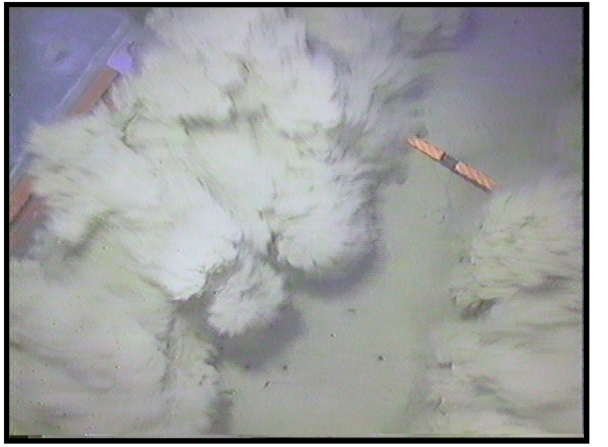


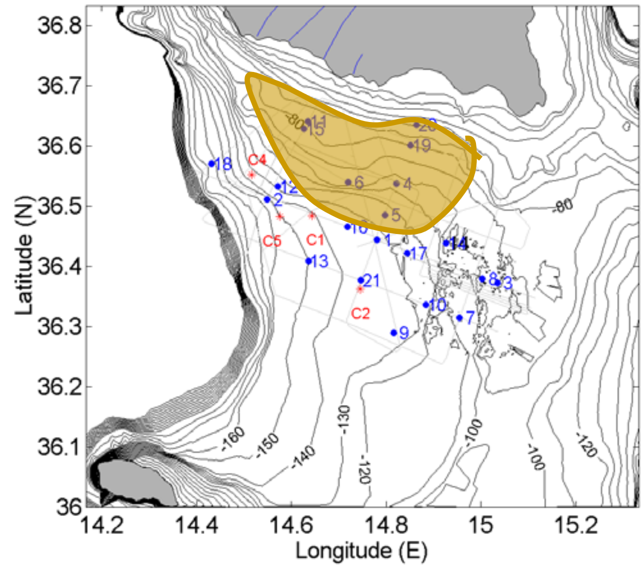
The inner to mid shelf of the Malta Plateau: an analog to the NE Mud Patch

Charles W. Holland
ARL-PSU

December 2014

Measurements sponsored by NATO SACLANT Centre
(now Centre for Maritime Experimentation) and ONR

Background:



ONR SCAE16 experiment will focus on fine-grained, cohesive (or muddy) sediments

Most prior sediment acoustics experiments have been sited to study sandy, i.e., granular sediment fabrics.

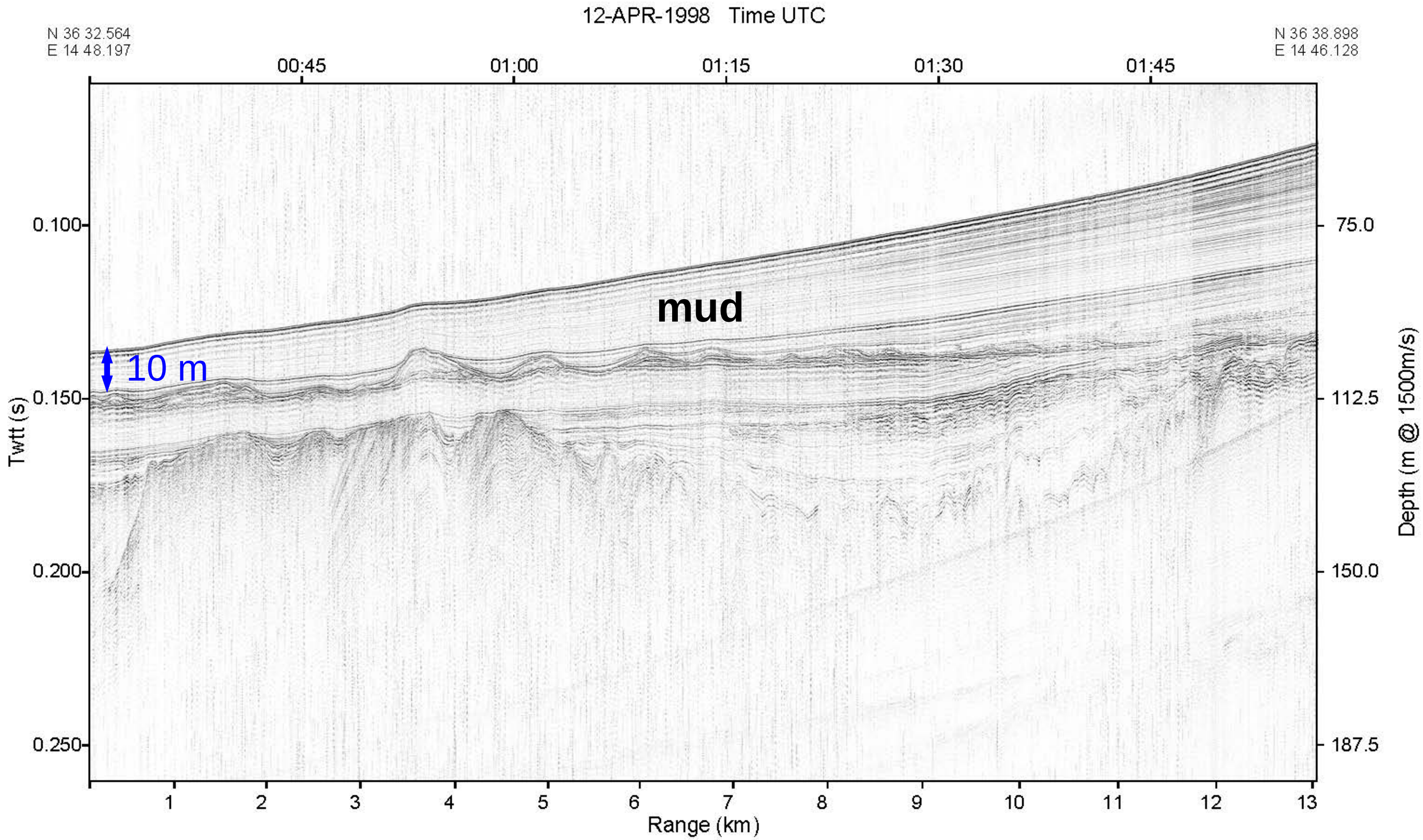
A notable exception are measurements conducted on the Malta Plateau.

The western Malta Plateau shares similarities with the NE Mud Patch

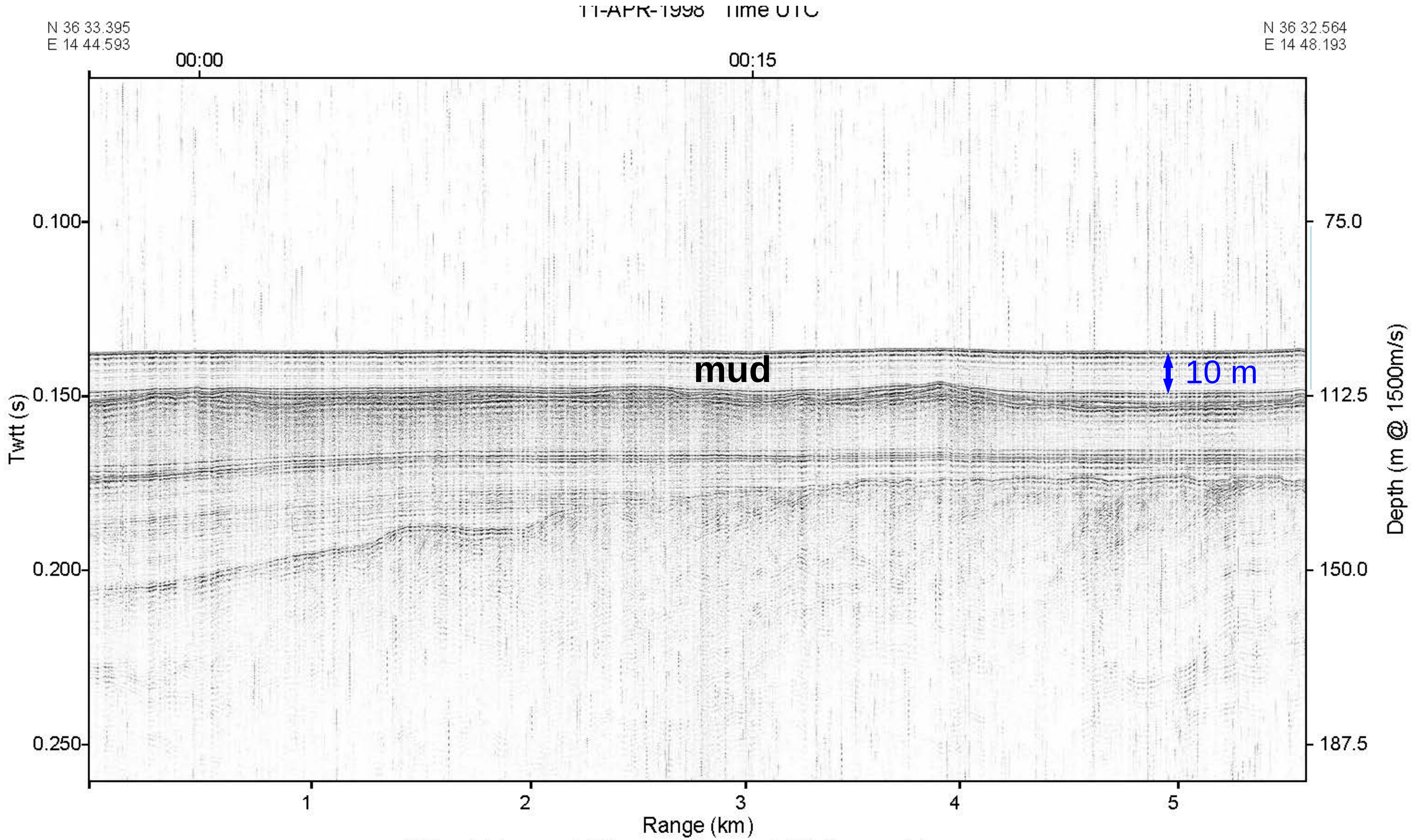
- ~ 10 m thick silty-clay (mud) at 100 m contour that thins seaward
- Underlying sediment is granular (sandy)
- structure may be due to similar processes (erosion/deposition) as on NE shelf

