Site Reconnaissance Surveys for Oil Spill Research using Deep-Sea AUVs.

A.-R. Diercks
National Institute for Undersea Science and Technology
University of Southern Mississippi
UM Field Station
15 CR 2078, Abbeville, MS 38601 USA

V. L. Asper
National Institute for Undersea Science and Technology
University of Southern Mississippi
1020 Balch Blvd.
Stennis Space Center, MS 39529 USA

M. Woolsey, R. Jarnagin
National Institute for Undersea Science and Technology
University of Southern Mississippi
UM Field Station
15 CR 2078, Abbeville, MS 38601 USA

C. Dike
University of Southern Mississippi
1020 Balch Blvd.
Stennis Space Center, MS 39529 USA

M. D'Emidio, S. Tidwell, A. Conti
Mississippi Mineral Resources Institute
University of Mississippi
111 Brevard Hall
University, MS 38677 USA

Abstract— **The National Institute for Undersea Science and Technology (NIUST) owns and operates two deep-sea AUVs [1, 2]. The International Submarine Engineering (ISE) built Eagle Ray a torpedo shaped, 2200 meter rated Autonomous Undersea Vehicle (AUV), typically operates 20 meters to 50 meters off the seafloor collecting multibeam and sub bottom data. Mola Mola is a 2000 meter rated hovering vehicle that records digital images with its primary sensor an AVT industrial camera typically from three meters altitude. Currently these AUVs provide deep site reconnaissance for instrument deployments and bathymetric and sub bottom surveys of selected areas for the Ecosystem Impacts of Oil and Gas Inputs to the Gulf (ECOGIG) consortium. The Eagle Ray AUV surveying at 50 meters off the seafloor, collects high resolution swath Multibeam Echo Sounder (MBES) and polarity preserved Sub Bottom profile data (SBP) along the nadir line of the vehicles dive track. The Mola Mola AUV is used for close-up high resolution photographic site investigations. The combination of these two AUV's is providing a unique tool to study seafloor morphology, sub bottom structure and provide high resolution imagery of targets of interest [3]. Data of the combined work of these two AUV's collected during the October 2012 Gulf of Mexico Research Initiative (GOMRI) funded ECOGIG cruise to MC297 and MC118 aboard the R/V Pelican will be presented at the meeting. Eagle Ray accomplished during this cruise 3 full length dives to a record depth of 1633 m and collected MBES and SBP data along 241 km of combined line length, covering an area of ~30 km2. Mola Mola took over 12,800 images on 4 full length missions. One of these dives went to a vehicle record depth of 1612 m near MC297 finding and imaging a 3 x 3m size target on the ocean floor, previously deployed on an earlier consortium cruise. This paper will discuss the approach of using autonomous underwater vehicles to collect background data in support of deep sea research aimed at understanding the process of natural oil and gas seeps in the deep Gulf of Mexico from dives completed successfully in 2012.**

Keywords: AUV, Oil Spill Research, ECOGIG, MBES, SBP, Eagle Ray, Mola Mola, NIUST, UVTC

I. INTRODUCTION

The National Institute for Undersea Science and Technology (NIUST), established in 2002 by the University of Southern Mississippi and the University of Mississippi in partnership with NOAA's Undersea Research Program (NURP) operates two advanced autonomous undersea vehicles (AUV).

The two AUVs, an International Submarine Engineering built Explorer class AUV, named Eagle Ray, and a Woods Hole Oceanographic Institution built Seabed AUV, named Mola Mola, have completely different operational requirements and tasks based on their physical layout and propulsion. The torpedo-shaped explorer class AUV with is forward set of planes is a perfect tool for high resolution seafloor and sub-bottom mapping [4]. The Seabed AUV, propelled by three independent thrusters, is used for close-up sub-sea photographic site investigation which takes advantage of its slow speed and maneuverability. The high resolution digital photography can be used to construct spatial photo-mosaics of the target area.

