OTC 20958

Strategies to Incorporate Pre-Development High-Resolution AUV Surveys Acquired for Archeological Requirements into the Project Lifecycle and Workflow

B.I. Monsalve, D.R. McConnell, AOA Geophysics Inc; J. Worthen, Mariner Energy, Inc; L. Landry, L. A. Landry & Associates, Inc.

This paper was prepared for presentation at the 2010 Offshore Technology Conference held in Houston, Texas, USA, 3–6 May 2010.

Abstract

Archeological regulations issued by the Minerals Management Service (MMS) in 2005 require the major elements of a development-type seabed and foundation zone survey be acquired in order to detect significant historical artifacts over large areas of the Gulf of Mexico in advance of any seafloor disturbance (MMS, 2005). Prior to this regulation, these specialized surveys would be acquired only for the planning of a seafloor development, a workscope that requires high-resolution topography and soils information. The effect of the archeological stipulation in the areas affected is to require major elements of these data very early in the exploration-development timeline, rather than during the field development phase. The acquisition and interpretation of pre-development high-resolution data, while fulfilling specific archeological regulatory objectives as its goal, affords an opportunity to integrate the high-resolution data into the efforts by other parallel and potential future users of the data. Parallel users include shallow hazards interpreters that have the task of assessing seafloor conditions, topography, and geologic conditions in advance of the exploration and development wells, and future users would include the post discovery site development team, should the prospect develop into a commercial discovery. Specialized high-resolution deepwater surveys have a high cost of mobilization, for this reason, operators should consider implementing incremental modifications in the survey design and include data from other sensors, which are not only important and useful to parallel users in the site hazard characterization, but if the site goes to development, they become critical to future users as well.

Several integrated strategies could be considered during the planning of seafloor engineering level data acquisition, improving workflows for the archeological interpretation and the site hazards characterization, and potentially eliminating expensive resurvey in the event that the site goes to development.

Introduction

As developments moved to deepwater, the MMS waived the requirement for magnetometer and side scan sonar for site surveys. Operators shifted from traditional high-resolution site survey to the use of 3-D exploration seismic data for site assessments and few to none of the deepwater blocks outboard of the shelf slope break had an archeological stipulation. As exploration and development continued, a number of wrecks were subsequently discovered during pipeline surveys and other construction activities. These include the Mica and Mardi Gras shipwrecks in the Mississippi Canyon Area, as well as others. The Mica shipwreck was discovered during a post-installation survey of a newly-laid pipeline when the inspection surveyors determined that the pipeline had been laid directly over an early 19th century copper clad schooner! As a result of these incidents and reevaluations of areas thought to have higher probability for shipwrecks, the MMS in 2005 added all of the the lease blocks in the Mississippi Canyon protraction area, many contiguous lease blocks in northwest Green Canyon, and Viosca Knoll, and isolated lease blocks in Atwater Valley, Lund, Henderson, Lloyd Ridge, DeSoto Canyon, Howell Rook, and The Elbow Protraction areas (Figure 1). In these new regulations, MMS specified that high-resolution side scan sonar, high-resolution subbottom profiler, and a depth sounder would be required for deepwater archeological surveys (NTL 2005-G07). The specification for accurate positioning of the sidescan sonar would require the deployment of a transponder array with a deeptow sidescan and subbottom fish, or advanced inertial and ultra short baseline positioning systems, or other adept survey platforms. The sidescan sonar and subbottom profiler deeptow platform was developed for deepwater foundation zone surveys by major oil companies in collaboration with major geotechnical/geophysical contractors in the early 1990s. While the data acquired were excellent, these surveys were characterized by long line turns and the use of heavy sediment keels that would keep the position of the fish at a constant distance above the seafloor but would, as a consequence, limit the surveys to virgin, undeveloped, areas so as to not snag or entangle on infrastructure. These drawbacks fomented the development of the AUV platform for industy deepwater engineering surveys. These specialized vehicles were primarily designed to deploy side-scan sonar, high-resolution multibeam echosounders, and subbottom profilers. These “robot submarines” are programmed to run a survey grid but, separated from any tether to the ship, line turns are eliminated. Furthermore since since AUVs fly untethered a set distance above the seabed, they can be navigated and survey in areas of seabed infrastructure (or over potential historical artifacts). The specifications for the archeological survey data acquisition parameters issued in 2005 would allow for deeptow surveys, but offshore engineering survey support technology has moved largely to the AUV survey platform for the reasons described. These two end uses, pre-disturbance archeological surveys and pre-development seabed engineering surveys, in a large part, require the same data. Hence a key concept in this article is to understand that a deepwater archeological survey is acquiring part of a seabed engineering survey in advance. Because of the high cost of mobilization (common to any marine survey but especially these marine advanced-technology surveys), small incremental costs added to the archeological survey will go far to meet the minimum pre-development survey requirements should the prospect go to deveopment. This article is based on information gathered from various professionals working in geohazards and site development capacities. Key concepts are: acquiring additional data beyond the archeological specifications at little to no additional cost, feeding valuable data to parallel users working in site assessments and other users, and eliminating the need to survey twice with small incremental expense. This article presents several common scenarios and describes strategies to add value while addressing the regulatory cultural resource preservation obligations.

