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# Development of a system for in situ measurements of geoacoustic properties during sediment coring

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Sediment cores provide valuable insight on the physical properties of the seabed, and laboratory measurements of sediment wave speed from cores are often considered “ground truth.” However, sound-speed estimates obtained from cores can be inaccurate due to changes in pressure, temperature, and mechanical properties of the sediment caused by removal of the core from the seabed and its subsequent transport to the laboratory. To begin to address this deficiency, we report on the development of a system for obtaining *in situ* measurements of geoacoustic properties. The system mounts on the nose of a coring barrel to obtain an *in situ* record of compressional and shear wave speed and attenuation as the core penetrates the seabed. The depth of the *in situ* record is limited only by the penetration of the core. The compressional wave measurements are obtained with rod-mounted piezoelectric cylinders, and the shear wave measurements are obtained with bender elements mounted in flat blades. For both the compressional and shear wave measurements, wave speed and attenuation are estimated from differential measurements made with two receivers. [Work supported by ONR]

## INTRODUCTION

Sediment cores provide valuable insight on the physical properties of the seabed, and laboratory measurements of sediment wave speed from cores are often considered "ground truth." However, sound-speed estimates obtained from cores can be inaccurate due to changes in pressure, temperature, and mechanical properties of the sediment caused by removal of the core from the seabed and its subsequent transport to the laboratory.

To address these issues, a system for obtaining *in situ* measurements of geoacoustic properties was developed at the Applied Research Laboratories at the University of Texas at Austin (ARL:UT) in the 1970s [1]. Compressional wave speed was estimated from travel time between a single source-receiver pair mounted inside the nose cone of the corer. The outputs of the measuring electronics were recorded on an analog cassette tape recorder. Using this approach, an *in situ* record of compressional wave speed was obtained as the corer penetrated the seabed. The depth of the *in situ* record was limited only by the penetration of the core.

Recently, a new system based on the original concept has been developed at ARL:UT. In the new system, the transducers are mounted outside the nose cone to minimize the effect of sediment disturbance caused by penetration of the corer. Compressional wave measurements are obtained with rod-mounted piezoelectric cylinders, and shear wave measurements are obtained with bender elements mounted in flat blades. Compressional and shear wave speed and attenuation are estimated from differential measurements made with two receivers.

This paper contains an description of the *in situ* measurement system and a summary of the results from a recent engineering test. Included in the system description is an overview of the system's components as well as details of both the compressional and shear measurement capabilities. The engineering test was conducted aboard the R/V Endeavor in a region of the southern New England Continental Shelf known as the New England Mud Patch from 27 April - 1 May, 2016. A preliminary analysis of the data are discussed in this paper, which is restricted to estimates of the compressional wave speed.

## SYSTEM DESCRIPTION

In this section, the acoustic coring system is described. First, an overview of the system components is presented, and then more details about the compressional and shear measurements are presented.

Figure 1(a) shows a schematic of the acoustic coring system assembled with a gravity core. The photographs in Fig. 1 were taken during the 2016 engineering test. The electronics pressure vessel (PV) and weighted head of the gravity core is shown Fig. 1(b). The PV houses battery-powered electronics for driving the acoustic sources and digitizing and storing the signals from the receivers. The PV also contains a pressure sensor used for measuring the depth of the system. The blue electronics cables which connect the electronics package to the probe assemblies are also visible in the photograph. The transducer probe assemblies are shown in Fig. 1(c). The shear wave probe assemblies, which look like flat blades, are on the left in the photograph, and the compressional wave probes assemblies, which look like spears, are on the right.

To assemble the system, a core catcher is press fit into an acrylic liner, which is then inserted into a 3" NPT steel pipe that acts as the core barrel. A core liner from a recovered core filled with sediment is shown in Fig. 1(d). The nose cone is then threaded on to the end of the core barrel to capture the core catcher and liner assembly. Next, the probe assemblies are screwed onto the nose cone as shown in Fig. 1(f). Transducer probe assemblies are individually attached to the nose cone with screws so a single probe can be replaced if one is damaged. The blue electronic cables were fastened in place during deployment with heavy-duty abrasion-resistant

