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BEACH AND SHOREFACE OOID DEPOSITION ON SHALLOW INTERIOR BANKS, TURKS AND CAICOS ISLANDS, BRITISH WEST INDIES[1]

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ABSTRACT: Modern ooids are forming and accumulating as beach-dune complexes which face into and prograde across the very shallow, broad, low-energy Caicos Bank. This contrasts with other modern oolite occurrences that are located at shelf margins or at the heads of steep ramps facing deeper water where tidal energy plays an important role in ooid generation.

Ooid quality and distribution coupled with radiocarbon dating indicates that the Caicos ooids are forming in the beach and shoreface environment in response to wave and current agitation generated by prevailing southeasterly trade winds.

The Caicos model is a useful analog for many ancient sheetlike oolite accumulations deposited on broad, epeiric shelves or gently sloping ramps.

INTRODUCTION

The formation of oolitically coated grains requires three basic conditions: 1) exposure of nuclei to waters that are saturated with calcium carbonate; 2) episodic but persistent agitation of the nuclei in order to form smooth, uniform carbonate coatings; and 3) continuous replenishment of calcium carbonate at the site of deposition.

In modern accumulations of marine oolitic sands these conditions are met within a variety of depositional settings. At the Cat Cays, Schooner Cays, and south end of the Tongue of the Ocean in the northern Bahamas, ooids accumulate as submarine shoals along the edge of well-defined shelf margins (Ball 1967). At these locations it is generally accepted that calcium carbonate supersaturation comes about by the warming of cooler, open-marine waters as they move into the shoal environment during tidal exchange. At the same time, the strong tidal currents generated in these exposed settings stir up the sand grains and throw them into suspension, resulting in even oolitic coatings.

Oolitic sands of the Trucial Coast in the Persian Gulf accumulate as beach-dune complexes that form a chain of barrier islands each about 4 km long and separated by tidal passes (Evans et al. 1964). The barrier islands form the updip termination of a sloping depositional ramp which has a uniform dip of about 0.5 m/km into the center of the Gulf. Partially blocking the tidal passes are tidal deltas consisting of dominantly oolitic carbonate sands. Observations of sand movement during tidal exchange led Loreau and Purser (1973) to conclude that ooids originate on the tidal delta and are transported to the barrier islands by longshore currents. As with Bahamian ooids, calcium carbonate supersaturation and replenishment are believed to be a result of warming of open-marine waters as they move onto the shoal waters of tidal deltas.

Cancun Island on the northeastern Yucatán shelf is an accumulation of modern oolitic sands also in the form of a barrier-island beach-dune complex (Ward and Brady 1973). The island lies at an acute angle to the shelf margin at a distance ranging from 5 to 12 km from the edge. The shelf is a steep ramp with slopes of 5 to 10 m/km from the beach to the shelf edge.

Cancun Island is about 12 km long and has no tidal passes or deltas. Water depths are 4 to 5 m only 60 m from shore, and there are no offshore shoals to serve as a source of ooids. In the absence of any other source, Ward and Brady (1973) speculated that ooids are forming in the shoreface zone immediately seaward of the beach by landward and seaward surges that accompany passing waves.

Although each of these modern occurrences of oolites represents a different environmental setting, they are similar in that they all reflect deposition under relatively high-energy, open-marine conditions, with ready access to daily tidal exchange. As such, they serve as useful analogs for ancient oolites deposited on steep ramps or near-shelf margins with similar high-energy conditions (Bossellini et al. 1981; Serg and Lehmann 1986).

There are, however, many ancient oolites which appear to have been deposited as broad, sheetlike layers covering thousands of square kilometers in epeiric seas or very gently sloping ramp environments removed by hundreds of kilometers from any recognizable slope break or shelf margin with attendant high-energy tidal currents. Some examples include the Middle Mississippian of the Illinois