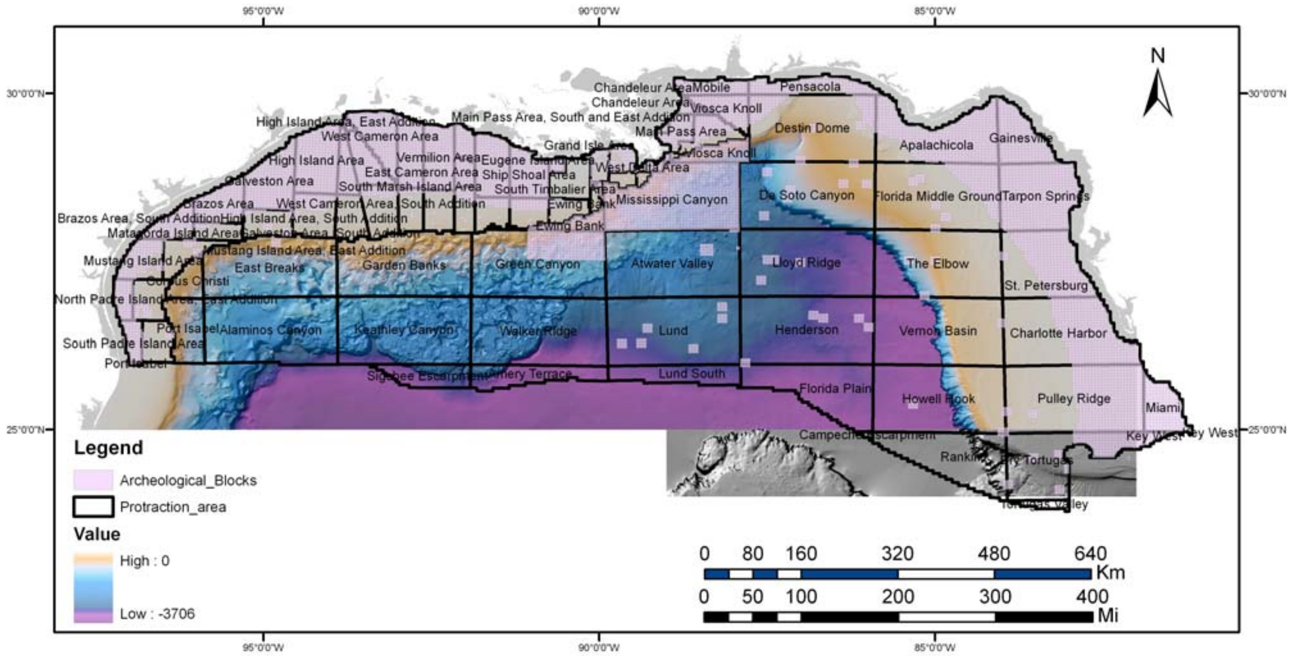

Figure 1. Lease Blocks in Gulf of Mexico that require Archeological Assessment (source: NGDC3sec. and MMS, 2006 and 2008)

Shared Data

A deepwater archeological survey and a predevelopment seafloor engineering survey are going to be acquiring much of the same data. Data that are critical to both the archeological analysis and the seabed engineering survey are the subbottom profiler that image the upper 30 ft of sediment (Figure 2).

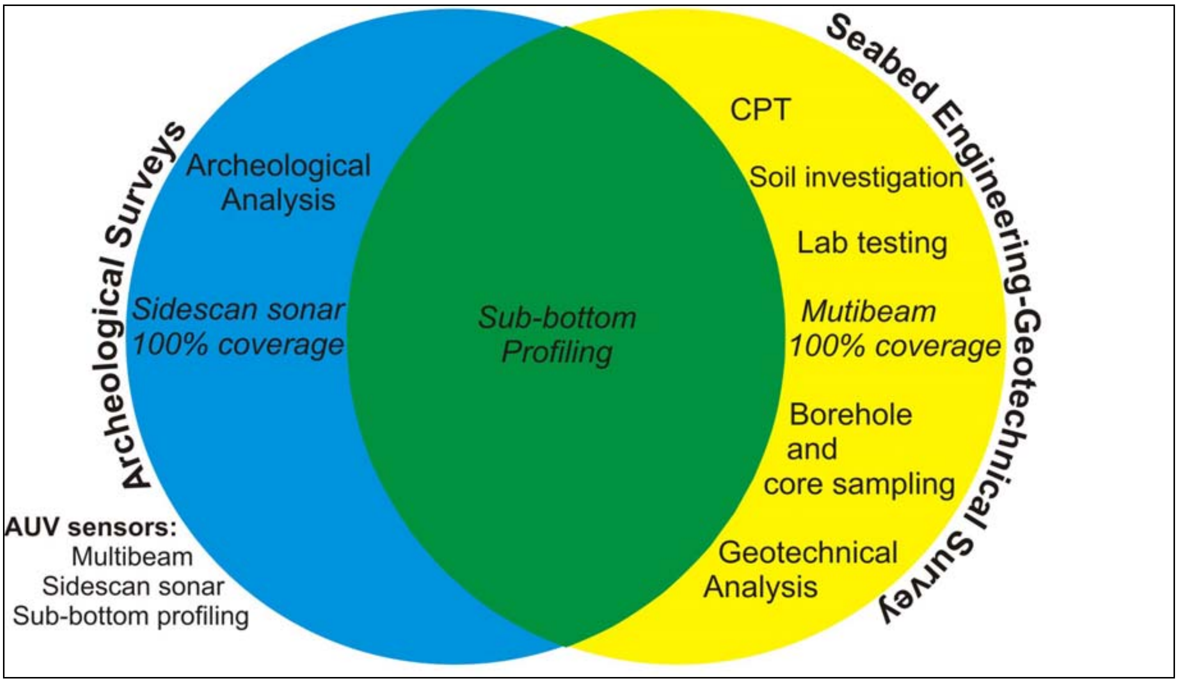

Figure 2. Venn diagram showing shared data between archeological surveys seafloor engineering surveys.

Archeologists use subbottom profiler to look for very shallow buried artifacts of historical significance e.g. shipwrecks (or on the shelf to map out Pleistocene channels, locations that could have greater likelihood for ice age encampments, etc). Likewise engineering geologists use the subbottom records to map shallow soil thickness that can be tied to geotechnical properties after sampling. Placement of anchors, suction piles, and subsea infrastructure are all critical building a subsea development that rely, in part, on high quality subbottom profiler data. Other data in the AUV payload are valuable and can be used but are not required. For instance, sidescan sonar data are required for archeological surveys. These data are used too for seabed engineering surveys, but in practice, sidescan sonar data are optimized by draping them over a high-resolution bathymetry surface acquired by the other major sensor typical of the AUV payload, the multibeam echosounder. Figure 2 graphically shows that 100% sidescan sonar coverage is required only of the archeological survey (blue), subbottom profiler is required by both the archeological survey and the seabed engineering survey (green), and that 100% multibeam echosounder is the requirement, in practice, for seabed engineering surveys (yellow). The other data in yellow, cone penetrometer (CPT), borehole and core sampling, and lab testing, are acquired in specific points to assess soil/infrastructure interaction for suction piles, tension leg anchors, etc. are integrated with the high-resolution geophysical survey upon commercial development.

Regulations vs Opportunity for additional value

One of the primary AUV survey components that is critical to the seabed engineering survey, but is not required by the archeological regulations is a multibeam echosounder. Multibeam echosounders are a recent development that paralleled the advances in small computing power in the 1990s that enabled software to work through large feeds of arrayed point echosoundings and real-time heave, pitch, and roll measurements. This hydrographic surveying method is an advance over single beam echosounders in that it produces a swath of bathymetric points rather than a single point beneath the vessel. If the swaths overlap, then a survey can be designed to acquire a complete bathymetric surface in the area of interest. Figure 2 shows that multibeam echosounders are not required in the archeological stipulation, but are a practical requirement for seabed engineering surveys. The detailed bathymetric data, however, can be useful in an archeological survey, in that the seabed signatures from a plunging, partially buried, ship can be more readily identified. Backscatter, a measurement of hardness and roughness, is additional data from the multibeam echosounder acqusition set that co-registers with the bathymetric data. High decibel backscatter returns could help indicate steel, wood, and copper cladding exposed on the seabed.

