SUPPORT OF GULF OF MEXICO HYDRATE RESEARCH CONSORTIUM: ACTIVITIES TO SUPPORT ESTABLISHMENT OF A SEA FLOOR MONITORING STATION PROJECT

SEMIANNUAL TECHNICAL REPORT
1 DECEMBER, 2004 THROUGH 31 MAY, 2005

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* includes seismo-acoustic characterization of sea-floor properties and processes at the hydrate monitoring station until VSP data can be collected

DISCLAIMER

ABSTRACT

The Gulf of Mexico Hydrates Research Consortium was established in 1999 to assemble leaders in gas hydrates research. The group is administered by the Center for Marine Resources and Environmental Technology, CMRET, at the University of Mississippi. The primary objective of the group is to design and emplace a remote monitoring station or sea floor observatory on the sea floor in the northern Gulf of Mexico by the year 2005, in an area where gas hydrates are known to be present at, or just below, the sea floor. This mission necessitates assembling a station that will monitor physical and chemical parameters of the sea water and sea floor sediments on a more-or-less continuous basis over an extended period of time. Development of the station has always included the possibility of expanding its capabilities to include biological monitoring, as a means of assessing environmental health. This possibility has recently received increased attention and the group of researchers working on the station has expanded to include several microbial biologists. Establishment of the Consortium has succeeded in fulfilling the critical need to coordinate activities, avoid redundancies and communicate effectively among researchers in this relatively new research arena. Complementary expertise, both scientific and technical, has been assembled to promote innovative research methods and construct necessary instrumentation.

Initial components of the observatory, a probe that collects pore-fluid samples and another that records sea floor temperatures, were deployed in Mississippi Canyon 118 in May of 2005. Follow-up deployments are planned for fall 2005 and center about the use of the vessel *M/V Ocean Quest* and its two manned submersibles. The subs will be used to effect bottom surveys, emplace sensors and sea floor experiments and make connections between sensor data loggers and the integrated data power unit (IDP). Station/observatory completion is anticipated for 2007 following the construction, testing and deployment of the horizontal line arrays, not yet funded.

The seafloor monitoring station/observatory is funded approximately equally by three federal Agencies: Minerals Management Services (MMS) of the Department of the Interior (DOI), National Energy Technology Laboratory (NETL) of the Department of Energy (DOE), and the National Institute for Undersea Science and Technology (NIUST), an agency of the National Oceanographic and Atmospheric Administration (NOAA).

Noteworthy achievements funded with DOE's contributions to this multiagency effort include:

- Progress on the vertical line array (VLA) of sensors:
  - One of the VLAs has been redesigned to collect near sea floor geochemical data and is readied to be equipped with thermistors, fluorometers, transmissometers, mass spectrometers, conductivity and current flow meters. Although the sensors have not yet been incorporated into the array, the sensor interface has been defined and includes options

  - for various serial communications, optional power levels and voltages, power drain monitoring, power and communications control, a mechanical protocol and in-water weight limits. This new array has been dubbed the oceanographic line array or OLA.
  - Repair attempts of the VLA cable damaged in the October, 2004, at >1000m water depth deployment failed; a new design has been tested successfully on 5 deployments in Italy and incorporated into the OLA and new VLA.
  - A new Remotely Operated Vehicle (ROV) mateable connector system was designed and installed in the VLA DATS system deployed in 2005. This improved design has been incorporated into the VLA and the OLA components of the observatory.
  - Additional acoustic modems with greater depth rating and the appropriate surface communications units have been purchased.
  - The VLA and OLA DATS computer and software programs were modified to include three forms of communications to the termination of a sea floor fiber optic link: a "T0" timing pulse for coordinating gun firing with the bottom VLA DATS, a serial command line for control and housekeeping functions, and a high speed Ethernet communications capability for large volumes of data recovery expected from the VLA DATS.
  - Positioning sensors – including compass and tilt sensors – have been completed and tested. Pressure housings rated twice that of any anticipated deployment have been built and pressure tested.
  - Enclosing most metal components in neoprene jackets with an oil fill has been accomplished in an effort to provide a barrier to sea water and, therefore, corrosion, thereby extending the deployed life of the components. Remaining metal components are being addressed with anodes and new coating methods to inhibit corrosion.

- Progress on the Sea Floor Probe:
  - The SFP penetrometer was tested on a January, 2005, cruise to MC118 to determine the depth to which the probe could penetrate bottom sediments at the observatory site.
  - The SFP geophysical and pore-fluid probes, sensor systems to be deployed via the SFP, were adapted for the appropriate depth.
  - In May, 2005, cores were recovered from MC118 via the SFP gravity driven corer to determine where the sensors should be deployed.
  - During the May, 2005, cruise, both a thermistor array and a pore-fluid sampling array were deployed at MC118 via the SFP.

- .Progress on the Acoustic Systems for Monitoring Gas Hydrates:
  - A second system concept was designed but not built for lack of continued funding.

- Progress on the Electromagnetic Bubble Detector and Counter:
    - This system was completed in the previous reporting period and is ready for deep water deployment.

- Progress on the Mid-Infrared Sensor for Continuous Methane Monitoring:
    - Experimental investigations of IR-ATR signal generation were performed to facilitate precise insight into ‘active’ sensing regions along planar ATR waveguides; Results reveal discrete sensing regions along multi-reflection waveguides providing valuable knowledge for optimizing construction designs of deep-sea IR-ATR sensing probes.
    - Complementary spectral ray tracing simulations establish a virtual environment for rational development and evaluation of deep-sea probe configurations. Spectral ray tracing simulations facilitate efficient evaluation of light guiding optics and sensor transducers. Resulting, an optimal selection and arrangement of optical components for deep-sea sensing probes and optics platform for ‘SphereIR’ can be established.
    - Modifications to the pressure vessel to simulate hydrate formation and spectroscopic investigations of hydrate formation and dissociation via fiber-optic evanescent field spectroscopy include development of a custom high-pressure viewport and custom high-pressure fiber-optic feed-throughs to confirm synthetic hydrate formation and evaluate this spectroscopic technique’s ability to monitor hydrate formation and decomposition.
    - State-specific changes to the infrared spectra of water provide the ability to monitor *in-situ* formation and dissociation of gas hydrates.

- Progress on the Seismo-acoustic Characterization of Sea Floor Properties and Processes at the Hydrate Monitoring Station:
    - All system components underwent extensive testing in preparation for determining sea floor acoustic reflection responses at the Gas Hydrate Monitoring Station.
    - The system is essentially ready for testing at sea.

- Progress on the Data Management and Processing Software for the Sea-floor Monitoring Station:
    - Sensor and data characterization for the monitoring station have been completed, although finalization of these selections remains open until deployment of the systems themselves.
    - The design of the data management and archive system that will accept data from station sensors and serve data requests from users of the monitoring station has been completed.

- Progress on the Applications of VSP Technology for Evaluation of Deep-Water Gas Hydrate Systems* at the University of Texas Bureau of Economic Geology's Exploration Geophysics Laboratory, EGL (seismo-acoustic characterization of sea-floor properties and processes at the hydrate monitoring station until VSP data can be collected):
    - EGL has developed software that will interpolate chirp sonar data to a uniform trace sampling interval.
    - EGL has developed software that will convert chirp sonar coordinates to standard seismic coordinates.
    - The above-mentioned developments will facilitate comparison of chirp-sonar data to other seismo-acoustic data

- Progress on the Coupling of Continuous Geochemical and Sea-floor Acoustic Measurements:
    - A sea-floor probe that enables geochemical sampling over a range of depths has been designed and built.
    - The sea-floor probe has been deployed in MC118 where its osmosamplers will collect samples continuously for about six months.
    - Core data have been collected from mC118 in an effort to characterize the site, geochemically.

- Progress on the Microbial Activity Related to Gas Hydrate Formation and Sea-floor Instabilities:
    - Laboratory tests were conducted on the Marion Dufresne core MD02-2570 from Mississippi Canyon to determine if natural-gas hydrates would form and if so, what conditions influence their formation.
    - In MD02-2570, it was found that both induction time and formation rate for gas hydrates are depth-dependent.
    - In MD02-2570, it was found that formation of gas hydrates was also impacted by the mineralogy of the clay fraction of the host material.

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Graphical materials used to illustrate reports can be found in the individual reports submitted by the subcontractors.

INTRODUCTION / PROJECT SUMMARY

The Gulf of Mexico-Hydrate Research Consortium (GOM-HRC) is in its fifth year of developing a sea floor station to monitor a mound where hydrates outcrop on the sea floor. The plan for the Monitoring Station/Sea Floor Observatory (MS/SFO) is that it be a multi-sensor station that provides more-or-less continuous monitoring of the near-seabed hydrocarbon system, within the hydrate stability zone (HSZ) of the northern Gulf of Mexico (GOM). The goal of the GOM-HRC, is to oversee the development and emplacement of such a facility to provide a better understanding of this complex hydrocarbon system, particularly hydrate formation and dissociation, fluid venting to the water column, and associated microbial and/or chemosynthetic communities. Models developed from these studies should provide a better understanding of gas hydrates and associated free gas as: 1) a geo-hazard to conventional deep oil and gas activities; 2) a future energy resource of considerable significance; and 3) a source of hydrocarbon gases, venting to the water column and eventually the atmosphere, with global climate implications.

The GOM-HRC initially received funding from the DOI Minerals Management Service (MMS) in FY1998. Funding from the DOE National Energy Technology Laboratory (NETL) began in FY2000 and from the Department of Commerce National Oceanographic and Atmospheric Administration's National Undersea Research Program (DOC NOAA-NURP) in 2002. Some ten industries and fifteen universities, the USGS and the US Navy, Naval Meteorology and Oceanography Command, Naval Research Laboratory and NOAA's National Data Buoy Center are involved at various levels of participation. Funded investigations include a range of physical, chemical, and, most recently, microbiological studies.

EXECUTIVE SUMMARY

A consortium has been assembled for the purpose of consolidating both laboratory and field efforts of leaders in gas hydrates research. The Consortium, established at and administered by the University of Mississippi's Center for Marine Resources and Environmental Technology (CMRET), has, as its primary objective, the design and emplacement of a remote monitoring station on the sea floor in the northern Gulf of Mexico by the year 2005. The primary purpose of the station is to monitor activity in an area where gas hydrates are known to be present at, or just below, the sea floor. In order to meet this goal, the Consortium has begun assembling a station that will monitor physical and chemical parameters of the sea water, sea floor sediments, and shallow subseafloor sediments on a more-or-less continuous basis over an extended period of time. Central to the establishment of the Consortium is the need to coordinate activities, avoid redundancies and promote effective and efficient communication among researchers in this growing area of research. Complementary expertise, both scientific and technical, has been assembled; collaborative research and coordinated research methods have grown out of the Consortium and instrumentation for the sea-floor station has been and continues to be designed and constructed.

The MS/SFO was designed to accommodate the possibility of expanding its capabilities to include biological monitoring. A portion of FY04 funding from the Department of the Interior's Minerals Management Services has been directed toward this effort. This option will facilitate the study of chemosynthetic communities and their interactions with geologic processes in addition to providing an assessment of environmental health. In addition, the NOAA-NURP has, as a focal point, investigations of the effects of deep sea activities on world atmosphere and therefore, weather. Two projects currently funded through NURP's National Institute for Undersea Science and Technology (NIUST) support this effort in collaborations with the Consortium. At the February meeting of the GOM-HRC, the Consortium received assurances from the new NIUST Director that emplacement of a sea-floor microbial observatory is an objective of that agency. The possibility of incorporating such a facility into the MS/SFO was discussed and numerous advantages noted. This direction will be pursued.

The centerpiece of the monitoring station, as originally conceived, is a series of vertical line arrays of sensors (VLAs), to be moored to the sea floor. Each VLA was to have extended approximately 200 meters from the sea-floor. Sensors in the VLAs include hydrophones to record water-borne acoustic energy (and measure sound speed in the lower water column), thermistors to measure water temperature, tilt meters to sense deviations from the vertical induced by water currents, and compasses to indicate the directions in which the deviations occur. During discussions among the members of the geophysical subgroup of the Consortium, it was discovered that the project may be better served if some vertical arrays are converted to horizontal line arrays (HLAs). The prospective horizontal water-bottom arrays, will consist of hydrophones and 3-component accelerometers and will be laid upon, and pressed into, the soft sediment of the sea floor. They will be arranged into a cross so that they simulate two perpendicular arrays. Their deployment will be accomplished by means of a sea-floor sled designed to lay cable and deploy probes into shallow, unconsolidated sediments. This sled will also be used as a seismic source of compressional and shear waves for calibrating the subsurface seismo-acoustic array commissioned by the Joint Industries Program (JIP).

The prototype DOE-funded VLA has been completed together with the associated data logging and processing systems. The system consists of 16 hydrophones spaced at 12.5 meter intervals with an overall length of 200 meters. The sensitivity and spacing of the hydrophones is critical to the data acquisition process with regard to the objective focus on near sea floor features such as hydrate bodies. This system has been tested in several locations and in various configurations. Adjustments have been made and the VLA now stands in readiness for deployment at the site of the observatory. In addition, an Oceanographic Line Array (OLA) is ready to be equipped with any of a variety of geochemical sensors - thermistors, fluorometers, transmissometers, mass spectrometers, conductivity and current flow meters – and deployed at the observatory site, Mississippi Canyon 118 (MC118). The sensor interface for this array has been defined and includes options for various serial communications, optional power levels and voltages, power drain monitoring, power and communications control, a mechanical protocol and in-water weight limits. Processing techniques continue to be developed for vertical array data by Consortium participants who are currently funded by the Minerals Management Service.

The VLA cable damaged in the October, 2004, at >1000m water depth deployment has been replaced and a new design has been tested successfully on 5 deployments in Italy and incorporated into the OLA and new VLA. A new Remotely Operated Vehicle (ROV) mateable connector system was designed and installed in the VLA DATS system deployed in 2005. This improved design has been incorporated into the VLA and the OLA components of the observatory. Additional acoustic modems with greater depth rating and the appropriate surface communications units have been purchased. The VLA and OLA DATS computer and software programs were modified to include three forms of communications to the termination of a sea floor fiber optic link: a "T0" timing pulse for coordinating gun firing with the bottom VLA DATS, a serial command line for control and housekeeping functions, and a high speed Ethernet communications capability for large volumes of data recovery expected from the VLA DATS.

Positioning sensors – including compass and tilt sensors – have been completed and tested. Pressure housings rated twice that of any anticipated deployment have been built and pressure tested. Enclosing most metal components in neoprene jackets with an oil fill has been accomplished in an effort to provide a barrier to sea water and, therefore, corrosion, thereby extending the deployed life of the components. Remaining metal components are being addressed with anodes and new coating methods to inhibit corrosion.

Modifications to the original design of the Sea Floor Probe (SFP) were made following a January, 2005 test of the penetration capabilities of the SFP in the sediments at the site of the MF/SFO, MC118. In May, 2005, the SFP was used to retrieve core samples from MC118 as part of the effort to select sites appropriate for deployment of the geophysical and geochemical probes. The northwestern portion of the mound area defined on images recovered during a C&C autonomous underwater vehicle (AUV) survey April 30-May 2, 2005, was selected for probe deployments based on information from these cores. Both the pore-fluid array and the geophysical line array were deployed via SFP at MC118 in May, 2005.

An acoustic system has been designed that will estimate bubbling activity and characteristics at gas hydrate vents. The system that was constructed was found to be impractical for deep sea environments.

The electromagnetic bubble detector and counter field unit has been built and laboratory tests have been performed. Field testing of the system in the shallow water environment, Cape Lookout Bight, offshore North Carolina, in June, 2005, produced very positive results. The system is ready for testing in deep water.

Investigations of IR-ATR signal generation were performed to facilitate precise insight into 'active' sensing regions along planar ATR waveguides; Results reveal discrete sensing regions along multi-reflection waveguides providing valuable knowledge for optimizing construction designs of deep-sea IR-ATR sensing probes for the Mid-Infrared Sensor System. Complementary spectral ray tracing simulations establish a virtual environment for rational development and evaluation of deep-sea probe configurations. Spectral ray tracing simulations facilitate efficient evaluation of light guiding optics and sensor transducers. An optimal selection and arrangement of optical components for deep-sea sensing probes and optics platform for 'SphereIR' can be established.

Modifications to the pressure vessel to simulate hydrate formation and spectroscopic investigations of hydrate formation and dissociation via fiber-optic evanescent field spectroscopy include development of a custom high-pressure viewport and custom high-pressure fiber-optic feed-throughs to confirm synthetic hydrate formation and evaluate this spectroscopic technique's ability to monitor hydrate formation and decomposition. State-specific changes to the infrared spectra of water provide the ability to monitor *in-situ* formation and dissociation of gas hydrates

Hardware for the Seismo-acoustic characterization of sea floor properties and processes instrumentation has been completely assembled. The device will measure variations in seabed acoustic responses as indicators of stability or instability of the hydrate stability zone. The final device meets all design specifications. Field testing in shallow water has been; optimizing transducer specifications and packaging for deep water operations must be completed prior to deep sea deployment.

In their efforts to characterize monitoring station sensors and the data they would collect, Barrodale Computing Services (BCS) characterized all sensors proposed as part of the station. Situations in which the sensors were to function as well as physical parameters were tabulated using input from researchers as well as manufacturers.

BCS has also designed the data management architecture for the station. They addressed data and sensor configuration, rates of data production, storage of data, and user access to data. They used synthetic data to test their designs and the software package performed well. As soon as real data are retrieved, they will be plugged into the package and tested for accuracy, ease of use, and ease of management.

The Vertical Seismic Profiling data that were to have been collected, processed and analyzed at the University of Texas' Bureau of Economic Geology (BEG) have yet to be collected as the borehole has yet to be drilled. Until such time as access to a borehole in MC118 is possible, the BEG has agreed to work to develop software that can process and manipulate chirp-sonar data. Completion of this project will facilitate interpretation of several forms of data acquired by autonomous underwater vehicles (AUVs).

The first series of osmosamplers has been designed, constructed, and deployed in the sea-floor at MC118 via the SFP deployment system, along with an array of thermistors. Data-collection should be ongoing. A submersibles cruise is scheduled to return to the site to retrieve the box containing the continuously collected pore-fluid samples. The pore-fluid data will be analyzed and, eventually, correlated to continuously-collected geophysical data with the goal of tying geochemical and geophysical changes to changes in the HSZ.

Sediment subsamples were collected at 3m intervals from a core recovered by the scientific party aboard the R/V Marion Dufresne in July 2002. The sediment samples were analyzed for rate of formation and induction time verses depth in the core. The samples were also analyzed to determine grain size distribution and clay mineralogy. Results of these laboratory analyses show that hydrate formation is a function of depth below the sea-floor and that mineralogy influences the extent to which hydrates form.

EXPERIMENTAL

Experiments are described in the individual reports submitted by the subcontractors and included in the "Results and Discussion" section, which follows.

RESULTS AND DISCUSSION

Results and discussion of those results are described in the individual reports submitted by the subcontractors. Reports from the subcontractors follow.

CONTINUATION OF WORK ON THE VERTICAL LINE ARRAY

DOE Award Number: **DE- FC26-02NT41628**

Annual Report covering the period

December 2004 – May 2005

Submitted by

Paul Higley

Submitted October, 2005

Gas Hydrate Sea Floor Observatory Vertical Line Array

Abstract
The vertical acoustic line array (VLA) and a similar oceanographic line array (OLA) were developed as part of the Gas Hydrates research program. The development of this array technology has evolved and been integrated into a part of a larger Sea Floor Observatory (SFO) to be installed in the Gulf of Mexico. The SFO is intended to provide a long term means to study characteristics of gas hydrate deposits. This report addresses the development of the VLA and OLA, the new technology developed during this process and the integration of this technology into the SFO. The report also discusses other technology testing opportunities that were undertaken during this program and the evolution of the two original stand alone VLAs into the new SFO-integrated VLA and OLA.

Introduction
The design for the vertical array includes an array of 16 hydrophones spaced 12.5 meters apart and extending approximately 200 meters up from a point just above the sea floor. A data logger was designed for the first version of the VLA which was self timed to record during the arrival of the acoustic signal of interest. Communication to the data logger was via an acoustic modem. Recovery of the array with its battery pack and data logger was accomplished through activation on an acoustic release connecting the array to the anchor. The design was intended to allow several days of data collection using a near-surface towed sound source.

The need for longer term deployments, more precise timing between surface-source firing and bottom recording, and the need to recover larger data sets required integration of the VLA into a SFO. This SFO is to be equipped with a real time communications link to the surface ship and a longer term power source. Modifications are required to interface the VLA data recorder to the SFO and to increase deployment durations from weeks to years. Interest within the Gas Hydrates Consortium for measurement of near sea-floor oceanographic parameters led to the conversion of one of the two VLAs into an OLA.

Summary
New technology developed following the original VLA development was utilized in the design and construction of a new VLA and an OLA. These improvements included cable design, modifications to software programs, addition of a remote real time “T0” timing command, faster data retrieval through a hardwired and fiber optic Ethernet capability and development of a ROV mateable underwater multi-conductor connector system. Software and hardware changes to the Data Acquisition and Telemetry System (DATS) recorders interfaced the DATS of the original VLA design to the SFO data retrieval system.

Experience gained in the deployments of the VLAs was applied to the design and deployment techniques of these arrays.

Experimental
The original VLA deployed beyond the design depth was not repairable. An engineering effort was initiated to improve the cable design and a cable was built for an application in Italy using this new design. Five deployments were performed in the Italy site without damage to the cable. This experience verified the improved design and was incorporated in the OLA and VLA for the SFO.

The acoustic modems on this deep deployment were repaired and will be used on the SFO Integrated Data Power unit (IDP). Additional acoustic modems were purchased with a deeper depth rating, along with the appropriate surface communications units for the deeper modems.

Integration of the VLA and OLA to the Sea Floor Observatory
Real time communications from the surface ship to the SFO IDP is provided using a radio telemetry to a surface buoy on the "M" mooring and a fiber optic cable to the seafloor mounted IDP. A hard wired cable connection will be used from the IDP to the VLA and OLA DATS. These extension cables require make and break under water connections with multiple conductors. These connections need to be ROV-mateable. Presently available connectors are limited to 4 conductors and are prohibitively expensive when ROV-mateable. As a result, a new connector system was designed and installed in the DATS system deployed in early 2005. This connector system is now a part of the VLA and OLAs.

The VLA and OLA DATS computer and software programs were modified to include three forms of communications to the termination of a sea floor fiber optic link. A "T0" timing pulse was needed for the coordination of the gun firing with the bottom VLA DATS. A serial command line provides control and house keeping functions and a high speed Ethernet communications capability was added for large volume data recovery from the VLA DATS. The development included hardware and software modifications to the VLA DATS computer and separate software code for retrieval of the OLA data.

VLA Positioning sensors
The positioning sensors including the compass and tilt sensors were completed. These sensors are to be used to define the offset of the acoustic sensors due to water currents during acquisition of geophysical data. The sensors and housings were completed and pressure tested. The pressure rating for these housing is twice that of any anticipated deployment. Similar heading and tilt sensors were also deployed on the Italy installations and functioned well.

Oceanographic Line Array
One of the VLA arrays has been re-designated to serve as a sensor platform for the collection of near sea-floor oceanographic parameters. Possible sensors to be included on this array include temperature distribution, flourometers, transmissometers, mass spectrometers, conductivity and current flow profiling. The OLA is designed to be integrated into the SFO power and provide a data recovery system for OLA data.

Results and Discussion

The oceanographic array resulted from requests for oceanographic sensors to be included on the VLA and a discussion at the March 2004 program review. The sensor interface has been defined and includes options for various serial communications, optional power levels and voltages, power drain monitoring, power and communications control, a mechanical protocol and in-water weight limits.

Other efforts included improving the design of the array connection, developing methods to lengthen the design life of components of the VLA, and investigation of power sources for the VLA and SFO energy requirements. Extending the deployed life of the SFO components to achieve five to ten year deployed life has been part of the efforts. Corrosion protection of most exposed metal components has been addressed by enclosing these components in neoprene jackets with an oil fill providing a barrier to sea water. Remaining metal components are being addressed with anodes and new coating methods to inhibit corrosion.

Conclusion

The VLA development program started with evaluation of the early VLA deployments and development of methods to implement improvements. The demise of the VLA cable led to changes in the construction of the cable intended to make this critical element more robust. These improvements were tested due to a fortunate opportunity to use similar application of this technology at a site in Italy. Alterations of the early VLA were made to allow integration of the VLA array into the SFO. The VLA and OLA arrays are planned for deployment later in 2006.

CONSTRUCTION OF THE PROTOTYPE SEA FLOOR PROBE

DOE Award Number: **DE- FC26-02NT41628**

Annual Report covering the period

DECEMBER, 2004 – MAY, 2005

Submitted by

J. Robert Woolsey

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DESIGN AND DEVELOPMENT OF THE SEA FLOOR PROBE

Abstract

The Sea Floor Probe (SFP) is a multiuse tool designed to effect sensor deployment into the shallow subsea-floor. Its penetrometer configuration has now been proven in a series of sea tests at MC118, January 2005. Its gravity coring capabilities were proven on this and a return trip to MC118 in May, 2005 when 3-7m cores were collected in the vicinity of a large carbonate mound structure known to have associated gas hydrates. Later in the May cruise two probes were deployed with the SFP: a pore-fluid sampler array and a geophysical thermistor array. The “box” from the pore-fluid array and the data-logger from the geophysical array will be collected at the earliest opportunity via remotely operated vehicle (ROV) or manned submersible.

Introduction

The concept of a Sea Floor Probe (SFP) has been a part the GOM Gas Hydrate Research Consortium plans for a Sea Floor Observatory since inception, but it has varied in design and mission due to changing program circumstances. Currently, in several configurations, it has become an important part of the overall observing system plan. Variances in design mainly related to changes in site location and opportunities for access to a borehole for installation of a multi-sensor down-hole array (altering original SFP requirements). In the fall of 2002 consultations with members of the GOM Joint Industry Program (JIP) gave hope for an opportunity to utilize one or more core-holes to be drilled in Atwater Valley Block 14 which could possibly serve a dual role for seabed sensor installation. The plan was expanded and in 2003 was advanced to include the design and development of a multi-sensor, borehole line array (Figure 1). However promising the plan, in 2004 it became increasingly apparent that the 1300m water depth at AV 14 was too problematic for the 1000m geochemical instrument depth limitations. Although hope remained high for an eventual opportunity to install a borehole array at a suitable hydrate site, in less than 1000m water depth, a return to the original SFP concept, however expanded, would be appropriate at least as a viable, interim measure. Factored into the design of the revised SFP plan was the recent experience with the mega coring technology of the French *R/V Marion Defresne*, which had consistently driven gravity core barrels to depths greater than 10m in the Mississippi Canyon area. Based on this experience, modifications to the SFP would include a simplified gravity drive, capable of array emplacement to approximately 10m. The system would provide valuable multi-sensor data at low cost, and aid in the development of the final bore-hole array design (Figure 2).

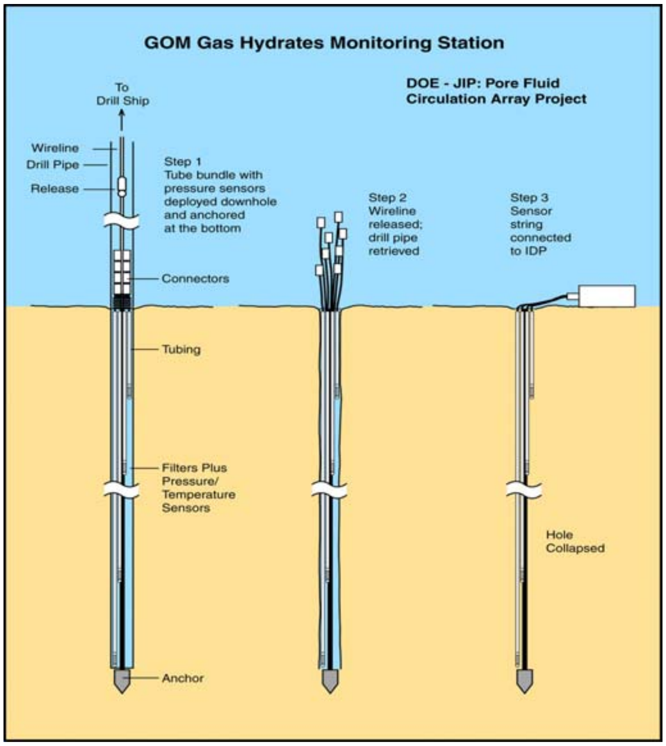

Figure 1

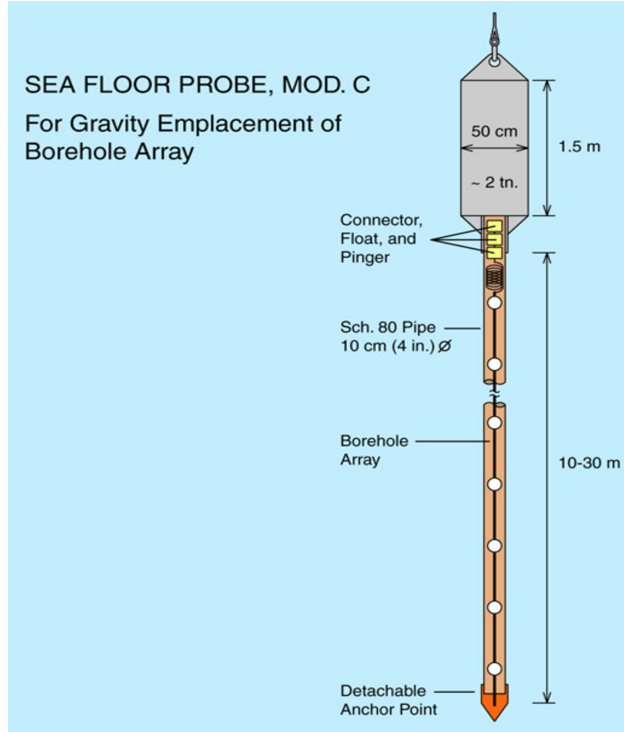

Figure 2

EXECUTIVE SUMMARY

Conceptual design and technology of the Sea Floor Probe (SFP) has evolved over the course of the project to accommodate changing circumstance; i.e., changes in site locations and opportunities for access to a borehole for installation of seabed sensors. As the project progressed, priority was given to the deployment of a multi-sensor borehole array to be installed in cooperation with the Joint Industry Program (JIP), utilizing for this purpose, one or more core-holes to be drilled in Atwater Valley Block 14. However promising this plan, it became increasingly apparent that the 1300m water depth at AV 14 would be insurmountable for the Geochemistry Team with their 1000m instrument depth limitation. Although hope remained high for an eventual opportunity to install a bore-hole array at a suitable hydrate site (in less than 1000m water depth), the original SFP concept was revisited as a viable, low cost interim measure. Factored into the design of the revived SFP plan was the recent experience with the mega-coring technology of the French ship, *R/V Marion Defresne*, which had consistently succeeded in gravity-driving core barrels to depths greater than 10m in the Mississippi Canyon area. Based on this experience, modification to the SFP would include a simplified means for gravity drive, capable of array emplacement to approximately 10m. The system would provide valuable multi-sensor data at low cost, and aid in the development of the final bore-hole array design. The SFP concept was expanded throughout the project to include a; Penetrometer, 10m Gravity Coring System, Pore Fluid Array, and Thermister Geophysical Line Array.

EXPERIMENTAL

Experimental work involving the Gravity SFP was established in two parts. First a SFP Penetrometer was constructed, more or less identical to the design shown in Figure 2, without the array and with a fixed point. The purpose of the Penetrometer was to determine the average depth to which the instrumented SFP could be expected to penetrate into the bottom sediments at the study site. Once determined, a good estimate could be established for the depth of array emplacement which could in turn be used to evaluate the feasibility of the system for geophysical and geochemical applications. If an appropriate depth could be achieved, the second task would involve the design and development of two sensor systems to be emplaced by the Gravity SFP. One, a thermister, geophysical line array (GLA), for monitoring thermal variations of the near-seafloor bottom sediments over time; the other, a pore fluid array (PFA), for monitoring the chemistry of pore fluids, including hydrocarbons, within the shallow sub-bottom sediments over time.

The basic multi-sensor SFP design, used for these latter purposes, would incorporate a channel beam fitted with a detachable point to deliver the array in the penetration drive (Figure 3). The channel beam would be fitted with a 1 ton concrete weight which can be detached from the beam by an acoustic release. The array cable is attached to the detachable point, strung through the channel beam, and connected to a recoverable instrument section fitted to the top of the concrete weight. Following impact and penetration into the sediment, the weight is released remotely and the channel beam retracted. The recoverable instrument section is designed to be recovered remotely and exchanged using an underwater vehicle, manned or remotely operated vehicle (ROV).

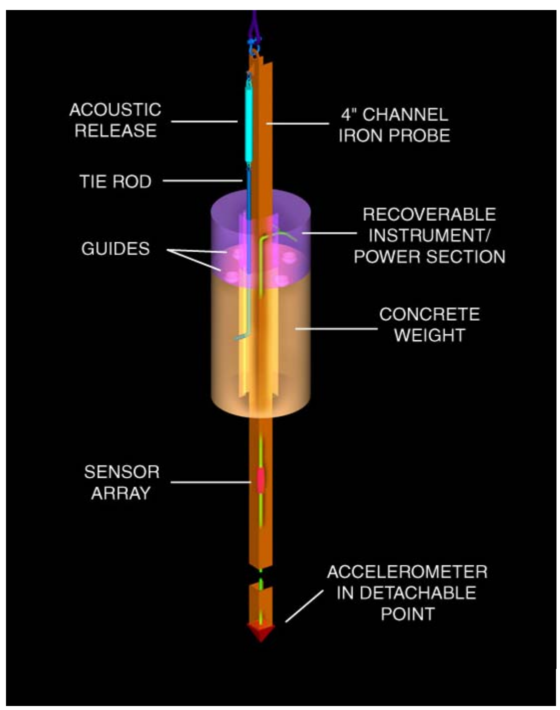

Figure 3. Conceptual Multi-Sensor SFP Design

Results

Deployment

Two cruises were conducted to Mississippi Canyon Block 118 (MC118) in winter, January 26-28, and spring, May 16-19, 2005 on board the *R/V Pelican*. Work involved the deployment of several versions of the Gravity SFP. The winter cruise was devoted to the determination of an average expected depth of penetration for the study area using the SFP Penetrometer (Figure 4).

