Progress Report on the
Gulf of Mexico Sea-Floor Observatory
June, 2003

PROGRAM BACKGROUND

The Gulf of Mexico-Hydrate Research Consortium (GOM-HRC) is in its fourth year of developing a Gulf of Mexico-Sea Floor Observatory (GOM-SFO). The GOM-SFO is planned to 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. It is anticipated that this station and studies conducted therein will provide a better understanding of this complex hydrocarbon system, particularly with regard to hydrate formation/dissociation, fluid venting to the water column, and associated microbial/chemosynthetic communities. More specifically, it is hoped that models can be developed from these studies that can provide a better understanding of gas hydrates and associated free gas as: 1) a geo-hazard to conventional deep oil and gas activities; 2) as a future energy resource of considerable significance; and 3) as a source of hydrocarbon gasses, 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 DOC NOAA-NURP in 2002. Some five industries and fifteen universities are involved at various levels of participation. A variety of mission-oriented projects are presently being conducted which include a range of physical, chemical, and biological observations/investigations.

SITE SELECTION

Site selection for the SFO has been a significant part of the overall mission, with the objective of locating as close as possible to pertinent, characteristic features and phenomenon of the HSZ. This effort has been greatly assisted by a wealth of direct and remotely sensed (geophysical) observations, collected over the past decade; much of it by participants of the HRC. Over the past several years a number of sites have been investigated which contain, within close proximity, most, but not all of the characteristic features and phenomenon of critical interest to the study; i.e. hydrates, massive and ephemeral; fluid vents, large and small, sub-surface “shallow flows” and chemosynthetic communities. It is evident that the probability of finding an all inclusive site is low; however, the selection plan is to establish a principal station which maximizes opportunities for accessing as many of the targeted features as possible. Recently, the DOE/DOI, Joint Industry Program (JIP), presented such an opportunity to the Consortium.

The JIP advised they would select several sites where the probability was favorable for locating a HSZ of sufficient thickness for the entrapment of gas in the underlying free gas zone. The selected sites would be cored throughout the entire section of the HSZ. The Consortium recognized the opportunity to access one of the more favorable sites for the emplacement of a multi-sensor bore-hole vertical line array (BVLA), the cost of which would be otherwise prohibitive.

Presently the most probable site, based on evidence to date, will be a JIP location in Mississippi Canyon in the Atwater Valley Block 14, at a water depth of 1300m. The most current JIP estimate of thickness of the hydrate section at this location is 400m. The Consortium plan is to instrument the hole with acoustic, thermal, pore fluid pressure and chemical sensors for long term observations. The JIP site would most likely become the principal location in the GOM-SFO network., providing a unique opportunity to make valuable, *in situ* observations throughout the HSZ; from the upper interface with the water column, including surficial hydrates, etc., through to the lower interface with the free gas zone, with the probability of intersecting deep seated hydrates and possibly an over pressurized (shallow flow) zone. The Consortium was recently advised by the JIP that the coring contract has been let to Fugro McCelland Marine Geosciences.

0ther satellite stations would be established, that would be better disposed to monitor isolated, but significant features, such as chemosynthetic communities, mega fluid vents, and pertinent environmental effects. Presently the western Bush Hill location, Green Canyon 185, approximately 550 m water depth; favored by the selection committee for its many attributes, will most likely be chosen by the full consortium, Board of Directors, as the significant other station. In simplest terms, these two sites, representing both a deep, more-or-less stable site; and, a shallow, more ephemeral site, would provide access for study of virtually all pertinent features and phenomenon critical to a comprehensive understanding of the near-seabed hydrocarbon system of the HSZ.

SURFACE LINK

Several options for the surface link, providing control, power, and data handling/transmission, are currently under consideration. Consultations are underway with the NOAA, National Data Buoy Center (NDBC) for the use of an appropriate buoy of either the 12-Meter or NOMAD class. Where candidate sites are in proximity of an oil and gas platform, and access may be granted to establish a surface link facility, such an option would be ideal. One such site has been located in Green Canyon, in the vicinity of Bush Hill, where a mega hydrocarbon fluid vent is known to occur, within a mile of the Conoco, Joliet platform. Conoco has granted limited access to Joliet to establish a surface link for this site which provides further enhancement for its selection. This would be an example of a satellite station established to monitor isolated, but critical components of the near-seabed hydrocarbon system. In the case of the JIP site, slated to become the principle SFO location, no platform currently exists within reasonable accessibility. In this situation a NDBC buoy would be the most appropriate current option.