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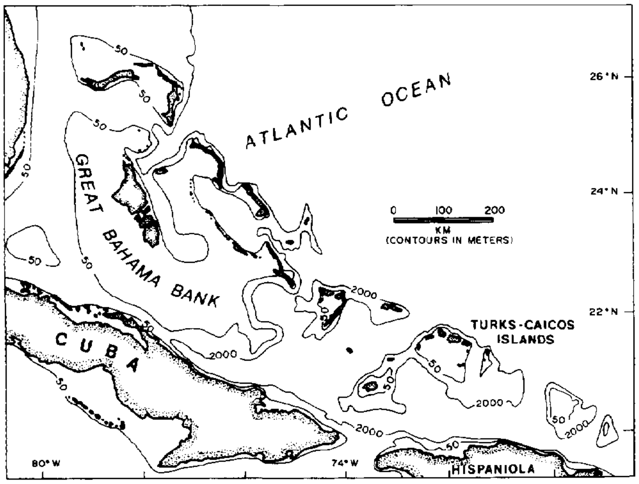

FIG. 1.—Index map showing regional setting of Turks and Caicos Islands.

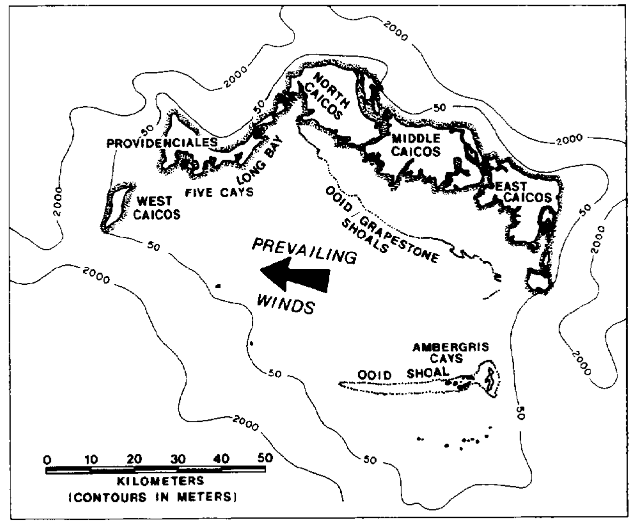

FIG. 2.—Index map of Caicos Bank. Ooid beach-dune complexes referred to in text are located at Long Bay and along the eastern shore of West Caicos. Note that these beaches face the open platform and are oriented into the prevailing winds. Other areas in which ooid sediments are accumulating are shoals south of North, Middle, and East Caicos and an elongate shoal west of Ambergris Cays.

Basin, the Pennsylvanian carbonates of the Mid-Continent, the Middle Jurassic of the Paris Basin, the Upper Jurassic of the Middle East, and the Upper Jurassic and Lower Cretaceous of the Gulf of Mexico Basin.

On the Caicos Bank in the southeastern Bahamas we have found areas of oolite deposition in a setting more like that of a broad, epeiric sea. Study of these areas provides some insight into the mechanisms of formation and deposition of these oolites which should be applicable to their ancient equivalents.

LOCATION

The Turks and Caicos Islands are located about 150 km north of Hispaniola near the southeastern end of the chain of Bahama Banks (Fig. 1). Caicos Bank measures roughly 60 by 100 km and has an area of about 6,700 km^2 (Fig. 2). The northwest, north, and northeast margins of the bank are rimmed by a chain of islands that have a Pleistocene rock core surrounded by Holocene deposits consisting of muddy tidal flats along low-energy, leeward shores, and accreting beach-dune complexes of skeletal and oolitic sands along higher-energy, windward shores. Islands occupy only 15 percent of the total bank surface with the remainder covered by shallow marine waters. Although no detailed bathymetric charts are available, observations from a few traverses coupled with aerial reconnaissance indicate water depths of 3 m or less over most of the submerged bank.

Modern oolitic sands are accumulating in four locations on the Caicos Bank (Fig. 2). Two of these represent submarine accumulations: an elongate oolitic sand spit projecting due west of the Ambergris Cays, and a series of en echelon ooid/grapestone bars paralleling the tidal flats of North, Middle, and East Caicos. The other two locations, which will be the focus of this report, are oolitic beach-dune complexes at Long Bay, Providenciales, and along the eastern shore of West Caicos Island (Fig. 2).