Figure 4: Gravity SFP Penetrometer

Gravity Core and Pore Fluid Array

The spring Cruise involved the deployment of the Pore Fluid Array (PFA) and the prototype thermister Geophysical Line Array (GLA). Prior to deployment of these two systems, core samples were collected to establish a suitable location. Twelve sites were cored with either the SFP 10m, or the ship's 3m Gravity Coring Systems. Cores recovered were examined on deck to check for evidence of hydrates and gas, (Figures 5 & 6). Positive indications were observed in areas corresponding to the northwestern periphery of the mound as determined by recently acquired AUV Multibeam, sidescan, and chirp data as well as visual observations made during a 2002 MMS Johnson Sea Link dive**.** Subsamples from the cores were collected for additional chemical, geological, and microbial analyses.

Figures 5 and 6. Section of sediment core with evidence of possible gas hydrate dissociation (left) and split core with section of gas expansion (right).

The Pore Fluid Array (PFA) was designed to provide continuous sampling of sediment interstitial fluids at several depths below the seabed. The PFA collects these samples by means of an osmotic fluid pump and coiled tube storage device mounted in a container on the top of the SFP weight. The container is arranged in such a way as to enable removal and replacement by underwater vehicle.

The PFA was installed using the 10m, Gravity SFP. This device is designed to drive a steel box beam into the seafloor, fitted with fluid acquisition ports and associated tubing. An osmotic pump brings these fluids to the coiled tube collecting/storage device. Specialty Devices, Inc. (SDI) constructed an underwater vehicle compatible, eight port, fluid coupler and a mating assembly which houses the osmotic pumps and master control shut-off valve. The fluid coupler and housing were designed to survive the installation process and be recoverable via underwater vehicle. The housing and coupler are also designed to be re-installed by a small remote vehicle to extend the potential sampling duration. Recovery and reinstallation will enable continued long-term monitoring of pore fluid chemistry by Jeff Chanton and Laura Lapham, Florida State University and University of North Carolina, Chapel Hill, respectively, (Figures 7 and 8).

Installation was performed by CMRET personnel and was accomplished by lowering the SFP/PFA using the ship trawl winch (Figure 8). The winch was operated at a maximum speed of approximately 90 m/minute. When the device was driven into the sea floor, an acoustic release was activated to free the trawl cable from the SFP. A second acoustic release remained on the SFP/PFA for use in locating the sea floor position of the array. This second release was activated and recovered following triangulation and recording of the location.

 

Figures 7 and 8. Recoverable osmo-pumps and sample storage units (left) and deployment of the Pore Fluid Array (right).

Thermister Geophysical Line Array

The prototype thermister geophysical line array (GLA) consisted of an array of temperature sensors with inline micro-controllers and an underwater vehicle recoverable DATS data logger and power supply (Figure 9). This deployment (Figures 10 and 11) served to test several new designs to be used in the geophysical study area of the Sea Floor Observatory. These designs are intended to allow servicing by small remote vehicles, reducing the costs associated with building and maintaining the Sea Floor Observatory geophysical section and extend the operational life of its components.

This deployed instrument array is similar to the deep bore-hole array design for installation through a 3.6” drill stem, planned for a later JIP bore-hole deployment. The goal of this installation was to test the design of components for the bore-hole system in addition to the continuous acquisition of high resolution near-seafloor sediment temperatures for the purpose of monitoring the thermal gradient over time. The acquisition of both acoustic data from the solid/gas phase discontinuity at the base of the hydrate stability zone (noted by a polarity reversal), and thermal gradient data over time will, hopefully, enable the monitoring of vertical migrations of the base of the hydrate stability zone and related consequences.

The prototype array consisted of two remote in-line temperature sensors and an in-line temperature acquisition module. The array is intended to provide long life with no required maintenance. The sensors and acquisition module were housed in anodized aluminum housings encased in neoprene bladders designed to prevent sea water contact with the pressure housings. This technique is intended to extend the useable life of the sensors and electronics to 5 to 10 years. Also included in this array installation is a new ROV mateable design for connectors and a remote vehicle recoverable/replaceable instrument housing.

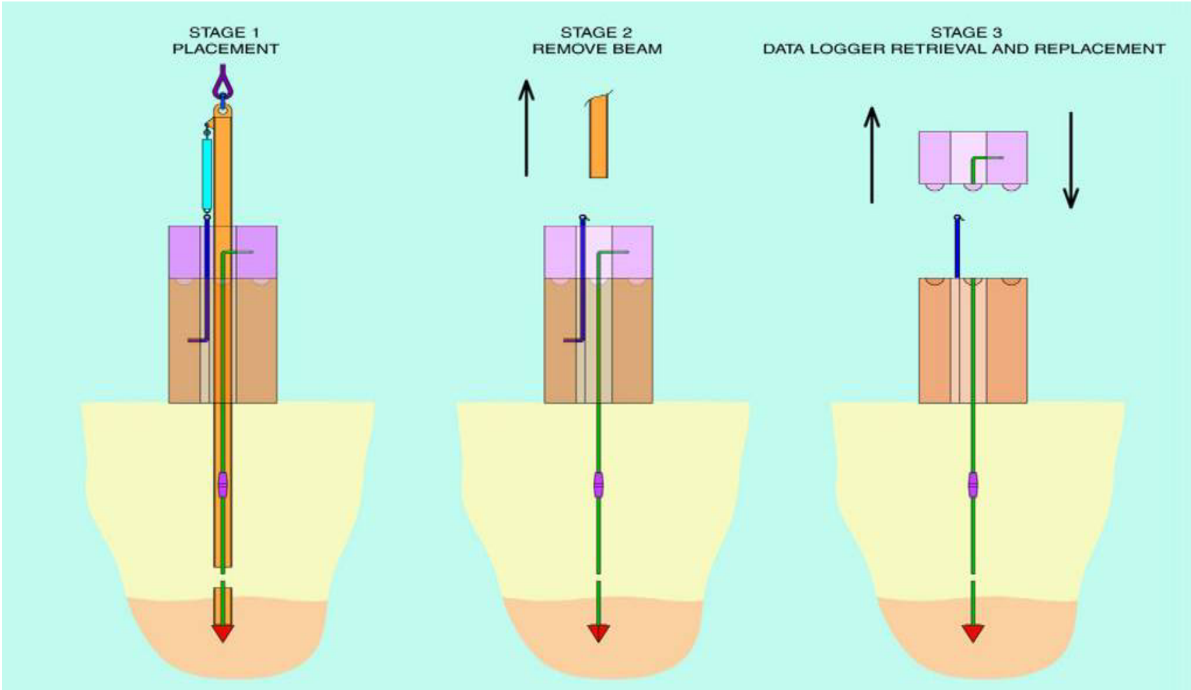

Figure 9. Conceptual drawing of GLA installation and DATS retrieval and replacement.

Figures 10 and 11. Prototype Thermister GLA with ROV replaceable DATS (left), GLA readied for deployment (right).

Positioning
The positions of these arrays were triangulated from slant range and ship position information following deployment. The Benthos acoustic transponder release and corresponding model 210 deck box provided the slant range. HYPACK navigation software coupled to the ship GPS positioning system was used to provide the Benthos surface transducer location. Slant range and position information was entered into SDI's "Angulate" program to resolve bottom transponder position and depth. Three slant range positions are used in the calculation with additional ranges used to verify the computed location. Positioning on future cruises will be accomplished using a recently acquired Ultra Short Base Line (USBL) system.

The resulting positions for the seabed locations for these arrays and for the cores used to determine the array placements are provided below and presented on the location map, Figure 12.

	Latitude	Longitude	UTM X (Easterly) (Zone 16)	UTM Y (Northerly)
Pore fluid array	28 51.47121	88 29.5199	354472.3	3193151.8
Geophysical	28 51.384413	88 29.554113	354414.6	3192992.2

CORE #	LATITUDE	LONGITUDE	TOTAL LENGTH	Water depth
MC118-505-1	28° 51.264′	88° 29.952′	231cm	903m
MC118-505-2	28° 51.337′	88° 29.635′	175.5cm	895m (wire)
MC118-505-3	28° 51.305′	88° 29.653′	337cm	908m
MC118-505-4	28° 51.461′	88° 29.490′	186cm	897.6m
MC118-505-5	28° 51.482′	88° 29.470′	211cm	887m
MC118-505-6	28° 51.432′	88° 29.490′	156cm	892.6m
MC118-505-7	28° 51.342′	88° 29.574′	228cm	895.3m
MC118-505-8	28° 51.353′	88° 29.586′	142cm	894m
MC118-505-9	28° 51.448′	88° 29.503′	724.5cm	877m
MC118-505-10	28° 51.488′	88° 29.503′	371cm	894m
MC118-505-11	28° 51.456′	88° 29.491′	~ 200cm	880m (wire)
MC118-505-12	28° 51.510′	88° 29.520′	~400cm	890m

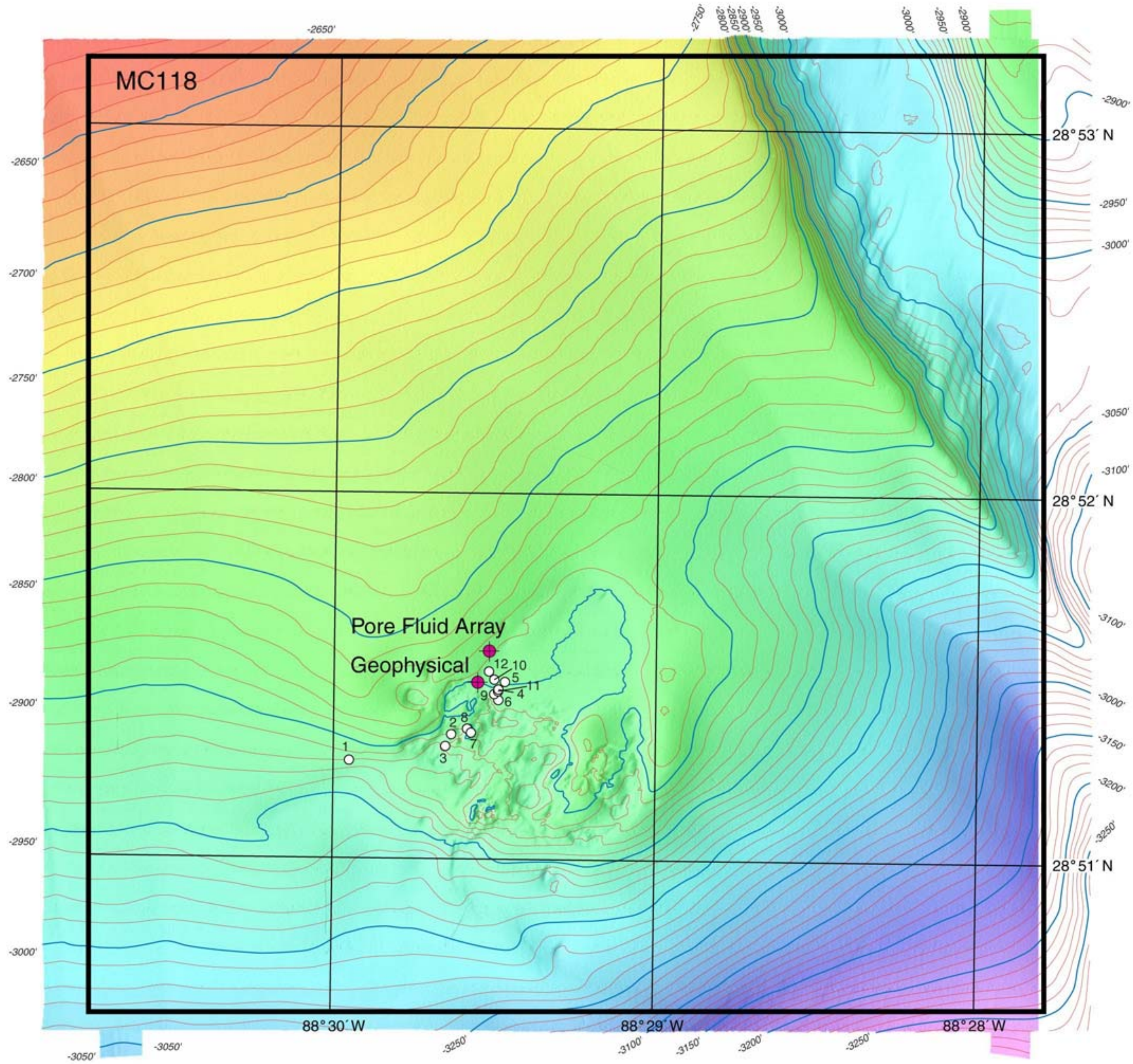

Figure 12. Mississippi Canyon 118. Cores 1-12, recovered in May, 2005, appear as open circles. The two probes deployed on the same cruise are labeled and appear as filled circles

ACOUSTIC SYSTEM FOR MONITORING GAS HYDRATES

DOE Award Number: **DE- FC26-02NT41628**

Final Report covering the period

November 2004 - May 2005

Submitted by

Jerald W. Caruthers and Ralph R. Goodman

University of Southern Mississippi, Department of Marine Science

November 14, 2005

ACOUSTIC SYSTEM FOR MONITORING GAS HYDRATES - Final Report

The work conducted under this project for FY2004 centered on trying to understand the nature of the gas-hydrate bubbles emitted from the seafloor at depths of 500 to 1000m, and design a sonar system to match the expected bubble characteristics. During the year TV images were analyzed to determine expected bubble diameters, rise rates, and density. The bubble radii ranged from about 500 to 5000 microns (mm) and the rise rates were in the expected range of 20 to 30 cm/sec. The expected density of bubbles was a bit more variable depending on the particular vent - and probably the local bottom temperature - and could not be estimated accurately.

A bubble at resonance is a very effective scatterer and absorber of sound. A given bubble with radius a_r, in microns, will resonate at a frequency f_r, in kilohertz, given by

$$f_r = 3270(1 + 0.1\sqrt{z}) / a_r$$

where z is depth in meters. The expected radii and depths to be investigated suggested a range of frequencies from about 2.4 to24 kHz in order to obtain resonant scattering from the bubbles, and thereby determine their distribution over their range of radii.

Most of the recent work on this project involved specifying the design of a measurement system. Two candidate systems were investigated: (1) A measurement system including an acoustic transmitter and a series of hydrophones on an arc of a circle about a meter in diameter was investigated. In final design, it was expected to cover the resonance frequency range. A prototype system was built and tested in a tank by the Naval Research Laboratory. This design appeared to be difficult to realize in hardware for deep operations. (2) The second system was to be based on three Neptune Science T70 transducers that we had in hand from previous Office of Naval Research funding. These transducers operate at 12 kHz (the middle of the expected resonance-frequency range) and each has two rows of five elements. The system was planed to be in a planar-block arrangement of five by six elements and to be approximately 0.72 by 0.46 m in size on their face. Beam-pattern and beam-steering algorithms were computed to determine the capability of the system to monitor the 3D volume of a gas-hydrates vent.

Due the lack of Department of Energy funding for FY2005, plans to construct this system were abandoned. A version of the system will be built with DURIP (Defense University Research Instrument Program) funding through ONR. This Department of Defense configuration of the system, however, will be a towed, wide-swath, subbottom profiler, and not configured or available for gas-hydrates work. The basic planar array and electronic components will be the same as the previously planned DOE configuration.

Construction and Testing of an Electromagnetic Bubble Detector and Counter
(Final Report submitted in previous reporting period)
Vernon L. Asper, Department of Marine Science, University of Southern Mississippi

Project: DE-FC26-00NT41628
(DOE, Subcontract to University of Mississippi)

Mid-Infrared Sensor Systems for Continuous
Methane Monitoring in Seawater

Methane detection using attenuated total reflection (ATR) spectroscopy.

Final Technical Report

Research Activities December 01, 2004 – November 30, 2005

Boris Mizaikoff (PI), Gary Dobbs

Atlanta, December 13, 2005

ABSTRACT/SUMMARY

This final technical report will summarize progress towards development of deep-sea detection and monitoring systems for methane and gas hydrates based on mid-infrared (MIR) attenuated total reflection (ATR) spectroscopy during the periods from December 01, 2004 – November 31, 2005. Representative figures from the reported project period are provided in the appendix; complete details from previous project periods can be found in the progress reports.

- A brief summary of the significant works performed in previous project periods, April 01, 2001 through November 30, 2004, is provided.
- Experimental investigations of IR-ATR signal generation were performed to facilitate precise insight into 'active' sensing regions along planar ATR waveguides.
    - Experimental results reveal discrete sensing regions along multi-reflection waveguides providing valuable knowledge for optimizing construction designs of deep-sea IR-ATR sensing probes.
- Complementary spectral ray tracing simulations establish a virtual environment for rational development and evaluation of deep-sea probe configurations.
    - Spectral ray tracing simulations facilitate efficient evaluation of light guiding optics and sensor transducers. Resulting, an optimal selection and arrangement of optical components for deep-sea sensing probes and optics platform for 'SphereIR' can be established.
- Modifications to the previously reported pressure vessel for simulated deep-sea measurements expand experimental capabilities for synthetic hydrate formation and spectroscopic investigations of hydrate formation and dissociation via fiber-optic evanescent field spectroscopy.
    - Development of a custom high-pressure viewport and custom high-pressure fiber-optic feed-throughs were successfully implemented to confirm synthetic hydrate formation and evaluate this spectroscopic techniques ability to monitor hydrate formation and decompsosition.
- Initial investigations reveal the capability of IR-ATR fiber-optic sensors for *in-situ* monitoring applications of gas hydrate formation and dissociation.
    - State-specific changes to the infrared spectra of water provide the ability to monitor *in-situ* formation and dissociation of gas hydrates.

Ongoing investigations to distinguish state-specific infrared absorption features of liquid water, ice, and the three hydrate structures (I, II, and H) are currently underway and will be concluded early in 2006. Based upon current progress, we anticipate the final construction and first field tests of a miniaturized multi-component IR sensor system capable of *in-situ*, deep-sea methane detection and passive monitoring of gas hydrate formation and dissociation by natural processes in deep-sea environments during continuation of this project in 2005/2006.

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LIST OF GRAPHICAL MATERIALS

FINAL TECHNICAL REPORT

Summary of Works from April 01, 2001 through November 30, 2004

Our contribution to the Gulf of Mexico Hydrates Research Consortium (GOMHRC) is the development of spectroscopic sensors for the determination of hydrocarbon concentrations (with focus on methane) in the liquid phase and in the gas phase. Most recently, the feasibility for *in-situ* monitoring of gas hydrate formation and dissociation via IR-ATR spectroscopy has been established. Deployment of these sensors will be an integral part of the station, continuously providing information on the measured parameters during long-term observation periods.

Our progress in the framework of this project demonstrated the feasibility for detection of dissolved methane via IR-ATR spectroscopy in a laboratory environment including evaluation of potential spectroscopic interferences by salt ions in year 1.[1] Significant strides in the development of a miniaturized deep-sea mid-infrared spectrometer ('sphere-IR') were completed in year 2 by establishing data evaluation strategies[2-5], selection and testing of the fundamental instrument components including a Stirling-cooled MCT detector ideal for extended maintenance free deployment, and design considerations for an improved deep-sea sensor system from past experience of the PI's research group.[6-11] During year 3, computer assisted drawings (CAD) developed in year 2 for the primary instrument components facilitated the complete design and construction of the electrical compartment for 'SphereIR'. Design and fabrication of fasteners for primary optical components for 'SphereIR' were also completed in year 3. Finalization of the optics compartment will follow successful construction and testing of optimized deep-sea sensing probes in year 5 of this project. Investigations of a novel fiber-optic/planar waveguide sensing probe were initiated at the end of year 3. Experimental measurements revealed the capability to successfully couple radiation into the planar sensing transducer via fiber-optics. This approach is expected to ensure robust performance in deep-sea conditions. This work was also extended into year 4 with details provided in this report. Furthermore, initial experimental investigations into pressure influences on water diffusion into polymer extraction membranes were also performed during year 3. No significant spectral changes were observed at pressures correlating to ocean depths of approx. 70m, warranting improvements to the experimental apparatus for more thorough evaluation of pressure equivalents of 1,000+ meters of operational depth. Complete details on previous work can be found in the annual and semiannual progress reports for the duration of our involvement with this project.

Experimental Investigations into IR-ATR Signal Generation along Planar Waveguides

As stated in previous reports, the mission critical aspect in developing viable submersible optical sensors is the engineering of optical chemical sensor probes for interfacing the encased spectrometer with the marine environment. Thus, it is of paramount importance to optimize the probe design for ensuring delivery of radiation to the transducer surface, maximizing signal transduction, and effectively guiding the generated signal to the detection module. To optimize design and construction of deep-sea IR-ATR sensing probes, it is of fundamental importance to have specific insight into light propagation inside the waveguide structure and resulting signal generation. Specific knowledge of these parameters ensures rational development for optimal operation by minimizing interferences from construction materials and radiation losses resulting from mounting the sensing transducer in a pressure proof housing.

To obtain this information, a novel experimental procedure was conceptualized to interrogate the signal generation along the sensing surface of a typical 72 x 10 x 6 mm ZnSe horizontal ATR crystal.[12] For a 72 x 10 x 6 mm trapezoidal crystal geometry, six individual reflection regions should be present along the measurement surface. Therefore, it was hypothesized that by consecutively depositing small, discrete residues at fixed intervals along the measurement surface, one could accurately identify individual 'active' sensing regions at the waveguide surface. To perform this experiment, 0.75 µL deposits of polystyrene-co-butadiene (PSCB) were deposited at 3 mm intervals along the waveguide surface while infrared spectra were collected after each sequential addition. A representative IR-ATR spectrum of PSCB is provided in Figure 1 with highlighted absorption features utilized in analytical evaluation. In 'active' sensing regions, strong PSCB spectral features are observed as opposed to 'inactive' sensing regions where no PSCB spectral features can be identified as displayed in Figure 2. The deposition frequency (based on a modified version of the Nyquist theorem) provided the ability to extract the specific locations of individual sensing regions for four of the six internal reflection elements and extrapolation of the two unidentified sensing regions. Figure 3 displays an optical image of polymer deposits along the planar waveguide (A), signal intensity for each residue at each deposit location (B), and a surface plot of extrapolated individual sensing regions.

The precise identification of individual sensing regions determined from these experiments provides specific information regarding the position of light coupled into the planar waveguide as well as the path of radiation propagation through the internal reflection element. Furthermore, the absorption data can be utilized to extrapolate other important optical parameters including the propagated cone of radiation and diameter of light coupling into the reflection element with the aid of complimentary spectral ray tracing analysis by emulating experimental measurements. Therefore, ray tracing procedures were developed and performed for this specific purpose and will be discussed in the following section.

Spectral Ray Tracing Analysis of IR-ATR Signal Generation along Planar Waveguides

Ray tracing software generally provides the capacity to simulate virtually any optical configuration, optical component, and many radiation parameters. Additionally, the spectral ray tracing software utilized in these experiments, SPRAY (W. Theiss, Aachen, Germany), provides the ability to incorporate simulated infrared absorbers for emulating analytical spectroscopic measurements. Thus, it was hypothesized and successfully demonstrated that this software could be utilized to produce identical analytical information collected during experimental measurements by matching the experimental radiation parameters in the simulation. The power of this approach is highlighted through the blind trial-and-error approach for extrapolating the radiation cone angle and size of radiation impinging upon the in-coupling facet of the IRE without *a priori* knowledge of such parameters (verified experimentally after simulation trials). Furthermore, the successful application of this virtual platform provides an excellent tool for optimizing optical configurations and probe designs for ‘SphereIR’ in a cost efficient manner.

For ray tracing analysis, a simple 5-component model was devised simulating the experimental configuration in real dimensions. The simulated set-up models the in-coupled radiation as a circular light source, and was configured such that the internal reflection angle ($\theta_{int,}$) equals the bevelled HATR in-coupling facet angle (45°). The position of the circular light source at the bevelled 45º in-coupling facet was off-set from the central axis of the modelled 72 x 10 x 6 mm HATR element to closely emulate the experimental conditions. A closed cylinder with a diameter of 2.5 mm was implemented with an IR absorption band at 1443 cm^{-1}, thereby simulating the spectral response of deposited PSCB residues. A 72 x 10 mm rectangular screen for imaging the radiation distribution along the measurement surface of the HATR element was also integrated in the model. Furthermore, a 40 x 42.4 mm rectangular detector was modelled and positioned parallel to the bevelled exit facet of the crystal. All photons transmitted through the ATR element were therefore collected at this simulated detector element generating infrared absorption spectra of simulated PSCB deposits. The application of a large simulated detector provides the capability of evaluating signal generation of residues for virtually any combination of in-coupled light source radius, radiation cone angle, and in-coupling position. Additionally, this model does not require precise dimensional modelling of optical components or their configuration for a particular experimental set-up, as normalized simulation data will only be comparable to normalized experimental data if the simulated radiation path, in-coupled light source radius, and radiation cone angle resemble the through-coupled radiation (detected radiation) for the experimental studies. However, precise dimensional modeling for developmental applications is required.

Procedures performed during experimental measurements were precisely followed during spectral ray tracing analysis. Many combinations of in-coupled cone angles ranging from 1° – 16° and light source radii from 0.00215 cm – 0.25 cm were evaluated. From all simulations, the combinations with a 0.1278 cm ± 0.042 cm light source radii with a constant cone angle of 2° (CCA), and combinations of a constant light source radius of 0.1278 cm with cone angles of 2° ± 1° (CLSR) most closely emulate the experimental results generated in this study. Figure 4 displays an overlay of normalized integrated peak values for averaged simulation trials with averaged and normalized experimental data. It is clear that the simulation platform was very capable of emulating experimental results indicated by total residual error values (sum-of-squares) of 0.110 for CLSR and 0.123 for CCA combinations. Cone angle values were later confirmed by additional experimental measurements resulting in a range of 1.9° to 2.9°. Furthermore, estimated sizes for individual sensing regions (Figure 5) in the experimental studies were calculated using both experimental and simulation results.

In addition to emulating experimental measurements, the ray tracing analysis was utilized to visualize the influence of radiation parameters on the actual sizes of 'active' sensing regions. Figure 6 displays the 'active' sensing regions along a 72 x 10 x 6 mm planar waveguide with select cone angles ranging from 2° – 16° and a light source radius of 0.1278 cm. The importance of optimizing the selection and configuration of optical components for the development of sensing probes and the optics compartment for 'SphereIR' is accented in these results. Clearly, smaller radiation cone angles are desired to minimize interferences from sensor probe materials and losses due to mounting the transducer in a pressure proof housing.

In the specific context of this project, this simulation platform accurately mimics experimental signal generation for IR-ATR experiments enabling optimization of optical configurations for 'SphereIR' and evaluation of deep-sea IR probe designs in a virtual environment. Resulting, a solid basis for predicting the performance and signal generation for deep-sea IR evanescent field probes is established facilitating the rational design and fabrication of a viable submersible mid-infrared sensing platform 'SphereIR' as our contribution to the GOMHRC. Additionally, this approach significantly reduces developmental costs associated with trial-and-error procedures (time and money). For, complete details on spectral ray tracing results presented here, please see the submitted manuscript to Applied Spectroscopy. An additional manuscript is currently in preparation for the Journal of Optical Engineering further expanding the discussion on simulation applications for predictive evaluation of sensor transducers.

In-situ Monitoring of Gas Hydrates

A variety of analytical tools has been successfully utilized to interrogate hydrate structures despite the low temperatures and high pressures needed to synthetically form gas hydrates in well-controlled laboratory environments. Currently, nuclear magnetic resonance (NMR)[13, 14], Raman[15-21] and Fourier transform infrared (FT-IR) spectroscopy[22-24], along with X-ray diffraction[20, 25], gas chromatography[25], and neutron diffraction[14] have provided a wealth of information on gas hydrates. In addition to fundamental studies, a great need exists for the capability to monitor *in-situ* hydrate formation and dissociation in both environmental and industrial settings. However, as a result of the harsh environments in which hydrates occur, almost every laboratory analytical tool used to evaluate hydrates cannot logistically be extended to real-world monitoring applications.

To date, Raman spectroscopy has shown excellent *in-situ* monitoring capabilities of hydrate formation.[15-21] When a host gas is 'caged' in hydrate lattice structures, the molecules become vibrationally, rotationally, and translationally restricted compared to the 'free' or 'dissolved' gas. As a result, the fundamental vibrational and rotational energies of the host gas vary significantly between the 'dissolved' and 'caged' molecules. Therefore, the formation of hydrates can be monitored as a result of changes in the Raman spectra for the host gas as the central peak positions shift corresponding to the difference of vibrational and rotational energies of the 'dissolved' and 'caged' molecules. As a result, Raman spectroscopy can be used to indirectly distinguish liquid water from different clathrate structures by monitoring the host gas absorption features. In addition to Raman spectroscopy, FT-IR spectroscopy has the potential for monitoring hydrate formation and dissociation by spectroscopically evaluating variations in the molecular rotational and vibrational energies for either the host gas and/or water structure.

FT-IR spectroscopy has had limited application in hydrate research primarily as a result of the strong absorption of water, which limits the practicality for standard transmission measurements. Devlin and co-workers have minimized bulk water absorption by vacuum and vapor depositing films of clathrate hydrates thereby accessing the clathrate structures; however, this approach cannot be extended to real-world, oceanic or industrial applications.[22, 23] Recently, H. Oyama and colleagues performed the first infrared attenuated total reflection (IR-ATR) measurements of gas hydrates for CO_2.[24] ATR circumvents limitations of conventional transmission-absorption measurements as a result of reduced analytical volumes located along the surface of ATR waveguides. However, details of the setup utilized by Oyama and colleagues were not publicized other than the use of a high-pressure ATR probe rendering the reproduction of those results difficult. Additionally, the report focused only on the spectral absorbance of CO_2 while neglecting the primary component and strongest infrared signal of hydrates, water.

In addition to the possibility of evaluating the ‘dissolved’ or ‘caged’ host gas vibrational and rotational energies, FT-IR ATR measurements provide the capability of probing state-specific spectroscopic changes in water vibrational and librational (lattice vibration) bands. Liquid water has a unique infrared absorption spectra (Figure 7) containing a large O-H stretch in the spectral region of 3100-3600 cm^{-1}, H-O-H bend mode from 1500-1700 cm^{-1}, and a broad combination peak at 2115 cm^{-1} (combination of the bend and libration bands). As liquid water changes to ice, the intensity of the H-O-H bending mode decreases sharply while the combination bend and libration band shifts to higher energies.[26] In addition to changes in peak intensities and locations, the band widths (as full width half maximum) also change during this process allowing multiple strategies for evaluating IR-ATR spectra. Because ice and hydrate structures have nominal similarities, it was hypothesized that IR-ATR could be utilized to monitor *in-situ* hydrate formation and dissociation by monitoring the infrared absorption features of water.

Development of Pressure Vessel and Testing for Synthetic Formation of Gas Hydrates

Hinging on the potential use of IR-ATR techniques for monitoring hydrate formation and dissociation, several modifications to our custom pressure vessel for simulating deep-sea environments were necessary. For successful ATR measurements, it was necessary to achieve hydrate conditions while coupling an infrared transparent silver halide fiber into the apparatus for benchmark laboratory ATR measurements (Figure 8). To visually verify hydrate formation, a custom designed high-pressure viewport was constructed for the pressure vessel (Figure 9). The viewport utilizes a 1/8” thick, 1” dia. sapphire window pressure rated to 865 psi with a 3-fold safety factor. Additionally, custom Teflon ferrules were fabricated to couple a silver halide fiber (700 µm dia.) into the pressure vessel and pressure proofed to at least 750 psig (Figure 10).

Once the pressure vessel was tested with all components necessary for spectroscopic measurements, initial hydrate tests were carried out to verify the capability of forming hydrates. First tests were carried out for methane hydrates requiring pressure up to 700 psig and a temperature range of 1 to 3 °C inside the vessel. A 290 ppm aqueous solution of sodium dodecyl sulfate (SDS) was utilized to reduce methane hydrate induction times to less than 1 hour similar to reports by Rogers and colleagues for ethane and natural gas hydrates.[27] A standard webcam was placed in front of the optical viewport to safely observe the progression of hydrate formation and dissociation. Figure 11 provides optical images collected throughout the first successful methane hydrate trial.

In addition to a decrease in system pressure, which is indicative of gas hydrate formation, a small sample of remaining solid structure present inside the pressure vessel was removed for *ex-situ* FT-IR transmission analysis after the cell was depressurized rapidly while maintaining a constant temperature. The solid structure that was removed from the pressure vessel was audibly degassing suggesting the encasement of gaseous methane. This was verified *via* IR transmission measurements of methane's two fundamental infrared absorption bands located at 3020 cm^{-1} and 1305 cm^{-1} as gas was released from the melting structure. Figure 12 provides the results of open path IR transmission spectra from a Bruker 66 spectrometer as the solid structure was allowed to melt (approx. liquid volume 20 mL) inside the enclosed sample compartment providing evidence that methane hydrate was indeed formed.

