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ABSTRACT

The primary accomplishment of the JOI Cooperative Agreement with DOE/NETL in this quarter was the preparation of tools and measurement systems for deployment, testing and use on ODP Leg 204, which will study hydrate deposits on Hydrate Ridge, offshore Oregon. Additional accomplishments were related to the postcruise evaluation of tools and measurements systems used on ODP Leg 201 along the Peru margin from January through March, 2002.

The operational results from the use of the Pressure Core Sampler (PCS) tool and the PCS Gas Manifold on ODP Leg 201 are evaluated in this progress report in order to prepare for the upcoming deployments on ODP Leg 204 in July, 2002.

The PCS was deployed 17 times during ODP Leg 201 and successfully retrieved cores from a broad range of lithologies and sediment depths along the Peru margin. Eleven deployments were entirely successful, collecting between 0.5 and 1.0 meters of sediment at greater than 75% of hydrostatic pressure. The PCS gas manifold was used in conjunction with the Pressure Core Sampler (PCS) throughout ODP Leg 201 to measure the total volume and composition of gases recovered in sediment cores associated with methane gas hydrates.

The FUGRO Pressure Corer (FPC), one of the HYACE/HYACINTH pressure coring tools, was also deployed on the D/V JOIDES *Resolution* during ODP Legs 201 to field-test this coring system at three shallow-water sites located offshore Peru. The field-testing of these tools provides a corollary benefit to DOE/NETL at no cost to this project. The testing of these tools on the D/V JOIDES *Resolution* was negotiated as part of a cooperative agreement between JOI/ODP and the HYACINTH partners.

The DVTP, DVTP-P, APC-methane, and APC-Temperature tools (ODP memory tools) were used extensively during ODP Leg 201. The data obtained from the successful deployments of these tools is still being evaluated by the scientists and engineers involved in this testing; however, preliminary results are presented in this report.

An infrared-thermal imaging system (IR-TIS) was deployed for the first time on ODP Leg 201. This system was used to identify methane hydrate intervals in the recovered cores. Initial discussions of these experiments are provided in this report.

This report is an overview of the field measurements made on recovered sediment cores and the downhole measurements made during ODP Leg 201. These results are currently being used to incorporate the “lessons learned” from these deployments to prepare for a dedicated ODP leg to study the characteristics of naturally-occurring hydrates in the subsurface environment of Hydrate Ridge, offshore Oregon during ODP Leg 204, which will take place from July through September, 2002.

TABLE OF CONTENTS

INTRODUCTION

DOE/NETL funding was used by JOI/ODP to upgrade or modify many of the existing downhole tools onboard the D/V JOIDES *Resolution* so that they could be used to better characterize methane hydrates on ODP Leg 204, on Hydrate Ridge. In preparation for the future deployment of these tools, a number of tools and experimental systems were used on ODP Leg 201 along the Peru margin to evaluate their capabilities and weaknesses.

During ODP Leg 201, several newly modified downhole tools were deployed to better characterize the subsurface lithologies and environments hosting microbial populations and gas hydrates. Methane hydrates were sampled in cores recovered from one of the sites drilled during the cruise (Site 1230) and tests of an infrared thermal imaging system were used to confirm the validity of this method for locating hydrate recovered in cores from the identification of their thermal anomaly.

The ODP Pressure Core System (PCS) was deployed 17 times during ODP Leg 201 and successfully retrieved cores from a broad range of lithologies and sediment depths along the Peru margin. Eleven deployments were entirely successful, collecting between 0.5 and 1.0 meters of sediment at greater than 75% of hydrostatic pressure. The PCS gas manifold was used in conjunction with the PCS throughout ODP Leg 201 to measure the total volume and composition of gases recovered in sediment cores, and especially in those cores associated with methane hydrate.

Solid pieces of gas hydrate were recovered from two discrete intervals at Site 1230. Evidence of gas hydrate was identified in several additional cores below 80 mbsf. Infrared camera core temperature measurements as well as chemical and physical property data suggest that gas hydrate occurs, at least intermittently, from ~70 mbsf to the base of the recovered interval at 278.3 mbsf. Preliminary calculations from methane gas volumes released from the PCS further show that methane concentrations highly exceed hydrate saturation at many depths sampled below about 70 mbsf.

The HYACE/HYACINTH Fugro Pressure Corer (FPC) was deployed 7 times on ODP Leg 201 with limited success in recovering pressurized cores, but much was learned about the operation of the tool with shipboard systems on the D/V JOIDES *Resolution.*

The DVTP, DVTP-P, APC-methane, and APC-Temperature tools (ODP memory tools) were used extensively and successfully during ODP Leg 201 aboard the D/V JOIDES *Resolution*. These systems will provide a strong operational capability for characterizing the in situ properties of methane hydrates in subsurface environments on Hydrate Ridge during ODP Leg 204, as well as in other offshore sedimentary environments.

EXECUTIVE SUMMARY

The primary accomplishments of the JOI Cooperative Agreement with DOE/NETL in this quarter was the preparation of tools and measurement systems for deployment, testing and use on ODP Leg 204, which will study hydrate deposits on Hydrate Ridge, offshore Oregon. Additional accomplishments were related to the postcruise evaluation of tools and measurements systems used on ODP Leg 201 along the Peru margin from January through March, 2002.

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The PCS is a downhole tool designed to recover a cylindrical sediment core -- including gas and interstitial water -- at in situ pressure (Pettigrew, 1992). When properly sealed at depth, controlled release of pressure from the PCS through a manifold (below) should permit collection of gases that would otherwise escape on the wireline trip. In late 1995, after several early attempts at coring under pressure (e.g., Kvenvolden et al., 1983), the PCS was used successfully to capture and analyze gases for their composition and volume on Leg 164 (Paull, Matsumoto, Wallace et al., 1996; Dickens et al., 1997, 2000a,b). The PCS was deployed on Leg 201 (1) to ensure that the tool was fully operational on future legs targeting gas-rich sediments, especially Leg 204 off the Oregon margin, and (2) to quantify gas abundance along the Peru margin where gas concentrations at depth exceed saturation on the ship.

The PCS was deployed 17 times during ODP Leg 201 and successfully retrieved cores from a broad range of lithologies and sediment depths along the Peru margin. Eleven deployments were entirely successful, collecting between 0.5 and 1.0 meters of sediment at greater than 75% of hydrostatic pressure. The PCS gas manifold was used in conjunction with the Pressure Core Sampler (PCS) throughout ODP Leg 201 to measure the total volume and composition of gases recovered in sediment cores associated with methane hydrates.

The FUGRO Pressure Corer (FPC), one of the HYACE/HYACINTH pressure coring tools, was also deployed on the D/V JOIDES *Resolution* during ODP Legs 201 to field-test this coring system at three shallow-water sites located offshore Peru. The field-testing of these tools provides a corollary benefit to DOE/NETL at no cost to this project. The testing of these tools on the D/V JOIDES *Resolution* was negotiated as part of a cooperative agreement between JOI/ODP and the HYACINTH partners.

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In addition to the Leg 201 activities during this quarter, other activities were continuing to prepare for deployments that will take place in July, 2002. For example, two core logging chambers (ODP-LC) were fabricated for use on ODP Leg 204 with the HYACINTH system. These chambers will be able to accept standard ODP APC/XCB core sections in their existing core liners and will allow them to be re-pressurized and logged to collect gamma ray attenuation (bulk density) and compressional-wave acoustic velocity measurements. These measurements will be made using a vertical multi-sensor (pressure) core logging (MSCL-V) system that will be deployed on Leg 204. These chambers will allow physical properties data to be collected on hydrate cores recovered using conventional coring techniques and re-pressurized. These data can then be compared with similar properties measured on cores recovered at in-situ pressures by the HYACINTH corers to evaluate the similarities and/or differences among data collected using these two approaches.

Discussions continued between Leg 204 scientists and LDEO logging engineers to define the specifics of LWD and VSP experiments planned for ODP Leg 204 (Task 5.0). Tool modifications were made to create a LWD Resistivity-at-the-Bit with Coring (RAB-C) tool for deployment on ODP Leg 204 in July of 2002. This tool resulted from the integration of the ODP motor-driven core barrel (MDCB) inner core tube with the Schlumberger/Anadrill RAB landing sub.

During this quarter, ODP and FUGRO engineers modified the FUGRO Piezoprobe tool for use with the ODP APC/XCB bottom hole assembly (BHA) on ODP Leg 204. This required changes to the lay out, space out, and completion of crossover subs for the piezoprobe deployment and the establishment of operational protocols for the deployment and use of this tool on Leg 204.

