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Cover photo: *Diploria strigosa*, the common brain coral, preserved in growth position at the Cockburn Town fossil coral reef site (Sangamon age) on San Salvador Island. Photo by Al Curran.

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THE FLUX AND DEPOSITION OF PERIPLATFORM CARBONATES IN NORTHWEST PROVIDENCE CHANNEL, BAHAMAS

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ABSTRACT

In a preliminary effort to quantify the off-bank tansport and vertical flux of shoal-water carbonates in the northern Bahamas, a sediment trap mooring was deployed in the periplatform environment of Northwest Providence Channel (NWPC), Bahamas. Previous studies have shown that 70-90% of the recent sediment covering this open seaway consists of bank-derived, lime muds. Planktonic elements make up the remainder of the periplatform sediment components. Two months of sediment trap data obtained during the relatively calm, storm-free period of the year between the end of February and the end of April (1985) revealed that the components of the carbonate particle flux varied significantly from the composition of the underlying sediments. Planktonic foram tests, pteropod shells and fragments, and coccoliths contributed 61% to the total flux of carbonate material, whereas bank-derived material represented by aragonitic needle aggregates and benthic foram fragments, constituted 39%. In the fine silt-clay sediment fraction, abundant bank-derived aragonite and magnesian calcite particles were observed as expected; however, calcite in the form of coccoliths represented 50% of the mass carbonate flux in this size fraction.

Considering the underlying periplatform ooze composition (80% bank-derived and 20% planktonic carbonate components), the 2-month sediment trap results indicate that half of the bank-derived components within the off-bank periplatform ooze is delivered during storm-free periods. It is hypothesized that the balance of shoal-water components in the periplatform muds is delivered to NWPC during the passage across the northern Bahamas of seasonal cold front systems and associated storms. This suggests that the flux and deposition in the Channel of bank-derived material is variable on a temporal scale and that possibly 50% of the periplatform muds represent "storm deposits" which are mixed through bioturbation.

INTRODUCTION

Carbonates are usually described as "homebodies" whose final resting place lies at or near their source. Probably the most wanderlust seen in carbonates are those sediments defined as "periplatform oozes" by Schlager and James (1978). A variable and often considerable fraction of these sediments have traveled from the shallow bank-tops and margins to the adjacent open-ocean where they mix with oceanic planktonic components and come to rest upon deep slopes and basin floors (Heath and Mullins, 1984). Of all the various types of carbonate sediments which are dominated by shoal-water components, periplatform oozes are carried the farthest from their bank-top source and their deposition is primarily controlled by lateral transport processes. These oozes are unique in that they consist of two mineralogically distinct assemblages of fine-grained biogenic carbonate constituents: 1) bank-derived high-Sr aragonite and magnesian calcite, and 2) calcite and pteropod aragonite produced in the pelagic water column. Properly read, periplatform oozes contain even more information than the purely oceanic oozes into which they grade. In the Quarternary record for instance, the presence of the shallow bank provides an amplifier that expands the interglacial, high sea level component of the climatic signal. This is useful because often

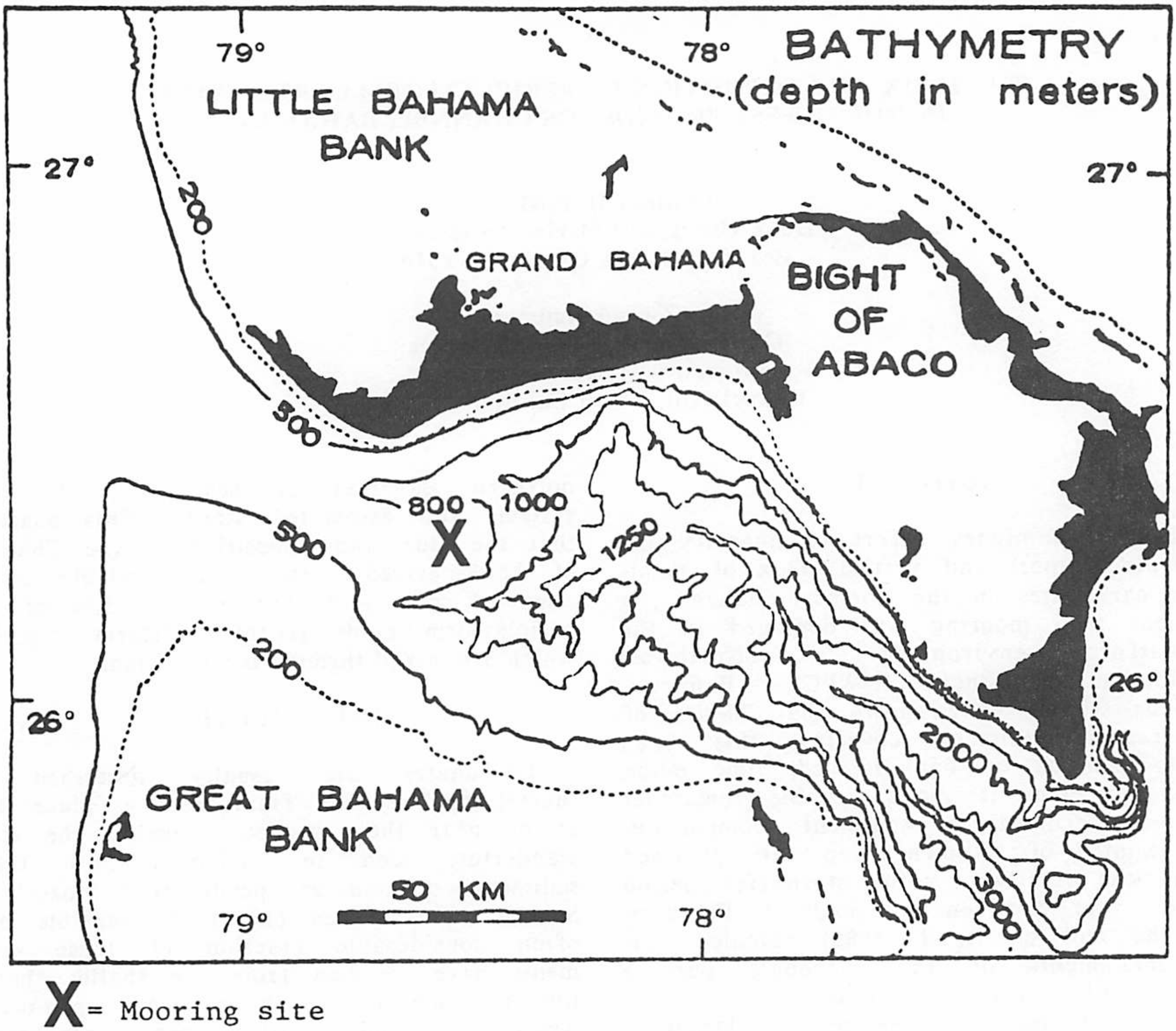


Fig. 1. Northwest Providence Channel, Bahamas: Bathymetry in meters. Location of sediment trap/current meter mooring site.

the oceanic record is compressed by virtue of lower open-ocean deposition rates, and the interglacial signal is not observed. In periplatform oozes, the bank-top component varies from dominant near the banks to a distal fringe, where diminishing supply and increasing dissolution gradually erase the platform-derived component with increasing depth and distance from its source (Droxler and others, 1983; Droxler and Schlager, 1986). The periplatform sediments tell both of bank-top and oceanic conditions, as well as recording processes at work in the water column through which they settle.

