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SEDIMENTOLOGY OF A HOLOCENE PLATFORM-MARGIN CARBONATE LAGOON: BLACKWOOD BAY SAN SALVADOR ISLAND, BAHAMAS

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ABSTRACT

Blackwood Bay, at the southern end of San Salvador Island Bahamas, is a quiet, shallow water lagoon. It is bounded to the north and east by the island, to the west by French Bay, and to the south by a barrier reef-rubble rampart along the platform margin. The lagoon floor consists of elevated mounds carpeted by *Thalassia* and other sea grasses and algae with intervening deeper sandy areas. The sandy areas contain occasional patch reefs, coral rubble, and chunks of *Thalassia*-bound sediment that have caved-off undercut *Thalassia* mounds.

Detailed analysis of surface samples and cores show the lagoon to have four main facies: 1) barren mobile sand facies; 2) sparse *Thalassia* facies; 3) moderate *Thalassia* facies; and 4) dense *Thalassia* facies. Among the four facies, the mobile sand facies contains the highest percentage of sand and the lowest percentages of mud, high-magnesium calcite, and living *Thalassia*. With increasing amounts of *Thalassia* (sparse to dense *Thalassia* facies) progressively lesser amounts of sand and greater amounts of mud and high-magnesium calcite occur. The cores exhibited a coarse sand and gravel base that typically graded upward into fine-grained deposits as a set of fining-upward sequences.

The increase in mud and high-magnesium calcite with increasing *Thalassia* abundance reflects the baffling effect of the grasses and the high-magnesium calcite secreting epibionts encrusting the grass blades. The overall fining upward core sequences represent the Holocene marine transgression across the lagoon, followed by progressive energy decrease as the barrier reef developed on the ocean side of the lagoon. The repeated fining upward sequences in the cores, scattered coral rubble debris, undercut banks of the *Thalassia* mounds with intervening sand scour pits, and the rubble rampart nature of the current barrier reef suggest repeated storm modification of Blackwood Bay.

INTRODUCTION

Blackwood Bay is located at the southern end of San Salvador Island, in the eastern portion of the large embayment known as French Bay (Fig. 1). The bay is bounded to the north and east by beaches and Pleistocene outcrops, to the south by a shallow-water reef-rubble rampart that trends east-west along the platform margin, and to the west it is open into French Bay. Immediately seaward of the reef, the upper fore--reef slope has a gentle gradient with well developed spur and groove topography. This area is barren of coral except for a few small isolated colonies. Further seaward, the fore-reef slope plunges nearly vertically to abyssal depths. Wilson (1975) classified this type of platform margin setting as a framebuilt reef rim.

The platform edge is an area of very high energy, as waves approaching from the south shoal rapidly and produce very large breakers.

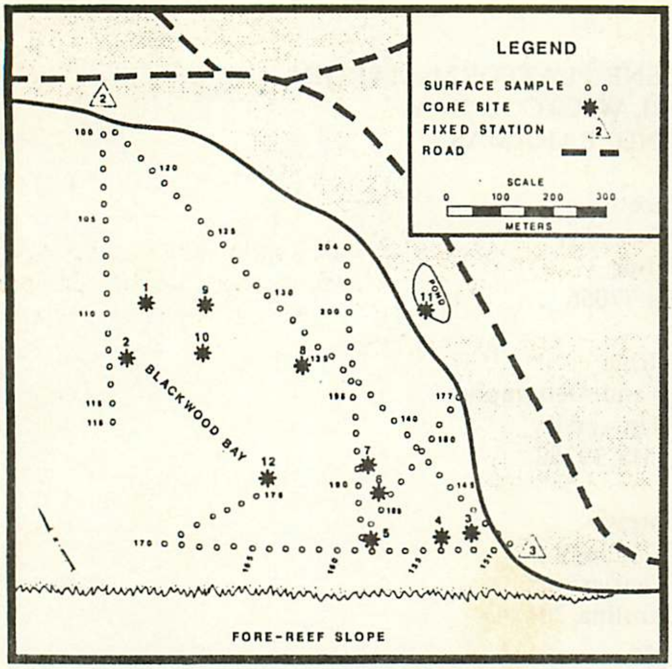


Fig. 1. Map of the study area, Blackwood Bay, showing location of cores and surface samples.

Active reef growth is minimal here except for small encrusting forms such as the hydrozoan *Millepora*. The majority of the platform edge consists of cobble to boulder size coral skeletal material sometimes bound together by *Millepora*. The barrier effect of this boulder rampart is chiefly responsible for the quiet water, low energy conditions in Blackwood Bay.

The back-reef contains many features characteristic of shallow water lagoonal settings. Water depth in the study area ranges from 0-2 meters at mean low tide. Three major features result in topographic irregularities on the lagoon floor: (1) *Thalassia* mounds and meadows; (2) intermound areas that are bowl-shaped depressions containing mostly sand and gravel; and (3) small patches of coral.

