least 50% coral, the *Gypsina*-*Lithothamnium* Facies is composed of 50% or more encrusting foraminifers and algae, the *Amphistegina* Facies contains at least 10% *Amphistegina* and 10% or less planktonic foraminifers, and the Quartz-Planktonic Foraminifers Facies contains a minimum count of 10% quartz and 10% planktonic foraminifers. The two other

Fig. 41. Chart of the sample stations.

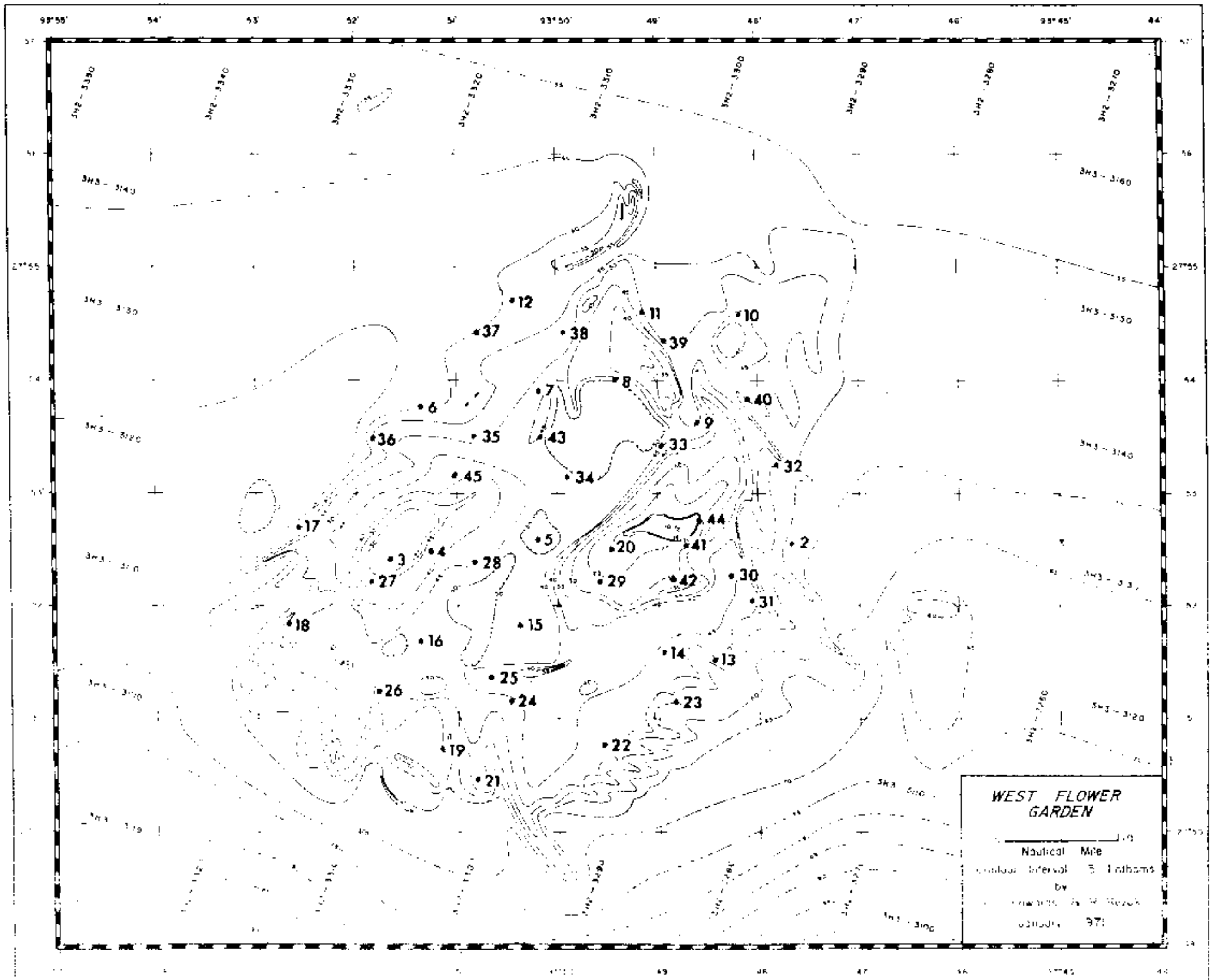

WEST FLOWER GARDEN
Nautical Mile
by

TABLE 4.

Point Count Results.

	Coral Debris Facies		Gypsina-Lithothamnium Facies							1st Trans. Facie[illegible]	
Lithothamnium	28	58	50	92	100	108	117	107	103	56	[illegible]
Lithophyllum	3	0	18	6	13	7	6	35	12	[illegible]	
Lithoporella	1	1	9	6	14	2	14	15	7	[illegible]	
Amphiroa	0	0	0	0	1	0	1	0	0	[illegible]	
Gypsina	6	13	11	33	33	12	35	14	24	14	
Pl. Forams	1	0	7	2	1	1	0	3	8	[illegible]	1
Benthonic Forams	1	0	3	1	3	5	2	2	5	13	1
Coral	136	119	11	29	11	45	6	1	18	[illegible]	[illegible]
Echinoids	1	0	2	3	3	1	0	2	0	[illegible]	
Worm Tubes	6	9	77	21	9	15	16	8	11	[illegible]	
Lithoclasts	5	0	0	0	4	0	0	0	0	3	
Mollusca	9	0	2	3	8	3	3	1	8	5	[illegible]
Quartz	2	0	0	2	0	0	0	5	0	0	
Agglutinated Forams	1	0	0	1	0	1	0	7	1	0	
Amphistegina Forams	0	0	0	0	0	0	0	0	3	[illegible]	[illegible]
Bryzoans	0	0	0	1	0	0	0	0	0	0	[illegible]
Halimeda	0	0	0	0	0	0	0	0	0	0	[illegible]
Sample No.	20	44	45	41	3	42	4	7	27	29	[illegible]

TABLE 4.

Point Count Results.

