THE GEOLOGY AND ORIGIN OF GRAY'S REEF, GEORGIA CONTINENTAL SHELF

by

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TABLE OF CONTENTS

	Page
ACKNOWLEDGEMENTS	iii
LIST OF ILLUSTRATIONS	vii
ABSTRACT	ix
INTRODUCTION	1
PROCEDURE	5
Description of Equipment Used	5
Field Methods	6
Laboratory Methods	7
GEOLOGICAL SETTING	9
Continental Shelf Topography	9
Continental Shelf Sediments	10
DESCRIPTION OF GRAY'S REEF	13
Bathymetry	13
Morphology	13
Sediments	19
Shallow Seismic Profile Data	21
Fossil Shell Material	21
Sessile Benthic Fauna	24
Reef Fishes	26
GRAY'S REEF SUBSTRATE	29
Description of Hand Specimens	29
Description of Thin-Sections	29

TABLE OF CONTENTS (Continued)

Page

DISCUSSION 40

Geological History of Gray's Reef 40
Geological Age of Gray's Reef 45

SUMMARY AND CONCLUSIONS 49

REFERENCES CITED 51

APPENDIX 56

LIST OF ILLUSTRATIONS

FIGURE		Page
Figure 1	Location Map with Transects and Station Locations (Fold Out)	Pocket
Figure 2	Rock Outcrop/Faunal Growth Map (Fold Out)	Pocket
Figure 3	Map of Bathymetry	14
Figure 4	Diagram of Morphology	15
Figure 5a, b	Stratigraphic Cross-Sections	23
PLATES		
Plate 1a	Ledge area at Dive Site 9 with associated undercut cave	17
1b	Same ledge area approximately 5 meters northeast of Plate 1a	17
Plate 2a	Large rock on the seafloor in a flat-bottomed trough at Dive Site 11	18
2b	Partially buried rock at Dive Site 11	18
Plate 3a	Sponges and gorgonian corals at Dive Site 10	20
3b	Sponges and gorgonian corals at Dive Site 5	20
Plate 4	Oyster (Crassostrea virginica) and clam (Mercenaria mercenaria) shells found at Gray's Reef	25
Plate 5a	Dense accumulations of epifauna at Dive Site 9	27
5b	Moderate accumulations of epifauna at Dive Site 5	27
5c	Sparse accumulations of epifauna at Dive Site 3	27

LIST OF ILLUSTRATIONS (continued)

PLATES

		Page
Plate 6a	Typical unbroken rock sample from Gray's Reef	30
6b	Rock in Plate 6a broken illustrating Lithophaga sp. burrows with some shells in place	30
Plate 7	Photomicrograph of a slide stained with Alizarin Red "S" showing dolomite rhombs scattered throughout the micrite (Micrite stained red)	32
Plate 8	Photomicrograph of a slide stained with Alizarin Red "S" showing pelletoidal phosphatic concretions (Micrite stained red)	33
Plate 9	Photomicrograph of dolomitic monocrystal syntaxial overgrowths over dolomitic echinoid plates	35
Plate 10	Photomicrograph of a slide stained with Alizarin Red "S" showing a foraminifer in the micrite and scattered dolomite rhombs (Micrite stained red)	36
Plate 11	Photomicrograph of a slide stained with Alizarin Red "S" showing a biogenic fragment in the micrite surrounded by a halo of dolomitization (Micrite stained red)	37
Plate 12	Photomicrograph of a slide stained with Alizarin Red "S" showing an extensively dolomitized bryozoan colony (Micrite stained red)	38

ABSTRACT

Gray's Reef is a live-bottom reef area located in about 19.8 meters (65 ft.) of water approximately 33 kilometers (18 naut. mi.) due east of Sapelo Island, Georgia. The reef substrate is a layer of rock composed of a moderately to strongly dolomitized, sandy biomicrite which occurs as an outcropping layer heavily encrusted by sessile benthos. The total vertical relief in the area is 6.6 meters (22 ft.).

A lithologically similar layer of rock tentatively identified as the Duplin Marl (Pliocene ?) crops out in Sapelo Sound and in Turtle River, near Brunswick, Georgia, and is encountered in core holes along the coast from north Florida to central Georgia. Seismic reflection profiles indicate stratigraphic continuity of the reef substrate to this regionally extensive horizon.

The reef rocks were apparently deposited in a shallow marine environment and were dolomitized following deposition. Several periods of subaerial exposure caused leaching of micrite in the upper part of the layer. Minor amounts of microsparry to sparry calcite were deposited in cracks and voids.

INTRODUCTION

For the purpose of this study, the word "reef" is defined as an outcrop of a body of rock on an otherwise sandy bottom which expresses relief above the surrounding bottom and supports an accumulation of sessile benthos. Such a feature is the subject of this study.

Gray's Reef, located approximately 33 kilometers (18 naut. mi.) east of Sapelo Island, Georgia, is an interfingering series of northeast-southwest trending ridges and troughs consisting of a limestone layer upon which abundant epifauna are attached. Interest in the study of this live-bottom reef area was initiated from the data obtained from several underwater television tows in the reef area in connection with a regional study of the continental shelf by University of Georgia personnel. Locally, the feature is called "Sapelo Reef". Because this name is a geographical designation and could lead to confusion if other live-bottom areas are found in the vicinity of Sapelo Island, the writer proposes the name "Gray's Reef" to specifically designate the study area in honor of the late Milton B. Gray of the University of Georgia Marine Institute.

The primary objectives of this study were: 1) to determine the geological origin and significance of Gray's Reef; 2) to obtain a more detailed picture of nearshore morphology of the continental shelf off the Central Georgia coast and 3) to better understand the relationship between coastal Neogene stratigraphy

and continental shelf morphology.

The study area is located between 31°22' N. and 31°25' N. Latitude and 80°50' W. and 80°55' W. Longitude. The western boundary is 32.2 kilometers (17.5 naut. mi.) due east of the southern tip of Sapelo Island (Figure 1 in pocket).

Water depth in the study area ranged from 16.8 to 23.5 meters (55 to 77 ft.). Based on SCUBA observations, horizontal visibility at the bottom varies from less than 1.5 meters (5 ft.) to more than 9 meters (30 ft.), depending on the sea condition and tide. Best visibility tends to occur at or near high tide in calm weather. Astronomical tides along the Georgia coast are semi-diurnal and have a maximum range of 2.75 to 3.0 meters (9 to 10 ft.) and a normal range of approximately 1.8 meters (6 ft.).

Data collected by Anderson and Gehringer (1956, 1959) indicate that salinity and dissolved oxygen content of the sea water show very slight seasonal variation. Salinity remains between 34 and 36 parts per thousand while dissolved oxygen content varies from around 4.5 milliliters per liter to about 6 milliliters per liter. Surface sea water temperature ranges from approximately 28° C during the summer to about 14°C during the winter months. During several SCUBA dives in the study area a thermocline of several degrees C was noted by the author at depths from 7.6 to 10.7 meters (25 to 35 ft).

Very little data on the currents are available for the study area. Bumpus (1955, 1965) studied surface currents along the Atlantic coast and found that off the Georgia coast a generally southerly flow prevails in the summer, autumn

and winter changing to a northerly flow in the spring. During late summer and early fall the northerly-flowing Gulf Stream currents shift westward nearer the coast in response to prevailing southeasterly winds. This condition is identified by the appearance of Gulf Weed (Sargassum) on the beaches and nearshore waters.

Previous Work in the Area

The first recorded recognition of the reef was in 1961 by the late Milton B. Gray (Gray, 1961), biological collector for the University of Georgia Marine Institute, Sapelo Island, Georgia. Mr. Gray's collections from the reef began in the latter part of 1960 as a part of the Institute's Systematics/Ecology program. Since 1961, this feature has been a popular collection site for various scientific investigators, university classes and high school groups visiting the Marine Institute.

The Marine Sports Fisheries Division of the Georgia Department of Natural Resources has recently become interested in Gray's Reef because of its large and varied fish population. The Division has bouyed several sites on the reef and has published a descriptive brochure on the fishing potential in the area (Georgia State Game and Fish Commission, 1970).

Except for a brief statement of its existence and possible origin by Henry and Hoyt (1968) the reef has not been studied geologically. A very similar feature has been described by Roberts and Pierce (1967) as an outcrop of the Yorktown Formation in Onslow Bay off North Carolina. Work has been done on sev-

eral shelf-edge reef structures (Pilkey and Giles, 1965; Eddy, et al, 1967; Henry and Hoyt, 1968), and is currently being carried out on another reef trend off the central Georgia coast in 30.5 to 38.1 meters (100 to 125 ft.) of water (V. J. Henry, personal communication, 1973).

PROCEDURE

Description of Equipment Used

Research vessels used for the survey were the 19.8 meter (65 ft.) R/V KIT JONES based at the University of Georgia Marine Institute at Sapelo Island and the 14.3 meter (47 ft.) R/V GOLDEN ISLES located at the Skidaway Institute of Oceanography, Savannah, Georgia.

An underwater television system consisting of a Cohu 3000 Series black and white camera adapted to an underwater housing was used for remote observations in the study area. The camera was mounted on a sled for towing and was coupled to a Sony Model EV-300 2.54 centimeter (1 in.) video-tape recorder through a Cohu 3900 Series camera control unit. The video signal was observed onaa Sony Model CVM-51-UWP 20.3 centimeter (8 in.) monitor.

Bathymetric profiles were made using an Electroacustic CASTOR Model recording fathometer mounted on the R/V KIT JONES and a Raytheon Model DE-719 recording fathometer aboard the R/V GOLDEN ISLES.

Sub-bottom profiles were obtained using an E.G. and G. high-resolution seismic reflection profiler consisting of a Model 234 seismic recorder, a Model 231 triggered capacitor bank with a Model 232A power supply, a Model 230 UNIBOOM (Unit Pulse Boomer) sound projector mounted on a catamaran float, and a Model 265 hydrophone. Several Loran-C receivers and Decca Models 202 and 914 radars were used for navigation.

A Nikonos II 35-millimeter underwater camera with a 35 millimeter Nikkor f 2.5 lens was used with a flash attachment and Kodachrome II film for color photography and without a flash attachment for black and white photography using Plus-X and Tri-X film. Visual observations and underwater photographs were made and limited reef sampling was carried out using standard SCUBA gear.

Field Methods

Based on specific locations obtained from Gray's unpublished records, initial SCUBA dives with hand-held television and television tows were made and the boundaries of the study area were subsequently established based on the decrease and disappearance of accumulations of sessile benthic fauna and rock outcrops. The rock outcrops, with their associated dense accumulations of epifauna, were found to occur in a band at least 5.5 kilometers (3 naut. mi.) long. Because the reef has no clear-cut boundaries to the south and east and is generally quite patchy, it was necessary to confine the study to a specific area of bottom. The entire area mapped, most of which contains the live-bottom, covers approximately 40.7 square kilometers (12 sq mi.) of seafloor. A total of nine cruises were made to the location.

Bottom mapping was accomplished by continuous and simultaneous use of the television system and recording fathometers. The video-tapes were coordinated with the fathometer profiles by contemporaneously marking 15-minute time intervals and station locations on each record. Sub-bottom pro-

filing was carried out separately from the television cruises.

Sediment, rock and shell samples were collected using bottom dredges. Additional rock and sediment samples were taken during 11 SCUBA dives along with samples of the sessile benthic organisms most commonly seen and recognizable on the TV screen. Still photographs, both black and white and color were taken during the dives and were coordinated with the sampling. (For transect, dive and sample locations, see Figures 1 and 2 in pocket).

Navigational control was accomplished using the Sapelo Whistle Bouy R "2S" and several radar reflector bouys placed on the reef for triangulation. Loran-C was also used along with "dead reckoning"

Laboratory Methods

Reduction of Video-tapes, Bathymetry Profiles and UNIBOOM Data: Following each of the cruises, video-tapes of the underwater television tows were viewed several times and edited. Faunal densities were catagorized as sparse, moderate and dense and, with other pertinent features such as ledges and rock outcrops, were transferred to a base map using times and footages of video-tape for control. Fathometer profiles were studied and the depths were also plotted on the base map along the various transects. Seismic profile records were interpreted and each prominant reflector was transferred to a cross-sectional map.

Sediment and Rock Sample Preparation: A total of 19 sediment samples were collected and stored in a cold room at temperatures just above freezing

until they were processed. After being washed to remove organic material, the sediment samples were examined with a binocular dissecting microscope at from 10 to 40 power.

Nine reef rocks were collected and cut on a rock saw or broken to reveal a fresh surface and were then described and photographed. Slabs were then cut and thin-sections made. In order to identify carbonate minerals, the thin-sections were treated with Alizarin Red "S" to stain calcite and aragonite red (Friedman, 1959), potassium ferricyanide to stain iron-rich dolomite blue (Friedman, 1959; Evamy, 1962), Feigl's Solution to stain aragonite black (Friedman, 1959) and Titan Yellow (Clayton Yellow) to stain dolomite yellow (Friedman, 1959). They were then studied under a petrographic microscope and a point count was done on each thin-section.