LONG BAY

Long Bay is a northeast-trending, linear beach approximately 5 km long that forms part of the southeastern margin of Providenciales Island (Figs. 2 and 3). Beach sand is medium-grained, well-sorted, and consists of well-rounded, oolitically coated particles with only a few percent of coarser, uncoated skeletal grains (Fig. 4A, B). Ooid nuclei consist primarily of peloids. The well-organized tangential crystal fabric characteristic of most modern Bahamian ooids is clearly discernible with the SEM (Fig. 4C). Intensive boring by endolithic microorganisms (Fig. 4D) makes it difficult at times to distinguish between nucleus and coating in thin sections (Fig. 4B). However, unbored zones within many grains indicate that the particles are true ooids with coatings as much as 100 μm in thickness.

The sand is about 2.5 m in thickness at the low-tide strandline, thinning rapidly in an offshore direction to less than 0.5 m. Nearshore sand is more poorly sorted than the beach sand and contains a higher proportion of skeletal fragments.

About 1 km offshore, a series of barlike sand buildups trend west-southwest and intersect Long Bay Beach at its southwestern extremity (Fig. 3). Individual buildups are of low relief (approximately 1.3 m from crest to trough) and are poorly defined laterally. They appear to be a series of sand waves migrating in a westerly direction over the Pleistocene rock floor. The sediment is fine to medium sand sized and appears to be mostly pelletal, although oolitically coated particles are present. At low tide the tops of the sand waves lie at a depth of 1.5 m with their surfaces ornamented by interference ripples. Under prevailing southeasterly tradewinds that average 10 knots, the only sand movement observed is oscillation at ripple

