

Rock Physics Model for Unconsolidated Sediment

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SEG Summer Research Workshop

Galway 2008

Original Goal/
Motivation:

Inversion of marine single-channel seismic profiling data from the *Irish National Seabed Survey* for acoustic and physical sediment properties

Use of Biot theory

Inversion Method:

Artificial Neural Networks (NN)

Use of synthetic seismograms for training of NN

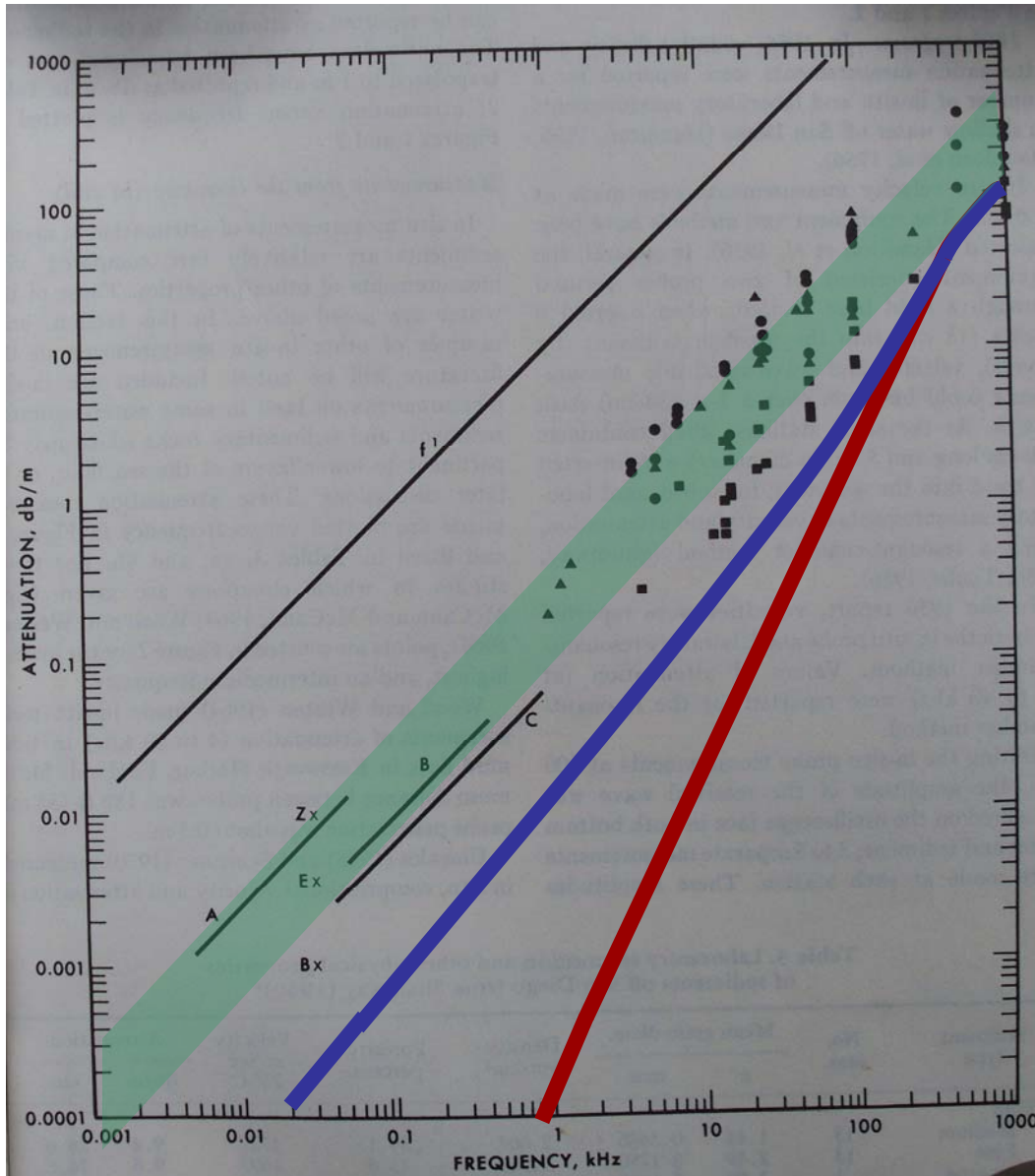
Challenges:

Extension of Biot theory

Reduction of the number of input parameters

Coverage of a wide range of sediments

P-wave Attenuation In Marine Unconsolidated Sediment



Linear relationship ?

Grain-to-grain friction?

