Combining Multicomponent Seismic Attributes, New Rock Physics Models, and In Situ Data to Estimate Gas-Hydrate Concentrations in Deep-Water, Near-Seafloor Strata of the Gulf of Mexico

Phase 1 Report: Research Database

Principal Investigators: Bob A. Hardage
Paul E. Murray
Diana C. Sava

Report Date: May 2006

DOE Award DE-PS26-05NT42405

Submitting Organization: Bureau of Economic Geology
The University of Texas at Austin
University Station, Box X
Austin, TX 78713-8924

Disclaimer

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Abstract

A research project has been initiated to determine whether concentrations of deep-water gas hydrate can be predicted using 4C OBC seismic data. This research requires the development of (1) rock physics models that describe how hydrates embedded in unconsolidated, high-porosity sediments in a low-effective-pressure environment affect seismic P-wave and S-wave velocities, and (2) seismic data-processing concepts that create optimal P-wave and S-wave images of near-seafloor geology. The success of this study requires the construction of a database that allows multicomponent seismic attributes to be correlated with sediment, hydrate, and pore-fluid properties of near-seafloor sediments. This report describes that database.

Table of Contents

Disclaimer 2
Abstract 3
Introduction 5
Executive Summary 5
Experimental 5
Results and Discussion 6
    Database Contribution 1: Seafloor Borings 7
        Porosity Profiles 7
            Porosity from Water-Content Data 7
            Porosity from Measurements of Submerged Unit Weight 8
        Shear Modulus 9
        Vertical Effective Pressure 10
    Database Contribution 2: AUV Data 11
    Database Contribution 3: Well Log Data 11
    Database Contribution 4: 4C OBC Seismic Data 13
Conclusions 14
References 14
Acronyms and Abbreviations 15
Appendix A: Research Data 28

List of Figures

1. Map of 4C OBC seismic coverage 16
2. Study Site 1 17
3. Study Site 2 18
4. Water-content and porosity data 19
5. Submerged unit weight and porosity 20
6. Shear-strength profiles 21
7. Vertical effective pressure profiles 22
8. AUV technology 23
9. AUV chirp-sonar data 24
10. Typical well log data 25
11. Predicted thicknesses of hydrate stability layers 26
12. Common-receiver gather of 4C OBC seismic data 27
A1. Map of well log control 29

Introduction

Constructing a research database to describe deep-water, near-seafloor strata is challenging because conventional cores and complete well log suites are not acquired by oil and gas companies over the first several hundred meters of stratigraphic section immediately below the mud line of deep-water wells. Fortunately, limited well log information starting as shallow as the base of surface casing has been acquired in many Gulf of Mexico (GOM) wells since operators began using measurement-while-drilling (MWD) logging technology in the early 1990's. Between the base of surface casing (typically about 80 meters below mud line) and the base of the hydrate stability zone, these MWD log data tend to consist of only resistivity and gamma-ray curves. Thus for deep-water gas hydrate research, a database has to be built that allows data other than sonic, porosity-sensitive, and mineralogy-sensitive well logs to be utilized. This report describes how

- seafloor borings used for geotechnical studies, and
- Autonomous Underwater Vehicle (AUV) technology

complement conventional well log data and 4C OBC seismic data and provide critical information needed to correlate sediment/hydrate properties with multicomponent seismic attributes.

Executive Summary

Two sites in the Green Canyon area of the Gulf of Mexico have been selected for studying deep-water gas-hydrate systems. These sites were introduced as **Area 1** and **Area 2** in the preceding Phase 1 report that assessed hydrate evidence across a broad area of Green Canyon (Hardage and others, 2006). One factor that caused these particular study sites to be chosen is that, in addition to compelling evidence of the presence of hydrates, there is a concentration of appropriate research data at each location. This report describes and illustrates key elements of the research database amassed at each study site: (1) samples from seafloor borings and their associated geotechnical laboratory tests, (2) AUV profiles, (3) conventional well logs, and (4) 4-component ocean-bottom-cable (4C OBC) seismic data.

Experimental

No experimental work was done in preparing this report.

Results and Discussion

A map view of the broad area covered by the grid of 4C OBC seismic data available for this research project is displayed as an overlay on a seafloor topography map in Figure 1. Two locations within this seismic survey area have been selected for a focused research study on the basis of (1) hard evidence that a gas-hydrate system exists at each location (Hardage and others, 2006), (2) a concentration of critical calibration data at each site, and (3) an appropriate coverage of 4C OBC seismic data across each area. These two locations are labeled Study Site **1** and Study Site **2** on the map.

Expanded views of each study site are shown as Figures 2 and 3 to define the distribution of hydrate evidence and the locations of various elements of the research database across each area. Key data shown on these maps that will be important for calibrating multicomponent seismic attributes to estimates of hydrate concentration are:

1. Seafloor borings. Geomechanical analyses of subseafloor samples acquired with seafloor borings provide critical information for this study. Laboratory tests of boring samples define depth profiles of mineralogy and porosity that we need for rock physics calculations, identify shear-strength layering that is needed for interpretation and depth registration of P-SV seismic data, and provide evidence of hydrate accumulations at specific depth coordinates. Seafloor borings have been done at the production facilities identified in Block GC237 (Fig. 2) and Block GC205 (Fig. 3), and the research team has acquired copies of the geotechnical reports generated from the boring samples at each location.

2. AUV profiles. Autonomous Underwater Vehicle (AUV) technology has become invaluable for studying deep-water seafloor properties. An AUV system uses inertial guidance to steer an unmanned, self-propelled vehicle along a preselected path at a height of about 50 meters above the seafloor. Navigation accuracy is precise, with deviations from a preprogrammed profile being on the order of 1 or 2 meters over a traverse of one lease block (4,800 meters [3 miles]). AUV data consist of side-scan sonar, multibeam bathymetry, and chirp-sonar profiles. Chirp-sonar data are particularly important in this study because these profiles provide high-resolution P-P images of seafloor strata to subseafloor depths of approximately 50 meters. Inspection of Figures 2 and 3 shows that 6 miles (9.6 km) of AUV data are available across Study Site 1, and 3 miles (4.8 km) of AUV profiling has been acquired across Study Site 2.

3. Well log data. Numerous exploration and production wells exist within both study areas (Figs. 2 and 3). Resistivity and gamma-ray data have been acquired across most of the hydrate stability zone in many of these wells.

The research team has obtained copies of many of these near-seafloor well logs.

4. 4C OBC seismic data. The most critical part of the research database is 4C OBC seismic data. These data exist as north-south and east-west 2D profiles spaced at intervals of 2 mi (3.2 km) across the seismic survey area defined in Figure 1. Inspection of Figure 2 shows that 27 miles (43 km) of 4C OBC data are inside Study Site 1, with an additional 36 miles (58 km) immediately surrounding the study boundary. Figure 3 shows that ~60 miles (96 km) of 4C OBC data span Study Site 2.

The remainder of this report will discuss these database items in the sequential order in which they have just been presented.

Database Contribution 1: Seafloor Borings

Copies of geotechnical reports have been obtained that summarize analyses of seafloor borings across Chevron’s Typhoon Field (Block GC237, Study Site 1) and Genesis Field (Block GC205, Study Site 2). Laboratory testing of subseafloor sediment samples acquired at each location was done by Fugro. The objectives of Fugro’s tests were to determine sediment properties needed to design pile foundations for production platforms, not to characterize subseafloor stratigraphy or to define properties of the seismic propagation medium. However, some geotechnical test data can be reformatted to define rock properties needed for this research investigation and to gain insights into subseafloor layering that will help calibrate P-P and P-SV images.

Porosity Profiles

To do rock physics modeling that will allow hydrate concentration to be estimated from seismic velocity attributes, it is necessary to know how the matrix porosity of the host sediment for varies with depth below the seafloor. Direct measurements of matrix porosity have not been found in any geotechnical reports examined to date. However, porosity information across the interval penetrated by seafloor borings can be determined from two common geotechnical measurements that are done to describe the load-bearing capability of seafloor sediments. These two measurements are (1) water content of the sediment, and (2) submerged unit weight of the sediment.

Porosity from Water-Content Data

In geotechnical reports that oil companies generate to improve their understanding of deep-water seafloor properties, water content of cored sediment is often measured to aid the engineering design of pile foundations that secure production platforms. Depth-dependent porosity functions that are needed for the rock physics calculations that have to be done in our hydrate study can be calculated from these water-content data. Water content **W** determined in laboratory geotechnical testing is defined as

$$(1) \quad W = \frac{\text{Mass of water in unit volume of sediment}}{\text{Mass of solid matrix in unit volume of sediment}},$$

or

$$(2) \quad W = \frac{\rho_w \Phi S_w}{\rho_g (1-\Phi)}.$$

In this expression, Φ is porosity, S_W is water saturation, ρ_W is water density, and ρ_g is grain density. Sediment porosity is then related to **W** by the equation

$$(3) \quad \Phi = \frac{\rho_g W}{\rho_w S_w + \rho_g W}.$$

An example of a water-content profile determined by laboratory analysis of seafloor borings acquired in Block GC237, Study Site 1, is shown in Figure 4a. Using Equation 3, this water-content profile is transformed to the porosity profile shown in Figure 4b. In this application of Equation 3, parameters ρ_W, S_W, and ρ_g were set to 1.025 gm/cm^3, 100%, and 2.55 gm/cm^3, respectively. This porosity profile is critical for defining a depth-dependent porosity function to use in our rock physics calculations of V_P and V_S across the shallowest part of the subseafloor hydrate system at Study Site 1.

