To: Dr. Ben Reeder and Dr. Robert Headrick, Office of Naval Research Code 321 Ocean Acoustics

From: David Knobles, Preston Wilson, and Megan Ballard, The University of Texas at Austin

Subject: Report for the Seabed Characterization Experiment (SBCEXP) Workshop I

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1. Executive Summary

The following is a report that describes discussions and decisions made during the Seabed Characterization Experiment (SBCEXP) Workshop I held at the Applied Research Laboratories, The University of Texas at Austin, Austin, Texas, April 5-6, 2011. It is expected that an Office of Naval Research (ONR) funded SBCEXP will occur in the 2014-2015 timeframe with a "pilot" experiment in 2014 and a larger experiment in 2015. Starting from the report of a previous ONR meeting held in San Francisco (28-29 September 2010), discussions at the Workshop were used to create a statement of the scientific goals for the seabed experiment. Further, after extensive discussion the members of the Workshop narrowed the site selection to three candidate locations. These candidate sites are consistent with the scientific goals adopted by the SBCEXP Workshop participants. Additional information will be collected between now and the next Workshop that will serve as the basis to select a single site from the three candidate sites.

2. Workshop Attendees

Several of the attendees of the SBCEXP Workshop I were not only representing their interests, but also the interests of their institute and other colleagues with whom they have scientific collaboration. Also, not everyone on the invitation list was able to attend the meeting. However, when possible their ideas and interests were represented by other attendees.

The attendees at the meeting were

1. Kyle Becker, NURC

2. N. Ross Chapman, University of Victoria,

3. Jan Dettmer School of Earth and Ocean Sciences University of Victoria,

4. Glen Gawarkiewicz, Woods Hole Oceanographic Institute

5. John Goff, University of Texas at Austin

6. William Hodgkiss, Scripps Institution of Oceanography, UCSD

7. Charles Holland, Applied Research Laboratory, Penn State University

8. David Knobles, Applied Research Laboratories, UT at Austin

9. Eliza (Z.-H.) Michalopoulou, New Jersey Institute of Technology

10. John Perkins, Naval Research Laboratory: DC

11. Gopu R. Potty Department of Ocean Engineering, University of Rhode Island

12. John Preston, Applied Research Laboratory, Penn State University,

13. D. Benjamin Reeder, Office of Naval Research

14. Cindy Sellers, Woods Hole Oceanographic Institute

15. Martin Siderius, Portland State University

16. Dag Tollefsen Forsvarets forskningsinstitutt Boks 115, NO3191 Horten, Norway

17. Altan Turgut, Naval Research Laboratory:DC

18. Preston Wilson, Applied Research Laboratories, UT at Austin

19. Jie Yang, Applied Physics Laboratory, University of Washington

Also, Dr. Meagan Ballard attended the meeting and graciously took notes. These notes are contained in an unedited format in Appendix II.

3. Introductory remarks by Dr. Ben Reeder, Office of Naval Research

The following is a synopsis of Dr. Reeder's opening remarks: This is one workshop in an iterative process. The product of this workshop is a final report and people not present at the workshop will have input through the iterative process. Due to budget restrictions, a large SW06-like experiment will not be possible. There is a desire to transition technology, but physics should drive the science.

4. Scientific Goals

Starting from the meeting report of the seabed characterization component of the San Francisco meeting (28-29 September 2010), the Workshop participants defined the scientific goals of the SBCEXP. The three scientific goals of the ONR SBCEXP are to

1) Understand the physical mechanisms that control propagation in the seabed, to include:

- sound speed and attenuation dispersion
- two to three sediment types, eg., sand, mud, and clay
- 10 Hz – 20 kHz (may need to constrain and/or keep this bandwidth but have a more focused band, perhaps 0.5-10 kHz)
- elastic properties of seabed (e.g. shear, etc)
- seabed roughness
- sediment volume scattering (clarification will be required to determine the level of physics needed to treat this mechanism.)
- layering and gradients
- deterministic versus stochastic part of environment

2) Quantify uncertainties

- quantifying seabed parameter uncertainty (quantifying information content of measured data)
- measurement and model/theory error
- propagation of uncertainties
- effect of stochastic part of environment on uncertainty
- need multiple data samples (data sets from a data ensemble) to quantify uncertainty
- in defining uncertainty need to distinguish between data uncertainty, parameterization uncertainty, and model errors
- mapping parameter uncertainty to TL uncertainty

