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FIGS. 1-40, JUNE, 1967

CARBONATE SAND BODIES OF FLORIDA AND THE BAHAMAS[1]

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Shell Development Company (A Division of Shell Oil Company), Exploration and Production Research Division, Houston, Texas—(Publication No. 470).

ABSTRACT

The report classifies sand bodies of the Florida-Bahamas area in order to facilitate their description. Types within this classification are marine sand belts, belts of tidal bars, eolian ridges, and platform interior sand blankets. Each type has its own characteristic relationship of the following descriptive attributes: setting, geometry, internal structure, composition, and texture.

The bottom topographic setting, through its influence on currents, controls sand body geometry, internal structure, composition, and texture. Sand bodies once formed are themselves bottom topographic features that influence the character of associated sediment accumulations and may, by means of a kind of feedback mechanism, exert some influence on their own characteristics.

Understanding the relationship of bottom topography to sand body attributes is important because knowledge of a sand body's topographic setting enables prediction of its other attributes. It follows that reconstruction of regional topographic setting at time of deposition of a particular formation is an important step in establishing the distribution of sand bodies within that formation.

INTRODUCTION

The main purpose of this report is to describe carbonate sand bodies of the Florida-Bahamas area. To simplify this description, these sand bodies are classified into four types—marine sand belts, belts of tidal bars, eolian ridges, and platform interior sand blankets.

Each type is distinguished by a special relationship of the following descriptive attributes: setting, geometry, internal structure, composition, and texture.

The plan of presentation of this report is first to consider the definition and natural relationship of the attributes of carbonate sand bodies and then to describe the sand body types in terms of these attributes. Variations of the sand body types are then discussed, and finally two examples of sand bodies in combinations are offered to show how the types may occur with other sediment accumulations.

Two main conclusions are reached:

1) The bottom topographic setting controls the current regimen that is the most important factor in determining the geometry, internal structure, composition, and texture of sand bodies.

2) The combinations in which sand bodies invariably occur with other sediment accumulations are in many instances cause-and-effect relationships that produce their own distinctive patterns of distribution and vertical sequence.

Continued study of carbonate sands will result in recognition of sand body types that are not treated in this report. The same is true of combinations of various sand body types with other sediment accumulations.

ATTRIBUTES OF CARBONATE SAND BODIES

Definitions

The descriptive attributes or characteristics of carbonate sand bodies are setting, geometry, internal structure, composition, and texture. These attributes are defined as follows.

A sand body's setting is its relation to bottom topography. For example, the setting might be the crest of a straight slope break on the sea floor. A slope break of this type is indicated in a schematic plan view in figure 1.

The geometry consists of the shape of the sand body and the relation of this shape to its setting. For instance, a belt parallel to a slope break constitutes a sand-body geometry (fig. 2).

Internal structures are the sedimentary structures within the sand body. Internal structures must be considered in regard to their positions in sequence, and where they have directional significance, their orientation must be considered as it is related to sand body shape. For example, internal structure may be composed of a cross-bedded sequence with cross-beds dipping in a direction that is at a high angle to the long axis of a sand belt and predominantly away from the deeper or more open water side of the sand belt (fig. 3).

The composition of a carbonate sand body in-

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cludes (1) grain kind, (2) material filling interstices, and (3) admixture of whole skeletons. For example, pelletoids, ellipsoids of indefinite origin including both fecal pellets and altered grains; sand size skeletal debris; and ooliths are grain kinds, See Illing, 1954 and more recently, Ginsburg and others (1963) for excellent reviews of grain kinds. Mud and cement are materials that may be found in the spaces between grains. Whole mollusks, brachiopods, etc., may occur as an admixture in carbonate sands.

Texture implies the size, shape, and arrangement of grains.

Natural Relationships of Attributes

The influence of bottom topography upon water movement is the connecting link between the setting and the shape, internal structure, composition, and texture of sand bodies within the setting.

Figure 4 illustrates how this influence may be exerted. Various sources of energy, such as tides, winds, earthquakes, and landslides, form waves in the deeper water adjacent to a slope break. Although their sizes vary, and wind waves are restricted to the surface part of the water mass, all these waves simply involve oscillatory motion of water particles. Trains of these waves move in all directions (fig. 4a). Those trains that move into the shoaling water on the slope break are impeded upon their sides nearest the shoal. This causes them to turn or refract so that they move more directly into the shallow-water area (fig. 4b). As the waves move toward the threshold at the crest of the slope break, they are increasingly distorted until they break or translate to form currents (fig. 4c). In this way the slope break initiates and directs the currents that concentrate sands upon it. If it were not for the constriction caused by the slope break, that is bottom topography, no appreciable current would develop.

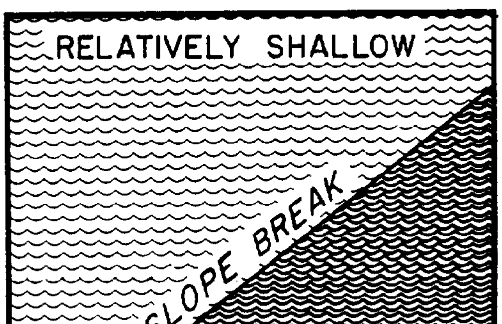


FIG. 1.—Slope break, Schematic plan view of a commonly encountered setting for concentrations of carbonate sand.

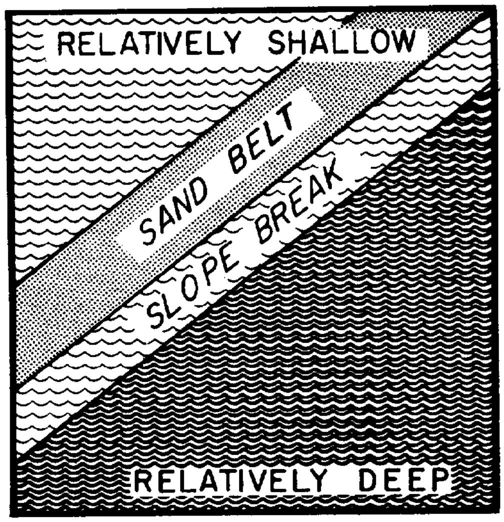


FIG. 2.—Sand belt parallel to a slope break is a common sand body geometry

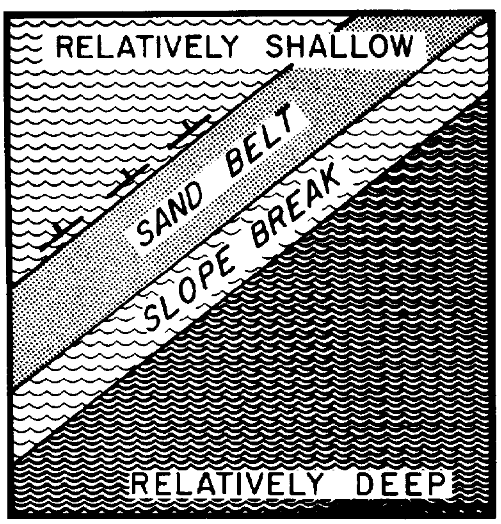
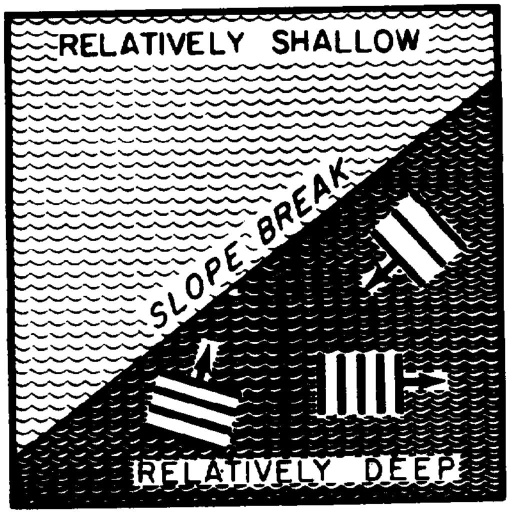
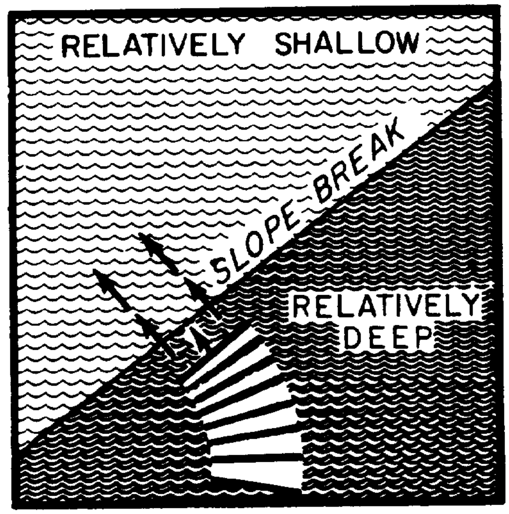


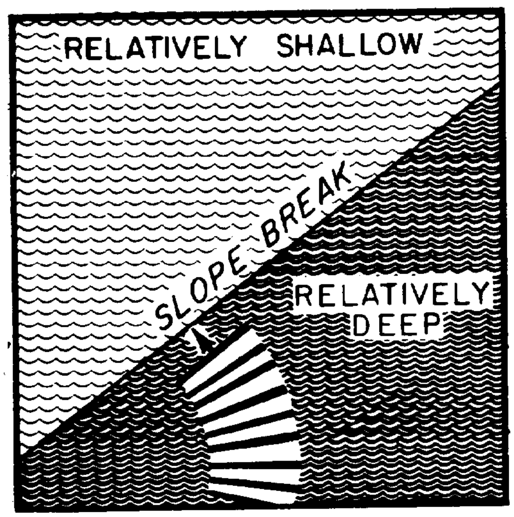
FIG. 3.—Internal structure of a sand belt. In this figure dip symbols are used to indicate cross-bedding within a sand belt, with dip direction at a high angle to the long axis of the sand belt and predominantly away from the direction of deeper or more open water.



(a)



(c)



(b)

FIG. 4.—The influence of setting on water movements. (a) Wave trains moving in different directions through deeper water adjacent to a slope break. (b) Refraction of a wave train due to the impeding effect of a shoaling bottom upon the side of the wave train nearest the shoal. (c) Current originated as a result of the vertical constriction exerted on waves moving into the threshold atop a slope break.

DESCRIPTION OF SAND BODY TYPES

Marine Sand Belt

The Cat Cay oolitic sand belt is the best studied example of this type fig. 5). Figure 6 shows a part of the mile-wide belt of oolitic sand south of the Cat Cays. The belt is parallel to the major slope break separating the Great Bahama Bank from the deep water of Florida Straits. Parts of the sand belt are awash at low tide, whereas the waters adjacent to the belt are 10 to 15 feet deep. The surface of the sand belt is ornamented with bars and ripples of varying size. The largest features are ridges (fig. 6) that trend at angles to the long axis of the sand belt. The relief of these ridges is up to 10 feet, and crest-to-crest distances are as great as 2000 feet. Within any specific group of ridges the crest-to-crest distance is approximately the same. The ridges have a steep face toward the platform (east) and a gentle back-slope toware the Florida Straits.

Spillover lobes (fig. 6) occur more commonly than the ridges and rival the ridges in size. These lobes are as much as 3000 feet long and 1500 feet wide. The relief at the nose of the larger lobes is about 5 feet. The noses terminate in steep fore-set beds.

The largest spillover lobes are directed onto the platform, away from the deeper waters of

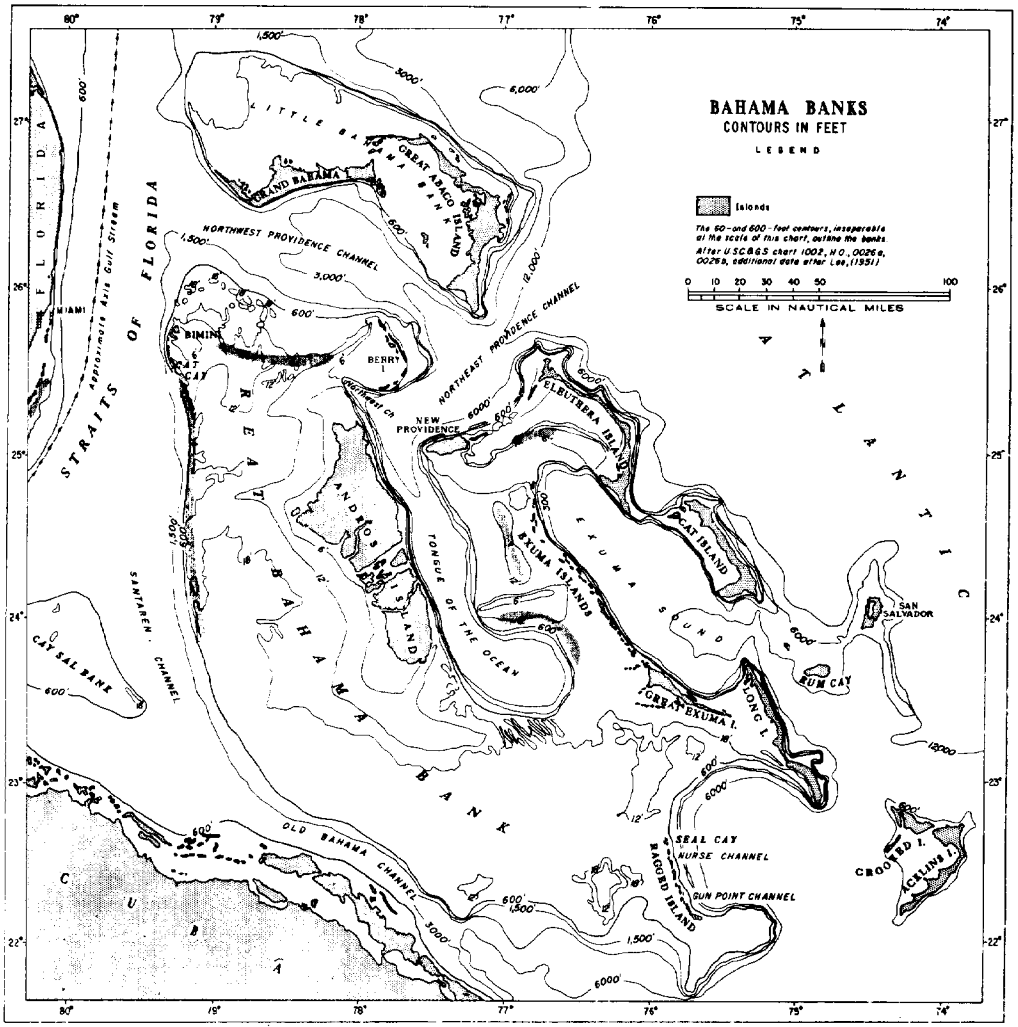


FIG. 5.—Location of marine sand belts of Florida and the Bahamas. Marine sand belts are indicated in gray. The belt on the west edge of the Great Bahama Bank, extending southward from Cat Cays is the Cat Cay oolitic sand belt.

Florida Straits. These larger lobes usually have an axial channel. Smaller spillover lobes, lacking axial channels, occur at various locations along both the seaward and platformward edges of the sand belt. The noses of the lobes on the seaward edge point toward the sea, and those on the platform ward edge point onto the platform. Thus, in all instances spillover lobes indicate sand movement across the sand belt. Because the larger lobes are directed onto the platform, and because most lobes point in this direction, the lobes further indicate a predominance of sand movement onto the platform, away from deeper, more open water.

The entire surface of the sand belt is covered by medium-scale ripples (amplitude 3 inches to 3 feet) with average amplitudes of 2 feet and wavelengths of about 150 feet (fig. 6). Most of these ripples are oriented with their long axes subparallel to the long axis of the sand belt. Grid analysis of aerial photos reveals that 75 percent of the medium-scale ripples trend within 30° of the trend of the long axis of the Cat Cay sand belt. The remaining 25 percent diverge up to 90° from the belt's long axis trend. They, like the spillover lobes, indicate sand transportation across the sand belt.