Porosity from Measurements of Submerged Unit Weight

A second measurement made in most geotechnical studies of deep-water sediment properties is submerged unit weight (SUW). This term is defined as

$$(4) \quad SUW = \delta_{sat} - \delta_w,$$

where δ_{sat} is the saturated unit weight of the sediment (in units of lb/ ft^3), and δ_w is the unit weight of the pore fluid (in units of lb/ft^3). This equation can be rewritten as

$$(5) \quad SUW = 62.4\{[\rho_g(1-\Phi) + \rho_w\Phi] - \rho_w\}.$$

In this form, Φ is porosity, ρ_g is grain density (in units of gm/cm^3), ρ_w is pore-fluid density (in units of gm/cm^3), and the constant 62.4 converts lb/ft^3 to gm/cm^3. This equation now allows laboratory measurements of SUW to be translated into measurements of matrix porosity.

An example of a submerged-unit-weight measurement is shown as Figure 5a. These SUW data are converted to porosity data in Figure 5b, using values of 2.55 gm/cm^3 and 1.025 gm/cm^3, respectively, for the quantities ρ_g and ρ_w in Equation 5. This depth-dependent porosity function will be invaluable for defining porosity conditions to use in rock physics modeling across the shallowest seafloor strata of Study Site 2, just as the function in Figure 4b will be used to define depth-dependent porosity across Study Site 1.

The importance of these porosity-defining functions (Figs. 4b, 5b) cannot be overstated. They are essential to our research because:

1. They define porosity across hydrate-bearing intervals where no well log data exist. MWD well logs do not begin until the bit drills out of surface casing that is set to depths of approximately 80 meters below the mudline, and
2. They describe the dynamic behavior of porosity across the subseafloor interval where porosity reduces from ~80 percent to ~45 percent. We must know this depth-dependent dynamics of sediment porosity in order to apply proper petrophysical constraints in our rock physics modeling.

Shear Modulus

The principal objective of seafloor borings is to determine geomechanical properties of the seafloor where deep-water production platforms will be constructed. Shear strength of deep-water sediment is perhaps the most critical elastic modulus that has to be known before platform design can be finalized. Knowledge of shear moduli is also critical in this gas-hydrate research because interval values of shear modulus provide constraints and calibration points for seismic-derived interval values of S-wave velocity V_S. Examples of shear-strength analyses of seafloor strata in Block GC237 (Study Site 1) and in Block GC205 (Study Site 2) are displayed as Figure 6.

These shear-strength profiles are excellent examples of the importance of seafloor borings to this research. Not only do the cored samples allow a depth profile of shear strength to be constructed for calibrating P-SV seismic images that we will construct from 4C OBC seismic data, but they also provide the following critical information about subseafloor geology:

1. Lithology profile. In this study, it is essential to know the mineralogy of deep-water sediment across a targeted subsea depth interval in order to use correct grain density and elastic moduli values in the rock physics calculations of P and S velocity attributes for that interval. In both cored intervals shown in Figure 6, the mineralogy is clay. Thus we have a valuable lithofacies calibration constraint for the topmost section of the gas-hydrate system underlying both Study Site 1 and Study Site 2.

2. Hydrate evidence. Cores from seafloor borings are not maintained at in situ temperature and pressure conditions as they are transferred to ship and onshore laboratories or as they are analyzed in various laboratory tests. Thus hydrate in sediment samples obtained from seafloor borings dissociates as the samples are retrieved and tested. It is rare to find hydrate in cores retrieved from seafloor borings that are done strictly for geotechnical purposes. Instead, evidence of hydrate is documented by the presence of expanded, vented sections of core that are created by escaping dissociated hydrate gases. Six of these expanded-sample intervals were observed in the core from Block 237 (arrows in Fig. 6a). Collectively, these gas blisters span the subseafloor depth interval from 110 feet (33 meters) to the base of the cored interval at 420 feet (128 meters), verifying that Study Site 1 spans a gas-hydrate system. The geotechnical report prepared by Fugro for Chevron' s Genesis Field platform in Block GC205 indicated that gas blisters were observed in core samples from 246 to 300 feet (75 to 91 meters) below the seafloor (black bar in Fig. 6b). The report also cited a DOE-funded study (Brooks and Bryant, 1985) in which those researchers observed hydrate chips up to 3 centimeters in diameter over an interval extending from 1 to 4 meters below the seafloor in an earlier study of this lease block. This direct evidence of gas hydrate in Block GC205, Study Site 2, is documented by the label **GH** positioned near the seafloor in Figure 6b.

3. Stratigraphic layering. Significant variations in the gradient trends of depth profiles of core-measured shear strength imply stratigraphic layering that should be observed with S-wave seismic data. These shear-strength layers may or may not be observed with P-wave seismic data or in depth profiles of bulk moduli. We interpreted and labeled six intervals across the cored interval of Block GC237 (Fig. 6a). This stratigraphic layering interpretation will be useful as calibration data for depth registering P-SV images across Study Site 1. Five different laboratory techniques, each shown by a different data-point symbol in Figure 6b, were used to determine shear-strength behavior across Block GC205. The use of different laboratory procedures contributed to the data scatter exhibited in the plot, but Fugro engineers nevertheless drew an average trend line and interpreted four shear-strength layers that they labeled as Unit I through Unit IV in the figure. Tentatively, we accept their stratigraphic interpretation for Study Site 2 and further consider subdividing Unit IV into three sublayers, that we have labeled Unit IV-A through IV-C in Figure 6b.

Vertical Effective Pressure

Additional core analyses done during geotechnical studies in Blocks GC237 and GC205 were laboratory tests that indicated the magnitudes of overburden pressure experienced by cored samples. Among our research team, we use the term *effective pressure* for this pressure quantity. Knowledge of depth profiles of effective pressure is essential for accurate rock physics modeling. Geotechnical engineers refer to data generated by these measurements as *effective vertical pressures*. Vertical effective pressure data generated at Study Sites 1 and 2 are shown in Figure 7. The implication of these data is that a zone of underconsolidation begins about 125 feet (38 m) below the seafloor at both study sites. This depth coincides with the tops of Layer 4 and Unit IV, respectively, that are defined on the shear-strength profiles at Study Sites 1 and 2 (Fig. 6a, b). The evidence of underconsolidation is rather definite at Study Site 2 (Fig. 7b) but is more tenuous at Study Site 1 (Fig. 7a). This evidence of undercompaction will be an important control on depth-dependent porosity and effective-pressure functions used in rock physics calculations across both study areas. It is also important to note that the first appearance of dissociated hydrate gas in the borings taken in Block GC237 (Fig. 6a) coincides with the onset of this undercompaction.

Database Contribution 2: AUV Data

The principle of deep-water AUV profiling is illustrated in Figure 8. The underwater vehicle is unmanned and self-propelled, not towed by surface ship. An AUV system travels close to the seafloor, usually at a height of about 50 meters, and uses inertial guidance to follow a preprogrammed path with great accuracy. Navigation precision is claimed to be approximately 1 meter over a traverse of 5,000 meters. Three types of data are acquired along an AUV profile: (1) side-scan sonar, (2) multibeam bathymetry, and (3) chirp-sonar reflections. Side-scan sonar and multibeam bathymetry data image seafloor features with great detail but provide no subseafloor information. Chirp-sonar profiling images subseafloor strata with chirp pulses having frequency spectra of 2 to 8 kHz. These high-frequency signals image only 50 to 60 meters (approximately) into subseafloor strata, but these images resolve bedding as thin as 1 meter and show faults with vertical throws as small as 1 meter. Chirp-sonar images are P-P images and have no P-SV component.

The AUV data used in this study were provided to the research team by Louisiana State University (LSU). Dr. Harry Roberts of LSU acquired two AUV profiles across Block GC237 (Fig. 2) and one profile across Block GC204 (Fig. 3) for an LSU/MMS project and kindly allowed our research project to have copies of the data. Each AUV profile was positioned to follow the track of an OBC line that will be used in this research study.

Part of a chirp-sonar profile across Block GC204, Study Site 2, is displayed in Figure 9. Profile coordinates along this line are defined as northing distances in meters. East-west AUV profiles across Block GC237 (Fig. 2) were acquired in terms of easting distances in meters. Software has to be written by the research team to transform AUV image coordinates to CDP image coordinates used in OBC seismic profiles so that AUV data and 4C OBC data can be compared in the same coordinate space.