3) Generate performance assessment of the geoacoustic model/characterization and inversion method

- comparisons of various geoacoustic characterizations and incorporations of multiple model candidates directly in the inversion procedure. Will require clarification on definition of metrics of how to make comparisons of different characterizations. Metrics defined by the Geoacoustic Inversion Toolkit (GAIT) committee may prove useful.
- assessing how characterization affects sonar performance predictions, (transmission loss, reverberation, clutter, ambient noise, and array coherence)
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A summary of some of the discussion on scientific goals is given below. Also, there were a number of comments made after the meeting during the revision process of the report and these comments are also included. Additional details with specific comments can be found in the unedited notes taken by Dr. Ballard in Appendix II.

There was a general consensus that determining the sound speed and attenuation dispersion in sand and a softer sediment such as mud over a wide frequency band would require independent measurements and assessments of seabed layering and roughness. Also, Dr. Holland emphasized the importance of including sound speed and attenuation depth gradients in the inference of sound speed and attenuation dispersion.

The measurement of elastic seabed properties will include taking into account the conversion of compressional waves into shear waves. Due to the strong attenuation of shear waves, it is critical that specific measurements of the shear speed be made from, for example, boundary wave measurements by geophones such as proposed by Dr. Potty and Dr. Miller.

Dr. Jim Lynch noted after the meeting that we should not try and avoid "more complicated bottoms" (e.g. like those near the shelfbreak). How one measures and describes a complex region (perhaps via some "effective bottom model") is necessary to address.

Complimentary to the scientific goals of the SBCEXP is the frequency regime of interest. The original email notification prior to the Workshop suggested 10 Hz to 20 kHz. A number of comments were made during the Workshop on the issue of specifying the frequency band because the 10 Hz-20 kHz band appeared to be too large. The concern was that too large of a band might give the perception that the experiment lacked focus. One point was made that the 3-5 kHz band had a greater naval relevance. Another comment suggested that 1-10 kHz was perhaps a more significant band to consider. However, it was pointed out that geoacoustic inversion methods have not been demonstrated beyond 1 kHz and in fact most of the literature reports on methods using acoustic data below 500 Hz. The reason for this is that environmental inhomogeneites become more difficult to model as the acoustic frequency increases, thus making it more difficult to model the spatial structure of the received acoustic field. Dr. Chapman noted that one of the goals in geoacoustic inversion is to push our low frequency methods to a higher frequency regime. Dr. Hodgkiss noted that this may be interpreted as that the lower frequency really will be 0.5 kHz so that we can look carefully at the transition between the techniques we understand and pushing these (and new inversion techniques) beyond 1 kHz. The discussion on this topic did not reach a definitive consensus and likely will have to be addressed in future SBCEXP Workshops.

The uncertainty assessment of geoacoustic inversion techniques received considerable discussion. At the beginning of the conference it was stated/thought by some participants that this research area was a necessary part of the experimental analysis, but subsidiary to the main physics goal of sound speed and attenuation dispersion and elastic classification of the seabed. However, a majority of the Workshop participants viewed the issue of quantifying the uncertainty on an equal par with the physical goals associated with frequency dispersion and elastic seabed properties. Further, Dr. Reeder reminded the Workshop participants that from the San Francisco Workshop the topic of uncertainty originated with a desire to “benchmark” geoacoustic inversion techniques. It was decided that “benchmarking” was too strong a word and the Workshop participants eventually agreed on the phrase “performance assessment”. Dr. Reeder pointed out that there was a need to assess the limitations of the current multiple inversion techniques to decide which techniques to keep funding. For example, which inversion methods can work well at both low and high frequencies? As such there is a desire for an experimental design to collect a single data set to meet everyone’s data needs to test and evaluate the multiple inversion and uncertainty approaches. There was a significant discussion on the issue of *what are we trying to benchmark*. For example are we trying to quantify the parameter values for the true seabed properties, and in computing the uncertainty are we trying to compute the true parameter value uncertainty over the geographical area of the experiment? Dr. Dettmer and Dr. Knobles made the statement that the uncertainty (marginal pdfs for geoacoustic parameter values) quantified in an analysis with acoustical measurements, say with a Bayesian inversion method, is not the same as an uncertainty that could be determined from direct physical measurements of parameter values over the experimental geographical area. Dr. Dettmer noted that the parameterization of the environment is of key importance in addressing such issues. Defining uncertainty as it pertains to the SBCEXP will clearly require additional work in future Workshops. Dr. Chapman also noted that much of the discussion had a heavy "Bayesian slant", and that the seabed characterization group should explore other means of assessing errors in estimates of geoacoustic model parameters.