Biological Sample Preparation: The 14 samples of sessile benthic organisms collected during the dives were frozen immediately upon arrival at the surface. The samples were later placed in a 90% isopropal alcohol and water solution and remained there for a sufficient time for the preservative to permeate the organisms.

GEOLOGICAL SETTING

Continental Shelf Topography

The continental shelf off the coast of Georgia is 130 to 150 kilometers (70 to 92 naut. mi.) wide with the shelf break occurring at an average depth of approximately 50.3 meters (165 ft.) Average slope on the shelf is approximately 36 centimeters per kilometer (2 ft. per mi.). Distinct changes in the slope occur at depths of 12.2, 19.8, 22.8, 33.8 and 47.5 meters (40, 65, 75, 110 and 150 ft.) which suggest possible "terraces" with associated scarps, although the scarps show no particular lineation (Pilkey and Giles, 1965; Henry and Hoyt, 1968).

A poorly defined valley of low relief lies across the shelf east of Sapelo Island, Georgia, and is bordered to the south by a gentle ridge. This feature is believed by Pilkey and Giles (1965) to be an old Altamaha River channel formed during the lower sea levels of the Pleistocene Epoch.

Based on bathymetric profiles and bucket dredge sampling only, several shelf edge rock ledges were noted by Pilkey and Giles (1965) and Henry and Hoyt (1968) exhibiting relief up to 6.1 meters (20 ft.) and having a topographic high on the crest of between 1.8 and 3.0 meters (6 and 10 ft.) and appearing laterally discontinuous. Henry and Hoyt (1968) also noted semi-consolidated to lithified rocks cropping out on the shelf at depths of approximately 18.3 and

45.7 meters (60 and 150 ft.). The rocks were believed to be either a submerged reef-like structure formed during periods of lower sea level or Tertiary rocks now covered by encrusting organisms.

Continental Shelf Sediments

Holocene paralic deposits of fine-to very fine-grained sand wedge out some 18 to 27 kilometers (10 to 15 naut. mi.) seaward of the barrier islands in 12 to 15 meters (40 to 50 ft.) of water. From the seaward extent of the recent sediments out to the shelf edge, apparently little sedimentation is occurring and the sediments present are considered to be relict Pleistocene sands (Gorsline, 1963; Pilkey and Frankenberg, 1964; Henry and Hoyt, 1968; Emery and Milliman, 1970; Gadow, 1972). Pilkey and Terlecky (1966) postulated that the linear distribution of sediments parallel to the coast reflects former shorelines or stillstand deposits. These older deposits are typically medium- to coarse-grained quartz sands containing abundant calcareous fossil debris. Much of the quartz is iron-stained suggesting subaerial exposure during lower stands of sea level (Henry and Hoyt, 1968; Pilkey, 1968).

According to Pilkey (1963), the most abundant heavy mineral species from the Georgia continental shelf are hornblende, epidote, staurolite and the opaques, mainly ilmenite and magnetite. The carbonate content of the shelf sediments generally remains below 25% and, based on external appearances, consists of two distinct assemblages: the first shows little wear and fragmentation and possibly exhibits the original color; the second is highly worn, fragmented, bored and has lost most of the original color (Pilkey, 1964). Both assemblages

consist of predominantly mollusk shells, particularly pelecypods, along with echinoid fragments and bryozoa.

Phosphorite, as P_2O_5, represents approximately 1% of the sediments on the Georgia continental shelf and although most of the phosphorite recovered from the shelf sediments was sand size, particles up to 1.5 centimeters (0.6 in.) long have been observed (Pevear and Pilkey, 1966). Gorsline (1963) believes the phosphate material found in the shelf sediments originated from Miocene outcrops on the shelf.

A fluvial provenance is generally agreed upon for the relict Pleistocene sediments on the continental shelf (Henry and Hoyt, 1968; Pilkey, 1968; Carver, 1971; Gadow, 1972). Heavy mineral assemblages studied by Pilkey (1963) and Gadow (1972) indicate both metamorphic and igneous provenance for the sediments. Gadow (1972) found that the inner continental shelf sediments appeared to be a mixture of river-derived sediments. The hornblende present in this band was found to come mostly from the Savannah River with minor amounts introduced by the Altamaha River. Carver (1971) believes the hornblende in the shelf sediments came from the Santee River in South Carolina. In any case, the distribution of hornblende indicates a longshore transport of sediments from north to south (Pilkey, 1968; Gadow, 1972). Studies of the clay mineral distributions in continental shelf waters and sediments indicate the same direction for longshore transport (Neiheisel and Weaver, 1967; Bigham, 1973). Pilkey (1968) believes that much of the sand present on the continental shelf was deposited during the late Wisconsin/Holocene regression-

transgression sequence.

Studies of the iron-stained quartz and phosphorite anomalies on the continental shelf adjacent to the Georgia and South Carolina coasts suggests that lateral transport of sediments is not extensive (Pilkey, 1968).

DESCRIPTION OF GRAY'S REEF

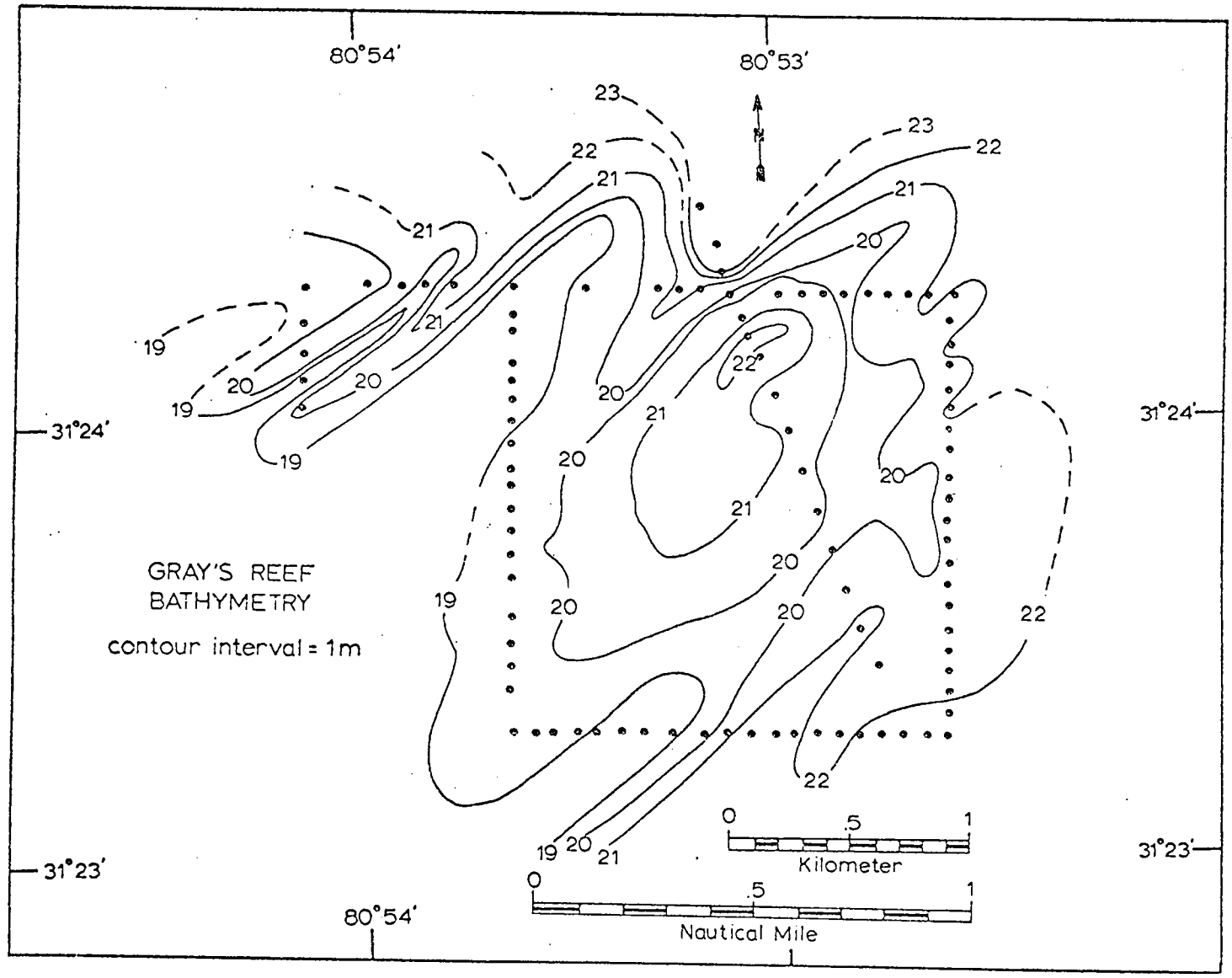
Bathymetry

The study area lies along a landward indentation of the 10-fathom contour (see Figure 1). Fathometer profiles run from the Sapelo Whistle Bouy (R "2S") across Gray's Reef show an increase in depth from 16.7 meters (55 ft.) at the bouy to 23.5 meters (77 ft.) 3.1 kilometers (1.7 naut. mi.) to the south-southeast. The bottom then rises sharply to about 19.8 meters (65 ft.) at the reef margin approximately 7.4 kilometers (4 naut. mi.) from the bouy.

The bathymetry of the study area (shown in Figure 3) is typified by a series of northeast-southwest trending ridges and troughs. Some of the associated slopes and scarps dip to the northwest while others dip to the southeast. The most prominent bathymetric expressions occur in the northern and northwestern portions of the study area (see Figure 3). The study of fathometer profiles obtained in the area, supported by personal observations and underwater television recordings, revealed that the more prominent slopes associated with the ridges are typified by small vertical scarps from 0.15 to 1.2 meters (0.5 to 4 ft.) in relief occurring at the bottom or top of the slopes, or both. Reef slopes dipped at from less than 1^{o} to approximately 6^{o}.

Morphology

Figure 4 is a composite cross-section illustrating the various morphologic


80°54'
80°53'
31°24'
31°23'
GRAY'S REEF
BATHYMETRY
contour interval = 1m
0 .5 1
Kilometer
0 .5 1
Nautical Mile

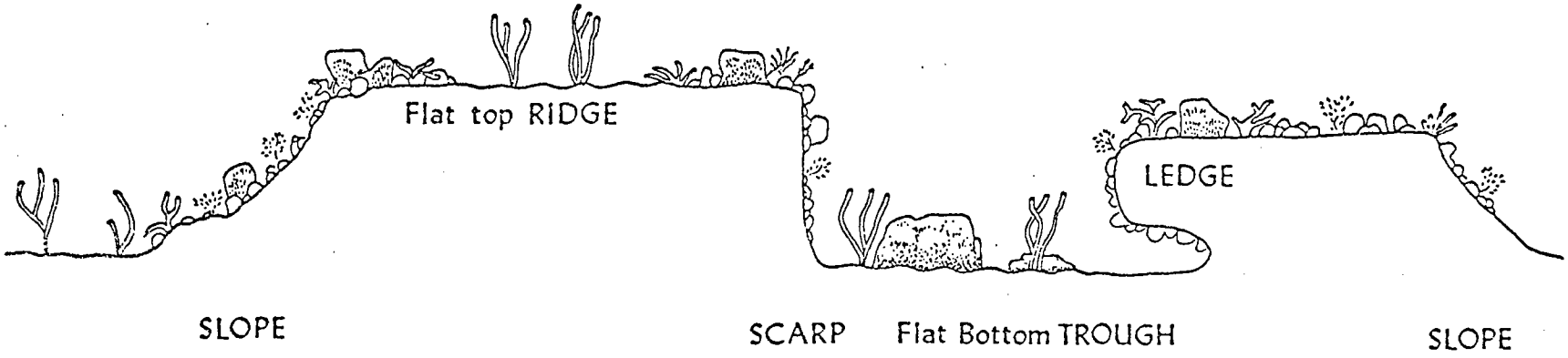


FIGURE 4. Diagram of morphology of Gray's Reef with description terminology used in the text.

features encountered in the study area along with the terminology used to describe those features.

The total vertical relief encountered in the study area was approximately 6.6 meters (22 ft.). Typically, the water depth on the relatively flat upper surfaces of the ridges ranged from 18.9 to 19.8 meters (62 to 65 ft.) and on the flat sandy bottoms of the troughs the depth varied from 21.0 to 22.0 meters (69 to 72 ft.).

