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NEW DISCOVERIES AT WOOLSEY MOUND, MC118, NORTHERN GULF OF MEXICO

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ABSTRACT

Woolsey Mound, a 1km-diameter carbonate-gas hydrate complex in the northern Gulf of Mexico, is the site of the Gulf's only seafloor monitoring station-observatory in its only research reserve, Mississippi Canyon 118. Active venting, outcropping hydrate, and a thriving chemosynthetic community recommend the site for study. Since 2005, the Gulf of Mexico Hydrates Research Consortium has been conducting multi-disciplinary studies to 1. Characterize the site, 2. Establish a facility for real-time monitoring-observing of gas hydrates in a natural setting, 3. Study the effects of gas hydrates on seafloor stability, 4. Establish fluid migration routes and estimates of fluid-flux at the site, 5. Establish the interrelationships between the organisms at the vent site and the association-dissociation of hydrates.

A variety of novel geological, geophysical, geochemical and biological studies has been designed and conducted, some in survey mode, others in monitoring mode. Geophysical studies involving merging multiple seismic data acquisition systems accompanied by the application of custom processing techniques verify communication of surface features with deep structures. Supporting geological data derive from innovative recovery techniques. Geochemical sensors, used experimentally in survey mode, including aboard an AUV, double as monitoring devices. A suite of pore-fluid sampling devices has returned data that capture change at the site in daily increments; using only noise as an energy source, hydrophones have returned daily fluctuations in physical properties. Ever-expanding capabilities of a custom-ROV have been determined by research needs. Processing of new as well as conventional data via unconventional means has resulted in the discovery of new features…..vents, faults, benthic fauna…..and modification of others including pockmarks, hydrate outcrops, vent activity, and water-column chemical plumes.

Though real-time monitoring awaits communications and power link to land, periodic data-collection reveals a carbonate-hydrate mound, part of an immensely complex hydrocarbon system.

Keywords: gas hydrates, plumbing system, Gulf of Mexico, multiple seismic resolution, observatory, seafloor sensors, hydrate stability, seafloor stability

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INTRODUCTION

Woolsey Mound is a carbonate-hydrates structure in the south-central portion of Mississippi Canyon Federal Lease Block 118 (MC118), Figure 1. The "mound" actually comprises bathymetric highs as well as lows within the 1-kilometer diameter of its seafloor expression (Fig 2), including three crater complexes, mini-basins, ridges, scarps and plains. The mound stands in stark contrast to the bulk of the remainder of the block whose only other morphological feature, located in the extreme northeastern corner, is a canyon that marks the faulted border of a prominent slump block.

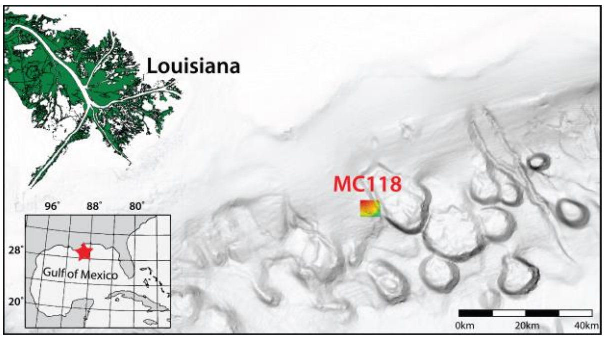

Figure 1. Location of MC118, continental slope, northern Gulf of Mexico.

In 2004, MC118 was chosen by consensus of the Hydrates Research Consortium as the location in the northern Gulf of Mexico (GOM) likeliest to satisfy all their research needs. The Consortium was founded by Gulf hydrates researchers to promote research cooperation and streamline research efforts. Its primary objective is the founding of a field research site or observatory where hydrates can be studied in their natural environment. Site criteria included outcropping hydrate, active venting, less than 1000m water depth (for instrument capabilities), thriving chemosynthetic communities, and an open lease. The choice of MC118 was followed by the immediate application by the Consortium for research reserve status through the Department of the Interior's Bureau of Ocean Management, Regulation, and Enforcement (BOEMRE, formerly Minerals Management Service, MMS). With the GOM's only Research Reserve, the Consortium members were ready to move laboratory research to the field.

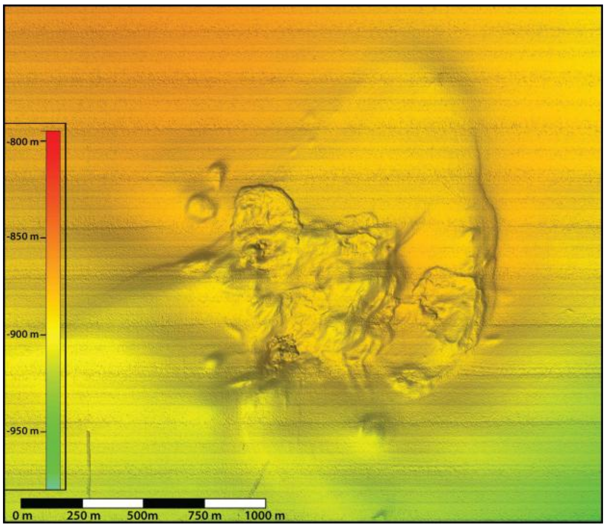

Figure 2. Bathymetry at Woolsey Mound.

GOALS

Consortium members represent diverse areas of expertise. They collaborate to achieve major goals to advance the understanding of gas hydrates. Drivers of the group include:

- characterizing the subsurface, seafloor and deep water-column at Woolsey Mound,
- capturing the element of time in hydrates association and dissociation by monitoring changes within the Hydrate stability zone (HSZ),
- capturing the effects of gas hydrates' formation and dissociation on seafloor stability,
- determining the factors influencing subsurface fluid flow and their relevance to stabilization/destabilization of gas hydrates,
- establishing the interrelationships between the organisms at the vent site and the association-dissociation of hydrates.

