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Geoacoustic Environments: (1) Northern Little Bahama Bank, (2) Transect Between the Bahamas and King's Bay, Georgia

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ABSTRACT

Two geoacoustic models characterize the water column and subbottom sediments on the northern Little Bahama Bank. A general model, applicable anywhere on the bank, and a model specific for Ocean Drilling Program (ODP) Site 628 are presented and documented. Values for geoacoustic parameters used in the general model are derived from core data collected by the USNS LYNCH and ODP Leg 101. Site specific measurements of compressional wave velocity and wet bulk density are used for the ODP Site 628 model. Values for the remaining geoacoustic parameters are the same for both models.

A transect between the northern Bahamas and King's Bay, Georgia passes from the bank through the Gulf Stream and terminates on the Florida Platform. Two geoacoustic models that describe the subbottom environment under the Gulf Stream and on the Florida Platform are documented for this transect. Values for geoacoustic parameters used in the Gulf Stream model are extrapolated from data collected on ODP Leg 101. Data used in the creation of the Florida Platform model are from seismic surveys sponsored by the United States Geological Survey, and the COST GE-1 well.

ACKNOWLEDGMENTS

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INTRODUCTION

The geoacoustic models presented in this techical note are in support of the Naval Oceanographic and Atmospheric Research Laboratory (NOARL) 6.1 Acoustic Transients Program. During the course of this program, an acoustic exercise was conducted along two track lines on Little Bahama Bank in the vicinity of Ocean Drilling Program (ODP) Site 628 (Figs. 1 and 2). Part I of this technical note presents the geology of Little Bahama Bank, an analysis of available data, and two geoacoustic models, one specific for an array placed over ODP Site 628, and another more general model that may be used anywhere over the bank. Part II is a similar presentation of data and geoacoustic models for the bottom and subbottom environments underlying a transect north of Little Bahama Bank to King's Bay, Georgia. Geoacoustic models were generated in anticipation of a future experiment.

To adequately model and interpret acoustic results, it is necessary to know sediment geoacoustic properties. These geoacoustic properties are presented in the form of geoacoustic models that contain basic information required to understand acoustic propagation in bottom-interacting situations. Geoacoustic models are models of the real seafloor with emphasis on measured, extrapolated and predicted values of those properties important in underwater acoustics and aspects of geophysics that involve sound transmission (Hamilton, 1980). Implicit in this definition is the understanding that measured data are frequently not available for modeling and must be estimated and predicted. Valid predictions can only be made when the seafloor properties within the range of interest (i.e., the water-sediment interface to a depth of several hundred meters, depending upon frequency) are well understood. The geoacoustic models contained here are a combination of measured data and estimated values based on well known physical principles and an understanding of the seafloor properties in the Little Bahama Bank region. The sediment properties required for modeling acoustic propagation include compressional wave velocity and attenuation, shear wave velocity and attenuation, and wet bulk density, all as a function of depth and lithology.

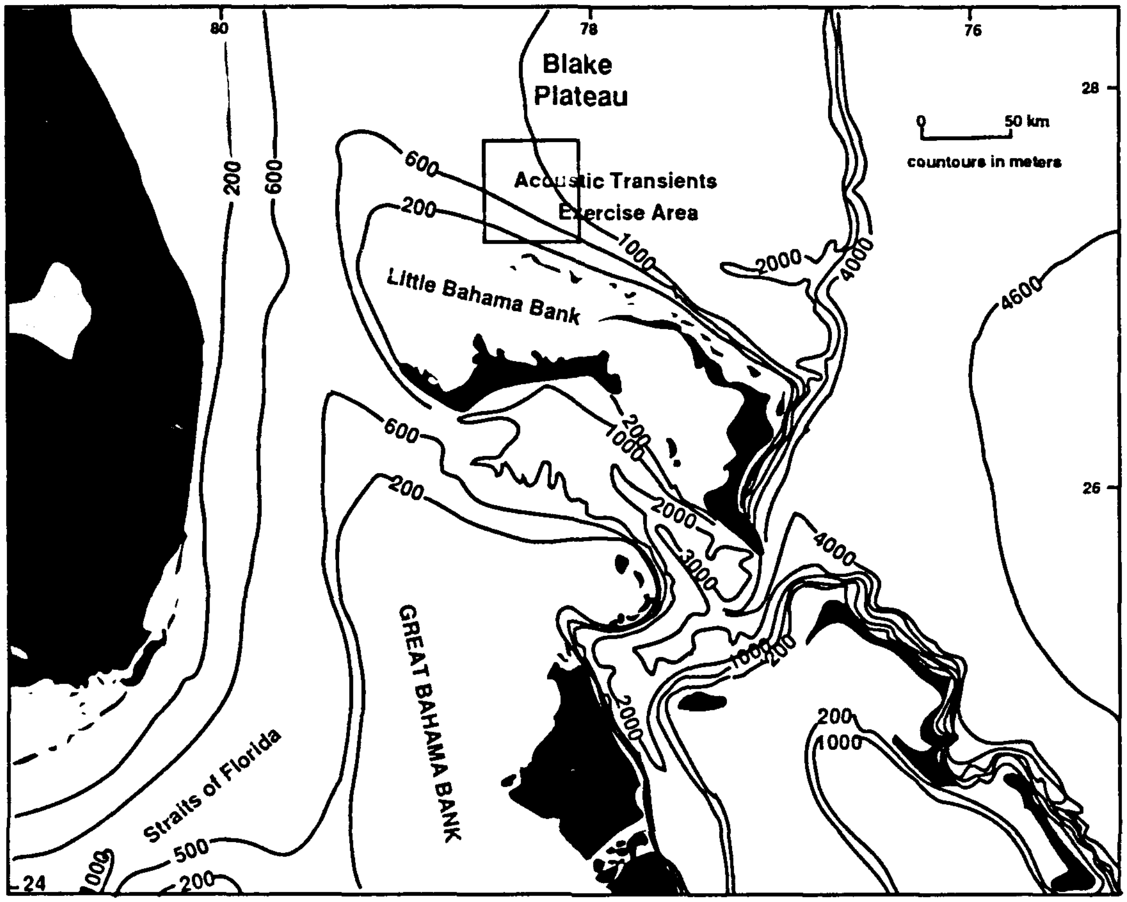

Figure 1: The Acoustic Transients exercise area is located on the northern portion of Little Bahama Bank in a bottom limited environment. Water depths range between 400 and 1000 m over the portion on the bank occupied by the experiment.

PART I: NORTHERN LITTLE BAHAMA BANK

Sediments of Northern Little Bahama Bank

Northern Little Bahama Bank (Fig. 2), a gentle 2 to 3 slope, represents an accretionary, depositional slope, an early stage in the evolution of carbonate slopes. Along the carbonate slopes of the Bahamas, the sediments are composed of two size fractions. The smaller size fraction, termed periplatform ooze, is a fine-grained, clayey-silt mix of platform-derived sediment and tests of planktonic organisms (Schlager and James, 1978) and forms the matrix material. The larger size fraction consists primarily of sand size foraminfer grains and shell fragments that are frequently deposited by turbidity currents. When these larger grains are in contact with each other, the sediment is classified as grain-supported; when the grains are floating within the matrix, the sediment is classified as matrix-supported.

Compositional and grain-size differences between matrix sediment and turbidites produce an initially heterogeneous sedimentary column. In carbonate slopes of the Bahama Islands, this heterogeneity is enhanced by differing rates of lithification between periplatform ooze and the interbedded turbidites. The large proportion of the metastable carbonates, aragonite and high-magnesian calcite, in the periplatform ooze enhances the