Objective: show measurements to provide insights / raise questions

Similar 'mud patches' seen in Yellow Sea, n. Tyrrhenian Sea, Scotian Shelf,…



/disc21/scarab98-swell/scarab98-boom03-f.su

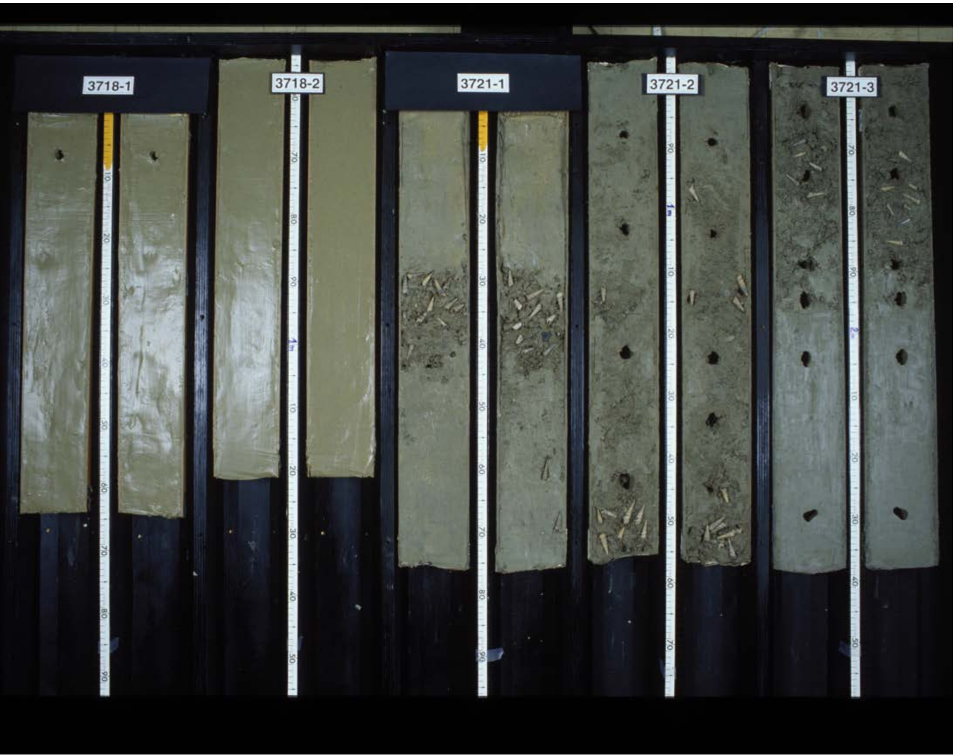


/disc21/scarab98-swell/scarab98-boom03-e.su

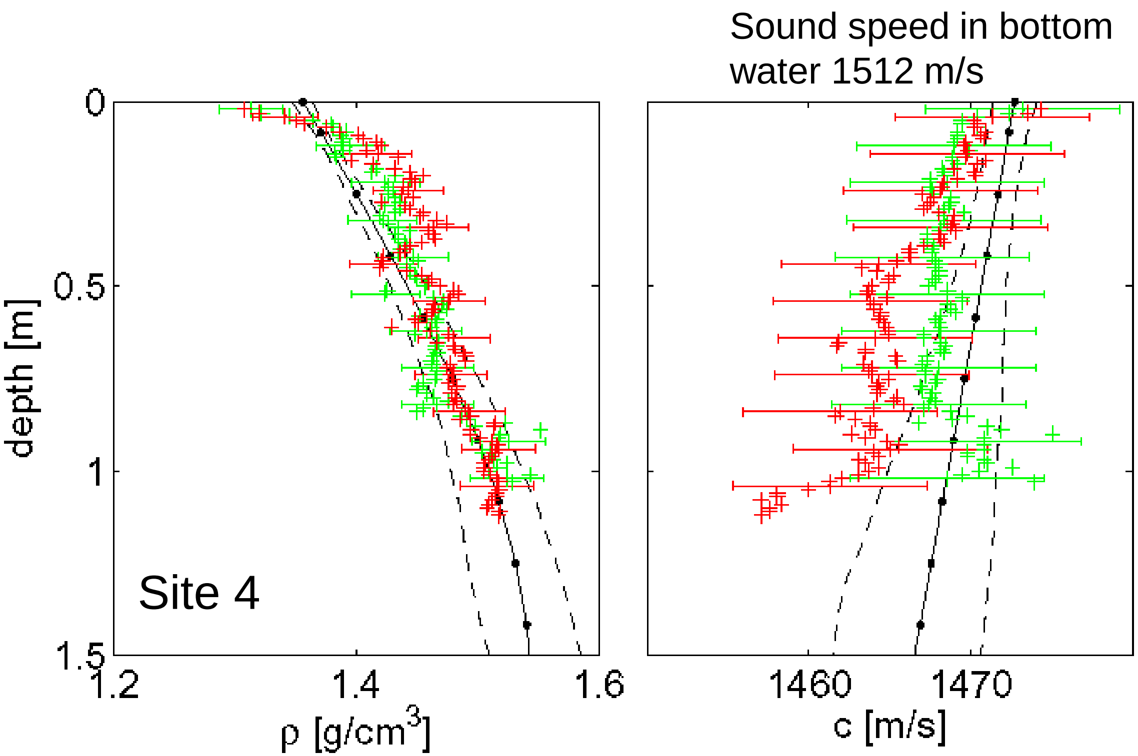
Coring notes:

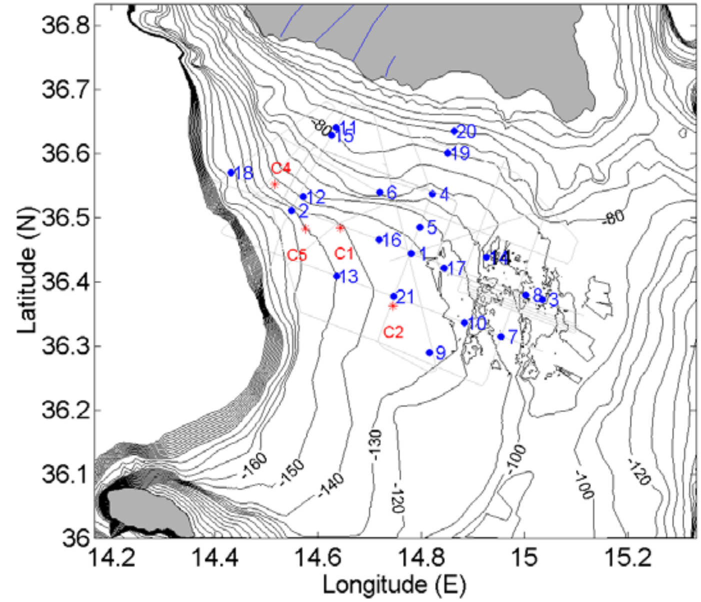
Because sediment structure is so fragile, esp at water-sed interface, great care should be taken in collecting cores to preserve the water sediment interface. Porosities at/near interface were ~90%

Specially designed gravity cores with 11 cm diameter barrel and very little weight worked quite well (piston core heavily disturbed the interface)



