Chapter 2

Geologic Setting and Context of Cores Taken During the IMAGES VIII/PAGE 127 Cruise of the RV *Marion Dufresne* in the Northern Gulf of Mexico

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Introduction

The northern Gulf of Mexico contains some of the best documented occurrences of gas hydrates in the world; gas hydrate samples have been recovered in near-sea-floor sediments at more than 50 locations associated with active sea-floor hydrocarbon seeps (Sassen, Sweet, Milkov, and others, 2001b). However, years of geophysical prospecting for hydrocarbons in the northern Gulf of Mexico have failed to reveal the vertical distribution of gas hydrate. Prior sampling studies in the region have focused principally on basin-edge structures with little emphasis on the extensive areas of the basin floors.

Background

In July 2002, the International Marine Past Global Changes Study (IMAGES) VIII/Paleoceanography of the Atlantic and Geochemistry (PAGE) 127 program cruise collected cores for the purpose of characterizing the hydrate stability zone in collaboration with the U.S. Geological Survey (USGS). Seventeen giant Calypso piston cores of up to 38 meters (m) in length and two box cores were collected. About 500 m of piston core were recovered, and 14 m of box core sediment were obtained for USGS-related studies. Gravity cores with thermal sensors welded to the core barrel also were obtained mainly to acquire heat-flow information from 17 cores at 9 stations.

The core locations for the cruise primarily were selected using seismic records obtained from two previous Department of Energy (DOE)-funded USGS cruises over the upper- and middle-continental slope (Cooper and Hart, 2003) described in more detail below. Targeted sites were chosen to help answer three main questions: First, what is the lateral extent of gas hydrate between near-surface hydrate deposits and in adjacent basins? Second, are there significant gas hydrate deposits in reservoir sediments at depth in these basins? Third, does gas hydrate have any effect on known submarine slides near the Mississippi Canyon where deep offshore platforms might be at risk?

Coring sites were chosen from (1) transects on the upper slope going from structural highs into minibasin environments, (2) a transect down the middle of a submarine slide feature, (3) the summits of diapirs and sea-floor mounds, (4) above seismically imaged gas chimneys, and (5) locations where gas hydrate had been previously recovered, which typically corresponded to areas noted in number 3 above. In addition, 11 cores were taken by other research interests of the IMAGES group within and around this study area. In particular, four cores were taken in Pigmy and Orca Basins, part of the middle slope region, for environment and climate studies.

Geologic Framework of the Gulf of Mexico

The complex geologic setting of the northern Gulf of Mexico results largely from interactions of active salt tectonics, rapid sedimentation, and gravity slope-failures (Diegel and others, 1995; Prather and others, 1998; Winker and Booth, 2000). The resulting suite of minibasin and ridge features are being actively modified by both deep-seated (kilometers) and shallow (meters) faults that are being buried by mass-transport debris flows and hemipelagic-draped deposits. Sediment types and deposition rates are highly variable in the minibasins,

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depending on fluvial input to the adjacent shelf and slope, and on input from slope failures. A large Gulf of Mexico salt basin extends from the coastal salt dome province to the lower continental slope. A series of smaller interior salt basins extends onshore from south Texas to Alabama. The basins formed during Late Triassic rifting and during Middle Jurassic marine incursions were filled by sediment of the Louann and Werner Formations (Salvador, 1987). Structural style is profoundly influenced by the effects of salt movement caused by rapid deposition of overlying siliciclastic sediment.

The Gulf of Mexico continental shelf is characterized by numerous salt domes. In deeper waters, the continental slope is affected by large sheet-like salt thrusts that extend from the shelf edge across the continental slope to the Sigsbee Escarpment, near the shallow limit of the abyssal plain (Worrall and Snelson, 1989). In general, the basins are areas of salt withdrawal, and the intervening ridges are areas of salt piercement or structural folds (Rowan, 1995). Structural pathways for upward-migrating fluids and gases are most common along ridge flanks, around isolated diapiric highs, near edges of basins, and close to slope failures. Where faults extend to the sea floor, the sea-floor morphology is characterized by vents, sea-floor mounds, pockmarks, authigenic carbonate deposits, gas hydrate mounds, debris flows, chaotic reflection zones, and other features related to water and hydrocarbon seeps (Roberts and Carney, 1997; Roberts, 2001). By contrast, basin floors usually do not show evidence of active seepage. Instead, alternating sections of chaotic sediments commonly overlie laminated sediments. The chaotic sediments are the result of mass transport deposits shed from the basin sides (Berryhill and others, 1987).

The geology of the Gulf of Mexico slope is conducive to seepage and venting from deeply buried petroleum systems to the sea floor because hydrocarbon generation took place geologically recently within the deep sediment section beneath the salt thrust and on the upper abyssal plain (Sassen, Losh, and others, 2001; Sassen, Sweet, DeFreitas, and others, 2001; Sassen, Sweet, Milkov, and others, 2001a, b). Hydrocarbons migrated vertically through the salt withdrawal basins that pierce the salt sheets. Rapid sedimentation in Pleistocene depocenters (Galloway and others, 2000) activates migration conduits from depth to the sea floor. Fractures and faults associated with moving salt provide efficient migration conduits for fluid flow of gas, oil, and brines to the sea floor. Hydrocarbon seepage manifests itself on the sea floor as gas hydrate, oil-stained sediments, authigenic carbonate rock with carbon depleted in carbon-13 (^{13}C), and hydrocarbon-driven chemosynthetic communities (for example, MacDonald and others, 1989; Roberts and Aharon, 1994; Aharon and others, 1997; Roberts and Carney, 1997; Sassen, Joye, and others, 1999).

Gas Hydrate in the Gulf of Mexico

Gas hydrate deposits commonly are associated with salt domes or other salt-related tectonics. Geophysical evidence for gas hydrate in the region is equivocal. Where sea-floor exposure of gas hydrate deposits are known from submersible observations and coring near sea-floor vents and diapirs, high-resolution seismic data indicate localized strong sea-floor reflections and shallow subbottom acoustic wipeout zones (for example, Roberts and others, 1999; Sager and others, 1999). Over the same regions, deep-tow side-scan sonar images show zones of high backscatter that are associated with diagenetic-carbonate, chemosynthetic-community, and gas hydrate deposits (Cooper and others, 1999; Sager and others, 1999), and sea-floor reflectance values derived from 3–D seismic surveys commonly show varied amplitudes and reversed polarity indicative of near-sea-floor gas (Roberts and others, 1992; Roberts, 1996). While sea-floor exposures of gas hydrate have clear seismic signatures, buried gas hydrate deposits are not as easily imaged with seismics. Bottom simulating reflections (BSRs), the most commonly cited evidence for gas hydrate, are rare in the northern Gulf of Mexico and typically are documented on the continental rise of the western and central Gulf of Mexico (Shipley and others, 1979; Hedberg, 1980).

Milkov and Sassen (2001) provided a conceptual model to explain the distribution of gas hydrate in the Gulf of Mexico. They proposed that thermogenic and biogenic gases are focused along basin-edge structures and that only disseminated bacterial gas is present in the centers of minibasins. Most prior gas hydrate studies in the northern Gulf of Mexico have focused on basin-edge structures containing active hydrocarbon venting. There have been few studies of the extensive areas of basin flanks and centers. The basin edges and structural highs are where the sea-floor gas hydrate mounds occur, and where gas hydrate has been sampled at subsurface depths of a few meters (Sassen, Sweet, Milkov, and others, 2001b), although disseminated bacterial gas hydrate was found in the Orca basin from 20 to 40 meters below sea floor (mbsf) (Pflaum and others, 1986). Toward the basin centers, there are few common geophysical markers (for example, BSRs) that indicate the presence of gas hydrate, although numerous discontinuous zones of enhanced reflectivity occur, possibly suggesting that gas might be trapped within or beneath the gas hydrate stability zone (Cooper and Hart, 2003). Geochemical studies in conjunction with this cruise and by others have demonstrated that salt inhibition is an important constraint on gas hydrate formation in the northern Gulf of Mexico (Paull and others, 2005; Ruppel and others, 2005). Models of gas hydrate stability using measured pore-water salt content and geothermal gradients (Appendix L) clearly show the shoaling of the gas hydrate stability zone caused in large part by the high salt concentration in pore water.