There was significant discussion in the area of defining performance assessment. Dr. Becker noted the importance of quantifying the consistency among the various methodologies. Dr. Perkins noted that previous attempts to "benchmark" geoacoustic inversion techniques had difficulties of comparing methods that used different data types. For example, some inversions use transmission loss, whereas some use reverberation data. Further, there was the issue of how to compare inversion schemes that attempt estimate true values vs. those that deliver a quick answer. Dr. Siderius noted that the GAIT committee generated a set of metrics to validate different inversion methods. These metrics included localization via matched-fields, sensitivity of detection range for a given figure of merit, and etc.

After the meeting several comments were made concerning performance metrics. Dr. Hodgkiss noted that there was the need to let the data be the deciding factor of which geoacoustic representation is best rather than determine *a priori* the model one is going to use and then simply optimize the parameter values. As an update, such inversion techniques were discussed at the previous Acoustical Society of America meeting in Seattle May 2011. A point raised by Dr. Jim Lynch concerning the intercomparison of methods, benchmarking, etc., is that the seabed inversion community generally does not look at the scales of the bottom features versus the resolutions (vertical and horizontal) of the techniques used to do the measuring, be they acoustic or physical. Reports of bottom inversions routinely compare point measurements to averages, measurements made over a correlation length apart, etc. followed by a discussion of why the physical measurements and the inversion results differ. It would thus be helpful to see this "instrument resolution scales vs physical scales" issue addressed in comparing different inversion results. Dr. Chapman noted that defining performance metrics will also involve planning an appropriate experiment to collect data that can be used by the various inversion techniques. The basic question is whether we need a benchmark or assessment experiment. He stressed the need for such an experimental data set with the qualifier that any data set has its limitations and will not be perfect. Also Dr. Chapman has suggested that further clarification on the point "assessing how characterization affects sonar performance predictions, (transmission loss, reverberation, clutter, ambient noise, and array coherence)" is needed. For example, are we (the seabed characterization group) referring to the mapping between environmental parameter uncertainty and sound field uncertainty?

Finally, Dr. Jim Lynch noted that how one mitigates the effects of water column variability when inferring the seabed properties did not appear to be addressed in the meeting discussions. The issue of bias due to mismatch that results from the water column errors in defining uncertainty is a topic that will likely require significant discussion at the next workshop.

5. Site Selection

The approach to selecting a site for the SBCEXP was centered on selecting an ocean environment in a geographical area that was optimally consistent with the scientific goals. A prime consideration was that there exist both a sandy seabed and a softer type of sediment such as a mud, a fine silt, or a clay-type water-saturated sediment. There was an understanding that the experiment would include recovery and redeployment at two geographical locations. However, the distance between these two sediment type locations needed to be not so large that they would create prohibitive logistical problems.

John Goff and Glen Gawarkiewicz were asked prior to the Workshop to assemble information on eight geographical locations that were identified at the San Francisco meeting as candidate sites for the SBCEXP. They provided a presentation to the Workshop and this presentation is included in Appendix I of this report. The candidate sites included

1. Southern California Bight- La Jolla
    a. eliminated the first day after initial vote
    b. too limited lateral area for experiment
    c. investigation of a single sediment type
2. Gulf of Mexico- Central Texas shelf
3. Gulf of Mexico- NW Florida shelf
4. Middle Atlantic Bight- New England shelf Mud Patch/Georges Bank
    a. redundant (see number 6)
5. NJ Shelf + Mud Patch
6. Gulf of Maine- Georges Bank
    a. eliminated the second day
    b. strong currents make it difficult to deploy equipment
    c. complicated oceanography (especially the bottom intrusion) make this area undesirable
7. Barents Sea- Bear Island Trough
8. Malta Plateau

The first location was eliminated because the width of the continental shelf was too small and further, it is anticipated that restrictions of source levels would make the attainment of the scientific goals very difficult to impossible to achieve. Also, it was recognized that sites 4 and 5 (Georges Bank) were redundant. This preliminary assessment reduced the number of candidate sites to six. Additional discussion eliminated the Georges Bank area due to severe complexities in the environment. This left five candidate sites. Table I shows a matrix of factors that were considered in the site selection process.