Geoacoustics of mud

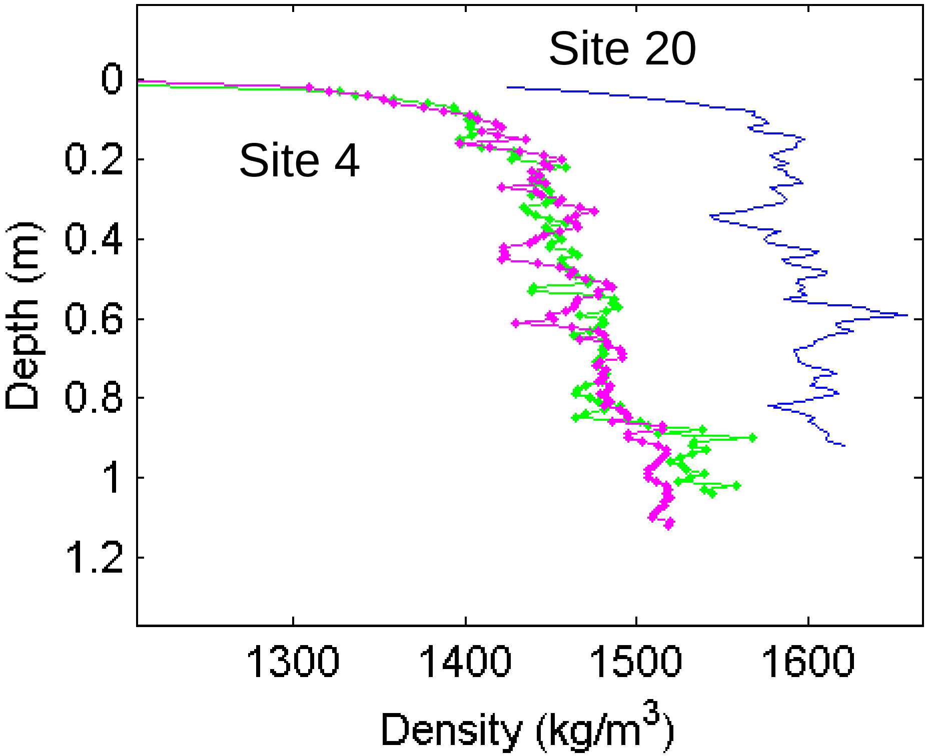


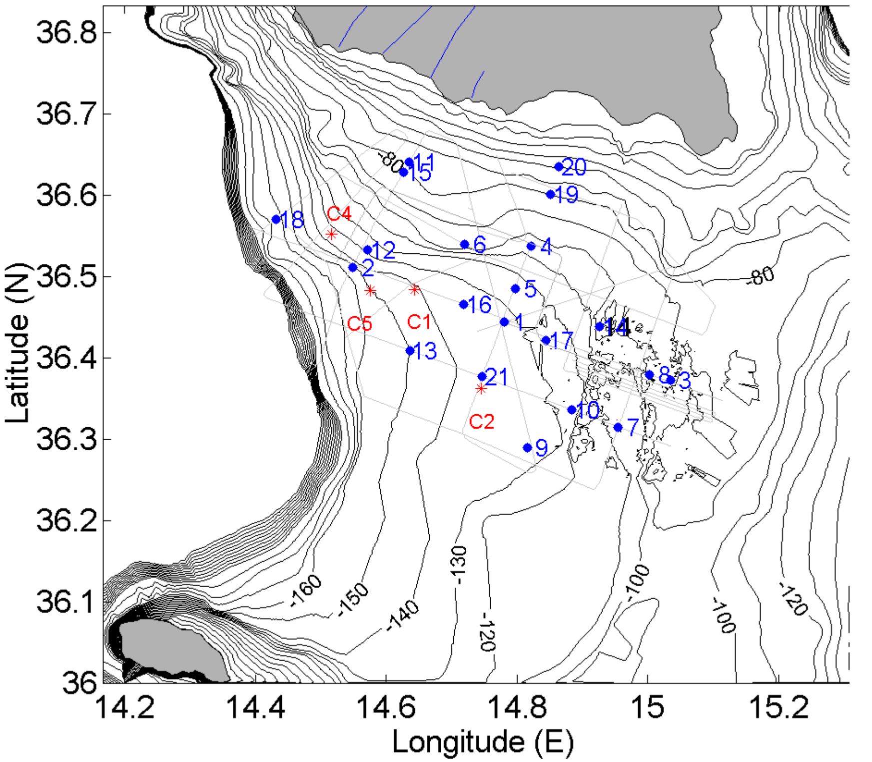


- Density gradients up to 2000 kg/m^4
- Note fluctuations esp in density (can lead to volume scattering)

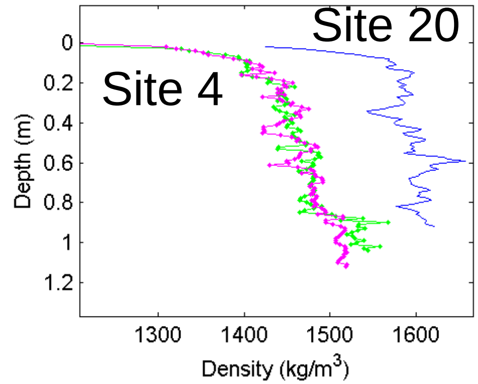
- Sediment sound speed ratio 0.974
- Negative sound speed gradient –4 sec^{-1} in upper meter
- Weak dispersion: sound speed varies 15 m/s from 0.3-200 kHz
- Attenuation (~f^1) and low! 0.009±0.003 dB/m/kHz (1-3.6 kHz)

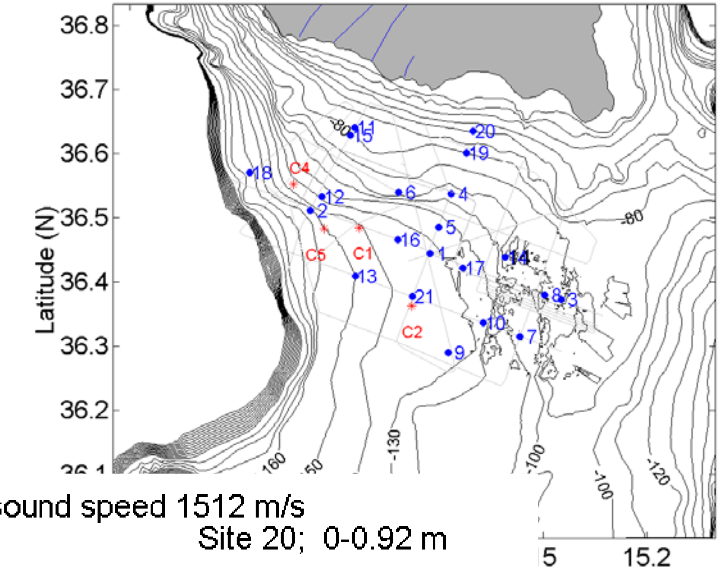
Density gradients strongly vary cross-shelf