	Amphistegina Facies											
Lithothamnium	63	68	55	66	61	75	55	50	43	38	55	4
Lithophyllum	7	5	3	6	2	2	3	3	1	[illegible]	3	[illegible]
Lithoporella	2	1	5	0	4	3	9	7	2	[illegible]	5	[illegible]
Amphiroa	7	0	0	0	0	0	0	0	0	2	0	[illegible]
Gypsina	2	4	2	0	5	5	0	10	4	2	2	[illegible]
Pl. Forams	4	4	7	7	5	1	4	10	6	9	7	20
Benthonic Forams	1	18	4	9	3	6	1	17	6	12	4	[illegible]
Coral	18	20	48	29	25	14	24	5	39	42	48	31
Echinoids	10	10	6	13	10	2	2	21	24	6	6	11
Worm Tubes	13	4	16	13	15	7	15	7	10	13	16	[illegible]
Lithoclasts	6	8	5	1	6	10	21	4	3	4	5	[illegible]
Mollusca	34	23	15	21	28	24	17	8	16	21	15	34
Quartz	2	1	0	0	1	0	1	2	2	0	0	11
Agglutinated Forams	11	0	4	2	2	5	5	0	8	9	4	[illegible]
Amphistegina Forams	20	28	30	32	33	45	42	49	36	35	30	23
Bryzoans	0	4	0	1	0	1	1	5	0	0	0	[illegible]
Halimeda	0	2	0	0	0	0	0	2	0	0	0	[illegible]
Sample No.	5	9	38	26	24	14	30	8	35	34	38	39

TABLE 4.

Point Count Results.

	2nd Transition Facies							
Lithothamnium	22	39	52	56	28	34	[illegible]	4
Lithophyllum	0	2	6	1	[illegible]	3	[illegible]	
Lithoporella	0	2	1	1	[illegible]	3	[illegible]	
Amphiroa	0	1	0	0	0	[illegible]	[illegible]	
Gypsina	3	1	3	11	3	14	[illegible]	
Pl. Forams	24	20	8	12	25	[illegible]	11	[illegible]
Benthonic Forams	17	9	9	6	17	13	[illegible]	[illegible]
Coral	25	42	26	7	44	19	27	[illegible]
Echinoids	18	7	11	21	5	[illegible]	[illegible]	
Worm Tubes	21	11	12	7	8	19	[illegible]	
Lithoclasts	13	12	2	4	3	4	3	[illegible]
Mollusca	45	25	36	42	28	21	34	[illegible]
Quartz	1	3	5	7	14	16	19	[illegible]
Agglutinated Forams	5	7	11	12	[illegible]	3	4	
Amphistegina Forams	3	18	18	12	17	19	14	[illegible]
Bryzoans	3	1	0	1	0	[illegible]	2	
Halimeda	0	0	0	0	0	[illegible]	[illegible]	
Sample No.	31	43	21	13	40	11	15	[illegible]

TABLE 4.

Point Count Results.

	Quartz - Planktonic Foraminifer Facies											
Lithothamnium	51	18	25	19	31	20	12	21	11	21	31	[illegible]
Lithophyllum	1	0	0	0	0	2	1	3	0	0	2	
Lithoporella	1	0	0	0	1	0	0	1	0	2	1	
Amphiroa	0	0	0	0	0	0	0	0	1	0	0	
Gypsina	1	0	4	0	1	2	5	0	1	1	0	
Pl. Forams	21	33	23	48	27	40	27	41	37	42	20	3[illegible]
Benthonic Forams	8	13	12	28	25	17	15	18	30	12	5	2[illegible]
Coral	26	42	28	2	21	8	7	24	3	9	11	
Echinoids	12	6	2	18	10	11	16	16	15	6	13	1[illegible]
Worm Tubes	7	15	12	9	12	13	8	8	16	4	5	1[illegible]
Lithoclasts	1	3	13	1	7	5	11	1	2	5	1	
Mollusca	19	15	39	32	27	38	35	19	32	25	38	
Quartz	24	27	28	28	29	29	36	38	41	41	48	9[illegible]
Agglutinated Forams	8	7	5	12	4	4	5	5	16	26	11	
Amphistegina Forams	18	16	9	3	4	11	21	4	3	6	12	
Bryzoans	1	5	0	0	1	0	1	1	2	0	2	
Halimeda	1	0	0	0	0	0	0	0	0	0	0	
Sample No.	33	32	23	19	18	22	17	36	12	6	10	3[illegible]

suites are transition facies between the *Gypsina-Lithothamnium* and *Amphistegina* Facies and the *Amphistegina* and Quartz-Planktonic Foraminifers Facies. Figure 42 is a graphic display of part of table 4 showing the frequency of occurrence of coral, *Lithothamnium*, *Gypsina*, *Amphistegina*, planktonic foraminifers and quartz at the different stations.

In order to determine the validity of the seven sediment facies, chi square analyses were performed on the sediment counts. In the analysis of the West Flower Garden Bank sediment facies, a significant chi square number for any of the within tables indicates a large degree of variability among the stations within that facies while a large (i.e., significant) chi square number for the between table indicates a large variability in the sediment compositions between the different facies. Table 5 lists the within and between chi square values. Since the variability of both the sum of the within values and the between values is large, a Fisher's F test was employed to determine which of the two groups contains the greatest degree of variance. A highly significant F value of 22.8 indicates that the variability between the facies is much larger than the variability within the facies. Therefore, the facies