In acquisition terms, the difference between archeological surveys and seabed engineering surveys is small. The controls for line spacing for each type of survey is determined by the requirement for 100% sidescan coverage for the archeological assessment and the "best practice" requirement for 100% multibeam echosounder data for the seabed engineering level survey. The sensors placed onboard an AUV are optimized to run approximately 20-40 m above the sea bottom. At that height, sidescan sonar has a 75-80 degree acquisition angle (Fig 3A). A multibeam echosounder, on the other hand, has a narrower acquisition angle, 65-70 degrees (Fig 3B), hence the different line spacings. The total line mile of survey is 47.8 miles (77 km) for the minimum standard for an archeological survey (100 % side scan) and a total line mile of 72 miles (116 km) for the minimum seabed engineering survey (100% multibeam) for a standard 9 sq mile OCS lease block.

At a speed of 3.5 knots, a block-wide AUV survey meeting the minimum archeological specifications takes about 13.8 hours of acquisition time. At the same speed, a block wide AUV survey meeting the minimum seafloor engineering specification (multibeam and subbottom profiling) takes about 20.8 hours of acquisition time. So, the difference between the minimum archeological specification and the ideal seafloor engineering survey is just seven (7) hours of acquisition time. Relative to the cost of survey mobilization, demobilization, and a 300m spaced lease block survey, the incremental cost of an additional seven hours of acquisition time is small (about 1.5% to 3% additional cost). The increase in cost is the survey time and not the additional survey sensors. The multibeam echosounder sensor is almost always in the payload of the AUV vehicle. Recording multibeam echosounder data while conducting an archeological survey adds little to no additional cost to the project. Running the survey for additional 7 hours over the lease block will result in a survey with greater than 200% sidescan coverage and 100% multibeam echosounder coverage.

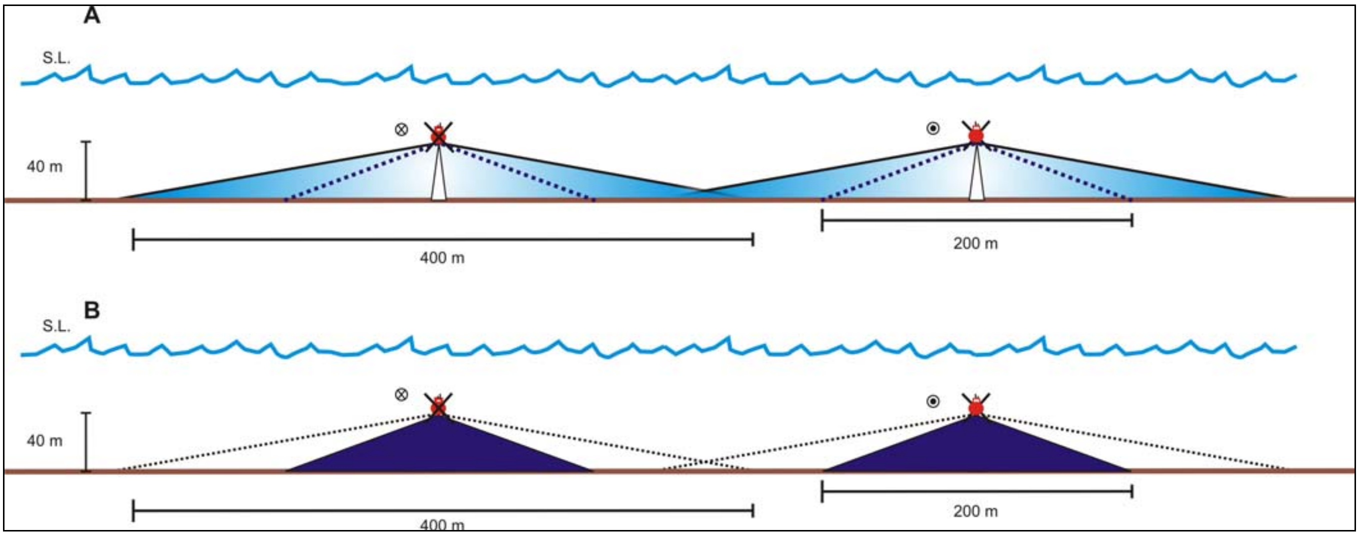

Figure 3. Display of swath coverage during AUV survey operations. 3A shows sidescan sonar system and 3B multibeam system. In this case, the parameters are designed to acquire overlapping sidescan sonar data (100% coverage) and ribbon multibeam data. The swath width of the multibeam bathymetric system is less than that of the sonar. Usually, AUV platform flies 40 m above seafloor. In this example, sidescan sonar range is 200 m (400 m swath coverage) and 200m swath width multibeam. Ship on left is moving into the page; ship on right is moving out of the page. The blind zone for sidescan sonar is generally, between 8-15º (10-20 m).

Strategic Decisions

Figure 4 shows the conceptual incremental cost and effort to acquire and integrate the data from the minimum archeological requirement to the integrated seabed engineering and geotechnical investigation end member requirement.

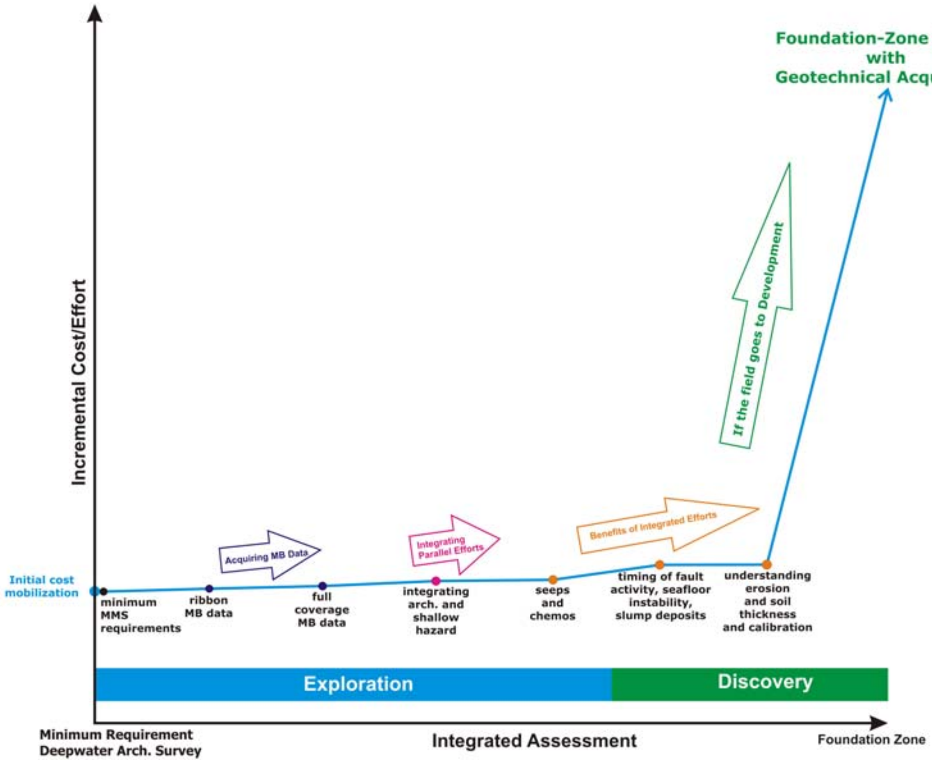

Figure 4. Incremental cost and effort versus degree of integrated assessment.