Pre-Cruise USGS Seismic Surveys

Extensive seismic surveys have been conducted by the oil and gas industry in the northern Gulf of Mexico, but most modern high-resolution seismic data are proprietary. Published seismic-reflection surveys across these regions by the USGS and others (for example, Berryhill and others, 1987; EEZ-SCAN, 1987; Weimer and others, 1998) are either not in digital format or are of lower resolution than required for this study. High-resolution seismic-reflection surveys of areas around gas hydrate deposits (for example, Roberts and others, 1999; Sager and others, 1999) do not extend across basin flanks and centers.

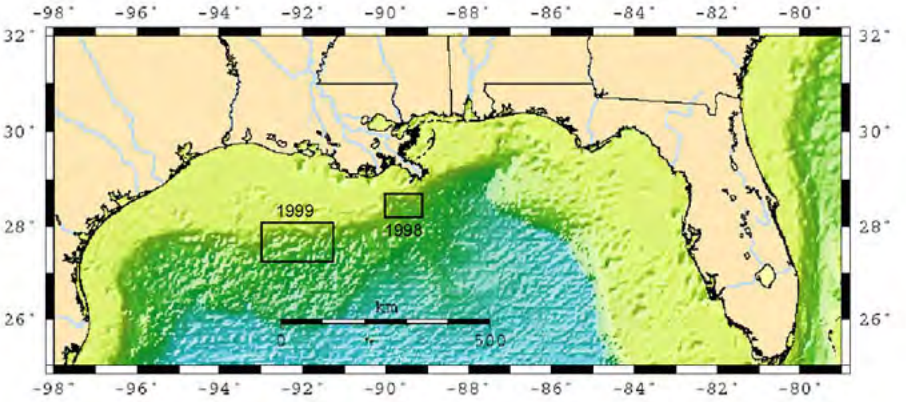

Figure 1. Previous (1998 and 1999) cruise areas studied by the USGS. Both areas were occupied during the 2002 cruise conducted aboard the RV *Marion Dufresne*.

In 1998 and 1999, the USGS conducted high-resolution seismic investigations of the Mississippi Canyon and Garden Banks-Green Canyon regions of the upper- and middle-continental slope to evaluate the distribution of gas hydrate, associated free gas, and their effects on slope stability (fig. 1). Track lines crossed several continental slope basins, including areas of known occurrences of gas hydrate, shallow water flows, chemosynthetic communities, and sea-floor slides. The region location names used above and throughout this report correspond to names of lease block areas defined by the Minerals Management Service (Minerals Management Service, 2002).

In 1998, multichannel high-resolution seismic-reflection data were acquired in the Mississippi Canyon region by using either a 35-cubic-inch dual-chamber airgun (that is, GI gun) or a 15-cubic-inch water gun and a 250-m long 24-channel solid-core streamer. The data imaged to depths greater than 1,300-m subbottom with nearly 5-m resolution. Single-channel data were recorded by a Huntec deep-tow boomer towed at 100- to 200-m subsea-surface, and achieved penetration greater than 200-m subbottom resolution and 0.25-m vertical resolution. A detailed ocean bottom seismometer (OBS) survey also was conducted on the west side of the Mississippi Canyon in an area where sea-floor gas hydrate deposits are known (Neurauter and Bryant, 1990).

The 1999 USGS cruise in the Garden Banks and Green Canyon region acquired multichannel high-resolution seismic-reflection data with the same water gun and streamer as used in 1998, and Huntec deep-tow boomer data and deep-tow side-scan and chirp seismic data also were recorded. The chirp seismic data penetrated to about 40-m subbottom with a resolution of about 0.1 m. Images and digital data for multichannel seismic-reflection data from both cruises are accessible on the Internet (Hart and others, 2002).

Both the 1998 and 1999 studies found widespread occurrence within the upper 500 to 700 m of the sedimentary sections of chaotic units with disrupted reflections that have high reflectivity zones that can be diffuse in places. Cooper and Hart (2003) refer to these as high reflectivity zones (HRZs). The report gives examples of the high-resolution seismic data across HRZs and discusses possible causes of these zones with regard to likely concentrations of free gas that may be a source for gas hydrate deposits in the gas hydrate stability zone (GHSZ). The report also describes evidence for fault and stratigraphic conduits, and evidence for the coincidence of HRZs with deep-seated faults, diapiric structures, shallow water flows, and décollements beneath sea-floor slides in the study areas. These may be important features in explaining fluid and gas flow through the GHSZ and, hence, the distribution of possible gas hydrates.

RV *Marion Dufresne* Piston Coring

The research vessel (RV) *Marion Dufresne* (fig. 2) has an unobstructed starboard main deck that allows the deployment and recovery of Institut Polaire Français' (IPEV) "Calypso" corer. The piston-coring system, driven by a 6-tonne weight stand, has obtained cores as long as 64.5 m. In the Gulf of Mexico, 17 giant Calypso piston cores as long as 38 m were collected at Tunica Mound, at Bush Hill, and near or within the Mississippi Canyon (fig. 3). Four gravity cores, up to 9 m long, were taken in areas suspected of being composed of carbonate or gas hydrate-hardened sediment. Box cores,

Figure 2. The RV *Marion Dufresne*.

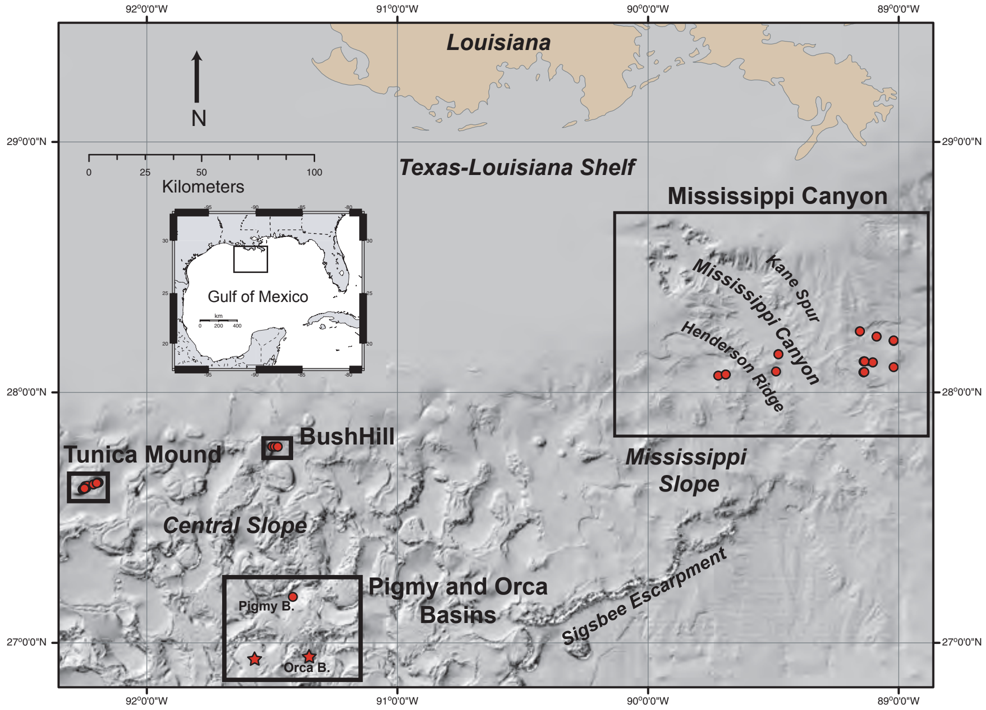

Figure 3. Coring sites. Boxes denote areas of interest and more detailed maps. Circular symbols represent dedicated USGS cores. Star symbols represent cores taken primarily for other studies.

up to 10 m long, were also recovered. These box cores were useful in obtaining the best surface record possible for climate and pollution history studies that were conducted by other researchers on board. Two box cores were recovered for gas hydrate studies; each targeted potential surficial gas hydrate. An additional 17 gravity cores at 9 stations were made to provide heat-flow and thermal gradient measurements at or near selected piston core sites. Metadata from the cruise, including navigation, personnel, and core locations, are available in Appendix M and on the Internet at the USGS Web site: *http://walrus.wr.usgs.gov/infobank/d/d102gm/html/d-1-02-gm.meta.html* .