In-situ Monitoring of Gas Hydrates via Fiberoptic Evanescent Field Spectroscopy

Following confirmation of hydrate formation in the pressure cell, a silver halide fiber was coupled through the cell and setup for *in-situ* measurements (Figure 13). Prior to hydrate formation the system was pressurized to record the infrared spectrum of water to determine if any spectral changes would be induced from pressure effects. Figure 14 clearly displays no measurable pressure-related changes in the water spectrum from 0 to 700 psig. Currently, the large O-H band in the 3000 cm^{-1} region cannot be used for analytical evaluation. Further advances in the fiber-optic coupling technique or the use of deuterated water will provide the capability of assessing this absorption feature.

The first fiber-optic spectroscopic hydrate measurements were taken for ethane hydrates as its formation conditions (300 psig and 3-5 °C) are milder than those for methane hydrate (600 psig and 1-4 °C). Additionally, ethane hydrate induction times are typically shorter than for methane hydrate. Furthermore, gaseous ethane is encased in the large cage of structure I hydrate, which has greater structural differences than the small cage when compared to the lattice structure of ice. Figure 15 displays selected regions of infrared spectra collected throughout the formation process of ethane hydrate.

As hypothesized, throughout the hydrate formation process, the combination band initially at 2110-2115 cm^{-1} shifts towards higher frequencies and the intensity of H-O-H bend at 1650 cm^{-1} decreases sharply. The combination bend and libration band shifts dramatically throughout the hydrate process after an initial peak shift to approximately 2128 cm^{-1} as a result of temperature induced reorganization of water at approximately 4 °C to a final observed peak position at approximately 2198 cm^{-1}. The gradual shift of this maximum peak amplitude provides an excellent marker for the progress of hydrate formation as the peak location is dependent upon the ratio of liquid:solid structure interrogated along the fiber-optic transducer. Furthermore, to display the capability of this sensing approach to monitor the dissociation of hydrate, spectroscopic measurements reveal that this spectral shift is reversible. Figure 16 displays the behavior of the combination bend and libration band throughout both hydrate formation and dissociation.

In Figure 16, the final peak maximum returns to 2120 cm^{-1} during the time spectroscopic measurements were collected for dissociation. It is known that after the formation of ice (or hydrate), some residual structural memory in the aqueous solution is acquired and it could account for this observation. Further investigations are ongoing to evaluate the capability of this procedure to detect and verify this phenomenon from the bulk aqueous solution subsequent to hydrate formation trials.

For monitoring applications, the change of peak location for the combination band indicates the progression of hydrate formation or hydrate decomposition. Figure 17 provides four plots of the pressure, temperature, and analyzed spectroscopic results throughout the measurement series of both ethane hydrate formation and dissociation. Upon hydrate induction the system pressure drops as gaseous ethane becomes encased in the hydrate structure (Figure 17, pressure plot). The overall system pressure fluctuates throughout hydrate formation as the ethane source was regulated to control the rate of formation through the manipulation of the ethane backing pressure. Additionally, the system temperature fluctuates throughout the formation process as energy from the latent heat of formation for ethane hydrate is released (Figure 17, temperature plot). In addition to visual confirmation, these two parameters are commonly used to identify and verify the formation of hydrate in laboratory environments. The analyzed spectroscopic data provide much greater detail of the formation process compared to the fluctuating pressure and temperature data (Figure 17, peak and FWHM plots). This results as the ratio of liquid:hydrate mass decreases throughout hydrate formation and the peak location of the combination band being dependant upon the ratio of liquid:hydrate mass in the analytically probed volume of the sensing transducer. Furthermore, the spectroscopic data provides superior information to pressure and temperature data throughout the decomposition process. As hydrate thermally decomposes at a constant pressure (excess ethane from degassing hydrate is removed from the system during this process via a pressure-regulating release valve) with the system temperature passively equilibrating to ambient conditions, there are no apparent pressure or temperature indicators to follow this process. This is clearly displayed when collectively comparing all four plots in Figure 17. In addition to the combination bend and libration band, analysis of the H-O-H bend mode at 1640 cm^{-1}

can be used as an indicator of hydrate formation and dissociation. Inspection of the peak intensity of this band reveals analogous information to peak location data obtained for the combination bend and libration band (Figure 18). In Figure 18, the peak intensity of the H-O-H band tracks the peak position data for the combination band very well. However, the band intensity is dependant upon the amount of water interaction with the fiber (solid and/or liquid); therefore, further quantitative analysis of the H-O-H bend intensity is warranted with control experiments.

The analyzed spectroscopic data provide a great deal of information about the bulk material inside the pressure chamber during hydrate formation and dissociation processes. Firstly, the combination bend and libration mode gradually shifts to higher frequencies throughout hydrate formation and gradually shifts to lower frequencies during the dissociation process. This is a result of the changing ratio of liquid:solid interaction at the transducer surface which visual, temperature, and pressure data cannot reliably provide. In fact, visual observation alone could be misleading during hydrate formation as one may see bulk hydrate structure which has significant amounts of liquid trapped as interstitial water inside the bulk structure. In fact, we observed this during these measurements. Within six minutes of catastrophic hydrate formation, the optical viewport was blocked by bulk hydrate mass preventing visual verification of continued hydrate growth (Figure 19). Over the next 100 minutes, significant hydrate formation continued by monitoring spectroscopic and pressure data. This most likely indicates significant amounts of both interstitial and residual bulk water being converted to solid hydrate and displaying advantages of this analytical technique. In real-world situations, pressure data will not fluctuate rendering substantial limitations when following hydrate formation solely based on visual observation. Furthermore, it is common to monitor the total gas volume introduced into the sample chamber during synthetic hydrate formation to determine the rate of interstitial water conversion.[27] However, this is again impractical for most real-world, environmental or industrial applications.

During the first measurements, we anticipated the capability of identifying the host gas as it was incorporated into the hydrate structure. Unfortunately, that was not observed in the initial measurements. However, we anticipate this will be possible as our experimental apparatus will be improved as our experience with this system increases. Additionally, we are also developing novel planar waveguide sensor probes that should provide the capability of detecting the host gas as displayed by Oyama and colleagues with the use of an ATR probe in their experiments.[24] Further investigations are currently underway to thoroughly evaluate the spectroscopic features of gas hydrates in addition to the possibility of identifying different hydrate structures based on the peak locations of pure hydrate structures as we hypothesize the vibrational and librational energies to be structure specific.

Finally, because the initial hydrate measurements only evaluated the spectroscopic changes of water, investigations of ice formation are currently ongoing. The formation of ice leads to similar changes in the spectroscopic data as hydrate formation. Therefore, the capability of distinguishing ice from hydrate becomes important in addition to identifying different hydrate structures. Figure 20 provides initial measurements that we have collected on ice formation in the pressure vessel. Because similar spectroscopic changes are observed during ice formation as in hydrate formation, it will be difficult in multi-phase systems to discern ice from hydrate without host gas information. However, in oceanic environments the potential for ice formation is significantly decreased as pressure, salinity, and temperature favor hydrate formation. Improvements to analytical procedures including evaluation of different sensing probes have great potential for providing host gas information that will further improve the assessment of hydrate formation and structures using IR-ATR spectroscopy.

FIGURES

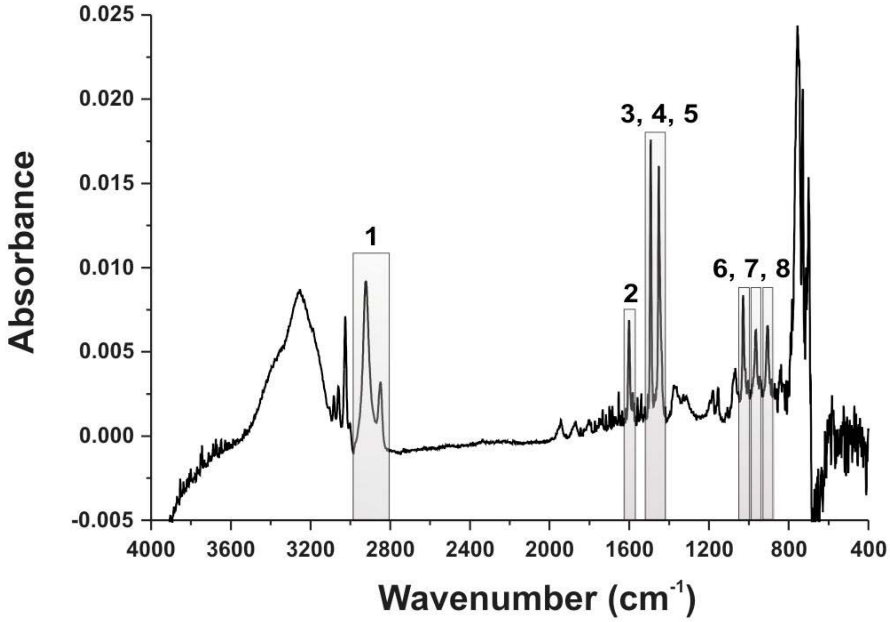

Figure 1: *Representative FT-IR ATR absorbance spectrum of PSCB with highlighted spectral regions utilized during data evaluation.*

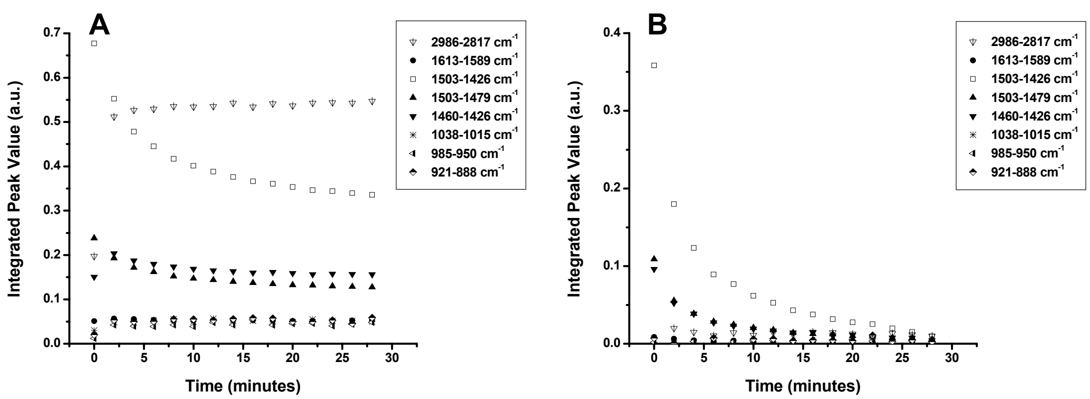

Figure 2: *(A) Exemplary representation of infrared absorption for a PSCB deposit at an active sensing region resulting in positive integrated peak values vs. time. (B) Exemplary representation of PSCB absorption for a deposit at an inactive region (no internal reflection) resulting in near zero integrated peak values. Stabilized IPVs are observed after approx. 25 min as the majority of solvent has evaporated leaving behind PSCB residues.*

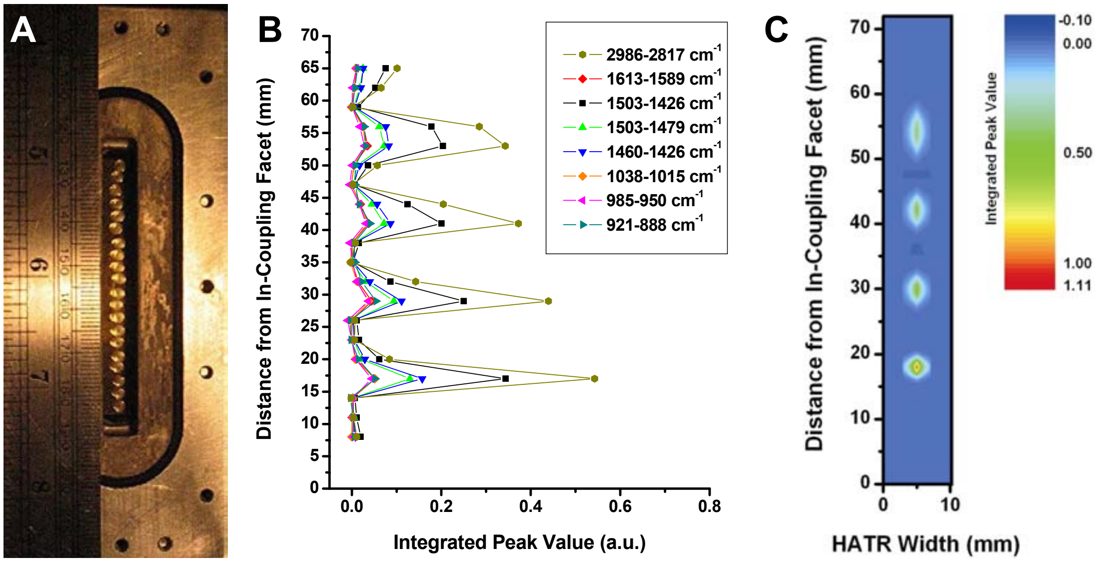

Figure 3: *(A) Optical image of PSCB deposits at a ZnSe HATR crystal surface mounted in a topless flow cell. (B) Absorption intensity (represented as IPVs) of PSCB vs. distance from the in-coupling facet of the HATR crystal.* (C) Surface map projecting the absorbance intensity of PSCB residues along the measurement surface of a HATR crystal displaying discrete 'active' sensing regions along the crystal surface. (*Lines are for assisting visual inspection.)*

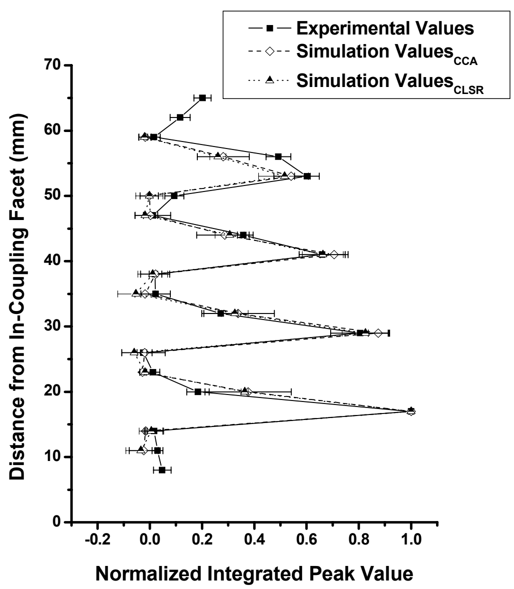

Figure 4: *Averages of normalized IPVs for experimental and simulation data*,** with respect to the measurement location plotted versus distance from the in-coupling facet of the horizontal ATR crystal (error bars are ± 1 standard deviation).*** (*Simulation Values$_{CCA}$ represent averaged IPVs for data obtained with combinations of a 0.1278 cm ± 0.042 cm light source radii with a constant cone angle (CCA) of 2°. **Simulation Values$_{CLSR}$ represent averaged IPVs for data obtained with combinations of a constant light source radius (CLSR) of 0.1278 cm with cone angles of 2° ± 1°. ***Lines are for assisting visual inspection.)*

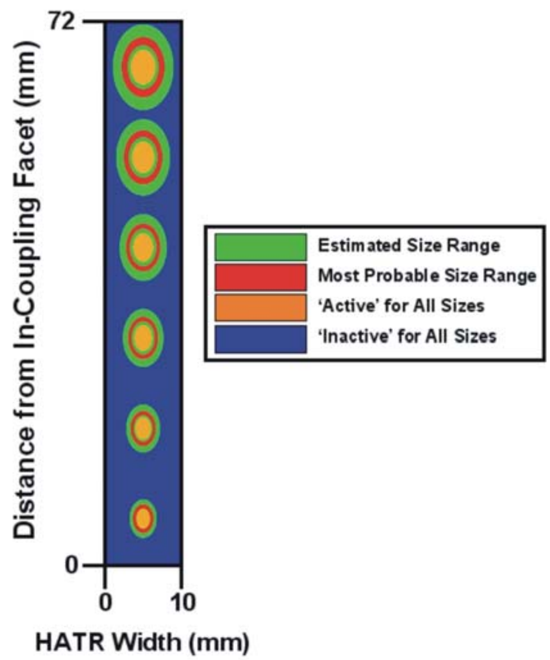

Figure 5: *Elliptical surface projections of (i) the range of dimensions of 'active' sensing regions shaded in green, (ii) the range of most probable dimensions of 'active' sensing regions shaded in red, (iii) always 'active' regions for the estimated range of dimensions of sensing regions shaded in orange, and (iv) always 'inactive' regions for the estimated range of dimensions of sensing regions shaded in blue.*

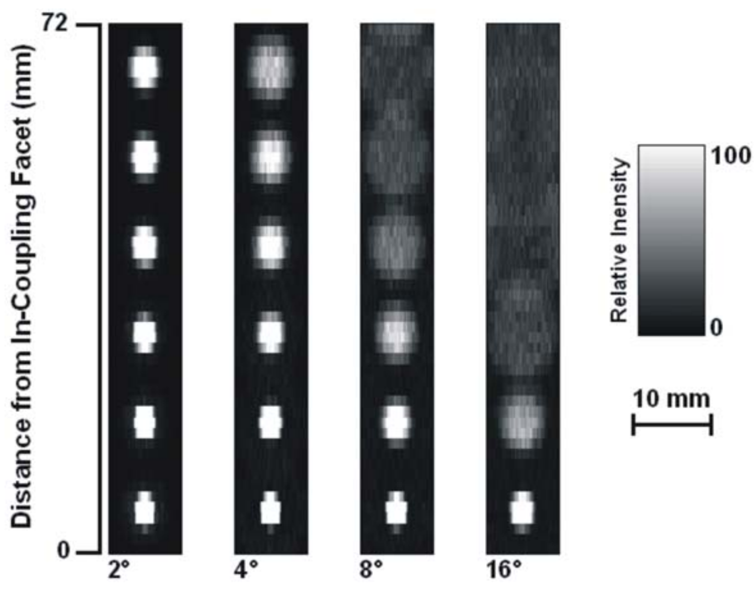

Figure 6: *Simulated radiation density maps displaying internal reflection regions and the changes in radiation distribution along the sensing surface of a HATR crystal with increasing radiation cone angles from left to right (2º, 4°, 8°, and 16°). The simulations were generated with a source radius of 0.1278 cm.*

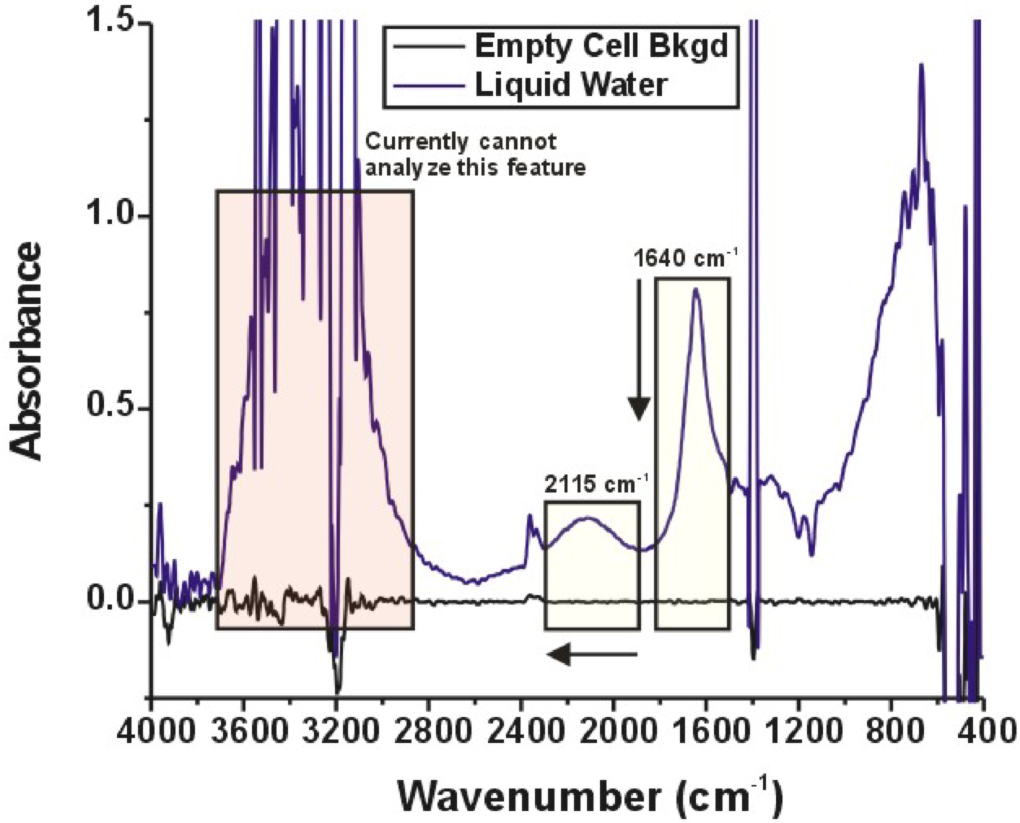

Figure 7: *IR-ATR spectrum of liquid water taken with a silver halide fiber coupled into the custom pressure vessel. (There is considerable noise in the broad O-H peak which currently excludes this region from being used in data analysis.) Arrows indicate changes in the water spectrum during ice/hydrate formation.*

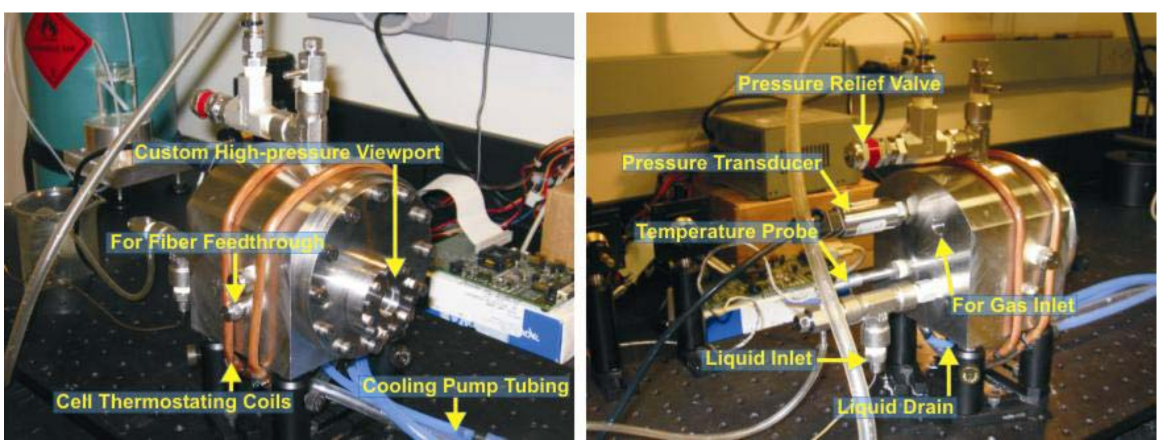

Figure 8: *Custom pressure vessel for synthetic formation of gas hydrates capable of achieving pressures > 750 psig. (Left) Front view of the custom pressure vessel. (Right) Rear view of the custom pressure vessel.*

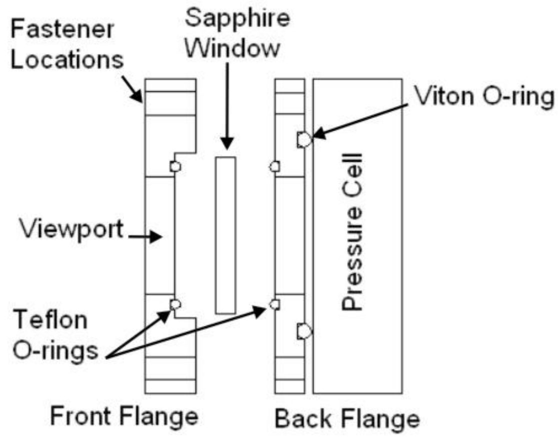

Figure 9: *CAD scheme of the custom high-pressure viewport design.*

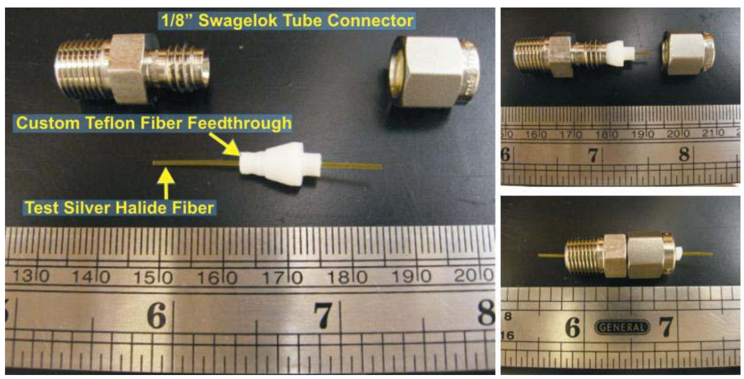

Figure 10: *(Left) Custom designed Teflon ferrule for coupling infrared transparent silver halide fibers into the pressure vessel for high-pressure measurements. (Right) Additional Images displaying assembly of the high-pressure fiber-optic feedthrough.*

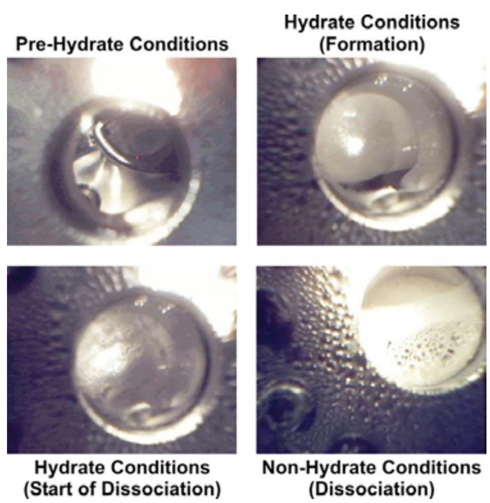

Figure 11: *(Top Left) Pre-hydrate conditions inside the pressure vessel filled with liquid water. (Top Right) Hydrate conditions inside the pressure vessel with bulk methane hydrate visible through the sapphire window. (Bottom Left) Start of hydrate dissociation as phase boundary is being crossed by decreasing the pressure. (Bottom Right) Non-hydrate conditions with hydrate structure dissociating and degassing methane indicated by bubbling of the surfactant solution.*

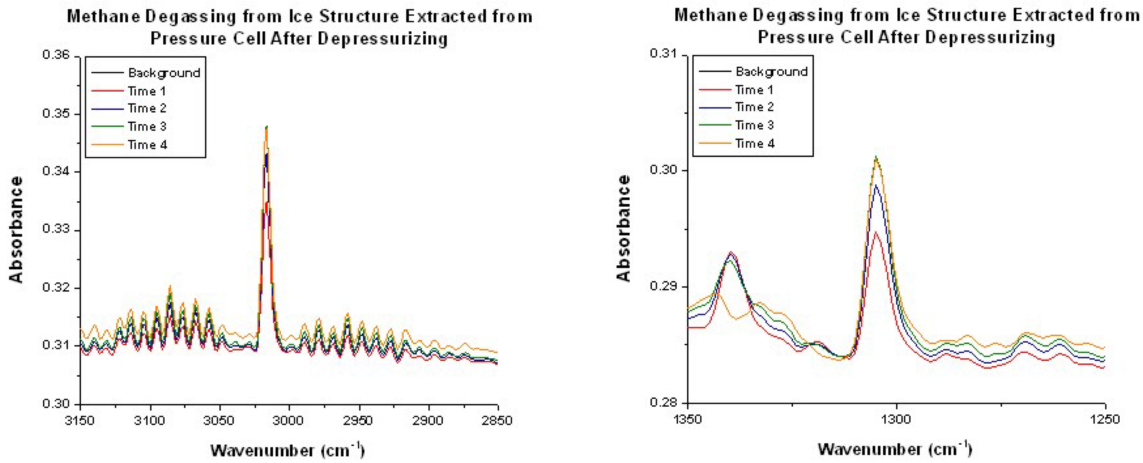

Figure 12: *FT-IR transmission spectra collected as solid hydrate extracted from the pressure vessel melted inside the sample compartment of a Bruker spectrometer. (Left) Methane absorption observed at 3020 cm^{-1}. (Right) Methane absorption observed at 1305 cm^{-1}.*

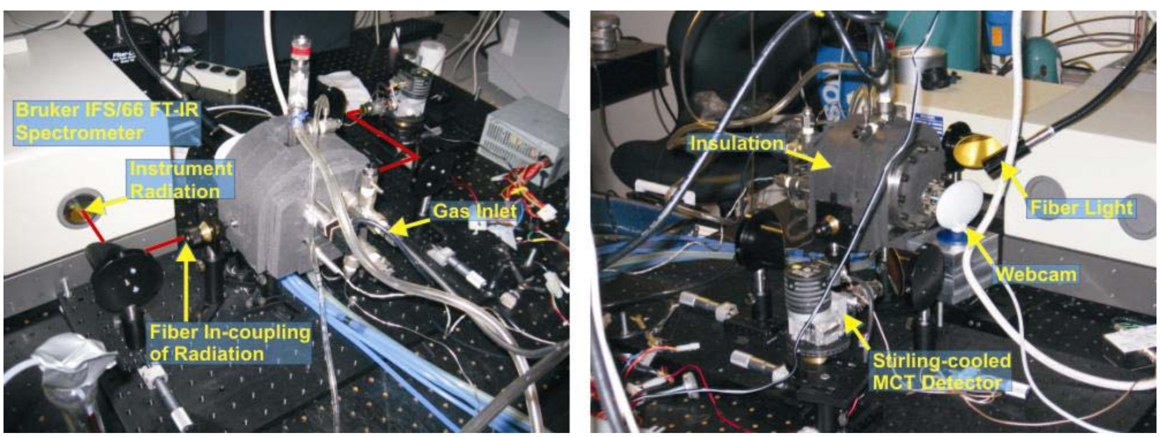

Figure 13: *Fiber-optic measurement setup for in-situ monitoring of hydrate formation and dissociation. (Left) Rear view of measurement setup. (Right) Front view of the measurement setup.*

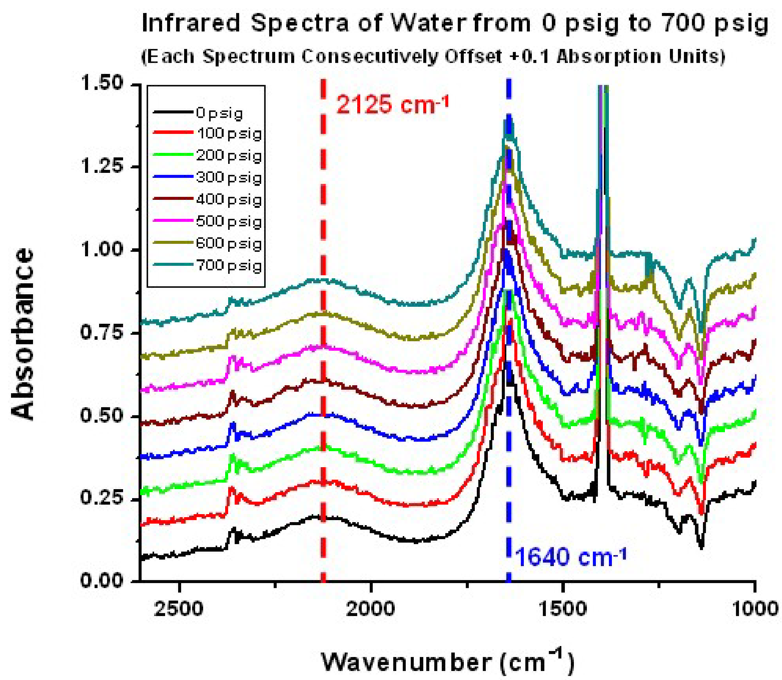

Figure 14: *Infrared water spectra from 0 psig to 700 psig.*

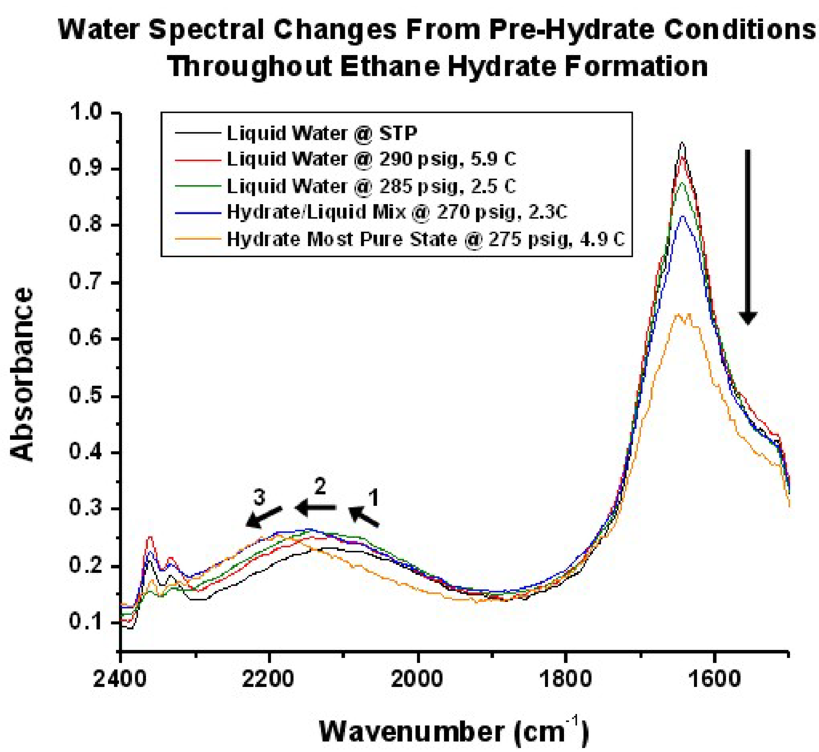

Figure 15: *Selected spectra taken throughout ethane hydrate formation in the region of 2400-1500 cm^{-1}.*