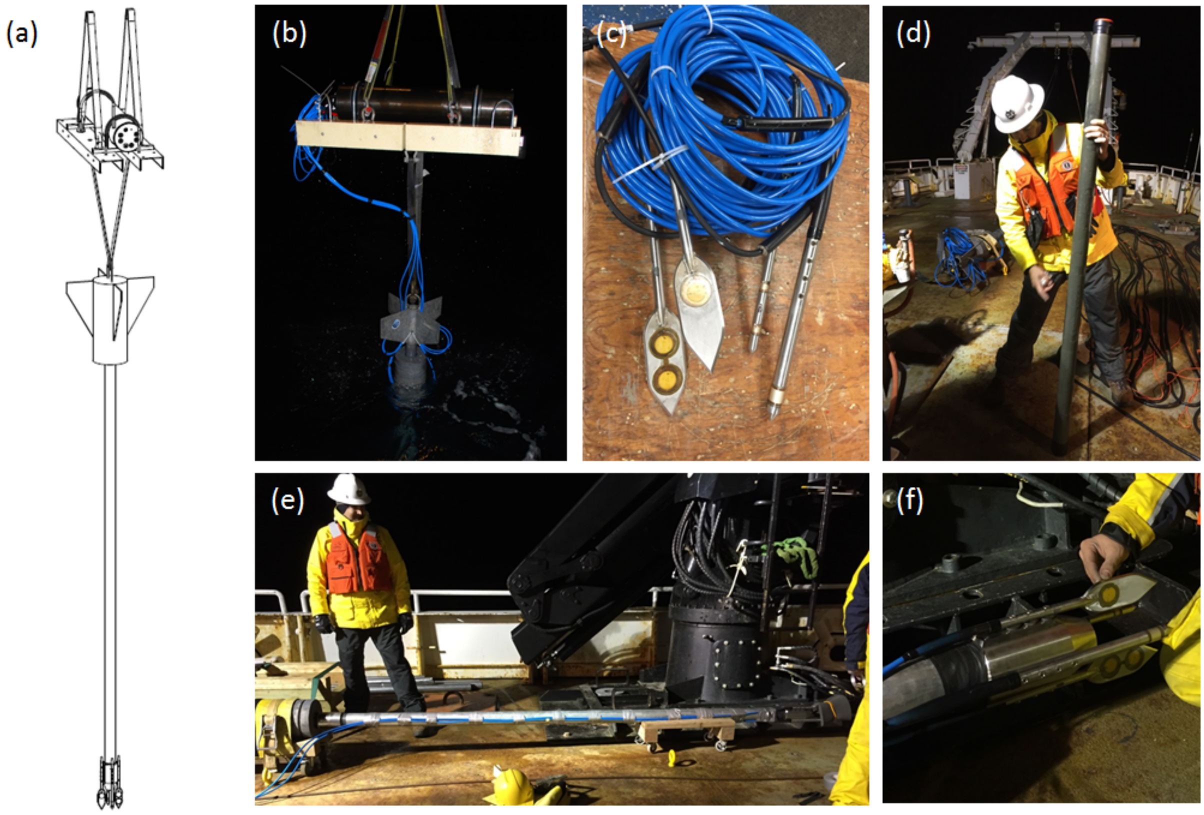

**FIGURE 1:** (a) Schematic of the acoustic coring system assembled with a gravity core. Photographs of the system components (b) the electronics package and weighted head of the gravity core during a deployment, (c) transducer probe assemblies, (d) core liner filled with sediment, (e) assembled system on the deck of the R/V Endeavor, and (f) probes attached to the nose cone of the core barrel.

tape as shown in Fig. 1(e). Then the electronics cables from the probe assemblies are connected to the electronics PV. The last step in readying the system for deployment is removing a shorting plug, located on the PV, which starts the sources and recorder.

CAD models of the nose cone with probe assemblies attached are shown in Fig. 2. As shown in the figure, both the compressional and shear wave probes are outside of the inner diameter of the corer, to minimize their effect on the sediment collected in the core barrel. The core catcher, consisting of stainless steel spring-fingers, which must be forced open to allow sediment to fill the core barrel, is expected to have a more significant impact on the material collected by the corer than the acoustic probes.

The compressional wave probes are clearly visible in Fig. 2(b), with the larger source element mounted in the rod on the right and the two receiver elements mounted in the rod on the left. The sizes of the cylindrical PZT elements are summarized in Table 1. For the data presented in this paper, the source signal was for the compressional waves is 20 cycles of a sinusoid with a frequency of 50 kHz. The data recorded by the compressional wave receivers was bandpass filtered (20 kHz to 300 kHz) and sampled at a frequency of 1 MHz. Uncertainty in the sound speed estimated from the propagation path from the source to the on axis receiver was estimated from the uncertainty in the arrival time $\sigma_t = 1 \times 10^{-6}$ s and uncertainty in the positioning $\sigma_x = 1 \times 10^{-3}$ m. The resulting uncertainty in the compressional wave speed from a propagation of error calculation was 20 m/s. The relatively high uncertainty in the compressional wave speed results from the short propagation paths combined with comparatively high wave speeds.