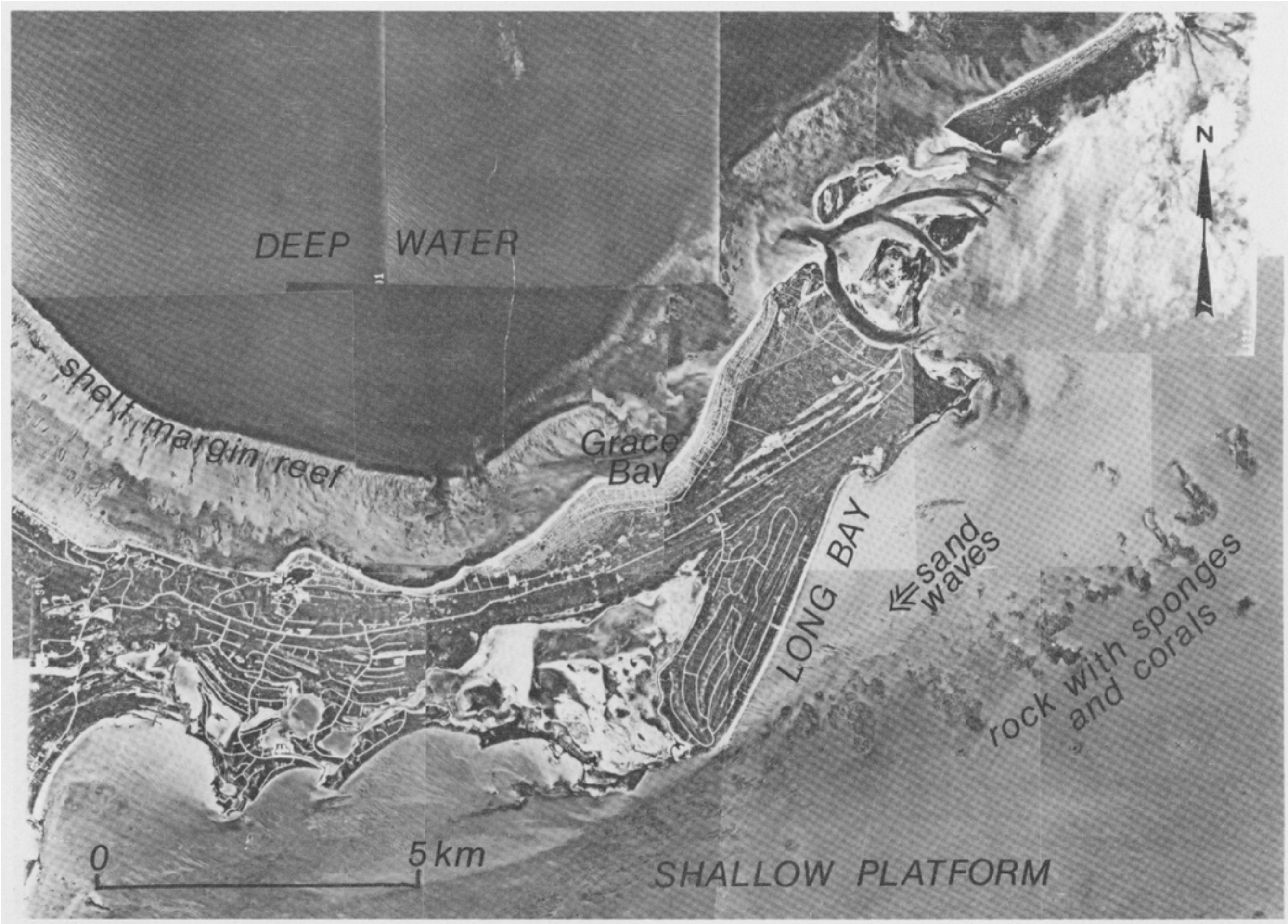

FIG. 3.—Aerial photo mosaic of eastern Providenciales Island ("Provo") showing the location of Long Bay. The offshore has a thin sediment cover over Pleistocene rock except for a NE-trending belt of low-relief sand waves. Onshore, Holocene sediment is confined to a band between the beach and the first road. Other NE-SW-trending roads mark prominent Pleistocene dune ridges.

crests. Because the open bank is very shallow and sheltered from the bank margins by islands or by long distances, the contribution of tidal exchange to bottom currents is minor compared to that produced by wind-generated currents. Sand-wave migration most likely takes place only episodically from currents generated by storm winds. Such episodic movement is unlikely to generate large volumes of oolitic coatings.

Shoreward of the Long Bay Beach, a storm berm has built up about 1.2 m above normal high tide. Landward of the berm is a Holocene dune standing 10 to 12 m above high tide (Fig. 4E). Both the berm and the dune consist of ooids identical to those found on the beach, but they are slightly lithified by calcite meniscus cement (Fig. 4F).

A parallel series of lithified Pleistocene dune ridges is found northwest of the Holocene dune crest. The positions and orientations of these Pleistocene dunes can be distinguished by the pattern of roads that have been constructed on the most prominent dune crests (Fig. 3).