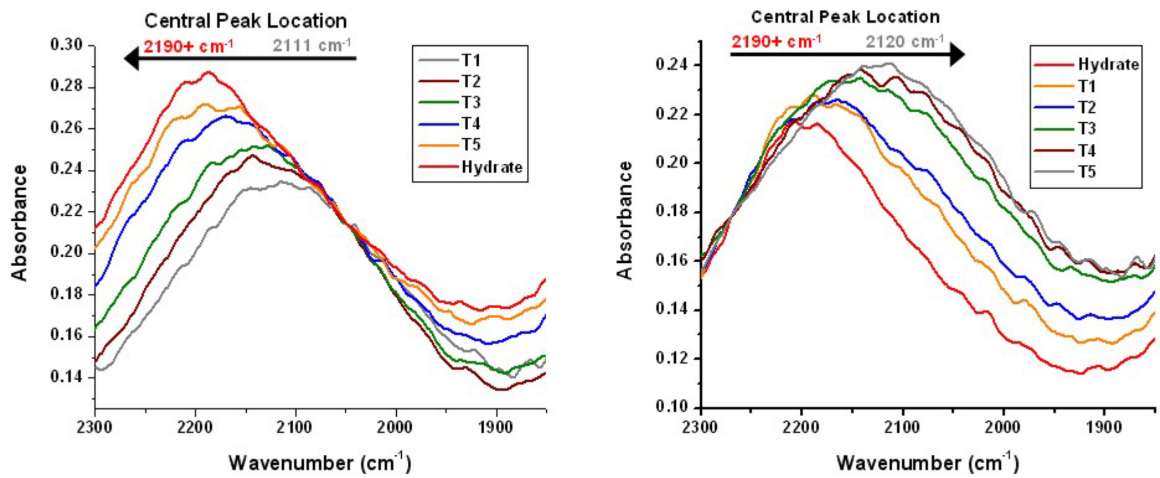

Figure 16: *Spectral shifting of the combination bend and libration band of water throughout (Left) formation and (Right) dissociation.*

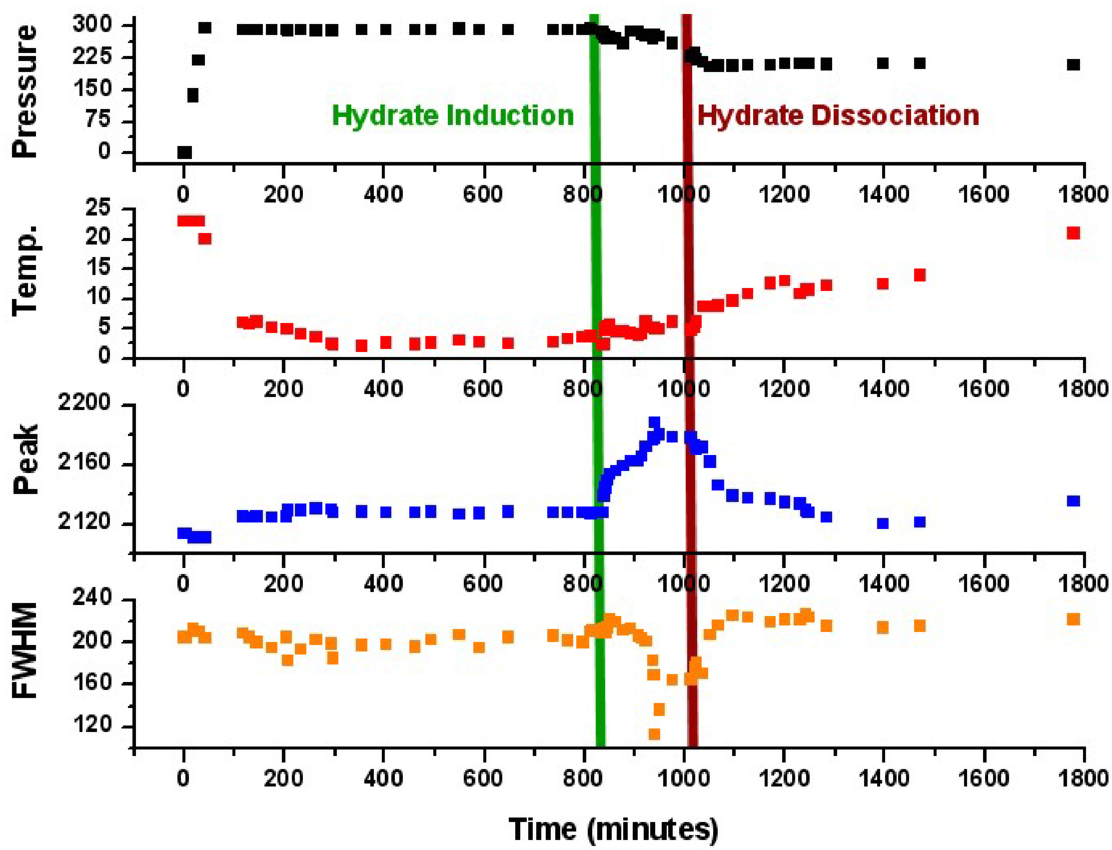

Figure 17: *Pressure (psig), temperature (°C), and spectroscopic results from first fiber-optic in-situ measurements of ethane hydrate formation. Analyzed spectral information is for the combination bend and libration band initially located at approx. 2115 cm^{-1} and the full width at half maximum of the absorption band.*

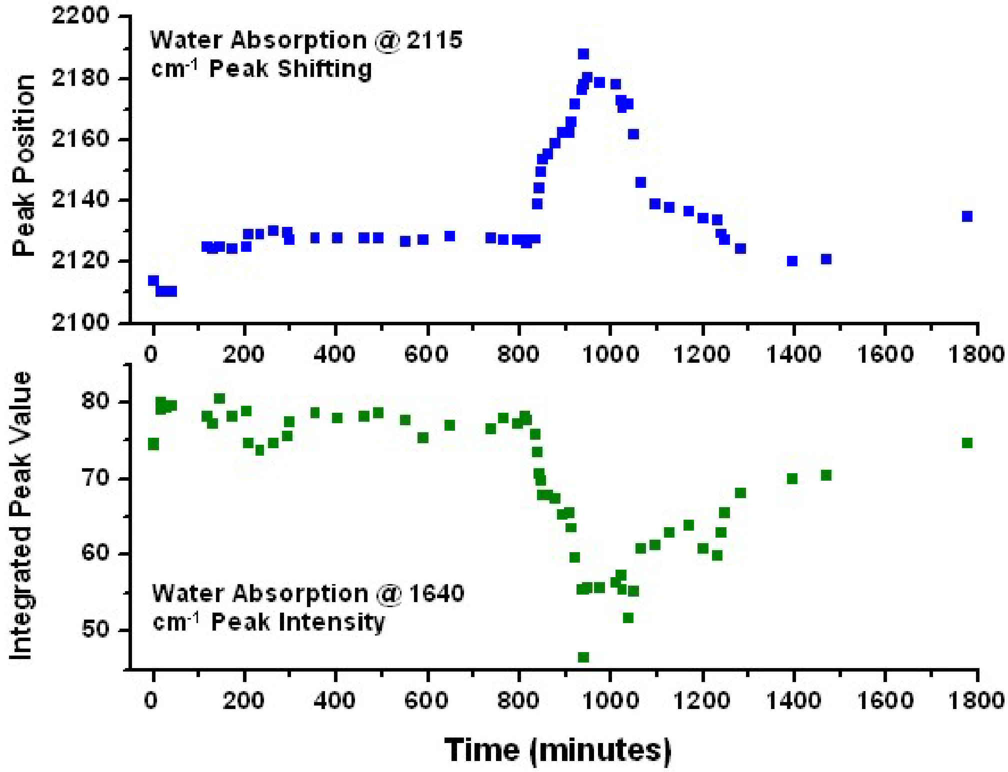

Figure 18: *Analyzed spectroscopic data comparison of the peak position for the combination bend and libration band at 2115 cm^{-1} and the intensity of the H-O-H bend band at 1640 cm^{-1}.*

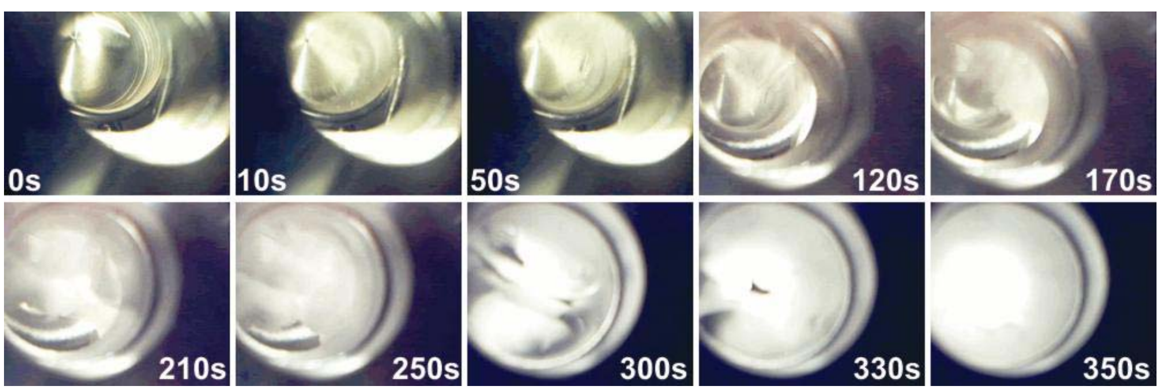

Figure 19: *Selected webcam captures beginning with the first image prior to ethane hydrate induction (0s) until the optical viewport was fully obstructed with bulk hydrate mass 350s after hydrate induction during in-situ spectroscopic measurements.*

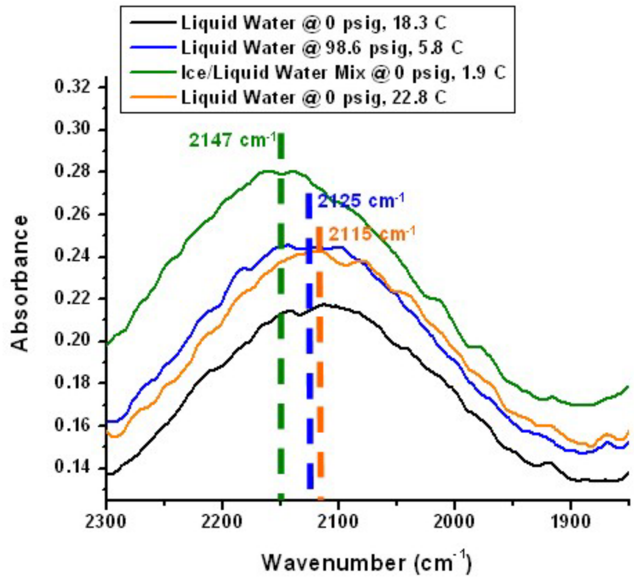

Figure 20: *Initial results from 2300 cm^{-1} – 1800 cm^{-1} for ice formation in the pressure vessel*

ABBREVIATIONS

MIR	mid-infrared
ATR	attenuated total reflection
IR-ATR	infrared attenuated total reflection (spectroscopy)
IR	infrared
FT-IR	Fourier transforms infrared (spectroscopy)
PSCB	polystyrene-co-butadiene
IPV/IPVs	integrated peak value/values
HATR	horizontal attenuated total reflection (waveguides)
CCA	constant cone angle of radiation
CLSR	constant light source radius
CAD	Computer Assisted Design
ASL	Applied Sensors Laboratory
ZnSe	Zinc Selinide
MCT	Mercury Cadmium Telluride (detector element)
GOMHRC	Gulf of Mexico Hydrates Research Consortium

SCIENTIFIC CONTRIBUTIONS

Oral Presentations:

“Update on the Design and Construction of a Mid-Infrared Spectroscopic Sensor for Methane in Seawater”, Gary T. Dobbs and Boris Mizaikoff, Semiannual Meeting of the Gulf of Mexico Hydrates Research Consortium, 02-05, Oxford, MS (oral presentation).

“IR-ATR Deep-Sea Sensing Interfaces: Optimizing Probe Designs through Experimental and Spectral Ray Tracing Analysis of Evanescent Field Interactions”, Gary T. Dobbs and Boris Mizaikoff, SPIE Optics in the Southeast Conference, 10-05, Atlanta, GA (oral presentation).

“First results of *In-Situ* Mid-Infrared Fiberoptic Evanescent Wave Detection of Ethane Hydrate Formation/Dissociation”, Gary T. Dobbs and Boris Mizaikoff, Semiannual Meeting of the Gulf of Mexico Hydrates Research Consortium, 11-05, Oxford, MS (oral presentation).

Manuscripts:

Gary T. Dobbs and Boris Mizaikoff, Shining New Light at Old Principles: Localization of Evanescent Field Interactions at IR-ATR Sensing Interfaces, Revised Manuscript Submission 12-05, Applied Spectroscopy (Journal Article).

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SEISMO-ACOUSTIC CHARACTERIZATION
OF
SEA FLOOR PROPERTIES AND PROCESSES AT THE HYDRATE MONITORING STATION

DOE Award Number: DE-FC26-02NT41628

Final Report covering the period

December 2003 – November 2004

Submitted by

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Date: April 2005

ABSTRACT

Work has continued on the final development of the electronic part of an acoustic logging system designed for investigating fine-scale temporal changes in sea floor acoustic reflection responses, both at the sediment water interface and in the surficial sediment layer. The hardware has now been built and extensively tested, and commissioning is complete.

Testing along the way involved laboratory simulations and shallow water sea trials, using the acoustic logging system alongside `off the shelf` shallow water transducers (5kHz and 33kHz) for signal transmit and receive. Subject to further funding, future efforts will be concentrated on optimizing transducer specifications and packaging for deep water operations at the Gulf of Mexico Gas Hydrate Monitoring Station.

CONTENTS

1. INTRODUCTION

The intention within this DOE funded project has been to design and construct an electronic instrument able to operate a fixed station, acoustic logging device that will ultimately be deployed at the Gas Hydrates Monitoring Station. The primary requirement is for an instrument that is able to be pre-programmed for remote operation whilst under long-term deployment in the deep water environment of the Gulf of Mexico. The development work is being carried out under a collaborative agreement between the University of Wales Bangor and Scimar Engineering Ltd. (as subcontractor to the University).

2. EXECUTIVE SUMMARY

The rationale underpinning the research development and experimental trials in this DOE funded project is recognition of the value of the acoustic reflection signature for monitoring physical changes at the sediment water interface and within the subsurface sediment structure. To this end, a research prototype acoustic system previously developed for an EU project is being further developed in readiness for deployment at the Gulf of Mexico Gas Hydrates Monitoring Station.

While the project did suffer some delays along the way (initial delays with the issue of the contract and some unforeseen developmental problems), the main project deliverable (a laboratory-tested, electronic instrument designed to remotely log high-resolution acoustic reflection signatures, supplied in the form of a working board set ready for insertion in a pressure tube) is now complete.

3. EXPERIMENTAL DEVELOPMENTS

Work undertaken on hardware development and operational software has resulted in an instrument with the following specification:

- Two channel impulsive transmitter, capable of putting 400V clamped voltage spikes onto one of two transmitters
- Two channel selectable receiver, with selectable gain of 6, 18, 30, 42, 54, 66, 78 db of gain, 8 pole high pass filter with selectable knee frequency in 500 Hz steps to 255 kHz, 16 bit A-D conversion with selectable sampling rates to 320 kHz, 512 kBytes of RAM and 128 Mbyte (expandable to 1 Gbyte) of FLASH memory.
- Four channel temperature and pressure sensing auxiliary functions, and battery supply voltage monitoring.
- Fully integrated switched mode power supplies requiring single wide-range DC input, 9-30V DC, allowing use of very high capacity alkaline battery packs.
- Board set mounted in a custom housing ready for pressure tube mounting, and with bench test lead set, and host computer program for data stripping and manual mode control.
- Autonomous and umbilical controlled modes are possible. Virtually all parameters (pulse length, sampling rate, record length, TX and RX channel selection, gain, filter setting, recording dead time) are software selectable and can either be controlled from a surface umbilical (or used in a bench mode for testing) or set into a 4 deep configuration stack so that mixed mode autonomous operation is possible with almost infinite parameter variability.
- Data stored in FLASH ram can be replayed over the umbilical or by physical removal and reading in a standard PC card reader (MCC format). A PC utility to strip the data directly out of the FLASH memory will be supplied

During the final build, all system components were extensively tested prior to the final instrument commissioning.

4. RESULTS AND DISCUSSION

The challenges of the system development can best be described in two parts: the design stage and the implementation and testing stage.

The seabed autonomous operation of the instrument offered several elements that had to be combined, making this device quite different to many sonars, and definitely at this stage making it a scientific rather than `run of the mill` instrument.

The instrument has a highly programmable structure so that parameters can be changed in response to field experience (e.g., knowledge of the exact nature of the signals to be received, optimization of the measurement process).

For future deployment at the Hydrates Monitoring Station, it is proposed that the electronic instrument be interfaced with transmitting and receiving transducers on a fixed frame. The whole will be deployed on the seabed with a recommended 2 m (approx.) clearance between the transducers and the sediment surface. Given the short water path travel time, the electronic system has been designed to produce a very short duration clamped source and very fast settling time. It will provide for high accuracy, high frequency and high resolution (16 bit) data recording, with filter responses with little ringing, optimized for impulsive signals. The instrument will allow very high volume and secure data recording. In addition, power management will provide for optimal bottom battery life.

It should perhaps at this final stage be pointed out that aspects of the project proved far harder than originally expected and that the development team experienced some severe problems along the way meaning that overall bench development time was at least twice that originally estimated. There was no single major problem, the problems that absorbed the time were essentially three, the first of these perhaps a bit surprising:

(i). Because of the ability now to realize circuit elements in simulation, and the accuracy and ease with which simulated designs can now be brought from paper to PCB and then to the bench, virtually all of the circuit elements when tested separately early on, worked first time. This sounds like a major advance, but the effect was that these circuit elements were adopted far faster than would have been possible a few years ago. However, the simulations have limits to the number of parameters that can be varied: when these circuit elements were put under software control problems emerged that the simulation would never have seen.

(ii). The major problem was that the sheer number of usefully variable parameters made this into a far more complex device than its size might suggest. By far the biggest single use of time was in debugging the vast number of variations that the system allows. An element of this that is common to all modern electronics development at component level is that IC manufacturers' data sheets tell you what you must know, and what they want you to know. However, all complex ICs have parameters that the manufacturers may want to hide, or at least not publicize, and parameter variations that they do not know about. The debugging process has to discover all such non-declared parameters.

(iii). It proved remarkably difficult to emulate the real acoustic world in the lab, and thus tests in real water with real batteries are needed. Very minor assumptions that were made to build a lab test rig were found not to be compatible with real testing, and so real-world testing has proved very time absorbing simply because test parameters have to be selected, and sometimes hardware modification has been needed, to make things work.

However, despite the above and the associated time over-runs, the final device met every element of the original specification.

5. CONCLUSIONS

The chosen electronic instrument design integrated many state of the art technologies, and tests have shown the data recording and source quality to be excellent. The project objectives have been fully realized, with the instrument meeting the hopes set at the outset.

Subject to the successful outcome of a follow-up proposal, future efforts will be concentrated on optimizing transducer specifications and packaging for deep water operations.

Sensor and Data Characterization for the

Gulf of Mexico Hydrates Monitoring Station

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Executive Summary

This Report by Barrodale Computing Services Ltd. (BCS) for the University of Mississippi Gulf of Mexico Hydrate Research project describes the results of our investigations into sensor data characteristics as they pertain to data management.

It is important to note that the final selection of sensor types, models, and numbers of sensors had not been made at the time of this report. The final sensor selection and their corresponding resolutions, accuracies, and sampling parameters will be determined by the science objectives and are therefore subject to change or further refinement. However, we have endeavored to address the critical aspects regarding the class of sensors being used and their data products so that a data set architecture and data management framework can be developed.

A list of 16 sensor types was examined in detail to characterize the data in terms of dimensionality, sampling rates, data transfer rates, metadata, operational modes, formats, and transmission practices. The sensors investigated and the corresponding vendors (where applicable) were as follows:

Sensor	**Vendor/Developer (where applicable)**
Hydrophone	Specialty Devices Inc.*
3D Accelerometers (Seismic)	I/O Systems, Specialty Devices Inc.*
Thermistor	Specialty Devices Inc.*
Orientation Sensor	Specialty Devices Inc.*
CTD	Seabird SBE 16plus
Current Meter (ADCP)	RDI (RD Instruments)
Fluorometer	Turner Designs
METS Methane Sensor	Capsum Technologie GmbH
IR Spectroscopic Methane Sensor	Georgia Tech.
Nephelometer	Seatech (Wetlabs), D-A Instruments
Mass Spectrometer	Applied Microsystems Ltd.
Digital Video Camera	Imenco IMDV
Digital Still Camera	Insite Pacific
Bubble Detector	Richard Brancker, Onset
Osmo-Sampler	Florida State U.
Pore-Fluid Pressure Sensor	To be determined

**Third-party sensing elements are interfaced and signal conditioned by SDI*

Each of the above sensors was characterized in terms of the following:

- requirements and limitations;
- physical quantities and their dimensionality;
- sampling rates and variability;

- typical and peak data output (transfer) rates;
- metadata; and
- data formats, processing software, protocols and interfaces.

Operational modes and topology of the sensor array are described along with the corresponding impacts on data management.

We note that power requirements though important, are not considered in this report, as this topic is outside the scope of the current investigation, whose aim is characterization of the data that will be produced by the monitoring station.

The information for the above sensors is summarized in tabular form, to allow for convenient reference and comparison. In addition, a CD-ROM containing supplemental information (brochures, manuals, data files and formats where available) is also provided separately.

Introduction

The Gulf of Mexico Hydrates Research Consortium and the Center for Marine Resources and Environmental Technologies are currently developing a multi-sensor monitoring station to be installed on the continental slope of the northern Gulf of Mexico. The aim of this station is to monitor and investigate the hydrocarbon system within the hydrate stability zone of the northern Gulf of Mexico, and to remotely observe changes in the physical and chemical parameters of gas hydrates. The intention has been to equip the station with a variety of sensors that would enable the determination of a steady-state description of physical, chemical and thermal conditions in its local environment, as well as to detect temporal changes of those conditions. Major components of this monitoring station are geochemical instruments, temperature sensors, accelerometers, and an array of hydrophones that will collect acoustic data.

All this data will need to be archived in an appropriately structured data management system. As a first step toward the development of such a system, it is necessary to define in detail the types of data that will be produced by the sensors of the monitoring station.

In December, 2004, Barrodale Computing Services Ltd. (BCS) was awarded a contract with the University of Mississippi to identify the sensors that will be components of the monitoring station, and to characterize the data produced by these sensors. The purpose of this work was to provide a basis for future design and implementation of an effective data management and archiving system for the station.

As a first step in obtaining the required information, Dr Cedric Zala of BCS attended a meeting of the Hydrates Research Consortium at Oxford, Mississippi in October 2004, and made a presentation on data management. He also made contact with a number of the principal investigators and with several Consortium members involved in sensor development and integration. BCS then sent out a questionnaire to the key contacts, with the request to provide information on specified data characteristics for the sensors of interest to the contacts. Unfortunately, there was a limited response to this request, and by the mid-January deadline, little specific information on either the choice of sensor or the data characteristics had been provided. Furthermore, in many cases, the final selection of sensor types, models, and numbers of sensors had not been made. Responding to this situation, BCS first undertook a number of phone interviews with some key contacts, and then, for cases where specific sensors had not yet been specified, selected representative sensors of the corresponding types for examination and data characterization. This approach provided an effective way of obtaining information required for the subsequent design by BCS of a data management and archiving system.

The results of this investigation are summarized in this report. Some important aspects of the instrumentation and configuration of the monitoring station are first discussed (including system topology, array configuration, and operational modes). Then the information obtained for each of the sixteen sensors identified and their associated data is provided in tabular form. In addition, a CD-ROM containing supplemental information (brochures, manuals, data files and formats where available) is also provided separately.

System Topology

The topology of the observatory and its operational modes are important to data access and management of the system. This section briefly addresses array configuration, instrument access, data logging and their impacts on data management.

The Gulf of Mexico Seafloor Observatory is designed as an integrated collection of sensor arrays (which are outlined in more detail in the next section):

VLA – Vertical Acoustic Line Array
OVA – Oceanographic Vertical Line Array
HLA – Horizontal Line Array (4)
BLA – Borehole Line Array
PCA – Pore Fluid Circulation Array

While the sensors, applications, and array orientations differ between the array types, they are similar from a data management and control perspective. The sensors in each independent and autonomous array are interfaced to a dedicated DATS (Data Acquisition and Telemetry System) that controls the instruments and logs the data for the array.

The components and their functions of the autonomous DATS modules include:

- digital or analog interfaces to all sensors in the array;
- signal conditioning electronics for analog sensors (A/D converters);
- microprocessors for sensor command, control and configuration;
- local file-based storage (20-60 GB); and
- RS-485 and/or Ethernet interfaces to the IDP.

The microprocessor in the DATS powers up the sensors in the array, sends any appropriate configuration and control sequences to each instrument to set up the data collection event, and then polls the sensors. Sensors polled in this manner would have the data logged to disk in the DATS. Some sensors (such as the RDI ADCP) can be configured to collect a data set and store it locally on the instrument. At the end of the sampling event, the data can be downloaded to the DATS or simply left in the instrument for later retrieval, though it is recommended that the data be stored in both units.

The DATS modules are all interfaced to a single IDP (Integrated Data Power unit) that distributes power to the individual arrays and serves as an Ethernet access point for the entire array. All communications with individual DATS on the arrays are performed through the IDP. The IDP Ethernet interface is accessed via fiber optic cables running to a waterproof termination suspended on a mooring (the “Big M” Fiber-Optic Buoy Mooring) at approximately 200 m depth.

From a data management perspective, the Ethernet connection provides access to file-based data structures stored locally on the individual DATS. Each DATS is interrogated via the IDP and the stored data files are downloaded to the SSD (Station Service Device) or to surface- or shore-based computers for processing. Prior to post-processing, an extraction step may be necessary to convert the DATS data files into native instrument file formats.

From an instrument and array control perspective, the Ethernet connection provides access to the IDP, which is used to address the DATS modules and change locally stored configuration files that control sensor operation.

In the near term, the data will be stored in a data logger, and will be retrieved at periodic intervals using the Big M mooring. Ultimately, the data will be transmitted continuously and directly to a shore station via a fiber optic cable.

Array Configurations and Numbers of Sensors

Acoustic Vertical Line Array – VLA

Sensor	**No. of sensors**
Hydrophone	16
Orientation Sensor	16
ADCP	1

Horizontal Line Array – HLA (4 Arrays)

Sensor	**No. of sensors per array**
Hydrophone	16
3D Accelerometers	6

Pore Fluid Circulation Array – PCA

Sensor	**No. of sensors**
Pore Fluid Pressure Sensor	3-6

Borehole Vertical Line Array – BLA

Sensor	**No. of sensors**
3D Accelerometers	6
Hydrophone	4-16
Thermistors	12

Oceanographic Vertical Line Array

Sensor	No. of sensors	Notes
CTD	2	
Fluorometer	2	
Nephelometer	2	
Methane Sensor (METS)	2	Jean Whelan noted that "More METS sensors will be added in future - one for each mass spec (2) and cameras (4?). We will be using 2 Capsum instruments initially, but will be adding our 'homemade' units later on."
ADCP	1	
Thermistor	3-6	
Mass Spectrometer	1-2	Jean Whelan noted that "one on bottom this year, a second probably on bottom next year. This will be the instrument which Rich Camilli is currently building."
IR Spectroscopic Methane Sensor	1	
Video Camera	1	
Still Camera	3-4	
Bubble Detector	1	
Osmo-Sampler	1	
General		Rich Camilli noted that "my wish list for each sensor node includes 3 dedicated serial lines, 14 channels for data, 3 channels for commands, and power at 12-48VDC . The power doesn't need to be clean, and I can handle AC if that is the only thing available."

Operational Modes

The primary limiting factors for the system as a whole are power, transmission bandwidth, and data storage volumes. To address these limitations it is possible to operate the sensor arrays in three distinct modes: episodic, periodic, and continuous. The data management system should be capable of processing data collected in all three modes.

Episodic operation is most appropriate for collecting full resolution seismic and acoustic data. In this mode a ship would connect to the Big M mooring by triggering an acoustic release and floating the buoyant mooring and fiber optic termination to the surface. The seismic and hydrophone arrays (VLA and HLAs) would be turned on and data collection would begin. A point or towed source would be used to generate shot points of 1 to 12 seconds (typically 6 seconds). After collection, the data would be dumped to the surface computers and the array would be put back into a dormant configuration. Until a permanent shore connection is made to the fiber optic interface, this mode of data collection would likely be used on a seasonal basis (every few months).

In periodic mode a sensor array would be turned on for a specified sampling duration at regular intervals. The OLA (Oceanographic Line Array) will likely be operated in this mode, with sensors sampling for 3-4 minutes every hour. Some sensors (such as the RDI ADCP) are internally logging, and data would be stored within the instrument. Data would be collected for up to one year and downloaded from the DATS on the OLA via the IDP.

In continuous mode (always on) the sensor array would collect and transmit data continuously via Ethernet (possibly by continuous requests for the most recently logged data file in a DATS). This mode will not be available until a permanent fiber optical connection to shore is established.

Sensor/Data Characteristics

The following sections describe the individual sensors selected for deployment on the arrays and their corresponding low-level data output record types. Many of the sensors can be used for a wide variety of applications, and the sampling parameters and sensor configuration are dependent on the science objectives that drive the experiment. As these objectives are better defined, more specific record types and formats can be specified. Additionally, the following information can be collected for each sensor once the science objectives are identified:

- Required metadata and how they are created
- Metadata standards
- QA standards or tests
- Operational modes (polled, streaming, internal logging, duty cycles)
- Software required
- Calibration requirements
- Post-processing requirements

Acoustic Hydrophone

Sensor	Information
Consortium contact(s)	Paul Higley
Product name/number	Analog Acoustic Hydrophone
Manufacturer	Specialty Devices, Inc.
Physical quantity measured	Pressure
Dimensionality of measurements	1D stream of voltages proportional to pressure (units in decibels)
Range	2 Hz – 30 kHz (123 dB peak to RMS)
Resolution	16 bits/sample
Sampling Modes:	The hydrophone is designed to be synchronized with shot points of 1-12 seconds in duration (typically 6 seconds) Initially (2005): sporadic, output to data logger during separate specified time periods Operationally (2006+): continuous
Typical sampling rate	10,000 samples/sec
Peak sampling rate	10,000 samples/sec
Typical data transfer rate (per sensor)	160 kbit/sec
Peak data transfer rate (per sensor)	160 kbit/sec
Data format(s) (proprietary or public standard)	Pseudo SEG Y (SDI to provide more details)
Required metadata and how they are created	A synchronized time signal is required for the acoustic signals. Sensor configuration, number of hydrophones, calibrations, and array geometry are required metadata fields.
Metadata standards	SEG Y format headers. (See http://www.seg.org/publications/tech-stand/seg_y_rev1.pdf)
Operational modes (polled, streaming, internal logging, duty cycles)	Polled (data logged in DATS) Streaming (when operated continuously)
Post-processing requirements	Conversion to pressure, signal processing, matched-field processing and inversion
Brochure/description available	No (third-party sensor information may be available)

Other relevant information	A synchronized time signal needs to be embedded in the data stream for many applications. Breaking wave processes in particular require these signals for computing time delays between hydrophones in array configurations.

