Eberli, G.P., Swart, P.K., Malone, M.J., et al., 1997
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1. INTRODUCTION[1]

Shipboard Scientific Party[2]

Scientific drilling during Ocean Drilling Program (ODP) Leg 166, the Bahamas Transect, addressed two important geologic themes: (1) causes and effects of eustatic sea-level fluctuations; and (2) fluid-flow processes in the margins of carbonate platforms. These themes were identified as first-order priorities by several planning groups of the Ocean Drilling Program [COSOD II (1987), JOI/USSAC Workshop El Paso (Watkins and Mountain, 1990), JOI/USSAC Lake Arrowhead Workshop (Kastner and Brass, 1990), the Sea-Level Working Group (1992), and the Long Range Planning Documents. Specific approaches and drilling strategies were recommended by the ODP planning structure to gather the data necessary to answer questions pertaining to these themes. Based on this mandate, the Bahamas Transect drilling program was designed as an integrated investigation of the designated themes within the context of a carbonate platform setting.

Sea Level: Multileg, Multiplatform Drilling Program

The Sea-Level Working Group (SL-WG, 1992) recognized that the success of the program is contingent upon global coverage in a variety of tectonic and sedimentary settings, such as the deep sea, carbonate platforms and atolls, and continental margins. Analysis of data from these settings provides three independent ways to measure sea-level change: (1) deep-sea sediments provide a proxy for glacioeustasy through variations in the $\delta^{18}O$ value of foraminifers; (2) aggradational packages separated by exposure horizons on atolls and platforms record variations in sea level, performing the function of a dipstick; and (3) continental margin sediments preserve the changes of sea level by means of unconformities and stratigraphic patterns in their sedimentary architecture.

By drilling legs that have paleoceanographic objectives, ODP has recovered numerous pelagic sections that have helped to estimate the glacio-eustatic history derived from $\delta^{18}O$ measurements on planktonic and benthic foraminifers. To supplement this oxygen-isotope stratigraphic approach, the SL-WG recommended a strategy of drilling transects of holes across several continental margins to retrieve sea-level fluctuations from the sedimentary record. The SL-WG further proposed that the testing for synchroneity of stratigraphic events begin with the investigation of Neogene sections, where optimum age control exists and a calibrated signature of sea level is best constrained. A first attempt at this multiregional approach to study the sea-level question had already been made with Leg 133, which drilled sediments on the northeastern Australian margin to determine sea-level control in a mixed carbonate-siliciclastic environment (McKenzie, Davies, Palmer-Julson, et al., 1993). Leg 150 on the New Jersey margin followed as the first transect in the ODP effort to examine the record of sea-level changes within the paradigm of sequence stratigraphy following the criteria established by COSOD II, JOI/USSAC Workshop El Paso, and the SL-WG.

As part of this multileg program, the SL-WG (1992) recommended as "an appropriate next step to drill the Neogene of the Bahamas, because this margin offers a test of the ability to correlate stratigraphic events between two areas of contrasting sedimentary settings." The Bahamas Transect takes into consideration two strategic recommendations of COSOD II and the SL-WG that have technological implications for a multiplatform drilling approach to achieve the scientific objectives: (1) the drill sites should form a transect across the margin from shallow to deep water; and (2) alternative platforms in addition to the *JOIDES Resolution* should be utilized for drilling the shallow-water sites of the transect. The attractiveness of an ODP sea-level transect in the Bahamas was enhanced in 1990 by the acquisition of two core borings in shallow water on the Great Bahama Bank, which meant that the prerequisite more proximal sites of the margin-to-basin transect were already available. These core borings, termed Unda and Clino, were drilled in 7 m of water from a self-propelled jack-up barge on the western margin of the Great Bahama Bank (see Eberli et al., this volume). Leg 166 drilled the deeper water portion of the transect with five drill sites positioned along an extension of the seismic line on which Unda and Clino were positioned (Fig. 1).

Fluid Flow in Continental Margins

The circulation of seawater through passive and active continental margins was recognized by COSOD II as one of the Earth's major processes controlling global geochemical cycles. Fluid flow and water/rock interactions within the massive sedimentary deposits on continental margins provide a mechanism whereby elements are cycled from the lithosphere to the hydrosphere. In addition to inorganic reactions, microbial activity from near the sediment/water interface down to hundreds of meters in the sediment package is a very important factor, contributing to the diagenesis of the sediments and alteration of the fluid chemistry. Fluid flow enhances this deep biological activity by providing reactants and transporting away the products of organic matter degradation, including gases such as methane and hydrogen sulfide. Together, these inorganic and organic processes alter the composition and character of the sediments. Frequently such flow is concentrated along distinct intervals within the sedimentary sequences, converting them into lithified horizons that define seismic sequence boundaries.

