Interaction of sound with the seafloor

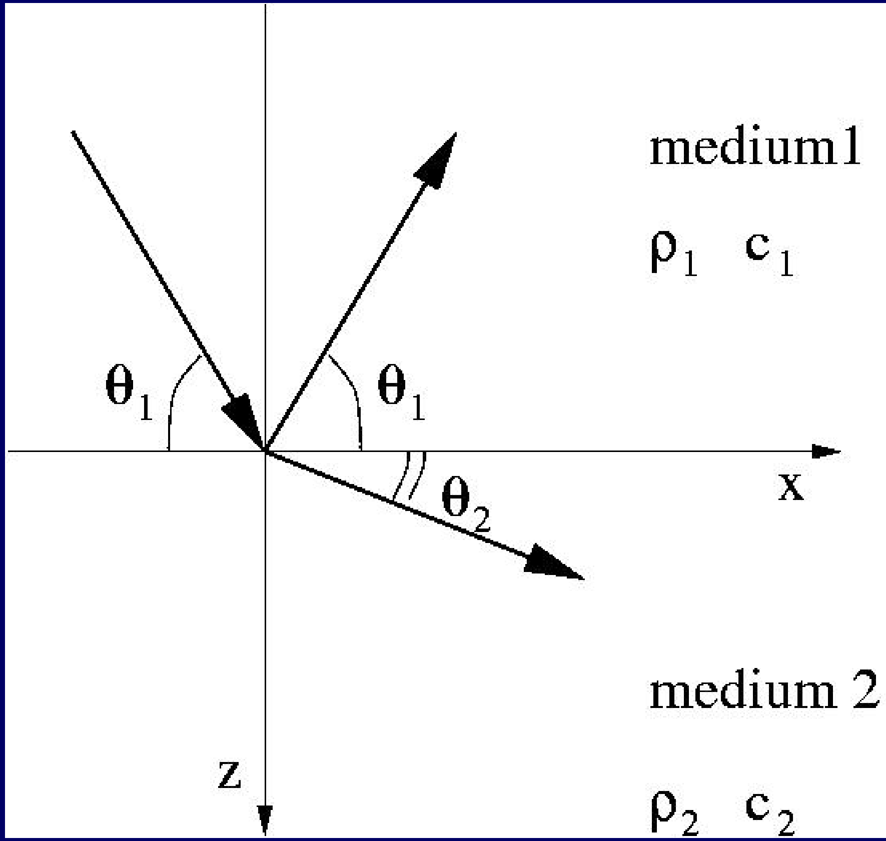
July 4, 2010

Delft Institute of Earth Observation and Space Systems

Delft University of Technology

Reflection of sound at the seafloor

Fluid-fluid interface



$$\frac{\cos\theta_2}{c_2} = \frac{\cos\theta_1}{c_1}$$

$$R = \frac{\rho_2 c_2 \sin\theta_1 - \rho_1 c_1 \sin\theta_2}{\rho_2 c_2 \sin\theta_1 + \rho_1 c_1 \sin\theta_2}$$

$$T = 1 + R = \frac{2\rho_2 c_2 \sin\theta_1}{\rho_2 c_2 \sin\theta_1 + \rho_1 c_1 \sin\theta_2}$$

$$c_2 > c_1$$

$$\theta_c = \arccos\left(\frac{c_1}{c_2}\right)$$

$$R = \frac{\rho_2 c_2 - \rho_1 c_1}{\rho_2 c_2 + \rho_1 c_1} \quad (\theta_1 = 90^\circ)$$

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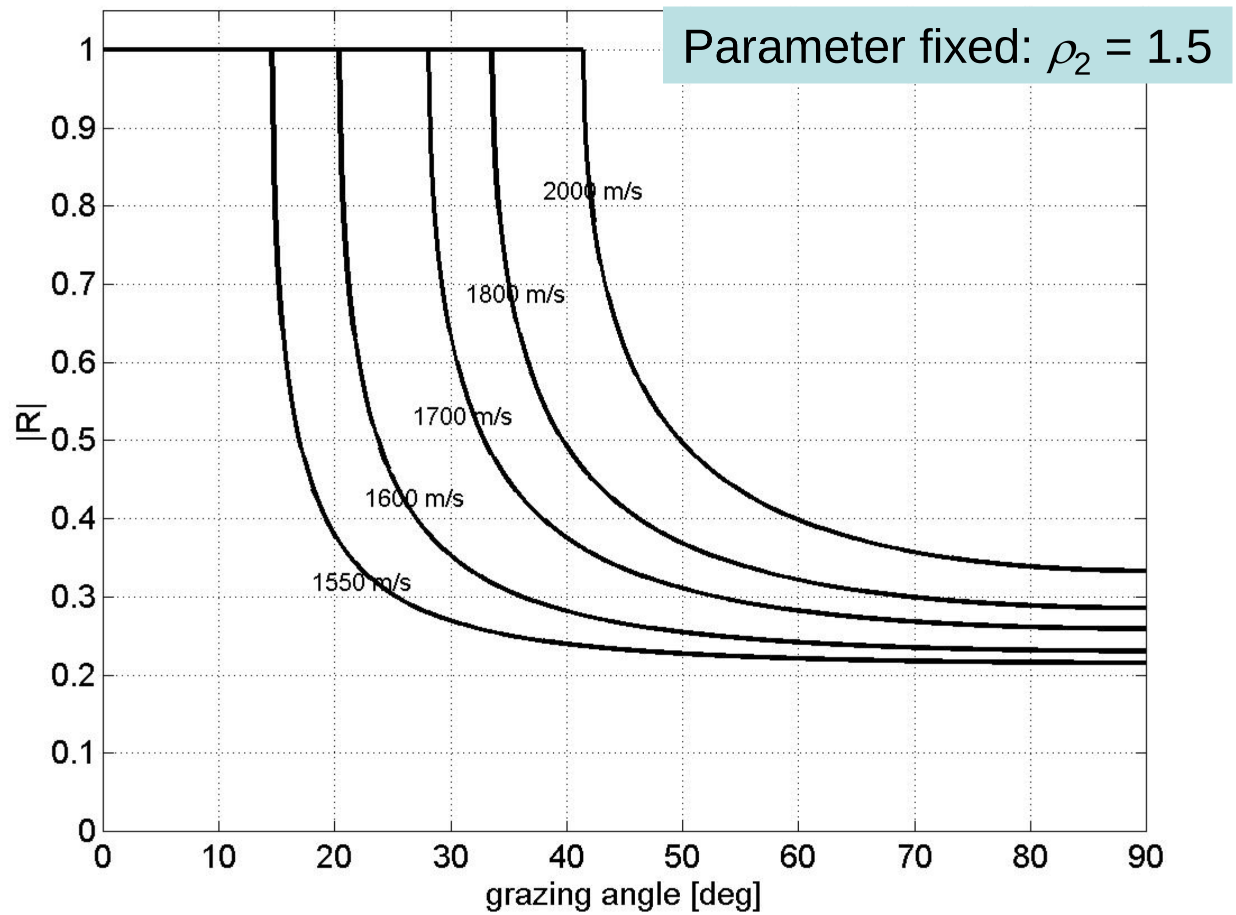
Reflection of sound at the seafloor