In the northern Bahamas, periplatform ooze sedimentation has been documented throughout the deep basins and troughs lying adjacent to the shallow platform banks (Pilkey and Rucker, 1966; Kier and Pilkey, 1971; Droxler and others, 1983; Boardman and Neumann, 1984; Droxler and Schlager, 1986). The last episode of sea level rise and subsequent flooding of the banks at the end of the Holocene has resulted in the sedimentation of a 50 cm-thick layer of periplatform sediment drape deposited across the deep-water realms adjacent to the shallow platforms (Kier and Pilkey, 1971; Droxler and others, 1983; Boardman and Neumann, 1984). Northwest Providence Channel (NWPC), a

200-2500 m-deep interplatform seaway lying between Little Bahama Bank and northern Great Bahama Bank, represents an extensive region of periplatform sedimentation where accumulation rates are on the order of 10 cm/10^3 years (Boardman and Neumann, 1984) (Fig. 1).

In an attempt to quantify the contribution of bank-derived versus pelagic-derived components to the periplatform ooze of NWPC, Boardman (1978) and Boardman and Neumann (1984) presented results of a geochemical end-member analysis of the Holocene periplatform sediments in NWPC. It was concluded in these studies that the 50 cm-thick Holocene sediment drape in NWPC, consists of a fine-grained lime mud (<62 um) in which 80% of the mud is bank-derived, with only a 20% contribution from pelagic carbonate sources (namely coccoliths and planktonic forams). Pteropod aragonite was found not to contribute significantly to the NWPC fine-grained sediment (Boardman and Neumann, 1984).

The high percentage of bank-derived muds in NWPC is not surprising considering the report by Neumann and Land (1975) of the massive volumes of fine-grained sediments produced by calcareous algae in the Bight of Abaco on Little Bahama Bank. Neumann and Land (1975) presented an algal lime-mud production and deposition budget in which they demonstrated that 1.5-3 times the mass of carbonate mud now in the Bight had been produced by the calcareous algal population over the Holocene lifetime of the lagoon. It was concluded that the "over-produced" volume of lime mud (=85-168 x 10^{10} kg) from the Bight of Abaco had been resuspended, laterally transported out of the subtidal basin, and deposited as periplatform ooze in Northwest Providence Channel. Cook and Mullins (1983) and Mullins and Cook (1986) note that these shoal-water lime muds also constitute an important component of the deep slope and carbonate apron deposits located along the platform margins. Gravity flow deposition occurring along some steep, channeled, margin slopes of the northern Bahamas is resposible for the sedimentation of wedge-shaped carbonate aprons consisting of a periplatform ooze facies (Mullins and Cook, 1986).

OBJECTIVES

Within the periplatform environment, the journey that carbonate particles take from their original source on the platform or in the surface waters to their ultimate resting place on the deep flanks and intervening basins can be considered as the "conduit" part of a source-conduit-sink system. It is important to examine how that conduit operates, both now and in the past, in order that we may better understand the Quanternary glacial/interglacial sedimentary cycles in the Northern Bahamas and begin to define the role which off-bank transported, metastable, shoal-water carbonates play in the global CO_2 budget.

The foregoing investigations into the sources and sinks of periplatform carbonate sediments in the northern Bahamas have raised a number of questions concerning the "conduit" portion of the overall periplatform sedimentation scheme, which represents the focus of this study. What pelagic particulate flux mechanisms/processes are at work in the deep water column of Northwest Providence Channel which facilitate the deposition of fine-grained lime muds so near their source? Are zooplankton fecal pellets important as suggested by Boardman and Neumann (1984) or are other biogenic aggregates ("marine snow") playing a major role? How does the composition of the periplatform particulate flux compare with the NWPC bottom sediments? What is the contribution to the flux of bank-derived versus planktonic carbonate material? Are there significant differences between the particulate flux and the periplatform sediment accumulation rate and composition which suggest some level of temporal variability in the delivery of bank-derived material?

The results of this sediment trap study in Northwest Providence Channel provide preliminary answers to these questions, while also demonstrating significant variability between the periplatform particulate rain and the underlying periplatform ooze sediment.

METHODS

A particulate sample was obtained from a PARFLUX MARK II sediment trap deployed at 500 m above a broad, intercanyon high located at the eastern end of Northwest Providence Channel where the bottom depth was 700 m (Figs. 1, 2). The trap design and single sample cup collection system are