To date, numerous ODP and Deep Sea Drilling Project (DSDP) programs have concentrated on circulation deep within the Earth's crust and at mid-ocean ridges and active continental margins. There has been much less emphasis on circulation through passive margins. COSOD II did consider passive margins adjacent to the continental land masses, where fluid flow can be driven by large hydraulic head differences. Fluid flow in isolated—but nevertheless volumetrically significant—carbonate platforms, however, has been virtually neglected. As a result, a general lack of information exists concerning the importance of passive margin processes in the compilation of global mass balances. The USSAC Lake Arrowhead Workshop (Kastner and Brass, 1990) addressed this deficiency by recommending that a greater emphasis be placed on understanding fluid-flow processes in passive margins, as well as in carbonate platforms.

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[2]Shipboard Scientific Party is given in the list preceding the Table of Contents.

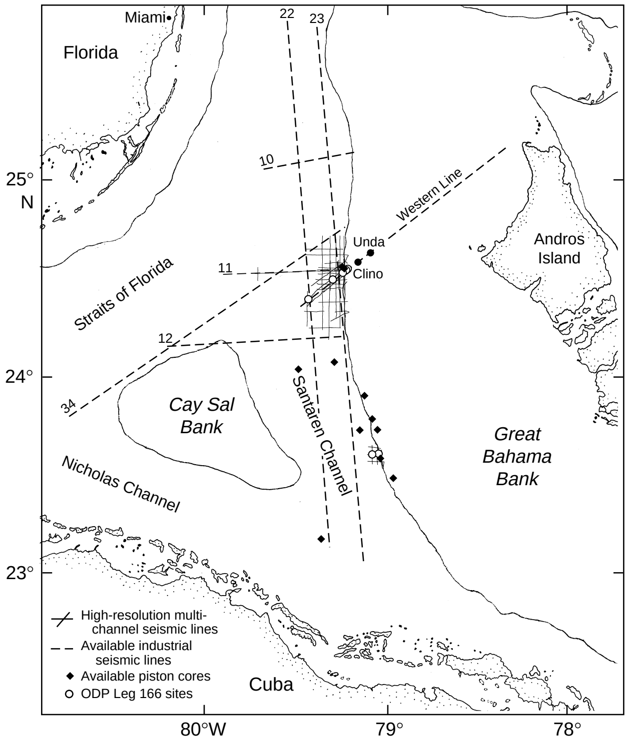

Figure 1. Location map of the Bahamas showing Leg 166 site-survey lines. Sites 1003 through 1007 are located along an extension of the Western Line. Sites 1008 and 1009 are situated 100 km to the south.

Regional Background

The Bahamas archipelago is a carbonate province consisting of several isolated platforms situated on the southern end of the eastern continental margin of the United States. This margin formed during the Jurassic period as a result of the opening of the Atlantic Ocean. The southern part of the margin collided with the Caribbean starting in the Late Cretaceous and culminating in the Eocene. The collision resulted in some folding and faulting and increased subsidence in the southern Bahamas (Ball et al., 1985; Walles, 1993; Denny et al., 1994). With the shift of the plate boundary to south of Cuba at the end of the Eocene, tectonic activity decreased and Cuba remained welded to the southern part of the American continental margin.

The foundation of the Bahamian platforms has been and still is a subject of debate that centers around two major questions: (1) whether the Bahamian basement is of continental or oceanic origin, and (2) whether the modern platform pattern still reflects the graben and horst topography that formed during the Jurassic rift stage (e.g., Mullins and Lynts, 1977; Sheridan et al., 1981). The basement underlying the platforms has not been drilled, but seismic refraction data indicate a 12- to 14-km-thick crust with a *P*-wave velocity of 7.2 km/s (Sheridan, 1974). These velocities can be interpreted as occurring in either altered continental crust or oceanic crust.

Two fundamentally different concepts were proposed for the origin of the spatial pattern of the Bahamian platforms. The horst and graben hypothesis (Mullins and Lynts, 1977) assumes that the modern array of platforms reflects the block-faulted topography of the Jurassic rift stage, whereby the intraplatform seaways are located over the ancient grabens and the platforms on the horsts. In contrast, the megabank hypothesis (Sheridan et al., 1981; Ladd and Sheridan, 1987) proposes that the Bahamian platforms were part of a much larger, extensive shallow-water carbonate platform under which the inherited rift topography was buried in an early stage of platform evolution. According to this hypothesis, the megabank drowned during the mid-Cretaceous, and only small isolated platforms were re-established, becoming the foundation of the modern Bahamas (Schlager and Ginsburg, 1981). Documenting the aerial extent and the cause and timing of the disintegration of the proposed megabank was one of the major objectives of ODP Leg 101, which was designed to resolve the controversy between the horst and graben and megabank hypotheses. The drilling results were inconclusive. Upper Albian shallow-water carbonates and evaporites were penetrated at Site 627 north of Little Bahama Bank, coincident with the mid-Cretaceous sequence boundary (MCSB), whereas upper Albian, deep-water, organic carbon–rich carbonates were recovered at Site 635 in the Northeast Providence Channel (Austin, Schlager, et al., 1988; Austin, Schlager, Palmer, et al., 1986). Thus, the ODP Leg 101 drilling could only partially settle the debate. However, an unexpected result showed a facies succession in the cores that indicated the occurrence of large-scale platform progradation (Austin, Schlager, Palmer, et al., 1986). This important finding received little publicity at the time.