This report will present an overview of the preliminary results obtained from tool and instrument deployments on ODP Leg 201, as well as providing a brief discussion of the laboratory analyses of the recovered cores.

EXPERIMENTAL

Infrared Thermal Imaging of Cores

An infrared thermal imaging system was deployed at sea for the first time to identify hydrate intervals in sediment cores from their thermal anomaly relative to background sediment temperatures along the core liner.

All cores were thermally imaged on the catwalk prior to sectioning. All other physical properties measurements were conducted after the cores had equilibrated to near ambient room temperature (i.e., 22°–24° C), a settling period of 2–4 hour. Physical properties measured on the MST and thermal conductivity measurements were normally made on whole-round core sections during the same time interval. Discrete moisture and density parameters, *P*-wave velocities, and electrical resistivity were subsequently measured on each split-core section. A summary of each of the physical properties measurement procedures for Leg 201 is outlined below; more detailed descriptions are provided in Blum (1997).

Methodology

A ThermaCam SC 2000 camera (FLIR Systems) was used. This camera measures temperatures from –40° to +1500°C. To use the system for this shipboard application, the camera was set to record a range of temperatures from –40° to +120°C (range 1).

By experimentation, we determined that a 10-centimeter field of view on the core was obtained with the camera lens located 34 centimeters from the highest point on the core. In order to minimize the effect of external IR radiation reflecting from the core liner, the camera and the space between the lens and the core was enclosed within a cardboard sheath covered on the outside with crumpled aluminum foil in order to disperse ambient IR energy.

To record data for each core, the mounted camera was placed on top of the core liner and the camera was focused on the edges of the core using computer controls. During focusing, camera span and level parameters were auto-adjusted to optimize visual contrast on the computer screen of the expected downcore temperature variation. Immediately after the core liner was cleaned, the camera was manually rolled along the core from top to bottom.

ThermaCam “Researcher” software was installed on a dedicated laptop computer, attached to the IR camera to acquire images from the camera at a rate of 5 frames per second. During initial experiments, we found that a ~45-second acquisition time for a 9.5-meter-long core produced images with minimal blurring and with considerable sequential overlap. While the images were being recorded by the computer, the computer screen would freeze at the first image frame, preventing real-time viewing of the core liner temperatures.

At ODP Site 1230, we discovered that the camera itself provided real-time images of the core; therefore, an optional external screen was attached to view the core as it was scanned. The screen span and level parameters were set to optimize visual contrast on the external screen of the expected downcore temperature variation (since the camera and computer spans and levels could be different). Initially, this was 0º–20º C. After hydrates were identified at ~16ºC, the span and level were set to show a range of 15º–25º C.

Depth Integration

To facilitate depth integration of the IR data with other physical properties measurements, a special depth scale was constructed using a 10-meter-long and 4-centimeter-wide piece of aluminum unistrut. A 5-centimeter spaced numbered scale was painted onto the unistrut using Rustoleum Specialty High Heat oil-based enamel (black #7778). This combination initially produced sufficient thermal contrast for subsequent discrimination of the scale markers. However, the scale was only visible in still images.

Images recorded while the camera was moving were too blurred to identify the scale. Holes were drilled in the unistrut, which proved to be of limited use. The thermal contrast of the holes was very clear, particularly during the day or when a hand was run under the unistrut while the camera was being rolled down the core. However, blurring remained a significant problem. Additionally, producing a single depth-matched downhole record of temperature variation based on the scale required extensive image processing, as only one image could be viewed at time. Several attempts at developing an automated technique proved unsuccessful. The process was further complicated by the variable scan rate of each core (the scanner walked at as constant pace as possible, but there were several scanners, and sometimes the cart’s wheels would get stuck).

At Site 1230, we decided to assign the curated top depth of the core to the first image. The curated interval assigned to the recovered length of the core was divided into the number of images taken for the core. This interval was sequentially added to the images to assign depths in a core to each image.

Additional measurements were made on all of the cores that had been imaged by the infrared thermal imaging system to record their physical and acoustic properties, as described in the following sections.

Physical Properties Measurements

A suite of physical properties measurements were made to support the main scientific objectives of Leg 201. Physical characterization of the subsurface environment, particularly including density, porosity, and matrix composition, is necessary for specification of the hydrodynamic environment that was expected to strongly affect the microbial community.

Multi-Sensor Track Measurements

The multi-sensor track (MST) comprises three physical properties sensors on an automated track that measure, sequentially, volume magnetic susceptibility, wet bulk density, and compressional wave velocity on whole-round intact core sections. Measurements are nondestructive of core fabric and are used principally to facilitate shipboard core-to-core correlation, to construct composite stratigraphic sections, and to correlate with downhole tools. Each device has an intrinsic spatial resolution determined by its design specifications (see discussion of each measurement below). Data quality depends on core condition and instrument precision. Optimal MST measurements require a completely filled liner with minimal drilling disturbance. Precision is generally a function of measurement time, especially with respect to magnetic susceptibility and wet bulk density. The final sensor-specific spatial resolution chosen for each site balances the spatial footprint and precision accuracy with core flow requirements and was particularly critical during rapid core recovery at the shallow-water sites along the Peru margin. In all cases, the scientific objectives of Leg 201 placed a primary importance on a high-resolution and precise determination of wet bulk density, so that the count times and spatial resolution on this instrument were maximized at the expense of other measurements.

Magnetic Susceptibility

Whole-core volume magnetic susceptibility was measured with the MST using a Bartington MS2 meter coupled to a MS2C sensor coil with a diameter of 8.8 centimeters operating at 565 Hz. The measurement resolution of the MS2C sensor is 4 centimeters. The instrument has two precision settings, a minimum statistically significant count time of 1 second and a 10-seconds count time. During Leg 201, MST magnetic susceptibility was routinely measured at a spacing of 5.0 centimeters, with the average of two 1-second (low resolution) data acquisitions being recorded for each sample location, unless otherwise stated. The instrument automatically zeros and records a free-air value for magnetic susceptibility at the start and end of each section run. Instrument drift during a section run is then accommodated by subtraction of a linear interpolation between the first and last free-air readings. Drift-corrected magnetic susceptibility data were archived as raw instrument units (SI) and were not corrected for changes in sediment volume.

Wet Bulk Density

Determination of wet bulk density is carried out by the gamma-ray attenuation (GRA) densitometer. This system is based on the principle that the attenuation, mainly by Compton scattering, of a collimated beam of gamma rays produced by a ^{137}Ce source passing through a known volume of sediment is related to material bulk density (Evans, 1965). Calibration of the GRA system was completed using known graduated seawater/aluminum density standards. The measurement width of the GRA sensor is ~5 milimeters, with sample spacing generally set at 5.0 centimeters for Leg 201 cores unless otherwise stated. The minimum integration time for a statistically significant GRA measurement is 1 second. During most legs, a count time of 2 seconds is used; however, during Leg 201, GRA measurements were acquired over longer periods, from 5 to 10 seconds integration time in order to reduce scatter and improve precision. A freshwater control was run with each section to measure instrument drift. GRA bulk density data are of highest quality when determined on APC cores because the liner is generally completely filled with sediment. In XCB cores, gamma-ray attenuation measurements are unreliable for the determination true bulk density on their own because of the breakdown of in situ density by the mixing of drilling slurry and core biscuits.

Compressional (P)-Wave Velocity

Transverse *P*-wave velocity was measured on the MST track with the *P*-wave logger (PWL) for all cores at a routine sample interval of 10 centimeters. The PWL transmits a 500-kHz compressional wave (*P*-wave) pulse through the core at a specified repetition rate (50/second). The transmitting and receiving ultrasonic transducers are aligned so that wave propagation is perpendicular to the core axis. The distance between two ultrasonic transducers was measured using two displacement transducers. The recorded velocity is the average of the user-defined number of acquisitions per location (10). Calibrations of the displacement transducers and measurement of electronic delay in the PWL circuitry were conducted using a series of acrylic blocks of known thickness and *P*-wave traveltime. Repeated measurement of *P*-wave velocity through a core liner filled with distilled water was used to check calibration validity.