Originally both vehicles were used to develop and apply new technologies that enhance undersea research. More recently their uses have shifted towards an operational data collection platform to provide high resolution sea floor data at depths that are hard to reach with normal surface

978-0-933957-40-4 ©2013 MTS

instrumentation, or provide larger systematic areal coverage per dive than can provided by Remotely Operated tethered Vehicles (ROV). Lately the Underwater Vehicle Technology Center (UVTC) one of three divisions of NIUST became involved with oil spill research as a part of a research consortia that, through the Gulf of Mexico Research Initiative (GOMRI), received funding from BP. The Ecosystem Impacts of Oil and Gas Inputs to the Gulf (ECOGIG) consortium is one of eight research consortia that were funded after a rigorous and competitive review of proposals submitted to GOMRI. UVTC's autonomous undersea vehicles are providing the ECOGIG consortium with high resolution sea floor and sub sea floor data for optimum instrument placement and other necessary background information about the individual sites. New sample locations are chosen based on the data provided by these maps.

ECOGIG's group of researchers includes microbiologists, geochemists, oceanographers and physiological ecologists, many with over 20 years of experience working productively in the waters and on the seafloor in the deep Gulf of Mexico using a wide variety of research platforms. Their work focuses on the effects of biological activity and physical processes of oil transfer between surface waters, deep water, and sediments as well as the impact of oil on the pelagic community composition & activity, carbon flow, and food web structure to only name a few.

II. AUV Capabilities

NIUST's Eagle Ray (ER) (Fig. 1) is a 2200 m Explorer class, torpedo shaped, 4.9 m long, 0.69 m in diameter AUV weighing 940 kg in air. ER is equipped with a 200 kHz EM2000 multibeam echo sounder (MBES) and a chirp Sub Bottom Profiler (SBP). The EM2000 MBES senses the seafloor with 111 beams, each having a beam-width of 2.5° across track and 1.5° along track at a rate of 1Hz. At 50m above the seafloor and operating at 1.75 m/s, the effective swath coverage width (without overlap to nearby swaths) is 150 m across track. This results in a depth measurement every 1.3 m across track and 0.9 m along track, with a vertical accuracy of 0.08 m.

The SBP sends a modulated sound pulse into the water column, receiving the returned signals from the nadir position along-track for the vehicle's flight path, using a single transmit / receive transducer located in the nose of the vehicle.

Figure 2: Mola Mola AUV

Figure 1: Eagle Ray AUV

Eagle Ray has collected high quality MBES and SBP data in over 65 successful dives along hundreds of kilometers. High quality hydrographic multibeam bathymetry maps are being produced routinely within the AUV group from acquired raw multibeam data. The AUV is powered by 18 Lithium Ion battery modules, giving it an endurance of approximately 30 hours, enabling a total survey distance travelled of approximately 150 to 180 km of survey lines or approximately 27 square kilometers per dive. (Transit to the survey starting point as well as dive to and return from its operational depth are not included in these estimates and will shorten the maximum survey length.) For navigation the vehicle is guided by a Kearfott SeaDeViL inertial navigation system (INS), which is aided by an integrated Doppler Velocity Log during a dive and a GPS receiver while maneuvering at the surface.

Mola Mola (MM) (Fig.2), a SEABED class AUV [5, 6] rated to 2000 m, is equipped with a downward looking high-resolution digital camera. The vehicle was modified from its original design to incorporate two high intensity LED strobes and an IXSea Phins INS [7]. The LED strobes support the camera to record digital images of the seafloor every 3 to 4 seconds. Each image captures an area measuring approximately 2.26 m x 1.70 m below the vehicle along its survey path. Forward motion of the vehicle during a survey is around 0.2 to 0.25 m/sec, providing a coverage area of approximately 10,000 square meters during a 6-hour survey. The camera, from a height of 3 m above the bottom, can resolve objects as small as 2.5 mm. Each image is time stamped and marked with a position coordinate from the onboard IXSea Phins INS. The INS is aided by GPS input at the surface and at depth by DVL. The navigation solution may also be improved by USBL derived corrections and Long Baseline (LBL) acoustic beacons. In addition to the camera system, Mola Mola has a 1.2 MHz Delta-T multibeam sonar, allowing it to acquire bathymetry along its survey path with an approximate resolution of 0.16 m along track and 0.04 m across track.