The boundaries between the sandy depressions and the *Thalassia* meadows are usually very steep with roots exposed along the steep face. Most of the steepest grass "cliffs" are oriented east-west and face south toward the platform edge and prevailing current. In most cases the current has undercut the lower roots leaving the upper *Thalassia* mat hanging over into the adjacent sand pit.

Several workers have referred to these sandy depressions as "blow-outs" or "deflation pits: (Ball, 1967; Perkins and Enos, 1968; Wanless, 1974; Patriquin, 1975; and Hine and Neumann, 1977). This has led to some confusion because these terms were originally applied to eolian environments (McKee and Ward, 1983). Herein, such features are referred to as subaqueous scour pits.

The subaqueous scour pits range in size from several meters to tens of meters across (Fig. 2). Most of the pits contain large sand-wave bedforms. These mega-ripples have the coarsest material in their troughs and the finest material on the crest, which is typical of subaqueous bedforms. Scour pits that are situated near the platform edge tend to contain large boulders.

Along the northern and eastern portions of the bay a prominent intertidal zone is present. During low tide, paleosol-covered Pleistocene bedrock and *Thalassia*-covered mudflats with abundant *Neogoniolithon* become subaerially exposed. Black mangrove (*Avicennia*) trees inhabit the landward portions of the intertidal zone and are presently overgrowing relict beach deposits. The relict beach deposits are interspersed with outcrops of paleosol-covered Pleistocene bedrock, and these grade westward into active sand beaches.

Inland of the mangroves, many large lobes of coral boulder debris are present. These lobes are best observed where they encroach on a small pond in the northeast portion of the study area. The individual lobes are one to two meters high and two to five meters across, and are composed of cobble to boulder-sized coral rubble. These individual lobes coalesce to form a mega-lobe. A large (15x10cm) piece of *Montastrea annularis* was collected from one of these lobes. XRD analysis showed the sample to be 100% aragonite, and radiocarbon analysis yielded an age of 3810±90 yBP, implying that the rubble lobes are less than 3900 years old (see Caputo and Kramer, this volume).

BOTTOM FACIES

Based upon field observations and analyses of more than 50 surface sediment samples, four facies or bottom types have been recognized in Blackwood Bay. These are:

1. Barren Mobile Sand Facies
2. Sparse *Thalassia* Facies
3. Moderate *Thalassia* Facies
4. Dense *Thalassia* Facies

Fig. 2. Subaqueous scour pit. Note the boulder-sized debris. Relief on the Thalassia *cliff face is 1 meter. Water depth: 2 meters.*

Fig. 3. Barren mobile sand facies containing asymmetrical wave ripples. Grass covered mound at left is 1 meter across. Water depth: 3 meters.

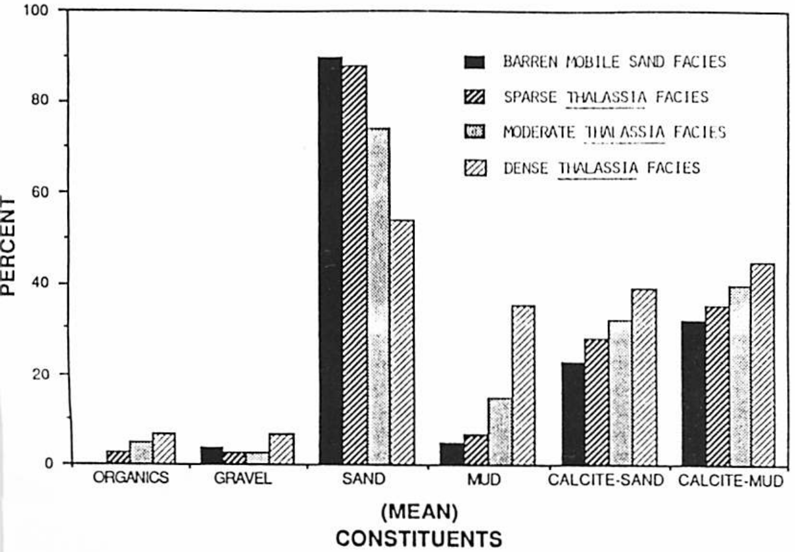


Fig. 4. Graph showing percent of constituents for each of the four facies from Blackwood Bay. Grain sizes and organics are weight percents; calcite values determined from XRD peak height ratios.

Fig. 5. The sparse Thalassia *facies. Blades are heavily encrusted with epibionts. Note the short, stunted nature of the blades. Field of view is approximately 20cm. Water depth: 2 meters.*

Fig. 6. The moderate Thalassia *facies. Blades are long and healthy compared to those of the sparse* Thalassia *facies. Spotted Trunkfish is approximately 5cm. wide. Water depth: 1.6 meters.*

Fig. 7. The dense Thalassia *facies. Note the abundance of rhizomes. Water depth: 1.8 meters.*

Barren Mobile Sand Facies

The barren mobile sand facies that occupy the subaqueous scour pits derives its name from a similar facies found in Snow Bay (to the east of the study area) and described by Andersen and Boardman (1987). Coarse to fine sand with little mud, no sea grass, and small amounts of algae are characteristics of the barren mobile sand facies. Asymmetrical wave ripples are a common feature (Fig. 3).

