PROCEEDINGS

OF THE

FIFTH SYMPOSIUM

ON THE

GEOLOGY OF THE BAHAMAS

Edited by

Roger J. Bain

Production Editor

Donald T. Gerace

Bahamian Field Station
San Salvador, Bahamas
1991

Printed in USA by Don Heuer

ISBN 0-935909-37-0

PETROLOGIC COMPARISON OF JOULTERS CAYS AND ANDROS ISLAND, BAHAMAS

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ABSTRACT

A detailed petrologic evaluation of surface samples and cores taken from Joulters Cays, Bahamas, was used to develop a set of criteria for distinguishing subenvironments of this modern ooid shoal complex commonly used as an analog for ancient oolitic deposits. Once criteria were established, they were applied to Pleistocene oolitic deposits (lithified) on North Andros Island. Although diagenesis has obscured some detail, enough of the original compositional and textural characteristics were preserved to allow differentiation of several environments. Petrologic criteria for distinguishing subenvironments of ooid shoals exists and are preserved from the Holocene to the Pleistocene. Therefore, it may be possible to use similar criteria for evaluation of subenvironments of ancient oolites.

INTRODUCTION

Ooids are accumulating today in a variety of subenvironments at Joulters Cays, Bahamas (Newell *et al.*, 1960; Imbrie and Buchanan, 1965; Ball, 1967; Harris, 1977; 1979; 1983), and Pleistocene oolitic rocks (>25% ooids; Folk, 1962) are exposed on nearby North Andros Island (Fig. 1).

Many of the recognition criteria of ooid shoals seen on Joulters Cays have been preserved on North Andros Island including grain composition, lateral variability of subenvironments and adjacent carbonate environments, topography and to some extent sedimentary structures (Boardman *et al.*, 1991). The ooid distribution on both Joulters and Andros shows a linear core of high ooid (>50% ooids) concentration. Seaward and bankward of this core the concentration of ooids decreases. Similar geomorphic features are present on both Joulters and Andros. For example, Joulters Cays is comprised of islands separated by tidal channels. The leeward portion is flat and low, while there is relief of up to three meters along the eastern margin. On Andros, extensive flat lands are present leeward of parallel ridges with elevations as high as 20 meters. These elevated ridges may represent Pleistocene dune islands like those of Joulters today. Low-lying, linear, marshy areas are oriented perpendicular to the ridges on Andros and are presumed to be paleo-tidal channels. Modern coral reefs are located offshore from Joulters Cays. Similarly, Pleistocene coral reefs are found exposed on the eastern margin of Andros Island.

All of these features point to a gross correspondence of original depositional environment - an ooid shoal complex. However, detailed petrologic study of the sediments and rocks is required to verify the presence of major subenvironments (channels, shoals, dunes etc.) of an ooid shoal as seen on Joulters Cays today.

Joulters Cays ooid shoal complex has been the focus of investigations concerning the development and dynamics of ooid shoals because of its importance as an analog to ancient oolitic sequences (Newell *et al.*, 1960; Imbrie and Buchanan, 1965; Ball, 1967; Harris, 1977, 1979; 1983; Halley and Harris, 1979; Halley *et al.*, 1983; Strasser and Davaud, 1986; Carney and Boardman, 1990a; 1990b; Bebout *et al.*, 1990). Joulters Cays is located about 10 kilometers north of North Andros Island and consists of three islands (North, Middle, and South Joulters) composed of partially cemented eolian sand

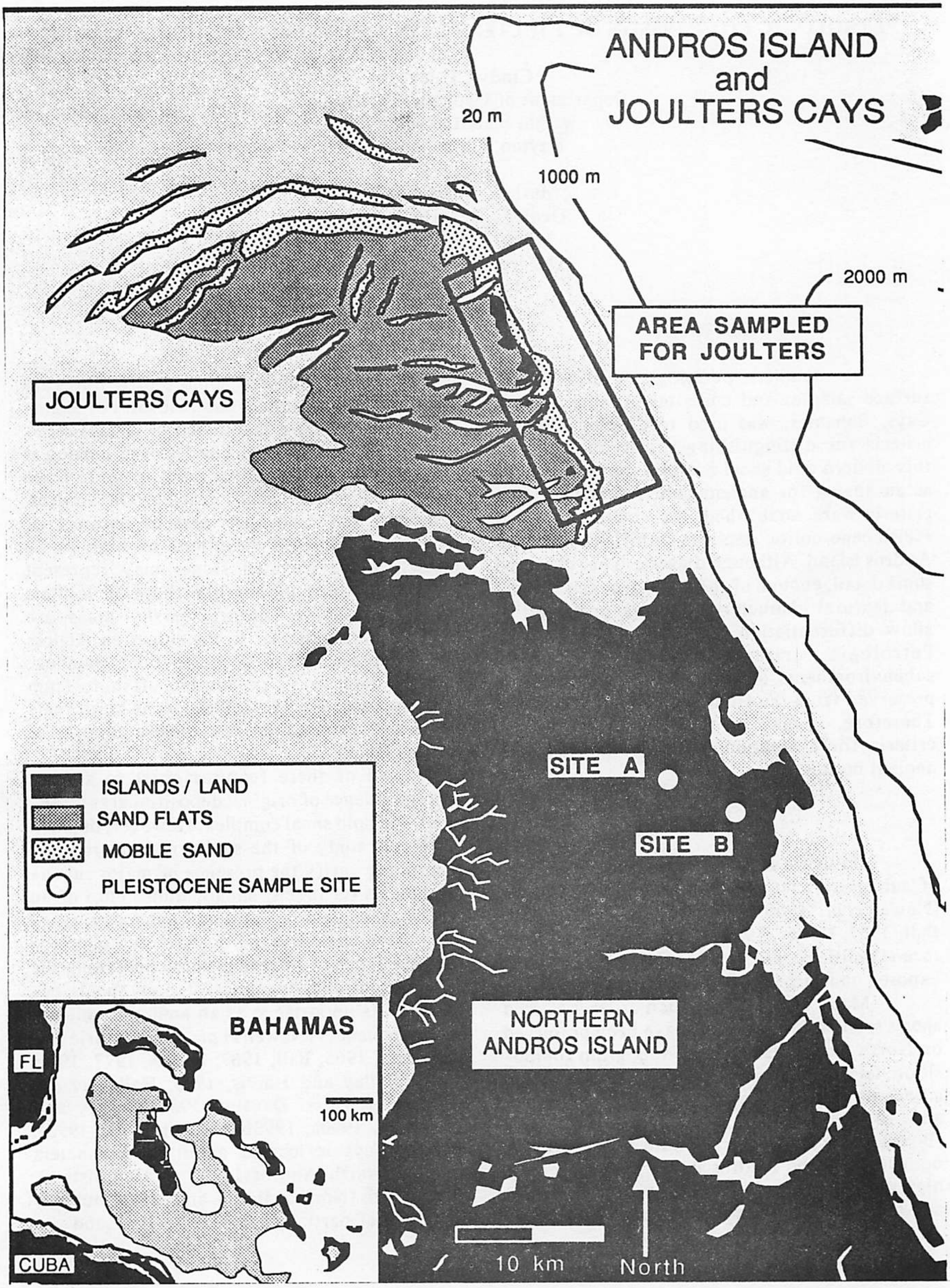

Fig. 1. Location map of Joulters Cays and North Andros Island, Bahamas. Area sampled for Joulters Cays is outlined by the black box. Outcrop A and outcrop B are sampling localities on North Andros.

dunes (Fig. 2). The islands are fringed to the east by ooid shoals, tidal deltas, and beaches and are separated by tidal channels. The quieter area north and west of the islands and shoal is termed the stabilized sand flat. Small sandy tidal flats are also present behind the cays.

Fig. 2. The Joulters Cays ooid shoal complex. View looking southeast towards North Andros Island

Harris (1977; 1979; 1983) described environments of deposition and evaluated the growth history of the shoal complex. He showed that at Joulters Cays there is considerable variation (distinct subenvironments) within the ooid shoal complex. The same should be true of ancient (including Pleistocene) oolitic sequences. In his examination, along with petrologic characteristics, Harris used topography, vegetation, and bedforms to distinguish subenvironments. The later are unlikely to be preserved and may not be useful criteria for ancient oolites. In order to recognize subenvironments of ooid shoals in the rock record, even more petrologic detail about modern examples like Joulters is needed. In particular, analysis of closely-spaced cores and surface samples are required to document variations within and between subenvironments. In the present study, a number of subenvironments of Joulters ooid shoal were sampled to determine differences among them that could be identified petrologically.

