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URI Assets and Interests

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University of Rhode Island

THINK BIG WE DO℠

This work was sponsored by a Defense University Research Instrumentation Program grant through the Office of Naval Research.

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Influence of Shear – Recent Work

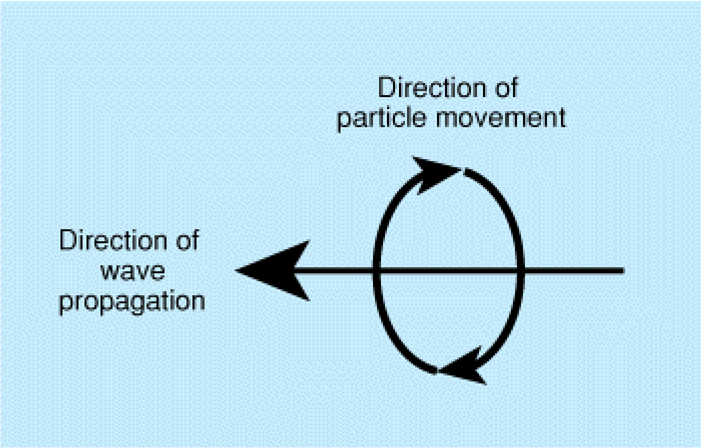
- Recent interest in studying the effect of shear on compressional wave attenuation, especially the frequency dependence.
- Recent results showing the effect of shear on modal travel times
- Some studies focusing on the removal of energy from the field due to shear wave conversion by Carey *et al., J. Acoust. Soc. Am. (2008).*
- Pierce and Carey (*POMA 8 005001 (2010)*) showed that geoacoustic inversions tend to deduce

$$\alpha_{\mathrm{pw}} + 8\sqrt{2}\left(\frac{c_{\mathrm{bot}}}{c_{\mathrm{wc}}} - 1\right)^{3/2} \frac{\omega c_{\mathrm{sh}}^3}{c^4}$$

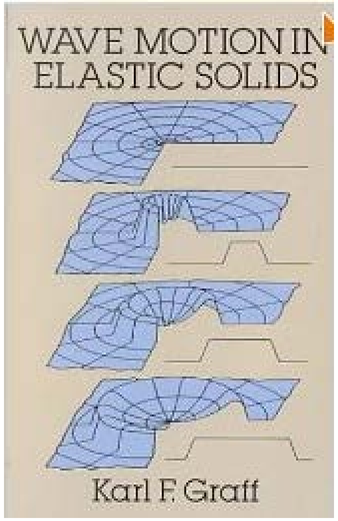
- Attenuation associated with shear is directly proportional to ω and cube of the shear speed

Shear is also important in geotech. applications (slope stability, foundations for deepwater structures etc.)

Interface Waves

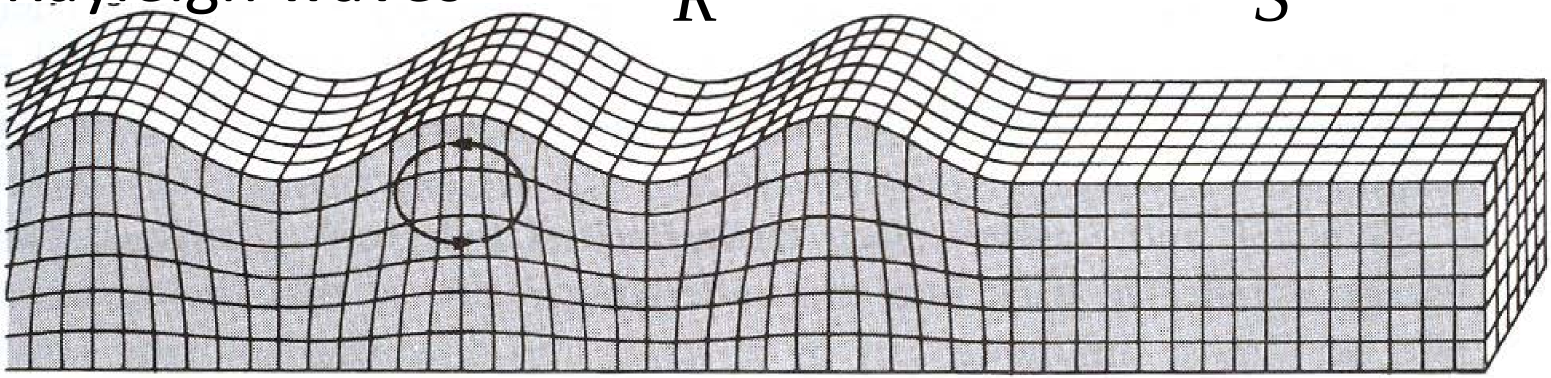


Interface Media	Interface Wave
Air/Solid	Rayleigh
Liquid/Solid	Scholte
Solid/Solid	Stonely



- Rayleigh waves

$$c_R = 0.9194 c_S$$



The particles in a Rayleigh wave oscillate in an elliptical path within the vertical plane containing the direction of wave propagation. Within the elliptical path, particles travel opposite to the direction of wave propagation at the top of the path and in the direction of propagation at the bottom of the path.

Scholte Waves

- **Decay exponentially in amplitude away from the boundary in either medium(i.e., the wave is evanescent in both media).**
- **The propagation speed and attenuation closely related to shear-wave speed and attenuation over a depth of 1-2 wavelengths in to the seabed, but are relatively insensitive to the compressional-wave properties.**
- **Dispersion characteristics of the Scholte wave provide information about the sediment shear-speed gradient, and a shear-speed model can be constructed by matching the observed dispersion properties.**

From Osler and Chapman, Canadian Acoustics, 24(3), 1996

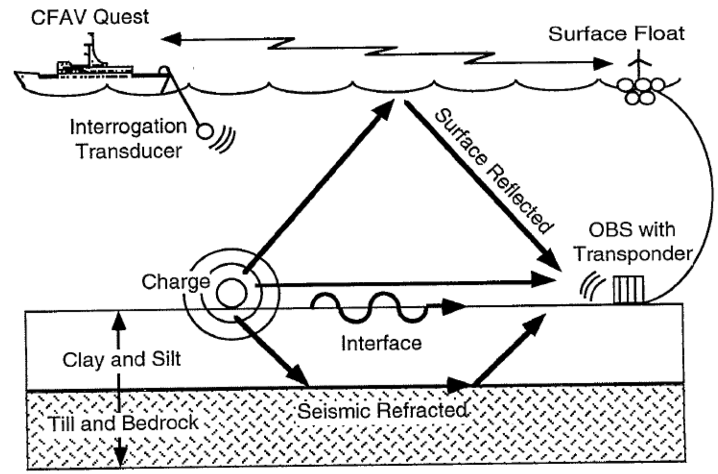
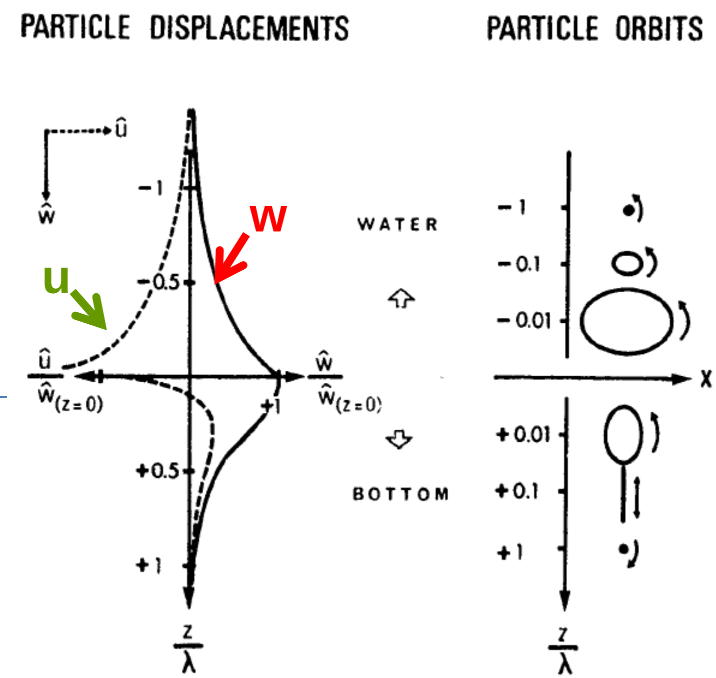
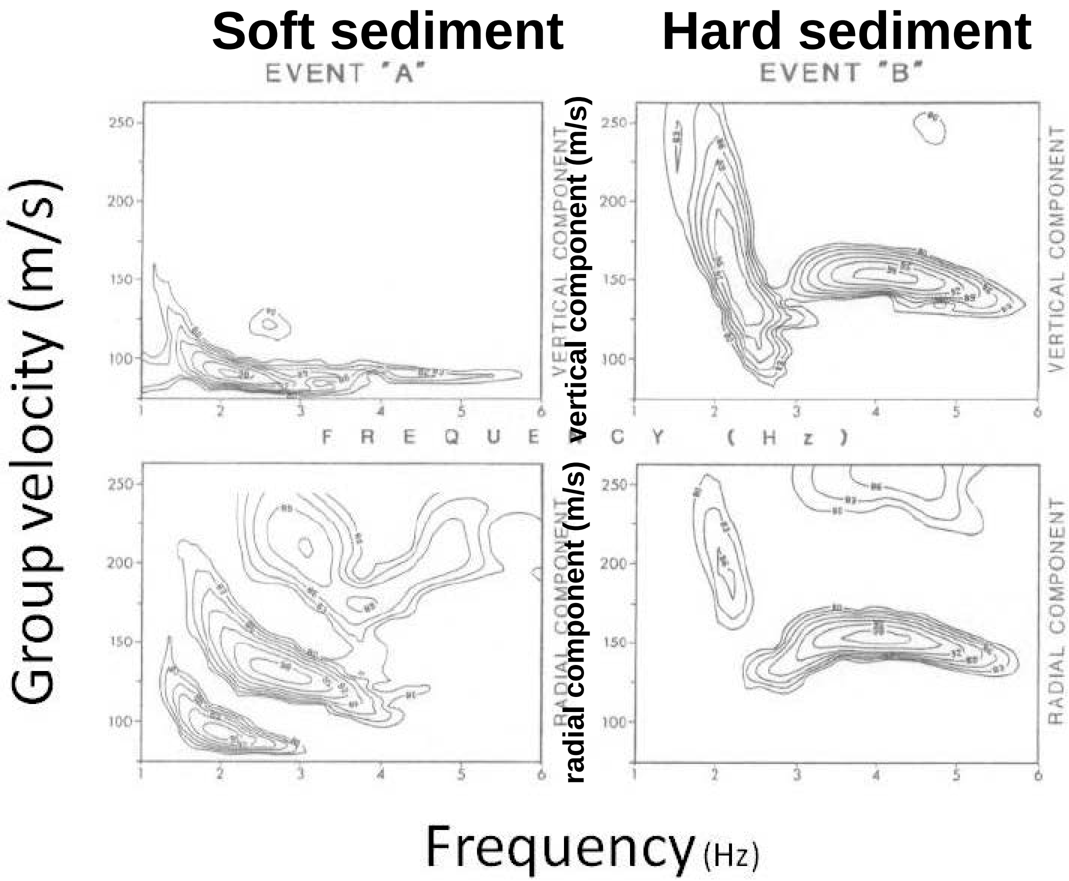


Figure 5: Source to receiver arrival paths and schematic of experimental setup.



Dosso and Brooke, J. Acoustic. Soc. A., 98(3), 1995
Rauch, Seismic interface waves in coastal waters: A review, SACLANT Report, 1980

Dispersion of interface waves



Dispersion of interface waves generated in a 'soft bottom'(Event A) and 'hard bottom' (Event B).

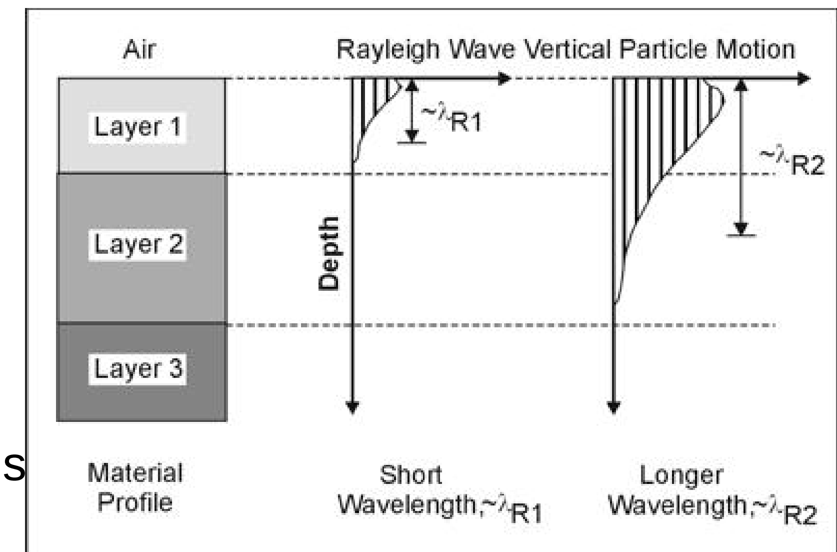
[Figure from Rauch, 1985]

Soft sediments

- 10s to few 100s of m/s
- Strong dispersion (many modes) due to sedimentary layering
- Higher attenuation

Hard sediments

- 1200s to 1500s of m/s
- Dispersion less pronounced
- Low attenuation



Different wavelengths sample to different depths causing dispersion in heterogeneous media.