Fourteen surface samples were collected and analyzed from the barren mobile sand facies. On average, sand particles (2.0-0.065mm) comprise 91% (Fig. 4), and mud content comprises an average of only 5.3% of the total sample. (All grain size and organic content percentages reported in this paper are weight percents, mineralogic percents were calculated from XRD peak height ratios). The average mineralogy for the sand is 24.2% high--magnesium calcite and 75.8% aragonite. The average mineralogy for the mud is 33% high- magnesium calcite and 67% aragonite. Megascopic observations indicate that the sediment of the barren mobile sand facies is a coarse to fine grained, moderately to well sorted bioclastic sand. The major constituents include abraded coral, mollusc, and foraminifera debris, with minor amounts of *Halimeda*, echinoderm, and ostracod fragments.

Thalassia Facies

Thalassia testudinum (Turtle grass) and other sea grasses such as *Syringodium* and *Halodule* are present in varying concentrations throughout the study area. Based upon visual observations of *Thalassia* density, three facies termed sparse, moderate, and dense *Thalassia* facies were defined.

Sparse *Thalassia* Facies. The sparse *Thalassia* facies supports a very limited *Thalassia* growth with somewhat greater amounts of *Syringodium* (Fig. 5). The sand is moderately to well sorted and is well rounded. Foraminifera, algae and coral fragments dominate most of the samples analyzed. Sand size particles average 88.1% for the 12 samples collected (Fig. 4). Gravel and mud average 3.0% and 6.3% respectively. High-magnesium calcite in the sand and mud fractions averaged 27% and 35% respectively, and aragonite comprised 73% and 65% respectively.

Moderate *Thalassia* Facies. Criteria for recognition of the moderate *Thalassia* facies was abundant *Thalassia* growth, but with the substrate still clearly visible when viewed from above (Fig. 6). Sediment in the moderate *Thalassia* facies is moderately to poorly sorted. Foraminifera, mollusc, and echinoderm fragments are the most abundant constituents. The gravel percentage is essentially the same as in the sparse *Thalassia* facies, but the greater mud content averages 15.2% while sand comprises 74% of the 8 samples collected (Fig. 4). High-magnesium calcite in the sand and mud fractions averaged 32% and 40% respectively, and aragonite comprises 68% and 60% respectively.

Dense *Thalassia* Facies. Dense grass growth that completely shields the substrate from view, characterizes the dense *Thalassia* facies (Fig. 7). Gravel is slightly more abundant than in the other facies, and comprised 5.5% of the 5 samples analyzed (Fig. 4). The amount of sand was markedly decreased to an average of only 53.7%, while the mud content (averaging 35%) was the highest among all the facies. High-magnesium calcite in the sand and mud fractions averaged 38% and 44% respectively, and aragonite averaged 62% and 56% respectively.

Megascopic observations indicate that the sand fraction of the dense *Thalassia* facies is composed of abundant foraminifera and mollusc fragments, echinoderm spines and pieces, ostracods, and *Halimeda* chips. Gravel-sized particles are almost exclusively whole mollusc shells and coral fragments.

Correlations Among the Surface Sediment Data

Along any of the transects in Blackwood Bay, the habitats or bottom facies of adjacent sample localities may differ drastically. Comparing parameters along transects would be meaningless because of the sudden changes in the facies. Therefore, the surface sediment samples were split into the four facies based on the relative abundance of *Thalassia* grass, and statistical correlation tests were made on several parameters in each of the facies.

The following parameters were correlated within each of the facies: percent organics, percent gravel, percent sand, percent mud, percent calcite in the sand fraction, percent calcite in the mud fraction, and water depth. The results of the correlation study are shown in Table 1. The bold numbers represent significant correlations.