Curatorial Procedures and Sample Depth Calculations

Numbering of sites, holes, cores, and samples follows the standard Ocean Drilling Program (ODP) procedure. A full curatorial identifier for a sample consists of the leg, site, hole, core number, core type, section number, and interval in centimeters measured from the top of the core section. For example, a sample identification of 201-1225A-1H-1, 10–12 centimeters, represents a sample removed from the interval between 10 and 12 centimeters below the top of Section 1, Core 1 (H designates that this core was taken with the APC system) of Hole 1225A during Leg 201. Cored intervals are also referred to in “curatorial” mbsf. The mbsf of a sample is calculated by adding the depth of the sample below the section top and the lengths of all higher sections in the core to the core top datum measured with the drill string.

A sediment core from less than one meter to a few hundreds of meters below sea floor may, in some cases, expand upon recovery (typically 10% in the upper 300 mbsf), and its length may not necessarily match the drilled interval. In addition, a coring gap is typically present between cores. Thus, a discrepancy may exist between the drilling mbsf and the curatorial mbsf. For instance, the curatorial mbsf of a sample taken from the bottom of a core may be larger than that of a sample from the top of the subsequent core, where the latter corresponds to the drilled core top datum.

If a core has incomplete recovery, all cored material is assumed to originate from the top of the drilled interval as a continuous section for curation purposes. The true depth interval within the cored interval is not known. This should be considered as a sampling uncertainty in age-depth analysis and correlation of core facies with downhole log signals.

Core Handling and Analysis

To ensure as little damage as possible to the microbiological community present in these cores, a unique core processing strategy was established for Leg 201. Since microorganisms existing at deepwater seafloor temperatures (2°–4°C) can be acutely sensitive to elevated temperature (>10°C) and oxygen, we recognized a critical need to prevent thermal equilibration and exposure to oxygen of the cores after recovery. To minimize equilibration of the cores, we modified the standard coring practice of shelving a recovered core barrel on the rig floor while a new core barrel is deployed and a joint of pipe is added. The core barrel was extracted from the drill string and immediately transferred to the catwalk and marked by the ODP curatorial staff into 1.5-meter sections. One of the shipboard microbiologists identified one 1.5-meter section (hereafter referred to as the MBIO section) for rapid microbiological processing. The remainder of the core on the catwalk was processed according to the ODP standard core handling procedures as described in previous *Initial Reports* volumes and the Shipboard Scientist’s Handbook (with minor modifications).

In brief, prior to sectioning, an infrared (IR) camera was passed along the length of the core, capturing a thermally calibrated image that was archived for shore-based processing in preparation for deployment of this tool during Leg 204. Routine shipboard safety and pollution prevention samples were collected on the catwalk. The core was then cut into nominally 1.5-meter-long sections. The remaining cut sections were transferred to the core laboratory for further processing.

The working half was sampled both for shipboard analysis, such as physical properties, carbonate, and bulk X-ray diffraction mineralogy, and for shore-based studies. Both halves of the core (i.e., working and archive) were then put into labeled plastic tubes, sealed, and placed in cold storage space aboard the ship. At the end of the leg, the cores were transferred from the ship into refrigerated containers and shipped to the ODP Gulf Coast Core Repository in College Station, Texas.

Moisture and Density Analysis

Moisture and density (MAD) parameters were determined from wet mass, dry mass, and dry volume measurements of split core sediments after Blum (1997). Push-core samples of ~10 cm^3 were placed in 10-mL beakers. In stiff sediments drilled with the XCB, minicore samples were cut using a drill press and processed without beakers. Care was taken to sample undisturbed parts of the core and to avoid drilling slurry. Immediately after the samples were collected, wet sediment mass was measured. Dry mass and volume were measured after samples were heated in an oven at 105^o +/- 5^o C for 24 hours and allowed to cool in a desiccator. Sample mass was determined to a precision of 0.01 grams using two Scientech 202 electronic balances and a computer averaging system to compensate for the ship's motion. Sample volumes were determined using a helium-displacement Quantachrome penta-pycnometer with a precision of 0.02 cm^3. Volume measurements were repeated five times, until the last two measurements exhibited <0.01% standard deviation. A reference volume was included within each sample set and rotated sequentially among the cells to check for instrument drift and systematic error. Standard sampling frequency was one per section. However, in many cases during Leg 201 we carried out high-resolution sampling through specific zones of interest. One of the MAD samples was always taken adjacent to any sample for dissolved methane and permeability.

Moisture content, grain density, bulk density, and porosity were calculated from the measured wet mass, dry mass, and dry volume as described by Blum (1997). Corrections were made for the mass and volume of evaporated seawater using a seawater density of 1.024 g/cm^3 and a salt density of 2.20 g/cm^3.

Compressional Wave Velocity

P-wave velocities were measured by the ODP standard insertion probe system comprising two transducer pairs that measure velocities along axial (PWS2) and transverse (PWS1) directions. The insertion probe system determines *P*-wave velocity based on the traveltime of a 500-kHz wave between a pair of piezoelectric crystals separated by a fixed distance. System accuracy was checked prior to testing the first section of each hole by measuring the velocity in distilled water at a specific temperature.

Routine sampling frequency and location for *P*-wave measurements was coincident with the discrete MAD samples. Note that the velocity data stored in the Janus database are uncorrected for in situ temperature and pressure. These corrections can be made using the relationships outlined in Wyllie et al. (1956), Wilson (1960), and Mackenzie (1981).

Pressure Core Sampler (PCS)

The PCS is a downhole tool designed to recover a cylindrical sediment core -- including gas and interstitial water -- at in situ pressure (Pettigrew, 1992). When properly sealed at depth, controlled release of pressure from the PCS through a manifold (below) should permit collection of gases that would otherwise escape on the wireline trip. In late 1995, after several early attempts at coring under pressure (e.g., Kvenvolden et al., 1983), the PCS was used successfully to capture and analyze gases for their composition and volume on Leg 164 (Paull, Matsumoto, Wallace et al., 1996; Dickens et al., 1997, 2000a,b). The PCS was deployed on Leg 201 (1) to ensure that the tool was fully operational on future legs targeting gas-rich sediments, especially Leg 204 off the Oregon margin, and (2) to quantify gas abundance along the Peru margin where gas concentrations at depth exceed saturation on the ship. This report describes basic PCS operations on Leg 201. Advanced interpretations of these experiments will be presented elsewhere.

Basic PCS Tool and Gas Manifold Description

The PCS is a tool designed to retrieve a ~1.00 meter-long sediment core from depth under pressure (Pettigrew, 1992). The basic principles of a PCS run are as follows. A cutting shoe is connected to the bottom of the tool. The tool is deployed, free falling within the drill string to reach the bottom of the hole where it mounts the bottom hole assembly. The drill string is turned to cut a core. When the wireline is pulled, a ball drops within the PCS to redirect internal fluid circulation, and stroke the core through a lower ball valve that seals the core at pressure. The tool is then retrieved to the rig floor like an ordinary APC or XCB core. The PCS is separated from the drill string and brought to a shipboard laboratory for experiments. Much more expansive descriptions of mechanical and wireline operations of the PCS are presented elsewhere (Pettigrew, 1992; Rack, 2001).

Once in a laboratory, the current protocol for releasing gas from the PCS is as follows (Dickens et al., 2000b). The tool is placed in a mounting sleeve and surrounded with ice to maintain the core at a constant temperature where gas hydrate will not dissociate at high pressure (Dickens et al., 2000a). A gas manifold system and bubbling chamber are attached to a port on the PCS. Incremental volumes of gas are then released through the port and manifold to the bubbling chamber over time until the inside of the PCS is at atmospheric pressure. The PCS is removed from the ice bath and warmed to at least 15ºC. Additional incremental volumes of gas are collected. Aliquots of gas for various analyses (e.g., hydrocarbon composition) are taken from individual gas volume increments by releasing gas from the bubbling chamber into a syringe. The PCS is completely opened and the sediment core is extruded. The core is then examined for length and overall condition, and sampled for physical properties, especially porosity.

Previous PCS Operations (Leg 164)

A long and mostly unsuccessful history of pressure coring operations marks scientific deep sea drilling prior to 1995 and drilling operations on Leg 164 (Pettigrew, 1992; Paull, Matsumoto, Wallace, et al., 1996). Two main problems particularly plagued early operations: (1) tools did not retrieve lengthy cores at pressure, and (2) available manifolds could not easily measure gas volumes. Both problems were mostly overcome during Leg 164 on the Blake Ridge off the southeast margin of the United States. At Sites 995 and 997 on this cruise, 17 cores having lengths of between 3 and 100 centimeters were recovered by the PCS at pressures between 750 and 4800 psi, and successfully degassed through a manifold to quantify gas volume (Dickens et al., 2000a, 2000b).