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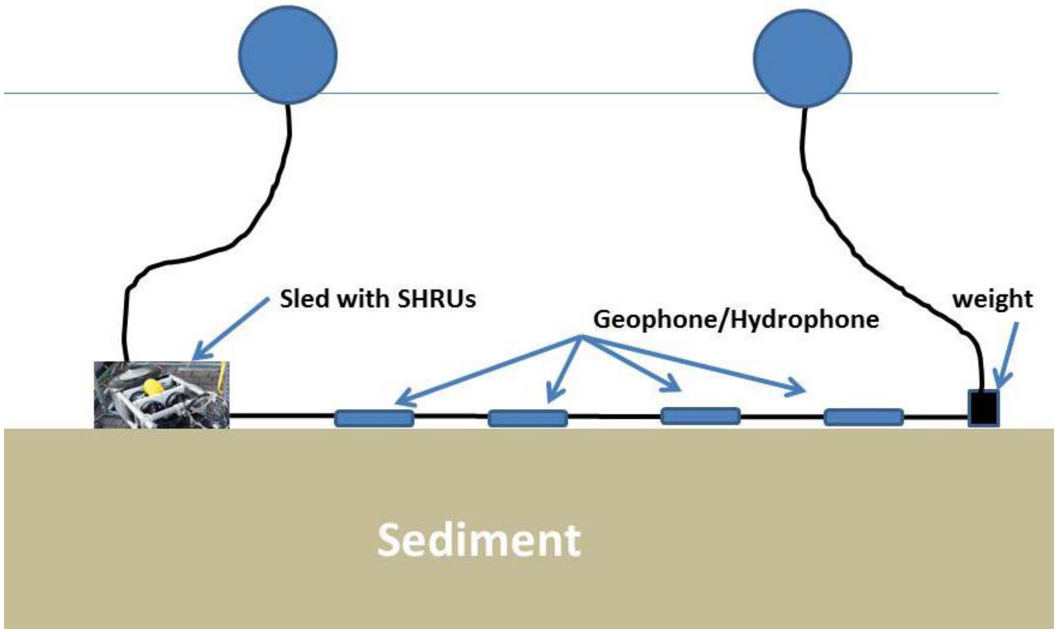
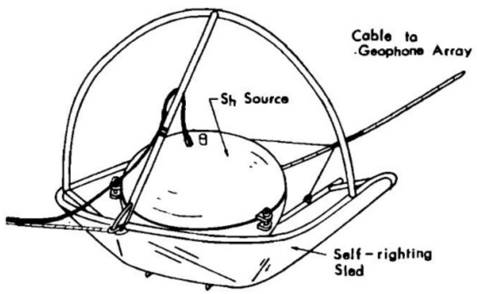
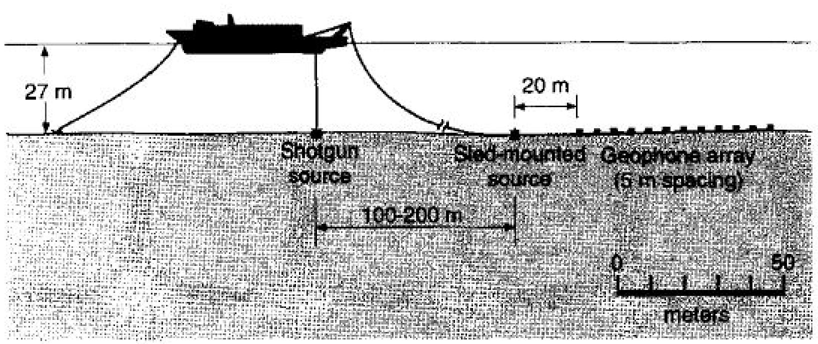
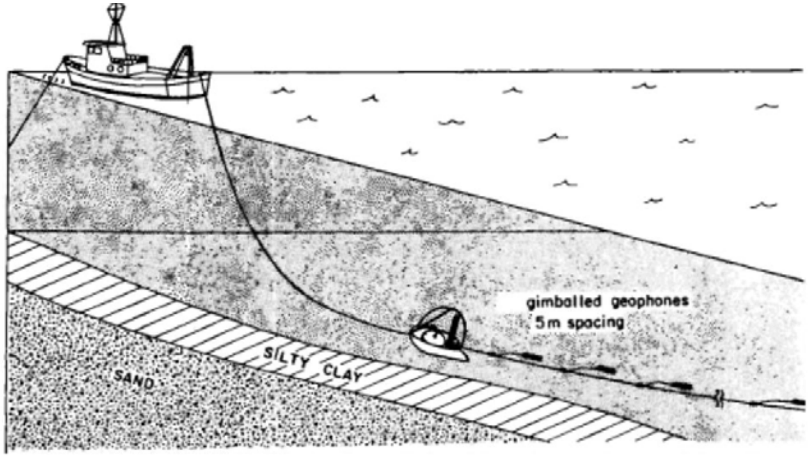
URI Shear Measurement System

Shear measurement system consisting of a geophone/hydrophone array and data collection system (SHRU)









John Ewing, Jerry A. Carter, George H. Sutton, and Noel Barstow, Shallow water sediment properties derived from high-frequency shear and interface waves, Journal of Geophysical Research 97 (1992), no. B4, 4739{4762.

A. Caiti, T. Akal, and R.D. Stoll, Estimation of shear wave velocity in shallow marine sediments, IEEE Journal of Oceanic Engineering 19 (1994), 58{72.

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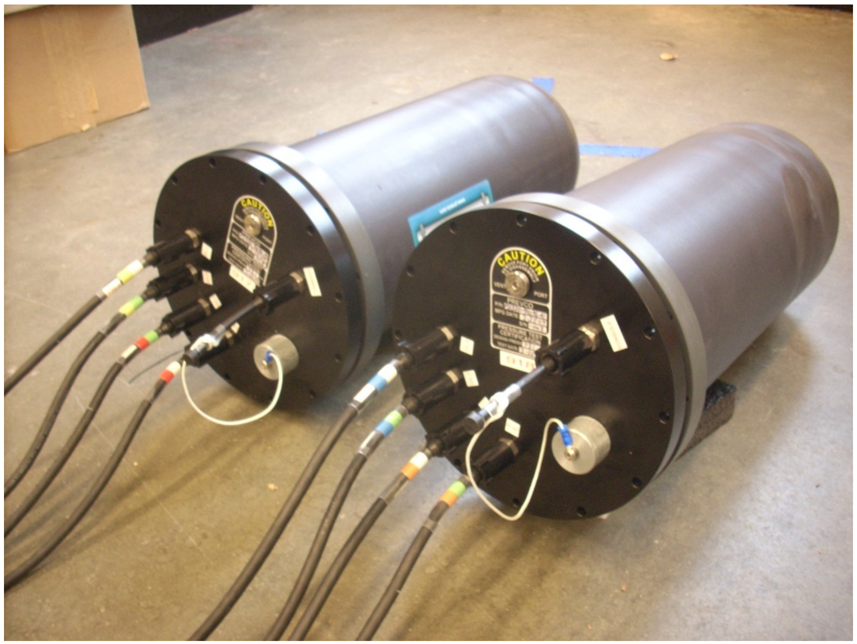
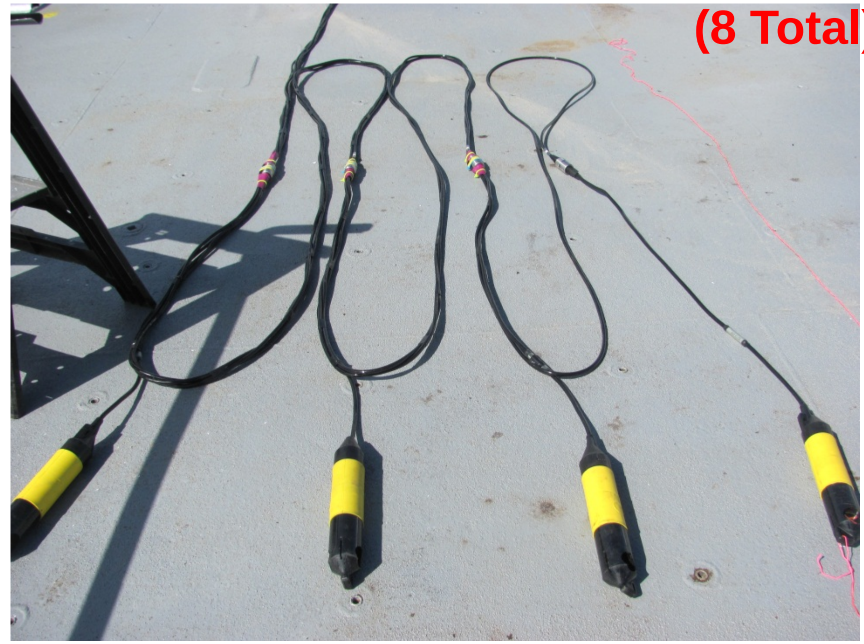
System Components

Several Hydrophone Receive Units (SHRUs) : 3 Units (12 Channels)



Vertical Geophones (gimbaled) and Hydrophone

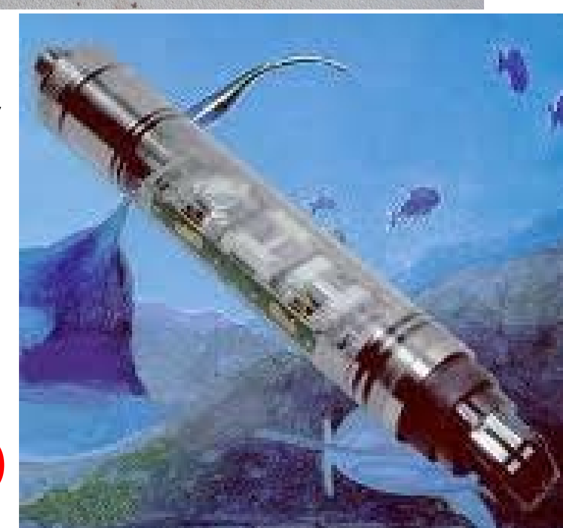
(8 Total)



HTI-94-SSQ SERIES -

HTI-94-SSQ Hydrophone (8 total)

Geospace Sea Array 3-axis Gimbaled Geophone (three mutually perpendicular geophones) and Hydrophone **(2 total)**



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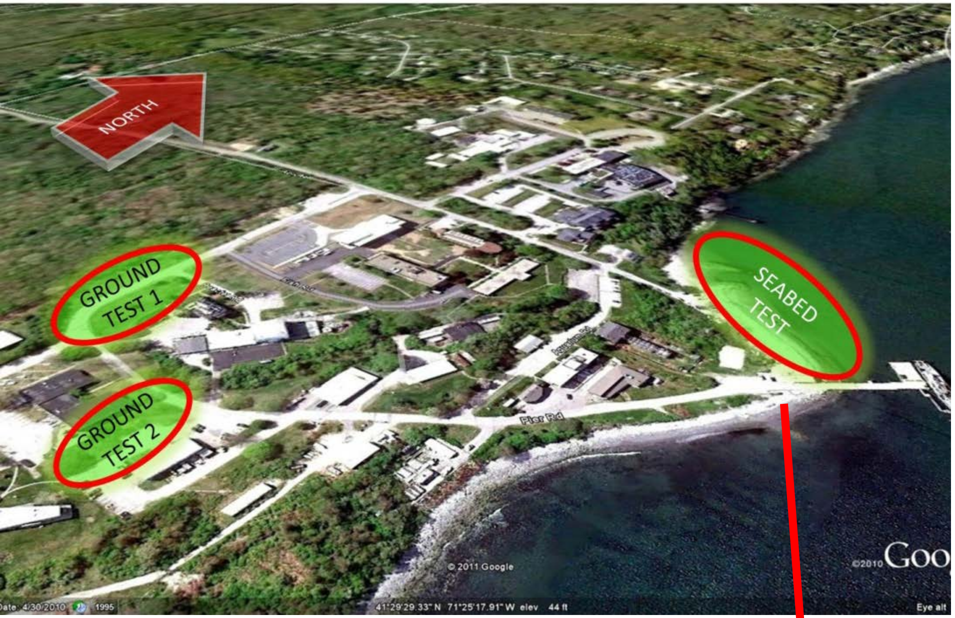
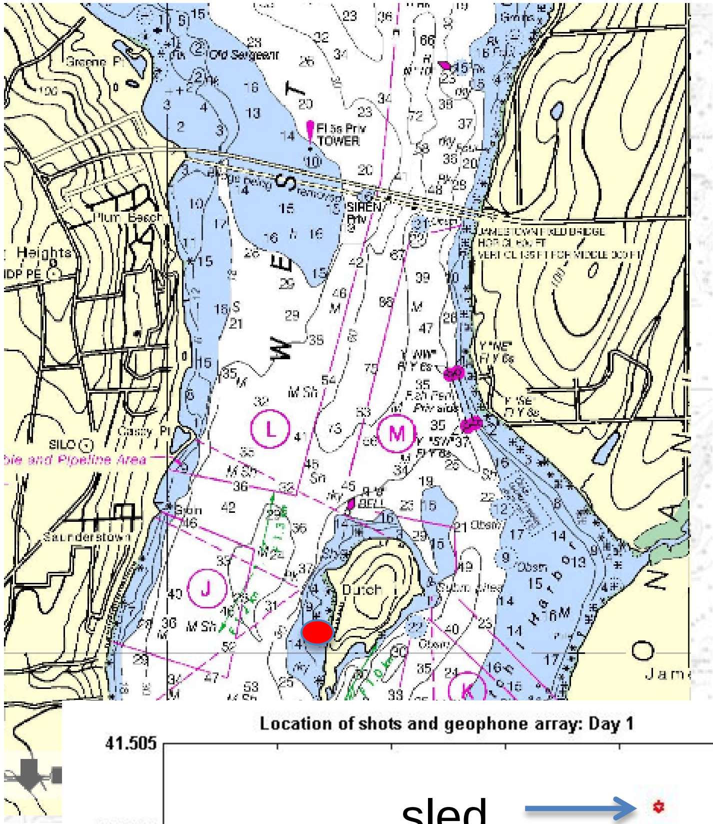
Tests: GSO Pier and Narragansett Bay

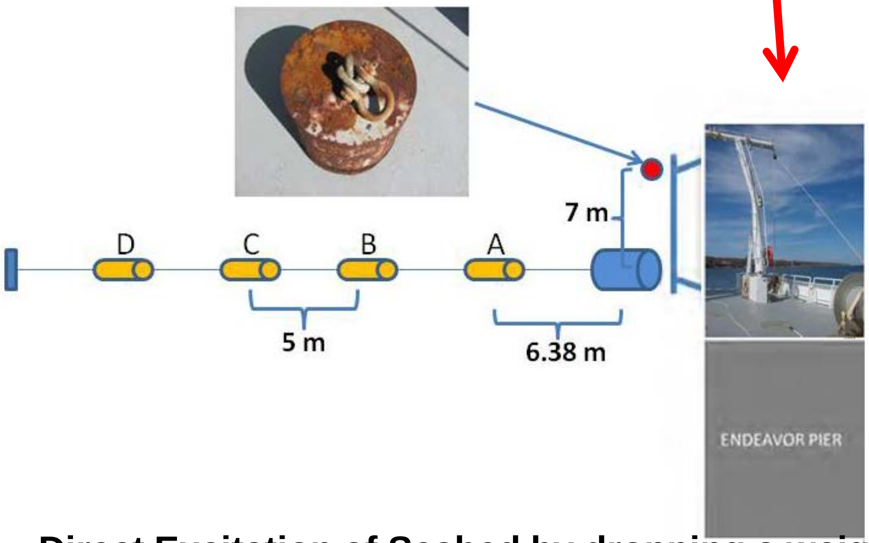


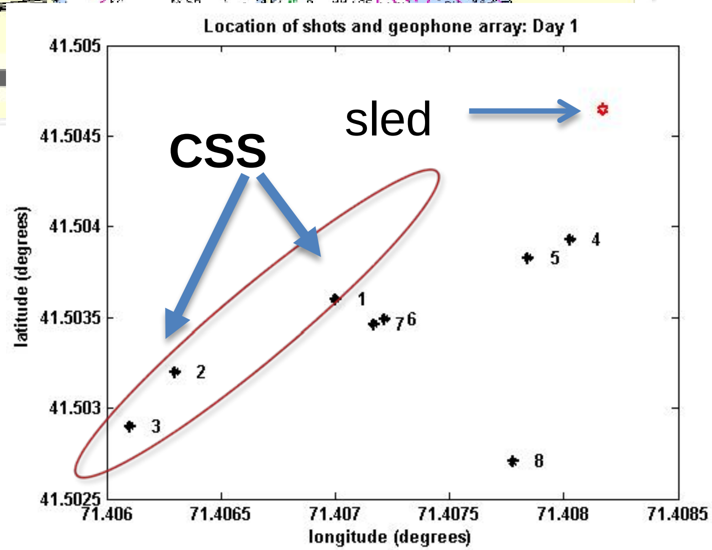


Two field tests

Simple source (thumping the bottom)