These AUV data are of great value to our research. They provide a P-P image that resolves stratigraphic and structural features as small as 1 meter within the first 50 meters of seafloor sediment. This resolution is approximately 100 times better than the resolution of conventional P-P seismic data used in oil and gas exploration. Such high-resolution P-P data are essential for demonstrating the high-resolution character of P-SV images that we will create from 4C OBC seismic data and for calibrating P-P and P-SV data across the shallowest part of the deep-water hydrate systems that we will study.

Database Contribution 3: Well Log Data

The only well log data known to exist across the deep-water, near-seafloor strata where hydrate occurs are resistivity and gamma-ray (GR) curves. Examples of log data acquired across parts of subseafloor intervals where pressure and temperature conditions are appropriate for hydrate stability are displayed as Figure 10. The two wells where these log data were acquired are in Green Canyon Block 248, a lease block that abuts the south edge of Study Site 2. In these wells, measurement-while-drilling (MWD) data acquisition began as soon as the bit passed below the 30-inch casing. Although these log data are limited to resistivity and gamma-ray profiles, the data are important for defining the host sediment of the hydrate (clay or sand), indicating possible stratigraphic boundaries and identifying units having high concentrations of hydrate (high resistivity, low GR).

For these two wells, operators set 30-inch casing approximately 270 ft (82 m) below the mudline. Only a few operators record MWD data as they drill the surface casing hole; most do not. Thus log data of any type will rarely be available across the shallowest 260 to 280 feet (80 to 85 m) of seafloor sediment. The absence of log data in this key part of a gas hydrate system emphasizes the importance of seafloor boring data that sample these shallowest strata. In most wells, 26-inch casing is set approximately 1,000 feet (305 m) below the 30-inch casing point, which is the situation for the two logged wells in Figure 10.

The bases of two hydrate stability zones are labeled by heavy-dash, horizontal lines on the log-curve displays. The shallower zone is the stability boundary for pure methane (100% CH_4). The second zone, approximately 660 feet (200 m) deeper, is the stability limit for a gas that has 95.9% methane content. The subseafloor depth of the base of each hydrate-stability zone is a prediction calculated by Milkov and Sassen (2001). These researchers used GOM seafloor temperature data and GOM subseafloor temperature gradient data to reach conclusions about the thickness of a hydrate stability zone for various water depths. The key result of their geothermal modeling is shown in Figure 11. Hydrate-stability curves were determined for three specific gases, 100% CH_4, 95.9% CH_4, and 90.4% CH_4, on the basis of geochemical analyses of hydrate gases venting into the water column in Block GC185, the famous Bush Hill site approximately 25 mi (40 km) west of Study Site 1 that has been extensively studied by several researchers. Some researchers question the validity of this Milkov/Sassen model for great water depths (various private communications), but most gas hydrate investigators accept its predictions for water depths in the range of 500 to 1000 meters where our work will be concentrated. For the time being, the hydrate stability thicknesses predicted by Milkov and Sassen (2001) will be used as a guideline in our study.

The research team is now attempting to define and obtain all well log data that span any part of the hydrate stability zone within and near the selected study areas. A surprisingly large number of logs from approximately 50 local wells are available through the commercial Offshore Well Log (OWL) database. It appears that these OWL well logs that we have located will be sufficient for the purposes of this project. The identification and location of the control wells that we have amassed are defined in Appendix A.

One point needs to be emphasized about the locations of the well log data specified in Appendix A. The OWL database may have logs from several wells that are drilled from the same platform. For example, the five wells listed in Appendix A as being located in Block GC158 are drilled from one platform. Although the bottom-hole locations of these wells are separated by several kilometers, those parts of the wells that penetrate to the base of the hydrate stability zone are vertical. Consequently, all of the holes drilled from a single platform are laterally separated by only a few meters across the shallow, hydrate-bearing interval that we wish to study. Thus, logs from several wells drilled from one platform provide little more information about the hydrate interval than do the logs from a single well. It is somewhat misleading to state that we have logs from 50-plus wells without adding this qualification about the redundant nature of some of the log data. It is correct to say that we have a good catalog of modern resistivity and gamma-ray logs from most of the production platforms across our study area. Figure A1 of Appendix A is probably a better indication of the well log coverage of our current database than is the tabular list of wells.

The Minerals Management Service (MMS) in New Orleans also has a large number of well logs across the Green Canyon area, and some of these logs may not be in the OWL database. However, these MMS files are in disarray following the damage to the archive database room by Hurricane Katrina. Access to MMS logs is problematic. Selected oil and gas operators may be approached to determine whether they will share shallow log data that traverse the hydrate stability zone in a few key areas where our log control is sparse or inadequate.

Database Contribution 4: 4C OBC Seismic Data

This research study is structured around an analysis of 4C OBC seismic data that traverse known deep-water gas hydrate systems. The positions of the 4C OBC profiles spanning Study Sites 1 and 2 that will be used in this study are illustrated in Figures 2 and 3. An example of one common-receiver gather taken from OBC Line 549 (Fig. 3) is illustrated in Figure 12. Although the source-receiver offsets extend to 9,000 meters for all OBC lines in the area, the offsets in this example are restricted to 2,500 meters for studying near-seafloor geology. These trace gathers are segregated according to the sensor that recorded the data: (1) hydrophone (P), (2) vertical geophone (Z), (3) inline horizontal geophone (X), and (4) crossline horizontal geophone (Y).

Because the surface-based air-gun energy source travels directly above and inline with the seafloor sensors, minimal energy will appear on crossline horizontal geophone Y if the propagation medium is isotropic. If the seafloor strata are anisotropic, some S-wave energy should be observed on the Y geophone. At the particular receiver location used to make the data display of Figure 12, there is negligible energy on the Y geophone, and near-seafloor strata at this location are reasonably isotropic.

An important point about the 4C OBC data used in this study is their excellent signal-to-noise ratio. The data in Figure 12 look more like synthetic model data than actual seismic field data. This exceptional data quality is greatly encouraging at the onset of this study.

Conclusions

We have segregated the critical information needed for our deep-water gas hydrate research into four categories: (1) seafloor borings and geotechnical testing, (2) AUV high-resolution P-P data, (3) conventional well logs, and (4) 4C OBC seismic data. We have also confirmed that all of these data types exist across the two areas of Green Canyon that we have selected for this gas hydrate research. Further, all of the database items available at each site are now in our possession, save for the 4C OBC seismic data across Study Site 2, and are being integrated into a flexible database system. The missing OBC data from Study Site 2 are now being copied by WesternGeco and should be sent to us soon. From the viewpoint of the appropriateness of the database that is required to do the planned research, it is indisputable that an appropriate database has been created and that this study should proceed to Phase 2.

References

Brooks, J. M., and Bryant, W. R., 1985, Geological and geochemical implications of gas hydrates in the Gulf of Mexico: Final report, Department of Energy, Morgantown Energy Technology Center, 131 p.

Hardage, B. A., Murray, P. E., and Sava, D. C., 2006, Assessment of hydrate evidence across the study area: Phase 1 Report for DOE/NETL project DE-PS26-05NT42405, Combining multicomponent seismic attributes, new rock-physics models, and in situ data to estimate gas-hydrate concentrations in deep-water, near-seafloor strata of the Gulf of Mexico.

Milkov, A. V., and Sassen, R., 2001, Estimate of gas hydrate resource, northwestern Gulf of Mexico continental slope: Marine Geology, 179, p. 71–83.

Acronyms and Abbreviations

4C: four-component
AUV: Autonomous Underwater Vehicle
CH_4: methane
GR: gamma ray
LSU: Louisiana State University
MMS: Minerals Management Service
MWD: measurement while drilling
OBC: ocean bottom cable
OWL: Offshore Well Logs (a commercial database)

