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RECENT SEDIMENTARY FACIES OF ISOLATED CARBONATE PLATFORMS, BELIZE–YUCATAN SYSTEM, CENTRAL AMERICA

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ABSTRACT: **Distribution of recent sedimentary facies is significantly different in four closely spaced, isolated carbonate platforms off the coasts of Belize and Yucatan (SE Mexico). These differences are largely controlled by variations in submarine topography, which are likely the result of differential subsidence and karstification from platform to platform. A variety of depositional styles and patterns is found in platform interiors that developed during the same Holocene sea-level rise. Composition and texture of surface sediment samples were used to define four major sediment types and to distinguish nine depositional environments within the platforms. Facies maps are based on analysis of 454 sediment samples and high-resolution satellite imagery.**

Glovers Reef is characterized by a circular facies distribution. The nearly continuous reef margin is composed of a coral–red coralline algae–*Halimeda* grainstone. Mixed nonskeletal (peloidal)/skeletal wackestones and packstones are present in shallow lagoon parts ($<$ 5 m water depth) behind the margin. The deep interior, from 5 to 18 m water depth, is characterized by mollusk–foram–*Halimeda* wackestones with over 860 patch reefs of coral–red algae–*Halimeda*–mollusk packstones. Lighthouse Reef also has a coral grainstone and coral–red algae–*Halimeda* grainstone rim, but the facies distribution in the interior is strongly asymmetrical. The 8-m-deep eastern lagoon is floored by mollusk–foram–*Halimeda* wackestones and packstones; the 3-m-deep western lagoon has the mixed peloidal/skeletal wackestone to grainstone facies. A linear trend of coalescing patch reefs and skeletal grainstone facies separates the two lagoons. Banco Chinchorro is similar to Lighthouse Reef, inasmuch as facies distribution patterns of the interior are strongly asymmetrical. Mollusk–foram–*Halimeda* wackestones–grainstones are present in eastern lagoon areas, whereas shallow ($<$ 5 m) western parts of the lagoon are composed of mixed peloidal/skeletal grainstones, packstones, and wackestones. Most of Turneffe Islands is protected on the east by Lighthouse Reef. Accordingly, Turneffe has a narrower reef and skeletal grainstone rim than the other two platforms. Restricted interior lagoons are up to 8 m deep, and are enclosed by wide mangrove rims and surface sediments dominated by *Halimeda*-rich wackestone rich in organic matter. Coral patch reefs are absent. In contrast, the unprotected northernmost part of Turneffe has a wide reef and grainstone rim and the open lagoon area consists of mollusk–foram–*Halimeda* wackestones–packstones with abundant patch reefs.

INTRODUCTION

In contrast to the 400 atolls in the Indo-Pacific region, there are only some 15 atolls or isolated carbonate platforms in the Atlantic. Surface sedimentary facies of most of these 15 platforms are well known. Great Bahama Bank, the largest Atlantic platform, has been studied extensively, whereas smaller ($<$ 1000 km^2) isolated platforms have attracted much less attention (for an overview see Milliman 1973; Geister 1983; Eberli 1991). Here, we present the results of a sediment study of four relatively small isolated carbonate platforms in the Caribbean. The sedimentary facies of these were largely unknown, with the exception of studies that focused on parts of Glovers Reef (Stoddart 1964; Wallace and Schafersman 1977) and a reconnaissance study that included the three Belizean platforms Glovers Reef, Lighthouse Reef, and Turneffe Islands (Gischler 1994).

The isolated platforms Glovers Reef, Lighthouse Reef, Turneffe Islands, and Banco Chinchorro are situated off the coasts of Belize and SE Mexico (Fig. 1). They are part of a 600-km-long reef system, which includes the Belize Barrier Reef, the fringing reefs off eastern Yucatan, the reef-fringed, elevated island of Cozumel, and Arrowsmith Bank, a drowned platform. A series of NNE-striking tilted fault blocks, characterizing the passive continental margin, forms the basement of the reef system (Dillon and Vedder 1973). Two deep boreholes on Glovers Reef and Turneffe Islands (Fig. 1) penetrated 560 m and 1030 m of reef-related facies of Tertiary age before reaching siliciclastics of late Cretaceous to Eocene age (Dillon and Vedder 1973). Seismic data (James and Ginsburg 1979) and rotated Pleistocene stalactites in the Blue Hole on Lighthouse Reef (Dill 1977) indicate neotectonic activity of the fault blocks, presumably due to the active lithospheric boundary between the North American and Caribbean plates (Dillon et al. 1987).

Holocene sedimentation offshore Belize is strongly controlled by underlying structure. Purdy (1974a, 1974b) concluded that Pleistocene karst processes on the subaerially exposed shelf were directed in their expression by underlying structure. Lara (1993) interpreted the present reef distribution on the southern Belize shelf to be controlled by Tertiary fault tectonics. Lomando and Harris (1994), Lomando et al. (1995), and Lomando and Ginsburg (1995) discussed the influence of structural control on sedimentation on the Belize isolated platforms and Banco Chinchorro. Topographic highs of Pleistocene limestones and reefs have been found as the foundation of Holocene reefs by drilling on the Belize shelf (Purdy 1974b; Halley et al. 1977; Shinn et al. 1979; Shinn et al. 1982; Mazzullo et al. 1992) and on the isolated platforms (Gischler and Hudson 1998). Pleistocene siliciclastic highs as Holocene reef foundations were interpreted by seismic data (Choi and Ginsburg 1982; Choi and Holmes 1982; Ferro et al. in press) on the southern Belize shelf. Unconsolidated sediment often accumulated during the Holocene in topographic lows of the Pleistocene surface (e.g., Purdy 1974b; Shinn et al. 1982; Gischler and Hudson 1998).

Drilling on the Belize isolated carbonate platforms also revealed considerable differences in Pleistocene elevation and relief between the platforms. Radiometric dating shows that the margins of the three platforms were flooded successively by the rising Holocene sea (Gischler and Hudson 1998; Gischler and Lomando, unpublished data). In accordance with the regional geologic setting, these findings were interpreted as the result of variation in subsidence and karst processes, in combination with variation in exposure to wave action. This study was designed to examine the influence of these variations on sedimentary environments and facies of Glovers Reef, Lighthouse Reef, Turneffe Islands, and Banco Chinchorro.

SETTING, CLIMATE, AND OCEANOGRAPHY

The mainland behind the four isolated platforms can be divided into two tectono-morphological regions. The low-relief northern region is composed of flat-lying Tertiary and Quaternary limestones. In the mountainous southern region, Paleozoic shales, schists, granites, porphyries, and Cretaceous limestones of the Maya Mountains crop out. The Cretaceous limestones are characterized by tower karst. Carbonate sedimentation prevails on the northern Belize shelf, which is up to 6 m deep (Purdy 1974b; Purdy et al.

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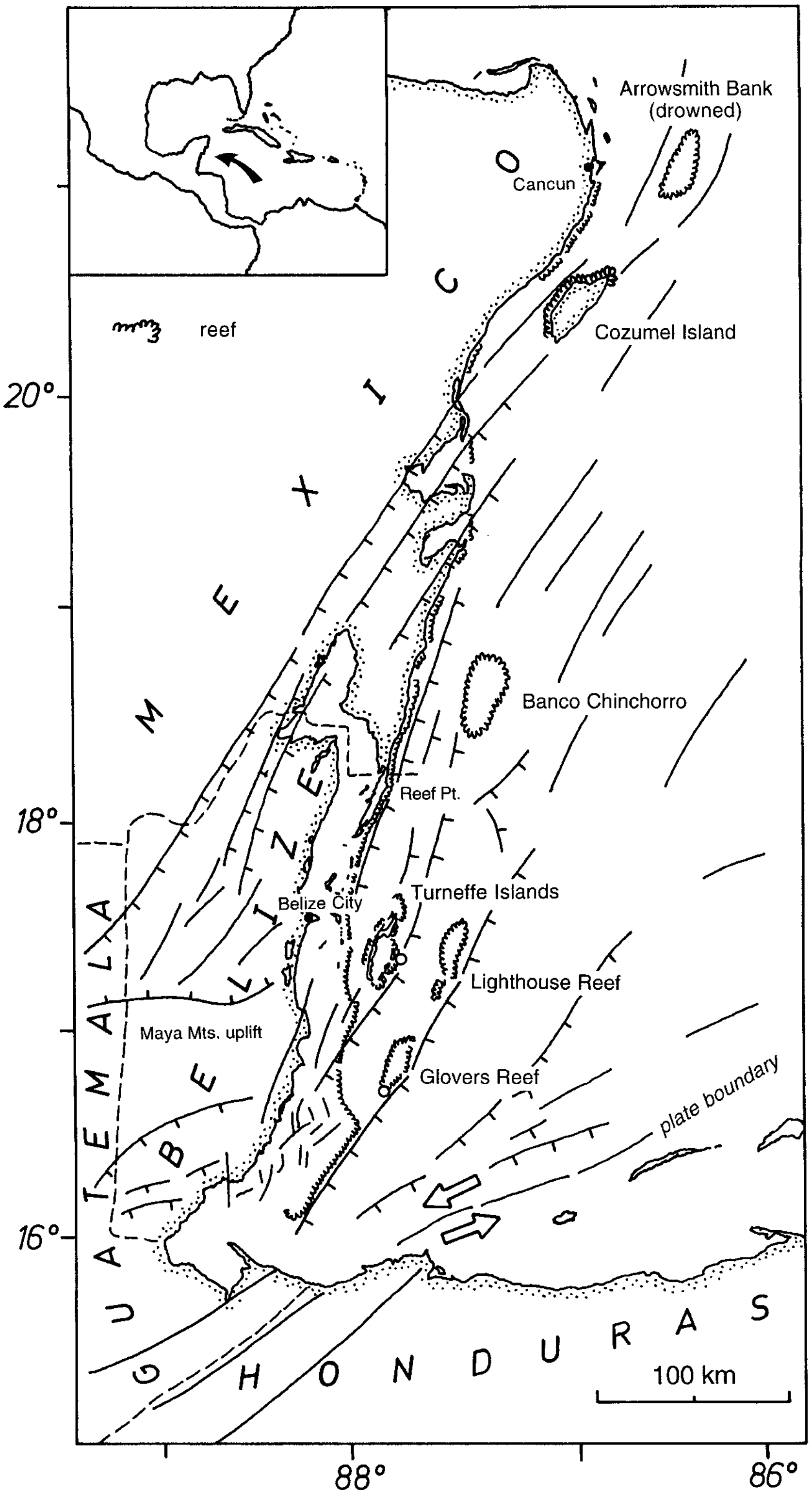


FIG. 1.—Tectonic setting of Belize and southeastern Mexico (only major structures shown). After Purdy (1974b), Case and Holcombe (1980), and Dillon and Vedder (1973). Locations of deep boreholes on Glovers Reef and Turneffe Islands (open circles) after Deal (1983).

1975; Pusey 1975). On the southern shelf, south of Belize City, an intrashelf basin deepens to more than 40 m at the end of the barrier reef, forming a transition from coastal terrigenous, through marly to carbonate-dominated sediments (Purdy 1974b; Purdy et al. 1975).