The set of recognition criteria developed are then applied to Pleistocene rocks of North Andros Island. Following the example of Harris (1979), the subenvironments of Joulters ooid shoal complex are subdivided into areas of active sediment movement (the "mobile fringe") and areas where the sediment is relatively stable.

METHODS

Over 100 surface samples were collected from areas near Joulters Cays, Bahamas (Fig. 3). Subenvironments of the mobile fringe sampled include the sand shoal itself, beaches and dunes on all three islands, and tidal channels and accompanying ebb-tidal deltas. Stabilized environments sampled include the stabilized sand flat, tidal flats on North and South Joulters, and offshore areas. A total of four cores were recovered from the tidal channel located directly north of North Joulters and the tidal channel between Middle and South Joulters. Sieve and pipette analyses of whole sediment samples were used to determine texture.

Sorting values for each subenvironment are shown in Table 1. Thin sections were prepared from plastic impregnated surface samples and cores, and the composition of the sediment was determined by point counting (300 counts/thin section). Average values of important constituents for each subenvironment are shown in Table 1. Because most of the samples consist of a high percentage of ooids, differences in ooid characteristics from the various subenvironments were particulary noted. Ooid diameter, nucleus diameter, thickness of cortex, and number of laminae were measured on selected ooids from a number of thin sections representing each subenvironment. The average and range of sizes of ooids from each subenvironment is noted in Table 1. These values were measured from thin section and probably represent minimum sizes, however, comparison with sieve analysis shows a good correspondence. Only ooids where the nucleus could be clearly seen were measured.

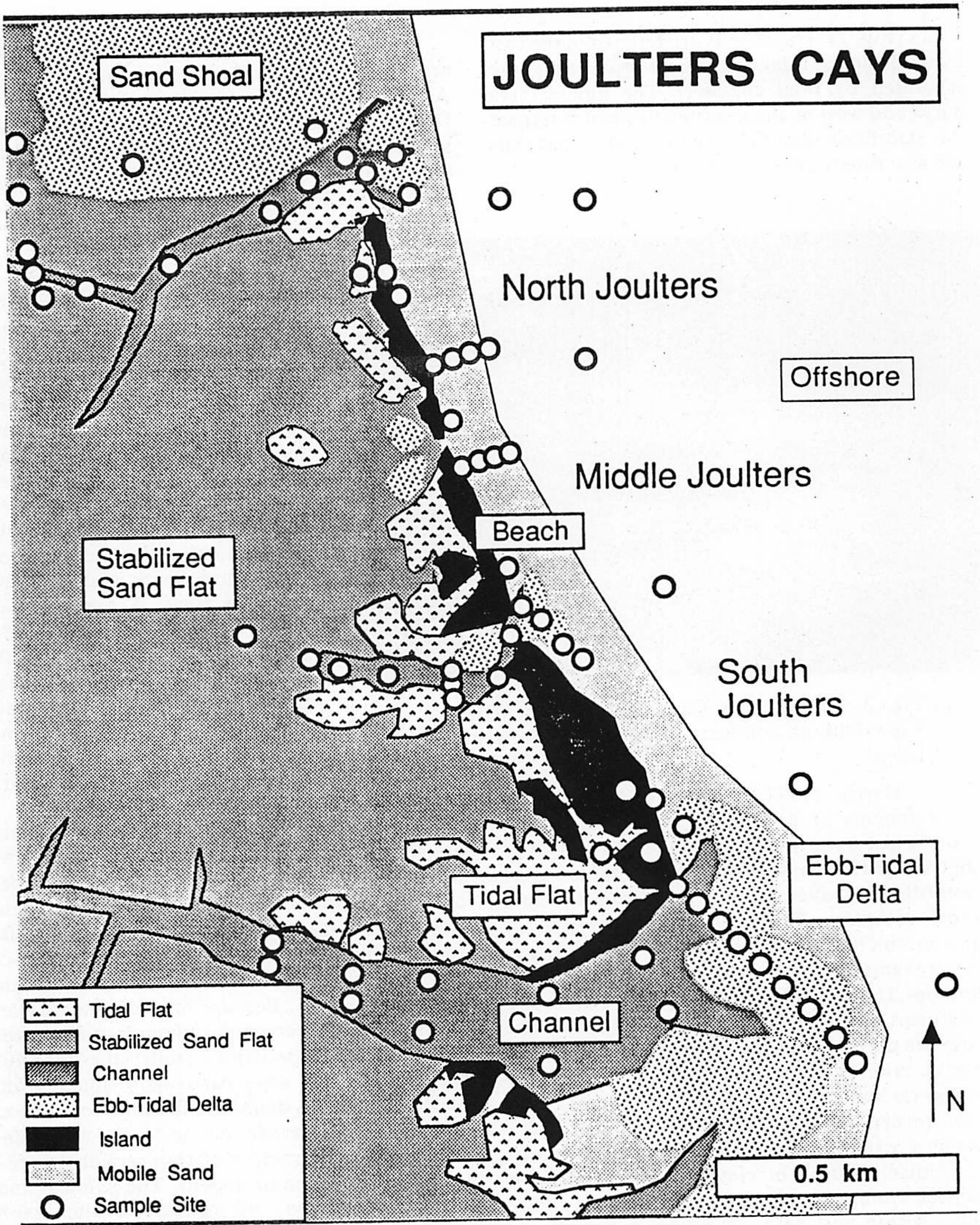

Fig. 3. Schematic map of Joulters Cays showing major subenvironments. Sample localities are shown by the white dots (some dots represent multiple, closely-spaced samples).

SUBENVIRONMENTS	COMPOSITION (%)				TEXTURE		
					Thin Section		Sieve
Joulters Cays	Ooids	Peloids/ Pellets	Uncoated Skeletal Grains	Aggregates	Average Ooid Size (mm)	Range of Ooid Size (mm)	Sediment Sorting (ϕ)
Sand Shoal	94.0	4.0	0.5	1.5	0.45	(0.11-0.85)	0.70
Beach	93.0	5.5	1.0	0.5	0.35	(0.11-0.69)	0.82
Dune	93.0	7.0	0.0	0.0	0.33	(0.12-0.44)	—
Tidal Channel	82.0	8.0	6.0	4.0	0.37	(0.12-0.89)	1.17
Tidal Delta	89.0	4.0	3.0	4.0	0.32	(0.10-0.74)	0.78
Stabilized Sand Flat	69.0	19.5	7.5	4.0	0.41	(0.10-0.73)	1.43
Tidal Flat	62.0	34.0	1.0	3.0	0.26	(0.11-0.61)	1.47
Offshore	40.0	37.0	13.0	10.0	0.23	(0.08-0.45)	1.95
North Andros Island							
Sand Shoal	80.0	18.5	0.5	1.0	0.45	(0.15-0.7)	Good
Dune	83.0	14.0	1.5	1.5	0.25	(0.10-0.6)	Good
Tidal Channel	73.0	21.0	1.0	5.0	0.39	(0.12-0.7)	Moderate
Stabilized Sand Flat	53.0	39.0	5.5	2.5	0.40	(0.15-0.65)	Moderate to poor

Table 1: Compositional and textural data for samples from Joulters Cays and North Andros Island

	BORING	MICRITIZATION
1	None	None
2	Fewer/Outer	Partial Rim
3	Few/Inner	Total Rim
4	Outer/Inner	Pervasive
5	Pervasive	Obliterative

Table 2: Relative values used for quantification of boring and micritization of oolitic samples.

	BORING	MICRITIZATION	TOTAL
Offshore	3.9	3.2	7.1
Tidal Flat	4.0	3.0	7.0
Stabilized Sand Flat	4.0	2.8	6.8
Shoal	4.0	2.4	6.4
Channel	3.9	2.4	6.3
Beach	3.9	2.3	6.2
Dune	3.8	2.2	6.0
Ebb-tidal delta	3.8	2.1	5.9

Table 3: Average values for boring and micritization calculated for each subenvironment. The total value represents the relative degree of bioerosion.