Using Combustive Sound Source





- Direct Excitation of Seabed by dropping a weight
- Geophones placed in position by divers

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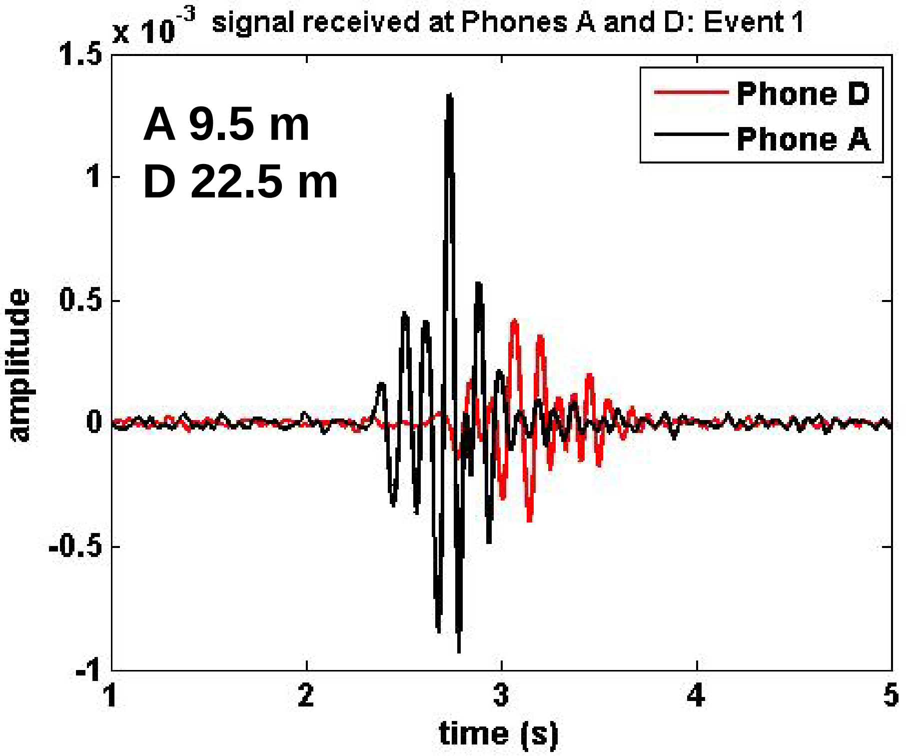
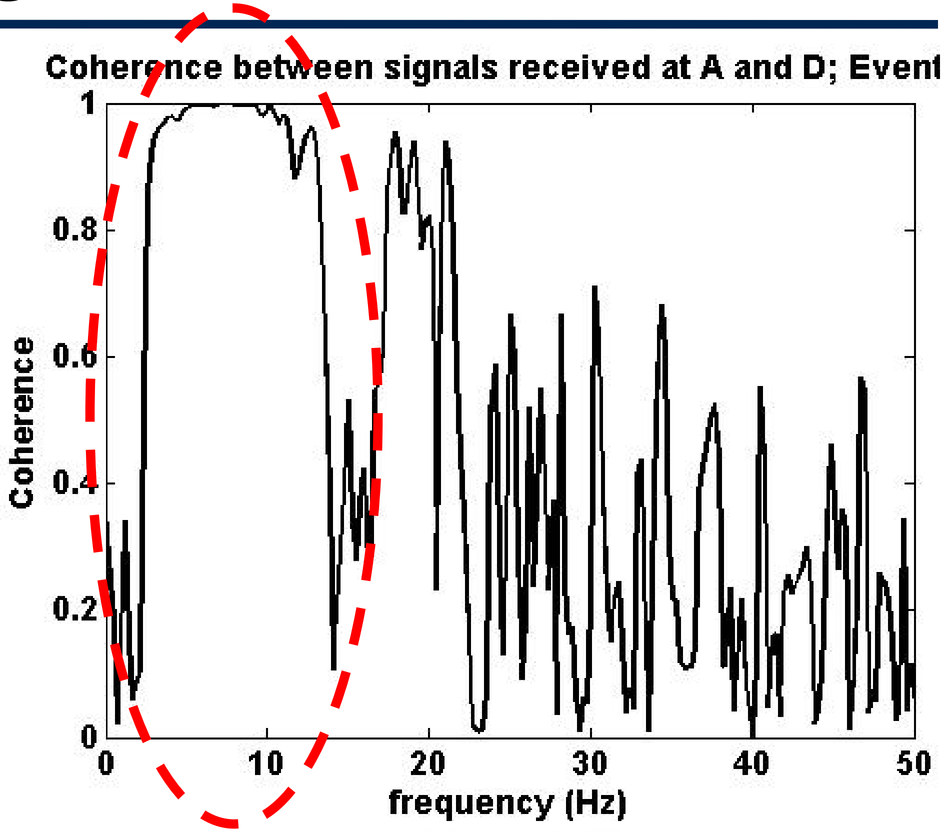
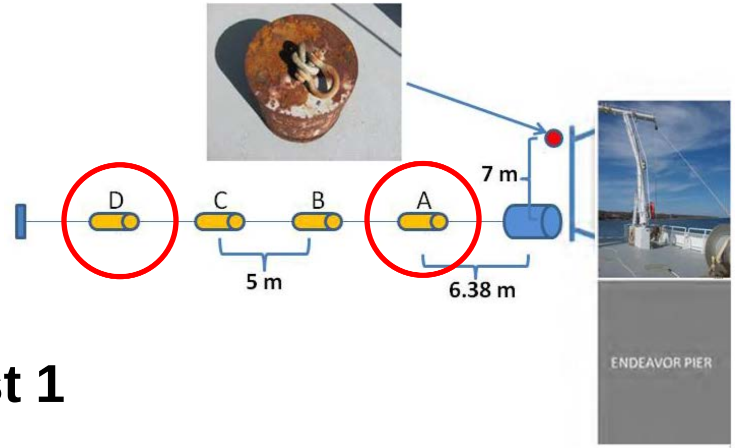
Received Signal and Coherence







Test 1

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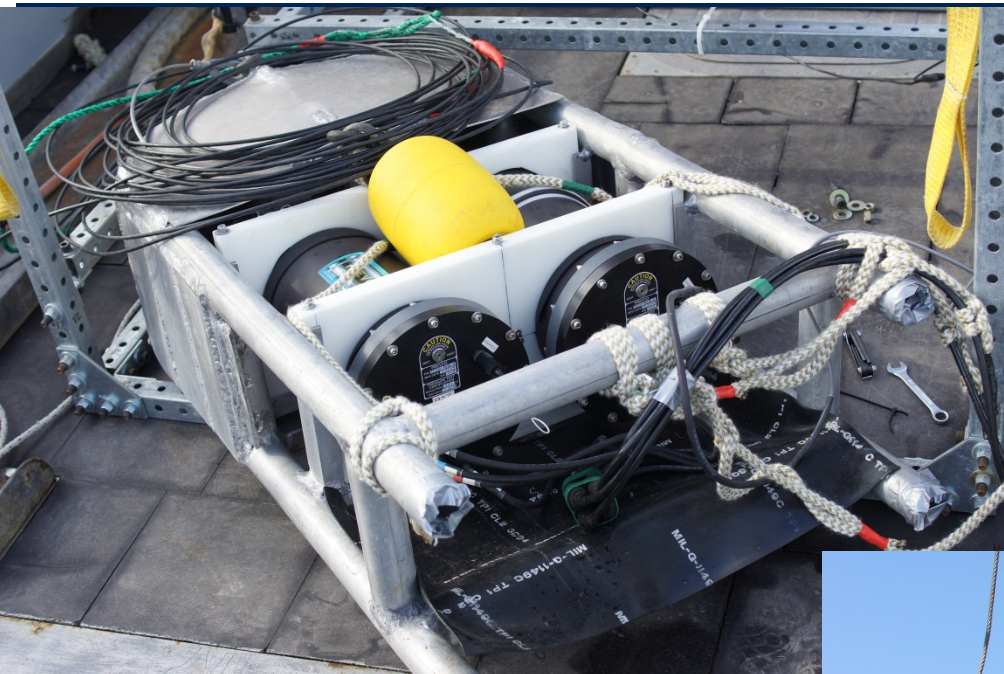
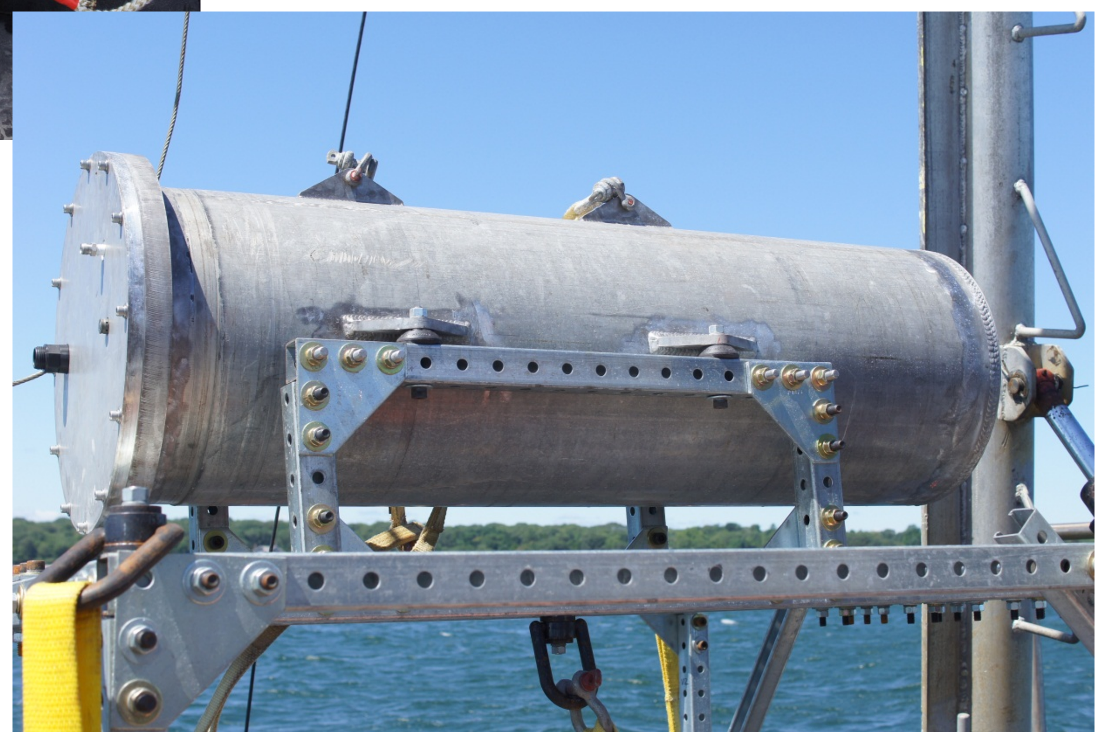
Shear Measurement System



Sled: Houses two SHRUs
The geophone array will follow the sled into the water

Gas generator for the CSS



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Shear Measurement System

Sled being deployed

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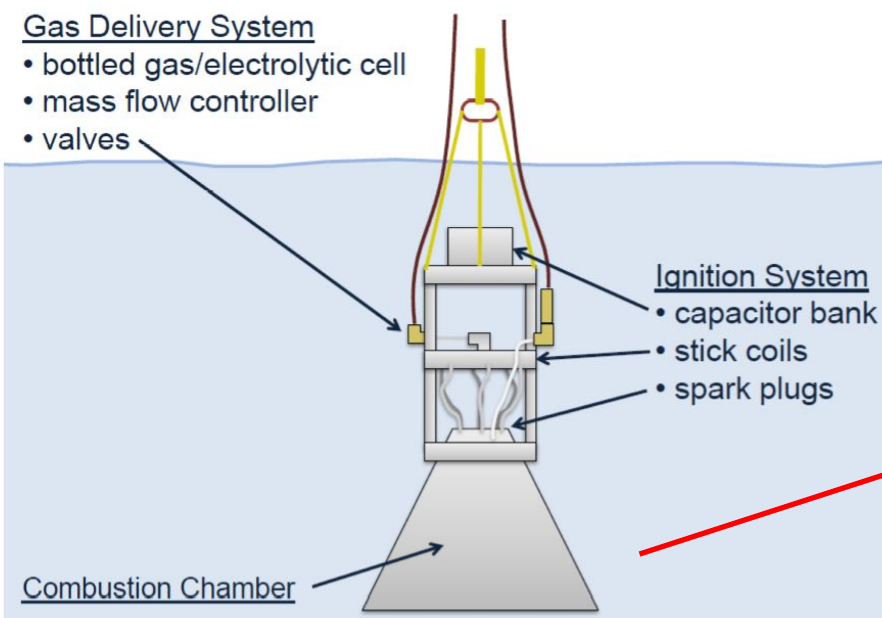
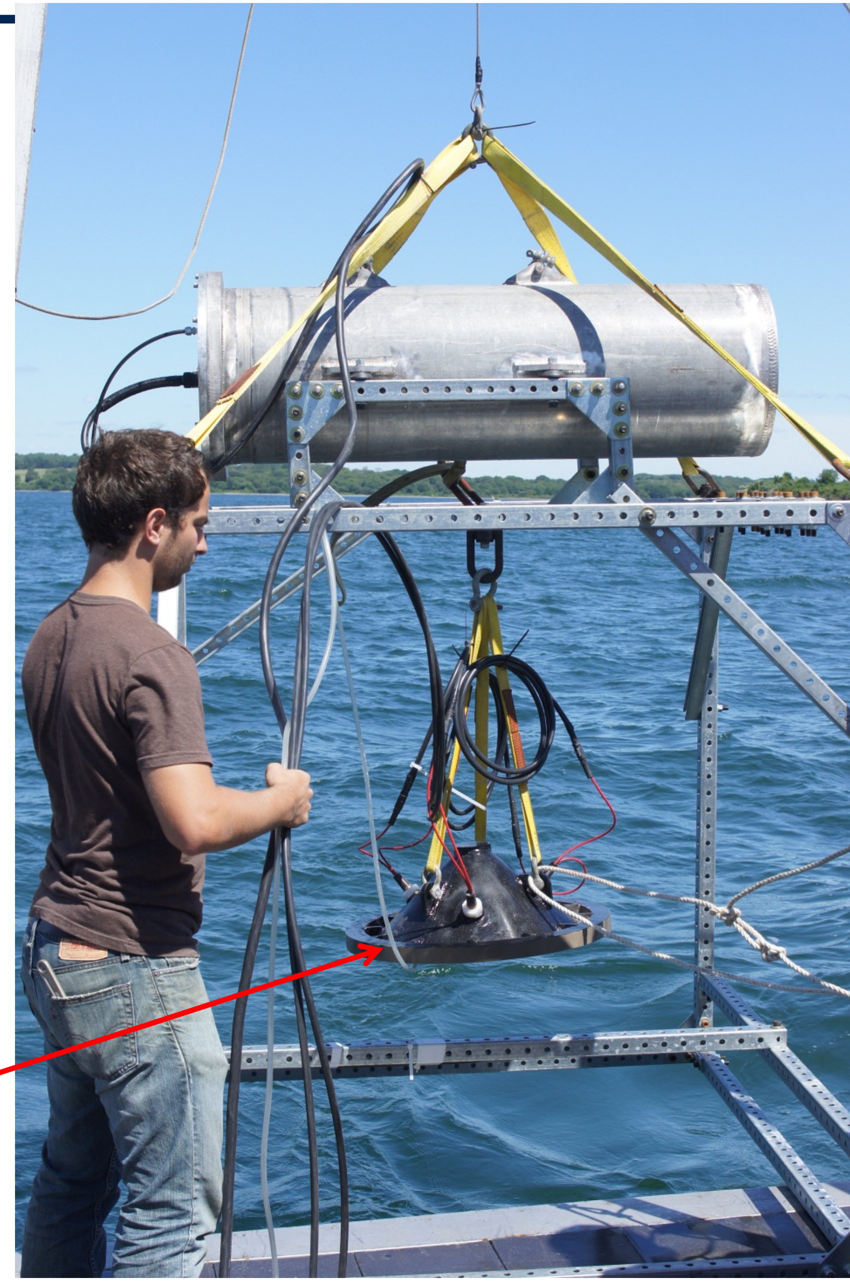
Shear Measurement System