APPROACHES

Approaches of the Consortium have been designed to characterize the site in order to define the system baseline upon which to base monitoring activity and develop and test technologies and methodologies which will overcome these difficulties. Geological, geophysical, geochemical and biological sensors and experiments have been designed and tested. Laboratory and field experiments have led to final deployment of some systems at the Observatory site (Fig 3). A summary of rationale and major observatory components follows:

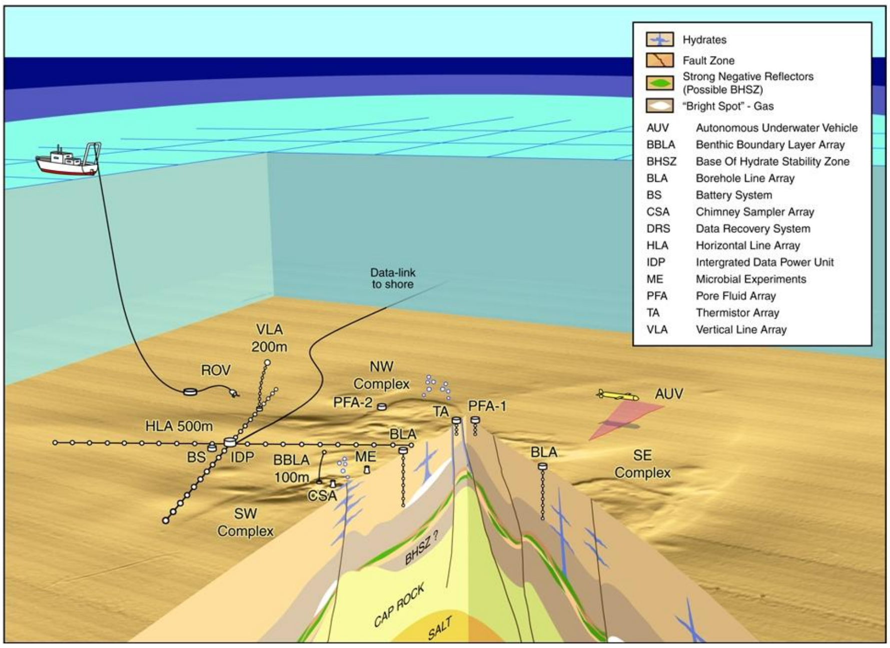

Figure 3. Major components of the Seafloor Observatory at MC118.

Geophysical –
Rationale: Determine lateral and vertical extent of hydrate deposits, the HSZ, changes in the HSZ, volume actually occupied by hydrate; determine deep structure, faulting, potential fluid migration pathways to/through the HSZ (how are gas molecules delivered to the HSZ?), and source and migration of fluids from depth. We are exploring prospects of defining a unique geophysical signature that will facilitate remote mapping of gas hydrates.
Geophysical Systems used:
Multibeam - seafloor features, bathymetry, backscatter;
side-scan sonar - seafloor features, extracted backscatter identifies hardgrounds;
electron magnetic method – infers hydrates distribution within the sediments;
chirp - very high resolution seismic data - provides detail of ~80m subseafloor;
surface-source deep-receiver (SSDR) - high resolution seismic data images the ~400-600m subseafloor HSZ and bridges the "gap" between oil industry seismic and chirp data,
oil industry high penetration seismic data – images deep and regional structures, including salt, major faults, etc.;
temperature – directly impacts presence/absence of hydrates;
vertical and horizontal line arrays (VLA, HLA) – developed to provide continuous data from the HSZ using ambient noise as an energy source.

Geological –
Rationale: Use cores to groundtruth geophysics by extracting sediment types (host materials), lateral and vertical extent of sediment types, structure within the shallow HSZ and sedimentation history; determine biostratigraphy and lithostratigraphy.
Geological Systems used: cores (gravity, piston, box, push) – By combining techniques, greater coverage and depth are achieved. An Ultra-Short Baseline (USBL) system is used for locating samples precisely.

Geochemical –
Rationale: Salinity, gas content (CH_4, O_2, CO_2), temperature, pH, and microbial activity all impact hydrate formation and stability. Our goal is to determine if conditions are right for hydrates to form, for microbial communities to become established and for benthic fauna to thrive.
Geochemical sensors/approaches used:
Pore-Fluid Arrays (PFA) – collect discreet, time series samples for measurements of methane, sulfate and salinity in pore waters to evaluate microbial activity, hydrate formation and/or hydrate dissociation;
Chimney Sampler Array (CSA) – collects a time series of in situ chemical and physical measurements on the sea floor; provides a direct measure of chemical gradients and flux at the sea floor by measuring methane, oxygen, carbon dioxide, pH, salinity, temperature, density and currents in a known volume;
Benthic Boundary Layer Array (BBLA) – Time series of chemical and physical measurements in the benthic zone and overlying water column; vertical separation of the nodes (approximately 20 meters) provides space and time data series to indicate rates and directions of advection; provides a direct measure of potential oceanographic forcing factors on hydrate stability; includes near-IR

methane sensor, CDOM, hydrocarbon fluorometers, Chyl-a fluorometers, CTD, O_2 and ORP/pH sensors;

water-column - CTD, Niskin bottles;

cores - pore-fluids extracted for chemical analyses;

mass spectrometer - capable of direct measurement of methane to estimate hydrate stability; functions in stationary or survey mode.

Biological –

Rationale: Seafloor organisms/communities survive where vents are or have been, as well as where gases are trapped in sediments. We want to explore relationships between microbial organisms and hydrate formation.

Biological Systems used:

Still/video cameras – on the seafloor, or mounted on an ROV or manned-submersible, cameras document what organisms thrive, where, and under what conditions; they are used to document change over time;

Cores – small intact organisms as well as remains of dead organisms can be recovered;

Water –samples are often recovered using rosettes and a programmable high throughput filter. Microbial communities can be documented from various levels in the water-column.

RESULTS

Autonomous Underwater Vehicle (AUV) multibeam, chirp sonar and side-scan surveys of the entire block have been performed. Reprocessed multibeam data produce the image that appears as Figure 2 and which serves as the background bathymetry onto which we plot or overlay all additional seafloor data.