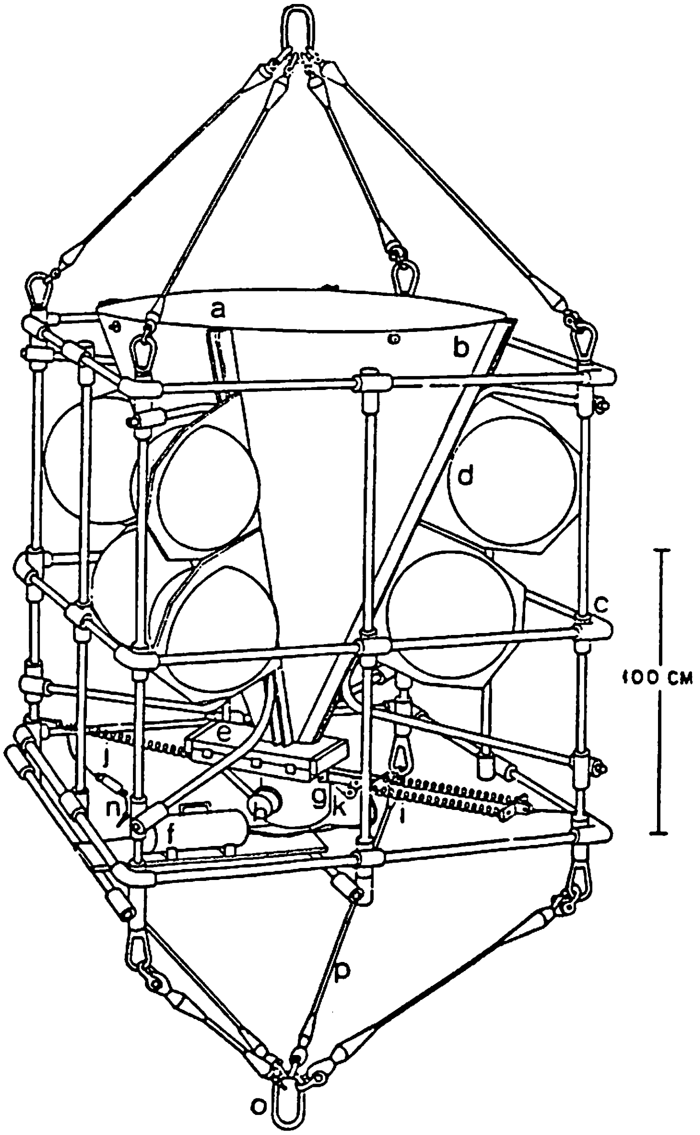


Fig. 2. An illustration of a PARFLUX Mark II sediment trap with an S type receiving cup. a: trap opening where a buffer (Fig. 1) is installed; b: a funnel; c: frame; d: floatation spheres (only hard hat covers are shown); e: "moving cup" mechanism; f: a pressure case for timer electronics and batteries; g: a receiving cup; h: bacteriacides diffusion chamber; i and j: spring to move and retain g; k: titanium burnwire. Magnesium corrodible link (n) is now released. Bridles (p) fasten a trap to the mooring line through O-rings (o) (Honjo and others, 1980).

described in detail in Honjo and others, (1980). In order to minimize bacterial oxidation of the particulate matter a dense, saline solution of 5% sodium azide poison was placed in the sample cup before deployment. A pre-programed BENTHOS timer was used to close the sample cup after a 2-month collection period between February 25 and April 25, 1985.

Upon return to the laboratory the trap material, which was refrigerated immediately upon recovery, was gently wet sieved into three size fractions >1 mm, 1 mm-63 um, and <63 um. The >1 mm material was split into 1/4 fractions and the smaller two sediment fractions were each split into two 1/4 splits and eight 1/16 splits. Replicate splits were weighted and analyzed for total carbonate, organic, and silicate content using the wet chemical methods outlined in Honjo (1980) and Pilskaln and Honjo (1987). Each sediment fraction was examined in detail with the SEM for component identification, including a <38 um fraction obtained by wet sieving two 1/4 splits of the <63 um material. The percentages of aragonite and total calcite in subsamples of all sediment fractions (bleached and non-bleached) was determined by X-ray diffraction using scanned integrated peak counts (Neumann, 1965; Neumann and Boardman, 1984). Two independent methods were used to determine the relative proportions of calcite and magnesian calcite in the samples. Values obtained by a scanned integrated peak count method of estimating calcite and magnesian calcite content (Neumann, 1965) were compared with such values obtained from peak height ratio calculations and the use of a standard curve (Boardman, 1978; Boardman and Neumann, 1984). No significant differences between the relative proportions of calcite and Mg-calcite determined by these two methods were observed. The mode mole percent of Mg in the magnesian calcite and calcite phases was obtained using a method in which the displacement of the calcite peak positions relative to that of a fluorite standard were measured (Neumann, 1965).

RESULTS

The particulate mass flux data from Northwest Providence Channel are presented in Table 1. A total mass flux of 59 mg/m^2/-day was measured of which 80% was provided by carbonate material. Swimmers in the form of uncoiled pteropods and isopods found in the >1 mm sediment fraction were identified by the presence of soft tissue and removed so as not to be included in the flux calculations. Particulate organic and silicate material (the latter represented

Sediment Fraction	Flux ($mg/m^2/day$)	% of Total Flux	Organic Flux	Carbonate Flux	Silicate Flux
>1mm	4.78	8.10	0.23	4.48	0.07
1mm-63um	15.01	25.44	1.44	12.14	1.43
<63um	39.20	66.45	3.59	30.99	4.62
Total	58.99	100	4.26	47.61	6.12

Table 1. Flux Constituents: NWPC (March-April 1985).

primarily by diatom frustules) contributed only 7 and 10%, respectively, to the total mass flux. The largest proportion of the flux in terms of sediment size, was provided by silt and clay material in the <63 um mud fraction. In fact, 50% of the total mass flux was represented by the <63 um-sized carbonate material (Table 1). This compares well with Boardman's (1978) NWPC sedimentological data showing that the mud fraction dominates NWPC periplatform sediments.

The specific carbonate mineralogy of the various sediment size fractions, combined with SEM observations, provided the means for determining the relative fluxes of bank-derived versus planktonic derived components. The >1 mm fraction consisted entirely of uncoiled pteropod aragonite and planktonic foraminiferal calcite and represented 8% of the total carbonate mass flux (Tables 1 and 2). Abundant planktonic forams were responsible for the majority of the 56% calcite composition of the 1 mm-63 um sediment fraction. *Globorotalia truncatulinoides*, *Globigerinoides sacculifer*, and *Globigerinoides rubra* were the dominant species (Plate 1). Coiled pteropods of the species *Limacina inflata* contributed 28% aragonite to the carbonate composition of the fine sand (1 mm-63 um) fraction of the trapped particulate sample (Plate 1). Sixteen percent of the carbonate in this fraction was high-magnesian calcite (15 mode mole % $MgCO_3$) (Table 2). The source of this high-Mg calcite was identified with SEM as benthic foraminifera tests and test fragments (Plate 1). Benthic forams are found abundant on the Bahama Platform, living in the shallow lagoons as well as along the exposed platform rim (Mackenzie and others, 1965;, Rose and Lidz, 1977). Studies of Bahamian lagoonal sediments have shown that benthic-foram fragments represent a small but consistent percentage of these shallow subtidal basin sediments (Stieglitz, 1972, 1973; Boardman, 1976). Conclusive evidence of their deposition in NWPC was presented by Boardman (1978) and Boardman and Neumann (1984).

Zooplankton fecal pellets (Plate 2) containing coccoliths, diatom fragments and amorphous organic matter, contributed to the fine sand fraction; however they were not as abundant as planktonic foraminifera or coiled pteropods. Fecal pellets represented only 3% of the total mass flux. The coccoliths contained in the pellets constitute a small (<5%) contribution to the total amount of calcite in the 1 mm-63 um trap material. The fine sand-sized particulate carbonate material represented 25% of the total carbonate flux. This is in close agreement with Boardman's (1978) surface sediment distribution map completed for sand-sized material in NWPC which shows a 20-40% sand contribution to the NWPC bottom sediments at our trap locality. Boardman's (1978) study also described a dominance of pteropods and planktonic forams in the sand fraction of the surface sediment samples obtained in the northwestern portion of NWPC.