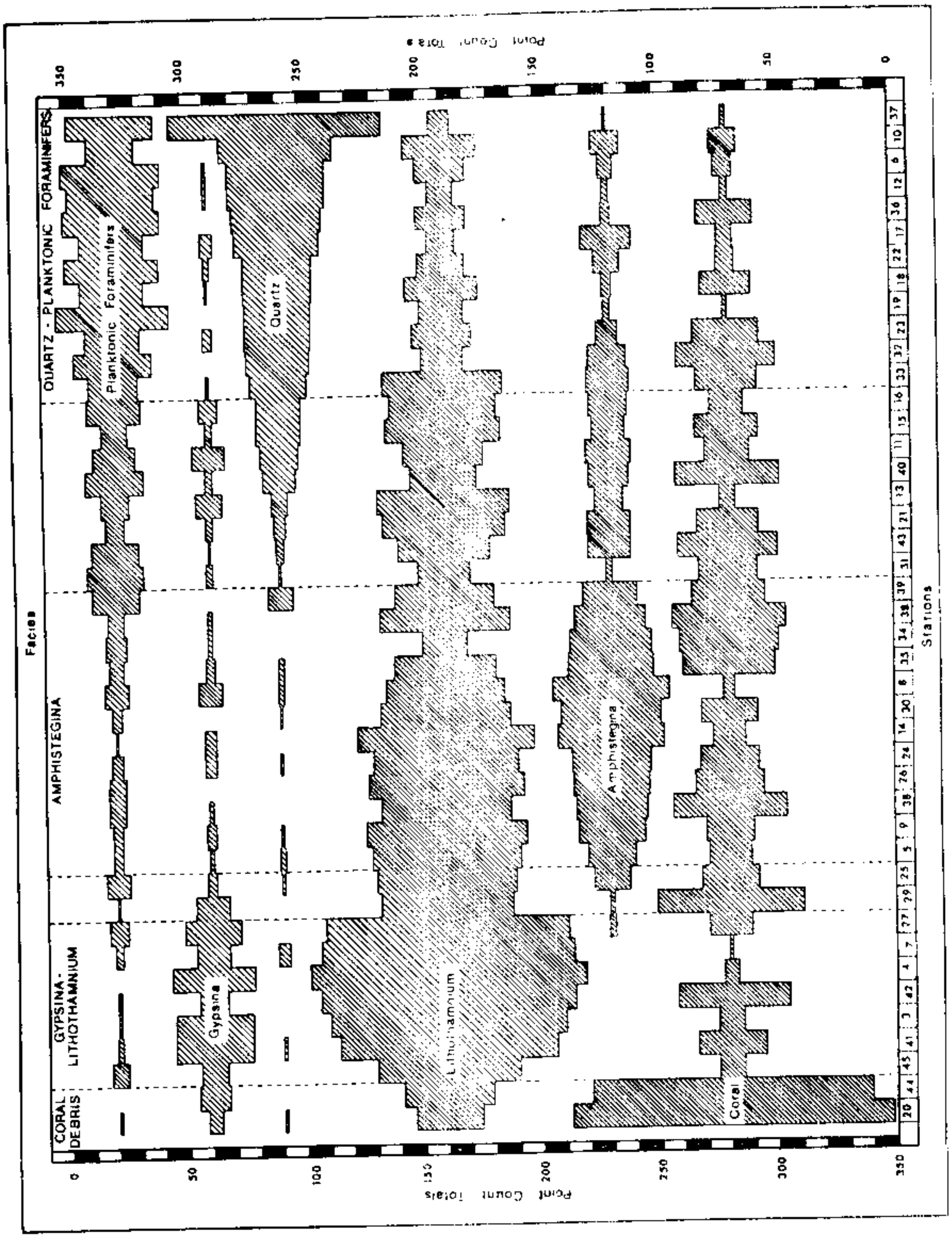

Facies
CORAL DEBRIS
GYPSINA-LITHOTHAMNIUM
AMPHISTEGINA
QUARTZ - PLANKTONIC FORAMINIFERS
Planktonic Foraminifers
Gypsina
Quartz
Lithothamnium
Amphistegina
Coral
Point Count Totals
0
50
100
150
200
250
300
350
Stations

TABLE 5

Chi-square and F-test Results.
All X^2 values are significant at the 99% level.

Division	X^2	degrees freedom	mean square	F-test
Total	6707	647		
Between Facies	4523	55	82.23	22.[illegible]
Within Facies (total)	2184	592	3.69	
Coral Debris Facies	37	16		
Gypsina-Lithothamnium Facies	465	96		
1st Transition Facies	101	16		
Amphistegina Facies	614	176		
2nd Transition Facies	298	112		
Quartz-Planktonic Foraminifers Facies	669	176		


WEST FLOWER GARDEN
Nautical Mile
93°55'
54'
53'
52'
51'
93°50
49'
48'
47'
46'
93°45'
44'
3H2 - 3350
3H2 - 3340
3H2 - 3330
3H2 - 3320
3H2 - 3310
3H2 - 3300
3H2 - 3290
3H2 - 3280
3H2 - 3270
3H3 - 3160

divisions based on the above criteria are legitimate.

Figure 43 is a chart of the West Flower Garden Bank showing the areal distribution of the coral, _Gypsina_-_Lithothamnium_, _Amphistegina_, Quartz-Planktonic Foraminifers and transition facies.

DISCUSSION

Definition of Terms

In the biological and geological literature the terms "community" and "facies" have been used in a variety of ways. For this study the term "community" is used to define a regularly recurring combination of organisms. Logan, et al., (1969) subdivided the bioherms and biostromes developing on the Campeche shelf into five zones or "biotic communities." Their definition of the term "community" is "a group of organisms, dominated by certain abundant and functionally important components, which is associated consistently throughout a biogeographic region" (p. 144). While failing to specify what made an organism "functionally important," the geological nature of their investigation suggests that the "important" members of a living community secrete hard parts and that these parts are capable of being incorporated into the fossil record. In this study the term "facies" defines a suite of sediments that exhibits characteristics significantly different from the other suites of sediments. It includes all of the sediments being incorporated into the rock record, irregardless of whether they are organically derived or reworked terrigenous particles. The facies from the West Flower Garden Bank may, therefore, include both the carbonate sediments from the "biotic communities" described by Logan, et al., (1969) and terrigenous sediments eroded from the pre-reef bank or it may be made up of only carbonate particles.

Introduction to the Sediment Facies

With the advent of scuba diving equipment it has become feasible to study "in situ" the deeper facies of coral reefs. In this investigation scuba equipment permitted the author to investigate the Diploria-Montastrea-Porites and Coral Debris facies, the shallowest sediment facies of the West Flower Garden Bank. Van Veen grab samples and bottom photographs taken by deep sea cameras were used in the examination of the deeper Gypsina-Lithothamnium, Amphistegina and Quartz-Planktonic Foraminifers facies. Although the species diversity of the scleractinians living on the West Flower Garden Reef is not as great as on other reefs in the Caribbean, the biota of the pinnacle represents a flourishing West Indian coral reef community.

Sediment Facies

Diploria-Montastrea-Porites Facies

Description. From the top of the reef structure at 10.5 fms (19 m) to a lower limit of approximately 22 fms (40 m) on the western end and 27 fms (50 m) on the eastern end of the main pinnacle, the scleractinian assemblage is dominated by the encrusting, dome-shaped colonies of *Diploria strigosa*, *Montastrea cavernosa*, *M. annularis*, and *Porites astreoides* (Figs. 29A, 29B, 33A and 33B). The other corals living in this facies, arranged according to their decreasing abundance, are *Madracis asperula*, *Mussa angulosa*, *Colpophyllia natans*, *Agaricia agaricites*, *Agaricia fragilis*, *Madracis decactis*, *Agaricia nobilis*, *Scolymia wellsii*, *Oculina* sp., and *Siderastrea* sp. The relief of the reef surface is extremely irregular with coral heads extending up to 15 feet (4.6 m) above the smaller domes and irregular colonies of coral, sponges and associated reef organisms. Upturned sides of coral colonies and the development of shingle-like morphology (Fig. 29B) gives some coral heads an appearance of being more massive than they really are, especially when viewed from above. Numerous small caves are present underneath the edges of coral colonies, but none approach the cavernous size of those described by Storr (1964) from Abaco Island, Bahamas. Colonies of Millepora and encrusting calcareous algae cover a large percentage of the irregular surface not occupied by sclerastinians. They bind together and strengthen the different structural elements of the reef mass.

