Glacial-to-Holocene sedimentation on the western slope of Great Bahama Bank

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Abstract

Thick, late Quaternary sediment sections were recovered at several sites on the leeward slope of Great Bahama Bank during Leg 166 of the Ocean Drilling Program. These sections have paleoceanographic records with potentially high temporal resolution. To make an initial assessment of the records corresponding to the Holocene highstand of sea level, we have identified and dated the sediments from the four upper slope sites (1004, 1005, 1008, and 1009) that were deposited during the period of time which spans the last glaciation through the Holocene. Age identifications are based upon the abundances of the *Globorotalia menardii* complex of planktonic foraminifera, the stable oxygen isotopic ratios of bulk sediment and the planktonic foraminifera *Globogerrinoides ruber*, and AMS C-14 dating of bulk sediment. Comparison of these data with the sediment lithologic and geoaoustic properties shows that consistent stratigraphic relationships exist at each site: The uppermost interval of aragonite-rich sediments corresponds to the Holocene highstand of sea level (i.e. oxygen isotope stage 1) and these sediments are underlain by a relatively thin interval of aragonite-poor, partially lithified sediments which corresponds to the last glaciation when sea level was significantly lower than today (i.e. oxygen isotope stages 2–4). The Leg 166 upper slope sites possess carbonate accumulation and paleoceanographic proxy records with very high temporal resolution, with Sites 1004, 1008, and 1009 appearing to have the greatest stratigraphic integrity. Comparison of core and high-resolution seismic profile data establishes the Holocene nature of the uppermost seismic unit in the stratigraphic package of the western slope of Great Bahama Bank. © 2002 Elsevier Science B.V. All rights reserved.

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1. Introduction

Sea-level fluctuations strongly influence the pro-

duction of sediments in the shallow waters about the Bahama Banks. When the bank tops are flooded during interglacial highstands, large amounts of fine-grained aragonite are produced and exported to the bank margins (Neumann and Land, 1975; Pilska et al., 1989). As a result, thick sections of highstand sediments accumulate

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along the slopes of the Bahama banks (e.g. Droxler et al., 1983; Droxler and Schlager, 1985; Boardman et al., 1986; Slowey and Curry, 1995; and references therein). This situation is epitomized by the western slope of Great Bahama Bank where tremendous volumes of banktop-derived sediment have accumulated during the current Holocene highstand of sea level, resulting in remarkable rates of vertical sedimentation and lateral slope progradation (Wilber et al., 1990). A knowledge of the sediments deposited along this modern slope should lead to significantly improved understanding of how fluctuations in global sea-level influence the development of carbonate sedimentary sequences in the Bahamas and elsewhere.

Eberli and Ginsburg (1987, 1989) used multi-channel seismic and well data to show that Great Bahama Bank formed by the coalescence of smaller platforms during the Cenozoic. The coalescence resulted largely from the lateral progradation of the leeward margins of the platforms, which apparently occurred in pulses associated with major falls and rises of sea level. Based on their studies of surficial sediments and interpretation of high-resolution seismic data collected from western Great Bahama Bank, Wilber et al. (1990) suggested that during Quaternary highstands, significant volumes of banktop-derived sediment have accumulated along the slope. Wilber et al.'s (1990) analysis presumes that the uppermost depositional sequence on their seismic profiles, delineated at the base by reflector II, was deposited during the Holocene. Although this is plausible, the constraints on the age of this sequence are very limited and sediments corresponding to the basal reflector have not been directly sampled and dated.

Absolute dating of these sediments is necessary to validate the conclusions of Wilber et al. (1990) and will also contribute basic information to sedimentary, seismic stratigraphic, and diagenetic studies of the timing of events and the rates of processes which affect the slope. Sediments deposited on the slopes of the Bahama Banks have also proven to be valuable archives of late Quaternary oceanographic conditions (Droxler et al., 1983; Slowey and Curry, 1995; Marchitto et al., 1998;

Lynch-Stieglitz et al., 1999) and sea level (Slowey et al., 1996; Henderson and Slowey, 2000). Given their potentially high temporal resolution, it is important to investigate the paleoceanographic records preserved by the rapidly deposited Great Bahama Bank slope sediments. Achievement of these objectives is important within Leg 166 goals (Eberli et al., 1997) as well as the broader frameworks of platform margin development and paleoceanography in general.