The composition of the mud fraction (<63 um) which comprised the majority of the particulate sample, was significantly different from the fine sand fraction. Mineralogic content was similar (Table 2) but a distinct size fractionation between the two sediment classes was observed in terms of the calcite and aragonite sources. Whereas the 1 mm-63 um fraction contained abundant planktonic forams, coccoliths (represented primarily by *Emiliani huxleyi*) dominated the <63 um trapped sediment and provided a calcite flux of 14 $mg/m^2/day$ to the trap. The coccolith calcite contributed 46% to the total car

Sediment Fraction	% Calcite	Flux ($mg/m^2/day$)	% High Mg-calcite	Flux ($mg/m^2/day$)	% Aragonite	Flux ($mg/m^2/day$)
>1 mm	45	2.01	0	0	55	2.47
1mm-63um	56	6.80	16	1.94	28	3.40
<63um	46	14.26	20	6.20	34	10.54

Total Shoal-water Carbonate Flux = 19 $mg/m^2/day$
= 39% of total CO_3 flux

Total Planktonic Carbonate Flux = 29 $mg/m^2/day$
= 61% of total CO_3 flux

Table 2. Carbonate Mineralogy of NWPC Trap Material and Resultant Fluxes.

bonate content of the mud-sized fraction (Table 2, Plate 3e and 3h). The coccoliths showed no evidence of dissolution, nor should it be expected in this region of the North Atlantic where the aragonite and calcite compensation depths occur at approximately 2,500 m and 4,500 m, respectively (Li and others, 1969; Broecker, 1974; Adelseck and Berger, 1975; Droxler and others, 1986). Planktonic forams were essentially absent from the mud fraction.

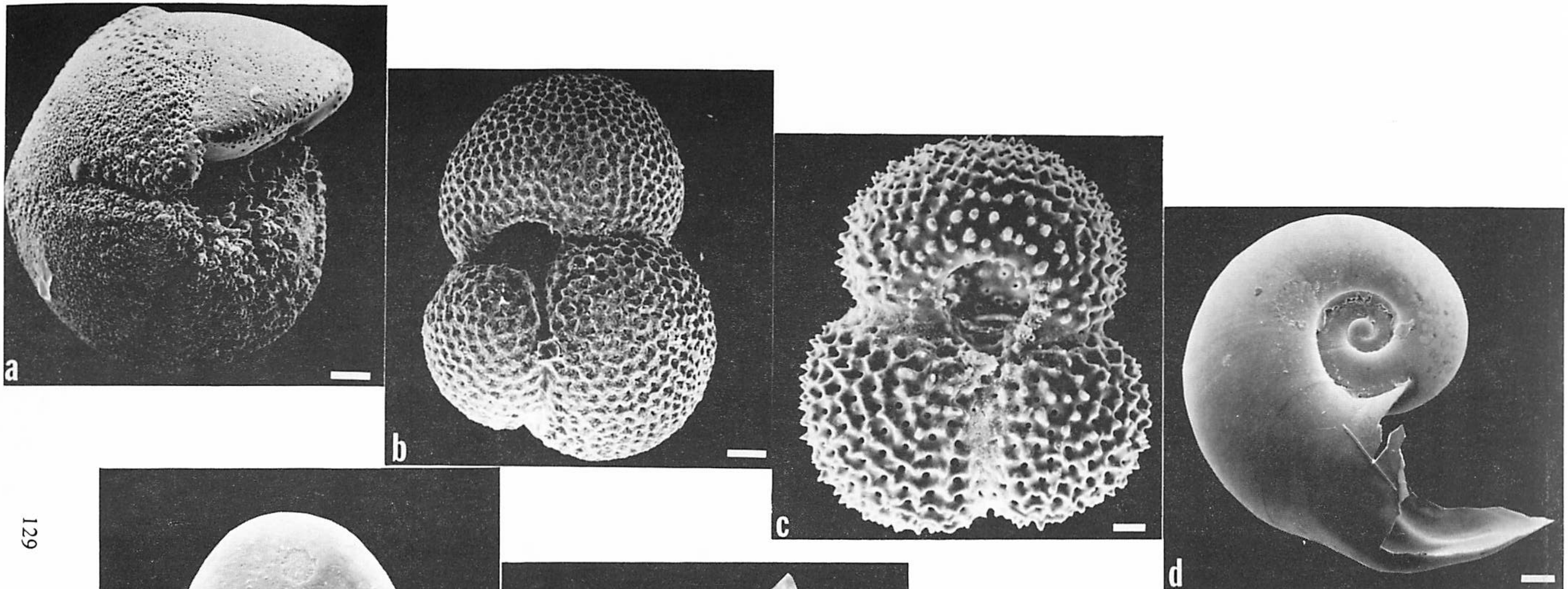
A notable difference in the dominant source of aragonite contained in the fine sand versus the mud fraction was observed. Aggregates of shoal-water aragonite needles, which were not present in the fine sand-sized sediment fraction constituted the major source of aragonite in the mud fraction (Plate 3). Pteropod shell fragments were not abundant in the <63 um fraction, indicating that this planktonic source of aragonite was not a major contributor to the aragonite material of the mud fraction. The algal aragonite needles contributed 34% to the total carbonate of the <63 um trapped sediment and provided an aragonite flux of 10.5 $mg/m^2/day$ (Table 2). High-Mg calcite in the form of benthic foram fragments contributed 20% to the total carbonate content of the trapped mud fraction, representing a high-Mg calcite flux of 6 $mg/m^2/day$ (Table 2, Plate 3). No significant differences were found between the carbonate mineralogy or the particle components of the 63 um-38 um versus the <38um mud fractions.

DISCUSSION

Shallow Bank Versus Planktonic Components

Combining the SEM, carbonate mineralogy, and mass flux data from the NWPC particulate samples, we are able to provide an estimate of the total carbonate flux which can be attributed to shoal-water versus pelagic planktonic sources. A carbonate flux of 2.47 $mg/m^2/day$ in the >1 mm fraction represents entirely planktonic-derived calcite and aragonite (planktonic forams and pteropods). In the 1 mm-63 um fraction, the calcite and aragonite fluxes (6.8 and 3.4 $mg/m^2/day$, respectively) are derived from planktonic foraminifera and pteropods. The high-Mg calcite flux of 1.93 $mg/m^2/day$ was provided by benthic foram tests and test fragments (Table 2). The carbonate flux in the <63 um mud fraction is almost equally split between shallow bank and pelagic water column sources, with a pelagic coccolith calcite flux of 14.26 $mg/m^2/day$, a bank-derived aragonite needle flux of 10.54 $mg/m^2/day$, and a bank-derived high-Mg calcite flux of 6.20 $mg/m^2/day$ attributed to benthic foram fragments.