Superimposed on all the medium-scale ripples

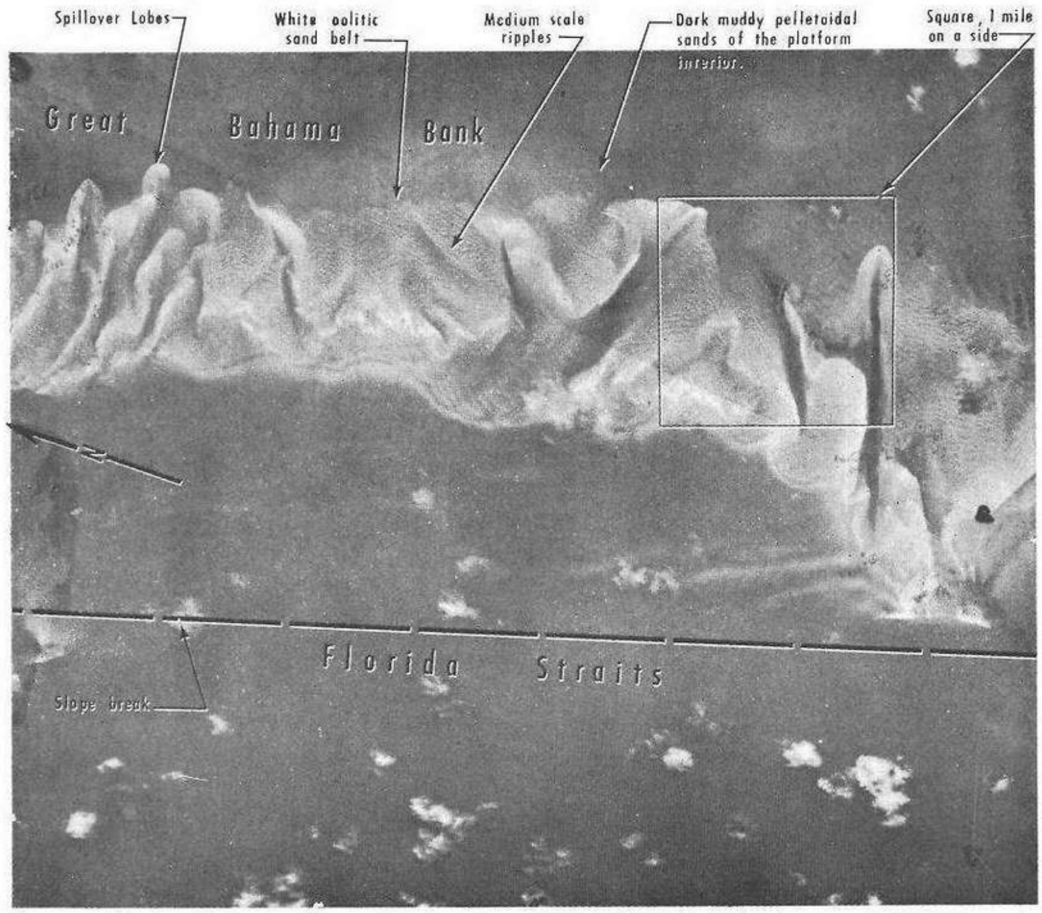


FIG. 6.—Cat Cay oolitic sand belt.

and spillover lobes are ephemeral, and sometimes conflicting sets of small-scale ripples (fig. 7). The height of these ripples is less than 3 inches, and the crest-to-crest length is rarely greater than 2 feet.

Currents resulting from the day-to-day distortion of tidal and wind waves form and move small-scale ripples such as those in figure 7. The day-to-day currents also shift the crests of medium-scale ripples with the change of tides. This continual agitation of the surface sand grains in the $CaCO_3$-saturated waters is inferred to be responsible for the precipitation of the oolitic coats.

The daily tidal and wind currents modify the large surface features of the sand belt, and at the same time they are subject to control by these features. The small breaks in slope occurring on medium-scale ripples and noses of spillover lobes are sufficient to refract these weaker currents in the same manner that the platform edge turns large waves into the shelf.

Comparison of aerial photographs of the Cat Cay sands taken in 1955 and 1958 shows that no new spillover lobes were formed during this interval. Medium-scale ripples remained unchanged in some areas on the sand belt during this 3-year period. From this, we conclude that these larger surface features of the sand belt are formed during intermittent higher-energy events, such as severe storms.

The internal structure and composition of the oolitic sand belt and adjacent sediments were determined from a study of a traverse across the sand belt of eighteen oriented cores taken with a pressure coring device. All of these cores were impregnated with plastic. True cross-bed dip directions were determined, by use of a stereographic net as described by Higgs and Tunell (1959), from apparent dips measured in north-south and east-west sections of these oriented cores.

Study of oriented cores shows that the typical sequence of internal structures within the Cat Cay sands comprises a basal set of large- or medium-scale cross-beds overlain by small-scale cross-bed sets. This sequence records (1) the migration of the edges of the sand belt during intermittent higher-energy events by extension of spillover lobes (fig. 8) and trains of medium-scale ripples and (2) the subsequent reworking of the surface sands of these medium-scale ripples and lobes by day-to-day tidal and wind currents. The amount of medium- and large-scale cross-bedding in the internal sturcture of the Cat Cay sand belt is evidence for a considerable bias toward preservation of the effects of intermittent higher-energy events in the construction of these marine sands.

The dip direction of cross-bedding indicates sand movement across the belt and predominantly onto the platform. The arithmetic mean of perpendiculars to mean cross-bed dip directions in the oriented cores was 10° from the trend of the Cat Cay oolitic sand belt. The standard deviation of these perpendiculars from the belt trend was 30°. Considered on an individual basis, in eight of the eighteen cores the perpendicular to the mean dip direction was within 10° of the belt trend. In fifteen of the cores it was within 30° of the belt trend. The perpendiculars to mean dip direction in three of the cores indicated belt trends that were in error by 45° to 65°. On the basis of these data, the generalization that mean cross-bed dip direction is perpendicular to sand belt trend was correct to within 30° in five out of six applications. The degree of consistency of orientation of surface features, for example, the medium-scale ripples and spillover lobes, is in good agreement with that of cross-bed dip directions.

Figure 9 is a schematic block diagram of the Cat Cay oolitic sand belt. The sand belt is up to 12 feet thick and is composed of cross-bedded, current-sorted, medium sand size grains, many of which are thickly coated. The cross-bedded sand (fig. 10) overlies a burrowed sand which contains some oolitically coated grains and a high percentage of fine sand size pelletoidal grains (fig. 11a). The basal contact of the belt sand is sharp beneath the platformward margin of the sand belt and is gradational elsewhere. The lack of distinctness of this basal contact and the admixture of thickly coated ooliths in the

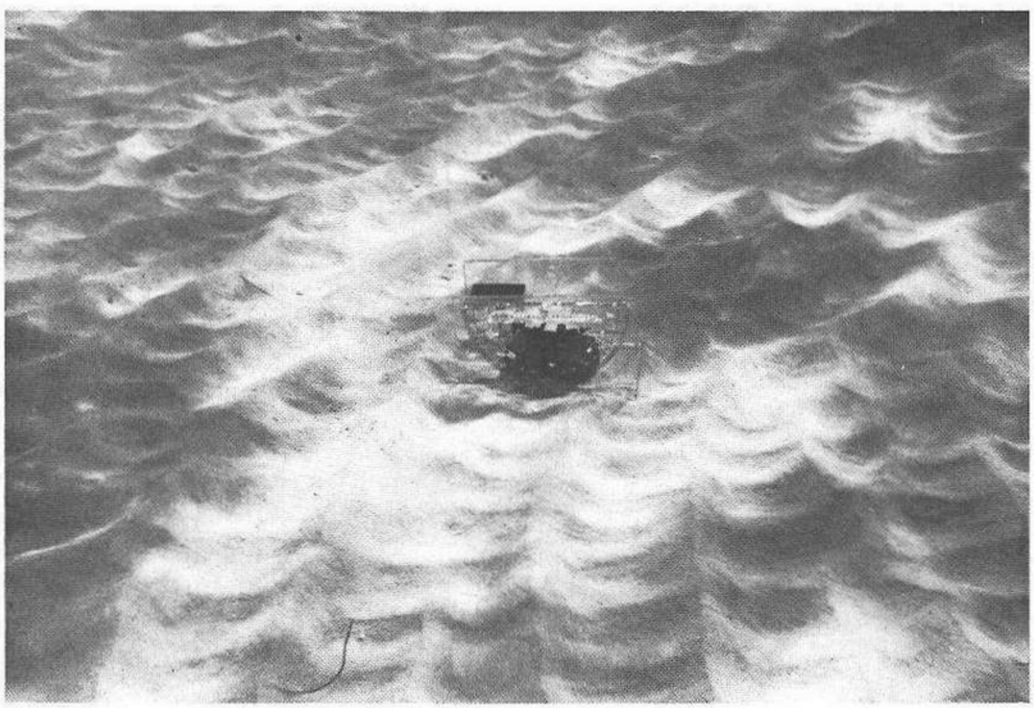


FIG. 7.—Conflicting sets of small-scale ripples. The diameter of the protractor is approximately 6 inches.

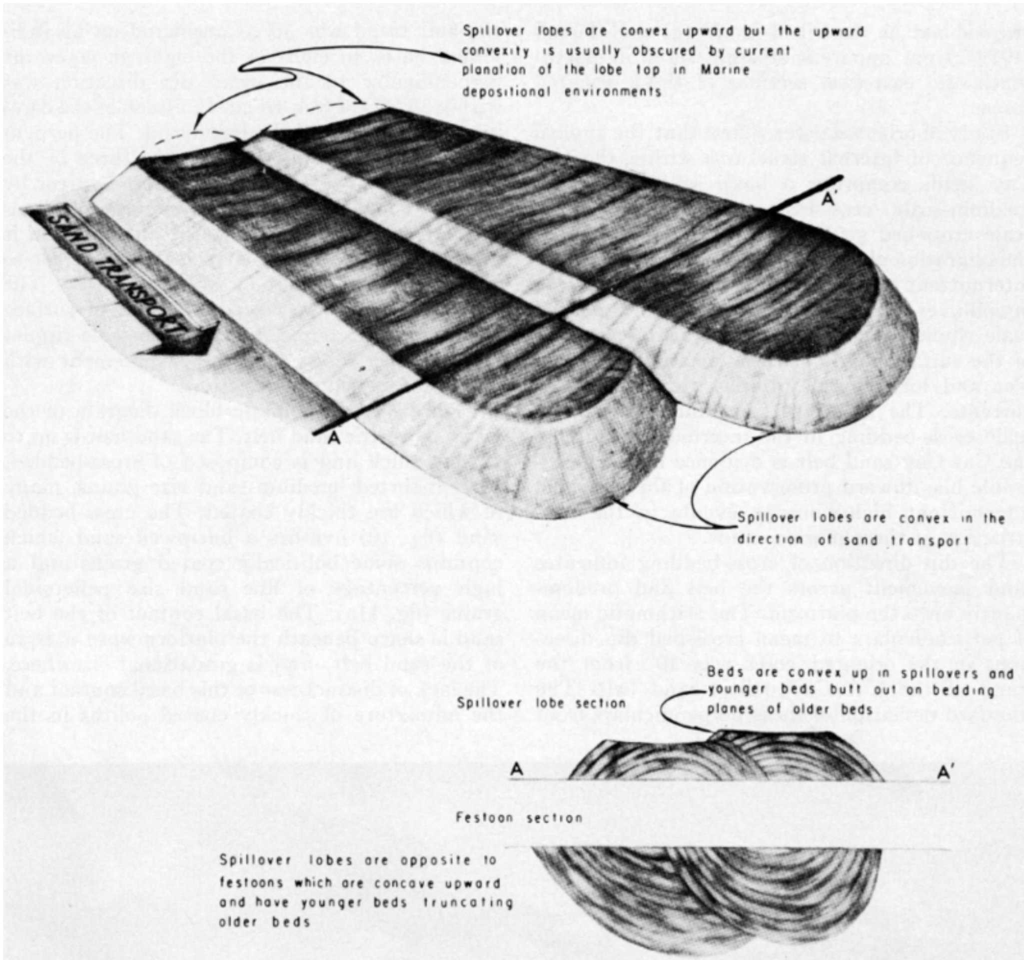


FIG. 8.—Spillover lobes contrasted with festoons.

underlying sand is probably due to burrowing across the contact. Grains in the sediments beneath the sand belt with well defined long axes arranged at all angles to the horizontal show that these sediments have been extensively churned by burrowers.

The percentage of ooliths with coats thicker than 0.1 mm is always at least 40 percent in the cross-bedded belt sand but does not exceed 20 percent in any of the adjacent sediments. In this study, oolitic grains with coats thinner than 0.1 mm were designated "superficial ooliths" and those with coats thicker than 0.1 mm were regarded as "well-developed ooliths," in order to see if the degree of oolitization varied in the several subenvironments mentioned, in some respect other than the percentage of coated grains. Skeletal admixture is greatest in the sands (fig. 11b) in the slightly deeper water just seaward of the cross-bedded sand belt. Fine sand and silt size particles are commonest in the sediments beneath (fig. 11a) and platformward (fig. 11c) from the cross-bedded oolitic sand belt.

In figure 12 bar graphs summarize various compositional and textural characteristics of the sediments in and adjacent to the sand belt. The graphs are based upon 200-point counts of one hundred thin sections made from plastic-impregnated slabs cut from various intervals of twenty-eight cores in and adjacent to the cross-bedded sand belt. From these data we should conclude that consideration of grain kind and skeletal admixture will reveal gradients or sharply defined differences in these characteristics that will be of value in delineating sand bodies. For example, the percentage of well-developed oolitic grains (fig. 12) is a good index for setting apart the cross-bedded sand belt from adjacent sediments.

In those areas of the surface of the oolitic sand belt where grains have remained immobile for some time and within the sand belt where burrowing organisms have altered the depositional packing of grains, segregating the finer particles in the mucoidal slime of the burrows boundary, the grains become cemented by a furry fringe of aragonite cement composed of crystals growing radially from grain boundaries into interstices (fig. 13). Broken fragments of the rocks thus formed are sometimes encountered as clasts in cores from the Cat Cay sands. The rocks formed with this cement occur at the surface of the sand belt in areas where presence of grass or other attached organisms attests to stability of the sand surface, and these rocks often preserve this surface in perfect conformance with adjacent uncemented sand. Such occurrences have been observed at depths as much as 6 feet below spring low tide and as far as 2 miles from any island from which the rocks could have been derived as clasts. The softness of the rocks in many of these examples is such that the rocks can only be picked up with difficulty else they fall apart. Such rocks cannot be transported. Because of these observations, we reason that the cement forming these rocks is contemporary and further that this cement originated in the shallow marine environment where it is found.

The sparse skeletal megafauna of the oolitic sand belt is composed primarily of clams and gastropods.

Tidal Bar Belts

The Schooner Cay area at the north end of Exuma Sound (fig. 14) contains an example of a tidal bar belt. The regional setting of this belt is upon the crest of an arcuate slope break at the end of an embayment into the platform. The sand belt is subdivided into approximately equally spaced and sized bars that curve across it (fig. 15). See Off, 1963, p. 324–341 for an excellent discussion of the worldwide occurrence of similar features. Individual bars average 5 miles in length and are $\frac{1}{4}$ to $\frac{1}{2}$ mile in width. The bars are convex toward the east and are asymmetrical in cross section with their crests adjacent to their steeper west edges. The widths of crests are about 300 feet. Bar crests are awash at spring low tide, whereas channels are about 15 feet deep.

The same surface features occur on the Schooner Cay tidal bars as upon the simple, unsegmented sand belt south of Cat Cays, but differences exist in the arrangement of these surface features. The large spillover lobes, 3000 feet long and 1500 feet wide, that typically have axial channels, bear the same relationship to the

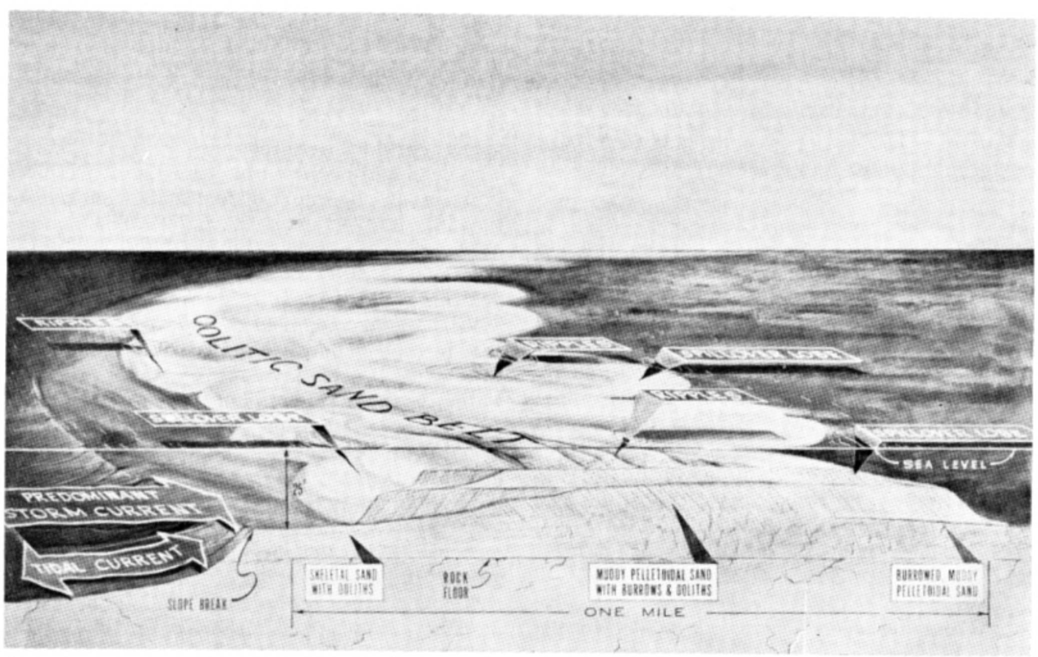


FIG. 9.—Schematic block diagram of the Cat Cay oolitic sand belt.