effect of c_2



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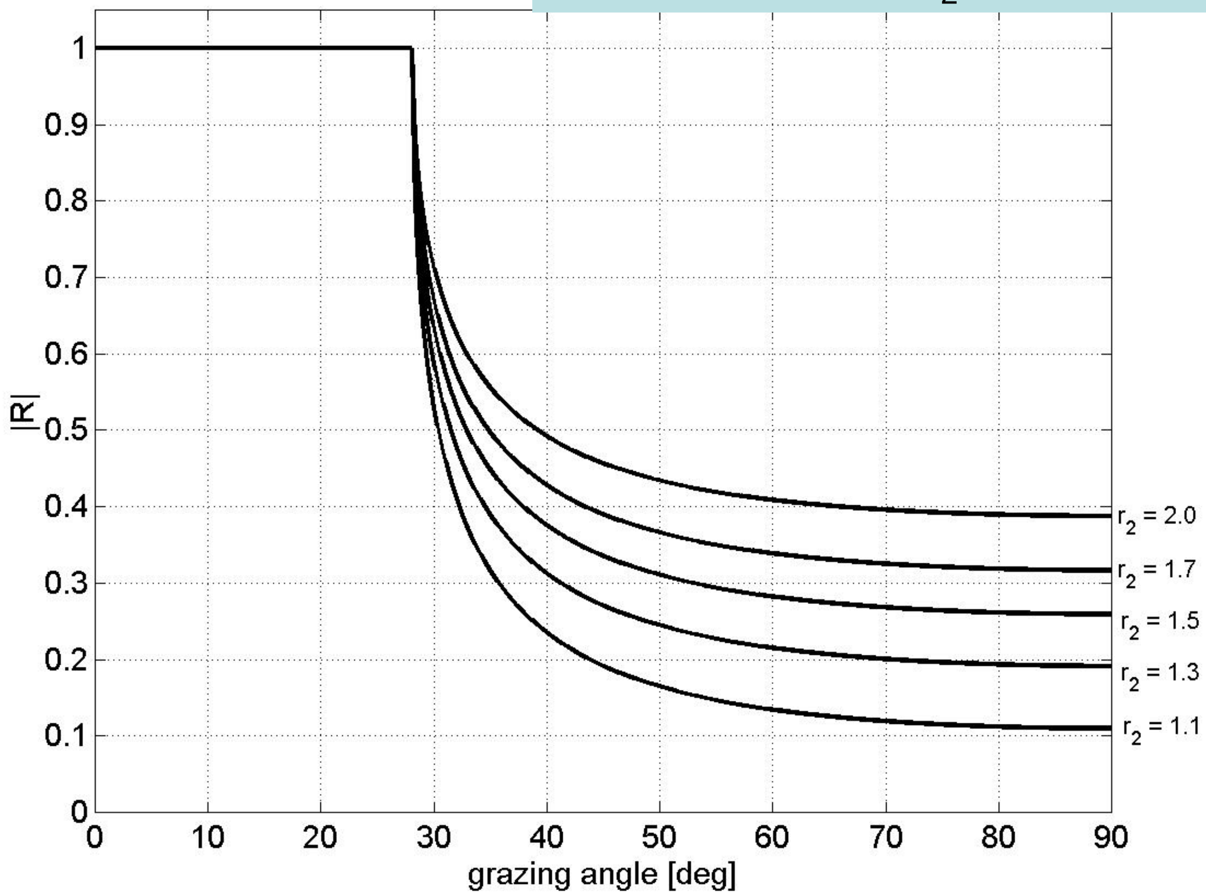
Reflection of sound at the seafloor

effect of ρ_2

Parameter fixed: c_2 = 1700 m/s



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Reflection of sound at the seafloor

Lossy reflecting medium

Make k_2 complex:

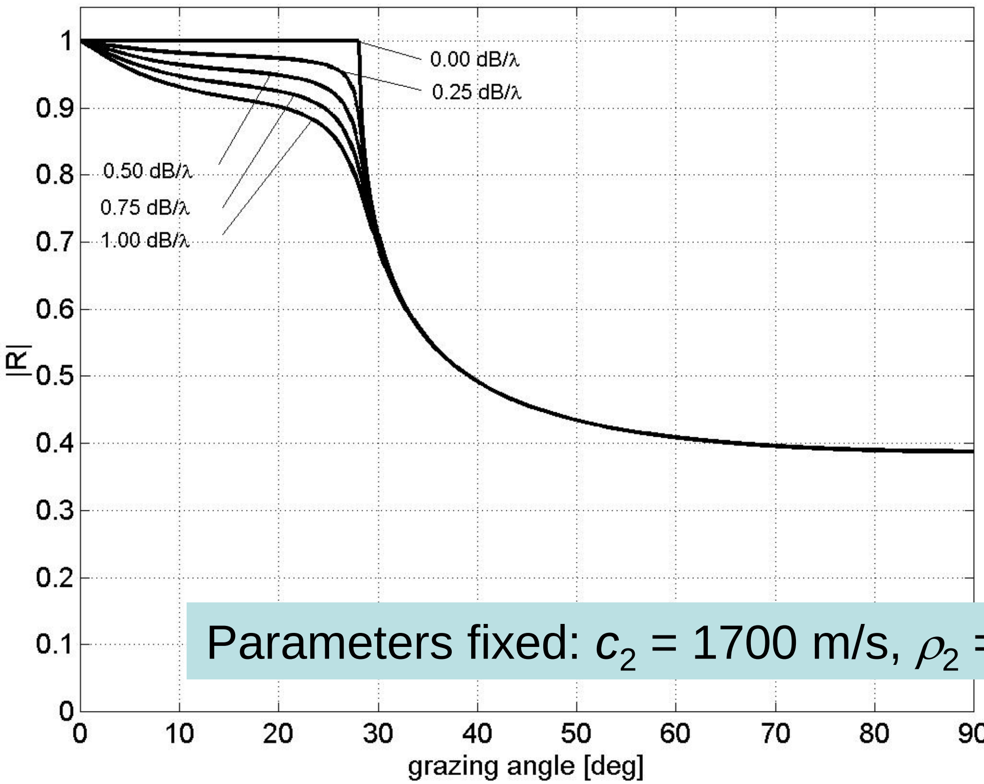
$$k_2 \rightarrow k_2 + i\alpha_2'$$

with

$$\alpha_2' = \frac{\alpha_2}{\lambda_2\, 20\, {}^{10}\log e}$$

α'_2 in m^{-1}
α_2 in dB/λ

$$\mathrm{Im}(c_2) \approx \frac{c_2 \alpha_2}{40\pi\, {}^{10}\log e}$$



Parameters fixed: c_2 = 1700 m/s, ρ_2 = 2

Exercise

Reflection of sound at unconsolidated sediments

Sediment type	M_z (ϕ)	n	ρ_2 g/cm^3]	c_2 [m/s]	α_2 [dB/λ]	$c_{s,2}$ [m/s]	h [cm]
Clay	9	0.80	1.2	1470	0.08	-	0.5
Silty clay	8	0.75	1.3	1485	0.10	-	0.5
Clayey silt	7	0.70	1.5	1515	0.15	125	0.6
Sand-silt-clay	6	0.65	1.6	1560	0.20	290	0.6
Sand-silt	5	0.60	1.7	1605	1.00	340	0.7
Silty sand	4	0.55	1.8	1650	1.10	390	0.7
Very fine sand	3	0.50	1.9	1680	1.00	410	1.0
Fine sand	2	0.45	1.95	1725	0.80	430	1.2
Coarse sand	1	0.40	2.0	1800	0.90	470	1.8

mean grain size M_z in phi units

$$M_z[\phi] = -{}^2\log(d[mm])$$

Density of the sediment

$$\rho_2 = n\rho_1 + (1-n)\rho_b$$

with n the porosity and ρ_b the bulk grain density (approx. 2.7 g/cm^3).