Scientific drilling during Leg 166 of the Ocean Drilling Program (ODP) recovered thick, late Quaternary sedimentary sections at several sites on the leeward slope of Great Bahama Bank (Eberli et al., 1997). We have investigated sediments from the four upper slope sites (Fig. 1) with two aims: (1) to identify and date the sediments deposited during the period of time which spans the last glaciation through the Holocene, and (2) to make an initial assessment of the stratigraphy of the expanded sediment sections deposited during the Holocene sea-level highstand.

2. Sampling strategy and analytical methods

Leg 166 advanced piston-cored late Quaternary

Fig. 1. Locations of ODP Sites 1004, 1005, 1008 and 1009 (stars) along the western margin of Great Bahama Bank where the sediments considered by this study were collected.

sedimentary sections along northern (Sites 1004 and 1005) and southern (Sites 1008 and 1009) transects of the upper leeward slope of Great Bahama Bank. Recovery was nearly 100% over the intervals of interest. These sediments consist of clay-sized to fine sand-sized, unlithified peloidal mudstones, wackestones, and packstones alternating with gray, cemented and encrusted hard layers (presumed to be submarine hardgrounds), phosphatic grains, and carbonate nodules (see Eberli et al., 1997). Onboard mineralogic analyses of these sediments show high aragonite content corresponds to unlithified intervals and low aragonite content corresponds to partially lithified intervals.

Cyclic fluctuations in the composition of Quaternary-aged sediments have been observed previously by authors studying piston cores collected from Tongue of the Ocean and Northwest Providence Channel, (e.g. Kier and Pilkey, 1971; Droxler et al., 1983; Boardman et al., 1986; Burns and Neumann, 1987; Slowey et al., 1989). These cycles correspond to the well-known fluctuations in the oxygen isotope record (Droxler et al., 1983) and thus have a clear link to ice-volume and sea-level change. Sediments deposited during interglacial highstands of sea level typically have higher aragonite contents and finer grain sizes than sediments deposited during glacial lowstands because the production of fine-grained aragonite largely by calcareous algae is greater when the bank tops are flooded during highstands (e.g. Kier and Pilkey, 1971; Boardman and Neumann, 1984). Variations in degree of sediment cementation also occur on a glacial–interglacial basis, such that degree of lithification increases during glacial lowstands (e.g. Mullins et al., 1980a,b; Slowey et al., 1989; Wilber and Neumann, 1993; Slowey et al., 1999).

Our strategy to obtain sediments deposited from the last glaciation through the Holocene from Leg 166 cores relies upon these previous results and the working hypothesis proposed by Wilber et al. (1990) for slope sediments along the leeward margin of Great Bahama Bank. We presumed that the uppermost interval of thick, unlithified, aragonite-rich sediments at a site was deposited since the onset of the present Holocene highstand of sea level (i.e. the most recent ‘high-

stand wedge’ of Wilber et al., 1990). The immediately underlying interval of relatively thin, aragonite-poor, lithified sediment was presumed to correspond to the lowstand of the last glaciation when the bank was exposed and sedimentation rates were low and sediments were coarse, permitting seafloor diagenesis to occur (see references above). Sediments corresponding to the last glaciation and Holocene at Sites 1004, 1005, 1008, and 1009 were tentatively identified and sampled at 50-cm intervals.

We used three independent approaches to establish the ages of these samples. First, shells of the *Globorotalia menardii* complex of planktonic foraminifera (*Globorotalia menardii*, *G. tumida* and *G. unguolata*) in the > 250- μ m fraction of sediment samples from Sites 1008 and 1009 were counted and downcore variations in *G. menardii* abundance were used to identify late Quaternary faunal zones defined by Ericson and Wollin (1968). Several samples from Site 1004 were also examined in this fashion.