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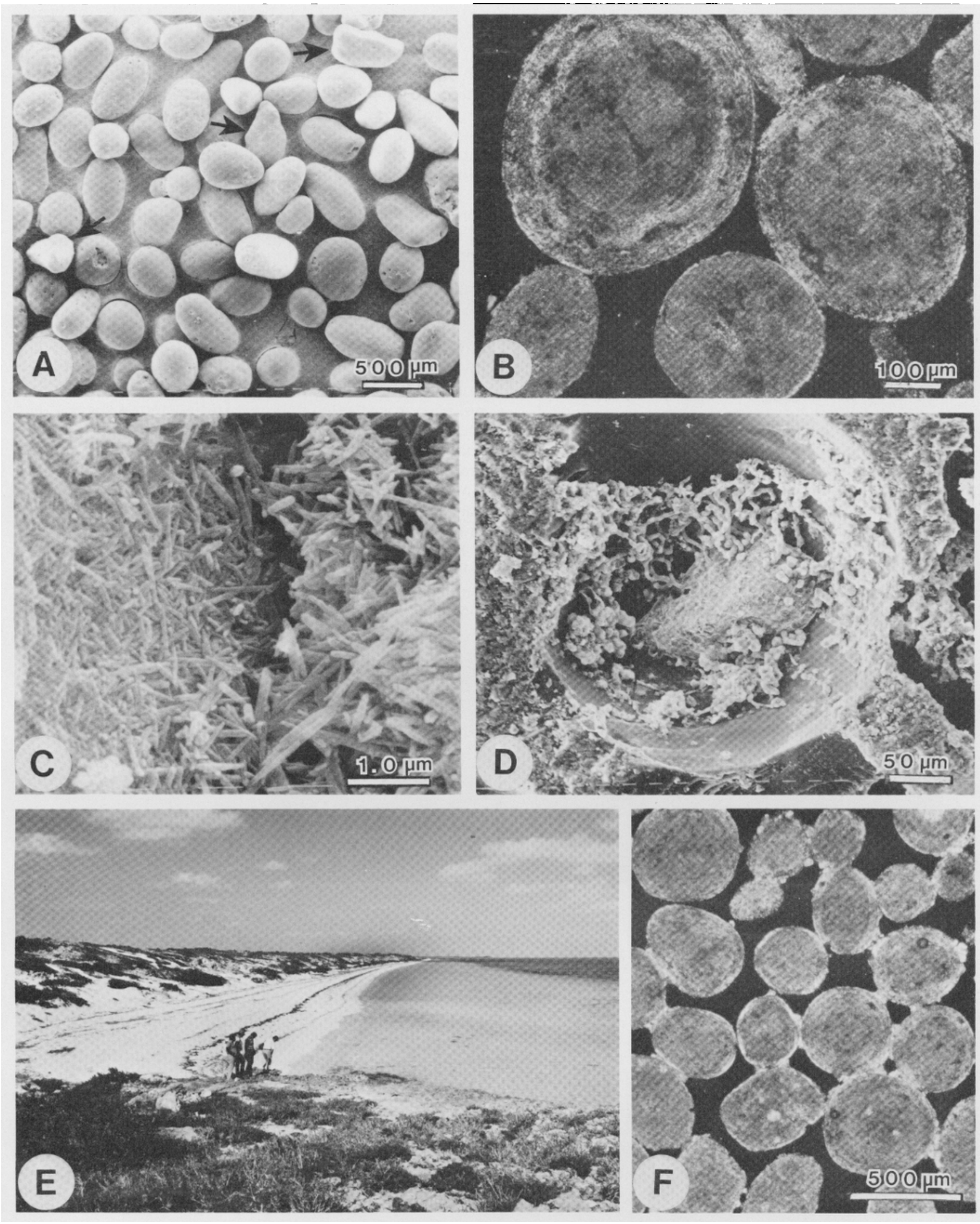
FIG. 4.—A) Oolitic beach sand from Long Bay. Note elongate nature of many of the grains reflecting pelletal nuclei as well as microborings and impact pits on outer surfaces. More irregular grains (arrows) are skeletal debris with thin oolitic coatings. B) Photomicrograph of ooids from Long Bay Beach. Note variation in thickness of oolitic coatings and micritized appearance of ooid nuclei. Cross-polarized light. C) SEM photomicrograph of broken ooid from Long Bay Beach showing variation in aragonite crystal size between two oolitic coatings. Note interlocking tangential orientation of crystals in left half of photo. D) Plastic casts of microboring organisms within an acid-etched ooid from Long Bay Beach. Extensive microbial degradation such as this results in micritization of ooids and loss of concentric structures. E) View of Long Bay beach-dune complex looking NE from a Pleistocene rock outlier at the southwest end of the beach. The Holocene dune crest is about 10 m above high tide. F) Photomicrograph of oolitic grainstone from storm berm about 1.5 m above high tide at Long Bay. Grains lightly cemented at point contacts with meniscus calcite. Radiocarbon age 770 yrs BP. Cross-polarized light.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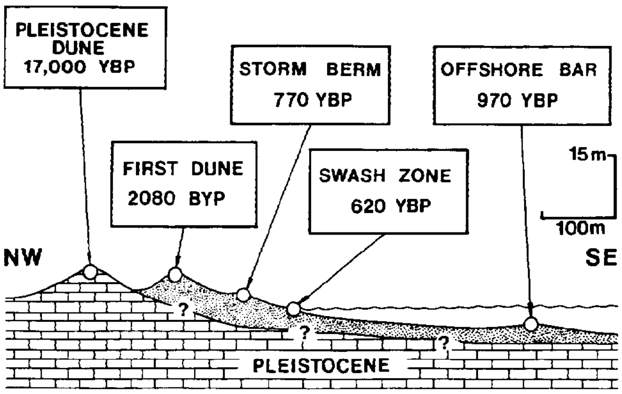

FIG. 5.—Schematic cross section at Long Bay showing radiocarbon ages of oolitic sediment and rock. The Pleistocene dune sample has been highly altered by subaerial diagenesis and undoubtedly has a much older depositional age than indicated by the radiocarbon date. Radiocarbon ages were determined by Beta Analytic. Data corrected for isotopic fractionation resulting in the addition of approximately 400 years to each dated sample.