Occasional patches of coarse sand and gravel floor the reef between areas of active growth. The ripples present in the sand flats average two feet (60 cm) long and their crests are capped with gravel size coral and mollusca debris. The movement of the loose sediments during the passage of cold fronts and summer storms has undercut some of the larger coral heads and polished the exposed surfaces of coral colonies underlying the detritus. The ability of storm waves to move sediment off the reef onto the surrounding sediment apron explains the apparent fluctuation in the percentages of sand flats in the Diploria-Montastrea-Porites Facies. The ease with which the detritus moves off the pinnacle is manifested in the lack of sandy zones on the western end of the reef structure.

Environmental controls. Light intensity, temperature and the type of substratum are the dominant agents limiting the downward growth of the Diploria-Montastrea-Porites Facies. During the summer, maximum light values at 10.5 fms (19 m) are approximately 30% of the surface illumination, while at 27 fms (50 m) they are 2% of the surface value. These values are from open ocean stations and, due to back scattering, should be increased slightly for areas close to the reef. The shingle-like corallum, common on the larger coral heads on top of the reef and universally present on the colonies flanking the main reef structure, has been interpreted as a growth form due to the better development of those polyps with the maximum exposure to the sun light (P. Braithwaite, personal communication, 1971).

Minimum temperatures occur on the reef during the passage of cold fronts. High winds associated with these fronts keep the mixing layer at approximately 55 fms (100 m) during most of the winter; therefore, a surface value of 18.8°C (the lowest ever recorded for this part of the shelf) corresponds to 18.2°C at 10.5 fms (20 m), 18.1°C at 27 fms (50 m) and 17.7°C at 55 fms (100 m). During the summer the 19°C isotherm seldom shoals to depths less than 55 fms (100 m), and the Diploria-Montastrea-Porites Facies usually falls within the 25-29°C range of maximum Scleractinia development (Vaughan and Wells, 1943).

Scleractinia attached to the sloping flanks of the reef pinnacle usually survive the periods of reduced temperature and illumination present during the passage of winter cold fronts. For individuals trying to colonize the sand and gravel.covered aprons and the flatter, nodule covered terraces, the combination of a mobile substratum with the other adverse conditions makes survival impossible.

Salinity and oxygen values are essentially constant for the upper 55 fms (100 m) of the Gulf of Mexico along the outer Texas-Louisiana continental shelf. Water currents, even though they are poorly understood, are not thought to be restricted to the upper 27 fms (50 m). The amount of suspended material in the water shows no sharp increase at 27 fms (50 m); visibility ranges from over 100 feet (31 m) on clear days to less than 35 feet (4 m) during periods of high productivity. Cold water, reduced illumination and high seas (i.e., mobile sediments) are the main environmental agents preventing the Diploria-Montastrea-Porites Facies from colonizing deeper sections of the bank.

Compared to other West Indian coral reef communities, the diversity of the Scleractina population on the West Flower Garden Reef is greatly restricted (table 6). The reefs offshore from the state of Veracruz, Mexico, experience as adverse conditions as those found at the Texas reefs, yet their faunas are richer than that of the study area (Freeman, 1971). The most important factors controlling the Scleractinia diversity on the Flower Garden Reefs are the distance the free floating planula larvae must migrate and their ability to find suitable substrata once they reach the bank (Vaughan and Wells, 1943). The nearest reefs from which the planula larvae could come are the Campeche reefs, 375 nautical miles to the south-southeast and the reefs between Tampico and Tuxpan, Veracruz, Mexico, 430 nautical miles to the southwest. The currents in the western Gulf are poorly understood, but the large gyres plotted by Nowlin (1971) suggest that the actual distance a larvae must travel before reaching the West Flower Gardens greatly exceeds these straight-line distances. The life span of the larvae stage and the effects of temperature, salinity, food supply, grazing by other organisms and other environmental parameters on the planula are poorly understood, but it is thought that they determine the survival chances of the coral larvae. Their survival ability, in turn, controls the diversity of the hermatypic coral fauna on the West Flower Garden Bank.

TABLE 6. Distribution of Scleractinia in the Atlantic, Caribbean and G. of Mexico

Phylum: Coelenterata Class: Anthozoa Order: Scleractinia		Florida	Bahamas	West Indies	Curacao	Alacran	Veracruz	Bermuda	W.F.G.	Brazil
Family: Astrocoeniidae	*Stephanocoenia michelini*	x	x	x	x			x		
Pocilloporodae	*Madracis decactis*	x	x		x			x	x	x
	Madracis mirabilis				x					x
	Madracis asperula				x				x	
Agariciidae	*Agaricia agaricites*	x	x	x	x	x			x	x
	Agaricia fragilis	x			x			x	x	x
	Agaricia nobilis	x	x	x					x	
Siderastreidae	*Siderastrea radians*	x	x	x	x	x	sp.	x	sp.	
	Siderastrea siderea	x	x	x	x	x		x		
	Siderastrea stellata									x
Poritidae	*Porites astreoides*	x	x	x	x	x	x	x	x	x
	P. branneri			x						x
	P. divaricata	x	x	x						
	P. furcata	x	x	x		x	x	x		
	P. porites	x	x	x	x	x				
	P. verrilli									
Faviidae	*Favia conferta*									x
	F. fragum	x	x	x	x	x		x		
	F. gravida									
	F. leptophylla									x
	Diploria clivosa	x	x	x	x	x				
	D. labyrinthiformis	x	x	x	x	x	x	x		
	Colpophyllia amaranthus	x		x		x				
	Colpophyllia natans	x	x	x	x				x	

TABLE 6. Distribution of Scleractinia in the Atlantic, Caribbean and G. of Mexico

			Florida	Bahamas	West Indies	Curacao	Alacran	Veracruz	Bermuda	W.F.G.	Brazil
Family:	Faviidae (cont.)	Manicina areolata	x	x	x		x				
		M. mayori	x								
		Cladocora arbuscula	x	x	x			x			
		Solenastrea bournoni	x		x	x					
		S. hyades	x	x	x						
		Montastrea annularis	x	x	x	x	x	x	x	x	x
		M. braziliana									
		M. aperta									
		M. cavernosa	x	x	x	x	x	x	x	x	x
	Astrangiidae	Astrangia solitaria	x	x	x				x		
		A. rathbuni									x
		A. brasiliensis									x
		Phyllangia americana									x
	Oculinidae	Oculina diffusa	x	x	x		spp.		x	spp.	
		O. valenciennesi			x				x		
		O. varicosa	x		x				x		
	Trochosmiliidae	Meandrina meandrites	x		x	x					
		M. brasiliensis	x		x						x
		M. danae									
		Dichocoenia stokesii	x	x	x	x					
		Dendrogyra cylindrus	x	x	x	x					
	Mussidae	Mussismilia brasiliensis									x
		M. harttii									x
		Mussa angulosa	x	x	x	x	x			x	

TABLE 6. Distribution of Scleractinia in the Atlantic, Caribbean and G. of Mexico.