A cave approximately 1.2 meters (4 ft.) in height, 9.1 meters (30 ft.) in width and at least 3 meters (10 ft.) in depth was discovered beneath an overhanging ledge at dive site 9 (Plate 1 and Figure 2). Parts of the ledge had collapsed (as seen below the diver in Plate 1a) and large blocks of heavily encrusted rock were scattered about the flat sandy floor of the trough (Plate 2). Epifauna included soft corals, sponges, ascidians, bryozoa, barnacles and some algae. Small caves and burrows up to 22 centimeters (8 in.) wide occurred under or in the rocks and ledges. Throughout the study area small ledges up to 22 centimeters high were common and showed no particular orientation.

Figure 2 (in pocket) is a map of rock outcrop patterns along with associated epifaunal densities. Most of the area of sparse and patchy epifauna is underlain by the rock exposed along the ledges and scarps in the northern part of the study area. This bottom type, with few exceptions, represents the top of the layer of rock. Areas of abundant growth generally represent areas of rock outcrop such as ledges and scarps.

PLATE I

A. Ledge area at Dive Site 9 with associated undercut cave. Note collapsed block beneath diver.

B. Same ledge area approximately 5 meters (15 ft.) northeast of location of Plate 1A. Ledge is approximately 1.5 meters (5 ft.) thick and mouth of cave is approximately 1.2 meters (4 ft.) high.

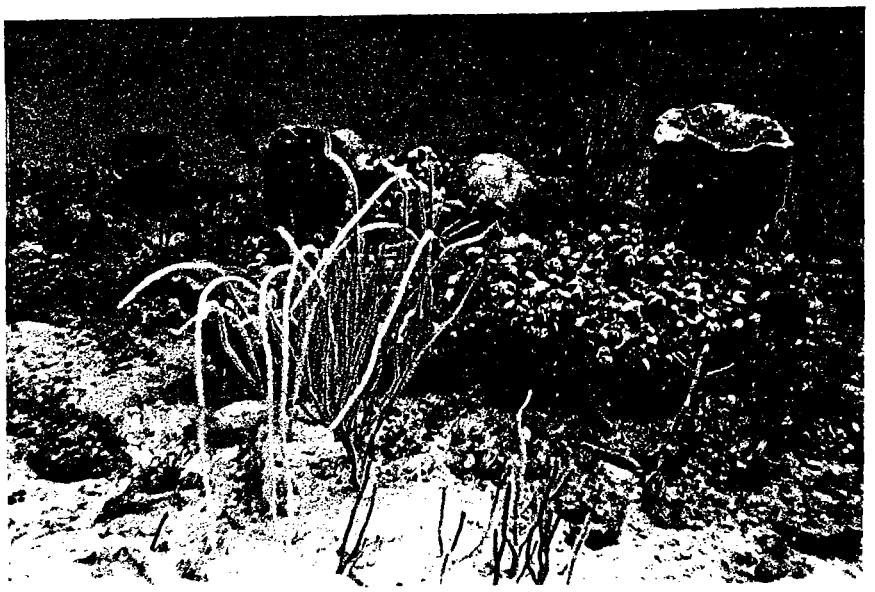


PLATE 2

A. Large rock on seafloor in a flat-bottomed trough at Dive Site 11. For scale, length of rock is approximately 1.5 meters (5 ft.).

B. Partially buried rock at Dive Site 11. For scale, length of rock is approximately 1.8 meters (6 ft.). Note shell material in sediment.

On the flat upper surface of the reef the rock is typically covered by a veneer of sediment up to about 30 centimeters (1 ft.) thick. The rock, easily exposed by wafting away the thin sediment cover, is relatively free of encrustations and exhibits cracks or joints up to 2.5 centimeters (1 in.) wide. Soft corals and sponges attach to the rock and protrude through the veneer of sediment giving the area its typical appearance (see Plate 3).

Shallow probing in the deep area between the Sapelo Whistle Bouy and the study area revealed no rock within 1.2 meters (4 ft.) of the bottom although rock was encountered 3.0 meters (10 ft.) below the bottom at the Whistle (J.R. Woolsey, personal communication, 1973).

Sediments

In the study area, 19 sediment samples were taken with a bucket dredge (see Figures 1 and 2 for locations). The samples consisted predominantly of medium-grained quartz sand with very fine-grained sand to granule-sized gravel (from 0.1 to 4.0 millimeters - 0.004 to 0.157 in.). Calcareous fossil debris represented about 15% to 20% of the samples, with mollusk fragments being the most abundant constituent. The sand grains were subangular to well-rounded; the larger grains tended to be more rounded than the smaller grains. Iron-stained quartz grains were common in most of the samples, especially in the larger grain sizes. Phosphorite was common in the samples and appeared mainly in the very fine- to medium-grained fractions. The phosphorite occurred as oval to round, occasionally flattened, brown to black opaque grains.

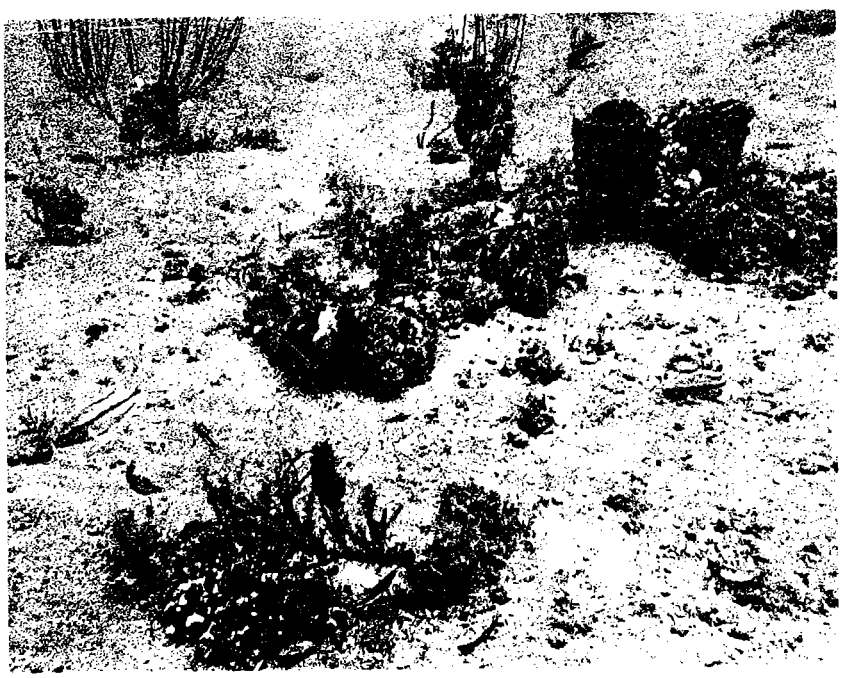


PLATE 3

A. Sponge and gorgonian corals at Dive Site 10. Organisms are attached to the rock and covered by approximately 2.5 centimeters (1 in.) of sediment. For scale, small sponges are approximately 10 centimeters (4 in.) high.

B. Sponges and gorgonian corals at Dive Site 5. Note shell material in sediment. For scale, basket sponge at upper right is approximately 36 centimeters (14 in.) wide.

The veneer of sediment covering the reef top typically exhibited oscillation ripple marks that were 0.3 to 0.6 meters (1 to 2 ft.) from crest to crest and 0.1 to 0.35 meters (4 to 14 in.) in height. The troughs commonly contained very coarse material, especially larger shell debris. Current activity at the bottom sufficient to move finer material was observed and noted to be oscillatory. Unidirectional currents have also been noted, but only the finest material was being transported during the time of observation.

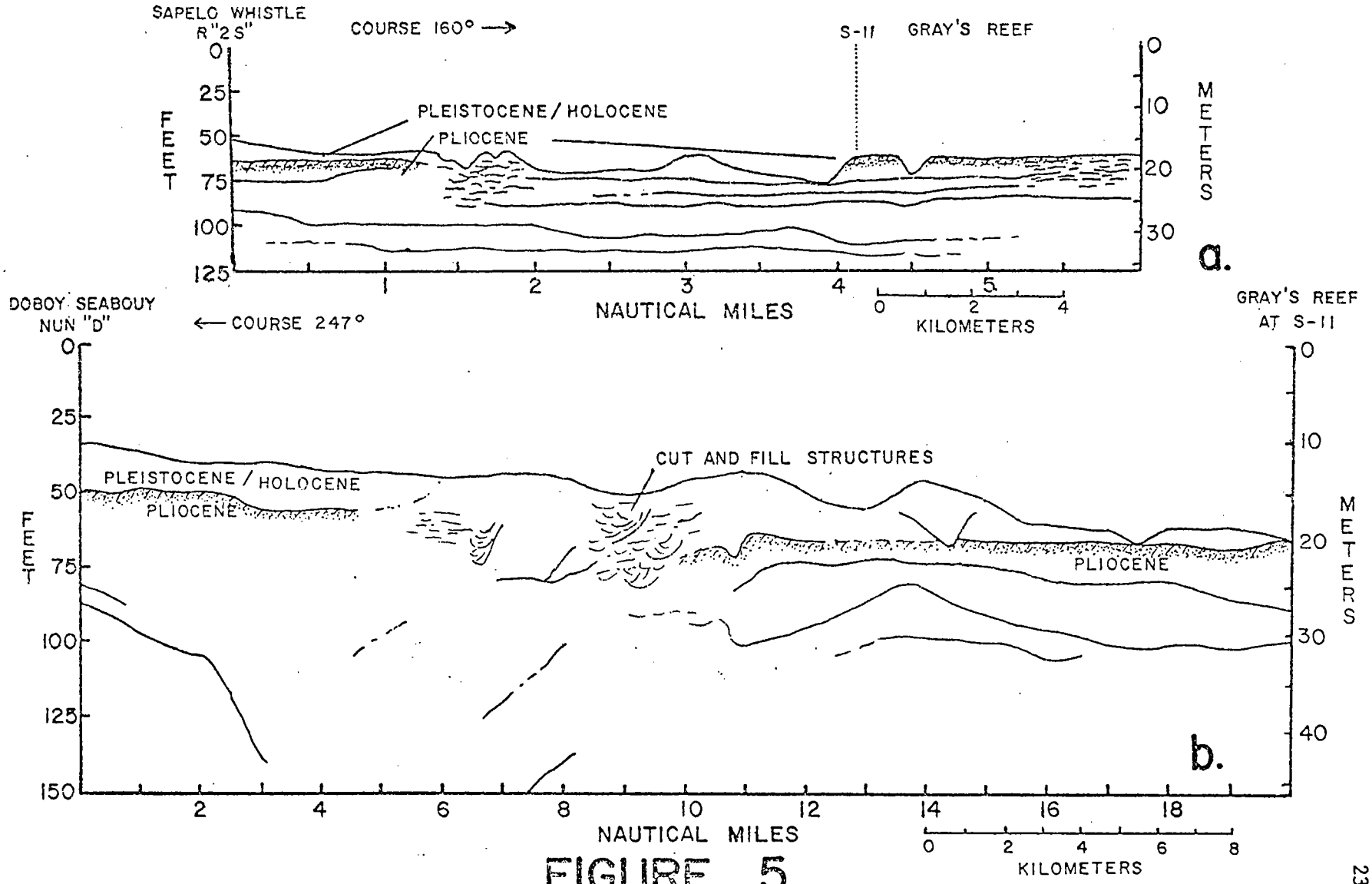
Shallow Seismic Profile Data

Sub-bottom profiles run from the Sapelo Whistle Bouy, R "2S", to the study area and from the study area to the vicinity of the Doboy Seabouy, Nun "D", revealed a shallow, somewhat discontinuous, principal reflector lying at -15.2 meters (-50 ft.) M.S.L. or approximately 6.1 meters (20 ft.) beneath the sediment-water interface near Nun "D" and rising to the surface of the sediment-water interface at the study area. The profile run from R "2S" to the live-bottom revealed a flat-lying reflector, also somewhat discontinuous, beneath approximately 3.0 meters (10 ft.) of sediment at the Whistle Bouy. The layer also appears to crop out in the study area (see Figure 5).

Fossil Shell Material

During the television tows large shells and shell fragments were frequently observed. Samples of this material were subsequently collected during several SCUBA dives and were identified by Dr. Robert Frey (personal communication, 1973) as valves of the oyster, Crassostrea virginica, and the clam, Mercenaria

FIGURE 5. Stratigraphic cross-sections from Gray's Reef area to the coast as interpreted from UNIBOOM profiles. Vertical exaggeration in Figure 5a is x 72, for Figure 5b is x 312.