The second approach was to measure foraminiferal and sediment $\delta^{18}\text{O}$ values and then correlate the downcore $\delta^{18}\text{O}$ records from each site to published well-dated Bahamian $\delta^{18}\text{O}$ records (see

Fig. 2. A radiocarbon-dated sediment core from the western margin of Little Bahama Bank that displays glacial-to-Holocene ranges of foraminiferal $\delta^{18}\text{O}$ and bulk sediment aragonite content typical of Bahamian slopes (data from Slowey and Curry, 1992, 1995).

Table 1

Accelerator mass spectrometer ^{14}C ages of bulk sediment

Hole	Core	Section	Depth in section (cm)	Depth below seafloor (m)	Age (yr BP)	Uncertainty ^a (yr)
1004A	3H	2	9–14	16.4	7 390	± 50
1004A	3H	3	59–64	18.4	39 900 ^b	± 270
1005A	2H	6	109–114	11.09	5 690	± 50
1008A	1H	1	12–14	0.12	1 330	± 40
1008A	1H	3	12–14	3.12	4 500	± 50
1008A	1H	5	12–14	3.12	11 300	± 380
1008A	2H	1	62–64	7.22	40 900	± 210
1009A	1H	1	5–9	0.07	1 010	± 280
1009A	2H	5	117–122	12	5 350	± 50
1009A	3H	6	5–9	21.86	10 000	± 180
1009A	4H	1	51–56	24.34	42 700	± 290

^a 1σ analytical and radiocarbon-to-calendar-year conversion uncertainties for ages < 25 000 years; 1σ analytical uncertainty only for ages > 25 000 years.

^b Probably biased by sediment disturbance (see text).

Fig. 2 for an example). Bulk sediment from samples taken at each site was dried, lightly crushed and homogenized, and stored under vacuum in a desiccator prior to isotopic analysis. Shells of the planktonic foraminifera *Globogerinoides sacculifer* (without sacs) were picked from the 300–350- μm fraction of washed sediment from Sites 1008 and 1009, cleaned in an ultrasonic bath, dried, and stored under vacuum in a desiccator prior to isotopic analysis. The oxygen isotopic compositions of the bulk sediment and *G. sacculifer* shells (typically four per analysis) were measured at Texas A&M University using a Finnigan 251 isotope ratio mass spectrometer with a Keil II automated sample acidification system. The $\delta^{18}\text{O}$ values are referred to the PDB standard through intercalibration of our reference gas with the NBS-19 standard. The analytical uncertainty of any individual $\delta^{18}\text{O}$ value (as represented by the standard deviation of replicate analyses of NBS-19) is less than 0.08 ‰.

Finally, after the $\delta^{18}\text{O}$ values of the bulk sediment and *Globogerinoides sacculifer* were measured, bulk sediment samples from each site were selected for absolute age determination by AMS C-14 dating (limited sample size and shell abundance precluded the dating of *G. sacculifer*). Sample preparation and C-14 measurements were done at the National Ocean Sciences AMS facility at Woods Hole, MA, USA. Ages (Table 1) are expressed as calendar years before 1950 (BP) –

these values were obtained by correcting conventional radiocarbon ages for the surface seawater reservoir effect of about 400 years and for temporal variations in the production of radiocarbon based upon a data set of paired radiocarbon and U/Th dates (Stuiver and Reimer, 1993; Bard et al., 1998; Stuiver et al., 1998).

3. Site stratigraphies

3.1. Site 1008

Sites 1008 and 1009 are located along the southern portion of the slope of the leeward margin of Great Bahama Bank (Fig. 1). The *Globogerinoides sacculifer* $\delta^{18}\text{O}$ record from the upper portion (0–8 mbsf) of Hole 1008A is consistent with these sediments being deposited from the last glaciation through the Holocene. Fig. 3 shows that the $\delta^{18}\text{O}$ of *G. sacculifer* is -1.6‰ at the top of the hole, which is similar to the $\delta^{18}\text{O}$ of late Holocene planktonic foraminifera in the tops of other Bahamian cores (e.g. Droxler et al., 1983, 1988; Boardman et al., 1986; Slowey and Curry, 1992). From 0 to 5.5 mbsf, the average $\delta^{18}\text{O}$ of *G. sacculifer* from these sediments is also -1.6‰ , suggesting that this entire unlithified, aragonite-rich section of sediments was deposited during the Holocene highstand of sea level. $\delta^{18}\text{O}$ increases below 5.5 mbsf to an average of 0.1‰