Biot theory

Poroelastic solid

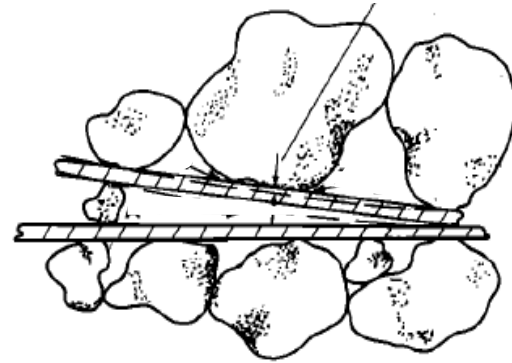
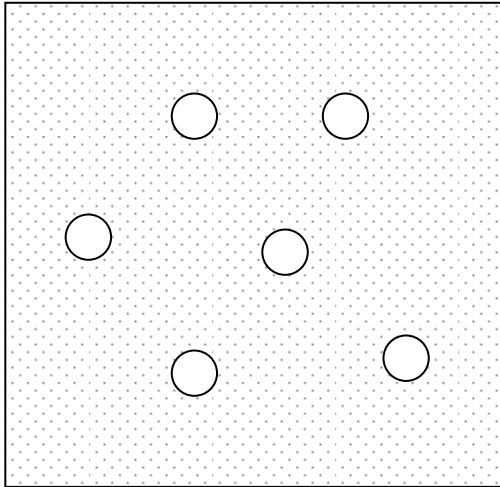
Biot-Stoll Model

Dissipative sediment frame,

Constant complex K_b , G_b

Hamilton (1972)

Biot Theory For Unconsolidated Sediment ?



Sediment Structural Model: Binary Grain-size Sphere Pack

Assumptions:

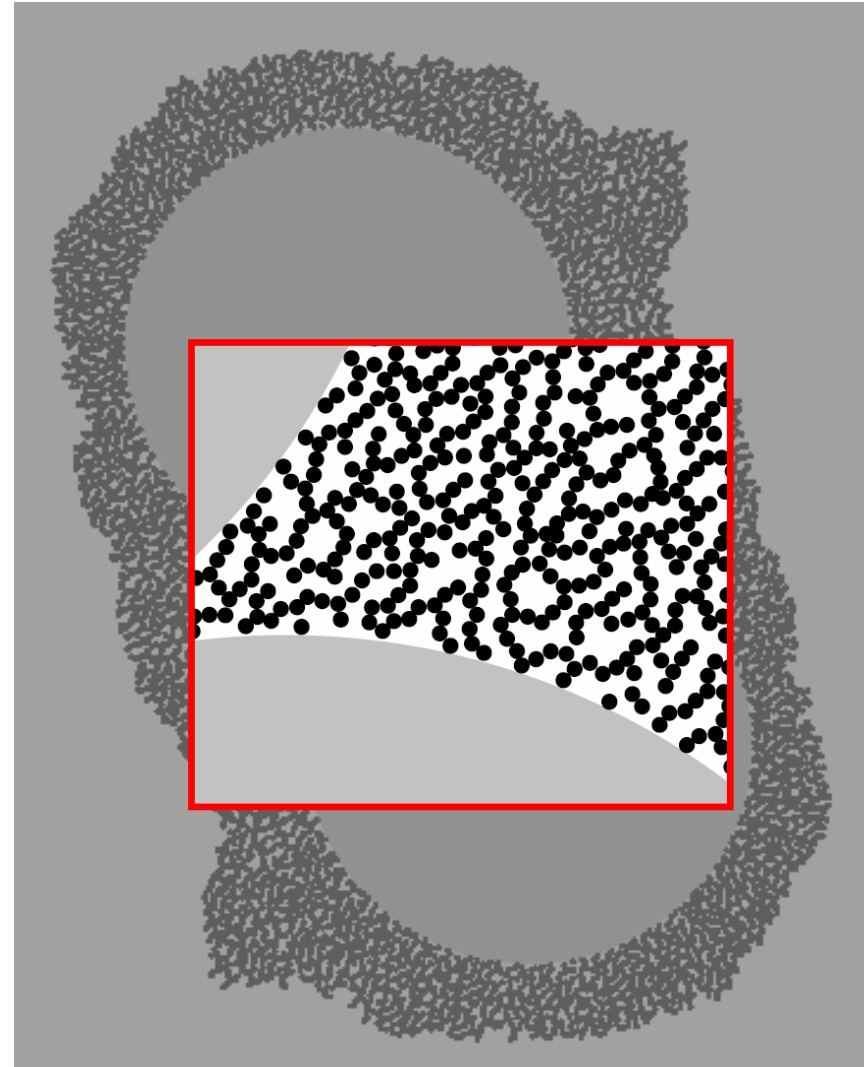
- Grains are spheres
- Grain sizes differ by a factor of 100
- Highest ... lowest porosity
 - Pure coarse fraction: 0.49 ... 0.32
 - Pure fine fraction: 0.92 ... 0.32
- Logarithmic porosity/depth function