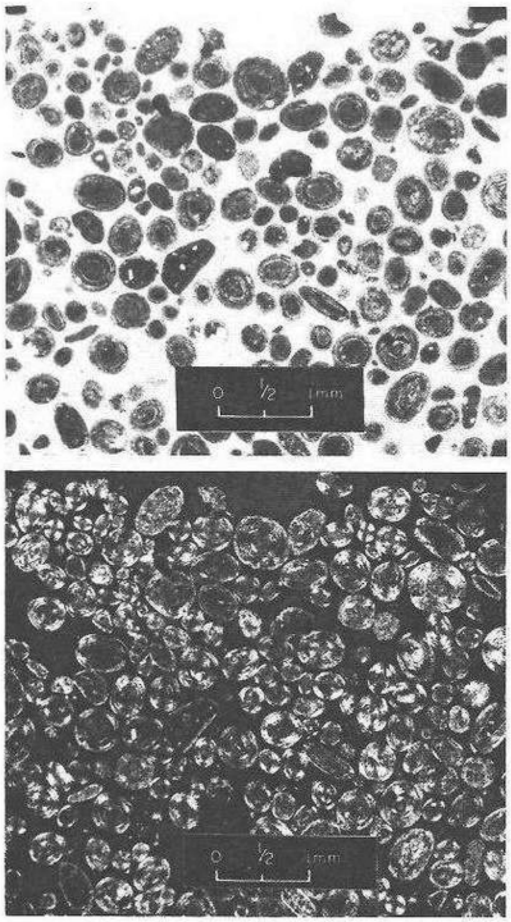


FIG. 10.—Oolitic sand from the Cat Cay oolitic sand belt. The upper view was taken with plain light, and the lower with crossed nicols.

Schooner Cay tidal bar belt as did the spillover lobes to the marine sand belt at Cat Cays. That is, they indicate sand transportation across the belt in a direction approximately 90° to the belt's long axis. It follows that the axial channels of the lobes cross individual tidal bars almost parallel to the bar trend (fig. 16). Most of these large spillover lobes are directed onto the platform, away from the deeper, more open water of Exuma Sound. The same is true of smaller spillover lobes, but where these occur on bar crests on the seaward side of the sand belt, they are often directed back toward the south or open sea.

Medium-scale ripples cover the tidal bar crests and are every-where subparallel to the trends of these bars (fig. 17). The same is true of the small-scale ripples that are superimposed upon the medium-scale ripples of the bar crests.

Ripples and streamlines upon the channel floor between the tidal bars indicate sand and current movement parallel to the channel axes. Jordan, 1962, p. 839–848 gives an excellent description of similar alignments of current features at Georges Bank.

The regional hydrographic setting, a slope break at the end of an embayment into the platform, is responsible for the tidal bar belt at Schooner Cays. The celestial tidal currents in this setting are unusually strong because of resonance between oceanic tidal waves and the natural frequency of the water mass within the embayment Exuma Sound. Oceanic tidal waves strike the interface between the ocean water and that of the embayment at a frequency that nearly matches the natural frequency of the water mass within the embayment. This causes large waves to be set up on the embayment. The crests of these waves do not progress along the axis of the embayment, and for this reason these waves are referred to as stationary or standing waves. Most tides are of the standing wave variety and are identifiable as such by the time of occurrence of currents associated with them. Such currents attain their maximum velocities midway between high and low water, whereas in tides resulting from progressive waves, maximum current velocities occur at high and low water. Tide gage information taken in conjunction with current observations at Schooner Cays during June of 1961 revealed that maximum tidal currents of about 3 knots occurred midway between high and low water in the Schooner Cays area and thus establishes that these tides were related to standing waves. The dead end of the embayment is invariably a position of maximum displacement of one of these waves (Defant, 1953, p. 69). The changes in water level associated with the wave motion at the basin end cause strong tidal currents to be developed.

With the development of these strong currents the interface between the relatively deeper waters of the embayment and the shallower waters of the platform is displaced rapidly with each change of the tide. A point is reached during this displacement at which the interface becomes unstable and separates into a number of approximately equally spaced and sized digits (fig. 18). This digitate flow is inferred to be responsible for the inception of tidal bar belt geometry. At some stage of the development of this flow pattern the tongues or digits of faster-moving water are transporting material and perhaps actively eroding the bottom while

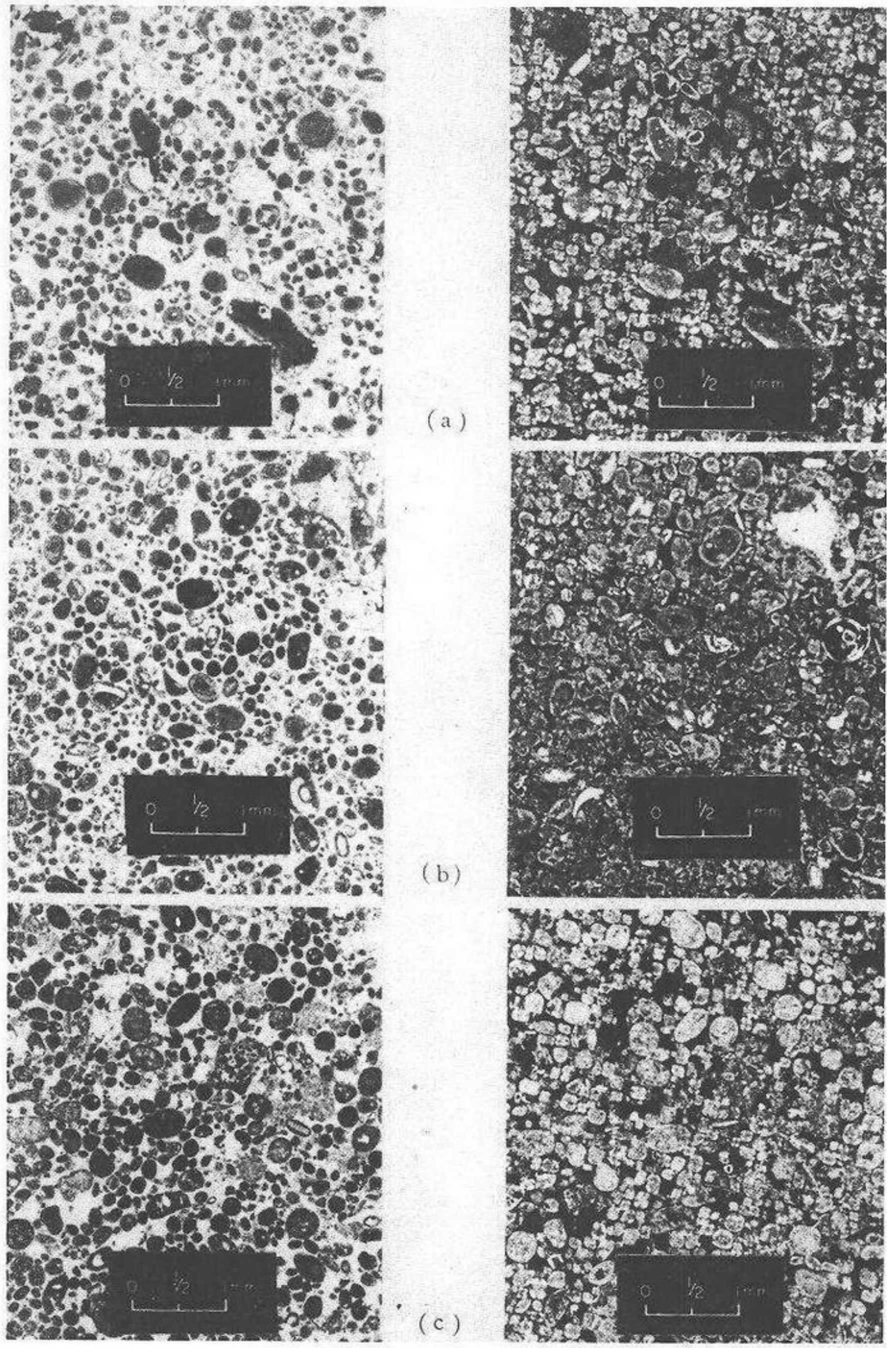
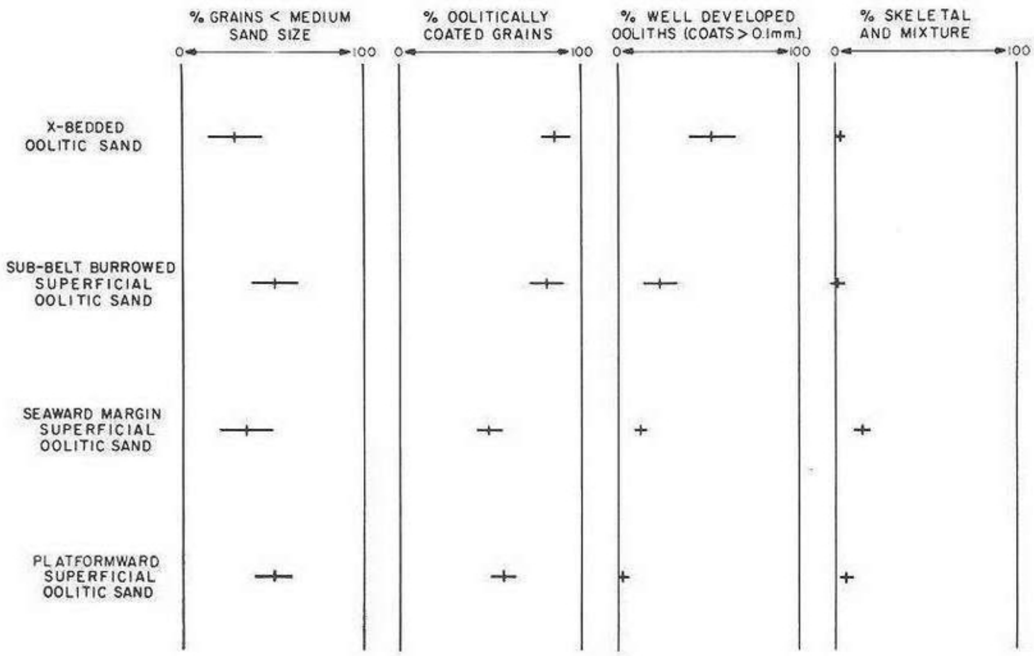


FIG. 11.—Sediments adjacent to the oolitic sand belt. The thin-section pictures on the right were taken with crossed nichols. (a) Pelletoidal, superficial oolitic sand with an admixture of well-developed ooliths. This sediment underlies the cross-bedded oolitic sand belt. (b) Pelletoidal, superficial oolitic sand with an admixture of skeletal grains. This sediment lies seaward of the cross-bedded oolitic sand belt. (c) Muddy, pelletoidal, superficial oolitic sand. This sediment extends platformward from the oolitic sand belt.


% GRAINS < MEDIUM SAND SIZE
% OOLITICALLY COATED GRAINS
% WELL DEVELOPED OOLITHS (COATS > 0.1mm)
% SKELETAL AND MIXTURE
0
100
X-BEDDED OOLITIC SAND
SUB-BELT BURROWED SUPERFICIAL OOLITIC SAND
SEAWARD MARGIN SUPERFICIAL OOLITIC SAND
PLATFORMWARD SUPERFICIAL OOLITIC SAND

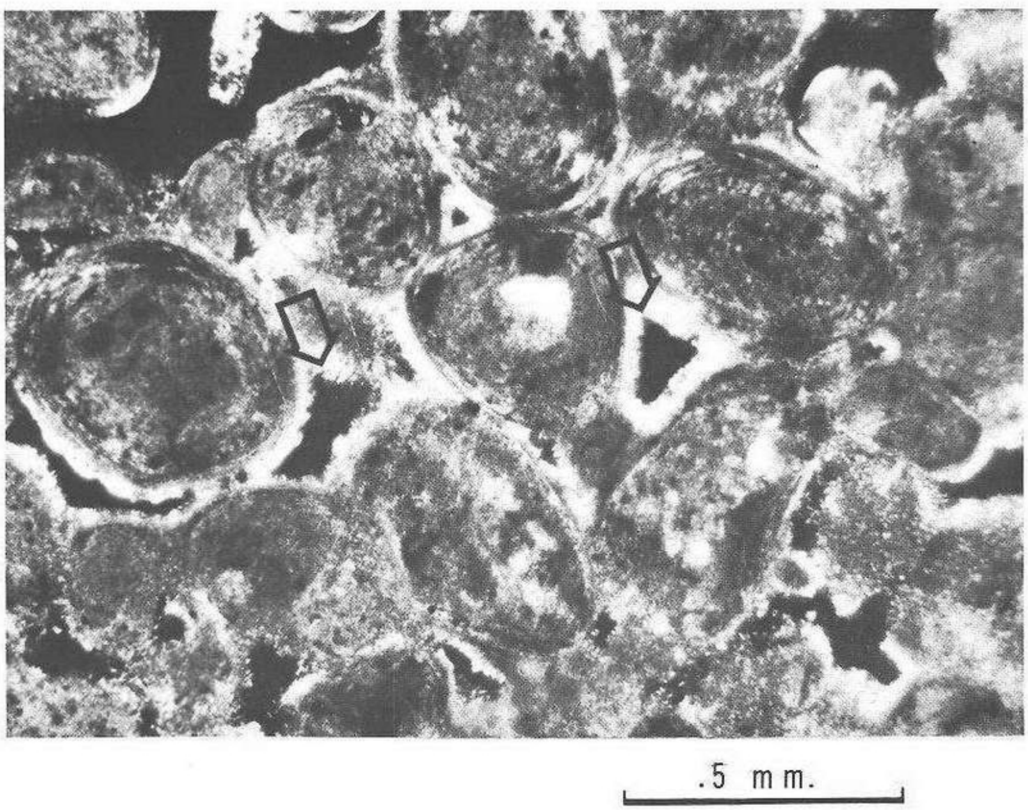

.5 mm.

FIG. 12.—Composition of the Cat Cay oolitic sand belt and adjacent sediments.

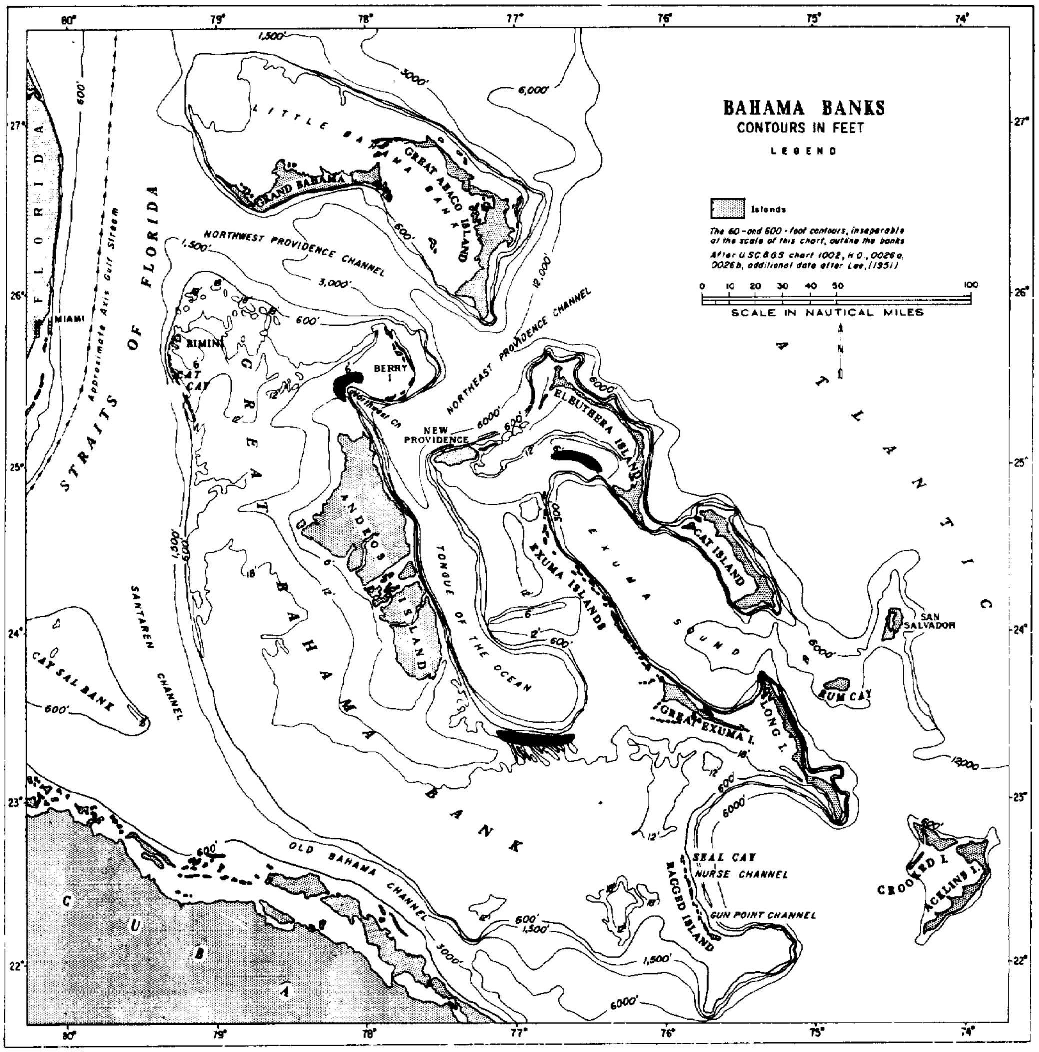


FIG. 14.—Location of Florida-Bahamas tidal bar belts. black indicates the location of tidal bar belts. The Schooner Cay tidal bar belt is located at the north end of Exuma Sound.

FIG. 13.—Fibrous aragonite cement. This cement, growing radially out from grain boundaries, formed in the interstices between ooliths in the Cat Cay sand belt.