CSS being lowered into water





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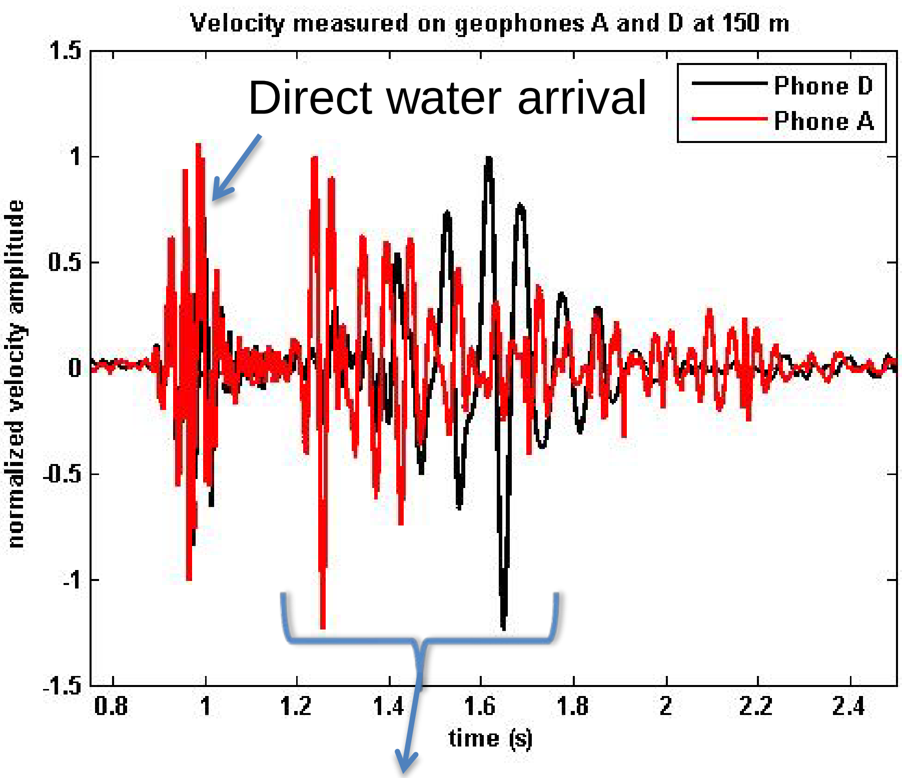
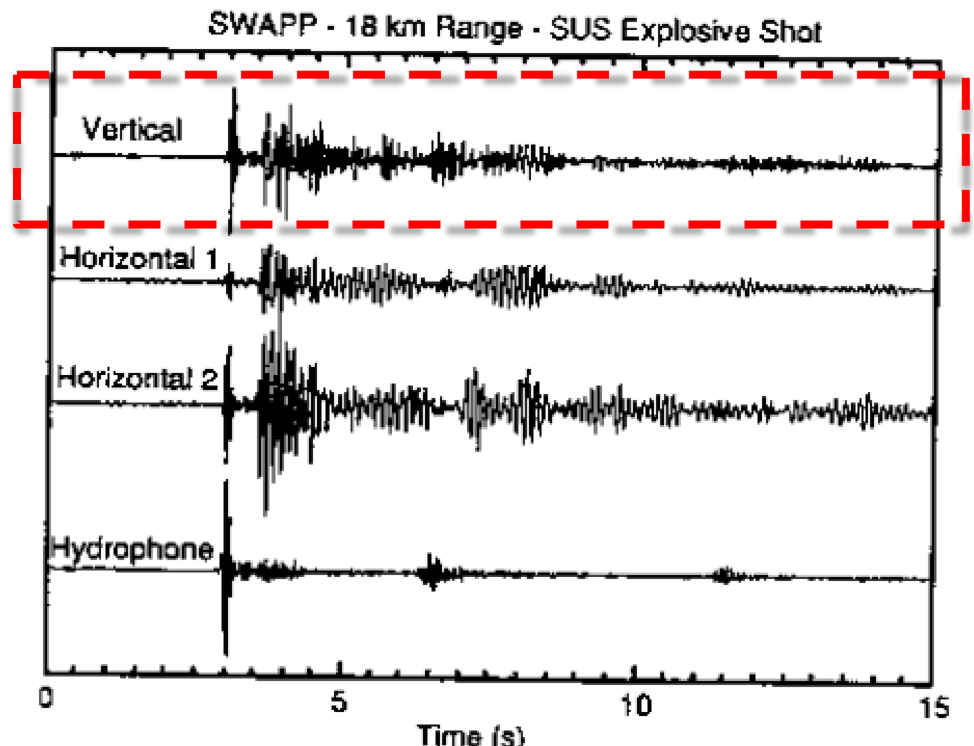
CSS Signals on geophones A and D

Vertical velocity component



Surface wave arrival

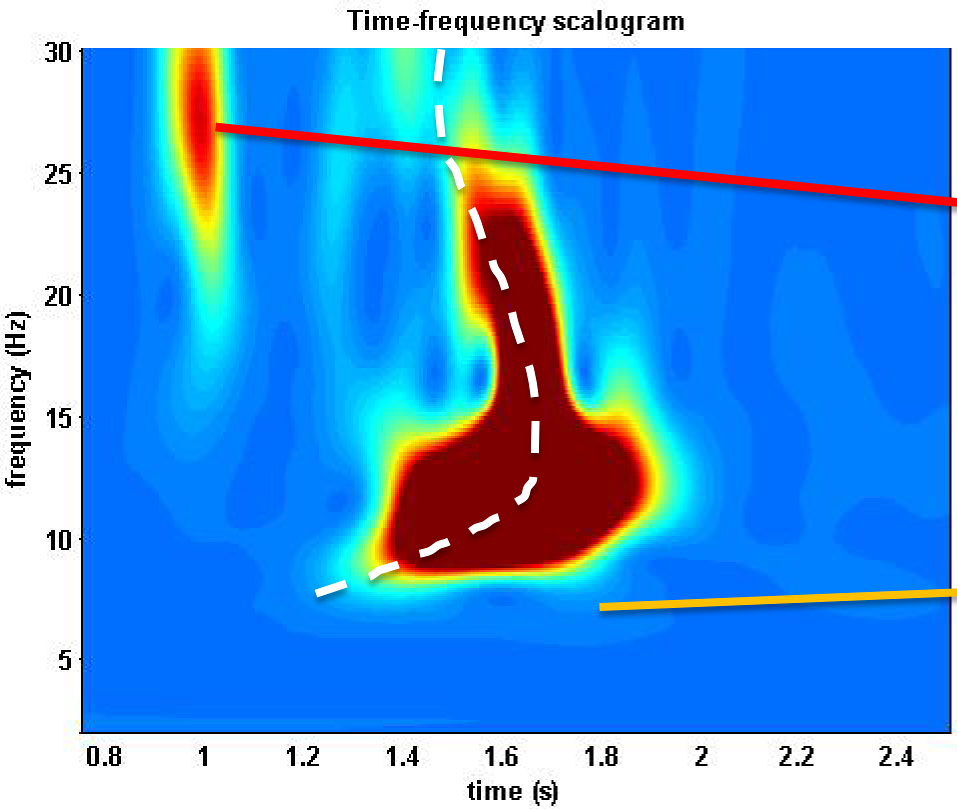


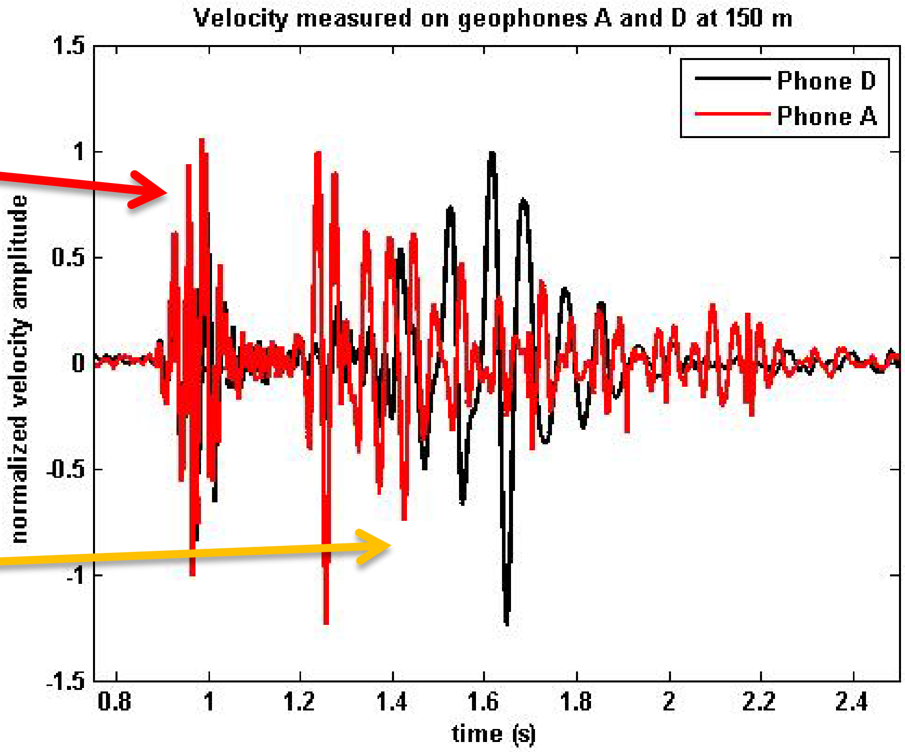
Bibee, "A comparison of seismometer and hydrophone recordings of VLF seismo acoustic signals," Oceans 1991.

Presence of seafloor roughness or lateral variations in sub-seafloor compressional and/or shear wave velocity may indirectly excite these propagation modes through scattering processes.

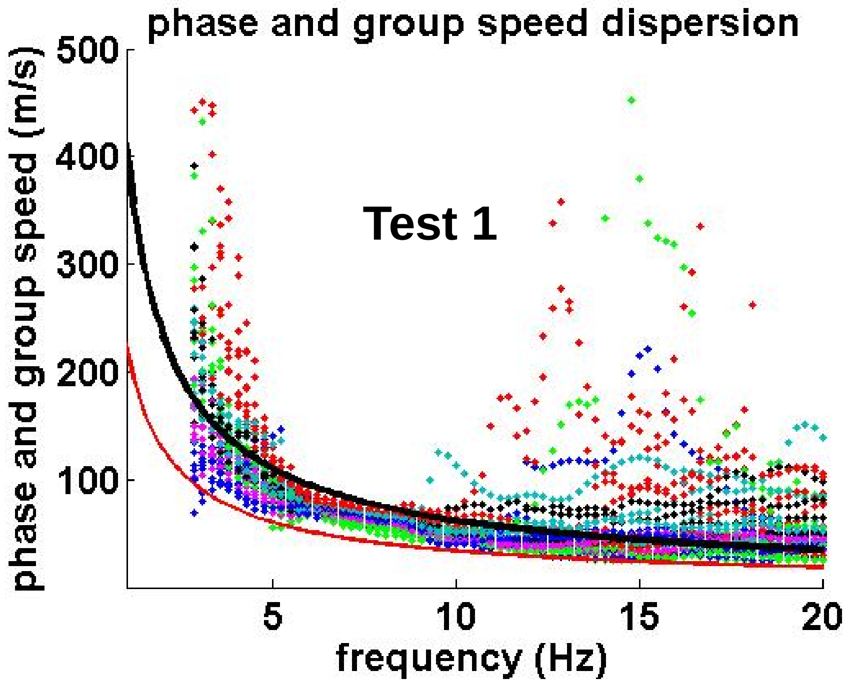
Hydrophone (co-located with geophone) not available for Day 1 due hardware problems