In 1987, seismic reflection profiles across the top of the Great Bahama Bank (GBB) revealed the anatomy of part of the bank and settled the debate to some extent. These profiles (Fig. 2) show that the modern pattern of banks and channels is not solely a reflection of the topography formed during the Jurassic or mid-Cretaceous, but rather the combined result of several cycles of destructive and prograding processes (Eberli and Ginsburg, 1987, 1989). The profiles indicate that tectonism controlled the initial pattern of the platforms, whereas progradation subsequently infilled some of the seaways.

Seismic stratigraphy reveals multiple repetitions of the dual process of tectonic segmentation and depositional coalescence, which continuously modifies the platform pattern (Eberli and Ginsburg, 1987, 1989). The productive bank tops provide material that both smooths the tectonic relief with the infilling of intraplatform seaways and promotes bank-margin progradation (Figs. 2, 3). For example, an ancient intraplatform seaway, the Straits of Andros, which was of a similar width as the modern Tongue of the Ocean, was completely filled in by this process (Fig. 2). Also, an extensive progradation imaged on the seismic lines of the western margin of the GBB has advanced the bank edge up to 27 km basinward over the original, now-buried, fault-induced topography (Fig. 2; Eberli and Ginsburg, 1989). Time-equivalent sediments drilled in the industrial well, Great Isaac, on northwestern GBB (Schlager et al., 1988), corroborated the facies successions proposed to explain the interpreted progradational sequence. With each sea-level cycle, the process of off-bank transport of sediment is apparently repeated and, in the Holocene, has resulted in the deposition of thick sedimentary units on the bank top (Hine et al., 1981) and adjacent slope (Wilber et al., 1990). The ODP Leg 166 Bahamas Transect is located on the western prograding margin of the GBB (Fig. 3).

Global Sea-Level Changes

Although sea-level fluctuations are known to have occurred throughout the Earth's history, their global synchroneity, amplitude, and rate are still largely unknown. The sedimentary record of the carbonate environment potentially encodes both the timing and amplitude of sea-level changes. In attempting to define amplitude changes, the most significant advantage carbonate environments have over their siliciclastic counterparts is their ability to give an indication of paleo-depth. Because the light-dependent sediment production in low-latitudes is an order of magnitude higher than most sea-level changes, carbonate platforms and reefs are able to keep up or catch up with most rates of sea level rise and maintain a relatively flat platform top or lateral migrating zone of production on gently sloping surfaces (Kendall and Schlager, 1981; Schlager, 1981, 1991). Sea-level falls usually expose the platform top, resulting in the development of a suite of characteristic features that are easily recognizable in the rock record (e.g., karst, red soils, caliche horizons, black pebble

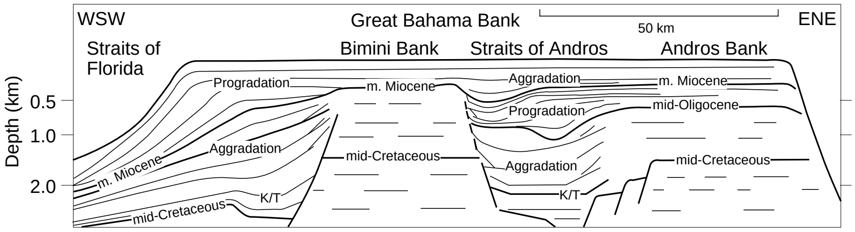

Figure 2. Cross section through the Great Bahama Bank displaying the complicated internal architecture of the bank. Two nuclear banks, Andros and Bimini, coalesced by the infilling of an intraplatform seaway, the Straits of Andros. Progradation of the western margin of the platform during the Neogene expanded the bank more than 25 km into the Straits of Florida (from Eberli et al., 1994)