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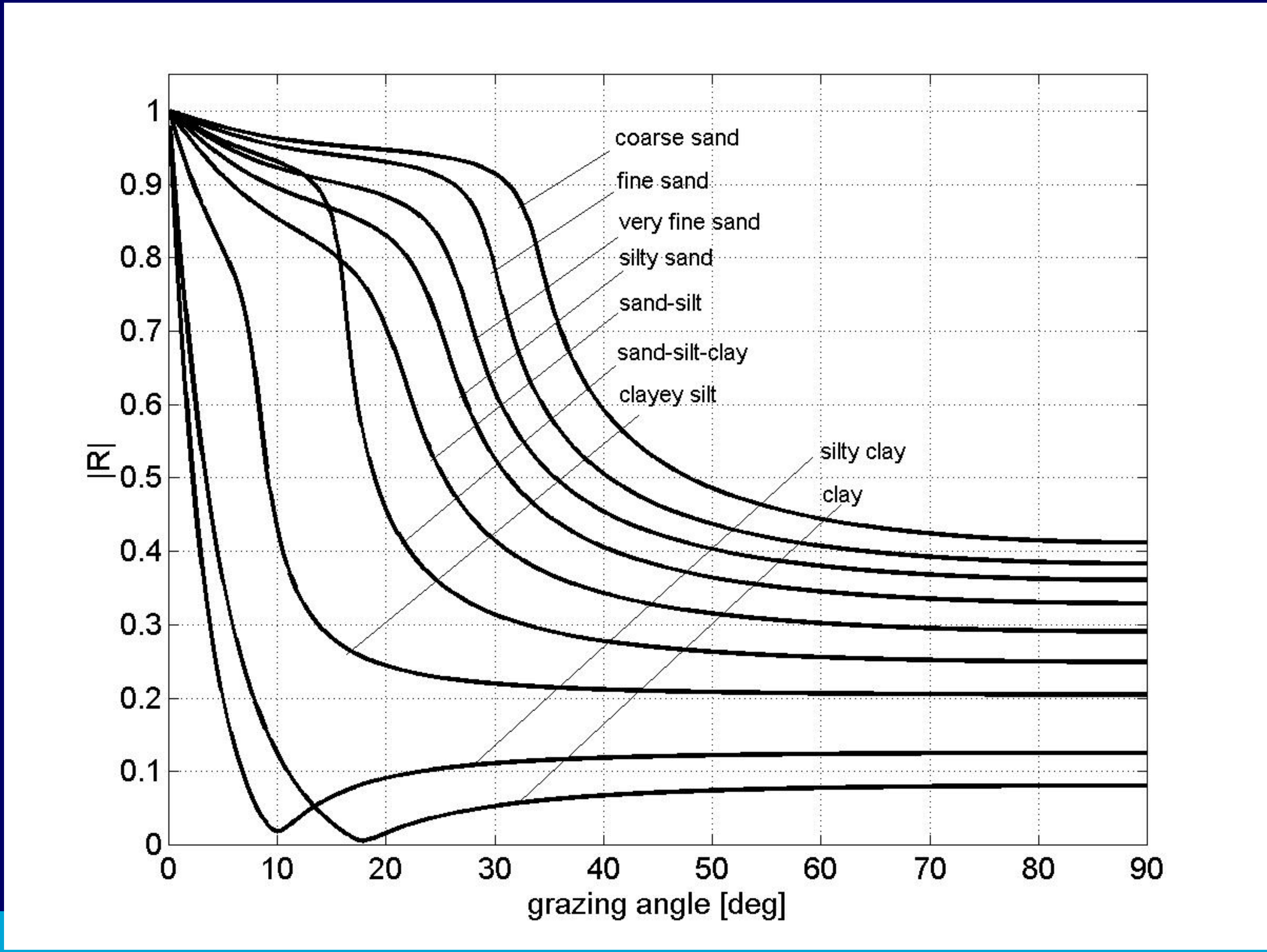
Reflection of sound at unconsolidated sediments



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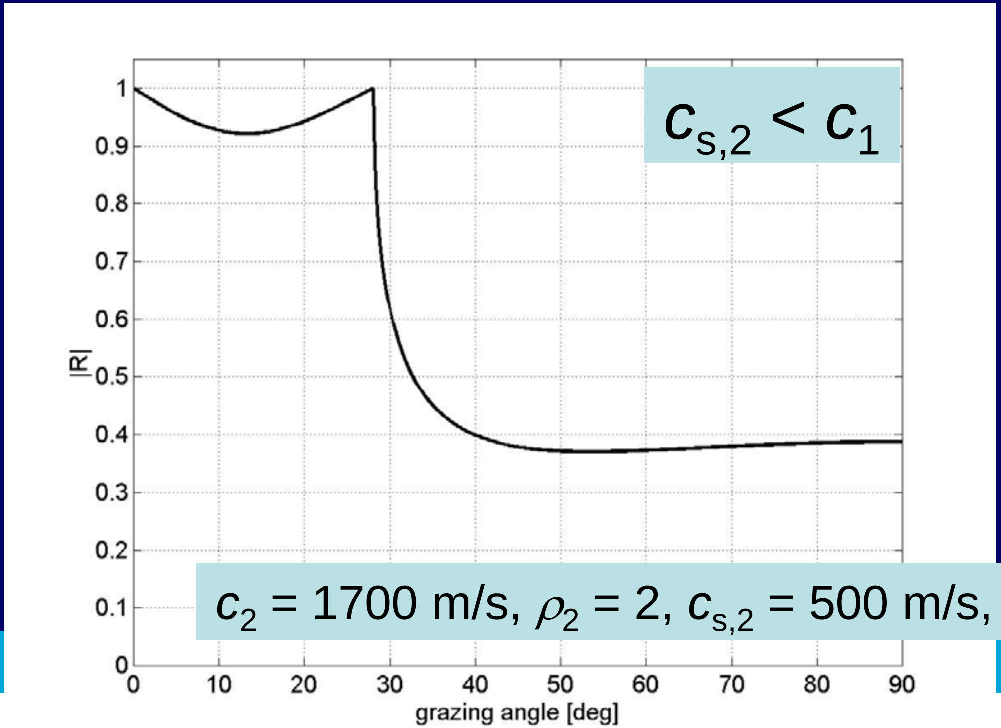
Reflection of sound at the seafloor
Elastic reflecting medium

Snell's law becomes:

$$\frac{\cos\theta_1}{c_1} = \frac{\cos\theta_2}{c_2} = \frac{\cos\theta_{s,2}}{c_{s,2}} \quad \text{with} \quad c_{s,2} < \frac{c_2}{\sqrt{2}}$$