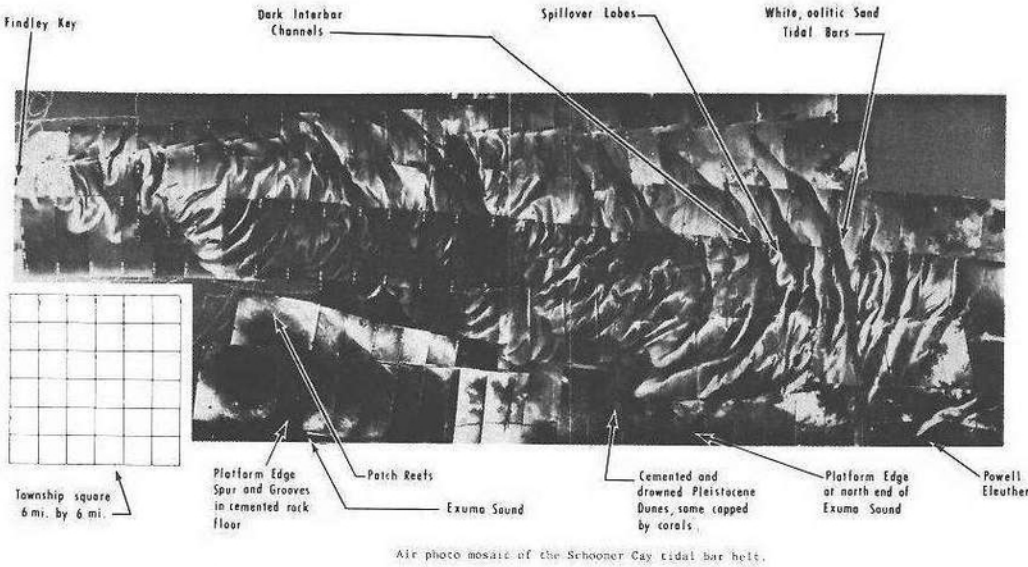


FIG. 15.—Air photo mosaic of the Schooner Cay tidal bar belt.

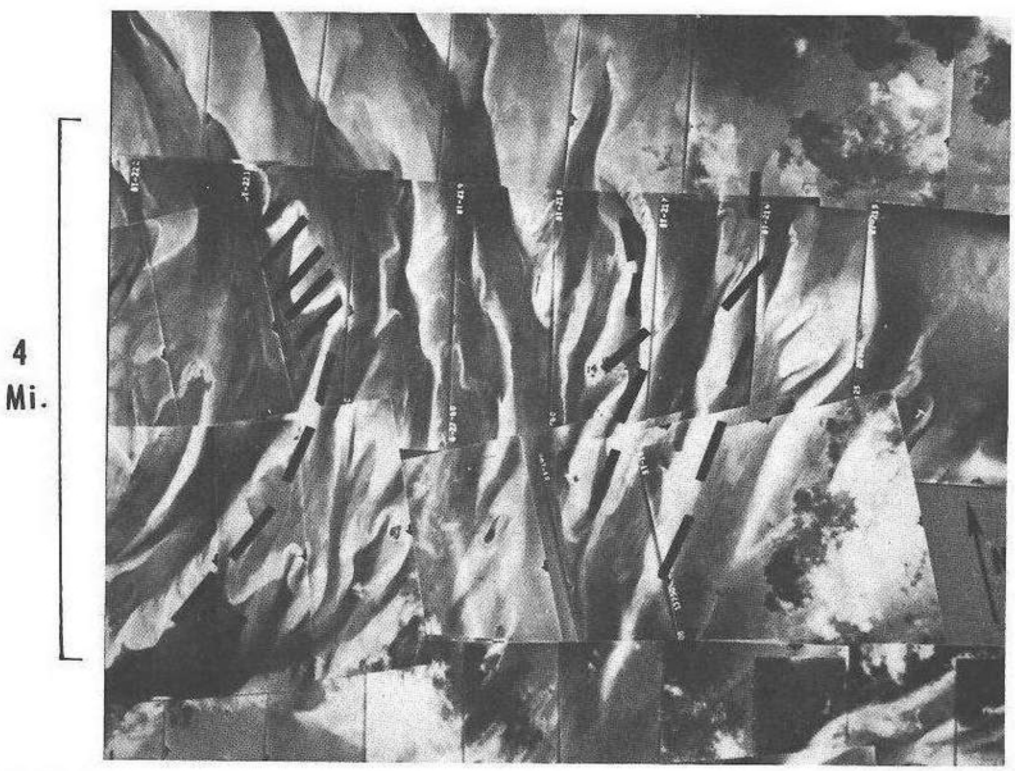


FIG. 16.—Relationship of bar crests to axes of spillover lobes. The dashed lines mark crests of individual tidal bars, and the solid lines indicate trends of axial channels of spillover lobes.

FIG. 17.—Medium-scale ripples. The medium-scale ripples on the bar crests are parallel to the bar crests. Ripples in the channels (dark areas between the white sand bars) trend across the channels.

deposition is taking place in the lower-velocity areas separating the digits. This initiates the separation of sand belts into more or less equally spaced and sized bars trending across them.

The alignment of the larger spillover lobes upon the Schooner Cay tidal bar belt indicates that intermittent strong currents move across the sand belt independent of the local topography comprising the tidal bars themselves. The alignment of medium- and small-scale ripples upon the tidal bar crests, however, shows that for a certain range of current energies the local topography of the individual tidal bar is an important control upon the pattern of flow. This control is born from the ability of the tidal bars to turn or refract weaker currents so that they move across the bar crests approximately perpendicular to the trend of the individual bar.

These weaker currents crossing the bar crests reverse their direction of flow with each change of tide. Thus, they keep the crestal sands in almost continuous motion without removing them from the bar crests. This condition of continuous sand movement promotes the most rapid development of thick-coated oolitic sand grains.

The parallelism of ripples to bar crests as these crests curve around positions where spillover lobes have altered the bar trends (fig. 17) is proof that refraction, and not the prevailing winds or some other external factor, is responsible for the orientation of the ripples on the bar crests. The reasoning upon which this statement is based is that prevailing winds or other external factors could not cause the local variation in ripple orientation on sinuous bar crests as these crests turn in distances of 1 or 2 miles through arcs of 180°.

Generalizations concerning the internal struc-

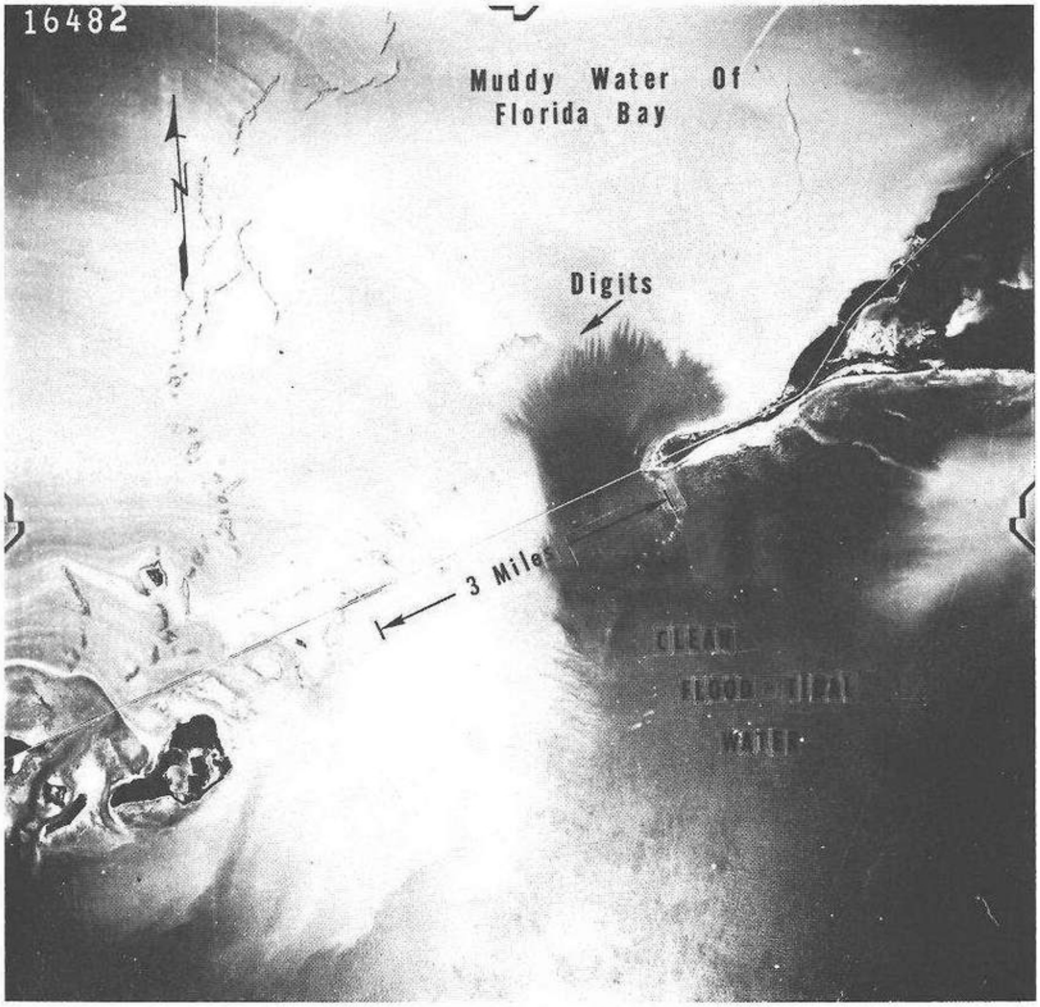


FIG. 18.—Unstable interface between clean flood tidal waters and muddy water of Florida Bay. The individua digits in this picture are as much as a quarter of a mile long and a tenth of a mile in breadth.

ture and composition of the Schooner Cay tidal bars are based upon studies of twenty-three oriented cores and inferences drawn from the knowledge of the internal structure of the various surface features visible on the tidal bars, such as ripples and spillover lobes. Figure 19 is a schematic block diagram in which the sequence of sedimentary structures and gross compositional and textural characteristics of the Schooner Cay tidal bar belt are portrayed. As indicated in the diagram, the rippled oolitic sands are thin or absent in the channels. The ripples on these channel sands trend across the channels and thus indicate current movement and sand transportation parallel to the axis of the channels.

The sequence of sedimentary structures in the thick sands of the tidal bars consists of (1) a basal unit of burrowed oolitic sand with an admixture of muddy pelletoidal sediment from below and (2) an upper unit of medium- and small-scale cross-bed sets dipping in a direction that is perpendicular to the bar trend.

The consistency of trend of surface features on these tidal bars is equal to that of similar features on the Cat Cay marine sand belt. From this, we reason that the relationship of the cross-bedded internal structure, that records the migration of the surface features on these tidal bars, to the shape and trend of the bars may be a significant aid in the prediction and projection of tidal bar trends.

Composition and texture within the Schooner Cay tidal bar belt (fig. 19) show considerable variation.

The oolitic sands of the bar crests are clean, well-sorted grains of medium sand size. They contain a small admixture of whole marine megaskeletons, such as clam or gastropod shells. The cross-bedded structure is well preserved in these sands, since the rate of reworking by the tidal currents over the bar crests far exceeds the rate of disruption of the resulting current structures by burrowing organisms. The bar sands in the slightly deeper waters off the bar crest are less well sorted and are almost always burrowed or churned. The slight depth increase over these sands is a critical factor in depriving them of daily reworking by tidal currents. The result is that burrowing organisms create the internal structure within these sediments.

Penecontemporaneous, submarine cementation is common in the burrowed sands. Areas of cementation of 2 to 3 square meters occur underlying only a few inches of unconsolidated sand, and numerous cemented, cobble size rocks occur on the surface of these sands. The cement is fibrous aragonite such as that shown in figure 13.

The thin veneers of rippled sand occurring in some places upon the channel floors contain admixtures of skeletal grains, such as Halimeda plates, and also fragments of submarine cemented rocks. Churned, muddy pelletoidal sand underlies the sparse and discontinuous sand carpet on the channel floor. It is similar to the muddy, soft pelletoidal sand that has been penetrated beneath the Cat Cay oolitic sand belt. The channel pelletoidal sand differs from that under the tidal bars in that it contains fewer oolitic grains.

Platformward of the tidal bar belt is a broad expanse of hard pellet sand. This platform interior sand blanket is burrowed extensively. The grains are in some instances superficially coated, and there is an admixture of dark grains. Cemented Pleistocene skeletal sands with some included corals and a thin, interrupted cover of unconsolidated skeletal sand border the tidal bar belt's seaward edge.

Eolian Ridges

Thick, eolian, carbonate sand deposits constitute the multiple seaward ridges that compose the highlands of most of the islands in the Bahamas (fig. 20). These carbonate dunes depend, for their source material, upon marine sand concentrations. For this reason the carbonate dunes occur as ridges paralleling slope breaks where marine sands have been concentrated in beaches or bars.

The dunes are exceptional among the sand bodies described in this report. Their relationship to setting is not directly dependent upon the setting's ability to originate and aim the currents that shape the sand body but is instead concerned only with the setting's role in concentrating source material. This indirect relationship is, nevertheless, an inflexible one.

Some eolian ridges are composed primarily of spillover lobes (fig. 21). These lobes differ from similar features in marine sands in that (1) their upward convex portions are preserved, so that the individual cross-bed sets have decreased dip angles on bedding planes in the upper part of the set (fig. 21a), and (2) the thickness of their contained cross-bed sets is considerably greater. The saddles between these lobes are in

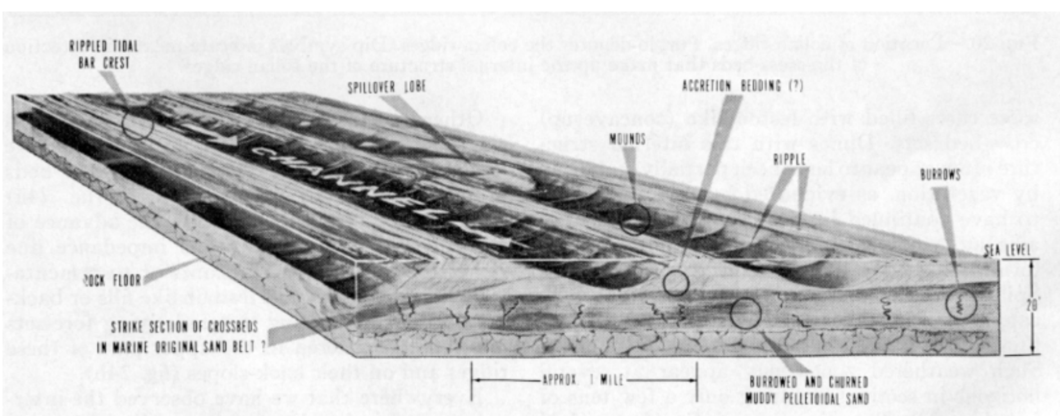


FIG. 19.—Schematic block diagram of Schooner Cay tidal bar belt.

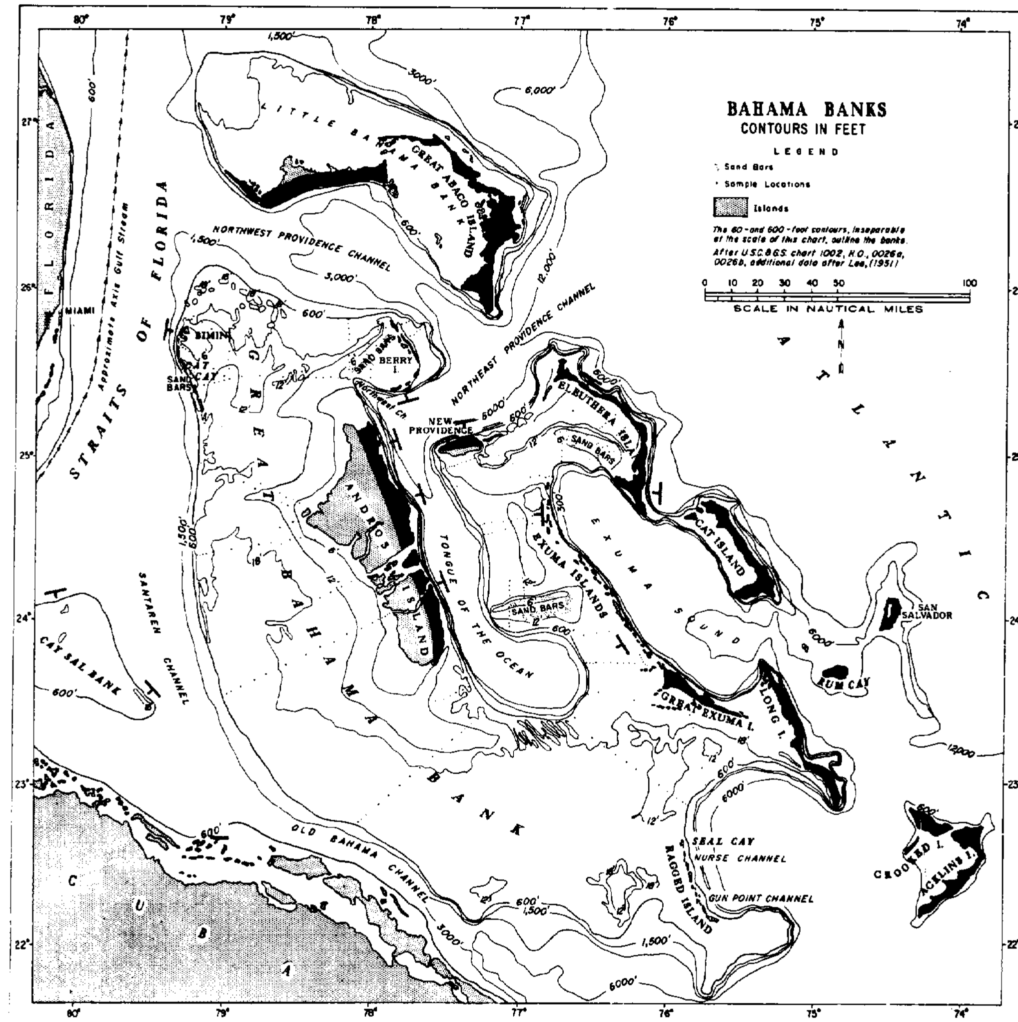


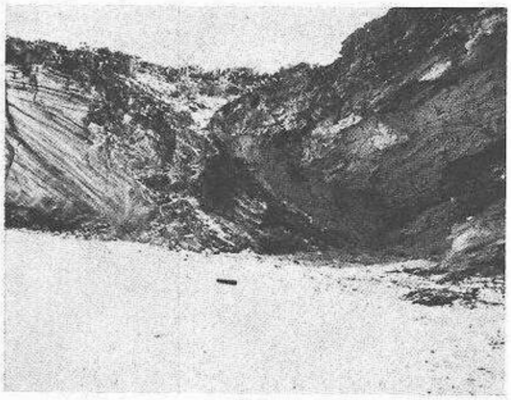
FIG. 20.—Location of eolian ridges. Purple denotes the eolian ridges. Dip symbols indicate mean dip direction of the cross-beds that make up the internal structure of the eolian ridges.

some cases filled with festoonlike (concave up) cross-bed sets. Dunes with this internal structure often appear to have been partially stabilized by vegetation, as evidenced by root casts, and to have continued in their movement by sporadic advance of spillover lobes building platformward at the breaches in the ridge crest. Spillover lobe cross-bed sets are frequently capped by red weathered zones (fig. 22) containing brecciated altered fragments of eolianite. Such weathered zones may appear at several horizons in sections exposing only a few tens of feet (fig. 23). The direction of dip of cross-bed sets in these spillover lobes ranges through an arc of about 180° centered onto the platform.