Strategies

Archeological Assessment Only.

Companies employ several strategies when they need to contract an archeological survey. Some direct their effort to the minimum expenditure possible for the archeological survey. In this scenario, 100 % sidescan sonar and subbottom profiling (at least 15-30 m penetration) are acquired. The multibeam echosounder is used but only the returns under the line are recorded (producing an output similar to that of a single beam echosounder). Figures 5A and 5B show a sidescan sonar image and subbottom profiling line, respectively. In this case the minimum required data will be sent to the archeologist (or the contractor's staff archeologist) that will use this information to write the archeological analysis report. In this scenario, the data are not distributed to other potential users.

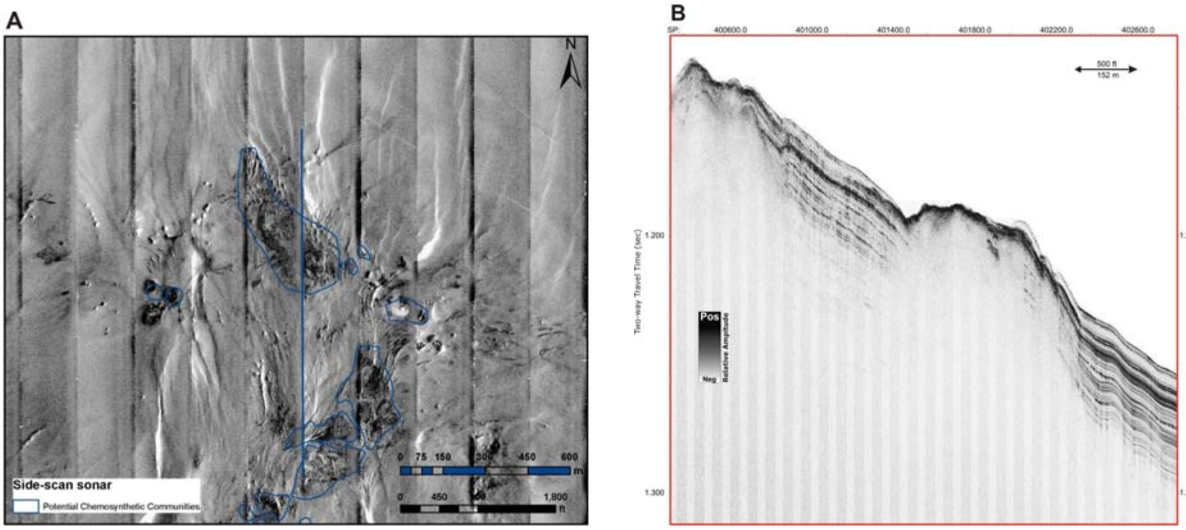

Figure 5. A. Sidescan sonar (100 % coverage) and B. Subbottom profiling data (Courtesy of Mariner Energy, Inc. and Noble Energy Inc.)

The data are archived by the contractor and no further analysis is performed. This single purpose strategy, to produce an archeological clearance report, is the least costly but probably not the most cost effective approach. Better approaches would be to acquire and process the multibeam data and integrate the data with the shallow hazards analysis and reporting.

Acquire Multibeam Echosounder Data.

The multibeam echosounder, in addition to the side-scan sonar and subbottom profiler, will be in the payload of most AUV survey systems. As mentioned, a multibeam ecosounder sends out a large number of sound pulses, making it possible to map a wide section of the seafloor underneath the surveying vessel or AUV platform. The collected depth data from each sounding also contains amplitude strength from the returning sound pulse. The backscatter is a function of grain size for sand and finer sediments, and the surface shape and roughness. Coarser sediments and other hard surfaces like reefs and shipwrecks can be readily identified with backscatter intensity (Kågesten, 2008). Sedimentary and geomorphological processes interpretation can be greatly aided with co-located bathymetry and backscatter data.

Figure 6 shows three types of images: sidescan sonar, multibeam bathymetry, and multibeam backscatter. Note that all are integrated data in the sidescan sonar, colored water depths, and backscatter all draped over shaded relief created from the multibeam echosounder soundings.

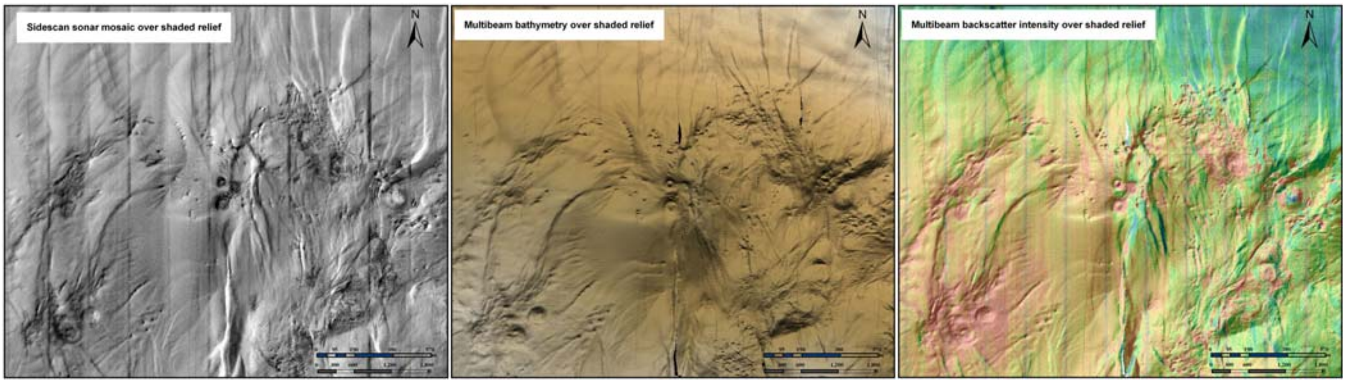

Figure 6. Sidescan sonar, multibeam bathymetry, and multibeam backscatter intensity images (Courtesy of Mariner Energy, Inc. and Noble Energy Inc.)