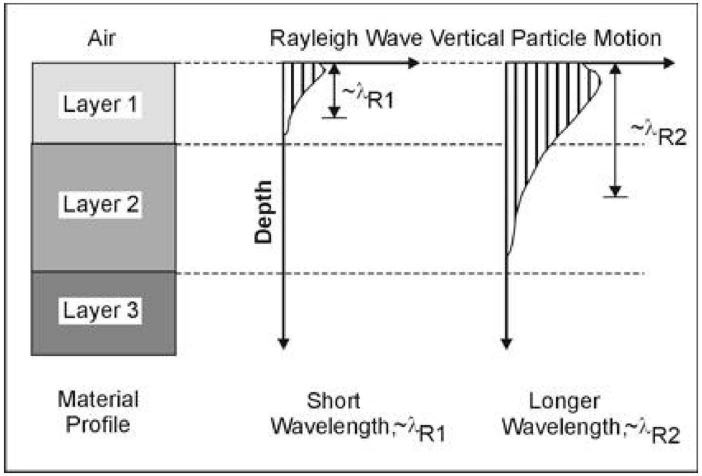
Time frequency diagram

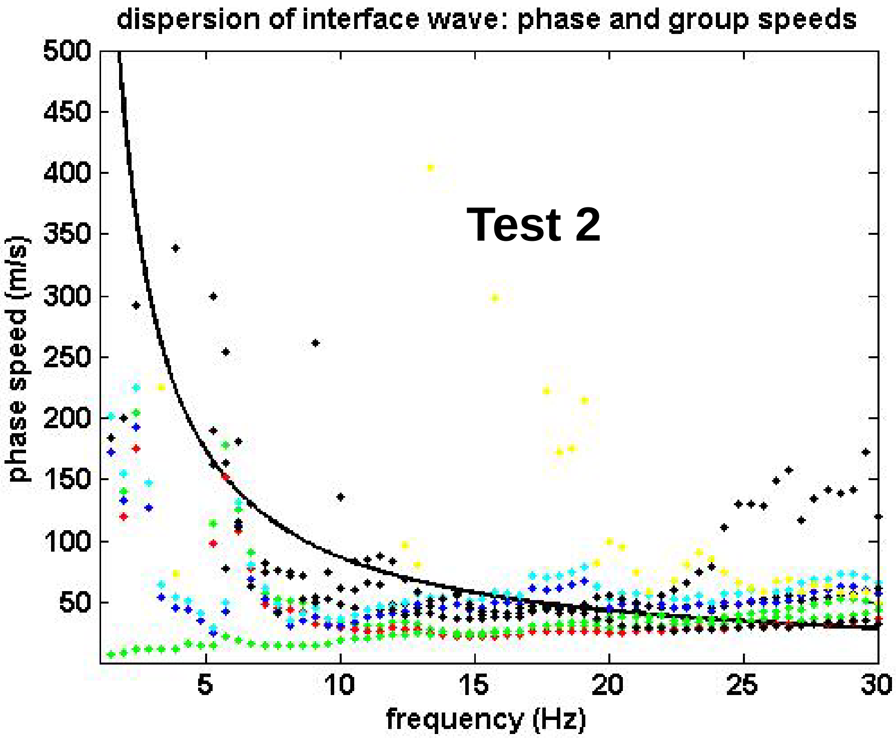


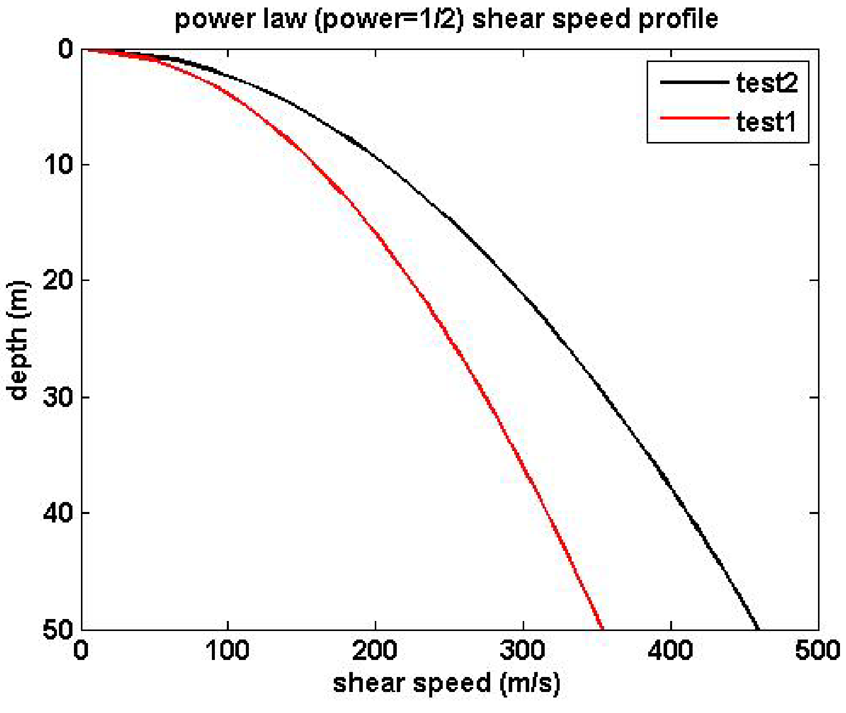


Phase Velocity Dispersion and Shear Speed Profile









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N. Bay Sediment Shear Properties

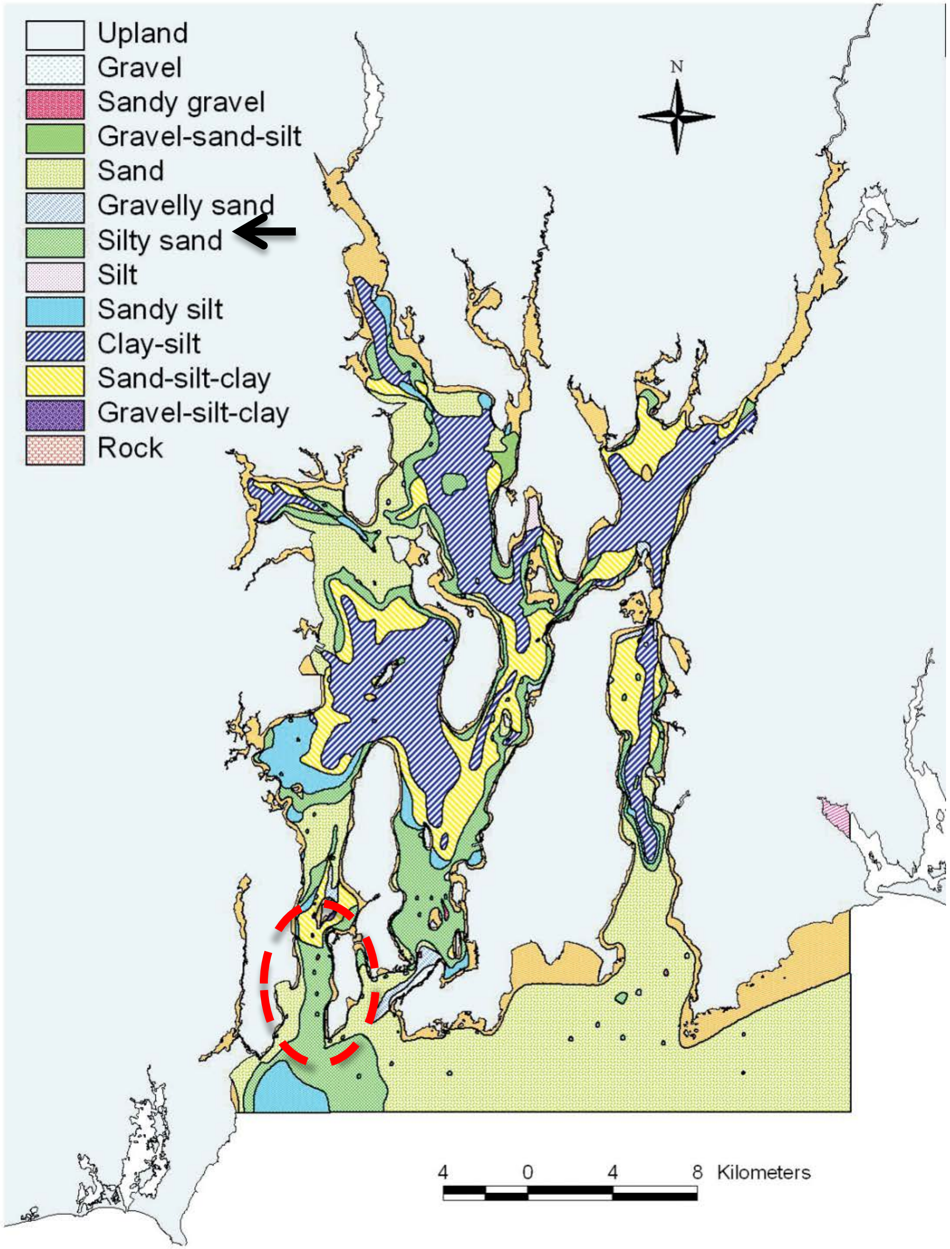


Table 1.3 Geoacoustic properties of continental shelf and slope environments.

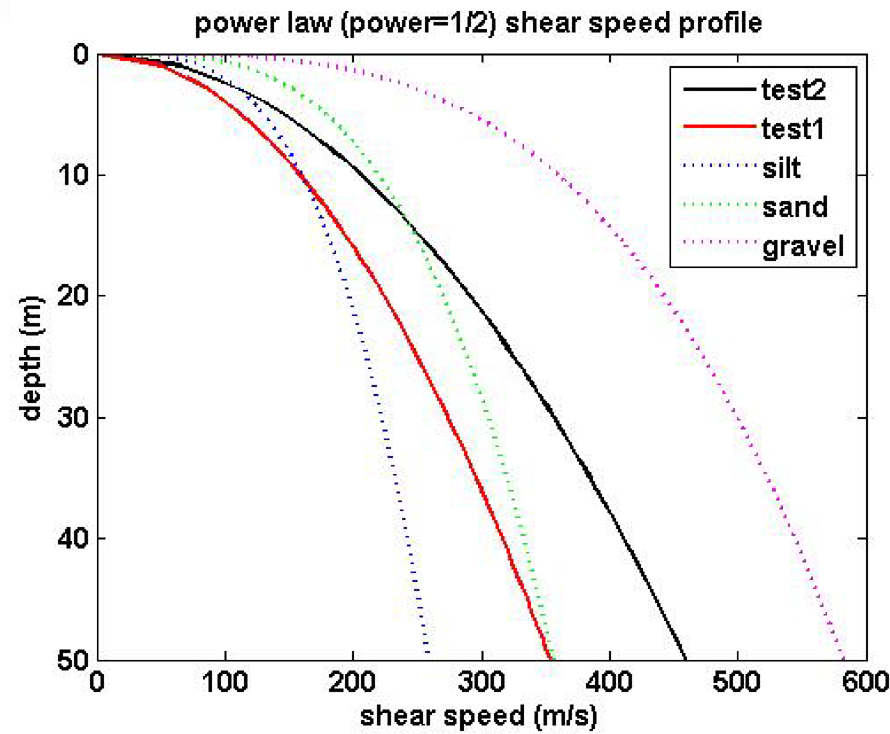
Bottom type	p (%)	ρ_b/ρ_w -	c_p/c_w -	c_p (m/s)	c_s (m/s)	α_p (dB/λ_p)	α_s (dB/λ_s)
Clay	70	1.5	1.00	1500	< 100	0.2	1.0
Silt	55	1.7	1.05	1575	$c_s^{(1)}$	1.0	1.5
Sand	45	1.9	1.1	1650	$c_s^{(2)}$	0.8	2.5
Gravel	35	2.0	1.2	1800	$c_s^{(3)}$	0.6	1.5
Moraine	25	2.1	1.3	1950	600	0.4	1.0
Chalk	-	2.2	1.6	2400	1000	0.2	0.5
Limestone	-	2.4	2.0	3000	1500	0.1	0.2
Basalt	-	2.7	3.5	5250	2500	0.1	0.2

$c_s^{(1)} = 80\,\tilde{z}$

$c_s^{(2)} = 110$

$c_s^{(3)} = 180\,\tilde{z}^{0.3}$

Jensen, Kuperman, Porter and Schmidt, *Computational Ocean Acoustics*, p. 38, (2000



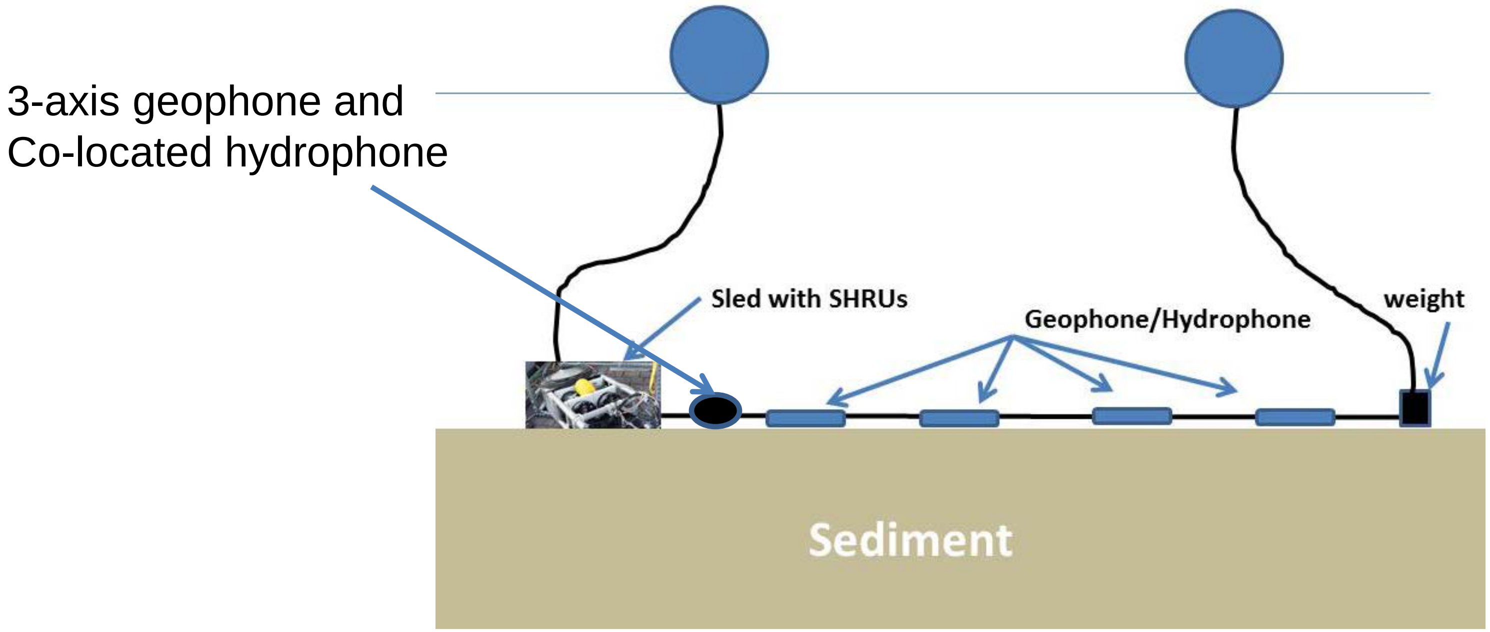
Modeling

Godin and Chapman (2001) developed an approach to model the interface wave dispersion assuming a power law shear speed profile.