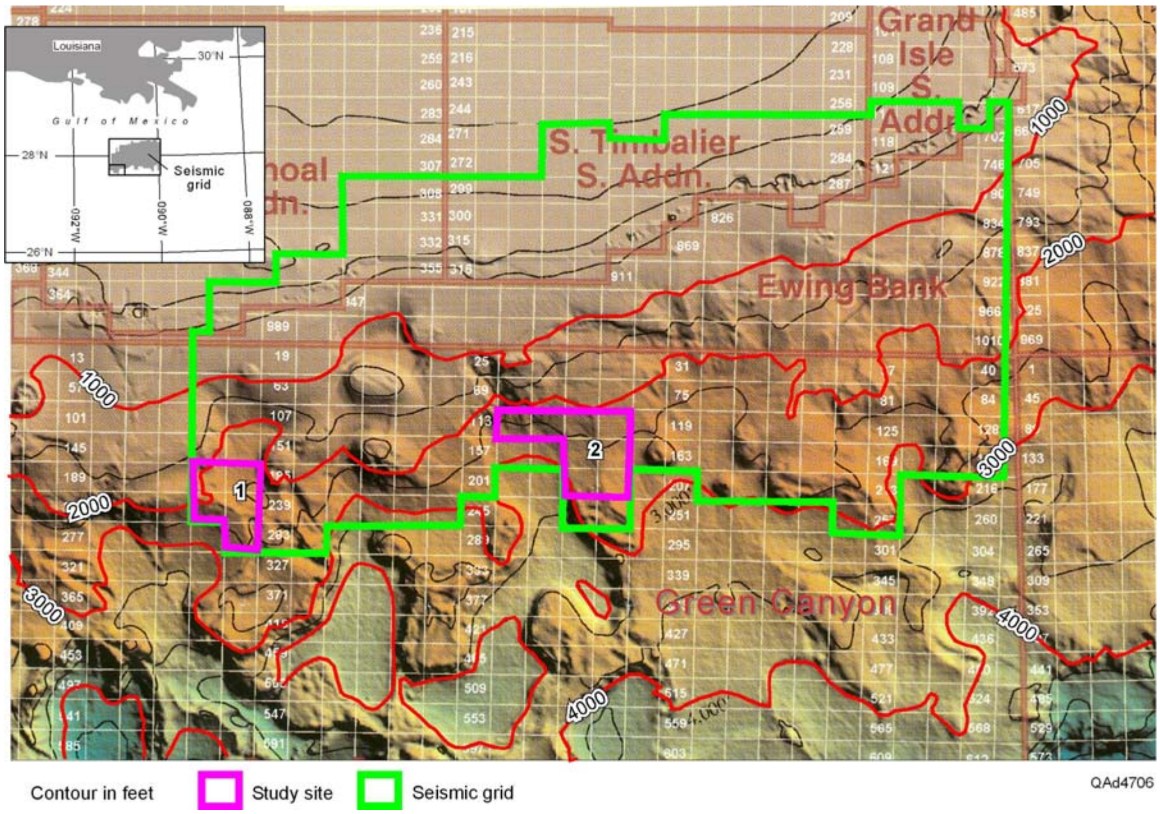


Figure 1. Map showing that part of the Green Canyon area where 4C OBC seismic data have been acquired. Only data acquired in water depths of 1,500 feet (~460 meters) or more will be used in this study. Contour interval of bathymetry lines is 500 ft (~150 m). Two locations labeled **1** and **2** have been selected as focal points for this research.

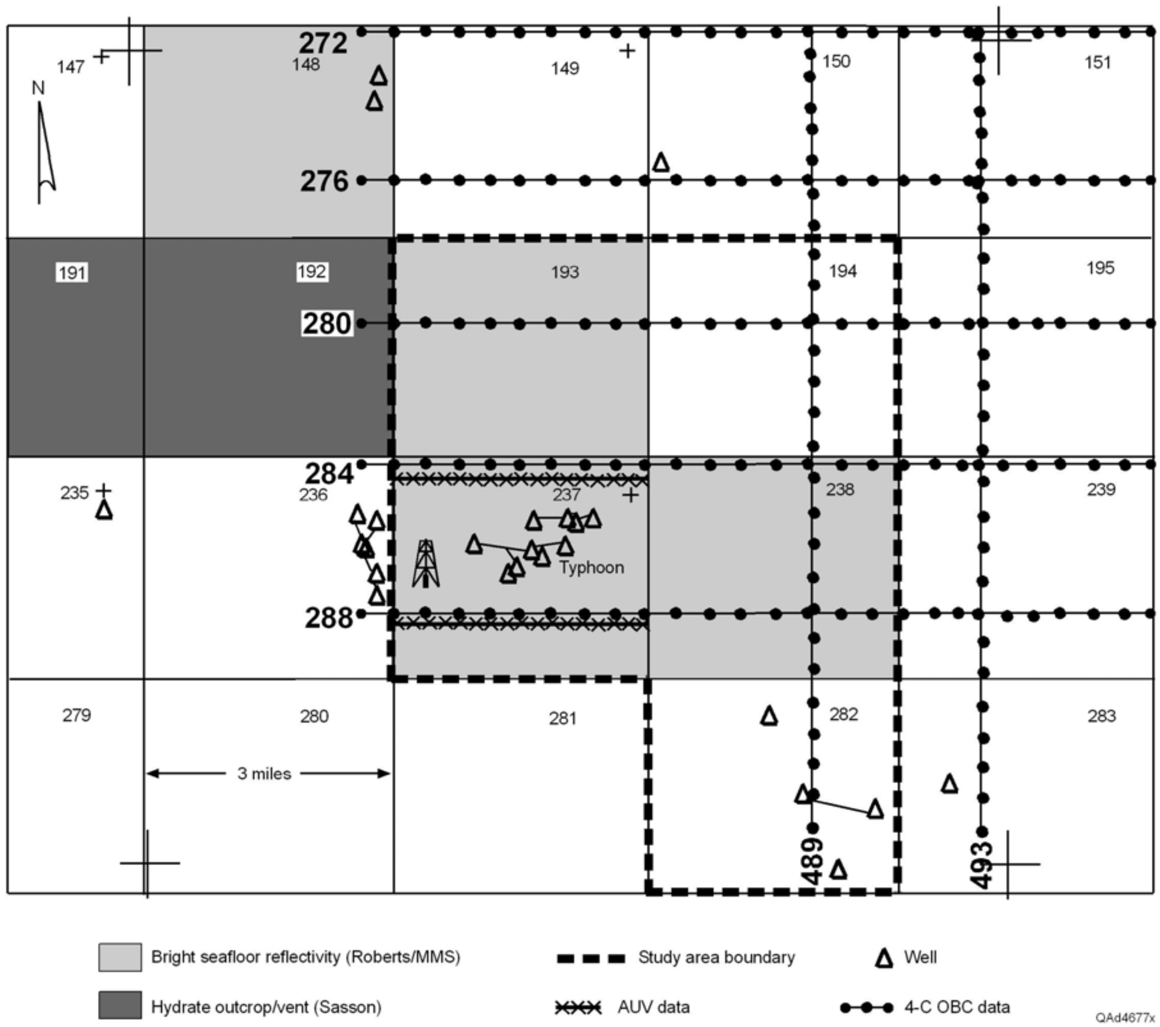


Figure 2. Study Site 1. This area extends across five lease blocks, or 45 mi^2 (115 km^2). AUV and OBC profiles are labeled. Critical calibration data in the form of seafloor borings and geotechnical reports exist at the production platform shown in Block GC237. Conventional well logs are available at most labeled well locations. Several lease blocks are shaded to indicate that hard evidence of hydrates exists within these blocks. The color code indicates the source of the hydrate evidence is either Roberts or Sassen as has been described by Hardage and others (2006).