In all four facies the percent sand versus

	Barren Mobile Sand Facies	Sparse Thalass. Fac.	Moderate Thalass. Fac.	Dense Thalass. Fac.
Organics vs. Gravel	0.21	0.04	**0.79**	**0.82**
Organics vs. Sand	-0.39	**-0.78**	**-0.97**	**-0.85**
Organics vs. Silt/Clay	0.08	**0.8**	**0.9**	**0.88**
Organics vs. Calcite-Sand	-0.12	0.08	**0.89**	**0.91**
Organics vs. Calcite-Silt/Clay	-0.15	-0.05	**0.82**	**0.87**
Organics vs. Water Depth	-0.05	-0.16	-0.2	-0.39
Gravel vs. Sand	-0.24	-0.52	-0.24	-0.42
Gravel vs. Silt/Clay	-0.21	0.11	0.1	-0.03
Gravel vs. Calcite-Sand	-0.28	0.14	0.32	0.04
Gravel vs. Calcite-Slit/Clay	-0.07	-0.001	0.32	0.8
Gravel vs. Water Depth	0.35	-0.21	0.18	-0.62
Sand vs. Silt/Clay	**-0.86**	**-0.89**	**-0.97**	**-0.87**
Sand vs. Calcite-Sand	0.21	-0.33	**-0.93**	**-0.9**
Sand vs. Calcite-Silt/Clay	-0.35	-0.28	-0.41	0.02
Sand vs. Water Depth	0.48	0.45	0.18	0.03
Silt/Clay vs. Calcite-Sand	-0.15	0.4	0.22	-0.03
Silt/Clay vs. Calcite-Silt/Clay	0.44	0.47	0.52	-0.49
Slit/Clay vs. Water Depth	-0.23	-0.18	-0.22	0.25
Calcite-Sand vs. Calcite-Silt/Clay	-0.19	0.51	0.61	-0.28
Calcite-Sand vs. Water Depth	0.34	-0.13	-0.03	0.14
Calcite-Silt/Clay vs. Water Depth	-0.65	-0.09	0.24	-0.68
Number of Samples	n=14	n=12	n=8	n=5
Critical Value	C.V.=.514	C.V.=.553	C.V.=.666	C.V.=.811

Table 1. Correlation of sedimentary parameters among the four facies. Boldface indicates a significant correlation.

the percent mud showed a strong inverse relationship. No other parameters exhibited significant correlations among all four of the facies. Parameters that revealed correlations among two or more of the facies included: organics versus mud (direct relationship), organics versus sand (inverse relationship), organics versus calcite in the sand fraction (direct relationship), organics versus calcite in the mud fraction (direct relationship), and sand versus calcite in the sand fraction (inverse relationship). The remaining combinations of parameters showed no significant correlations.

DISCUSSION OF MODERN FACIES

In Blackwood Bay, currents and bottom topography play an important role in the distribution and texture of the sediments. The shallow water conditions in the lagoon enable the currents to affect bottom topography which in turn exhibits controls on the currents. Such a feed-back mechanism was documented by Ball (1967). Each of the facies studied has its own characteristic bottom topographic setting that results in a predictable suite of sediments.

Barren Mobile Sand Facies

The barren mobile sand facies is characteristic of the highest energy areas of the bay. During calm conditions in the lagoon, subaqueous asymmetrical wave ripples form on the sand sheets indicating that they are probably being reworked by normal currents. Correlations show that the amount of sand (averaging 91%) increases as mud content decreases suggesting that winnowing by currents is very effective.

Patch reefs along the platform edge appear to contribute significantly to the sediments of the adjacent barren mobile sand facies. Sands in this area contain large amounts of coral debris. In contrast, sands collected farther shoreward are predominantly composed of foraminifera and algal debris. Almost all of the sediments within the barren mobile sand facies are rounded to well rounded and polished, indicating that mechanical breakdown is dominant over biological breakdown.

