Integration of a Polarity-Preserving Chirp Subbottom Profiler into the NIUST AUV Eagle Ray

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***Abstract*–A chirp subbottom profiler was integrated into the NIUST AUV Eagle Ray to expand its mapping capabilities. Previously this vehicle has been used primarily for seafloor mapping using a multibeam sonar. The subbottom profiler provides an additional dimension of data, which allows one to visualize up to 60 meters below the seafloor and correlate surface expressions with subbottom structure. The profiler system was integrated into the vehicle's structure, control software, and operations protocol. The resulting profiler files are merged with the vehicle's logs and processed to infer physical properties of the seafloor and create pseudo 3D volumes.**

***Keywords*—subbottom profiler; seafloor survey**

I. Introduction

Integrating a subbottom profiler (SBP) into an AUV provides a high resolution seismic source in deep-water environments. High resolution seismic sources can image the shallow subsurface in great detail using a high frequency pulse. Such a pulse will be greatly attenuated in the water column before reaching the seabed if it is generated from a ship or shallow tow body. An AUV, however, can operate close to the seafloor and can also run a tighter, terrain-following grid pattern that facilitates post processing and the production of pseudo-3D volumes.

The presented SBP system enhances traditional chirp systems by preserving the polarity of the signal while operating at a high sampling rate (50 kHz) and wide dynamic range. It is also capable of logging both the raw and match filtered pulses. Having these parameters properly recorded, a more accurate reflection coefficient can now be calculated and used in the derivation of the sediment elastic properties.

The effort to commission and integrate the SBP system was shared between two divisions of the National Institute for Undersea Science and Technology: the Seabed Technology Research Center at the Mississippi Mineral Resources Institute (MMRI) and the Undersea Vehicles Technology Center at the University of Southern Mississippi. MMRI researchers provided the design specifications for the SBP, with emphasis on the system's geophysical capabilities. Input was invited from the vehicle team who would integrate the system into the Eagle Ray AUV. Additional specifications were declared with regard to form factor, power requirements, and communications protocol.

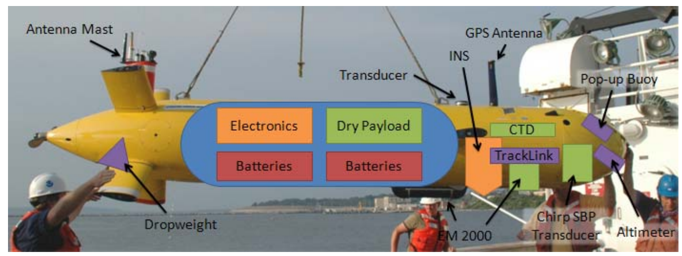

Figure 1. NIUST Eagle Ray AUV.

II. Physical Integration

The SBP equipment was produced for MMRI by GeoAcoustics, a Kongsberg company. At its heart are the profiler electronics. This assembly contains the power supplies, amplifiers, and DSP components which generate and amplify the outgoing waveforms and process incoming signals. A PC/104 stack runs software that serves as the bridge between the AUV and the profiler electronics. It has an ethernet interface connecting to Eagle Ray's control computer and various TTL and higher level communications lines connecting to the profiler electronics. This computer also logs all SBP data which can be accessed by FTP or remote desktop upon recovering the AUV. A single transducer mounted in the nose of the AUV is used to generate and receive the acoustic signals.

The SBP computer stack and its profiler electronics are located within Eagle Ray's single large pressure housing. The profiler was designed to fit into a long narrow bottle, so it was reconfigured slightly to better utilize available space within the housing. Power was provided to these components through an existing switched source that was put in place to support modular payloads. A bulkhead connector links the profiler with the transducer in the flooded payload space. The transducer is mounted on a fiberglass bracket, and it transmits and receives through the curved fiberglass nose section with no obvious detrimental effects. A towed hydrophone array was also supplied with the hardware. The profiler has the capability of using the hydrophone array as a second input channel, but this feature has not yet been utilized.

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Figure 2. Nose-mounted transducer

III. Software Integration

GeoAcoustics produced the SBP system by extending the capabilities of their existing operator-controlled technology. This provided a solid foundation, but the add-on functionality allowing the AUV to interact with the SBP computer required significant post-delivery development by the support team at GeoAcoustics. In-house efforts were concentrated on keeping up with an ever-changing communications protocol during this development time.