Figure 5 is a schematic cross section of the Long Bay area showing radiocarbon ages of ooids collected at various localities (analyses were made on untreated bulk grab samples by Beta Analytical of Coral Gables). Dates are reported herein as radiocarbon years before present with a correction for carbon isotope fractionation by adding 400 years.

The most striking feature of these data is the very young ages of the beach and berm samples (620 and 770 ± 80 yrs BP, respectively). In contrast, bulk samples of beach and berm sediments from a skeletal beach at Grace Bay on the north shore of Providenciales (Fig. 3) dated 1190 ± 50 and 1330 ± 50 ka. These older ages are more characteristic of bulk samples of modern sediment, which usually contains a small portion of very young material mixed with older particles. Therefore, the Long Bay ooids must have very young nuclei, and the oolitic coatings must be forming very rapidly.

The Holocene dune sample was collected from lightly cemented rock at the top of the dune buried under 0.5 m of loose sand. The age (2080 yrs BP) suggests that it is part of a slightly older beach-dune complex.

WEST CAICOS ISLAND

West Caicos Island is located along the western margin of the Caicos Bank (Figs. 2 and 6). The western two-thirds of the island consists of Pleistocene rock that has not been investigated in detail. Initial studies suggest that the western margin has a slightly raised rim of exposed coralgal reef that has been partially covered by prograding grainstones of younger Pleistocene age (Wanless and Rossinsky 1986). The eastern margin of the Pleistocene core consists of north-northeast-trending dune ridges with elevations as great as 18 m.

East of the Pleistocene dune ridge lies a broad, flat salina that contains hypersaline waters and is floored by bedded gypsum and muddy, partially dolomitized Holocene carbonates. This salina is bounded on the east by