3D Accelerometer

Sensor	**Information**
Consortium contact(s)	Paul Higley
Product name/number	VectorSeis SVSM
Manufacturer	Input/Output Inc.
Physical quantity measured	Acceleration (g)
Dimensionality of measurements	Scalar values in 3 orthogonal planes; units in g
Range	+/- 1.225 g static, +/- 0.225 g dynamic
Resolution	24 bit (40 ng)
Type of sampling (continuous or sporadic, variability)	Episodic/periodic mode: typically 3 second records every 6-12 seconds at 2 kHz, or 6 second records every 12-18 seconds at 1 kHz. Continuous: 1 kHz – 2 kHz
Typical sampling rate	1 kHz
Peak sampling rate	2 kHz
Typical data transfer rate (per sensor)	72 kbit/sec
Peak data transfer rate (per sensor)	144 kbit/sec
Data format(s) (proprietary or public standard)	I/O Inc. has proprietary data formats; SDI has access to these formats and will be able to poll the sensors, manipulate the data, and store them in the DATS in a format known to SDI and suitable for extraction.
Operational modes (polled, streaming, internal logging, duty cycles)	Polled (data logged in DATS) Streaming (when operated continuously)
Brochure/description available	Yes

Thermistor

Sensor	Information
Consortium contact(s)	Paul Higley
Product name/number	Third-party thermistors integrated by SDI (SDI Borehole 24 bit system)
Manufacturer	SDI
Physical quantity measured	Temperature
Dimensionality of measurements	Degrees Celsius
Range	-10 to 100
Resolution	24 bits > 0.001 C resolution > 0.01 C repeatability > 0.05 C accuracy
Type of sampling (continuous or sporadic, variability)	Periodic (3-4 minutes every hour) Continuous
Typical sampling rate	10 Hz
Peak sampling rate	10 Hz
Typical data transfer rate (per sensor)	240 bps
Peak data transfer rate (per sensor)	240 bps
Data format(s) (proprietary or public standard)	Digitized voltage converted to engineering units using a polynomial calibration equation
Operational modes (polled, streaming, internal logging, duty cycles)	Polled Continuous
Brochure/description available	No

Orientation Sensor

Sensor	Information
Consortium contact(s)	Paul Higley
Product name/number	Third-party compass/tilt sensors integrated by SDI
Manufacturer	SDI
Physical quantity measured	Magnetic direction (compass heading) Tilt (2-axis)
Dimensionality of measurements	Compass: degrees magnetic Tilt: degrees
Range	Compass: 0 to 360 degrees Tilt: 0 to 40.96 degrees
Resolution	12 bits for compass (1 degree)

	12 bits for tilt (0.01 degree)
Type of sampling (continuous or sporadic, variability)	Active concurrently with vertical hydrophone array (VLA)
Typical sampling rate	1 Hz
Peak sampling rate	10 Hz
Typical data transfer rate (per sensor)	24 bps
Peak data transfer rate (per sensor)	240 bps
Data format(s) (proprietary or public standard)	Digitized voltage converted to engineering units using a polynomial calibration equation
Operational modes (polled, streaming, internal logging, duty cycles)	Polled
Brochure/description available	No (third-party sensor information may be available)

CTD Sensor

Sensor	Information
Consortium contact(s)	Jean Whelan / Rich Camilli / Paul Higley
Product name/number	SBE-16 plus
Manufacturer	Seabird Electronics Inc.
Physical quantity measured	a) Temperature b) Conductivity c) Pressure
Dimensionality of measurements	a) Scalar (units deg C) b) Scalar (units S/m) c) Scalar (units dbar)
Range	a) –5 to +35 b) 0 to 9 c) 0 to 7,000
Resolution	a) 24 bits = 0.001 (accuracy 0.005) b) 24 bits = 0.00005 (accuracy 0.003) c) 40 bits = 0.002% (accuracy 0.1%)
Type of sampling (continuous or sporadic, variability)	Periodic (specified sample duration every hour) Continuous
Typical sampling rate	1 Hz
Peak sampling rate	4 Hz
Typical data transfer rate (per sensor)	184 bps
Peak data transfer rate (per sensor)	736 bps

Data format(s) (proprietary or public standard)	Variable; formats available in product. The SBE 16plus can be configured to output ASCII data in hexadecimal format or in calibrated engineering units.
Required metadata and how they are created	A comprehensive list of instrument-specific metadata is provided in the instrument manual (available on the companion CD-ROM).
Operational modes (polled, streaming, internal logging, duty cycles)	Polled Streaming Internally logging
Calibration requirements	To resolve fine structure and detect very small changes in property measurements, the sensors must be calibrated periodically. In particular, the conductivity cell is susceptible to biofouling and needs both cleaning and calibration at an interval determined by the rate of algal growth on the sensing elements.
Brochure/description available	Yes
Other relevant information	Rich Camilli noted that "the CTD will require its own RS232/485 line, I think we should plan on using a SeaBird. I am working on some circuitry to multiplex all of the fluorometers and mets type sensors together. The data from each sensor will be output to a RS232/485, where a single polling command string will yield a data string that will need to be parsed into the appropriate sensor channels. Each of the sensor data channels will be a 12 bit voltage value ranging from 0 to 5 volts (appearing on the serial line as a low and high byte). The conversion from raw voltages to concentrations can be done on the topside. For each sensor node on the mooring we should expect to parse and store at least 14 channels (this could be expanded later to 25 channels with an additional serial line) at up to 1Hz."

Current Meter (ADCP)

Sensor	**Information**
Consortium contact(s)	Vernon Asper / Jean Whelan / Paul Higley
Product name/number	Deep Water Workhorse 300 kHz
Manufacturer	RD Instruments
Physical quantity measured	a) Velocity b) Direction c) Tilt

	d) Temperature
Dimensionality of measurements	a) Vector array (units cm/s) b) Vector array (units degrees magnetic) c) Scalar (units degrees) d) Scalar (units degrees Celsius)
Range	a) 0 to 500 b) 0 to 360 c) 0 to 15 d) –5 to 45
Resolution	a) 0.1 b) 0.01 c) 0.01 d) 0.01
Type of sampling (continuous or sporadic, variability)	Periodic (specified sample duration every hour) Continuous
Typical sampling rate	1 Hz sampling averaged to mean values for a specified sampling duration (5-60 minutes per hour)
Peak sampling rate	2 Hz
Typical data transfer rate (per sensor)	1 record (a few kilobytes) per sampling event
Peak data transfer rate (per sensor)	50,720 bps
Data format(s) (proprietary or public standard)	Variable; formats available in product manuals
Required metadata and how they are created	The RDI family of ADCPs has an extensive command set for instrument configuration and operation. For metadata, operational modes, dynamic configuration and data formats, please refer to the document "Workhorse Commands and Output Data Format" in the companion CD-ROM.
Operational modes (polled, streaming, internal logging, duty cycles)	Polled Streaming Internally logging
Calibration requirements	Calibrations are not typically required for the transducers, although the compass may require swinging. The sensing elements are not particularly susceptible to biofouling.
Brochure/description available	Yes

Fluorometer

Sensor	Information
Consortium contact(s)	Jean Whelan / Rich Camilli
Product name/number	SCUFA (Self Contained Underwater Fluorescence Apparatus)
Manufacturer	Turner Designs
Physical quantity measured	a) Fluorescence b) Turbidity
Dimensionality of measurements	a) µg/L (chlorophyll) or cells/ml (cyanobacteria) b) NTU
Range	a) 0.02 µg/L detection limit; 4 orders of magnitude dynamic range b) 150 cells/ml detection limit; 4 orders of magnitude dynamic range
Resolution	12 bit 0-5V signal (1.22 mV)
Type of sampling (continuous or sporadic, variability)	Periodic (polled) Continuous (polled)
Typical sampling rate	1 Hz
Peak sampling rate	5 Hz
Typical data transfer rate (per sensor)	528 bps (528 bit data string)
Peak data transfer rate (per sensor)	2640 bps
Data format(s) (proprietary or public standard)	Digitized voltage converted to engineering units using a polynomial calibration equation
Operational modes (polled, streaming, internal logging, duty cycles)	Polled
Brochure/description available	Yes

METS Methane Sensor

Sensor	Information
Consortium contact(s)	Jean Whelan / Rich Camilli
Product name/number	METS
Manufacturer	Capsum Technologie GmbH
Physical quantity measured	Methane concentration
Dimensionality of measurements	nmol/l
Range	50 nmol/l to 10 µmol/l
Resolution	Up to 24 bit (SDI A/D converter) 0-5V
Type of sampling	Periodic (Polled)

(continuous or sporadic, variability)	Continuous (Polled)
Typical sampling rate	1 second (sensor has 1-3 sec response time and a t90 time of up to 3 minutes)
Peak sampling rate	1 Hz
Typical data transfer rate (per sensor)	24 bps
Peak data transfer rate (per sensor)	24 bps
Data format(s) (proprietary or public standard)	Digitized voltage converted to engineering units using a polynomial calibration equation
Operational modes (polled, streaming, internal logging, duty cycles)	Polled
Brochure/description available	Yes
Other relevant information	Transmission protocol: 9600 baud, 8 data bits, 1 stop bit, no parity Rich Camilli noted that "the methane and temperature voltages are used to calculate the actual methane concentration using a unique algorithm specific to each sensor. That algorithm is supplied in the documentation that comes with each instrument."

IR Spectroscopic Methane Sensor

Category	Information
Consortium contact(s)	Gary Dobbs, Boris Mizaikoff
Product name/number	SphereIR
Manufacturer	FT-IR instrument by Bruker, Deep-sea housing by Benthos, Re-design and sensor head by Gary Dobbs and Boris Mizaikoff at Georgia Tech.
Number of sensors	1
Physical quantity measured	Infrared absorption
Dimensionality of measurements	Scalar. Three parameters: wavelength of light, transmission of light converted to absorption, and time (with the number of discrete measurements taken)
Range	
Resolution	Generally 4 wavenumber spectral resolution that may be increased to 1 wavenumber. Temporal resolution will depend on power budget.
Type of sampling (continuous or sporadic, variability)	Initially, measurements should be continuous for a designated period of time. In the future, variable measurement times will be possible with either on-

	board data analysis (existing capability) or if there is a sea-to-shore uplink.
Typical sampling rate	Initially every 2-5 minutes with averaging 50-100 measurements.
Peak sampling rate	Every 2 minutes
Typical data transfer rate (per sensor)	There is an on-board computer so it depends whether Ethernet or RS232 is used
Peak data transfer rate (per sensor)	Only have one sensor
Data format(s) (proprietary or public standard)	Proprietary for data acquisition and public standard for analysis results
Operational modes (polled, streaming, internal logging, duty cycles)	There is a fully operational mode. Also, individual components can be selectively shut down to reduce power consumption. There is also a sleep mode which shuts down all components except the embedded PC.
Brochure/description available	Descriptions of the on-board PC are available as well as the FTIR instrument descriptions.
Other relevant information	Gary Dobbs noted that “the instrument we are currently running requires a Windows operating system onboard (which we have). The software we run to take measurements and collect was developed by the company that built our instrument. In the past, we have developed analysis software for the incoming data (pre-processed and processed). The only thing I believe we need is a means for storing and transferring the data at the current time. Ideally it would be nice to do on-line data analysis to trigger the measurement goals of the sensor; however, we are not at that point. Additionally, it would be nice to have a program that could display the analyzed results on-line. But again, this seems to be beyond the current status and capabilities of the consortium being that we are only planning to extract data once every 3-6 months. If this indeed turns out to be the case where we are only extracting data every 3-6 months, we only need the data extraction and archiving capabilities that we can access.”

Nephelometer

Note: Two instruments are described in this section; the D-A Instruments OBS-3A and the Wetlabs (Seatech) ECO VSF3. The latter instrument is included to address a multiple-wavelength and multiple-angle capability that may be a requirement of the selected sensor.

D-A Instruments OBS-3A

Sensor	Information
Consortium contact(s)	Vernon Asper / Jean Whelan
Product name/number	OBS-3A
Manufacturer	D-A Instruments
Physical quantity measured	Volume Scattering The physical quantity measured by the OBS-3A is optical backscatter. This measurement is quantified by value into NTUs.
Dimensionality of measurements	Scalar pairs of values: a) Turbidity (units NTU) b) Sediment concentration (mg/l)
Range	a) 0 to 4,000 b) 0 to 5,000
Resolution	0.1
Type of sampling (continuous or sporadic, variability)	Periodic (polled) Continuous (polled)
Typical sampling rate	See table below
Peak sampling rate	10 Hz
Typical data transfer rate (per sensor)	See table below
Peak data transfer rate (per sensor)	1600 bps
Data format(s) (proprietary or public standard)	ASCII data formats are described in the supplied instrument documentation
Operational modes (polled, streaming, internal logging, duty cycles)	Polled
Brochure/description available	Yes
Other relevant information	Light attenuation is caused by the combined absorption and scattering properties of everything in the water column, including the water itself. The attenuation coefficient is the sum of the absorption coefficient and the scattering coefficient (a+b=c). The OBS-3A provides an estimate of the scattering coefficient (b), but a

	value for the absorption coefficient (a) is required to completely characterize the optical attenuation of a sample. A transmissometer or related instrument can provide the absorption value. It is important to recognize that two different models of optical backscatter instruments will produce different NTU values for the same sample due to the differences in sensing elements and principles of operation. Cautious interpretation of NTU values should consider whether the same model of instrument and mode of data collection were used between data sets. The infrared light-emitting diode (IRLED) deteriorates with use and will become less bright over time (on the order of a few percent per year). The optical face may change with biofouling on the order of weeks to months. Optically clear TBT (tributyl tin) compounds are available to mitigate these effects. The instrument needs periodic cleaning and calibration. Calibration procedures are documented and can be performed by the user.

Note: scan rates and numbers of scans to average per sample depend on the application and the environmental conditions. Typical sampling rates are:

Environment	Scan Rate (Hz)	Scans per sample	Sample interval (sec)
River	2	60-200	900
Beach	4-10	256-1024	300-900
Estuary	4-8	60-1024	900-3600

Wetlabs (Seatech) ECO VSF3

Sensor	Information
Consortium contact(s)	Vernon Asper / Jean Whelan
Product name/number	ECO VSF-3
Manufacturer	Wet Labs (Seatech)
Physical quantity measured	Volume Scattering The physical quantity measured by the VSF-3 is optical backscatter. The scattering measurement is quantified at 3 wavelengths (470, 530, 660 nm).
Dimensionality of	Scalar (units m^{-1})

measurements	
Range	0 to 1
Resolution	12 bit Sensitivity (blue) 4.1 x 10^{-5} m^{-1} sr^{-1} Sensitivity (green) 5.6 x 10^{-6} m^{-1} sr^{-1} Sensitivity (red) 2.1 x 10^{-6} m^{-1} sr^{-1}
Type of sampling (continuous or sporadic, variability)	Periodic (polled) Continuous (polled)
Typical sampling rate	1 Hz
Peak sampling rate	Up to 8 Hz
Typical data transfer rate (per sensor)	800 bps
Peak data transfer rate (per sensor)	6400 bps
Data format(s) (proprietary or public standard)	ASCII data formats are described in the supplied instrument documentation. Reference and signal values are provided at each wavelength, as well as thermistor, time and date values (for a total of 9 channels). Channel configuration and output are user-definable.
Operational modes (polled, streaming, internal logging, duty cycles)	Polled Internal logging
Brochure/description available	Yes
Other relevant information	The Wet Labs instrument has a mechanical wiper that is effective in cleaning the optical elements of the sensor. See “Other relevant information” for OBS-3A. Vernon Asper noted that “we should look into the multi-wavelength and possibly the multi-angle units so that we can distinguish the particles better, if the budget will allow. The Wetlabs units incorporate wipers and antifouling that are very effective.”

Mass Spectrometer

Sensor	Information
Consortium contact(s)	Jean Whelan / Rich Camilli
Product name/number	In-Spectr
Manufacturer	Applied Microsystems Ltd.
Physical quantity measured	Relative abundance and absolute concentrations of chemical species / mass units
Dimensionality of measurements	Power spectra
Range	N/A
Resolution	N/A
Type of sampling (continuous or sporadic, variability)	Discrete samples are analyzed and processing results are internally logged to data files
Typical sampling rate	40 kbyte/hour (depends on setup)
Peak sampling rate	100 kbyte/hour (depends on setup)
Typical data transfer rate (per sensor)	Dependent on logged data file size
Peak data transfer rate (per sensor)	Dependent on logged data file size
Data format(s) (proprietary or public standard)	See product documentation
Operational modes (polled, streaming, internal logging, duty cycles)	Processed files are polled from the instrument
Brochure/description available	Yes
Other relevant information	Rich Camilli noted that "I believe that the mass spectrometer is not viable unless we can guarantee continuous power ~40 Watts, and periodic (about 1 minute duration) peak power ~100 Watts. At the moment, it doesn't appear that the mooring will be able to support these power demands. That being said, the complexity of the mass spectrometer is such the design is intended to be fully self-contained - just 24VDC input. It will have its own dedicated PC-104, and will be capable of independently logging and processing its own data. The processed data could be echo-typed out, but this would probably eat up enough bandwidth to require an ethernet connection, or at least a high-speed dedicated serial. If the mooring is intended to allow for intermittent data uploads to a ship or satellite, then this might be worthwhile; otherwise we should probably keep the mass spec

	data in its own can.”

Digital Video Camera

Sensor	Information
Consortium contact(s)	Jean Whelan / Oscar Pizarro / Vernon Asper
Product name/number	IMDV 3018 Digital Video Camera
Manufacturer	Imenco
Physical quantity measured	Imagery
Dimensionality of measurements	N/A
Range	N/A
Resolution	N/A
Type of sampling (continuous or sporadic, variability)	Episodic, periodic or continuous
Typical sampling rate	
Peak sampling rate	
Typical data transfer rate (per sensor)	1244 Mbps
Peak data transfer rate (per sensor)	1244 Mbps
Data format(s) (proprietary or public standard)	HDTV
Operational modes (polled, streaming, internal logging, duty cycles)	Polled still images (internally logged) Streaming Video
Brochure/description available	Yes

Typical and Peak Data Output (Transfer) Rates

Data rates are dependent on the resolution of the image, the frame rate, and whether the signal is interlaced (i) or progressive (p) scan. The following table summarizes data rates for varying resolutions, frame rates, and interlacing.

Resolution	Data Rate
640x480x30i	184Mbps
720x480x30p	207Mbps
1280x720x30p	553Mbps
1280x720x60p	1106Mbps
1920x1080x30i	1244Mbps
1920x1080x30p	1244Mbps

Data Formats, Processing Software, Protocols and Interfaces

The protocol for transmitting the video information over IP at the SC01 conference was defined by engineers from ISI, Tektronix, and UW, using the IETF standard Real Time Protocol (RTP) specification as a foundation.

The current 292M standards are provided in the supplemental information on CD-ROM: "RTP Payload Format for Society of Motion Picture and Television Engineers (SMPTE) 292M Video".

Digital Still Camera

Sensor	Information
Consortium contact(s)	Vernon Asper / Jean Whelan / Oscar Pizarro
Product name/number	Scorpio
Manufacturer	Insite Pacific
Physical quantity measured	Imagery
Dimensionality of measurements	3.2 Mpixel 2D image
Range	
Resolution	Up to 2048 x 1536
Type of sampling (continuous or sporadic, variability)	Periodic or event-based. 1 Mbyte internal storage, can provide constant video
Typical sampling rate	
Peak sampling rate	
Typical data transfer rate (per sensor)	
Peak data transfer rate (per sensor)	
Data format(s) (proprietary or public standard)	JPEG, TIFF
Operational modes (polled, streaming, internal logging, duty cycles)	
Post-processing requirements	1) bottom reconstruction from imagery. 2) gas flux estimation (from tracking bubble sizes and speeds) For 1) only one image per camera is needed every time a reconstruction is required (say once an hour). For 2) at least two images for each camera taken in close succession are needed. A typical scheme would be to acquire an image pair 5-50 ms apart every second while the camera is on (while an

	event is occurring). This could last for a few minutes.
Brochure/description available	
Other relevant information	Vernon Asper noted that "I recently acquired a nice digital still camera in a titanium housing that I intend to couple with my bubble detector to look at the sizes and shapes of bubbles percolating out of the seafloor. I don't intend to leave this in place permanently, but it would work well in this application and is pre-wired for the external input that we'll need. It also has an intervalometer installed and enough battery power (using its external DSP&L SeaBattery) to last a long, long time. But the video camera might be a better choice; we can certainly use more than one camera." He also noted that "illumination is provided by a strobe that is pretty low power; normally operates on 5 AA batteries, but is set up for external power, as is the camera." Oscar Pizarro noted that "given low power operation constraints, I'm assuming all we should do is acquire images and post-process them. The basic setup at this point consists of three firewire cameras connected to a PC/104 stack running Linux. I'm in the process of selecting the specific cameras but for now we can assume 1600x1200 16 bit TIFF files from 3 cameras (could be less resolution but it doesn't hurt to ask for that much). Talking to the scientists it seems that the vision package would spend most of the time asleep. And would only acquire images with sporadic sampling, say event-based (triggered by a chemical sensor). Periodic sampling would also be used (for example, turn on once an hour for 10 seconds)… At this point I'm thinking of saving the images to a local hard drive. The images could then FTP'd to wherever they are needed. In addition, we might include an inclinometer and compass module to record orientation of the package. The data would consist of 3 measurements (pitch, roll, yaw) and a time stamp. These would be sampled whenever the package acquires imagery. I'd log them as ASCII strings with 6 significant figures each."

Bubble Detector

Sensor	Information
Consortium contact(s)	Vernon Asper
Product name/number	Analog conductivity cell, Tattletale data logger
Manufacturer	Richard Brancker, Onset
Physical quantity measured	Conductivity
Dimensionality of measurements	Scalar
Range	
Resolution	
Type of sampling (continuous or sporadic, variability)	Sporadic, the system will detect bubbles and just send in the events
Typical sampling rate	Low
Peak sampling rate	
Typical data transfer rate (per sensor)	
Peak data transfer rate (per sensor)	100 byte/sec maximum
Data format(s) (proprietary or public standard)	
Operational modes (polled, streaming, internal logging, duty cycles)	
Brochure/description available	
Other relevant information	Vernon Asper noted that "total power consumption is probably around 5mA at 9VDC maximum; normally much less".

Osmo-Sampler

Category	Information
Consortium contact(s)	Jeff Chanton
Product name/number	Home built
Manufacturer	Laura Lapham and Jeff Chanton
Number of sensors	No sensors *per se*, collectors of fluid
Physical quantity measured	Cl, CH_4
Dimensionality of measurements	µM
Resolution	cm
Type of sampling (continuous or sporadic, variability)	Continuous, but recorded at specific intervals
Typical sampling rate	Weekly

Peak sampling rate	Weekly
Typical data transfer rate (per sensor)	N/A
Peak data transfer rate (per sensor)	N/A
Data format(s) (proprietary or public standard)	Molar concentration versus depth at a certain time
Operational modes (polled, streaming, internal logging, duty cycles)	None
Calibration requirements	Laboratory based
Brochure/description available	No
Other relevant information	None

Pore Fluid Pressure Sensor

No information on the choice for this sensor has been provided to date, and so the data volumes, etc. have been estimated.

Sensor	Information
Consortium contact(s)	
Product name/number	
Manufacturer	
Physical quantity measured	Pressure
Dimensionality of measurements	Scalar
Range	
Resolution	24 bit (estimated)
Type of sampling (continuous or sporadic, variability)	
Typical sampling rate	10 Hz (estimated)
Peak sampling rate	10 Hz (estimated)
Typical data transfer rate (per sensor)	
Peak data transfer rate (per sensor)	
Data format(s) (proprietary or public standard)	
Operational modes (polled, streaming, internal logging, duty cycles)	
Brochure/description available	
Other relevant information	

Summary: Data Rates and Storage Requirements

(a) Initial installation (2005)
(b) Full installation (2006/7+)

Sensor	Number of Sensors	Average Data Rate (/Sensor)	Average Data Rate (Total)	Storage Requirement (Mbyte/day)
Hydrophone	(a) 12 (b) 80	10,000 samp/s, 16 bit/samp	a) 1.83 Mbit/s b) 12.2 Mbit/s	a) 19,775 b) 131,833
3D Accelerometer	(a) 6 (b) 30	1000 samp/s, 24 bit/samp	a) 140 kbit/s b) 703 kbit/s	a) 1,476 b) 7,383
Thermistor	(a) 12 (b) 18 (*)	10 samp/s, 24 bit/samp	a) 2.81 kbit/s b) 4.22 kbit/s	a) 29.6 b) 44.5
Orientation Sensor	(a) 16 (b) 16	1 samp/s, 24 bit/samp	a) 384 bit/s b) 384 bit/s	a) 4.0 b) 4.0
CTD	(a) 2 (b) 2	1 samp/s, 184 bit/samp	a) 368 bit/s b) 368 bit/s	a) 3.8 b) 3.8
Current Meter (ADCP)	(a) 1 (b) 1	1 samp/s, 5000 bit/samp (*)	a) 4.9 kbit/s b) 4.9 kbit/s	a) 51 b) 51
Fluorometer	(a) 2 (b) 2	1 samp/s, 528 bit/samp	a) 1.0 kbit/s b) 1.0 kbit/s	a) 11 b) 11
METS Methane Sensor	(a) 1 (b) 2 (*)	1 samp/s, 24 bit/samp	a) 24 bit/s b) 48 bit/s	a) 0.25 b) 0.49
IR Spectroscopic Methane Sensor	(a) 1 (b) 1	100 samp/min, 24 bit/samp (*)	a) 40 bit/s b) 40 bit/s	a) 0.41 b) 0.41
Nephelometer	(a) 2 (b) 2	1 samp/s, 800 bit/samp	a) 1.56 kbit/s b) 1.56 kbit/s	a) 16.5 b) 16.5
Mass Spectrometer	(a) 1 (b) 2 (*)	800 kbit/hr (*)	a) 228 bit/s b) 456 bit/s	a) 2.3 b) 4.7
Digital Video Camera	(a) 0 (b) 1	1244 Mbit/s (when on) (**)	a) 0 b) 3.45 Mbit/s(**)	a) 0 b) 37,320
Digital Still Camera	(a) 1 (b) 4 (*)	1 samp/5min, 30 Mbit/samp	a) 102 kbit/s b) 410 kbit/s	a) 1,080 b) 4,320
Bubble Detector	(a) 1 (b) 1	800 bit/s	a) 800 bit/s b) 800 bit/s	a) 8.2 b) 8.2
Osmo-Sampler	(a) 1 (b) 1	0	a) 0 b) 0	a) 0 b) 0
Pore-Fluid Pressure Sensor	(a) 0 (b) 6 (*)	10 samp/s, (*) 24 bit/samp	a) 0 b) 1440 bit/s	a) 0 b) 14.8
Total			**a) 2.08 Mbit/s** **b) 16.8 Mbit/s**	**a) 22,458** **b) 181,300**

(*) estimated (**) assume camera is on 10 sec/hour

Data Management Architecture Design for the

Gulf of Mexico Hydrates Seafloor Observatory

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Executive Summary

This Report by Barrodale Computing Services Ltd. (BCS) for the University of Mississippi Gulf of Mexico Hydrate Research project describes an architecture for the data management and archive system (DMAS) for the Gulf of Mexico Hydrates Seafloor Observatory.

It is important to note that the final selection of sensor types, models, and numbers of sensors had not been made at the time of this report. The final selection of sensors and their corresponding resolutions, accuracies, and sampling parameters will be determined by the science objectives and are therefore subject to change or further refinement. Hence the degree to which the detailed aspects of the DMAS architecture can be specified at this time is limited. Nonetheless, this report first describes the context in which the DMAS of the Gulf of Mexico Hydrates Seafloor Observatory will operate. In simple terms, the DMAS will accept data from observatory instruments, and accept and serve data requests from users.

Following a discussion of the DMAS context, the proposed overall architecture of the DMAS itself is described. This architecture consists of several servers which together provide services for authenticating users, responding to data catalog lookups, and providing access to the observatory data itself. The data are stored in a combination of object-relational databases and file systems.

In order to build upon the foundation presented in this document, it will be necessary to obtain further information on user requirements. To this end, a questionnaire was sent on February 14, 2005 to members of the Gulf of Mexico Hydrates Research Consortium (see Appendix 3 for a list of the members to which the questionnaire was sent). To date, no response to this questionnaire has been received, and so this document concludes by discussing how the different possible answers to the questionnaire will influence the detailed design. Once user requirements are further defined, this discussion will provide direction and input to the system design process.

Introduction

The Gulf of Mexico Hydrates Research Consortium and the Center for Marine Resources and Environmental Technologies are currently developing a multi-sensor Seafloor Observatory to be installed on the continental slope of the northern Gulf of Mexico. The aim of this station is to monitor and investigate the hydrocarbon system within the hydrate stability zone of the northern Gulf of Mexico, and to remotely observe changes in the physical and chemical parameters of gas hydrates. The intention has been to equip the station with a variety of sensors that would enable the determination of a steady-state description of physical, chemical and thermal conditions in its local environment, as well as to detect temporal changes of those conditions. Major components of this Seafloor Observatory are geochemical instruments, temperature sensors, accelerometers, and an array of hydrophones that will collect acoustic data.

All this data will need to be archived in an appropriately structured data management and archive system (DMAS). In December 2004, Barrodale Computing Services Ltd. (BCS) was awarded a contract by the University of Mississippi to design the architecture of such a system.

As a first step toward the development of the DMAS, BCS undertook an investigation to define in detail the types of data that will be produced by the sensors of the Seafloor Observatory. The results of that investigation are summarized in the report Sensor and Data Characterization for the Gulf of Mexico Hydrates Seafloor Observatory, by Barrodale Computing Services, January 31, 2005. Two tables from that report, one summarizing the array / sensor configurations and one listing sensor data rates and storage requirements, are provided in Appendices 1 and 2 of this report.

This report builds on the previous one by describing a suitable architecture for the DMAS. In Appendix 3, the report presents a questionnaire on user requirements. The questionnaire was sent out to members of the Gulf of Mexico Hydrates Research Consortium (see Appendix 3 for a list of the members who received the questionnaire). However, no responses have been received to date. Future responses to the questionnaire, along with the description of the basic architecture presented in this document, will provide input and direction as the detailed design (the database design, file system design, and web services design) continues. This report concludes with a discussion of how various answers to this questionnaire will impact the design decisions.

DMAS Context

The following diagram illustrates the context in which the DMAS of the Gulf of Mexico Hydrates Seafloor Observatory will operate.

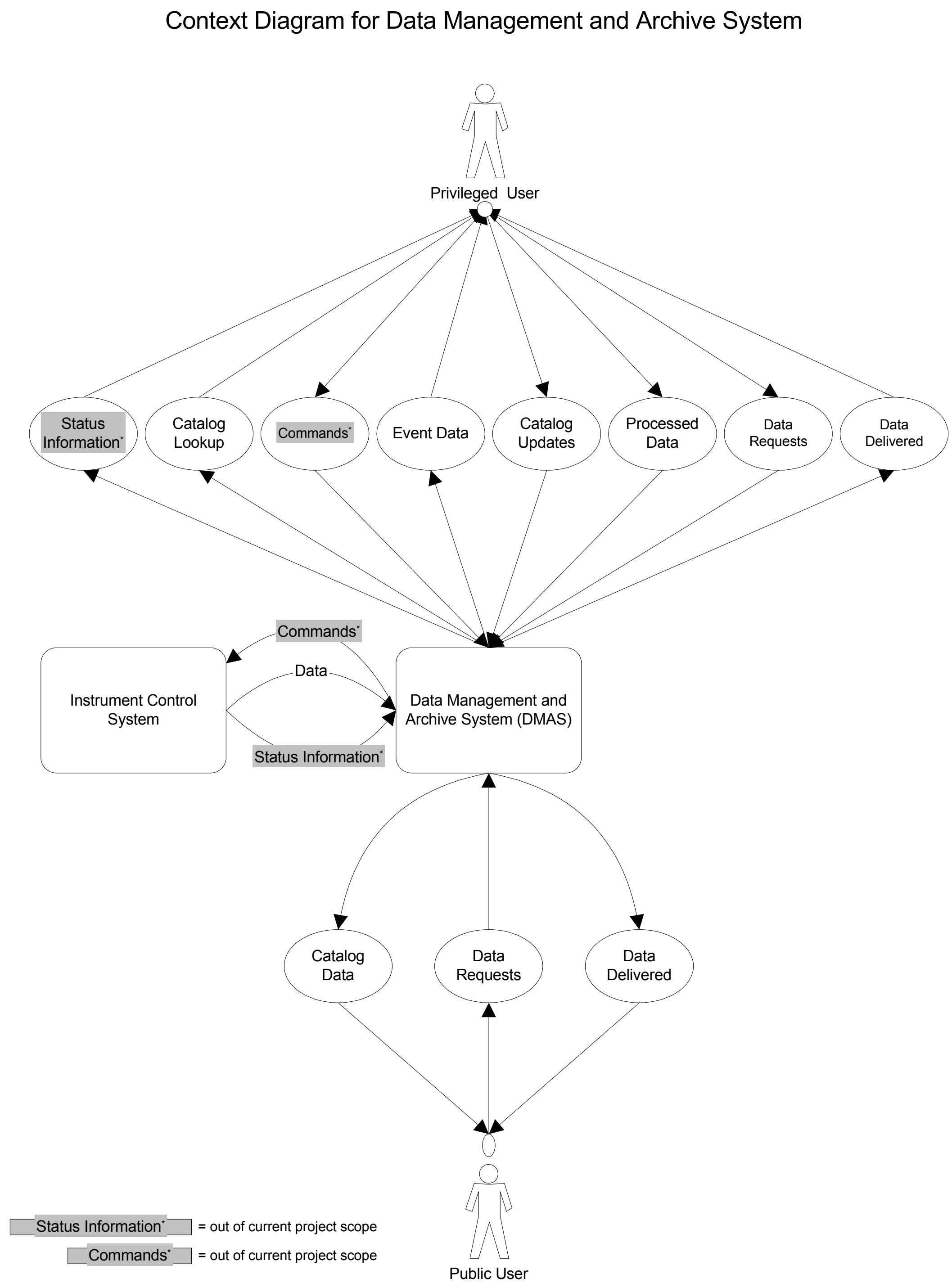

Figure 1: DMAS Context Activity Diagram

The context diagram on the previous page shows 2 “actors” – *public users* and *privileged users* – and a number of ways in which these actors will interact with the DMAS. The basic difference between these types of users is that privileged users will be able to control the observatory instruments and add data to the DMAS, while public users operate in a more *read-only* mode. It may be that initially there are no public users, but the architecture should accommodate this role as it may be pertinent in the future.

Privileged users will have the following interactions with the DMAS:

- Retrieve instrument status information from the DMAS.
- Retrieve catalog data from the DMAS.
- Send instrument control commands to the DMAS, to be relayed to the Instrument Control System.
- Monitor events (e.g., some property of the data reaching some threshold value).
- Update the DMAS data catalog.
- Load external data into the DMAS.
- Send data requests to the DMAS.
- Retrieve near-real-time data and data products from the DMAS.

Public users will have the following interactions:

- Retrieve catalog data from the DMAS.
- Send data requests to the DMAS.
- Retrieve near-real-time data and data products from the DMAS.