Fig. 3. Profiles of the $\delta^{18}O$ of planktonic foraminifera and bulk sediment, aragonite content, and the abundances of *Globorotalia menardii* complex foraminifera (>250- μm fraction) plotted versus depth in Hole 1008A. Also shown are the ages obtained through AMS C-14 dating of bulk sediment and basic sediment lithologies. Shading denotes soft, fine-grained ooze and the vertical lines denote at least partially lithified sediments. Aragonite data are from Malone (2000) and sediment lithologies are based upon core photographs and descriptions by the Shipboard Scientific Party (1997).

between 6.5 and 7.5 mbsf. This value is 1.7‰ greater than the $\delta^{18}O$ of *G. sacculifer* in the overlying sediments – a difference which is typical of the glacial–interglacial change in planktonic foraminiferal $\delta^{18}O$ observed in cores from the Atlantic Ocean. Thus, if the sediments in the upper portion of Hole 1008A were deposited continuously through time, then the partially lithified, aragonite-poor sediments corresponding to the maximum $\delta^{18}O$ must have been deposited during the most recent glaciation.

Radiocarbon dates of bulk sediment from Hole 1008A (Fig. 3) confirm this interpretation. The depth interval where the maximum *Globorotalia menardii* $\delta^{18}O$ and partially lithified, aragonite-poor sediments occur is bracketed by radiocarbon dates of 11.3 and 40.9 kyr BP, consistent with these sediments being deposited during the last glaciation. The 11.3 kyr BP date is also consistent with the mid-point of the transition to lighter *G. sacculifer* $\delta^{18}O$ in the overlying aragonite-rich sediments, marking the boundary between marine oxygen isotope stages 1 and 2 and the approximate beginning of the Holocene (e.g. Emiliani, 1955; Shackleton and Opkyke, 1973). Sediments from the middle of the aragonite-rich interval and the top of the hole yield clearly Holocene ages.

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The downhole profiles of foraminiferal and bulk sediment $\delta^{18}O$ in Hole 1008A are quite similar (Fig. 3). From ~0 to 6 mbsf, the average $\delta^{18}O$ of bulk sediment is -0.1‰ and little variability occurs, then $\delta^{18}O$ increases to a maximum value of 2.8‰ at 6.75 mbsf. The sediment has a greater $\delta^{18}O$ range than the foraminifera, presumably because the composition of the sediment varies with depth in the hole. Importantly, major changes in sediment $\delta^{18}O$ do occur over the same depth interval as changes in foraminiferal $\delta^{18}O$, suggesting that downhole changes in the $\delta^{18}O$ of Bahamian sediment can be used to delineate the boundaries between marine oxygen isotope stages. This conclusion is consistent with results from the slope of the leeward margin of Little Bahama Bank, where major changes in the $\delta^{18}O$ of bulk sediment and foraminifera occur simultaneously (Slowey et al., 1996) and pairs of bulk sediment and foraminifera AMS C-14 dates from glacial-to-Holocene-aged sediments do not show significant age offsets (Slowey and Henderson, manuscript in preparation).

Sediments in the interval from ~7.5 to 9 mbsf

have $\delta^{18}\text{O}$ values that are similar to those of Holocene-aged sediments, implying that they were deposited during the last interglacial highstand of sea level (oxygen isotope stage 5). The pattern of *Globorotalia menardii* abundance (abundant from ~ 0 to 6 mbsf, rare from ~ 6 to 7.5 mbsf, abundant from ~ 7.5 to 9 mbsf) is consistent with this interpretation. The radiocarbon date of >40 kyr BP for sediments at ~ 7.25 mbsf suggests that they were deposited sometime during oxygen isotope stage 4 or early stage 3; however, it is not possible to determine with certainty if sediment deposition was continuous throughout the entire last glaciation (oxygen isotope stages 2–4) on the basis of these data alone.