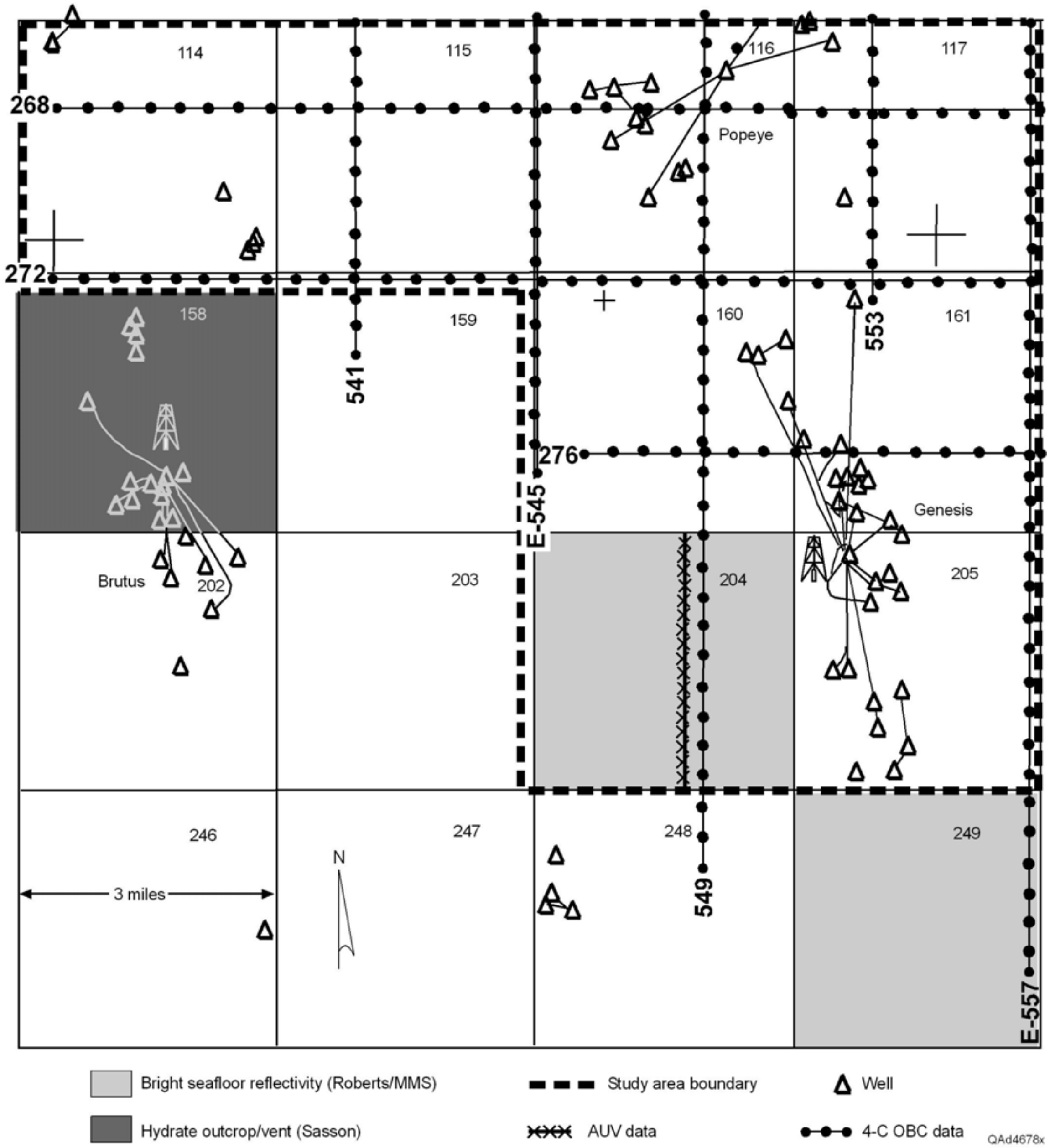


Figure 3. Study Site 2. This area covers nine lease blocks, or 72 mi^2 (184 km^2). AUV and OBC profiles are labeled. Seafloor boring analyses are available as contractor geotechnical reports in Block GC205, where the production platform is shown. Conventional well logs are available at most labeled well locations. Several lease blocks are shaded to indicate that hard evidence of hydrate exists within these blocks. The color code indicates the source of the hydrate evidence is either Roberts or Sassen as has been described by Hardage and others (2006).

(a) (b)

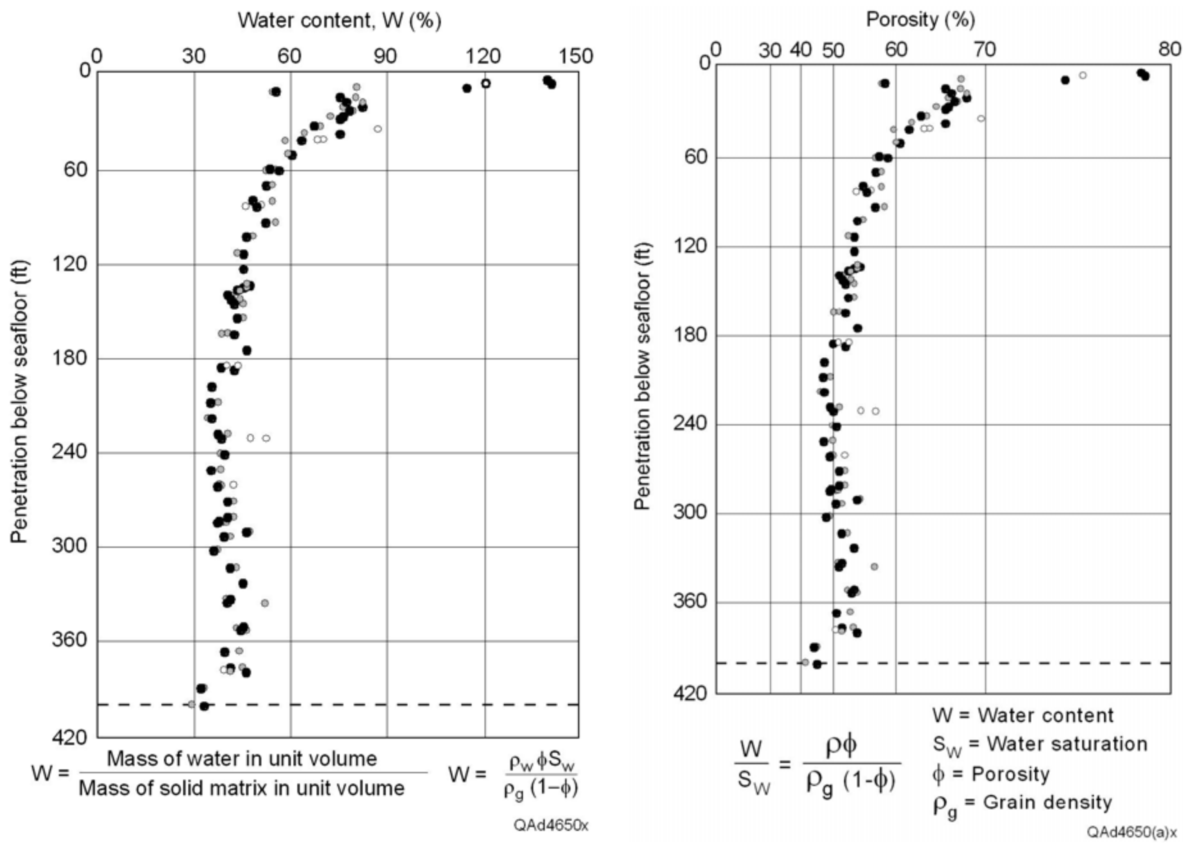


Figure 4. (a) Water-content data measured from a seafloor boring in Lease Block GC237, Study Site 1. Data were extracted and reformatted from a geotechnical report prepared by Fugro for Chevron, the operator of Typhoon Field in Block GC237. (b) Porosity profile calculated from the water-content data assuming S_W = 100%, ρ_w = 1.025 gm/cm^2, and ρ_g = 2.55 gm/cm^3 in Equation 3.

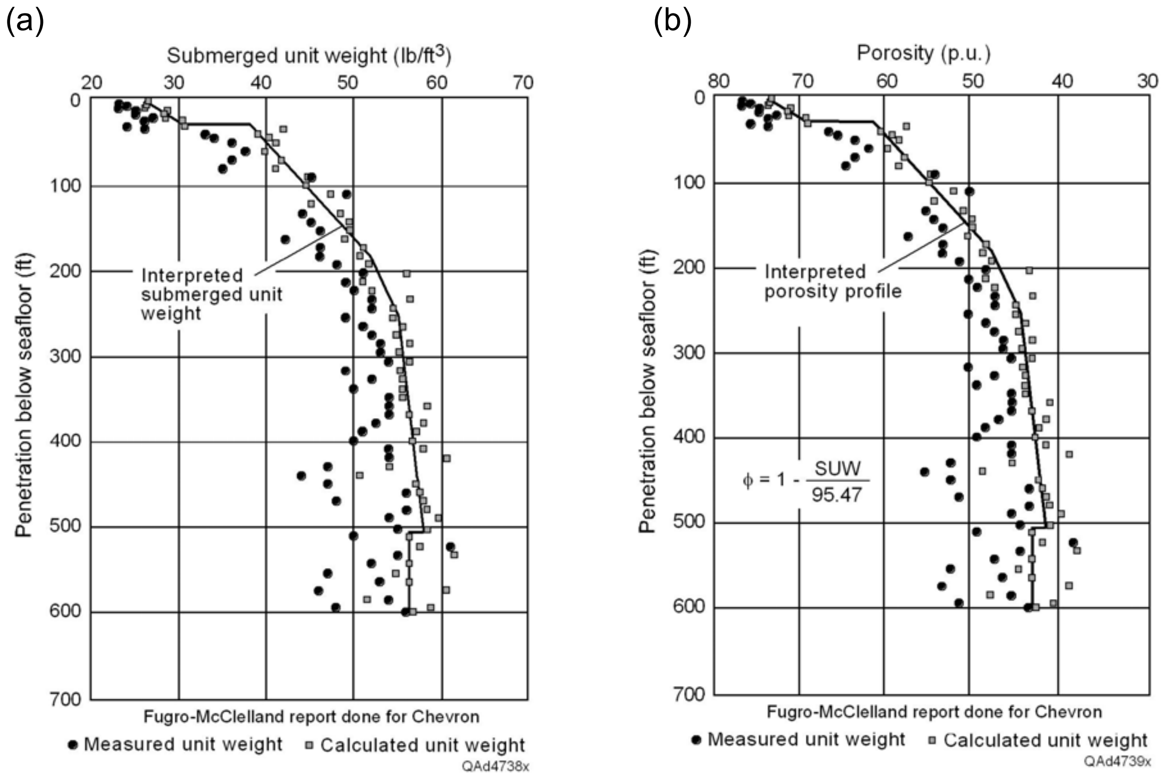


Figure 5. (a) Submerged unit weight measurements from Block GC205, Study Area 2. (b) Porosity profile derived from submerged unit weight measurements.