The sidescan sonar, at left, shows side scan reflectivity with darker colors relating to higher reflectivity. Some of the features such as the smaller pocks would be indeterminate features without the high-resolution bathymetry that give them geomorphological context. Likewise, seafloor faulting is suggested in the side-scan sonar data but is confirmed and clear with integrated with high-resolution bathymetry and backscatter. The backscatter image, on right, shows where stiffer soils are exposed on the seafloor faults and where authigentic carbonates within the soils are distributed.

Full MB coverage or Ribbon survey?

Even though we make the argument that the minimum line spacing be decreased from the regulatory 300 m spacing (Figure 7A) to 200 m spacing in order to get full multibeam coverage (Figure 7B), a 300 m spaced survey can also acquire multibeam data that will be useful for the archeological, site survey, and the field development. Because of the narrower angle and the flight height of the AUV fish, 300 m line spacing will result in a ribbon survey for the multibeam echosounder. Figure 7A, however, shows that the lease block is mostly covered but there are nineteen 210 ft wide gaps in the data. These gaps do not necessarily adversely affect the interpretation of the features (remember there is 100% sidescan coverage to fill in the gaps). Note that the variability of the soils in the erosion rills is apparent; the high backscatter characterizing the seafloor vents is perfectly interpretable as well.

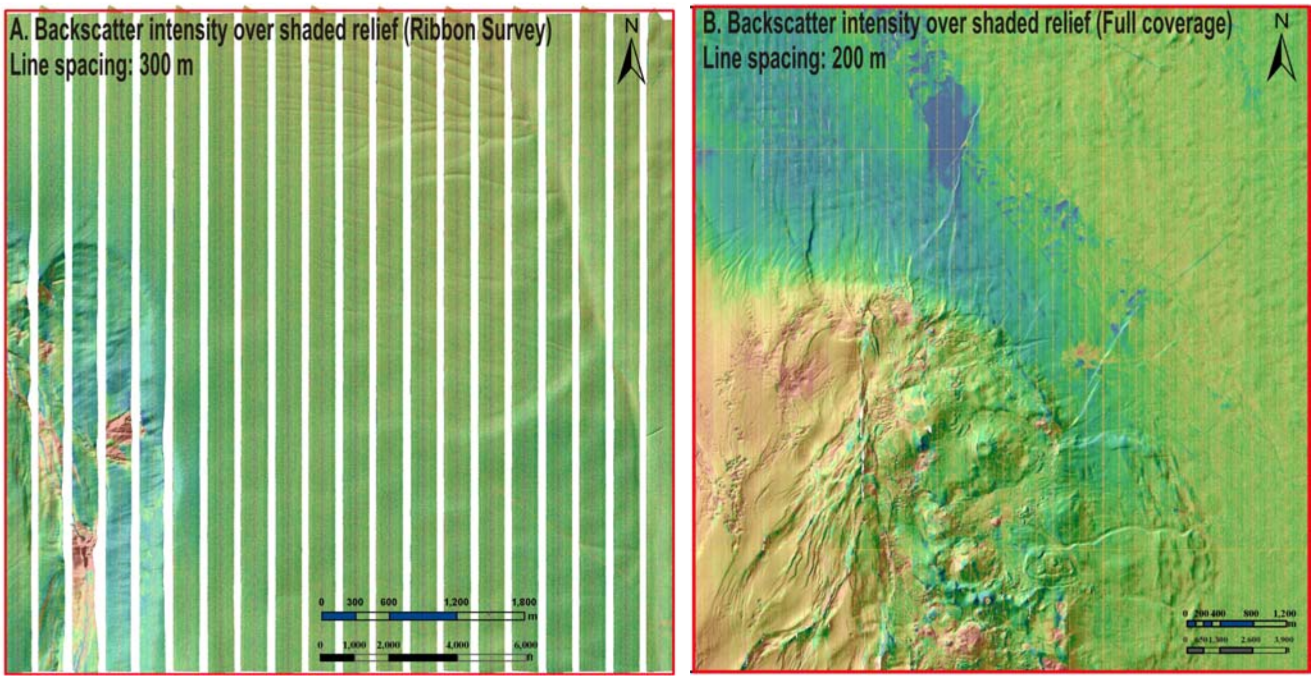

Figure 7. A. Partially multibeam covered and B. Full coverage multibeam survey (Courtesy of Anadarko Petroleum Corporation, Mariner Energy, Inc., and Noble Energy Inc.).

The ribbon survey is quite acceptable for geological and geotechnical interpretations, although geologists have to perform an interpolation which is not needed with a full coverage survey. The only difference is that at the development scale, bathymetric gaps would not be acceptable at the subsea development location.

Integrate with Parallel efforts

Figure 4 illustrates the cost/effort increase to futher integrate the data from the narrow focus of the archeological survey. In many typical scenarios, the shallow hazards intepreters will be evaluating hazards from the seafloor to about 4,500 feet below seafloor using 3-D exploration data. Often these efforts are near-concurrent in that both are pre-spud permitting requirements. Seafloor features can be adequately interpreted from 3-D seismic data, the detail from seafoor rendering is far superior to what was produced from data from the traditional surface-towed site survey spread. The bin size is often 20m by 25m for an exploration 3-D seismic data set. The equivalent bin from the AUV acquired data is about 1 m. The effect of the increase in resolution is to produce a more detailed characterization. The archeological report will focus just on the presence or absence of historically significant objects. The findings in the final report, if no artifacts are found, will be quite succinct. Natural features will not be described and if not recorded in the shallow hazards assessment, this critical knowledge and detail of site conditions may not make it to the field development team. The site survey scope includes detailed topography and water depths, slope calculations, detection of seeps, other fluid expulsion features and chemosynthetic communities, faults and their activity, soil thickness and their variability, hardgrounds, gullies, rills, shallow salt, and seabed gas hydrates. All of these can be reasonably performed in support of temporary occupation by a drilling rig with 3-D seismic data; however, integrating the high- resolution data when the questions and assessment is being made will lead to more accurate and precise interpretations. In some cases integrating the high-resolution data will lead to smaller exclusion zones afforded by the precise interpretations than would be possible using 3-D data alone.