Another approach is the *Thomson–Haskell method* based on *the* propagator matrix solution (sediment layering)

A propagation model like OASIS or elastic PE could also provide the forward modeling tool.

Spring 2012: Modification



3-axis geophone and co-located hydrophone will be added to the existing system

These will be connected to the third available SHRU (4 channels)

Full system will be tested in Narragansett Bay

Other interests:

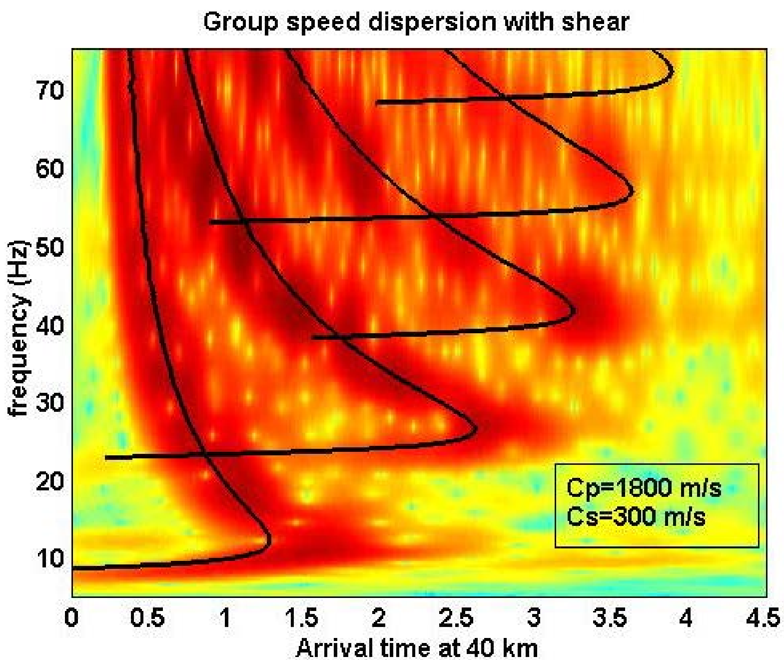
Compressional wave speed and attenuation estimates based on mode travel time dispersion and mode amplitude ratios using broadband source (CSS)

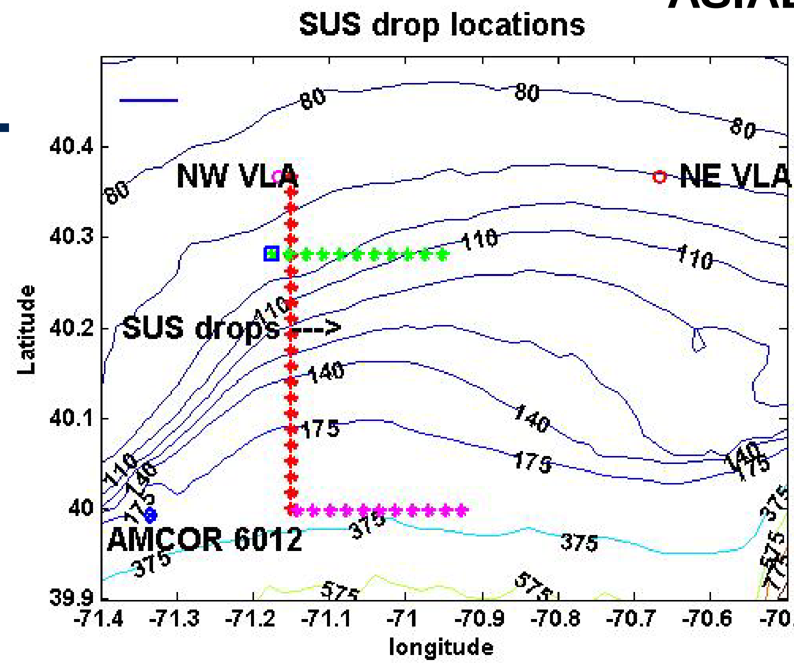
Effect of shear on mode travel times and mode attenuation

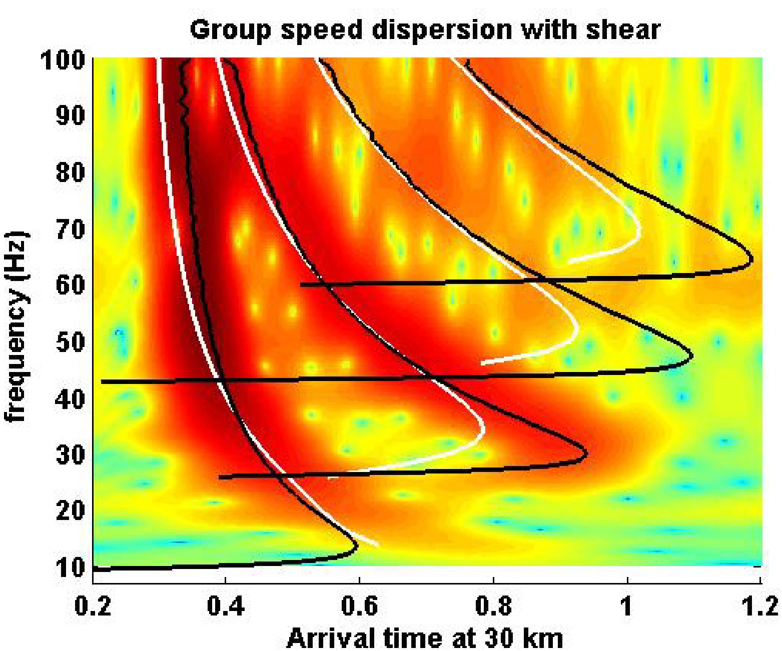
THE

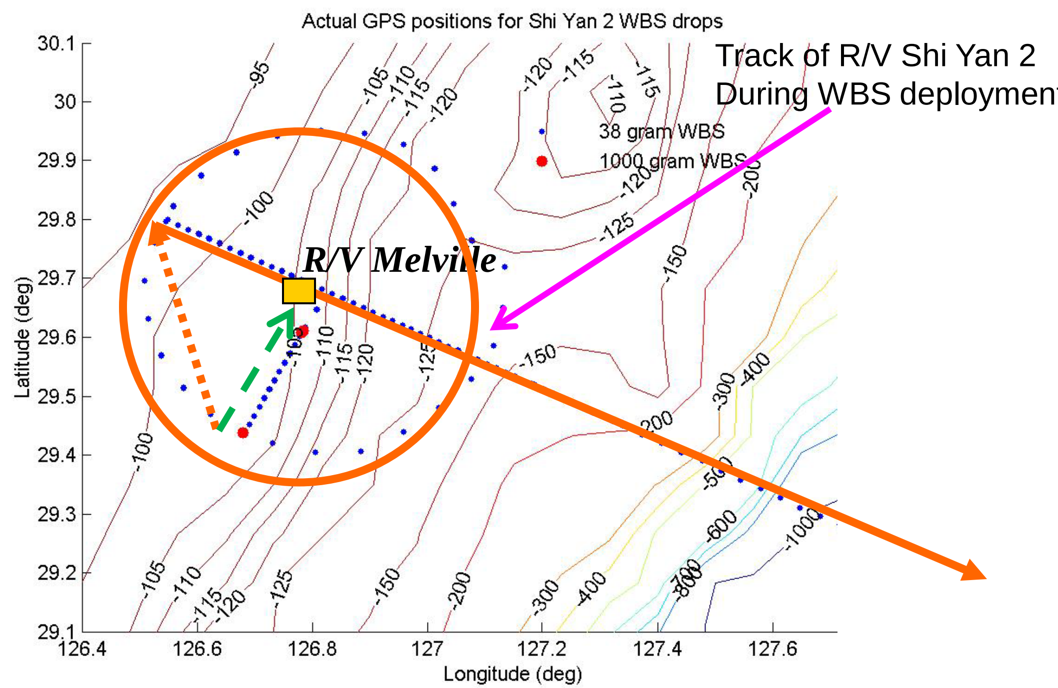
Primer

ASIAEX



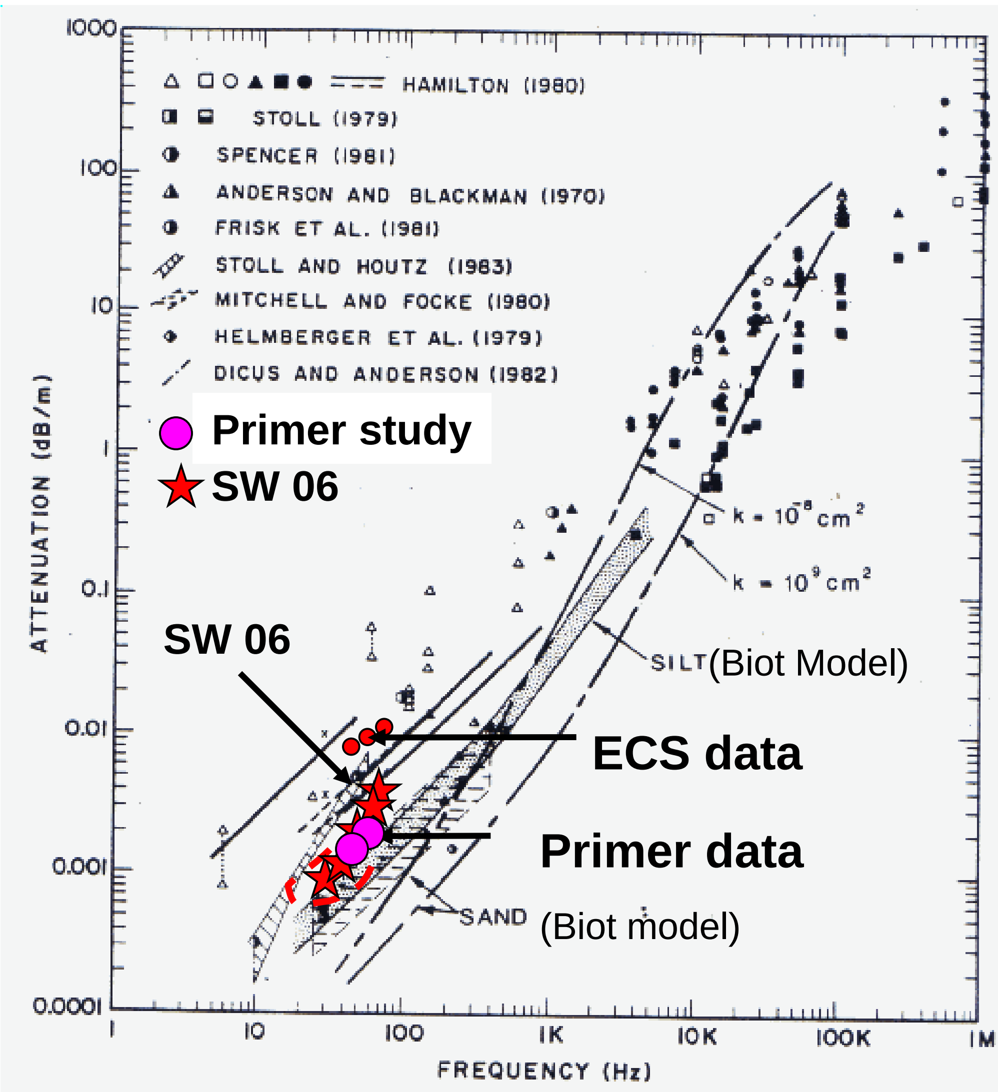




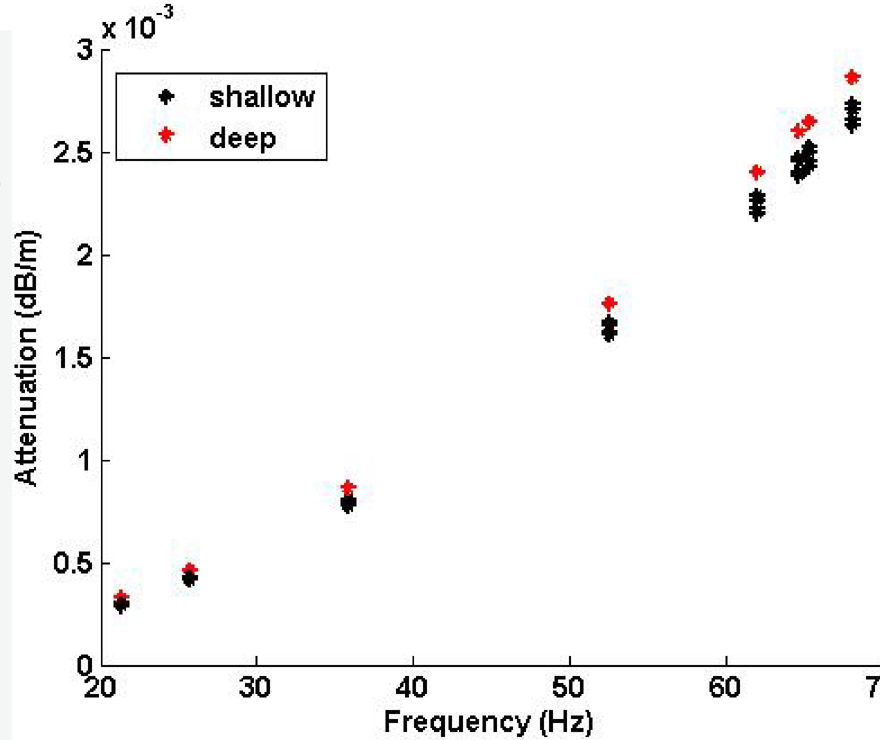


Attenuation: Mode 1 and 2

Published data – all types of sediments (Stoll- 85)



Freq. exponent ~ 1.86 (deep)
1.89 (shallow)



Inversions compare well with earlier (Primer) inversions

Frequency exponent agrees with Holmes et al. (JASA-EL;2007) value of 1.8 +/- 0.2

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Seafloor Characterization Using Gliders

Jim Miller

NATO Undersea Research Centre

La Spezia, Italy

Efforts to measure sediment properties with gliders in 2012

- NURC will be carrying out two sea tests in 2012 with gliders to measure sediment properties:
  - NATO exercise Proud Manta 2012 off the coast of Sicily: NURC will deploy SLOCUM gliders with a single hydrophone to measure ambient noise for measuring sediment properties (Feb. 2012)
  - NURC experiment GLASS 2012 off the coast of Italy will deploy a FOLAGA glider with a tetrahedral array of hydrophones in tow. (July 2012)

Assets for PROUD MANTA and GLASS* 2012

SLOCUM glider fleet at NURC to be used in NATO exercise PROUD MANTA in Feb. 2012: Single towed hydrophone.