Following the construction of the matrix in Table I there was a *vote* on site selection. The New Jersey Shelf+Mud Patch site had the most votes, but the Gulf of Mexico-Central Texas shelf and Gulf of Mexico-NW Florida shelf sites received a significant number of votes. Near the end of the Workshop, Dr. Goff reported that there was a significant sized sand patch south of the silt sediment location for the Gulf of Mexico-Central Texas shelf, potentially making this site more attractive. The Workshop concluded with the understanding that the SBCEXP had three strong candidate sites, and as additional information become available and considerations are taken into account, a single site could then be selected from these three sites in the next Workshop. Charles Holland noted that even though one might have a location that has small bottom slopes, there still could exist strong range-dependent seabed characteristics, and this point required discussion and clarification in the next workshop in the final site selection process.

Figures 1-5 were provided by Dr. Goff and give information such as the location of the various sediment types within a geographical region for the three candidate sites. These figures were taken from various references in the scientific literature listed within the figures.

Figures 1-2 are concerned with the Gulf of Mexico South Texas shelf. There is a distinction between a northern versus a southern location. The northern location shown in Fig. 1 (off Port Aransas and Corpus Christi, TX) has a soft silt layer sediment that becomes more thick as the water depth increases. For example in previous experiments by Rubano and Frisk/Lynch in what has been referred to as the *Gemini location* the sediment thickness is on the order of 10 m in about 40 m of water whereas the sediment thickness is on the order of 40-50 m in about 100 m of water. The southern location shown in Fig. 2 (just to the north of Brownsville, TX) has both a sand patch of about 15 m thickness and a mud patch. The northern and the southern sites are separated by about 100 miles and thus do not pose any serious logistical issues.

Figure 3 is concerned with the Gulf of Mexico NW Florida sand shelf. Near the 150 m depth contour (about 100 miles south of Panama City, FL) the top sediment layer of about 5 m thickness is reported to be mud with a carbonate content. Underneath this layer is sand. As the water depth decreases in the direction towards the shore, the top sediment layer becomes sand. The precise location of this transition will require additional survey work. The sand layer becomes thicker with decreasing water depth.

Figures 4-5 are concerned with the New Jersey Shelf + Mud Patch location. The mud patch has a thickness of about 15 m. Discussions during the Workshop suggested that complicated oceanography and fishing could be avoided (to some degree) by a deployment in the western part of the mud patch. In a shallow region of the New Jersey shelf (about 40-50 m water depth) there exist significant areas that can be characterized as sandy sediments. The mud patch and the shallow region of the New Jersey shelf are close enough such that they are not logistically prohibitive.

In conclusion, a major accomplishment of the Workshop was to identify three strong candidate locations to conduct a future ONR SBCEXP. These three locations are strongly consistent with the scientific goals of the experiment. With additional considerations and research, the next Workshop should be able to select a single site from these three locations.