Example: Identifying possible chemosynthetic communities

Exclusion zones for potential chemosynthetic communities will almost always be larger when derived from exploration 3-D seismic data alone (Gharib et al., 2008), whereas high-resolution multibeam echosounder data and importantly, high-resolution subbottom profiler data, interpreted together with the 3-D seismic will almost always produce smaller exclusion zones. Figure 6B shows an area of prolific seeps. The 3-D data, both, the seafloor and the subsurface data, reveals that the whole area under the block is seep prone, but the resolution of the 3-D data is not good enough to determine where discrete seeps are. Therefore, out of conservatism, a large part of this lease block would need to be classified as an exclusion zone. The multibeam echosounder and high-resolution subbottom profiler data, on the other hand, can determine areas of active seepage with much higher precision, and can, therefore reduce the potential exclusion zones. Areas that may contain high-density chemosynthetic communities can be identified based on indirect geophysical data such as hard discrete reflections and/or diffractions in the sub-bottom profiler data and high backscatter anomalies in multibeam echosounder data. Detection of high densities can be delineated with precision by with high-resolution subbottom profiler data because of the ability to directly detect fossil and active buried and surface shelly parts or discrete authigenic carbonates. Figure 10 illustrates a seepage feature on a ribbon survey, which shows that even within a partially covered area, a detailed and accurate data interpretation can be performed.

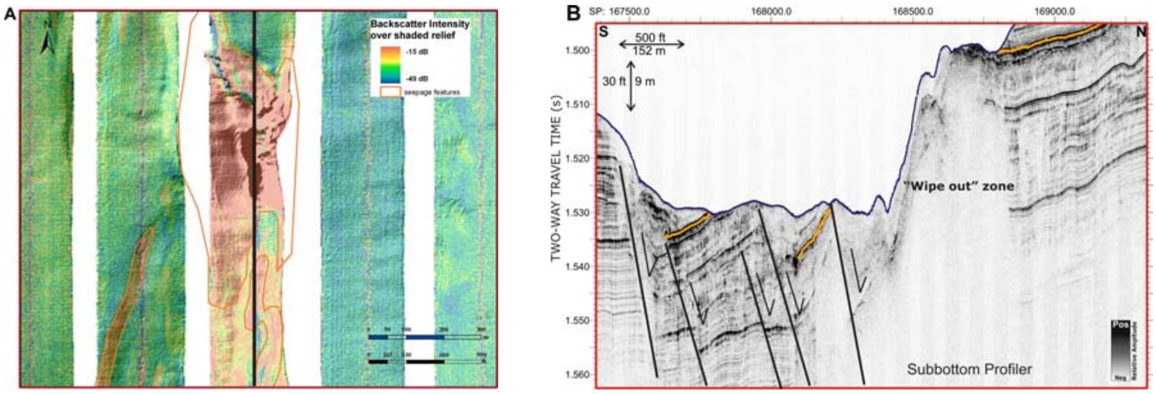

Figure 8. A. Multibeam backscatter intensity over a partially covered area and B. Subbottom profiler data showing hydrocarbon seepage features (Courtesy of Anadarko Petroleum Corporation)

Updating Past Seafloor Characterizations

In the case where a site hazards report has already been completed and filed in the past, but an archeological survey need to be acquired before a new well spud or other activity, it is still just as important to integrate the natural site conditions interpreted from the archeological survey data into the previous findings and update them as needed. The principal reason for updating is that the old site conditions report will become a key document for any field development. If the archeological data are not integrated into the existing site characterization report, then there is a risk that the high-resolution data used for archeological purposes may not be known to the field development team or the field development team may mistakenly believe that the site hazard report is complete. In the worst case, an AUV survey for seabed engineering might be contracted in advance of the field development that would duplicate the data acquired in the archeological survey.

Example: Updating existing infrastructure

In this example, the integration of the archeological survey data into site survey report shows that it directly detects the pipeline trench by multibeam backscatter and with the subbottom profiler. Figure 9 illustrates the high backscatter signal on the pipeline trench and seabed chain scars on a ribbon multibeam backscatter intensity image. A pipeline trench and its corresponding sub-bottom profiling line are shown in Figure 10 (A and B). In this case, the status of the pipeline in the MMS database was shown as a 'planned pipeline' rather than an existing pipeline. The archeological survey data clearly show the pipline as in place- a critical status for any well drilling and anchoring operations planned in the area.

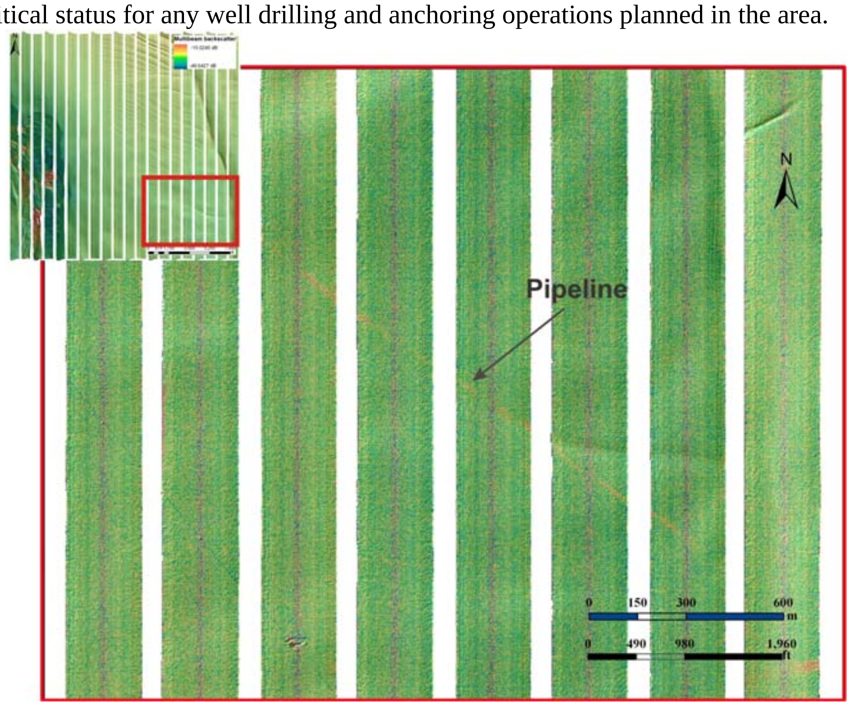

Figure 9 Pipeline and Anchor Chain scars shown on a ribbon multibeam backscatter image (Courtesy of Anadarko Petroleum Corporation)