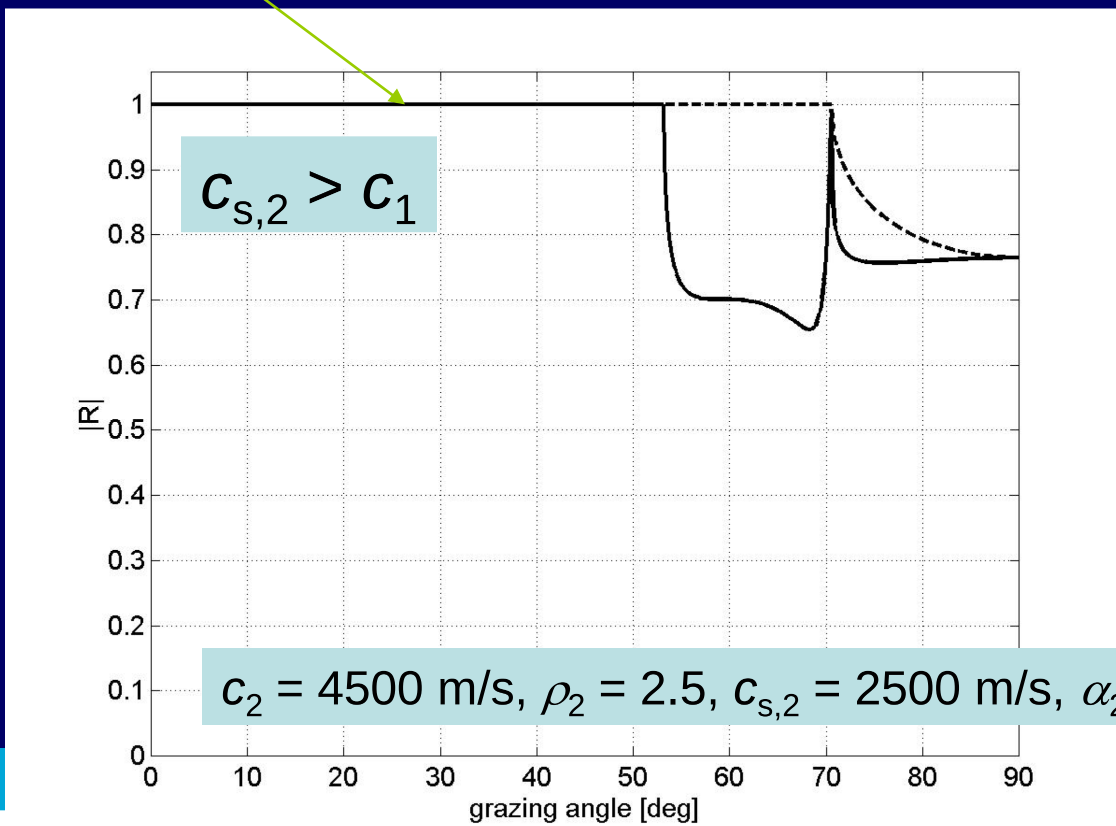


$c_{s,2} < c_1$

c_2 = 1700 m/s, ρ_2 = 2, $c_{s,2}$ = 500 m/s, α_2 = 0

Reflection of sound at the seafloor
Elastic reflecting medium, continued

total reflection



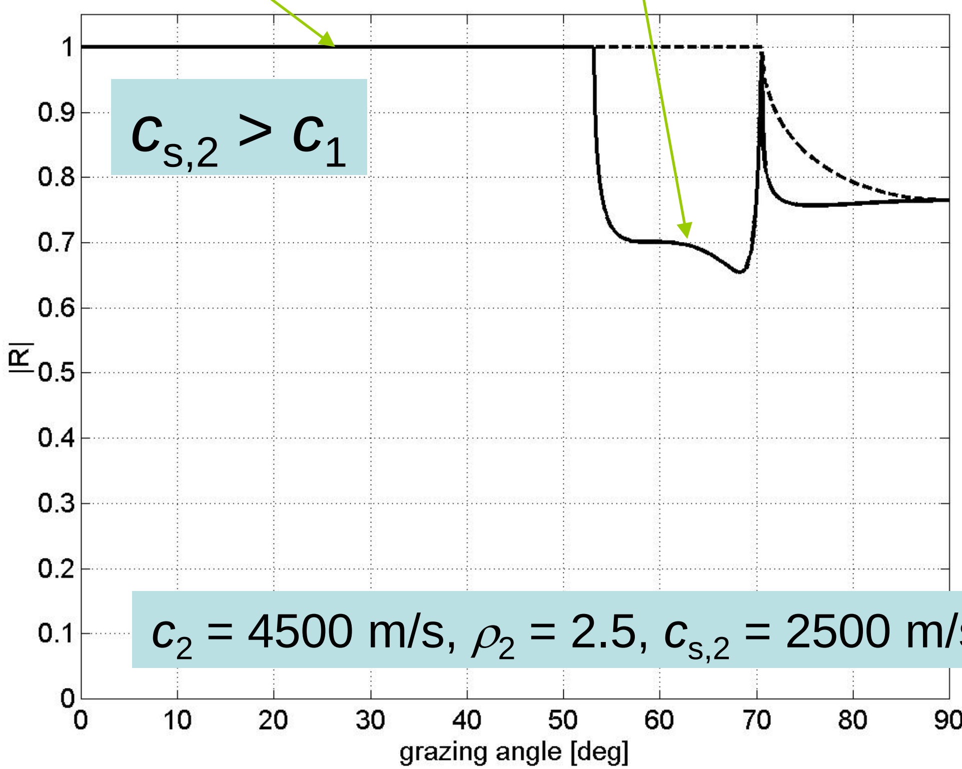
$c_{s,2} > c_1$

c_2 = 4500 m/s, ρ_2 = 2.5, $c_{s,2}$ = 2500 m/s, α_2 = 0 (dashed line: $c_{s,2}$ = 0 m/s).

Reflection of sound at the seafloor
Elastic reflecting medium, continued

total reflection

only shear transmitted



$c_{s,2} > c_1$

c_2 = 4500 m/s, ρ_2 = 2.5, $c_{s,2}$ = 2500 m/s, α_2 = 0 (dashed line: $c_{s,2}$ = 0 m/s).

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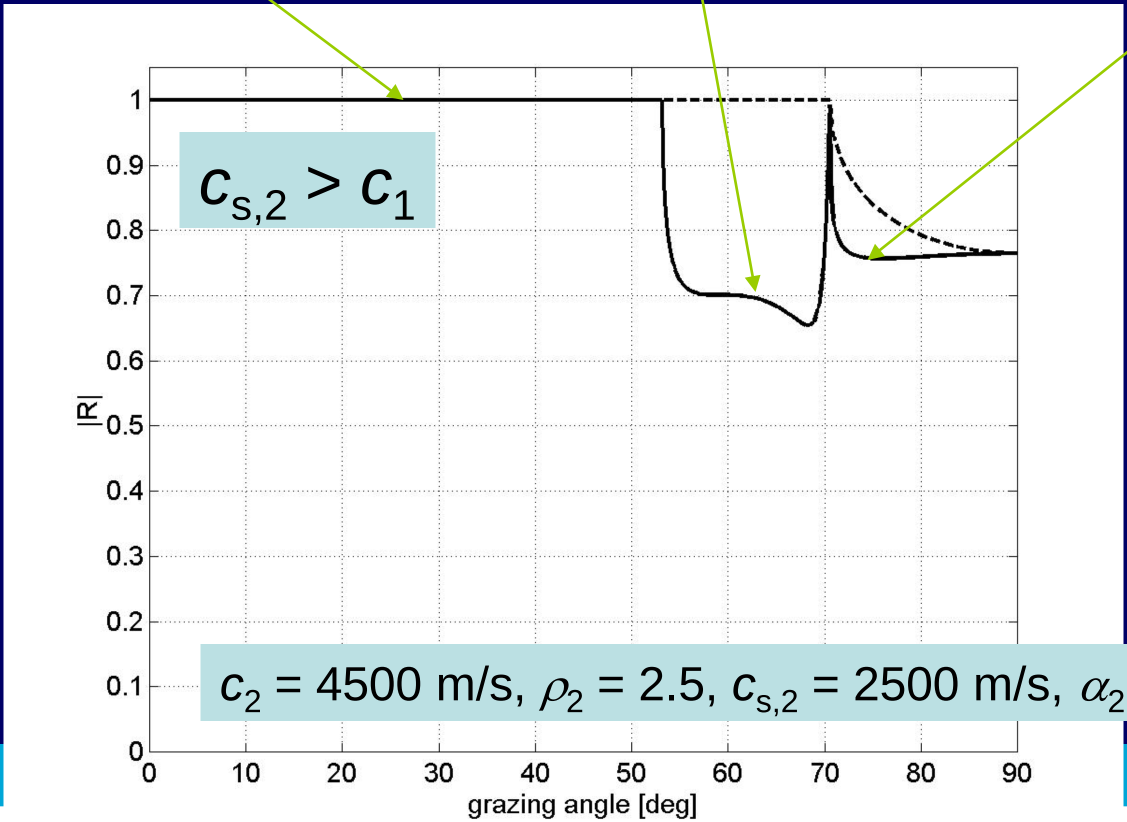
Reflection of sound at the seafloor