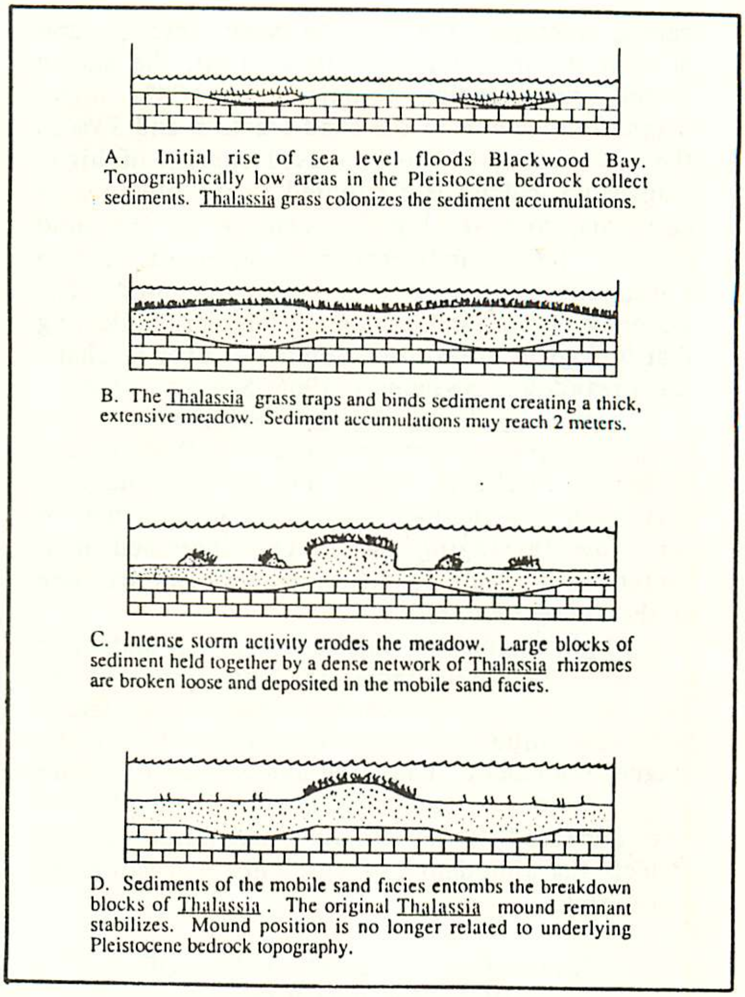
Thalassia Facies

The influence of *Thalassia* grass on bottom topography and currents has been well documented (Ginsburg and Lowenstam, 1958; Swinchatt, 1965; Scoffin, 1970). As currents pass over the *Thalassia* meadows, the velocity is reduced and sediment in suspension is deposited. Through time, carbonate mud accumulates and produces a local buildup supported by *Thalassia* grass. Within the study area, small isolated mounds and extensive meadows of sparse to dense growth of *Thalassia* occur.

Several studies have indicated that *Thalassia* mounds form in topographic lows (Howard and others, 1970; Scoffin, 1970; Zieman, 1972; Ebanks and Bubb, 1975; Turmel and Swanson, 1976; Boscence and others, 1985; Andersen and Boardman, 1987). In Blackwood Bay, the living *Thalassia* mounds may have originally formed in topographic lows, but their present position shows no relationship to underlying bedrock topography. Sediment probing across many of the mounds revealed no depressions in which the mounds could have originated. Fig. 8 is an interpretive illustration of the origin of *Thalassia* mounds in Blackwood Bay.

Associated with the *Thalassia* buildups are significant amounts of carbonate mud. Particular attention has focused on the sources of this mud. Cloud (1962) in his study of the Great Bahama Bank concluded that much of the carbonate mud was produced by direct precipitation. Lowenstam (1955) discovered that calcareous green algae disintegrate upon death into needles and plates small enough to form carbonate mud. Additional studies have shown that the breakdown of calcareous algae is a major contributor of carbonate mud (Neumann, 1965; Stockman and others, 1967; Neumann and Land, 1975; Bosence and others, 1985). Physical and chemical breakdown can also contribute to the mud fraction (Folk and Robles, 1964; Neumann, 1965; Matthews, 1966; Stieglitz and Wise, 1969; Hay and others, 1970; Howard and others, 1970; Stieglitz, 1970). Carbonate production by epibionts encrusting *Thalassia* blades is also an important contributor of lime mud (Land, 1970; Patriquin, 1972; Nelson and Ginsburg, 1986). In Blackwood Bay, skeletal breakdown (by mechanical and algal processes) and epibiont growth are the most important contributors of carbonate mud.

<u>Sparse</u> <u>*Thalassia*</u> <u>Facies</u>. The sparse *Thalassia* facies is similar in many ways to the barren mobile sand facies. Sand content is high (averaging 88%) and mud content is low (averaging 6.3%). Grains, especially foraminifera, are rounded and polished indicating reworking and mechanical breakdown are dominant processes.



A. Initial rise of sea level floods Blackwood Bay. Topographically low areas in the Pleistocene bedrock collect sediments. Thalassia grass colonizes the sediment accumulations.

B. The Thalassia grass traps and binds sediment creating a thick, extensive meadow. Sediment accumulations may reach 2 meters.

C. Intense storm activity erodes the meadow. Large blocks of sediment held together by a dense network of Thalassia rhizomes are broken loose and deposited in the mobile sand facies.

D. Sediments of the mobile sand facies entombs the breakdown blocks of Thalassia. The original Thalassia mound remnant stabilizes. Mound position is no longer related to underlying Pleistocene bedrock topography.

Fig. 8. Interpretive illustration of the origin of Thalassia *mounds in Blackwood Bay.*

Correlation data reveals that the amount of organics (primarily *Thalassia* blades and rhizomes), sand, and mud are interrelated (Table 1). Organic content shows a direct relationship with mud content and an inverse relationship with sand. The slight increase in mud content with increased organics is attributed to a very limited baffling effect of the sparse *Thalassia* grass.

<u>Moderate</u> <u>*Thalassia*</u> <u>Facies</u>. The trapping and binding of sediment in the moderate *Thalassia* facies is fairly efficient. Sand content averages 74% and mud content averages 15%. The decrease in sand and the increase in mud with respect to the mobile sand facies is a direct result of the baffling effect of the grass.

Epibionts of red algae and foraminifera composed of high-magnesium calcite, and aragonitic serpulid worms encrust the broad, thin blades of *Thalassia* (Land, 1970; Patriquin, 1972; Nelson and Ginsburg, 1986). High-magnesium calcite averages 32% in the sand fraction and 40% in the mud fraction. In contrast, the barren mobile sand facies contains only 24% high-magnesium calcite in the sand fraction and 33% in the mud fraction. The increased amount of high-magnesium calcite is attributed to the presence of epibionts, and its high percentage in the mud fraction (40%) indicates that epibionts are a significant contributor of carbonate mud. The majority of the sand grains are angular, indicating that biological breakdown dominates over mechanical breakdown (Swinchatt, 1965; Scoffin, 1970).