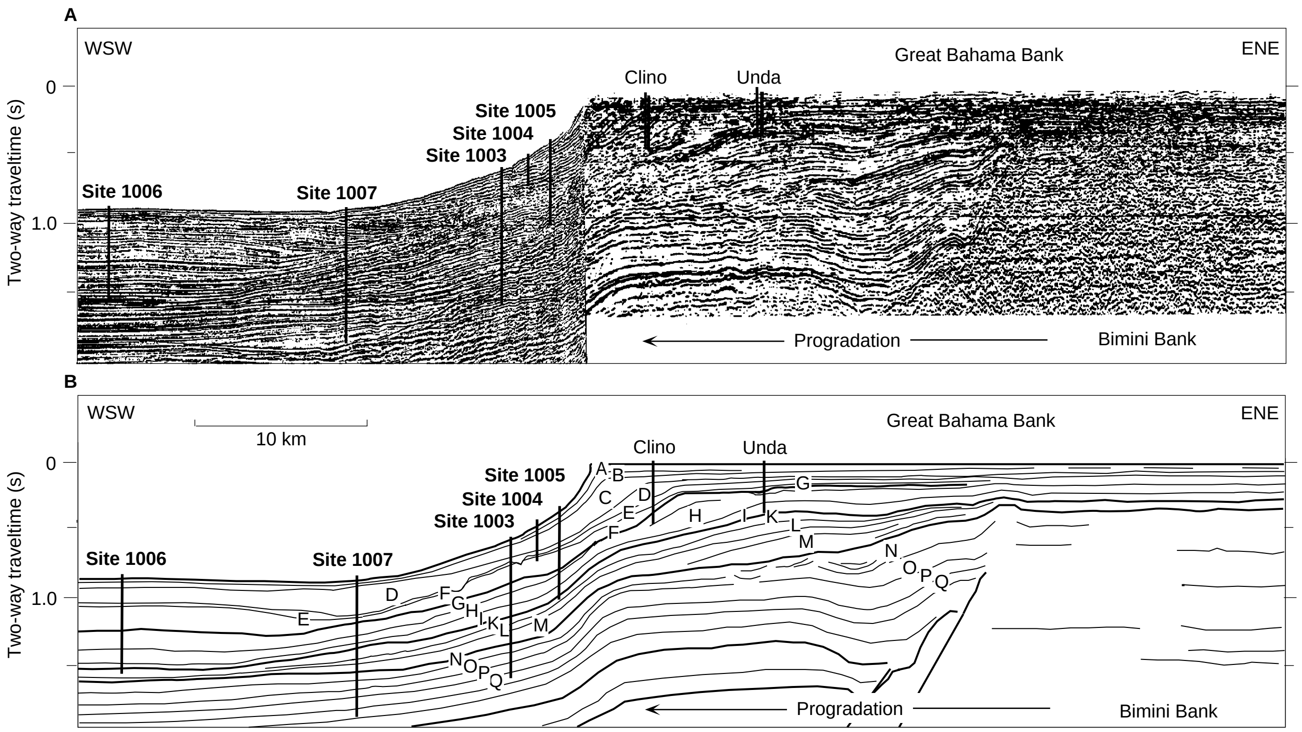

Figure 3. **A.** Section of the high-resolution seismic line on the extension of the Western Geophysical seismic line with the drilling locations of Leg 166: Sites 1005, 1004, 1003, 1007, and 1006 in order from proximal to distal. **B.** Schematic diagram of the Bahamas Transect showing the geometries of the margin, the position of the boreholes Unda and Clino drilled with an alternative platform, and the five Leg 166 sites.

horizons, etc.) or diagenetic zones with typical petrographic and stable isotopic signal (Allan and Matthews, 1982).

The Great Bahama Bank is a pure carbonate environment in a subtropical, low-latitude setting and, as such, is an ideal place to evaluate the sedimentary record and timing of global sea-level changes. Its western margin comprises numerous Miocene to Holocene, laterally stacked, prograding sequences, as revealed in seismic stratigraphic studies, making it an especially suitable location for a high-resolution study of Neogene to Quaternary sea-level changes (Eberli and Ginsburg, 1987, 1989). Onlapping patterns can be used to separate sequences within the prograding package and to reconstruct the local sea-level history. Comparison with the global cycle chart of Haq et al. (1987) led to the interpretation that each pulse of progradation is the record of one sea-level fall and rise (Eberli and Ginsburg, 1989).

Considering that one of the primary objectives of the ODP sea-level program is to ascertain the timing and amplitude of Neogene sea-level changes, the GBB is an ideal location to drill because it combines all three independent ways of measuring sea-level changes: (1) it is a flat-topped platform on a passive continental margin, and, as such, its flat top should record sea-level variations like a dipstick; (2) the prograding sequences on its margin should record sea-level changes in their stratigraphic pattern; and (3) the correlative deep-water deposits encode the $\delta^{18}O$ proxy of sea-level changes in their foraminifer assemblages. Correlation of the glacio-eustatic oxygen isotopic record with the sequence stratigraphic pattern of sea-level change can potentially document a causal link between glacio-eustasy and the stratal pattern. This correlation should also provide insights into how high-frequency sea-level fluctuations are recorded in these sediments and how the stacking of these high-frequency cycles combines to produce the lower-order seismic sequences. At present there exists a discrepancy between the number of sea-level fluctuations during the Neogene determined from the oxygen isotopic record and the number of Neogene seismic sequences. For example, sequence stratigraphy recognizes seven Pliocene–Pleistocene third-order sequences (Haq et al., 1987), while the benthic isotopic record shows 120 variations relating to 60 full sea-level cycles for the last 3 Ma alone (Tiedemann et al., 1994). These high-frequency sea-level changes are believed to be the result of orbitally driven climate changes that resulted in waxing and waning of polar ice sheets (Emiliani, 1955; Shackleton and Opdyke, 1973; Miller et al., 1987, 1991). On seismic data, generally two orders of sequences are recognized; third-order sequences with a duration of 0.5–3 m.y., and fourth-order sequences with a duration of 100–500 k.y. Variations in glacio-eustasy were also proposed as the driving mechanism for formation of third-order depositional sequences (Vail et al., 1977, 1991; Vail, 1987). If seismic sequences are recording sea level, then sedimentary units formed from higher frequency sea-level changes must stack into the lower-order seismic sequences. One possibility is that the orbitally driven, high-frequency, sea-level changes are superimposed on a fluctuation of lower frequency, which would indicate a hierarchy of sea-level changes. However, in the isotopic record, repeating longer term trends are not obvious, although shifts of the isotope base level might be the expression of such a low-frequency variability. Another possibility is that the seismic sequences are random events whose expression is enhanced by tectonic overprint. Tectonic subsidence of the GBB during the Neogene, however, was that of a slowly subsiding, passive continental margin.