Criteria			South and Central Texas Shelf	Northwest Florida Shelf	New Jersey Shelf + Mud Patch	Barent Sea	Malta Plateau
Biologics	**fishing**		not significant	not significant	concentrated at shelf break	not significant	not significant
	marine mammals		some	some	some	not significant	not significant
physical oceanography	**currents**		weak	weak	weak	strong tides	modest
	internal waves		in the summer		in the summer	not significant	
	other		Large eddies, avoidable	Large eddies, avoidable Loop current effects important at mud sight	bottom intrusions important	Polar water mass	
Sediment	**structure**	**Sand**	Sand layer near Rio Grand delta 50 ms thick	Mafla sand sheet, sand is a few meters thick located 50 m depth	Sand available at 80 m depth in sand ridges. More sand inshore	Carbonate 30 to 60 m depth, Diamicton/coarse grain clastics at 60 to 200 m depth	Limestone, sand over limestone, layering (complicated)
		Mud	layer cake, mud blanket 10 to 40 m thick	carbonate mud is at 130 m depth	12 m at thickest point, mud overlays complicated subsurface topography	Mud found deeper than 300 m water depth	extensive mud on western portion 10 m thick at 100m contour, 0.1 m at 140 m contour
	multiple sediment types		multiple sediment types	multiple sediment types	multiple sediment types	multiple sediment types	multiple sediment types
	significant shear		possible	probable	possible	In sediment *and* substrate	probable
	seafloor roughness						
	volume scattering		?	very likely	?	significant	very likely
	Potential for bathymetric range-independent areas or areas that have small slopes		yes	yes	Yes, with Isolated patches of sand at deeper depths	30x30km area	Long, moderately range-independent tracks
Weather			favorable	favorable	seasonal	May-Sept.	favorable
logistics			favorable	favorable	favorable	Travel to Norway	Travel to Italy
noise	**shipping**		not significant	not significant		Along the coast	Yes
	oil industry		yes	not significant	none	seasonal	Minor (there is an offshore rig Campo Vega, but noise has not generally been a problem)
water depth			good	good	good	150 – 300 m	80 – 200 m
prior information			Yes, but require more information about the sand	Yes, including the reverb experiment at shallow depths	SW06 and other prior work	on specific regions	A lot
gas seeps			none	localized	none	localized	significant methane fluxes on several areas of the shelf
other			simplest stratigraphy		OOI moorings, gliders, seismic surveys in mud patch	Arctic	Opportunity with NURC