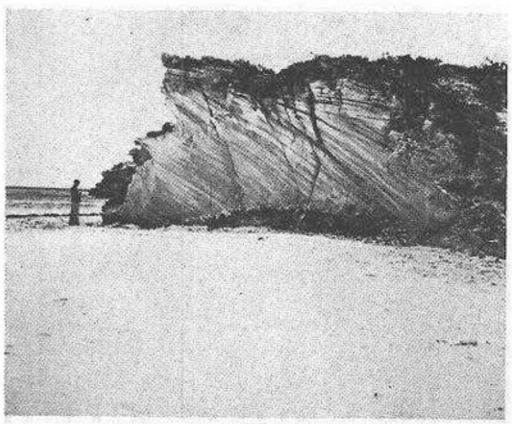
Other eolian ridges consist primarily of a single huge sand wave whose internal structure is one very large scale set of fore-set cross-beds dipping toward the platform interior (fig. 24a) This internal structure indicates the advance of the ridge as a whole with no impedance due either to stabilization by plants or to cementation. Spillover lobes and festoon like fills or back-set bedding truncating the underlying fore-sets may be encountered in the upper part of these ridges and on their back-slopes (fig. 24b).

Everywhere that we have observed the internal structure of carbonate dunes, dip of fore-set cross-beds has been toward the platform interior (fig. 20). The reason for this is that the source material for these dunes was at the shore; thus, the only winds effective in dune construction were those directed onshore. Winds directed toward the sea return the sand to the sea. The resulting dunes were rapidly stabilized before the prevailing wind could make itself felt in controlling direction of migration of the dunes away from the source area.

In some instances the character of individual crossed laminae appears to be a criterion for recognition of eolian carbonates. Where these wind-blown sands are fine grained, the cross-beds constituting their internal structure are often true laminae (fig. 25). We have not observed paper-thin laminae such as these in marine carbonate cross-bedded sequences. The combination of fine grain size with currents sufficient to arrange the grains in large-scale cross-bed sets is apparently unusual in marine carbonate depositional environments.



(a)



(b)

FIG. 21.—Internal structure of eolian ridges composed of spillover lobes. (a) Strike section of two eolian spillover lobes at their contact. The cliff face cutting the spillover on the right is about 15 feet high at the highest point shown in this view. (b) Dip section of an eolian spillover constituting part of an eolian ridge. Note the decrease in the angle of dip as one views up the cliff face on the right-hand side. This decrease is due to preservation of the upward convex part of the spillover.

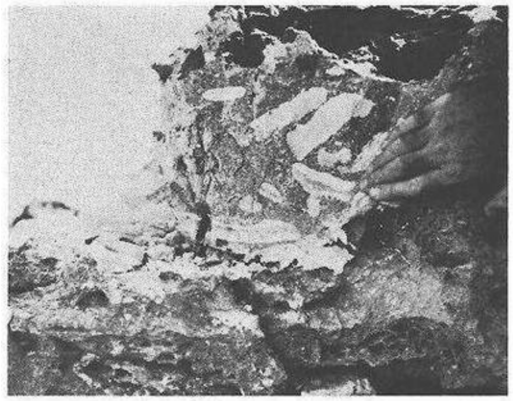


FIG. 22.—Red weathered zone. These zones containing brecciated and altered fragments of eolian calcarenite frequently cap eolian spillover lobe cross-bed sets.

Burrowing is rare in the wind-blown carbonates, but root casts that are easily mistaken for burrows are quite common. One means of distinguishing between the two is that the root casts may be observed to decrease in diameter as they branch out from their central stalks. Burrow casts do not decrease in diameter upon branching.

The composition of the eolian carbonate sand grains includes all compositions that occur in marine carbonate sands, i.e., skeletal, pelletoidal, and oolitic. The grain size may be fine, but this is not invariably true. The wind-blown carbonate sands are characteristically well sorted. No admixture of whole marine megaskeletons occurs in these sands. The only whole shells that have been observed in abundance are those of lunged gastropods, and these are usually concentrated only in weathered zones. In regard to megafauna, the unweathered portions of the eolian sands are typically unfossiliferous. The cement is a calcite mosaic that is precipitated as fresh water percolated downward through the dunes. Except in the hardened outer surface of the dunes, cementation is restricted largely to grain point contacts.

Platform Interior Sand Blankets

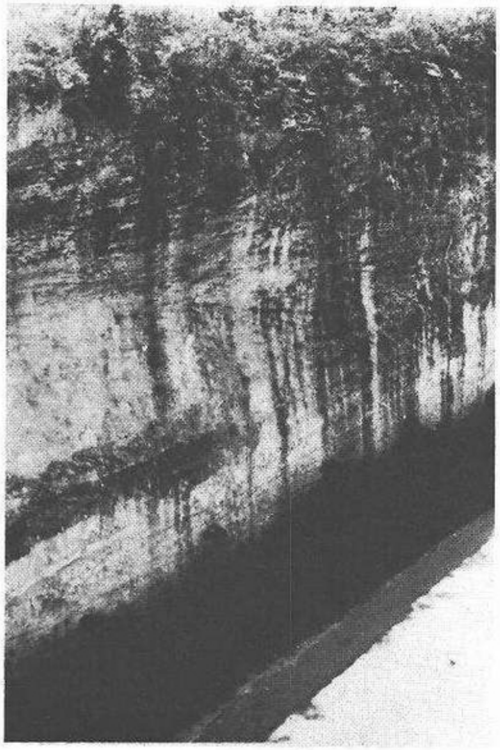
From the standpoint of areal extent, the platform interior sand blankets (fig. 26) are the most impressive carbonate sand bodies. As

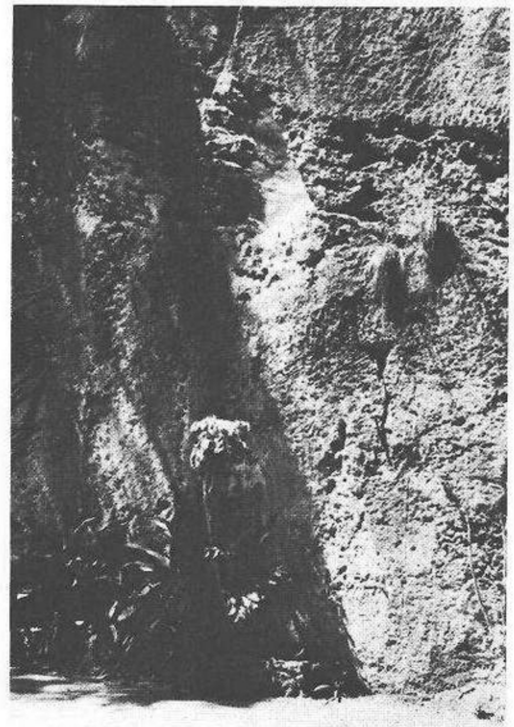
FIG. 23.—Red weathered zones separating older and young eolian spillover lobes. The surface on which the geologist is standing, the cliff top, and a surface beneath that on which the geologist is standing are all red weathered zones.

is evident from consideration of the blanket sand west of Andros Island in figure 26, the gross setting of this sand body type is that area bounded by the relatively high energy deposits related to slope breaks at the platform edge and by the relatively low energy sediments related to shadows of low energy in the lee of obstacles to current movement, such as Andros Island.

The internal structure of the sand blankets for the most part records the work of burrowing organisms. In many cores this work is revealed by the appearance of discrete burrows (fig. 27). In other examples organic churning is so extensive that individual burrows are obscured. The orientation of long axes of grains at all angles to the depositional horizon may be the only indication of this churning.

There are some relatively widely spaced (2 or more feet apart), horizontal bedding planes





(a) (b)

FIG. 24.—Large scale eolian cross-bed sets. (a) Single, large-scale fore-set with small spillover lobes at its crest. The relief of this road cut is approximately 60 feet. (b) Large-scale fore-set truncated by back-set beds. The view is approximately 10 feet from top to base.

marked by the occurrence of (1) coarse lags representing violent reworking by occasional large storms and (2) cemented horizons resulting from submarine cementation during periods of relative stagnancy, when sediments are not moved by currents. A larger-scale vertical subdivision of these platform interior sands probably results from periods of exposure, during which subaerial weathering and cementation produce well-defined unconformities.

Platform interior sands may contain a significant mud fraction. This is especially true for that part of the sand blanket that is adjacent to the muddy, low-energy shadow in the lee of large barriers. The amount of mud contained in the pelletoidal sand blanket increases in the direction of the shadow until the muddy sand eventually becomes a sandy carbonate mud.

The open platform interior sands are clean, and thin oolitic coats are common on these hard pelletoidal grains. Despite current activity sufficient to coat many of the grains, the arrangement of these clean sands by the currents is at

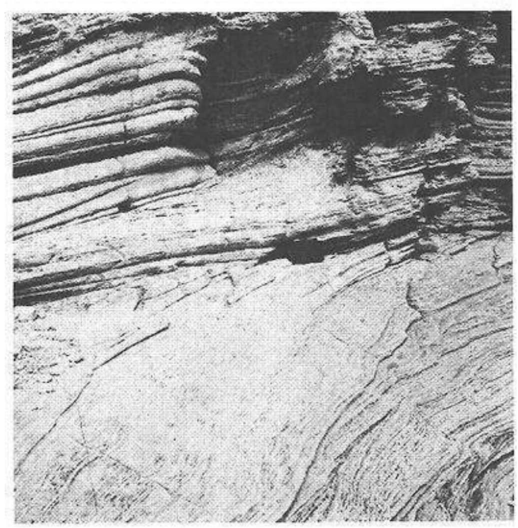
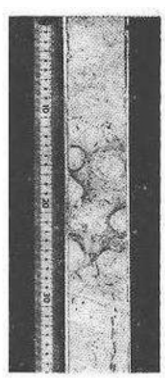


FIG. 25.—Thin cross-laminae in fine eolian crabonate sand. The notebook in the center of this view is 8 inches long.

FIG. 26.—Location of platform interior sand blankets. Platform interior sand blankets are indicated in gray.



a pace that lags far behind the rate of reworking by organisms. Figure 28 summarizes schematically the internal structure and composition of the platform interior sand blanket west of Andros Island.

FIG. 27.—Burrowed platform interior sand. Scale is in centimeters.

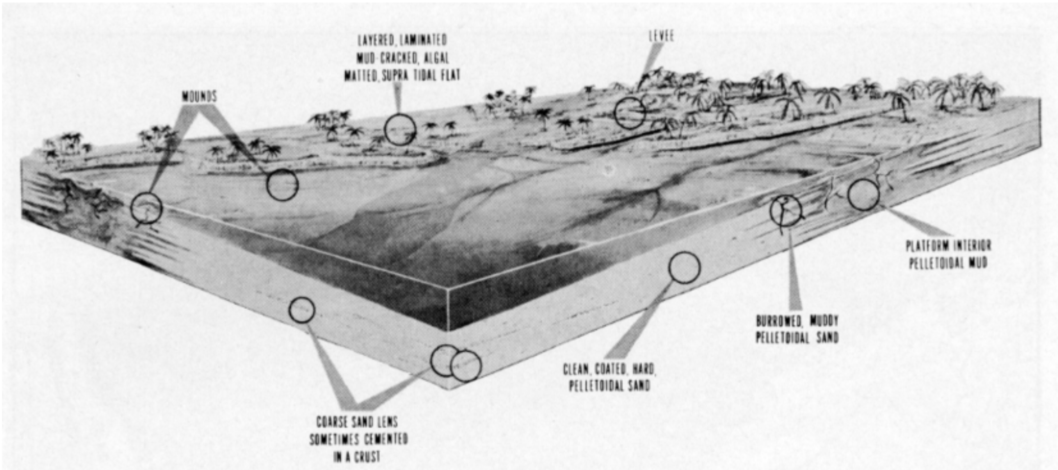


FIG. 28.—Schematic block diagram of platform interior sand blanket west of Andros Island.

VARIATIONS IN THE CHARACTERISTICS OF SAND BODIES

This section treats some of the variations of marine sand belts, tidal bar belts, eolian ridges, and platform interior sand blankets. The purpose of this treatment is to establish more concisely the general characteristics of these sand body types.

Marine Sand Belts

The size of slope break effective in concentrating sands varies between extremes represented by high platform edge escarpments such as those of Florida and the Bahamas and the minute edges of shoals in the interior of these platforms.

The example of the Cat Cay sands illustrates one end of this spectrum. The incipient, discontinuous sand belt on the western edge of the mud accumulation in Florida Bay is an example of the other extreme. This sand belt lies in the interior of the Florida platform. The belt is at least 100 miles from the only platform edge across which currents have free access to the belt (fig. 29). The broad expanse of drowned platform west of the sand belt forms a ramp that rises almost imperceptibly to the east. The edge of the mud blanket of Florida Bay forms a small but sharp break in slope. Relief upon this slope break is less than 10 feet. This is sufficient to cause a concentration of skeletal sands in a a belt along the crest of the break.

Storm winds and tides were the source for the currents that shaped the spillover lobes and medium-scale ripples visible on the surface of this sand belt (fig. 30). Everglades National Park rangers fly weekly over this part of Florida Bay. The various spillover lobes and ripples seen in figure 30 were first sighted by the rangers during the week after hurricane Donna. The en- this sand belt (fig. 30). Everglades National ulation built by increments during each of the storms that have affected this area during late Recent times. These marine sands were deposited during storm flood tides. When these tides ebbed, some of the higher parts of the sand belt were exposed above normal high water. Beaches have subsequently formed on the seaward or open water side of the resulting islands. The relationship of the cross-bedded internal structure indicated by surface features to the belt's shape and setting is, with the exception of the occurrence of the beach bedding, the same as that of the Cat Cay sand belt; i.e., the cross-beds dip across the belt and away from deeper or more open water.

Tidal Bar Belts

The setting of a tidal bar belt is invariably one that promotes strong currents. Embayments such as Tongue of the Ocean, Exuma Sound, and Northwest Channel (fig. 14) are all examples of a particular setting that gives rise to strong currents by amplification of tidal flow. These examples are, however, representative of only a single special case in the over-all class of settings to which we may refer as embayments. Their case is special in that the thresholds at the ends of these embayments distort tidal waves, but these shallow thresholds do not obstruct the outflow of the strong tidal current that results from the wave distortion.