Carbonate depositional sequences, like their siliciclastic counterparts, are unconformity-bounded depositional packages. Carbonate environments, however, record changes of climate and relative sea level in a characteristic way, resulting in a system-specific, depositional sequence architecture (Sarg, 1988; Eberli and Ginsburg, 1989; Schlager, 1992; Handford and Loucks, 1993). The difference between the carbonate and siliciclastic systems arises because the flat-topped carbonate platforms and shelves can produce, and therefore export, more sediment during sea-level highstands when they are flooded. Export of sediment during sea-level highstands, known as highstand shedding, places the carbonate environment 180° out of phase with the siliciclastic environment, where most of the sediment is exported into deeper water during sea-level lowstands (Mullins, 1983; Droxler and Schlager, 1985; Schlager, 1991). As a result, carbonate sequences tend to develop relatively thin sediment packages during sea-level lowstands (lowstand systems tracts) without developing large slope fan systems. However, the main difference in the amount of sediment exported from carbonate environments during sea-level highstands or lowstands is related to the hypsography of the platform. Steep-sided isolated platforms tend to show an abrupt cessation in the export of platform-derived carbonates during sea-level lowstands (Droxler and Schlager, 1985; Reymer et al., 1988), followed by a rapid increase of carbonate production and offbank transport when the platform is reflooded (Wilber et al., 1990; Glaser and Droxler, 1991). In contrast, along low-angle carbonate ramps, the difference between the amount of sediment exported during highstands and lowstands becomes more subtle or may even disappear altogether because, with changing sea level, the area of production does not vary but tends to simply move either seaward or shoreward along the inclined slope. During the Neogene, the GBB was progressively transformed from a low-angle to a steep-sided platform (Eberli and Ginsburg, 1989), offering the unique opportunity during ODP Leg 166 to document the response of the carbonate environment to sea-level changes with respect to the different margin profiles along the Bahamas Transect.

Bahamas Sea-Level Transect

As stated by the SL-WG (1992), transects of drill sites from marginal to deep basin environments are an essential requirement for the study of the response of sedimentary systems to sea-level changes. Such sites should be located on seismic lines that display sequences where a sea-level controlled deposition is likely and facies can be determined through drilling. As such transects extend into water too shallow for the *JOIDES Resolution* to operate safely, alternate drilling platforms are required for coring the more proximal sites.

A high-quality multichannel seismic (MCS) line across the western margin of the GBB connects the shallow platform environment with the deeper water areas. This line shows a series of prograding sequences that were interpreted to be controlled by sea level (Eberli and Ginsburg, 1989). On the reprocessed version of this seismic line, done by Exxon Production Research, erosional truncations are visible, making it easier to redefine more precisely the position of sequence boundaries. In addition, the reprocessed data revealed the geometry of pre-upper Miocene prograding sequences that were difficult to discern on the line used in the earlier study (Eberli and Ginsburg, 1989). In 1994, the University of Miami in collaboration with Rice University collected 1200 km of seismic data using a newly developed high-resolution MCS system (DELPH24) aboard the *Lone Star*. The newly acquired MCS data have a frequency of 10–500 Hz, compared with the 10–60 Hz frequency of the western geophysical data. The new data improved the stratigraphic resolution and helped better locate drill sites for ODP Leg 166. In addition, imaging of the same sequences with different frequencies offers the opportunity to analyze the stacking of cycles caused by high-frequency sea-level changes into third-order seismic sequences, similar to those seen in the original seismic data. The new lines image the three-dimensional architecture of the prograding sequences and their lateral continuity into the adjacent basinal deposits in the Straits of Florida. The progradation on the GBB is defined as a stack of basinward-thinning downlapping wedges in which each of the prograding wedges has a discontinuous seismic facies at the base that is overlain by continuous reflections. In their distal portions, the prograding clinoforms interfinger with continuous reflections that onlap onto the margin. The reflections are the eastern portion of a thick unit from the axis of the Straits of Florida that is interpreted as a current-influenced drift deposit (Mullins et al., 1980).

In 1990, two core borings, Unda and Clino, were drilled from a self-propelled jack-up barge through the seismic sequences on the shallow top of the GBB. These borings provide the sedimentary record of the proximal parts of the sequences and information on the fluid chemistry in the platform interior (Figs. 1, 3). These cores were analyzed in a series of studies resulting in a comprehensive description of lithology, ages, diagenetic alteration, and petrophysical characteristics of the upper Miocene to Holocene seismic sequences within the GBB (see Eberli et al., this volume). Timing of unconformities in these platform core borings was achieved by an integrated age-dating effort that included the incorporation of planktonic foraminiferal and nannofossil biostratigraphy, strontium-isotopic stratigraphy, and magnetostratigraphy. Age dating in these proximal portions of the transect was difficult, as pulses of platform-derived sediments diluted the microfossil abundances (Lidz and Bralower, 1994; Lidz and McNeill, 1995a, 1995b). The effects of dilution are minimized on the slopes away from the depocenter of platform-derived sediment (Melillo, 1988). Thus, the precise dating of the sequence boundaries can be accomplished at the ODP sites of the Bahamas Transect and traced back to the Unda and Clino sites on the platform top.