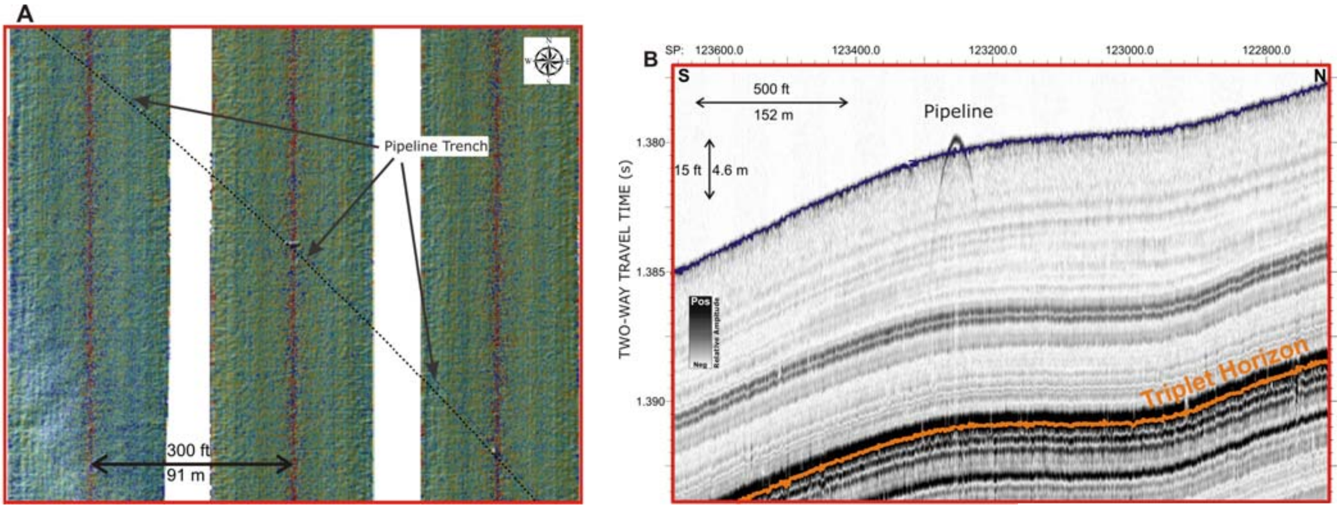

Figure 10. A. Multibeam backscatter and B. Subbottom profiler data showing pipeline trench and pipe (Courtesy of Anadarko Petroleum Corporation)

Pipeline routing

As mentioned in the introduction, one of the primary reasons for the development of the AUV as a high-resolution survey platform to replace the deeptow survey platform was to acquire deepwater pipeline surveys with snagging on infrastructure. Assembling 3-D data seafloor renderings and any archeolgical surveys along the proposed route will be of immense help with the initial pipeline routing. Many times in a pipeline or cable route survey, the initial route is chosen with very little data input, often limited to just the shortest distance between start and finish. The findings as they are interpreted during the pipeline survey are used to optimally route the pipeline, but this approach will use the active pipeline survey operations, to some degree, for reconnaissance. Integrating seabed features from 3-D seismic with any archeological or seabed engineering level survey data will add value by reducing the potential cost of survey reconnaissance. In some cases, where parts of the proposed pipeline route are covered by archeological or seabed engineering survey data, the scope of the pipeline survey might be reduced in areas with redundant data.

Example: Active faulting indentification and detection of variable soils

In the Gulf of Mexico active faults occur in many of structural environments. When projecting the construction of facilities for the development of oil fields, it should be noted that the proximity to faulting areas represents a potential risk throughout the project cycle. High-resolution AUV data are used to detect more easily sediments that have been affected by recent movements of faults. In some areas there are ponded sediments that are easily seen in acoustic backscatter maps, with very low values in dB scales (Figure 11). The backscatter data give us information about morphology and composition of the seafloor. The figure below is showing an active fault zone in the Green Canyon, GoM. Figures 11 A and B show an active fault zone that is affecting channeled recent sediments. Figure 11 C shows a subbottom profiling line across the sediments ponded upslope of the fault.

When pipeline, anchors and other oil field facilities are planned to be deployed through these active areas, knowing the fault displacement can represent saving cost, time, and effort in the route planning.

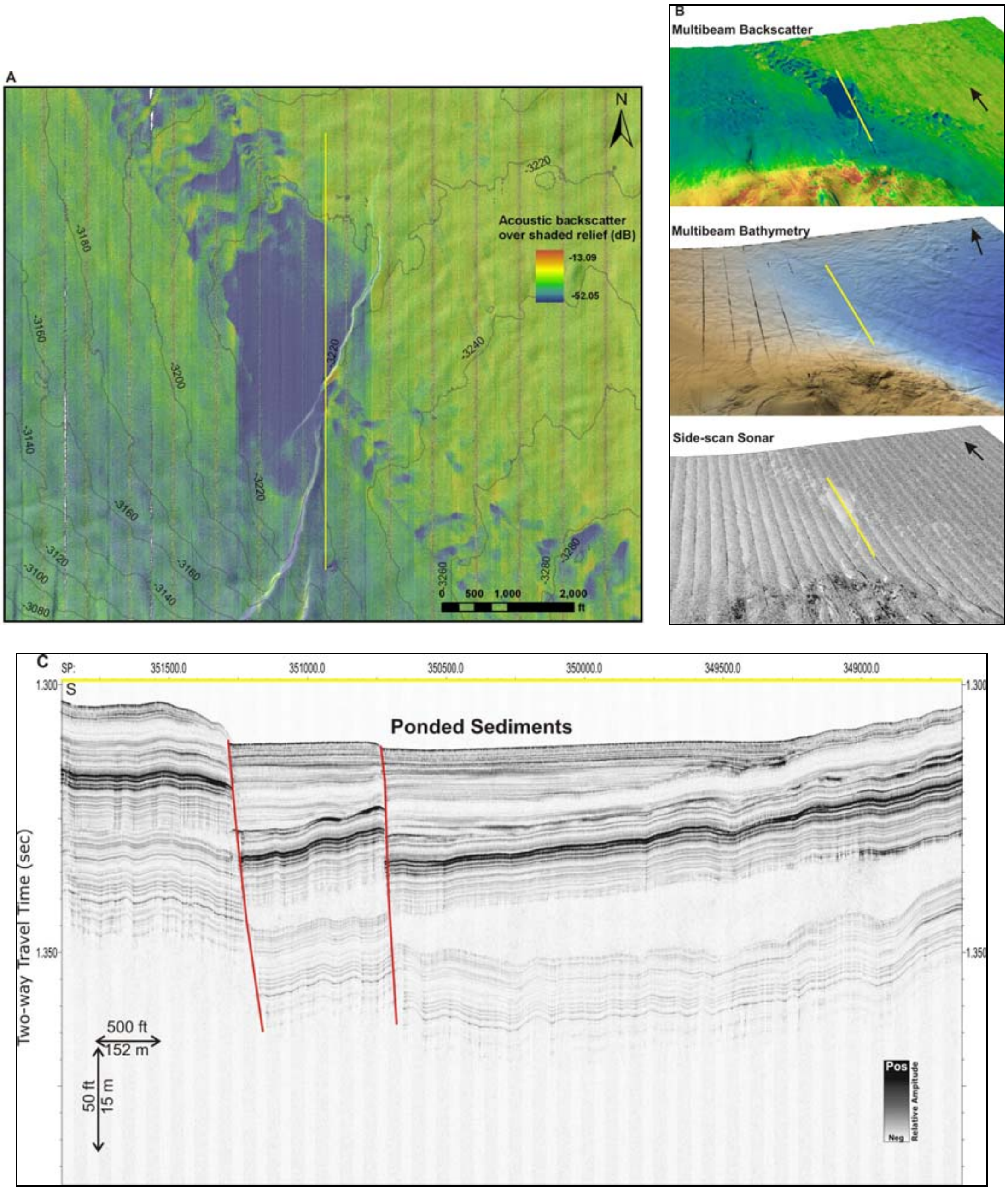

Figure 11. A. Multibeam backscatter intensity image showing channelized debris-apron cross cut by an active fault. The AUV Multibeam Backscatter images the sediment being ponded upslope of the fault. B. 3D view multibeam bathymetry, backscatter intensity, and sidescan sonar of the same active fault. C. The AUV Subbottom Profile shows about 8 ft of relief on the fault scarp and about 30 ft of displacement (Courtesy of Mariner Energy, Inc. and Noble Energy Inc.)