The AUV interface ultimately manages user control and autonomous operation of the SBP. Setup and control functionality is provided to the operator through a new dialog of the vehicle GUI which runs on the vehicle's surface control computer. This allows for manual testing and pre-mission configuration. Configurable settings include waveform selection, transmit level, sample rate, and timing parameters. Ping triggering can be derived internal to the profiler or provided externally. The vehicle uses a ping control regime implemented previously to manage pings of various onboard sonars. This system was modified to add payload triggering, and trigger wiring was connected between the payload space and the vehicle's digital I/O board.

Status of the SBP system is displayed on the GUI. More direct access into the system can be achieved by remote desktop connection to the PC/104 computer stack. Eventually, selected SBP parameters may be passed through the vehicle's acoustic telemetry system to allow feedback to the surface control computer during missions.

The operator may request the current SBP configuration and the hard drive space remaining on the logging computer. Pinging and logging can be manually controlled by the operator as well. For autonomous control, the vehicle's mission interpreter was amended so that commands within a mission file could be used to start and stop acquisition. Lower level programming handles the transfer of commands between the vehicle and topside control station and the exchanges between the AUV computer and SBP computer.

A polling system checks the status of the SBP system. While the original protocol provided by GeoAcoustics returned a full status message in response to a single status request, later versions of their software required separate requests for each status value with a short delay between each request. The status values represent the boolean states of logging, pinging, readiness, and power. Additionally a count of logged pings is requested on each five second polling cycle. A parser to interpret all messages from the SBP control computer was written in C++ and integrated into the AUV control software.

IV. Field Testing

The polarity preserving chirp SBP was initially field tested as a payload of the Eagle Ray AUV in July of 2011. This testing was performed as a component of an engineering cruise after extensive updates to Eagle Ray, including a new battery system and wiring. Because of the sheer quantity of hardware and software modifications to the vehicle prior to the dive, acoustic updates from the vehicle were requested frequently, at the determent of the SBP data quality.

The wideband acoustic communications are visible in the SBP records as vertical bands of noise. Vehicle tracking pings, initiated by the same acoustic system that handles communication, also caused interference, which appeared as single bursts within the time series profiles. Both of these noise sources are apparent in the profile shown in Fig. 3. Although this profile has been cleaned, the vertical bands from communication are visible at the right side of the image. The tracking bursts can be seen below the 2000 meter heading. In uncleaned data, both of these noise types are also seen rising up ino the water column portion of the profile.

The interference by communication and tracking could not have been avoided by any trivial means since the acoustic requests are initiated asynchronously from a shipboard computer and because the communication itself lasts for several seconds. The interference appearing in the profiles comes from the response to the tracking and communication requests which are wideband signals generated several meters from the SBP transducer.

No obvious interactions occurred between the chirp pulse and the acoustic navigation sensors, and no interference contributed by the SBP was observed in analysis of the multibeam bathymetry collected at the same time as the subbottom survey. The resulting profiles indicated that changes in operations protocol were necessary, and they provided data, albeit noisy, that were used to study processing techniques.

During its missions in 2012 and 2013, Eagle Ray acquired multibeam and subbottom profiles at various sites in the Gulf of Mexico [1], including regions containing natural oil seeps and methane gas hydrate formation. This research was part of the ECOGIG project, funded by the Gulf of Mexico Research Initiative (GoMRI), which studies the effects of oil and gas input into the Gulf of Mexico. To reduce interference, acoustic communication was carried out during turns between lines and minimized during the survey lines themselves. The frequency of acoustic tracking pings was reduced during the survey as well to reduce noise. The interrogation rate was reduced to 15 to 30 seconds depending on the mission.

V. Navigation Merge

Using a converter developed in-house, the files logged by the SBP in GeoAcoustics condensed format (.gcf) are merged with vehicle log files and exported in a variant of the SEG-Y (.sgy) geophysical data format. This allows additional processing to be carried out using standard seismic tools, thereby allowing for analysis of sediment elastic properties and, eventually, the creation of pseudo-3D volumes.

Ideally, Eagle Ray surveys at a constant altitude. Thus, the resulting profiles are not immediately a true representation of geologic structure. Despite the varying bathymetry in the survey areas, seafloor returns for each trace appear fairly consistent throughout the profile. For a survey altitude of 50 meters, the first arrivals from the seafloor should arrive at nominally 66 miliseconds from the transmit pulse, as is indicated in the upper panel of Fig. 3. For proper representation, each trace must be offset by the AUV's depth during the ping. Since each trace is recorded as a time series, the depth offset is computed as a time delay. During the conversion from GeoAcoustics condensed format to SEG-Y, the appropriate “depth” delay and vehicle position (from Eagle Ray’s inertial navigation system) are embedded into each trace header. During this step, known static errors observed during a mission can be applied to the positions.