Yet another option has recently arisen. The Consortium has learned that Ocean Specialist Services, Inc. Stuart, FL, is seriously considering the establishment of a fiber optic cable network which would link subscriber platforms in the deep-water Gulf of Mexico with an appropriate land base. Current plans are for the cable to pass near to both the JIP Atwater and Bush Hill sites where junction boxes could be placed for SFO hook-up. This of course, would provide the best possible solution for an eventual surface link capable of handling the large data sets anticipated.

GOM-SFO SENSOR SYSTEMS

The GOM-HRC has developed a number of sensor systems for use in the observatory. Early on, Mississippi Canyon Blocks 798, 841 and 842 were considered as test sites for sensor systems. The water depths there range from 600m to 850m and hydrates are known to be present. Also, there is no lease holder and therefore no complicated permitting procedure is required to place objects on the sea floor.

The vicinity was reconnoitered seismically in June, 1998, during a joint cruise of the University of Mississippi and the U.S.G.S. which was funded principally by MMS.

Interesting sub-bottom features having been observed on the seismic profiles, MMS made funds available for the University of Mississippi to contract TDI-Brooks International Inc. to carry out a series of heat-flow measurements along one of the seismic profiles in MC798. The heat-flow program was carried out during November, 2000, and verified that the sea floor in MC798 was within the HSZ and that the base of the HSZ is about 400m below the sea floor.

Seismo-acoustic Systems

From the inception of the GOM-SFO project, it has been considered that seismo-acoustic data would form the core of monitoring observations. The principal idea is that the geologic configuration of the sea floor and sub-bottom in the vicinity of the observatory will be modeled using high-resolution seismic reflection profiles and then, after a model is determined, the observatory itself would monitor the noise of passing ships to detect changes to the model. Four types of seismo-acoustic systems are involved: a single-channel reflection profiling system; a network of vertical arrays in the water column; a single vertical array in the sub-bottom and a horizontal array on the sea floor.

The single-channel reflection profiling system deploys a seismic energy source at the water surface and tows a single-channel hydrophone array far enough below the surface to be in the far field of the source. This so-called surface-source/deep-receiver (SSDR) technique allows a far-field source signature to be recorded for every shot. A digital processing scheme uses the source signature to compress the waveforms reflected from sub-bottom interfaces. This greatly enhances the resolution to which geologic configurations are imaged and makes it possible to calibrate reflection amplitudes, thereby measuring reflection coefficients and obtaining estimates of physical properties within the sub-bottom.

The SSDR system has been tested on three cruises during 2000-2002. Results have been better than originally expected, the best resolution to date being 0.1ms (approx. 7.5cm) at the sea floor in 1450m of water and 1ms (approx. 75cm) 400m below the sea floor in the same water depth. Thus far, the principal limitation of the technique is imposed by the arrival of a reflection from the water surface, the so-called “ghost” reflection, which overprints deeper reflections, thus restricting the depth of useful penetration. A digital process to remove the ghost is in the final stage of development.

The P.I. for the SSDR technique is Tom McGee of the University of Mississippi. The deployment hardware was designed and constructed by the technical staff of CMRET. Processing algorithms are developed by Thalassic Data Limited of Vancouver, B.C., and executable software is coded by Lookout Geophysical Company of Palisade, CO. Funding has been provided by MMS.

Development of the SSDR technique is essentially complete although some technical improvements could be made. In particular, *operational efficiency would be greatly improved if the deep receiver were mounted on an autonomous submarine rather than being towed from a surface vessel.*

The network of vertical arrays in the water column will consist of five vertical line arrays (VLAs) of hydrophones anchored to the sea floor and supported by floats. Each VLA provides two essential kinds of information. First, during determination of the geologic model, each VLA records seismic waveforms as a function of both travel time and source offset. This allows speeds of propagation in the geologic strata to be estimated and spatial corrections to be made to the model by "migrating" the profiling data. Second, during the monitoring phase, the VLA network would triangulate upon and track the sounds of ships. The use of five VLAs will reduce tracking errors by providing a 20-times redundancy in the triangulation. If the patterns observed in the propagation of ship sounds do not match those expected from the model, it would indicate a possible change in the geologic configuration and further investigation could be initiated.