Consequences:

Geometrical parameters can be calculated

Remaining input parameters are:

- Effective pressure (or depth)
- Composition of solid fraction



Viscoelastic Extensions to Biot Theory

Effective-grain model:

Intracrystalline water layers in expandable clay are low-aspect ratio inclusions in otherwise elastic mineral phase

Viscoelastic relaxation by pressure-induced local fluid (squirt-) flow from these inclusions

Distribution of aspect ratios to reflect size distribution of clay crystallites

Applied to small-sphere fraction only

Viscous-contact model:

Based on Hertz-Mindlin contact laws

Viscoelastic relaxation by pressure-induced radial squirt flow in the immediate vicinity of the grain contacts

Binary grain-size model

Porosity
Permeability
Tortuosity
Pore size

Grain bulk modulus
Grain shear modulus
Grain density

Frame bulk modulus
Frame shear modulus

Pore water bulk modulus
Pore water density
Pore water viscosity

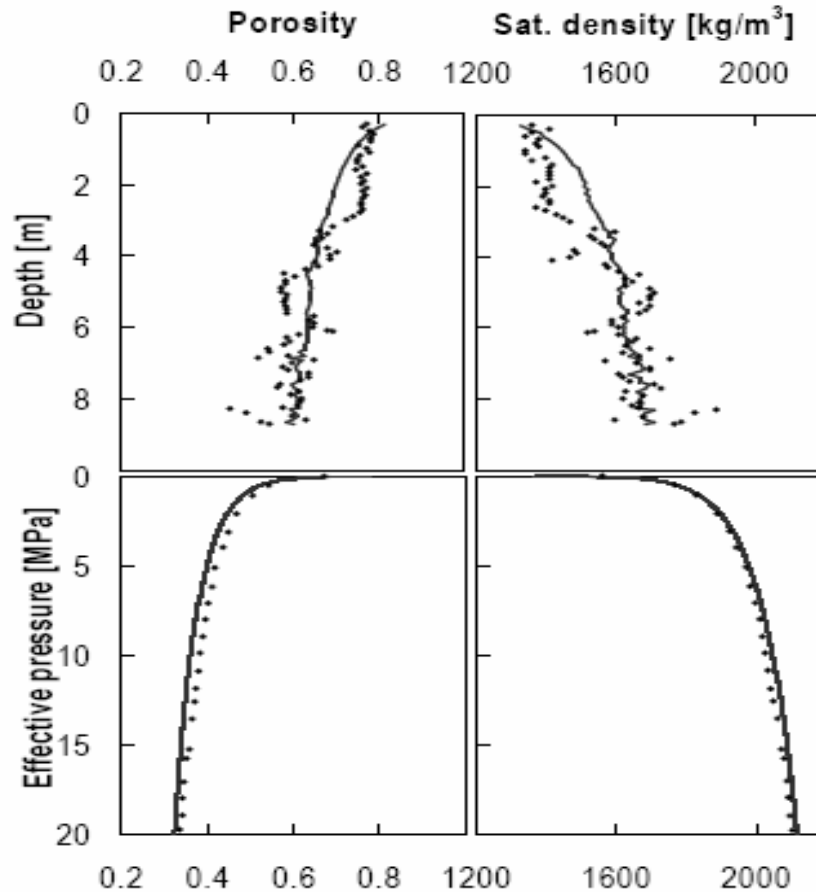
**Hydrost. Pressure,
Temperature,
Salinity**

Previous Work

General framework:	Biot (1956, 1962)
Binary grain-size:	Nur, Marion, Yin (1991) Dvorkin and Gutierrez (2001) + explicit consideration of particles + log. porosity/depth function
Sphere pack:	Berryman (1981)
Effective-grain model:	Eshelby (1957) Wu (1966) Mavko and Nur (1975) Toksoz, Cheng, Timur (1976) Johnston, Toksoz, Timur (1979) Leurer (1997)
Viscous-contact model:	Hertz (1882) Mindlin (1949) Walton (1987) Dvorkin and Nur (1996) Leurer and Dvorkin (2006) + heuristic correction term