The GBB has a relatively predictable subsidence history (Williams et al., 1988) and, therefore, is a suitable candidate for the evaluation of the amplitude of Neogene sea-level changes. On the platform tops, sea-level rises are recorded in the sediment deposited between exposure horizons. When corrected for compaction, subsidence, and erosion, these units give an approximate estimate of the amount of sea-level rise. With the completion of the chronostratigraphy for Unda and Clino and three other short core borings located farther from the platform margin (McNeill et al., 1988), recalculation of the subsidence curve of the GBB was possible and provided a relatively accurate measurement of the amplitude of sea-level changes for the upper Miocene to Pleistocene sequences (McNeill, pers. comm., 1996).

The platform cores, together with those from the ODP Leg 166 sites, helped determine for the first time the age-dated facies in carbonate sequences along an entire depth transect from the platform top to a water depth of approximately 600 m. This transect facilitated a full assessment of the sedimentary response of carbonates to sea-level changes. The sediments recovered along the Bahamas Transect can now be compared with the sea-level-controlled siliciclastic sequences of the New Jersey/Mid-Atlantic Margin Transect (NJ/MAT) (ODP Leg 150) and sequence stratigraphic models (e.g., Posamentier and Vail, 1988) to assess the difference in sedimentary response for siliciclastic and carbonate margins.

Summary of Sea-Level Objectives

The sea-level objectives of ODP Leg 166 are to:

1. Determine the timing of the sequence boundaries and relative sea-level fluctuations. The ages of these sequences will contribute to the data base that is necessary to eventually evaluate the global synchroneity of sea-level fluctuations in the Neogene.
2. Determine the stratigraphic response of carbonates to sea-level changes by analyzing the facies of the recovered depositional sequences. A special emphasis is placed on documenting the amount and nature of lowstand deposits in carbonates and on the hierarchical stacking of high-frequency cycles into seismic sequences.
3. Retrieve low-latitude isotopic signals of the Icehouse World in the Neogene and Quaternary, and compare it with the stratigraphic record to evaluate whether there is a causal link between eustasy and sequence stratigraphic pattern.
4. Estimate the magnitudes and rates of sea-level changes, using ages and recovered facies for a precise subsidence analysis.

Fluid Flow Through the Margin of the Great Bahama Bank

Fluid movement within carbonate platforms is suggested by the results from ODP Leg 133 on the Queensland Plateau, Australia; ODP Leg 143 in the Pacific Ocean (Elderfield et al., 1993; Paull et al., 1995); and from the Bahamas Drilling Project (Swart et al., in press a and b). Evidence for fluid flow can be observed in temperature and geochemical profiles. Temperature measurements in the sediment can detect nondiffusive geothermal gradients that are indicative of water movement either into or out of the formation. A good example of such a profile is seen at Site 812 situated on the Queensland Plateau (Davies, McKenzie, Palmer-Julson, et al., 1991). At this site, the temperature is essentially isothermal from the seafloor to a depth of 225 mbsf, indicating the flow of cold bottom seawater into the formation. Geochemical measurements can indicate the influence of waters other than those indigenous to the formation. In a manner analogous to the temperature profiles, a uniform profile with depth could indicate fluid movement into the formation. Conversely, a concave-upward profile could imply fluids moving out of the formation. In addition, anomalous fluids may be identified by their unusual Sr, O, or H isotopic ratios. Lateral fluid movement may be indicated by erratic changes in the nature of the geochemical or temperature profiles. Fluid movement also can be indicated by the presence of diagenetic minerals such as dolomite and celestite. The formation of these minerals necessitates the movement of large amounts of water through the formation to provide the necessary reactants and remove the solute by-products of the dissolution/reprecitations reactions.

The shallow-water drilling at Unda and Clino provided strong evidence of significant fluid movement in the subsurface of the platform (Swart et al., in press b). First, geochemical analyses of fluids collected from the drill holes indicate an active upper zone of fluid circulation (0–100 m) with no appreciable geochemical gradients detectable. Beneath this zone, there is an interval with slower circulation in which levels of minor elements, such as strontium, are increased to several times that of the concentrations normally reported in seawater. Throughout this lower zone, which extends to the bottom of the drilled cores, there is evidence of extensive recrystallization and formation of celestite and dolomite, features consistent with fluid movement. Hence, the samples collected during the Bahamas Drilling Project support the concept of fluid movement in the subsurface, but there is still insufficient information to resolve the fundamental question about the mechanism driving fluid flow within the platform.