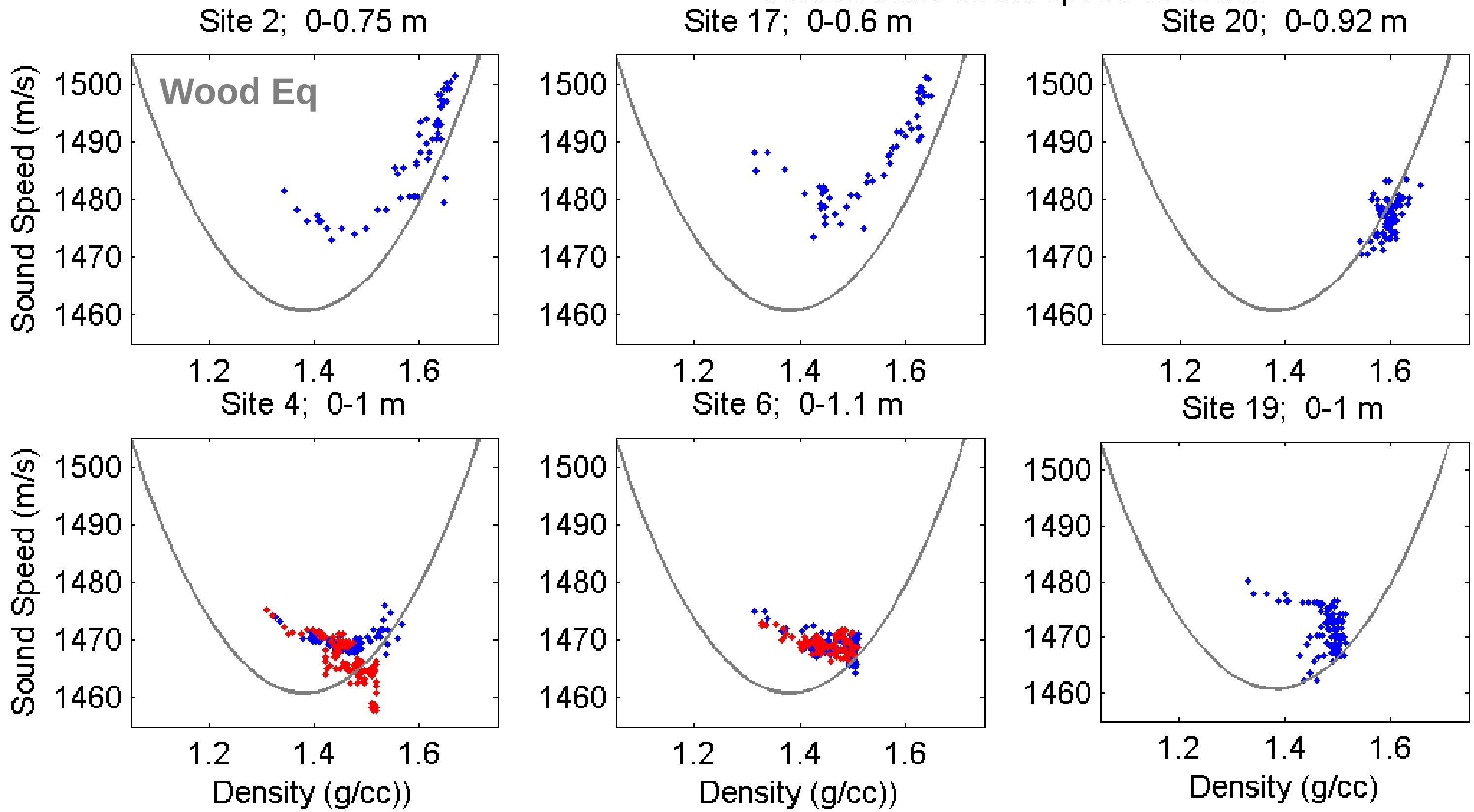




Sound Speed-vs Density: Wood Equation







Science questions

What role does mud

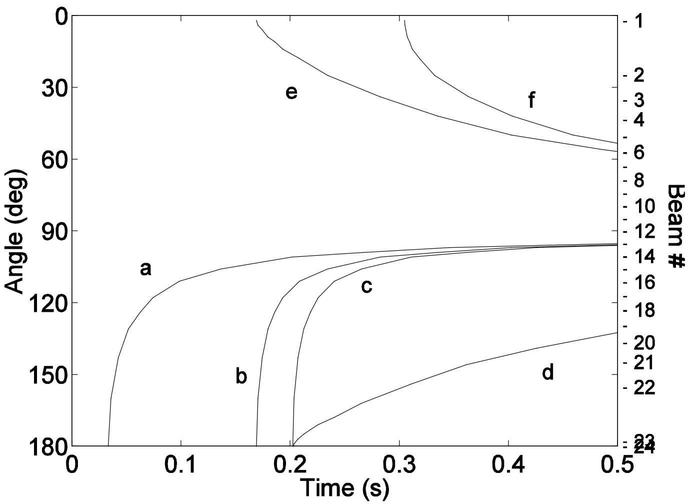
- vertical density/vel fluctuations
- vertical density/vel gradients
- range-dependent density/vel gradients
- range-dependent layer thickness

play in propagation, scattering and reverberation?

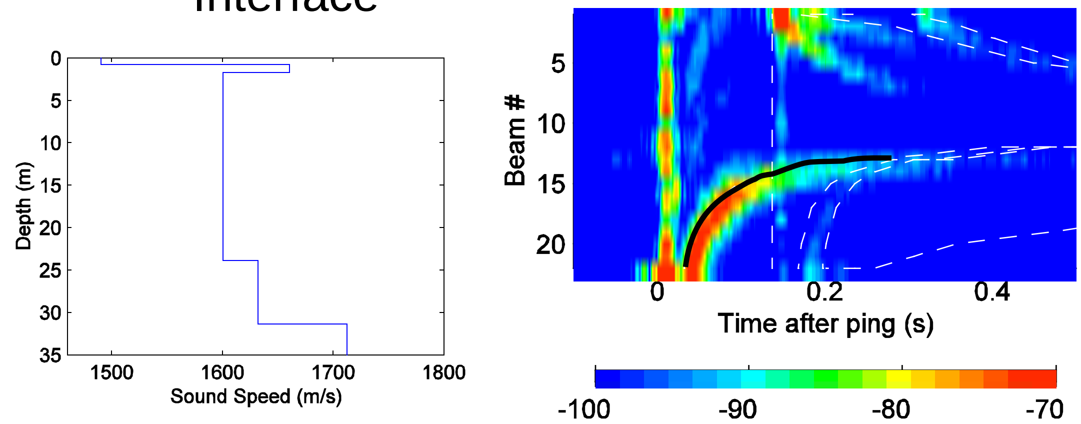
How do we adequately measure the above?

Scattering mechanism

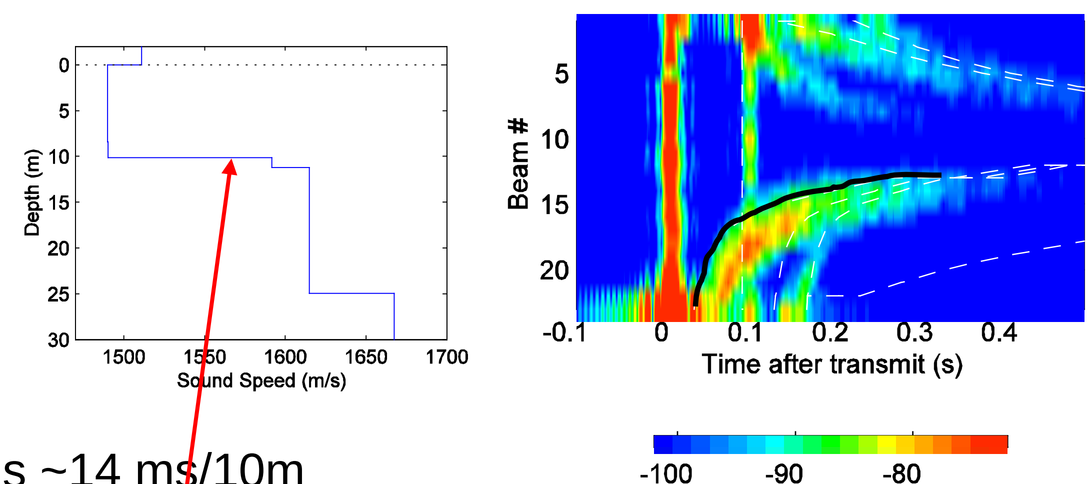
In thick mud region there is strong evidence that scattering arises from mud-sand interface and not from mud volume



3600 Hz Scattering from Water-Sediment Interface

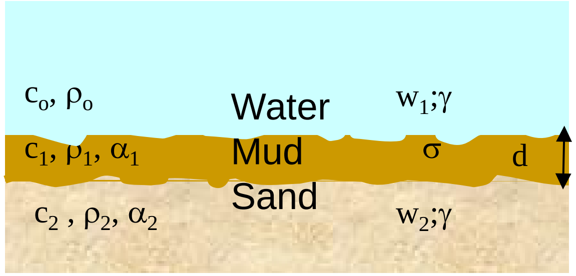


3600 Hz Scattering from Sub-Sediment Interface



1) Delay between bottom returns is ~14 ms/10m
2) Scattering coming from sub-bottom layer not volume

Holland, C.W., Shallow water coupled scattering and reflection measurements, IEEE JOE., 27, 454-470, 2002.



Some notes on Physics of Propagation for mud layer over a sand halfspace

A. Range Independent

B. Range Dependent

C. Effects of range dependence on reverberation, clutter

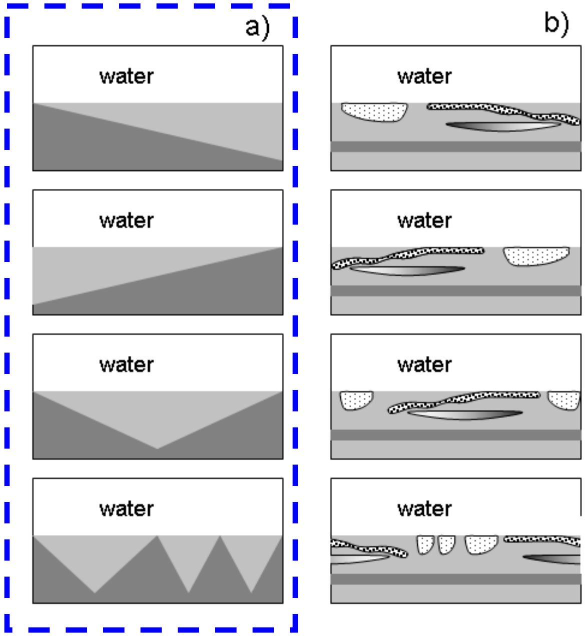
Holland, C.W., Propagation in a waveguide with range-dependent seabed properties, *JASA*, 128, 2596-2609, 2010.