Table I: Site selection factor matrix

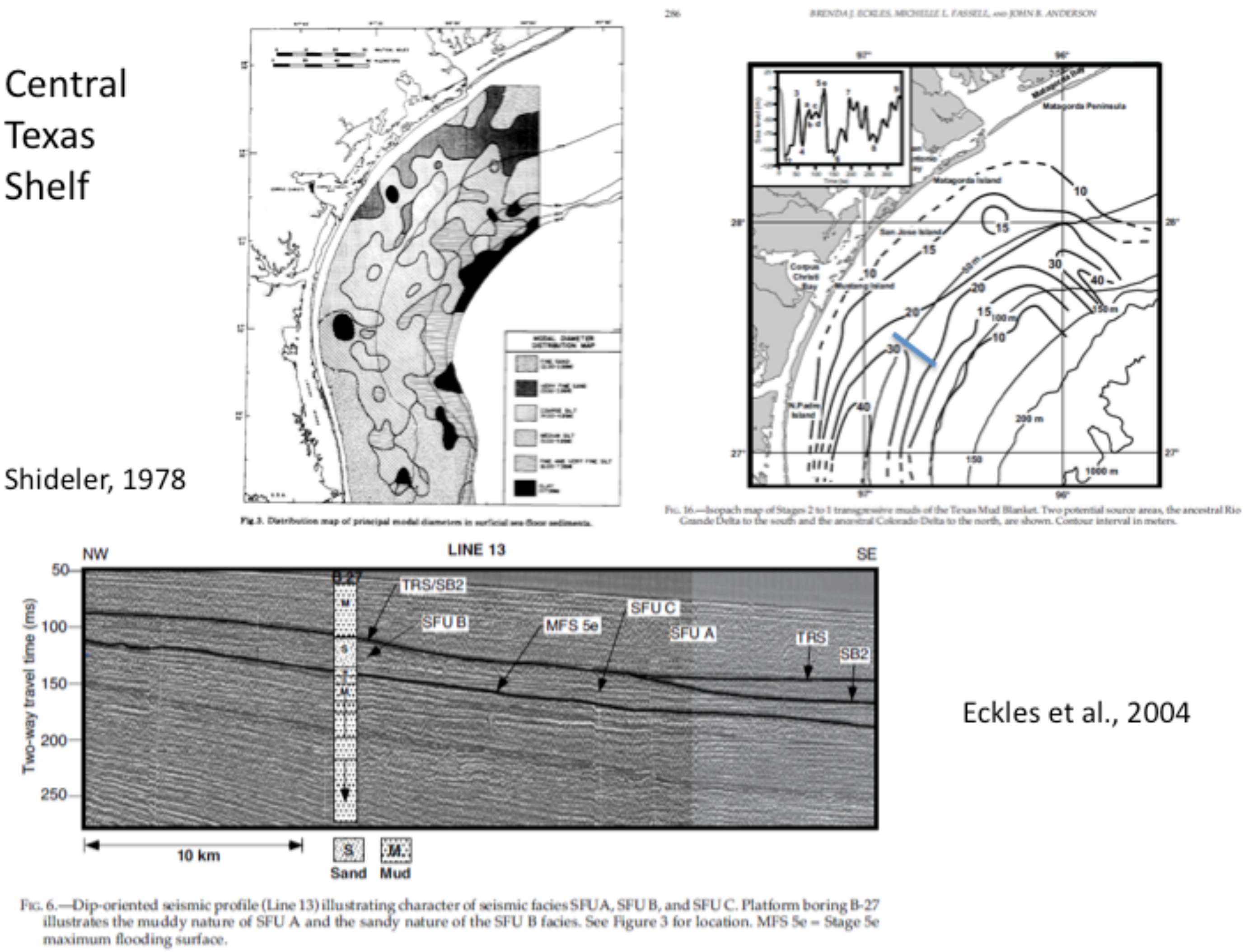

Figure 1: Northern Texas shelf site for soft silt sediment

Texas Mud Blanket (southern sector) Isopach

FIG. 17.—Isochron map of seismic unit Tst 4, which is interpreted as a hemipelagic mud blanket. Seismic lines 16ab (Fig. 17) and 3 (Fig. 18) are used to illustrate the seismic character of this unit.

Rio Grande Delta Sands Isopach

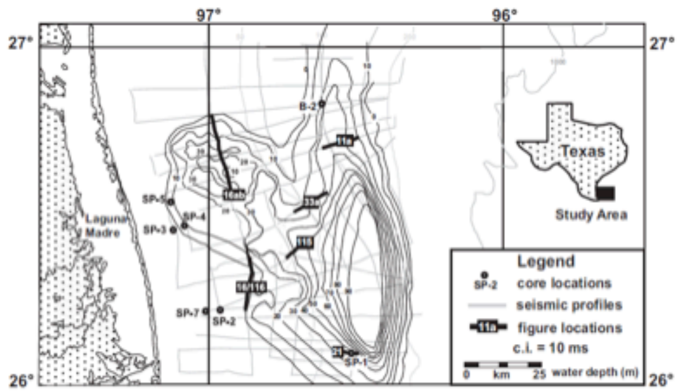

FIG. 10.—Isochron map of the Hst 2 and Hst 3 delta. Also shown are the locations of seismic lines, used to illustrate the seismic character of the delta, and the locations of platform borings that provide lithological information about the delta.

Banfield and Anderson, 2004

Figure 2: Southern Texas shelf site for sand and mud sediments

NW Florida Shelf

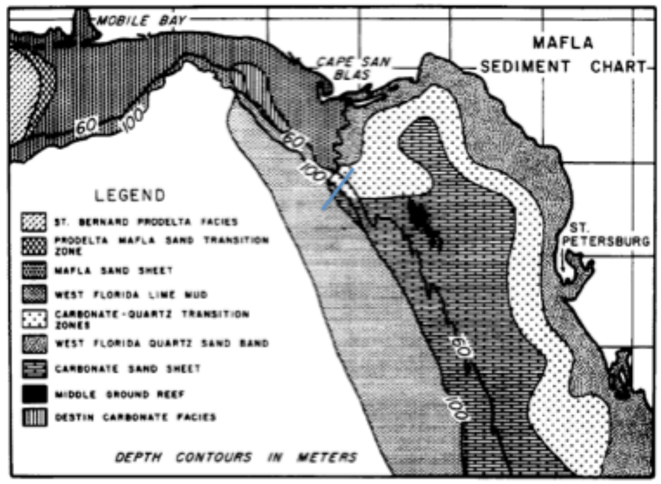

Fig. 9.—Sedimentary facies of the MAFLA margin.