3.2. Site 1009

Sediments from Hole 1009A (Fig. 4) display stratigraphic relationships similar to those seen in Hole 1008A. The $\delta^{18}\text{O}$ of *Globogerinoides sacculifer* in the aragonite-rich sediments at the uppermost portion of Hole 1009A (~ 0 to 21 mbsf) average -1.5‰ and radiocarbon dates confirm that these are Holocene-aged sediments. The $\delta^{18}\text{O}$ of *G. sacculifer* in the underlying ara-

gonite-poor, partially lithified sediments (~ 21 – 26 mbsf in Hole 1009A) increases to a maximum of 0.1‰ , consistent with this interval of sediments being deposited during the last glaciation. Our foraminiferal and sediment $\delta^{18}\text{O}$ records for this interval are incomplete due to a gap in samples; however, the radiocarbon dates from samples bracketing the shallower partially lithified layer indicate that it was deposited during oxygen isotope stage 2. The radiocarbon date above the deeper partially lithified layer suggests that it was deposited during oxygen isotope stage 4 or early stage 3.

The *Globogerinoides sacculifer* and bulk sediment $\delta^{18}\text{O}$ records from Hole 1009A display the same general downhole trends as those from Hole 1008A. However, more variability is evident within the Holocene portion of the *G. sacculifer* $\delta^{18}\text{O}$ record from Hole 1009A than that from Hole 1008A. We suspect that this difference is a consequence of how the cores were sampled. Samples were taken from both holes at ~ 50 -cm intervals but the Holocene sedimentation rate at Site 1009 is about four times that at Site 1008 (2.1 m/kyr versus 0.5 m/kyr). The $\delta^{18}\text{O}$ record from Hole 1009A therefore possesses higher temporal resolu-

Fig. 4. Profiles of the $\delta^{18}\text{O}$ of planktonic foraminifera and bulk sediment, aragonite content, and the abundances of *Globorotalia menardii* complex foraminifera ($>250\text{-}\mu\text{m}$ fraction) plotted versus depth in Hole 1009A. Also shown are the ages obtained through AMS C-14 dating of bulk sediment and basic sediment lithologies. Shading denotes soft, fine-grained ooze and the vertical lines denote at least partially lithified sediments. Aragonite data are from Malone (2000) and sediment lithologies are based upon core photographs and descriptions by the Shipboard Scientific Party (1997).

tion than that from Hole 1008A (260 yr versus 1000 yr between samples) and better represents short period variations in $\delta^{18}\text{O}$. That a difference exists between these two records implies that significant variability in the $\delta^{18}\text{O}$ of *G. sacculifer* does occur over time periods less than 2 kyr. This is not the case for the $\delta^{18}\text{O}$ of records of Holocene bulk sediment from Holes 1009A and 1008A, neither of which displays much variability over periods of less than a few kyr.

While *Globorotalia menardii* do occur in the sediments of Hole 1009A (Fig. 4), their absolute abundance per sample is generally much lower than in Hole 1008A. Why? There are at least two reasons: *G. menardii* are relatively deep-dwelling planktonic foraminifera while the sea-floor depth of Site 1009 is quite shallow and less than Site 1008, so the flux of *G. menardii* to Site 1009 is less than the flux of *G. menardii* to Site 1008. Second, the concentration of *G. menardii* shells in the sediment is inversely proportional to the accumulation rate of other sediment components. Since the accumulation rate of banktop-derived aragonite is greater at Site 1009 than at Site 1008, the concentration of *G. menardii* in sediments is lower. The downcore profile of *G. menardii* abundance in Hole 1009A is therefore ambiguous as a chronostratigraphic indicator, still, it does provide clues about how the rate of sediment accumulation at Site 1009 varied over time. For example, *G. menardii* concentrations are quite low from ~ 7.5 to 19 mbsf, implying that the sediment accumulation rate during this portion of the Holocene was very high. Also, there is a dramatic peak in the abundance of both *G. menardii* during the early Holocene: the sample at 21.85 mbsf has at least 2.5 times more shells than any of our other samples from Hole 1009A (a similar peak in *G. menardii* occurs in the early Holocene of Hole 1008A). Why? After being very low in abundance or absent during the last glaciation, the species *G. menardii* and the species *G. tumida* repopulated the Caribbean and Gulf of Mexico at about 6250 and 8200 yr BP, respectively (Jones, in press). Thus, the concentration of shells increases from the last glaciation to the early Holocene. As sea level rises and banktop-derived aragonite begins to be exported to the

leeward slope of Great Bahama Bank, the concentration of *G. menardii* decreases. The existence of the *G. menardii* abundance peak implies that significant production of aragonite on the banktop began more recently than 6250 yr BP (i.e. when *G. menardii* became repopulated in the Atlantic). By this time, sea level was within 15 m of its present value (e.g. Fairbanks, 1989; Rasmussen et al., 1990) and much of Great Bahama Bank was flooded (Droxler et al., 1983).