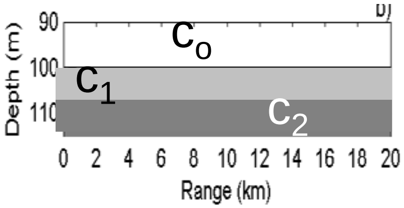
Holland, C.W. and D.D. Ellis, Clutter from non-discrete seabed structures, JASA, 131, 4442-4449, 2012.

Implications and 'Principles'

$$I(r,z) = I_o 4e^{-2\beta r} \frac{r_{re}^2}{r} \int_{\theta_{\min}}^{\theta_{\max}} B(\theta) \frac{\cos\theta}{\zeta^{(w)}(\theta) \sin\theta_z} \left| \hat{R}(\theta_H; r) \right|^{2r/\langle \zeta(\theta;r) \rangle} d\theta$$

- Lossy seds control prop. e.g., R_i =[1 1 1 1 0.1] geomean(R_i)= 0.63 <R_i>=0.82
- RD seabed impacts prop. cumulatively, largest effect at short ranges
- Multiplication is commutative, thus at range *r*, prop. is insensitive to 1) direction and 2) number of symmetric periods in the variability.
- Counter-intuitive: RD seabed can lead to less variability / uncertainty





fluid layer RI

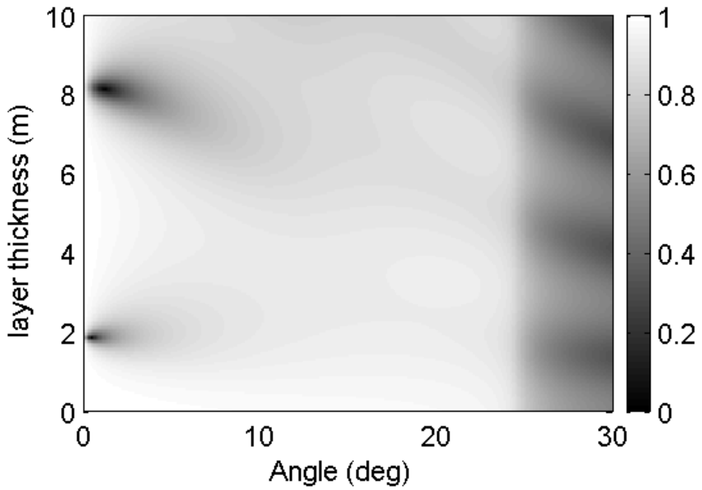
c2>co>c1; silty clay over sand

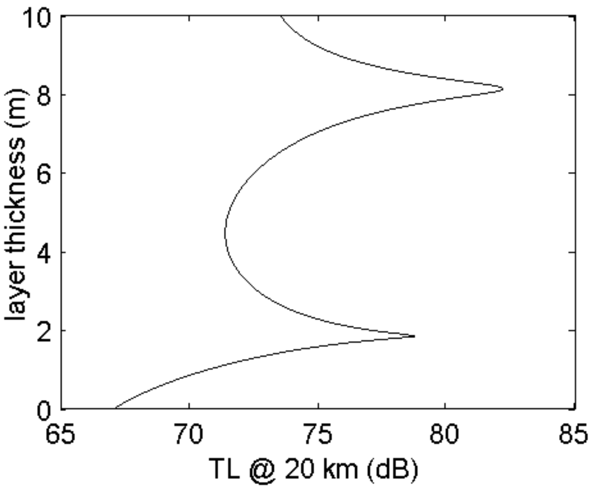
	Sound Speed m/s	Density g/cm^3	Attenuation dB/m-kHz
water c_o	1512	1	0
silty-clay c_1	1470	1.4	0.05
sand c_2	1660	1.8	0.1

$$R = \frac{R_{01} + R_{12} e^{i2k_{1z}d}}{1 + R_{12} R_{01} e^{i2k_{1z}d}}$$

$$k^{(n)} d \sim \frac{\pi(2n+1)}{2\cos^{-1}(c_1/c_0)} - \frac{2\rho_2}{\rho_1 \cos^{-1}(c_1/c_2)};\ n = 0,1,2...$$

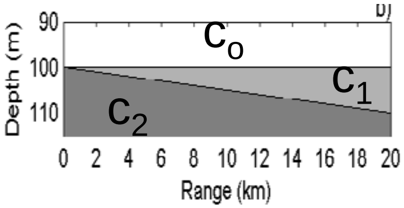
500 Hz





Hastrup, first studied the null in R and postulated that they might lead to nulls in propagation. Rubano first observation in data.

What will happen if *d* depends on range?? Do nulls wash out or no?

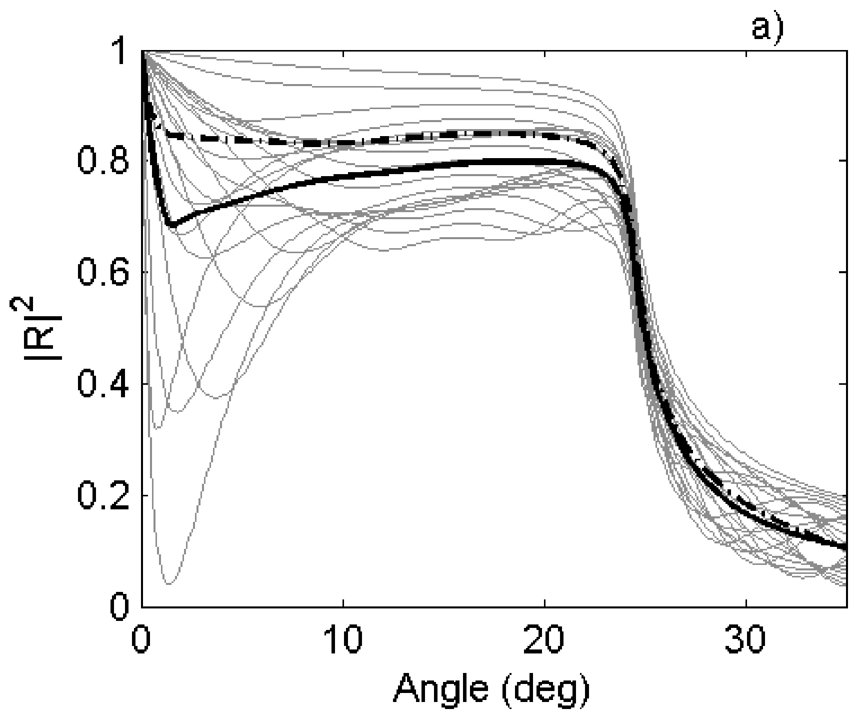


fluid layer wedge

c2>co>c1; silty clay over sand

RD

500 Hz, Δr=1 km

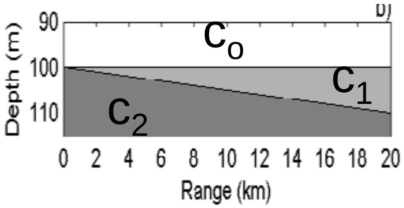


— |R(r)|

--- geometric mean |R| @ 10km

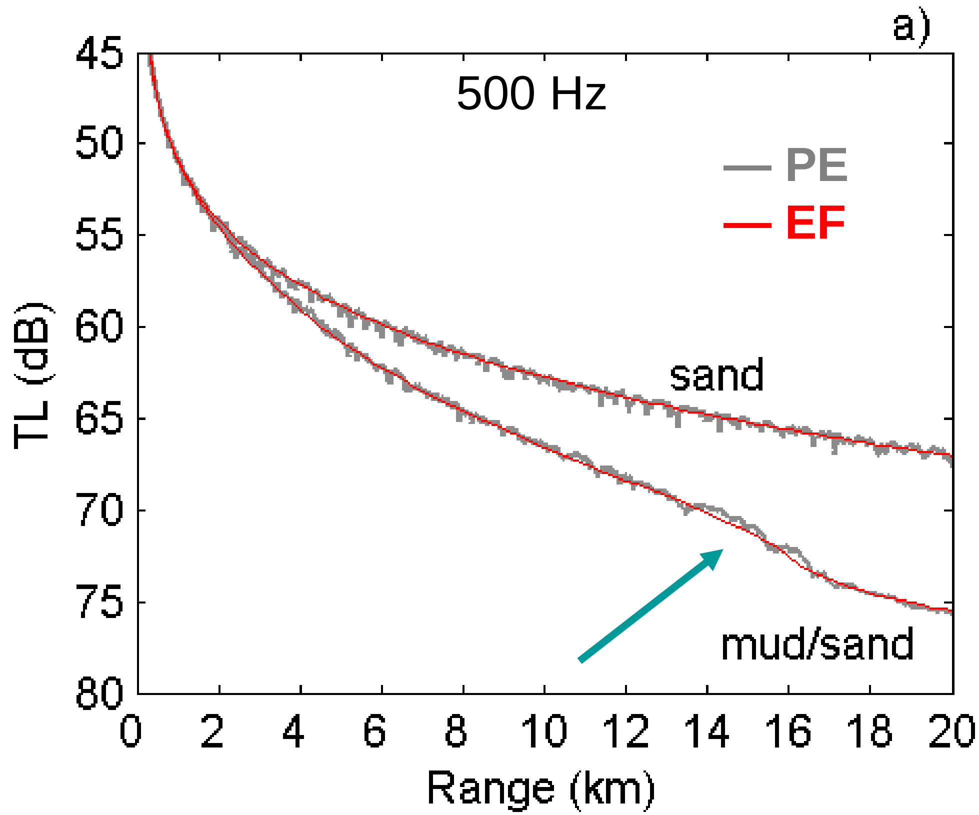
— geometric mean |R| @ 20km

Nulls do affect geomean(R)