The degree of bioerosion of ooids from each environment was also evaluated (Tables 2 and 3). Individual borings were considered along with micritization where separate borings could not be recognized. Boring and micritization are thought to occur in the submarine environment by endolithic algae, fungi, etc. (Bathurst, 1966; 1975; Golubic, 1969; Margolis and Rex, 1971; Harris *et al.*, 1979). Boring and micritization were individually quantified using a scale of one to five as shown in Table 2, then a total value for relative degree of bioerosion was calculated.

Fig. 4A. View across the ooid sand shoal of Joulters Cays at low tide.

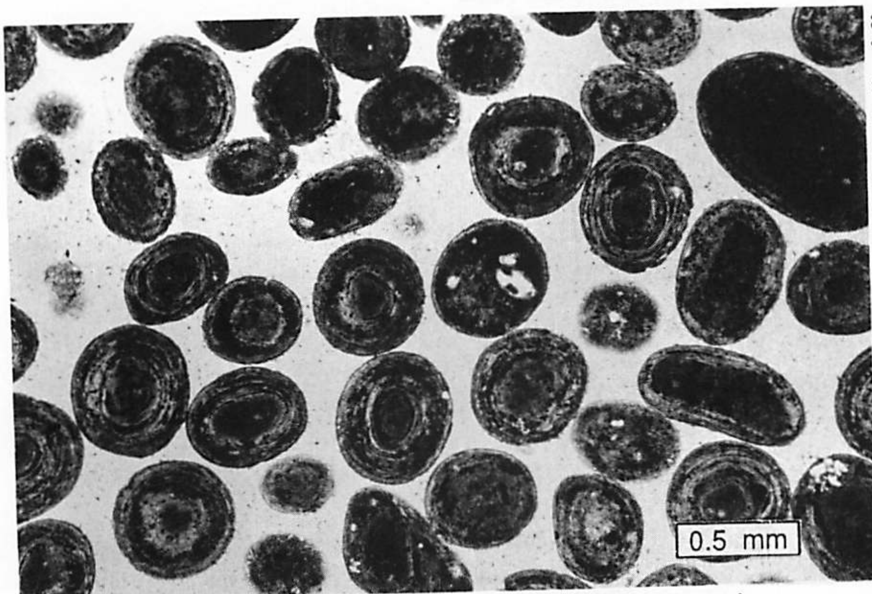

Fig. 4B. Photomicrograph of typical sand shoal sediment. Note numerous, well-developed ooids.

RESULTS

Sand Shoal

The sand shoal is a large (several square kilometers) intertidal sand body the surface of which is characterized by a variety of low relief bedforms produced by tidal flow as well as wind driven sheet flow (Fig. 4A). On the bankward margin, spillover lobes with high-angle slopes are present. Small tufts of algae are commonly seen attached to cemented burrows and crusts. Algal mats of ooids are found in more stabilized areas of the shoal. The dominant process on the shoal is grain movements. It is likely that grains are swept bankward during flooding and high tide and when onshore winds generate shallow westerly currents. This movement commonly would be assisted by onshore trade winds. Spillover lobes are likely formed during storm events (e.g. Hine, 1977). Sedimentary structures are often difficult to see even in cores because the grains are well sorted and because of minor bioturbation (Harris, 1979; Bebout *et al.*, 1990).

Sand shoal sediments are very well sorted and contain some of the best developed ooids found near Joulters (Fig. 4B). Ooids average over 94% of the total grains, the highest of any subenvironment of Joulters. The remainder of the grains are peloids (fecal pellets, micritized ooids and other grains, 4%) and aggregates of ooids and peloids (2%, Table 1). Uncoated skeletal grains are almost non-existent. No mud was present in the sediments. Ooid size can vary to 0.8mm but averages 0.45mm in diameter as measured from thin section. Ooids are characterized by numerous laminae (average 11.5 laminae per ooid) surrounding a nucleus which is nearly always a peloid. These characteristics (good sorting, high percentages of ooids, numerous/laminae) reflect the optimum conditions for ooid development/accumulation present on the sand shoal.

Evidence that ooids are not or were not in constant motion, however, is seen in the bioerosion present in many of the ooids (Table 3). Shoal ooids are bored both on the exterior and interior, and rims are commonly micritized.

Beach

Beaches are found on the eastern side of the cays and are part of the active longshore transport system (Fig. 5A). Driving the system are waves produced by the fairly constant trade winds. Typically, beaches are narrow (a few meters) and abut portions of the eroding dune ridges. Beachrock (grains of a beach cemented in place by acicular aragonite) is common and dips seaward. Offshore from the beaches are shoreface-connected ridges with relief of about 1 meter.

Fig. 5A. Beach along the eastern margin of South Joulters.

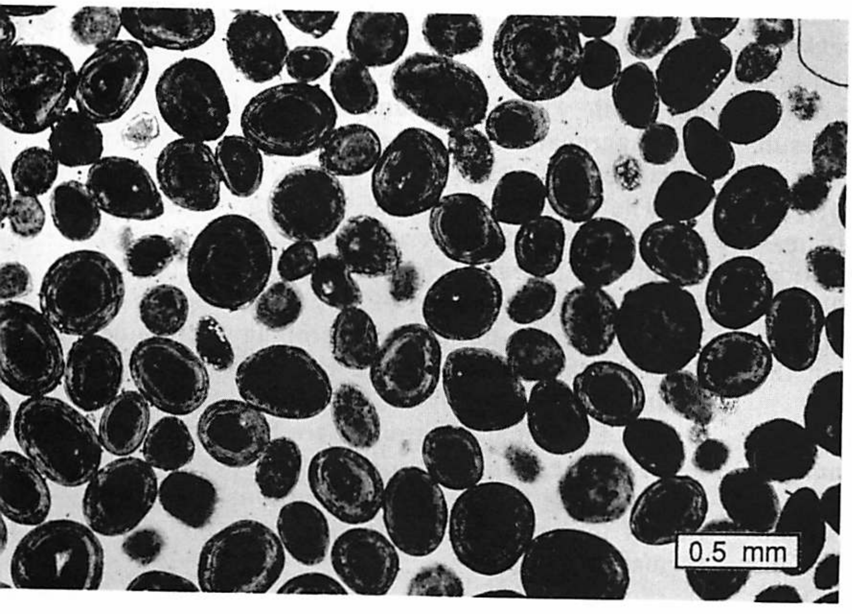

Fig. 5B. Photomicrograph of beach sediments from the foreshore of South Joulters.

Parts of the adjacent dune system are eroding and adding sediment to the beach (Fig. 5A). Large dune clasts are embedded in the beach sand. Erosion of dune ridges indicates either that sea level has risen since the ridges were created and/or that the wave climate has changed (Strasser and Davaud, 1986).

Beach sediments are well sorted, although not as well sorted as shoal or ebb-tidal delta sediments (Table 1). Ooids, again, make up a high percentage (93%) of the sediment (Fig. 5B). Peloids are the only other major constituent (5.5%). A few uncoated skeletal grains and aggregrates are also present. Ooids range from 0.1 to 0.7mm in diameter and average 0.35mm. Nuclei are comprised of peloids and minor mollusc and red and green algal fragments. Mud was not present in the sediment.

Beach ooids show slightly less boring and micritization than shoal ooids although exterior and interior boring and rim micritization is present (Table 3).

Dune

The eolian dune subenvironment is comprised of a series of partially cemented ooid sand ridges averaging 3 meters in height and separated by swales (Fig. 6A; Harris, 1979). Ridges are spaced 50 meters or less apart. Dunes on the bankward sides of the islands are better cemented, more highly vegetated and probably older than seaward dunes (Halley and Harris, 1979). A thin veneer of uncemented sand is present in the lee of dunes. Dunes are penetrated by roots of the sparse vegetation.

Dune ridges arranged parallel to the shore are likely formed by seaward progradation. Each of the dunes was probably part of a beach-dune system. Thus the dunes have a composition similar to the beach except that dune sands rarely contain "large" ooids (see Table 1). Seaward growth of the dune system and stranding of the dune ridges requires abundant sand relative to stable sea level. These dunes are about 1000 years old, and are presently eroding (Halley and Harris, 1979; Strasser and Davaud, 1986).