SAPELO WHISTLE
R "2 S"
COURSE 160° →
S-11 GRAY'S REEF
FEET
0
25
50
75
100
125
PLEISTOCENE / HOLOCENE
PLIOCENE
METERS
0
10
20
30
a.
1
2
3
4
5
NAUTICAL MILES
0
2
4
KILOMETERS
DOBOY SEABOUY
NUN "D"
← COURSE 247°
GRAY'S REEF
AT S-11
CUT AND FILL STRUCTURES
PLEISTOCENE / HOLOCENE
PLIOCENE
PLIOCENE
40
b.
2
4
6
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10
12
14
16
18
NAUTICAL MILES
0
2
4
6
8
KILOMETERS

FIGURE 5

mercenaria (see Plate 4). The oyster shells were white to dark gray, slightly to moderately bored and were encrusted with bryozoa, barnacles, serpulid worm tubes and minor amounts of calcareous algae. Some shells were up to 10.2 centimeters (4 in.) long and 5.1 centimeters (2 in.) wide. The clam shells were white to reddish-gray and exhibited similar encrustations and borings. The shells appeared randomly scattered about the area. Numerous other fossil mollusk shells were present. Shells and shell fragments of the thin-shelled pelecypod, Amusium sp., were found in the uppermost layer of rocks on the reef. These fossil bivalves are indicative of a calm, shallow marine environment and will be discussed in detail in a later section.

Sessile Benthic Fauna

No attempt has been made to identify all of the sessile benthos in the study area because of the diversity and number of species present. Only the larger specimens most commonly seen and most easily recognizable on the television screen were identified. The most abundant larger fauna in the study area are the gorgonian corals. Most frequently seen are the sea fan, Titanideum frauenfeldi (Killiker), and the sea whips, Leptogorgia setacea (Pallas), Lophogorgia hebes (Verrill) and 3 species of Telesto, one of which is a range extension (John Kraeuter, personal communication, 1973). Also abundant are the sponges which are attached directly to the rock surfaces such as Cinachyra cavernosa (Lamark), Speciospongia vesparia (Lamark), Homaxinella rosacea (Verrill) and Ircinia campana (Lamark). The stinker sponge, Ircinia fasciculata (Pallas),

PLATE 4

Oyster (Crassostrea virginica) and clam (Mercenaria mercenaria) shells found on Gray's Reef. Ruler at the bottom is 15.2 centimeters (6 in.).

was found both attached to the rock surfaces and encrusted over the sea whip, Leptogorgia setacea (Pallas). The two ascidians which commonly occur in the study area are Clavelina picta, (Verrill) and Amaroucium stellatum (Verrill).

The distribution of faunal accumulations on Gray's Reef is shown in Figure 2 (in pocket) and the relative abundance, classified as sparse, moderate and dense accumulations, is illustrated in Plate 5.

Reef Fishes

The Gray's Reef area is inhabited by a large fish population, some species of which are year-round residents and others of which are seasonal. Below are listed some of the species commonly seen in the area (American Fisheries Society, 1970; Georgia State Game and Fish Commission, 1970). Most of the identifications were made by David Miller and Richard Vahan (personal communication, 1973).

Cobia	Rachycentron canadum
King Mackeral	Scomberomorus cavalla
Atlantic Bonito	Sarda sarda
Great Barracuda	Sphyraena barracuda
Bluefish	Pomatomus saltatrix
Crevalle Jack	Caranx hippos
Summer Flounder	Paralichthys oblongus
Greater Amberjack	Seriola dumerili
Atlantic Spadefish	Chaetodipterus faber
Cubbyu	Equetus umbrosus
Slippery Dick	Halichoeres bivittatus
Sheepshead	Archosargus probatocephalus
Spottail Pinfish	Diplodus holbrooki
White Grunt	Haemulon plumieri
Black Sea Bass	Centropristis striata
Black Grouper	Mycteroperca bonaci

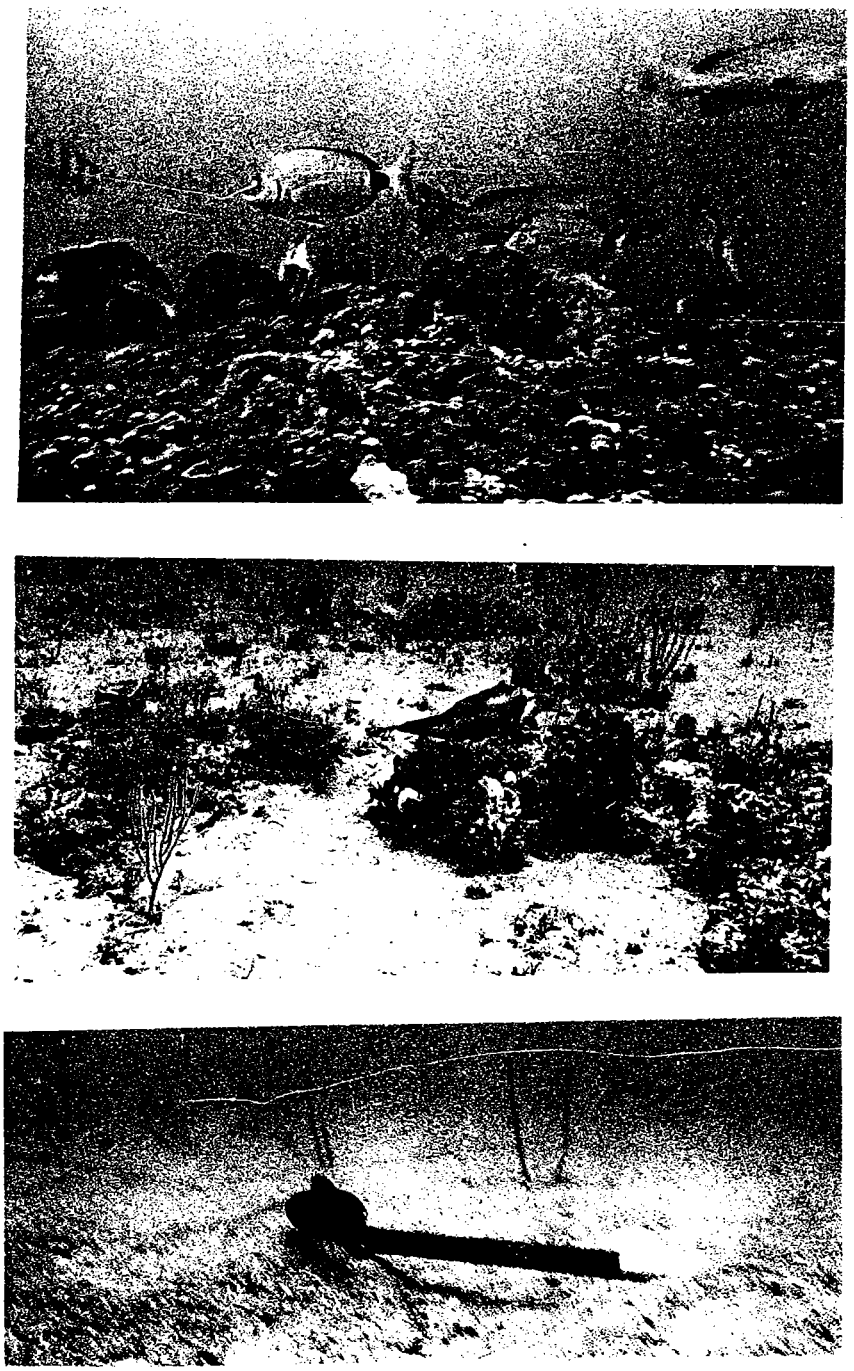

PLATE 5

Dense, moderate and sparse accumulations of epifauna at Dive Sites 9, 5 and 3, respectively. For scale, fish in foreground in Plate 5a is approximately 25.4 centimeters (10 in.) long and in Plate 5c the snorkle is 38.1 centimeters (15 in.) long.

Sand Perch	Diplectrum formosum
Redspotted Hawkfish	Amblycirrhitus pinos
Gray Triggerfish	Balistes capriscus
Planehead Filefish	Monacanthus hispidus
Spotted Moray	Gymnothorax moringa
Flamefish	Apogon maculatus
Red Snapper	Lutjanus campechanus
Pigfish (?)	Orthopristis chysoptera
Toadfish	Opsanus sp.
Cardinalfish	Apogon sp.
Tuna	Thunnus sp.
Porgy (Sapridae)	Calamus sp. (Saucer-eye Porgy?)
Nurse Shark	Ginglymostoma cirratum
Bull Shark	Carcharhinus leucas
Blue Shark	Prionace glauca
Southern Hammerhead Shark	Sphyrna diplana
Common Hammerhead Shark	Sphyrna zygaena

GRAY'S REEF SUBSTRATE

Description of Hand Specimens

As shown in Plate 5 and Figure 2 and discussed in previous sections, the layer of limestone forming the substrate of Gray's Reef was extensively covered by sand and abundant epifauna and, therefore, few fresh surfaces of the rock were exposed. Even smaller rocks scattered about the area were heavily encrusted by bryozoa, mollusk shells, serpulid worm tubes, and calcareous algae (Lithothamnion sp.?) and appeared highly bored by the burrowing mollusk, Lithophaga sp. Some of the bore holes still contained the organisms (Plate 6). Encrusting foraminifera were rare. On a freshly exposed surface the rocks varied in color from light and olive gray to very dark gray. Quartz grains and fossil fragments were abundantly distributed in a fine-grained limestone matrix. The hand specimens exhibited low to high porosity and were poorly to well indurated.

Description of Thin Sections

The rock forming the substrate of Gray's Reef was a moderately to strongly dolomitized, sandy biomicrite. All rocks collected in the area were very similar in composition. Allochemical constituents varied from 9% to 10% in the rocks and were predominantly mollusk and echinoid fragments with minor amounts of foraminifera, bryozoa, coral, pelletoidal grains and intraclasts.

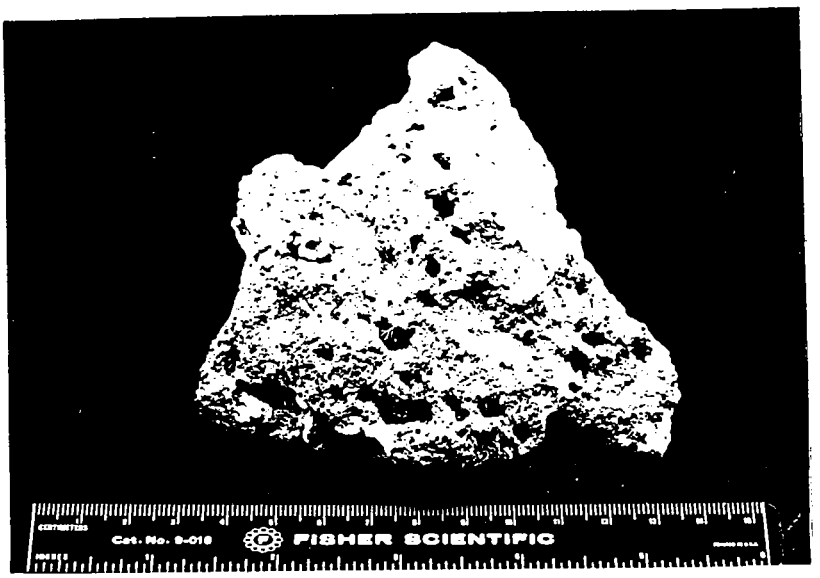

PLATE 6

A. Unbroken rock sample from Gray's Reef. For scale, ruler is 15.2 centimeters (6 in.) long.

B. Same rock broken. Note Lithophaga sp. burrows with organisms in them.

Terrigenous constituents accounted for 22% to 35% of the rocks with fine- to medium-grained quartz being the predominant mineral. The quartz grains were subrounded to subangular, depending on the grain size, and were poorly sorted. Some quartz grains appeared strained and others were fractured. Quartz grains containing hornblende inclusions were rare. Microcline represented between 1% and 2% of the rocks and plagioclase was rare.

Orthochemical constituents ranged from 54% to 63% of the rocks. Micrite was present in all of the rocks but the percentages varied widely from 7% to 37% and appeared to have been the original cement in the rocks. Dolomite represented from 20% to 46% of the rocks and appeared to have replaced the micrite (Plate 7). Pelletoidal phosphatic concretions were scattered throughout and represented 1% to 4% of the rocks. The grains ranged in size from 0.1 to 0.4 millimeters (0.004 to 0.015 in.) and were oval to round, light yellowish-green to brown under plane polarized light and were extinct under crossed nichols (Plate 8).

The rocks varied from low to high porosity. Pore space appeared to be the result of partial solution. Voids commonly occurred on one side of mollusk fragments and appeared randomly oriented with respect to the concave or convex sides of the shells. In some cases, the mollusk fragments themselves had been leached away leaving external casts in the matrix.