Belize and southeastern Mexico have a subtropical climate with average air temperatures of 27°C in the summer and 24°C in the winter. Average wind speed is highest in March (13 knots) and lowest in October (7 knots). According to monthly weather data of the Belize Weather Bureau from 1971 to 1981, average wind direction is from the east from January to April and from the northeast during July to December. During May and June the wind blows from the southeast and in November from the northwest. From November to February, northers may cause colder temperatures and storms (Purdy et al. 1975). Hurricanes have repeatedly hit Belize, such as Hurricane Hattie, which caused immense damage on the Belize reefs and coast in October 1961 (Stoddart 1963, 1965a). The majority of storms come from the east–southeast. The average rainfall in southeastern Mexico is 1400 mm/y, in the north of Belize it is between 1240 and 1780 mm/y, and it is more than 3800 mm/y in the mountainous south. Rainfall is about 1750 mm/y on the isolated platforms (Stoddart 1962; Purdy et al. 1975; Jordan and Martin 1987).

Water temperatures range between 29°C in the summer and 26°C in the winter. The tide range is approximately 0.3 m (microtidal). Trade winds result in easterly winds and in a mean wave approach from east–northeast (75°) (Burke 1982). The main Caribbean current flows westward with velocities between 2.8 and 3.7 km/h and is diverted to the north in the Gulf of Honduras. This creates a southward-flowing countercurrent that is stronger in the winter than in the summer. The dominant current direction within Glovers Reef is southwest. Little hydrographic data exist on the platform interiors. The lagoons of Glovers and Lighthouse Reefs and Banco Chinchorro appear open to ocean and normal marine circulation. The lagoons of Turneffe Islands are restricted, and water temperatures and salinity may climb to 31°C and over 70‰, respectively (Smith 1941).

PREVIOUS ENVIRONMENTAL AND SEDIMENT STUDIES ON THE ISOLATED PLATFORMS

Stoddart (1962) described morphology, cays, vegetation, and reefs of the Belize platforms and assessed damage after Hurricane Hattie (Stoddart 1963, 1965a). He also described the history of post-Hurricane recovery. Stoddart (1964) made a textural analysis of island sediments of Halfmoon Cay, Lighthouse Reef. Dill (1977) described the morphology of the Blue Hole, a 125-m-deep submerged sinkhole in the eastern lagoon of Lighthouse Reef. Wallace and Schafersman (1977) studied the coral composition of patch reefs in Glovers Reef and compared those patch-reef sediments with adjacent sediments of the lagoon floor. They distinguished three zones of patch reefs that presumably represent a succession following an earlier destructive event. James et al. (1976) and James and Ginsburg (1979) described morphology, organisms, zonation, and submarine cementation of the reef and fore reef of the southern Belize Barrier Reef and Glovers Reef. Gischler (1994) did a reconnaissance investigation of surface sediments of the three Belize platforms and found significant differences in texture and composition of marginal-reef and fore-reef sediments compared to platform-interior sediments. Chavez and Hidalgo (1984) and Jordan and Martin (1987) described geomorphology and benthic organisms of Banco Chinchorro and are the only published works prior to this study.

METHODS

A total of 454 surface sediment samples (200–400 g each) were taken by free diving, SCUBA diving, and sediment grab sampling (model ‘‘mudsnapper’’, KAHLSICO) on Glovers Reef (145), Lighthouse Reef (101), Turneffe Islands (109), and Banco Chinchorro (99). All samples were located with a GPS receiver (Figs. 3D, 4D, 5D, 6D). At each sample station, water depth was measured and qualitative observations of bottom characteristics were made. Water depths were measured at over 100 additional stations to support accuracy of bathymetric maps and sediment mapping.

A large portion of each sample was washed with a dilute solution of Clorox™ and later dried. The dry sediment was sieved into the classes $>$ 2 mm, 2–1 mm, 1–0.5 mm, 0.5–0.25 mm, 0.25–0.125 mm, 0.125–0.63 mm, and $<$ 0.063 mm, and mean grain sizes were calculated. Coarse gravel- to cobble-size fragments of coral are present, particularly in some of the marginal reef samples. Because their estimated abundances are $<$ 1%, they were not included in the determination of textural parameters. The fraction larger than 125 μm of dry sediment samples was split with a sample splitter and impregnated with plastic in ice-cube containers (cube size 40 mm × 20 mm × 20 mm). Plastic-impregnated billets were cut vertically, thin-sectioned, and investigated with a petrographic microscope. Composition was determined by point-counting 200 points per thin section. The counting grid was placed in such a way that it covered the entire thin section. Sediment was categorized on the basis of composition and depositional texture using Dunham's (1962) classification. We followed Enos (1974), who also used Dunham textures for the sediment map of the northern Caribbean. We modified Dunham's (1962) parameters, because his nomenclature was developed for rocks:

‘‘Grainstone’’: sediments with less than 4% of the $<$ 125 μm fraction (‘‘matrix’’),

‘‘packstone’’: sediments with 4–20% of the $<$ 125 μm fraction,

‘‘grain-rich wackestone’’: sediments with 21–40% of the $<$ 125 μm fraction,

‘‘mud-rich wackestone’’: sediments with more than 40% of the $<$ 125 μm fraction.

As suggested by Wright (1992) we used a larger maximum grain size for ‘‘mud’’ or ‘‘matrix’’ (125 μm) than Dunham (1962) because most constituents smaller than silt size cannot clearly be identified in thin section. According to Dunham (1962) and Wright (1992), 35–70% ‘‘matrix’’ is necessary in a rock, dependent on grain shapes, to produce a mud-supported texture. However, these numbers cannot be applied directly to unconsolidated sediment because it is unknown to what extent pore-volume reduction (up to 80%) in the transition from sediment to rock is due to compaction or to cementation (Shinn et al. 1977; Enos and Sawatsky 1981).

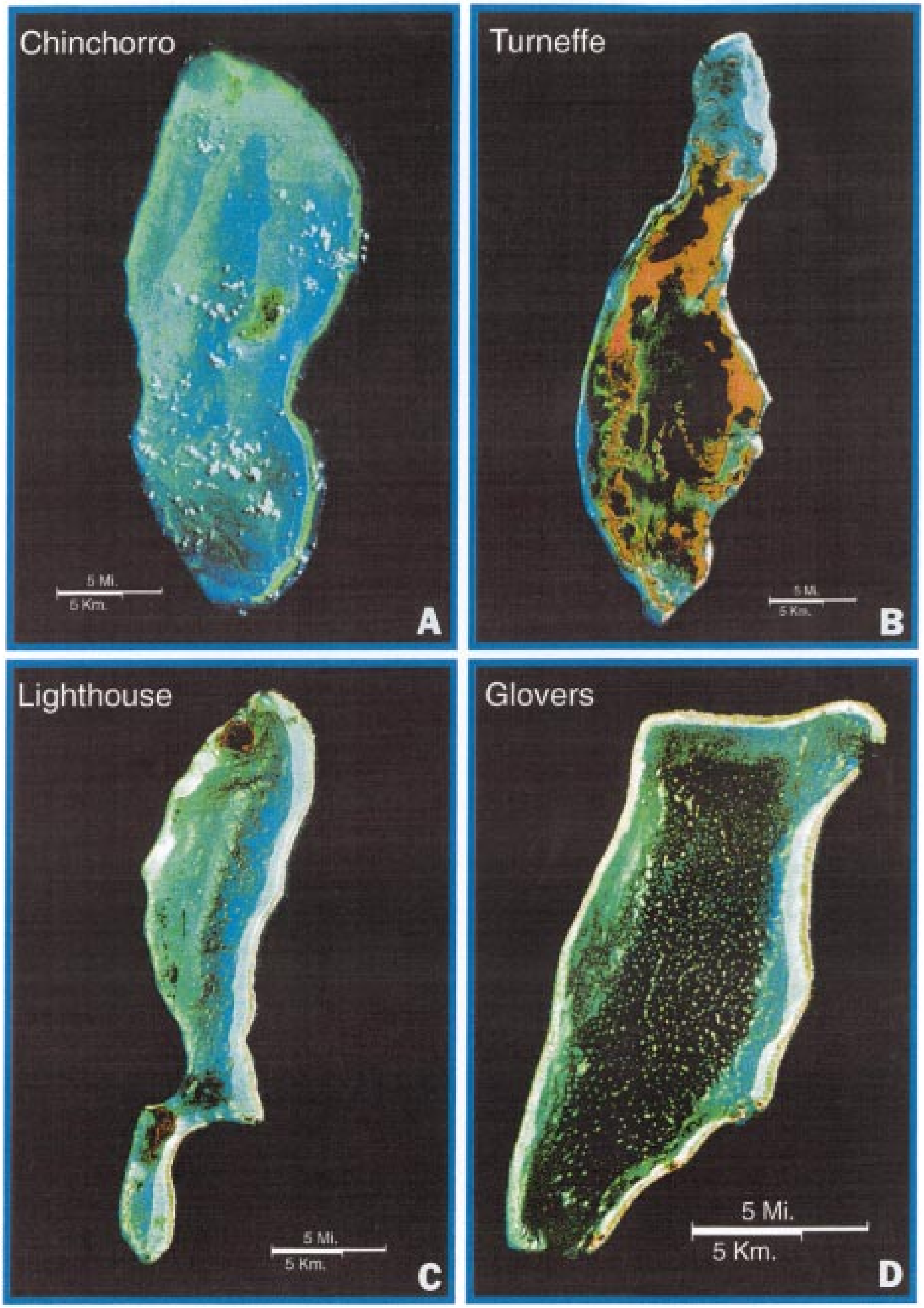
Several samples of the fraction smaller than 125 μm from the platform interiors were investigated under SEM to get some qualitative data on composition of the ‘‘matrix’’. Approximately 30 g of fresh sediment of each sample were stored in a dilute solution of formaldehyde or glutaraldehyde. Some of these samples from the peloidal facies were dehydrated, critical-point-dried, and examined under SEM. Eight sediment samples from the restricted Turneffe lagoons were investigated with X-ray diffraction to detect possible dolomite occurrence. Nineteen samples from Turneffe lagoons were analyzed for total organic carbon (TOC).

Maps of surface sediment maps were completed in conjunction with bathymetric maps and high-resolution satellite imagery of the platforms. The applicability of satellite imagery for shallow marine carbonate environments was tested by comparing sedimentary facies zones with mappable environmental zones on the images.

ENVIRONMENTS ON THE PLATFORMS

The sizes of the isolated platforms range between 550 km^2 (Banco Chinchorro) and 200 km^2 (Lighthouse Reef). Turneffe Islands covers 525 km^2. The area of Glovers Reef is 260 km^2. The platforms are surrounded by deep water. East of Glovers Reef, Lighthouse Reef, and Banco Chinchorro, water depths reach several thousands of meters. West of the platforms, water depths reach 450 m between the Belize barrier reef and Glovers Reef and 250 m between the barrier reef and Turneffe Islands. Maximum depths between Turneffe Islands and Lighthouse Reef are 1000 m. Between the Mexican mainland and Banco Chinchorro, water depths are less than 500 m. On the platforms, we distinguished the following environments (Figs. 2–6).

Reef/Pavement.—All four platforms have almost continuous surface-breaking reef rims on their windward sides, which are several tens of meters wide. The width of the windward margin part of Turneffe Islands, which is protected by Lighthouse Reef on the east, is narrower than on the northernmost, unprotected part. It is also narrower than on the other platforms (Fig. 2). The reef margin is characterized by a rubble pavement that is cemented by crustose coralline algae and early submarine cement. James et al. (1976) described this phenomenon in detail on Glovers Reef. Gischler and Pisera (in press) detailed occurrence and composition of rhodoliths from the reef pavements of the Belize platforms. Channels and tidal passes


Chinchorro
5 Mi.
5 Km.
A
Turneffe
5 Mi.
5 Km.
B
Lighthouse
5 Mi.
5 Km.
C
Glovers
5 Mi.
5 Km.
D

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in the windward reef margins are most numerous on the protected part of Turneffe Islands. On Glovers Reef there are three windward channels through the margin; there are two on Lighthouse Reef, near Halfmoon Cay and at the northern end of the platform. Major channels through the margin of Banco Chinchorro are noted at the northern and southern ends of the platform (Fig. 6).