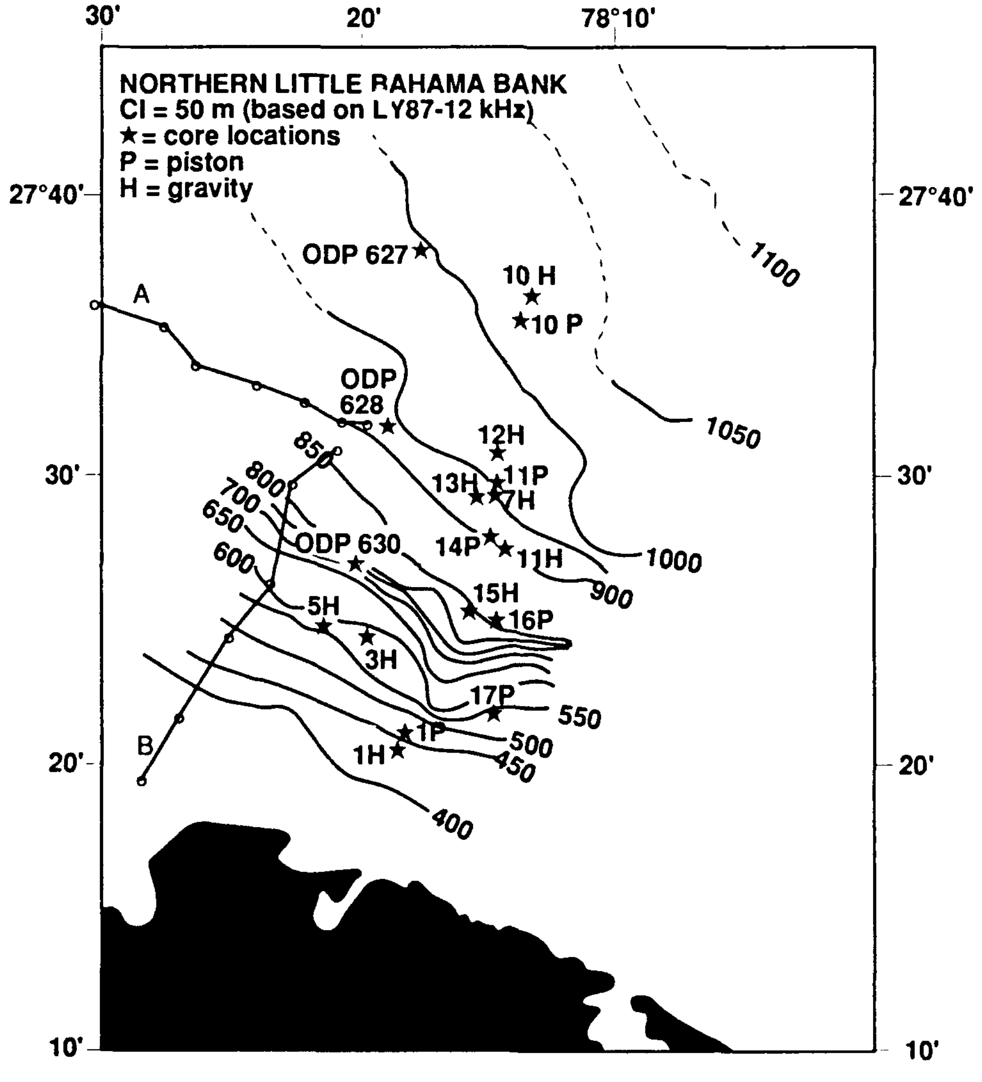

Figure 2: The location of ODP sites and cores recovered by the USNS LYNCH are marked by ★s. The array tracks occupied during the Acoustic Transients field exercise are marked by o's.

potential for dissolution and diagenetic alteration (Droxler and others, 1983; Mullins and others, 1985). This leads to an earlier induration of the periplatform ooze compared to the normally coarser, redeposited turbidite beds. The interbedded carbonate turbidites are composed of the stable low-magnesian calcite. As a result, they resist lithification longer than do the adjacent partly or completely indurated chalks. In these periplatform sediments, rapid burial diagenesis is indicated by shallow, partly lithified ooze and chalk (Eberli, 1988; Austin, Schlager, Palmer, and others, 1986). The early diagenetic alteration of the periplatform ooze leads to a shallower, partial lithification of the ooze in the upper parts of the sections and occasionally produces chalk-ooze couplets, which are spaced regularly at 5- to 25-cm intervals (for example, Site 631, Austin, Schlager, Palmer and others, 1986). Diagenetic gradients and, consequently, the depths of complete induration, vary at different sites (Swart and Guzidowski, 1988). Along the Little Bahama Bank transect, ODP Sites 627, 628, and 630, turbidite sands remain unlithified, even where the interlayer ooze has been altered to chalk.

Lateral variability of sediments on the slope is generally perpendicular to the contour of the bank. Figure 3 is a schematic that illustrates the lateral variation in sediment types. The sediment facies labeled proximal apron facies, characterized by mud-supported debris flow deposits and thick coarse-grained turbidites, underlies the entire length of array A. However, array B cuts across the contours (Fig. 2) and is underlain by a hardground at its shallow end and periplatform oozes and the proximal apron facies as the water deepens.

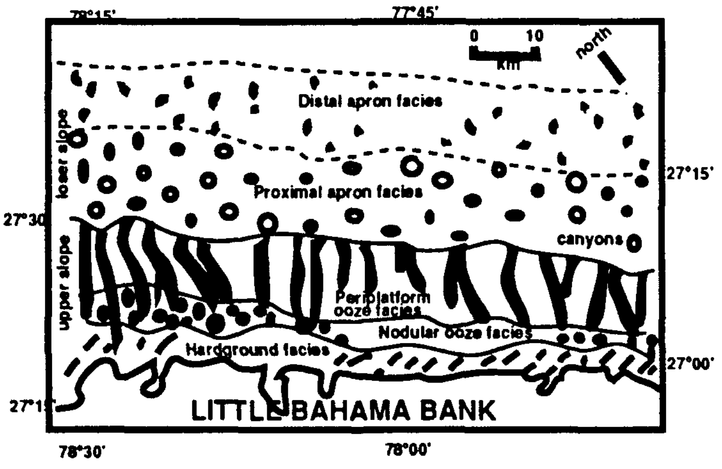

Figure 3: Near-surface sediment facies map for the slope north of Little Bahama Bank (after Mullins et al., 1984).

Analyses of seismic profiles and descriptions of sediments from ODP Sites 627, 628, and 630 were used by Harwood and Towers (1988) to investigate the evolution of Little Bahama Bank, which has been prograding northward since the early Miocene. It was found that midslope and lower slope depositional systems are not characteristic of ancient sedimentary environments in that the modern lower slope contains no meandering channels. Gullies incised into the slope funnel sediments to the base of the slope apron, which results in significant by-passing of sediment to the bank. Bottom contour currents on the lower slope disperse, erode and redeposit sediments leaving coarse-grained sediments in place. Thus, sediments on the lower slopes around Sites 627 and 628 are significantly less altered diagenetically than sediments on the upper slopes. Holocene gravitational creep has produced large-scale rotational movement of unlithified sediments. Creep lobes extend far into the lower slope, where sediments are disturbed by propagation and movement along multiple minor detachment surfaces (Harwood and Towers, 1988).

Geochemical results from Leg 101 on Little Bahama Bank indicate that diagenetic alteration is particularly rapid in the upper 10 m of the section. However, two factors result in slow rates of burial lithification over Little Bahama Bank: first, stable calcite minerals (tests of sand size foraminifers) persist in these sediments, and secondly, the content of high-magnesian calcite is low (Austin, Schlager, Palmer and others, 1986).

Model Development

The main objective of this effort was to determine the values of geoacoustic parameters for the northern Little Bahama Bank environment as accurately as possible from the available geologic/geophysical information. ODP Sites 627, 628, and 630 were the main sources of subbottom physical property data. A significant amount of physical property data from these sites, analyzed at NOARL (Lavoie, 1990; Lavoie and Anderson, 1991) and on board the JOIDES RESOLUTION, were available. In addition, a number of piston and gravity cores were collected from the USNS Lynch in the same region in 1987 (Fig. 2) from which sediment samples were analyzed for geotechnical and acoustic properties. Empirical relationships derived from these analyses, compressional and shear wave velocity, and wet bulk density versus depth, were extensively used in the construction of these models.

Two models are presented. The first is a general model that can be applied anywhere over the Little Bahama Bank. Geoacoustic parameters are derived from laboratory measurements made on a number of UNSN LYNCH cores as well as ODP data. The second model is specific for ODP Site 628, the primary location of interest for the Acoustic Transients Project. Measured compressional wave velocity and wet bulk density from Site 628 are used in the construction of this model. The two models are labeled general and specific (Models 1 and 2, Appendix A 3).

General Model: Northern Little Bahama Bank

The lithology presented in this generalized model was determined from visual examination of cores recovered from ODP Sites 627, 628, and 630. The depths to Layers I, II, and III will vary somewhat over the bank. The thickness of the unconsolidated sediment column increases downslope. For example, depth to basement is about 468 m at ODP Site 627, about 298 m at ODP Site 628, and about 249 m at ODP Site 630. The lithology boundaries and depth to basement presented here are representative of ODP Site 628.

Empirical relationships between depth and compressional and shear wave velocity and wet bulk density, for sediments in the Bahamas used in the construction of this model, were derived primarily from measurements on sediments collected by the USNS LYNCH in 1987 (Lavoie, 1990, Lavoie and Anderson, 1991) and are presented in Table 1. Sediments on Little Bahama Bank are predominantly coarse-grained and are classified as grain-supported sediments (Rezak and Lavoie, 1990; Lavoie, 1990). Therefore, the regression equations for grain-supported sediments were used in the construction of this model.