Recrystallization and dolomitization appeared to have been extensive in all rocks collected from the reef area. Monocrystal syntaxial overgrowths of dolomite were abundant over dolomitic echinoid plates and spines throughout

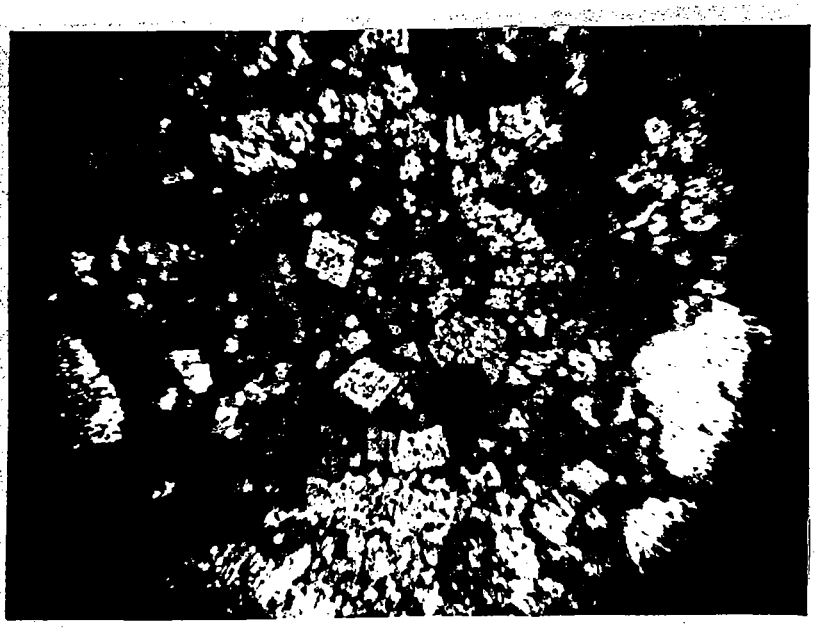

PLATE 7

Photomicrograph of dolomite rhombs scattered throughout micrite. Slide stained with Alizarin Red "S" to stain micrite red (Plane Polarized Light), x80.

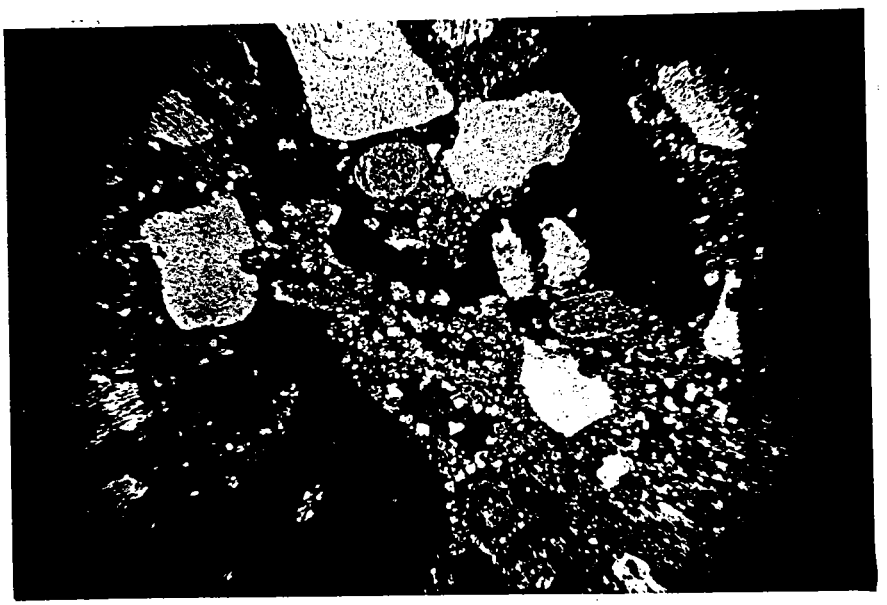

PLATE 8

Photomicrograph of pelletoidal phosphatic concretions (upper center, center right). Slide stained with Alizarin Red "S" to stain micrite red (Plane Polarized Light), x80.

the rocks. Overgrowth thicknesses as large as 0.15 millimeters (0.006 in.) were common (Plate 9). In some areas of micrite complete recrystallization of foraminifera tests, mollusk fragments and other biogenic fragments had occurred leaving only a color difference in an otherwise evenly textured groundmass (Plate 10). Dolomitization could be observed around most grains in the micrite and, in some rare case, could be seen partially digesting fossil fragments or pelletoidal grains and intraclasts. Some pelletoidal grains and intraclasts had been completely dolomitized and appeared as clusters of anhedral to subhedral dolomite crystals retaining the original grain boundaries. Dolomite also occurred as subhedral to euhedral rhombs scattered throughout the micrite and commonly lined grains floating in the micrite (Plates 7, 11, and 12). Sparry calcite was rare and appeared to have formed at the expense of the micrite. The calcite was very fine-grained and was occasionally seen filling cracks in quartz grains. Some of the larger mollusk fragments had undergone complete recrystallization to mosaic calcite, however, this condition was rare.

Samples collected in the upper layer of rock had more quartz and less micrite. Dolomitization appeared slightly more extensive in those rocks and they were less indurated and were more porous. In two rock samples (reference numbers A-4-72 and JH-1 in Appendix) which were collected in the upper layers of the reef, fragments of the thin-shelled pelecypod, Amusium sp., were found whereas they were found nowhere else in the study area. These animals are indicative of shallow, calm water (Woolsey, personal

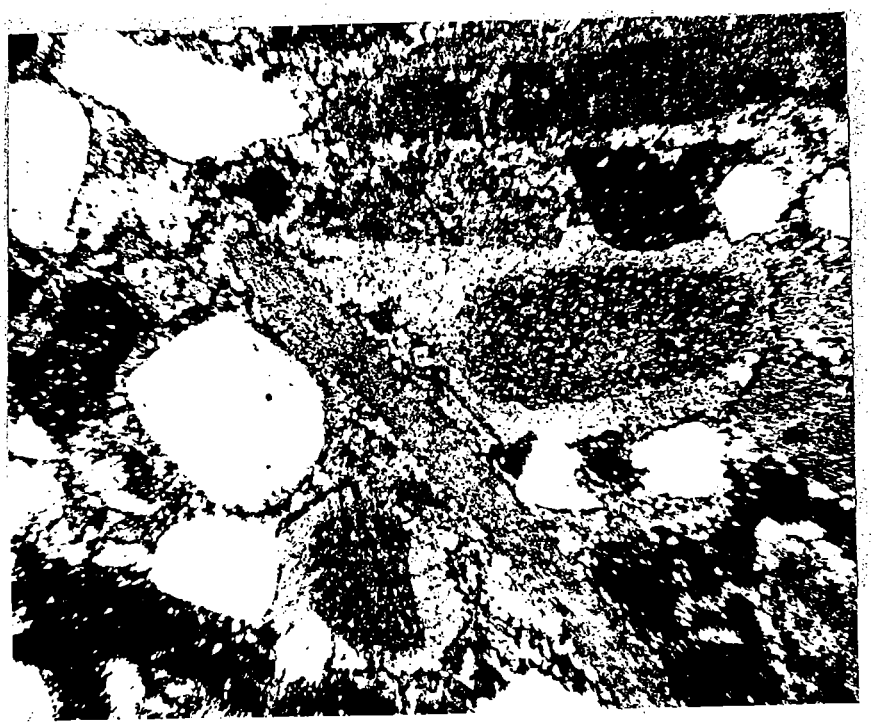

PLATE 9

Photomicrograph of dolomitic monocrystal syntaxial overgrowths over dolomitic echinoid plates (lower center and right center) (crossed Nichols) x 80.

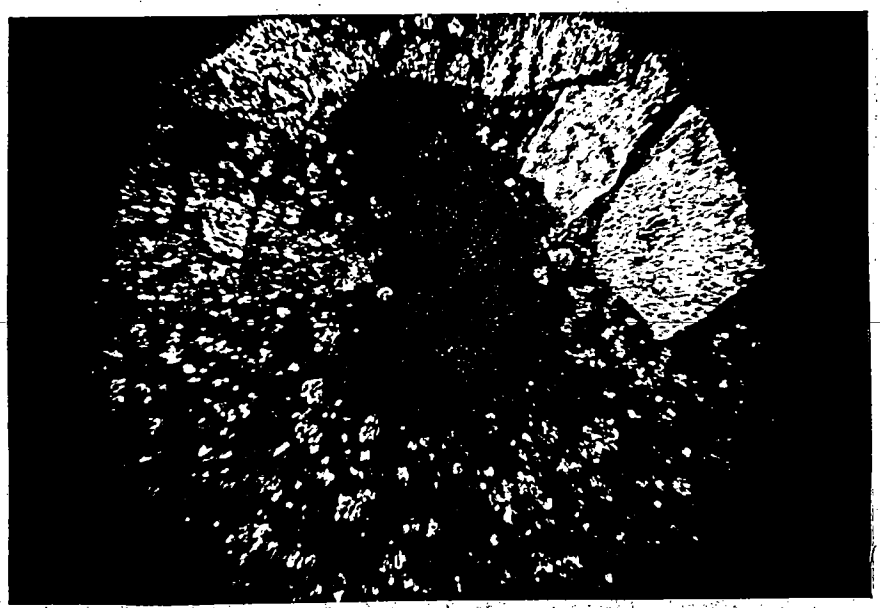

PLATE 10

Photomicrograph of a foraminifer in micrite. Also note dolomite rhombs scattered in micrite. Slide stained with Alizarin Red "S" to stain micrite red (Plane Polarized Light), x200.

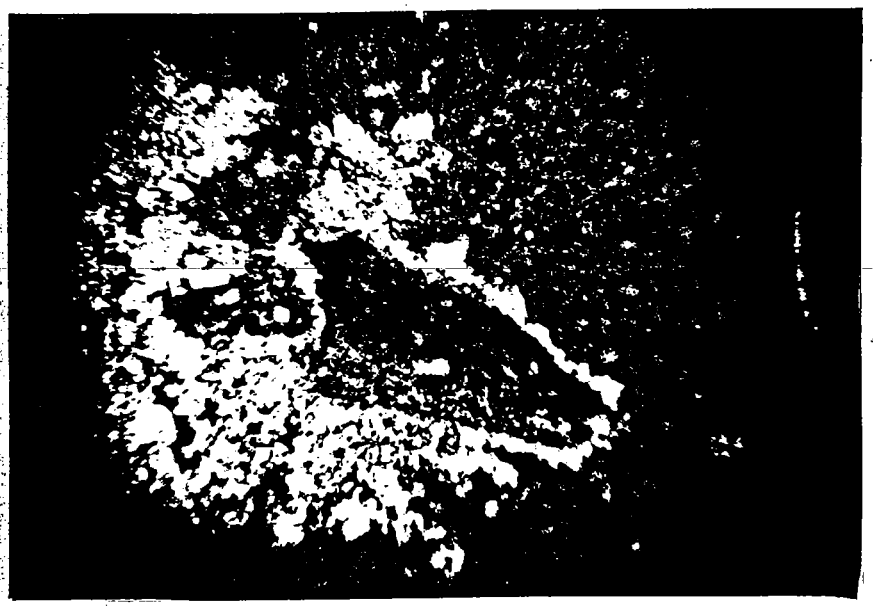

PLATE 11

Photomicrograph of a biogenic fragment in micrite surrounded by a halo of dolomite. Slide stained with Alizarin Red "S" to stain micrite red (Plane Polarized Light), x200.

communication, 1973).

A detailed description of each rock, both hand specimens and thin-sections, as well as Sapelo Sound and Turtle River rocks, is given in the Appendix. Similarity of the Gray's Reef rocks to the Sapelo Sound and Turtle River rocks may be noted.

DISCUSSION

Geological History of Gray's Reef Substrate

The reef substrate appears to have been formed under intermittantly wave-agitated conditions. A moderate amount of energy had to be present in the depositional environment to fragment most of the fossils and to introduce intraclasts. Conversely, there must have been periods of relatively low energy to permit the deposition of lime mud (as described by Plumley, et al, 1964).

The site of the present reef was probably located between a carbonate and a terrigenous sedimentary regime as indicated by the moderate amount of quartz sand present in the rocks. The occurrence of mollusk, bryozoa and coral remains, and their fragmentary condition would suggest a shallow marine environment, possibly along a bar or shoal. Amusium sp. shells in the rocks from the upper portion of the reef indicate that the environment was of very low energy during its formation (Woolsey, personal communication, 1973; Furlow, 1969).

Staining indicated that the micrite matrix was calcite in composition. Since mosaic calcite was found infilling a solution void of a mollusk fragment, which suggest exposure to ground water activity, the micrite is probably low-magnesium calcite because it is more stable than high-magnesium calcite or aragonite in a surface diagenetic environment (Murray, 1960; Chave, et al,

1962; Friedman, 1964).