There are basically three processes that can account for fluid circulation in the subsurface of the GBB. First, there is currently a hydraulic head difference between Andros Island and the adjacent platform and seaways. This head-driven circulation only involves freshwater under Andros Island itself. Freshwater flowing downward through the meteoric lens would induce a similar upward flow of seawater. In addition, there is a slight, but nevertheless significant, difference in the mean sea level between the platform and adjacent waters. This difference has been proposed to be responsible for the pumping of seawater through supratidal sediments (Carballo et al., 1987) and reefs (Buddemeier and Oberdorfer, 1986). Whittaker and Smart (1990) suggested that this mechanism might be responsible for subsurface movement of fluids from the GBB under Andros Island. Although the extent of the difference is unknown on the western margin, it is probable that the sea level on the platform is higher than in the Straits of Florida. This would cause a difference in the hydraulic head between these two bodies of water with a resultant downward and outward flow through the slope.

Second, as a result of evaporation, there are distinct salinity differences between the waters on the surface of the GBB and the adjacent Straits of Florida. During the summer months, when evaporation of the surface waters is the most intense, the density difference may be between 5 and 10 g/kg. Simms (1984) suggested that this density difference alone may be sufficient to cause downward convection through the platform up to depths of hundreds of meters.

A third possible mechanism, known as Kohout convection, postulates that cold water is circulated through the flanks of the platform and advected upward by the higher heat gradient within the platform relative to the adjacent oceans (Kohout, 1966, 1967). Simms (1984) concluded that such a flow should be present in all steep-sided platforms where there is a strong horizontal pore-water density gradient. The water recharge for this process would take place at some depth on the platform flanks covered by a thin veneer of impermeable sediment.

Based on mathematical models of all three proposed fluid flow mechanisms, Bahr (pers. comm., 1995) concluded that heat flow differences between the platform interior and adjacent seaways are probably responsible for most of the fluid flow observed in the lower portions of the Bahamian platform. This flow would be directed mostly from the margins of the platform toward the interior, where the fluids rise toward the surface (Fig. 4).

Summary of Fluid Flow Objectives

The proposed drilling is designed to assess the possibility that there is fluid flow into and out of the platform along the margins, and to test the proposed mechanisms of fluid flow.

Drilling Strategy

To achieve a complete understanding of the sedimentary response of carbonate platforms to sea-level changes, a transect of sites from the shallow-water proximal to the adjacent deep-water is necessary. The sediments at these sites must be able to be dated, and sequences should be traceable from site to site. Two core borings, Unda and Clino, in conjunction with three shallow borings into islands on the platform provide the record in the proximal part of the sequences (Figs. 1, 3; Eberli et al., this volume). Holes at five sites drilled by the *JOIDES Resolution* during Leg 166 provide the deep-water record (Sites 1005, 1004, 1003, 1007, and 1006, in order from proximal to distal). The sites are positioned on the basinward part of a cross-bank seismic line in order to have a direct correlation to the shallow-water drill sites, Unda and Clino (Figs. 3, 5).

The proximal site, Site 1005, is located in 352 m water depth, approximately 1150 m from the modern platform edge on the upper slope, 30 shotpoints southwest of the crossing of seismic Lines 106 and 107 (Fig. 5). It is positioned on the thickest portion of the prograding Neogene sequences seen on the seismic line; the total thickness was approximately 1035 m. The upper Pliocene-Quaternary

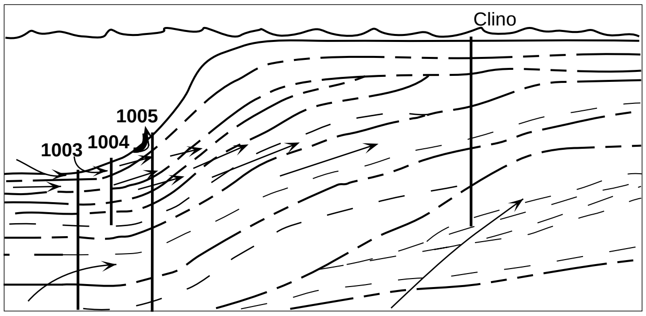

Figure 4. Schematic representation of fluid flow induced by temperature differences between the platform interior and the adjacent seaways. Fluid is drawn into the sediments by underpressure created by the heating of the platform interior. Fluids have a net downward movement but are channelized along permeability barriers, moving into the platform and ultimately being heated and rising.

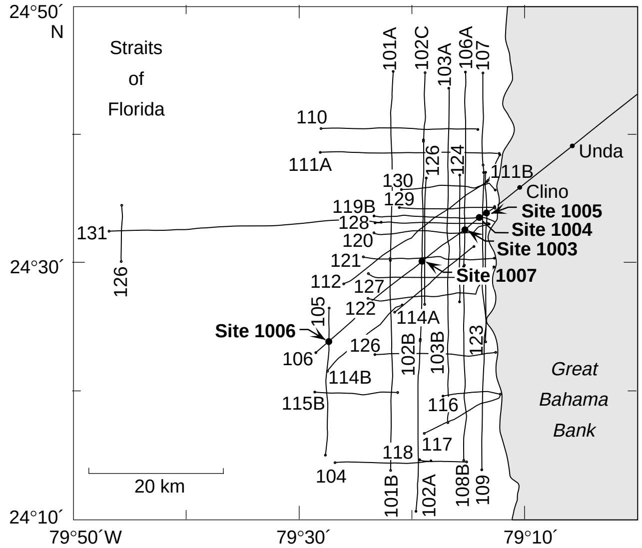

Figure 5. Detailed location map of the Leg 166 sites and the seismic grid of the site survey and the cross-bank Western Geophysical seismic line.