Dense *Thalassia* Facies. Sediments of the dense *Thalassia* facies are similar to those of the moderate *Thalassia* facies but mud content is very high (averaging 35%) and sand content is very low (averaging 54%). The increased mud content is a result of the more efficient baffling of the dense *Thalassia*.

High-magnesium calcite is more abundant in the dense *Thalassia* facies than any other facies. The sand fraction is 38% high-magnesium calcite and the mud fraction contains 44% high-magnesium calcite. The large amounts of *Thalassia* grass provide an extensive habitat for epibionts. The increased levels of high-magnesium calcite reflects the abundance of epibionts encrusting the dense grass.

DEPOSITIONAL EVOLUTION OF BLACKWOOD BAY

Blackwood Bay, situated on the southern edge of the San Salvador platform, provides an unique setting in which to study modern carbonate sedimentation. To the south, the lagoon is bounded by the platform edge and steep fore-reef slope. To the north and east, Pleistocene outcrops border Blackwood Bay. The closeness of the lagoon to the platform edge and the ramp-like nature of the platform above the fore-reef slope indicate that as sea level encroached upon the platform, the "carbonate factory" was initiated early and *in situ* sedimentation began immediately. As no low-magnesium calcite was detected in any of the sediments of the bay, reworked Pleistocene material has not been a significant contributor to the sediment.

Based on analyses of cores, surface sediment samples, and study of the present facies distribution, the depositional evolution of Blackwood Bay can be presented as follows. Prior to flooding, Blackwood Bay existed as an exposed Pleistocene bedrock surface covered with a thin soil. The remnants of this soil has been preserved in the form of a dark red paleosol exposed in many parts of the study area. The presence of black micrite pebbles in the base of core 9 (Fig. 9) is also indicative of subaerial exposure (Strasser, 1984). These well rounded pebbles are interpreted as relics of paleosol reworked by waves, currents, and storm activity, and represent the only detected Pleistocene sediments in Blackwood Bay.

The timing of the marine inundation of Blackwood Bay can be surmised from data obtained from two cores collected in Snow Bay to the east. The basal sands yielded radiocarbon dates of 3850±190 yBP and 3630±120 yBP (Anderson and Boardman, 1987). These dates are also consistent with the Holocene chronology of Carew and Mylroie (1987) and the age (3810±90 yBP) of the coral from the landward coral rubble lobes previously mentioned. Although it cannot be proven that the sediments were formed where found today, it appears that the gently sloping Pleistocene floors of Snow Bay and Blackwood Bay were flooded around 3800 years ago.

As sea level inundated the ramp-like platform, high energy conditions existed in the partially flooded lagoon. The absence of any barrier reef framework or consolidated coral rubble along the platform edge resulted in the high energy conditions. Cores 3, 4, 9 and 12 have very coarse coral fragments which are believed to be derived from the fore-reef slope or from local patch reefs colonizing hardgrounds within the early lagoon.

Point count analysis of the sediments in core 3 indicates that molluscs, echinoderms, *Lithophyllum*, *Halimeda*, and *Neogoniolithon* algae were all very abundant during the flooding. Extensive hardgrounds, depressions in the Pleistocene bedrock surface, and initial *Thalassia* sediments would have provided excellent habitats for the those organisms (Howard and others, 1970; Scoffin, 1970; Zieman, 1972; Ebanks and Bubb, 1975; Turmel and Swanson, 1976; Bosence and others, 1985; Andersen and Boardman, 1987). While algae and other organisms were flourishing, foraminifera and ostracod abundance was low.

The continued transgression of the sea resulted in the deposition of overall fining-upward sequences present in all eleven of the lagoon cores. Boardman and others (1987) in a study of three Bahamian lagoons found that the depth and type of seaward sill, along with sea level rise, control the deposition of sediments. In Blackwood Bay, stabilization of the coral-rubble rampart along the platform edge provided a sill that produced a gradual decrease in physical energy conditions that produced the fining upward sequences. Localized buildups of patch reefs and colonization of current-baffling *Thalassia* grass also resulted in decreased energy conditions.

The present day sediment accumulation patterns observed in Blackwood Bay are a result of several processes. Sediments of the *Thalassia* facies are angular, poorly sorted, and contain elevated amounts of mud that reflect the low energy conditions brought on by the baffling effect of the grass. Higher velocity currents active in the barren mobile sand facies are evidenced by the clean, well rounded sediments found there. However, the process that exerts long term control over sediment distribution appears to be storm activity.