The shear wave probes can be observed in Fig. 2(c), where the source transducer is mounted

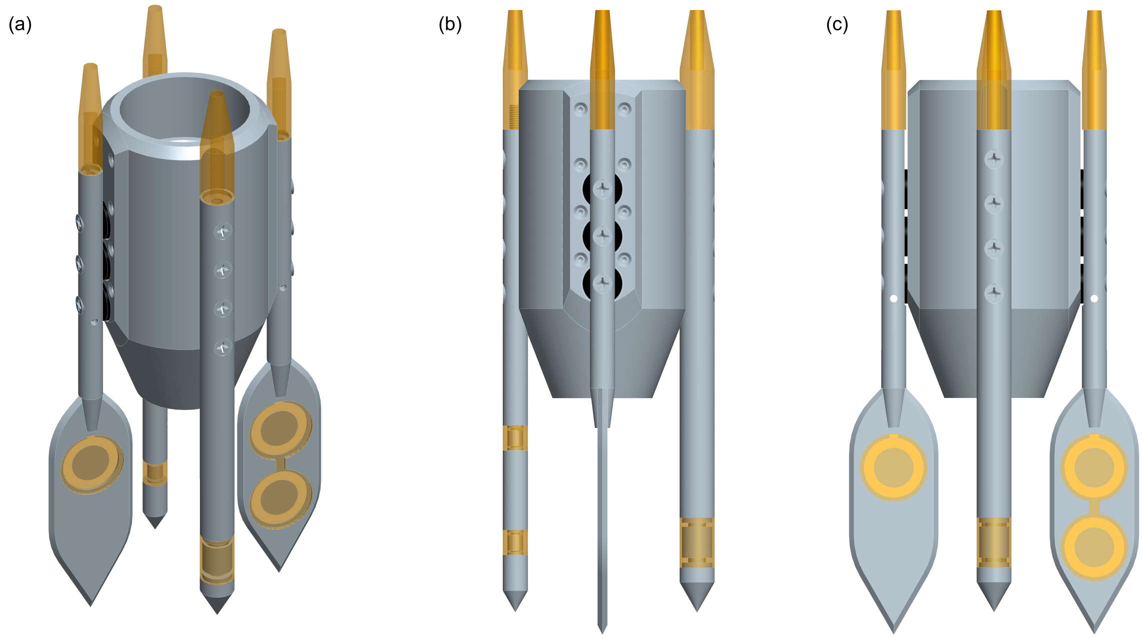


**FIGURE 2:** (a) Oblique and (b, c) side views of the corer nose cone with transducer probes attached.

**TABLE 1:** Sizes of the compressional wave transducers.

| | ID (mm) | OD (mm) | Length (mm) |
|---|---|---|---|
| source | 19.0 | 16.0 | 20.0 |
| receiver | 10.0 | 8.0 | 10.0 |

in the blade on the left and the receivers are mounted in the blade on the right. Both source and receiver are bender elements transducers with the same dimensions, having a diameter of 26.0 mm and thickness of 0.36 mm. The bender consists of circular, thin piezoceramic plates rigidly bonded along their sides. The two plates are driven 180 degrees out of phase so that the differential change in diameter of each plate causes the composite element to bend. When the bender is embedded in a medium, shear waves propagate in the radial direction and compressional waves propagate in the perpendicular direction [2]. For the source element, the bender is configured in parallel, so that the two piezoelectric layers have the same poling direction. The receiver elements are configured in series, such that the poling directions of the two piezoelectric layers are opposite to each other. For a given displacement, the series configuration produces a larger output voltage compared to the parallel configuration [3].

For the data presented in this paper, the source signal for the shear waves was 8 cycles of a sinusoid with a frequency of 1 kHz. The data recorded by the shear wave receivers was bandpass filtered (100 Hz to 20 kHz) and sampled at a frequency of 50 kHz. Uncertainty in the sound speed estimated from the propagation path from the source to the on axis receiver was estimated from the uncertainty in the arrival time $\sigma_t = 2 \times 10^{-5}$ s and uncertainty in the positioning $\sigma_x = 1 \times 10^{-3}$ m. The resulting uncertainty in the shear wave speed was 3 m/s.