		Florida	Bahamas	West Indies	Curacao	Alacran	Veracruz	Bermuda	W.F.G.	Brazil
Family: Mussidae (cont.)	*Scolymia lacera*			x						
	Scolymia wellsii								x	x
	Isophyllastrea rigidia	x	x	x	x			x		
	Mycetopyllia lamarckiana				x					
	Isophyllia sinuosa	x			x					
	I. multiflora									
Caryophylliidae	*Eusmilia fastigiata*	x	x	x	x	x				
Acroporidae	*Acropora cervicornis*	x	x	x	x	x	x			
	A. palmata	x	x	x	x	x	x			
	A. prolifera	x	x	x						

Species distribution after: Bahamas (Smith, 1971); Bermuda (Smith, 1971); Brazil (Laborel, 1967); Curacao (Roos, 1964); Florida (Smith, 1971) and Veracruz (Heilprin, 1890).

Stetson Bank, a salt dome structure 30 nautical miles to the northwest of the West Flower Garden Bank, contains isolated heads of Siderastrea sp., Montastrea annularis, Madracis asperula and Diploria strigosa. These small colonies range in depth from 12 fms (22 m) to 25 fms (46 m) and are found growing on outcrops of Miocene shales. The sparce colonization of this bank by the West Indian coral reef community is due to the low temperatures and salinities which are adverse to the development of coral reefs.

Age and Thickness of the Reef. The maximum age of the reef and the thickness of the reef mass can only be approximated at this time. Between 10,000 and 11,000 years B.P. the waters of the Gulf warmed (Curray, 1960) and sometime between 10,000 and 8,000 years B.P. the seas totally submerged the West Flower Garden Bank (Shepard, 1960). The exact date depends on whether or not there is a slender pinnacle of terrigenous, pre-Pleistocene sediments within the reef structure. The lack of lithoclasts and quartz grains shallower than 27 fms (50 m) suggests a solid carbonate core for the structure rising above the 27 fms (50 m) terrace. Also unknown is the date when the Scleractinia and calcareous algae started populating the bank. Assuming the reef was populated 7,000 years B.P. by the West Indian coral reef community and that the prereef consisted of a level platform, the reef structure is approximately 100 feet (30 m) thick. This is well within the measured growth rates of 1.07 and 0.6 to 0.7 cm/year for Montastrea colonies measured by Hoffmeister and Multer (1964) and Vaughan (1919). Mayor (1924, in Stoddard, 1969) estimated the upward growth for the entire Indo-Pacific coral reef off Pago Pago, Samoa, to be eight mm/year.

Another possibility for the time when the corals colonized the bank is sometime prior to 10,000 years B.P. It has been postulated that during this time period numerous coral reefs were growing on the outer margins of the northern Florida and Alabama shelves (Ludwick and Walton, 1957). The lower seas of this period made the West Flower Garden Bank one or two islands, depending on the exact time and corresponding sea level. If the bank was populated by hermatypic corals during this period they should have formed fringing reefs around the island or islands. Evidence of these older coral reefs is totally lacking. In none of the deeper photographs from the bank are reef structures present, nor has coarse, reef derived rubble been seen or recovered from the appropriate depths. The low temperatures, low salinities and high turbidity of the nearshore water found around the dome would not have supported a West Indian coral reef community during late Pleistocene times. Nor does the evidence indicate that the corals presently inhabiting the bank represent the surviving fauna of a more diverse Pleistocene coral reef.

Coral Debris Facies

Description. The Coral Debris Facies is essentially a transitional facies between the *Diploria-Montastrea-Porites* Facies and the *Gypsina-Lithothamnium* Facies and is restricted to the main pinnacle of the bank. This facies interfingers with the active coral reef community with 17 fms (31 m) being the shallowest observed depth of one of these sediment filled tongues. Unlike the spur and groove structure found on emergent reefs, the coral heads growing on the flanks of the tongues curve gently downward to the sediment, with an average slope of 45 degrees. Occasionally, vertical drops of up to three feet (1 m) in height are found between the coral heads and the sediment. These small cliffs are produced by the erosion of the base of coral colonies as the sediment moves downslope. At 25 to 27 fms (46-

50 m) the organic carbonate dominating the gravel particles switches from the coral hash to the Corallinaceae and foraminifer crusts. The exact depth of the lower transition fluctuates, depending on the length of time between storms and the rate of sediment supply to the apron.

Gypsina-Lithothamnium Facies

Description. The Gypsina-Lithothamnium Facies ranges in depth from 25 fms (46 m) to 40-45 fms (73-82 m) on both of the larger pinnacles of the West Flower Garden Bank and probably exists on the smaller pinnacles in this depth range. At the shallower depths, the facies is composed of "lithothamnium" nodules (Fig. 27A) with the encrusting *Lithothamnium* sp. two to three times as abundant as the encrusting foraminifer *Gypsina* sp., *Lithophyllum*, *Lithoporella* and *Mesophyllum*. At greater depths the growth form changes to a platy or free crust that blankets the loose sediments. Table 4 lists the relative abundance of the encrusting organisms that form the "lithothamnium" deposits. These counts represent averages from several nodules or free crusts with the individual nodules or crusts varying in composition from nearly 100% one genus to 100% another genus. From the number of samples available for this study, it is impossible to determine if the Gypsina-Lithothamnium Facies replaced an older Lithophyllum-Lithoporella Facies. At all seven stations of this facies individuals from the different genera were interwoven. The generic group that forms the outer layer depends upon its abundance and not on the age of the crust.

Environmental controls. The effect of temperature, salinity and nutrient supply are thought to be of minimal importance in limiting this facies to its observed depth range. Illumination and water turbulence are the dominant controlling agents. Light values shown in figure 13 indicate that Corallinaceae can build nodules and free crusts in greatly reduced levels of illumination while water turbulence controls the shape of the crusts.