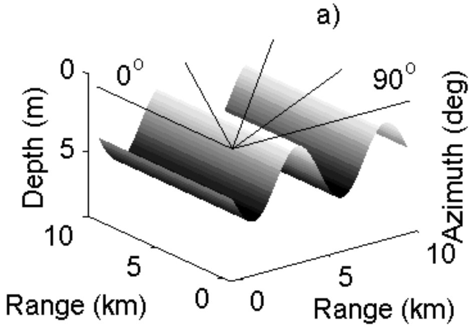
fluid layer wedge

c2>co>c1; silty clay over sand



Theory provides understanding of main features of TL

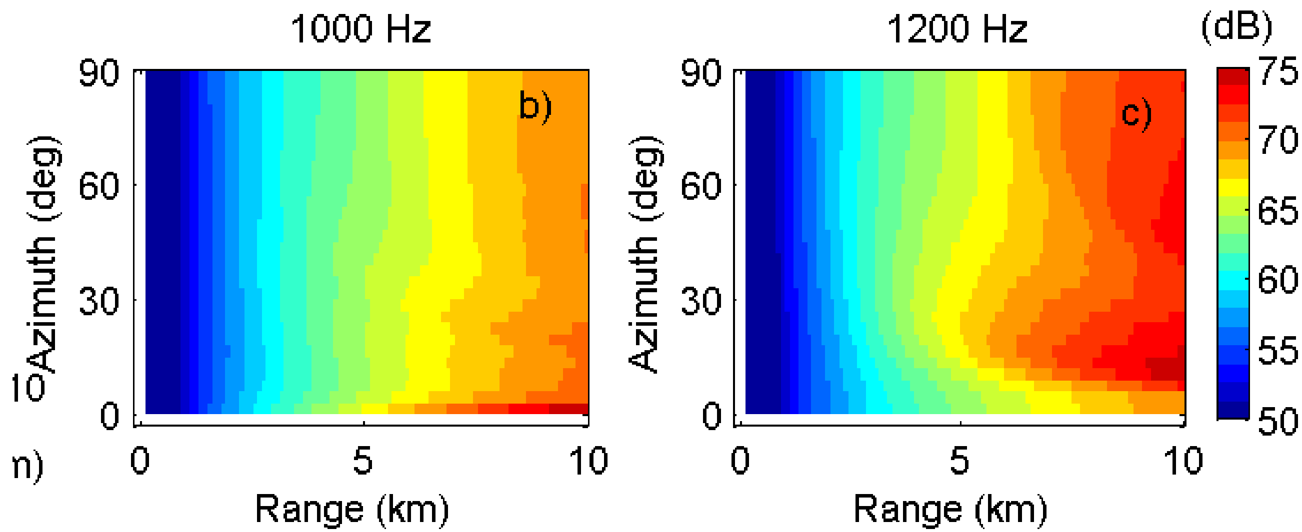
- growing losses due to increase in attenuating layer
- rapid drop at ~16 km due to null in reflection coefficient



fluid sinusoidal layer

c2>co>c1; silty clay over sand

impact on propagation (Nx2D) of sinusoidal variations
Peak-to-peak variation 2m to 6m sub-bottom.

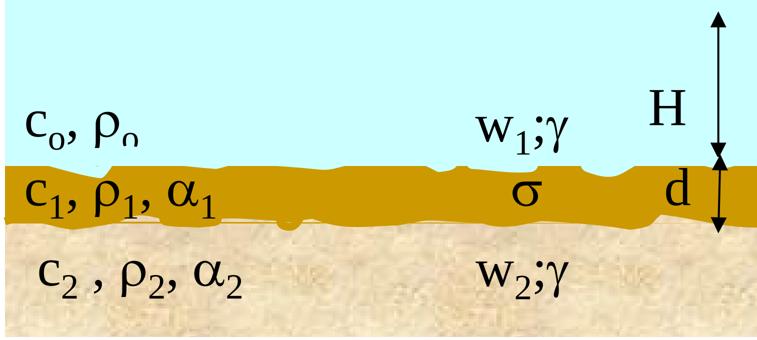


The richness of propagation in range, azimuth and frequency can be understood, by appeal to simple ‘principles’:

- Lossy seds (e.g., R nulls) tend to control RD propagation
- RD prop is independent of number of variability periods

Simple Env leads Clutter

Mud layer over sand, $c_1 < c_o < c_2$



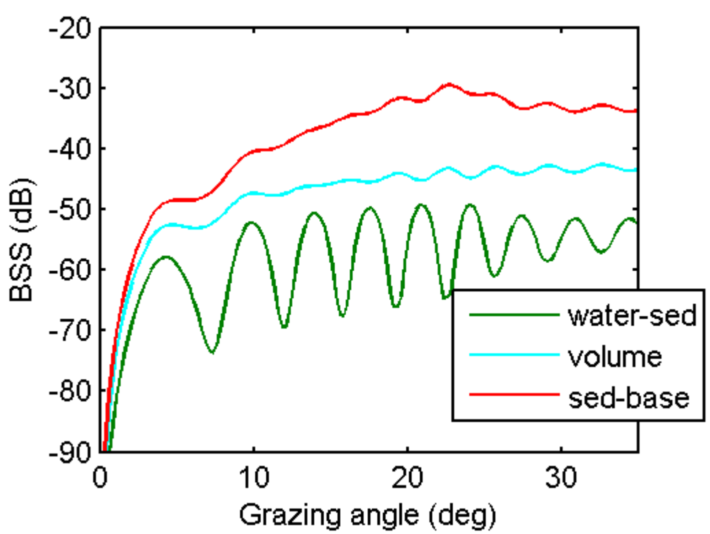
- not uncommon env., esp. in areas of river outflow: SSicily , GoM, ECS, Yellow sea

- scattering via perturbation theory
  - rough interfaces described with spectrum
  - sed volume as uncorrelated point scatterer

- reverberation via energy flux (and modes)

Layer number	Layer Thickness (m)	Sound speed (m/s)	Attenuation (dB/m/kHz)	Density (g/cm^3)
0	-	1512	0	1.0
1	Variable	1470	0.05	1.4
2	-	1660	0.10	1.8