FOLAGA hybrid AUV/glider to be used in NURC GLASS* experiment in July 2012:
Tetrahedral towed hydrophone array and active down looking sona

*GLider Acoustics Sensing of Sediments

http://www.graaltech.it/en/project.php?cid=2&pid=5

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Extra Slides

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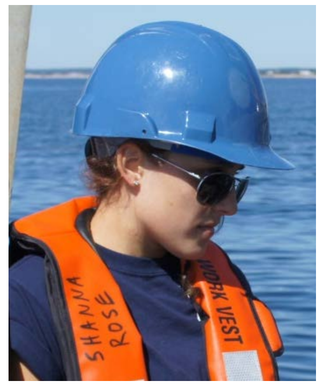
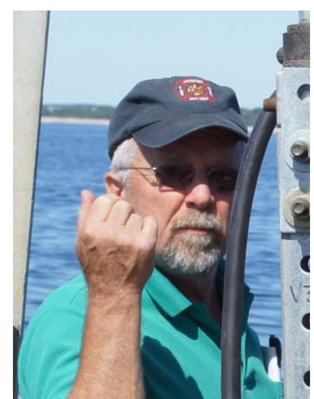
Conclusions/ Future Work

- Geophone array designed for shear and interface wave investigations in shallow water.
- Successful tests in shallow waters off RI.
- Further work:
  - Process the remaining data
  - integrate the remaining sensors into the system
  - implement better modeling techniques (sediment layering)

Questions ???????

August Sea Test Participants





GEOSPACE TECHNOLOGIES
An OYO Geospace Company

seismic exploratior

MP-25 Specifications

	MP-25-250	MP-25-350	MP-25-656
Natural Frequency ± 15 *	10 Hz	10 Hz	10 Hz
Voltage Sensitivity ± 1.5 dB	11.2 Volts/Bar	8.0 Volts/Bar	6.4 Volts/Bar
Impedance	250 Ohms	250 Ohms	250 Ohms
DC Resistance ± 10%	160 Ohms	160 Ohms	160 Ohms
Operating Temperature Range	0-35°C	0-35°C	0-35°C
Operational Depth	1-250 ft (.30-76 m)	1-350 ft (.30-107 m)	1-656 ft (.30-200 m)
Dimensions:	Without Outer Case	With Outer Case	Sidewinder
Length:	4.75 in (12.07 cm)	5.50 in (13.97 cm)	6.60 in (16.76 cm)
Diameter:	2.00 in (5.08 cm)	2.40 in (6.10 cm)	2.00 in (5.08 cm)
Weight:	.52 lbs (236 g)	.77 lbs (349 g)	.58 lbs (263 g)

2. HTI-94-SSQ SERIES Hydrophone

Sensitivity	with preamp (max) -165 dB re: 1 V/uPa
Frequency Response	2 Hz to 30 KHz
Equivalent Input Self Noise	RMS from 1 Hz to 1000 Hz - 75 dB re: 1 uPa - 0.06 uBar Spectral - 54 dB re: 1 uPa/sq.root Hz @ 10 Hz - 40 dB re: 1 uPa/sq.root Hz @ 100 Hz - 38 dB re: 1 uPa/sq.root Hz @ 1000 Hz
Maximum Operating Depth	20,000 feet (6096 meters)
Size	1.50 inches (3.8 cm) length X 1.25 inches (3.2 cm) diameter

Outline

- Importance of shear waves for low frequency acoustic propagation in shallow water
  - Frequency dependence of attenuation (Pierce-Carey)
  - Modal group velocity (Tolstoy, our work)
  - Reflection coefft. (Zhang and Tindle, 1995)
  - Geotechnical applications
- Dispersive interface waves as sensing scheme for shear wave profiles
- Geophone array for measuring interface waves
- Test results to date including using Combustion Sound Source (CSS) this summer

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August, 2011 Sea-test

Tests conducted for 3 days in Narragansett Bay and shallow waters off Block Island

Tests were conducted in Narragansett Bay (~ 10 m water depth) on Day 1

Source: Combustive Sound Source (CSS) in water (close to the bottom)

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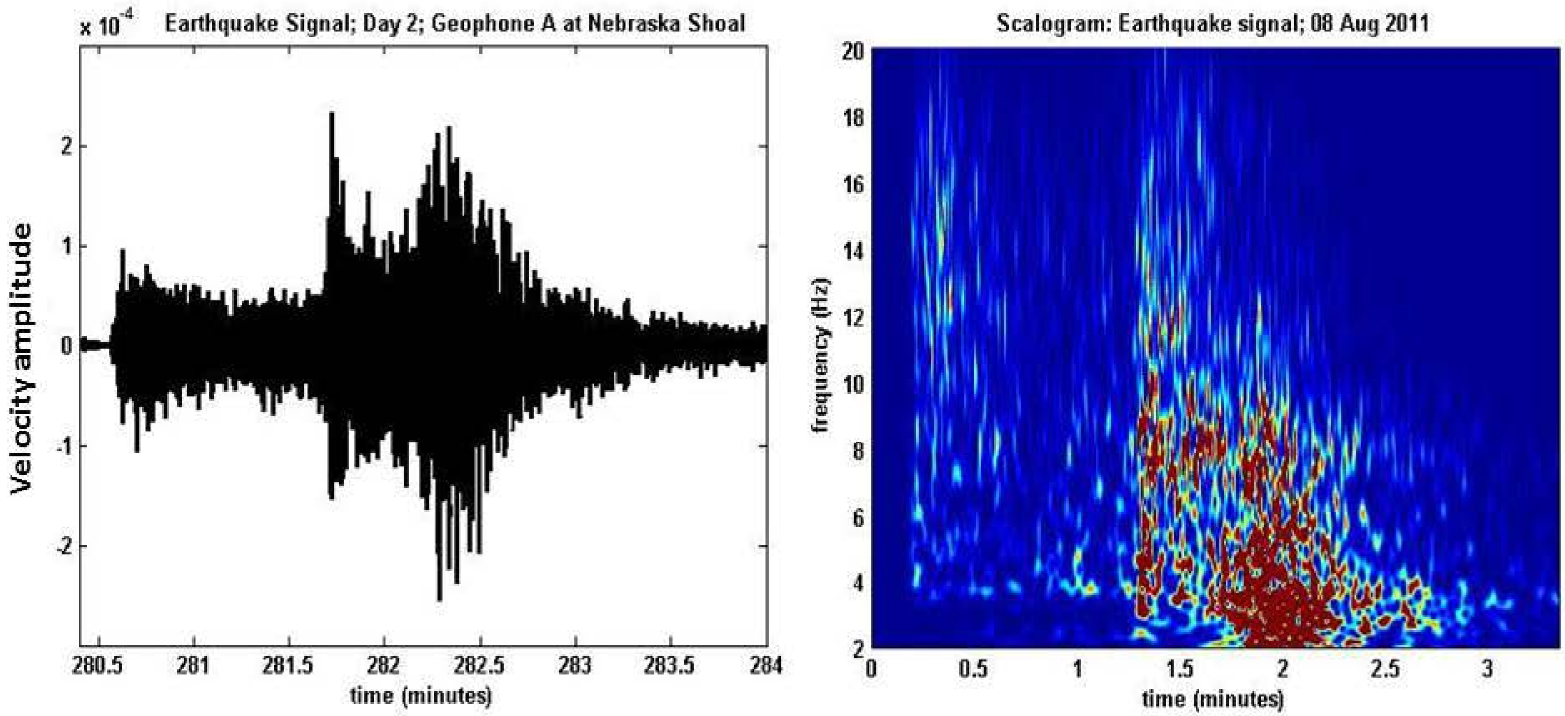
Earth quake Signal

East Coast earthquake on August 23, 2011



Signals generated by the East Coast earthquake on August 23, 2011 at approximately 17:52:30 UTC, received at one of the geophones. This sensor was at (41.35965582, -71.55043477). The x- axis is in minutes since switching on the data acquisition system (which was at 13:11:52 UTC)

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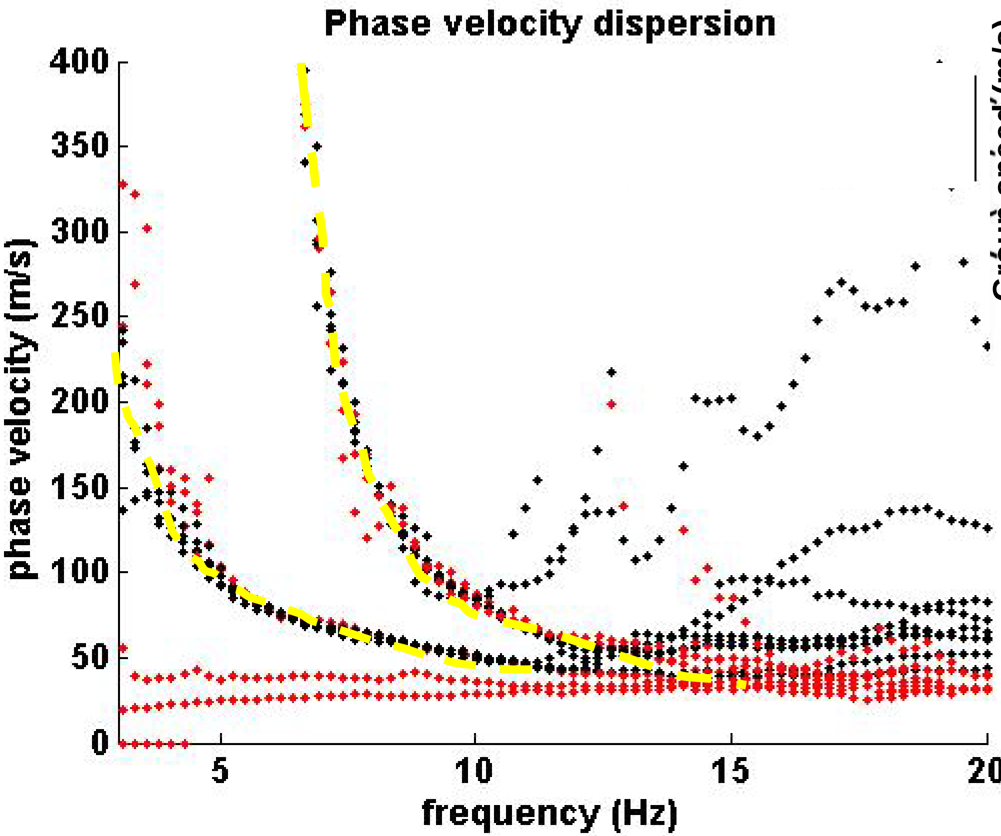
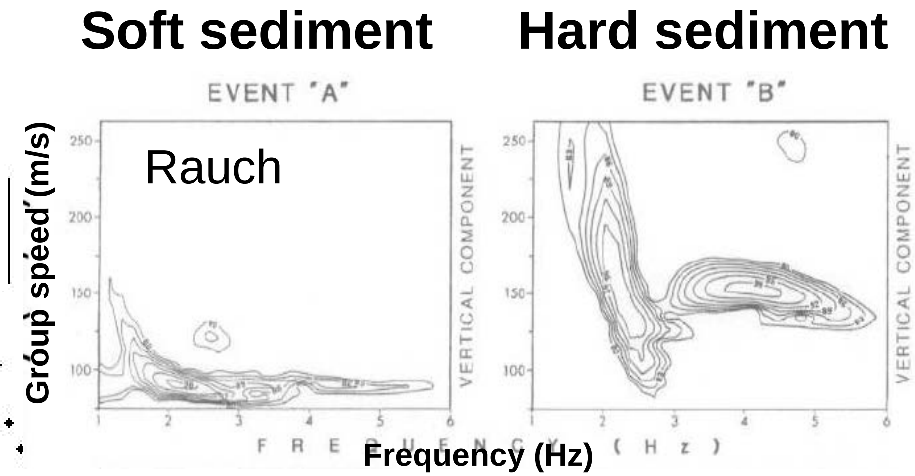
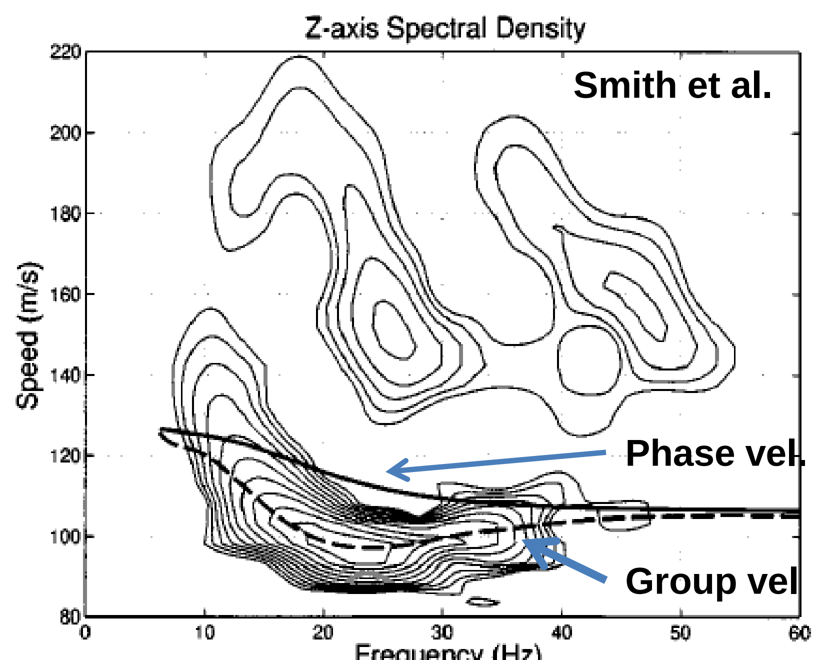
Phase and Group velocity of interface waves



Interface wave velocity for all (10) events received on geophones A and D.