package alone was believed to be about 200 m thick. These high rates of sedimentation allowed for a detailed analysis of the high-frequency climate and sea-level changes. The objectives of Site 1005 were to (1) date precisely the sequence boundaries, (2) determine the facies within the different systems tracts, especially the nature of the onlapping units that were interpreted as lowstand deposits, and (3) retrieve a high-resolution record of climate and sea-level fluctuations for the Quaternary and late Pliocene. This site served also as the proximal site for the fluid-flow transect.

Sites 1003 and 1004 are located at the crossing of seismic Lines 106/108A and 106/119B, respectively (Fig. 5), farther basinward than Site 1005. They are positioned on the middle and lower slopes of the sequences. The seismic data show a facies pattern of continuous reflections alternating with channelized and discontinuous reflections. Channelized intervals were interpreted as being packages of redeposited carbonates. The timing of the main redeposition in carbonates is still controversial. Classical sequence stratigraphic models predict an increase of mass gravity flow deposits during relative sea-level falls (Sarg, 1988; Vail et al., 1991). In contrast, offbank transport of sediment from carbonate platforms is highest during sea-level highstands when it is flooded (Droxler and Schlager, 1985; Reymer et al., 1988; Haak and Schlager, 1989; Schlager, 1991). One of the major sea-level objectives of Site 1003 was to evaluate lowstand facies vs. highstand deposits and determine the respective amount of redeposited strata in both systems tracts. Additional objectives were to (1) refine the ages of the sequence boundaries, (2) determine the nature of a prominent unconformity on top of a low-amplitude to transparent seismic zone at 0.75 s (TWT) that is interpreted as the top of the lower Pliocene, and (3) produce a high-resolution isotope stratigraphy of the Neogene to Holocene. The target horizon at Site 1003 was the base of the Neogene. In addition, Site 1003 was designed as a calibration site in which an extended downhole logging program was planned to produce an optimal correlation between the cores and the geophysical data. To assure a precise correlation between the seismic and sedimentary record at this site and at Sites 1006 and 1007, a vertical seismic profile (VSP) experiment was planned.

Site 1007, at the crossing of seismic Lines 106 and 102B, was located on the toe of slope in 647 m of water (Fig. 5). The site was positioned to penetrate the thin basinal portions of the prograding clinoforms and, in the upper part, a thick onlapping wedge that could be either a drift deposit or an accumulation of mass gravity flows. To the east the distal portions of the clinoforms interfinger with the drift deposits of Site 1006. Site 1007 was therefore the link between this basinal site and the proximal slope sites. In addition, a higher content of microfossils was expected than in the more proximal Sites 1005, 1004, and 1003. Therefore, the main objectives of this site in regard to sea level were to precisely date the sequence boundaries, determine the facies in the distal portions of carbonate sequences, and assemble a data set suitable to compare the sedimentary record with the $\delta^{18}O$ record of the Neogene to Holocene sea-level fluctuations.

Site 1006, the most distal site of the transect, is located approximately 20 km from the modern platform margin at the crossing of seismic Lines 106 and 105 (Fig. 5). It is situated on the thickest portion of the sediment drift in the axis of the Straits of Florida. At this location, parallel horizontal reflections indicate undisturbed deposition with few hiatuses. Toward the east, these sediment-drift deposits interfinger with the distal toes of the prograding sequences. The primary goal of this site was to retrieve a complete $\delta^{18}O$ record of the Neogene to Holocene that can be correlated with the sedimentary record of sea-level changes. In addition, the best preserved fossils were expected at this site for precise dating of the reflections. Variations in the sedimentary record of the drift should help to establish times of changes in the vigor of the current and its relationship to sea-level fluctuations.

Fluid-flow objectives were accomplished by drilling two transects of closely spaced holes away from the margin of the Great Bahama Bank. At these sites, heat flow and geochemistry were studied to ascertain the nature of the profiles and any deviation from steady-state conditions. The first transect corresponded partially with the first seal-level transect at Sites 1005, 1004, and 1003 along the extension of the Western Line on which the holes Clino and Unda were drilled. This transect also makes use of information retrieved from Sites 1006 and 1007. The second transect is positioned in an area to the south, Sites 1008 and 1009, where conditions might be different because of differing accumulation rates, sediment characteristics, slope angle, and proximity to the Gulf Stream. In both of these areas, the sediments should act as receptacles for fluids moving through the flanks of the platform as predicted from computer modeling experiments. The presence of flow was identified by examining gradients in various conservative and nonconservative geochemical pore water parameters (Ca^{2+}, Sr^{2+}, Mg^{2+}, salinity) and from temperature measurements in the sediments. In addition, diagenetic alteration will document evidence of fluid flow in the sediments.

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