VI. Processing and Data Fusion

After the profiles are acquired and converted into a useful format by merging with the AUV logs, the data must be processed. Integrating the SBP records with other AUV data products is beneficial during this post processing phase. By simultaneously logging multibeam bathymetry and subbottom profiles, additional information about the seafloor can be derived. The SBP data reveal the structure along the nadir path of the vehicle, while the multibeam bathymetry indicates the surface expression of some of these structures over a wide area of the seafloor. Thus subtle features observed from one source can often be explained with the added dimension of the complementary sensor.

During several of the ECOGIG missions, surveys were conducted over areas of known seeps previously mapped by the NOAA ship Okeanos Explorer in 2011 [2] and the Schmidt Ocean Institute ship Falkor during its 2012 cruise in support of ECOGIG research. [3]. One such survey is shown in Fig. 4. These seep sites correlate with depressions visible in Eagle Ray’s high resolution bathymetry, and also with discontinuities present in the subbottom profiles [1]. In the profile (uncorrected for depth) the hardground structure at right coincides with the seeps. Two large faults are also crossed by this profile, and both faults have a clear surface expression in the bathymetry

SEG-Y files are imported into the HIS Kingdom Suite for display and interpretation. The first step is to identify the bottom track and check its position with the bathymetric data.

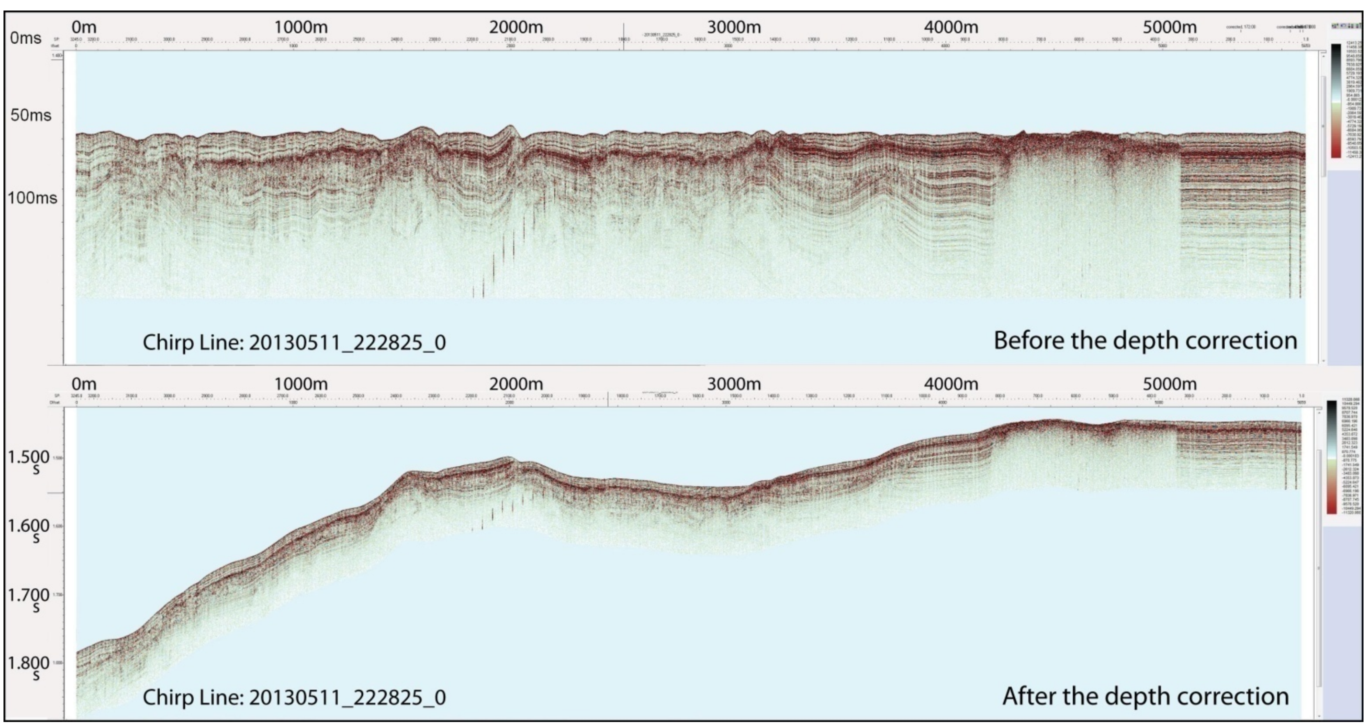

Figure 3. Before and after applying vehicle depth correction (GoMRI data identifier: R1.x132.137:0029).