Porosity and Density in Clay-rich Marine Unconsolidated Sediment

Laboratory Measurements vs. Binary Model

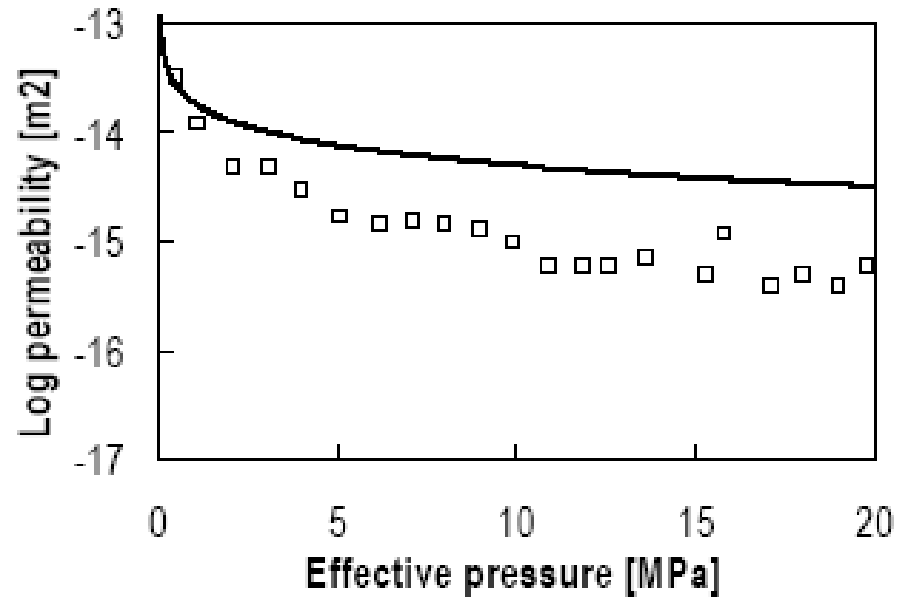


Sediment Core

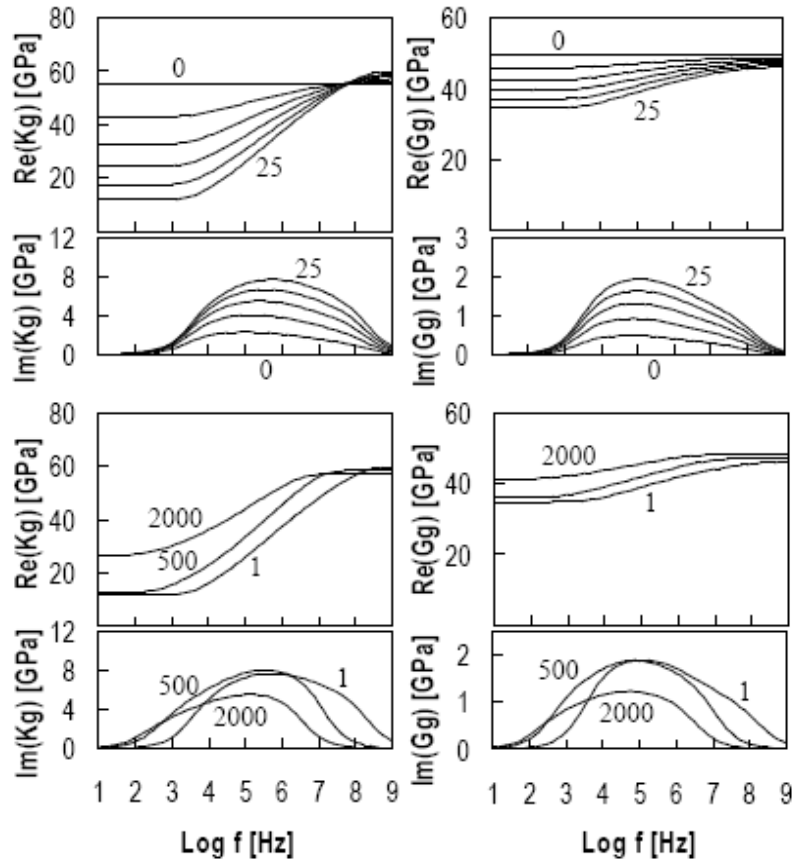
Silty Clay
20% large spheres

Permeability in Silty Clay

Laboratory Measurements vs. Binary Model



Effective Grain Bulk- and Shear Moduli vs. Frequency in (Model-) Silty Clay



Variable volume fraction of expandable clay at constant depth (near-surface) , in % of clay fraction