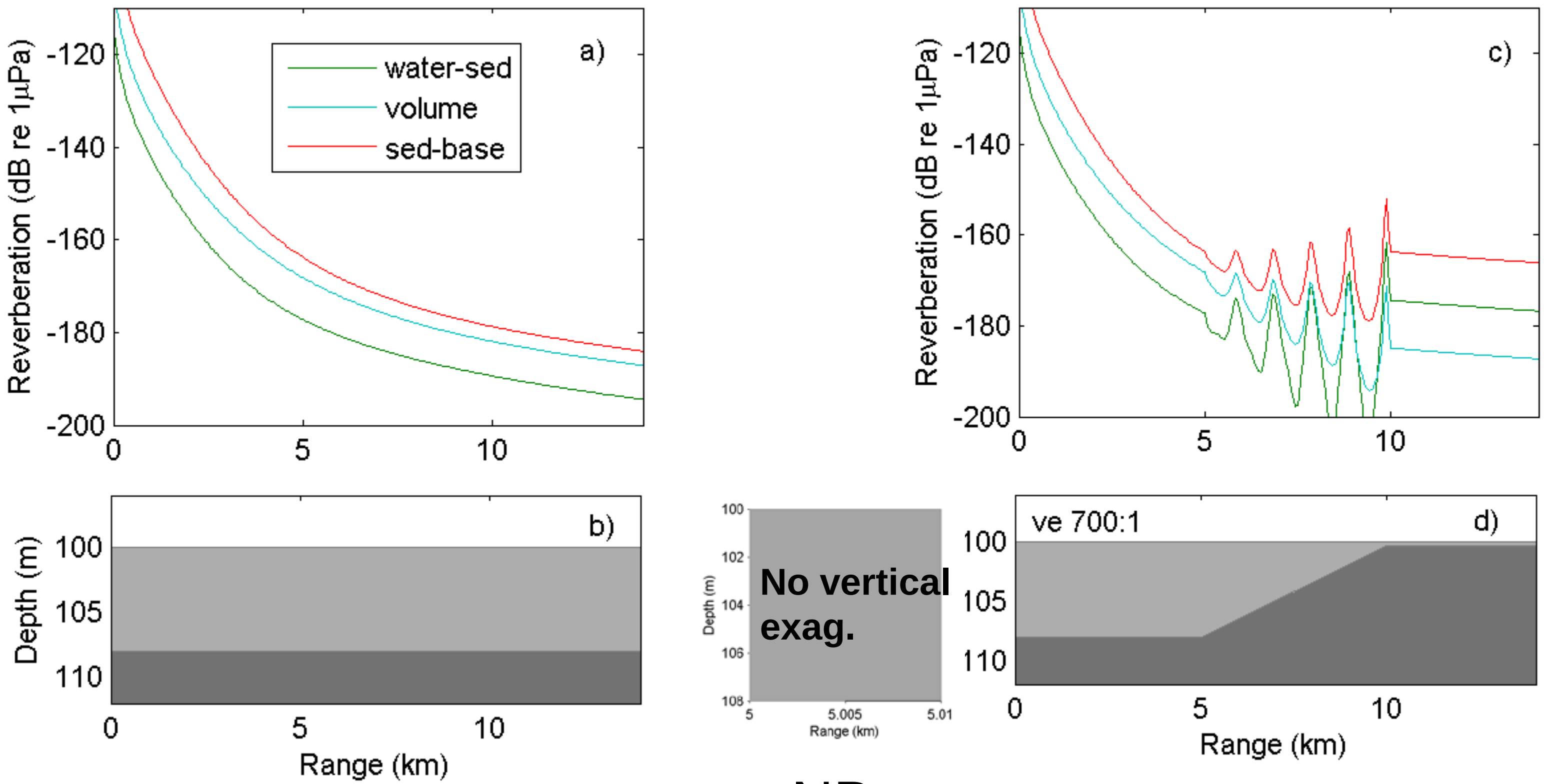
values consistent w/ experimental observations



w_1=2e-5 m^4 ; γ_1=3
σ_v=1e-5
w_2=2e-3 m^4 ; γ_2=3

Sediment Wedge

Reverberation at 2 kHz, BW=100 Hz

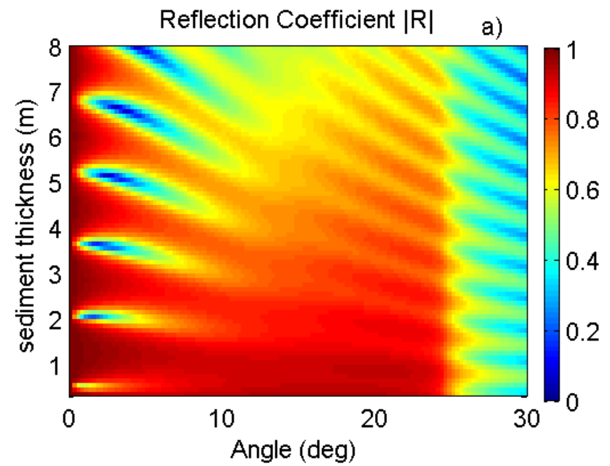


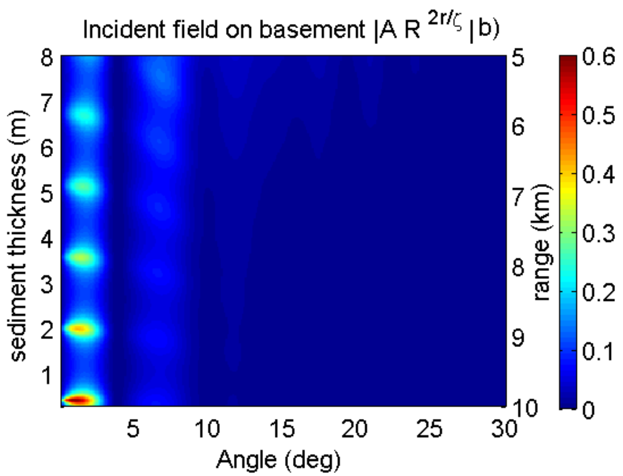
NB:

- reverb peaks for all mech.
- wedge slope is 0.1º

Clutter from sediment wedge explanation

energy flux point of view





$$R = \frac{R_{01} + R_{12} e^{i2k_{1z}d}}{1 + R_{12} R_{01} e^{i2k_{1z}d}}$$

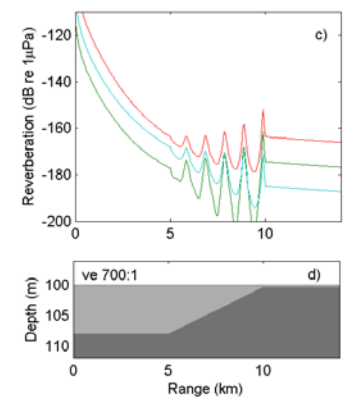
R has nulls at distinct values of *kd*

$$k\ d \sim \frac{(2n+1)\pi}{2\cos^{-1}(c_1/c_0)} - \frac{\rho_2}{\rho_1\sqrt{1-(c_1/c_2)^2}};\ n = 0,1,2\ldots$$

At the nulls, the transmission coeff *T=1+R* is large, ~1, and the scattering mechanisms are strongly illuminated.

Some clutter scaling

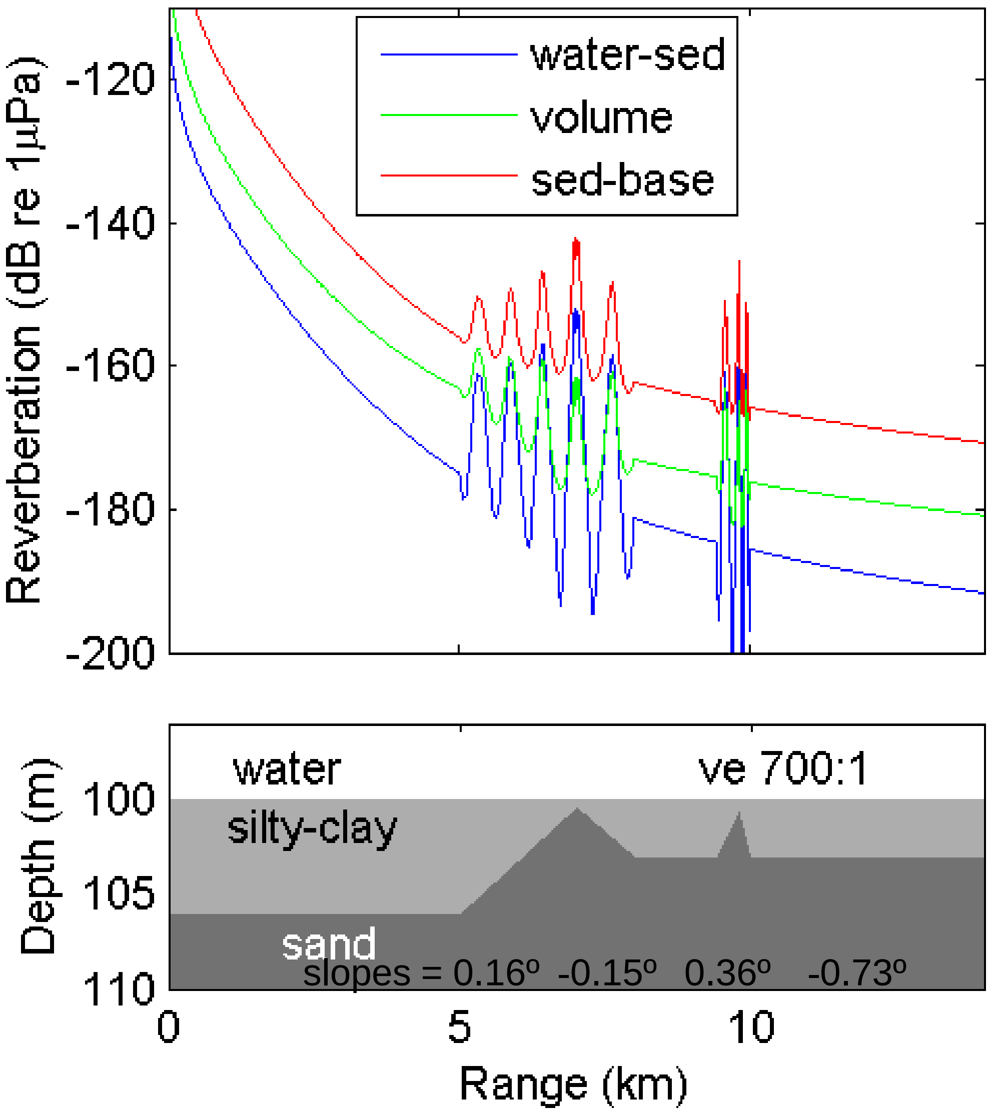
- *R and reverb scale with ~kd*
- *height of clutter peak with $k''_1 d$*
- *temporal width w/ $k_1''d$, $\partial d/\partial r$, BW*



$$A_1 = (1+R)\big/\big(\cos(k_{1z}d) - i\sin(k_{1z}d)\, Z_1/Z_2\big)\big/\big(1+R_{12}\big)$$