Glovers Reef, Lighthouse Reef, and Banco Chinchorro have somewhat continuous surface-breaking leeward reef margins, formed by a loose framework of *Acropora palmata.* Small channels through the leeward margins are numerous. The channels are floored by coarse sand. On the leeward side of Turneffe Islands, a similar surface-breaking reef is developed only west of Crickozeen Creek and the northern lagoon (Fig. 3D).

Fore Reef/Deep Reef.—Windward and leeward fore-reef areas dip between 10° and 20° towards the open ocean. A break in slope or drop-off at depths between 10 m and 60 m with abundant coral growth gives way to almost vertical walls that lead to greater depths. Windward fore-reef slopes are characterized by spur-and-groove systems. Grooves are dominated by branched and foliaceous corals such as *Acropora palmata, Agaricia* spp., and *Millepora* spp. The relief of the spur-and-groove is several meters in Glovers Reef, Lighthouse Reef, Banco Chinchorro, and the northernmost part of Turneffe Islands. A low-relief spur-and-groove system is developed locally along the protected part of Turneffe Islands.

Leeward fore-reef slopes are characterized by a dominance of massive coral *Montastraea annularis* and sandy areas with large sponges (*Xestospongia muta*). Corals form linear accumulations reminiscent of a spur-and-groove system on Glovers Reef and Lighthouse Reef.

Sand Apron.—West of the windward reef pavements and at the northern end of Banco Chinchorro, sand aprons are developed up to 500 m wide. Water depths do not exceed 2 m. Coral cover is low; massive corals are found occasionally. The western ends of the sand aprons are marked by well-developed, uncemented slopes (sand cliffs *sensu* Milliman 1973). Within all platforms, this slope is prograding westward and filling in windward lagoon areas. Evidence for the latter process is seen in half-buried patch reefs located in the sand cliffs. Along the protected eastern side of Turneffe Islands, a moat 2–3 m deep has developed between the sand cliff and the eastern mangrove rim. In places, sand has completely filled the moat and the sand cliff has reached the mangroves, forming a continuous sand flat.

Shallow and Deep Lagoons.—We distinguished these environments by water depths of less than or more than 5 m, respectively. The bottom consists of unconsolidated sediment and can be either barren or covered with sea grasses (*Thalassia testudinum, Syringodium filiforme*) and codiacean algae such as *Halimeda, Penicillus,* and *Udotea. Callianassa* mounds occur locally. The distribution of shallow and deep lagoon environments and water depths varies among the platforms. In Glovers Reef and the northernmost part of Turneffe Islands, the distribution of environments is concentric (Figs. 3A, 5A). In Lighthouse Reef and Banco Chinchorro shallow and deep lagoon environments are aligned somewhat parallel to each other and parallel to the long axis of the individual platform (Figs. 4A, 6A).

Shallow lagoon areas in Glovers Reef have depths to 5 m. The bathymetry of the platform shows that there are two areas up to 18 m deep in the south and in the north that are separated by a generally E–W-striking submarine high, known to local fishermen as the Broken Ground (Fig. 5D). In the major part of Lighthouse Reef, the eastern deep lagoon reaches 8 m water depth whereas the western lagoon is up to 3 m deep. Farther to the south, the lagoon area between Halfmoon Cay and Long Cay is up to 6 m deep; south of Long Cay, water depths do not exceed 3 m (Fig. 4D). In the northern two-thirds of Banco Chinchorro two shallow areas up to 4 m deep and three areas up to 8 m deep that all strike NNE are distinguished. The northernmost part of the platform around Cayo Norte is not deeper than 3 m. The southern third of Chinchorro is generally deeper, with average lagoon floor depths between 7–9 m and a maximum of 12 m in the southwestern corner (Fig. 6D).

Restricted Lagoon.—Two large restricted lagoons (Smith 1941) are found on Turneffe Islands. These are the central lagoon, 8 m deep, and the northern lagoon, 3 m deep (Fig. 3D). The deepest parts in the central lagoon are located in the western part near the entrance of Crickozeen Creek. Lagoon floors are densely covered with *Thalassia* and the green alga *Halimeda.* Loggerhead sponges (*Spheciospongia vesparium*) are common. Small branched coral colonies of *Porites* sp. and *Manicina areolata* are present locally. The lagoons are enclosed by a rim complex of mangrove swamps and islands which, in turn, contain restricted ephemeral ponds (see below). Interior lagoons are connected to the leeward platform margin by small, sinuous channels and creeks, called bogues in Belize. These bogues are densely floored with living *Halimeda.* The central lagoon is also connected to the windward platform margin by three wide channels over 100 m wide.

Pond.—Several smaller, ephemeral, subtidal ponds are located within the western mangrove rim of Turneffe Islands. Pond floors are densely covered by *Thalassia,* and *Halimeda* is less common than in the two large Turneffe lagoons. A shallow pond is also developed in the interior of Northern Cay on Lighthouse Reef. It does not become deeper than 1 m in the center. Large areas of the pond shore fall dry during the dry season.

Patch Reef.—Patch reefs of coral are common in interior lagoons of Glovers Reef, Lighthouse Reef, Banco Chinchorro, and the northernmost part of Turneffe Islands. They are very rare in the restricted central lagoon of Turneffe Islands. The distribution and species composition of patch reefs is different among the four platforms. In Glovers Reef, the majority of the more than 860 patch reefs are distributed randomly. Only in the western and northeastern part of the interior are patch reefs aligned along NNE-striking trends (Fig. 5C). Patch reefs are dominated from SE to NW by *Montastraea annularis, Acropora* sp., and *Porites* and algae (Wallace and Schafersman 1977). In Lighthouse Reef, a continuous, NNE-striking trend of coalescing patch reefs, called Middle Reef, separates the deep eastern lagoon from the shallow western lagoon (Fig. 4C). Patch reefs of Middle Reef and the western lagoon are dominated by *Montastraea annularis,* and those in the eastern lagoon by *Acropora palmata.* In the northern two-thirds of Banco Chinchorro, patch-reef distributions sometimes follow the NNE-striking bathymetric trend, but there is no major coalescing trend such as Middle Reef on Lighthouse Reef (Fig. 6C). *Montastraea annularis* dominates the patch reefs. In the southern platform area, patch reefs are abundant and some form trends up to 3 km long. Close to the southwestern platform margin they are characterized by the occurrence of *Acropora palmata.* In the northernmost part of Turneffe Islands, patch reefs are randomly distributed and dominated by *Montastraea annularis.* A few small, low-diversity patch reefs with the corals *Siderastrea siderea* or *Solenastrea hyades* are found only near major channels through the mangrove rims of the central lagoon of Turneffe. These species are known to tolerate large fluctuations of turbidity and temperature.

Cay/Island.—Several types of islands, or cays, are found on the platforms. They make up 0.2% of Glovers Reef, 1% of Banco Chinchorro, 2.9% of Lighthouse Reef, and 25% of Turneffe Islands. Stoddart (1962, 1965b) classified the cays of the Belize isolated platforms and the barrier

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FIG. 2.—Satellite images of the isolated platforms **A)** Banco Chinchorro, **B)** Turneffe Islands, **C)** Lighthouse Reef, and **D)** Glovers Reef. Shallower areas appear light blue and deeper areas are dark blue. Mangrove areas on Turneffe Islands are light brown. Interior lagoon depths of Turneffe Islands are similar to those in Lighthouse Reef but appear darker because of extensive cover of lagoon floor by sea grasses.

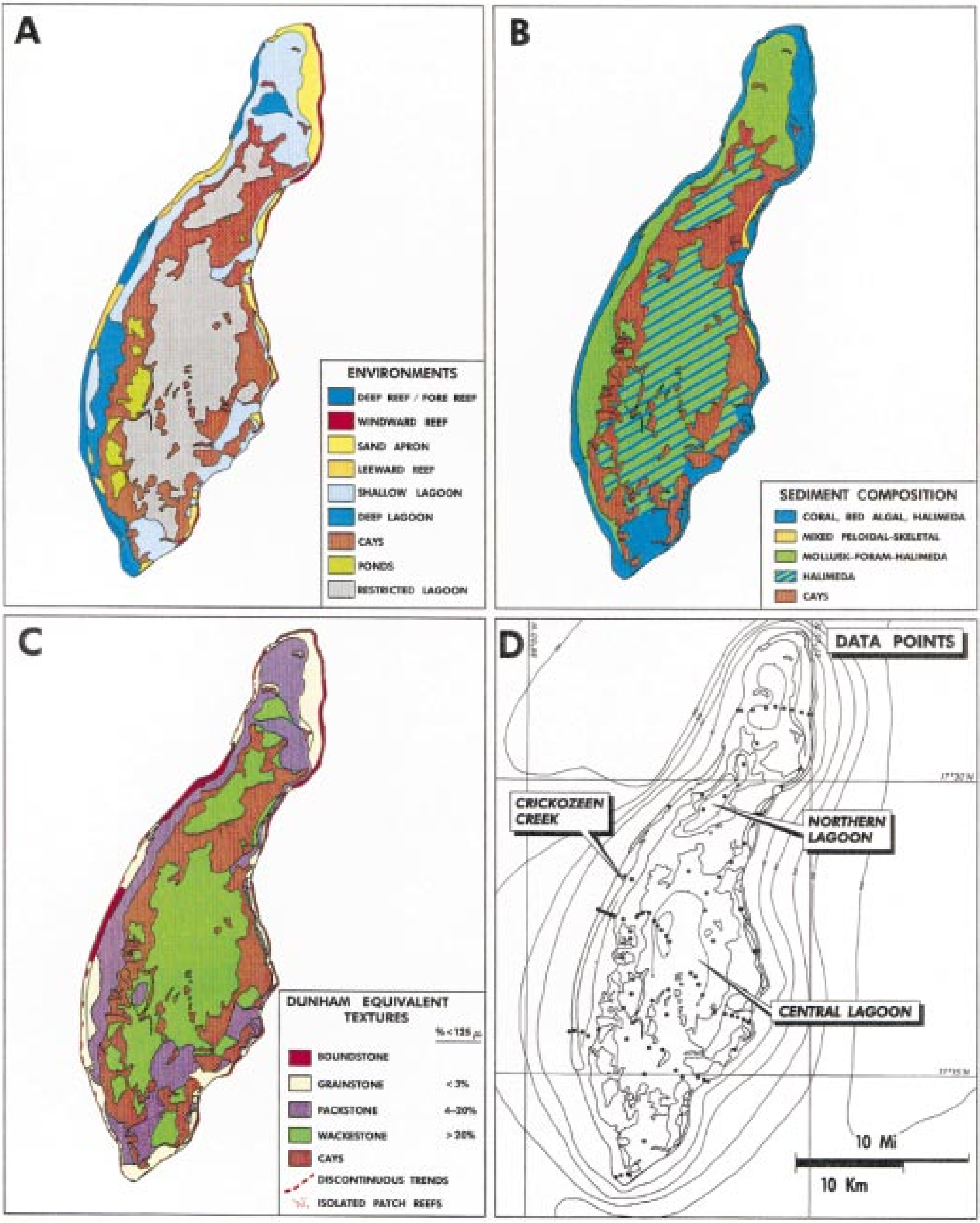

FIG. 3.—Maps of Turneffe Islands showing **A)** environments, **B)** composition, and **C)** texture of surface sediments, and **D)** bathymetry and 109 sample locations. Note deep reef facies on leeward platform margin in A. Fore reef facies belt (windward side) is very narrow and therefore does not show up on figure. Sand cays on windward reef are not shown.