Variable depth at constant composition, 25% of clay fraction

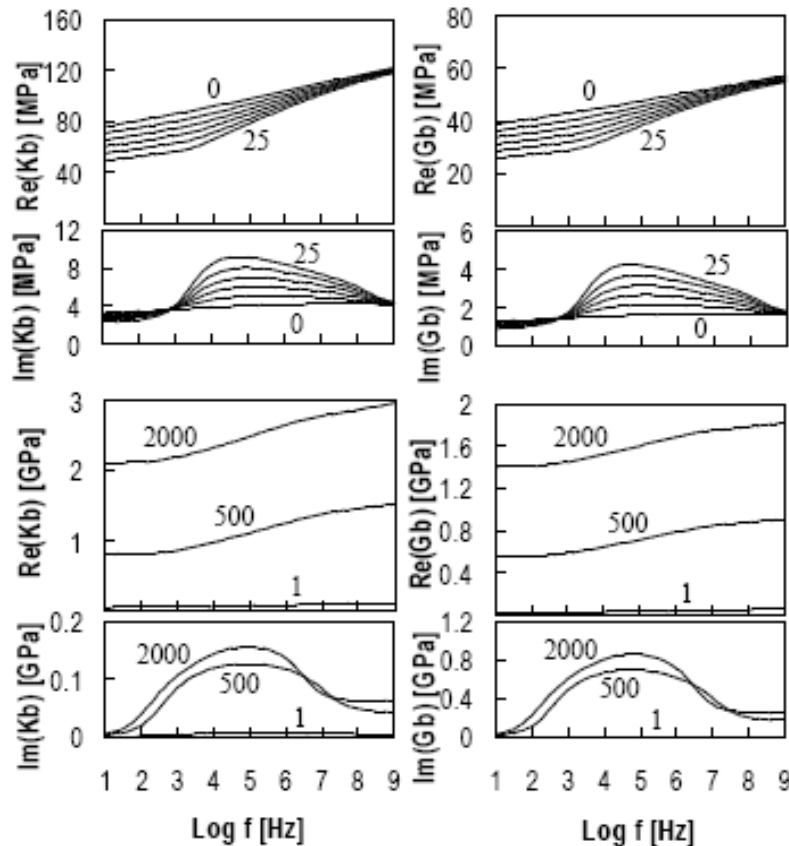
Heuristic Correction Factor for Frame Moduli

$$K_b = \frac{1}{L} \frac{N(1-\phi)}{12\pi R} S_n ,$$

$$G_b = \frac{N(1-\phi)}{20\pi R} \left(S_n + L^2 \frac{3}{2} S_t \right) , \text{ with}$$

$$L = \frac{2}{3} .$$

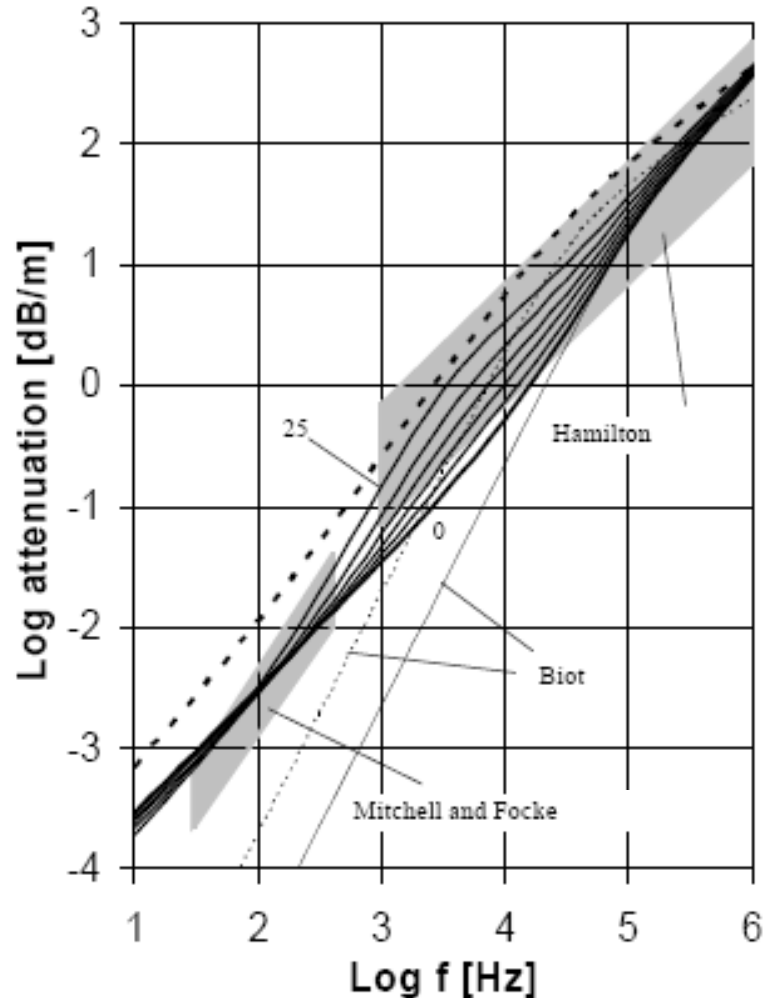
Frame Bulk- and Shear Moduli vs. Frequency in (Model-) Silty Clay



Variable volume fraction of expandable clay at constant depth (near-surface), in % of clay fraction