Figure 4, a plot of measured compressional wave velocity versus depth for the Bank sediments, includes values computed using empirical relationships derived by Hamilton (1980) for deep water carbonate sediments for comparison. The compressional wave velocity values used in the construction of the general model were calculated from the regression line fitted through the data representing actual Bahamian carbonates. This data is valid for unconsolidated sediments on the bank.

Shear wave velocity was measured on samples from ODP Site 630 using bender element transducers. Data from Site 630 are presented (Figure 5a) along with a calculated curve of shear wave velocity as a function of depth from Richart (1970).

Table 1. Physical and Geoacoustic Properties of Periplatform Unconsolidated Sediments

	Total	Grain-supported	Matrix-supported
Vp (m/s)			
(average)	1552	1587	1502
as (f) of z	$1552 + .13944 (z) + 1.6276 \times 10^{-4} (z^2)$	$1587 + .40797 (z) - 4.1148 \times 10^{-4} (z^2)$;	$1502 + 5.5272(z) + 3.535 \times 10^{-4}(z^2)$
Vs (m/s)			
(average)	37.17	---------------------	---------------------
as (f) of z	$37.17 + 7.59 \times 10^{-2} (z) - 9.56 \times 10^{-5} (z^2)$		
G (N/m²)			
(average)	9.46×10^5		
as (f) of z	$G = 2.86 \times 10^6 + 6.23 \times 10^4 (z) - 15.87 \times 10^{-5} (z^2)$		
Wet Bulk Density (Mg/m³)			
(average)	1.74	1.78	1.72
as (f) of σ'	$\rho = 1.74 + 3.499 \times 10^{-5} (\sigma')$		

$\sigma' = 4.72 + 6.8(z) + 0.003 (z^2)$ for these periplatform sediments from the Bahamas.

Legend:

Geotechnical properties (wet bulk density) (38 samples)
Geoacoustic properties (Shear modulus (G), compressional velocity (Vp), shear wave velocity (Vs)) (7 samples)

z = depth in meters below the seafloor

σ' = effective stress
Vp values are temperature and pressure corrected.

Shear modulus was measured on numerous sediment samples collected on northern Little Bahama Bank with piston and gravity cores. Meaurements were made using the duomorphs (Breeding and Lavoie, 1988; Lavoie, 1990; Lavoie and Anderson, 1991) under controlled temperature and pressure conditions. Shear wave velocity was calculated from shear modulus and measured density from those same samples. Figure 5b presents shear wave velocity measured using NOARL duomorphs on selected samples from the Little Bahama Bank. The important points to note are the low values of shear wave velocity and the negligible gradient over the unconsolidated and uncemented portion of the sediment column. When the sediment consolidates (such as in Lithology II), the shear wave velocity increases dramatically and empirical relationships between shear wave velocity and depth developed by Hamilton (1980) should be used. Values for shear wave velocity generated using Hamilton's empirical relationships in Model 1 for Li-

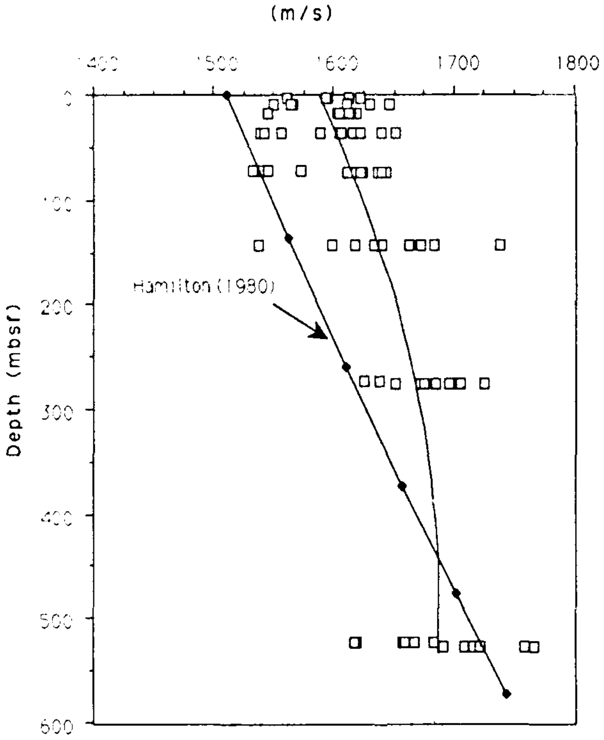

Figure 4: Compressional wave velocity as a function of estimated depth. Velocity was measured in a laboratory oedometer that simulates in situ stresses.

thology II, labeled Vs(O) in the appendix, should be used, especially if higher values of shear wave velocity are required to match field data (see notes after Model 1).

Compressional wave attenuation at the seafloor (kp_0)was scaled from Hamilton (1980), Figure 18. Compressional wave attenuation as a function of depth (kp_z) was determined using the equation derived from Hamilton (1980):

$$Kp_z = 0.214 - 0.00014\ z - [0.214 - Kp_0]\ e^{-z/200}. \tag{1}$$

Calculated results are in dB/m/kHz and were subsequently converted to dB/l (wavelength) and expressed ap. Values for limestone are general estimates and were taken from Clark (1966).

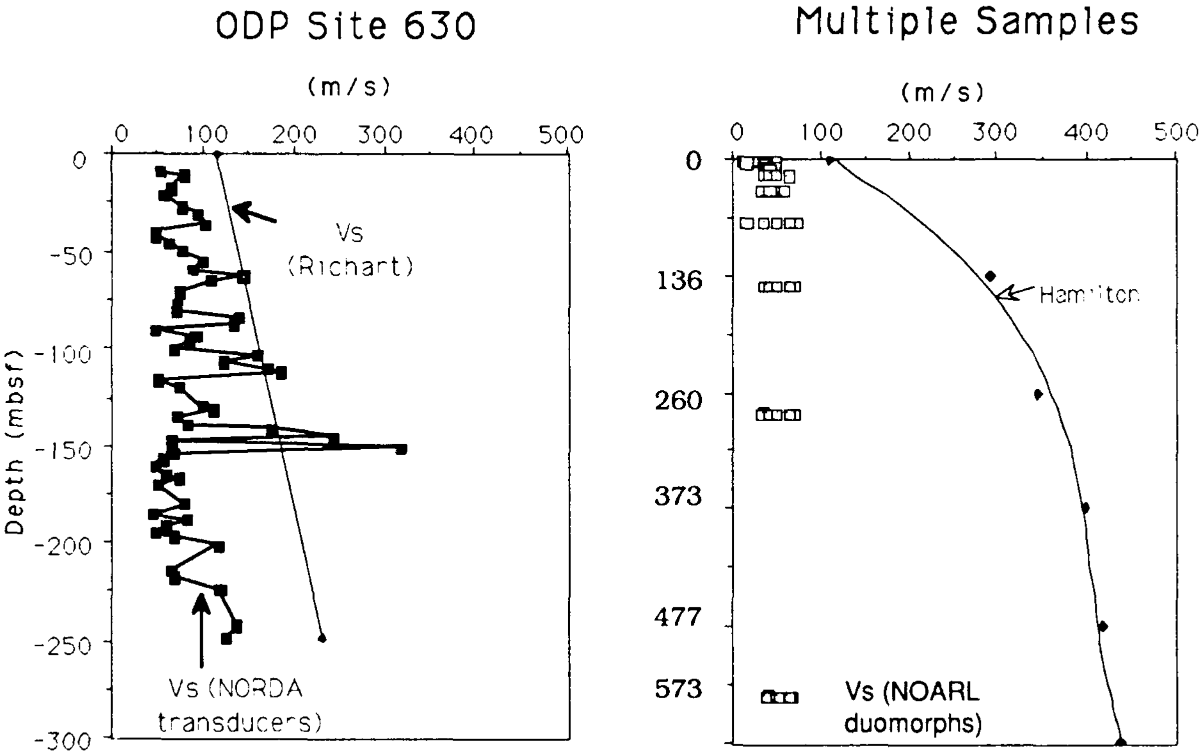

Figure 5: Meaurements of shear wave velocity on numerous samples from Site 630 made using the NORDA transducers (a) and made on samples from the USNS LYNCH with increasing pressure to simulate depth using NOARL duomorphs (b) are significantly lower than predicted by Richart (19 70) and Hamilton (1980) and show little increase with depth within the unconsolidated sediment. Variations in velocity values correspond to lithologic changes rather than increases in overburden pressure downhole.