Site Characterization: Mississippi Canyon Region

The east and west sides of the Mississippi Canyon (fig. 4) are characterized by extreme sedimentation rates up to 15 to 20 meters per thousand years (m/k.y.), pelagic drape, and mass wasting over the last 20 thousand years (ka), when the principal filling of the ancestral Mississippi Canyon and its side canyons occurred (Goodwin and Prior, 1989). The age of the sedimentary sections in the upper 600 to 700 m (that is, the estimated GHSZ) in our operating areas is likely younger than late Pleistocene age (Goodwin and Prior, 1989).

East Side of Mississippi Canyon, Kane Spur, MC853 Diapir

A large slide, about 15 kilometers (km) wide and at least 15 km long, covering at least 225 square kilometers (km^2) is a prominent feature on Kane Spur on the east side of the canyon. Extensional faults occur at the head of the slide. In addition, there is a 1- to 2-km wide shear zone along the southwest edge of the slide. The subbottom is cut by two categories of faults: a suite of high-angle faults that converge with depth and extend beyond the depth of seismic-reflection data, and a set of faults that appear to be related to stratigraphic sliding within the upper sedimentary section. Cooper and Hart (2003) infer that the high-angle faults are rooted in deep-seated salt that is the principal driving mechanism for the sea-floor slide. The shallow faults sole out within a chaotic unit at about 2.2 seconds (sec) subbottom, where they partly accommodate the slide motion that includes extension near the slide's head and compression near the toe.

The slide lies within a broader zone of extensional subsidence of salt withdrawal. The western edge of the subsidence zone is marked by a number of boundary faults, one of which is the probable conduit for a large elliptical diapir-like structure present in lease blocks MC853 and MC852. Gas hydrate was cored at the sea floor from the diapiric structure and is suspected to exist within other smaller sea-floor mounds

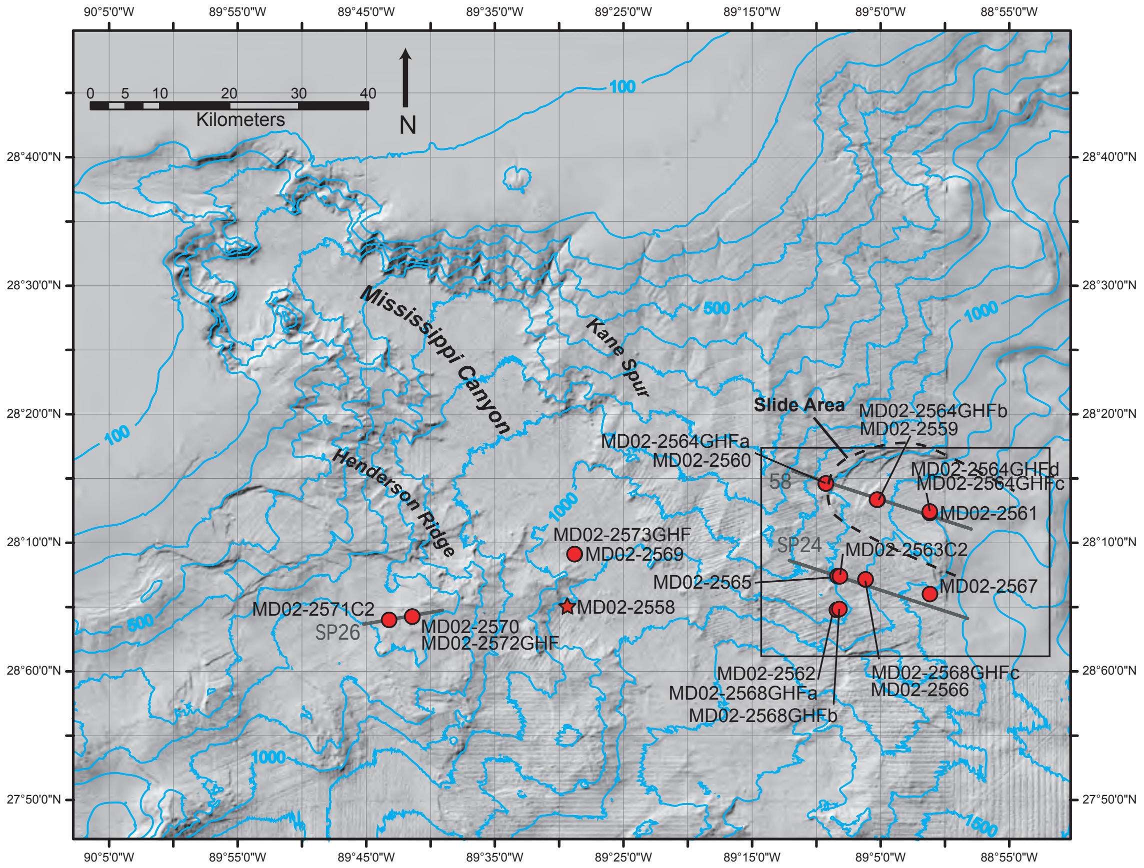

Figure 4. Coring locations in and around Mississippi Canyon. Boxed area indicates area of detail shown in figure 5. Gray lines denote seismic lines shown in figures 6 and 7. Core MD02-2558, part of the IMAGES program, is shown for reference.

over nearby faults within the slide's shear and extension zones (Sager and Kennicutt, 2000; Sassen, Sweet, Milkov, and others, 2001a).

Within the boundaries of the extensional subsidence zone, a chaotic stratigraphic unit occurs with disrupted reflections and high reflectivity zones (HRZ). The top of the HRZ under the slide lies at a subbottom depth of about 500 to 550 milliseconds (ms; 440 to 480 m), is about 100 to 150 ms (90 to 130 m) thick, and generally mimics the sea floor. The high reflectivity zones occur mostly where reflections are discontinuous and chaotic. The unit can be traced regionally, but reflectivity is greatest under the slide and near large fault zones. Drilling at multiple sites along the southwest side of the slide during development of the Ursa Field encountered wet sands from about 300 mbsf to 550 mbsf, with overpressure shallow-water flows and some gas (Eaton, 1999). Such shallow-water flows are common in the northern Gulf of Mexico (Minerals Management Service, 2001).

Our coring effort on the eastern Mississippi Canyon focused on two primary objectives: (1) A transect of the Kane Spur slide beginning above the headwall, into the main body, and ending in the toe (MD02-2560, -2559, and -2561, respectively, fig. 5). The watergun-sourced USGS 2–D seismic section, including these core locations, is shown in figure 6. (2) A transect from the summit of the MC853 diapiric structure known to be roofed by gas hydrate and oil-laden sediments, proceeding southeast into deeper waters along a previous USGS seismic line (MD02-2565, -2563C2, and -2566, respectively, fig. 5, with a chirp seismic section seen in fig. 7).

