Seabed Geoacoustic Structure at the Meso-Scale

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LONG TERM GOALS

The long term science goals are to understand the nature of the seabed at the geoacoustic meso-scale O(10^0–10^3) m and determine how these structures impact acoustic propagation, diffuse reverberation, and clutter.

OBJECTIVES

The objectives are to develop new observational methods to quantify meso-scale seabed variability/uncertainty and also develop modeling techniques to understand the impact of spatial variability on propagation and reverberation.

APPROACH

The FY14 approach included both theoretical and measurement components. The latter was comprised of direct path seabed reflection and scattering measurements both of which exhibit very high geoacoustic information content. These data along with other independent measurements, including cores and seismic reflection data were collected in prior at-sea experiments.

WORK COMPLETED

The FY14 research, building upon prior years, focused on a) understanding fundamental acoustic properties of the sediments including dispersion, b) seabed scattering mechanisms and c) new sediment acoustic measurement techniques. A brief summary of the work completed is listed below:

- In-situ geoacoustic measurements of sediments that exhibit a very wide range of grain sizes and include very large grains (e.g., shells, pebbles and cobbles). This is a sediment type for which no sediment acoustic models currently exist, and very little has been published. However, this kind of sediment may in fact be relatively common. The measurements are intended to provide data where little exists and also to motivate development of models that can treat a wide range of grain sizes. The results are in Ref [1], in collaboration with partners at U. Victoria.

- In collaboration with Gavin Steininger and others at U. Victoria, developed models and methods to determine whether seabed scattering was dominated by interface roughness or...
sediment volume heterogeneities; 2) if the latter, determine the probability of volume heterogeneities as a function of depth in the sediment stack; and 3) the outer scale of the heterogeneities, Ref [2]) The ability to determine the scattering mechanism (e.g., interface roughness versus volume heterogeneities) from acoustic data is important for both scientific and operational purposes. For the former, it will permit a deeper understanding of the seabed processes that lead to scattering; for the latter, an emerging bottom scattering database will require provisioning methods (e.g., is it possible to extrapolate observations in one area to another that has no measurements?). This, and other provisioning questions are greatly aided by identification of the dominant scattering mechanism.

- In collaboration with Samuel Pinson (a post-doc at ARL/Penn State funded by DGA, France) developed a method for rapidly measuring and accounting for dip angles in geoacoustic inversion. The importance of this is that even small dip angles can lead to non-trivial errors in sediment sound speed estimates. (see Ref [3]). This method is particularly well suited to seabed reflection data collected by autonomous undersea vehicles (AUV). Work is underway to apply the method to existing measurements from an AUV towing a source and a 32 m array 15 meters above the seabed on an outer shelf exhibiting geologic complexity.

RESULTS

Here, we briefly summarize the research for heterogeneous sediments with wide grain size distributions (see Ref [1]). Details of the other work completed can be found in Refs [2] and [3].

Introduction

Marine sediment grain sizes span an enormous range, greater than 7 orders of magnitude, from sub-micron size clay platelets, to boulders. However, the vast corpus of work on sediment acoustics has focused on the relatively narrow regime of sandy (0.063 to 2 mm) sediments. There has been almost no work on sediments with pebbles (0.2 to 6.4 cm) or cobbles (6 cm to 26 cm). The largest grain size reported in Hamilton’s seminal compilation [4] was coarse sand (mean grain size of 1 mm), with a sound speed of 1816 m/s and a density of 2.03 g/cm³. Even for this sediment, there were too few measurements to provide uncertainty statistics. Akal [6] measured a sound speed of ~1875 m/s in coarse sand and fine gravel in very shallow water (15 m water depth). Lucas et al. [5] measured various mixtures of gravel and shells from 1-8 kHz. Their findings showed that adding a 25% gravel content to a well-sorted sand (sound speed of 1700 m/s) did not change the mean sound speed, but increasing gravel content to 50-75% decreased the sound speed. The striking dearth of sound speed measurements for large particles (very few for gravel, and none for pebbles or cobbles) may be partially responsible for the widespread assumption that most marine sediments contain little if any pebble or cobble component.

Significant pebble and cobble content were observed on the Malta Plateau at about 130 m water depth, from 1 to 3.2 meters below seafloor (mbsf), see Fig 1. The surprising occurrence of such large grains on the mid-shelf motivated measurements to better understand the sediment geoacoustic properties. This particular sediment exhibits an enormous range of grain sizes, pebbles and cobbles intermixed with clay, silt, and sand spanning more than 5 orders of magnitude, i.e., from sub-micron to 0.1 m. One of the difficulties in studying such an assemblage is the lack of a suitable sediment acoustics model. State-of-the-art sediment acoustics models, e.g., Biot theory [7] or the Viscous Grain Shearing (VGS) model [8] treat the physics of sand sized particles, not a mixture of clay, sand and cobble.
The main objectives of the research are twofold, to provide: 1) estimates of geoacoustic properties of a naturally occurring sediment with grain sizes ranging from clay to cobble and 2) motivation for sediment acoustic model development for sediment fabrics exhibiting a wide grain size distribution. There is a growing recognition in the marine geology community ([9]) that heterogeneous sediments may be relatively common in coastal regions and that state-of-the-art geologic models (e.g., sediment transport models) also are inadequate in that they tend to treat rather uniform homogeneous assemblages. This is to say that our two communities (sediment acoustics and marine geology) have similar issues with overly simplistic sediment models that tend to assume narrow grain size distributions.