Occasional winter northers and summer hurricanes produce the waves necessary to turn over the nodules found on the terraces at 27 fms (50 m), destroying attempts of the algae and foraminifera to bind together the gravel. This aggitation permits growth of the encrusting organisms on all sides of the nodules, producing oblong nodules up to 8 cm long and 6 cm wide which weigh 250 g. The platy, free crusts were recovered from depths of 40-45 fms (73-82 m) and, except during severe hurricanes, were unaffected by surface waves. Water currents induced by tides, storms, or geostrophic forces are sufficient to keep the plants and protistans free of fine debris and to supply them with needed nutrients.

Figures 44 are "in situ" photographs of the nodules and free crusts found in the *Gypsina*-*Lithothamnium* Facies.

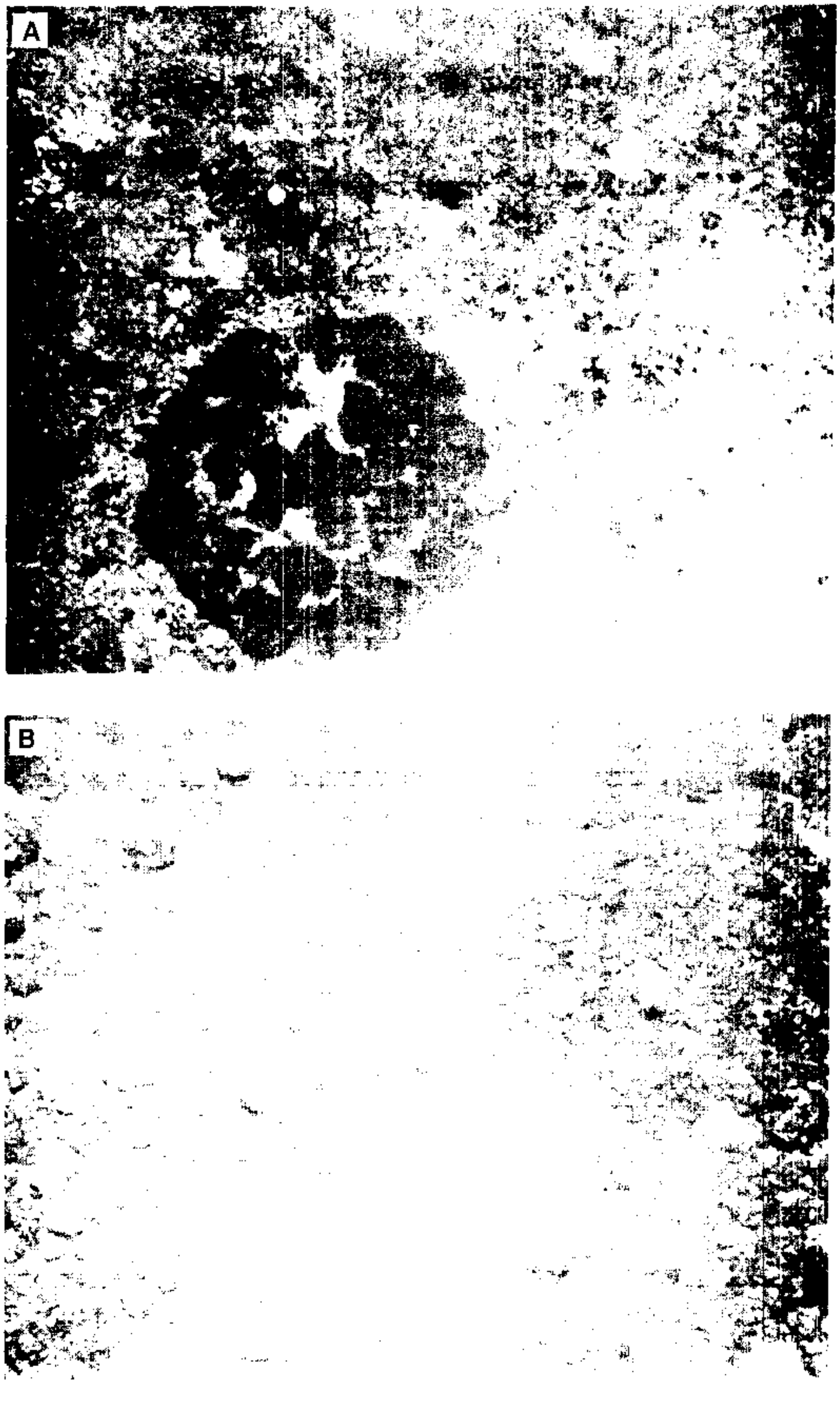
First Transition Facies

Description. Sediment of the First Transition Facies contains less than 1% quartz grains, less than 10% *Amphistegina* tests and approximately 30% *Lithothamnium* crusts. Its depth range varies from 28 fms (51 m) to 50 fms (91 m) and represents an intermixing of the coral debris, *Gypsina*-*Lithothamnium* and *Amphistegina* facies.

Amphistegina Facies

Description. The *Amphistegina* Facies ranges in depth from approximately 40 fms (73 m) to 55 fms (100 m).

Fig. 44. Underwater photographs of the _Gypsina-Lithothamnium_ Facies at station 41. (A) Spong colony on nodule covered terrace, 25 fms (46 m) and (B) "lithothamnium" nodules and free crust, 28 fms (51 m).


A
B

Amphistegina tests form up to 25% of the sediment with the tests varying in appearance from whole tests to rounded fragments. The genus *Amphistegina* is found living from the top of the reef at 10.5 fms (20 m) to 48 fms (88 m). Except for samples from the reef top, no attempts were made to find protoplasm in the test, but the tests are found attached to the outer crusts of living Corallinaceae in the *Gypsina*-*Lithothamnium* Facies (Dr. C. Wylie Poag, personal communication, 1971). Based on counts of foraminiferal tests, Bandy (1956) and Ludwick and Walton (1957) described locally abundant *Amphistegina* zones from depths of 30 to 58 fms (53-106 m) in the northeast Gulf of Mexico.

Since *Amphistegina* is an abundant foraminifer in the shallower parts of the reef and reef apron, the tests probably belong to a death assemblage of recently living individuals. They may live on the exposed bed-rock and algae found at these depths and be carried into the sandy areas after death or they may inhabit shallower depths and be carried into the deeper zones by local currents. Another important control on the live-dead ratios and whether this is an active deposi-tional Facies or a relict Pleistocene one is the growth rate of the protistans. If *Amphistegina* grows rapidly and has a short lifespan, a sparse living population might produce a dominant fossil assemblage. Based on the observations from the study area, the *Amphistegina* Facies is believed to be receiving sediments from organisms living at this depth and from debris carried downslope from the shallower facies. Figures 45A and 45B are bottom photographs of this facies showing the generally sandy bottom with the coarser debris from shallower depths irregularly distributed about the bottom.