The seismic sections summarize important findings of the cruise. Each section shows the location of cores with the relative penetration into sediments at scale, the measured geothermal gradient, and the calculated base of the gas hydrate stability zone (BGHSZ) (fig. 7). The calculations of gas hydrate stability are given in more detail in Appendix L. Important features included measured geothermal gradient, pore water salinity (chlorinity as proxy) measured and projected to depth, the observed bottom water temperature, and gas compositions reflecting pure methane and wet gas compositions from Bush Hill and Mississippi Canyon given in Cooper and Hart (2003).

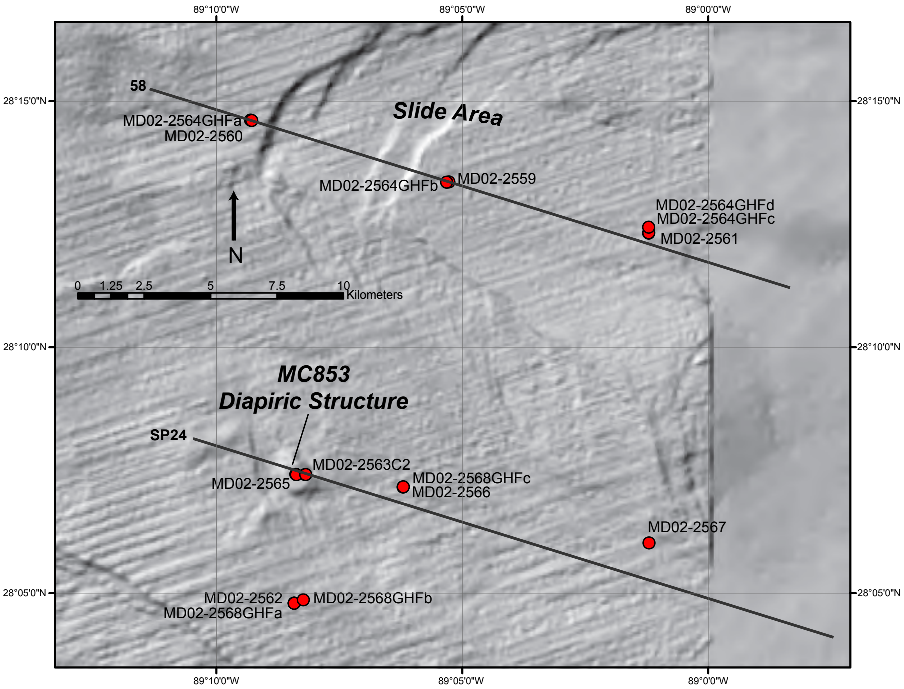

Figure 5. Detailed map of the east side of Mississippi Canyon coring area showing the core sites relative to the sea-floor slide, Kane Spur, and the MC853 diapiric structure.

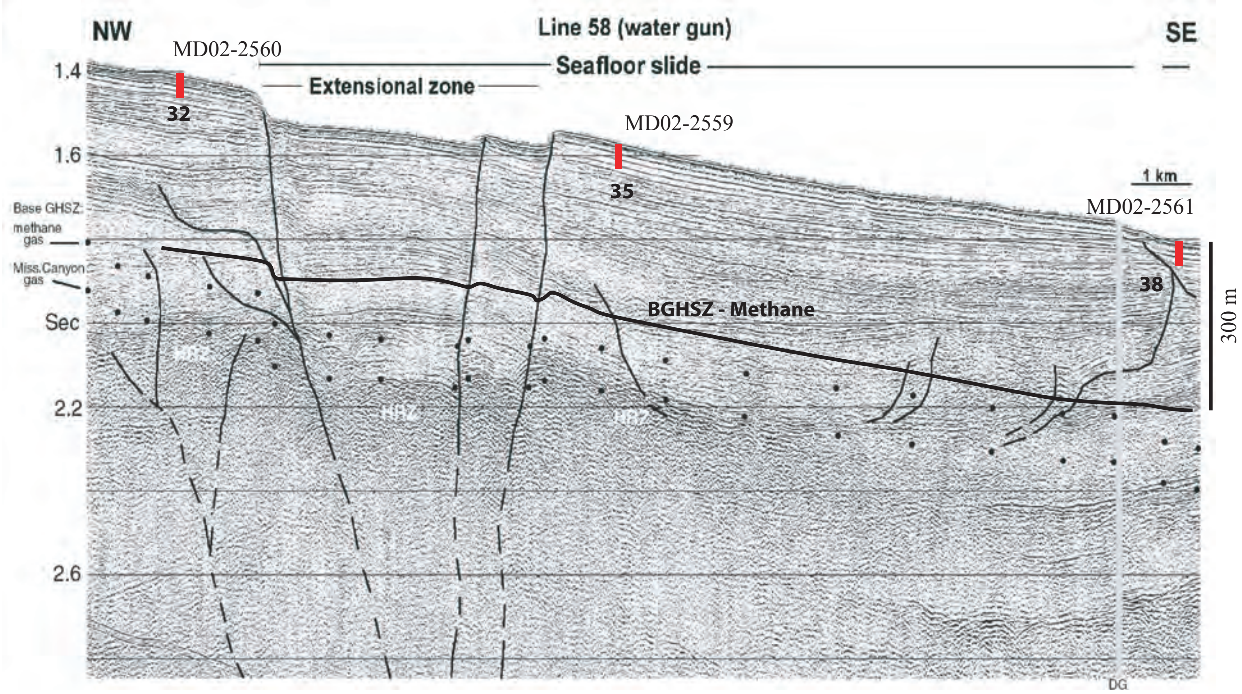

Figure 6. Watergun 2–D seismic line 58 from east of the Mississippi Canyon modified from Cooper and Hart (2003). Red lines denote the location and penetration of recovered cores. Interpreted faults are indicated as solid and dashed lines; dotted lines indicate theoretical base of gas hydrate as given by Cooper and Hart (2003). Measured geothermal gradients (degrees Celsius per kilometer) are given next to core sites. The line labeled BGHSZ is the calculated theoretical base of gas hydrate for structure I methane hydrate based on the measured geothermal gradient. The lack of any significant methane concentrations measured in pore water or sediment by Ussler and others, this volume, chapter 8; and Lorenson and others, this volume, chapter 9, make it unlikely gas hydrate exists near these locations.