While successful PCS operations on Leg 164 led to long-desired gas concentration profiles across a bottom-simulating reflector (Dickens et al., 1997), they immediately raised several issues relevant to future use in scientific drilling operations. In particular:

(1.) Sediment on the Blake Ridge consists of very fine-grained and fairly homogenous “nannofossil-bearing clay”. Can the PCS be used to collect cores at high pressure on other margins or in other lithologies?

(2.) Only one PCS deployment retrieved a full 1.00 meter-long sediment core and most deployments recovered cores less than 50 centimeters long. Can the PCS be modified to collect longer cores?

(3.) Many of the cores were unconsolidated after removal from the tool. Can cores be extruded from the tool so they retain their dimensions?

(4.) Only cores below 150 mbsf were successfully degassed at Sites 995 and 997 because unlithified sediment at shallow depth clogged the manifold. Can the manifold and PCS be reconfigured to collect gas at shallow sediment depth?

PCS Modifications for ODP Leg 201

Three modifications were made to the PCS prior to Leg 201 in an attempt to improve the length and quality of cores. First, three new cutting shoes for rotary coring were developed. These shoes are the: (1) the “Christensen” auger type shoe with carbide cutters, (2) a tapered auger with PDC cutters, (and RBI), and (3) a PDC cutting shoe. Second, to minimize washing of sediment during coring, the cutting shoe was placed approximately 50 centimeters ahead of the XCB bit. Third, the core barrel was lengthened to an effective 100 centimeter-long x 4.32 centimeter-diameter (1465 cm^3).

Following designs constructed late on Leg 164 (“PCS-M4”; Paull, Matsumoto, Wallace, et al., 1996, p. 25), a new free-standing, lightweight gas manifold was constructed for Leg 201. However, the basic components and operational principles are the same.

To construct the manifold, we connected several short lengths of high-pressure pipe. This design allows: (1) air to be displaced through one valve; (2) gas to enter at high pressure from the PCS through a second valve; (3) pressure to be measured by a gauge or transducer; and (4) gas to be released into a bubbling chamber through a third valve. The bubbling chamber, which consisted of an inverted, 1-liter graduated cylinder in a plexiglass tube filled with a saturated NaCl solution, was the same as was used on Leg 164.

Downhole Tool Deployments

During ODP Leg 201, downhole tool deployments, in addition to the PCS, included the APC-temperature tool (Adara; APC-T), the Davis-Villinger Temperature Probe (DVTP), the Davis-Villinger Temperature Probe with Pressure (DVTP-P), and the APC-Methane (APC-M) tool. The APC-T and DVTP were used to make *in situ* sediment thermal measurements. Formation pore pressures were measured using a DVTP-P, which was modified to include a pressure port and sensor during ODP Leg 190. The instruments and procedures are summarized in Technical Progress Report #2 of this project.

RESULTS AND DISCUSSION

LEG 201 - INFRARED THERMAL IMAGING

Infrared thermal imaging was introduced on this leg for technique development, prior to expected critical use during Leg 204. The deployment of this system was made possible by DOE/NETL funding to Joint Oceanographic Institutions (JOI) through Cooperative Agreement DE-FC26-01NT41329.

IR imaging was shown to successfully identify thermal anomalies in sediment cores, attributed to the location of gas hydrate (cold anomalies) and voids (warm anomalies). The primary benefits of using IR (rather than running a hand down the length of the core) include more precise identification of thermal anomalies and the estimation of hydrate volume in processed images. It is also quicker, simpler, and more compact than a system of thermistors.

Small-scale hydrate nodules and disseminated gas hydrate were the primary form of hydrate identified, suggesting the camera can detect small quantities. Volumetric analysis will require further study. Another proposed use for the camera is for the lithologic characterization of ambient-temperature cores because of slight variations in their thermal emission properties attributable to sediment composition or water content. Data were collected during Leg 201 to examine this possibility. The necessary data processing will be completed postcruise and will reported in a future ODP Technical Note.

Infrared (IR) Thermal Image Processing

In order to develop downcore temperature profiles from the infrared thermal image data, the following process was established through experimentation over the course of ODP Leg 201:

(1) ThermaCam “Researcher” software was embedded as an object into an Excel spreadsheet. The sequence file containing each image from the core scan was selected and opened in “Researcher”.

(2) An analysis box was hand selected in the first image of the sequence file. The analysis box was placed to avoid areas of significant reflection or other interference.

(3) The sequence file was played from beginning to end to ensure appropriate box placement. The sequence file was reset to the beginning.

(4) In Excel, a macro was written to run the sequence file and extract the maximum, minimum, and average temperature from the analysis box in each image, as well as the time at which each image was taken.

(5) The curated depth was assigned as the depth of the first image.

(6) The recovered interval of core was divided into the total number of images in the sequence file. This interval was sequentially added to the top depth, providing a depth for each image (or temperature distribution).

Following this process, the data files were plotted individually as downcore temperature profiles and combined to provide downhole temperature profiles. Where core recovery was in excess of 100%, the overlapping depth interval was removed from the upper core by hand.

Troubleshooting

Several things would improve this method. The most important improvement involves the development of a track for the camera. Ideally, the camera would be still when an image is taken so that maximum resolution is achieved. There are several factors that must be taken into consideration when developing this track. First, reflection significantly alters the images, so a shield from the camera to the area being scanned should be incorporated. Second, high resolution is required for the best results. This requires a separate camera lens, or the camera needs to be close to the track (the zoom function on the camera is digital, not optical). Having a system in which the camera can be adjusted closer or farther to the core based on the required resolution would be ideal. This introduces a logistical point: the track must be out of the way, or its design flexible enough for it to be moved out of the way immediately after the scan. The other major concern is time. For still images to be taken every 10 centimeters over the length of a 9.5-meter-long core, time could be a significant factor to consider. Third, the track needs to be controlled by software that assigns a depth to each image. The software needs to be able to adjust to the camera resolution and should display a real-time view of the core liner temperatures on the computer screen. The inclusion of a scale bar (the one already developed should be adequate if the images are taken while the camera is still) will help with quality control until the software system is fully in place.

Another critical issue that requires improvement is image processing. A software package needs to be developed that automatically creates downcore and downhole temperature profiles, incorporating the curated depth of the cores. Ideally, it would be flexible enough to allow variable image analysis (i.e., the selection of various analysis tools) and the selection of core temperatures in areas of interest. Similar software (LabView) exists for tracks currently used in the core laboratory, including the MST and the AMST. However, the camera software needs to be more robust. Image processing should be an integral part, blending overlapping images and providing a way to create downcore and downhole composite IR images that can be used in reports.

LEG 201 - PRESSURE CORE SAMPLER (PCS)

The PCS was deployed at six locations drilled during ODP Leg 201. Sites 1225 and 1226 are located in the eastern Equatorial Pacific in 3771 and 3308 meters of water depth, respectively. Sites 1227, 1228 and 1229 are located along the Peruvian Margin in 439, 274, and 151 meters of water depth, respectively. Site 1230 is located on the lower slope of the Peru Trench in 5086 meters of water depth. All six of these locations had been drilled previously on either ODP Legs 112 or 138 (Suess, E., von Huene, R., et al., 1988; Pisias et al., 1993).

Sediments at the six locations vary considerably (Suess, E., von Huene, R., et al., 1988; Pisias et al., 1993). The sequences at Sites 1225 and 1226 consist mostly of stiff, fine-grained nannofossil ooze. By contrast, the sediment records at Sites 1227, 1228 and 1229 are composed of alternating diatomaceous and siliciclastic pakages with occasional hardgrounds and coarse-grained units. The sequence at Site 1230 consists mostly of clay and diatom ooze.

The PCS was deployed 17 times on Leg 201, a total surpassed previously only by operations on Leg 164. The first seven runs, at Sites 1225 to 1229, were primarily undertaken to test whether the modified tool and cutting shoes would operate in rotary mode across a range of lithologies. The ten runs at Site 1230 were specifically targeted to construct an “in situ” gas concentration profile from shallow depths near the seafloor to deeper depths below intervals with gas hydrate.

Observations made from conventional cores on Leg 201 and the previous legs suggest that significant gas loss on the wireline trip may have occured at one site and possibly at two additional sites. Visible gas escape structures appeared in cores below 30 m at Site 685/1230. Structures potentially representing gas release also were documented between 58 and 62 mbsf at Site 681/1229. High headspace methane concentrations (>1000 L/L), which may signify gas concentrations approaching or exceeding saturation at depth, occurred at these two sites as well as at ODP Site 684/1227. Gas hydrate also exists in sediment at Site 685/1230 (Kvenvolden and Kastner, 1990).