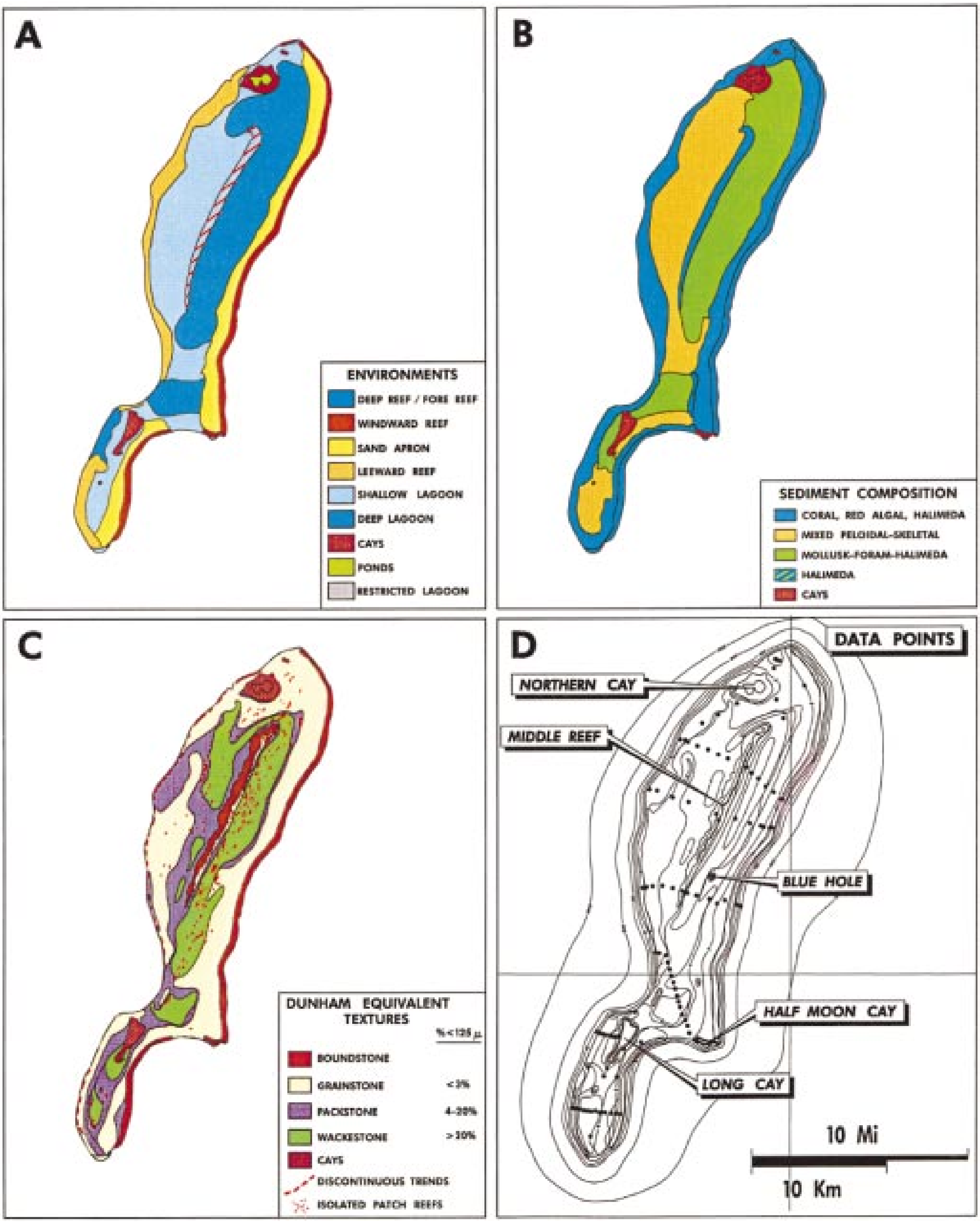

FIG. 4.—Maps of Lighthouse Reef showing **A)** environments, **B)** composition, and **C)** texture of surface sediments, and **D)** bathymetry and 101 sample locations. Bathymetry is in meters. Fore-reef facies belt is very narrow and therefore does not show up on figure. Patch reefs are shown only on the texture map.

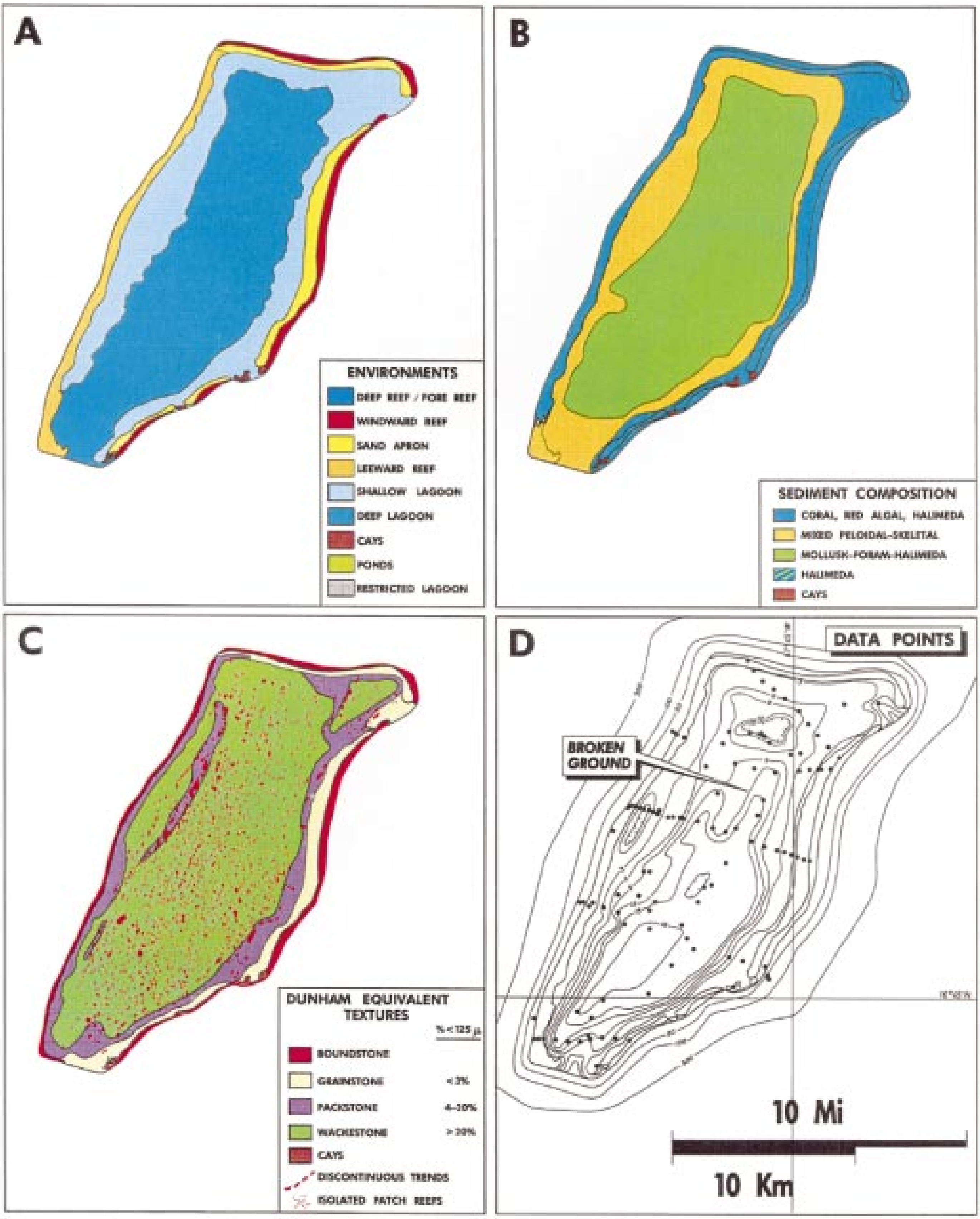

FIG. 5.—Maps of Glovers Reef showing **A)** environments, **B)** composition, and **C)** texture of surface sediments, and **D)** bathymetry and 145 sample locations. Bathymetry is in meters. Fore-reef facies belt is very narrow and therefore does not show up on figure. Patch reefs are shown only on the texture map.

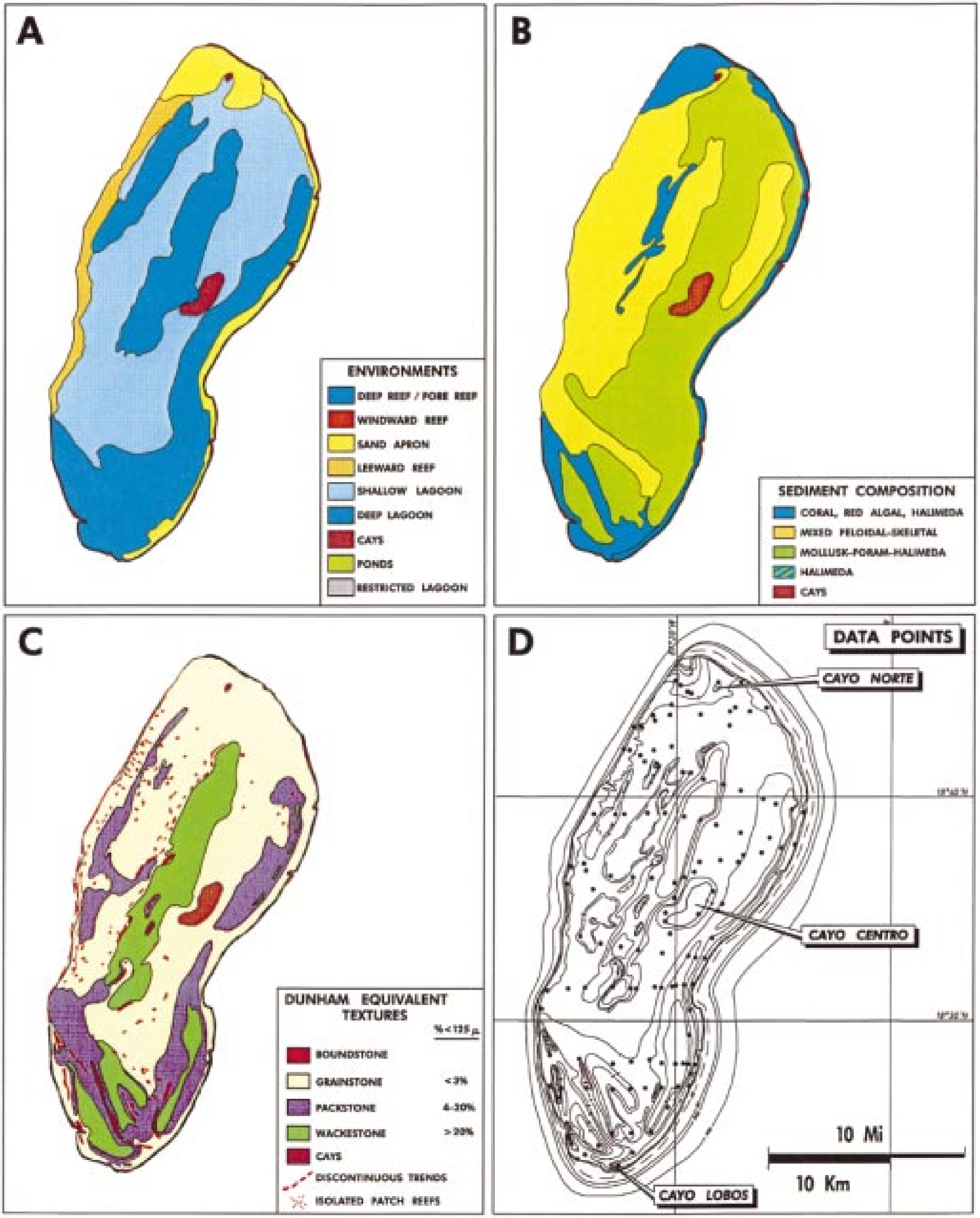

FIG. 6.—Maps of Banco Chinchorro showing **A)** environments, **B)** composition, and **C)** texture of surface sediments, and **D)** bathymetry and 99 sample locations. Bathymetry is in meters. Fore-reef facies belt is very narrow and therefore does not show up in the figure. Patch reefs are shown only on the texture map.