EVIDENCE FOR STORMS

The importance of storms within carbonate settings has been stressed by many workers (Ball, 1967; Hayes, 1967; Perkins and Enos, 1968; Patriquin, 1975; Hine and Neumann, 1977; Morton, 1981). In Blackwood Bay, cores 3, 4, 8, 9, 10, and 12 are characterized by small packages of fining--upward sequences, the basal portions of which are characteristically medium to coarse sands of the barren mobile sand facies deposited during peak storm activity. The remaining portion of the fining-upward sequences within the cores are fine sands, silts, and muds of the *Thalassia* facies deposited during waning storm activity and calm, more normal conditions.

Core 11, collected in a nearby pond, also shows evidence of storm activity. The base consists of a dark brown peat. Above the peat is a thick sequence of dark gray muds. Laden with ostracods, this deposit is typical of San Salvador pond environments (Teeter and Thalman 1984). Encased within the mud section are several thin layers of sand. Three of these layers are composed of marine sediment identical to those currently forming in the lagoon. The layers are thought to be the result of storm events that transported lagoonal sediments landward and deposited them in the pond.

During the latter days of December 1986, San Salvador Island was hit by an intense storm that lasted for two days. In Blackwood Bay, entire blocks of sediment held together by *Thalassia* rhizomes were torn from their mounds, thus producing subaqueous scour pits (Fig. 10). Sediments of the barren mobile sand facies immediately began entombing the breakdown blocks (Fig. 11). Evidence for a past similar event can be found in core 6 (see Fig. 12). That core contains one large (~120 centimeters) fining-upward sequence. The base of the core is a medium to fine moderately sorted bioclastic sand. This grades upward into a well sorted very fine bioclastic sand with abundant *Thalassia* rhizomes. The center of the sequence (40 to 80 centimeter level) shows abundant *Thalassia* rhizomes encased above and below by clean, well sorted sands. This anamolous package of *Thalassia* rhizomes is interpreted to be a breakdown block similar to the ones described above.

The presence of the cobble to boulder size coral rubble in many parts of the lagoon and back-beach area suggests that storms are important to the morphology of the lagoon. Although a coral-rubble boulder rampart presently forms the barrier to the south, this rubble has been stabilized on the platform edge by encrusting algae and *Millepora* and many of the primary internal coral structures have been obliterated, making taxonomic identification difficult. In contrast, the coral rubble deposited as lobes in the back-beach area shows no signs of having been submerged on the lagoon floor for very long. The coral rubble there is not bored or encrusted and preservation of primary structures is excellent. Most of the coral can be identified to the species level.

As mentioned above, the age (3810 +/- 90 yBP) of a coral sample from one of these lobes seems to coincide with the flooding of the bank top. The age of the coral and the excellent preservation of primary structures suggest that the coral was uprooted, transported across Blackwood Bay and deposited at its current location during one severe storm event.

Today, there exists a dynamic equilibrium between *Thalassia* grass colonization of the barren mobile sand facies and mound erosion primarily by storm activity. The fining-upward packages capped with *Thalassia* rhizomes in core 9 suggest that stabilization of the barren mobile sand facies by *Thalassia* is a continually occurring process. *Thalassia* breakdown blocks observed today and in core 6 suggest that erosion of *Thalassia*-stabilized sediment has also been occurring in the lagoon. Mound stabilization and subsequent erosion of those mounds results in an equilibrium reflected in the present day mound and scour pit topography in Blackwood Bay.

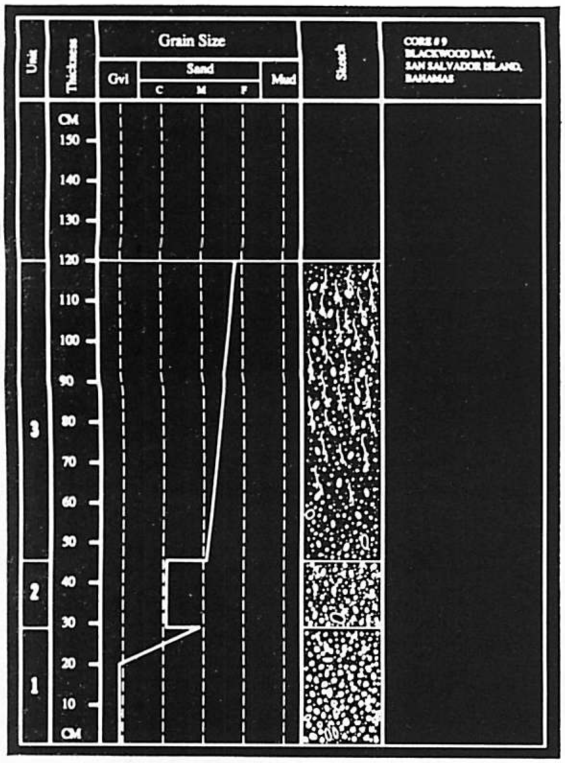


Fig. 9. Graphic display of core #9, collected in the center of the Blackwood Bay lagoon. Moderate Thalassia *growth on the bottom. Water depth: 54cm.*