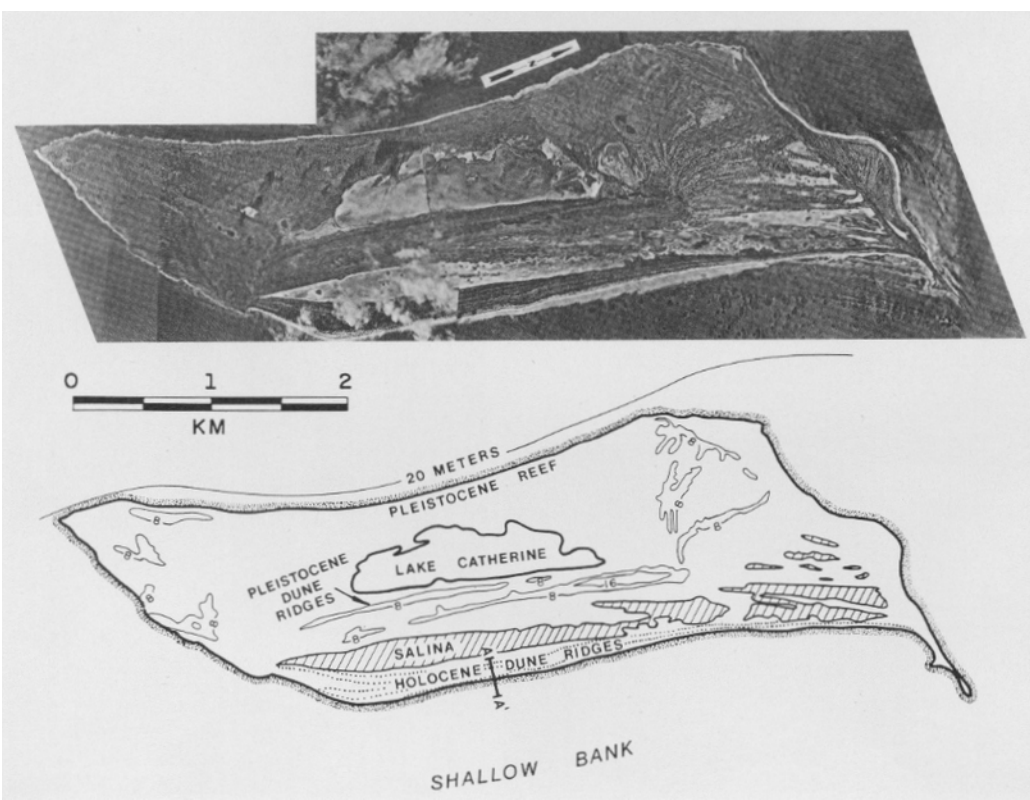

FIG. 6.—Aerial photo of West Caicos Island with corresponding map that indicates more salient features. Narrow, lighter-colored zone adjacent to eastern shore on photo delineates zone of active ooid growth. Map contours in meters. The linear feature crossing Lake Catherine is an abandoned railroad causeway once used for transporting sisal to the western shore.

a parallel set of Holocene oolitic dune ridges up to 16 m in elevation.

The configuration of Holocene ooid sand and oolitic grainstone deposits along the eastern shore of West Caicos is very similar to that of Long Bay with some notable differences: 1) at West Caicos, the Holocene consists of a series of prograding dune ridges building toward the bank, whereas at Long Bay there is only one dune ridge of Holocene age; 2) Holocene dunes at West Caicos are separated from the Pleistocene dunes by a salina; at Long Bay, the Holocene has accreted directly to the Pleistocene; 3) at West Caicos, the offshore bank is floored by exposed Pleistocene bedrock with a thin veneer of muddy sediment and lacks the migrating sand waves at Long Bay (cf. Figs. 3 and 6).

Shoreline Holocene sediments are predominantly oolitic with admixtures of uncoated skeletal grains that increase in abundance toward the northern end of the beach-dune complex. As at Long Bay, the beach sample yields a very young age (790 yrs BP). Dune samples show progressively younger ages from west to east reflecting the progradational nature of the accreting beach-dune complex (Fig. 7). The apparent reversal in age of the westernmost dune is probably due to diagenetic contamination from the addition of young carbon as calcite cement.

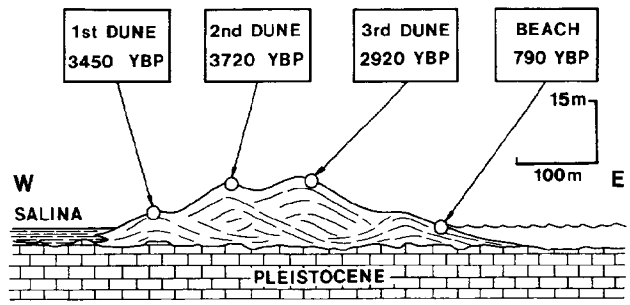

FIG. 7.—Schematic cross section of the prograding Holocene beach-dune complex at West Caicos along line A-A′ of Figure 6. The sample from the first dune to the west is well cemented, with young calcite resulting in an age reversal. The second and third dunes are only lightly cemented and the radiocarbon dates are probably close to the depositional age. Age data corrected for isotopic fractionation.

DISCUSSION

The very young age of the ooids in the beach zones at Long Bay and West Caicos as compared to the surrounding sediments and rock indicates that the formation of oolitic coatings is taking place in the beach environment. As shown in Figure 5, the slightly oolitic, pelletal sands of the sand waves offshore of Long Bay are older (970 yrs BP) than the better-developed oolitic beach sands (620 yrs BP) and therefore cannot be the main site of ooid formation. Offshore pelletal sands most likely provide nuclei that are subsequently more heavily coated in the beach environment. In the case of West Caicos, there are no offshore bars and the beach is clearly the site of ooid formation (Fig. 6).

The strandline swash zone should provide an excellent environment for ooid formation. With prevailing onshore wind, there is constant roiling of water and beach sand at all levels of the tide. This constant agitation degases water of its carbon dioxide, thereby raising the carbonate saturation, while simultaneously suspending the particles, allowing for uniform coating. As the tide rises, water comes in contact with sand particles that have been warmed by exposure to the sun, which elevates the temperature and accelerates degassing to further increase the carbonate saturation. The period of falling tide may well provide the "resting stage" that the experiments of Weyl (1967) and Davies et al. (1978) indicate is necessary for ooid growth.