A prototype 16-channel VLA has been constructed and was tested on two cruises during the summer of 2002. Electrical problems found during the first cruise were corrected and data were recorded successfully during the second. Erratic shot timing precluded successful processing of these initial data, however. This is expected to be solved before the next research cruise, scheduled for August, 2003, during which the prototype VLA is expected to be deployed at two sites; Mississippi Canyon Block 798 and Atwater Valley Block 14. At each site, data will be collected using both a seismic source and ship noise.

The P.I. for the VLA system is Ross Chapman of the University of Victoria, B.C. Technical hardware design and construction is being done by Specialty Devices Inc. of Plano, TX. The processing software is under development on three fronts and techniques employed in the processing will be the subject of three graduate dissertations. Work on two fronts will take place at the University of Victoria, B.C., where two students, one Ph.D. and one M.Sc., will work under the supervision of Prof. Ross Chapman. The Ph.D. problem will be to build on military anti-submarine techniques used during the Cold War (Prof. Chapman is a world expert in this). The M.Sc. problem will be the use of ship noise for monitoring purposes. Work on the third front will take place at the University of South Carolina where a Ph.D. student will build on petroleum industry techniques under the supervision of Dr. Camelia Knapp. Funding for design and testing of the prototype VLA was provided by MMS. Funding for VLA construction has been provided by DOE. Financial support for the students is provided by MMS.

Development of the VLA system is still at an early stage. One prototype has been constructed and tested. Funding is in hand for building two production arrays during 2003. Funds have been requested to build another three arrays during 2004. A research cruise in August, 2003, will use the prototype array to collect data for use in the software development. The students will begin work in September, 2003. Preliminary software algorithms are expected to be tested during 2005.

The single vertical array in the sub-bottom will consist of a linear array of sensors placed in a borehole. The borehole vertical line array (BVLA) will be emplaced as the casing is withdrawn. It is expected that the hole will collapse and that, after some time, the sediments in the hole will return to approximately their original state, thus leaving the array to monitor material in something like its natural setting.

The BVLA will be equipped with hydrophones, three-component accelerometers, thermisters and resistivity sensors. Conductors from the sensors will be left exposed on the sea floor. Every few months or so, an ROV would attach a data logger to the conductors and shots from a seismic source at the surface of the water would be recorded together with the temperature and resistivity data.

The BVLA will be designed to take advantage of the JIP coring program which is scheduled to commence in May 2004. The most probable site, favored by the JIP, is in the Atwater Valley Block 14, where the HSZ is estimated to be 400m thick. If that is confirmed, the array will be constructed approximately 400m in length.

A meeting is scheduled in July, 2003, with Fugro McCelland Marine Geosciences, Houston, TX, and representatives of the JIP and Consortium to determine the final BVLA design and an appropriate procedure for emplacing it to ensure adequate coupling of the accelerometers to the side-wall for s-wave acquisition, etc.

P. I. for the BVLA project is Bob Hardage, Texas Bureau of Economic Geology at the University of Texas in Austin. Fabrication of the array and associated data-logger will be done by Specialty Devices, Plano, TX. Overall support for the project will be from the DOE/NETL.

The horizontal array on the sea floor is essentially a horizontal version of the BVLA. It would be buried beneath the surficial hemipelagic ooze in order to couple directly to the more dense sediments. Although the horizontal line array (HLA) is still in the conceptual stage, the recognition of the complementary value of a compatible horizontal array to the BVLA is well established. It is expected to greatly enhance resolution and facilitate interpretation of features and phenomenon within the HSZ.

P.I. for the HLA project, which is essentially a complementary phase of the BVLA, will also be Bob Hardage. The project will be introduced as a part of the second year of the up-coming DOE/NETL request for funding.