The chirp sonar reveals numerous faults and fractures not visible on lower resolution data. SSDR data image subsurface structures as deep as 450-600m and in many cases illustrate the continuation of pathways from depth to the seafloor that are not visible on industry data alone. The industry data, however, image structures at depths great enough to reveal communication to the seafloor from regions of thermogenic hydrocarbons (Fig 4). Backscatter data reveal the hardgrounds over the mound (Fig 5). Lateral and vertical extent of litho- and bio-stratigraphic units plotted as a series of isopach maps reveal thickening of these units away from the mound.

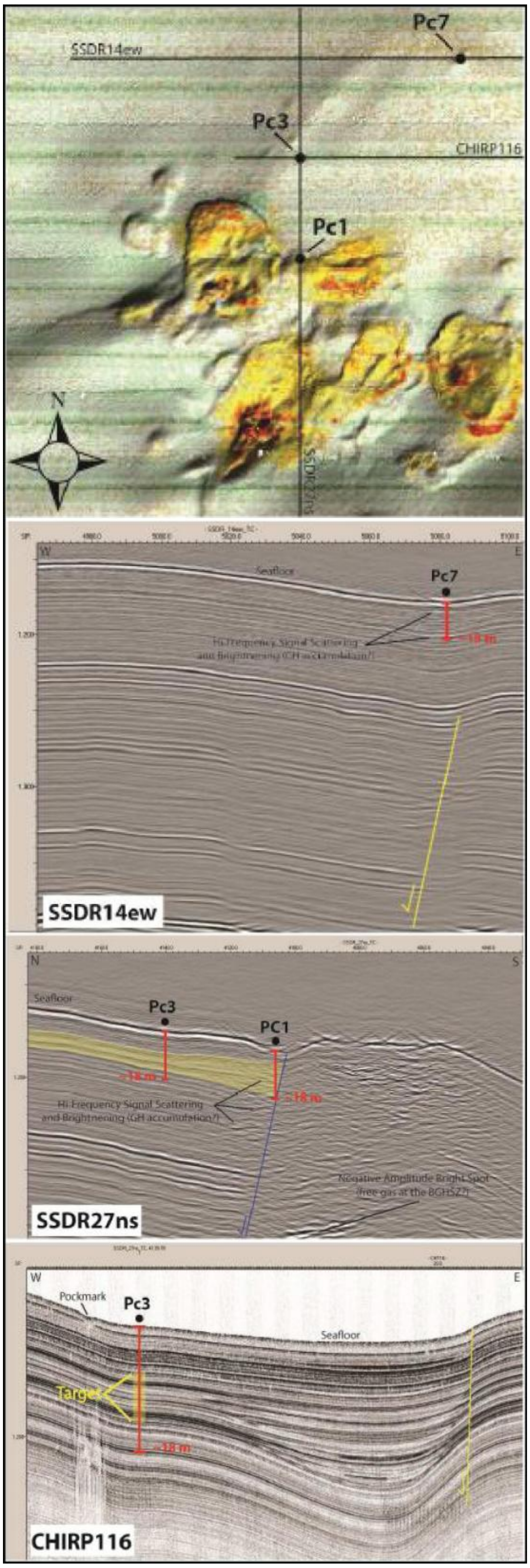

Figure 4. Criteria used to select core sites includes identifying surface features on seismic data profiles: top to bottom; bathymetry and transect location; SSDR east-west transect; SSDR north-south transect; close-up CHIRP transect.

The PFA collects pore-fluid samples analyzed for salinity and concentrations of sulfate and methane. Since hydrates exclude salt from their structure, elevated salinities accompany hydrate formation while hydrate dissociation will decrease salinity with the influx of fresh water. Since sulfate reduction is directly related to microbial activity, changes in the depth to the base of sulfate reduction indicate changes in the amount of microbial activity at the site. Formation and stability of gas hydrate is directly related to methane concentrations in pore waters so this measure is an indicator of hydrate stability.

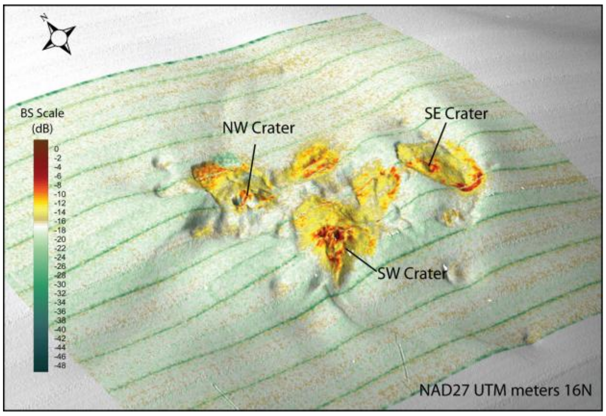

Figure 5. Backscatter data overlapped on multibeam 3D bathymetry of Woolsey Mound.

The CSA collects time-series data of in situ chemical and physical measurements on the sea floor, inside a cylinder of known wash-out rate, giving an approximation of flux of various compounds from the seafloor to the water-column. The two nodes of the BBLA are designed to determine fate of fluids expelled from the subseafloor into the water-column and to determine chemical gradient direction. Additional geochemical information has been recovered periodically using survey instruments: landers, AUV-borne mass spectrometer, CTD rosette.

Bacterial mats have been observed in all three vent complexes and in the seafloor between. Microbial studies have been performed from the shallow subseafloor sediments through the benthic boundary layer and into the water-column. Benthic faunal assemblages have been evaluated through still and video imaging. A composite biological assemblage image appears as Figure 6.