Our observations of ooid formation are similar to those of Ward and Brady (1973) at Cancun Island on the Yucatán Shelf. They suggested that sites of ooid coating were in the subtidal shoreface environment immediately seaward of the beach, whereas we have emphasized the potential of the intertidal beach swash zone as the primary ooid factory. It is possible that both interpretations are correct and, in the absence of detailed petrographic and geochemical studies, ooids from either setting are probably indistinguishable. In either case, the source of energy for agitation is wind rather than tidal currents, allowing oolites to accumulate in areas far removed from high-energy ramps and shelf margins.

If the beach environment is so favorable for ooid formation, the question naturally arises—why don't all carbonate beaches have a large component of oolitic grains? For example, on the north side of Providenciales, there is an actively prograding beach complex of Holocene carbonate sands (Fig. 3) that is almost totally skeletal, with some pelletal and only rarely oolitically coated grains, perhaps brought in by storm winds. The great abundance of skeletal grains reflects the fact that northern beaches are part of a shelf-margin complex that is ecologically favorable for the development of coralgal reefs and associated organisms that yield prodigious quantities of skeletal carbonate. The preferential fixation of carbonate by organisms may effectively preclude any signigicant carbonate contribution from inorganic precipitation.

By contrast, the beaches at Long Bay and West Caicos face a broad, shallow bank that exhibits very low organic productivity. This probably results from a combination of circumstances. Organic nutrients are stripped from the open-ocean water as it crosses the eastern bank margin, leaving a water mass of reduced biological potential drifting westwardly across the bank. Shallow bank water is also subject to broader fluctuations in temperature, salinity, and turbidity, which would tend to reduce productivity. In any event, the central bank is populated by small, scattered patch reefs dominated by sponges and soft corals, a somewhat restricted molluscan fauna, and a variety of both calcifying and noncalcifying algae.

As the bank water drifts westward, it most likely maintains a state of saturation in equilibrium with carbonate bottom sediments. When this saturated water mass impinges on the beach, the combination of warming and agitation results in inorganic precipitation and the formation of ooids. In this light, the ooids might be considered particles of default; that is, in the absence of an active skeletal sink to fix most available carbonate, the system defaults to inorganic precipitation as oolitic coatings.

At Long Bay and West Caicos, the default mechanism appears obvious. The bankward-facing beaches represent the final carbonate depositional environment encountered by the westward-drifting bank waters. The rapid rate of oolite accumulation in the beach-dune complex indicated by the very young radiocarbon ages is not difficult to accept when one considers the dynamics of the system. Except for short-lived winter cold fronts and the occasional hurricane, there is a year-round, persistent southeasterly trade wind moving large volumes of water across the bank that provide both the raw materials and the energy of agitation for the "ooid factory." Given the rate of progradation indicated at West Caicos, the present system could produce a sheet of oolitic sand averaging 5 m thick that would extend to the eastern edge of the bank (approximately 120 km) in less than a million years.

GEOLOGICAL SIGNIFICANCE

The observations at Long Bay and West Caicos provide a useful alternative model for understanding ancient oolite deposits. The fact that ooids can form in the moderate to high-energy beach and shoreface zone removes the necessity of invoking high-energy tidal currents to produce oolite accumulations. Although beaches studied in the Caicos Islands are long, linear features with accompanying dunes, oolitic beaches could also form as low-relief features scattered irregularly over a broad, epeiric platform. They might also constitute part of the island facies sequence that often caps mounds and other low-relief buildups found in such areas.

SUMMARY AND CONCLUSIONS

Ooids are forming and oolite deposits are accumulating at a very rapid rate in beach-dune complexes on the Caicos Bank. These oolitic deposits appear to originate in the beach and shoreface zone and are a product of wind-generated waves and currents rather than tidal-generated currents. This process allows oolite deposits to form in areas far removed from the shelf margins or steep ramps required for high tidal energy. By lateral accretion of such beach-dune complexes through time, the potential exists for developing widespread oolitic deposits of sand-sheet geometery. The beach mechanism for oolite deposition suggested by occurrences on the Caicos shelf provides a useful analog for better understanding oolite deposition on epeiric platforms.

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