At various depths in the *Amphistegina* Facies are outcrops of the uplifted Cenozoic sediments. Figure 46A from 43 fms (79 m) and figure 46B from 45 fms (82 m) are examples of these exposures. Biodegradation and mechanical erosion of these fault blocks account for the lithoclasts and some of the quartz grains found in the predominantly carbonate sediments of the bank.

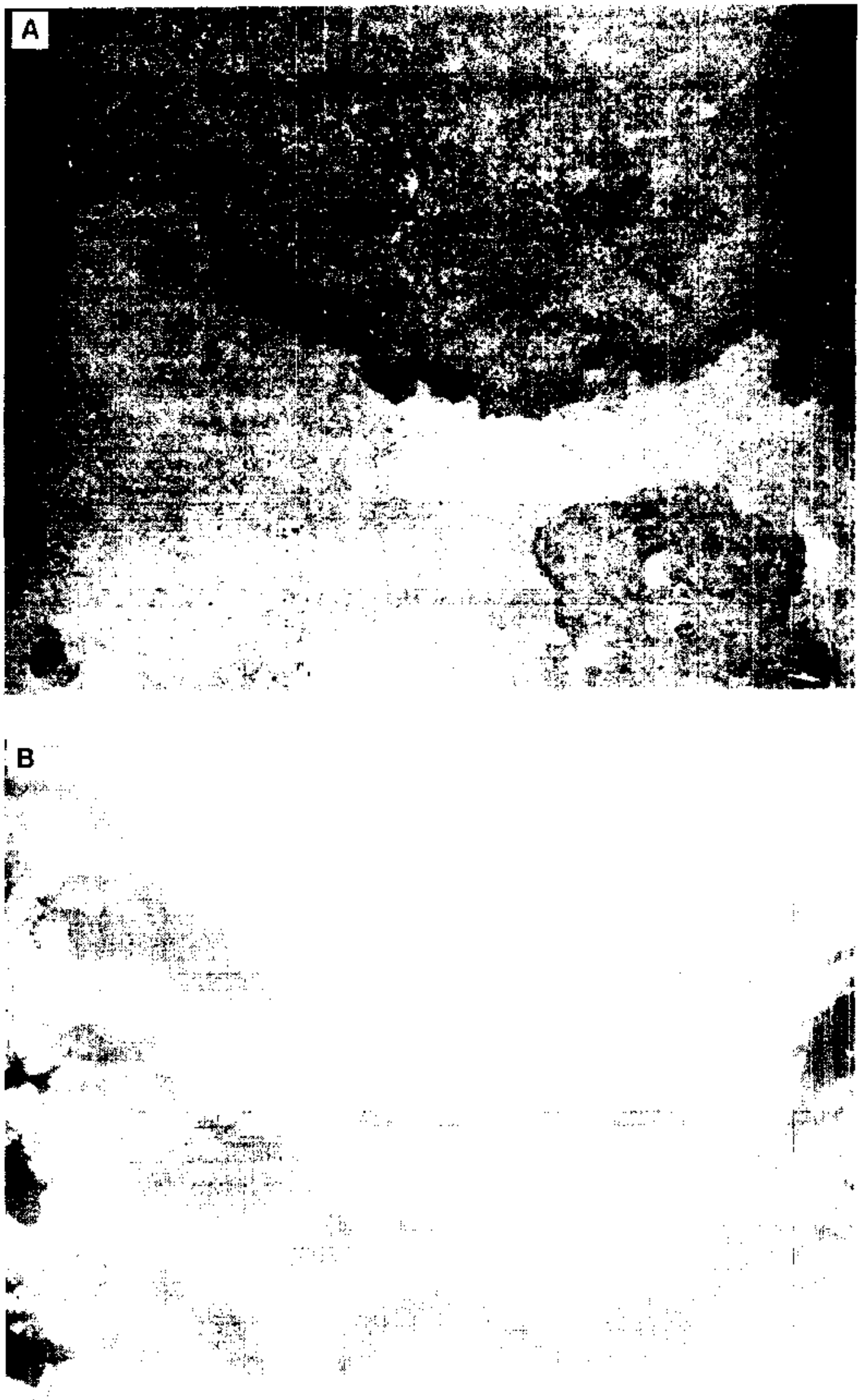
Second Transition Facies

Description. The Second Transition Facies contains sediments with less than 10% quartz and 10% *Amphistegina* remains. It is found between the *Amphistegina* Facies and the deeper Quartz-Planktonic Foraminifers Facies and in the central depression between the two main pinnacles.

Fig. 45. Underwater photographs of the *Amphistegina* Facies. (A) station 8, 45 fms (82 m) and (B) station 20, 47 fms (86 m).


A
B

Fig. 46. Underwater photographs of Tertiary (?) outcrops. (A) station 42, 43 fms (79 m) and (B) station 39, 45 fms (82 m).



In some locals it is a combination of the *Gypsina-Lithothamnium*, *Amphistegina*, and Quartz-Planktonic Foraminifers facies. Outcrops of rocks uplifted by the salt intrusion are found at various locals in this facies.

Quartz-Planktonic Foraminifers Facies

Description. Ranging from 10% silt and fine sand-size quartz grains and 10% planktonic foraminifers to a terrigenous silty-sand with few carbonate sediments, the Quartz-Planktonic Foraminifers Facies is the deepest facies of the study area. The stations of this study were restricted to the bank (i.e., 64 fms - 117 m), but it is thought that this facies extends from approximately 50 fms (91 m) onto the surrounding shelf. The foraminifer tests in the sediment are the remains of free floating species currently inhabiting the waters of the Gulf of Mexico while most of the quartz grains are derived from the drowned Pleistocene beaches that were formed during the lower sea levels.

SUMMARY AND CONCLUSIONS

Based on the bathymetry, subsurface structures, fauna, flora and carbonate detritus found on the West Flower Garden Bank, the following conclusions concerning the origin, surface topography and sediment facies of the bank have been drawn:

(1) The temperature range of 18.3°C to 29.8°C places the coral reef in the lower end of the accepted temperature range for coral reef development.

(2) The Scleractinia polyp can build coral reefs in light levels as low as 4-6% of the surface value; the coralline algae deposit well developed crusts in light levels down to 1% of the surface illumination and *Amphistegina* inhabits the zone between 30% to less than 1% of the surface illumination.

(3) Waves from hurricanes and gale force winter northers are responsible for removing sediments up to gravel size off the pinnacle and for agitating the algal nodules, permitting growth on all sides of the nodules.

(4) Salinity, oxygen, phosphate, pH and primary productivity of the water masses surrounding the bank are not the primary inhibitors in the vertical distribution of Scleractinia living on the bank.