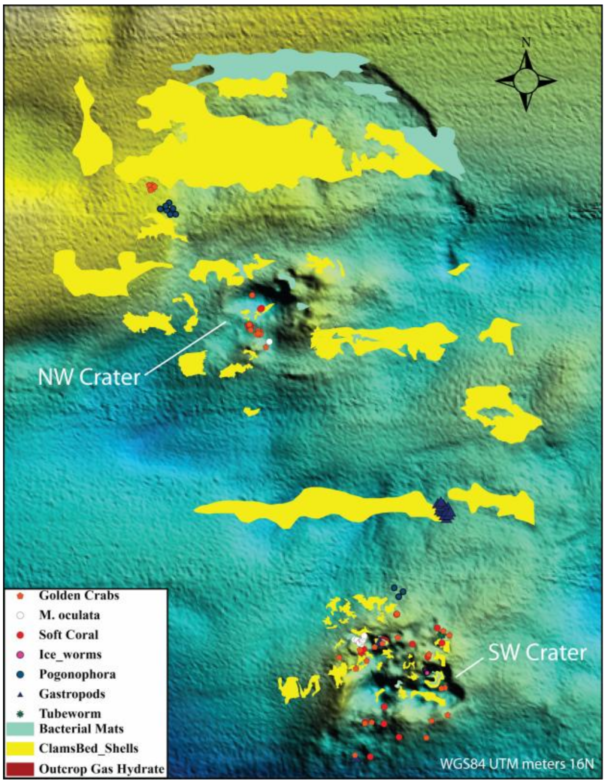

Figure 6. Biological assemblages identified, to date, at Woolsey Mound.

DISCUSSION

The complex geology of the Gulf of Mexico is attributable to high sedimentation rates in a highly dynamic salt tectonic province. This scenario has created a unique setting for gas hydrate formation/dissociation. Where water depths are greater than ~500m, the zone of hydrate stability consists of the several hundred meters of sediments immediately below the seafloor. These areas do not show a clear presence of BSRs (bottom simulating reflectors), are usually highly segmented, laterally, being intersected by a wide variety of vertical anomalies such gas expulsion conduits, faults, fractures, and gas chimneys. Imaging this setting using conventional geophysical methods is challenging; this challenge is met by employing multiple methods of analysis.

We have developed good seismic imagery of the site by integrating multiple resolution seismic datasets: high quality oil industry 3D data, a shallow-source deep-receiver (SSDR) custom system, and an AUV-borne chirp subbottom profiler. Integrating these three different resolution systems allows seismic coverage from depth to the seafloor and maximizes detail within the HSZ. While the HSZ is the area of greatest interest, this method links it with deeper structures - not within range of high resolution data - that impact it structurally and chemically by supplying fluids to the fault and fracture systems. Details of the integration are reported in this volume [1], and include development of custom processing [2], that identifies like features on different datasets and merging results.

These composite seismic studies have shown that Woolsey Mound is the product of recent salt diapiric movements [3]; this movement originates normal crestal faults that serve as primary pathways for deep, thermogenic fluids to enter the hydrate stability field (Fig 7). Pore-fluid, vent gas, hydrate and core data all produce evidence that the hydrocarbons at MC118 are thermogenically-sourced (Table 1).

Table I. Reports of thermogenic hydrocarbons at MC118.

$\delta^{13}C$ of CH_4	Samples	Location	Reference
-46 to -47‰	Vent Gas	Woolsey Mound, MC-118	Sassen, 2006
-53.8 ± 1.3‰ (n=5)	600m below sea level	Woolsey Mound, MC-118	June 2010 Pelican Cruise
-57.4 ± 0.5 ‰ (n= 27)	Deep water plumes	10 to 20 miles SW of DWH incident site	May 2010 Walton Smith Cruise Courtesy of Mandy Joye

Thermogenic fluids provide the hydrocarbon gases that are subsequently encaged in lattices of frozen water molecules to form hydrates. Hydrate formation appears to occur in proximity to the major faults, although the fine-grained recent quaternary sediments complicate the structural scenario. While deep sand deposits break along the fault planes, the muds contain an intricate network of small- offset faults and fractures that integrates the plumbing system, and shallow hydrates seem to access these mechanical boundaries. Geological

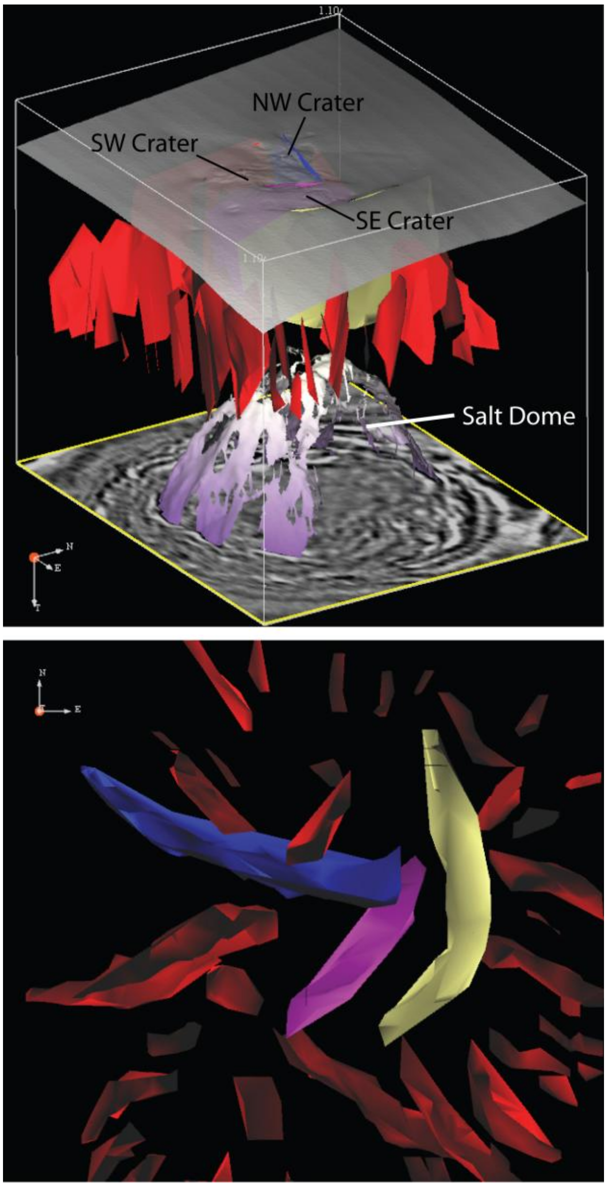

Figure 7. Composite high and low resolution seismic data: Upper figure presents an oblique view of major structural features identified under Woolsey Mound; Lower figure is the plan view of the fault system at Woolsey Mound. Red radiating faults are only seen on high resolution data while the major crestal faults - blue, pink, yellow - can only be seen on the industry data.