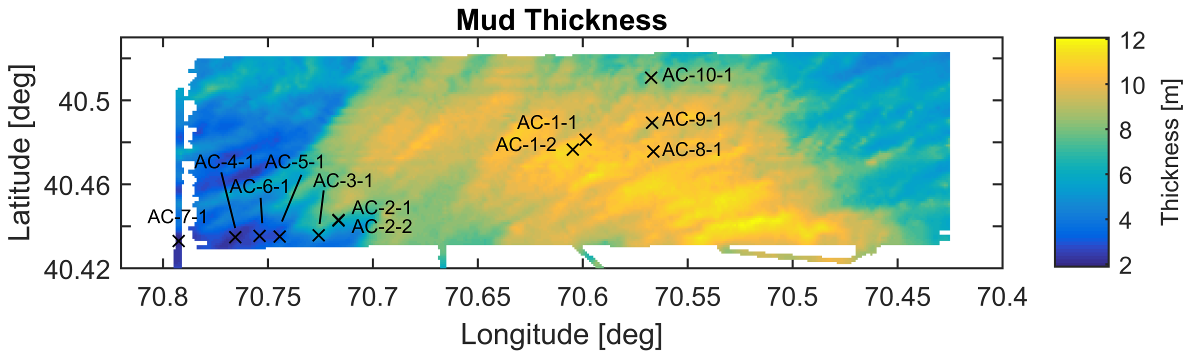


**FIGURE 3:** Thickness of the mud layer estimated from CHIRP seismic data (courtesy John Goff), assuming a sound speed of 1480 m/s. Coring locations are indicated by the “x” marks.

## ENGINEERING TEST

An engineering test was conducted aboard the R/V Endeavor in the New England Mud Patch as part of the environmental survey for the ONR Seabed Characterization Experiment. The Mud Patch is an area in the southern New England continental shelf composed of fine-grained sediments that overlay a sand sheet that is similar to and continuous with the sediment exposed on the shelf to the west. The Mud Patch covers 13,000 km$^2$ and is as much as 13 m thick [4, 5].

During a survey cruise conducted in July of 2015 aboard the R/V Hugh R. Sharp, the experiment region was mapped with a CHIRP seismic system. The CHIRP data was collected and analyzed by John Goff of the University of Texas Institute of Geophysics (UTIG). The thickness of the mud layer was estimated from two-way travel time data by assuming a sound speed of 1480 m/s. As shown in Fig. 3, the thickest part of the mud layer is near the center of the experiment region and thins near the edges.

Over four nights of testing, 12 gravity cores were collected in 10 locations with the *in situ* acoustic system attached. All cores were collected using a 3 m core barrel. Coring locations are indicated by the “x” marks on the mud thickness map. A number of cores concentrated on the southwest corner of the experiment region where the mud layer is the thinnest. These locations were selected to sample both the mud layer and the uppermost portion of the sand beneath.

The penetration depth of the acoustic probes was estimated from acoustic signature of impact with the seafloor and penetration into the seabed: the amplitude of the received signals is constant in the water column, has a spike at impact with the seafloor, and fluctuates as the core penetrates through the seabed. On average the acoustic record extends to a depth 50% deeper than the length of the recovered core. Potential reasons for the difference are (1) loss of material during recovery, (2) plugging of the core during penetration into the seabed, and (3) compaction of the sediment in the core barrel. As corroborating evidence, in many cases, sediment was observed on the outside of the core barrel significantly farther from the penetrating tip than the length of the sediment collected in the core liner.

The estimated compressional wave speed profiles for the five cores collected in the southwest corner of the mud patch are shown in Fig. 4. In the figure, the sound speed estimated from the *in situ* profile is shown by the blue dots. The 20 m/s uncertainty in the estimate is observed from the discretization of the estimated profiles. For visualization purposes, and curve has been fit to the data and is shown by the orange line. The horizontal lines in each of the plots represent the depth of the seafloor (upper line) and the base of the mud layer (lower line). The depth of the seafloor was estimated from the pressure sensor on the acoustic coring system, and the depth of the mud base was estimated from the CHIRP seismic data shown in Fig. 3. The vertical scales