Variable depth at constant composition, 25% of clay fraction

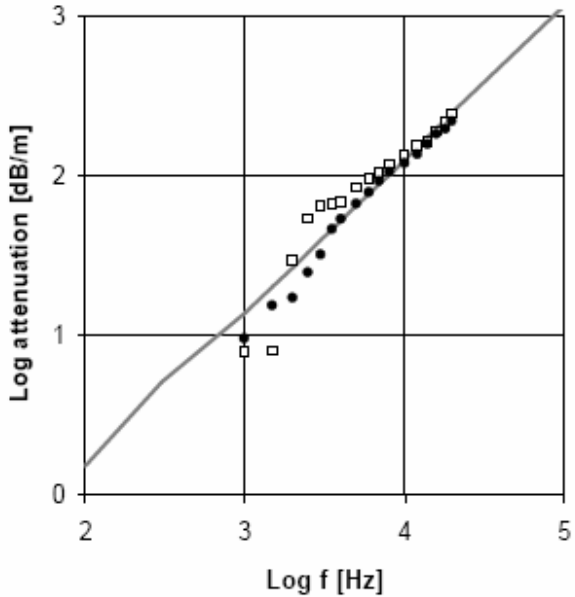
P-wave Attenuation In Near-surface Marine Unconsolidated Sediment vs. Frequency



Heavy solid lines:
Model predictions for silty clay with
varying volume fraction of
expandable clay