cores have sampled solid hydrates along the faults, and have shown that hydrates fill associated fractures and microfractures. Resistivity studies [4], corroborate this evidence while laboratory experiments in hydrates synthesis [5], [6] have demonstrated the powerful catalyzing effect of certain clay minerals in hydrate nucleation. So while the primary force driving the structural framework at Woolsey Mound is the underlying salt diapir with associated major faults, the shallow, fine-grained sediments of the HSZ provide conduits and fracture porosity primarily through apparent successive generations of faulting. This is the system that intersects the seafloor and impacts its stability. Although sediment sampling is far from comprehensive, it supports an HSZ greatly undersaturated with respect to hydrates and, therefore, profoundly variable seafloor stability.

Core and water-column data [7], [8], reveal that the waters surrounding hydrate deposits are undersaturated with respect to methane. In spite of the latter observation, hydrate outcrops, observed on many ROV dives, persist in the area. Microbial activity, determined by depth (below seafloor) to sulfate reduction, is at least influenced by proximity to faults. Mass spectrometer data from an AUV survey identified a new vent and spikes in PFA time-series methane concentrations can be correlated to seismic events in the northern Gulf.

The three geochemical arrays provide a powerful monitoring capability when used in concert to evaluate a release of methane by the dissociation of gas hydrates. The PFA identifies the breakdown of gas hydrates in the subsurface, the Chimney Array determines the rate of flux at the seafloor and the Benthic Boundary Layer Array evaluates the fate of the release in the water column. Combining the data from the geochemical and geophysical arrays provides key information to evaluate tectonic and oceanographic triggers for hydrate dissociation and seafloor stability.

Hardgrounds, sites of likely biological activity as well as sites from which sediment sampling is not likely to be successful, are revealed in the backscatter imagery (Fig 5). Multibeam data over the hardgrounds reveal three crater complexes, each overlying a major crestal fault, as shown in the subbottom data (Upper Fig 7). Photo data show seep communities associated with these complexes (Fig 8); expanses of relatively barren seafloor are found in-between the crater complexes. These data illustrate that the seep communities associated with the crater complexes derive their sustenance from fluids that arrive at the seafloor at Woolsey Mound via fault-derived fluid migration pathways. Additionally, remains of dead organisms litter discrete portions of the seafloor, evidence that vents that once supported thriving communities are no longer active. We hypothesize that here, where the seafloor resides within the HSZ, hydrates periodically form within the fluid conduits, stopping the flow of fluids to the seep-dependent communities causing them to expire. It follows that altered biological and/or chemical activity at the seafloor and in the shallow subseafloor environment reflect changes in the geological/geophysical environment - temperature, salinity, pressure, fluid flow - and therefore translate to altered subsurface plumbing and, potentially, stability of the seafloor.

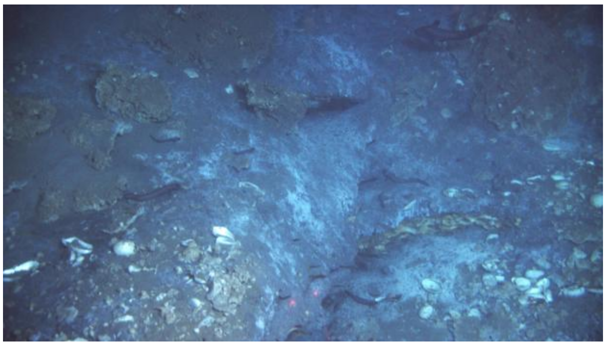

Figure 8. A seep community on Woolsey Mound.

Several stages of sediment sampling on and around the mound have been effected with benefit of seismic data profiles. Multiple gravity and piston-coring efforts, together with ROV-push-cores have recovered sediments comprised almost entirely of fine-grained materials, the 1-10% sand fraction found in some areas composed entirely of foraminiferal tests. Analysis of isopachs based on bio- and litho-stratigraphy reveals great variation in thickness of correlative units across and around the mound; isopach units near the vents are thin while those distant from the vents and off the mound are as much 10-20 times thicker [9], [10]. This scenario suggests that the vents are expelling sediments from their immediate vicinity or that the mound is elevating or building – and therefore eroding - at a rate nearly equal to the sedimentation rate. Either case supports a geologically dynamic system and fits with the finding of a plethora of small faults radiating from the mound (Fig 7), as supported by the high resolution seismic data.

The importance of microbes in the hydrate cycle has been demonstrated in laboratory work. Rogers has shown that microbially-produced surfactants promote the formation of hydrates and that their cell walls produce inhibitors to hydrate formation [11]. Numerous microbial/bacterial colonies have been photographed and/or videoed at Woolsey Mound. Samples have been recovered and analyzed showing a wide range of population types in the sediments as well as in the water-column. Since microorganisms create calcium carbonate as a product of their metabolism, they provide hardground at vent sites, the necessary foundation for many higher organisms.

While microbial mats are widely observed at Woolsey Mound, chemosynthetic communities and deep-water coral communities are also present. Benthic faunal studies at MC118 have begun only recently but reveal a variety of habitats both chemosynthetic and biocenosis (Figs 9, 10).

Figure 9. A chemosynthetic community at MC118.