Elastic reflecting medium, continued

total reflection

only shear transmitted

both pressure and shear transmitted

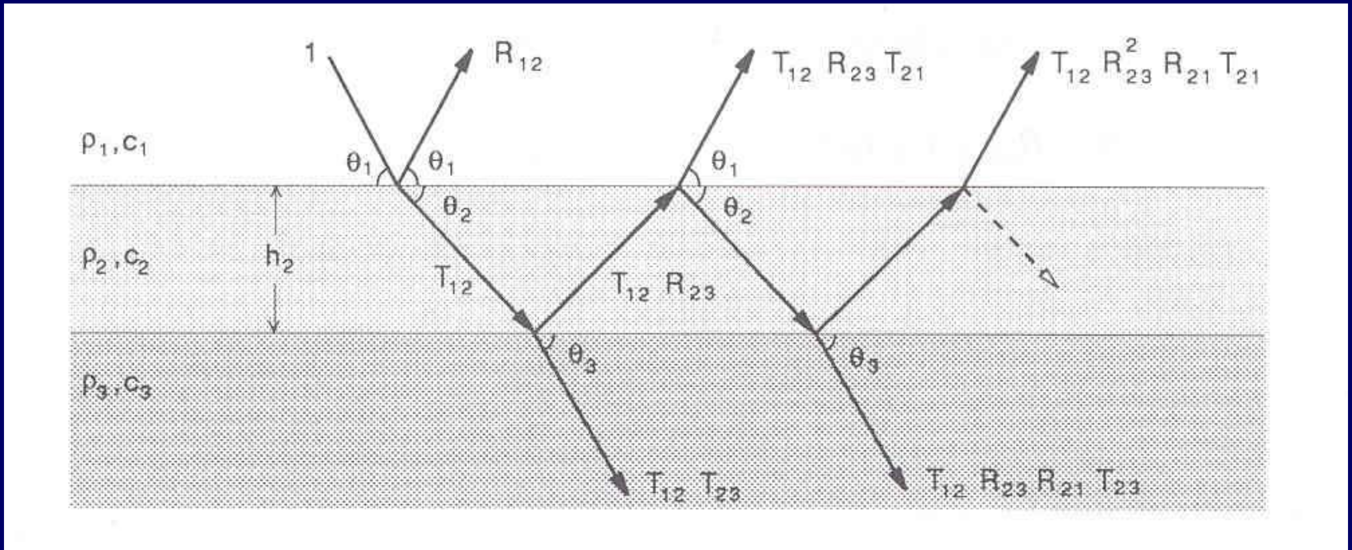


$$\theta_c = \arccos\left(\frac{c_1}{c_2}\right)$$

$$\theta_{c,s} = \arccos\left(\frac{c_1}{c_{s,2}}\right)$$

c_2 = 4500 m/s, ρ_2 = 2.5, $c_{s,2}$ = 2500 m/s, α_2 = 0 (dashed line: $c_{s,2}$ = 0 m/s).

Reflection of sound at the seafloor
Layered reflecting medium



Total reflection coefficient:

$$R = \frac{R_{12} + R_{23}\, e^{2i\varphi_2}}{1 + R_{12} R_{23}\, e^{2i\varphi_2}}$$

with

$$\varphi_2 = k_2 h_2 \sin\theta_2$$

***R* is now frequency-dependent !**

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Reflection of sound at the seafloor
Layered reflecting medium, example

Water

First sediment layer

Second sediment layer

c_2 = 1600 m/s, ρ_2 = 1.5, α_2 = 0.2 dB/λ, h_2 = 10 m,
c_3 = 2000 m/s, ρ_3 = 1.5, α_3 = 0.5 dB/λ.

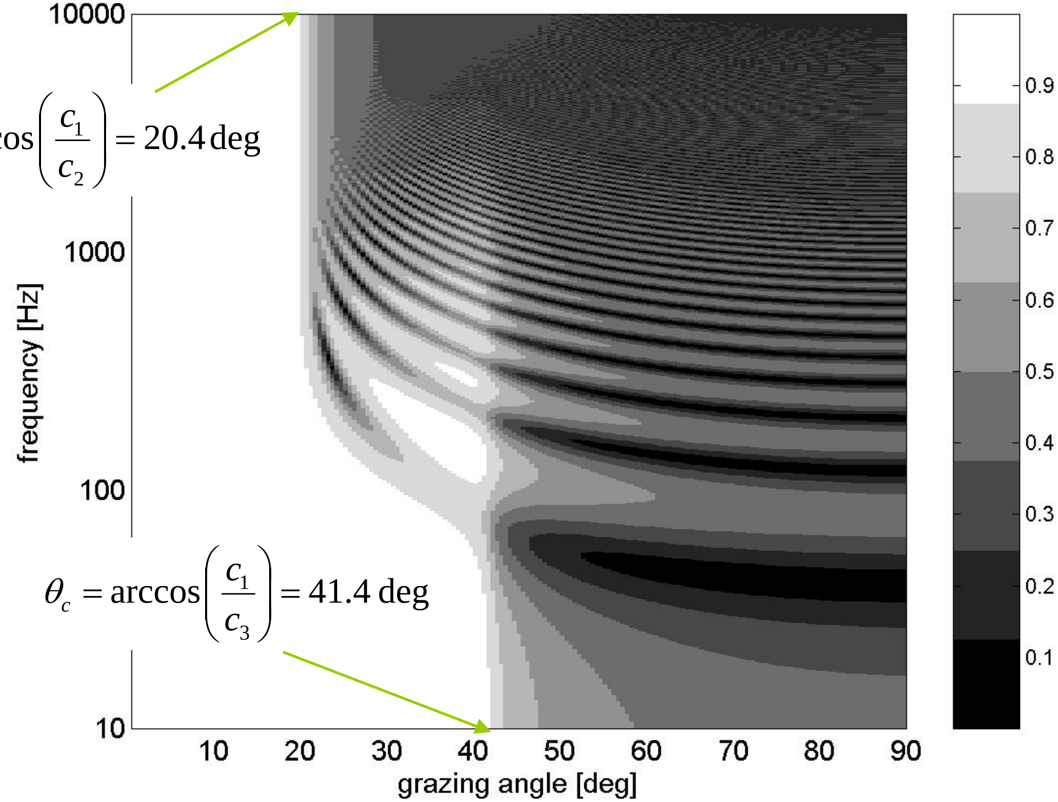
Exercise:
calculate the critical angles corresponding to c_2 and c_3