By adding and comparing these flux values, it is concluded that planktonic carbonate source component dominated the periplatform carbonate flux over the 2-month collection period (Table 2). Sixty-one percent of the total carbonate flux measured can be attributed to planktonic sources which provided a flux of 29 $mg/m^2/day$ (Table 2). Shoal-water carbonate sources contributed 39% to the total carbonate mass flux, with a flux of 19 $mg/m^2/day$ (Table 2). Considering the NWPC bottom sediment composition presented by Boardman (1978)



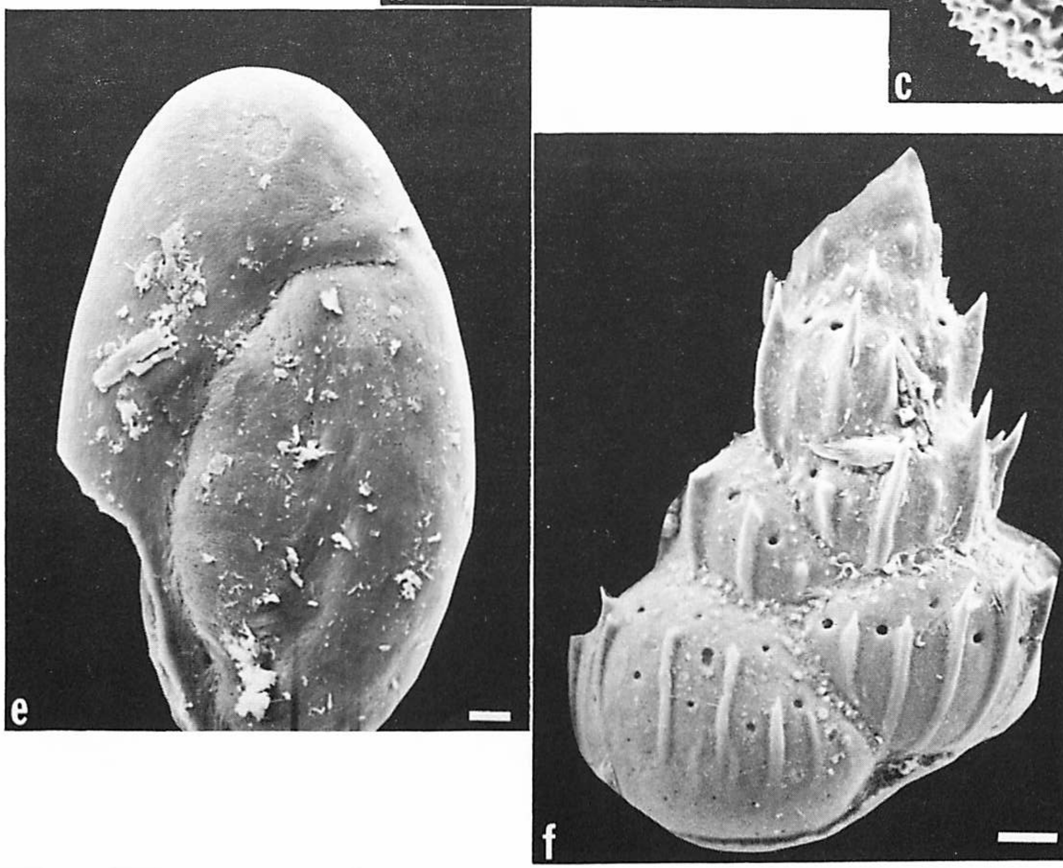
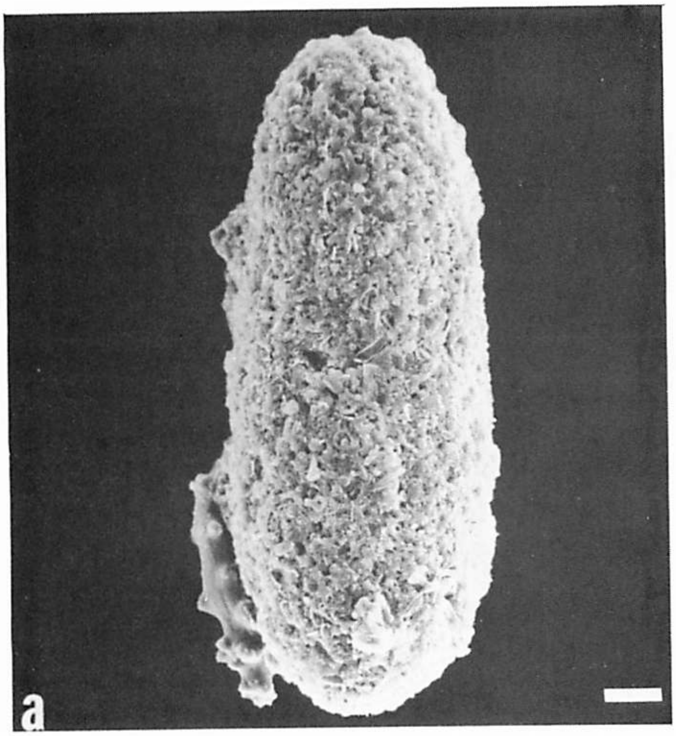


Plate 1. Sediment trap sample constituents from the 1mm-63um sieve fraction.

a. Planktonic foram *Globorotalia truncatulinoides*. Bar = 50um.
b. Planktonic foram *Globigerinoides sacculifer*. Bar = 50um.
c. Planktonic foram *Globigerinoides ruber*. Bar = 20um.
d. Coiled pteropod *Limacina inflata*. Bar = 50um.
e. Benthic miliolid foram. Bar = 15um.
f. Benthic foram *Bulimina*. Bar = 20um.



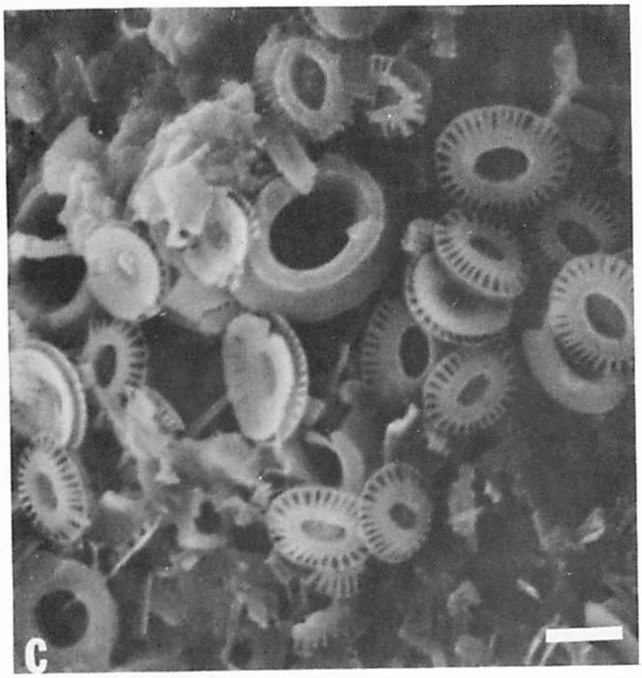


Plate 2. Zooplankton fecal pellets: 1mm-63um sieve fraction.