The exact time of dolomitization of the reef substrate is difficult to ascertain although five modes of dolomite occurrence indicate diagenetic as opposed to primary origin:

1) subhedral to euhedral rhombs of dolomite scattered randomly throughout the micrite matrix (Plate 7);
2) "dolomite rim cement" (as described by Schmidt, 1965) around void spaces and surrounding allochemical grains throughout the rocks (Plate 11);
3) total replacement, destructive in many cases, of intraclasts by anhedral dolomite rhombs, some of which cross the grain boundaries;
4) dolomitic echinoid plates and spines with dolomitic monocrystal syntaxial overgrowths (Plate 9);
5) total dolomitization of a bryozoan colony (Plate 12).

Schmidt (1965) introduced the terms "early and late diagenesis" to imply diagenesis influenced by the depositional and post-depositional environments, respectively. One feature all dolomite has in common is that the mineral has to form in a dynamic environment; that is, actively circulating fluids must be present to supply magnesium ions (Hanshaw and Back, 1972). Little evidence was found to indicate whether the circulation of magnesium-rich brines allowed dolomitization to occur while the sediment was still under the influence of the environment of deposition (syngenetic) or whether the dolomitization occurred later (epigenetic).

Two widely accepted theories for sources of magnesium ions have been advanced by Goodell and Garmon (1969) and Adams and Rhodes (1960).

Goodell and Garmon described the process of "solution-cannibalization" as solution of the upper high-magnesium carbonate rocks in a sequence as a source of the magnesium ions and the dolomitization of the rocks below the area of solution by the downward percolation of magnesium-rich water. Substantial amounts of high-magnesium calcite have to be dissolved to dolomitize even a relatively small unit of rocks below the zone of solution. In the case of the Gray's Reef rocks, this process is a doubtful explanation for the origin of the magnesium ions required for dolomitization because the entire sequence is relatively thin. A thick sequence above the reef substrate to supply the necessary ions could have initially been present and subsequently eroded away; however this phenomenon is highly unlikely. The time factor alone would be prohibitive. For a thick unit of carbonate rocks to completely deteriorate and erode away would involve much more time than has been available.

Adams and Rhodes' (1960) theory for dolomitization envisions a process of "seepage-refluxion" with the seepage of ocean water through or over a natural barrier into a semi-closed or closed hypersaline lagoon. The sea salts are concentrated in the lagoon and the dense brines formed percolate through the underlying strata and back into the sea, thereby dolomitizing the underlying rocks or sediments.

A modified version of Adams and Rhodes' theory is the most likely explanation for the dolomitization of the study area rocks. The environment of deposition became a very shallow, quiet body of water as indicated by the Amusium sp. shells found in the uppermost rocks in the Gray's Reef sequence. Recent work by J. R. Woolsey (personal communication, 1973) indicates a more arid climate than present during the time of deposition of the reef rocks. In this arid climate evaporation of the sea water in a shallow, possibly restricted, body of water could cause dense, rich brines which in turn would percolate downward through the porous sediments or rocks and thereby dolomitize the beds over the entire area.

Further evidence supporting this theory is the fact that the rocks were dolomitized prior to the first subaerial exposure of the area as indicated by the higher percentage of dolomite in the uppermost layer of rocks. The sequence of rocks being dealt with is relatively thin so that dolomitization would be fairly even. Ground water percolation would dissolve much of the micrite out of the uppermost rocks leaving behind the sand and dolomite. The uppermost rocks of Gray's Reef exhibit a leached appearance while the rocks below this zone are much more consolidated and have a slightly higher micrite content. Exposure to ground waters is indicated by the mollusk fragments that were recrystallized to mosaic calcite, probably by dissolution-reprecipitation (Friedman, 1964). Exposure to ground water would also remove any evaporite minerals, particularly anhydrite, leaving molds of the crystals (Murray, 1960). This process would explain the occurrence of some of the pore space

in the rocks. Also, as described by Murray (1960), calcite dissolution must accompany dolomitization if the fluids bearing the magnesium ions are carrying insufficient carbonate ions which could also cause some of the porosity evident in the Gray's Reef substrate.

Although the number, time and extent of sea level fluctuations during the Pleistocene Epoch are highly speculative, the oldest Carbon-14 dates obtained from continental shelf material indicate a sea level of approximately -148 meters (-485 ft.) around 40,000 years b.p. with a rise to around -10 meters (-33 ft.) approximately 29,000 years b.p. and another regression to a level of approximately -100 meters (-330 ft.) about 18,000 years ago (Curray, 1965; Emery, 1967). Although the exact time of subaerial exposure of the Gray's Reef area is not definite, the fact that the rocks were subaerially exposed is suggested by the prevalent jointing in the substrate caused by dessication and settling.

Carbon-14 dates obtained from the oyster, Crassostrea virginica, shell samples collected in the study area were 31,520 years b.p. $\pm$ 1,000 years. When this date was plotted on Curray's (1965) graph of late Quaternary sea levels versus time, a level of approximately -20 meters (-65 ft.) was obtained. This sea level approximates the present depth of water over the study area indicating that perhaps the Gray's Reef area was an estuarine environment during the mid-Wisconsin regression. According to Emery (1967), sea level reached approximately -20 meters (-65 ft.) around 9,000 years b.p. when the rate of transgression decreased. The latter age is more feasible for the

study area to be an estuarine environment because the shells would be less likely to be scattered and fragmented.

The outcrop patterns seen in certain parts of the study area (i.e., the ledge and undercut cave seen in Plate 1), indicate a period of exposure to the surf action. The rock was consolidated prior to exposure to the surf in as much as it could not have survived the action of the surf had it been unconsolidated. No fine rubble was found anywhere on or beneath the bottom under the ledges.

The reef rock has undergone little change other than being encrusted by the luxurient growth of sessile benthos and perhaps some settling and collapsing of the ledge areas since inundation by the advancing sea. Some sediment transport has probably taken place across the study area during severe weather; however, no thick accumulation of sediment has occurred in the immediate past otherwise the encrusting organisms would have been killed off.

Geological Age of the Gray's Reef Substrate

Rock samples from Turtle River near Brunswick, Georgia, and from Sapelo Sound were obtained from J.R. Woolsey, and were thin-sectioned. The Turtle River Rock (reference number D-1-72 in the Appendix) closely resembled the Gray's Reef rocks in external appearance, except for the smaller number of encrustations. The color of the rock was dark gray to dark grayish brown. The surface of the rock was highly bored by mollusks. Thin-sections examination revealed the rock to be a sandy, moderately dolomitized, micritic, skeletal limestone. Allochemical grains constituted 24% of the

rock with echinoid and mollusk fragments being most common. Intraclasts were common and foraminifera, fish bones and pelletoidal grains rare. Terrigenous constituents, mainly quartz, represented about 32% of the rock. Microcline and plagioclase were rare. The terrigenous grains were subangular to subrounded and poorly sorted. Some quartz grains were fractured and some showed strain. Orthochemical constituents were the most abundant in the rock and represented 44%. Micrite constituted about 8%, microspar to mosaic calcite about 8% and dolomite around 28%. The Sapelo Sound rock was very similar in appearance to the uppermost rock of Gray's Reef. The rock was higher in quartz sand, micrite and dolomite content and less fossiliferous than the Turtle River rock, although the fossil assemblage was very similar. The rock from Sapelo Sound also contained a cluster of Amusium sp. shells.

Several core samples were collected on Sapelo Island, Georgia, and Amelia Island, Florida, and a hard crust underlain by marly, gravelly sand was found at depths of 13.7 to 21.3 meters (45 to 70 ft.) and 10.7 to 18.3 meters (35 to 60 ft.), respectively. One sample on Sapelo Island at a depth of 13.7 meters (45 ft.) contained large Amusium sp. fragments. Rock was also encountered in several airlift holes drilled by J. R. Woolsey. East of St. Simons Island, Georgia, rock was encountered at a depth of 10.7 meters (35 ft.) (Woolsey, personal communication, 1973).

Before postulating the age of the reef substrate a review of the current status of late Neogene stratigraphy in the southeastern United States, and especially in coastal Georgia, is felt necessary because of the possible eminant re-

vision of stratigraphic nomenclature (Henry, Giles and Woolsey, 1973). The question of revision involves the Duplin Marl, traditionally regarded in the literature as Upper Miocene in age (Veatch and Stephenson, 1911; Richards, 1955; Herrick and Vorhis, 1963; Herrick, 1965). Recent work by Huddleston (personal communication, 1973) and Woolsey (personal communication, 1973) indicates a Lower Pliocene age for the Duplin Marl.

According to Woolsey (personal communication, 1973), the layer of rock cropping out in Turtle River and Sapelo Sound and encountered in core holes on Sapelo Island, Georgia, and Amelia Island, Florida, is the Duplin Marl Formation.

As previously discussed, seismic profiles run from Gray's Reef to the vicinity of Doboy Sound immediately south of Sapelo Island revealed a somewhat discontinuous reflector at a depth of 15.0 meters (50 ft.) near the sound and that cropped out at Gray's Reef. A lithologically similar layer identified by Woolsey as the Duplin Marl was encountered in core holes on Sapelo Island and in Sapelo Sound at approximately the same depth as the reflector discussed above near Doboy Sound (Figure 5). There is therefore strong evidence that the Gray's Reef substrate directly correlates with the Duplin Marl formation of coastal Georgia.

The Duplin Marl crops out mainly along the major rivers in coastal Georgia. Exposures are found along the St. Mary's River south and southwest of Folkston, Georgia (Herrick and Vorhis, 1963) just north of Brunswick, Georgia, along the Turtle River (Brantley, 1916), along the Altamaha River at

Doctortown, Buzzard's Roost Bluff and at Bugs Bluff (Brantley, 1916; Cooke, 1943; Richards, 1955; Herrick and Vorhis, 1963) and at Porter's Landing on the Savannah River (Brantley, 1916; Cooke, 1943; Richards, 1955; Herrick and Vorhis, 1963).

In the updip section in Georgia the Duplin Marl is primarily composed of marly, clayey sands (Veatch and Stephenson, 1911; Brantley, 1916; Herrick, 1961; Herrick and Vorhis, 1963). Near the coastline from south of Brunswick to the Ogeechee River south of Savannah, the Duplin grades to a sandy, poorly to moderately consolidate, shallow marine limestone (McCollum and Herrick, 1964; Logan, 1968; Furlow, 1969; unpublished core data collected by Henry, Woolsey and Hunt, 1971). North of the Ogeechee River in the Savannah-Chatham County area the Duplin is apparently absent (Huddleston, personal communication, 1973).

SUMMARY AND CONCLUSIONS

The outcrop pattern, bathymetry and sessile benthic accumulations of a live-bottom reef have been mapped in an area 33 kilometers (18 naut. mi.) east of Sapelo Island, Georgia. The author proposes that the name of this feature be changed from "Sapelo Reef", a geographically vague local identification, to "Gray's Reef", as specifically located and described in this study.

The reef was found to be an outcrop of a moderately to strongly dolomitized, sandy biomicrite and, on the basis of similar stratigraphic position (Figure 5) and similar lithology, a correlation with the Pliocene (?) Duplin Marl is apparent.

Fossil fragments of certain mollusks, bryozoa, echinoids and coral, and their state of fragmentation, indicate that the rock was deposited in a shallow marine environment, possibly along a bar or shoal. Although the exact time of dolomitization was difficult to determine, evidence indicates that the dolomite was diagenetic in origin and occurred as a result of evaporation of sea water in a broad, shallow, possibly restricted, body of water. The heavily-laden brines then percolated downward through the sandy biomicrite causing extensive dolomitization.

Following lithification the study area rocks were subaerially exposed at least twice during the Pleistocene Epoch as the result of eustatic fluctuations

of sea level (Curray, 1965; Emery, 1967). Fresh ground water percolation leached some of the micrite from the uppermost layer of rocks in the area resulting in a higher dolomite and quartz sand content than in the lower layers of rock. During the latest transgression approximately 18, 000 years b.p. the study area appears to have been exposed to the action of the surf. The consolidated rock was undercut by wave action and some of the larger blocks were left scattered about the base of the ledges. Following inundation by the sea, the rocks were heavily encrusted sponges, soft corals, barnacles, coral, calcareous algae, ascidians, serpulid worms and various other organisms and have remained in such a condition until the present time. Apparently little sediment is moving across the reef surface.

Other live-bottom reef areas are known to exist in deeper water and further offshore than Gray's Reef (Pilkey and Giles, 1965; Eddy, et al, 1967; Henry and Hoyt, 1968; Henry, personal communication, 1973). The investigation of age, origin and composition of the deeper reefs and their relationships to Gray's Reef would provide an excellent subject for further study. The Duplin Marl is a regionally extensive layer (Woolsey, personal communication, 1973) and probably crops out along approximately the same depth contour, As a consequence, other live-bottom reefs similar to Gray's Reef probably exist within this trend.

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ROCK DESCRIPTIONS

REFERENCE NUMBER: A-3-72 Location: Gray's Reef

Hand Specimen

Color: Olive Gray, (Munsell 5Y 5/2)

Structures: Vague orientation of elongate grains, partial solution around mollusk fragments.