Reflection of sound at the seafloor
Layered reflecting medium, example

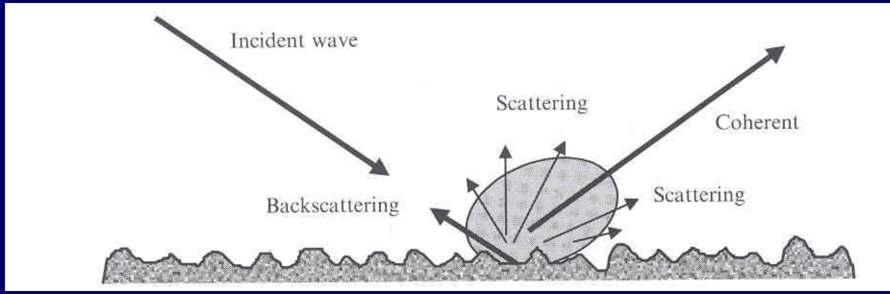
c_2 = 1600 m/s, ρ_2 = 1.5, α_2 = 0.2 dB/λ, h_2 = 10 m,
c_3 = 2000 m/s, ρ_3 = 1.5, α_3 = 0.5 dB/λ.

$$\theta_c = \arccos\left(\frac{c_1}{c_2}\right) = 20.4\,\text{deg}$$

$$\theta_c = \arccos\left(\frac{c_1}{c_3}\right) = 41.4\,\text{deg}$$

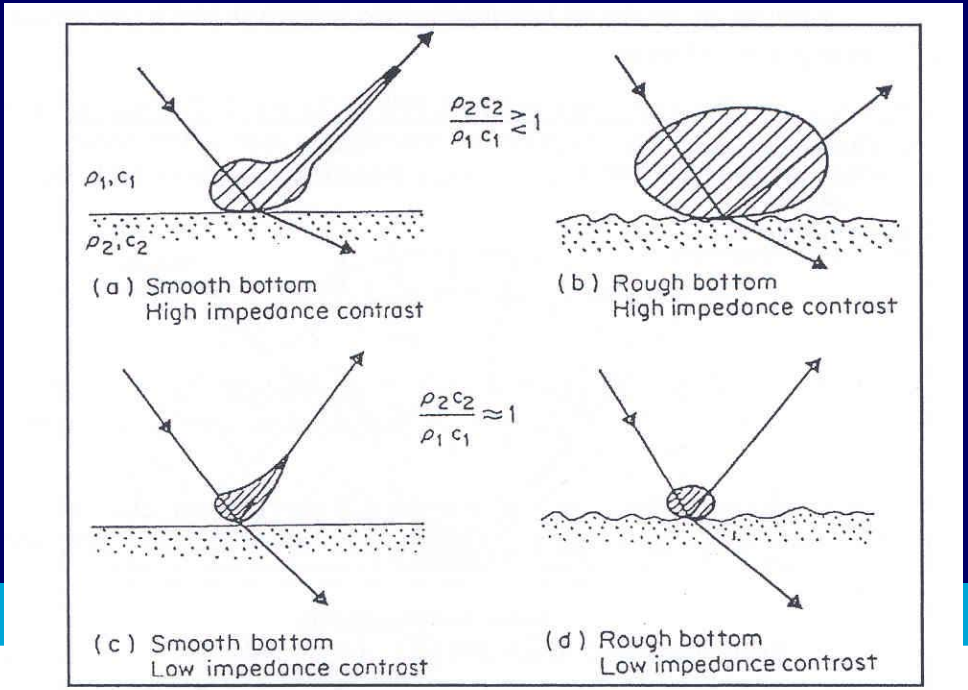


Scattering of sound at the seafloor
Physics of scattering



Process depends on:
- frequency
- angle of incidence
- characteristics of relief

Directivity patterns as a function of
- seafloor roughness
- impedance contrast



Roughness in terms of the acoustic wavelength !

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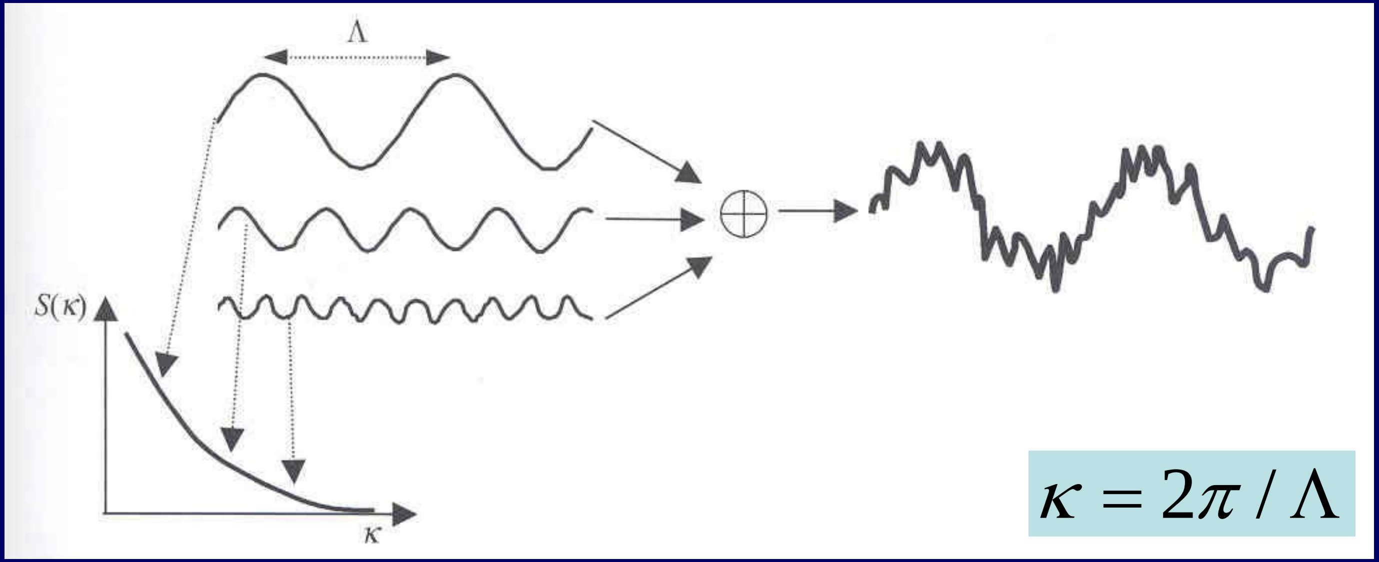
Intermezzo: the spatial roughness spectrum