In contemporary quartz sand depositional environments, there are many examples (Bay of Fundy, Delaware Bay, the Wash, etc.) of embayments that are closed so that they allow no

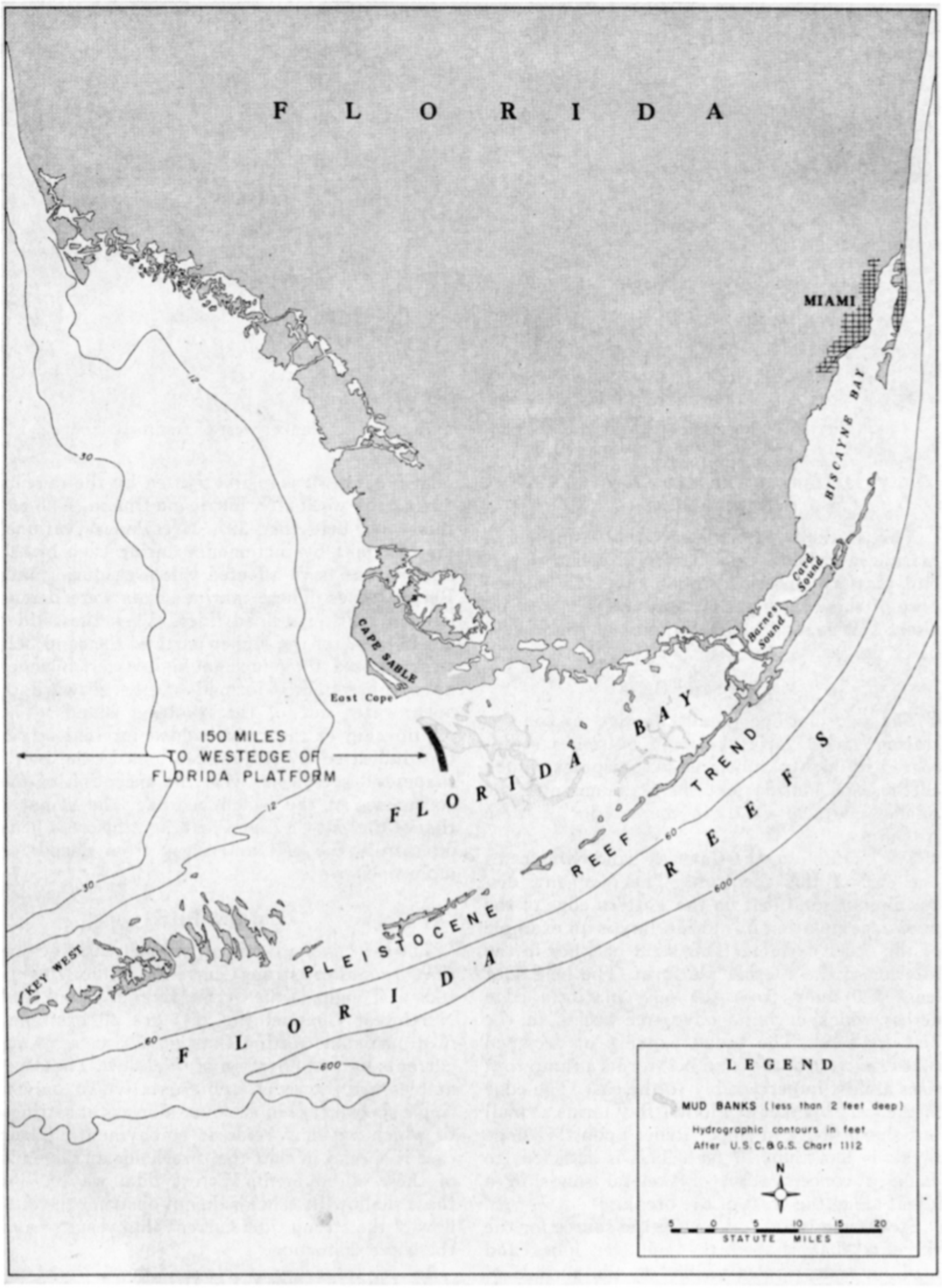


FIG. 29.—Sand belt at west edge of Florida Bay mud accumulation. Black indicates location of sand belt rimming the west edge of the mud accumulation in Florida Bay.

flow of tidal currents to develop in order to relieve tidal waves that are distorted at their ends. In these completely closed embayments, exceptionally high tidal ranges occur at the embayment ends (up to 50 feet in the Bay of Fundy and 20 feet in the Wash), and tidal currents are channeled along the embayment axes and in the embayment mouths, where sands are concentrated in response to these currents.

Straits present another setting in which tidal currents are intensified, and tidal bar belts may occur as a result of this intensification (See Off, 1963 for references). Where these straits are regional in their extent, as in the combined North Sea and Dover Straits (fig. 31), current amplification sufficient for the development of large tidal bar belts may occur only where there is added obstruction to flow due to vertical constriction over shoals. The tidal bar belt off the Norfolk headland (fig. 31) is an example in which perhaps both lateral and vertical constriction play a part in the origin and direction of the currents responsible for the sand accumulation. The individual tidal bars in this belt are up to 30 miles long, 1 mile wide, and 50 feet thick. In every dimension these quartz sand bars surpass the largest of our carbonate examples, yet the relief of the shoal upon which these North Sea tidal bars lie is less than 100 feet. It follows that shoals rising from oceanic depths such as the platform edges at the south end of Tongue of the Ocean and the north end of Exuma Sound are not necessary for the formation of large tidal bar belts.

Tidal bar belts do occur on a much more local scale than that of the Schooner Cay, Tongue of the Ocean, and North Sea examples. The Safety Valve sands on Biscayne Flats (fig. 32), just east of Miami, Florida, provide good examples of some of the differences between small tidal bar

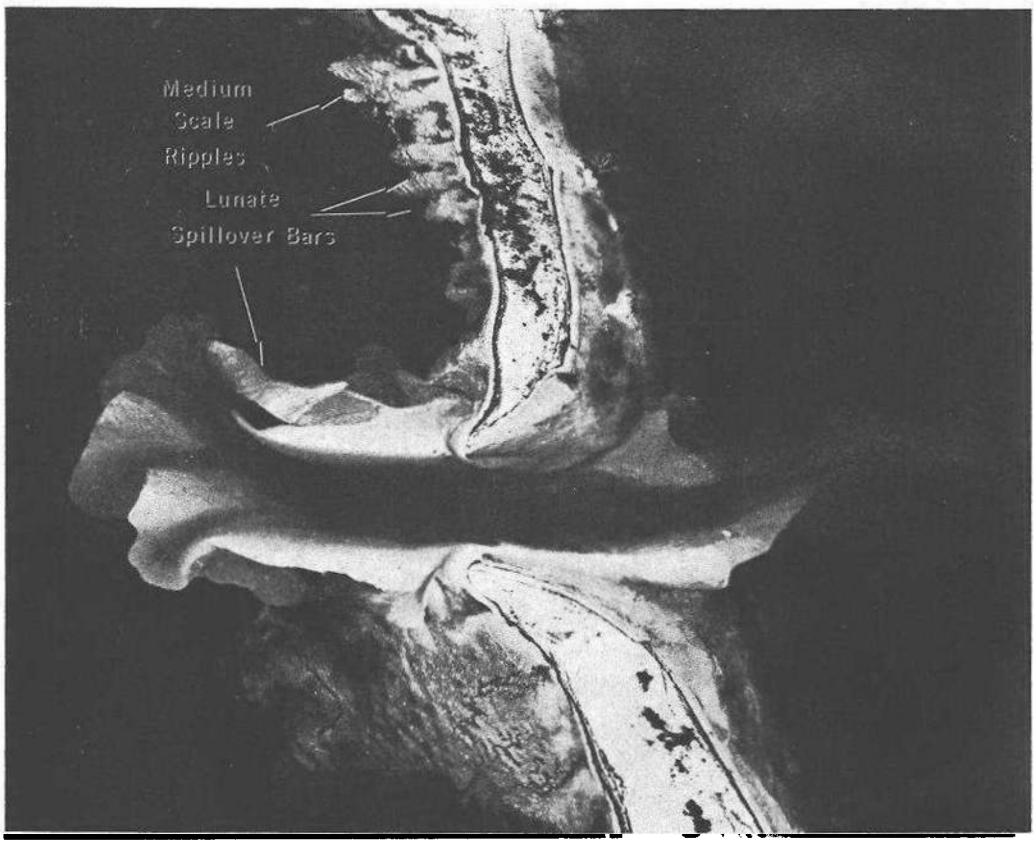


FIG. 30.—Spillover lobes and medium-scale ripples on Sand Key, western Florida Bay. The view is toward the south. The breach in the island and the large spillover lobe (300 feet wide) built eastward into the platform interior at its end, together with the smaller spillover lobes and medium-scale ripples, were all formed during hurricane Donna, September 10, 1960.

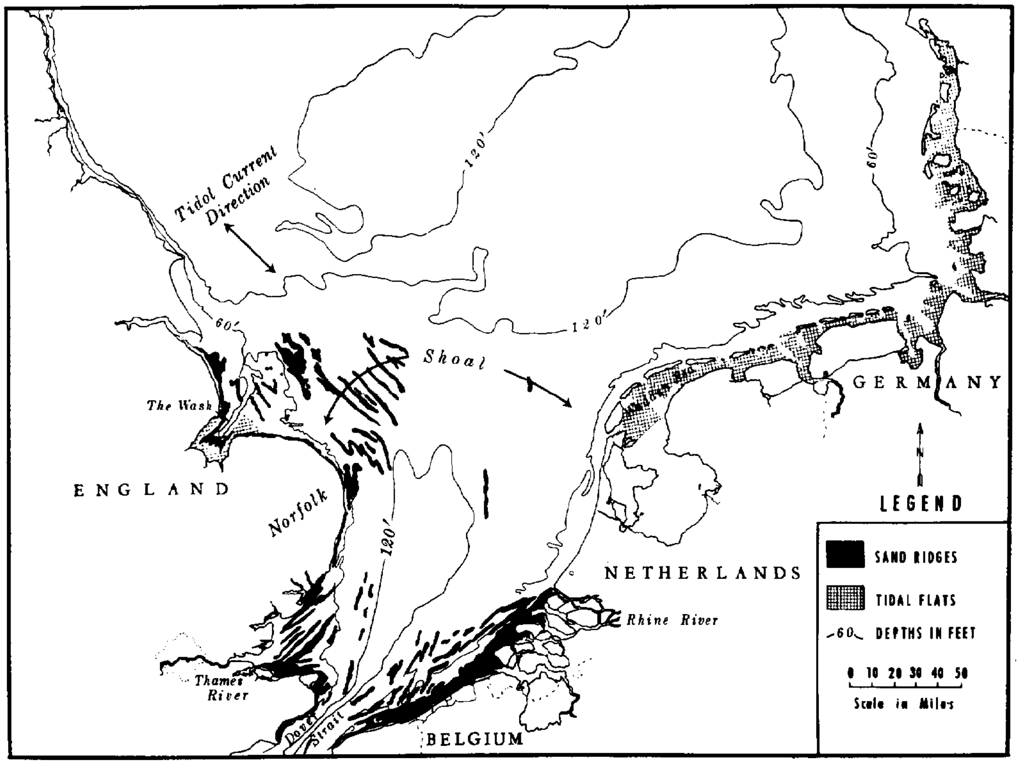


FIG. 31.—North Sea and Dover Straits.

belts and the larger belts such as that described at Schooner Cays.

At the Safety Valves a small slope break and very shallow threshold at the edge of a linear, muddy algal plate bank have resulted in high enough current velocity to initiate a digitate pattern of flow across the bank. This flow pattern has impressed itself upon the bank and has eroded narrow but more or less evenly spaced channels, with the resulting shallow interareas remaining as bars. The current velocities in the channels are sufficient to winnow and clean the algal plate sand grains but are insufficient to carry these grains either platformward or seaward from the channel ends. The result is a belt of bars and channels, in which the bars consist of algal plate (Halimeda) packstone or wackestone with lime mud and quartz silt filling the interstices between or separating the algal plates (fig. 33), and channel floor sediments are composed of current cleaned and sorted algal plate sands.

This is opposite to the Schooner Cay tidal bar belt in that in the latter the bars were composed of current cleaned and sorted sands bounded by channels that were floored largely by muddy pelletoidal sands. The channel currents at Schooner Cays are much stronger than those at the Safety Valves (3 versus 1 knot) and do not allow significant accumulation of sand upon the channel floor. On the bar crests a delicate balance of current velocity allows more or less continuous back-and-forth movement of oolitic sand grains with each change of the tide with insufficient net movement to remove these grains from the bar crests. In this state of almost continuous agitation the oolitic grains are coated, and the bar crest grows at the same time that the channel floor is being downcut to increase further the relief of the bars.

Eolian Ridges

The size of eolian ridges differs with setting. The largest carbonate dunes, those with thicknesses of 100 to 150 feet, occur on east edges of the platforms. This is where exposure to the prevailing east winds provides the continual wave action that is most effective in making a sand

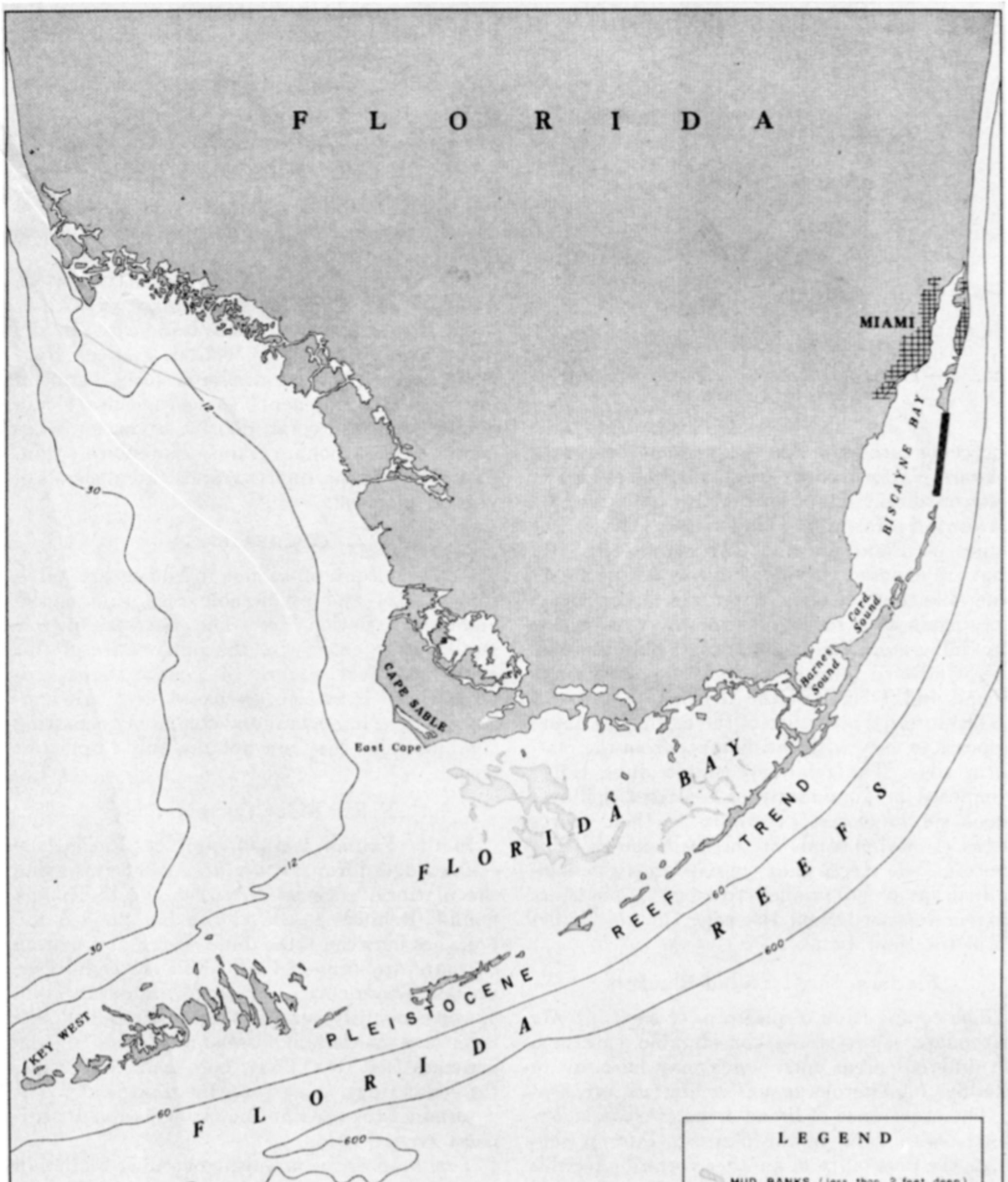


FIG. 32.—Location of Safety Valve sands tidal bar belt. Bar marks the position of this tidal bar belt.

FIG. 33.—Tidal bar composed of algal plate packstone. Scale is in centimeters.

source for carbonate dunes. Dunes on the west or leeward platform edges are small (30 feet high or less) or absent. Dune size is also influenced by downwind proximity of land masses. That is, the dunes on Eleuthera and Cat islands (fig. 20), that are exposed to winds blowing across a considerable fetch of open water, are larger (probably again as a result of stronger wave action providing more building material) than those on the windward platform edges of both Exuma Sound and Tongue of the Ocean.

The internal structure of the carbonate dunes appears to vary with the distance from the platform edge. The relatively stable dune ridges composed predominantly of coalesced spillover lobes are in closest proximity to their source areas of marine sands at the shelf margin. The more mobile ridges that consist largely of individual, large, subparallel cross-bed fore-sets are farther removed from the edge (up to 5 miles from the slope break).

Platform Interior Sand Blankets

The composition of platform or shelf interior carbonate sands shows considerable variation. In different areas such sands may be clean or muddy, fossiliferous or unfossiliferous, etc.