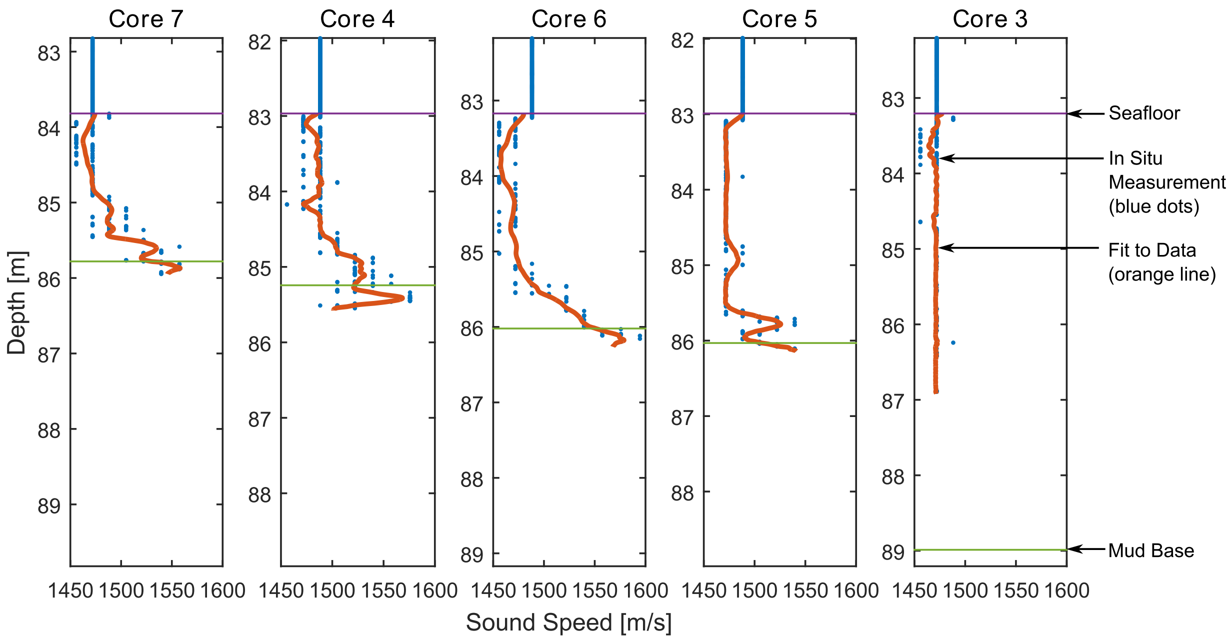


**FIGURE 4:** *in situ* sound speed measured by the acoustic coring system (blue dots) with a fit to the data (orange curve). The horizontal lines represent the depth of the seafloor (purple line) and the depth of the base of the mud layer (green line). The core numbers correspond to the locations shown in Fig. 3.

on the individual plots in Fig. 4 are aligned relative to the seafloor depth.

In each of the plots shown in Fig. 4, the sound speed above the seafloor is the sound speed in the water column. During the engineering test, the water column sound speed varied on the order of 10 m/s, which is less than the uncertainty in the compressional wave speed estimated by the acoustic coring system. The water column sound speed estimated by the acoustic coring system was consistent with CTDs measured during the experiment.

For cores AC-7, AC-4, AC-6, and AC-5, the depth of the acoustic record is correlated with the depth of the mud base estimated from the CHIRP data. The penetration depth of the gravity core is affected by the sediment composition: the corer was able to penetrate the mud layer, but stopped when it reached the coarser material beneath. The longest of the five cores was collected at site AC-3, where the mud layer is more than 5 m thick. For this core, the acoustic record extends more than 3 m in to the seabed and muddy sediment was observed on the weights above the core barrel.

In addition to their truncated length, the four cores that penetrate through the bottom of the mud layer all show an increase in the compressional wave speed in the vicinity of the mud base. This is consistent with the presence of sand underlying the mud, as sand has a faster sound speed than mud. Likewise, core AC-3 which only samples the mud layer, is characterized by a more homogeneous sound speed profile in the sediment.

Finally, all of the estimated sound speed profiles in the upper portion of the seabed are characterized by a sound speed less than that of the water column. A sound speed ratio less than one is characteristic of fine-grained sediments [6]. Several of the cores show a minimum in the sound speed profile in the first meter below the seafloor. The cause of this feature is under investigation.

## Conclusion

This paper described a new system to obtain *in situ* measurements of compressional and shear wave speed and attenuation. The system consists of transducers housed in probes, which mount on the penetrating tip of a sediment corer. The system provides a profile of the geoacoustic properties of the seabed from the seafloor to the penetration depth of the corer.

Compressional wave speed profiles estimated from the *in situ* measurements were presented for cores collected in the New England Mud Patch. The results were interpreted using CHIRP seismic data, and the compression wave speed profiles were were consistent with the environmental description from the CHIRP survey. Estimates of compressional wave attenuation and shear wave properties are part of an on-going analysis.

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