An Architectural Framework for the DMAS

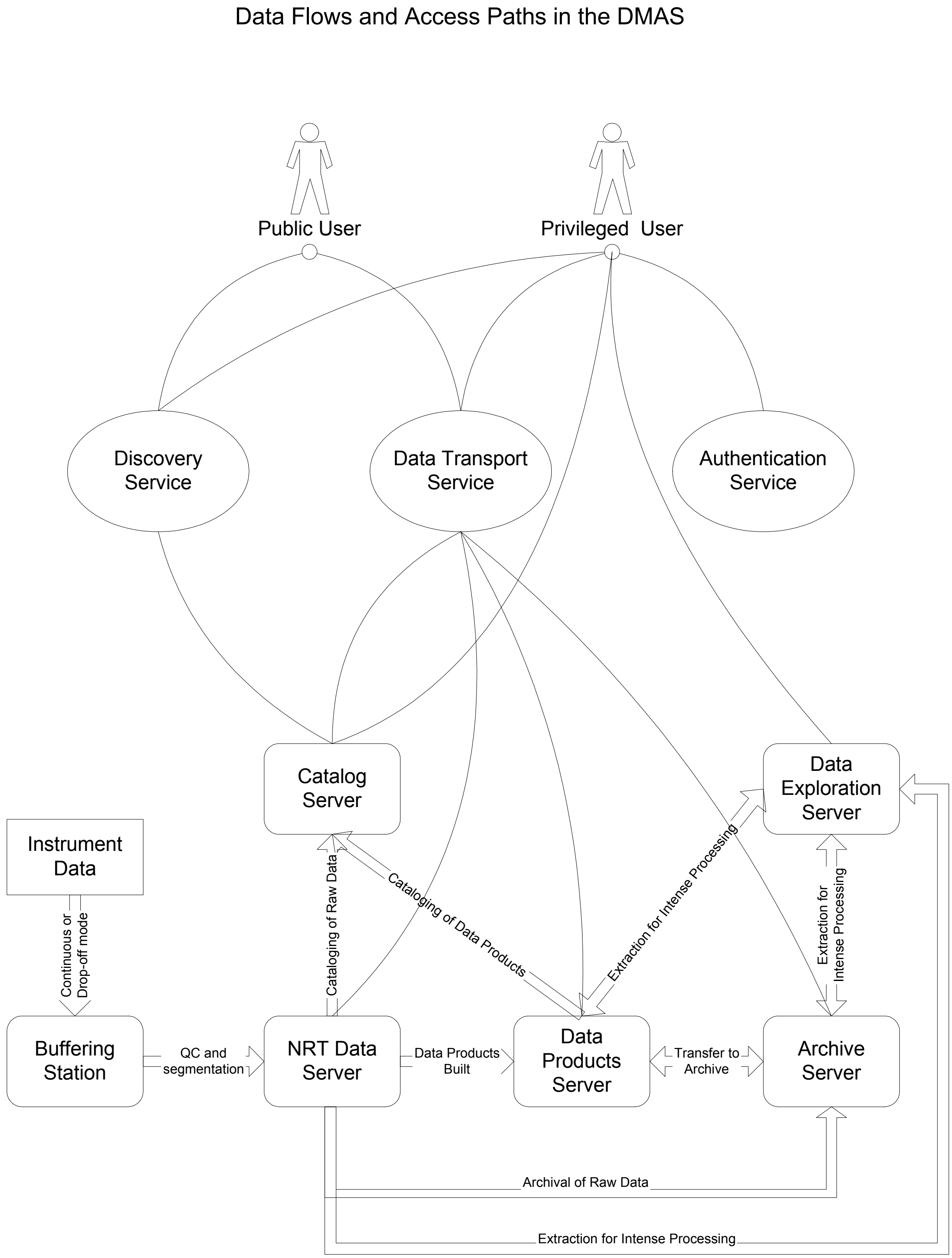

Figure 2: General Framework for the Hydrates Seafloor Observatory DMAS Architecture

Figure 2 shows a general framework for the DMAS architecture, with three levels of objects:

1) "Actors" are shown as stylized human figures. In this simple depiction there are just two types of actors:
   i) privileged users; and
   ii) general users ("public users").

   Initially all users of the Hydrates Seafloor Observatory DMAS will be privileged, but it is expected that in the future there may be some data that is made available to the general public.
2) "Repositories" are shown in boxes with rounded corners. In this model there are six repositories:
   i) the Near Real Time Data Server (holding the data as they exist after a rudimentary level of QC is applied);
   ii) the Catalog Server, hosting a database of metadata;
   iii) the Data Products Server, hosting a database of quality controlled data products;
   iv) the Data Exploration Server, hosting a database of data extracts within data- and computationally-intensive processing can be performed; and
   v) the Archive Server, hosting a long-term data archive.
   vi) the Buffering Station, which holds the data before it is ingested into the DMAS.
3) "Services" are shown in oval shaped boxes. Services are provided to the Actors, based on Data in the Repositories. There are three services shown:
   i) a Discovery Service, which can be used by both public and privileged users to determine what data are available;
   ii) a Data Transport Service, which is responsible for delivering requested data to the users; and
   iii) an Authentication Service, which is responsible for authentication of privileged users and determination of access levels.

The thin lines in the diagram simply link together actors, services, and repositories that have some relationship. No specific directionality, data flow, or control flow is implied. A line joins an actor with a service if the actor uses the service; a line joins a service with a repository if the service accesses that repository. In one case there is a line directly joining an actor (privileged user) and a repository (data mine), meaning that the actor can use that repository directly.

The thick, directed lines show data flows. Data from the instruments are collected in a buffering station, where some initial quality control is performed and the data are segmented (essentially the continuous time series are chopped into discrete time slices). Following this segmentation, the data are stored in the Near Real-time (NRT) Data Server, with metadata being copied to the Catalog Server. Once data have been stored on the NRT Data Server they can be converted to data products (such as SEG Y format files) and stored on the Data Products Server, with metadata for these products being copied to the Catalog Server. Once the NRT Data and Data Products are no longer needed “on-line” they are moved to the Archive Server. A final server, the Data Exploration Server, is used as a “sandbox” where ad-hoc, computational- or data-intensive processing can be performed without risk of adversely affecting production throughput (i.e., the processing and serving of regular data products).

In this architecture, data and metadata are stored together, in the same rows, in tables in object-relational databases. A short discussion of object-relational databases, and their features and benefits, is provided in Appendix 4. With respect to an architecture for the Gulf of Mexico Hydrates Seafloor Observatory, the object-relational approach offers the following benefits:

1) ***Complex data type / operation support***. The structure of measurements need not be lost. New data types can be defined to represent complex data objects such as depth versus temperature profiles and time series; instances of these data types can be stored as objects in the database, and methods can be defined to operate on these objects.
2) ***Metadata / data treated in a uniform manner***. Since the metadata are stored together with the data they describe, the risk that they will become out of synch with respect to each other can be eliminated. A method (operation) that is written to operate on a particular type of object (e.g., a time series), can be written in a way that creates an appropriate version of the metadata.
3) ***Data mining opportunities***. This architecture offers an isolated data mine. Privileged users can request that large volumes of data-of-interest be copied to a private database on the data mine server for subsequent analysis (using the complex object methods mentioned above) and, perhaps, new data product creation. The data mine can be hosted on a server separate from the Data Products Server in order to avoid hampering the throughput and responsiveness of the Data Products Server.
4) ***Automatically enforced data integrity***. Since metadata and the data they describe are stored together in the same rows, already-existing database mechanisms for enforcing referential integrity can be exploited.
5) ***Unlimited ability to subset or aggregate data***. Storing data in an object-relational database rather than in files allows one to postpone the decision on what constitutes a “package”. (Storing data in files requires that one determine how much data to put in each file.) Data are essentially “packaged,” from one or more database rows, on the fly. Some sample queries might be:

    Selection:
    Find the temperature-depth profiles from BLA thermistor readings for all periods of time where the temperature starts to exceed a certain value and later dips below that value. These ranges are further constrained to be between TIME1 and TIME2, where the maximum temperature occurred between DEPTH1 and DEPTH2, and this maximum temperature was

between TEMP1 and TEMP2

Aggregation:
Return the “average” temperature-depth profile, for profiles satisfying the preceding selection criteria.

The following sections describe each of the services and servers in more detail.

Architectural Components

Discovery Service

On a web page, the user will specify search criteria consisting of

- a start time and end time,
- a subset of the Observatory’s sensors and/or arrays,
- other selection criteria (based on metadata fields), and
- a list of metadata fields to display.

In response, the Discovery Service will generate (on the web page) a report identifying those NRT data and data products, available on the servers, which satisfy the search criteria.

Data Transport Service

Three modes of service will be provided.

1) An OPeNDAP server will be used for delivering raw data and some precomputed data products.
2) A mechanism for directing that a data product be built will be provided. For example, this mechanism could accept parameter values from the user, then build an appropriate SEG Y file, and then send the user an email.
3) The service will provide the ability to download computed files via FTP.

The first two modes are discussed in the following sections; the third mode is self-explanatory.

OPeNDAP

OPeNDAP[1] (http://opendap.org/), the Open source Project for a Network Data Access Protocol, is a data transport protocol in wide use in over 40 US oceanographic and meteorological organizations. OPeNDAP provides a means for data analysis and visualization packages such as Matlab, IDL and Ferret to access files over a network (local or Internet) without needing to know how the data are actually stored at the server site. Even though the data might be stored in netCDF, HDF, Matlab binary format, a JDBC-enabled Relational Database Management System (RDBMS), or some other supported format[2], the Matlab

[1] formerly known as DODS – *Distributed Oceanographic Data System*.
[2] See http://www.opendap.org/faq/whatServers.html for a list of these.

user can open the file as if it were a Matlab binary format file sitting on his or her own workstation.

Even though OPeNDAP currently supports a limited number of server and client file formats, it is possible to create custom clients and servers using the OPeNDAP development frameworks (C++ and Java Toolkits). Once the appropriate extended data types for the DMAS have been determined it will be possible to create OPeNDAP servers for the NRT data and other data products.

Directing that Data Files be Built or Incorporated

One way for programs to communicate with servers is via web services. These are simple interfaces that allow a client program (a server consumer) to request that a server program (a service provider) perform some task (a service). These services are functions that are well-defined, self-contained, and independent. One such service might be to accept a set of SEG Y file generation parameters, generate a SEG Y file, and then inform the requestor (by email) of the creation of the file. Other services might be used for cataloging and incorporating externally created data files. The DMAS will host a set of such web services and include a web services directory which clients may query.

Authentication Service

Databases will have defined access rules by database role (and users will each be assigned to one or more roles). A general read-only userid will be established and will provide general read-only access to the public. For creating data products or accessing the data exploration server, a user must specify a userid / password.

Buffering Station

In the short term, data will be downloaded after retrieval from a data logger located at the “Big M” Fiber-Optic Buoy Mooring. In the longer term, data will arrive continuously via fiber-optic cable directly from the instruments. The buffering station should be able to hold all arriving data for some short period of time (days) should the rest of the DMAS be unavailable, the buffering station serveing as a data buffer. It is also here where the data are assembled into finite-time length pieces, before being stored on the NRT Data Server. After the data have been stored on the NRT Data server, they can be deleted from the Buffering Station.

NRT Data Server

The NRT Data Server houses a database where each of the tables reflects one of the data collection instruments. Each row in each table stores a set of measurements (data and metadata) from one sensor, collected over some defined period of time. As stated in the previous report (Sensor and Data Characterization for the Gulf of Mexico Hydrates Monitoring Station), many of the sensors can be used for a wide variety of applications, and the sampling parameters and sensor configuration are dependent on the science objectives that drive the experiment. Once these objectives are better defined, the following specific database characteristics can be determined:

- abstract data types and methods for sensor measurements,
- metadata fields required,
- metadata standards,
- physical space required to store the table for the sensor,
- the need for specific indices and constraints.

Data Products Server

The Data Products Server will host SEG Y and possibly other types of files (e.g., netCDF) that have been built from NRT Data Server extracts or which have been built using the Data Exploration Server.

Catalog Server

The Catalog Server will host a database that stores metadata for the NRT Data database and the Data Products Server data files.

Archive Server

Once NRT data, and possibly some data products, have reached a certain age they will be archived to a tape-based archive server.

Data Exploration Server

The Data Exploration Server will provide an environment where scientists can run computational- or data-intensive applications without adversely affecting the performance seen by general catalog queries, NRT data ingestion, data product generation, etc.

Architectural Options

The architecture presented so far has components that require the following features of a computing environment:

1) Scalability: as the data volume and processing requirements grow, the architecture must be able to scale to support these requirements.
2) Extensibility of database data types: the database management system must be able to support the creation of custom data types and methods.
3) Ease of administration: the architecture consists of several servers that must be centrally administered.
4) Ability to add new components easily: interfaces must be simple so that functionality can be added without unduly increasing the complexity.

These requirements suggest the use of object-relational database, such as Informix (http://www.ibm.com/informix) or PostgreSQL (http://www.postgresql.org), hosted in a Unix environment, such as Solaris (http://www.sun.com/software/solaris/) or Linux (http://www.linux.org).

Impact of Questionnaire Results on System Design

As part of this study a questionnaire (reproduced in Appendix 3) was sent on February 14, 2005 to all registered members of the Consortium (see Appendix 3). While no responses to this questionnaire have yet been received, the answers when received will provide valuable guidance in adding detail to the general framework presented so far in this document. In anticipation of this input, this section states the questions from the questionnaire and describes how possible answers will influence the detailed system design.

The Data Management and Archive System (DMAS) will contain a searchable catalog of metadata describing the instrument data received from the observatory as well as data products that have been built from this data. When querying the catalog, which of the following will form part of your search criteria: array, sensor within array, start time, end time, spatial location? Will you be using combinations of these? Will you be using any other parameters in your search criteria?

The answer to these questions will dictate which data attributes are copied from the databases residing on the NRT Data Server and the files stored on the Data Products Server to the database on the Catalog Server. It will influence what indices are built and what indexable methods[3], if any, are defined on the sensor data streams.

Which types of sensor data will you be using?

The answer to these questions will dictate what gets stored.

- Will every measurement produced by a sensor be stored?
- Are users interested in just those measurements that fall within a certain range?
- Can any data reduction be performed to reduce the amount of data stored?

Consortium members with interests in specific sensors can be identified and contacted to get information that is more detailed on what needs to be stored.

Once the observatory is operating in continuous mode (with fiber cable running from the instruments to the DMAS), the DMAS will allow users to register their interest in specific data events. What types of events would you like to be notified of? What sensor variables would be used in the event detection criteria for these events? Do you know what threshold values would be appropriate?

[3] For example, suppose that there is some property that can be expressed as a function *f*(sensor data), and there is a need to find all time values for which *f* is between values X and Y. Object relational databases allow indices to be built on functions such as *f*, making queries like this very easy to cast and efficient to perform.

Answers to these questions will allow the event detection and notification components of the Data Transport Service to be designed.

The DMAS may perform a simple level of quality control (QC) before the data are cataloged and saved in the DMAS. What form of quality control (if any) should be performed on the data at this point?

The answer to this question will determine some of the processing logic of the Buffering Station.

Once the data have been saved should further stages of QC be performed? What should these stages be? Should data from these intermediate stages be available for extraction?

Answers to these questions will influence the design of the database residing on the NRT Data Server.

Are there any metadata that you will be adding to the metadata that are automatically collected from the sensors? Do you know of any metadata standards (e.g., FGDC) that should be followed?

Answers to these questions will dictate whether metadata need to be computed or whether there needs to be a mechanism to allow users to augment the metadata already present.

Upon ingestion to the DMAS, the data will be chopped into time-limited segments. While the data will be able to be reassembled to form time series with arbitrary start times, end times, and durations, is there a natural time length that you would see as being appropriate for the data segments?

The answer to this question will help design the custom data type used to store sensor data.

What data products do you see being built from the sensor data on a regular basis? Examples include SEG Y files from a specific sensor or group of sensors, matched-field inversion, post-processing (FFT, filtering, advanced QC), etc.

The answer to this question will dictate the applications that need to be written for the Data Products server.

Aside from the standard, regularly performed, processing of sensor data described in the last question, are there any other individual data products that you would be adding to the repository from time to time?

The answer to this question will dictate the Data Transport web services that will need to be built to facilitate user insertion of data products into the DMAS repository. It will also influence the design of backup and recovery systems.

When requesting data from the repository, which of the following will form part of your selection criteria: array, sensor within array, start time, end time? Will you be using combinations of these? Will you be using any other parameters in your selection criteria?

The answers to these questions will influence the design details for the Data Transport Service.

In what form would you like data delivered to you? File (which format)?; OPeNDAP connection from a client application (e.g., IDL, Matlab) (which client applications?). Is there another form? Must the data be made available in near real time? What time lag is acceptable? Is there a need for automated delivery (i.e., pushing) of data to your site?

The answers to these questions will influence the design details for the Data Transport Service. They will also influence how quickly data needs to be transported from the Buffering Station and processed.

What length of time should sensor data be kept online, before being archived to tape or some other offline medium? What length of time should other data products be kept online? Do data need to be kept once they are taken offline (i.e., is there a need for an archive?)

Answers to these questions will influence the design of the Archive Server (and in fact determine whether an archive server is needed).

Is there a need to control access (read or update) to data within the community of eligible users? For example, should the ability to add metadata, create new data products, perform post-processing, remove data products, etc. be limited to certain classes of uses? How many such classes can you identify, and how would you define these classes?

Answers to these questions will influence the design of the Authentication Service.

What viewing / visualization / analysis capability (if any) should be provided?

Answers to these questions will influence the design of the Data Transport Service and possibly determine the format of files stored in the Data Products Server.

Appendix 1: Array Configurations and Numbers of Sensors

Acoustic Vertical Line Array – VLA

Sensor	No. of sensors
Hydrophone	16
Orientation Sensor	16
ADCP	1

Horizontal Line Array – HLA (4 Arrays)

Sensor	No. of sensors per array
Hydrophone	16
3D Accelerometers	6

Pore Fluid Circulation Array – PCA

Sensor	No. of sensors
Pore Fluid Pressure Sensor	3-6

Borehole Vertical Line Array – BLA

Sensor	No. of sensors
3D Accelerometers	6
Hydrophone	4-16
Thermistors	12

Oceanographic Vertical Line Array

Sensor	No. of sensors
CTD	2
Fluorometer	2
Nephelometer	2
Methane Sensor (METS)	2
ADCP	1
Thermistor	3-6
Mass Spectrometer	1-2
IR Spectroscopic Methane Sensor	1
Video Camera	1
Still Camera	3-4
Bubble Detector	1
Osmo-Sampler	1
General	

Appendix 2: Data Rates and Storage Requirements

(c) Initial installation (2005)
(d) Full installation (2006/7+)

Sensor	Number of Sensors	Average Data Rate (/Sensor)	Average Data Rate (Total)	Storage Requirement (Mbyte/day)
Hydrophone	(c) 12 (d) 80	10,000 samp/s, 16 bit/samp	a) 1.83 Mbit/s b) 12.2 Mbit/s	a) 19,775 b) 131,833
3D Accelerometer	(a) 6 (b) 30	1000 samp/s, 24 bit/samp	a) 140 kbit/s b) 703 kbit/s	a) 1,476 b) 7,383
Thermistor	(a) 12 (b) 18 (*)	10 samp/s, 24 bit/samp	a) 2.81 kbit/s b) 4.22 kbit/s	a) 29.6 b) 44.5
Orientation Sensor	(a) 16 (b) 16	1 samp/s, 24 bit/samp	a) 384 bit/s b) 384 bit/s	a) 4.0 b) 4.0
CTD	(a) 2 (b) 2	1 samp/s, 184 bit/samp	a) 368 bit/s b) 368 bit/s	a) 3.8 b) 3.8
Current Meter (ADCP)	(a) 1 (b) 1	1 samp/s, 5000 bit/samp (*)	a) 4.9 kbit/s b) 4.9 kbit/s	a) 51 b) 51
Fluorometer	(a) 2 (b) 2	1 samp/s, 528 bit/samp	a) 1.0 kbit/s b) 1.0 kbit/s	a) 11 b) 11
METS Methane Sensor	(a) 1 (b) 2 (*)	1 samp/s, 24 bit/samp	a) 24 bit/s b) 48 bit/s	a) 0.25 b) 0.49
IR Spectroscopic Methane Sensor	(a) 1 (b) 1	100 samp/min, 24 bit/samp (*)	a) 40 bit/s b) 40 bit/s	a) 0.41 b) 0.41
Nephelometer	(a) 2 (b) 2	1 samp/s, 800 bit/samp	a) 1.56 kbit/s b) 1.56 kbit/s	a) 16.5 b) 16.5
Mass Spectrometer	(a) 1 (b) 2 (*)	800 kbit/hr (*)	a) 228 bit/s b) 456 bit/s	a) 2.3 b) 4.7
Digital Video Camera	(a) 0 (b) 1	1244 Mbit/s (when on) (**)	a) 0 b) 3.45 Mbit/s(**)	a) 0 b) 37,320
Digital Still Camera	(a) 1 (b) 4 (*)	1 samp/5min, 30 Mbit/samp	a) 102 kbit/s b) 410 kbit/s	a) 1,080 b) 4,320
Bubble Detector	(a) 1 (b) 1	800 bit/s	a) 800 bit/s b) 800 bit/s	a) 8.2 b) 8.2
Osmo-Sampler	(a) 1 (b) 1	0	a) 0 b) 0	a) 0 b) 0
Pore-Fluid Pressure Sensor	(a) 0 (b) 6 (*)	10 samp/s, (*) 24 bit/samp	a) 0 b) 1440 bit/s	a) 0 b) 14.8
Total			**a) 2.08 Mbit/s** **b) 16.8 Mbit/s**	**a) 22,458** **b) 181,300**

(*) estimated
(**) assume camera is on 10 sec/hour

Appendix 3: User Requirements Questionnaire

This appendix presents a user requirements questionnaire that was sent to current members of the Gulf of Mexico Hydrates Research Consortium. A list of these members is presented at the end of this appendix.

1 The Data Management and Archive System (DMAS) will contain a searchable catalog of metadata describing the instrument data received from the observatory as well as data products that have been built from this data. When querying the catalog, which of the following will form part of your search criteria: array, sensor within array, start time, end time, spatial location? Will you be using combinations of these? Will you be using any other parameters in your search criteria?

2 Which types of sensor data will you be using?

3 Once the observatory is operating in continuous mode (with fiber cable running from the instruments to the DMAS), the DMAS will allow users to register their interest in specific data events. What types of events would you like to be notified of? What sensor variables would be used in the event detection criteria for these events? Do you know what threshold values would be appropriate?

4 The DMAS may perform a simple level of quality control (QC) before the data is cataloged and saved in the DMAS. What form of quality control (if any) should be performed on the data at this point?

5 Once the data has been saved should further stages of QC be performed? What should these stages be? Should data from these intermediate stages be available for extraction?

6 Is there any metadata that you will be adding to that which is automatically collected from the sensors? Do you know of any metadata standards (e.g., FGDC) that should be followed?

7 Upon ingestion to the DMAS, the data will be chopped into time-limited segments. While the data will be able to be reassembled to form time series with arbitrary start times, end times, and durations, is there a ***natural*** time length that you would see as being appropriate for the data segments?

8 What data products do you see being built from the sensor data on a regular basis? Examples include SEG Y files from a specific sensor or group of sensors, matched-field inversion, post-processing (FFT, filtering, advanced QC), etc.

9 Aside from the standard, regularly performed, processing of sensor data described in the last question, are there any other individual data products that you would be

adding to the repository from time to time?

10 When requesting data from the repository, which of the following will form part of your selection criteria: array, sensor within array, start time, end time? Will you be using combinations of these? Will you be using any other parameters in your selection criteria?

11 In what form would you like data delivered to you? File (which format)?; OPeNDAP connection from a client application (e.g., IDL, Matlab) (which client applications?). Is there another form? Must the data be made available in near real time? What time lag is acceptable? Is there a need for automated delivery (i.e., ***pushing***) of data to your site?

12 What length of time should sensor data be kept online, before being archived to tape or some other offline media? What length of time should other data products be kept online? Does data need to be kept once it is taken offline (i.e., is there a need for an archive?)

13 Is there a need to control access (read or update) to data within the community of eligible users? For example, should the ability to add metadata, create new data products, perform post-processing, remove data products, etc. be limited to certain classes of uses? How many such classes can you identify, and how would you define these classes?

14 What viewing / visualization / analysis capability (if any) should be provided?

Members of the Gulf of Mexico Hydrates Research Consortium Receiving the Questionnaire

The questionnaire was sent to the following people via email on February 14, 2005, with the names and email addresses used being those that appear on the October 2004 Consortium Members list. Some of the emails were not successfully delivered, as noted below.

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Appendix 4: Object-Relational Databases

This appendix provides an introduction to object-relational database systems, highlights their benefits with respect to traditional relational database systems, and discusses their suitability to the Gulf of Mexico Hydrates Seafloor Observatory DMAS.

Relational Databases

A relational database is a set of tables containing data fitted into predefined categories. Each table represents either a real world object, a relationship between objects, or both. When the table represents a real world object, the predefined categories (called columns) are comprised of attributes that describe the object, and each row represents a single object. When the table represents a relationship, the predefined categories identify the objects taking part in the relationship, and each row represents a single instance of the relationship.

Consider as an example a database with three tables: STUDENT, COURSE, and ENROLLED-IN. The STUDENT table might have the following columns: StudentID (a unique identifier for the student represented by the row), Name, Address, etc. The COURSE table might have the following columns: CourseNum (unique identifier), CourseName, ClassHours, LabHours, etc. Finally, the ENROLLED-IN table, representing a relationship between STUDENTs and COURSEs, would have columns identifying the specific STUDENTs and COURSEs in a relationship, as well as possibly attributes of this relationship (e.g., Grade).

The following diagram illustrates a few rows of this database:

STUDENT		
StudentID	Name	Address
792221	Jane Doe	123 Main Street
782045	Tom Brown	12 Brown Drive
792080	John Smith	4030 Jason Ave

COURSES			
CourseNum	CourseName	ClassHours	LabHours
ABC501	Intro to ABC	3	0
XYZ599	Advanced XYZ	3	3

ENROLLED-IN		
StudentID	CourseNum	Grade
792221	ABC501	94
782045	XYZ599	73
792080	XYZ599	85

Using Structured Query Language (SQL), the user of this database can ask the following sorts of questions:

i) What is John Smith's address?
ii) What courses are being taken by Jane Doe?
iii) Who is taking ABC501?
iv) What is the average grade for Advanced XYZ?
v) What was the highest grade for Advanced XYZ? Who got this grade?
vi) Produce a report showing grades for Intro to ABC.

Drawbacks of Relational Databases

The relational database model is perfectly suitable for the sort of application just described, where the data types are simple (just numbers and text strings) and the operations are simple (e.g., arithmetic, comparison). Where the limitations in the relational model show is when the objects are complex. Consider for example a database that contains time series measurements taken by various instruments. The following are two possible implementations of this database:

1) One row per instrument:

Traditional relational databases offer just scalar data types (integer, floating point, text string) plus a "binary large object" (blob) catch-all data type for unstructured data (e.g., text pages, pictures), so if we're going to store a time series as an object in a relational database we have to store it as a binary large object.

Instrument	Time series
1	<Time series as binary large object>
2	<Time series as binary large object>
3	<Time series as binary large object>

2) One row per instrument per time step:

Another approach is to store the time series as a series of rows, one row per instrument per time step.

Instrument	Time	Time Series Data Value
1	1.0	43.5
1	2.0	43.2
…	…	
2	1.0	12.4
2	2.0	12.5
…	…	
3	1.0	33.1
3	2.0	34.2
…	…	

One problem with option 1 is that there is very little the user can do with a time series while it is in the database – about all the user can do is extract the entire time series for an instrument, and then perform any analysis on their own workstation. A second problem is that it is very impractical to keep the time series up to date. The time series is continually changing, but since it is stored as an atomic blob in the database, updating the time series requires completely overwriting this blob, an operation that takes time. So the effect is that what is in the database at any given time is just an out-of-date snapshot.

Option 2 suffers from neither of these two problems, but nonetheless it is a very inefficient design. Each instrument id is stored multiple times, and since there is an overhead to storing a row, this overhead is repeated multiple times for each time series.

We will come back to this example in a later section when we discuss the benefits of object-relational databases.

Object-Relational Databases

In their book **Object-Relational DBMS's – Tracking the Next Great Wave** (http://www.amazon.com/exec/obidos/tg/detail/-/1558604529?v=glance), Stonebraker and Brown list the following three characteristics of object-relational databases:

1. Support for base type extension in an SQL context.
2. Support for complex objects in an SQL context.
3. Support for inheritance in an SQL context.

The following three sections discuss each of these characteristics in turn.

Data Type Extension

As mentioned earlier, traditional relational database servers support just a few data types: integer, floating point, string, date, and sometimes simple binary large object (blob), and on each of these there is defined a limited number of operations. Object-relational technology provides the ability to define new data types and operations on both original and new data types.[4]

There are two varieties of extended data types:

1) ***"Distinct" data types***. These are user-defined data types that share their internal representation with an existing type (their "source" type), but which are considered to be a separate and incompatible type for most operations. They can be viewed as restricted (in terms of their domain) and/or extended (in terms of

[4] Traditional relational database management systems do provide the ability to define new operations on existing data types, but it is important to note that in those cases the operations execute outside the database server, on the client side of the client-server wall. Operating on the client-side rather than the server-side results in performance degradation and means that the operations cannot be used in server-side mechanisms such as indices.

their available operations) versions of the source data type. For example, we might define a "sound speed" data type that is restricted to floating point numbers that are in the physically realizable range of sound speed values. We might also define some operations on sound speed values that might make sense in the physics of sound speeds but wouldn't be applicable to floating point numbers in general. Distinct data types provide a mechanism for data integrity to be enforced almost automatically – it is impossible for the database server to store a bad sound speed value in a sound speed data type column.

2) ***"Opaque" data types***. These are data types whose precise definition is not documented (hence they are opaque), and which are intended to be manipulated only using the documented interface, which consists of a set of functions. Many Geographic Information System object relational databases have opaque data types for polygons (used to represent the geographic extents of lakes, islands, and large rivers), lines (used for highways and streams), and points (used for spot elevations, points of interest, etc.). The complement to opaque data types is a set of functions that operate on the data type. For the polygon data type the operations might include:
    a. the geometric constructors Intersection, Union, Difference, etc. These would take two or more polygons and return a new set of geometries representing their intersection, union, difference, etc.
    b. the Boolean operations Intersects, Contains, IsContainedIn, etc. These would take two polygons and return 'True' if they intersected (for example), and 'False' if they didn't.

    In the context of the Gulf of Mexico Hydrates Seafloor Observatory DMAS, we might use opaque data types for multidimensional arrays of data (e.g., time series, grids and profiles), images, seismic recordings, etc. A time-image data type could be used to manipulate image grids (image slices stacked in time) allowing, for example, a time series of pixel values to be extracted.

Support for Complex Objects

The basic building blocks for creating complex types in object-relational databases are "composites" and "sets".

Composites are built from two or more other data types. For example, in the Gulf of Mexico Hydrates Seafloor Observatory DMAS we might define a data type called "ThreeD_accelerometer_attime", consisting of a time value and 3 acceleration values.

A set is a grouping of objects of the same type. A "ThreeD_accelerometer" set data type, for example, might be defined as a set of "ThreeD_accelerometer_attime" values.

Inheritance

The third distinguishing characteristic of object-relational databases is inheritance, whereby one data type can inherit the characteristics (e.g., functions that operate on the data type) from one or more parent data types. Operations available for an inheritor may include the operations available on the parent, customized versions of the operations available for the parent, or completely new operations.

In the context of the Gulf of Mexico Hydrates Seafloor Observatory DMAS we might have a data type called “sensor”, with an inheriting data type called “Sensor_at_depth” and “Sensor_at_XY.” The operations defined for the Sensor_at_depth data type would include all the operations defined for the sensor data type, possibly customized to deal with the specifics of sensors in a vertical array.

Benefits of Object-Relational Databases

Let’s revisit the time series example from the Drawbacks of Relational Databases section. With an object-relational database we can construct a distinct data type called “instrument_recording” and a time series set data type called “timeseries(instrument_recording).”

Instrument	Time series
1	Timeseries(instrument_recording) for instrument 1
2	Timeseries(instrument_recording) for instrument 2
3	Timeseries(instrument_recording) for instrument 3

However, unlike the blob implementation, with this implementation we can perform operations (other than simple extract) on each Timeseries(instrument_recording) value. Operations might include:

i) append(Timeseries(instrument_recording), instrument_recording)
$\Rightarrow$ add an instrument recording to the end of the time series

ii) extract(Timeseries(instrument_recording), startTime, endTime, deltaTime)
$\Rightarrow$ subsample and/or window a time series, returning a new time series

iii) fft(Timeseries(instrument_recording))
$\Rightarrow$ return a new time series that is the Fast Fourier Transformed version of the input time series.

The benefits of using an object-relational database for the Gulf of Mexico Hydrates Seafloor Observatory DMAS can be summarized as follows:

1) Storage efficiency is improved (relative to the one-row-per-simple-element approach).
2) Network use is reduced (relative to blob approach, where entire blobs, instead of just the relevant pieces, must be sent to the client machine).

3) Concurrency is improved, since pieces of large data type objects can be locked independently of other pieces of the same object (e.g., a time series can be appended to while earlier parts of the time series are being read). Multiple users can safely query the same data concurrently.
4) Composite data types allow data to be “bundled” with their metadata. This bundling enables data base implementers to build operations in such a way that metadata are updated appropriately and consistently.
5) Integrity is improved, since distinct data type constraints and opaque data type operations can ensure that bad data are rejected before they are stored in the database.
6) Database extensibility is improved: the object-oriented paradigm facilitates re-use of code. Additional data types and operations can be added easily, without breaking existing applications.
7) The approach fosters the uniform treatment of data items. The traditional approach is to access metadata with SQL and the actual data with file access mechanisms. By instead storing all data types in the same framework, applications can use the same SQL interface to perform complex queries that are based on any of these data items, including dynamically-derived properties of the data.
8) Object-relational databases can be extended to include custom data access methods. Traditional relational database management systems include b-tree indices, which are very effective for indexing types of data that have natural linear orderings (numbers, text strings, etc.), but not effective for querying spatial data. As new data types are added to an object-relational database, appropriate access methods can be added as well.