Shear wave attenuation was calculated assuming a high initial value of 17.3 dB/m/kHz (Hamilton, 1980). Shear wave attenuation was assumed to be proportional to compressional wave attenuation with depth and scaled accordingly. Again calculated results were converted to dB/l (wavelength) using the recommended shear wave velocity and expressed as αs. Past experience has shown that shear wave attenuation values calculated proportionally to αp are often too high (Lavoie and others, 1991) for acoustic models to accept. In that case, shear wave attenuation may be assumed to be equal to compressional wave attenuation at depth (in limestone). Then with the limestone velocity shear attenuation as a reference, the attenuation in the sediment column can be assumed to vary as the shear velocity.

Acoustic basement is limestone with dolostones and chert stringers. Compressional wave velocity is a measured value from ODP Site 628. Shear wave velocity was estimated from Vp/Vs = 1.9 (Hamilton, 1980). This general geoacoustic model (Appendix A) is apprpriate for use anywhere on the north side of Little Bahama Bank. Depths to chalk and limestone should be varied depending upon position on the bank. An average water column sound speed extracted from the GDEM data base is presented in Appendix B.

Specific Model: ODP Site 628

ODP Site 628 is located on North Little Bahama Bank in 966 m of water. The major difference between this model and the more general model presented above lies in the availablility and use of site specific compressional wave velocity and wet bulk density data. The remaining geoacoustic parameters, shear wave velocity, and attenuation, both compressional and shear, are calculated in same manner for both models.

Interval velocites calculated from seismic line LBB-18 (Austin, Schlager, Palmer and others, 1986) are presented for comparison with laboratory measured compressional wave velocities (Model 2, Appendix A). Compressional wave velocity measured onboard the JOIDES RESOLUTION (Fig. 6) shows little increase with depth. Rather than using every data point in the model, or averaging groups of data points, two curves were fitted through the compressional wave velocity data measured in the core liner.

$$1386 + 8.19\,(z) - 0.0428\,(z^2) \quad \text{between 0 and 136 mbsf} \qquad (2)$$

$$1685 + 0.608\,(z) - 0.00103\,(z^2) \quad \text{between 137 and 278 mbsf} \qquad (3)$$

Compressional wave velocity measurements made in the core liner were used because

(a) there are more data points and (b) measurements in the core liner are made on less disturbed material and are probably more representative of the sediment than measurements made on disturbed material removed from the core liner. Measurements made in the first 3 to 4 m are generally low due to disturbance during the coring process. The initial value of 1386 m/s is artificially low and the value at 5 m below seafloor (mbsf) of 1426 m/s is the first value that can be used with confidence. The high value of 2064 m/s at about 100 mbsf may be indicative of a thin, high velocity layer. An optional high velocity layer may be used at the modeler's discretion (see notes after Model 2, Appendix A.)

Wet bulk density (ρ) at Site 628 showed significant variability down hole (Fig. 7) which correlated with the consolidation state of the sediment. For example, slump

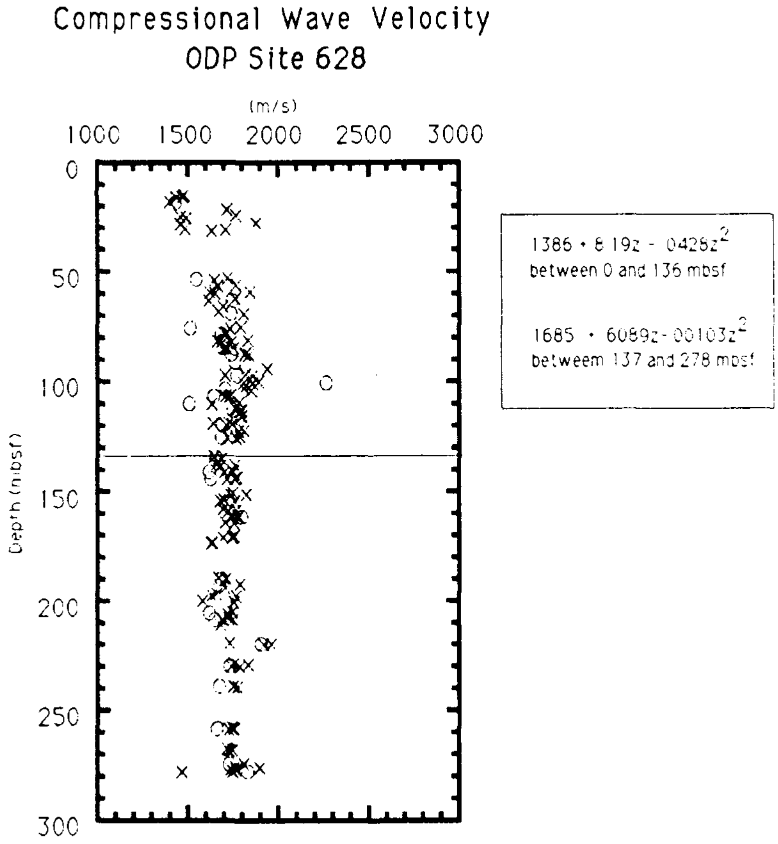

Figure 6: Measured compressional wave velocity data from ODP Site 628. O = compressional wave velocity measured on discrete samples removed from the core. X = measurements made within the split core line, with travel-time through the core liner subtracted from travel-tiime through the sediment.

turbidite sediments, "unconsolidated and soft", display decreasing density values and periplatform sediments beginning to consolidate display increasing density values. Rather than use individual values in the model, four regression lines were fitted to the data and model values were derived from these equations. The increasing density values at 100 mbsf support the possibility of a "hard" layer at that depth.

This model is appropriate for ODP Site 628 and can be used with confidence for all locations along array A. Water column data presented in Appendix B for the general model is also appropriate for the ODP Site 628 geoacoustic model.

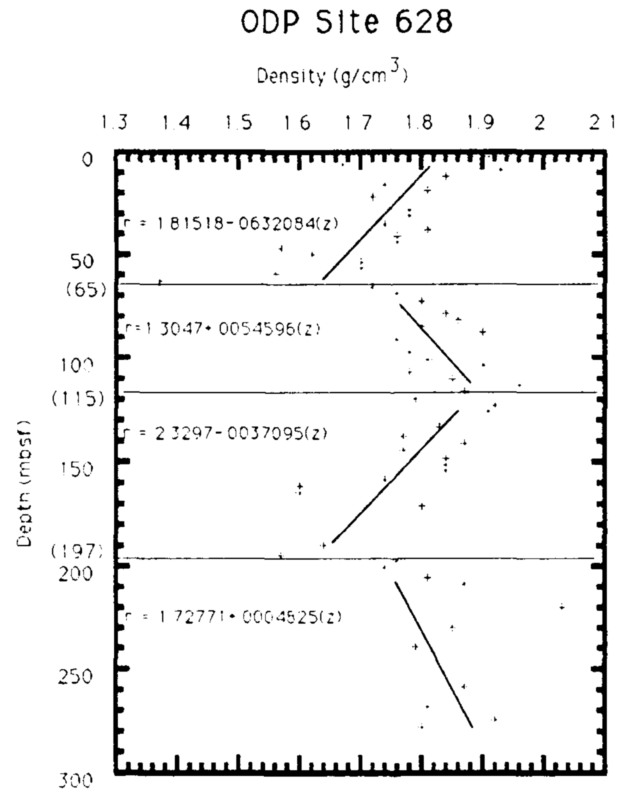

Figure 7: Wet bulk density measured using weight/volumn techniques. The four regression equations and the depths between which they are used are outlined in the figure.

PART II: TRANSECT BETWEEN NORTHERN LITTLE BAHAMA BANK AND KING'S BAY, GEORGIA

Two basic geoacoustic models are provided which can be used as input for future acoustic modeling along a transect between northern Little Bahama Bank and King's Bay, Georgia. Such a transect traverses three very different geologic provinces with different bottom and subbottom environments (Fig. 8). Little Bahama Bank on the very southern portion of the Blake Plateau, is discussed and modeled in Part I. Sediments consist of coarse carbonate sediments, predominantly sands interspersed with ooze and chalk couplets in the subsurface.

The transect crosses the continental shelf, the Florida Platform, east of Florida and Georgia It is a constructed of nearly level sedimentary strata that extend eastward to the Blake Plateau (Uchupi, 1970). The morphology of the slope is normal for a passive continental margin but the presence of the Blake Plateau (350 to 1000 m) is unusual. The Florida-Hatteras slope is a transitional zone connecting the Blake Plateau and the Florida-Hatteras shelf.

The transect (A-B) passes through the Gulf Stream. The Gulf Stream is a highly erosive current that has been in place at least since the Oligocene (~36 ma) resulting in a subbottom consisting of coarse sands and gravels for several hundred meters.