III. Data Processing

A. Multibeam Echo Sounder

Since the MBES data are collected by a moving platform that navigates autonomously based on sensor inputs with inherent limits and errors, all MBES data are post-processed

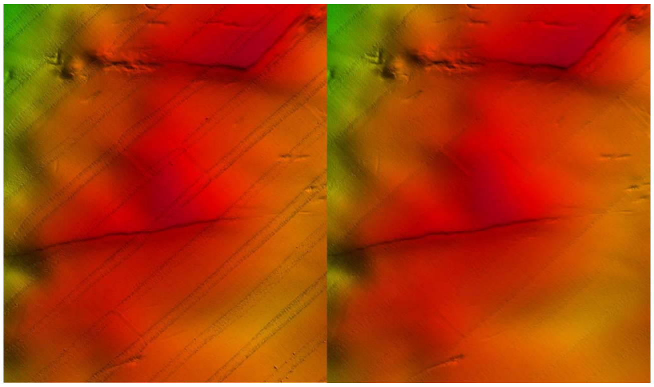

Figure 3: Section of MBES data acquired by ER. Left side shows uncorrected data and right side shows cleaned data. Fault lines and degassing pockmarks are clearly visible in the data. Pixel resolution is 1m.

(Fig. 3) for noise, navigation, vehicle movement and other environmental influences including tide induced pressure changes and variation in sound velocity caused by changes in water masses along the vehicle track. Vehicle movement is recorded during data acquisition, as the Kearfott SeDeVil INS transmits measurements of pitch, yaw and roll to the EM2000. A vehicle mounted CTD measures conductivity, temperature and depth which is then used by the main vehicle computer to calculate pressure compensated sound speed at the water intake for the CTD at the vehicle nose. The EM2000 archives this information in its data files while using it in real time for formulation of the acoustic beam pattern.

Navigation errors occurring during a dive caused by instrument drift, are corrected in post processing using Ultra Short Baseline (USBL) position data acquired by a tracking system onboard the surface vessel following the vehicle. A significant positional error accumulates during the time the vehicle descents from the surface (where the INS is GPS aided) until the INS / DVL acquires bottom lock near the survey altitude above the seafloor. The typical accuracy of the vehicle position is about 0.1 % of the cumulative track distance.

Acoustic MBES data are processed into digital bathymetry maps showing the morphology of the seafloor. In addition to the bathymetry, the acquired raw acoustic MBES data contain information about the intensity of the returned signal which can be extracted and processed into maps of backscatter intensity. Higher levels of reflected energy indicate harder acoustic character of the bottom material. Acoustic hardness can be associated with geologically hard sediments or with sediments that contain a high concentration of gas. Backscatter data are grouped into classes of different intensities to indicate regions of similar sediments and/or acoustic hardness. The acoustic characteristics from each of these different groups are then compared with backscatter intensities of known sediment types to classify the in-situ surface sediments. Backscatter data can be ground truthed with bottom imagery from Mola Mola or by other sources to produce maps that display regions of similar sedimentological facies.

B. Chirp Sub Bottom Profiler

A GeoAcoustics chirp sonar system was integrated into ER to acquire sub bottom profiles along the survey track of ER dives. See further details in this issue [8]. A synchronized ping regime of all ERs onboard acoustic sound sources together with a controlled schedule of surface to vehicle acoustic telemetry, allow for collection of high resolution acoustic sediment profiles. A penetration depth of as much as 60 meters (Fig. 4) into the sediment is possible where acoustic propagation is favorable. Layers of gas rich sediments or surface crusts of Carbonates (usually found around active gas and oil seeps) can reduce the penetration depth of the acoustic signal. The SBP can be programmed through the ER program GUI to use different frequencies and pulse lengths, facilitating the use of the SBP during all dive altitudes of ER while minimizing interference and avoiding an overpowering of the signal.

C. Images

Mola Mola is programmed to take pictures at predetermined intervals using its high resolution digital still camera manufactured by AVT mounted in a DeepSea Power and Light housing. A modification to the vehicle [9] employs an expendable weight to allow for a fast unpowered descent in water depths of more than 500m. The vehicle records bottom images (Fig. 5) that provide detailed information of site morphology, surface sediments, and the presence of fauna and flora on the surface of the sediments.