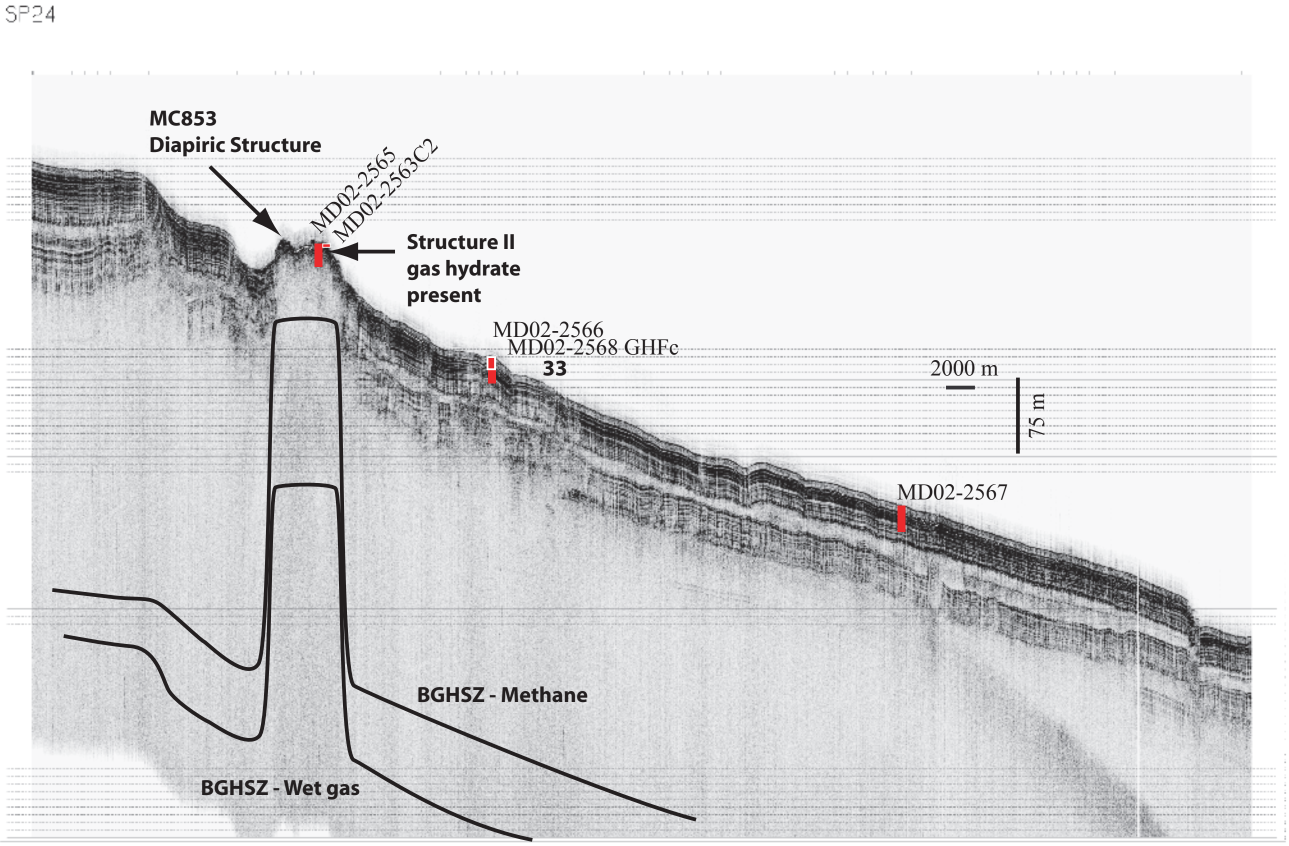

Figure 7. Chirp seismic line SP24 recorded during the cruise showing core locations east of the Mississippi Canyon, the position and penetration of selected cores, and the calculated base of the gas hydrate stability zone for methane and Mississippi Canyon wet gas compositions. Calculations are based on measured geothermal gradients (degrees Celsius per kilometer) shown, the bottom water temperature recorded at the time of coring, and the salinity of pore water both measured and extrapolated to depth.

Two additional sites were cored to the south primarily for researchers at Pennsylvania State University for studies of over-pressured shallow-water flows and sediment physical properties. These sites were subsequently drilled as part of the Integrated Ocean Drilling Program Leg 309 expedition in June 2005.

West Side of Mississippi Canyon

High-resolution seismic-reflection data were recorded in 1998 (Hart and others, 2002; Cooper and Hart, 2003) over a strongly deformed area on the west side of the canyon where shallow structures and sea floor deformation are common and gas hydrate is known from sea-floor cores. Here, irregular and diffuse HRZs lie within the upper 0.6-second (s) subbottom above diapiric structures, along fault zones, laterally within layered and chaotic stratal units bounded by faults, and adjacent to acoustic “wipeout” zones. Gas hydrate was cored from the westernmost diapir (Sassen and others, 1994). In other areas of the Gulf of Mexico’s upper continental slope where acoustic wipeout zones and diffuse HRZs are seen, massive deformation, flow units, gas hydrate, and diagenetic carbonates are found within the near-sea-floor sediments (Roberts, 2001).

A detailed seismic survey, including ocean bottom seismometers, was conducted during the 1999 USGS cruise across a small semi-circular basin where Neurauter and Bryant (1990) cored gas hydrate from a sea-floor mound that directly overlies a shallow HRZ (Cooper and others, 1998). Their high-resolution profiles across this area illustrated that many near-vertical faults extend to the sea floor and delineate different reflection packages of both enhanced reflectivity and diminished reflectivity zones. In the higher-resolution Huntec boomer data, the upper 90-ms subbottom is characterized by acoustic “chimney” features with diffractions and abrupt reflectivity changes that cut through the layered stratigraphy, which may denote local accumulations of gas (and gas hydrate) (for example, Anderson and Bryant, 1990). Directly below (that is, between 90- to 200- ms subbottom), the boomer data indicate few reflections in an apparent wipeout zone directly above the HRZ. Strata here may be deformed or contain gas (and gas hydrate), as suggested for wipeout zones in other parts of the Gulf of Mexico (for example, Roberts and others, 1999).

On the western Mississippi Canyon, we cored two gas-rich sites previously identified by gas chimneys (MD02-2570 and 2571C2) (fig. 8). Important objectives were to determine if gas hydrate was present within and above gas chimneys and to determine the microbial communities around the sulfate methane interface. One additional site (MD02-2569) known to be a gas hydrate mound was cored in the thalweg of Mississippi Canyon (MC802) resulting in the best hydrate recovery of the cruise.