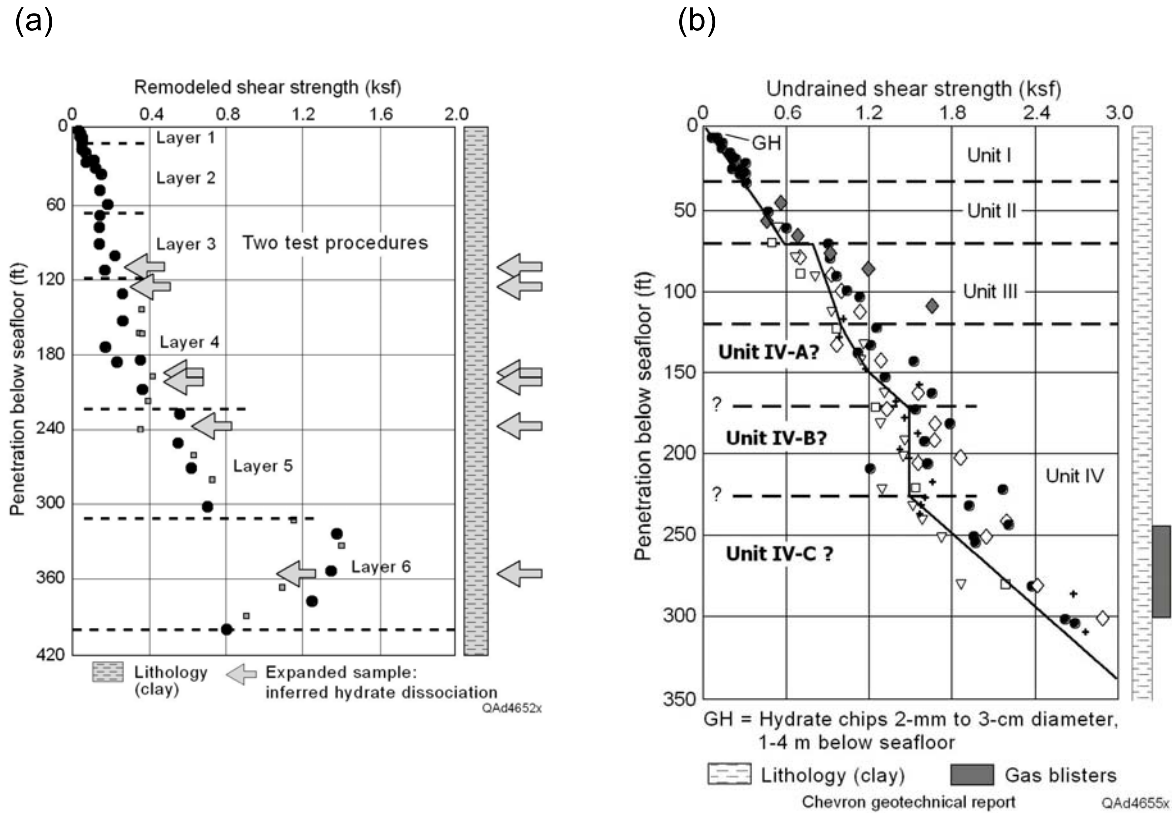
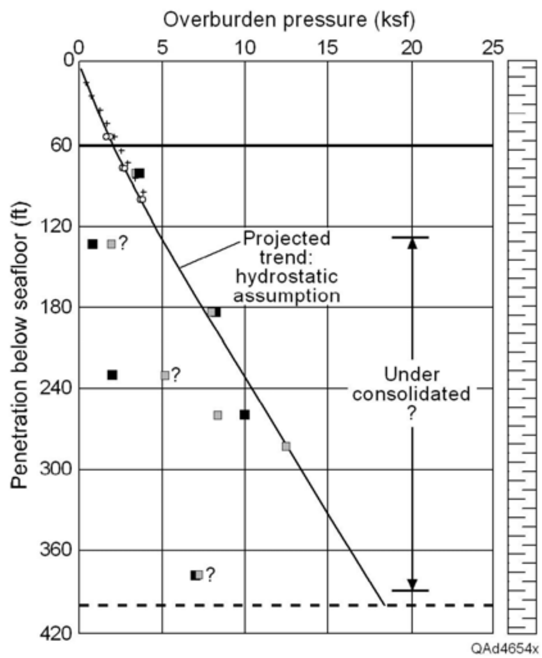


Figure 6. Shear-strength profile for (a) Block GC237, Study Site 1, and (b) Block GC205, Study Site 2. Each type of data-point symbol indicates a different laboratory test procedure. Data were extracted from two Fugro geotechnical reports prepared for Chevron for Typhoon Field (Block GC237) and Genesis Field (Block GC205) and reformatted for this study. The profiles define subseafloor lithology and shear-strength-based stratigraphic layering at each study site and document gas-hydrate evidence encountered in seafloor borings [arrows in (a) and the label **GH** in (b)].

(a)

(b)



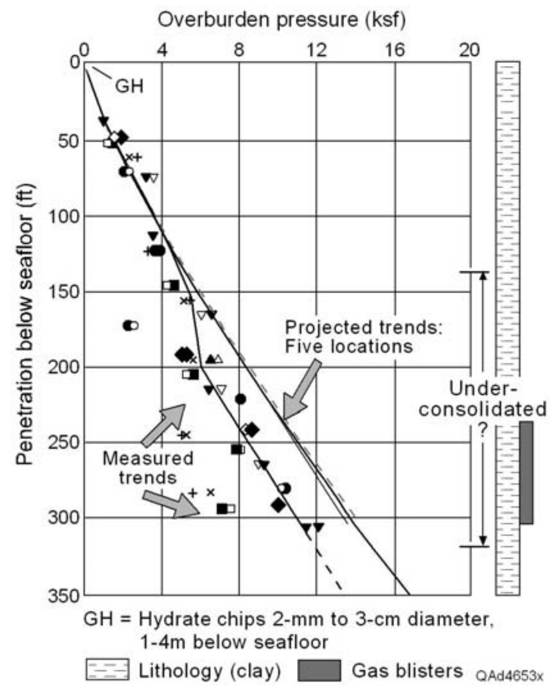


Figure 7. Vertical effective pressure data for (a) Block GC237, Study Site 1, and (b) Block GC205, Study Site 2. At each site, there is evidence of under-compaction starting about 125 feet below the seafloor.

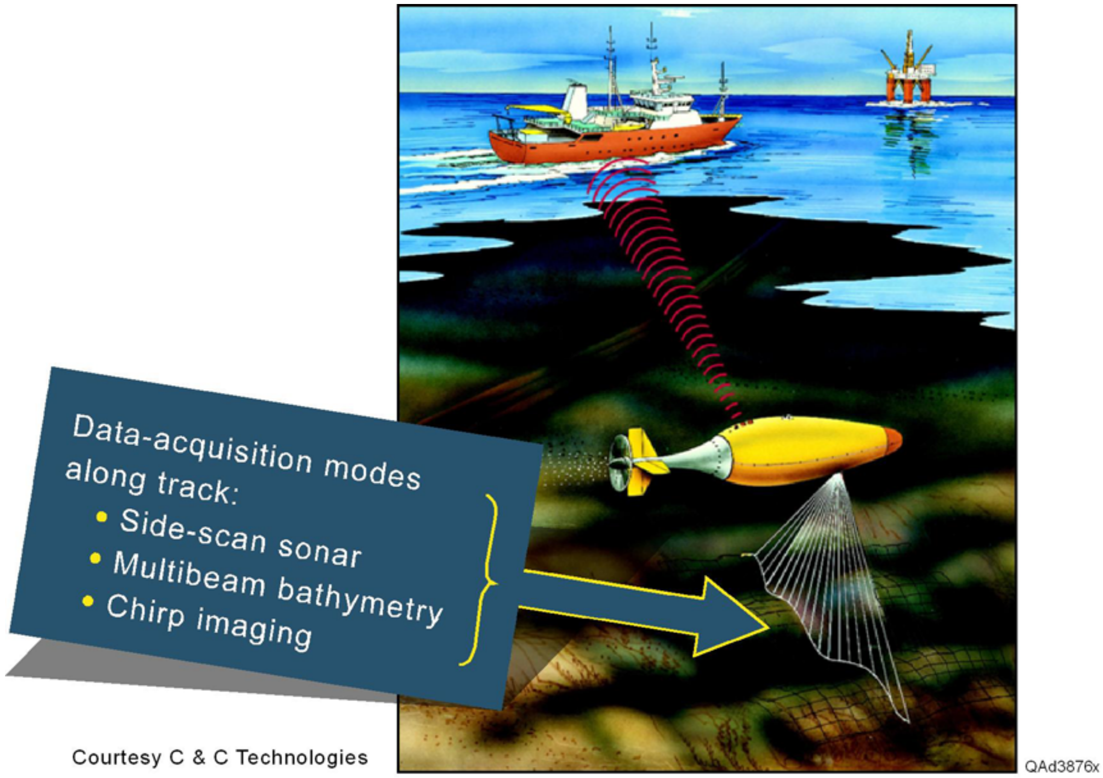


Figure 8. An AUV system operating in deep water.