Surficial Sands and Subbottom Sediments of the Florida Platform

The surface of the Florida Platform is covered almost entirely by a thin veneer of well-sorted relict sands -1 to 2ϕ (2-0.25 mm) in size (Hollister, 1973). South of Cape Hatteras, this sand has a significant carbonate component. The shelf morphology is dominated by a series of prominent sand ridges 10-30 m high. These ridges are 2 to 40 km long with 2-18 km between crests (Popenoe, 1979). These features may be produced by present hydraulic conditions of high velocity bottom currents generated by winter gales (Uchupi, 1968).

Shelf sands are generally well sorted and reworked by physical and biological presses; there is little fine-grained material (clay) available for resuspension. Coarse-grained sand and gravel occurs only in a few scattered places near the coast of South Georgia.

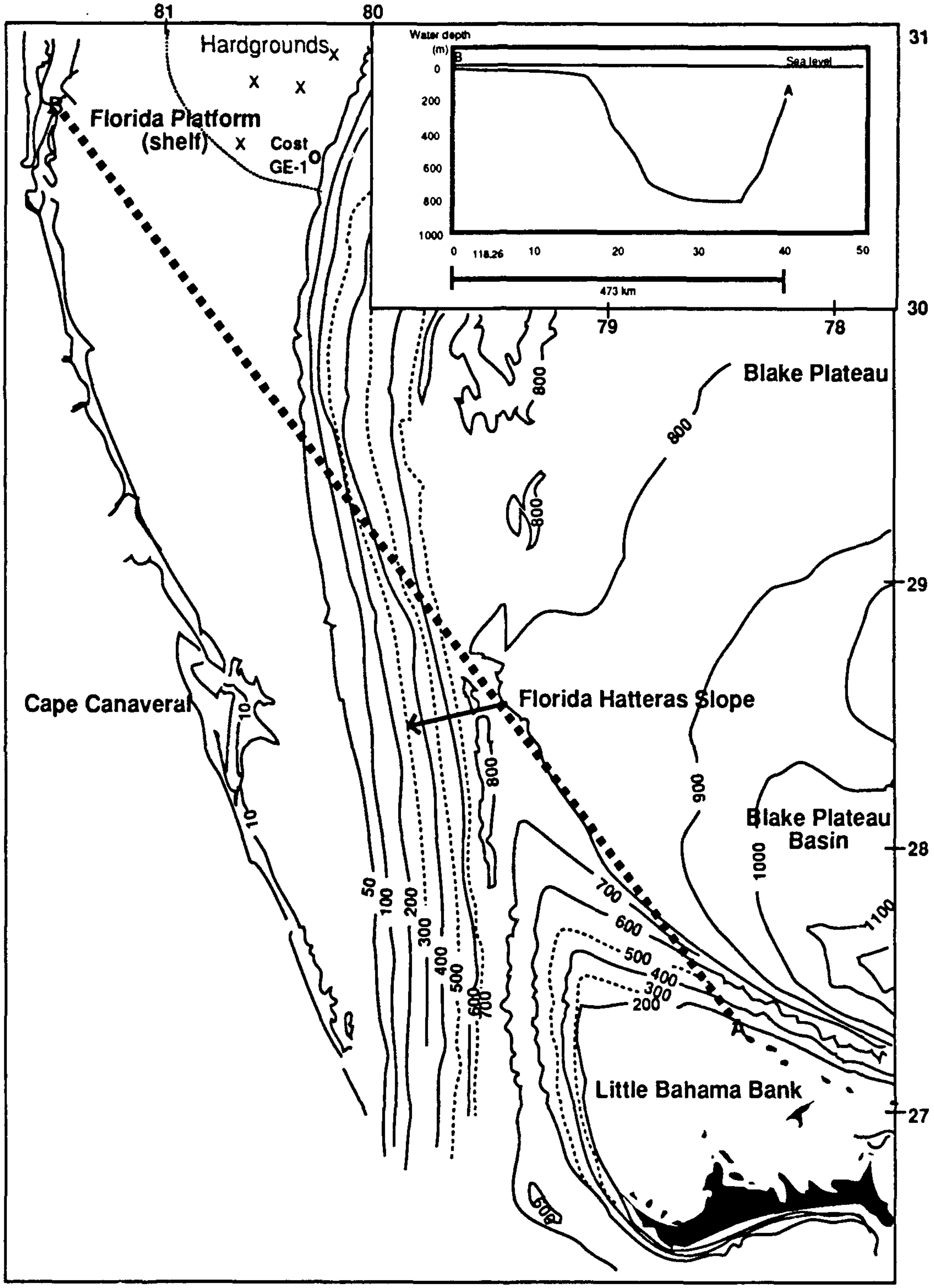

Figure 8: Location map of the transect between Kings's Bay (A) and northern Little Bahama Bank (B). The transect is marked with a dashed line. Inset illustrates the depth profile between King's Bay and Little Bahama Bank.

The sand cover is absent in places exposing a harder more indurated substrate of cemented sand. These areas of harder bottom are patchy and discontinuously scattered. Where exposed, they can be either smooth or broken roughly with relief to 15 m. These hardgrounds (Fig. 8) allow the attachment of various sessile invertebrates, sea fans, whip anemones, sponges byrozoans, hard corals, etc. Most of these hardgrounds occur at the shelf edge (Popenoe, 1979) and should be considered if the transect is moved northward.

Finer sediments, 2 to 4 ϕ (0.25-0.0625 mm), are present both near the coast and along the slope. Along the base of the continental slope off Florida, just beneath the counter current of the Gulf Stream, is a deposit of clayey silt (4-8ϕ, 0.0625-0.0039 mm) that runs north to Jacksonville (Hollister, 1973).

The subsurface data for the Florida Platform comes from shallow subbottom stratigraphic interpretations of seismic refraction and reflection profiles and cores. In addition, the Consortium Offshore Stratigraphic Test Georgia Embayment 1 (COST GE-1) well was drilled in 1977 in the center of the Georgia Bight (30°31' N, 80°N18' W) to geologic basement (Fig. 8).

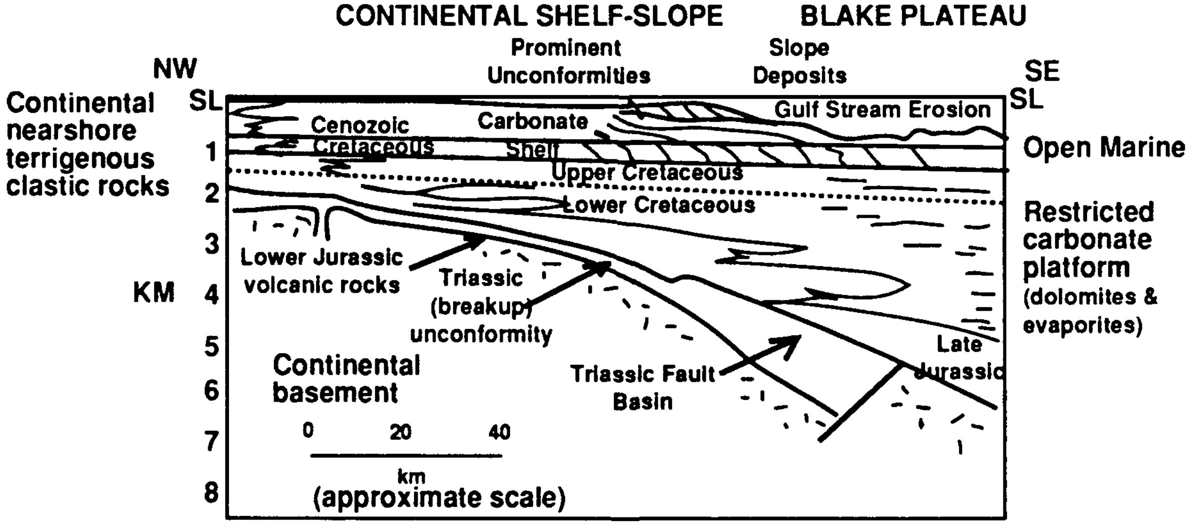

Figure 9: Schematic cross section from NW to SE across the SE Georgia embayment showing inferred geological and structural configuration of basement (after Buffler and others, 1979).

Subbottom Model Development for the Florida Platform

The Florida Platform represents a transition zone between predominantly carbonate sediments and rocks to the south in Florida and predominantly terrigenous sediments and rocks north of Cape Hatteras. The basic structure was not well known until the United States Geologic Survey (USGS) sponsored a series of multichannel seismic surveys that estimated the gross configuration and subbottom velocity structure. From these data, a general schematic cross section from northwest to southeast across the SE Georgia Embayment was constructed (Buffler and others, Fig. 9). This schematic depicts the structural configuration of basement and the ages of the seismic intervals. This geological cross-section was used in conjunction with sedimentary data from the COST GE-1 well to construct the Florida Platform geoacoustic model presented in Appendix A.