Ninety-three percent of the dune sediment consists of very well sorted ooids which average 0.33mm in diameter (range from 0.1 - 0.45mm, Fig. 6B, Table 1). These characteristics (size and sorting) reflect the wind's ability to move sediment. Nuclei are predominantly peloids with a few molluscs, forams and algae. Peloids are the only other component. The sands contain no uncoated skeletal grains and no mud. Ooids are poorly cemented with cements found commonly at grain boundaries and/or as discontinous rims. Minor dissolution of laminae occurs in some ooids.

Dune ooids exhibit some of the lowest values for bioerosion (Table 3), probably because these ooids are removed from the marine environment. Borings are present on both the interior and exterior of grains, and rims are sometimes partially micritized. Micritization (chalkification) resulting from weathering on outcrop (Chafetz, 1972) does not seem to have been a significant process probably because of the relatively short time of exposure and lack of soil/caliche development (Halley and Harris, 1979).

Tidal Channel

Tidal channels at Joulters are of various sizes and can be up to 5 meters deep and 100 meters wide (Fig. 7A; Harris, 1979). Channels are usually floored by migrating sand waves (both ebb and flood oriented) up to 2.5 meter high with wavelengths of several meters although parts are stabilized by sea grasses (Harris, 1979). Large skeletal fragments and layers and clasts of pure lime mud are found in troughs between sand waves (Shinn *et al.*, 1989; Boardman and Carney, 1991). In the more active portion of the channels flora and fauna are limited as a result of the mobile substrate.

High energy in the form of tidal currents is the dominant influence. Currents of 100 cm/sec and greater have been observed in some tidal channels in the Bahamas (Dill *et al.*, 1989). The throats of channels are often nearly cut off with sediment of the ebb tidal delta moving in the longshore system.

Sediments of the channel are the least well sorted of the mobile fringe environments (Table 1) and are composed of ooids (82%), peloids (8%), uncoated skeletal grains (6%) and aggregates (4%). Less than 0.5% mud was present in the sediment (outside the mud layers). Ooids are generally well developed but are bimodal in size at approximately 0.2mm and 0.4mm in diameter (Fig. 7B). The bimodality of the sediment may result from input of smaller grains by wind or storm transport or by erosion of nearby dunes or beaches. Alternately, ooids may be carried from the associated ebb-tidal delta where ooids have smaller diameters (see Table 1). Once in the channel, some ooids may continue to grow forming the larger ooids. Nuclei are predominantly composed of peloids and more rarely, aggregates. Uncoated skeletal grains are more abundant than in other mobile fringe environments and include forams, red and green algae, and mollusc fragments.

The mud layers and clasts are nearly pure lime mud (<63microns), aragonite-rich (>80%) and often peloidal. The layers are a few to several centimenters thick and form small chips upon excavation and erosion during migration of sand waves.

Bioerosion of channel ooids is similar to the shoal with exterior and interior borings and rim micritization (Table 3).

Ebb-Tidal Delta

Ebb tidal deltas are present as large, shallow-subtidal (<1 meter) sand bodies at the mouth of tidal channels (Fig. 8A). The ebb-tidal deltas are affected by high energy from waves as well as tidal currents and are part of the longshore transport system. At low tide, waves break on the tidal delta. Ebb-tidal deltas are mostly formed of undulating sand with a few deeper troughs (distributary channels) in which occasional patches of seagrass occur.

Nearly 90% of the grains are ooids (Fig. 8B, Table 1). Peloids, uncoated skeletal grains and aggregates are present in approximately equal percentages, 4.0, 3.0, and 4.0% respectively. The sediments of the ebb-tidal delta are better sorted than their associated tidal channels. No mud is present. The average size of ooids is 0.3mm (average number of laminae is 8 per ooid) with sizes and number of laminae increasing from south to north where the active shoal is located.

Ebb-tidal delta ooids are bioeroded to a lesser degree than ooids in any other subenvironment perhaps reflecting the more constant agitation of the sediment or the length of time since formation (Table 3).

Stabilized Sand Flat

The stabilized sand flat lies bankward of

Fig. 6A. Partially stabilized eolian dunes from Joulters.

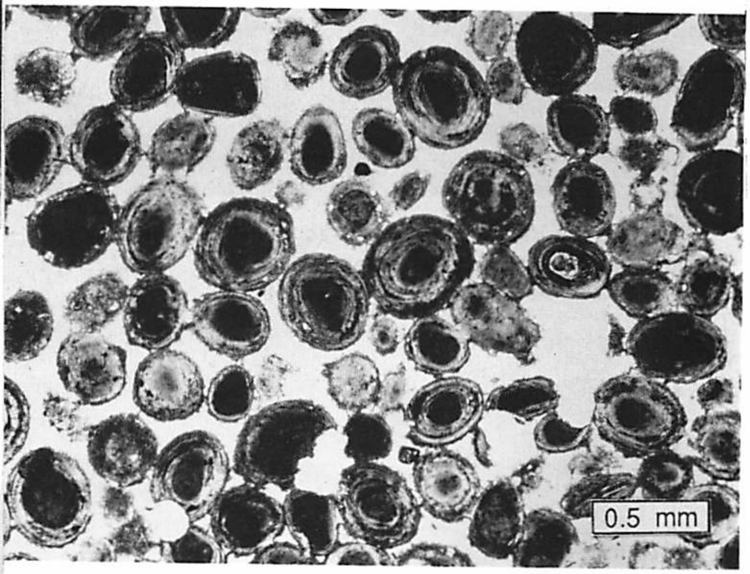

Fig. 6B. Photomicrograph of eolian dune sediments. Note grain-contact cements.

Fig. 7A. Rippled tidal channel deposits of the channel south of South Joulters.

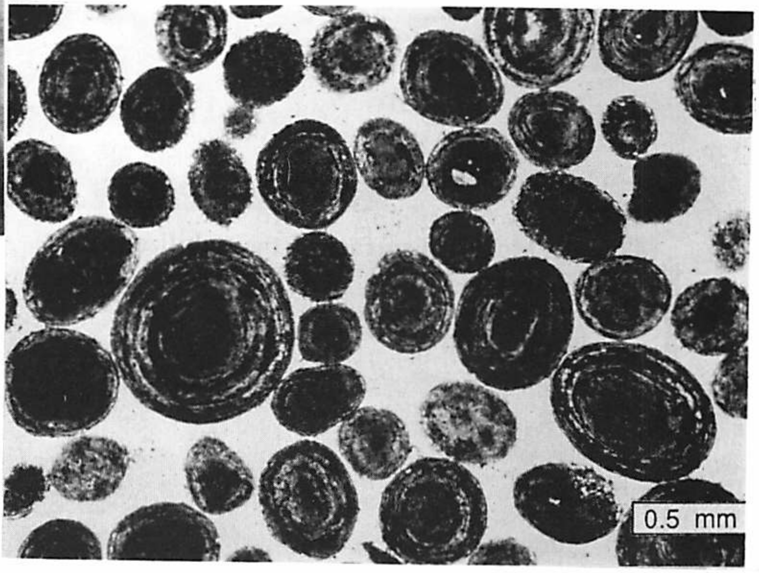

Fig. 7B. Photomicrograph of bimodal tidal channel sediments from the same channel.

Fig. 8A. Extensive tidal delta associated with the channel south of South Joulters.

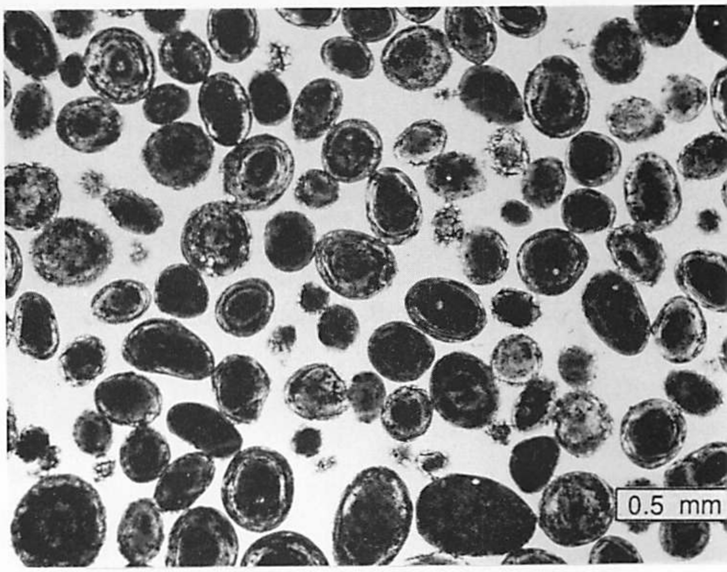

Fig. 8B. Photomicrograph of extremely well sorted oolitic sediment of the tidal delta.