a. One of the numerous fecal pellets collected in the sediment trap and produced by suspension-feeding crustacean zooplankton. Bar = 20um.
b. Fecal pellet contents of (a): diatom frustule fragments, coccoliths, and amorphous organic material. No evidence of pelletal surface membrane remaining. Bar = 5um.
c. Abundant coccoliths of *Emiliania huxleyi* contained in fecal pellet (a). Bar = 2um.

and Boardman and Neumann (1984), it was expected that the periplatform carbonate flux would be dominated by bank-derived components, especially in the mud fraction. However, planktonic calcite in the form of coccoliths represented almost 50% of the total carbonate flux in the mud fraction (Table 2).

The results from this short-term sediment trap experiment indicate that in order to account for the total proportion (80%) of shoal-water fines within the periplatform muds, temporal variations in the resuspension, lateral off-bank transport, and deposition of bank-derived carbonates must exist. We confer with the hypotheses presented by Ball and others, 1967; Perkins and Enos (1968), Neumann and Land (1975), and Boardman and Neumann (1984) that seasonal storm activity is the mechanism responsible for the periodic influx of large volumes of fine, bank-derived sediment into adjacent deep-water environments. Such events must deliver twice as much bank-derived components to NWPC as compared to that delivered during fair weather periods (represented by our March-April flux data).

Lateral Off-Bank Transport

The prevailing surface winds in the northern Bahamas are from the east, producing a windward-leeward asymmetry in the shallow margins (Hine and Neumann, 1977; Hine and others, 1981). However, such asymmetry does not exist in the distribution pattern of the fine, bank-derived, sediment in NWPC. Boardman (1978) and Boardman and Neumann (1984) presented trend-surface maps of NWPC periplatform muds derived from both Little and Great Bahama Banks. The maps reveal not only that the two shallow platform sources co-dominate sedimentation in the deep basin, but also that there is no windward-leeward asymmetry associated with the distribution pattern in NWPC of the silt and clay-sized sediment derived from the banktops (Fig. 3). Boardman and Neumann (1984) concluded, based on the NWPC sediment pattern, that storm and tidal exchange must sweep equally across both platforms, resuspending and transporting fine material off the banks and into NWPC.

Observations of milky-white, sediment-laden plumes of water exiting the Bahamas Banks have been noted following 3-4 day fall-winter storm events initiated by the passage of regional cold fronts (Newell and Rigby, 1957; Neumann and Land, 1975). Proni and others (1975) suggested from data obtained off the east coast of Florida, that such plumes of resuspended carbonate muds exported off of a shelf/platform region will initially sink to several hundred meters before spreading out laterally as the density of the cooler, sediment-laden water may be greater than the surrounding waters.

The importance of storm and tidal activity in the Bahamas to the lateral off-bank transport of shoal-water carbonate muds was demonstrated by Neumann and Land (1975) in their lime mud budget study in the Bight of Abaco. Using measured suspended particle concentrations, it was calculated that tidal exchange and seasonal storms (excluding those of hurricane intensity) could account for the resuspension and lateral export into NWPC of all the algal lime mud "overproduction" from the Bight of Abaco lagoon. Over the Holocene lifetime of this subtidal lagoon, the total amount of storm and tidal-induced transport was calculated to be 172 x 10^{10} kg (Neumann and Land, 1975). This value compares remarkably well with, and as such can account for, the total amount of Little Bahama Bank-derived (Bight of Abaco) mud which has been deposited in NWPC throughout the Holocene, calculated to be between 99-198 x 10^{10} kg (Boardman and Neumann, 1984).

Hine and Neumann (1977) report that hurricane frequency in the northern Bahamas is 8-10 per 10 years. The effects on local sedimentation of these high intensity, low frequency events which may persist for only a few hours, can be substantial (Ball et al., 1967; Perkins and Enos, 1968; Shinn and others, 1969). However, the frequent passage across the Bahama Banks of winter cold fronts and associated storm systems may result in cumulative off-bank sediment transport events which exceed that of the occasional tropical cyclones. Seasonal storms act to amplify the tidal exchange and thus the lateral transport out of the lagoons and into adjacent deep water of resuspended lagoonal muds.