The occurrence of broad areas of clean superficial oolitic sand in the platform interior suggests the possibility of another variation for this sand body type that we have not encountered in Florida and the Bahamas. The clean superficial oolitic sands testify to a level of current activity that prevents deposition of mud. One can imagine a slightly higher level of current energies extant in a platform interior that might cause rate of sediment reworking by currents to exceed that of reworking by organisms. In this hypothetical instance we should expect to see a blanket type deposit containing aligned grains and perhaps cross-bed sets with no particularly well defined orientation, since no variation of bottom topography would exist to direct the wind-driven currents that would make this internal structure.

Tabular Summary of General Attributes of Carbonate Sand Bodies

Table 1 contains a summary of the general characteristics of the four carbonate sand bodies described in this report.

The variety of particle types that may be found as predominant or subordinate grain kinds in the platform interior sands is indicated by the following list: pelletoids, oolites, mollusk fragments, algal plates, foraminifer tests, ostracod tests, echinoid fragments, sponge spicules, alcyonarian spicules, coral debris, bryozoan fragments, dark carbonate grains of unknown origin, phosphatic grains, quartz grains, and macerals of vegetal material.

COMBINATIONS

Combinations of sediment bodies are often recognizable and predictable results of cause-and-effect relationships. The purpose of this section is to emphasize the importance of this cause-and-effect nature of combinations. Although the examples discussed here are considered to be important and commonly occurring combinations, they are not the only important ones.

Eolian Ridge Combinations

In the Exuma Islands (fig. 26), Pleistocene eolian ridges form a discontinuous barrier along the platform edge on the west side of Exuma Sound. Relative sea level rise has flooded the breaches between these dune ridges, and marine currents are funneled into and through these breaks. These currents control the distribution of contemporary marine sands that build platformward in deltalike fashion at each of the breaches (fig. 34). Thus, one sand body type, the eolian ridge, constitutes the topography that determines the distribution of a subsequent sediment accumulation.

The dune ridges are also governing factors in control of distribution of another type of sediment accumulation. Where the ridges are sufficiently large, they frequently create a lee shadow of low energy in which muddy sediments accumulate. These muds provide source material for tidal flats that eventually accrete platformward and cap the sequence (fig. 35). This combination of sediment bodies—eolian ridges, tidal bars, platform interior muds, and tidal flats—occurs on all scales related to eolian island barriers ranging from a few miles long to up to 90 miles long in the case of Andros Island.

Cape Sands

Another combination of sand bodies occurs off the capes or headlands formed at the ends of islands. Currents are constricted against island barriers and are deflected and refracted so that they flow around their end (fig. 36a). Initially, the constriction of these currents ceases as soon as they round the barrier end or cape, and at this point their velocities accordingly decrease, and they commence to deposit the sediment which they carried. These deposits first build a submarine extension from the cape onto the platform (fig. 36b). Subsequent wave and current action builds up this extension and causes its capeward end to become emergent (fig. 36c). Currents then continue to flow around the cape, move laterally along the spit, and deposit more sediment, where current constriction ceases, at the end of the spit or bar. Thus, the spit lengthens as a sequence of sedimentary structures which are diagnostic of a regressive shoreline built by longshore currents is formed (fig. 36d). This sequence consists of a basal unit of cross-bedded marine sands dipping parallel to the strike of beach beds that have accreted over them to cap the sequence.

A Pleistocene sequence that crops out on the west end of New Providence Island records the southwesterly extension of a spit from a cape formed on the west end of the island. This sequence is composed of a basal unit of festoon cross-bedded marine sands, with cross-bed dip direction to the southwest, overlain by a conglomerate that marks the base of a capping unit of beach bedding whose direction of low-angle inclination is to the northwest (fig. 37). The

FIG. 34.—Marine sands around breaches between eolian ridges that constitute the Exuma Islands. The view is toward the north. The white carbonate sands are building platformward (west) around the breaks between the eolian ridge islands.

TABLE 1.—*Attributes of carbonate sand bodies*

	Marine Sand Belt	Tidal Bar Belt	Eolian Ridge	Platform Interior Sand Blanket
Setting	Slope break.	May be slope break at end of embayment, or in straits, or in mouth or along axis of closed-off embayment.	Adjacent to areas where marine sands have been concentrated, such as at the platform or shelf edge.	Platform interior.
Geometry	Belt parallel to slope break.	Belt parallel to slope break composed of equally spaced and sized bars oriented perpendicular to belt's long axis.	Ridge parallel to slope break where marine sands are concentrated.	Blanket.
Internal Structure	Cross-beds dipping perpendicular to belt's long axis with largest sets at base and dipping predominantly away from deeper or more open water.	Cross-beds dipping perpendicular to long axes of bars in the bar crests and parallel to channel axes in the channels.	Large-scale spill-over or parallel cross-bed sets dipping perpendicular to ridge long axis and toward the platform interior.	Burrows and churns.
Composition	Skeletal, pelletoidal, or oolitic with whole marine megaskeletons and varying amounts of fibrous aragonite cement.	Skeletal, pelletoidal, or oolitic with whole marine megaskeletons and varying amounts of fibrous aragonite cement.	Skeletal, pelletoidal, or oolitic with land snails as megaskeletons and varying amounts of calcite mosaic cement.	Skeletal, pelletoidal, or oolitic with admixture of fines, whole marine skeletons, and fibrous aragonite cement.

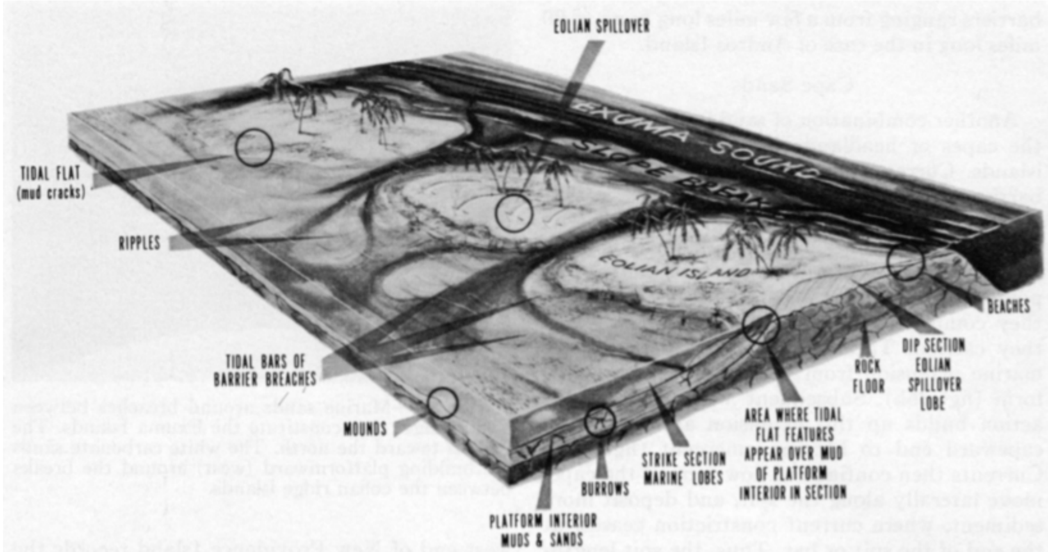


FIG. 35.—Schematic block diagram of combination of sediment bodies associated with eolian ridges forming the Exuma Islands.

conglomeratic zone contains rounded, cobble and boulder size fragments of bedded and cemented skeletal sand similar to that in the undisrupted beach beds. These fragments were probably broken from a penecontemporaneously cemented beach rock like those that are so commonly formed in the intertidal zone on tropical beaches. The lower end of the beach bedding in some instances terminates in a steeply dipping set of fore-set cross-beds dipping northwest and composed of coarse, worn skeletal debris with contained beach rock fragments. These steep fore-set cross-beds are the internal structure of parallel ripples formed at the base of the beach by backwash of breaking waves.

Spit accretion similar to that recorded in the Pleistocene outcrop described above can be observed in operation on the spit extending southeastward from the cape formed by the north end

(a)

(b)

FIG. 36.—Schematic block diagrams showing spit accretion off capes formed by ends of barrier islands. (a) Waves from deeper or more open water on the windward side of the island are refracted into the island, constricted against it, and the resulting currents are directed along it to be ultimately refracted about its end. (b) Once past the constriction of the island's windward shoreline, the currents weaken and deposit sediments to form a submarine bar or spit projecting leeward from the island end or cape.

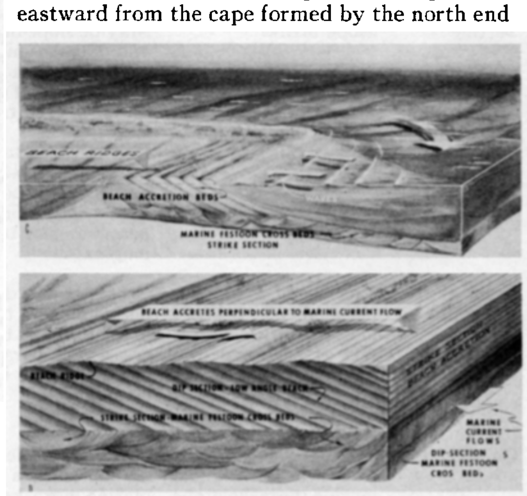


FIG. 36.—(c) Waves refracted onto the bar build it above sea level and rework the upper part of the sand into beach accretion bedding. (d) This sequence is diagnostic of regressive shoreline built by longshore currents.

of the island of Bimini (figure 38) on the northwest corner of the Great Bahama Bank. Bimini is a Pleistocene eolian ridge that constitutes a barrier to the waves and currents approaching the platform edge from the deep waters of Florida Straits. Currents from the straits are constricted against this barrier and are deflected and refracted so that they flow around its end and, as indicated by the orientation of offshore ripple marks (fig. 38), move laterally along the foot of the spit, shepherding sand as they go. This sand is eventually added at the spit's end. Thus, the spit continues to grow to the southeast as the beaches that cap it (as shown by the beach accretion ridges, fig. 38) accrete toward the northeast.

Consideration of contemporary terrigenous clastic capes (fig. 39) shows that vertical constriction over the sand shoals at the ends of capes may be sufficient to initiate a pattern of flow across the shoals which results in the subdivision of the shoal into approximately equally spaced and sized bars trending across it. When the cape consists of an offset shoreline (fig. 39a) and is built by longshore currents, these bars have tidal bar orientation; that is, they are perpendicular to regional depositional strike or shoreline trend. When the cape consists of a shoreline promontory extending out into the sea (fig. 39b) and is extended by longshore currents, the individual bars on the submarine spit have a longshore trend. From figure 39, it is apparent that the shoals off capes are often ornamented by approximately equally sized and spaced bars. The bars show considerable variety in scale, orientation relative to shoreline trend, and curvature from shoal to shoal.

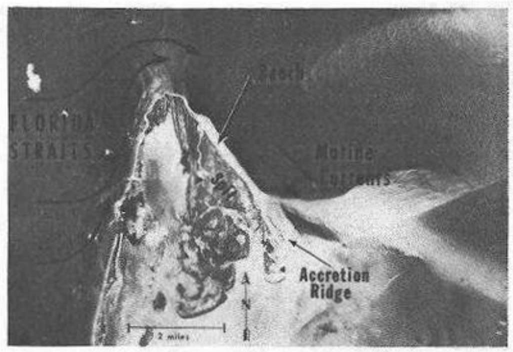


FIG. 38.—Air photo of spit accreting southeast from the north end of the island of Bimini.

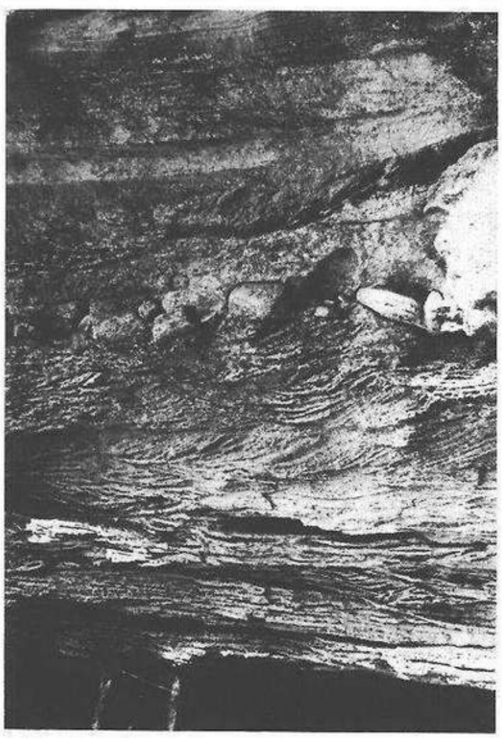


FIG. 37.—A Pleistocene sequence resulting from spit accretion. The view is approximately 5 feet from top to bottom.

The evolution of the combination of sand bodies grouped under the heading cape sands provides still another example of the applicability of the rule that hydrographic setting controls the currents that initiate and shape sand concentrations. The cape sand combination is, however, exceptional in that a host of different sand bodies—beaches, dunes, spits, and belts of bars—together with low-energy deposits in the lees created by the sand bodies may all emerge in a chain reaction set off by the influence of a coastal promontory, an offset shoreline, or the end of a barrier island upon the current pattern.

SUMMARY

Main Conclusion

The implication of the interrelationship of topography with sand body orientation, shape, internal structure, and composition is that knowledge of a sand body's topographic setting enables us to predict its other attributes. It follows that reconstruction of the regional topographic setting for the time of deposition of the particular subsurface formation is an important step in establishing the distribution of sand bodies within this formation.

Processes

The water motions caused by various sources of energy, such as winds and tides, are all basi-

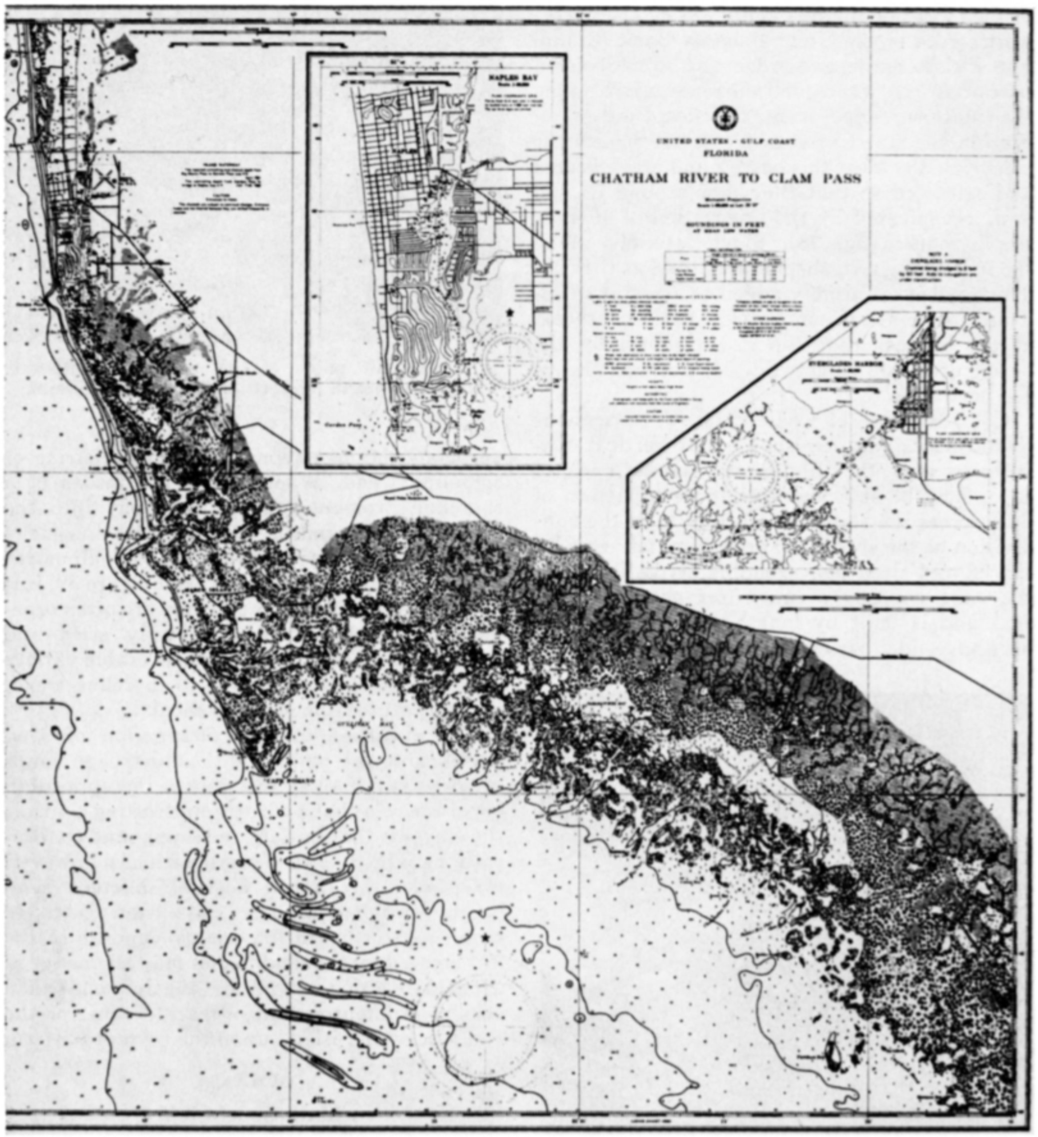


FIG. 39a.—Contemporary terrigenous clastic capes. Cape Romano—Chatham River to Clam Pass.

cally the same. That is, they consist of oscillatory waves. Once such waves are influenced by bottom topography, several processes can be set into operation:

1) Waves can be amplified as a result of resonance (see pages 561–562).
2) Waves can be refracted (see page 557).
3) Waves can be distorted to form currents (see page 557).
4) Currents can be deflected by emerged topography (see page 582).
5) Currents can be refracted by submerged topography (see pages 569–570).
6) Currents can be channeled (see page 582).
7) The interface upon which moving water displaces adjacent water masses can become digitate (see pages 563–564).