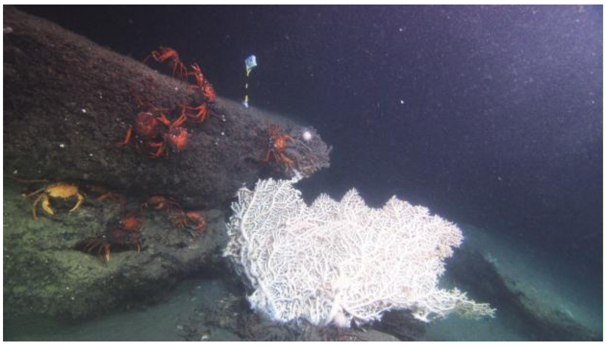

Figure 10. Part of a diverse community, the deep-water coral, *Madrepora oculata*, thrives at MC118.

Documentation of faunal diversity at the site continues with each visit (via ROV) to the seafloor. Relative ages of communities, inferred from their composition, can be extended to the seeps that support them.

Serendipitously, a series of 2010 cruises to MC118 corresponded to hydrocarbon spill and burning activities at the Macondo site, MC252. With a suite of sensors already developed for geochemical analyses at Woolsey Mound - an in-situ mass spectrometer, infrared methane detector, CDOM fluorometer and a CTD - we were able to identify and "track" methane plumes at our site 10 miles from the spill. Figures 11 and 12 illustrate the methane spikes in the water column in June 2010;

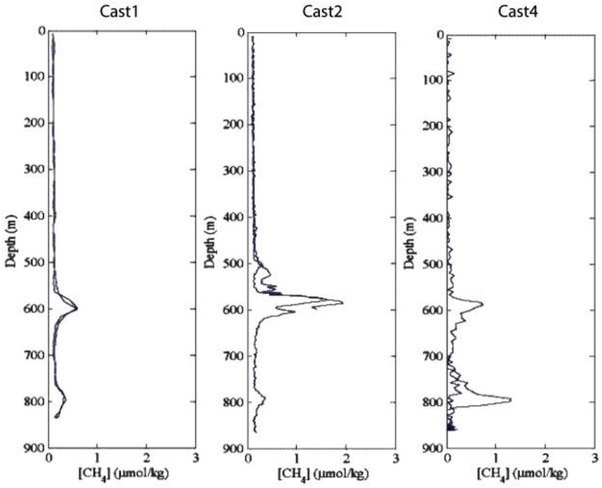

Figure 11. Mass spectrometer data collected during three casts over MC118. Note methane spikes at ~600m and ~800m water depth.

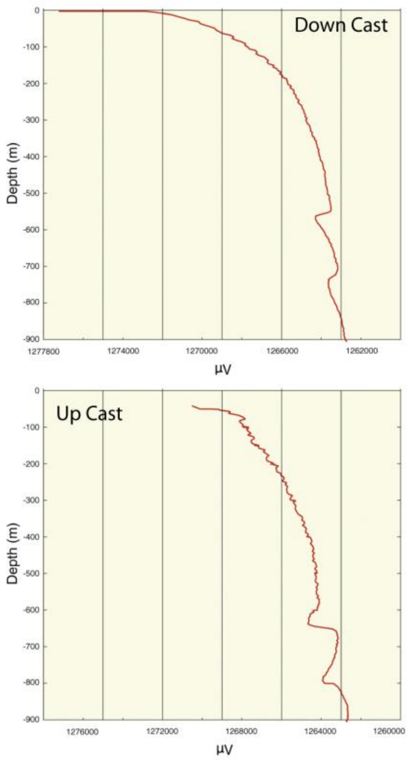

Figure 12. Data from a near infrared sensor deployed at MC118, June 2010. Note spikes at ~600m and ~800m water depth.

Figure 13 illustrates gas chromotography (laboratory) confirmation. Methods of site characterization of benthic fauna are being used to document changes at MC118 that may derive from chemical impact of the spill.

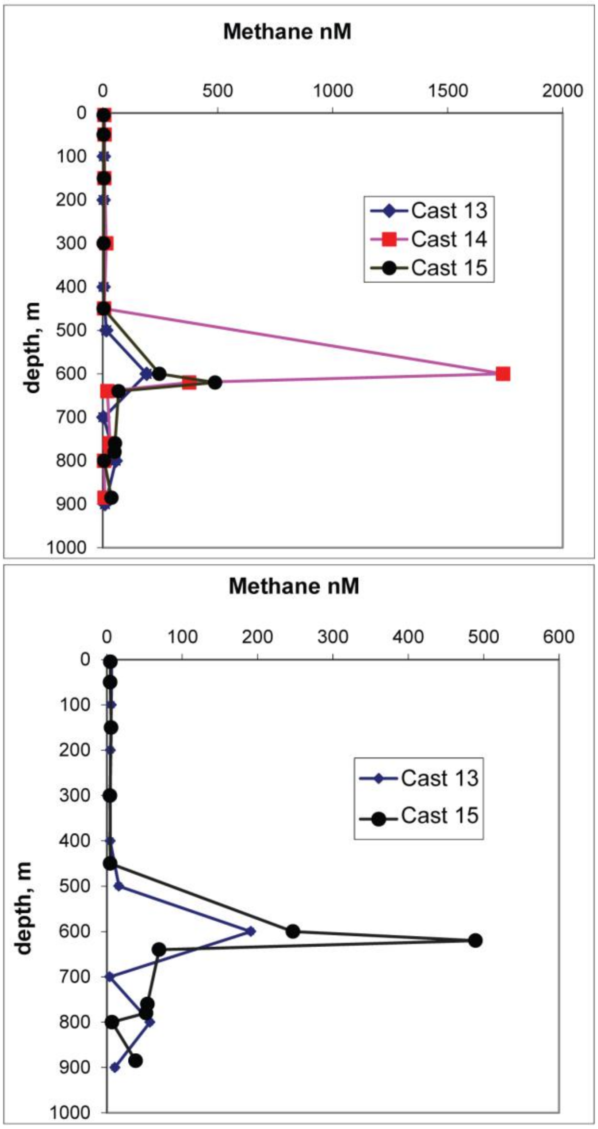

Figure 13. Water samples were collected from the sites of the mass spectrometer casts and gas chromatographs produced. Note the evidence for a pronounced methane plume at ~600m and a lesser one at ~800m.