Fig. 9A. Mounded surface of the stabilized sand flat.

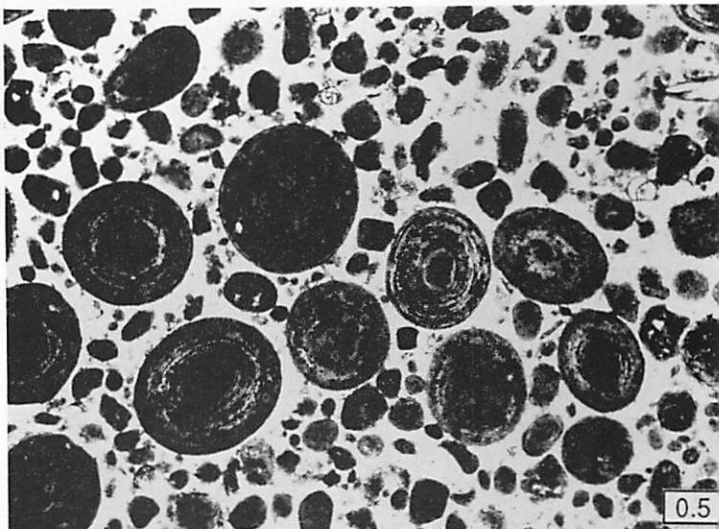

Fig. 9B. Photomicrograph of typical stabilized sand flat sediments. Note abundant peloids/pellets and uncoated skeletal grains.

the islands and sand shoal. The water is very shallow (<1 meter) and the bottom is colonized by algae and seagrass and burrowed by shrimp and crabs (Fig. 9A; Harris, 1979).

The lower energy of this environment results from protection by the islands and sand shoal. Seagrass and algal growth is relatively luxuriant, but is probably restricted by extremes of salinity and temperature. The sediment is stable enough to allow micritization to occur (Harris *et al.*, 1979). Bioturbation is intense. Apparently, ooids are transported to this environment by storms.

Sediments of the stabilized sand flat are poorly sorted. Ooids are the most abundant grain type averaging 69% of the sediment (Fig. 9B, Table 1). Ooids have average diameters similar to the shoal (0.41mm), suggesting a source/sink relationship between these two environments or that the stabilized sand flat is a reworked (bioturbated) sand shoal (Harris, 1977; 1979). Peloids and pellets are also abundant (20%) and many of the peloids are probably micritized ooids. Uncoated skeletal grains make up 7% of the sediment and include forams, molluscs, and green algae. Aggregates of peloids, mud and skeletal material comprise 4% of the sediment. The stabilized sand flat is one of the muddiest subenvironments of Joulters but still averages less than 5% mud.

Ooids of the stabilized sand flat are extensively bioeroded (Table 3). Borings are present on the exterior and interior of ooids and rims are often completely micritized. Some ooids (especially smaller sizes) are completely micritized and only occasional ghosts of laminae are seen.

Tidal Flat

Tidal flats are present behind the island/dune system. These areas are flooded daily and are covered with a thin algal mat (Fig. 10A; Harris, 1979). Thin cemented crusts are occasionally found below the surface. The fauna and flora are restricted to a few species which suggests that significant changes of salinity and temperature may occur in this environment. These fluctuations are not extreme enough, however, to eliminate the burrowing organisms that are prevalent here.

Sediments are moderately to poorly sorted and consist predominantly of ooids (average 62%) and pellets and peloids (34%) (Fig. 10B, Table 1). Aggregates average 3% of the sediment, and some mud is present (<3%). Uncoated skeletal grains are rare. Ooids are bimodal at approximately 0.15 and 0.3mm diameter, indicating multiple sources. The composition of the nuclei of ooids is mostly indeterminable but are probably peloids. Very small ooids have been transported from the dunes and upper beach to the tidal flats by eolian processes (wind) and larger ooids by overwash from the beach (water), and this dual mode of transport may produce the bimodal size distribution observed here. Intensity of bioerosion of tidal flat ooids is similar to that of the stabilized sand flat (Table 3) with numerous borings and extensive micritization.

Offshore

Patches of sparse seagrass (predominantly *Thalassia* and *Syringodium*), sand, and occasional patch reefs are located offshore from the islands and sand shoal (Fig. 11A; Harris, 1979). Water depth gradually increases to about 5 to 8 meters two kilometers offshore where reefs are better developed.

Sediments are very poorly sorted. Ooids average only 40% of the sediment and decrease in abundance further offshore. They are small averaging approximately 0.2mm in diameter. Peloids and pellets make up 37% of the sediment, and a relatively high percentage of skeletal grains (13%, forams, molluscs and algae) and aggregates (10%) are also characteristic (Fig. 11B, Table 1). Many of the peloids are micritized ooids. Mud comprises up to 8% of the sediment.

Ooids are probably transported to this area by storms and exceptionally high ebb-tidal currents. Bankward areas are more continually supplied with ooids. The presence of mud suggests limited winowing, and it seems likely that the ooid grains are only periodically moved. Thus micritization and boring are ubiquitous and many ooids are completely obliterated (Table 3). The degree of this obliteration appears to increase farther offshore and at some point, recognition of ooids as discrete grains may become impossible.

DISCUSSION

Composition

All subenvironments of the mobile fringe (sand shoal, beach, dune, tidal channel, and tidal delta) contain very high percentages (80% or

Fig. 10A. Protected sandy tidal flat behind North Joulters.

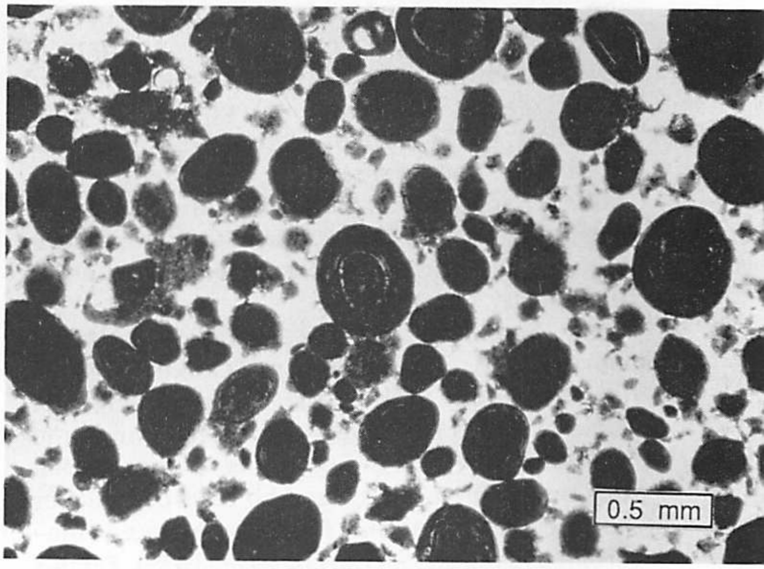

Fig. 10B. Photomicrograph of partially to totally micritized tidal flat sediments.

Fig. 11A. View of the sea bottom, offshore Joulters Cays.

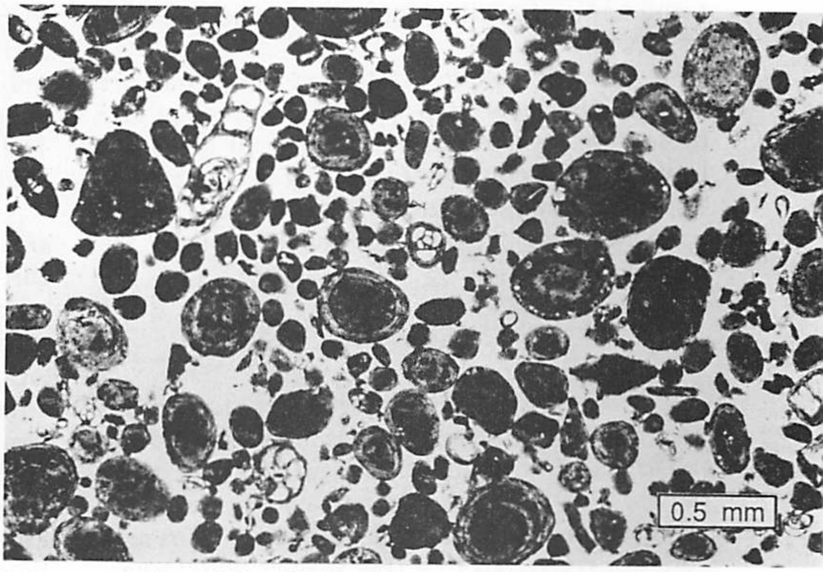

Fig. 11B. Photomicrograph of offshore sediments.

greater) of ooids and few uncoated skeletal grains. The sand shoal, tidal channels and tidal deltas are areas of active grain movements and possible ooid formation and growth. Beaches and dunes are sites of ooid accumulation from the more agitated environments. In stabilized environments (stabilized sand flat, tidal flat, offshore) ooids are mixed with other grain types including fecal pellets, skeletal grains, and some mud. These areas are not sites of present-day ooid formation.