MARINE ELECTROMAGNETIC PROFILER

Hydrates exhibit higher electrical resistance than sea water or marine sediments and therefore are good targets for electrical profiling methods. A marine electromagnetic profiler (MEM) developed by the Geological Survey of Canada (GSC) in the 1990s was found to be very successful at locating marine gravels, which are resistive targets, so it became one of the first systems to be considered for locating hydrates in the Gulf of Mexico.

Unfortunately, the prototype (analogue) MEM was lost at sea in 1999 and the GSC did not replace it. Rather, they opted to redesign it as a digital system but then ran short of funds to build a digital prototype. The Woods Hole Oceanographic Institution (WHOI) obtained a license to the technology and has constructed a digital prototype.

The P.I. for the MEM system is Rob Evans of WHOI. Using funds provided by NOAA, he will participate in an NRL/DOE cruise in the Gulf of Mexico during August, 2003. A number of MEM reconnaissance profiles will be run in areas of interest to the JIP drilling project. These data will be indicative of the usefulness of the MEM in the context gas hydrates.

OPTICAL SPECTROMETERS FOR *IN SITU* GEOCHEMICAL ANALYSIS

Work has been done on two types of optical spectrometer for the purpose of providing a means to carry out geochemical analyses *in situ*. These are a Raman spectrometer and a mid-infra-red (mid-IR) spectrometer.

The P.I. for the Raman system is Jean Whelan of WHOI. A Raman prototype, funded by MMS, was built and tested in 2001 but found to be of insufficient sensitivity. Using DOE funding, it was redesigned in 2002 as a hybrid Raman/METS system. NOAA funds are being used to construct the hybrid system during the summer of 2003. It is expected to be tested by Prof. Michael Whiticar of the University of Victoria, B.C., during the autumn of 2003

The P.I. for the mid-IR system is Boris Mizaikoff of the Georgia Institute of Technology. The first year of that development was funded by MMS. The second year was funded by DOE. It is currently entering its third year and is about one-third to one-half completed.

MULTIPURPOSE TOWED SLED (MTS)

In order for the all-important accelerometer component of the sea-floor probe (SFP) and HLA systems to couple with proximal, s-wave permissive sedimentary materials, an appropriate deployment system must be employed. A prototype MTS was designed for this purpose in FY 2000 with support from the DOI-MMS. The following year the system was further developed to incorporate a detachable, recoverable instrument section, i.e. data-logger, modem, battery, etc. and an s-wave energy generator/source modeled after the Angela Davis design (University of Wales- Bangor).

The system was tested in the summer of 2002 and found basically sound. With the advent of the JIP/VSP Project, the need for a horizontal array component as previously described was evident. To accommodate the requirement of laying the array in-couple with s-wave permissive sediments, approximately three-quarters to one meter, a simple adaptation has been designed. The array cable stored on a free spooling reel passes under a pivoted idler wheel, two meters in diameter, and is depressed through the surficial ooze to couple with the more dense underlying sediments as the sled is towed away from its detached, instrument package.

On spool-out of the array cable the s-wave energy source is activated. P- and s-wave energy transmitted from the sled serves both the VSP and HLA systems. In addition to use with the VSP and HLA systems, the MTS may also be used to deploy horizontal arrays between components of the vertical line array network at some future date to further enhance resolution if required.

P.I. and designer for the project is Bob Woolsey, University of Mississippi. Further testing of the MTS is scheduled for October 2003.

ACOUSTIC DOPPLER CURRENT PROFILER (ADCP)

The acoustic Doppler current profiler is a NORTEK AQUADOPP system and has been used to study the effects of thermal loading from the water column on the stability of surficial outcrops of gas hydrate. Impacts of Loop Current intrusions and eddies on the upper continental slope of the northern Gulf of Mexico have been of particular interest. At the experimental site, Green Canyon Block 185, a short current meter mooring with two Aanderaa current meters and two self-recording thermistors was placed to monitor current speed and direction over the top of the mound and the thermistors recorded temperature changes at 10m and 2m above the seafloor. At the gas hydrate exposure site, the ADCP was mounted on a specially built stand with thermistors on the leg 10cm above the Sea floor. A gas collector cone was mounted on top of the stand. A calibrated rotor in the throat of the cone estimated the gas flux while the ADCP mounted on the stand below the cone measured movement below the cone (bubbles). Results were obtained by the ADCP showing a highly coherent signal with temperature elevation in the water column associated with the passage of a weak warm core Loop eddy. Results are still being analyzed, but there is no question that gas flux over exposed gas hydrate increases with increasing water temperature, even though the composition of surficial gas hydrate suggests it should be stable. This result suggests that gas hydrates are multicompositional and that surface exposures are composed of the most stable phases while unstable compsitions disssociate with temperature loading.