3.3. Sites 1004 and 1005

Sites 1004 and 1005 are located along the northern portion of the slope of the leeward margin of Great Bahama Bank (Fig. 1). The sediments in Hole 1004A which correspond to the last glaciation and Holocene can be readily identified from the $\delta^{18}\text{O}$ of bulk sediment (Fig. 5). Holocene-aged sediments occur from ~ 0 to 17 mbsf and possess an average $\delta^{18}\text{O}$ of -0.1‰ (like Holocene sediments in Holes 1008A and 1009A). A relative maximum in $\delta^{18}\text{O}$ (3.0‰) occurs in the glacial-aged, aragonite-poor interval between 17 and 18 mbsf and corresponds to a

Fig. 5. The $\delta^{18}\text{O}$ and ages of bulk sediment obtained through AMS C-14 dating plotted versus depth in Hole 1004A, together with basic sediment lithologies. Shading denotes soft, fine-grained ooze and the vertical lines denote at least partially lithified sediments. Sediment lithologies are based upon core photographs and descriptions by the Shipboard Scientific Party (1997).

partially lithified layer. The radiocarbon date of sediments found just above this $\delta^{18}\text{O}$ maximum and lithified layer is consistent with uppermost sediments in Hole 1004A being deposited during the Holocene and the partially lithified layer being deposited during the latter part of last glaciation.

The $\delta^{18}\text{O}$ values at 18.3 and 18.9 mbsf are as isotopically light as the Holocene values, consistent with an interglacial age, while the bulk sediment from 18.3 mbsf yields a radiocarbon age of nearly 40 kyr BP, which corresponds to the last glaciation. How is this possible? Sediments with light $\delta^{18}\text{O}$ values from 18.3 to 18.9 mbsf have abundant *Globorotalia menardii* suggesting these are indeed interglacial-aged sediments (e.g. Ericson and Wollin, 1968). We therefore suspect a depositional hiatus exists such that sediments corresponding to the early portion of the last glaciation and at least part of the last interglacial are missing. If so, an unconformity at ~ 18 mbsf separates sediments from the latter part of the last glaciation and an incomplete section of sediments from the last interglacial (oxygen isotope stage 5) or an older interglacial stage. The partially lithified, isotopically heavy sediments at ~ 20 mbsf sediments would correspond to the penultimate glaciation (oxygen isotope stage 6) or an older glacial stage. If a small amount of young sediment was mixed across the unconformity into the older, radiocarbon-dead interglacial sediments, they would yield (as observed) an apparent radiocarbon age corresponding to the last glaciation. Also, if the section of interglacial sediments below the unconformity is incomplete, a simple explanation exists for why the thickness of this interglacial sediment section is an order of magnitude less than the thickness of the Holocene sediment section. The possibility of a hiatus can be tested by extending the isotopic record of Site 1004 in depth and detail, and by identifying of the precise depths of stratigraphic datums (e.g. *Emiliania huxleyi*).

Fig. 6 shows that the $\delta^{18}\text{O}$ of bulk sediment from ~ 0 to 11.5 mbsf in Hole 1005A averages -0.1‰ , indicating that these aragonite-rich sediments are Holocene aged. The radiocarbon date of 5.69 kyr BP for sediments at ~ 11 mbsf implies that the immediately underlying sediments were deposited during the early portion of the Holo-

Fig. 6. The $\delta^{18}\text{O}$ and age of bulk sediment obtained through AMS C-14 dating plotted versus depth in Hole 1005A, together with basic sediment lithologies. Shading denotes soft, fine-grained ooze, the vertical lines denote at least partially lithified sediments, and the open circles indicate sediments that may be disturbed. Sediment lithologies are based upon core photographs and descriptions by the Shipboard Scientific Party (1997).