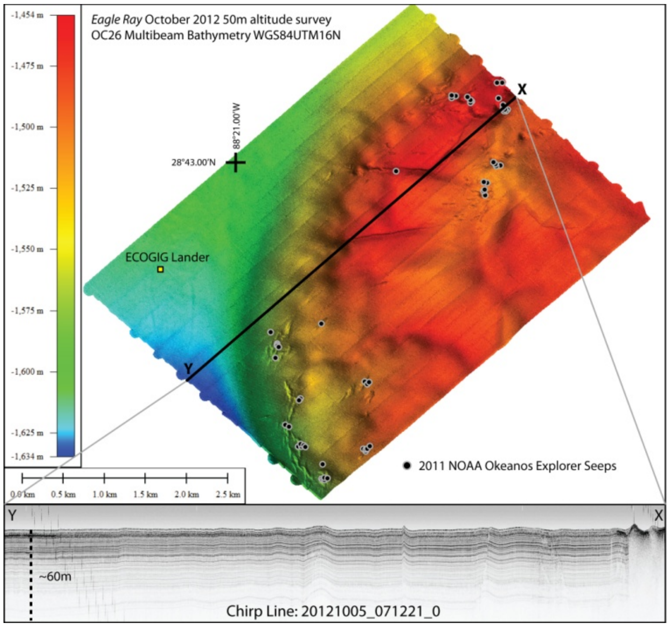

Figure 4. Subbottom profile shown with known seeps [2] and bathymetry. (GoMRI data identification numbers: bathymetry-R1.x132.137:0011, profile-R1.x132.137:0014)

An error in depth indicates improper application of the depth correction. Next, faults and horizons can be picked for stratigraphic analysis. Further interpretation requires examination of regions within a profile with similar seismic structure, known as seismic facies. Since the polarity is preserved, sediment interpretation can be performed via a technique called seismic facies analysis, which uses polarity, amplitude, and geometric continuity to derive physical properties from the subbottom profiles. Fig. 5 shows one such example of polarity dependent interpretation.

During interpretation, hardgrounds are usually recognizable because below them the acoustic signal has lost its power due the physical characteristics of the sediment (i.e. authigenic carbonates) showing an acoustic “wipe out” (less penetration). Acoustic “wipe out” is also possible due the presence of gas and fluid vertical migration throughout the sediments or via preferential pathways such as faults and fractures. The high resolution profiles allow one to identify faults and fractures with a centimeter vertical resolution.

Once the interpretation has been completed, Kingdom Suite allows the creation of a pseudo-3D volume (3D surface) according to the spacing and orientation of the lines. Closer lines provide higher the accuracy of the 3D model. Perpendicular profiles are helpful in that they can uncover features that may be obscured by the bias of a unidirectional survey. Using this processing chain, the sediment layers (horizons), faults, fractures, and acoustic anomalies are displayed in pseudo-3D. Currently, in-house software is being developed for the interpolation of 2D lines in order to create a real 3D volume. Further studies will involve determining sediment physical properties and characteristics via unconventional signal data analysis.

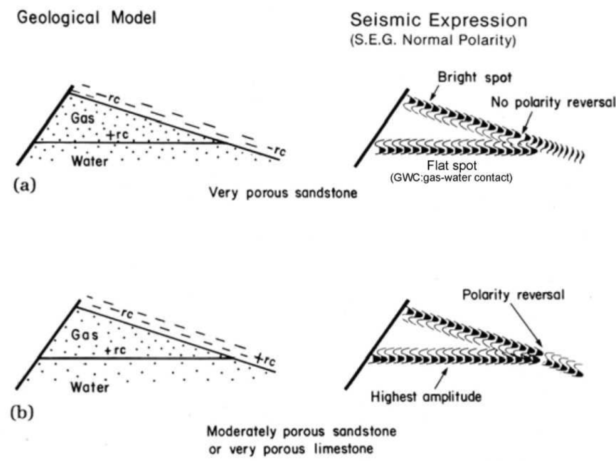

Figure 5. Example of polarity dependent seismic interpretation [4]

VII. Summary

Integration of the chirp subbottom profiler has produced exceptional results and greatly enhanced the capability of the Eagle Ray AUV. After working with GeoAcoustics on the capabilities required by the SBP system, work was begun to develop a software interface that met with the protocol they defined. After delivery of the SBP, integration of the hardware and cabling was pursued along with tests of the software interface. Field trials revealed additional changes needed by the software and general operational protocol. After applying these changes the SBP has become a valuable tool for seafloor mapping.

Acknowledgments

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