Doyle and Sparks, 1980

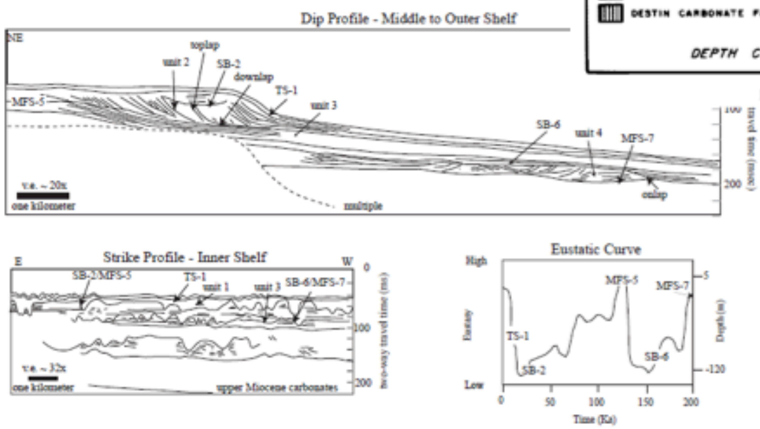

Fig. 3.—Line drawings of dip (APL 08) and strike (APL 04) seismic profiles to illustrate ages of seismic stratigraphic boundaries. The dip-oriented profile best illustrates the generalized stratigraphic architecture and flooding (downlap) surfaces, whereas strike-oriented profiles best image sequence boundaries (fluvial incision). Surfaces are also indicated on the eustatic curve showing their approximate time of formation. Ages are inferred from the relative positioning of surfaces beneath the sea floor, with TS-1 being the upper transgressive surface, SB-2 being the upper sequence boundary, and MFS-5 being the upper maximum flooding surface.