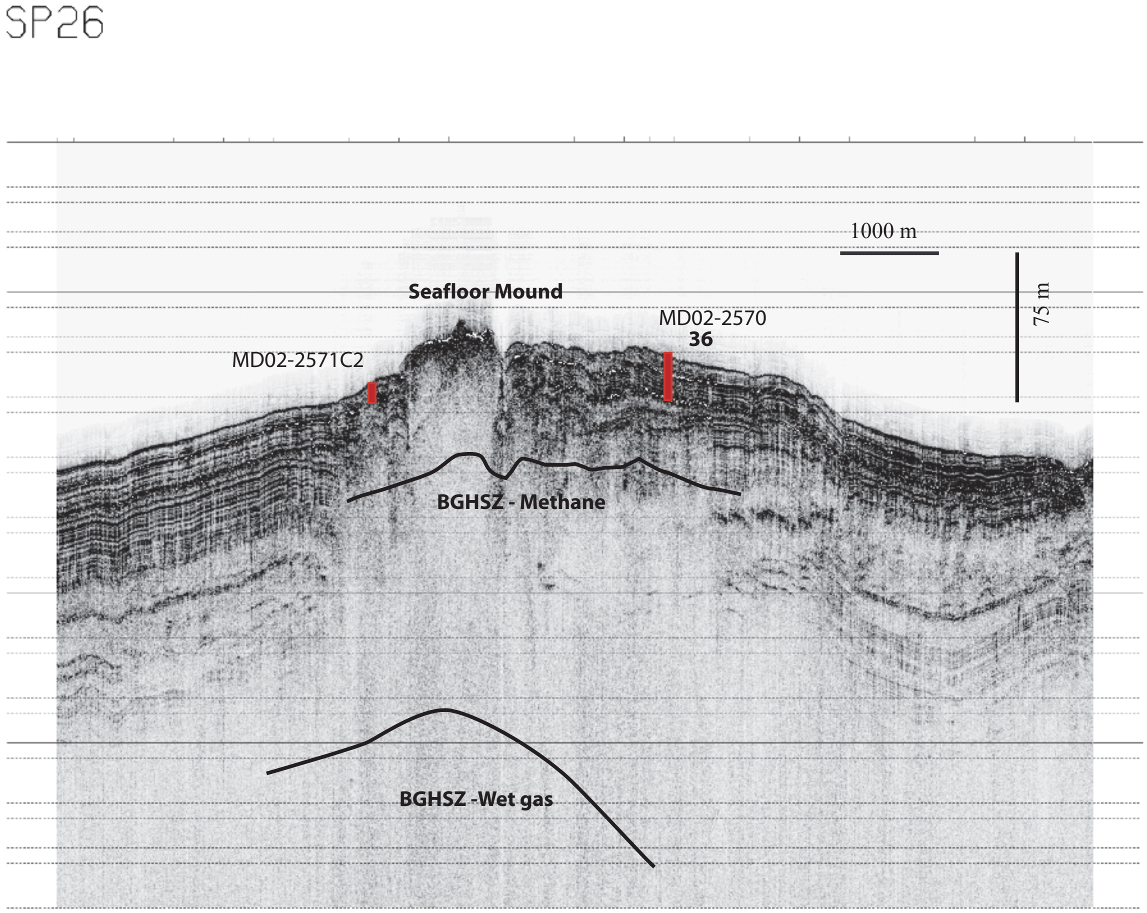

Figure 8. Chirp seismic line recorded during the cruise showing core locations MD02-2570 and MD02-2571C2 located west of the Mississippi Canyon. The line bisects a semicircular ridge of about 3 kilometer diameter that is dotted with mounds such as this one. Approximate depth of core penetration is indicated. Core MD02-2571C2 penetrated about 10 meters of gas-charged sediments on the flank of a sea-floor mound. Core MD02-2570 penetrated laminated sediments, also gas-charged, starting at depths below about 5 meters. Also indicated are the calculated base of the gas hydrate stability zone for methane and Mississippi Canyon wet gas compositions. Calculations are based on measured geothermal gradients (degrees Celsius per kilometer) shown, the bottom water temperature recorded at the time of coring, and the salinity of pore water both measured and extrapolated to depth.

Site Characterization: Green Canyon Region

The Green Canyon region, like the Mississippi Canyon region, is also known for locally high sedimentation rates of 7 to 11 m/k.y. for the upper sedimentary section, extensive late Neogene salt deformation, and slope failures with mass-wasting along oversteepened parts of the continental slope (Rowan and Weimer, 1998). Sediment ages in the upper 600 to 700 mbsf are likely no older than 0.5 million years (m.y.) in the study area (Berryhill and others, 1987; Weimer and others, 1998). This region includes the Tunica Mound and Bush Hill coring sites.

The upper sedimentary section of the continental slope in the Green Canyon region is characterized by layered and chaotic units that are faulted near basin edges, and by slope failures on basin flanks. Deformation is greater near salt structures and on oversteepened slopes. The HRZs are common and may be broad and diffuse with associated wipeout regions, especially where salt deformation is greatest beneath the uppermost slope (Cooper and Hart, 2003). Elsewhere in the northern Gulf of Mexico, on a local scale (for example, near fault scarps and sea-floor mounds) such wipeout zones are documented as sites of gas expulsion, gas hydrate, authigenic carbonates, and(or) chemosynthetic communities (Sager and others, 1999; Roberts, 2001).

Tunica Mound

Downslope from the diffuse HRZ under the shelf edge, well-layered reflections at 150- to 300-ms subbottom have many vertical acoustic “chimney” features (that is, small faults) and are encased by chaotic units directly below and above. The underlying chaotic unit has HRZs that are dispersed within chaotic stratal units and similar to those in other slope basins at about the same depth. “Chimney” features extend up from this chaotic unit to the overlying chaotic unit, which has low seismic amplitudes and evidence of faulting and sliding.

A transect of nine gravity and piston cores was taken along the southern flank of Tunica Mound verging toward but not entering the basin to the east (fig. 9). Tunica Mound is about 14 km square with a fault running through the southwest to northeast corners. The northwest side of the mound is uplifted in contrast to the southeast corner. The transect runs for about 7 km at a subparallel angle to the fault in the southeast quadrant. Water depths along the transect range from about 600 m to 630 m. Figure 10 shows the chirp seismic section, SP2, annotated with core locations, geothermal gradients, and the base of the gas hydrate stability zone for methane and Bush Hill gas compositions. All sites on the transect remain within the confines of the dome; however, the site to the northeast appears to enter the basin between Tunica Mound and Caddo Mound to the east. Most of the gravity cores were taken on or near a subsidiary mound with features that indicate active fluid flow, for example, authigenic carbonate, sea-floor relief, and seismic indications of gas. Piston cores were obtained from the sub-mound. As seen in figure 10, the BGHSZ does not necessarily follow the contours of the sea floor; instead, it can be quite variable. This is the consequence mainly of large changes of the geothermal gradient over short distances and the shoaling effects of increased salinity in pore water that drastically decreases the depth of the gas hydrate stability zone.

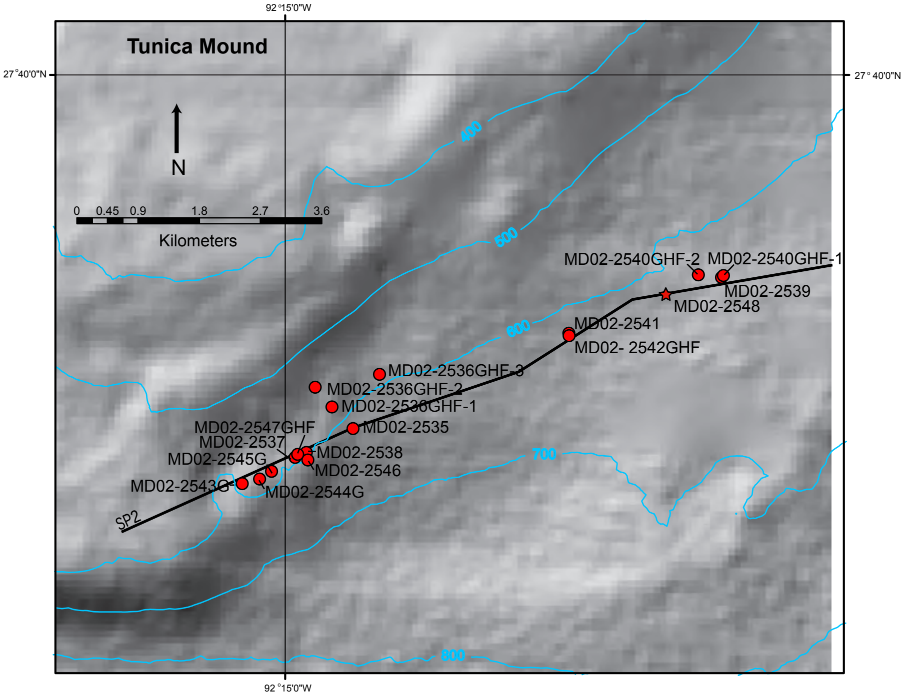

Figure 9. Coring locations in and around Tunica Mound. Gray line denotes the seismic lines shown in figure 10. IMAGES core MD02-2548 is shown for reference.

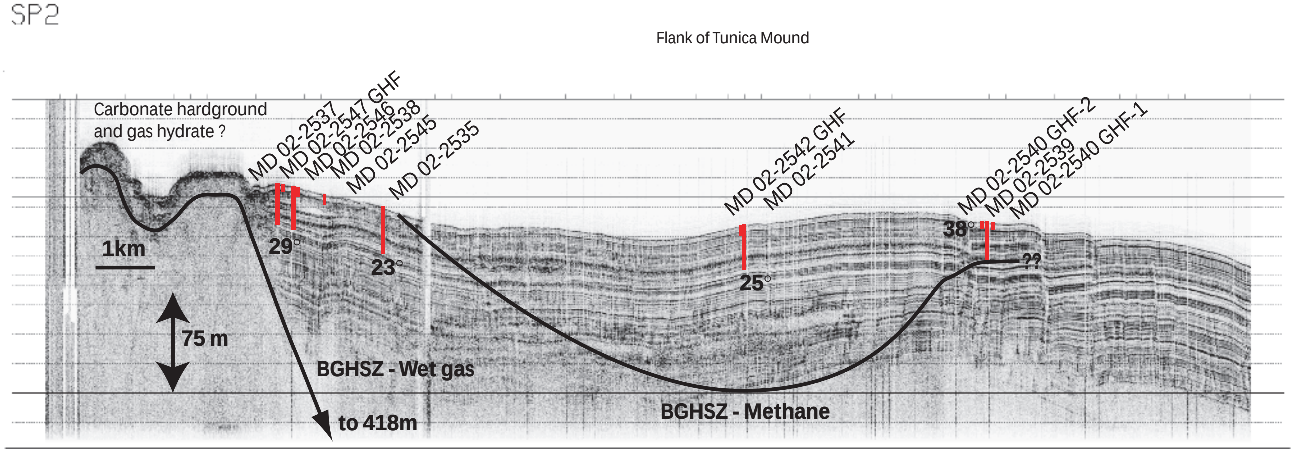

Figure 10. Chirp seismic line SP2 recorded during the cruise showing core locations, the penetration of selected cores, and the calculated base of the gas hydrate stability zone for methane and Bush Hill wet gas compositions. Calculations are based on measured geothermal gradients (degrees Celsius per kilometer) shown, the bottom water temperature recorded at the time of coring, and the salinity of pore water both measured and extrapolated to depth.