The page references listed above give examples of specific processes and show how these processes affect sand body geometry.

Importance of Scale

The scale of the plan dimensions of bottom topography limits the scale of plan dimensions of the sand bodies that are formed in response to the currents which the topography controls. This means that we may infer sand bodies of sizes equal to or smaller than the topographic feature that controlled their accumulation. The scale of vertical dimensions of bottom topography does not seem so closely related to sand body size. That is, the ramp of 100-foot relief on the North Sea floor has larger bars related to it than the 5000-foot platform edge at the south end of Tongue of the Ocean.

Importance of Depth

Although the processes set off by constriction of water motion operate at all depths, there are some important differences in their operation at different depths. For instance, where vertical constriction on a topographic feature that rises

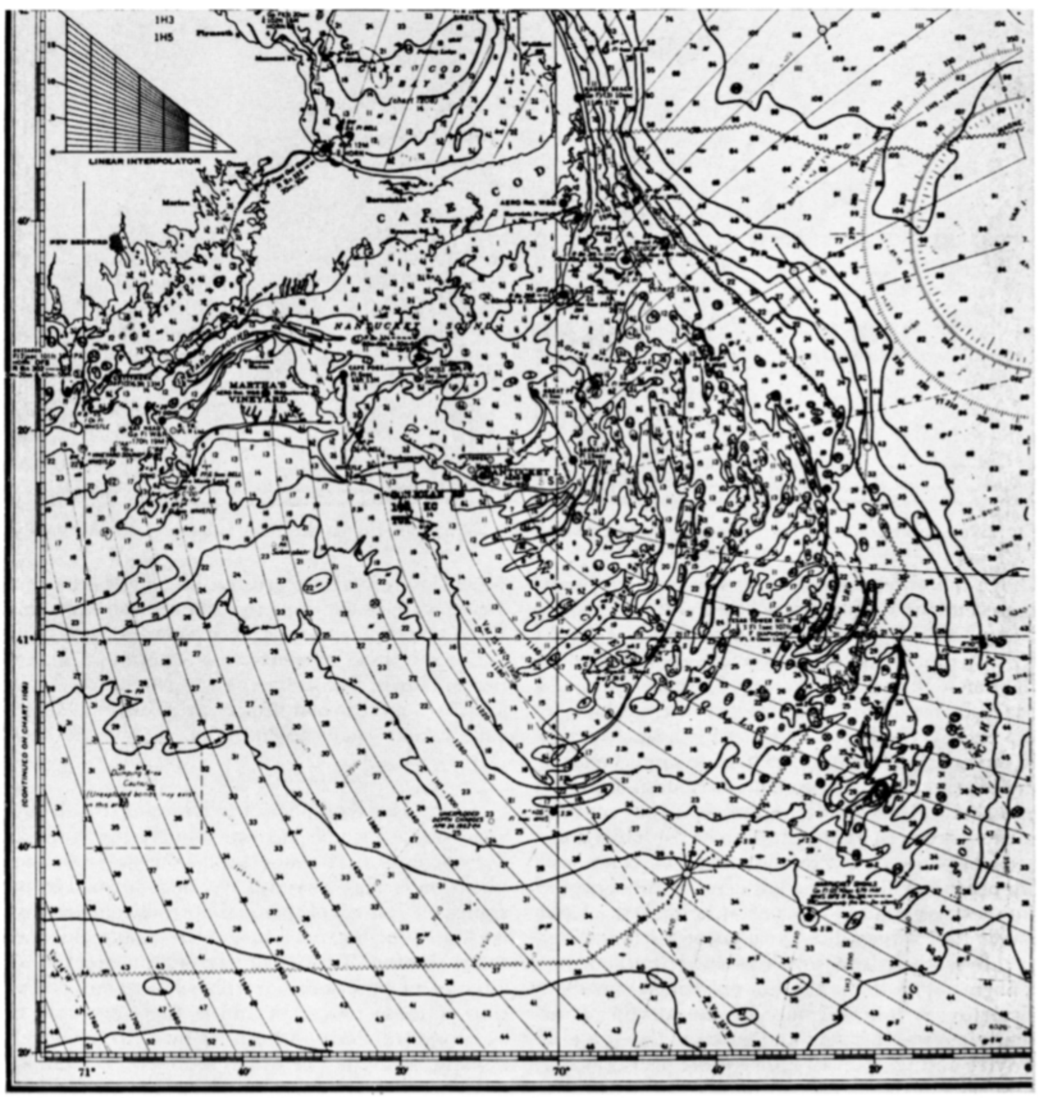


FIG. 39b.—Contemporary terrigenous clastic capes. Cape Cod—Nantucket Shoals.

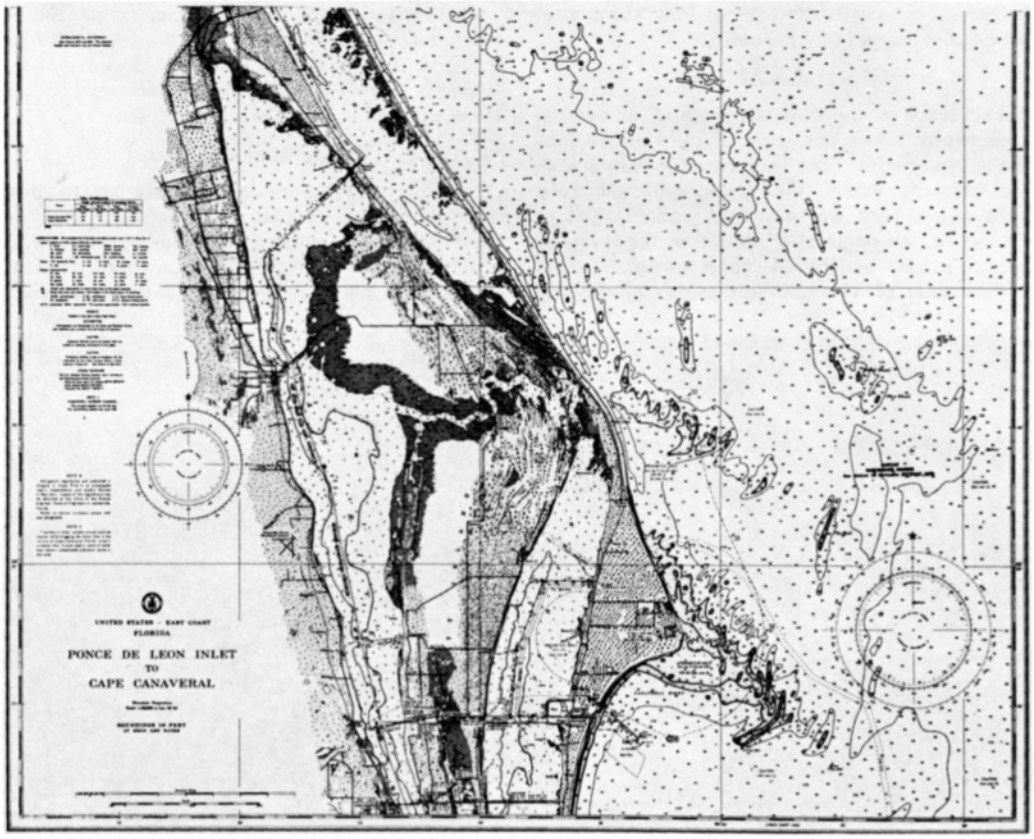


FIG. 39c.—Contemporary terrigenous clastic capes. Cape Kennedy—Ponce de Leon Inlet to Cape Kennedy.

above the water distorts waves to form currents, these currents must be relieved by flow, off or along the topographic feature. Sands concentrated in response to these currents may reflect the emerged topography by (1) their contained beach beds, (2) dips back to sea in cross-beds at the base of the beach beds, and (3) dips parallel to topographic highs in the marine sands beneath the beach beds. The same distortion on the crest of a shallow bar results in currents that may be entirely relieved by flowing across the bar. Cross-beds in sands reworked by these currents will dip perpendicular to the bar crest or topographic high across which the currents flowed. Tidal waves and waves due to subaqueous landslides in abyssal depths are distorted by bottom topography, but the motion resulting from their distortion is confined only by the inertia of the overlying water mass and not by the force of gravity acting upon an appreciable part of water mass within the wave, as would be the case for a wave at the surface. The result is that deep topographic barriers are not so efficient in constricting wave motions to form currents crossing their thresholds. Sands accumulated under the action of these currents may contain a higher percentage of fine sediment and would have only small-scale cross-bed sets as their internal structure rather than medium- or large-scale sets.

Regenerative Feedback

There is a complication inherent to all the processes by which bottom topography controls the currents that shape sand bodies. This complication is that a sand body, once formed in response to control of regional bottom topography, is itself local bottom topography that influences water motion. Thus, to a degree, the effect of an alliance of processes controls subsequent operation of these processes and is therefore able to exert an influence on both its own future development and that of other sediment accumulations in its vicinity.

This regenerative feedback is involved in the evolution of individual sand bodies and cause-and-effect combinations of sand bodies with other sediment accumulations.

At Schooner Cays (pages 563–564) the refraction of currents across tidal bar crests to create the distinctive facet of their internal structure, that is, cross-bed sets in the bar crests dipping perpendicular to the bar's long axis and parallel to belt trend, is an example of feedback.

Cause-and-effect combinations are all straightforward examples of regenerative feedback, whereby the construction of one sediment body alters the current pattern so that another sediment body is brought into being. In such combinations feedback determines both plan distribution and sequential relationship of sediment bodies.

Pictorial Summary

Figure 40 summarized different settings or topographic configurations that affect water motion.

Background Information

There are several facets of the contents of this report that qualify as important background information. First among these is the recognition that geometrically similar topographic settings, through their ability to affect currents in similar ways, will give rise to sediment bodies of similar

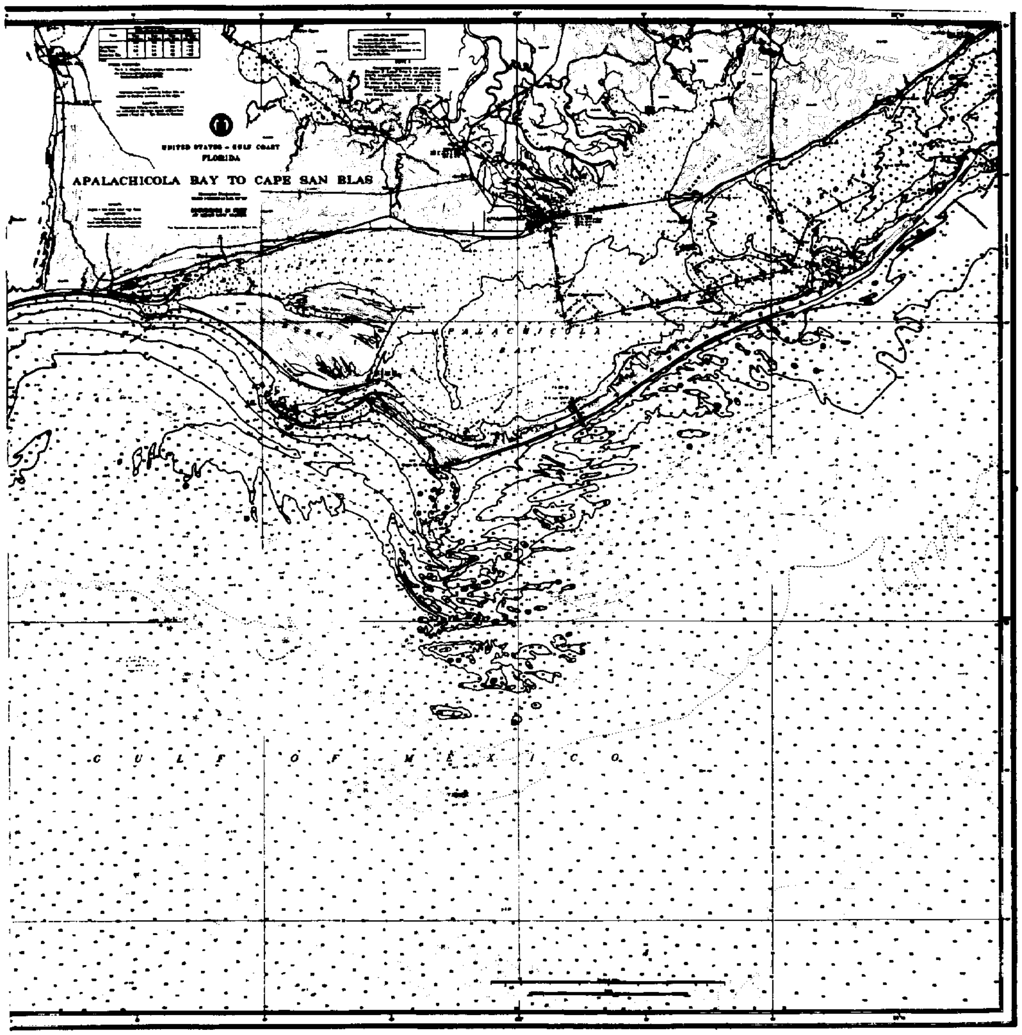


FIG. 39d.—Contemporary terrigenous clastic capes. Cape St. George—Apalachicola Bay to Cape San Blas.

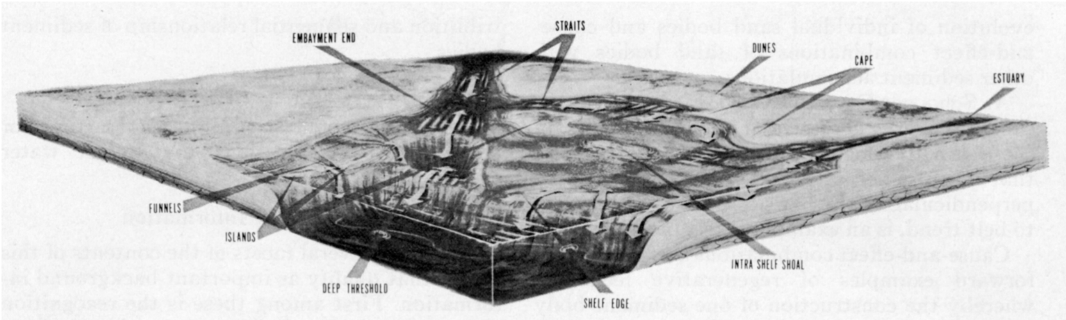


FIG. 40.—A schematic pictorial summary of the various bottom topographic features that influence water motion and that have been discussed in this report.

geometry, internal structure, and texture. Differences of grain kind of these sediment bodies may reflect climatic factors, such as clear, warm water necessary for growth of carbonate sand-producing organisms, or the availability of source material for a particular type of terrigenous clastic grain. Grain kind, therefore, is not so directly related to current setting and pattern as are sediment body shape, internal structure, and texture. Because of this we are able to see striking similarities between geometries of both carbonate and terrigenous clastic sand bodies in similar bottom topographic settings, that is, carbonate and quartz sand tidal bars, cape sand combinations, quartz barrier bars and marine carbonate sand belts, and quartz and carbonate shelf sands.

The differences of sand bodies of these two broad classes of sediment accumulation, quartz and carbonate, are often not nearly so numerous or well defined as their similarities. The reason for these similarities is that moving water reacts in the same fashion to a given topographic setting, regardless of the nature of the sedimentary particles upon which it acts.

Another addition to geologic background information is that what we read in the rocks may show us the strength and direction of currents but not the source or sources of current energy. Current is transitory water motion. Once set in motion, this water reacts to topography independently of the source of energy from which its motion stemmed. Tidal currents, wind-driven currents, and currents set in operation by earthquakes and landslides, depending upon their scale and velocity, react to similar topographic settings in the same way. The source of current energy and the influence of the material upon which the currents work are, at best, weak secondary controls upon the way in which the currents will behave.

Some of the words used in sediment body classification, such as tidal deposits or turbidities, are not applicable in their strict sense to studies of the rocks. We frequently avoid this difficulty by using these words that suggest source of current energy for something else, such as a particular orientation or setting. For instance, we refer to turbidites for deposits in relatively deep water adjacent to a slope or escarpment from which we believe the sediments were derived.

Classification of sediment body types accordding to their setting is argued for by this report because such classification focuses our attention on the paleogeographic application of this relationship, that is, the ability to relate the location and trend of sediment accumulations to their stratigraphic settings. Many of the semantic ambiguities of scale and orientation of sand body types disappear when one uses such a classification in working with the rocks because we interpret on the scale that we are able to reconstruct setting.

Finally, the recognition that sediment bodies themselves are in many instances topographic features capable of influencing currents, and the realization that this influence explains cause-and-effect combinations of sediment bodies together with their areal distributions and their sequences are important additions to the feeling for the dynamic nature of sediment accumulations in general and sand body types in particular.

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