Support of Gulf of Mexico Hydrate Research Consortium:
Activities to Support Establishment of Seafloor Monitoring Station

TECHNICAL PROGRESS REPORT

Reporting Period Start Date: December 1, 2004

Reporting Period End Date: May 31, 2005

Principal Investigator (Author): Bob A. Hardage

Date Issued: September 30, 2005

DOE Cooperative Agreement No. DE-FC26-02NT41628

Task 6: Seismo-acoustic characterization of seafloor properties
and processes at the hydrate monitoring station

Submitting Organization:
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Abstract

We have developed software that can read, process, manipulate, and display chirp-sonar data, multibeam bathymetry data, and side-scan sonar data acquired with autonomous underwater vehicle (AUV) technology. These AUV data can now be better utilized by participants in the hydrate-monitoring-station consortium. In particular, critical chirp-sonar data needed for interpreting near-seafloor geology can now be more easily integrated into standard seismic interpretation workstations. Other software was developed and tested that creates high-resolution, converted-shear images of near-seafloor geology. We show that these converted-shear images, produced in water depths of 900 meters with low-frequency (10–100 Hz) wavefields generated by an air gun source positioned on the sea surface, have a spatial resolution equivalent to that of high-frequency (2–10 kHz) AUV chirp-sonar images acquired with source and receiver only 40 meters above the seafloor.

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Introduction

The initial work subcontracted to the Bureau of Economic Geology (Bureau) was for the Exploration Geophysics Laboratory (EGL) at the Bureau to process and interpret vertical seismic profile (VSP) data acquired in a borehole drilled within the boundaries of the hydrate monitoring station area in Block MC 118. Logistical complications did not allow a VSP borehole to be drilled, and no VSP data have been acquired. The work task subcontracted to EGL was then altered to require EGL to process and interpret high-resolution chirp-sonar data and multicomponent seismic data acquired across the monitoring station. This new task required EGL researchers to develop and test a significant amount of software that could transform these unique data into images of near-seafloor geology.

Executive Summary

Researchers at the EGL were subcontracted to create some of the deliverables for Work Task 6, *Seismo-acoustic characterization of seafloor properties and processes at the hydrate monitoring station*. Initially, EGL was to process VSP data acquired at the monitoring station. Logistical complications did not allow a borehole to be drilled inside Block MC 118, so the task assigned to EGL was altered to require EGL to process and interpret seafloor-sensor seismic data acquired across the monitoring station, in addition to any VSP data that may eventually be acquired. Two critical types of data will be acquired across the station site: (1) high-frequency (2–10 kHz) chirp-sonar data produced by an AUV system traveling approximately 40 meters above the seafloor, and (2) multicomponent P-wave and S-wave data acquired with receivers positioned on the seafloor and with seismic sources positioned either on the seafloor or at the sea surface. EGL scientists are writing new software that will convert all of these data types into images of near-seafloor geology. Software developed during the period was tested using AUV data and multicomponent seismic data acquired at deep-water sites near Block MC 118.

Experimental

Experimental activity during this period focused on developing and testing software that reads, manipulates, and processes multicomponent seismic data acquired with four-component (4-C) seafloor-positioned sensors and AUV chirp-sonar data. Software was developed for processing and utilizing (1) chirp-sonar data and (2) converted-shear component of 4-C seafloor-sensor data. Future software development will concentrate on improving the quality and resolution of P-wave images extracted from 4-C data.

Results and Discussion

An example of AUV chirp-sonar data processed with newly developed EGL software is displayed as Figure 1. AUV data are acquired with variable distances between traces. These variable trace spacings make it difficult to match chirp-sonar data with other seismic data. Chirp-sonar data coordinates are also defined with a different navigation coordinate system than that used for standard seismic data. EGL software overcomes these two bothersome aspects of chirp-sonar data by interpolating the data to a uniform trace sampling interval and by transforming chirp-sonar coordinates to standard seismic coordinates. This software technology can now be applied to AUV data acquired across the hydrate monitoring station so AUV data acquired there can be better utilized by consortium members.

An example of EGL software used to create a converted-shear (P-SV) image from 4-C seismic data acquired with a long line of closely spaced ocean-bottom sensors is shown as Figure 2. Each data trace in this image represents an individual seafloor receiver station. The horizontal sensor array that will be deployed across the monitoring station will have only a small number of receiver stations, so the P-SV image made at Block MC 118 will have fewer image traces than shown in this example.

An important research finding is that deep-water P-SV data generated by a low-frequency (10–100 Hz) air gun source stationed at the sea surface have a spatial resolution equivalent to that of high-frequency (2–10 kHz) chirp-sonar data. This principle can be confirmed by visual comparison of the images in Figures 1 and 2. EGL software used to make these high-resolution P-SV images will be an invaluable research tool for the monitoring station.

Conclusions

Important software needed for ongoing research at the hydrate monitoring station has been developed and tested using data similar to that expected to be acquired across Block MC 118. Test results indicate the software developed to date is robust and creates high-resolution images of near-seafloor geology. Additional software now needs to be developed to create better quality and higher-resolution P-wave images from low-frequency 4-C data acquired with seafloor sensors.

References

None.

Abbreviations and Acronyms

4-C: four-component
AUV: autonomous underwater vehicle
EGL: Exploration Geophysics Laboratory
MC: Mississippi Canyon
OBC: ocean-bottom cable
P-wave: compressional wave
P-SV: converted-shear mode (P-wave to SV-shear wave conversion)
S-wave: shear wave
VSP: vertical seismic profile

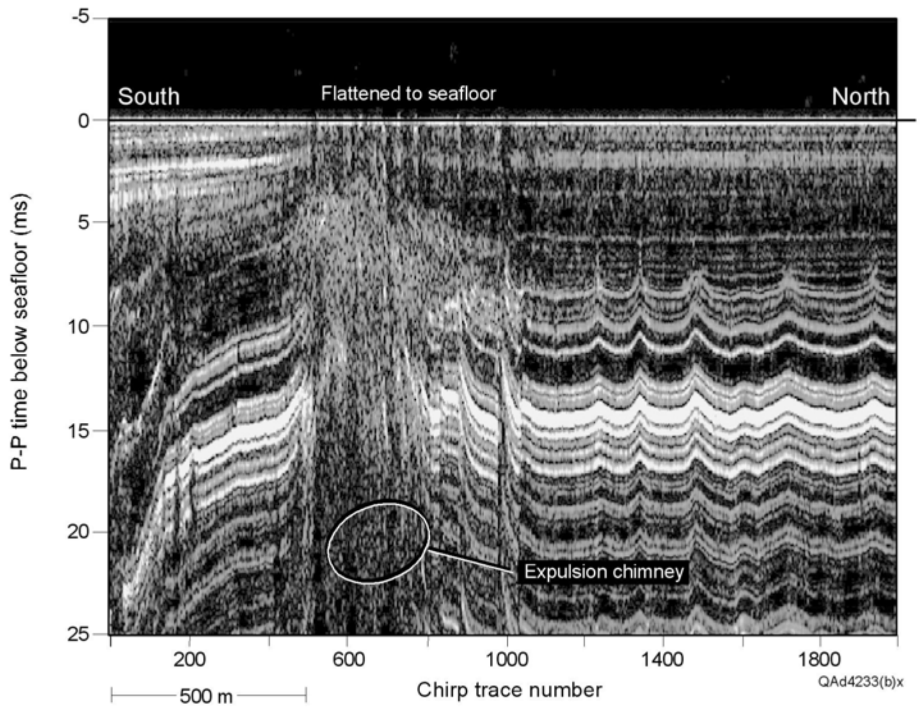

Figure 1. AUV chirp-sonar data along an OBC profile near Block MC 118.

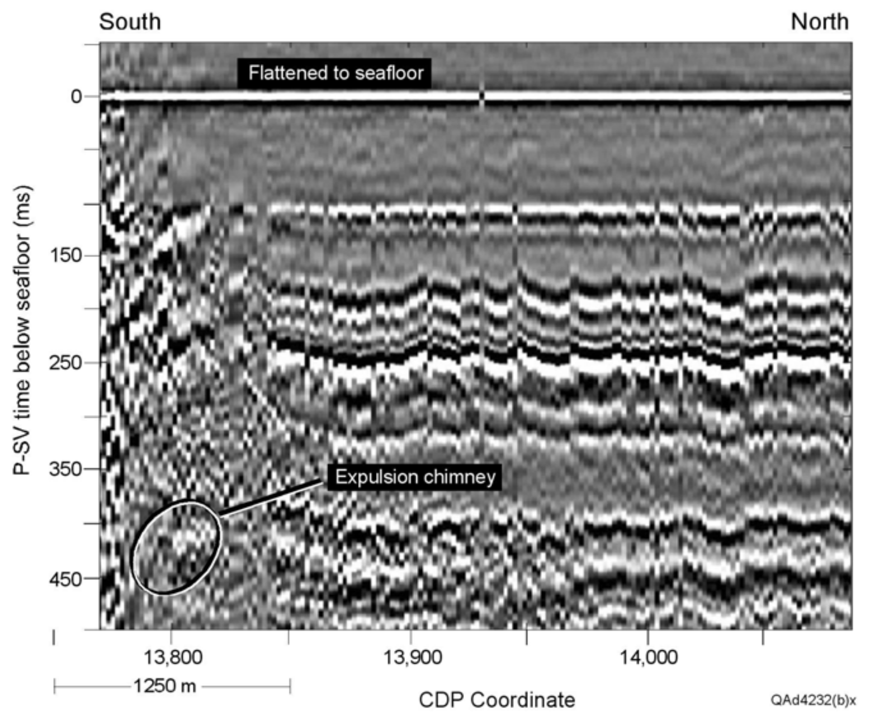

Figure 2. P-SV image along the same profile shown in Figure 1. The P-SV data do not extend as far south as the AUV data.

Coupling of continuous geochemical and sea floor acoustic measurements
6 month progress report

Gulf of Mexico Gas Hydrate Research Consortium

From Florida State University

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Abstract

The goal of this project is to couple continuous geochemical sampling of pore fluid chemistry with sea floor acoustic and accelerometer measurements. In collaboration with the University of Mississippi and Specialty Devices, we have constructed and deployed a sea-floor probe that enables continuous geochemical sample collection from 8 depths over a 10 m interval at Mississippi Canyon 118, in coordination with a geophysical thermistor sea-floor probe. Geochemical parameters we will monitor include methane and other light dissolved hydrocarbon gas concentrations and perturbations in salinity. Our objective is to calibrate seismic events, as measured with the down-hole acoustic array, with gas hydrate decomposition or formation by determining geochemical perturbations. We collected 10 cores which will be analyzed for dissolved hydrocarbons, sulfate and nitrate to characterize the site.

1. Project Description: six month progress

Continuous sample collection from gravity emplaced osmo pump samplers (OsmoSamplers, (Jannasch et al., 2004; 1994)**.** Our objective is to calibrate seismic events with their corresponding geochemical signal. In May, 2005 we placed sampling equipment in 900 m water depth at MC-118 as part of the Gas Hydrates Monitoring Station, managed by the Gulf of Mexico Hydrates Research Consortium - University of Mississippi.

*Figure 1. Osmo pump samplers (*Jannasch et al., 1994, 2004)*. The udders contain a membrane which allows water to pass from below into the upper salt reservoir. This water pulls sample water from the seafloor probe tips into a 100m 1/16 inch diameter tube. Preserved along the length of this extremely narrow tube is a time series record of pore water salinity and hydrocarbon gas concentrations, which we can retrieve and analyze in the lab. These pumps require no electrical power. Periodically we need to change out the salt pumps and exchange the sample loop.*

In May, 2005, we deployed a 10 meter probe tip which was built at the University of Mississippi. Specific depths on the probe tip were connected to an osmo pump which uses osmotic pressure to draw water up the tube from each depth. Associated with each pump is a sample loop through which the sample water flows. These sample loops consist of 100 meters of narrow diameter tubing and thus a time sequence is preserved along the length of this tubing (Jannasch et al., 1994, 2004). Each sample loop is connected to a pressure tight multi port valve for isolating the sample and keeping it at in situ pressure. A single zero dead volume keyed connector interface was designed and constructed by Paul Higley of SDI and this device connected the two components of our sampling system. The two parts consist of the seafloor portion (sampling head—4 osmo pumps (Figure 1), valve and 4 sample loops) and the seabed portion which consists of a weight, and a rigid pipe containing tubes which penetrate to differing depths down the probe tip (Figure 2).

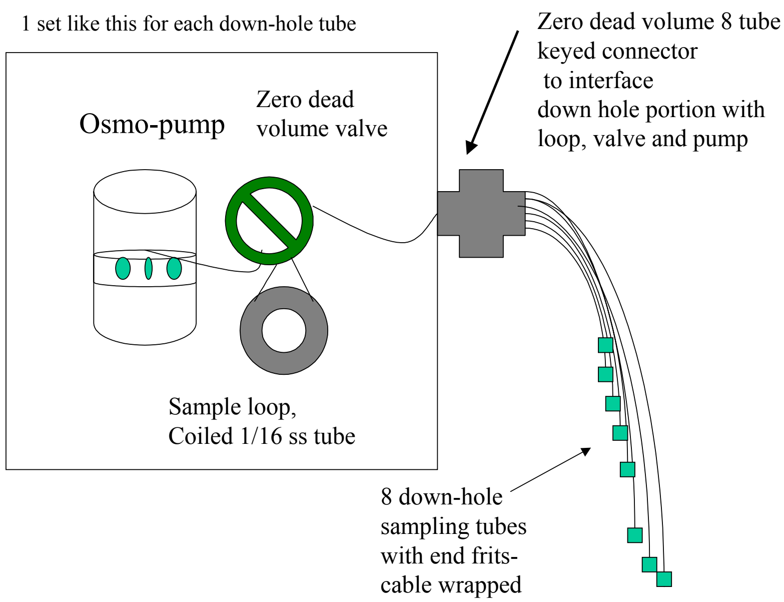

Figure 2. The sampling system consists of a down hole probe which was inserted into sediment and a 4 unit osmo pump-valve and sample loop component which was coupled and mounted to the probe The upper and lower units are coupled through a zero dead volume 8 tube connector designed and constructed by Paul D. Higley of Specialty Devices, Inc.

Figure 3. The 10 meter probe tip is shown protruding over the stern of the boat, R.V. Pelican in May, 2005. The upper box is the weight for gravity emplacement.

Figure 4. Eight sampling ports are located along the length of the probe tip. The sampling tips are screened and connect by small diameter tubing to the osmo samplers which draw water from the seafloor (Figure 1). The sampling probe and ports were designed and constructed at the University of Mississippi.

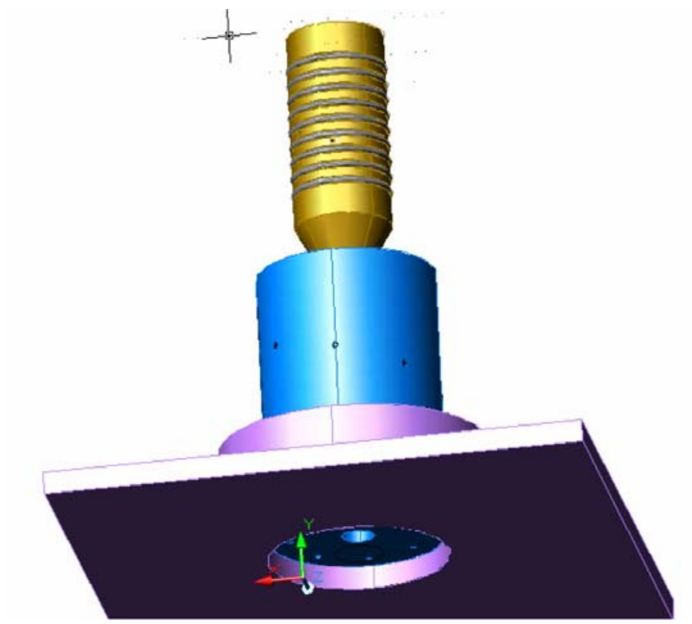

Figure 5. Paul Higley of Specialty Devices Inc. designed and constructed a special zero dead volume 8 port connector to allow the pumps and tubing to be interchanged with a submersible or ROV. This allows new pumps and sampling tubing to be interchanged on the probe tips which will stay in place.

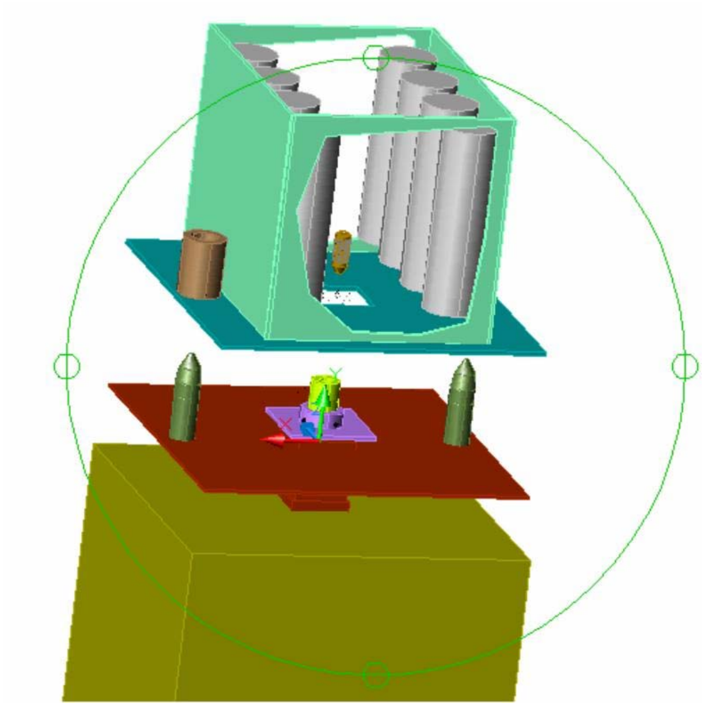

Figure 6. Shows the interface of the upper sampling head portion of the system with the seabed portion. The cylinders represent the osmo samplers.

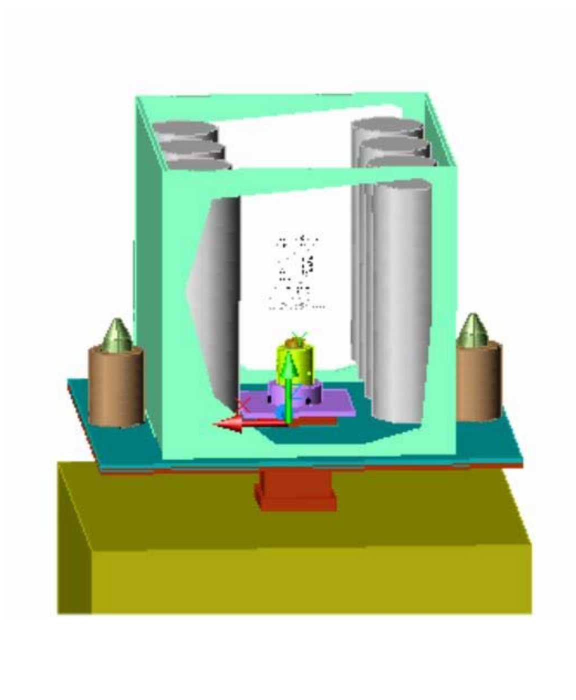

Figure 7. The interfaced device. The sampling head basket containing the osmo samplers, valve and sample loop tubing. The upper portion is designed to be interchangeable by ROV or submersible to allow sample recovery and redeployment.

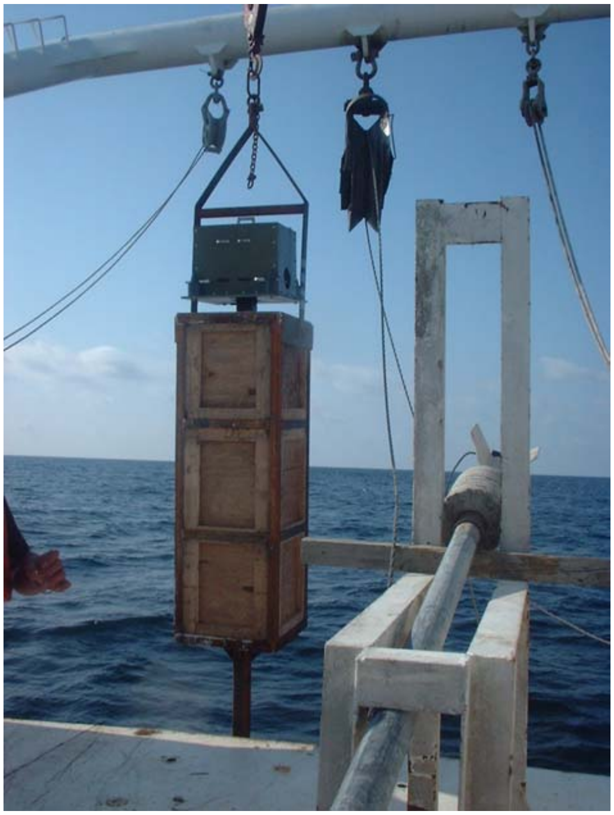

Figure 8. Deployment of the device in May, 2005.

The GOM Hydrate Stability Zone, with exposed and shallow hydrate occurrences, provides a natural laboratory for studying hydrate formation and dissociation. Deployment of the osmosamplers will provide the means by which dissolved gas and salt concentration data can be acquired. This information is critical for understanding the processes and environmental conditions controlling gas hydrate occurrences within the sediments of the GOM and for interpretation of seismic data.

We sampled 10 cores for dissolved hydrocarbon concentrations and stable isotopic composition, sulfate and dissolved nitrate. The data will aid in site characterization (Figure 9).

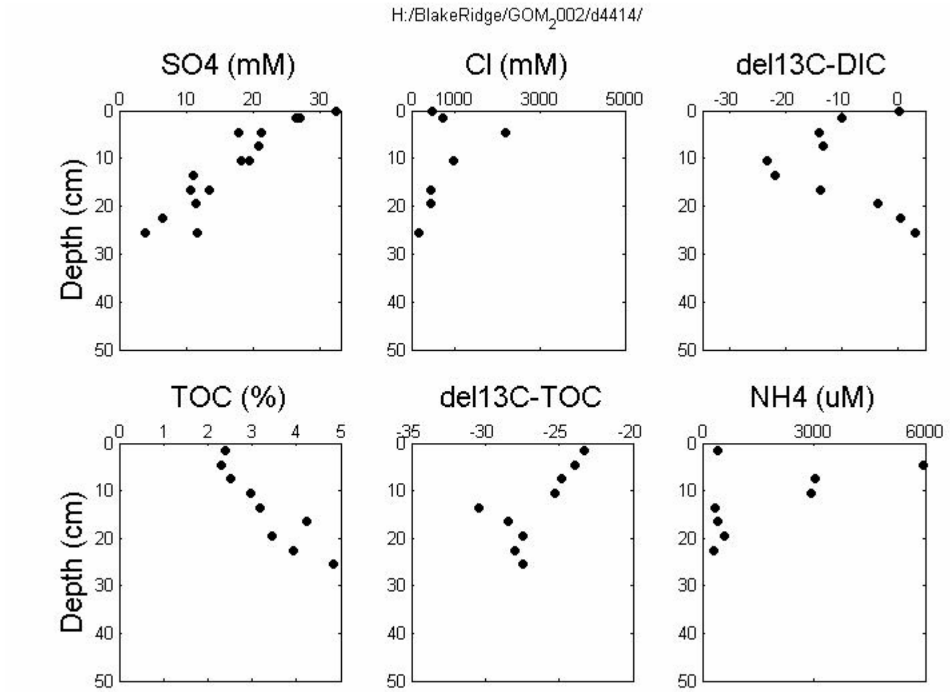

Figure 9. Preliminary data from Ms-118 shows a strong Cl anomaly in the surficial sediments indicative of gas hydrate formation (salt ions excluded). Salinity fluctuations recorded through time by our osmo sampler will be indicative of gas hydrate formation or de-composition (pore water freshening). Additionally methane is consumed in the sulfate zone and produced below it, so it is useful to monitor this constituent.

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Analysis of Dufresne Sediments for Gas Hydrate Promotion in Mississippi Canyon

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ABSTRACT

Laboratory tests were conducted on sediment samples from the core MD02-2570 taken on the Marion Dufresne cruise in 631 m water depth at the West Mississippi site of the Mississippi Canyon. The objective was to determine if natural-gas hydrate formation rates and induction times varied with depth for the MD02-2570 sediments. Could any variations be related to minerals, bioagents, or mineral/bioagent interactions in those sediments?

The core was extracted from the seafloor to about 30 mbsf, providing sediment samples to a depth that has only infrequently been tested in hydrate zones of the Gulf of Mexico. Laboratory results showed hydrate formation rates maximized in 15 -18 mbsf sediments. After being held 96.5 hours at hydrate-forming conditions in the laboratory test cell, hydrates had not formed on surface sediments. From near-surface, hydrate induction time decreased substantially and reached a minimum value at about 12 m depth. Sand, silt, and clay fractions were determined for each sediment sample. Percentages of smectite, illite, chlorite, and kaolinite were found for each sample. Bioagents in each sample are still under investigation.

Distinct trends of hydrate formation with depth exist in the MD02-2570 sediment samples. Mineral contents have been established, and studies are continuing to relate microbial activity and the hydrate-formation trends.

INTRODUCTION

Gas Hydrate Occurrence and Microbial Influences in Hydrate Zones

Most analyses of gas hydrates in the GOM have been done on the top 6 meters of sediments (Milkov and Sassen, 2000), although the bottom of the gas hydrate zone in the Gulf of Mexico might extend 200- 1000 m (Milkov and Sassen, 2002). The Dufresne core MD02-2570 takes on added importance because it extends to depths of about 30 meters and allows the study of hydrate formation in sediments deeper than usual.

Microbial activity in the Gulf of Mexico around gas hydrate occurrences is prolific (Roberts, 2004; Sassen et al., 2001). For lack of research, it has been too easy to assume that extensive microbial occurrences near massive hydrate mounds are coincidental. The association is probably much more complex than just biogenic gases being supplied as guest gases for hydrates. Microbes insert abundant lipids into the hydrate –bearing sediments that may promote hydrates; these hydrates prefer the proximity of complex microbial consortia and chemosynthetic communities (Sassen et al., 1999).

In the Cascadia Margin, bacterial populations and activity were found to increase by about an order of magnitude throughout gas hydrate zones wherever hydrates occurred, except in places of high H_2S concentration (Cragg et al., 1996).

Laboratory Study of Bioagents and Gas Hydrate Relationships

When bacteria produce surfactants, the surface-active agent falls into one of five classifications: (1) hydroxylated and crosslinked fatty acids, (2) polysaccharide-lipid complexes, (3) glycolipids, (4) lipoprotein-lipopeptides, or (5) phospholipids (Kosaric, 1992; Fujii, 1998).

To test the hypothesis that biosurfactants could catalyze hydrate formation, a sample of at least one biosurfactant from each classification was obtained from commercial sources. The results were emphatic. These biosurfactants catalyzed hydrate formation in packed porous media (Rogers et al., 2003). The following effects of biosurfactants in the porous media were observed: (1) Hydrate formation rates were usually increased. (2) Hydrate induction times were usually decreased. (3) Specific mineral surface-biosurfactant interactions developed. (4) Very low threshold concentrations of biosurfactants were required to catalyze hydrates.

Porous media of sand and sodium montmorillonite packed in a laboratory test cell and saturated with seawater containing 1000 ppm of biosurfactant showed a two to four-fold increase in hydrate formation rate over a control of the same media saturated with seawater without surfactant (See Fig. 1). Of the biosurfactants tested in Fig. 1, surfactin is classified a lipopeptide, and snomax and emulsan are polysaccharide-lipid complexes.

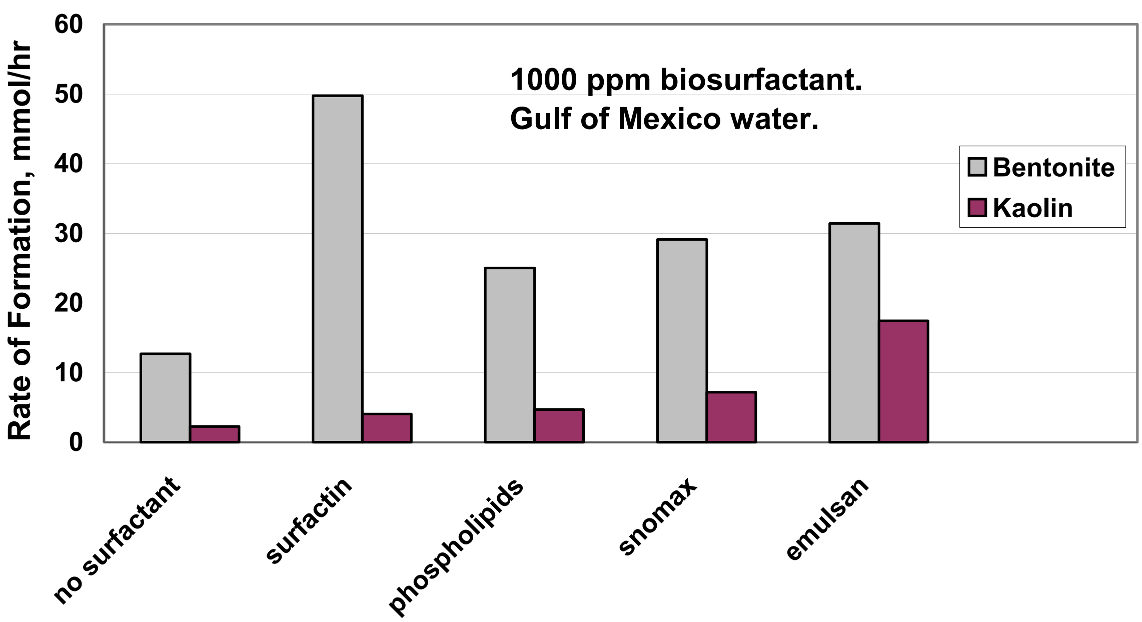

Fig. 1. Hydrate formation rate increase from biosurfactant (Kothapalli, 2002).

Another way to determine the ease of hydrate formation is to measure the time necessary for hydrates to form, i.e., induction time. For example, hydrates may take a very lengthy time to begin forming in a distilled water/hydrocarbon gas quiescent-system that is chilled and pressurized to hydrate-forming conditions. On the other hand, if an anionic surfactant is dissolved in the water solution, hydrocarbon gas and structured water are united by the surfactant to initiate hydrates faster than a random connection. This occurs because hydrocarbon gas attaches to the hydrophobic segment of the surfactant molecule while structured water assembles nearby around the hydrophilic segment, thus acting as a nucleation site. The more rapid initiation of hydrates has a significant meaning in seafloor hydrate occurrence where residence time of migrating gas may be limited while traversing the hydrate zone.

Comparisons of hydrate induction times under the influence of biosurfactant-water solutions saturating porous media in a laboratory test cell are presented in Fig. 2.

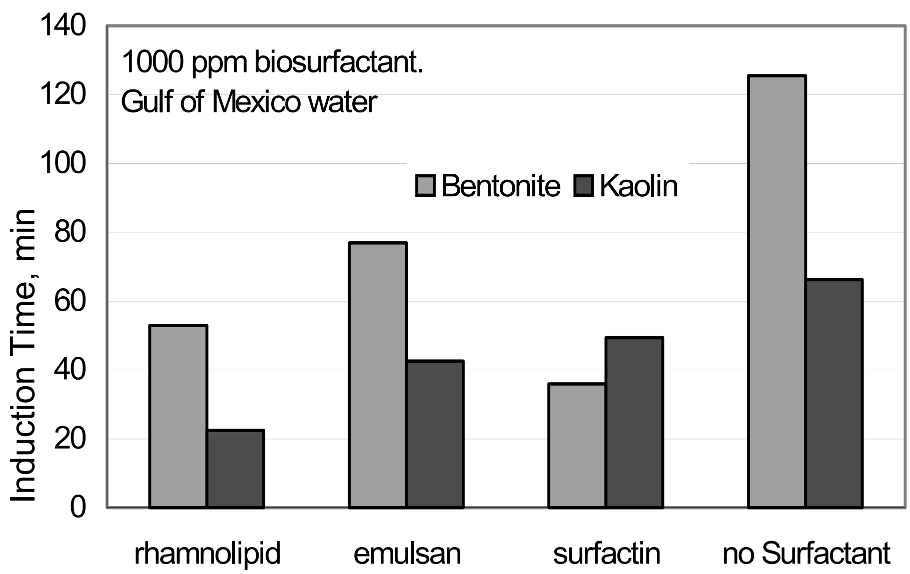

Fig. 2. Biosurfactants shorten hydrate induction times (Kothapalli, 2002).

Laboratory Study of Minerals/Bioagents/Gas-Hydrate Relationships

The anionic biosurfactants have distinctive selectivities for specific mineral surfaces in laboratory porous media packings. For example, in Figure 1 and Figure 2 are seen the efficacy of the smectite clay (bentonite) for hydrate formation in the presence of biosurfactants. Adsorption of biosurfactant on a mineral surface does not necessarily mean that hydrate formation will be enhanced, suggesting molecular orientations of the surfactant on the mineral surfaces may be important (Kothapalli, 2002; Woods, 2004).

EXPERIMENTAL PROCEDURE

Sediment samples were taken from the core at the depths summarized in Table I. Generally, samples were taken from the core in 3-meter intervals. The mud was immediately placed in Zip-lock plastic bags and remained sealed in air-conditioned rooms until tested.