IV. Site Investigations

Being part of the ECOGIG research consortium, the UVTC AUVs are tasked with providing high resolution maps of bathymetry, back scatter and chirp sub bottom profiles of the underlying sediments. The two vehicles are working together based on their specific designs to provide a comprehensive data set of the targeted sites. Eagle Ray, the fast and more powerful AUV, provides overview surveys from initially 50m above the seafloor, followed, after brief evaluation of the recorded multibeam data, with a 25 m or even a 15m altitude survey

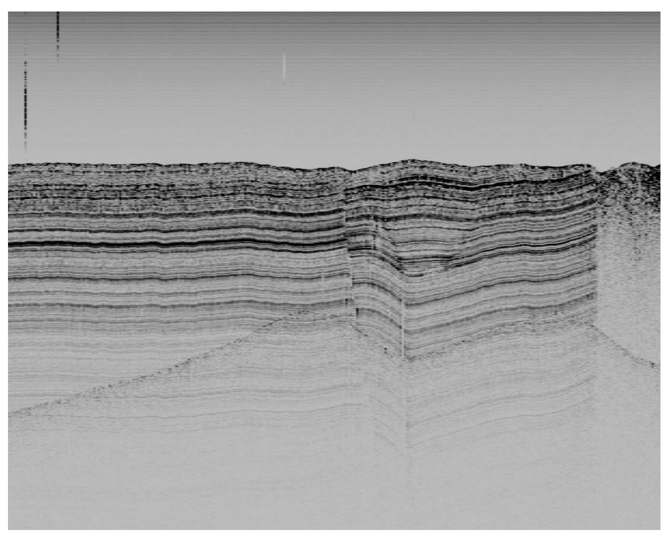

Figure 4: Example of processed chirp SBP data showing fine layered sediment structure and several fault lines. Acoustic blanking zone on the right side indicates either the presence of acoustically hard material in the uppermost sediment layers or a zone of vertical gas/fluid migration, which absorb most of the energy. Faint line in lower section of the data is a multiple

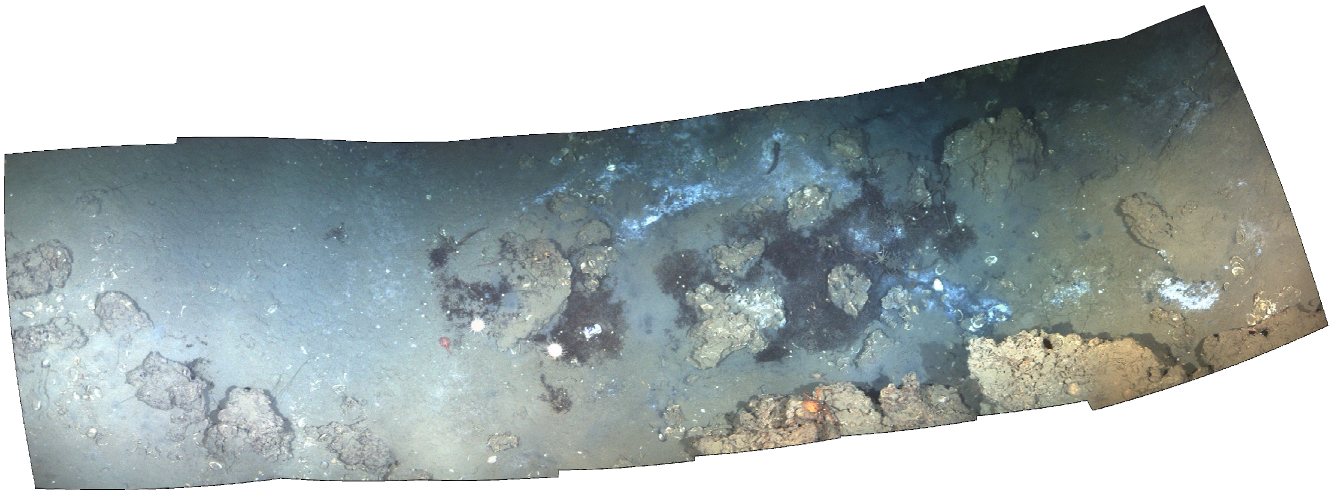

Figure 5: Photo mosaic of 8 images taken by Mola Mola across ass a natural gas seepage area in the northern Gulf of Mexico. Image dimensions are across track approximately 1.7m and along track approximately 10 meters.