Heavy dashed line:
Model prediction for sand-
dominated sediment

Shear-wave Attenuation vs. Frequency at Low Pressure in Sand and Glass Beads

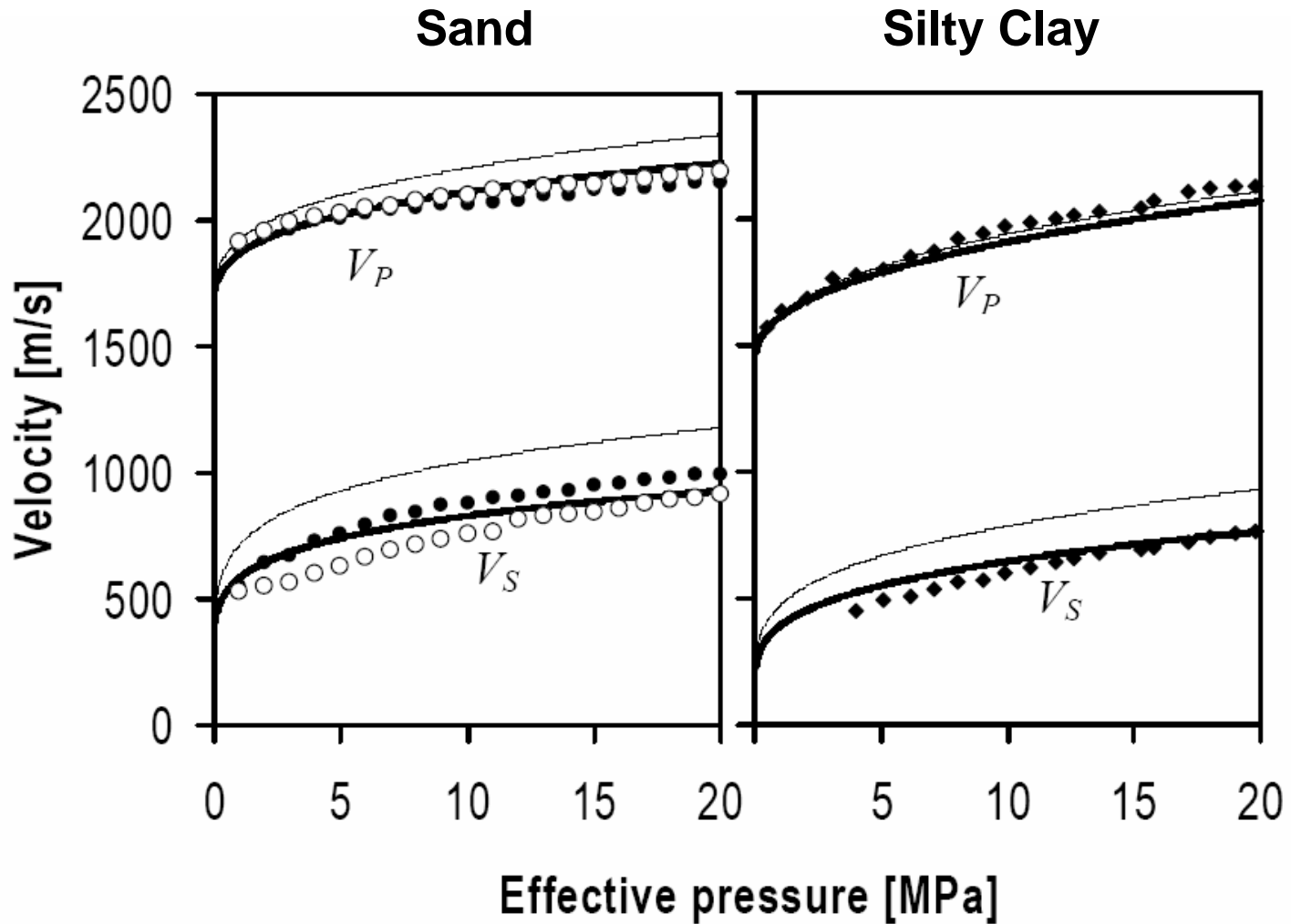


Open Symbols: Sorted Sand
Filled Symbols: Glass Beads

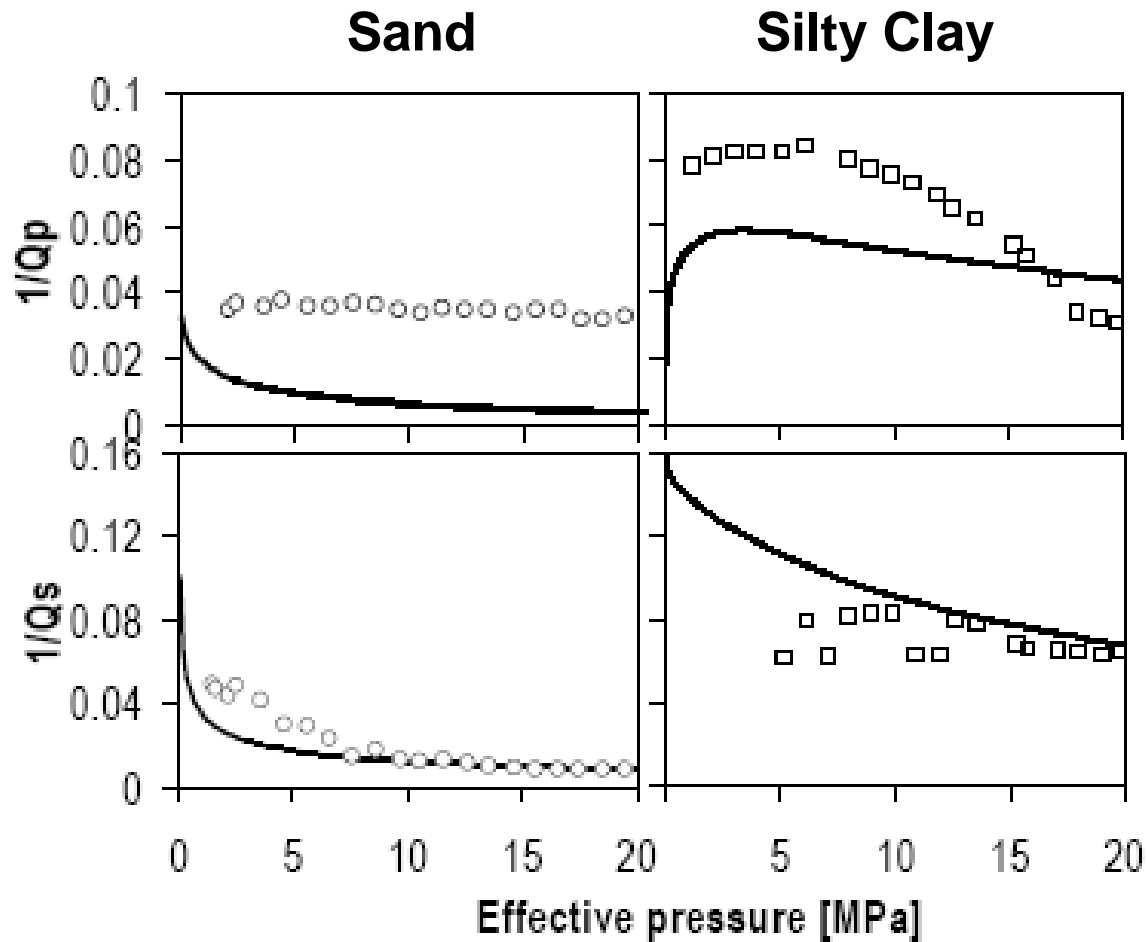
Brunson (1991)

Velocity in Unconsolidated Sediment vs. Effective Pressure

in



Specific Dissipation In Unconsolidated Sediment in



Summary

We have made a quantitative attempt to adapt Biot's theory to unconsolidated marine sediment.