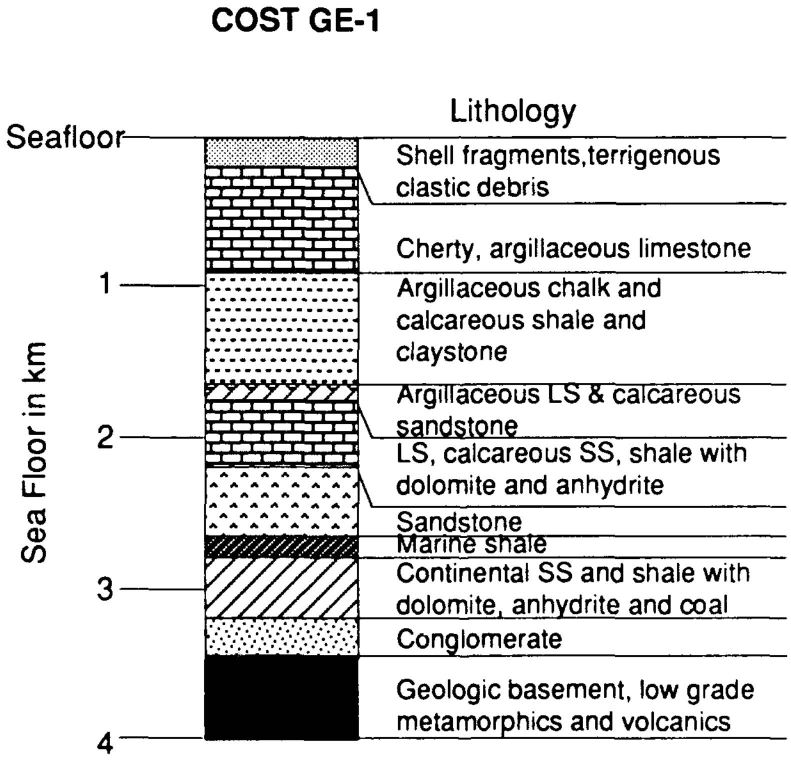

Figure 10: Subsurface stratigraphy on the Florida Platform from the COST GE-1 well.

The COST GE-1 well (Fig. 10) was drilled to geologic basement and revealed the lithologic composition of the shelf subsurface. These data correlated well with the USGS seismic information (Buffler and others, 1979; Dillon and others, 1979) and were used to estimate lithologic units and layer thicknesses for the Florida Platform model. The compressional wave velocity assigned to the units comes from Buffler and others (1979).

Values of the remaining geoacoustic parameters, shear wave velocity, compressional and shear wave attenuation, and wet bulk density, were estimated from a knowledge of sediment type (see notes immediately after Model 3, Appendix A).

Gulf Stream Sediments

The Gulf Stream is underlain by deep water carbonate sediments of Pleistocene to Oligocene (0.01 to 36 ma) age. From top to bottom the subbottom sequence consists of three major units:

I. Skeletal carbonate sands and gravels composed of planktonic foraminifers and skeletal grains from adjacent platforms (Fig.11a).

II. Muddly lime rubble, graded rubble and sand, interpreted as debris flows and turbidite deposits (Fig. 11b).

III. Skeletal carbonate sands and gravels similar to Unit I with numerous intercalations of lithified layers.

Units I and III are interpreted to be contourite deposits of the Gulf Stream. The current presently sweeps the bottom with velocities of 20 to 40 cm/s winnowing most of the planktonic and platform-derived carbonate mud and mixing the remaining globogerinid sands with coarse residue of neritic turbidite material (Austin, Schlager, Palmer and others, 1986). Unit II was emplaced during 4 million years in the mid Miocene when debris flows and turbidites were emplaced too rapidly to be reworked by the bottom current.

Diagenetic alteration of subbottom sediment occurs more frequently with sediment depth and results in an increase in the number and thickness of cemented (hard) layers in Units I and III deeper in the column.

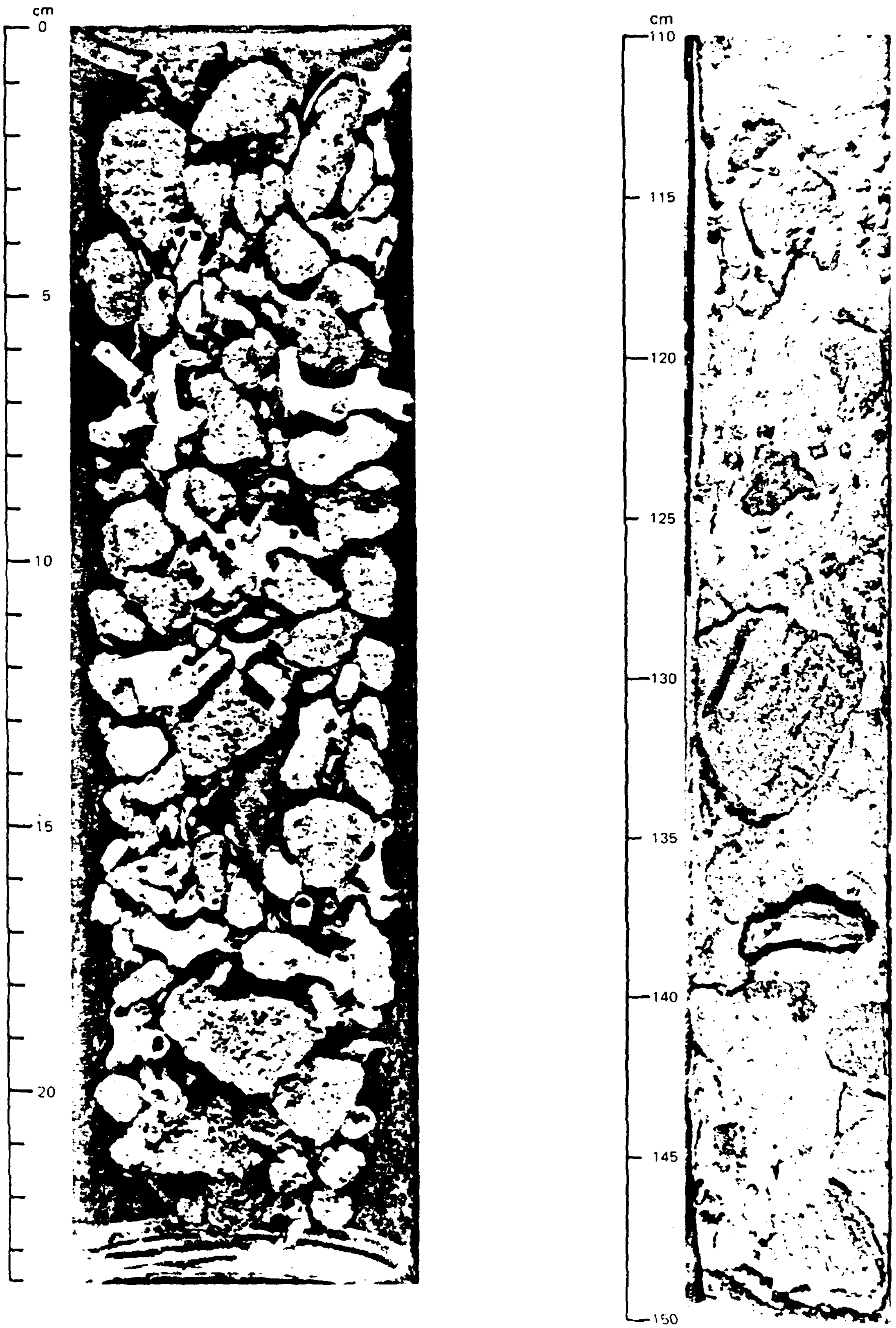

Figure 11: (A) Coarse gravel recovered from ODP Site 626. This is representative of Unit I in Model 4 (Appendix A). (B) Debris flow sediments with unlithified matrix sediment and lithified clasts and skeletal fragments. This is reprentative of Unit II.

Gulf Stream Model Development

The lithology presented in the Gulf Stream (Model 4, Appendix A) model was determined from four holes (ODP 626A, B, C, and D) drilled in sediments beneath the Gulf Stream at 25°36'N, 79°32'W, considerably south of the transect. However, the strong currents of the Gulf Stream have the same winnowing effect throughout this region and the bottom sediments, derived from both banks (Florida Platform and Little Bahama Bank), should be the same.

Laboratory measurements of compressional wave velocity are suspect because of the coarse grain size and rubbly nature of the sediments. Therefore, compressional wave velocities used in this model were derived from down-hole logging done by the Lamont Borehole Group (Austin, Schlager, Palmer and others, 1986). Postlogging processing resulted in average velocities over a broad depth interval and a range of values for Units II and III. Compressional wave velocities for Unit I are estimated from sediment type because the upper 50 m of the hole were not logged.