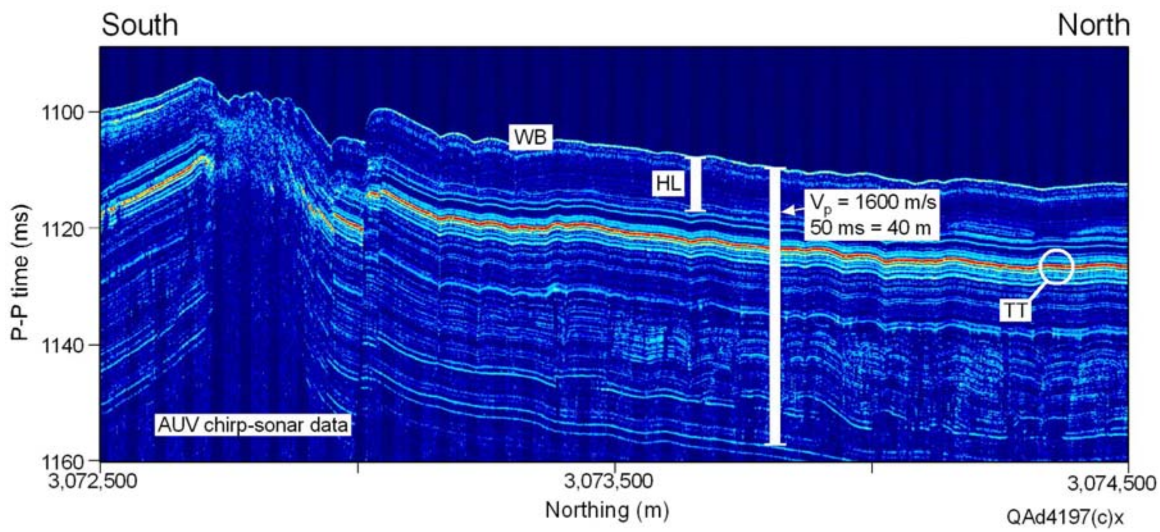


Figure 9. AUV chirp-sonar data acquired across a part of Block GC204, Study Site 2. **WB** is the water bottom. **HL** is a regional hemipelagic layer ranging in thickness from 6 to 8 meters across this area, and **TT** is a layer of thin heterolithic turbidites that extend across a wide area of the northern shelf of the Gulf of Mexico (Harry Roberts, Louisiana State University, private communication). The base of the P-P image is about 50 ms below the seafloor, which corresponds to a subseafloor depth of about 40 meters.

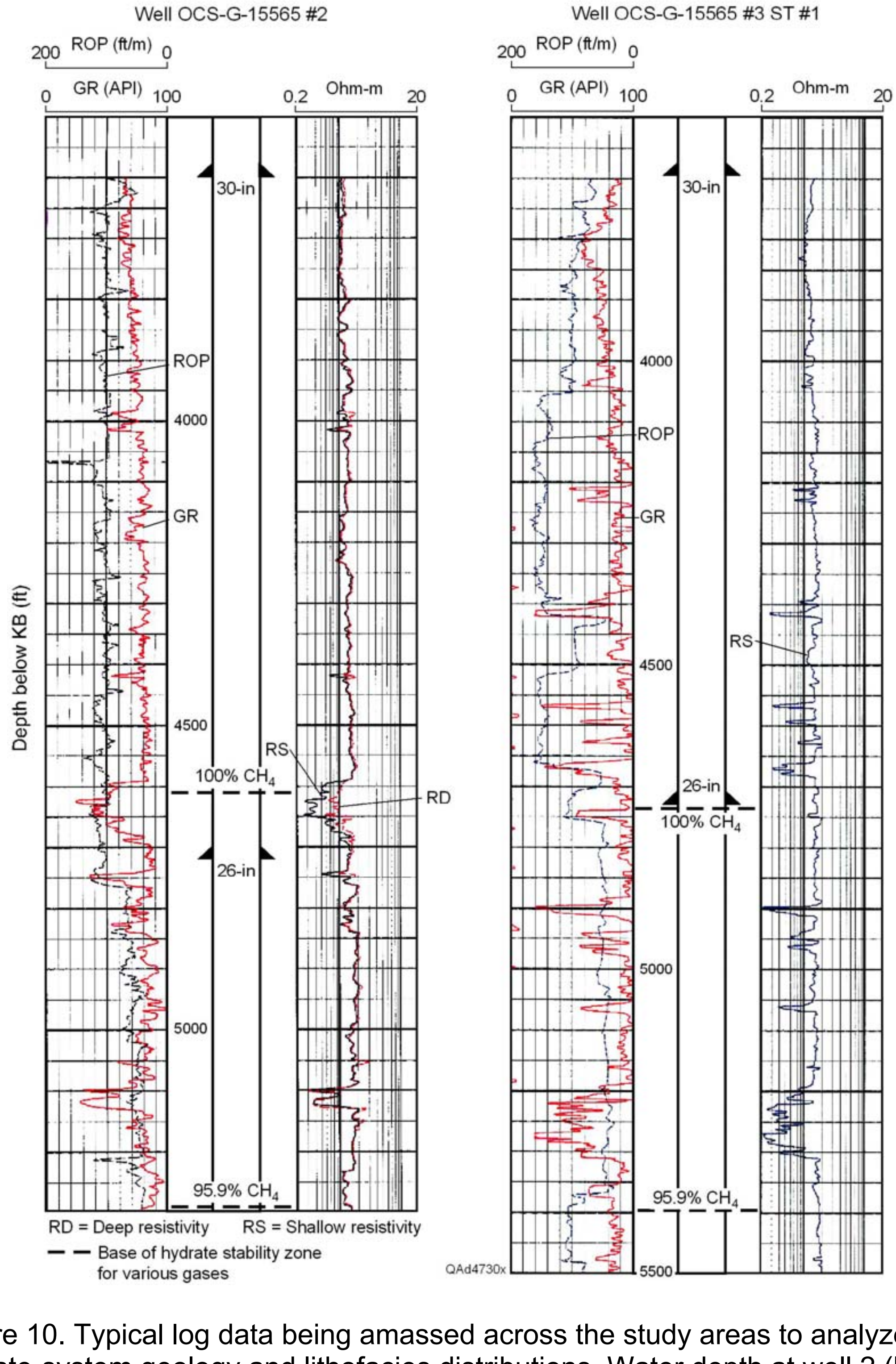


Figure 10. Typical log data being amassed across the study areas to analyze hydrate-system geology and lithofacies distributions. Water depth at well 2 (left) is 3,326 ft (1,014 m). Well 3ST1 (right) was drilled in 3,432 ft (1,046 m) of water. The bases of hydrate stability zones for various gases are marked by horizontal dashed lines. The log curves on the left start 274 ft below the mudline; those on the right start 268 ft below the mudline.

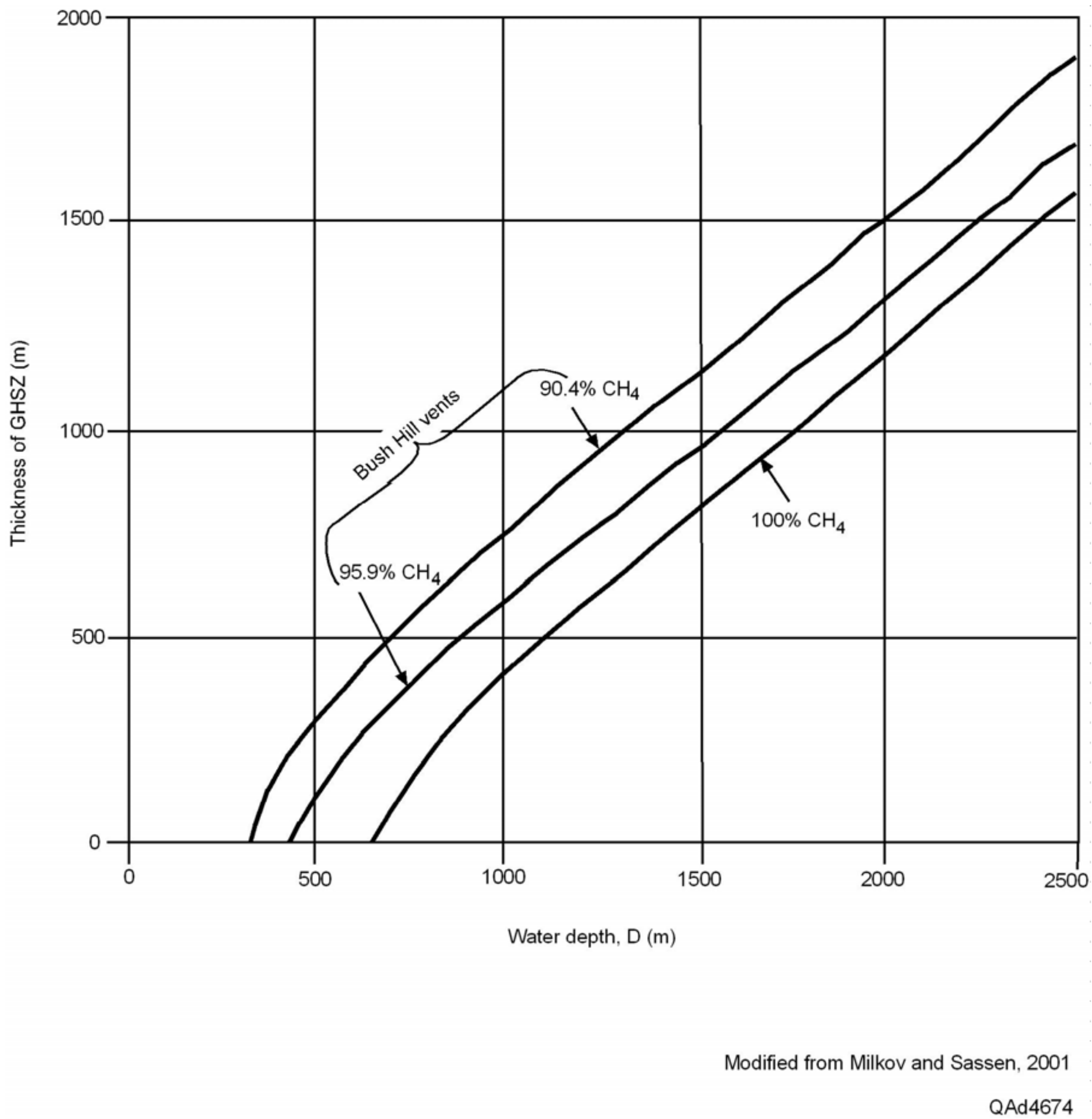


Figure 11. Thicknesses of hydrate stability zones calculated for the Green Canyon area by Milkov and Sassen (2001) using local seafloor temperatures and temperature-gradient data. The gas chemistry labeled *Bush Hill vents* comes from seafloor vent gas collected in Block GC185 located 25 miles (40 km) almost due west of Study Area 1.