Vertical Transport and Deposition Mechanisms

Periplatform sediment composition and

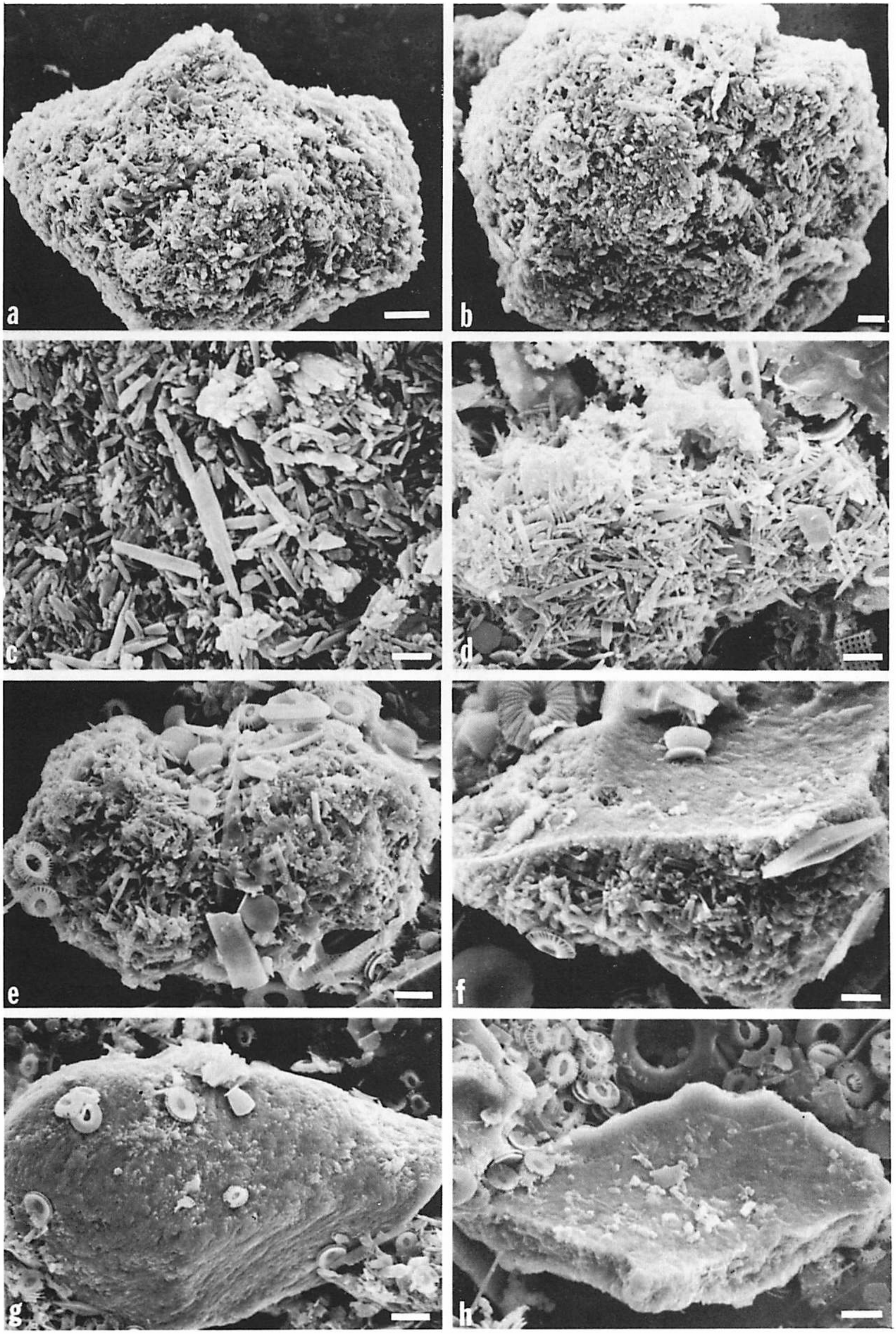
distribution patterns in NWPC indicate that pelagic processes of sedimentation dominate over gravity flow and current winnowing processes (Boardman, 1978; Mullins and Neumann, 1979; Mullins and others, 1979; Boardman and Neumann, 1984). The "concentric-to-source" distribution patterns of Little and Great Bahama Bank-derived muds in NWPC strongly suggest that the fine sediment is not dispersed over great distances by NWPC surface currents which are easterly near Great Bahama Bank and westerly near Little Bahama Bank (Richardson and Finlen, 1967; Lee, 1977; Boardman and Neumann, 1984) (Fig. 3).

Based on the NWPC sediment distribution data, Boardman and Neumann (1984) concluded that zooplankton fecal pellet transport must be the major mechanism responsible for the rapid settling and ultimate deposition of periplatform ooze in NWPC. However, the results of this sediment trap study indicate that pellet transport is not significant to periplatform ooze deposition. In Northwest Providence Channel, zooplankton fecal pellets were found to contribute only 3% to the total mass flux of periplatform particulate material. This finding is in agreement with the data presented by Pilskaln (1985) and Pilskaln and Honjo (1986) from five open-ocean sediment trap studies, demonstrating that fecal pellets produced by crustacean zooplankton contribute <5% to the total measured mass flux of particulate matter in the pelagic ocean. Additionally, the fecal pellets collected in NWPC contained planktonic coccoliths and diatom frustule fragments, not bank-derived carbonate particles.

The aragonite needles which represent the dominant bank-derived component of the trap material and the underlying periplatform ooze, are delivered to the NWPC seafloor in the form of small (<63 um) aggregates (Plate 3). These aggregates appear to be the end-products of the natural disintegration of calcareous green algae occurring within the shallow bank-top lagoons where such algae are known to grow in abundance (Lowenstam, 1955; Lowenstam and Epstein, 1957; Chave, 1962; Stockman and others, 1967). A comparison of the trap-collected needle aggregates to those obtained in suspension in the Bight of Abaco lagoon following a 3-day, March, 1985 storm, revealed marked similarities between the particle morphologies (Plate 3). Based on previously published reports and micrographs of algal disaggregation products, we conclude at this point that the needle aggregates collected in the trap and in suspension in the Bight of Abaco resulted from the in-situ break-down of erect, green calcareous algae in the platform lagoons (Stieglitz, 1972, 1973; Neumann and Land, 1975; Boardman, 1976). Once in the NWPC water column, some of the needle aggregates may be incorporated into larger (>1 mm) macroaggregates or flocs (Shanks and Trent, 1980; Silver and Aldredge, 1981). Upon immediate examination of the particulate sample (prior to wet sieving and splitting) flocs of >1 mm in size and containing small fecal

Plate 3. Sediment trap sample: <63um sieve fraction.