$$\kappa = 2\pi / \Lambda$$

$$S(\kappa) = S_0\,\kappa^{-\gamma}$$ with $$\int S(\kappa)\,d\kappa = h^2$$

with *h* the standard deviation of the relief amplitudes

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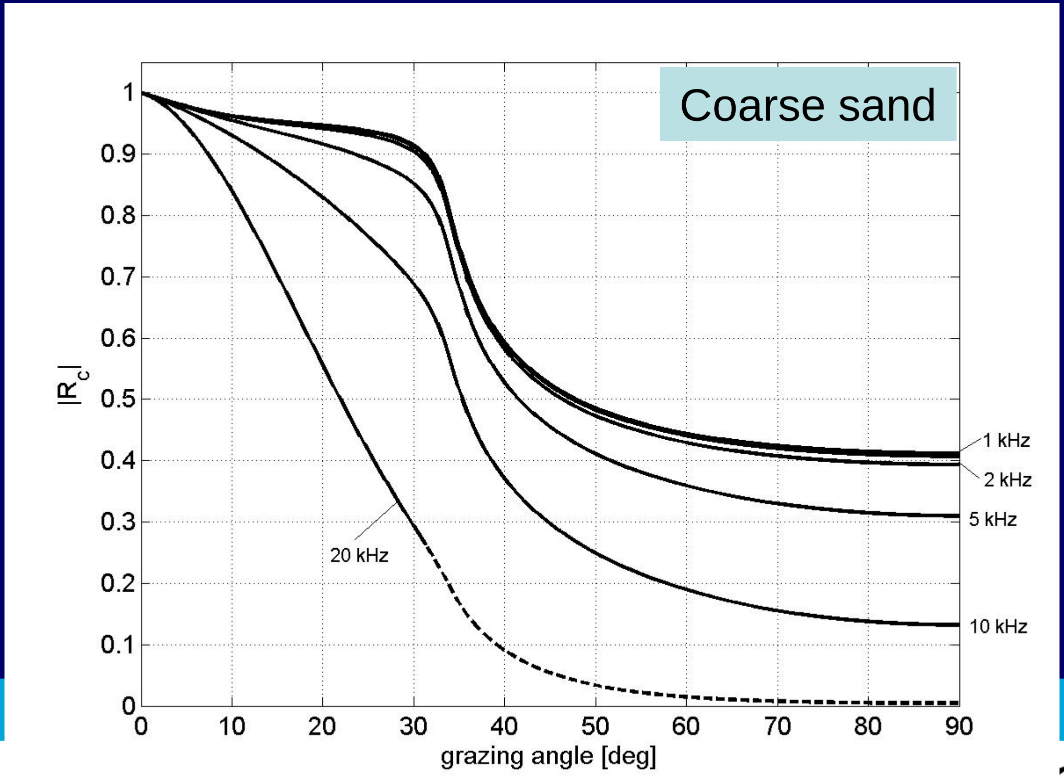
Reflection revisited - Rayleigh parameter

Roughness in terms of the acoustic wavelength ! → $P = 2kh\sin\theta$

Modify reflection coefficient → $R_c(\theta) = R(\theta)\,e^{-P^2/2} = R(\theta)\,e^{-2k^2h^2\sin^2\theta}$



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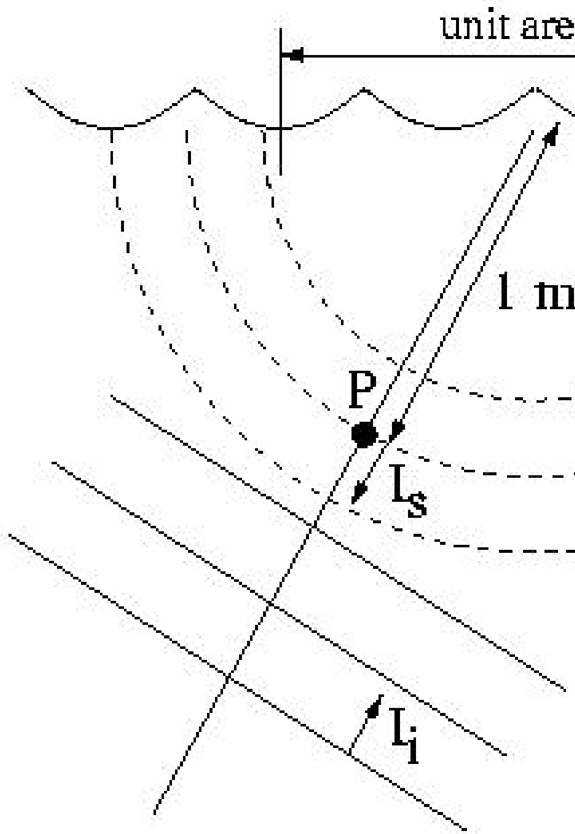
Scattering of sound at the seafloor

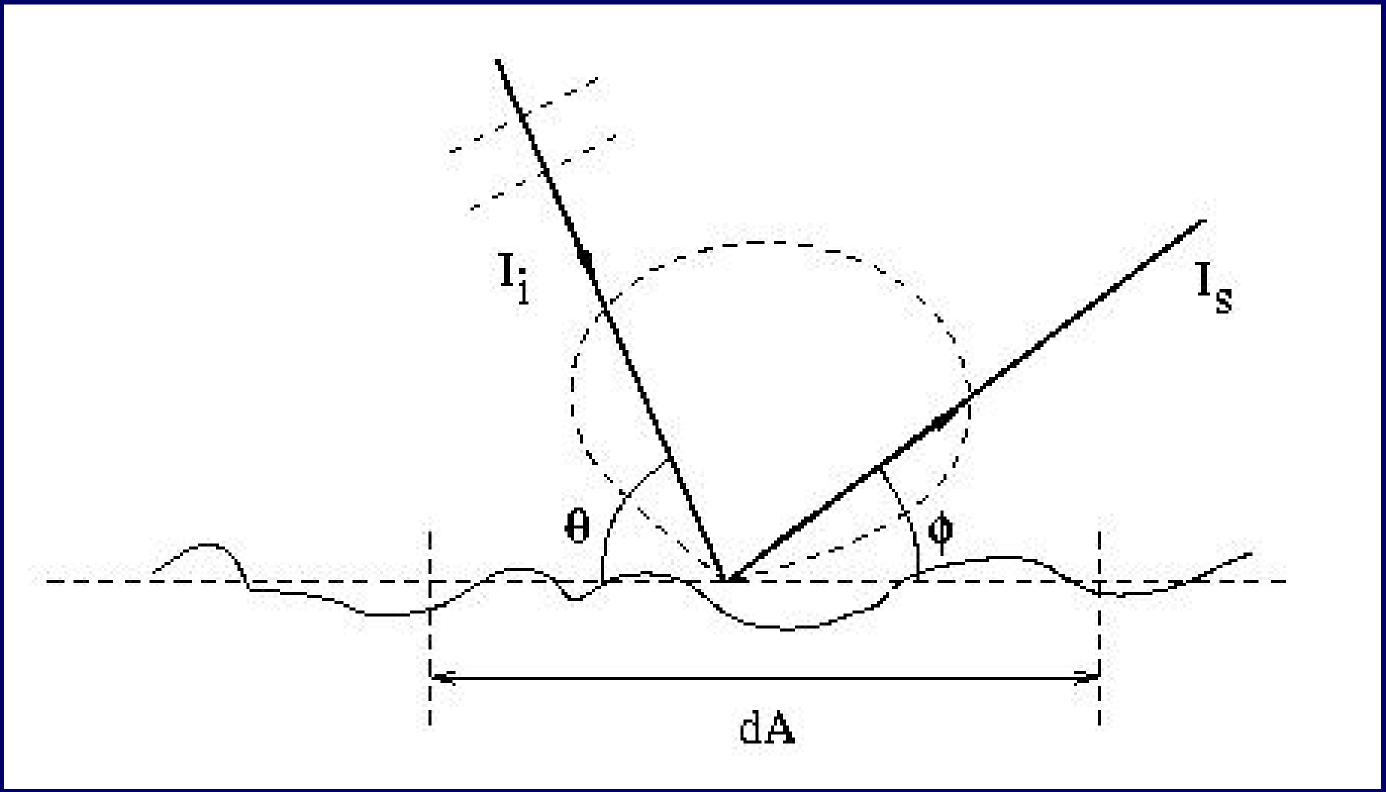
backscattering strength



$$S = 10\,{}^{10}\log \frac{I_s}{I_i}$$

Depends on
- grazing incidence angle θ
- frequency f
- seafloor type
  (roughness, volume inhomogeneities)