Bush Hill Mound and Adjacent Basin

The Bush Hill Mound, interpreted as a sea-floor-piercing mud diapir (Neurauter and Bryant, 1990), is located along the boundary between GC blocks 184 and 185, and is a fault-related seep mound at a water depth of ~540 m. Subbottom profiles of 3.5 kilohertz across the Bush Hill Mound indicate that the structure is acoustically amorphous with abrupt lateral contacts and is surrounded by upturned stratified reflectors (Neurauter and Bryant, 1990; Lee, 1995). Well-defined vertically oriented acoustic wipeout zones are recorded both at shallow acoustic profiles (Lee, 1995) and deep 3–D seismic profiles (Roberts, 2001). Acoustic profiles suggest the occurrence of hard substrate below the sea floor commonly associated with carbonates (Roberts and Carney, 1997) and gas hydrate (Sager and others, 1999). Deep seismic profiles (Roberts, 2001) suggest that reflections are disturbed below Bush Hill, which suggests the presence of a mud diapir or gas-charged sediments to a depth of at least 700 m.

An antithetic fault related to a major growth fault (Neurauter and Bryant, 1990; Cook and D'Onfro, 1991) at Bush Hill is structurally related to nearby growth faults that constitute the structural trap at Jolliet Field just a few kilometers to the south (Cook and D'Onfro, 1991). These faults are active conduits for vertically migrating hydrocarbons. There appears to be a larger area of numerous, shallow faults serving as migration conduits for fluids that surround the Bush Hill mound area (Neurauter and Bryant, 1990). The oil and gas at the Bush Hill site correlate with reservoirs of Pliocene to Pleistocene age at ~2 to 3 km depth in the Jolliet Field (for example, Kennicutt and others, 1988; Cook and D'Onfro, 1991; Sassen, Losh, and others, 2001).

The Bush Hill area is a complex location where thermogenic gas hydrate was first recovered by piston cores in the Gulf of Mexico (Brooks and others, 1984; Brooks and others, 1986). Previous research focused on vent gas, gas hydrate, and chemosynthetic communities (MacDonald and others, 1989, 1994, 1996; Roberts and Carney, 1997; Roberts, 2001; Sassen and others, 1993, 1998; Sassen, Joye, and others, 1999; Sassen, Sweet, and others, 1999; Sassen, Losh, and others, 2001; Sassen, Sweet, Milkov, and others, 2001a, b).

Chemosynthetic organisms and authigenic carbonate rocks are widely distributed across the area at water depths of 250 to 880 m (Kennicutt and others, 1985; Roberts, and others, 1990). Only thermogenic structure II and H gas hydrates containing methane through pentane hydrocarbon gases have been found in the area (Sassen and MacDonald, 1994). Mounds of structure II gas hydrate outcrop on the sea floor and have been persistently observed since 1991 (Sassen and others, 2004). Gas hydrate occurs as sea-floor mounds (1–2 m across) and at shallow depth in sediments (MacDonald and others, 1994), mainly around Bush Hill. Gas hydrate gas and vent gas collected at the Bush Hill site have molecular and isotopic properties that correlate with hydrocarbon gases from reservoirs of Jolliet Field (Sassen, Sweet, Milkov, and others, 2001a).

Sparse data of gas hydrate concentration in the sediment at Bush Hill indicate that 5 to 20 percent by volume of gas hydrate may be present in the upper 6 m of sediments. Gas hydrate mounds (90-percent gas hydrate by volume) crop out at the sea floor. Gas hydrate concentration in sediments below 6 m is largely unknown. Models based on molecular composition of Jolliet reservoir gas, vent gas, and hydrate-bound gas suggest that gas hydrate concentration remains constant throughout the upper part of the GHSZ and decreases at the base of the GHSZ (Chen and Cathles, 2003).

Previously recovered piston cores taken on the Bush Hill mound contain oil-saturated silty mud with small (1 to

2 millimeters (mm)) deposits of yellowish hydrate up to large 40- to 50-mm diameter nodules of hydrate (Brooks and others, 1986; Neurauter and Bryant, 1990). Gas is abundant in cores recovered from Bush Hill (Lee, 1995), as well as in the water column just above the mound (Sassen, Losh, and others, 2001). Shallow sediment is under-consolidated hemipelagic mud with near-normal salinity (~38 parts per thousand (ppt)), high concentration of hydrogen sulfide (as much as 20.3 millimoles [mM]), and high pH (8.3–9.0) (Aharon and Fu, 2000). Sassen, Losh, and others (2001) report that piston cores collected in the area of reflections contain expansion cracks and a strong hydrogen sulfide smell, both evidence of abundant gas in the sediments.

Coring commenced in the small basin just east of Bush Hill (fig. 11) along an east-west transect with three cores spaced about 2 km apart. The primary objectives of the transect were to investigate the occurrence, if any, of thermogenic gases and surficial gas hydrate along a track into the adjacent basin, and to determine if gas hydrate is likely to exist at depth in the basin. Figure 12 shows the chirp seismic profile (SP17) annotated with core locations, geothermal gradients, and the calculated BGHSZ. The BGHSZ methane remains deep within the basin and shoals abruptly near Bush Hill, reflecting the increased geothermal gradient near the mound. The lack of any recovered gas hydrate in cores suggests that the structure II and H gas hydrates reported on Bush Hill are not widespread in the adjacent basin. However, the presence of methane in the shallow sediments of the adjacent basin suggest that gas hydrate could be present in small concentrations at depths greater than 10 to 20 mbsf.

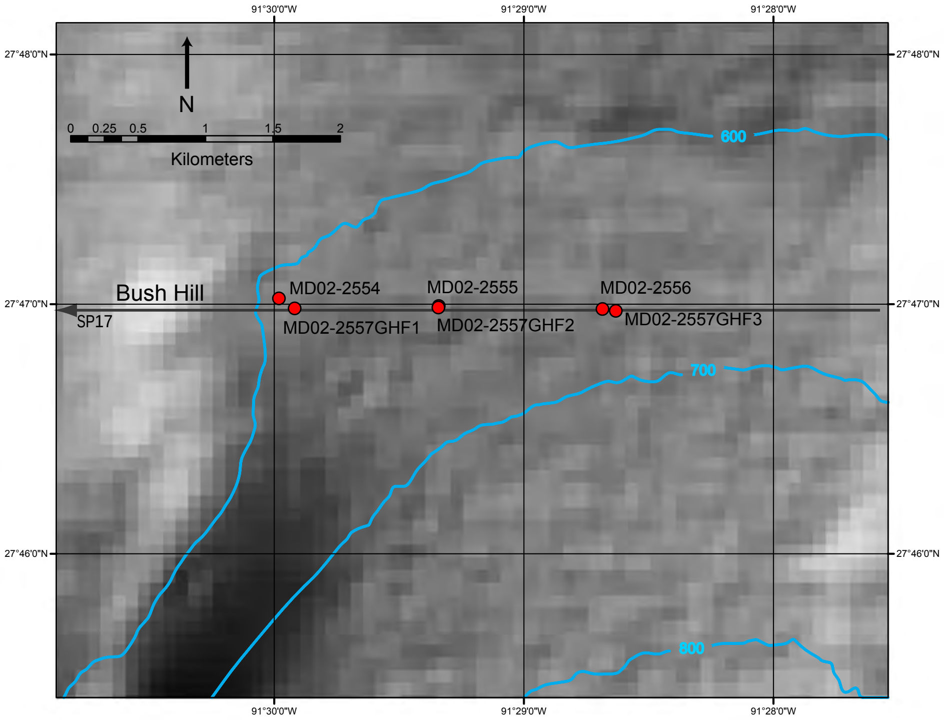

Figure 11. Coring locations east of Bush Hill (GC185). Dark gray line denotes the seismic line shown in figure 12.