There are no actual shear wave velocity measurements for these sediments; therefore, shear wave velocity was calculated using empirical relationships derived by Hamilton (1980, see notes immediately after the model). These calculated shear wave velocity values were based on the average logging velocities and are also average values to be used over the entire interval outlined.

Both compressional and shear wave attenuation are best estimates based on work done by Hamilton (1980) on sands and rocks (see notes after the model). These are in dB/m/kHz and a gradient can be derived over the interval using the equations given.

Wet bulk density is derived from average logging and laboratory measured values for ODP Site 626 for these sediment types. Basement density values are estimated from Clark (1966).

DISCUSSION AND SUMMARY

The four models are presented in this technical note, two for northern Little Bahama Bank, one for the Florida Platform and one for the Gulf Stream, provide appropriate geoacoustic inputs for use with various acoustic models. The two northern Little Bahama Bank models represent different approaches to creating a descriptive geoacoustic model. The first approach, illustrated by the general model, is to use as much data as possible over a given geographic area and combine it such that representative values and gradients are determined for each geoacoustic parameter. The second approach, illustrated the by model for ODP Site 628, is more specific in that actual measured values down hole in the particular site are used. This model is the best possible for this particular latitude and longitude, but it may not be applicable over the remainder of the bank. Both these models have been constructed such that an optional, thin, high velocity layer may be inserted if desired. This method of presenting a layer was chosen because the presence of such a layer is suggested by seismic data (Line LBB-18) but is supported by only one sample with a high measured compressional wave velocity and the measured density on that same sample is low. The Florida Platform and Gulf Stream models are generated with little measured data but a good understanding of the lithology in the two environments. Therefore, most of the actual values are best estimates.

These Bahama Bank models should be modified based on location on the bank.

First, the thickness of the unconsolidated sediment section increases downslope. Therefore, the depth to basement and layer thicknesses should be varied depending on position on the slope.

Second, since the sediments on the upper slopes tend to lithify earlier than those in deeper water depths, the optional, higher shear wave values should be used on upper slope locations.

Third, the user may wish to use actual measured water column data. The profile presented in Appendix B is based on historical data for Little Bahama Bank. Water column sound speed may vary significantly over short periods thoughout the Gulf Stream and a profile that represents theperiod during the acoustic experiment should be used. Similarly, the sound speed profile will vary considerably on a seasonal basis on the Florida Platfom due to the shallow water depths. A measured profile taken during the time of the experiment will provide optimal results.

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APPENDIX A

Geoacoustic Model 1: General, Little Bahama Bank
Geoacoustic Model 2: Specific, ODP Site 628
Geoacoustic Model 3: Florida Platform
Geoacoustic Model 4: Gulf Stream

Legend for the following models

msbf	meters below the seafloor
Vp(G)	compressional wave velocity derived using equatons from Table 1
Vp(I)	interval velocity derived from seismic data
Vs(G)	shear wave velocity derived using equations from Table 1
Vs(O)	optional shear wave velocity for indurated sediments calculated from Hamil ton (1980)
Kp	compressional wave attenuation in dB/m/kHz
αp	compressional wave attenuation in dB/λ
Ks	shear wave attenuation
αs	shear wave attenuation in dB/λ
ρ	wet bulk density

Geoacoustic Model 1: General, Northern Little Bahama Bank

	Water depth	*Bottom water sound speed*	*Water density*
Sea Surface			
	966m (variable)	1495m/s (variable, see Appendix B)	1.025 g/cm^3
Seafloor			

Lithology	*Depth (mbsf)*	*Vp(G) (m/s)*	*Vs(G) (m/s)*	*Vs(O) (m/s)*	*kp(G) (dB/m/kHz)*	*αp (G) (dB/λ)*	*ks(G) (dB/m/kHz)*	*αs (G) (dB/λ)*	*ρ (G) (g/cm^3)*
(debris flows) Carbonate ooze with slumps & turbidites (ie., with 5-10 cm thick layers of sand). I	0	1587	37		.45	.71	17.30	.64	1.78
	5	1589	38		.34	.55	13.23	.50	1.78
	10	1591	38		.31	.49	11.79	.45	1.78
	15	1593	38		.29	.46	11.02	.42	1.78
	20	1595	39		.27	.44	10.50	.41	1.78
	25	1597	39		.26	.42	10.12	.39	1.79
	30	1599	39		.26	.41	9.81	.39	1.79
	35	1601	40		.25	.40	9.57	.38	1.79
	40	1603	40		.24	.39	9.35	.37	1.79
	45	1605	40		.24	.38	9.17	.37	1.79
	50	1606	41		.24	.38	9.01	.37	1.79
	52	1607	41		.23	.37	8.95	.37	1.79
	75	1615	42		.22	.35	8.42	.36	1.80
	100	1624	44		.21	.34	8.03	.35	1.81
	120	1630	45		.20	.33	7.79	.35	1.81
	125	1632	45		.20	.33	7.74	.35	1.81
	136	1635	46		.20	.32	7.63	.35	1.81
Stiff carbonate ooze & chalk II	138	1635	46	370	.20	.32	7.61	.35	1.81
	150	1639	46	380	.20	.32	7.51	.35	1.82
	175	1646	18	390	.19	.31	7.31	.35	1.83
	200	1652	19	390	.19	.31	7.15	.35	1.83
	250	1663	50	410	.18	.30	6.89	.35	1.85
	270	1669	51	410	.18	.29	6.77	.34	1.85
Limestone & chert Basement III	271	3966	2087		.05	.18	.06	.18	3-3.5

Geoacoustic Model 2: Specific, ODP Site 628

	Depth (m)	*Vp(I) (km/s)*	*Vp(628) (m/s)*	*Vs(G) (m/s)*	*αp (628) (dB/λ)*	*αs (G) (dB/λ)*	*ρ (628) (g/cm^3)*
Sea Surface							
	966	1495 m/s					1.025
Seafloor							
Lithology							
(debris	0		----	37	.62	.64	1.85
flows)	5		1426	38	.49	.50	1.84
	10		1464	38	.45	.45	1.82
Carbonate	15		1499	38	.43	.42	1.80
ooze with	20		1533	39	.42	.41	1.79
slumps &	2	1.75	1564	39	.41	.39	1.77
turbidites	30		1593	39	.41	.39	1.76
(ie., with	35		1620	40	.40	.38	1.74
5-10 cm	40		1645	40	.40	.37	1.72
thick layers	45		1668	40	.40	.37	1.71
of sand).	50		1689	41	.40	.37	1.69
	52	A	1696	41	.40	.37	1.68
	75		1760	42	.39	.36	1.71
I	100	1.75	1777	44	.37	.35	1.85
	120	B	1752	45	.36	.35	1.88
	125		1741	45	.35	.35	1.87
	136	1.75	1708	46	.34	.35	1.83
Stiff	138	C	1749	46	.35	.35	1.82
carbonate	150		1753	46	.34	.35	1.77
ooze &	175		1760	18	.33	.35	1.68
chalk	200		1766	19	.33	.35	1.82
	250	2.26	1773	50	.32	.35	1.85
II	270		1775	51	.31	.34	1.86
Limestone		D					
& chert							
basement	271	2.94	3966	2087		.20	.20
III							

Geoacoustic Model 3: Gulf Stream

	Depth (m)	*Ave Vp (m/s)*	*Ave. Vs (m/s)*	*Kp (dB/m/kHz)*	*Ks (dB/m/kHz)*	*Ave. ρ (g/cm^3)*
Sea Level						
	400-800 (anywhere between)	1523-1514 (see sound speed profile Appendix B)	-			1.025
Sediment/water interface						
I coral rubble (sand & gravel)	0 ↕ 90	1550 to 1600	263	0.35 ↕ 0.16	13.0 ↕ 5.94	1.6 to 1.9
II Debris flows (somewhat cemented)	90 ↕ 165	1980 +/-50	585 +/-35	0.16 ↕ 0.15	5.94 ↕ 5.57	1.9 to 2.0
III Sand and gravel sized coral with intercalated cemented layers	165 ↕ 320	2110 +/-20	704 +/-17	0.15 ↕ 0.13	5.57 ↕ 4.8	1.8 to 2.2
Basement (chert & limestone)	320	2740	1580	.04	.06	3.0 to 3.5

Geoacoustic Model 4: Florida Platform

	Depth (m)	Ave. Vp (m/s)	Ave. Vs (m/s)	Kp (dB/m/kHz)	Ks (dB/m/kHz)	Ave. ρ (g/cm³)
Sea Level						
	50-200 (anywhere between)	- (see sound speed profile)				1.025
Sediment/water interface						
Shell fragments, terrigenous clastic debris	0 ↕ 190	1.7 to 2.8	.42 to 1.22	.53 to .71	3.4	1.8 to 2.3
cherty argillaceous limestone	190 to 810	2.8 to 3.2	1.22 to 1.68	.4	1 .05	2.3 to 2.4
fined-grained carbonates	810 ↕ 1100	2.1 to 3.0	.68 to 1.58	.15 to .14	.2 to .15	2.0 to 2.1
chalk, calcareous shale & claystone	1100 ↕ 1700	3.2 to 5.0	1.68 to 2.63	.06	.02 to .05	2.3 to 2.5

Below 1700 m, there are more shales, limestones, calcareous sandstones, increasing amounts of dolomite, anhydrite, coal. Acoustic basement is somewhere below 1100 m depending on frequency. Geologic basement is found about 3400 m where metamorphic rocks are encountered. Vp is 5.5 km/s or higher.