Investigations at Woolsey Mound are effected through the employment of unique deployment/recovery techniques that include both survey and permanently configured devices (Fig14). In many cases, sensors and sensor arrays are deployed for several months, to be recovered acoustically or via the Station Service Device, Remotely Operated Vehicle (Fig 15). This vehicle's efficiency is improved by means of a deployment technique that isolates it from the movement of the vessel, enabling it to survey in moderate seas and from a non-dynamically positioned vessel. All seafloor activities are documented with USBL-assisted HyPack navigation with <10meter accuracy assuring the ability to return to individual sites with relative ease.

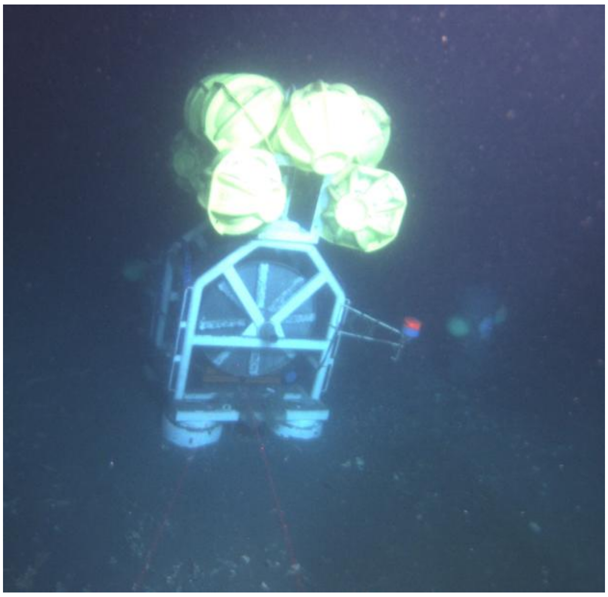

Figure 14. The ROVARD deployment platform, with instruments attached; central spool with cable will facilitate recovery (SSD-placed chimney is back and right).

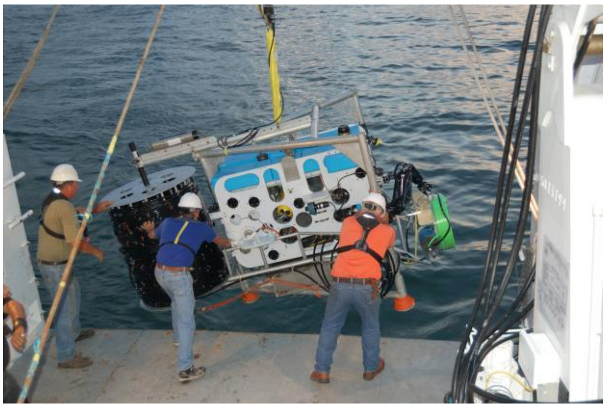

Figure 15. The Station Service Device ROV being deployed with cable and data-logger for seafloor data-recovery.

FUTURE INVESTIGATIONS

Additional geophysical investigations are being carried out. A 4C Ocean Bottom Seismometer (OBS) experiment has been conducted along one of the main faults where hydrates have been sampled at a pronounced resistivity anomaly. It is hoped that this high resolution effort will reveal the shear characteristics of the HSZ, including hydrate saturation. Benefits of seismic multicomponent survey for hydrates assessment have been illustrated by [12] and [13], and include implications for seafloor stability/instability related to hydrate and host materials. A heat-flow study aims to provide evidence of fluid migration along the fault planes by measuring geothermal gradients across major faults.

A configuration of hydrophone arrays to be deployed in the near-future will record changes in the HSZ by using ambient noise – wave noise, boat noise, drilling/platform activities - as an energy source. This approach will provide a geophysical component of true monitoring if power and communications are provided to the station via a link to land or a production platform. An optic modem for high speed data transfer from a seafloor array to an elevator, ROV or AUV is being developed in the interim.

A polarity-preserving chirp survey integrated with a sound velocity probe core survey will be performed in an attempt to discriminate hydrates from gas, determine geotechnical properties of the shallow sediment, and evaluate mechanisms of hydrate accumulation in fine-grained sediment. The 100% coverage AUV-photo-mosaic will enable us to observe details of surface expressions of faults and correlate them with seafloor features and phenomena including vents, outcropping hydrates, and faunal community distribution.

Future coring efforts are designed to constrain regional sedimentological history, describe specific sedimentological histories of the minibasins, and date activity of the faults with seafloor expression. Additional coring efforts are designed to constrain movement on faults over the mound, document presence/absence of hydrate in faulted zones suspected of being extinct fluid conduits, confirm/refute the hypothesis that high-frequency scatter in the SSDR data represents hydrated material, and test additional resistivity anomalies as indicators of the presence of hydrate.

Recently, the suitability of the site for additional research endeavors has begun to be explored. Functioning as a permanent facility in the Gulf's only research reserve, the Observatory has already proven a strategic asset during the Deep Water Horizon disaster, providing geochemical and additional oceanographic data prior, during, and following the spill. With geophysical sensors, the site can be adapted to monitoring natural seismic activity as well as marine mammal activities. It has recently been designated as a permanent site on BOEMRE's Lophelia II inventory due to the presence and abundance of deep sea coral communities in the vicinities of the western crater complexes.

CONCLUSIONS

Woolsey Mound is comprised of carbonate-hydrate hardground surrounded and covered by very fine-grained materials that host gas hydrates. Through the integration of multiple geophysical systems, a continuous structural scenario emerges for Woolsey Mound. The mound overlies a deep salt structure from which crestal faults emanate. Together with secondary and tertiary faulting, these provide likely fluid migration pathways through the HSZ to the seafloor. Micro and macrofauna occupy the seafloor in and near active seafloor vents, their presence revealing areas of likely methane and sulfate release. Remains of organisms litter areas suggesting that fluids vented to the seafloor in the past but that active venting has ceased. Geochemical and biological data support the possibility of migration of vents over time. Major faults underlie each of the three very different crater complexes. The NW complex appears to be intermediate in activity and communities between the very active SW complex and the apparently extinct SE complex [14].