Figure 1. Photograph of a) split piston core, with pebbles and cobbles disturbed in the splitting procedure placed at their approximate original position. The core diameter is 10 cm and the core has been cut in 4 ~0.8 m sections; the core top/bottom is at the upper left/lower right. The kidney shaped cobble in the right-most section is ~10 cm long. b) Sediments from the core catcher (bottom of core); the cobble at the lower right is about 6 cm in its largest dimension. The rounded nature of the pebbles/cobble suggest that the origins may be a relict pebble beach from the last Ice Age when sea level was roughly at mid shelf. Seismic data indicate that the cobble layer extends at least several tens of km along shelf and about 10 km cross shelf.

Summary and Conclusions
Details of the density measurements and the low and high frequency sound speed measurements (the main part of the research) are given in Ref [1]. For brevity, we summarize that pebbles/cobbles were found in two distinct sediment layers on a mid-shelf environment from about 1-3 meters below the seafloor (the maximum depth of the core). The upper layer exhibited a low frequency (0.4-2 kHz) in situ sound speed of 1818±30 m/s and the lower layer 1528± 8 m/s. The uncertainties are reported at the at the 95% credibility interval. For these measurements, kd<1 (where k is wavenumber and d is scale length) and thus scattering from the cobble is expected to be weak. For the core sound speed measurements (at 50 and 200 kHz) kd>>1 and multiple scattering is expected with concomitant decrease in sound speed with increasing frequency. The core sound speeds bear this out and are much lower than the in-situ measurements: in the upper layer at 200 kHz, 1594±61 m/s (9 points) and in the
lower layer at 50 kHz, 1482±53 m/s (7 points) with the measurement variability represented by 2 standard deviations.

Without a sediment acoustics model that includes the wide range of grain sizes of the sediments examined here (from micron to 0.1 m) it is not possible to compare the low frequency in-situ estimates with the core measurements, other than to note general trends. One of the objectives of this work was to motivate the need for such a model and provide needed measurements for validation. A sediment acoustics model with a wide range of grain sizes (and pore sizes) would also be important for a more self-consistent treatment of scattering in sediments with discrete particles that are large with respect to wavelength. Also note that current scattering models generally consider the sediment sound speed to be non-dispersive whereas over a large band or at high frequencies, cobble or other large particles will induce significant dispersion.

The global distribution of pebbles and cobbles in sediments on the mid to outer shelf was also briefly explored. While evidence is lacking for their widespread existence, it is pointed out that this may be entirely due to the lack of current tools for their detection and sampling. Two conditions for cobble are required, the presence of a source (i.e., consolidated material) and sufficient energy for erosion and/or transport. Given the fact that many mid-shelf regions were sub-aerially exposed during the last Ice Age, wave action and flood events could provide sufficient energy to erode and transport cobbles to the present day mid-shelf region if there were a suitable source of consolidated material. Emery and Kuhn [10] estimate that 80% of the worlds’ coastlines are clifed, i.e., the majority of continental shelves have a nearby source of consolidated sediment for pebble/cobble production. Thus, cobble sediments on mid-shelf regions might be much more prevalent than generally assumed in this community. The amount of sediment covering the cobble would depend upon local sedimentation rates since the last sea-level lowstand.

The presence of cobbles has several important implications. First, their presence even in relatively low volume fractions (as here) may make a significant difference in the sound speed. The sound speed at relatively low frequencies (say less than 5 kHz for the cobbles here) might be reasonably well-predicted by empirical equations or more sophisticated models (e.g., [7],[8]). However, at many tens or hundreds of kilohertz, the sound speeds would be considerably lower. A second implication is that the presence of cobble, even in relatively low volume fractions, could lead to significant scattering which may dominate seabed (back) scattering and reverberation from hundreds of hertz to hundreds of kilohertz. Finally, the presence of cobbles can be expected to lead to a strong frequency dependence of attenuation, i.e., greater than frequency to the first power.

IMPACT/APPLICATIONS

The research is intended in part to motivate the need for better sediment acoustics models, that can treat realistic heterogeneous sediments. It is believed that such heterogeneous sediments are quite common in shelf environments around the globe. Thus, for military and commercial applications as well scientific understanding, suitable acoustic models are necessary.

A second research motivation was to better understand through measurements a marine sediment that has significant implications for scattering and reverberation in shelf environments. Recent evidence [11] indicates that there is an outer scale of order 0.1 m, that is common across several diverse continental shelf areas. This outer scale controls the frequency dependence of scattering and reverberation of active sonar systems. The corresponding sedimentary/biologic/geologic feature
responsible for this common outer scale is not known, but sediments containing a pebble/cobble constituent is one of several working hypotheses.

RELATED PROJECTS

**ONR shallow water field experiments:** the advances here will motivate experiment design to distendangle effects of sediment dispersion from other frequency dependent effects.

REFERENCES


PUBLICATIONS


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