Benefits of Integrating Efforts and Conclusions

MMS regulations for archeological surveys currently require high-resolution AUV data to be collected earlier in the lifecycle of the project. Due to the costly mobilization required for these deepwater surveys, operators should incorporate all available AUV sensors. One of the AUV sensors is multibeam echosounder, which is a requirement for the development phase but not for archeological analyses. Nevertheless, multibeam bathymetry and backscatter data could be used for archeological analysis because they can easily identify buried ships or objects with their high-resolution level of detail. This acquisition provides an opportunity to combine high-resolution data into the parallel efforts of multiple users. Among them are the shallow hazard interpreters that assess seafloor topography and geologic conditions before the exploration and development wells are drilled. Other users that could benefit include the post-discovery site teams in the event that the field is commercially developed.

Since AUV high-resolution data provide valuable information about the seafloor and subsurface, they compliment the interpretation of conventional seismic data.

Integrating archeological, shallow hazards, and seabed engineering surveys (in the case of development), using high-resolution data, the risk in foundation planning can be minimized. Having a better knowledge of the area, the constraints can be reduced and the area to deploy infrastructure can be enlarged. Figure 12 illustrates a Venn diagram showing the existing relation between these three surveys and the common information required and shared between them.

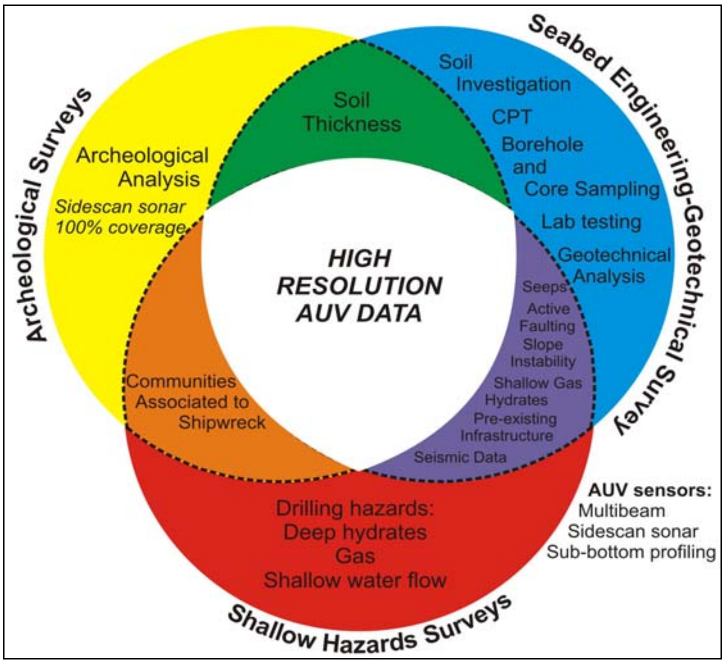

Figure 12. Venn diagram showing common data between surveys.

Several strategies could be implemented in order to make the best possible use and optimize the acquired AUV high-resolution data for archeological purposes. The available choices include fulfilling only the minimum requirements for archeological surveys, or using all the AUV sensors to acquire multibeam echosounder data; which could be integrated with shallow hazard assessments, to making a detailed reconnaissance analysis of the seafloor features and of the natural and non-natural obstructions. In addition, these data could be incorporated with some of the already established development processes.

Considering strategic incremental modifications in the survey design, operators could greatly improve the workflow of a project by eliminating double work and expenses, thus saving in cost and effort.

Acknowledgments

The authors wish to thank Mariner Energy, Inc., Noble Energy Inc., and Anadarko Petroleum Corporation for the use of the high-resolution datasets. We also thank to Mike Taylor, Shawn Williamson, and Melissa Jeansonne for their helpful co-operation within this document. To Jim Gharib, Ana Garcia G., Hunter Danque, Adrian Digby, and Mariana Zabak for reading an early draft of this article and suggested ways to improve its content and organization.

References

Gharib J., McConnell D., Digby A., Henderson J., Danque H., and Orange D., 2008, Improved Assessment of Chemosynthetic Community Presence in Areas of Potential Deepwater Oil and Gas Development by Modification of Routine Sampling Methods: Proceedings, Offshore Technology Conference, OTC 19461.

Kagesten Gustav, 2008. Geological seafloor mapping with backscatter data from a multibeam echo sounder. Department of Earth Sciences, Gothenburg University. UPTEC W08 011. ISSN 1401-5765.

Minerals Management Service, 2005, Notice to lessees and operators of federal oil, gas, and sulfur leases in the Outer Continental Shelf, Gulf of Mexico OCS region, Archaeological Resource Surveys and Reports. U. S. Department of the Interior, Gulf of Mexico, NTL no.2005-G07.

Minerals Management Service, 2006, Mica Shipwreck Project Deepwater Archaeological Investigation of a 19th Century Shipwreck in the Gulf of Mexico. OCS Study, MMS 2006-072.

Minerals Management Service, 2008, Notice to lessees and operators (NTL) of federal oil and gas leases and pipeline right-of-way (row) holders on the Outer Continental Shelf (OCS), Gulf of Mexico OCS region (GOMR), Revisions to the List of OCS Lease Blocks Requiring Archaeological Resource Surveys and Reports, NTL no. 2008-G20.

Minerals Management Service, 2008, Archaeological Excavation of the Mardi Gras Shipwreck (16GM01) Gulf of Mexico Continental Slope. OCS Report, MMS 2008-037.

Topographic data are from the USGS 3-arc-second DEMs and Shuttle Radar Topography data (SRTM). The gridded database contains data for the entire coastal zone of the conterminous US, including Hawaii and Puerto Rico. Gridded data for the Great Lakes, and integrated grids of these and additional U.S. Coastal areas, including Alaska are also available at other resolutions.