Events of 2010 show that the chemical sensors at Woolsey Mound are capable of detecting chemical changes in the water column and probably in the sediments over short periods of time. Time series data, when they are recovered, are expected to provide some constraint on the timing of such events when researchers are not in the area to collect "live" data.

Resistivity data, combined with high resolution shallow seismic data provide hydrate targets, verifiable with a careful coring plan and execution.

Combinations of geological sedimentation history, shallow seismic fault movements, and diverse and dynamic benthic faunal communities combine to illustrate a complex system revealing new characteristics with each visit.

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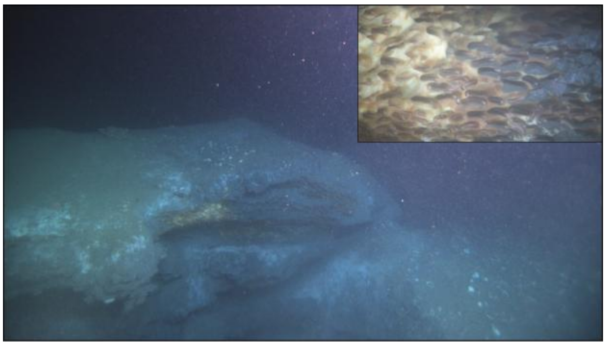

Figure 16. The "Sleeping Dragon" at MC118 is the largest documented outcropping hydrate in the GOM. The insert shows ice worms that inhabit the hydrate.

REFERENCES

[1] Simonetti Antonello, James H. Knapp, Camelia C. Knapp, Leonardo Macelloni and Carol B. Lutken, 2011, *Defining the hydrocarbon plumbing system and the possible accumulation model for marine gas hydrates in a salt tectonic driven cold seep: examples from Woolsey Mound, MC118, northern Gulf of Mexico*. Proceedings of the 7th International Conference on Gas Hydrates (ICGH 2011), Edinburgh, Scotland, United Kingdom, July 17-21.

[2] Battista, Bradley M., 2008, *Advanced Nonlinear Signal Processing Tools for use with High-Resolution Seismic Reflection and Ground-Penetrating Radar Data*, PhD Thesis, University of South Carolina.

[3] Knapp, James H., Camelia C. Knapp, Leonardo Macelloni, Antonello Simonetti, Carol Lutken, 2010, *Subsurface Structure and Stratigraphy of a Transient, Fault-Controlled Thermogenic Hydrate System at MC-118, Gulf of Mexico*, AAPG 2010 Annual Convention Oral Presentation, Abstracts Volume, p.134.

[4] Dunbar, John, 2009, *Direct Current Resistivity Survey at MC-118*, GOM Hydrates Research Consortium Fall Meeting, Columbia, SC. http://www.olemiss.edu/depts/mmri/publications/11-09%20Hydrates/12A%20Dunbar.pdf

[5] Rogers, R., J. Dearman, and G. Zhang, *Interactions of bioagents and fine mineral particles to promote gas hydrates*, 2005, Vancouver, Island, B.C., MMS Workshop on Marine Gels and Polygonal Fault Systems, July.

[6] Rogers, R., Zhang, G., Dearman, J., and Woods, C., 2007, *Investigation into surfactant/gas-hydrate relationship*, <u>in Gas Hydrates and Clathrates</u>, special volume of the Journal of Petroleum Science & Engineering, 56, 1-3.

[7] Lapham, L. R. Wilson, C. Paull, J. Chanton and M. Riedel. *Measuring in situ dissolved methane concentrations in gas hydrate-rich systems Part 1: Investigating the correlation between tectonics and methane release from sediments*, presented at 2010 Fall Meeting, AGU, San Francisco, Calif., 13-17 Dec.

[8] Wilson, R M., L. L. Lapham, M. Riedel, and J. P. Chanton. *Measuring In situ Dissolved Methane Concentrations in Gas Hydrate-Rich Systems. Part 2: Investigating Mechanisms Controlling Hydrate Dissolution*, presented at 2010 Fall Meeting, AGU, San Francisco, Calif., 13-17 Dec.

[9] Ingram, W.C., Meyers, S.R., Brunner, C.A., and Martins, C.S., 2010, *Evaluation of Late Pleistocene-Holocene sedimentation surrounding an active seafloor gas hydrate and cold seep field on the Northern Gulf of Mexico Slope*, Marine Geology, v. 278, no. 104, p. 43-53.
[10] Brunner, C.A., Ingram, W., Meyers, S., and Lutken, C., 2011, *Sedimentation at the Woolsey gas-vent complex in the northern Gulf of Mexico*, Journal of the Mississippi Academy of Sciences, v. 56, No. 1, p. 69.
[11] Rogers, R.E., 2011, *Microbial techniques to extract carbon from stored hydrocarbon gases: Exploring extent of microbial involvement in seafloor hydrate formations/decompositions and establishing that Mechanism* , in Hydrate Research Activities That Both Support And Derive From The Monitoring Station/Sea-Floor Observatory, Mississippi Canyon 118, Northern Gulf Of Mexico, Semiannual Report to NETL-DOE by the Hydrates Research Consortium, July-December, 2010.
[12] Backus, M. M., Murray, Paul, Hardage, B. A., and Graebner, R. J., 2006: *High-resolution multicomponent seismic imaging of deepwater gas-hydrate systems*, The Leading Edge, v. 25, no. 5, p. 578– 598.
[13] Hardage B.H., Roberts H.H., Gas Hydrates in the Gulf of Mexico*: What and Where is the seismic target?*, The Leading Edge, Vol. 25, No. 5, pp.566-571, 2006.
[14] Lapham, L., J. Chanton, C. Martens, K. Sleeper and J. Robert Woolsey, 2008, *Microbial activity in surficial sediments overlying acoustic wipeout zones at a Gulf of Mexico cold seep*, Geochemistry, Geophysics, Geosystems, Volume 9, No. 6, June 4.