Post-retrieval Processing

The PCS cores were degassed in rock polishing room at the top of the laboratory stack. Other than the pre-cruise cutting shoe modifications, the most significant change between Leg 164 and Leg 201 PCS operations was the location of gas venting. The PCS has connected inner and outer chambers with a sampling port to each. The inner chamber contains the sediment core (and excess borehole water in the case of a short core) of approximately 1465 mL, while the outer chamber contains borehole water of approximately 2700 mL. For many of the PCS cores on Leg 164, gas was released from the port to the inner chamber. With this configuration, however, unconsolidated sediment often extruded into the port and manifold at high pressure, clogging the system and preventing gas release. To rectify this problem, gas was released through the port of the outer chamber on PCS cores retrieved toward the end of Leg 164 (Dickens et al., 2000b). This configuration was used for all PCS cores on Leg 201.

Measurements of PCS data were kept simple on Leg 201. Time was recorded to the nearest half minute with a clock. Discrete pressures were obtained in psi using a pressure transducer inside of the PCS. When possible, these pressures were then corrected to account for the expected 14 psi reading at atmospheric pressure. Incremental gas volumes were recorded to the nearest 5 mL. The length of the sediment core was determined to the nearest 1 cm. Unlike on Leg 164, most of the extruded cores were in sufficiently good condition to accurately measure length A thermometer showed that the temperature inside of the laboratory stayed at 21 ± 2° C.

Sites 1225 and 1226 (Eastern Equatorial Pacific)

Two runs of the PCS were made at Site 1225. Core 201-1225A-29P recovered 1.00 meters of sediment under pressure using the Christensen auger shoe, and an additional 0.41 meters of sediment in the extended shoe. However, the recovery pressure was not determined because the port for the internal pressure transducer leaked. After ~30 minutes and possible release of some internal pressure, a gauge inserted into a side port indicated ~1200 psi. Approximately 70 mL of gas escaped through the manifold when the PCS was opened to atmospheric pressure. Core 201-1225C-32P recovered 1.00 meters of sediment using the RBI auger shoe. A gauge inserted ~30 min after recovery and several minutes after placement on ice showed 4800 psi. Over the following hour, the pressure of this core dropped to 4010 psi. No gas volume was determined when the PCS was opened to atmospheric pressure.

The PCS was also deployed twice at Site 1226, although targeted intervals were significantly deeper and harder than at Site 1225. Core 201-1226B-42P reached the rig floor at 6208 psig (6222 psi) with 1.00 meters of sediment using the Christensen auger shoe with cutting edges broken off in the hole. After placing this core on ice, the pressure decreased logarithmically to 4907 psi over 150 minutes. Approximately 60 mL of gas were released upon opening the tool to atmospheric pressure. Using the RBI Auger with PDC cutters, Core 201-1226E-21P recovered 1.00 m of sediment, but at atmospheric pressure. A post mortem autopsy revealed that a chert layer was present at the level of the ball valve and prevented the tool from sealing at depth. There was no damage to the cutting shoe or tool.

Numerous gas release experiments on Leg 164 demonstrated that all PCS cores consistently release 60 to 120 mL of air at high pressure (Paull, Matsumoto, Wallace, et al., 1996; Dickens et al., 2000). Experiments at Sites 1225 and 1226, which have very little methane according to headspace analyses, confirm this finding. Presumably, the air becomes trapped inside of the tool during deployment. Although PCS cores at these sites are scientifically uninteresting, they clearly show that the tool can collect full 1.00 meter-long cores at pressure in sediment other than fine-grained clay of the Blake Ridge.

Sites 1227, 1228 and 1229 (Peru Shelf)

One run of the PCS was made at Site 1227. However, Core 201-1227A-15P failed to recover a sediment core. Gas was not released from this core.

A single PCS run was also made at Site 1228. Core 201-1228A-23P recovered only 0.07 meter of sediment. A gauge inserted into the side port of the PCS gave a reading of 35 psi before placing the tool on ice. Approximately 60 mL of gas were released when the core was opened to atmospheric pressure. This gas was air as expected.

The PCS was deployed once at Site 1229 in an interval near where gas escape structures were described on Leg 112 (Suess et al., 1988). Core 1229-10P recovered a 0.86 meters of sediment at 78 mbsf. However, the release of gas from this core was not straight-forward. First, the pressure transducer apparently failed so a gauge was inserted into the side port. This gauge read 420 psi, a pressure slightly higher than expected assuming hydrostatic loading at this location. A second transducer was then connected to the side port but pressures oscillated between 19 and 100 psi over time even when the tool was closed on ice. After about an hour, the tool was opened and 2880 mL of gas were incrementally released though the manifold. Essentially all of this “gas” was composed of air. We assume the air was introduced during drilling; however, we do not understand where and how such a large amount of air entered the tool, or whether it relates to the anomalous pressure readings.

PCS Deployments at Site 1230 (Peru Trench)

Pressures measured on the rig floor for the 10 PCS deployments at Site 1230 ranged between 280 and 8086 psi, or 4 to 105% of hydrostatic pressure. The range in observed pressures, including values higher than hydrostatic, is similar to that obtained at sites on the Blake Ridge (Paull, Matsumoto, Wallace et al., 1996). However, these PCS pressures should not be used to accurately assess downcore variations in pressure. All PCS deployments trap a small volume of headspace air, as noted previously. Consequently, pressures inside of the PCS change as this headspace volume warms and cools between the subsurface and the first measurement on the rig floor (Dickens et al., 2000b).

The length of core recovered by the PCS at Site 1230 varied from 0.18 meters to 1.00 meters, with six of the deployments retrieving the maximum length. This overall core recovery is much better than at Sites 994, 995 and 997 where many PCS runs retrieved cores less than 0.50 meters (Paull, Matsumoto, Wallace, et al., 1996). Core-1230A-25P was extruded as a series of incoherent sediment masses that totaled 0.18 meters, a length that probably represents a maximum. All sediment cores recovered by the PCS are lithologically similar to surrounding cores recovered by APC or XCB at adjacent depths.

Total gas volumes released from the PCS ranged from 200 to 6330 mL. These volumes are primarily mixtures of He, air (N_2 and O_2), CH_4 and CO_2, although not all incremental volumes were analyzed. In general, He and air dominate the first 150 mL of gas because He was used to purge the small manifold volume (~30 mL) prior to gas release, and a small volume of air is trapped in the tool during deployment. With the exception of Core-1230B-4P, the total amount of air does not exceed 110 mL. Methane comprises most of the remaining gas after release of air, although CO_2 increasing constitutes a minor component at low pressure. These results are the same as found on Leg 164.

Gas Release Experiments

Gas escapes the PCS in a predictable manner. After recording an initial pressure on the rig floor (generally greater than 6000 psig at Site 1230), the pressure rises until the core is surrounded with ice and cooled. Pressure then decreases almost exponentially to reach a baseline value in about 100 minutes. Upon first opening the PCS to the manifold, a small volume of gas escapes and pressure plummets to less than 500 psig. With each successive opening of the PCS, an incremental loss of gas and drop in pressure occurs. The change in volume and pressure during these openings decrease with time until warmed, when an additional volume of gas exits the tool. These time-pressure-volume relationships are entirely consistent with gas release experiments at Sites 995 and 997 on the Blake Ridge (Paull, Matsumoto, Wallace, et al., 1996; Dickens et al., 2000a,b).

LEG 201 - DOWNHOLE TOOLS

Site 1225 – Preliminary Results from Downhole Tools

At Site 1225, five types of downhole tools were employed consisting of the (Adara) APC-temperature shoe, the DVTP, the DVTP-P, the APC methane tool, and the Fugro Pressure Corer (FPC). The results of these deployments are described below.

In Situ Temperature Measurements

Six reliable determinations of downhole temperatures were made at depths between 0 and 303 mbsf in Hole 1225A using the APC-temperature tool (APC-T) and the DVTP. *In situ* temperatures were estimated by extrapolation of the station data using thermal conductivities measured on adjacent cores to correct for the frictional heating on penetration. The 95% confidence intervals from the temperature fits are all less than 0.03° C. The estimated in situ temperatures from both the APC-T and DVTP define a gradient of 0.0174° C/m in the 300 mbsf of the sediment column.