Sorting

A summary diagram of textural characteristics of oolitic sediments from Joulters Cays shows that sediments from the active mobile fringe, where there is more constant movement of grains, are also all well sorted (Fig. 12 and Table 1).

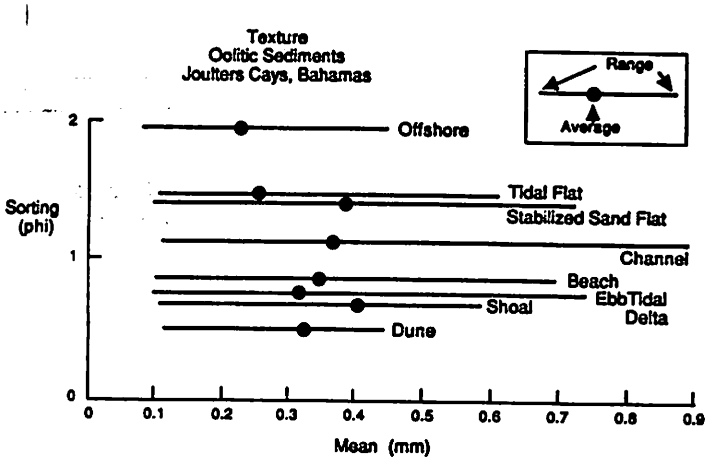

Fig. 12. Variations of sorting and mean ooid size for the subenvironments of Joulters Cays.

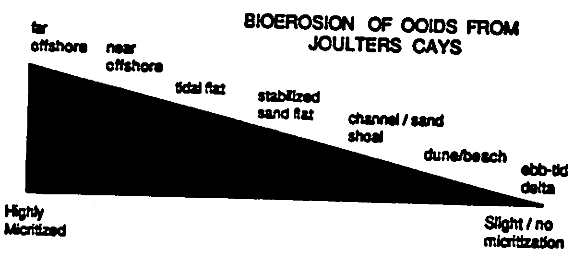

Fig. 13. Relative degree of bioerosion among the subenvironments of Joulters Cays.

Sorting of beach and dune sediments are a reflection of movement by wind and waves. Poorest sorting is found in more stabilized environments including offshore areas, tidal flats and the stabilized sand flat. Tidal channel sediments fall somewhere in between. In general, the size of ooids, as measured from thin section, reflects number of laminae around the nucleus rather than size of the nucleus itself. Nuclei are surprisingly similar in diameter in all environments. Ooid size increases systematically from south to north in the direction of longshore drift. Ooids are apparently growing during their journey north towards the sand shoal. The sand shoal and stabilized sand flat sediments are comprised of the largest ooids (Fig. 12). Similarities in size of these ooids indicate that either the stabilized sand flat was once a shoal or that it receives ooids from the shoal. The smallest ooids are found in offshore areas, perhaps only small ooids are transported by waves and currents to the offshore. Ebb-tidal delta, beach and dune ooids also have relatively small diameters. Beach and dune sediments are removed from the "ooid forming" environment by wind and waves, and further growth of ooids is prevented. Ebb-tidal deltas may be where ooids form originally and where subsequent growth occurs. Tidal flat and channel ooids are bimodal reflecting multiple sources for these grains.

Bioerosion

Intensity of bioerosion of ooids depends on energy level which controls the movement of ooids and amount of time the ooids remain on the sea floor. Ooids which are more continually moved are less likely to be bioeroded.

Variation in the amount of bioerosion of ooids (individual borings and micritization) occurs among the subenvironments of Joulters Cays ooid shoal (Fig. 13). Ebb tidal delta, upper beach and dune sediments are only slightly affected by bioerosion (borings and partial micritization of laminae only; Fig.14A). Lack of bioerosion of beach and dune sediments probably reflects removal from the subtidal environment

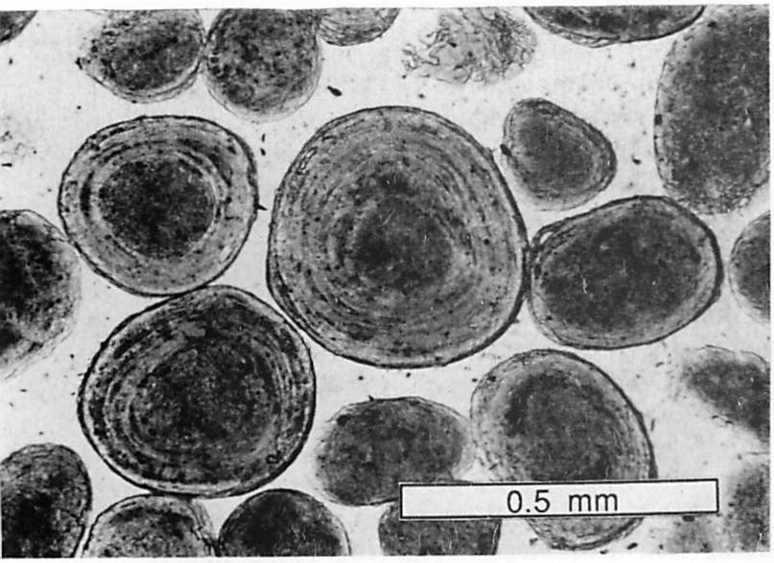

Fig. 14A. Photomicrograph of ooids of the tidal delta south of South Joulters. Only minor bio-erosion is evident.

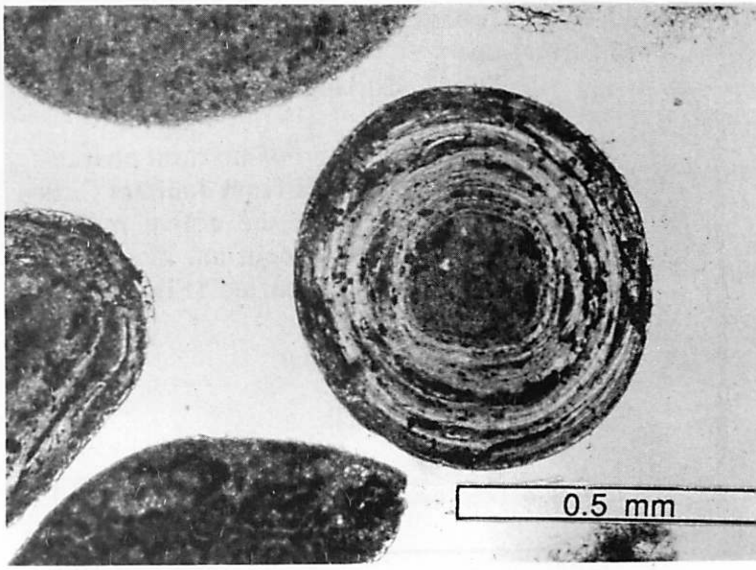

Fig. 14B. Photomicrograph of sand shoal ooids with numerous individual borings and micritization of entire laminae.