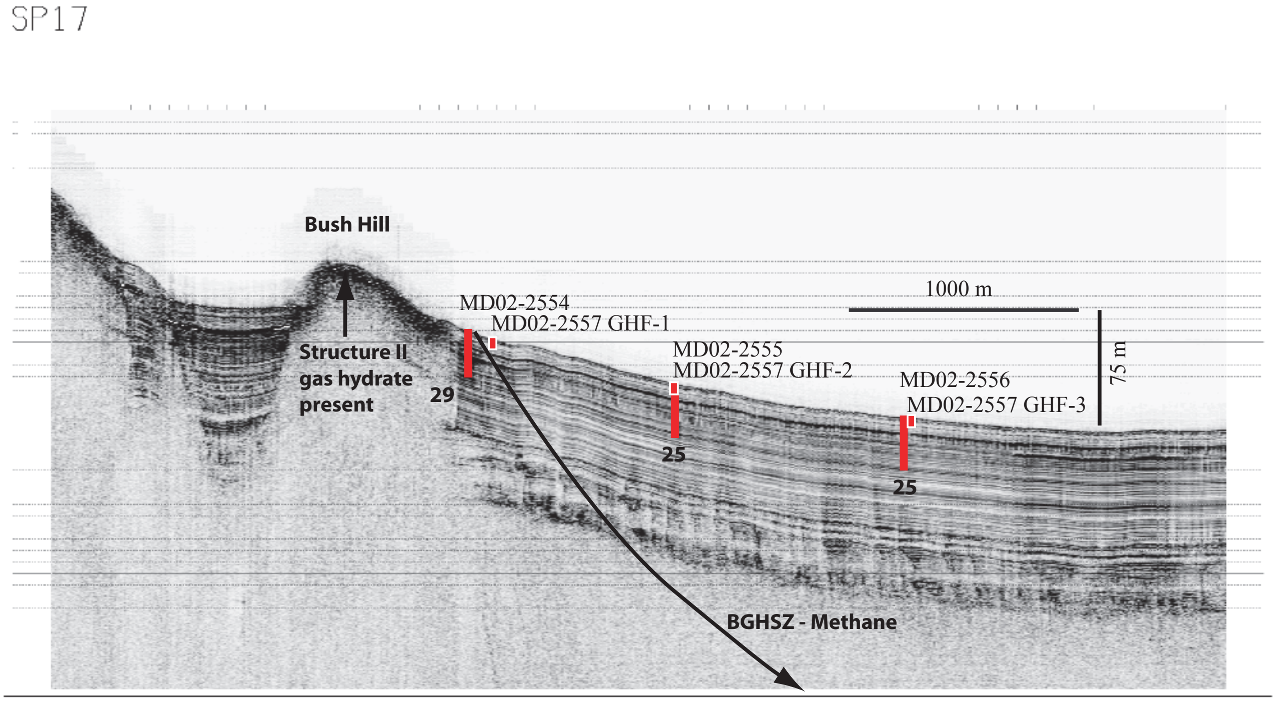

Figure 12. Chirp seismic line SP17 recorded during the cruise showing core locations, the penetration of selected cores, and the calculated base of the gas hydrate stability zone for methane and Bush Hill wet gas compositions. Calculations are based on measured geothermal gradients (degrees Celsius per kilometer) shown, the bottom water temperature recorded at the time of coring, and the salinity of pore water both measured and extrapolated to depth.

Site Characterization—Pigmy and Orca Basins

Coring in Pigmy and Orca basins was conducted for paleoceanographic research studies (fig. 13). The basins presumably have similar depositional histories. However, Orca basin has been submerged by a seawater brine for an unknown time, which has resulted in an anoxic environment and organic preservation. In contrast, Pigmy basin has been subject to oxic conditions. USGS researchers at St. Petersburg, Florida, obtained samples to study the pollution history of the Mississippi River as revealed by sediments in the two basins having contrasting redox potentials.

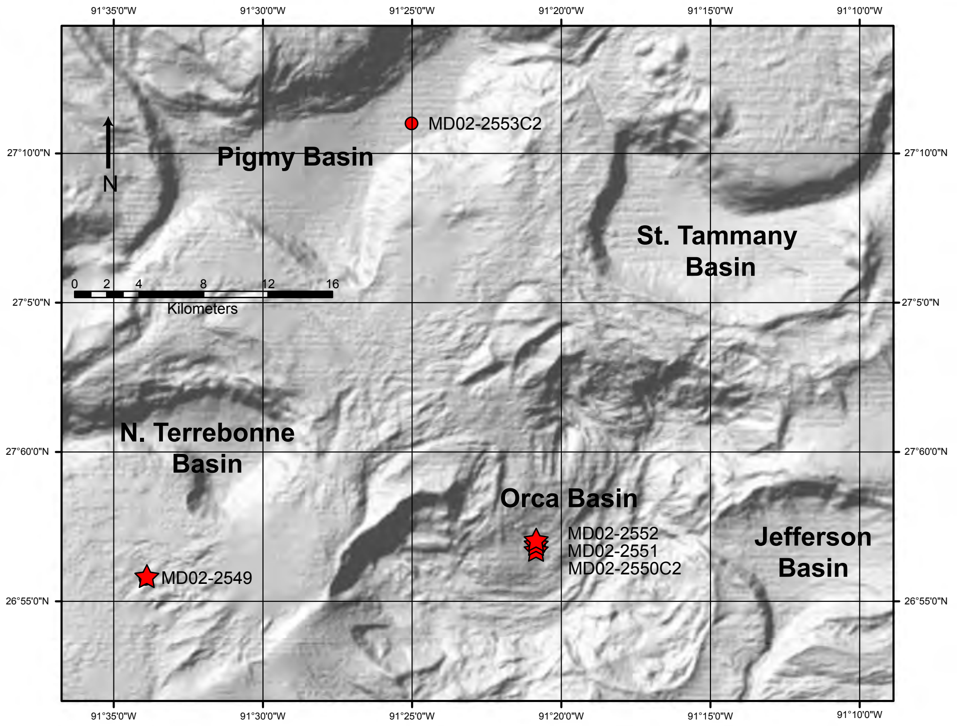

Figure 13. Coring locations in Pygmy and Orca basins. IMAGES core MD02-2549 is shown for reference.

Summary

Piston coring during the RV *Marion Dufresne* cruise was designed primarily to look at a series of three transects extending from known gas hydrate mounds in regions where high reflectivity zones have been identified. We found that the lateral extent of gas hydrate between near-surface hydrate deposits and in adjacent basins was limited. Surficial gas hydrates found on sea-floor mound tops did not extend into the adjoining basins. We were not able to confirm or deny that any significant gas hydrate deposits occur in reservoir sediments at depth in these basins. A lack of methane (and gas hydrate) in sediments in and around the Kane spur slide suggest that gas hydrate dissociation had little or no effect on known submarine slides near the Mississippi Canyon where deep offshore platforms might be at risk.

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