Scattering of sound at the seafloor
Lambert's rule



$$S = 10^{10}\log\mu + 10^{10}\log\left(\sin^2\theta\right)$$

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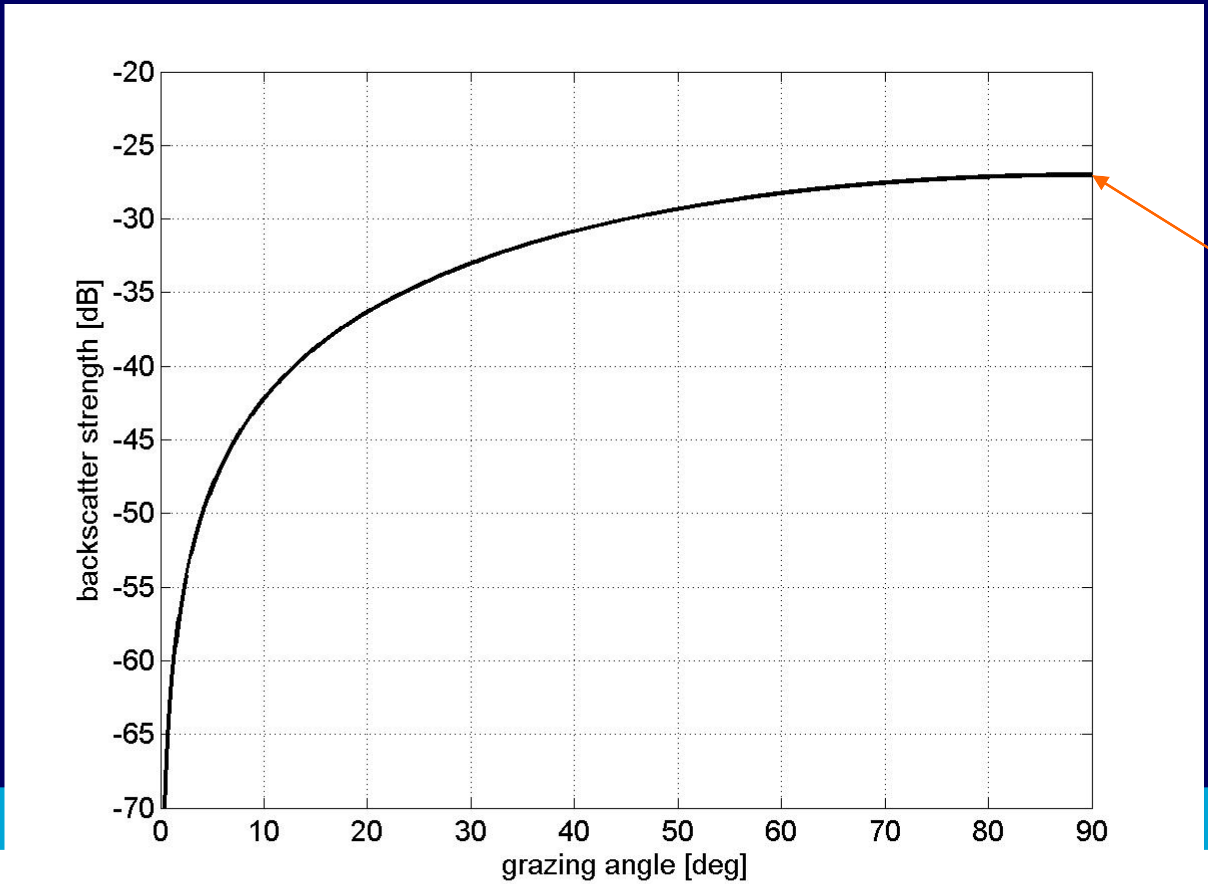
Scattering of sound at the seafloor

Lambert's rule, continued



$10 \, ^{10}\log \mu$

- ranges between –40 dB and –10 dB
- useful starting value -27 dB
- maximum value -5 dB (exercise)

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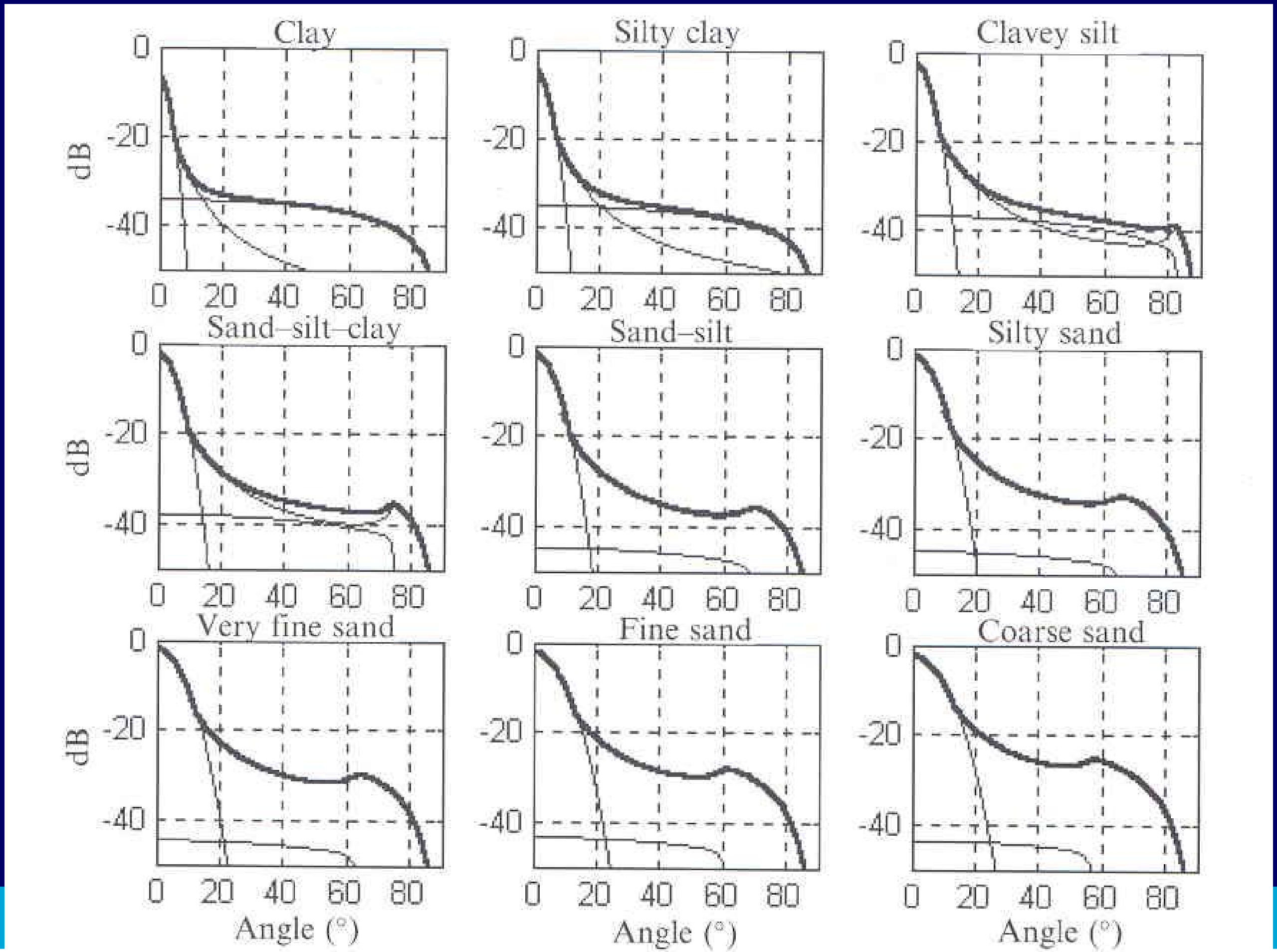
Scattering of sound at the seafloor
Sophisticated backscattering strength models



- facet scattering near vertical incidence
- Bragg scattering (micro-roughness)
- volume scattering due to inhomogeneities in the sediment volume