cene. The $\delta^{18}\text{O}$ record is incomplete from ~ 11.5 to 16 mbsf due to a gap in samples, however, the presence of a partially lithified layer at ~ 12.25 mbsf is consistent with these sediments being deposited during the last glaciation (e.g. Holes 1008A, 1009A, and 1004A). If these are glacial-aged sediments, then either the sedimentation rate in the early Holocene was significantly less than during the late Holocene, or there is a hiatus in the 1005A record due to slope failure or incomplete core recovery. The shipboard description of Hole 1005A indicates that the sediments underlying the lithified layer to at least 20 mbsf were disturbed during core recovery.

4. Holocene seismic stratigraphic unit

Comparison of the oxygen isotope records, faunal abundances, radiocarbon ages and lithologic characteristics of the sediments in the upper portions of the Leg 166 sites we examined shows that consistent stratigraphic relationships exist at each

site. The uppermost interval of aragonite-rich sediments corresponds to the Holocene highstand of sea level (i.e. marine oxygen isotope stage 1) and these sediments are underlain by a relatively thin interval of aragonite-poor, partially lithified sediments which corresponds to the last glaciation when sea level was significantly lower than today (i.e. oxygen isotope stages 2–4).

Fig. 7 shows the shipboard measurements of compressional wave velocity and saturated bulk density (Shipboard Scientific Party, 1997) together with our foraminiferal isotope stratigraphy for the uppermost portion of Site 1008. Both the velocity and density of glacial-aged sediments, and hence their acoustic impedance (velocity $\times$ density), are greater than those of interglacial-aged sediments. This relationship is similar to that displayed by the sediments in Northwest Providence Channel, Bahamas, (undisturbed by turbidity flows) where certain glacial-to-interglacial transitions correlate one-to-one with reflectors on high-resolution seismic profiles (Slowey et al., 1989, 1999). Do the reflectors on seismic profiles of the leeward margin of Great Bahama Bank also correlate with the glacial–interglacial changes of acoustic impedance in the Quaternary sediments there? Here we focus on the uppermost seismic reflector observed by

Wilber et al. (1990) on the western slope of Great Bahama Bank; the significance of the entire sequence of observed seismic reflectors will be considered elsewhere (Slowey et al., submitted). Wilber et al. (1990) assumed that the uppermost seismic unit on their seismic profiles, delineated at its base by reflector II, was deposited during the Holocene and comprises the most recent highstand wedge of sediments which form the leeward margin of Great Bahama Bank. Fig. 7 shows that at Site 1008 this reflector does correspond directly with the change of acoustic impedance associated with the transition from glacial-aged to Holocene-aged sediments.

Knowledge of the nature of the stratigraphic package of the western slope of Great Bahama Bank lays necessary groundwork for geologic interpretation of the seismic stratigraphy for the margin and more detailed study of the Holocene sediment record. Our results clearly establish the nature of the uppermost seismic unit in this package: It is a true depositional sequence composed of primarily fine-grained aragonite which was deposited during the Holocene highstand of sea level and it is bounded by a marine discontinuity surface formed during the last glaciation as a result of greatly reduced deposition and cementation.

Fig. 7. Downcore profiles of saturated bulk density, compressional wave velocity, acoustic impedance, and the $\delta^{18}O$ of the planktonic foraminifera *Globogerinoides sacculifer* in Hole 1008A. The thick dashed line indicates the depth at the shallowest prominent seismic reflector present on a high-resolution seismic profile taken near the hole.

5. Slope sedimentation

The thick section of Holocene sediments on the western slope of Great Bahama Bank records a wealth of information related to the processes of banktop production and margin accretion, and the contribution of slope carbonates to the marine sediment reservoir of the global carbon budget. It also has a high-resolution record of Holocene paleoceanographic events. Our purpose in this section is to make a preliminary assessment of fidelity of the sedimentologic and paleoceanographic information preserved in these sediments.