Induration: Well indurated, low porosity.

Surface Features: Exterior of the rock is heavily encrusted by bryozoa, oysters (?), various sponges, tunicates and serpulid worm tubes. The rock has been extensively bored by Lithophaga sp. Barnacles and solitary corals are rare. One large quartz grain (11 mm) was found adhering to the exterior of the rock.

Thin Section A-3-72/A

Allochemical Constituents:	8%	
Echinoid Fragments	4%	Plates and spines, dolomitic and exhibited dolomitic syntaxial overgrowths, grains up to 0.8 mm.
Mollusk Fragments	2%	0.2 to 2.0 mm, highly fragmented, some showed halo of dolomitization.
Intraclasts	2%	0.2 to 0.4 mm, dark brown and micritic, most have halo of dolomitization, some partially to entirely digested by dolomitization.
Orthochemical Constituents:	65%	
Micrite	34%	Light to dark brown, probably original matrix.
Dolomite	29%	0.05 to 0.12 mm, anhedral to euhedral rhombs in micrite and commonly surrounding and partially digesting allochemical grains in micrite.

Orthochemical Constituents Cont'		
Pelletoidal Phosphatic Concretions	2%	Up to 0.2 mm, light green to brown, oval to round grains, isotropic.
Terrigenous Constituents:	27%	
Quartz	26%	0.1 to 5.0 mm, grains subangular to subrounded, some show inclusions.
Microcline	1%	0.2 to 0.8 mm, subangular to subrounded.
Thin Section A-3-72/B		
Allochemical Constituents:	18%	
Echinoid Fragments	8%	0.04 mm, plates commonly show syntaxial overgrowths of dolomite.
Mollusk Fragments	5%	Up to 0.3 mm, highly fragmented, some highly dolomitized.
Intraclasts	4%	0.2 to 0.45 mm, typically show halo of dolomite, some partially to entirely dolomitized.
Pellets	1%	0.15 to 0.2 mm, exhibit halos of dolomitization.
Forams, Coral, Ostracods	Rare	
Orthochemical Constituents:	57%	
Micrite	33%	Light to dark brown.
Dolomite	23%	0.02 mm, occurs as anhedral to euhedral rhombs in micrite and around allochems.
Pelletoidal Phosphatic Concretions	1%	0.2 mm, light green to brown, oval to round grains, isotropic.
Microsparry Calcite	Rare	

Terrigenous Constituents:	25%	
Quartz	24%	0.1 to 3.0 mm, amphibole inclusions rare, subangular to subrounded.
Microcline	1%	1.0 to 2.0 mm, subangular to subrounded, appears fresh and unaltered.

REFERENCE NUMBER: A-4-72 Locations: Gray's Reef

Hand Specimen

Color:	Gray to light gray, (Munsell 5Y 6/1)
Structures:	Parallel orientation of large Amusium sp. fragments indicate primary bedding in one layer of the rock.
Induration:	Poorly indurated, high porosity.
Surface Features:	Exterior of the rock is extensively encrusted by bryozoa and mollusks. Serpulid worm tubes are common. The rock has been extensively bored by Lithophaga sp.

Thin Section A-4-72

Allochemical Constituents:	18%	
Echinoid Fragments	8%	0.1 to 1.5 mm, most plates exhibit dolomitic syntaxial overgrowths.
Mollusk Fragments	7%	0.2 mm, highly fragmented and some extensively dolomitized.
Intraclasts	2%	Up to 1.2 mm, most have halo of dolomitization, some partially digested.
Foraminifera	1%	0.2 to 0.8 mm, almost completely recrystalized, some highly dolomitized.
Orthochemical Constituents:	55%	
Micrite	21%	Light to dark brown.
Dolomite	28%	0.04 to 0.05 mm, anhedral to euhedral rhombs in micrite and around allochems.
Sparry Calcite	4%	0.01 to 0.03 mm, filling cracks in quartz grains and small voids.
Pelletoidal Phosphatic Concretions	2%	Up to 0.2 mm, round to oval, light green to brown, isotropic, show vague coincentric structure around periphery.

Terrigenous Constituents:	27%	
Quartz	24%	0.1 to 4.0 mm, subangular to subrounded.
Microcline	Rare	
Carbonaceous (?) Material	3%	Well packed and filling pore space, dark, semi-opague.

REFERENCE NUMBER: A-5-72 Location: Gray's Reef

Hand Specimen

Color:	Dark gray, (Munsell 2.5Y N4/)
Structures:	Very vague primary bedding, partial solution has left numerous voids throughout the rock. The voids are typically lined with quartz sand grains.
Induration:	Well indurated, moderate porosity.
Surface Features:	Exterior is extremely encrusted, almost entirely by bryozoa. Small mollusk shells are encrusted on the rock and serpulid worm tubes are common. Barnacles are rare.

Thin Section A-5-72/A

Allochemical Constituents:	10%	
Echinoid Fragments	5%	0.2 to 1.5 mm, appear dolomitic and most plates exhibit dolomitic syntaxial overgrowths.
Mollusk Fragments	3%	0.2 to 1.0 mm, highly fragmented, some grains had internal structure destroyed by dolomitization.
Intraclasts	2%	0.2 to 0.7 mm, dark brown and micritic, show rim of dolomitization, some digested by dolomitization.
Foraminifera, Coral (?) Fish Bones, Bryozoa	Rare	
Orthochemical Constituents:	55%	
Micrite	33%	Dark to light brown
Dolomite	20%	0.01 to 0.02 mm, anhedral to euhedral rhombs, some areas have undergone nearly complete dolomitization.
Pelletoidal Phosphatic Concretions	2%	0.2 mm, isotopic, light green to brown, round to oval.

Orthochemical Constituents Cont'

Microsparry Calcite	Rare	

Terrigenous Constituents: 35%

Quartz	34%	0.2 to 2.0 mm, many grains fractured and strained, some filled with microspar.
Microcline	1%	0.1 to 0.4 mm, subangular to subrounded, appears fresh and unaltered.

Thin Section A-5-72/B

Allochemical Constituents: 9%

Echinoid Fragments	4%	0.2 to 1.2 mm, show syntaxial overgrowths of dolomite.
Mollusk Fragments	3%	0.2 to 4.0 mm, highly fragmented and show halos of dolomite.
Intraclasts	2%	0.2 to 80 mm, dark brown and micritic, commonly surrounded and partially digested by dolomitization.
Pellets, Forams, Bryozoa, Coral	Rare	

Orthochemical Constituents: 60%

Micrite	37%	Dark brown to light brown, stains red with Alizarin Red "S".
Dolomite	20%	0.02 to 0.05 mm, anhedral to euhedral rhombs.
Pelletoidal Phosphatic Concretions	3%	0.15 to 0.2 mm, round to oval, light green to brown, isotropic.
Microsparry Calcite	Rare	

Terrigenous Constituents: 31%

Quartz	30%	0.1 to 2.0 mm, subangular to subrounded, some fractured and filled with microspar, amphibole inclusions rare.
Microcline	1%	1.5 mm, subangular to subrounded, grains elongated.

Thin Section A-5-72/C

Allochemical Constituents: 15%

Echinoid Fragments	6%	0.2 to 2.0 mm, plates show syntaxial overgrowths of dolomite.
Mollusk Fragments	5%	Up to 1.0 mm, highly fragmented, some extensively dolomitized.
Intraclasts	3%	0.2 to 0.4 mm, brown micrite, typically surrounded or partially digested by dolomitization.
Bryozoa	1%	Up to 0.6 mm, grains crushed and partially dolomitized.
Foraminifera	Rare	

Orthochemical Constituents: 56%

Micrite	22%	Light to dark brown.
Dolomite	31%	0.02 mm, anhedral to euhedral rhombs.
Pelletoidal Phosphatic Concretions	3%	0.2 mm, oval to round, light green to light brown, isotropic.

Terrigenous Constituents: 29%

Quartz	29%	0.02 to 2.0 mm, subangular to subrounded.
Microcline	Rare	

REFERENCE NUMBER: A-6-72 Location: Gray's Reef

Hand Specimen

Color:	Gray, (Munsell 5Y 5/1)
Structures:	Very faint bedding is apparent and is accentuated by solution pitting. Partial solution is common, particularly in mollusk fragments, as some of the larger voids take the shape of the original fossils.
Induration:	Moderate induration, moderate porosity.
Surface Features:	Exterior of the rock is extensively encrusted, predominantly by bryozoa. Barnacles are abundant, mollusk shells are common and serpulid worm tubes are abundant. Rock has undergone extensive boring by Lithophaga sp.

Thin Section A-6-72/A

Allochemical Constituents:	13%	
Echinoid Fragments	5%	0.2 to 1.5 mm, commonly exhibit dolomitic syntaxial overgrowths.
Mollusk Fragments	4%	Up to 2.2 mm, highly fragmented and dolomitized.
Intraclasts	4%	Up to 1.0 mm, brown micrite, irregular shaped, extensively dolomitized.
Coral, Forams, Pelletoidal Grains	Rare	
Orthochemical Constituents:	57%	
Micrite	19%	Light to dark brown.
Dolomite	34%	0.01 to 0.1 mm, anhedral to euhedral rhombs.
Pelletoidal Phosphate Concretions	4%	0.1 to 0.2 mm, oval to round, light green to light brown, isotropic.
Microsparry Calcite	Rare	0.01 to 0.1 mm

Terrigenous Constituents:	30%	
Quartz	29%	0.1 to 2.0 mm, subangular to subrounded, some fractured and filled with microsparry calcite.
Microcline	1%	0.1 to 1.0 mm, shows typical twinning, subangular to subrounded and appears fresh and unaltered.

Thin Section A-6-72/B

Allochemical Constituents:	13%	
Echinoid Fragments	4%	0.1 to 1.0 mm, plates commonly show dolomitic syntaxial overgrowths.
Mollusk Fragments	5%	Up to 2.0 mm, highly fragmented, some partially digested by dolomitization.
Intraclasts	4%	Brown micritic lumps, typically show halo of dolomitization.
Coral, Forams, Pellets	Rare	
Orthochemical Constituents:	56%	
Micrite	14%	Light to dark brown.
Dolomite	39%	0.01 to 0.04 mm, anhedral to euhedral rhombs scattered throughout the micrite.
Pelletoidal Phosphatic Concretions	3%	0.1 to 0.2 mm, oval to round, light green to light brown, isotropic.
Microsparry Calcite	Rare	
Terrigenous Constituents:	31%	
Quartz	29%	0.1 to 1.5 mm, subangular to subrounded, fractured and strained.
Microcline	2%	0.2 to 0.9 mm, subangular to subrounded, appears fresh and unaltered.

Terrigenous Constituents Cont'

Plagioclase	Rare	

Thin Section A-6-72/C

Allochemical Constituents:	11%	
Echinoid Fragments	4%	Up to 2.0 mm, plates commonly show dolomitic syntaxial overgrowths.
Mollusk Fragments	5%	Up to 3.0 mm, highly fragmented, varying degrees of dolomitization seen in different grains.
Intraclasts	2%	Up to 1.0 mm, brown micrite, some highly dolomitized, some show halo of dolomitization.
Orthochemical Constituents:	61%	
Micrite	11%	Light to dark brown.
Dolomite	46%	0.01 to 0.07 mm, anhedral to euhedral rhombs in micrite and around allochems.
Pelletoidal Phosphatic Concretions	4%	0.1 to 0.2 mm, round to oval, light green to light brown, shows hints of coincentric structure in poriphery.
Microsparry Calcite	Rare	
Terrigenous Constituents:	28%	
Quartz	26%	0.07 to 1.5 mm, subangular to subrounded, some fractured and strained.
Microcline	2%	0.2 to 1.0 mm, exhibits typical twinning, subangular to subrounded and appears fresh and unaltered.

REFERENCE NUMBER: A-7-72 Location: Gray's Reef

Hand Specimen

Color: Dark Gray, (Munsell 2.5Y N4/)

Structures: Lineation, probably bedding, is vaguely exhibited by roughly parallel orientation of fossil grains. Solution voids are common and typically lined with unconsolidated carbonate material and quartz grains.

Induration: Well indurated, moderate porosity.

Surface Features: Exterior is highly encrusted by bryozoa. Barnacles are common as are oyster (?) shells. Serpulid worm tubes are abundant and calcareous algae (Lithothamnion sp. ?) is rare. Rock is extensively bored by Lithophaga sp.