McKeown et al., 2004

Figure 3: Northwest Florida sand shelf location

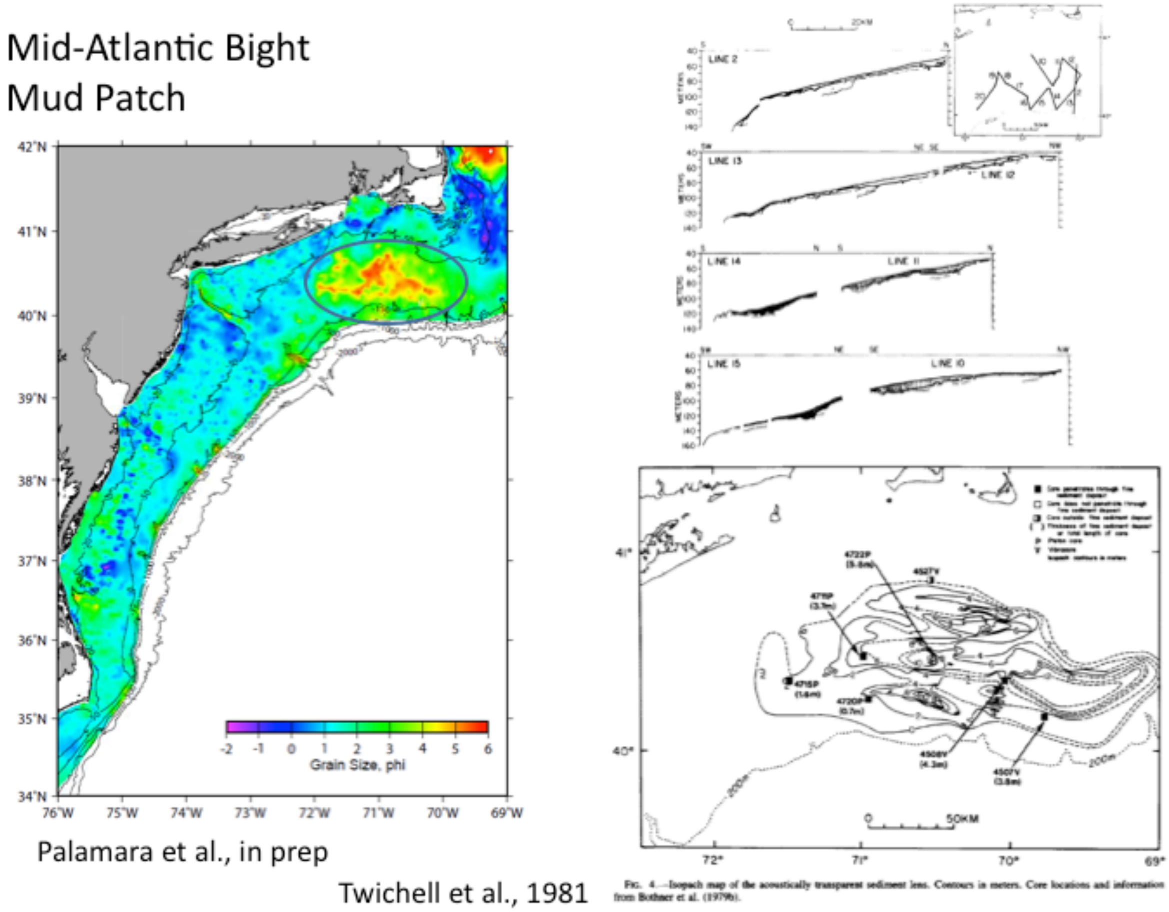

Figure 4: Mid-Atlantic mud patch location

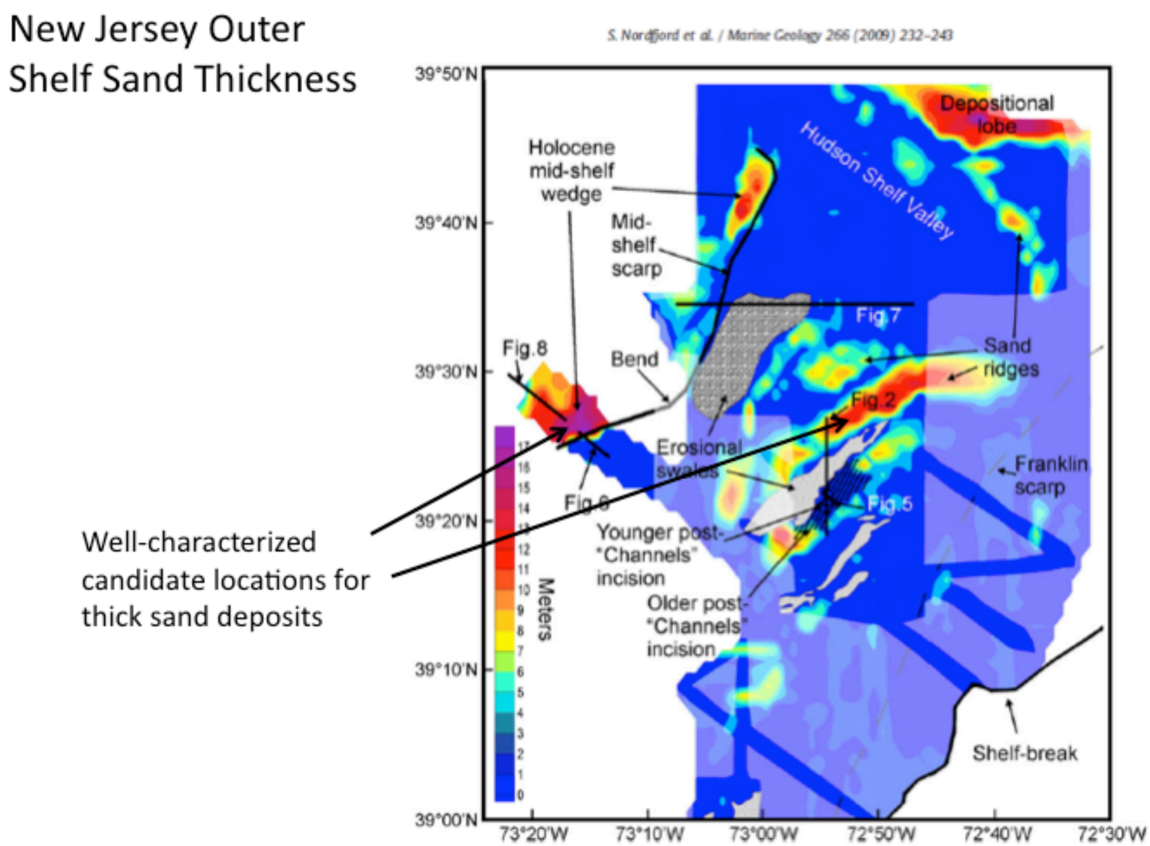

Figure 5: Larger geographical area containing Mid-Atlantic mud patch location and sand locations on the New Jersey continental shelf.

6. Action Items and time frame for second Workshop

The agenda for the next workshop will include making a primary site selection with a backup location and to create a *straw man* experimental plan. The participants at the Workshop submitted outlines of their experimental plans and experimental assets. Prior to the next Workshop it will be necessary to take the information provided by the participants and organize into an experimental plan. The time frame for the 2nd Workshop is January 2012,

7. Appendix I: Combined presentation made by Glen Gawarkiewicz and John Goff

8. Appendix II: Unedited notes taken by Dr. Megan Ballard