Fig. 10. A breakdown block of Thalassia *produced during a severe storm that struck Blackwood Bay in December, 1986. Water depth: 1.7 meters.*

Fig. 11. Photo of Thalassia *breakdown blocks entombed by sediments of the barren mobile sand facies. Water depth: 1.7 meters.*

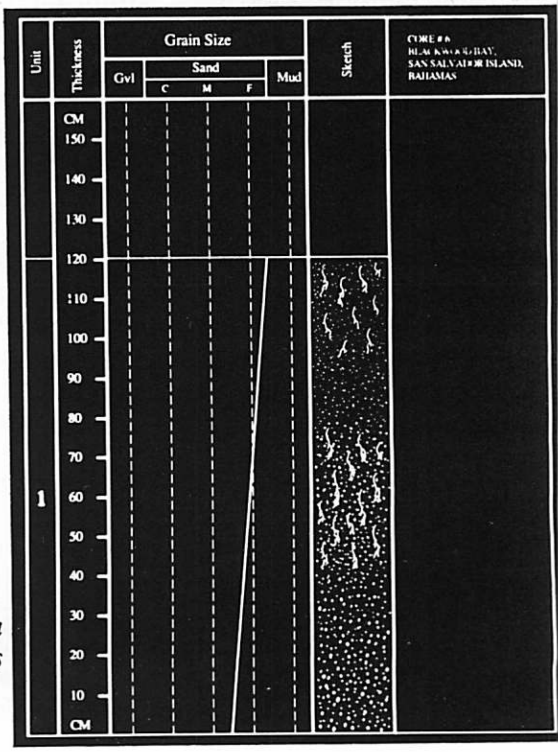


Fig. 12. Graphic display of core #6, collected from an elevated moderate Thalassia *area surrounded by numerous subaqueous scour pits. Water depth: 76cm.*

SUMMARY AND CONCLUSIONS

Blackwood Bay is a medium to low energy lagoon shielded from full wave energy by a boulder-rampart platform edge to the south. The fore-reef slope is very steep, plunging nearly vertically to abyssal depths.

Four sedimentary facies are recognized based on field observations and laboratory analyses of more than 50 surface sediment samples and twelve cores. The barren mobile sand facies consists of a clean, medium to well sorted, well rounded bioclastic sand which is largely deposited and reworked during sporadic high energy conditions produced by storms. Sediment composition varies depending on the location within the lagoon. Foraminifera, coral debris and algal fragments are most common, with coral debris very abundant along the platform edge. Mineralogically, the barren mobile sand facies contains the highest proportion of aragonite.

The sparse *Thalassia* facies is very similar to the barren mobile sand facies. Sediments are moderately to well sorted and do not contain appreciable mud. Sediment composition and mineralogy are almost identical to that of the barren mobile sand facies.

The moderate *Thalassia* facies exhibits signs of the baffling effect of the grass. Mud averages 15% of the samples analyzed. The sands are unabraided and angular, indicating that biological breakdown is dominant. Foraminifera, mollusc fragments, echinoid spines and pieces, algae, and ostracods dominate this facies.

The dense *Thalassia* facies shows the greatest effect of baffling as indicated by the very high average mud content (35%). Sand content is the least of any facies, averaging only 54%. Mineralogically, this facies contains the highest amount of high-magnesium calcite (38% of the sand and 44% of the mud). The steady increase in the amount of high-magnesium calcite with increasing amounts of grass is interpreted to be a function of epibionts inhabiting the surface of the grass blades. The increased level of magnesium calcite in the muds also suggests that epibionts are a significant contributor of lime mud in Blackwood Bay.

Summary of the Depositional History of Blackwood Bay

1. Holocene sea level rise flooded the majority of the San Salvador platform between 3600 and 4000 years ago.
2. Approximately 3800 years ago a major storm deposited gravels, sands and coral rubble throughout the lagoon. Much of the coral boulder rubble was concentrated into lobes deposited in the back-beach area.
3. As sea level continued to rise, stabilization of coral rubble by encrusting algae and *Millepora* along the platform margin reduced incoming wave energy and created quiet water conditions in the lagoon. The colonization of *Thalassia* on early lagoonal sediments reduced current energy. The decreasing energy conditions resulted in overall fining-upward sequences found in all eleven cores collected in the lagoon.
4. Storm activity reworked sediments producing small fining-upward sequences within an overall fining-upward package. The lower portion of each sequence represents deposition within the barren mobile sand facies while the upper portions show evidence of *Thalassia* grass colonization. The baffling effect of the grass trapped and bound sediment thus producing the *Thalassia* facies at the top of each sequence.
5. Today, a dynamic equilibrium exists between barren mobile sand facies stabilization by *Thalassia*, and *Thalassia* mound erosion by storm activity. This results in the present mound and subaqueous scour pit topography.

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