P.I. for current profiling and geologic setting for the observatory is Dr. Harry Roberts, Coastal Studies Institute, Louisiana State University.

MEASURING DEEP GAS-HYDRATE BUBBLES BY ACOUSTIC METHODS

Acoustic concepts for measuring the bubble volume density and size distribution of gas hydrates in the water column near the sediment interface are based on the principle that bubbles, even in very small amounts, cause significant changes in sound speed, attenuation, and scattering and that the sound emitted from oscillating bubbles is a measurable quantity. Both sound speed and attenuation are very sensitive to the size, density, and distribution of bubbles. The measurement of the rate of upward flow and the bubble-size distribution give important information on the evolution of gas hydrates. The application of acoustics to measure these quantities has good possibilities since bubbles and bubble clouds can cause significant changes in sound speed, attenuation, scattering and noise.

Hydrates, in their gaseous phase as bubbles in the sea, will produce significant changes in the acoustic properties of the seawater. The measurement of the changes in these acoustic properties could be used to determine the physical properties of the bubble field. The effects of gases on seawater are well known, but have not been applied to this problem. Gas hydrates monitoring station research has addressed four acoustics effects: sound speed, attenuation, scattering, and radiated noise. It is concluded that all four have possibilities, but that their efficacy will depend critically on: (1) the local ambient noise,

(2) estimates of the bubble size distribution and extent in both space and time of the bubble fields of interest, and (3) how the bubbles are created.

Measuring effects of propagation through a gas-hydrate bubble field would allow measurements such as sound speed and attenuation. This would also allow for tomographic reconstructions of the bubble field. For the measurement of noise, hydrophones of a relatively high sensitivity would be required, depending on a presently unknown level of noise generation at the creation of the bubbles.

P.I.s Ralph R. Goodman and Jerald W. Caruthers, Department of Marine Science, The University of Southern Mississippi have conducted initial research for this component of the monitoring station development. They have designed a device to measure these parameters but have not yet constructed it. It is anticipated that construction will begin in the near future as DOE funding for the current fiscal year has been acquired in recent weeks.

PORE WATER SAMPLERS

An understanding of the geochemistry of gas hydrates and associated pore fluids is critical to the understanding of where and how these deposits occur as well as to conditions influencing their formation and dissociation. However, a persistent and critical obstacle to successful sampling of these compounds from the sea floor has been maintenance of the extreme pressures under which gas hydrates exist in nature.

Two probes have been designed specifically in support of the GOM-HRC effort. Both probes seal the sample, maintaining sea floor pressures, hence, allowing for more precise geochemical analyses, especially of the minor accessory fluids. The pore water sampler provides measurements over microintervals (within approximately 1m) at a moment in time, whereas the osmosampler collects a continuous sample over extended periods of weeks, months or years.

Successful testing of both probes was achieved in August of 2002, onboard the Johnson Sea Link, on which occasion the pressurized sampling of pore fluids from surfical sediments of the HSZ was successfully achieved. Analysis of these samples indicated the presence of hydrocarbon fluids in greater concentrations than had been previously documented. Both samplers are scheduled for further testing in a variety of seabed environments within the HSZ during August, 2003.

The goal is to combine this technology with optical spectroscopy (currently being researched and developed under the supervision of Dr. Jean Whelan of WHOI) to sample and analyze pore fluids from various sites and sections of interest, more-or-less continuously over extended periods of time. It is anticipated that these sampling devices will be operational in the observatory and could be modified for deployment on an AUV/ROV platform serving both in a reconnaissance mode and as a means of extending the geographic range of the observatory.

P.I.s for the pore water samplers are Dr. Chris Martens, the University of North Carolina at Chapel Hill and Dr. Jeff Chanton, Florida State University, Tallahassee. The work has been funded by DOE and has supported the work of a Ph.D graduate student, Laura Lapham.