Sedimentation rates were calculated for the sites we studied using ages obtained by radiocarbon dating and, when additional age control was needed, by taking the Pleistocene–Holocene boundary (mid-point of deglaciation indicated by oxygen isotopes) to be 10 kyr BP and the age of core-top sediments (0.1 mbsf) to be 1 kyr BP. The depths of the boundary between early and late Holocene-aged sediments (5 kyr BP) were determined by linear interpolation between the other age–depth control points for each site. These assumptions are reasonable given existing radiocarbon ages from these sites and other Bahamian cores. Sediments were deposited at rates that range from about 60 to 260 cm/kyr for the entire Holocene and average nearly 170 cm/kyr; in contrast, glacial sediments were deposited at about 4 cm/kyr.

Two aspects of sedimentation are apparent. First, the fluxes of shallow water-derived material to the slope, and so sedimentation rates along the slope, are generally greater at the sites that are shallower and closer to the edge of a banktop (Fig. 8a). Second, a dramatic increase in the amount of sediment accumulating along the slope of western Great Bahama Bank occurred from the last glaciation to the Holocene. Given the shallow water depths of these Leg 166 sites, it is unlikely that this temporal variability is primarily the result of aragonite dissolution at the seafloor during the last glaciation and not during the Holocene; rather, it probably results from an increase in the production of shallow water carbonate constituents due to the flooding of the top of Great Bahama Bank during the Holocene highstand of sea level.

Fig. 8. (a) Average Holocene sedimentation rates at Sites 1004, 1005, 1008 and 1009 plotted as function of the water depth of the sites, together with the linear fit to these data. (b) A comparison of the early and late Holocene sedimentation rates at each site.

Temporal variation of sedimentation rate also occurs within the Holocene. Fig. 8b shows that at the upper slope Leg 166 sites, late Holocene sedimentation rates are up to four times those of the early Holocene. This increase in sedimentation rate is consistent with the notion that as sea level rose during the deglaciation, the flooded, shallow area of Great Bahama Bank grew rapidly about 6–8 kyr ago, leading to increased shallow water

production of sediments and export to the slope (Neumann and Land, 1975; Droxler et al., 1983; Wilber et al., 1990; Rasmussen et al., 1990).

Further radiocarbon dating of the expanded Holocene sections collected along the slope of Great Bahama Bank during Leg 166 will allow the temporal character of sediment accumulation to be resolved in detail. A better understanding of the mass of calcium carbonate stored on the slopes is one of the key needs for constraining models of the global carbonate budget (Milliman and Droxler, 1995, 1996). It will also allow the spatial patterns of sedimentation to be considered; for example, do sedimentation rates within the Holocene begin to increase sooner along the upper slope than the lower slope, or does the increase happen simultaneously? The answer to this question will contribute to our understanding of the relative importance of the various processes involved in the evolution of slope morphology (e.g. Schlager and Camber, 1986).

6. Conclusions

The deposition of carbonate sediments and its relationship to changing sea level during the Quaternary has been studied along upper slope of western Great Bahama Bank. At each of ODP Leg 166 Sites 1004, 1005, 1008, and 1009, the uppermost sequence of sediments is composed of a thick section of soft fine-grained aragonite-rich sediments that overlies a thinner section of coarse, aragonite-poor, partially lithified sediments. Oxygen isotopic ratios of bulk sediment and *Globogerrinoides sacculifer*, abundances of *Globorotalia menardii*, and AMS C-14 dating demonstrate that these two sediment types were deposited during the Holocene and last glaciation, respectively. The boundary between glacial and Holocene sediments is marked by a strong contrast of sediment geoacoustic properties, which results in a prominent seismic reflector that can be readily identified and traced on seismic profiles of the slope. Increased production of shallow water carbonates as sea level rose following the last glaciation resulted in very high sedimentation rates along the upper slope: ~170 cm/kyr on average for the

entire Holocene and at even greater rates during the late Holocene. Sites 1004, 1005, 1008, and 1009 therefore possess carbonate accumulation and paleoceanographic proxy records with very high temporal resolution, with Sites 1004, 1008, and 1009 appearing to have the greatest stratigraphic integrity. These sites are excellent candidates for further study of the processes of carbonate slope sedimentation and bank progradation, the temporal pattern of Holocene climate/oceanographic variability, and the role of slope carbonates as a reservoir in the global carbon cycle.

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