- * **Binary grain-size model** is one small step further in manageable complexity as opposed to an identical-sphere pack
- * **Effective-grain model** accounts for grain anelasticity caused by expandable clay minerals
- * **Viscous-contact model** accounts for frame anelasticity
- * Number of inputs to Biot theory is reduced
- * The combined model covers a fairly wide range of marine soft sediment types ranging from sand-dominated to clay-dominated sediments

P-wave Attenuation In Marine Sediment vs. Depth

in

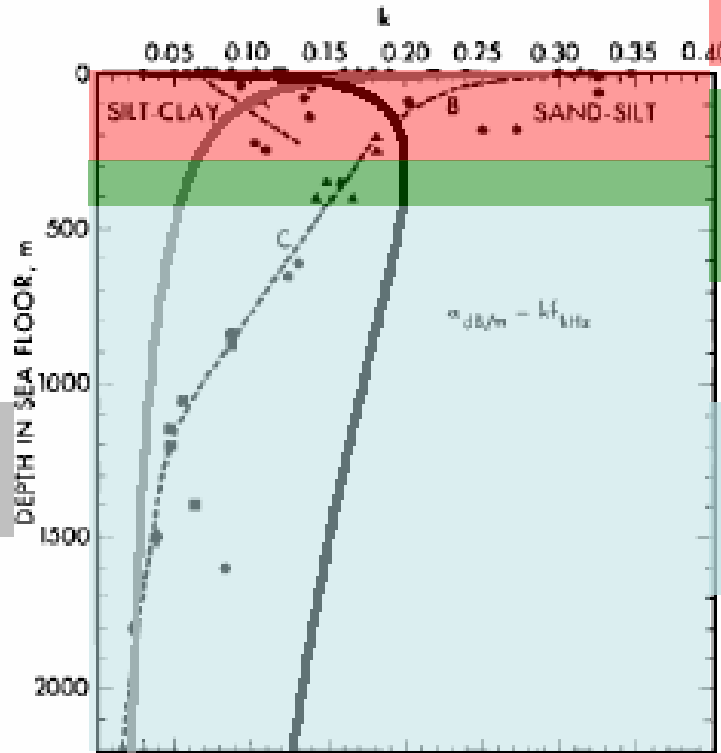
Sand (gray curve)

Silty Clay (black curve)

Strong Porosity Reduction
Intracrust. Water Retained
=> Attenuation Increase

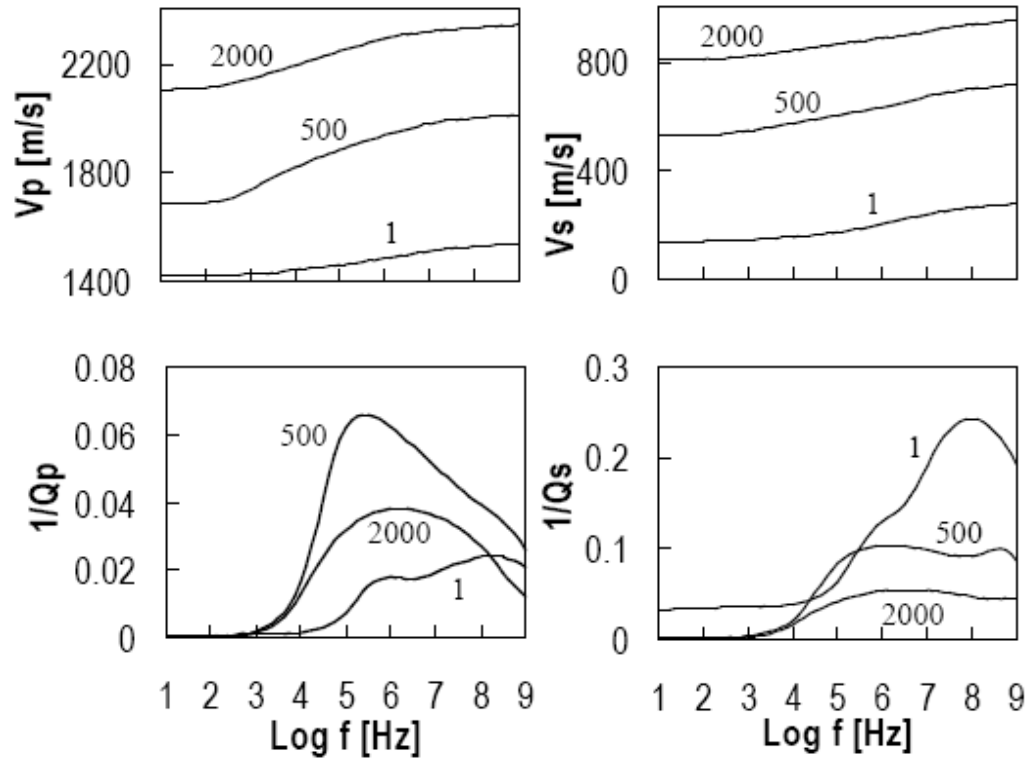
Expulsion of Intracrust.
Water Starts
=> Attenuation Maximum

Weak Porosity Reduction
Intracrust. Water Expelled
=> Attenuation Decrease



Monotonic Decrease of
Attenuation

Model Velocity and Specific Dissipation vs. Frequency at various depths in Silty Clay



P-wave Velocity In Marine Unconsolidated Sediment vs. Density and Porosity