Davis-Villinger Temperature Probe with Pressure (DVTP-P)

The Davis-Villinger Temperature Probe with Pressure (DVTP-P) was deployed unsuccessfully twice in Hole 1225A at depths of 205.3 and 303.7 mbsf. The recorded data indicated that during both runs the non-indurated, fine-grained, formation sediments clogged the filter. During the second run, there was a pressure drop to roughly atmospheric level during penetration. This failure was attributed to a leak in the line connecting the pressure transducer to the probe tip.

Other Tools

The APC Methane tool (APC-M) under development is designed to continuously record temperature, pressure, and conductivity at the face of the ODP APC piston assembly during core ascent. The APC-M provides a continuous record of sediment gas temperatures, internal pressure, and timing of gas headspace formation during core recovery. The APC methane tool was deployed in Hole 1225A continuously from Core 1225A-5H through Core 1225A-14H. The recovered data from this run showed that the tool and data logger initially functioned correctly. Part way through the run during Core 1225A-10H, the data logger stopped recording. Upon recovery, the failure was attributed to a loose battery connection. The data from the APC-M will be analyzed post cruise.

Site 1226 – Preliminary Results from Downhole Tools

At Site 1226, three different downhole tools were employed: the APC-temperature shoe, the DVTP, and the DVTP-P. The results of these deployments are described below.

In Situ Temperature Measurements

Fourteen reliable determinations of downhole temperature were made at depths between 0 and 400 mbsf at Site 1226 using the (Adara) APC-temperature tool and the DVTP. In situ temperatures were estimated by extrapolation of the station data using thermal conductivities measured on adjacent cores to correct for the frictional heating on penetration. With the exception of the measurement from 310 mbsf, all of the temperature fits had 95% confidence intervals less than 0.01° C.

The estimated in situ temperatures from both the APC-T and the DVTP define a gradient of 0.0572° C m^{-1} in the upper 400 meters of the sediment column.

Davis-Villinger Temperature Probe with Pressure (DVTP-P)

The DVTP-P was deployed twice at Site 1226. During the first run in Hole 1226B at 241.9 mbsf, there was an initial pressure increase of 0.2 MPa during penetration followed by a drop of 12 MPa. Within two minutes pressures abruptly rose again to roughly hydrostatic levels. An average pressure signal equivalent to in situ hydrostatic pressure with ~0.1–0.2 Mpa of noise was recorded during the remainder of the 30-minute deployment. The abrupt drop in pressure was attributed to a leak near the probe tip. The results of the second deployment in Hole 1226E at 326 mbsf show that the pressure leak was successfully repaired. The pressure record rose as expected on penetration and then dropped to hydrostatic over the next minute. The pressure then remained constant at hydrostatic with 0.1–0.2 MPa noise for the remainder of the 20 minute deployment interval. These data indicate that the seal of the formation around the probe tip was probably not very good and that the tool should be pushed in with greater force in the future.

Site 1227 – Preliminary Results from Downhole Tools

At Site 1227, the three downhole tools deployed were the APC-temperature shoe, the DVTP, and the DVTP-P. The results of the temperature and pressure measurements at Site 1227 are described in the two sections below.

In situ Temperature Measurements

Determinations of temperature were made at Site 1227 using the APC-temperature tool and the DVTP. Both of these downhole temperature records were either of poor quality or deviated from the values expected from the ODP Leg 112 Site 684 data (Suess et al., 1988). Data were collected from two DVTP deployments at 81.6 and 110.1 mbsf. Both records show considerable small-scale oscillations and double peaks when the tool is first pushed into the sediments. The record from 81.6 mbsf (after Core 201-1227A- 9H) lasts for only five minutes before the temperature jumps up and again decays for the remainder of the 10 minute deployment. The record for the lower thermistor from 110.1 mbsf (after Core 201-1227A-12H) is too noisy to be used.

In situ temperatures were estimated by extrapolation of the station data using thermal conductivities measured on adjacent cores to correct for the frictional heating on. Generally, the data from the lower thermistor are used to extrapolate the in situ temperature. The poor lower thermistor data quality for the deployment at 110.1 mbsf (after Core 201-1227A-9H) necessitated using the upper thermistor record instead.

The combined in situ temperatures of Sites 1227 and 684 (ODP Leg 112) define a gradient of 0.0492° C m^{-1} in the upper 110 meters of the sediment column.

Comparing lithology from locations that produced good and bad temperature decay profiles showed some differences that may be used to optimize future DVTP deployments. The better DVTP deployment at 81.6 mbsf occurred between cores comprised of clay and nannofossil-bearing diatom ooze (Cores 201-1227A- 9H and -10H). These fine-grained sediments are similar to those from Site 1225 and 1226 where the acquired temperature data were excellent. In contrast, the second deployment location at 100.1 mbsf occurred between cores of pyrite and diatom-rich silty clays with sandsized particles (Cores 201-1227A- 12H and -13H). These sediments were significantly more coarse-grained than those cored from above and below the better deployment. Accumulation of gravel in the base of the hole does not appear to have differed between the two deployments. Both locations had about 40 centimeters of gravel at the top of the subsequent core.

Another aspect of Site 1227 that may be important is the shallow 423 meters water depth compared to over 3000 meters water depth at Sites 1225 and 1226. The increased noise in the data may be due to the greater influence of heave or currents on the tool in shallow water. It appears that for deployments in shallow water the best strategy may be to choose fine-grained intervals for the deployments.

Davis-Villinger Temperature Probe with Pressure (DVTP-P)

The DVTP-P was deployed once at Site 1227 at a depth of 132 mbsf (after Core 201-1227A- 14H). The record shows a relatively noise free signal with the expected sharp pressure increase when the tool was pushed into the sediments. Within two minutes the pressure drops to the value initially recorded at the base of the hole. A pressure signal equivalent to in situ hydrostatic pressure with relatively little noise was recorded during the remainder of the 30-minute deployment. The rapid return to hydrostatic pressure suggests that the sealing of the formation around the tool was poor. The abrupt drop in pressure for one data value after 40 seconds appears to be a less severe version of the problem experienced at Site 1226 and is attributed to a leak near the probe tip.

Site 1228 – Preliminary Results from Downhole Tools

At Site 1228, the downhole tools employed were the APC-temperature shoe, DVTP, DVTP-P, APC-M, and the Fugro Pressure Corer. The results of the temperature and pressure measurements at Site 1228 are described in the sections below.

In Situ Temperature Measurements

Two reasonably good downhole temperature determinations were made in Hole 1228A using the DVTP. An APC-temperature shoe deployment before Core 201-1228A-1 yielded a value for the bottom water temperature of 13.7° C. There were two successful DVTP deployments at 80.9 and 194.6 mbsf. Two other deployments at 42 mbsf and 137.9 mbsf resulted in unsatisfactory records.

In situ temperatures were estimated by extrapolation of the station data using thermal conductivities measured on adjacent cores to correct for the frictional heating on penetration. For both of the successful Site 1228 deployments, the data from the lower thermistor were used to extrapolate the in situ temperature. Because we obtained only two good downhole temperature estimates at Site 1228, the results from ODP Leg 112, Site 680 (Suess, et al., 1988) were included in the thermal gradient estimate.

The combined downhole temperatures of Sites 1228 and 680 define a gradient of 0.0336° C m^{-1} in the upper 196 mbsf of the sediment column.

Comparing lithology and depth from locations that produced good and bad temperature data showed some differences that may be used to optimize future DVTP deployments. The two successful deployments were located at 80.9 mbsf and 194.9 mbsf. The sediments surrounding the first location were comprised of diatom-rich silty clay and recoveries averaged 70% (Cores 201-1228A-9H and 10H). The second location, near the base of the hole, was overlain by clay-bearing quartz feldspar sand and recovery was 41% (Core 201-1228A-22H). Two failed deployments were located at 42.9 mbsf and 137.9 mbsf. The first interval was comprised of silt, ash, and diatom ooze and the recoveries for the surrounding cores (Cores 201-1228A-5H and 6H) were 80% and 98%. However, for sediments cored in Hole 201-1228B over this same interval, recovery dropped to 60% (Core 201-1228B-5H). The worst deployment was at 137.9 mbsf in sandy clay where no sediments recovered in the subsequent core (Core 201-1228A-17H). Site 1228 was located in shallow water at a depth of 261 meters. These observations indicate that in shallow water sites where recoveries can be poor, deployments may be more successful deeper in the hole and in intervals with higher recoveries.