over specific areas of interest. Once these data are recovered and have undergone a preliminary evaluation, targets for Mola Mola dives are selected within the boundaries of the ER dives. Locations for the MM dives are carefully chosen as the vehicles build and dive technique allow for investigations of comparatively smaller targets. The dives need careful planning to be able to reach their intended targets at great depths.

A. OC26 / MC297

One of the sites visited by the UVTC AUVs in October 2012 is located just to the West of one of the large dome shaped bathymetric features called Gloria Dome. The site is one of ECOGIG's main study sites, chosen to investigate natural oil and gas seeps and their long and short term effects to the benthic community in their vicinity. MC297 or ECOGIG identifier OC26, named after a site visited by a 2010 research cruise on the RV Oceanus, was investigated with both AUV's to study the bottom morphology and sub bottom stratification around known gas seeps (found earlier in 2011 by the NOAA ship Okeanos explorer). Photographing the area of around a benthic lander deployed earlier in the year by another ECOGIG cruise was an additional task that was successfully accomplished by the Mola Mola AUV. The Okeanos Explorer had found several natural gas seeps as bubble plumes in the water column using their Kongsberg Maritime EM302 on their EX1105 cruise in November of 2011. Limited by the pixel resolution of the EM302, exact origins of these seeps on the seafloor could not be resolved. Eagle Ray's EM2000 together with the chirp SBP provided an abundance of subsurface structure measurements down to about 60m into the seabed along with 1.0m pixel resolution of the surface morphology of the area. Most all of the mid water column gas plumes found by the Okeanos could be linked to bottom features associated with either fault lines or degassing funnels in the sediment. A detailed report of these results will be published separately in the Deep Sea Research Journal.

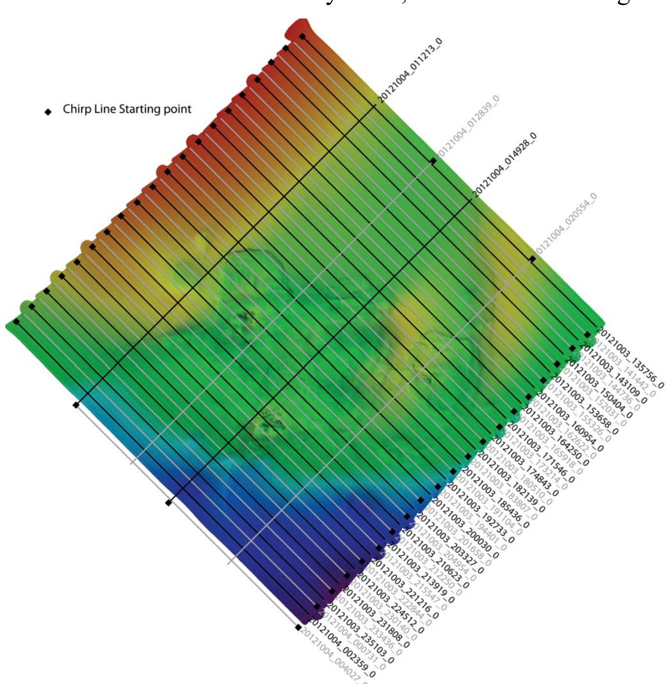

Figure 6: MBES survey at MC118 showing coverage of SBP chirp lines over the Woolsey Mound.