To prepare samples for testing, constant 20 g weights of sediment were taken from each interval and dispersed in a constant 60 g weight of cleaned sand to provide adequate permeability and porosity of the packed media so that maximum surface area of sediments in each experimental run would be exposed to the hydrocarbon gas pressurizing the test cell. Original porewaters were preserved in the sediments; no other water was added to the samples. The mixture was placed in a 60 ml Teflon container with twelve 1/8 in. holes drilled in the sides for gas access. The sample container was placed in a 400 ml stainless steel test cell from Parr Instrument Company. An RTD resistance temperature detector was placed just below the surface of the sand/sediment mixture. A pressure transducer measured internal pressure of the reaction vessel. The cell was purged of air and then pressurized with natural gas (90% methane, 6% ethane, 4% propane) to 330 psig. After the system had equilibrated at 70^{o}F in a constant temperature bath for two hours, pressure was adjusted to 320 psig and the system allowed to re-equilibrate for another hour. The test cell was immersed in a constant-temperature bath at 0.5^{o}C and data collected every 2 minutes with Omega Daqbook 120 equipped with DBK9 Data Acquisition System and DasyLab Software. Pressure versus temperature was plotted.

Induction time of the hydrates was calculated by the elapsed time between the equilibrium pressure-temperature and hydrate formation during cool-down. Standardized induction time was calculated by dividing the induction time of the specific sample by the induction time for the sediment test sample of 1.0 m depth.

Formation rate of the hydrates was determined for each 2-minute interval as the number of moles of gas going into solid solution from the gas phase per unit time; the Peng-Robinson equation of state was used. Maximum formation rate was divided by the maximum formation rate for the 1 m sediment control to obtain a standardized maximum formation rate. Duplicate runs were made for each sample.

RESULTS AND DISCUSSION

Hydrate Formation Rate Change with Depth

The Marion Dufresne MD02-2570 core samples extracted to a depth of about 30 m provide an opportunity to study hydrate formation in sediments below the 6 m commonly tested in the Gulf of Mexico. The approach was to evaluate sediments from the surface to the 30 m bottom in 3 m intervals. Cores were from 28°04.26'N and 89°41.39'W.

Several facts regarding the laboratory hydrate tests should be repeated for emphasis: (1) The only water in the test sample was the original in-situ porewater. (2) Each sediment sample from the core was dispersed in cleaned sand to give porosity and permeability to the test sample. (3) Sample dispersion throughout the sand gave maximum contact of sediment minerals with natural gas. (4) Natural gas of 90% methane, 6% ethane, and 4% propane pressurized the hydrate test cell.

The gas-hydrate formation rates determined for each sample are given in Table I. The formation rates listed in Table I and plotted in Figure 1 are averages of multiple, independent runs on each sample.

TABLE I. Gas-hydrate formation rates of sediments from Well MD02-2570

Depth, meters	Formation Rate, mmol/hr	Standardized Form. Rate
0.00	0.00 Did not form	0.00
1.00	5.26	1.00
3.00	20.37	3.87
6.00	22.02	4.19
9.00	26.32	5.00
12.00	27.06	5.14
15.00	39.02	7.42
18.00	37.15	7.06
21.00	35.13	6.68
24.00	27.79	5.28
27.00	24.87	4.73
27+ (Plotted as 30 m)	23.96	4.56

An apparent trend in the gas-hydrate formation rates as a function of distance below sea floor can be detected in Fig. 1. Hydrates would not form in the very top sediments after holding the test sample at hydrate-forming conditions for 96.5 hours, whereupon this zero-depth test was terminated. As depths increased, however, hydrate formation rates in the sediment samples increased until a maximum rate was indicated for the mud at 15- 20 meters depth.

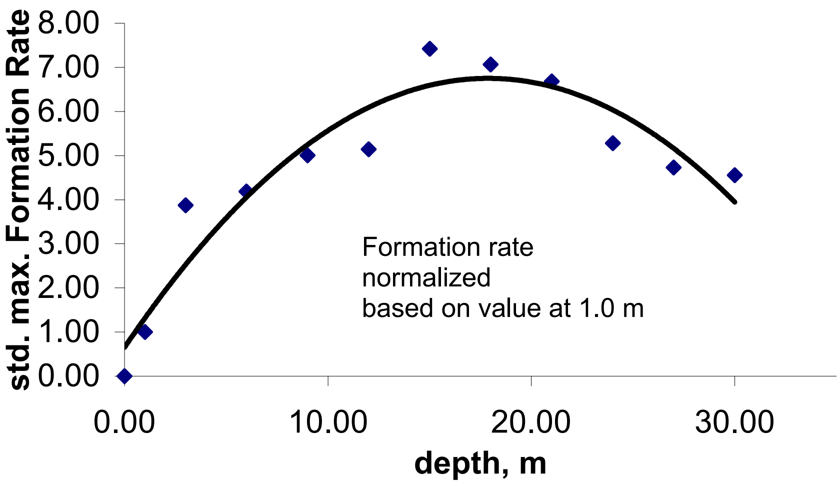

Fig. 1. Evaluation of core sediments for rate of hydrate formation

The correlation of hydrate formation rate with depth in Figure 1 may be represented by the regression Equation (1).

$$FR = -0.0191D^2 + 0.6823D + 0.6512 \quad (1)$$

In the equation FR is the standardized maximum formation rate, D is the depth of sediments as meters. The R^2 for the correlation is 0.9034.

Hydrate Induction Time Change with Depth

Sediment samples from the core were generally tested every 3.00 meters. Exceptions were a surface sample and a sample 1.00 meters below the surface. In the context of hydrocarbon gas migrating through seafloor sediments, induction time would be an indication of the gas residence time necessary to initiate hydrates. The parameter may be taken as one indication of the propensity for hydrate occurrence.

In Table II are the gas hydrate induction times for each sample depth; each data point represents an average of multiple runs. A standardized, dimensionless time is calculated by taking the induction time of the 1.00 sample as the reference. In the case of the surface sample, note that gas hydrates had not formed after 95.6 hours under hydrate conditions.

TABLE II. Gas-hydrate induction times of sediments from Well MD02-2570

Depth, meters	Induction Time, hr	Standardized Induction Time
0.00	Did not form.	∞
1.00	4.33	1.00
3.00	5.82	1.34
6.00	2.00	0.46
9.00	1.00	0.23
12.00	0.53	0.12
15.00	0.42	0.10
18.00	0.37	0.08
21.00	0.60	0.14
24.00	0.63	0.15
27.00	0.58	0.13
27+ (Plotted as 30 m)	0.43	0.10

The trend is more readily envisioned with the help of Figure 2.

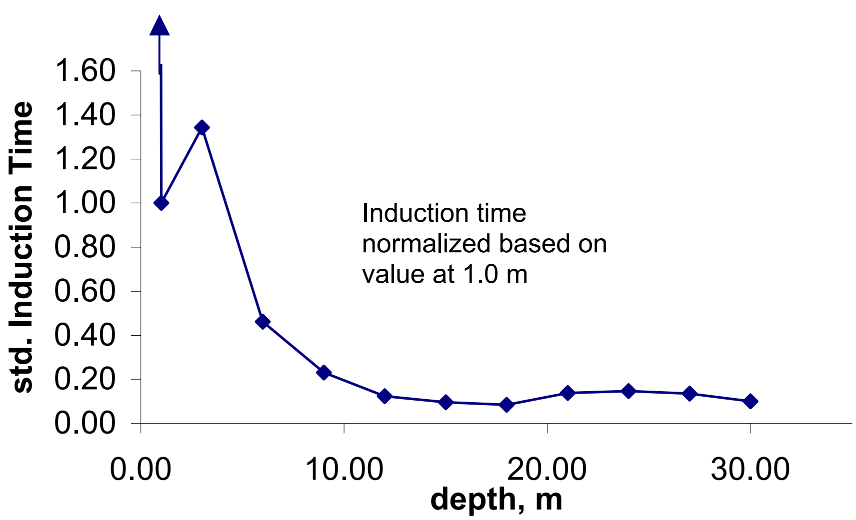

Fig. 2. Evaluation of core sediments to determine time for hydrate initiation

A rapid decrease in induction time, i.e., an improvement in the ease with which hydrates will initially form, is evident down to a depth of about 12 meters. At about 12 m the induction time reaches a minimum and remains at that rapid initiation for the remainder of the 30 m.

In the top few meters of sediments, the trend is disrupted.

It is helpful to superpose the induction time and formation rate curves in Figure 3, where the two phenomena are compared.

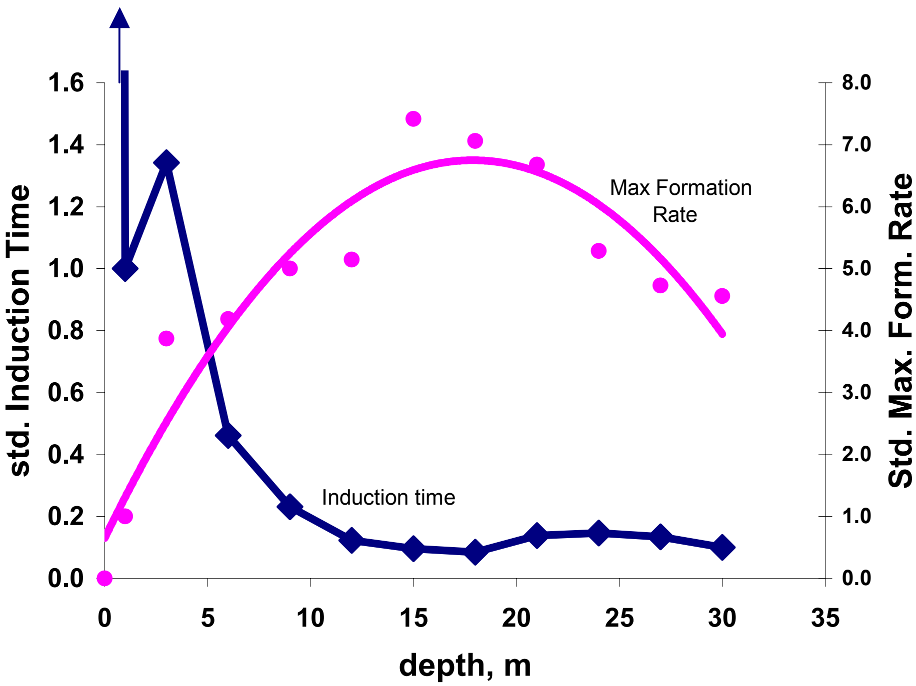

Fig. 3. Relative formation rates and induction times of gas hydrates

Induction time would probably be most dependent upon the ease of hydrate nucleation in the sediments as influenced by the density and quality of nucleation sites. General studies in our laboratory of hydrate formation in sediments suggest the importance of smectite clay particles and the presence of bioproducts that may adsorb on those small clay particles as promoting short hydrate induction times, although apparently there are other influences on induction time that remain an enigma. The bioproducts bring hydrocarbon gas and possibly structured water together at the nucleation site, thus reducing induction time.

After hydrate initiation, the rate of hydrate particle agglomeration must obviously depend on mass (hydrocarbon gas as well as water) transfer rate, heat transfer rate, surface area and porosity for hydrate particles to grow, temperature, pressure, bioproducts, and mineral surfaces—an imposing array of variables. In the experiments mass transfer rates, heat transfer rates, temperatures, and pressures could be considered constant for each run.

From the data of MD02-2570 from the Dufresne cruise, it is concluded from Figure 3 that hydrates would occur in the sediments with varying degrees of difficulty and with varying rates of formation as a function of depth below the seafloor.

Laboratory investigations continue the laborious task of defining important parameters and determining mechanisms that cause the trends of hydrate formation exhibited in Figure 3.

Silt, Clay, Sand Compositions

Sand, silt, and clay contents were analyzed for each of the samples of the 30 m core. In order to compare results directly with the hydrate formation rate and induction time trends, the sand/silt/clay contents were normalized and plotted versus depth in Figure 4.

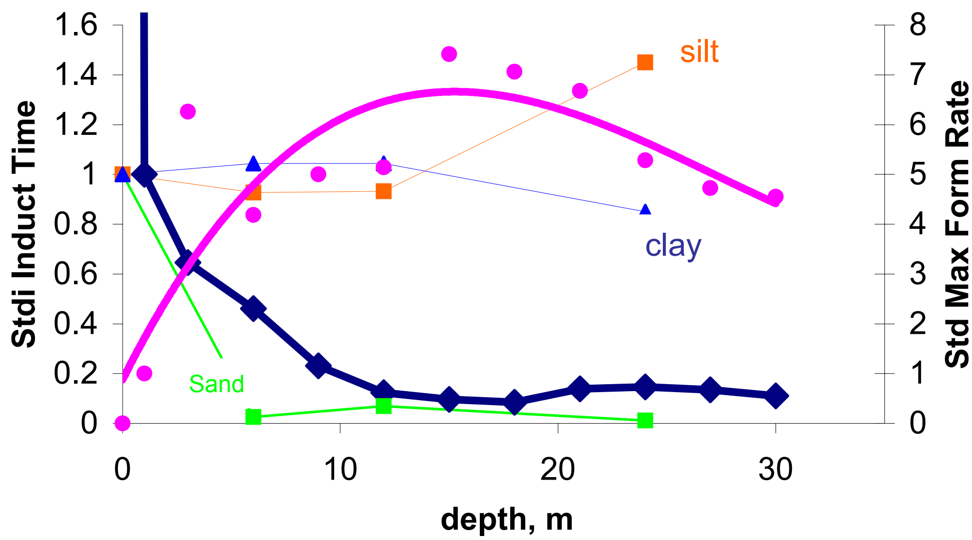

Fig. 4. Sand/silt/clay contents

It is interesting that breaks in the trends of sand/silt/clay roughly occur near where the breaks develop in induction time and formation rate trends. Although no definitive conclusion can be drawn from this limited number of data points, the relative trends suggest future verification in other cores and suggest tangential experiments that will be undertaken.

Clay Contents of the Sediments

Clay minerals in each sediment sample were analyzed and the percentage compositions are presented in Table III. These data represent compositions of particles ≤ 2 μm diameter.

TABLE III. Clay content of MD 02 2570

Depth (m)	% smectite	% illite	%chlorite	% kaolinite
3	32	43	8	18
6	40	37	6	18
9	26	45	6	23
12	43	32	5	20
15	39	37	7	17
18	30	45	6	20
21	10	69	10	11
24	29	50	9	12
27	30	43	8	19
27.1	12	67	10	11

In Table III it is seen that kaolinite and chlorite represent a lower fraction of clay content, and the percentages of these two minerals with depth are fairly constant. It therefore seems more important to concentrate on the smectite and illite contents, so these clay contents are plotted versus depth in Figure 5.

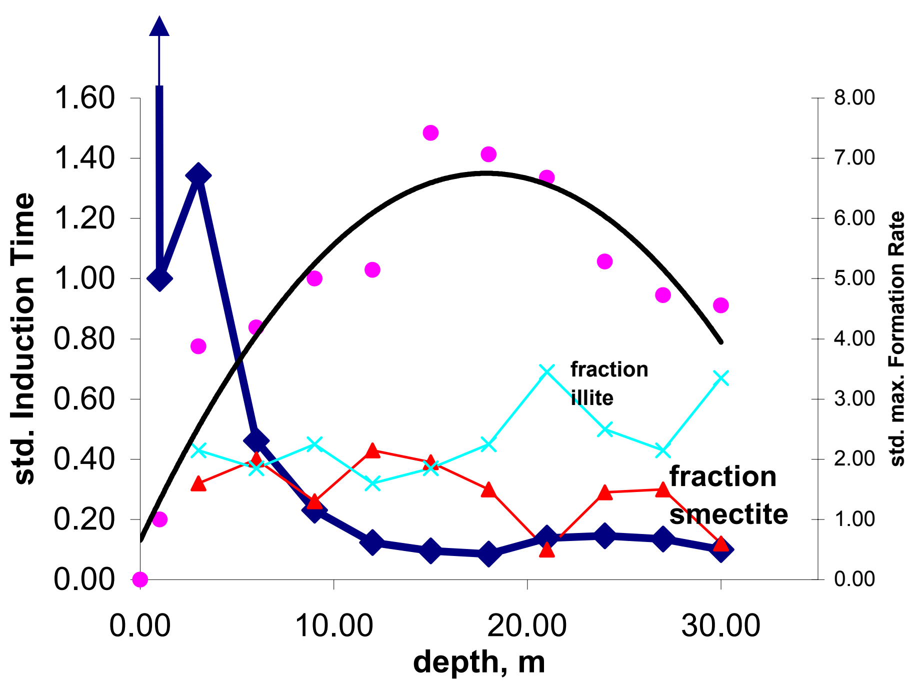

Fig. 5. Predominant clay content of sediments; <2 micron diameter particles

CONCLUSIONS

The following conclusions are drawn from laboratory studies to date of the MD02-2570 core extracted at 28°04.26'N and 89°41.39'W in the Mississippi Canyon.

1. A correlation exists between hydrate formation rate and depth of the sediments below seafloor. Hydrate formation rate in the sediments is most rapid at about 15-18 m depth.
2. A correlation exists between hydrate induction time and depth of the sediments below seafloor. Hydrate induction time reaches a minimum at about 12 m and remains at that very short induction time to the bottom of the core at 30 m.
3. Silt, sand, and clay percentages in the sediments show trends with depth that suggest a contributing factor to the hydrate formation ease.
4. Smectite, illite, chlorite, and kaolinite percentages in the sediments were determined. Smectite and illite may influence the hydrate formation trends found in the tests.

Tests are ongoing to relate bioagents and bioagent-mineral interactions with hydrate formation trends.

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CONCLUSIONS

This report covers the accomplishments of the fifth six-month period funding of Cooperative agreement Project #DE-FC26-02NT41628, between the Department of Energy and the Center for Marine Resources and Environmental Technology, University of Mississippi. The efforts of the Hydrates Research Consortium are reviewed and plans for the final phases of the project presented. Conclusions of various projects are happening and every effort is being made to coordinate site surveys and sensor emplacements in a sequence that allows all participants maximum access to and benefit from the cruises scheduled for late summer and fall, 2005.

Project summaries of the subcontractors' efforts appear in their reports contained within this document. All FY03 subcontractors have completed their technical reporting although financial reports are not yet complete. The CMRET is working with the sponsored programs officials at several institutions to resolve these delays. The VLA and the SFP are complete and have been proven. The "bubble counter" is complete but awaits testing in deep water, something that the Consortium is arranging. The "SphereIR" is essentially complete though it has never been field tested. Both it and the acoustic device have depleted funds prior to completion of their sensor packages. Laboratory studies of gas hydrates have expanded to new areas and new depths revealing more of the complex "habitat" hosting gas hydrates.

Software development and innovative processing techniques are on schedule as are the pore-fluid experiments. The initial components of the station, a pore-fluid sampling probe and a thermistor geophysical probe, were emplaced on the sea floor in May of 2005. Additional components will be added during subsequent visits to the station site with completion of the station expected in 2007.

An Appendix is included for informational/historical purposes. Revision to it since the previous progress report has been minimal but it provides a useful reference when reviewing current projects.

REFERENCES

Relevant references appear following the contributions by the individual subcontractors.

ACRONYMS

3D	three-dimensional
4-C	four-component
AC	alternating current
ADCP	Attenuated Doppler Current Profiler
A-D	alternating-direct (current)
ALA (=VLA)	acoustic line array
ASL	Applied Sensors Laboratory
ATR	attenuated total reflection
AUV	autonomous underwater vehicle
AV	Atwater Valley
BCS	Barrodale Computing Services, Ltd.
BEG	Bureau of Economic Geology (University of Texas)
BHA (=BLA)	borehole array
BLA (=BHA)	borehole line array
CAD	Computer Assisted Design
CCA	constant cone angle
CLSR	Constant Light Source Radius
CTD	conductivity, temperature, depth (sensors)
CMRET	Center for Marine Resources and Environmental Technology
DATS	Data Acquisition and Telemetry System
DBMS	Data Base Management System
DC	Direct Current
DIC	Dissolved Inorganic Carbon
DOC	Department of Commerce
DOE	Department of Energy
DOI	Department of the Interior
DMAS	Data Management Architecture Design
DRS	Data Recovery System
DURIP	Defense University Research Instrument Program
EU	European Union
EGL	Exploration Geophysics Laboratory
FT-IR	Fourier Transform Infrared Spectroscopy
FY	Fiscal Year
GLA	geophysical line array
GOM	Gulf of Mexico
GOM-HRC	Gulf of Mexico-Hydrates Research Consortium
GPS	global positioning system
HATR	horizontal attenuated total reflection
HLA	horizontal line array
HRC	Hydrates Research Consortium
HSZ	Hydrate Stability Zone
IDP	Integrated Data Power Unit
IPV	integrated peak value

I/O	Input/Output Systems
IR	infrared (spectroscopy)
IRLED	Infrared Light-Emitting Diode
JIP	Joint Industries Program
mbsf	meters below sea floor
MC	Mississippi Canyon
MCT	mercury cadmium telluride (detector element)
MD	Marion Dufresne
METS	methane sensor
MFP	matched field processing
MIR	mid-infrared
MMRI	Mississippi Mineral Resources Institute
MMS	Minerals Management Service
MS	monitoring station
M/V	Merchant Vessel
NETL	National Energy Technology Laboratory
NIUST	National Institute for Undersea Science and Technology
NMR	Nuclear Magnetic Resonance
NOAA	National Oceanographic and Atmospheric Administration
NRT	near real time
NURP	National Undersea Research Program
OBC	ocean-bottom cable
OLA (=OVA)	Oceanographic Line Array
ONR	Office of Naval Research
OPeNDAP	Open source Project for a Network Data Access Protocol
OVA (=OLA)	Oceanographic Vertical Line Array
PC	Personal Computer
PCB	pressure compensated battery
PCA (=PFA)	pore-fluid array
PFA (=PCA)	pore-fluid array
PDMS	polydimethylsiloxane
PSCB	poly(styrene-co-butadiene)
P-SV	converted-shear mode (P-wave to SV-shear wave conversion)
P-wave	compressional wave
QA	quality assurance
QC	quality control
RDBMS	Relational Data Base Management System
RDI	RD Instruments
ROV	remotely operated vehicle
RTP	Real-Time Protocol
RTD	residence temperature detector
R/V	Research Vessel
SCUFA	Self-Contained Underwater Fluorescence
SDI	Specialty Devices, Inc.
SDS	sodium dodecyl sulfate

SFO	Sea Floor Observatory
SFP	Sea Floor Probe
SMPTE	Society of Motion Picture and Television Engineers
SQL	Structured Query Language
SSD	Station Service Device
S-wave	shear wave
TBT	tributyl tin
T-O (=T0)	Time Zero
TOC	Totoal Organic Carbon
UNC	University of North Carolina at Chapel Hill
US	United States
USBL	ultra-short base-line (locating system)
UTM	universal trans-Mercator
VLA	vertical line array
VSP	vertical seismic profile
ZnSe	Zinc selenide

APPENDIX

GULF OF MEXICO HYDRATE RESEARCH CONSORTIUM: ESTABLISHMENT OF A SEA FLOOR MONITORING STATION, AN UPDATE

Introduction

Since the Gulf of Mexico Gas Hydrates Research Consortium (GOM-HRC) was organized in 1999, it has made considerable progress toward establishing a sea-floor observatory (SFO) to monitor and investigate the hydrocarbon system within the hydrate stability zone of the northern Gulf of Mexico. The intention has been to equip the SFO with a variety of sensors designed to determine a steady-state description of physical, chemical, thermal and, most recently, microbiological conditions in its local environment as well as to detect temporal changes of those conditions.

In the original design, the heart of the SFO was a network of five vertical line arrays (VLAs), each of which would consist of 16 channels of hydrophones spaced over the lower 200m of the water column. Each VLA would be suspended from glass floats and would have been anchored to the sea floor. Since water currents would cause the VLAs to deviate from vertical, each would also include inclinometers and compasses for determining the location of each hydrophone within the water column.

The intention was to use standard surveying techniques to determine the configuration of sub-bottom strata and to monitor that configuration by applying Matched Field Processing (MFP) to the acoustic energy received by the VLAs. The source of the energy could be either the intentional firing of conventional seismic devices or the opportunistic noise of passing ships.

In either case, MFP would require knowledge of the source location. In the former, the location would be measured directly. In the latter, it would be estimated relative to the known location of the VLAs by triangulation. The net of five VLAs would provide 20 independent estimations that would be analyzed statistically to minimize error in the final determination.

Significant disagreement between the MFP results and the sub-bottom configuration determined previously would indicate that a change had occurred within the sea floor. A new survey could then be carried out to determine the structural nature of the change and the output of other sensors examined to determine chemical and thermal changes.

This original strategy came under question during 2003, however, due to a number of external factors that surfaced. Discussions arose among some Consortium members as to whether or not the design of the SFO could be modified to accommodate, and perhaps even to capitalize on, those factors. There was agreement to explore a number of modifications but not to alter the original intention or basic mission of the SFO. This update documents that exploration and other developments.

Modifications

Modifications to the design of the monitoring station/sea floor observatory are described below and are illustrated in Figure 1.

CHANGE 1: ARRAY TYPE

One external factor affecting the establishment of the station is the development of an ocean acoustics technique by which the sound of waves at the sea surface can be used to image the sea floor. The method requires that at least two horizontal line arrays (HLAs) be deployed on the sea floor perpendicular to each other. Each HLA should be as long as the water is deep and contain as many hydrophones as is feasible. If each hydrophone comprises a separate data channel, the cross of HLAs will also be capable of triangulating on ship noise. One VLA would still be required to separate the up-going and down-going wave-fields, but the sound of waves could be utilized as an energy source by redeploying the other four VLAs as two HLAs. This would allow the sound of wind-driven waves to be used without forfeiting the use of either intentional seismic sources or ship noise.

A second external factor is the opportunity to deploy an array of sensors in a borehole that will be drilled by the Department of Energy/Joint Industry Program (DOE/JIP) Consortium. The borehole array (BHA) will consist of hydrophones, three-component accelerometers and temperature sensors that would remain in the hole after the drill stem is recovered, letting the hole collapse and making the installation permanent. It would provide long-term monitoring from within the hydrate stability zone. If located at a site appropriate to the other requirements of the monitoring station, it would comprise a valuable addition to the SFO.

If both these array modifications were to be incorporated, the seismo-acoustic components of the SFO would comprise three mutually perpendicular axes of a Cartesian coordinate system. One VLA would be the vertical axis in the water column and the horizontal axes would consist of the other four VLAs deployed horizontally. The BHA would comprise the sub-bottom portion of the vertical axis.

A second VLA has been constructed to accommodate geochemical sensors: off-the-shelf thermistors, CTDs, fluorometers and transmissometers. This array will provide the capability of studying hydrate-related hydrocarbon fluids in the water column. It will be possible to deploy this array either in an autonomous mode or as a component of the SFO.

The original design of the SFO calls for each of the VLAs to be equipped with a sea-floor data logger. The five data loggers were to be connected to a central integrated data/power (IDP) module that would collect data from, and supply power to, the individual loggers. The change to using HLAs would not affect this arrangement.

The BHA has been funded separately by DOE/JIP and it would not represent a cost increase to the SFO. The only cost increase would be associated with increasing the length of the four VLAs so they could be re-deployed as two HLAs with lengths equivalent to the water depth. This could be a factor in whether or not the BHA becomes an integral part of the SFO.

Since the Consortium's break from the JIP plan, appears likely that the placement of a BHA will not happen in the near future. For this reason and because the

BHA concept adds so much to the overall station capability, the idea of emplacing shorter arrays via the Sea Floor Probe has been revived. Ten meter arrays, both geochemical and geophysical have been added to the plan for the station. Although these arrays are temporary, they will provide much valuable data at a fraction of the cost of a borehole array. These are the arrays that were emplaced on the sea-floor in May, 2005. The data will be retrieved at the earliest opportunity.

The JIP has indicated that there may be a 2006 hydrate drilling program. If this materializes, the opportunity to emplace a borehole array in a JIP borehole can be revived. Otherwise, other opportunities will be pursued.

CHANGE 2: DATA RECOVERY

External factors have also impacted the way SFO data will be recovered. For some time it was thought that a commercial service would be available in 2004 which would allow the IDP to stream data onto an optic-fiber link for near-to-real time transmission to shore. It was learned in the autumn of 2003, however, that the service would not become available until 2006 or later.

The use of a remotely operated vehicle (ROV) to download data directly from the SFO's data loggers was found to be prohibitively expensive due to the depth of water and the weight of the battery packs that would need to be exchanged. Therefore, until such a link becomes available, the IDP module will stream data onto an optic-fiber data recovery system (DRS) which will be connected via optic fiber to an access connector. Whenever downloading is required, a system of buoys will bring the DRS access connector to the surface so that the data can be downloaded onto computer in a boat. The system has been used successfully before and involves far less expense than repeated use of a deep-water ROV. The system has been dubbed the "Big M" and is illustrated in Fig.1.

CHANGE 3: POSITIVE SYNCHRONIZATION OF TEST SIGNALS

The DRS will serve yet another need. While surveying to determine the configuration of sub-bottom strata in the vicinity of the SFO, the towed sea-floor sled will be used to generate shear waves for recording by the SFO's arrays. During the course of that survey, an access connector will be brought to the surface and connected to a radio telemetry buoy that will synchronize the firing and receiving of signals.

CHANGE 4: ELECTRICAL POWER FOR THE SFO

The Gulf of Mexico Hydrates Research Consortium funds the development of microbial batteries but it will be some time before they can provide electrical power to the SFO. In the meantime, the IDP module will supply electricity to the SFO by exchanging the pressure compensated battery (PCB) component about once a year. This will involve unplugging the depleted PCB from the IDP and plugging in a fresh one. The emplacement and exchange of PCBs will be accomplished by a station service device (SSD) especially designed for the task.

A docking station will be incorporated into the IDP module to facilitate changing the PCB. The SSD will carry the recharged PCB unit to the sea floor and return with the depleted unit. In addition, the SSD will be capable of recovering pore-fluid samples at *in* *situ* pressures. Perhaps most significantly, the SSD will be the means by which all station systems are connected to the IDP for data recovery and electrical power.

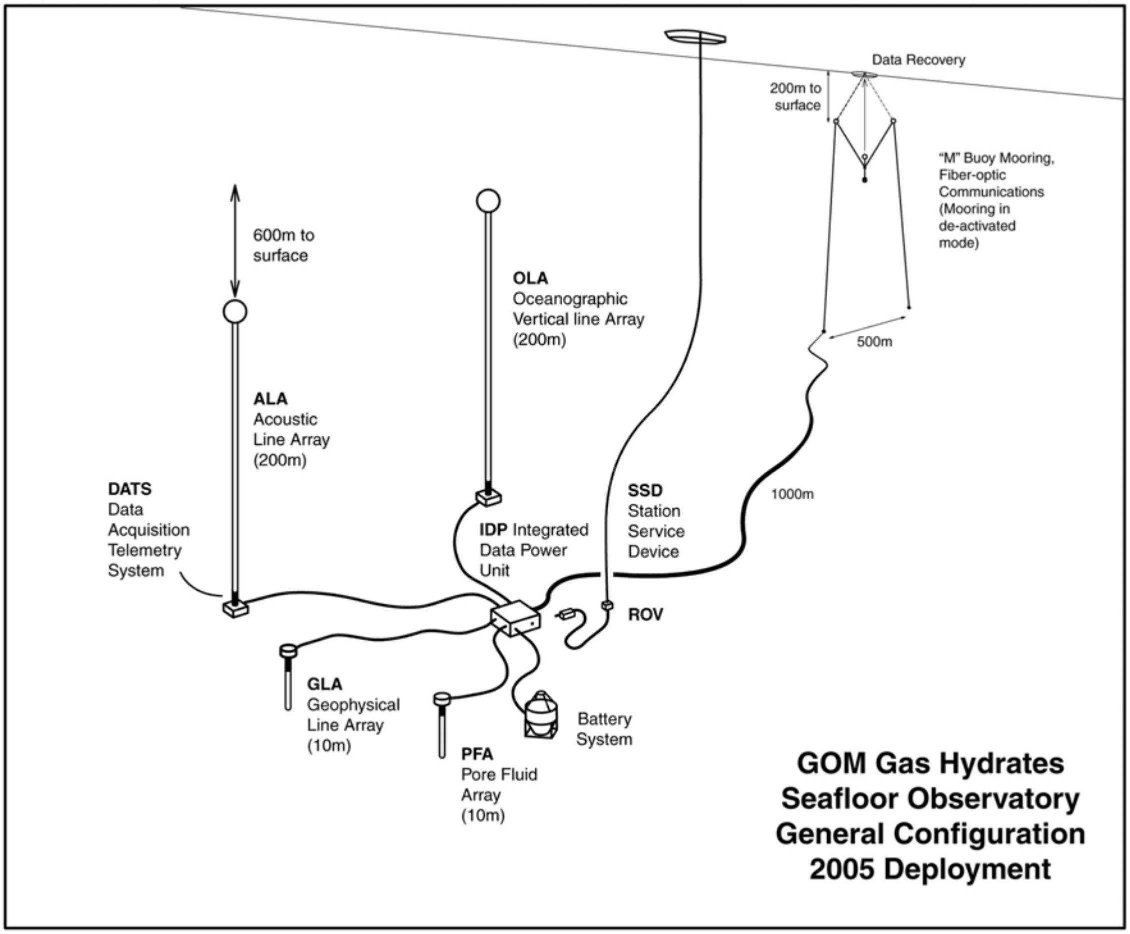

Figure 1. Diagram of the monitoring station/sea floor observatory.

Conclusion

Modifications discussed herein are not intended to change the basic concepts, overall plans and mission for the SFO. Instead, they are expected to enhance the accomplishment of that mission.

Funding has been requested for the supply of components and construction of the new systems in order to adapt to the changing circumstances, as well as for the continuation of the, all-important, on-going studies and systems development projects. On the positive side, the SFO will gain a significant degree of autonomy, provide time on the learning curve to deal with the large data sets generated by the station, provide an ROV-like SSD capable of conducting a wide range of support activities, and, probably most important, keep on task towards station operation by 2006.