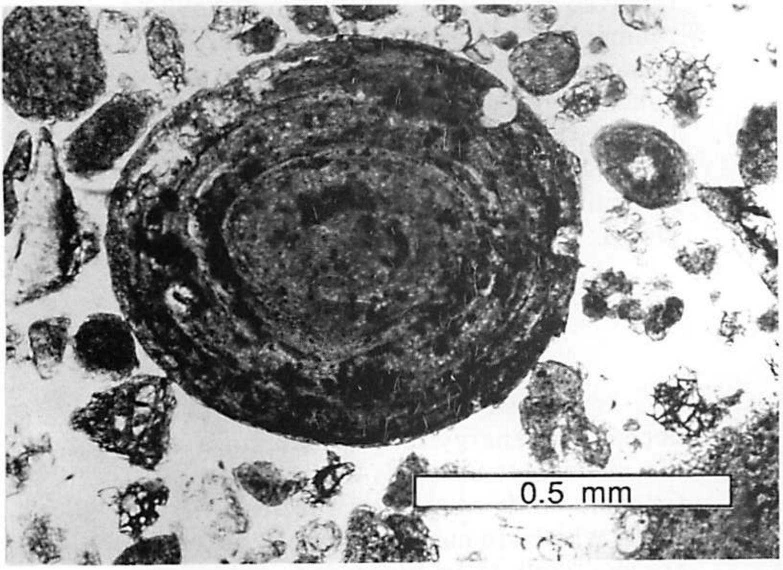

Fig. 14C. Photomicrograph of oolitic sediments of the stabilized sand flat showing extensive boring and micritization of grains.

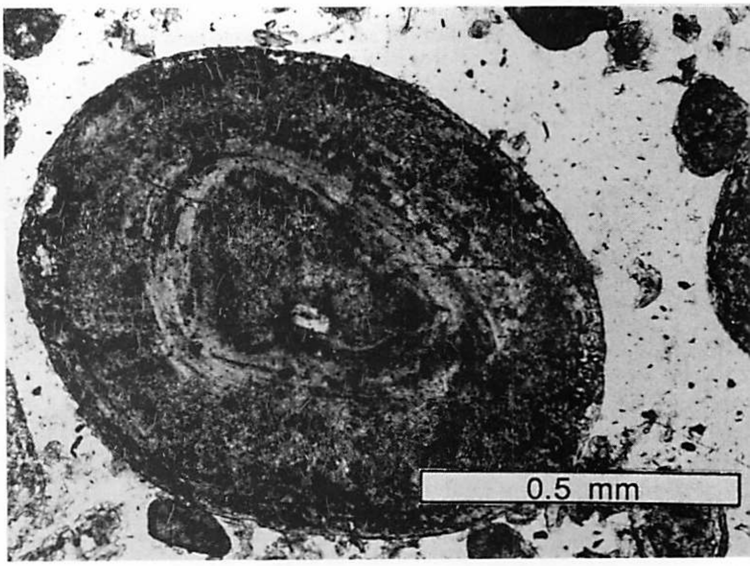

Fig. 14D. Photomicrograph of offshore ooids almost completely micritized and heavily bored.

while high mobility of sediment may be the reason behind lack of bioerosion in ebb-tidal delta ooids. Sand shoal and channel ooids show slightly more bioerosion with numerous borings and micritization of entire laminae (Fig. 14B). Sediments in these environments must experience periods of stabilization during which processes of bioerosion are active. Stabilized sand flat and tidal flat ooids are significantly affected by bioerosion, reflecting the stabilized nature of the sediments in these environments. Borings are ubiquitous and micritization is extensive (Fig. 14C). Many ooids are completely micritized (especially smaller sizes). Offshore sediments are the most severely affected by bioerosion with increasing micritization of ooids further offshore as movement of grains becomes more infrequent (Fig. 14D).

APPLICATION OF CRITERIA TO PLEISTOCENE EXAMPLES

Subenvironments of the modern ooid shoal complex at Joulters Cays are distinguishable based on petrologic characteristics of ooids and sediments and the degree of bioerosion. As a test of the usefulness of these criteria for interpretation of more ancient oolitic rocks, two Pleistocene outcrops were examined on North Andros Island (see Fig. 1).

Fig. 15. Photograph showing three zones present at Outcrop A. The burrowed zone is especially evident in the central portion of the photo.

Outcrop A is located approximately three kilometers north of the San Andros airport (about eight kilometers west of Mastic Point). It is slightly more than 2.5 meters in thickness and approximately 60 meters long (Fig. 15). The rocks are comprised entirely of oolitic grainstone (50-80% ooids). A basal massive layer is overlain by a burrowed/bioturbated portion and an upper cross-laminated layer caps the outcrop.

Portions of the basal massive and upper cross-laminated sections of the outcrop consist of very well developed, well sorted ooids which average 0.45mm in diameter (range of 0.15 to 0.7mm; Table 1). Ooids comprise 80% of the grains with peloids also abundant (average 18%). Many of the peloids possibly are ooids that have been diagenetically altered (chalkified) during weathering on the outcrop. If so, ooid concentrations could be well over 90%. Uncoated skeletal grains are very rare. Grain composition, sorting and size of ooids of these zones match well with those of the present day Joulters sand shoal subenvironment (Fig.16A).

Samples from the central portion of the basal massive zone and from the uppermost portion of the cross-laminated zone resemble the tidal channel subenvironment of Joulters in texture and composition (Fig.16B; Table 1). In addition, sediments are less well sorted and consist of bimodal ooids (0.2 and 0.4mm) which average 73% of the total grains. Peloids (again, possibly some portion are micritized ooids) are relatively abundant (21%). In contrast to the channels on Joulters, the percentage of skeletal grains is extremely low (1%), however, the percentage of aggregates is comparable in both the Holocene and Pleistocene channel deposits (Table1).

Grainstones of the burrowed zone contain a higher percentage of skeletal fragments (molluscs, forams, algae; Fig. 16C). Average ooid content decreases to 53% and peloids increase in abundance (39%). Sorting is moderate to poor. This zone may represent an environment something like the stabilized sand flat (Table 1), or may be characteristic of a period when sediments were less mobile during blockage of a tidal channel.

Outcrop B is located about one kilometer east of the San Andros airport

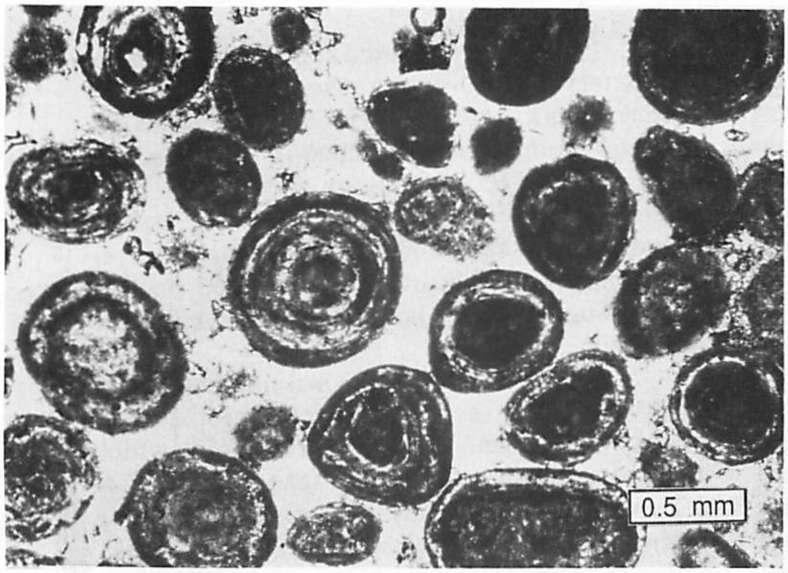

Fig. 16A. Photomicrograph of oolitic grainstone with characteristics of the ooid sand shoal, basal portion of Outcrop A.

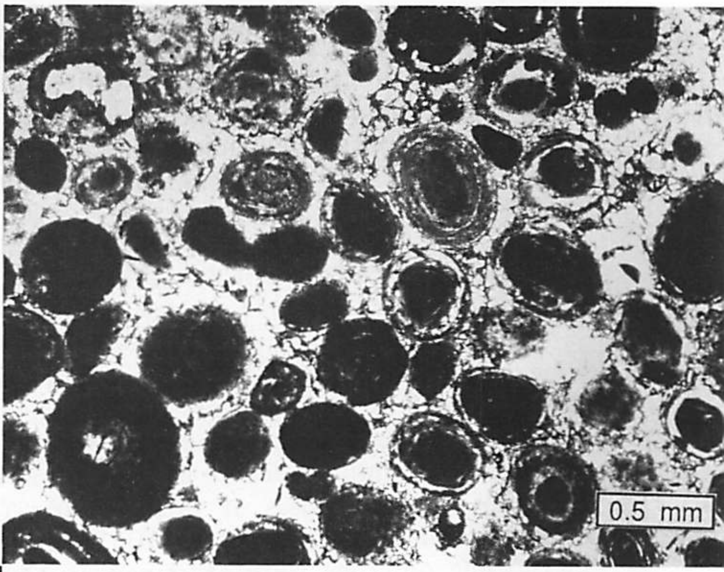

Fig. 16B. Photomicrograph of oolitic grainstone with characteristics of modern tidal channels, cross-laminated zone, Outcrop A.