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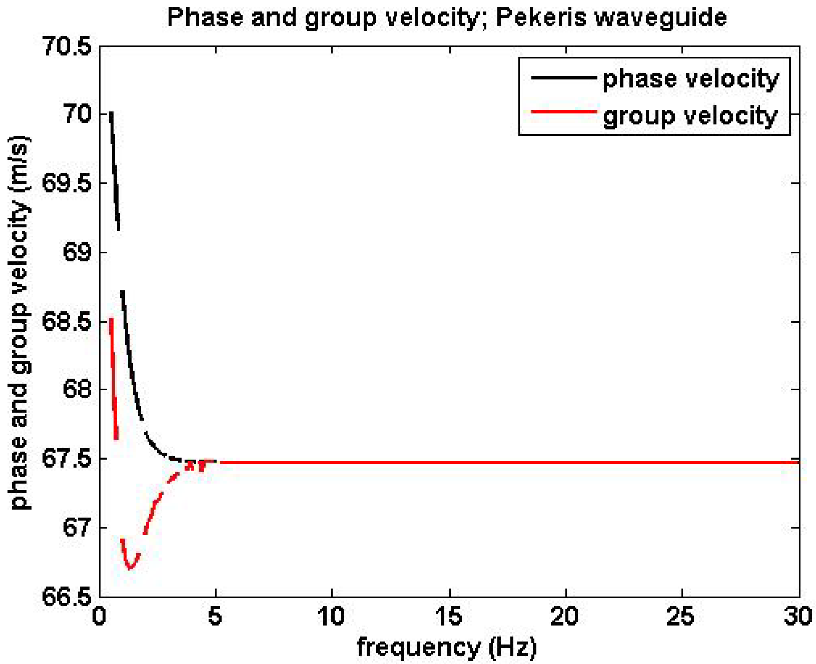
Simple Waveguide

$$4\sqrt{1-\left(\frac{v_p}{c_{p1}}\right)^2}\sqrt{1-\left(\frac{v_p}{c_{s1}}\right)^2}-\left(2-\frac{v_p^2}{c_{s1}^2}\right)^2$$

$$=\frac{\rho_0}{\rho_1}\left(\frac{v_p}{c_{s1}}\right)^4\frac{\sqrt{1-\left(\frac{v_p}{c_{p1}}\right)^2}}{\sqrt{1-\left(\frac{v_p}{c_{p0}}\right)^2}}\tanh\left(\frac{\omega D}{v_p}\sqrt{1-\left(\frac{v_p}{c_{p0}}\right)^2}\right)$$



Cp1=1650 m/s
Cs1=100 m/s
Cp0=1500 m/s
D=10 m
Density Ratio=2.0

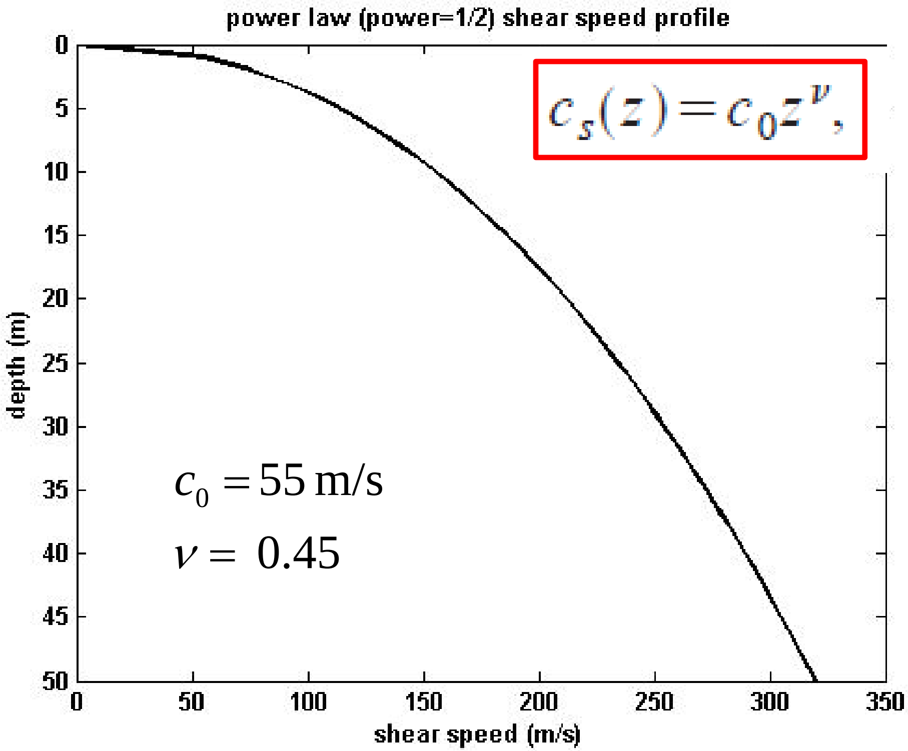
Godin and Chapman (2001) developed an approach to model the interface wave dispersion assuming a power law shear speed profile.

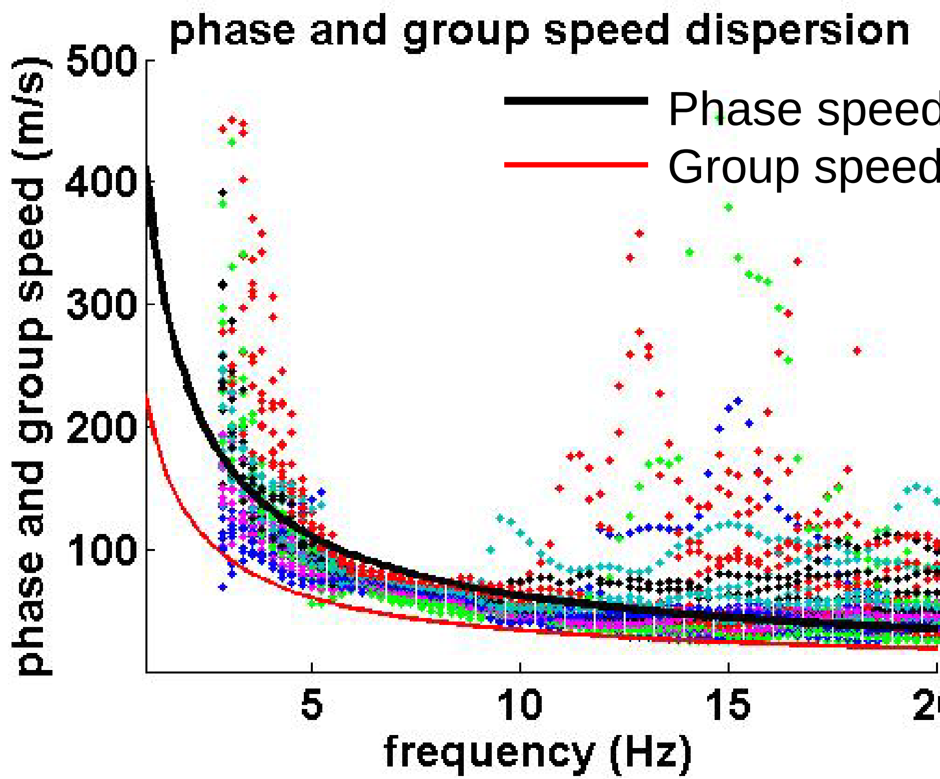
Another approach is the *Thomson–Haskell method* based on *the* propagator matrix solution

A propagation model like OASIS or elastic PE could also provide the forward modeling tool.

Hefeng Dong and Jens M. Hovem, Interface Waves, in *Waves in Fluids and Solids* , Edited by Ruben Pico Vila, InTech Publishers, 2011

Dispersion of interface waves in sediments with power-law shear speed profiles (Chapman & Godin,2001)





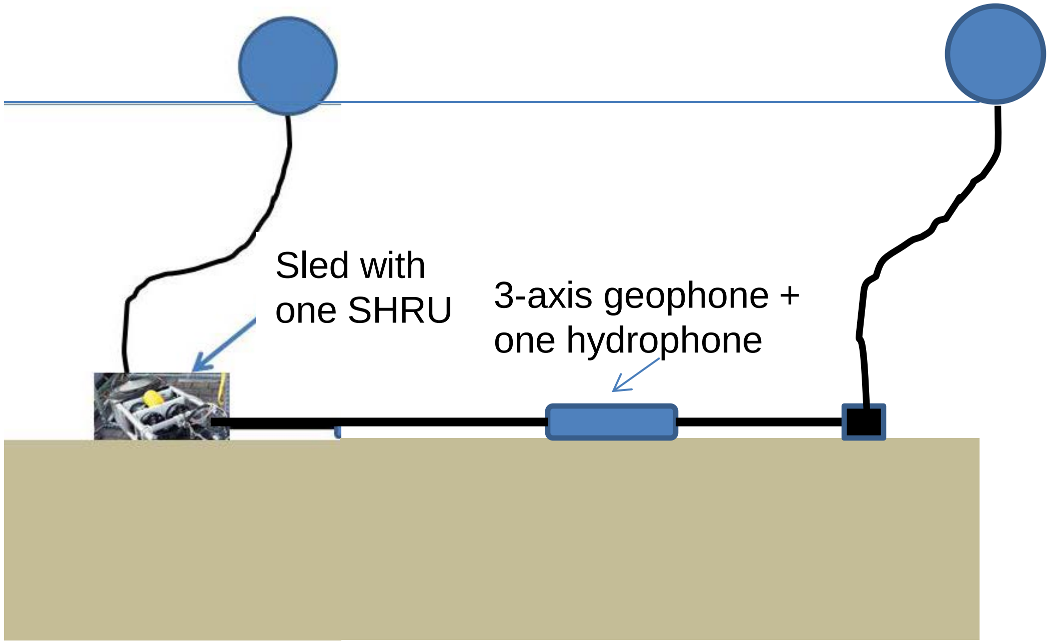
$$V_n = \left(\frac{c_0^{1/\nu} n_{\text{eff}}(n, \nu, R)}{f B_\nu} \right)^{\nu/(1-\nu)} \qquad U_n = (1-\nu) V_n \qquad B_\nu = \sqrt{\pi}\,\Gamma\left(\frac{1-\nu}{2\nu}\right) \Big/ \Gamma\left(\frac{1}{2\nu}\right)$$

$R = \rho_w / \rho$ (Ratio of the water density to sediment bulk density

n – mode number $\quad$ V_n – phase velocity $\quad$ U_n – group velocity

N_{eff} – effective mode number (a dimensionless number which is a function of n, R, and

Spring 2012



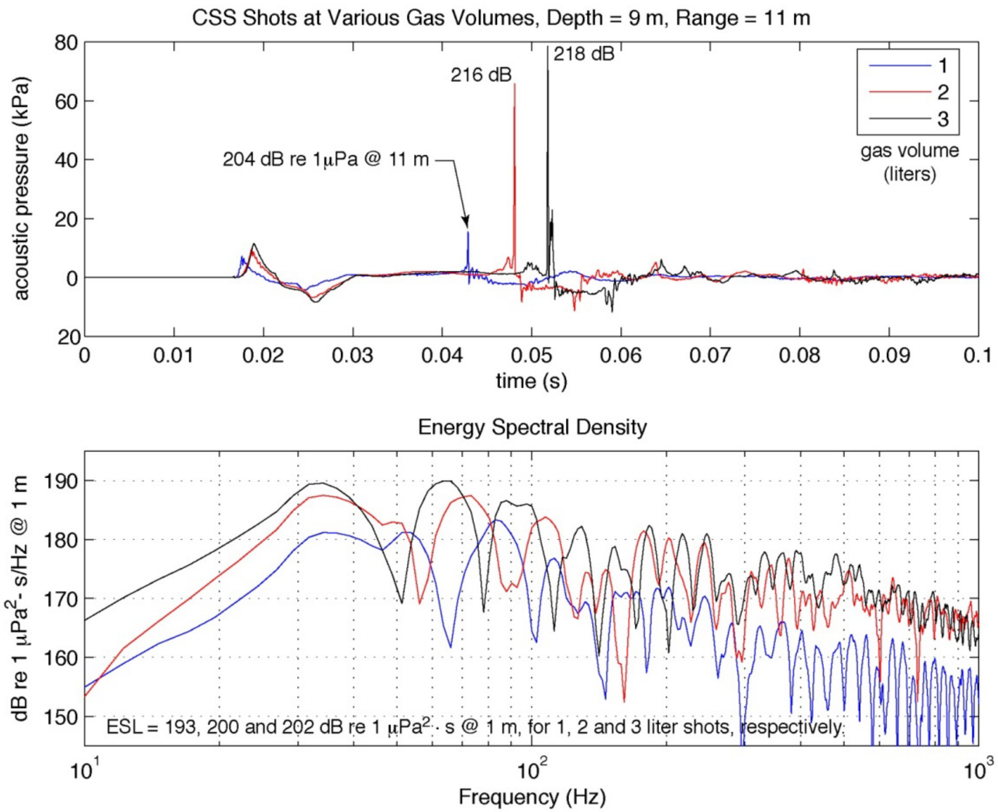
Shear Measurement methods

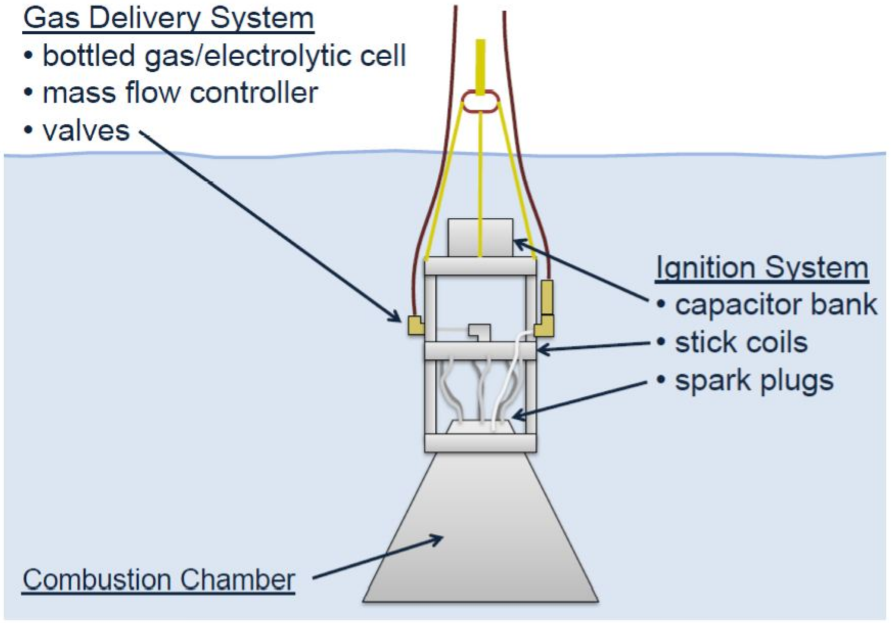
- Direct measurements (probes-shear wave transducers or cone penetrometers)
- In the lab using probes
- In situ measurements are limited in depth, time consuming and often require support from divers or submersibles.
- Laboratory measurements have consistently shown lower values than in situ measurements (due to disturbance during collection, transportation and storage and reduction in confining pressure.
- Probes typically (especially lab ones) make measurements at frequencies higher than at which shear conversion is significant.

Analysis of interface waves provide a tool for shear speed estimation

Osler and Chapman, Canadian Acoustics, 24(3), 11-22, 1996

Typical Pressure Signatures and Spectra (ARL –UT)





A combustible mixture of hydrogen and oxygen is produced by an electrolytic cell.
The gas is captured in a combustion chamber that is immersed in the water column or on the seabed.
The gas mixture is ignited by a spark and the ensuing combustion and bubble activity produce low-frequency, broad band acoustic pulses.

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Geophone: GS-32

Geospace PV-1 Dual Vertical Axis Gimbaled Geophone and Hydrophone