Thin Section A-7-72

Allochemical Constituents:	10%	
Echinoid Fragments	5%	Up to 1.5 mm, commonly show dolomitic syntaxial overgrowths.
Mollusk Fragments	5%	Up to 2.0 mm, highly fragmented, shows various stages of dolomitization, most grains have halo of dolomite.
Intraclasts, Pellets, Forams, Coral, Bryozoa	Rare	
Orthochemical Constituents:	58%	
Micrite	14%	Light to dark brown
Dolomite	38%	0.01 to 0.05 mm, anhedral to euhedral rhombs.
Microsparry Calcite	3%	0.01 to 0.04 mm, occurs as infillings in fractures in quartz grains and voids.
Pelletoidal Phosphatic Concretions	3%	0.1 to 0.2 mm, isotropic, light green to light brown.

Terrigenous Constituents:	32%	
Quartz	31%	0.04 to 2.0 mm, subangular to subrounded, some fractured or strained.
Microcline	1%	0.1 to 1.1 mm, subangular to subrounded, appears fresh and unaltered.

REFERENCE NUMBER: A-8-72 Location: Gray's Reef

Hand Specimen

Color: Very dark gray, (Munsell 2.5Y N3/)

Structures: Dark to light parallel bands probably indicate original bedding. Bands are typically enhanced by solution pitting. Voids are commonly lined with unconsolidated carbonate material and quartz grains.

Induration: Well indurated, moderate porosity.

Surface Features: Exterior of the rock is relatively bare. One side is covered by calcareous algae (Lithothamnion sp.?). Serpulid worm tubes are abundant and bryozoa rare. Rock is extensively bored by Lithophaga sp.

Thin Section A-8-72/A

Allochemical Constituents:	15%	
Echinoid Fragments	6%	0.2 to 1.0 mm, commonly show dolomitic syntaxial overgrowths.
Mollusk Fragments	4%	0.3 to 1.5 mm, highly fragmented, partly to entirely digested by dolomitization.
Intraclasts	5%	Brown micrite, many partially to entirely digested by dolomitization, typically surrounded by a halo of dolomitization.
Pelletoidal Grains, Foraminifera, Bryozoa	Rare	
Orthochemical Constituents:	63%	
Micrite	26%	Light to dark brown, some appears to have come from burrowing algae.
Dolomite	37%	0.01 to 0.06 mm, anhedral to euhedral rhombs in micrite and around in all allochems.

Orthochemical Constituents Cont'

Microsparry Calcite	Rare	
Terrigenous Constituents:	22%	
Quartz	21%	0.1 to 2.2 mm, subangular to subrounded.
Microcline	1%	0.2 to 0.4 mm, exhibits typical twinning extinctions, appears fresh and unaltered.

Thin Section A-8-72/B

Allochemical Constituents:	16%	
Echinoid Fragments	6%	Up to 6.0 mm, most exhibit dolomitic monocrystal syntaxial overgrowths.
Mollusk Fragments	5%	0.3 to 2.0 mm, most surrounded by a halo of dolomitization, highly fragmented.
Intraclasts	5%	0.2 to 2.5 mm, brown micrite, most have undergone extensive dolomitization.
Bryozoa, Coral, Foraminifera	Rare	
Orthochemical Consituents:	59%	
Micrite	25%	Light to dark brown.
Dolomite	32%	0.01 to 0.07 mm, anhedral to euhedral rhombs in micrite and around allochems.
Pelletoidal Phosphatic Concretions	2%	0.1 to 0.2 mm, isotropic, light green to light brown.
Microsparry Calcite	Rare	
Terrigenous Constituents:	25%	
Quartz	23%	0.07 to 1.5 mm, subangular to subrounded, some grains fractured or strained.

Terrigenous Constituents Cont'

Microcline	2%	0.2 mm, subangular to subrounded, appears fresh and unaltered.

REFERENCE NUMBER: A-9-72

Location: Gray's Reef, near top of section

Hand Specimen

Color: Light gray, (Munsell 5Y 7/1)

Structures: None apparent.

Induration: Poorly indurated, high porosity.

Surface Features: Exterior of the rock is encrusted by sponges, tunicates, bryozoa and barnacles. Serpulid worm tubes are common and encrusting foraminifera rare. Extensively bored by Lithophaga sp.

Thin Section A-9-72

Allochemical Constituents: 7%

Echinoid Fragments	4%	0.1 to 0.9 mm, exhibits dolomitic syntaxial overgrowths.
Mollusk Fragments	3%	0.1 to 1.2 mm, highly fragmented, some partially to entirely digested by dolomitization.
Intraclasts, bryozoa, coral fragments	Rare	Highly dolomitized.

Orthochemical Constituents: 52%

Micrite	11%	Light brown to brown.
Dolomite	39%	0.01 to 0.07 mm, anhedral to euhedral rhombs throughout micrite and around and partially digesting allochemical grains.
Pelletoidal Phosphate Concretions	2%	0.1 to 0.2 mm, isotropic, light green to light brown.

Terrigenous Constituents: 41%

Quartz	39%	0.05 to 1.5 mm, subangular to subrounded, some show strain or fracture.

Terrigenous Constituents Cont'

Microcline	2%	0.1 to 0.9 mm, subangular to subrounded, shows typical extinctions, appears fresh and unaltered.

REFERENCE NUMBER: JH-1

Hand Specimen

Color: Olive gray, (Munsell 5Y 5/2).

Structures: The few mollusk shell fragments present appear roughly parallel indicating possible bedding. Extensive solution pitting has removed mollusk shells leaving external casts.

Induration: Moderately indurated, medium to high porosity.

Surface Features: Exterior about 90% covered by encrusting bryozoa. Encrusting algae common, serpuled worm tubes common, and the rock is extensively bored by Lithophaga sp.

Thin Section JH-1

Allochemical Constituents: 14%

Echinoid Fragments	5%	Up to 2.5 mm, many spines present, most plates covered by dolomitic syntaxial overgrowths.
'usk Fragments	5%	Up to 3.0 mm, highly fragmented, extensively dolomitized.
Intraclasts	3%	Up to 1.5 mm, dark to light brown micrite, partially to entirely dolomitized.
Bryozoa	1%	0.5 to 2.5 mm, appears extensively dolomitized, inside cavities lined with subhedral dolomite rhombs.
Pellets, Fish Bones, and Foraminifera	Rare	

Orthochemical Constituents: 54%

Micrite	9%	Light to dark brown.
Dolomite	43%	0.01 to 0.06 mm, anhedral to euhedral rhombs in and around allochemical grains in the micrite.

Orthochemical Constituents Cont'		
Pelletoidal Phosphatic Concretions	2%	0.1 to 0.2 mm, oval to round, light green to brown.
Terrigenous Constituents:	32%	
Quartz	31%	0.1 to 1.2 mm, subangular to subrounded, many grains strained, some fractured.
Microcline	1%	Exhibits typical twinning.
Plagioclase	Rare	

REFERENCE NUMBER: JH-2

Location: Gray's Reef

Hand Specimen

Color: Dark gray, (Munsell 2.5Y N4/)

Structures: No primary structures apparent. Rock has a black reduced core surrounded by a halo of oxidation. Rock is extensively pitted by solution.

Induration: Moderately indurated, moderate porosity.

Surface Features: Mollusk fragments are common, exterior of the rock is heavily encrusted by bryozoa, encrusting algae (Lithothamnion sp. ?) and oysters (?) common. Barnacles and serpulid worm tubes common and encrusting foraminifera abundant.

Thin Section JH-2/A

Allochemical Constituents: 16%

Echinoid Fragments	6%	0.2 to 1.0 mm, plates commonly exhibit dolomitic syntaxial overgrowths.
Mollusk Fragments	5%	Up to 4.0 mm, highly fragmented, extensively dolomitized.
Serpulid Tubes (?)	1%	Up to 1.5 mm, highly fragmented, slightly dolomitized.
Intraclasts	4%	Up to 2.0 mm, brown micrite, extensively dolomitized.
Algae, Fish Bones, and Bryozoa	Rare	

rthochemical Constituents: 54%

Micrite	26%	Much appears to be residual from boring algae (?). Some mollusk and echinoid fragments bored and replaced by micrite.
Dolomite	26%	0.01 to 0.1 mm, anhedral to euhedral rhombs in and around allochems and in micrite.

Orthochemical Constituents Cont'

Pelletoidal Phosphatic Concretions	2%	0.1 to 0.2 mm, light green to light brown oval to round, isotropic.

Terrigenous Constituents: 30%

Quartz	28%	0.08 to 1.2 mm, subangular to subrounded, some grains show fracture and strain.
Microcline	2%	0.1 to 0.7 mm, subangular to subrounded.

Thin Section JH-2/B

Allochemical Constituents: 20%

Echinoid Fragments	8%	0.1 to 2.0 mm, mostly plates, typically show dolomitic syntaxial overgrowths.
Mollusk Fragments	6%	Up to 3.0 mm, highly fragmented, some extensively dolomitized.
Intraclasts	5%	0.3 to 2.5 mm, brown micrite typically surrounded by halo of dolomite, some extensively dolomitized.

Orthochemical Constituents: 54%

Micrite	25%	Light brown to dark brown.
Dolomite	25%	0.01 to 0.1 mm, anhedral to euhedral rhombs in micrite and around allochems.
Pelletoidal Phosphatic Concretions	4%	0.1 to 0.2 mm, light green to light brown, isotropic, oval to round.

Terrigenous Constituents: 26%

Quartz	24%	0.05 to 1.3 mm, subangular to subrounded, exhibits typical twinning, appears fresh and unaltered.
Microcline	2%	0.1 to 0.7 mm, subangular to subrounded, exhibits typical twinning, appears fresh and unaltered.

Terrigenous Constituents Cont'

Carbonaceous (?) Material

10 by 15 mm, central core of rock, fills pore space in rock and is surrounded by an oxidized (iron-stained ?) zone.

Orthochemical Constituents Cont'

Dolomite		partially digesting allochemical grains.
Microsparry Calcite to Mosaic Calcite	7%	0.01 to 0.4 mm, occurs in voids and in external casts of mollusk shells.
Pelletoidal Phosphatic Concretions	1%	0.2 to 0.4 mm, oval to round, isotropic, light green to light brown.

Terrigenous Constituents: 32%

Quartz	30%	0.05 to 1.0 mm, subrounded to subangular some grains fractured or stained.
Microcline	2%	0.4 to 0.8 mm, subangular to subrounded, exhibited typical extinction, appears fresh and unaltered.
Plagioclase	Rare	

hin Section D-1-72/B

llochemical Constituents: 25%

Echinoid Fragments	10%	0.3 to 5.0 mm, spines and plates, plates typically exhibit dolomitic syntaxial overgrowths.
Mollusk Fragments	8%	0.2 to 3.5 mm, highly fragmented, some partly to entirely dolomitized.
Intraclasts	3%	0.3 to 2.0 mm, brown micrite, some partially to entirely dolomitized.
Foraminifera	3%	0.2 to 0.4 mm, partially dolomitized, some of internal cavities filled with sparry calcite.
Bryozoa, pellets	1%	

hochemical Constituents: 45%

Micrite	8%	Light to dark brown.
Dolomite	24%	0.05 to 0.1 mm, anhedral to euhedral

rthochemical Constituents Cont'

Dolomite		rhombs in micrite and around or partly to entirely digesting allochemical grains.
Microsparry to Mosaic Calcite	11%	0.5 to 1.0 mm, occurs in cavities, particularly in allochemical grains.
Pelletoidal Phosphatic Concretions	2%	0.2 to 0.4 mm, isotropic, light green to light brown, oval to round.
errigenous Constituents:	30%	
Quartz	27%	0.1 to 1.5 mm, subangular to subrounded, some fractured, some strained.
Microcline	2%	0.4 to 0.6 mm, subangular to subrounded, appears fresh and unaltered.
Plagioclase	1%	0.1 to 0.3 mm, appears fresh and unaltered.

EFERENCE NUMBER: A-5-73 Location: Sapelo Sound

land Specimen

olor: Light gray, (Munsell 5Y 7/2)

tructures: Bedding planes accented by large Amusium sp. fragments and shells.

duration: Poorly indurated, moderate to high porosity.

rface Features: Rock encrusted to a minor degree by bryozoa, sponges, tunicates, serpulid worm tubes, etc. Large Amusium sp. shell fragments are evident in the rock. Exterior appears quite sandy.

in Section A-5-72

lochemical Constituents: 7%

Echinoid Fragments	2%	0.2 to 1.5 mm, dolomitic syntaxial overgrowths common.
Mollusk Fragments	5%	Up to 40 mm, Amusium sp. fragments mostly, minor dolomitization around grains, others highly dolomitized.
ellets	Rare	

emical Constituents: 51%

Micrite	16%	Light to dark brown.
Dolomite	35%	0.01 to 0.05 mm, anhedral to euhedral rhombs, some areas almost entirely dolomitized.

rrigenous Constituents: 42%

Quartz	40%	0.1 to 1.5 mm, subangular to subrounded, some fractured, some strained.
Microcline	2%	0.2 to 0.8 mm, subangular to subrounded, shows typical extinction, appears fresh and unaltered.