Davis-Villinger Temperature Probe with Pressure (DVTP-P)

The DVTP-P was deployed once at Site 1228 at a depth of 196.9 mbsf (after Core 201-1228A- 22H). There was a sharp pressure increase when the tool was pushed into the sediments. The pressure drops within three minutes to about 4.74 MPa, which equals the predicted hydrostatic value for the hole depth and measured salinity gradient. For remainder of the 30-minute deployment, the pressure oscillates at 4.76 +/- 0.02 MPa. The amplitude of the oscillation corresponds to ~4 meters of head making it larger than the ~1-meter heave of the ship. However, periodic displacement of the drillpipe in the borehole, could amplify the oscillations caused by heave.

Other Tools

The APC-Methane tool was successfully run continuously from Cores 201-1228A-9H to 14H. The tool appeared to function correctly and the data will be analyzed post cruise.

The Fugro Pressure Corer (FPC) was tested three times at Site 1228 at 7.3 mbsf, 54.3 mbsf, and 109.4 mbsf (Cores 201-1228E-2M, 1228B-7M, and 1228A-13M respectively). Due to a number of mechanical problems, the FPC failed to retrieve pressurized cores on any of the deployments. The one attempted use of the PCs (201-1228A-23P) resulted in only 7-centimeters of recovery from the 2 meter-long cored interval.

Site 1229 – Preliminary Results from Downhole Tools

At Site 1229, the downhole tools employed were the Adara temperature shoe, DVTP, DVTP-P, APC-M, and the Fugro Pressure Corer. The results of the temperature and pressure measurements at Site 1229 are described in the sections below.

In situ Temperature Measurements

One good downhole temperature determination was made in Hole 1229A using the DVTP. An APC-temperature shoe deployment before Core 201-1229A-1H yielded a value for the bottom water temperature of 14.9° C. A successful DVTP deployment was made at 164.9 mbsf. Four other deployments at 33.4 mbsf, 64.8 mbsf, 77.8 mbsf, and 107.9 mbsf resulted in records that could not be used.

Because we obtained only one good downhole temperature value at Site 1229, the results from ODP Leg 112, Site 681 (Suess, et al., 1988) were included in the thermal gradient estimate. Due to a variety of problems documented by the Leg 112 Shipboard Scientific Party (1988), each of the estimates for Site 681 is denoted as either an upper or lower bound on the true formation temperature. These constraints were used to define a line that passed through the single value for Site 1229 and honored the Site 681estimates. The combined downhole temperatures yield a linear gradient of 0.0355° C m^{-1} in the upper 187 meters of the sediment column.

The failure rate for DVTP measurements attributed to formation conditions increased at Site 1229 to a high of 80% compared to 50% at Sites 1227 and 1228 and 0% at Sites 1225 and 1226. The one successful measurement at Site 1229 was the deepest deployment attempted at 164.9 mbsf. It was located in lithologic Unit II, which is comprised of alternating sand and silt, and the subsequent core had the lowest recovery compared to the other four deployments (43%). The four unsuccessful deployments were located at shallower depths in silt, clay, or diatom ooze. These results indicate that deployments of the DVTP in shallow water (<200 meters) may be less likely to succeed at depths below 150 mbsf.

Davis-Villinger Temperature Probe with Pressure (DVTP-P)

The DVTP-P was deployed once at Site 1229 at a depth of 79.4 mbsf (after Core 201-1229A- 9H). The lithology for this depth was comprised of diatom-rich ooze with an average porosity of 75%. The expected sharp pressure increase occurred when the tool entered the formation, followed by a sharp drop within one minute to about 2.42 MPa, which equals the predicted hydrostatic value for the hole depth and measured salinity gradient. For the remainder of the 30-minute deployment, the pressure oscillates at 2.42 +/- 0.02 MPa. The amplitude of the oscillation corresponds to ~4 meters of head, which was comparable to the oscillations at Site 1228. An investigation into the cause of the oscillations is needed.

Other Tools

The APC Methane tool was run continuously from Cores 201-1229A-1H to 1229A-10H. The tool appeared to function correctly and the data will be analyzed postcruise.

The Fugro Pressure Corer (FPC) was tested twice at Site 1229 at 24.4 mbsf and 174.4 mbsf (Cores 201-1229B-4M and -1229A-20M respectively). Due to a number of mechanical problems, the FPC failed to retrieve pressurized cores on either deployment. The single deployment of the PCS (201-1229D-10P) successfully recovered 0.86 meters of sediment from the 2 meter-long cored interval.

Site 1230 – Preliminary Results from Downhole Tools

At Site 1230, the downhole tools employed were the APC-temperature shoe, DVTP, and the DVTP-P. The results of the temperature and pressure measurements at Site 1230 are described in the sections below.

In situ Temperature Measurements

Three downhole temperature determinations were made at Site 1230 using two DVTP deployments in Hole 1230A and one in Hole 1230B. Two APC-temperature shoe deployments at the seafloor yielded values for the bottom water temperature of 1.74–1.75° C. Data were collected from successful DVTP deployments at 33.3 mbsf, 100 mbsf, and 254.6 mbsf. Three other deployments at 73.5 mbsf, 79.9 mbsf, and 148.3 mbsf resulted in records that could not be used.

The combined downhole temperatures yield a linear gradient of 0.034° C m^{-1} in the upper 255 meters of the sediment column.

The failure rate for DVTP measurements attributed to formation conditions at Site 1230 was 50%, compared to 80% at Site 1229, 50% at Sites 1227 and 1228, and 0% at Sites 1225 and 1226. To evaluate the causes of the failures, the conditions of the formation at each location were evaluated by noting the recovery, lithology, and disturbance of the subsequent core. The differences in outcome do not appear to be related to either lithology or core recovery. Instead, the degree of disturbance in the subsequent core may be significant. Although the cause of core disturbance on recovery is not known, areas of multiple fractures, voids, and crumbly fabric were common in the interval with high methane concentrations and gas hydrates. Moreover, the three failed deployments were located at 70–80 mbsf and 148–150 mbsf where the pore water lithium concentrations indicate the highest hydrate concentrations. On the basis of these observations, the best strategy for obtaining high quality temperature data in hydrate-bearing formations may be to identify depths of highest hydrate concentrations in the first hole and avoid these depths by deploying the tool in subsequent holes.

Davis-Villinger Temperature Probe with Pressure (DVTP-P)

The DVTP-P was deployed twice at Site 1230 with one successful run at a depth of 102.5 mbsf (after Core 201-1230A-14H). The results of this deployment indicate overpressure in the formation relative to the base of the hole. This deployment did not get a pressure spike at the start because the tool was pushed in extremely slowly over several minutes. The slow deployment strategy was suggested to increase the penetration depth of the tool without exceeding acceptable pressure on bit in the relatively stiff formation. The success of this strategy is evident from the 0.14 MPa difference between formation pressure and the hydrostatic pressure measured in the base of the hole for 5 minutes at the end of the deployment. For a reasonable formation permeability of ~10^{-16} m^2, the measured overpressure is adequate to produce flow at a rate of ~5 mm/yr.

HYDRATE STUDIES – SITE 1230

Solid pieces of gas hydrate were recovered from two discrete intervals at Site 1230. Evidence of gas hydrate was identified in several additional cores below 80 mbsf. Infrared camera core temperature measurements as well as chemical and physical property data suggest that gas hydrate occurs, at least intermittently, from ~70 mbsf to the base of the recovered interval at 278.3 mbsf. Preliminary calculations from methane gas volumes released from the PCS further show that methane concentrations highly exceed hydrate saturation at many depths sampled below about 70 mbsf.

Initial Core Inspection and Hydrate Sampling

All cores from Site 1230 were inspected immediately after retrieval for indications of gas hydrate using visual identification and thermal scanning with an infrared camera. Signals of interest included the presence of white nodules, fizzing materials, or unusually cold spots. As soon as the core liner had been placed on the catwalk, the IR camera was run along the core to identify unusually cold core liner temperatures. Intervals recognized by the camera operator as potential gas hydrate zones were immediately cut out of the core and split. The split core surfaces were inspected for hydrate nodules or areas that were fizzing, which might indicate the occurrence of disseminated gas hydrate in the sediment.