==

Notes

Model 1, General, Northern Little Bahama Bank

1. Water depth will vary depending on position on the slope. Bottom water sound speeds will vary depending on water depth and season and should be adjusted using the sound speed profile and data in Appendix B and measured water column data where possible.

2. An optional high velocity layer may be added. Data plotted on figure 6 (p.11) for Site 628 at about 100 mbsf suggest that there may be a thin, high velocity layer present. The presence of this layer is documented, however, by only one laboratory measurement. Use of this layer is up to the judgement of the modeler and is, therefore, called an "optional" high velocity layer. Values for this layer are the following: Vp = 2064 m/s; Vs = 1086 m/s; Kp = 0.21; αp = 0.23; Ks = 8.07, αs = 8.76; and ρ =1.81.The depth of this layer within the sedimentary column will vary depending on position on the bank. Seismic line LBB-18 (Austin, Schlager, Palmer and others, 1986) suggests that layers thin downslope. Therefore, the location of this layer can be adjusted depending on position on the slope.

3. Optional values for Vs using Hamilton (1980) regressional equations are labeled Vs(O) and may be substituted for Vs(G) values in Lithologic Unit II between 138 and 270 mbsf. Depending on position on the bank, this layer may be more or less indurated. For example, Lithology II sediments deposited in shallow water will be more indurated than those deposited in deeper water. Vs(o) values should be used whenever Vp(O) values are used.

Model 2, Specific, ODP Site 628

1. An optional high velocity layer may be added between 97 and 103 mbsf. The geoacoustic values are the same as in model 1 (see notes above).

2. Vp(I) - Interval velocities and confidence limits from ODP Site 628 were calculated along line LBB-18 by Austin, Schlager, Palmer, and others (1986). The sequence boundaries correlate loosely with sequence boundaries or hiatuses determined from core analyses.

3. Vp(G) - Compressional wave velocity calculated using regressions derived from laboratory measured velocities from Site 628 and numerous other USNS Lynch piston core data (Fig. 4).

Data are both temperature and pressure corrected.

4. Vp (ODP 628) - Compressional wave velocities calculated using regressions derived from laboratory data measured at ambient laboratory pressures from Site 628. The data are not temperature corrected.

Model 3, Gulf Stream Model

1. Vp is taken from logging data (ODP Site 626) and is an average value to be used for the entire layer.

2. Vs for sediments is an average value for the entire layer computed using (Hamilton, 1980):

For $Vp=1.555$ to 1.650 km/s	$Vs=1.137Vp-1.485$
$Vp=1.650$ to 2.150	$Vs = 0.991-1.136Vp+0.47Vp^2$
$Vp > 2.150$	$Vs = 0.78Vp-0.962$

Vs for rocks estimated from $Vp/Vs=1.9$ for limestone.

3. Kp decreases to -1/6 power of depth for sands,

$$Kpz = Kp0(z^{-1/6})$$

where Kp) is estimated based on grain size and sediment type and z is depth below the seafloor.

4. Ks is estimated from sediment type and is proportional to Kp. It can also be considered a gradient within each layer.

5. ρ was determined from a combination of logging and laboratory measurements from ODP Site 626 and is an average value to be used for the entire layer.

6. Limestone and chert basement values: Vp is taken from downhole logging data, remaining parameters are taken from Handbook of Physical Constants (Clark, 1966).

Model 4, Florida Platform

1. Lithology is known from the COST GE-1 well, drilled to geologic basement (Dillon,1981).

2. Vp is an interval velocity based on seismic data (Dillon, 1981).

2. Vs for sediments is computed using Hamilton (1980).
   Vs for rocks Vp/Vs=1.9 for LS.

3. Kp, Ks and ρ are best estimates based on sediment type (Clark, 1966; Dobrin, 1976; and Hamilton, 1980). Where possible, a range of values is given, otherwise the single value represents our best estimate.

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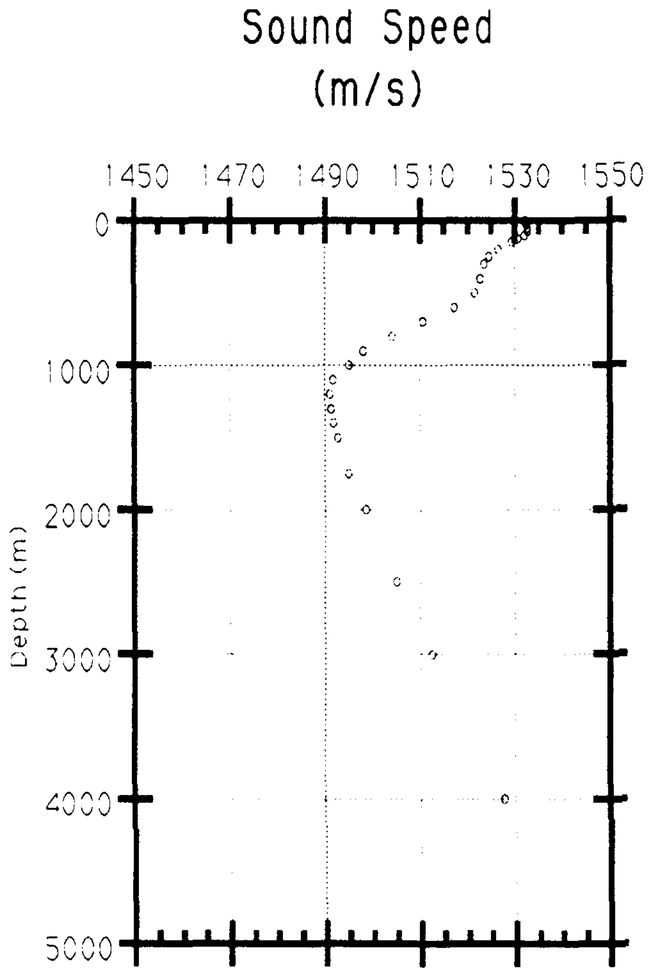
APPENDIX B

Water Sound Speed Profile and Data



Depth (m)	Sound speed (m/s)
0.0000	1532.2
10.000	1532.3
20.000	1532.4
30.000	1532.5
50.000	1532.6
75.000	1532.7
100.00	1532.1
125.00	1530.7
150.00	1529.4
200.00	1526.6
250.00	1524.6
300.00	1523.6
400.00	1522.8
500.00	1521.5
600.00	1517.2
700.00	1510.6
800.00	1504.2
900.00	1498.1
1000.0	1495.1
1100.0	1491.7
1200.0	1491.1
1300.0	1491.2
1400.0	1491.7
1500.0	1492.7
1750.0	1495.0
2000.0	1498.5
2500.0	1505.1
3000.0	1512.4
4000.0	1527.7

Sound speed data is from the NOARL GDEM data base compiled using historical data and averaged over four seasons. It is valid for northern Little Bahama Bank.

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Two geoacoustic models characterize the water column and subbottom sediments on the northern Little Bahama Bank. A general model, applicable anywhere on the bank, and a model specific for Ocean Drilling Program (ODP) Site 628 are presented and documented. Values for geoacoustic parameters used in the general model are derived from core data collected by the USNS LYNCH and ODP Leg 101. Site specific measurements of compressional wave velocity and wet bulk density are used for the ODP Site 628 model. Values for the remaining geoacoustic parameters are the same for both models.

A transect between the northern Bahamas and King's Bay, Georgia passes from the bank through the Gulf Stream and terminates on the Florida Platform. Two geoacoustic models that describe the subbottom environment under the Gulf Stream and on the Florida Platform are documented for this transect. Values for geoacoustic parameters used in the Gulf Stream model are extrapolated from data collected on ODP Leg 101. Data used in the creation of the Florida Platform model are from seismic surveys sponsored by the United States Geological Survey, and the COST GE-1 well.

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