TABLE 1.—*Composition and texture of sediment types. All samples (n = 454).*

	Range	Average	Standard Deviation
Coral-red algae-*Halimeda*			
Mean, mm	0.21–1.97	0.66	0.27
Halimeda, %	2.3–88.3	23.5	13.05
Coral, %	0–69.4	35.5	14.85
Red algae, %	0–30.8	14.1	7.40
Mollusk, %	0–42.6	11.0	7.08
Foram, %	0–28.7	5.5	4.50
Non-skeletal, %	0–33.0	2.3	5.17
Matrix, %	0–41.7	5.4	7.27
Mollusk-foram-*Halimeda*			
Mean, mm	0.06–1.58	0.44	0.25
Halimeda, %	0–81.3	23.8	18.30
Coral, %	0–27.9	3.6	5.47
Red algae, %	0–23.8	3.4	4.72
Mollusk, %	3.4–52.0	22.6	10.01
Foram, %	1.0–58.8	16.5	13.49
Non-skeletal, %	0–41.7	4.2	8.11
Matrix, %	0–87.1	26.5	23.20
Mixed peloidal/skeletal			
Mean, mm	0.12–0.83	0.34	0.14
Halimeda, %	0–41.5	10.3	6.80
Coral, %	0–39.7	5.8	9.48
Red algae, %	0–22.5	2.1	3.14
Mollusk, %	1.8–34.9	12.8	6.93
Foram, %	0–21.0	4.8	3.83
Non-skeletal, %	0–93.2	40.2	23.92
Matrix, %	0–62.6	22.8	18.40
Halimeda			
Mean, mm	0.06–2.05	0.72	0.46
Halimeda, %	0–85.8	48.9	21.71
Coral, %	0–44.9	2.7	7.67
Red algae, %	0–5.7	0.4	1.09
Mollusk, %	0–36.9	17.1	9.70
Foram, %	0–41.1	6.2	6.88
Non-skeletal, %	0	0	0
Matrix, %	1.1–100	24.1	26.00

reef and explained the large-scale distribution of island types with a model of variation in exposure to waves and currents. The highest-energy reefs have no cays at all. High-energy, small sand-shingle cays occur on the windward reef margins of all four platforms. There is one each on Banco Chinchorro and Lighthouse Reef, four on Glovers Reef, and 40 on Turneffe Islands (Stoddart 1962). In shallow lagoon areas of both Banco Chinchorro and Lighthouse Reef there are two moderate-energy mangrove–sand cays. On Turneffe Islands, almost the entire eastern mangrove rim consists of mangrove–sand cays. The backshore beach ridge on the eastern side of the cays is up to 1.5 m above mean sea level. In places it is cemented to form a supratidal cayrock (Gischler and Lomando 1997). In the interior of Turneffe Islands, low-energy mangrove cays are found. Some are aligned along a NNW-striking trend (Fig. 3). The western mangrove cay rim of the platform changes character from north to south. In the north, the shoreline maintains a constant distance from the platform margin. In the southern area, south of Crickozeen Creek, the distance between shoreline and margin increases. At the same time, the shoreline becomes more irregular, with an increase in the abundance of small channels into the lagoon and in the number of small, mangrove-encircled lagoons.

SEDIMENTS ON THE PLATFORMS

Composition, Texture, and Distribution

Both skeletal and nonskeletal constituent grains are present in surface sediments of the isolated platforms. *Halimeda* is an important producer on the platforms investigated, inasmuch as fragments are common in all sediment types. Four sediment types are distinguished, primarily on the basis of compositional differences (Table 1). These sediment types are often characteristic of certain environments (Figs. 3–7, Tables 2, 3).

TABLE 2.—*Occurrence of sediment types in major environments. All samples (n = 454).*

Environment	CORA	MOFO	NS	HA
Island	8.6	0	0	0
Reef	22.4	0	4.1	0
Patch reef	5.7	0	0	0
Fore reef	17.8	0.9	4.1	0
Sand apron	26.4	2.7	22.8	0
Shallow lagoon	16.7	35.1	43.9	9.1
Deep lagoon	2.3	58.6	25.2	2.3
Restricted Turneffe lagoon	0	2.7	0	88.6

Numbers are in %. CORA = coral-red algae-*Halimeda* type, MOFO = mollusk-foram-*Halimeda* type, NS = mixed peloidal/skeletal type, HA = *Halimeda* type. Pond environment is included in Turneffe lagoon environment.

Coral–Red Algae—*Halimeda* Type.—This type is characterized by high contents of corals, red coralline algae, and *Halimeda* fragments. Fragments of the red encrusting foraminifer *Homotrema rubrum* are also common (Fig. 7A, B). Mean grain sizes average approximately 0.65 mm, and the $< 125\ \mu\text{m}$ fraction amounts to a little more than 5% (Table 1). The coral–red algae–*Halimeda* type is most abundant in the marginal platform areas such as the reef, fore-reef, and sand-apron environments, as well as in platform-interior patch reefs of all four platforms. It also occurs in marginal shallow lagoon areas. In the reef and fore-reef environments, a grainstone texture prevails, whereas packstones can be more common in the sand-apron, shallow-lagoon, and patch-reef environments. Early submarine cements in skeletal grains, usually microcrystalline high-Mg calcite, and micrite envelopes around grains are common in the marginal reef environments.

Mollusk–Foram–*Halimeda* Type.—High concentrations of mollusk, miliolid foraminifera, and *Halimeda* fragments are characteristic of this sediment type (Fig. 7D). Mean grain sizes average 0.45 mm. Average contents of the $< 125\ \mu\text{m}$ fraction reach over 23% (Table 1). This sediment type is most common in the environments of the platform interiors in wackestone to packstone textures. In the deep lagoon environments of Glovers Reef and Lighthouse Reef this sediment type covers deep lagoon areas. West of the leeward mangrove rim and in the northernmost lagoon areas of Turneffe Islands, the mollusk–foram–*Halimeda* type occurs in a packstone texture. In the interior of Banco Chinchorro the sediment type is represented by grainstones and packstones.

***Halimeda* Type.**—This sediment type consists dominantly of fragments of *Halimeda* (Fig. 7E, F). Average values reach 50%. Fine sediment ($< 125\ \mu\text{m}$ fraction) averages 24% (Table 1); textures are mainly wackestones. The *Halimeda* sediment type is confined to the restricted lagoons of Turneffe Islands. *Halimeda* fragments locally exceed 90% in the channels through the eastern mangrove rim of the platform. Miliolid foram fragments can reach values of 30% in smaller ponds within the western mangrove rim. Furthermore, this type of sediment is rich in organic matter (Table 4). Fresh sediment has a dark brown to black stain, in contrast to the white to buff color of fresh platform-interior sediments of the other three platforms investigated. TOC values within Turneffe average 5.6% and reach values of over 15% in places. This is very high in comparison to usual contents of shallow marine carbonate sediments, which range from 0.2 to 2.5% TOC (Crevello et al. 1984; Emerson 1985). Samples from the northern Belize shelf reach values of 5% TOC (Rafalska-Bloch 1985). X-ray diffractometry of eight samples from the restricted central lagoon in Turneffe detected high- and low-magnesium calcites and aragonite but did not reveal dolomite (Table 4).

Mixed Peloidal/Skeletal Type.—This sediment type is characterized by the abundance of peloids (Fig. 7C); lumps and grapestones are rare. Average values of nonskeletal grains amount to 40%; the fine fraction ($< 125\ \mu\text{m}$) reaches values of 23%. The abundance of skeletal grains is moderate to low. Fragments of *Halimeda* and mollusks are most common. The ma-

TABLE 3.—*Compositional and textural characteristics (ranges and averages) of surface sediment samples from major environments of the platforms. Based on all samples ($n = 454$).*

Environment, # of Samples		HA	CO	RA	MO	FO	NS	Matrix	Mean Grain-Size in mm
Fore reef/deep reef, 37	Range	10–60	15–55	5–25	2–25	1–12	0–70	0–14	0.34–1.28
	Average	27.1	33.4	11.4	9.6	4.7	9.0	3.4	0.68
Reef/pavement, 43	Range	10–50	25–55	10–25	0–30	0–10	0	0–21	0.35–1.46
	Average	19.6	38.8	16.3	9.5	3.7	6.9	3.7	0.77
Cays, 15	Range	10–40	20–50	15–25	7–15	1–25	0	0–6.6	0.44–1.11
	Average	19.1	31.9	12.9	9.0	6.8	0.4	1.6	0.67
Patch reefs, 11	Range	15–40	10–40	2–12	5–30	1–12	0	1.5–15	0.67
	Average	30.6	32.2	9.2	15.5	4.3	0.4	5.2	0.46–0.85
Sand apron, 77	Range	5–35	5–65	0–25	5–30	0–25	0–70	0–45	0.18–0.76
	Average	16.1	25.9	10.6	12.8	5.0	15.9	12.3	0.47
Shallow lagoon, 134	Range	5–60	0–50	0–20	5–35	2–50	0–90	0–100	0.06–1.13
	Average	21.4	8.9	4.8	16.2	11.2	20.0	17.1	0.47
Deep lagoon, 95	Range	5–50	0–15	0–10	15–45	5–40	0–75	0.2–87	0.06–1.02
	Average	15.0	4.3	2.2	19.3	11.1	13.5	34.2	0.32
Mangrove-encircled Lagoons (Turneffe), 42	Range	15–90	0–20	0–5	2–40	0–40	0	0–100	0.06–2.05
	Average	53.3	1.5	0.3	17.1	5.9	0	21.3	0.81

HA = *Halimeda,* CO = coral, RA = red algae, MO = mollusk, FO = foraminifera, NS = peloids. Numbers are in %. Pond environment is included in Turneffe lagoon environment.

jority of peloids are of fecal origin. Most common are ellipsoidal, hardened fecal pellets with diameters of 150–300 μm. Recognizable skeletal grains in these pellets are rare sponge and tunicate spicules. Less common are larger peloids, with diameters of 400–800 μm, that contain skeletal fragments, mostly foraminifer or mollusk, with the fragments reaching the sizes of the peloids. Embedded skeletal grains are found in various stages of micritization. Both kinds of peloids are found in various stages of cementation from soft to semi-hard and hard (Fig. 8A, B). They are *in statu nascendi,* with aragonite needles being the dominant cement. The mixed peloidal/skeletal type is most common in the leeward shallow lagoon parts of platform interiors; it is also found in the windward sand aprons. In Glovers Reef it occurs in a wackestone to packstone texture. It is also found in some places on the windward side of Turneffe Islands between the reef margin and the eastern mangrove rim. The mixed peloidal/skeletal type is present in wackestone to grainstone textures in the interiors of Lighthouse Reef and Banco Chinchorro. The peloidal/skeletal type also occurs in deep lagoon environments and in the leeward fore reef areas of Banco Chinchorro.