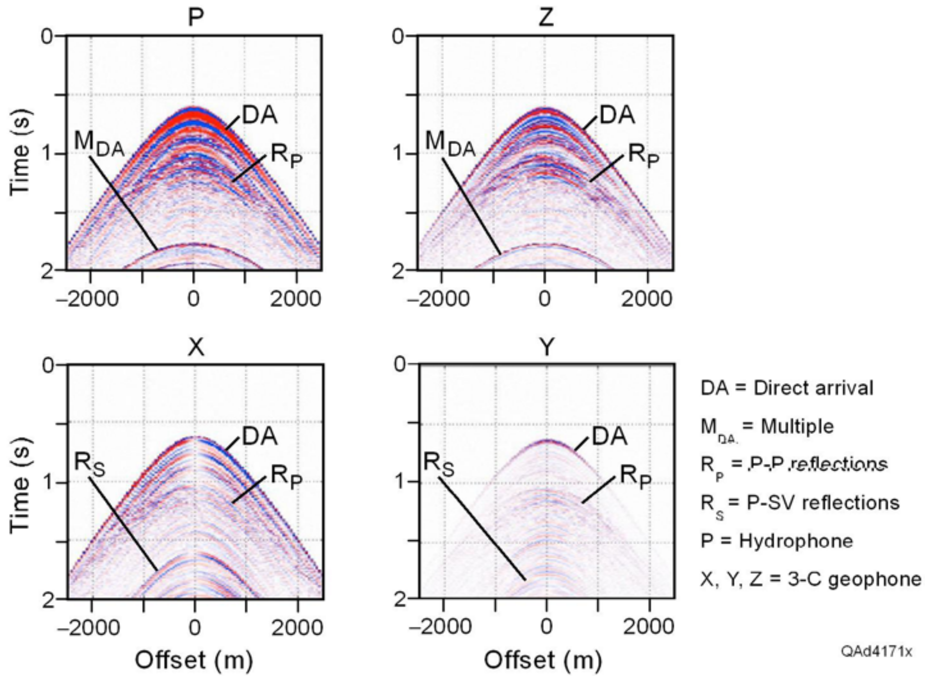


Figure 12. A common-receiver gather of 4C OBC seismic data from Line 549, Block GC204, Study Site 2.

Appendix A: Research Data

We segregate our gas hydrate research database into four data types:

1. seafloor borings and geotechnical analyses,
2. AUV chirp-sonar data,
3. conventional well log data, and
4. 4C OBC seismic data.

Figures 2 and 3 in the text illustrate the locations of the seafloor borings, geotechnical reports, AUV profiles, and 4C OBC seismic lines that we have assembled across **Study Site 1** and **Study Site 2**, respectively. Figure A1 defines locations of the wells where log curves have been added to the project database. All database items are listed in a concise format in Table A1.

Table A1. Itemized Research Database

Seafloor Borings and Geotechnical Reports

- Study Site 1: Block GC237, 1 platform location
- Study Site 2: Block GC205, 1 platform location

AUV Data

- Study Site 1: Block GC237, 6 mi (9.6 km)
- Study Site 2: Block GC204, 3 mi (4.8 km)

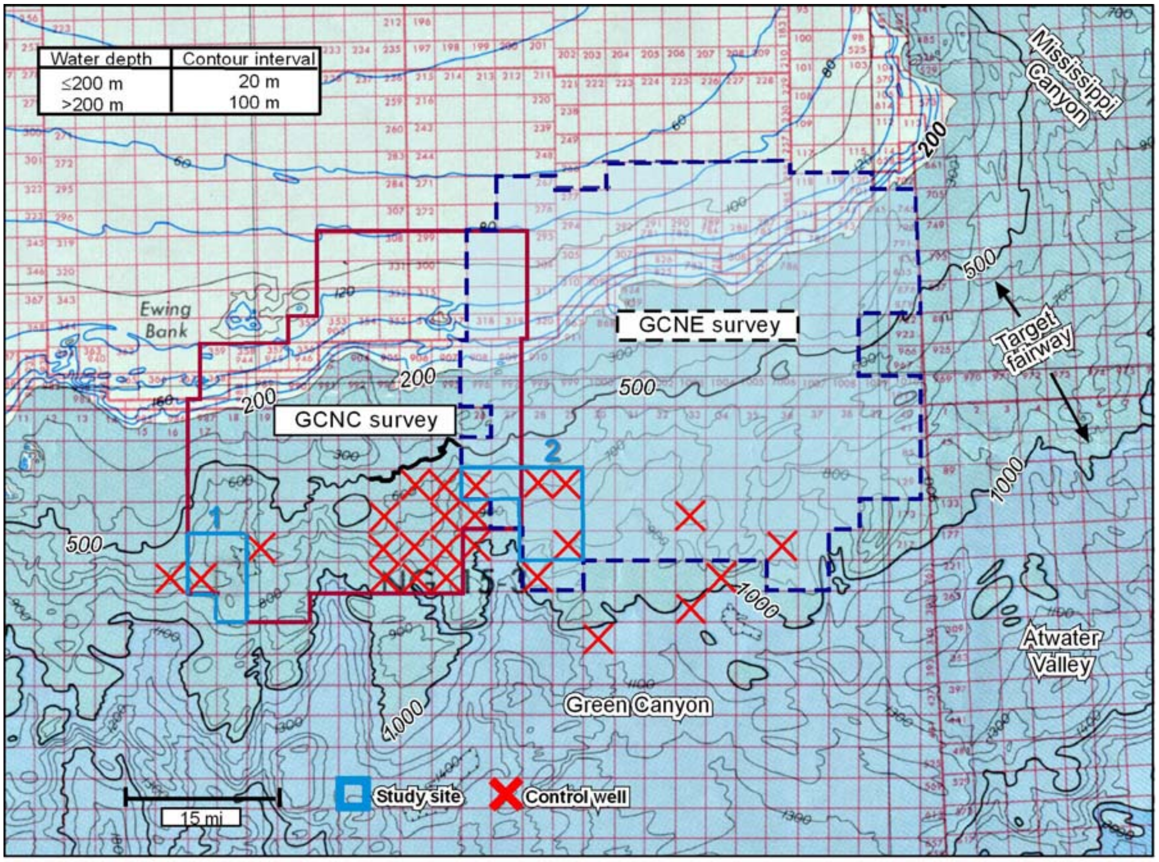
4C OBC Seismic Data

- Study Site 1: 63 mi (101 km)
- Study Site 2: 60 mi (96 km)

Well Logs (By lease block and ID number)

Block	Well	Block	Well	Block	Well
GC112	4024500	GC112	4024501	GC113	5012100
GC113	5012700	GC113	5012701	GC113	5013100
GC114	4025400	GC114	5011700	GC116	5012200
GC117	4033100	GC117	4033500	GC155	4022800
GC155	4022801	GC155	4031100	GC157	4037100
GC158	4026200	GC158	4026201	GC158	4026601
GC158	4026700	GC158	5008770	GC165	4027800
GC165	4028700	GC195	4037600	GC199	4036600
GC200	4020500	GC200	4021600	GC200	4021800
GC200	4021900	GC201	4027500	GC202	4026800
GC202	4026900	GC202	4035100	GC202	5012300
GC205	5007800	GC212	4023200	GC236	4021400
GC237	4023100	GC237	4024100	GC237	4024700
GC243	4027601	GC243	4034000	GC244	4021700

GC245	4032900	GC245	5008900	GC248	0155652
GC248	0155653	GC254	5008300	GC282	4030800
GC282	4033700	GC283	4029900	GC297	4027900
GC326	4022700	GC338	5012600		



U.S. Department of Commerce (1986)
QAd3453(aaa)x

Figure A1. Map defining locations of **Study Site 1** and **Study Site 2**, critical water-depth contours of 500 and 1,000 meters that define the boundaries of our hydrate ***Target fairway***, and current well control. Blocks where well log data have been added to the research database are marked with an ×.