Scaling: Temporal Width of Clutter

Reverberation at 2 kHz, BW=100 Hz

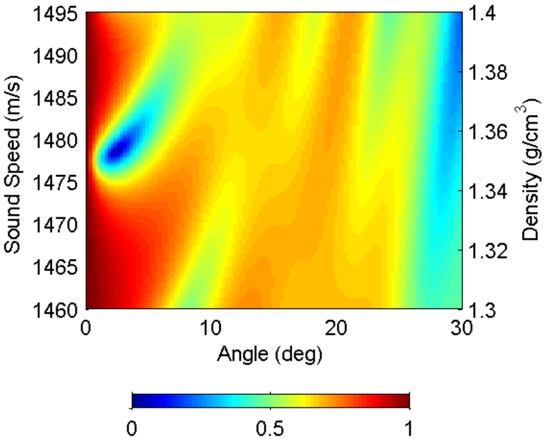


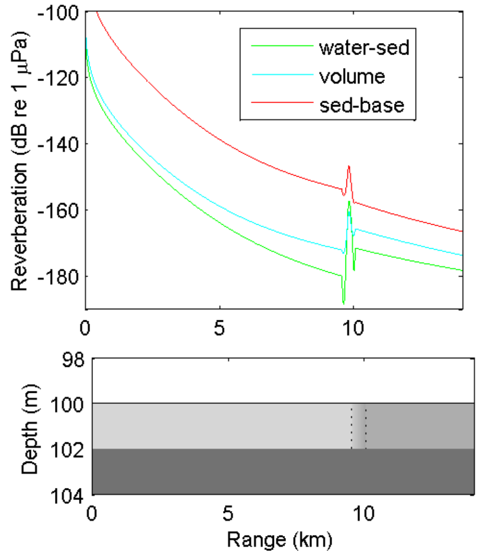
NB:

- Sub-bottom slopes < 1º yield sharp peaks, 25 -125 ms temporal width (3 dB)
- For example a slowly undulating layer with small slopes would lead to many clutter peaks, strongly non-Rayleigh reverberation

Clutter: other related environments

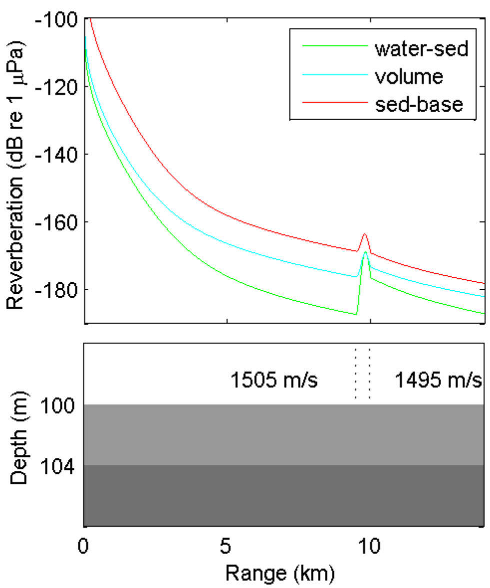
$$k\ d \sim \frac{(2n+1)\pi}{2\cos^{-1}(c_1/c_0)} - \frac{\rho_2}{\rho_1\sqrt{1-(c_1/c_2)^2}}\ ;\ n = 0,1,2...$$





Nulls (and associated clutter) also occur for fixed d, but variable c_1

- Silty-clay layer properties are known to change, e.g. wrt to proximity to riverine source
- For realism we allow density and sound speed to vary together with the weak gradients 0.07 sec^{-1}, 0.2 kg/m^4



Nulls (and associated clutter) also occur for fixed d, c_1 but variable c_o

- gradient 0.02 sec^{-1}

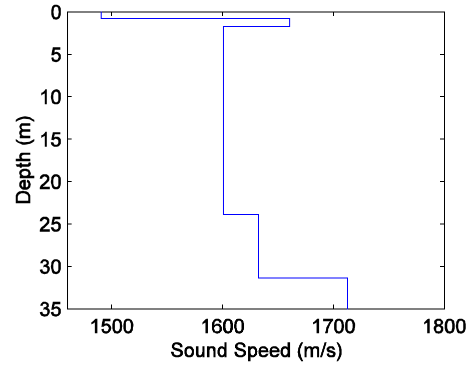
Nulls (and associated clutter) also occur for variable c_2 and/or ρ_2

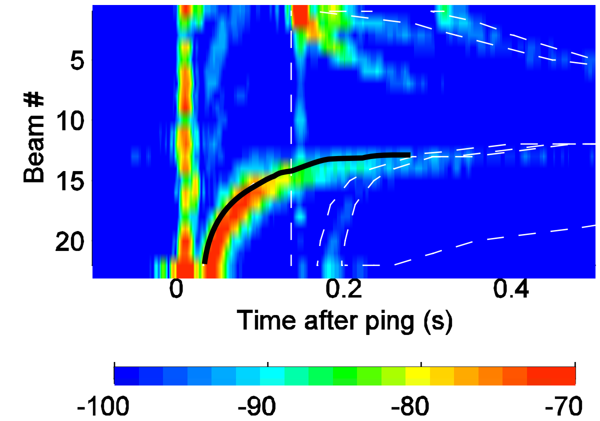
- Typical variability lead to weak clutter (see eq)

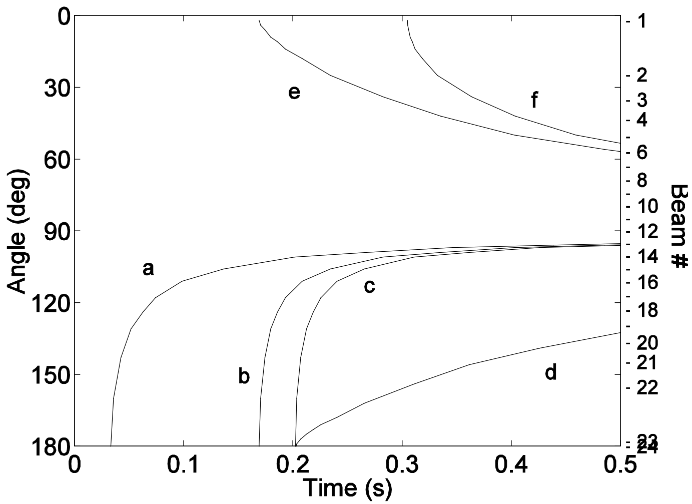
Scattering mechanism

In thick mud region there is strong evidence that scattering arises from mud-sand interface and not from mud volume

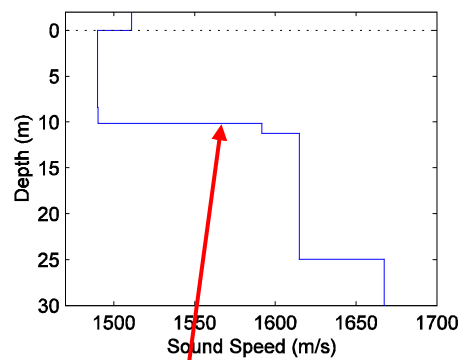
3600 Hz Scattering from Water-Sediment Interface

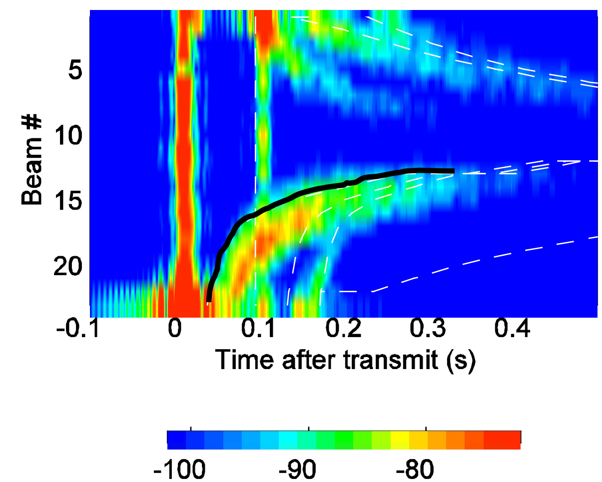






3600 Hz Scattering from Sub-Sediment Interface





1) Delay between bottom returns is ~14 ms/10m
2) Scattering coming from sub-bottom layer not volume

Holland, C.W., Shallow water coupled scattering and reflection measurements, IEEE JOE., 27, 454-470, 2002.