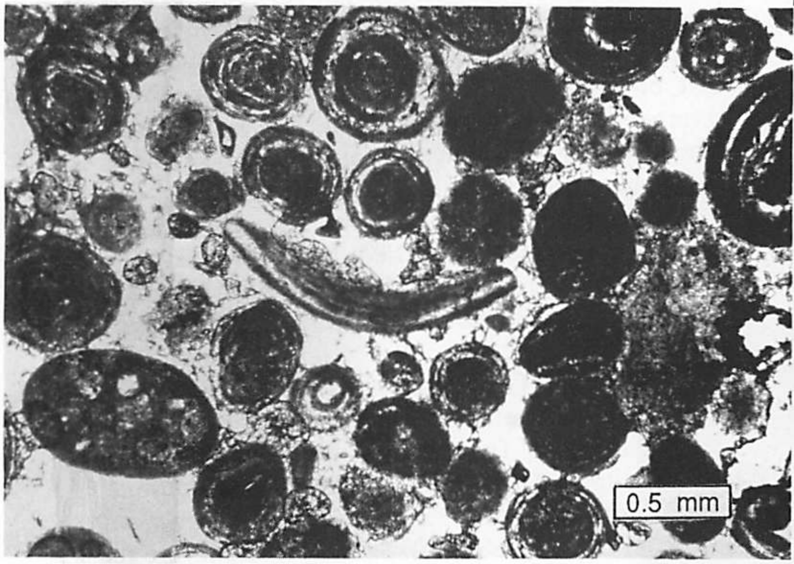

Fig. 16C. Photomicrograph of oolitic grainstone of the burrowed zone of Outcrop A showing characteristics of the modern stabilized sand flat.

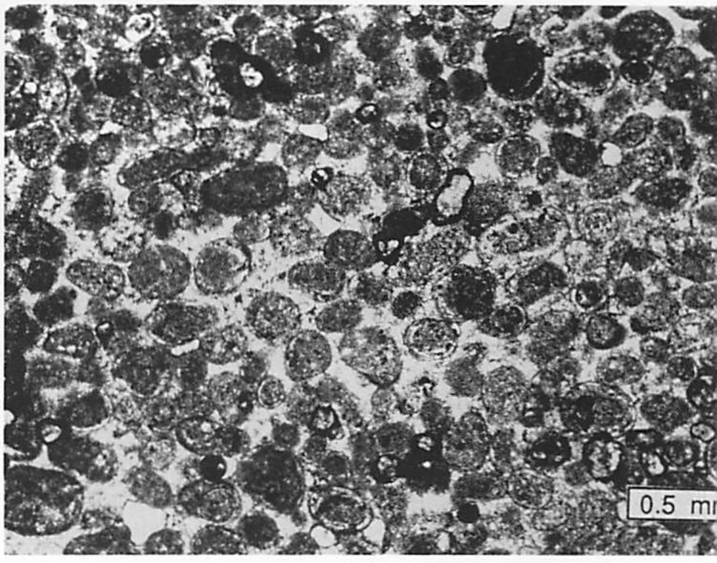

Fig. 16D. Photomicrograph of oolitic grainstone typical of Outcrop B, interpreted as eolian dune sediments.

and approximately six kilometers west of Mastic Point on a ridge approximately 10m above sea level (see Fig. 1). Petrologic characteristics are compatible with a dune or upper beach subenvironment of deposition (Fig. 16D; Table 1).

Sediments are very well sorted and consist of a very high percentage of ooids (83%). Peloids (micritized ooids) comprise 14% of the total grains, thus maximum ooid content is again well over 90%. Both uncoated skeletal grains and aggregates are rare. Ooids are relatively small and average 0.25mm in diameter (range of 0.1 to 0.6mm). Based on these petrologic characteristics and overall topography, an eolian ooid sand dune interpretation is favored.

Oolitic grainstones from the outcrops of North Joulters are diagenetically overprinted by dissolution, cementation, calcification and chalkification. Cements are characteristically fine to medium crystalline blocky calcite but micritic cements are also present. Cements are patchy, some areas are completely cemented while others nearby contain little cement. Laminae of ooids are commonly dissolved and some ooids are calcified or chalkified (Fig. 16 and 17). Chalkification can occur when sediments are exposed to weathering on outcrop (Chafetz, 1972). Additional diagenesis of these rocks has obliterated some ooids and skeletal grains and prevents the use of the degree of bioerosion as an environmental indicator.

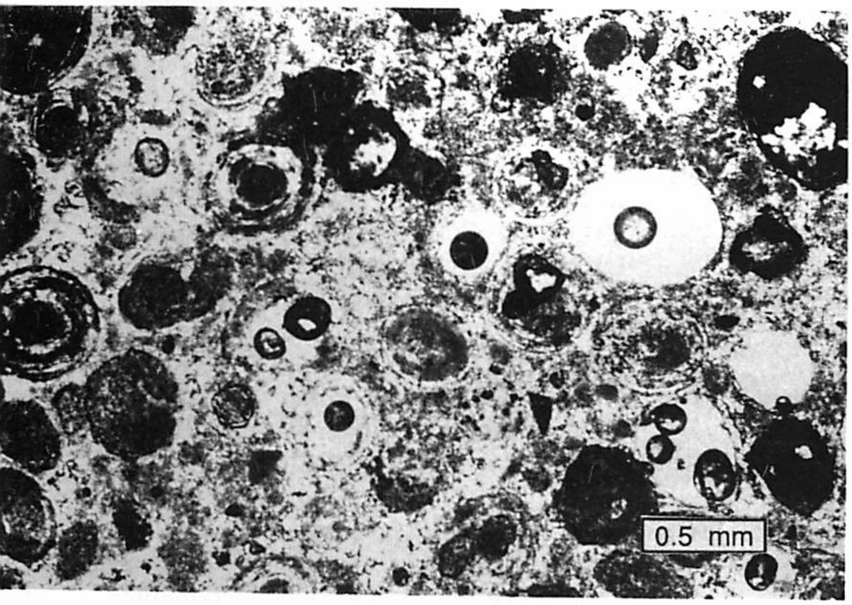

Fig. 17. Photomicrograph of Pleistocene oolitic grainstone. Laminae of ooids are partially/totally dissolved and some ooids are calcified.

Diagenesis, therefore, complicates application of petrologic criteria from the Holocene to the Pleistocene but enough characteristics are preserved to make recognition of major subenvironments possible.

CONCLUSIONS

Detailed petrologic examination of ooid rich sediments from the ooid shoal complex at Joulters Cays indicates that subenvironments within the shoal differ in composition, texture, and degree of bioerosion. Using petrologic criteria developed from Joulters, sand shoal, tidal channel, stabilized sand flat and dune deposits were recognized in Pleistocene-aged sediments on North Andros. The scale of bioerosion used to quantify the degree of boring and micritization of modern oolitic sediments was not useful for Pleistocene oolites because of diagenesis on the outcrop.

It would be an important next step to apply these criteria to oolitic rocks of even more ancient ooid shoals. Examples of rocks comprised of high percentages of well developed, fairly well sorted ooids with minimal bioerosion can be found in many sequences, as can oolitic deposits where the ooids are almost completely micritized or contain a relatively high percentage of uncoated skeletal grains.

ACKNOWLEDGMENTS

Logistical support for our research on Andros and Joulters was provided by Dr. Ben Bohl and the staff of the Forfar Field Station. Special thanks to Ricardo and K.P. for piloting the boats. Financial support for the several trips to Joulters and Andros Island was provided by Miami University through the annual field course, Modern Carbonate Deposition. Students participating in the course assisted with surface sample collection and coring. We are thankful to Cheryl Folda (Wright State University) for preparations of thin sections, and to Danielle Foye for photographic reproductions.

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