Small pieces of massive gas hydrate were recovered from sediments of lithologic Subunit IB at ~80 mbsf (Hole 1230B) and the top of Subunit ID at ~148 mbsf (Hole 1230A). A 5 cm^3 hydrate piece from Core 201-1230B-12H was scraped with a spatula to remove surrounding sediment and placed into a syringe to collect gas and water for geochemical analyses. The remaining scraped sediment was then collected for microbiological analyses. Most other hydrate pieces were too small to be sampled in this manner. One fizzing and anomalously cold 15-centimeter-long whole-round section (Sample 201-1230A-19H-1, 135–150 cm) was also squeezed for interstitial water. Three other sections probably contained disseminated gas hydrate based on observed fizzing and temperatures as low as –3.2°C, but discrete hydrate pieces were not recovered.

IR Camera

Infrared (IR) thermal imaging was used to compare non-hydrate bearing and hydrate-bearing cores from Site 1230. Core 1230A-6H did not contain hydrate, and has a homogeneous temperature distribution downcore. In contrast, Core 1230A-19H exhibits wide temperature changes between hydrate-bearing sediment, which is cold compared to surrounding sediment, and voids, which are warm compared to surrounding sediment. The occurrence of gas hydrate in this core was confirmed at the core top (148.3 mbsf). Several other cores exhibited negative temperature excursions of about –5° C and also may have contained hydrate layers. The shallowest temperature anomaly occurred at ~71 mbsf in Core 1230A-10H. These results from Site 1230 illustrate the potential benefit of infrared thermal imaging for identifying gas hydrate in sediment cores immediately after retrieval.

Lithology and Gas Hydrate Occurrence

Sediments surrounding the interval of the upper hydrate sample consist of dark gray to olive clay- bearing diatom silt and diatom-rich nannofossil silt (Cores 1230B-11H and 12H; 73.5 mbsf to 90.5 mbsf). Diatom contents range between 20% and 40%. High angle normal faults with offsets of several centimeters occur in Sections 1230B-11H-4, 11H-5, and 12H-6. The sediments are characterized by pervasive cleavage with both low-angle and horizontal attitude. The recovered hydrate samples from Core 1230B-12H consisted of several vertical to sub-vertical wavy veins of white gas hydrate, up to 3 mm thick, separated by dark gray sediment.

Sediments surrounding the lower hydrate consist of dark gray to black quartz-bearing clay-rich diatom ooze (Cores 1230A-18H and 19H; 138.8 mbsf to 156.8 mbsf). Diatom contents vary between 40% and 75%. The sediments have a stiff and highly fractured appearance and recovery was generally low throughout the subunit, possibly due to a combination of fracturing and high gas concentrations, which may have caused part of the sediment to blow out of the core barrel during retrieval. Horizontal to low-angle foliation is common in most cores of Subunit ID. In addition, Section 1230A-19H-2 was characterized by two high-angle (~30%) cleavage directions. The co- occurrence of steeply dipping gas hydrate veins, pervasive cleavage, and the presence of high-angle normal faults at least in the upper part of the hydrate-bearing interval suggests a possible close relationship between locations of gas hydrate precipitation and tectonic features at Site 1230.

Core Disturbance

Extensive core disturbance was noted in most of the cores below Core 1230A-3H. The following types of disturbance (ranging from a few cm to tens of cm in vertical extent) were described from this interval and compared with other evidence for gas hydrate:

1. Voids marked by clear separation of sediment and bounded on either side by disturbances of either type 2 or 3 below. In this category we specifically did not include voids where the separation was bounded by planar surfaces without other disturbance, because these can (and were observed to) form on the catwalk when the core liners were drilled to relieve pressure for safety reasons.

2. Crumbling of the sediment. Zones where the sediments are wholly or partially disaggregated adjacent to undisturbed sediment. For this category, we did not consider any core disturbance that was located at the top of a core.

3. Zones of splitting perpendicular to the core axis (i.e., parallel to bedding) where cracks are commonly more closely spaced than elsewhere in the core. In many cases there is a gradation from very closely spaced cracks near the center of the zone, to more widely spaced cracks.

While disturbance alone does not indicate hydrate occurrence, it suggests depth intervals where very high concentrations of methane could potentially support hydrate formation.

CONCLUSION

The primary accomplishment of the JOI Cooperative Agreement with DOE/NETL in this quarter was the preparation for deployment of tools and measurement systems for use on ODP Leg 204, to characterize and investigate gas hydrate deposits on Hydrate Ridge, offshore Oregon in July 2002. An additional accomplishment was a review of the results obtained from the deployment of these systems on ODP Leg 201 to incorporate the "lessons learned" from that testing into the planning for Leg 204.

Following several modifications to the tool since ODP Leg 164, the PCS was deployed 17 times on Leg 201. Eleven deployments were entirely successful, collecting between 0.5 and 1.0 meters of sediment at greater than 75% of hydrostatic pressure. The PCS gas manifold was used in conjunction with the PCS throughout ODP Leg 201 to measure the total volume and composition of gases recovered in sediment cores, and especially in those cores associated with methane hydrate.

These deployments were designed to address two primary purposes: (1) to test the capabilities of the tool across a range of lithologies and depths, and (2) to generate a gas concentration profile where all abundant evidence indicates the extreme loss of gas on the wireline trip. Both objectives were met fairly successfully. Eleven cores of greater than 50 cm length were retrieved at greater than 75% hydrostatic pressure. Another two PCS deployments collected cores less than 50 cm length but at greater than 75% hydrostatic pressure, and another two PCS deployments came to the ship with cores greater than 50 cm length but less than 20% hydrostatic pressure. Only two PCS deployments, both taken on the Peru Shelf, failed to recover a significant sediment core or core barrel at pressure. Of the sediment cores collected, all could be extruded as coherent masses except Core 1230A-25P. The tool definitely performed better on Leg 201 compared to Leg 164.

The DVTP, DVTP-P, APC-Methane, and APC-Temperature tools (ODP memory tools) were used extensively during ODP Leg 201 aboard the D/V JOIDES *Resolution*. These systems will provide a strong operational capability for characterizing the in situ properties of methane hydrates in subsurface environments on Hydrate Ridge during ODP Leg 204, as well as in other offshore sedimentary environments.

Previous work at (ODP Leg 112) Site 685 suggested that gas hydrates occurred below 40 mbsf but were concentrated in two intervals at about 107 mbsf and 165 mbsf (Suess et al., 1988; Kastner and Kvenvolden, 1990). Information collected at Site 1230 supplements these findings. The gas hydrate samples found at Site 1230 are offset from those of Site 685 by approximately 20 meters. One of the gas hydrate pieces recovered at Site 1230 was composed of several-millimeter thick layers oriented at a high angle to bedding surfaces. It is suspected that this gas hydrate was associated with a fault plane, because small high- angle faults were common at Site 1230 and because previous work has shown a link between faults and gas hydrate occurrence.

At other ODP sites with gas hydrate much of the hydrate is inferred to be disseminated in pore space and most does not survive the wireline trip (e.g., the Blake Ridge, Paull et al., 1996). This may also be the case at Site 1230.

The deployment of modified downhole measurement tools and pressure core sampling systems on ODP Leg 201 provides a wealth of experience for meeting the challenges of a dedicated hydrate coring program on ODP Leg 204 on Hydrate Ridge, offshore Oregon during July through September of 2002.

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LIST OF ACRONYMS AND ABBREVIATIONS

APC	Advanced Piston Corer
BHA	Bottom Hole Assembly
DOE	Department of Energy
DVTP	Davis Villinger Temperature Probe
DVTP-P	Davis Villinger Temperature Probe with Pressure
FPC	Fugro Pressure Corer
HRC	HYACE Rotary Corer
HYACE	Hydrate Autoclave Coring Equipment
HYACINTH	Deployment of HYACE tools In New Tests on Hydrates
IR-TIS	Infrared Thermal Imaging System
JOI	Joint Oceanographic Institutions
JOIDES	Joint Oceanographic Institutions for Deep Earth Sampling
KHz	Kilohertz
LDEO	Lamont Doherty Earth Observatory (Columbia University)
L/L	Liters per Liter
LTC	Laboratory Transfer Chamber
MBRF	Meters Below Rig Floor
MBSF	Meters Below Sea Floor
MCDB	Motor Driven Core Barrel
mL	Milliliter
MSCL-V	Multi-Sensor Core Logger - Vertical
NETL	National Energy Technology Laboratory
NSF	National Science Foundation
ODP	Ocean Drilling Program
ODP-LC	Ocean Drilling Program – Logging Chamber
PCS	Pressure Core Sampler
PSI	Pounds per Square Inch
RAB	Resistivity at the Bit
RAB-c	Resistivity at the Bit with Coring
R/V	Research Vessel
TAMU	Texas A&M University
XCB	Extended Core Barrel

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