Correlation analysis (Table 5) shows that sediment composition cannot be correlated with either water depth or water agitation, but it does show that there are statistically significant correlations between constituent particles that occur in similar sediment types. For example, corals and red coralline algae as well as mollusks and foraminifera are positively correlated. Corals are negatively correlated with mollusks and forams; red algae are negatively correlated with mollusks. Nonskeletal grains are negatively correlated with skeletal grains of coral, red algae, and *Halimeda.* Water depth and the fine fraction are positively correlated, confirming that the proportion of fines in the sediment increases with decreasing water energy.

Principal component analysis (Fig. 9A) further shows that there is a good separation between sediment types based on grain composition, proportion of fines, and mean grain size. Data clouds of the coral–red algae–*Halimeda,* mollusk–foram–*Halimeda,* and mixed peloidal/skeletal types are clearly separated. Data points of the *Halimeda* type appear to be closest to the mollusk–foram–*Halimeda* cloud. This result is not unexpected, because the two sediment types are characterized by similar constituent grains, only in different abundances. A second principal component analysis based on the same parameters but comparing eight environments (Fig. 9B) shows a good separation between data points of the platform margins (reef, fore reef, island, sand apron) from those of platform interiors (deep lagoons, shallow lagoons, and restricted lagoons).

A comparison of high-resolution satellite images with sediment distribution maps (Figs. 2–6) shows that the correlation between image characters, which represent certain depositional environments, and sediment composition and texture is very good in Glovers Reef and Turneffe Islands. Sediment composition correlates much better with image characters than with texture in Lighthouse Reef. Correlation of both texture and composition of sediment with image characters is limited in the interior of Banco Chinchorro.

Fine Sediment

This study focuses on the fraction of sediment samples larger than 125 μm. Qualitative investigations show that the fraction smaller than 63 μm, however, is dominated by aragonite needles and nanograins (Fig. 8C, D). The morphology of the aragonite needles resembles that of aragonite needles typical in whitings on Great Bahama Bank. Their morphology differs from that of codiacean algae needles (Macintyre and Reid 1992). The nanograins may be derived either from the breakdown of codiacean algae (Macintyre and Reid 1995) or from micritization of skeletal grains as described by Reid et al. (1992) from the northern Belize shelf. Coccoliths were found in some of the samples from the deep interior lagoons.

DISCUSSION

Aspects of Sediment Dynamics

Composition and grain size of carbonate sediments in reef systems is strongly controlled by the depositional environment (e.g., Ginsburg 1956; Milliman 1973). Important processes governing these sediments are production, breakdown, and transport (Scoffin 1992). Gross production of calcium carbonate is highest in areas of high cover of corals and algae such as the marginal-reef and fore-reef environments. It is generally lowest in the back-reef environments and intermediate in lagoonal coral patch reefs (Chave et al. 1972). Physical breakdown predominates in marginal reef settings, whereas biologic breakdown might be more important in lagoonal settings (e.g., Swinchatt 1965; Scoffin 1992). Studies of sediment cycling in reefs have shown that net production, i.e., the amount of calcium carbonate retained in the reef as sediment and framework, may be significantly lower than gross production, because sediment tends to be exported to deeper water (Land 1979; Hubbard et al. 1990).

In the platforms studied here, there is a major transport of sediment from the marginal-reef and fore-reef environments over the drop-offs to deeper water, as seen in the enrichment of *Halimeda* fragments in sediments of

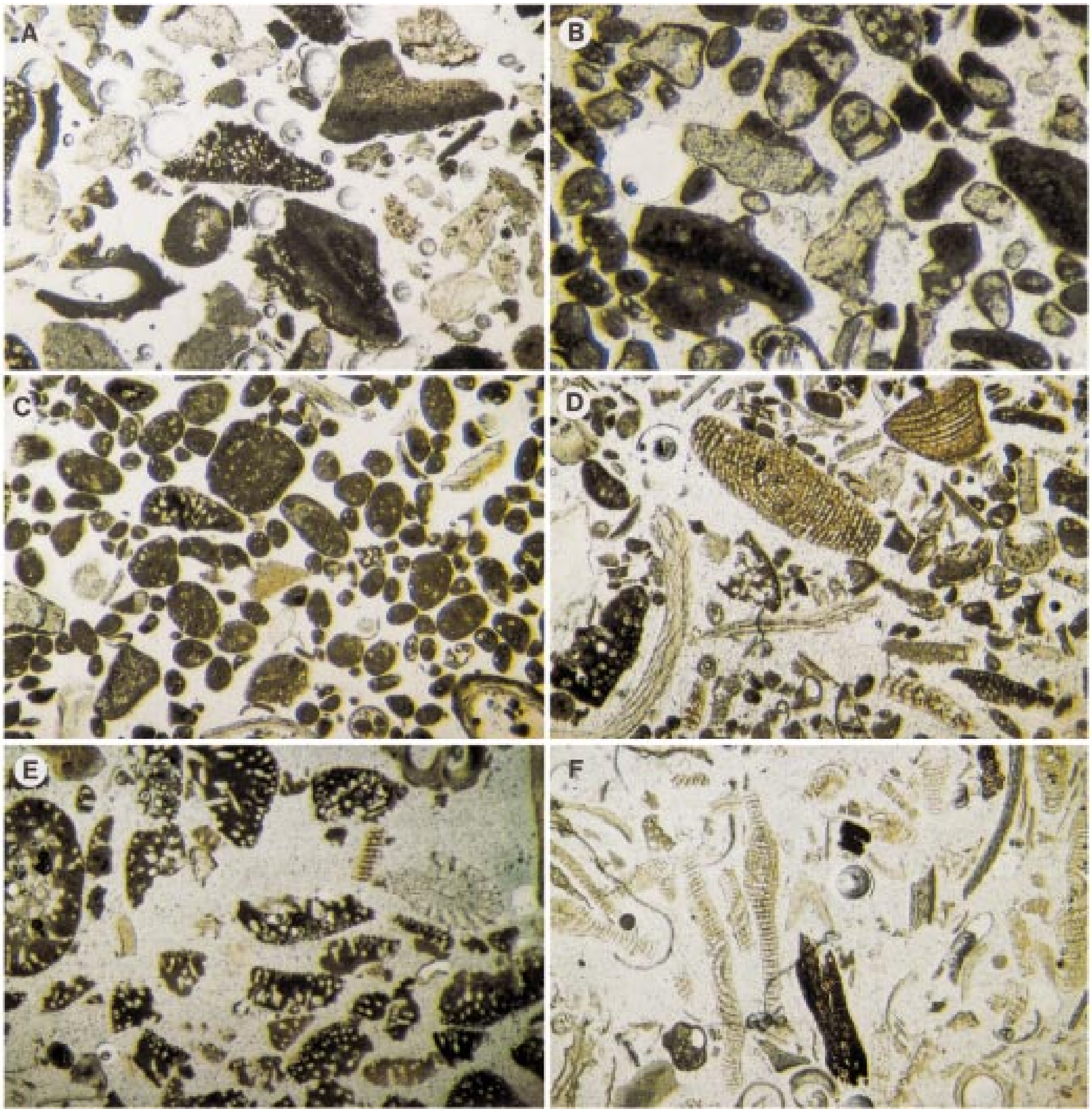

FIG. 7.—Thin-section photographs of major sediment types. **A)** Marginal reef sediment with fragments of coral, *Halimeda*, and coralline algae dominating. Sample L 204. Width of picture is 6 mm. **B)** Marginal-reef sediment with accretional features in grains (microcrystalline high-Mg calcite cements weld coral grains). Sample T 221. Width of picture is 3 mm. **C)** Mixed nonskeletal (peloidal)/skeletal facies from shallow lagoon areas. Sample L 215. Width of picture is 4 mm. **D)** Mollusk–foram facies from deeper lagoon area. Sample G 118. Width of picture is 5 mm. **E)** *Halimeda* facies from interior of Turneffe Islands. Sample T 206. Width of picture is 5 mm. **F)** Sample from isolated pond in leeward mangrove rim with miliolid (soritid) foram *Archaias angulatus* dominating. Sample T 166. Width of picture is 7 mm.

the reef wall and the deeper slope of Glovers Reef (James and Ginsburg 1979; Gischler 1994). Within the platforms, transport from patch reefs down to the surrounding lagoon floors is minimal, as shown by Wallace and Schafersman (1977) in Glovers Reef and in this study by the occurrence of the narrow grainstone fringe around Middle Reef in Lighthouse Reef. However, there is a constant transport of grains that are produced on the windward marginal reefs towards the back-reef areas. This transport produces the wide sand aprons that end in the leeward-migrating sand cliffs and that fill in the interior lagoons. Radiometric dates from beachrock of 1200–1900 yr BP (Gischler and Lomando 1997), and from marginal cores, where ages of 3000–4000 yr BP occur only 1–2 m below present sea level (Gischler and Hudson 1998), indicate that platform margins are ‘‘caught

TABLE 4.—*Total organic carbon (TOC) of sediment samples from restricted interior lagoons and channels on the leeward platform side of Turneffe Islands.*

Sample	Environment	Depth in m	TOC in %	Dolomite
T 105	W′ channel	2	2.2	—
T 108	W′ channel	2.5	6.72	—
T 110	W′ channel	1.0	2.41	—
T 111	W′ channel	1.0	5.67	—
T 115	Central lagoon	4.0	6.08	None
T 117	Central lagoon	8.0	2.82	None
T 119	Central lagoon	4.0	5.52	None
T 121	Central lagoon	4.0	4.68	None
T 123	Central lagoon	4.0	4.84	None
T 125	Central lagoon	4.0	2.49	None
T 133	Central lagoon	4.0	3.93	None
T 135	Central lagoon	3.0	2.65	None
T 155	N′ lagoon	3.5	5.61	—
T 157	N′ lagoon	3.0	4.43	—
T 158	N′ lagoon	3.0	15.41	—
T 159	N′ lagoon	5.0	6.84	—
T 160	N′ lagoon	3.0	1.32	—
T 165	Central lagoon W	2.0	7.88	—
T 166	Central lagoon W	2.0	14.81	—

The eight samples from the central lagoon were analyzed for dolomite occurrence by means of X-ray diffraction.

up'' at sea level because of lack of accommodation space. Marginal reefs can be interpreted as areas that are largely bypassed by sediment that is filling in interior lagoons. The constant transport of fine sediment from leeward reef margins to the leeward fore reefs can be observed in the field in the form of mostly turbid waters on the leeward-reef and fore-reef areas of the platforms. High percentages of peloids in the western fore reef of Banco Chinchorro further demonstrate the transport of sediment from the shallow platform interior towards the leeward fore reef (Fig. 6B).