(5) The circulation and water masses over the Texas-Louisiana shelf are extremely confused due to either upwelling or advection of gyres of foreign water onto the shelf.

(6) The poorly developed currents in the western Gulf of Mexico are responsible for limiting the diversity of the scleractinian species present on the reef.

(7) Subsurface and sediment-water profiles indicate that the salt plug beneath the bank uplifted the prereef sediments, forming a topographic high on the outer edge of the Texas-Louisiana shelf.

(8) Based on the presence of terraces and changes in slope, stillstands of the sea during the last transgression occurred at 66-73 fms (121-134 m) prior to 18,000 years B.P., 40-45 fms (73-82 m) at 17,000-15,000 years B.P., 48-50 fms (89-90 m) at 14,000-13,000 years B.P., and 28 fms (51 m) 13,000-12,000 years B.P.

(9) The *Diploria*-*Montastrea*-*Porites* Facies inhabits the pinnacle from 10.5 fms (19 m) to 27 fms (50 m). The scleractinian members of the West Indian reef community present on the West Flower Garden Reef are, in order of decreasing abundance: *Diploria strigosa*, *Montastrea annularis*, *Montastrea cavernosa*, *Porites astreoides*, *Madracis asperula*, *Mussa angulosa*, *Colpophyllia natans*, *Agaricia agaricites*, *Agaricia fragilis*, *Madracis decactis*, *Agaricia nobilis*, *Scolymia wellsii*, *Oculina* spp. and *Siderastrea* sp.

(10) The reef mass may form the upper 100 feet (30 m) of the pinnacle, indicating a growth rate of 0.43 cm/year for the entire reef.

(11) The *Gypsina*-*Lithothamnium* Facies lives in depths from 25 fms (46 m) to 40-45 fms (73-82 m). The dominant Corallinaceae is *Lithothamnium* which together with the less abundant *Lithophyllum*, *Lithoporella* and *Mesophyllum* and the encrusting foraminifer *Gypsina*, form nodules up to eight cm long and six cm wide that weigh up to 250 g.

(12) An *Amphistegina* Facies is found in depths from 40 fms (73 m) to 55 fms (100 m) with *Amphistegina* tests forming up to 25% of the sediments.

(13) The Quartz-Planktonic Foraminifera Facies ranges in depth from 50 fms (91 m) out onto the surrounding shelf with the quartz grains being reworked from Pleistocene beaches and the foraminifer tests being deposited from the overlying water.

(14) Rare, poorly developed colonies of Diploria strigosa, Montastrea annularis, Madracis asperula and Siderastrea sp. live on Stetson Bank, 30 nautical miles to the northwest; but they do not form a reef structure. The East and West Flower Garden Banks are the sites of the most northern, well developed coral reefs in the Gulf of Mexico.

With the ability of man to live and work beneath the ocean surface comes the capability to examine in detail the processes and resulting structures formed by coral reef communities. To this end this study is only a beginning. This report has examined a small, isolated coral reef situated on the seaward margin of a broad, terrigenous continental shelf. The environment surrounding the active West Indian coral reef community and the bank that formed the proper foundation for the first corals to settle on were described so that the West

Flower Garden Reef and associated sediment facies can be used as a model by paleoecologists studying similar, ancient environments. It is hoped that this dissertation will stimulate future studies of the Flower Garden Banks, that by thoroughly understanding the reef and its environment the Flower Garden Reefs can be preserved for future generations to enjoy.

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APPENDIX

Glossary of Coral Terms

CALICE. Oral or upper surface of corallite, generally bowl-shaped.

COENOSTEUM. Skeletal deposits formed between individual corallites.

COLUMELLA. Solid or nonsolid calcareous axial structure formed by various modifications of inner edge of septa; commonly projects into calice in form of a calicular boss.

CORALLITE. Exoskeleton formed by an individual coral polyp.

CORALLUM. Exoskeleton of a coral colony or solitary coral.

COSTA. Prolongation of septum on outer side of corallite wall.

PALUS (pl., PALI). Vertical lamella or pillar developed along inner edge of certain entosepta, comprising remnant part of a pair of exosepta joined at their inner margins.

PATELLATE. Low, solitary corallite with sides expanding from apex at angle of about 120 degrees.

POLYP. The soft tissue or body of the individual.

PLANULA. Free-swimming larval stage of coral polyp.

SCLERODERMITE. Center of calcification and surrounding cluster of calcareous fibers; apparent primary element in septa.

SEPTUM. Radially disposed longitudinal partition of corallite occurring between or within mesenterial pairs.

TURBINATE. Solitary, horn shaped corallite with sides expanding from apex at an angle of about 40 degrees.

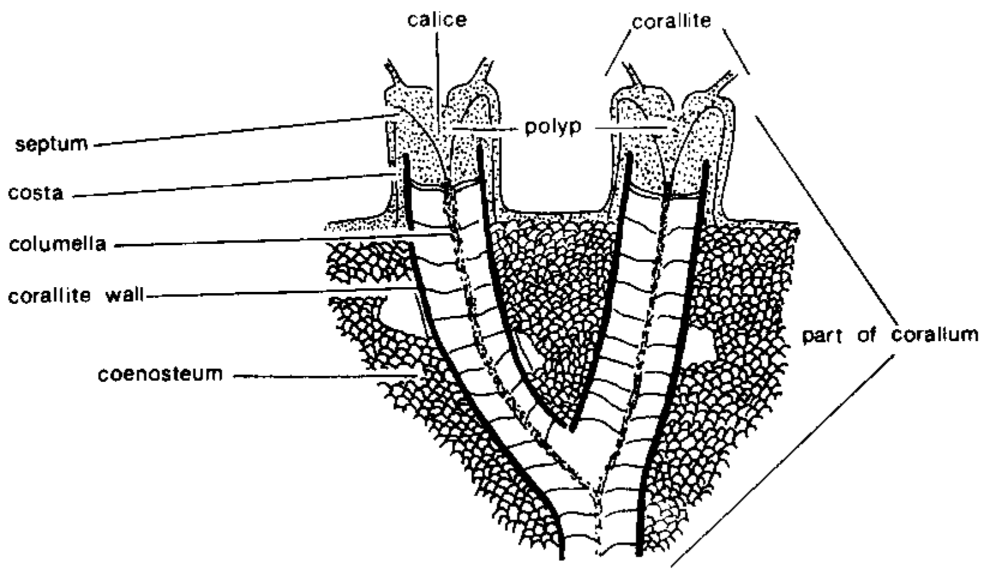

Fig. 47. Generalized cross-section of a scleractinian polyp and corallum (after Wells, 1956).