a. An example of the abundant needle aggregates found in the mud-sized fraction of the trap sample. Bar = 5um.
b. One of the needle aggregates collected from the Bight of Abaco by gentle filtration of water sample obtained following as 3-day storm. Note similarity between this aggregate and that collected in trap (a). Bar = 2um.
c. High magnification view of needle constitutents in aggregate (b). Bar = 1um.
d. Example of a needle "raft", numerous in the <63um trap sediment fraction. Needles appear more loosely bound than in the aggregates such as that shown in (a). Bar = 2um.
e. Needle aggregate. Coccoliths, a dominant component of the <63um sediment fraction, are seen stuck to the surface of the aggregate as are diatom frustule fragments. Bar = 3um.
f. Example of a benthic foram fragment, most numerous in the <63um fraction and the major source of high Mg-calcite in the trap sample. Note that external surface is characterized by a typical "veneer" or "pavement" created by a single layer of needles. The underlying needles are densely packed and ramdomly arrayed. Bar = 2um.
g. Benthic foram fragment. Bar = 4um.
h. Platy benthic foram fragment. Abundant coccoliths of *Emiliania huxleyi* seen in background. Bar = 4um.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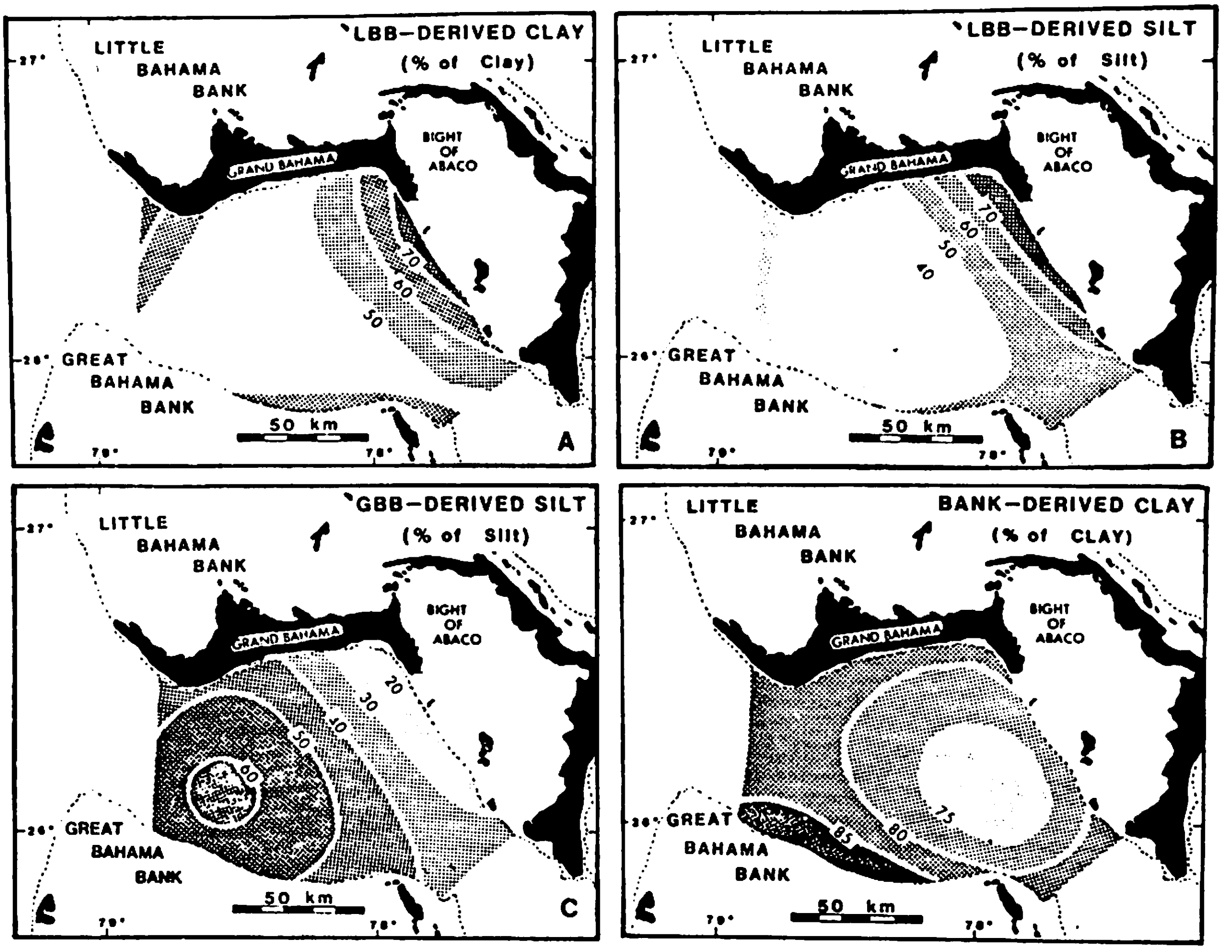

Fig. 3. Distributions of sediment sources to Northwest Providence Channel generated by trend surface analysis using textural and sediment origin data (from Boardman and Newmann, 1984). A) Clay-sized material in NWPC from Little Bahama Bank. B) Silt-sized material in NWPC from Great Bahama Bank. C) Silt-sized material from Great Bahama Bank. D) The distribution of clay-sized material in NWPC derived from both Great and Little Bahama Banks (Boardman and Neumann, 1984).

pellets, planktonic forams, and coiled pteropods were observed. These brown, amorphous macroaggregates presumably contained micron-sized coccoliths and needle aggregates as well. Large marine snow aggregates are known to scavenge smaller, suspended particles as well as other settling particulates as they sink through the pelagic water column (Silver and Aldredge, 1981; Honjo and others, 1982). Abundant marine snow flocs and detrital strings were in fact observed by the present authors from the DRSV ALVIN on a dive in 1983 immediately west of Andros Island at a depth of 100-600 m.

The relatively low organic content of the NWPC periplatform particulate matter (9-10%) and the small resultant organic fluxes (Table 1) calculated for all three sediment fractions, suggests that organic macroaggregate transport is not a major factor in the deposition of shoal-water carbonates in NWPC.

CONCLUSIONS

This study has provided the first detailed description of particulate flux occurring within the periplatform environment. Significant conclusions concerning the "conduit" portion of the source-conduit-sink system of periplatform carbonate sedimentation in the northern Bahamas are summarized below:

1) The mud fraction (<63 um) of the trapped particulates represented 80% of the

total mass flux, similar to the bottom sediment composition which is primarily of mud-size.

2) A significant compositional difference exists between the mud fraction of the particulate sample and the bottom sediments. Whereas shoal-water aragonite needles and high-Mg calcite constitute 80% of the periplatform lime muds, these bank-derived carbonates represent 50% of the mud fraction in the particulate sample. Coccoliths which are relatively unimportant in the bottom sediments, constitute the remaining 50% of the particulate mud fraction.

3) Examination of the particulate sample as a whole shows that planktonic carbonate sources dominate over shoal-water sources. Sixty-one percent of the total mass flux is attributed to planktonic carbonate, whereas 39% is of shoal-water origin.

4) Algal needle aggregates resulting from in-situ breakdown of green calcareous algae within bank lagoons, are exported out into the adjacent NWPC water column and constitute a primary source of aragonite needles in the periplatform sediments. Such aggregates, generally $\leq$63 um in size, appear to settle through the water column primarily as individual particles with an undetermined percentage being incorporated into large, amorphous organic aggregates within the pelagic water column.

5) Magnesian-calcite in the form of benthic foraminifera tests and test fragments represent 16-20% of the total carbonate material obtained in the fine sand and mud fractions of the particulate sample.

6) Planktonic petropods and forams are the dominant constituents of the fine sand portion (1 mm-63 um) of the periplatform particulate material. These components also dominate the fine sand fraction of the periplatform sediments (Boardman and Neumann, 1984). Fragmentation of pteropods and planktonic forams do not contribute significantly to the smaller mud-sized (<63 um) fraction of the particulate sample.

7) Zooplankton fecal pellets do not play a significant role in the vertical transport and pelagic deposition of shoal-water carbonate fines in periplatform environments, exemplified by the NWPC data. Their contribution to the total particulate mass flux is small (<5%), and consists of coccoliths, diatom frustules, and organic matter contained within the pellets.

8) Based on the results of this study, we suggest that in order to account for the high percentage of bank-derived carbonates in the NWPC periplatform ooze as well as the high accumulation rate of these sediments, there must exist some level of temporal variability in the off-bank transport and delivery to the deep water column of fine, shoal-water carbonates. It appears that approximately 50% of the bank-derived components in the periplatform ooze of NWPC is delivered during calm, storm-free periods through tidal-flushing of the lagoons. The remaining portion must be delivered following the frequent passage of seasonal storm fronts and the occasional tropical cyclone. This suggests that half of the shoal-water components within annually deposited periplatform sediment represent storm deposits which are mixed through bioturbation with the continuously deposited planktonic elements and bank-derived material delivered during storm-free intervals.

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