Comparison with Other Isolated Platforms

A comparison of average marginal sediment compositions of shallow marine Caribbean platforms (Table 6) shows that fundamental differences exist only with respect to percentages of *Halimeda* and nonskeletal grains. Fragments of *Halimeda* are extremely rare in Hogsty Reef as compared to the other platforms. Banco Chinchorro, Hogsty Reef, and Serrana Bank have elevated percentages of nonskeletal grains in sediments of leeward margins (Milliman 1973). Variations in abundance of constituent grains is much higher in interior sediments (Table 6). With a few exceptions (Turneffe, Courtown, and Serrana east) nonskeletal grains are common in plat-

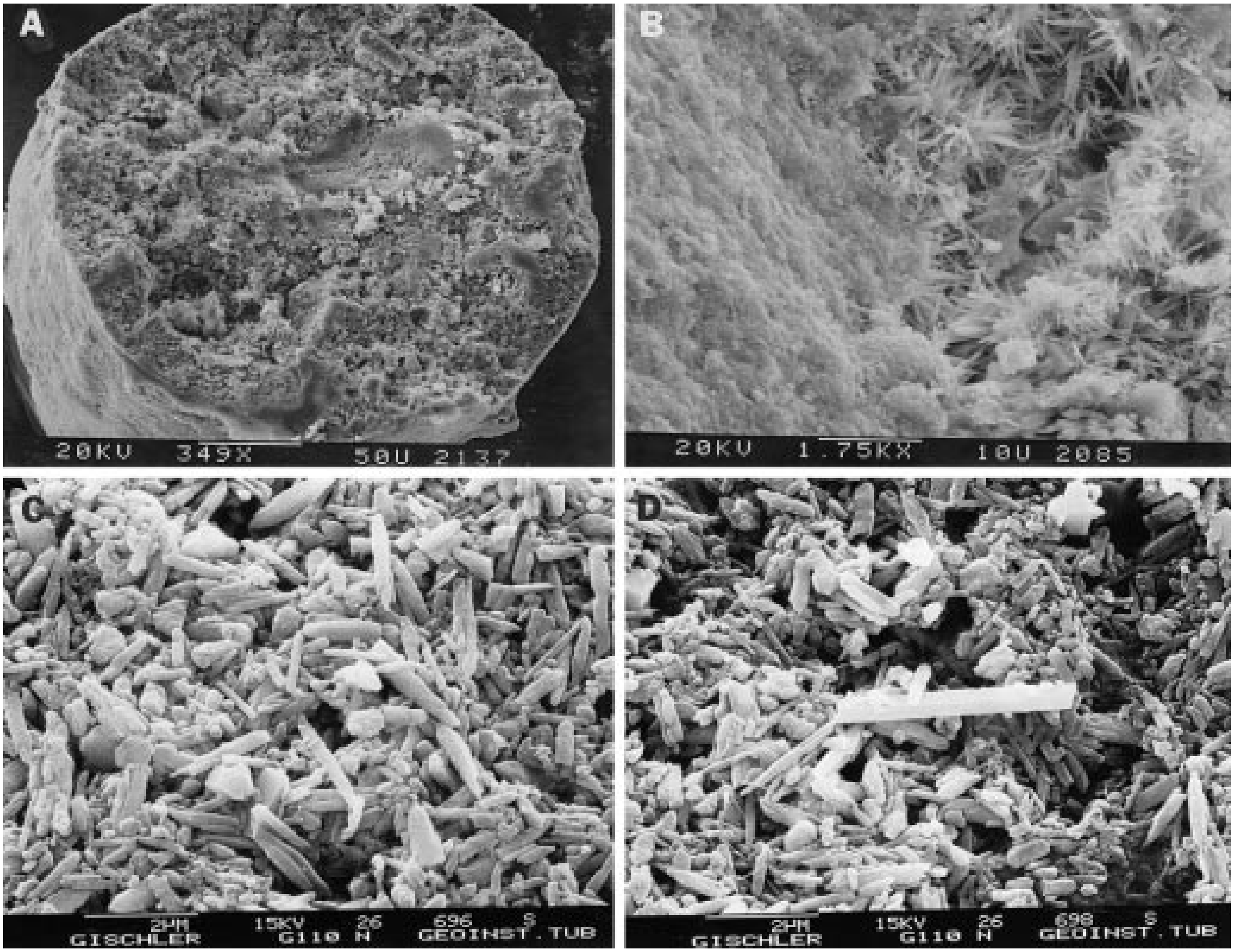

FIG. 8.—SEM micrographs of fecal pellets and of the < 125 μm fraction. **A)** Semi-hardened fecal pellet from Glovers Reef. Note the consolidated rim. Sample G 4. **B)** Close-up of consolidated rim of the same sample. Note the aragonite needle cement. **C)** Fine fraction smaller than 20 μm. Morphology of aragonite needles is similar to that from whitings on Great Bahama Bank. Nanograins are presumably from codiacean algae. **D)** Same sample with a typical larger aragonite needle, which presumably comes from a green alga.

TABLE 5.—*Results of a correlation analysis (Pearson Product-Moment correlation, unweighted pair-group average, Euclidian distances) based on data of all samples ($n = 454$).*

	Depth	Mean	Matrix	HA	CO	RA	MO	FO	NS
Depth	1								
Mean	−0.112	1							
Matrix	0.338*	−0.248*	1						
HA	−0.078	0.170	−0.308*	1					
CO	−0.160	0.152	−0.509*	−0.076	1				
RA	−0.202	0.255*	−0.446*	−0.088	0.739*	1			
MO	0.090	−0.099	0.056	0.021	−0.426*	−0.269*	1		
FO	0.022	−0.022	−0.065	−0.023	−0.290*	−0.191	0.451*	1	
NS	−0.046	−0.114	−0.025	−0.434*	−0.323*	−0.358*	−0.194	−0.203	1

Matrix = < 125 μm fraction, depth = water depth in m, HA = *Halimeda*, CO = coral, RA = coralline red algae, MO = mollusk, FO = foraminifera, NS = non-skeletal grains.
* = significant correlation.

form interiors. These grains usually occur in shallow water depths between 2 and 5 m and areas with relatively low abundance of skeletal sediment producers. Shallow water usually has elevated temperatures and salinities and is supersaturated with respect to calcium carbonate, so that interstitial precipitation of carbonate cement is favored. Also, higher current velocities remove fine sediments, thereby reducing the sedimentation rate and increasing interstitial permeability (Milliman 1967, 1969, 1973). The usually low percentages of cemented nonskeletal grains in deeper lagoon parts of the platforms support the contention that in these fine-grained sediments interstitial flux of cement-precipitating pore waters is hampered because of lower permeabilities. The composition of platform-interior sediments of Turneffe Islands is comparable to that of the eastern lagoon of Serrana Bank (Table 6; Milliman 1969, 1973) and the interior lagoon of the Marquesas in the Florida Reef Tract (Hudson 1985). In both areas abundant *Halimeda* is the major sediment producer, just as in Turneffe's southern and northern lagoons. A possible explanation for the absence of nonskeletal grains in shallow lagoon parts of Turneffe Islands might be the high contents of organic matter in the sediment. Organic films on constituent particles are presumably not oxidized and therefore prevent cement growth and welding of particles.

Antecedent Topography and Exposure as a Control on Facies Distribution

Variation in bathymetry in platform interiors leads to variation in exposure to waves and currents (depositional energy), which in turn controls facies distribution in the four isolated platforms. Variation in bathymetry from platform to platform is most probably a consequence of differences in antecedent topography, which in turn might be controlled by tectonics and karst.

Exposure to Waves and Currents.—Glovers Reef, Lighthouse Reef, Banco Chinchorro, and the northernmost part of Turneffe Islands are open to the Caribbean Sea and receive the maximum wave force. Marginal reefs are well developed, and platform margins are characterized by wide grainstone rims. In contrast, the major part of Turneffe Islands is protected from the open Caribbean Sea by Lighthouse Reef to the east and is exposed only to reduced wave forces (Burke 1982; Gischler and Hudson 1998). As a consequence, marginal reefs are less developed and peripheral areas of grainstone are narrower. Within the predominantly shallow platform interiors of Lighthouse Reef and Banco Chinchorro, grainstone textures are widespread. The lower abundance of grainstone inside Lighthouse Reef might be a consequence of the deep eastern lagoon part and of the sheltering effect of the continuous mid-platform reef. The interior of Glovers Reef, which is also open to the Caribbean Sea, is dominated by wackestones in the deep, low-energy lagoon. The wackestone predominance in the low-energy interior of Turneffe Islands results from the protecting effect of the mangrove rims.

Antecedent Topography.—Topographic highs of Pleistocene limestones have been identified as foundations of Holocene reefs on the Belize shelf and isolated platforms by drilling (Purdy 1974b; Halley et al. 1977; Shinn et al. 1979, 1982; Mazzullo et al. 1992; Gischler and Hudson 1998). Holocene unconsolidated sediment accumulated in topographic lows of the Pleistocene. Purdy (1974b, 1998) further interpreted linear sedimentary features as products of structurally directed karst erosion. He found direct evidence of underlying structure in seismic profiles through the southern Belize shelf and barrier reef and Glovers and Lighthouse Reefs. Platform-edge faulting was documented at the southern and northern ends of Glovers Reef and at one windward and two leeward locations of Lighthouse Reef (Purdy 1974b, figs. 24, 25). Underlying fault control of the Middle Reef patch-reef trend in Lighthouse Reef can be seen in unpublished seismic lines (E.G. Purdy, personal communication, September 1998). Possible further examples are the linear, NNE-striking patch-reef trends in the northwestern lagoon parts of Glovers Reef and in the central part of Banco Chinchorro, as well as the SE-striking trends of islands in Turneffe Islands and of patch reefs in southern Chinchorro (Fig. 2; Lomando et al. 1995).

Coring on the platforms (Fig. 10) shows that Holocene reef thickness is 9.4–11.7 m on Glovers Reef, 6.4–7.9 m on Lighthouse Reef, and 3.1–3.8 m on Turneffe Islands (Gischler and Hudson 1998; Gischler and Lomando, unpublished data). On the basis of these values and lagoon depths, Pleistocene relief is > 10 m on Glovers Reef and > 4–5 m on Turneffe Islands and Lighthouse Reef. There are no data on Holocene reef thickness on Banco Chinchorro. The different Pleistocene elevations of the margins of the three Belize platforms might be the consequence of differential subsidence. The lower Pleistocene elevation on Glovers Reef as opposed to Lighthouse Reef, which are situated on a similar fault block, could be a consequence of a southward tectonic tilt. Pleistocene stalactites in the Blue Hole are tilted up to 15° towards the north (Dill 1977). Karst effects could be responsible for the variation in Pleistocene relief. Similarly to the interpretations of Purdy (1974b) on the Belize shelf, stronger karstification towards the south is presumed to be an effect of higher precipitation rates. These assumptions, however, will have to be further validated by seismic data and vibracoring in platform interiors.