B. MC118 - Woolsey Mound

During the October 2013 research cruise on the R/V Pelican, two dives with ER and two dives with MM over the Woolsey Mound at Mississippi Canyon Block 118 were completed. Figs 5 and 6 are examples of the data acquired during these dives. Fig 5 shows a series of images taken by Mola Mola. These images are color corrected and mosaicked to show bottom feature along MM's survey track. Fig. 6 depicts a composite of MBES data acquired at 50m altitude showing the nadir lines of the vehicle track. Along these lines data from the SBP were collected. An example of the resolution of these SBP data is shown in Fig. 4. Further discussion of the SBP data handling is provided in [8].

V. SUMMARY:

The combined use of the two NIUST AUV's for site investigations for the ECOGIG consortium has proven to be a very effective approach to explore established sample locations and provide information about new sites. Survey data from both AUVs have expanded the knowledge about these sites by showing details combined with spatial coverage of the sampling locations that are not easily obtainable by surface vessels or tethered ROVs. The combined information of 1m/pixel MBES coverage with up to 60m vertical penetration of the SBP, provides valuable information about pathways within the sediment of oil and gas seepage near the surface that cannot be obtained from other geophysical surveys.

ACKNOWLEDGMENTS

This research was made possible by a grant from BP/The Gulf of Mexico Research Initiative (GOMRI) and funding from NOAA. GOMRI is a 10-year independent research program established by an agreement between BP and the Gulf of Mexico Alliance to study the effects of the *Deepwater Horizon* incident and the potential associated impact of this and similar incidents on the environment and public health. We would like to thank the officers and crew of the RV Pelican and the team members at the MMRI shop for their assistance prior and during the operation of the vehicles at sea.

REFERENCES

[1] Diercks, A.-R., V. L. Asper, M. Woolsey, J. L. Williams, F. Cantelas, R. Camilli, P. Rona, V. Guida (2010); NIUST AUVs – Expanding Possibilities" in: Proceedings of the OCEANS 2010 MTS/IEEE Seattle Conference & Exhibition, 978-1-4244-4333-8

[2] Asper., V.L.; Woolsey, M.; Diercks, A.-R.; Jarangin, R.; Lowe, M.; Gossett, A.; Highsmith, R.; Expanding the capabilities of the NIUST AUVs. OCEANS 2011 MTS/IEEE Kona Hawaii Conference & Exhibition (110422-075)

[3] Diercks, A.-R., V. L. Asper, M. Woolsey, J. L. Williams, F. Cantelas (2010): NIUST AUV's study Shipwrecks in the Northern Gulf of

[4] Diercks, A.-R.; Jarnagin, R.; Woolsey, M.; Asper, V. L.; Dike, C.: AUV Sub Sea Surveys. 2013 GOMRI Conference, New Orleans, LA (20-23 Jan, 2013)

[5] Woolsey, M., A.-R. Diercks, V. L. Asper (2010): Mola Mola, NIUST's Low-Altitude Photo and Multibeam AUV; in: Proceedings of the OCEANS 2010 MTS/IEEE Seattle Conference & Exhibition, 978-1-4244-4333-8

[6] Woolsey, M; Diercks, A.-R.; Asper, V.L.; Surveying With the SeaBED-Class AUV Mola Mola National Institute for Undersea Science and Technology Improves Navigation and Data Quality on the Mola Mola AUV. 2011 Sea Technology Magazine

[7] Woolsey, M.; Jarnagin, R.; Diercks, A.-R.; Asper, V. L.; New developments for the NIUST AUVs, in: Proceedings of the OCEANS 2012 MTS/IEEE Conference & Exhibition, 14-19 Oct. 2012, doi: 10.1109/OCEANS.2012.6404860

[8] Woolsey, M.; Jarnagin, R.; Sleeper, K.; Macelloni, L.; D'Emidio, M.; Diercks, A.-R.; Asper V. L.: Integration of a Polarity-Preserving Chirp Subbottom Profiler into the NIUST AUV Eagle Ray; in: Proceedings of the OCEANS 2013 MTS/IEEE San Diego Conference & Exhibition Oceans 2013, Sept. 23-26, 2013 (in press).

[9] Woolsey, M.; Jarnagin, R.; Diercks, A.-R.; An electromagnet-operated descent weight mechanism designed for a hovering AUV, Oceans, 2012, 14-19 Oct. 2012, doi: 10.1109/OCEANS.2012.6404858