CONCLUSIONS

Sedimentary facies of the Belize–Yucatan isolated carbonate platforms Turneffe Islands, Lighthouse Reef, Glovers Reef, and Banco Chinchorro have been detailed for the first time. Marginal facies of skeletal (coral, red coralline algae, *Halimeda*) grainstone occur in all platforms. However, facies distribution of platform interiors is markedly different. Glovers Reef has circular facies belts, whereas Lighthouse Reef and Banco Chinchorro are characterized by more or less linear facies belts. Shallow lagoon parts in Glovers and Lighthouse Reefs are characterized by a mixed peloidal/skeletal wackestone–packstone facies, whereas deeper lagoon parts are composed of skeletal (mollusk, foram, *Halimeda*) wackestone–packstone facies. In Lighthouse Reef and Banco Chinchorro the peloidal facies is abundant on the leeward platform sides. Shallow platform-interior sediments are mainly grainstones and packstones. The interior of Turneffe Is-

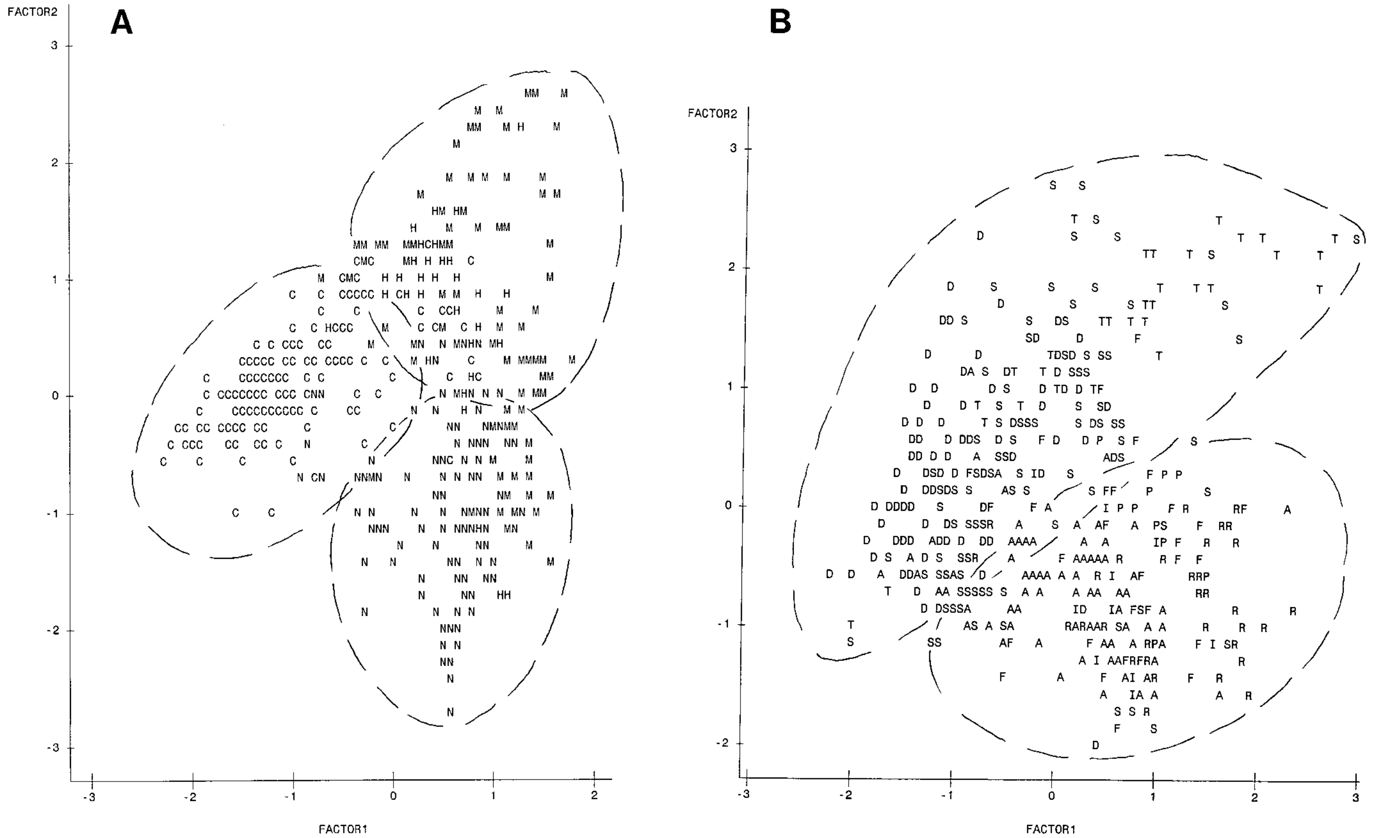

FIG. 9.—Results of factor analyses. **A)** Factors 1 and 2 derived from a principle component analysis based on facies parameters (C = coral–red algae–*Halimeda* facies; N = mixed nonskeletal/skeletal facies; M = mollusk–foram–*Halimeda* facies; H = *Halimeda* facies). Factors 1 and 2 account for 55% of the variance. Note that there is a good separation of data clouds of C, N, and M; H appears to be part of the M cloud. **B)** Factors 1 and 2 derived from a principal component analysis based on the parameters matrix, mean, *Halimeda*, coral, red algae, mollusk, foram, nonskeletal. Factors 1 and 2 account for 55% of the total variance. Environments: D = deep lagoon, S = shallow lagoon, P = patch reef, R = marginal reef, F = fore reef, A = sand apron, T = restricted Turneffe lagoon, I = island. Note that there is a separation between marginal (F, R, I) and patch-reef (P) environments versus interior (D, S, T) environments.

TABLE 6.—*Comparison of average composition of marginal and platform-interior sediment samples from Glovers Reef, Lighthouse Reef, Turneffe Islands, and Banco Chinchorro with those of other Caribbean isolated platforms/atolls.*

Platform	*Halimeda*	Coral	Red Algae	Mollusk	Foram	Non-skeletal
Marginal sediments						
Turneffe	28	33	12	10	8	0
Lighthouse	22	33	15	12	5	4
Glovers	24	40	14	8	3	3
Chinchorro	12	27	11	13	3	32
Alacrán	40	26	11	7	8	6
Hogsty	2	27	19	22	5	18
Courtown	28	35	21	10	3	0
Albuquerque	32	30	21	9	2	2
Serrana	17	33	24	5	3	13
Interior sediments						
Turneffe	42	8	4	17	8	1
Lighthouse	19	14	7	15	7	14
Glovers	15	12	5	16	6	15
Chinchorro	15	8	3	17	17	28
Alacrán	23	15	5	7	7	42
Hogsty	1	4	1	10	4	76
Courtown	28	28	21	12	6	2
Albuquerque	31	20	14	12	6	12
Serrana east	61	9	4	7	5	6
Serrana west	13	8	1	10	3	59

"Margin" includes the following sub-environments: fore reef, reef, island; "interior" includes apron, shallow and deep lagoons, and restricted lagoons of Turneffe. Data on other platforms from Milliman (1973).

lands, for the most part, is characterized by an organic-rich *Halimeda* wackestone facies. Peloidal grains in shallow lagoon parts are interpreted to form from interstitial cementation by warm, supersaturated water flushing the sediment. In Turneffe Islands, abundant organic films around grains presumably hamper cementation, thus limiting the development of hardened peloids.

The facies distribution of platform interiors is a consequence of variation in submarine topography (depth distribution) from platform to platform. Submarine topography is likely an expression of differential subsidence along underlying tectonic structures that were enhanced by karst. The interior of Glovers Reef is dominated by mud and patch reefs, reflecting a greater subsidence rate in comparison to Lighthouse Reef and Banco Chinchorro, which are dominated by grain-supported textures. The reasons for the exceptional development of muddy, restricted lagoons on Turneffe Islands are presumably multifold, but one logical explanation is the sheltering effect of Lighthouse Reef to the east.

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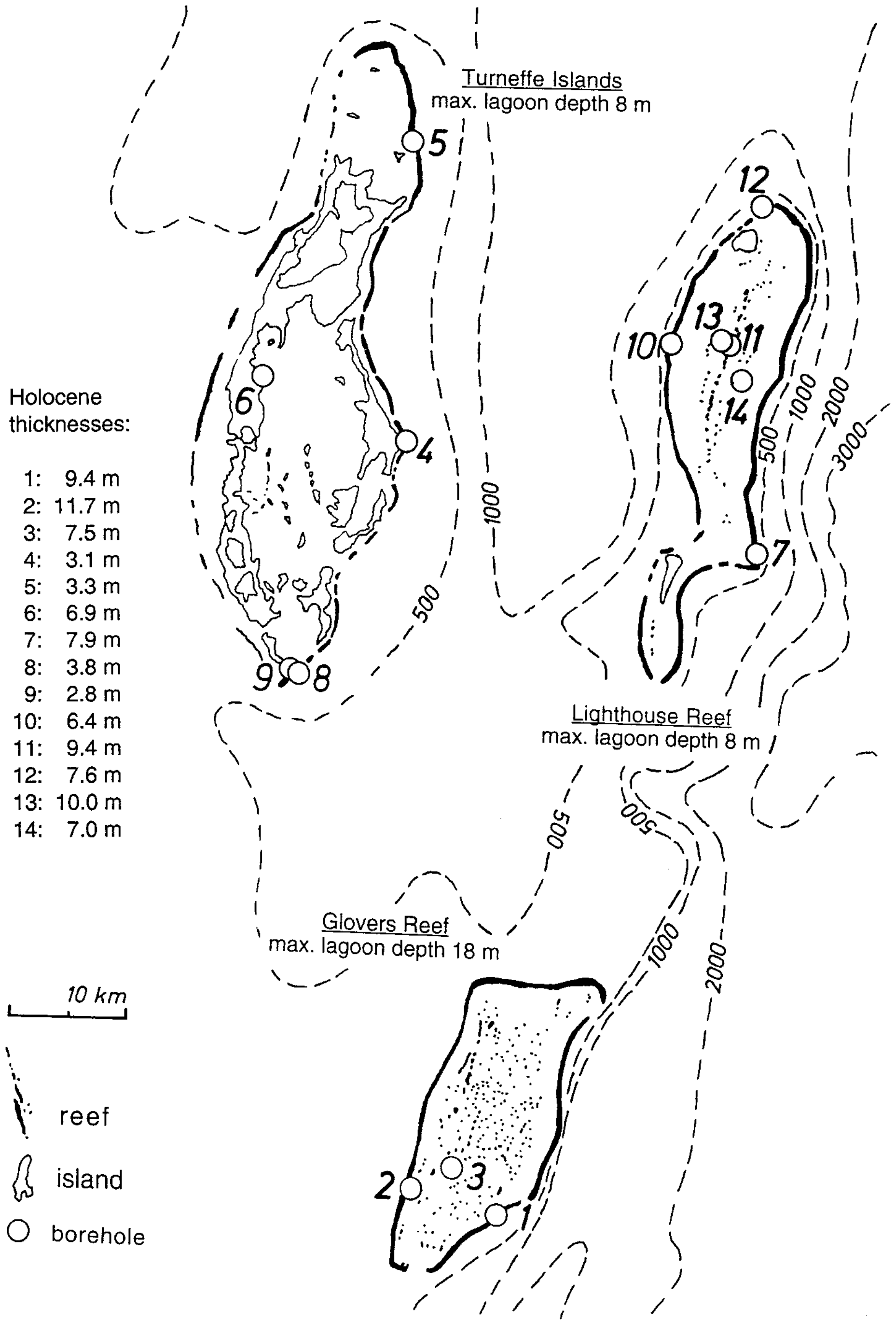

FIG. 10.—Locations of rotary core holes and bathymetry on the Belize isolated platforms including Holocene thicknesses (data on holes 1–9 from Gischler and Hudson 1998; data on holes 10–14 from Gischler and Lomando, unpublished data). Holes 1, 2, 4, 5, 7, 8, 10, and 12 were drilled into marginal reefs. Holes 3, 11, 13, and 14 were drilled into platform-interior patch reefs. Hole 6 was drilled into the lagoon floor; hole 9 was drilled on an island.

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The data described in this paper have been archived, and are available in digital form, at the World Data Center-A for Marine Geology and Geophysics, NOAA/NGDC, 325 Broadway, Boulder, CO 80303; (phone 303-497-6339; fax 303-497-6513; E-mail: wdcamgg@ngdc.noaa.gov; URL http://www.ngdc.noaa.gov/mgg/sepm/jsr/).

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