INSTITUTE FOR
Geophysical Research

Modelling on frequency dependent attenuation – effects of viscosity

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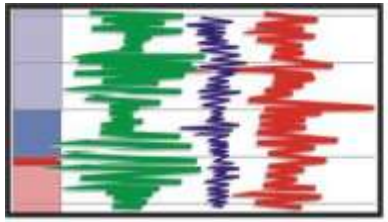
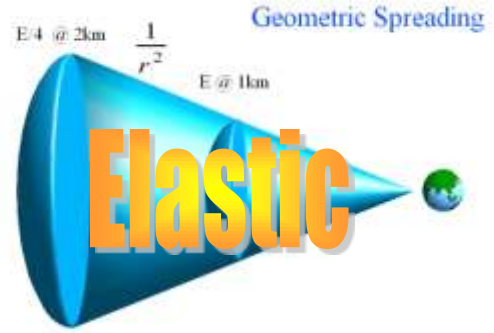


CHORUS

Consortium for Heavy Oil Research by University Scientists

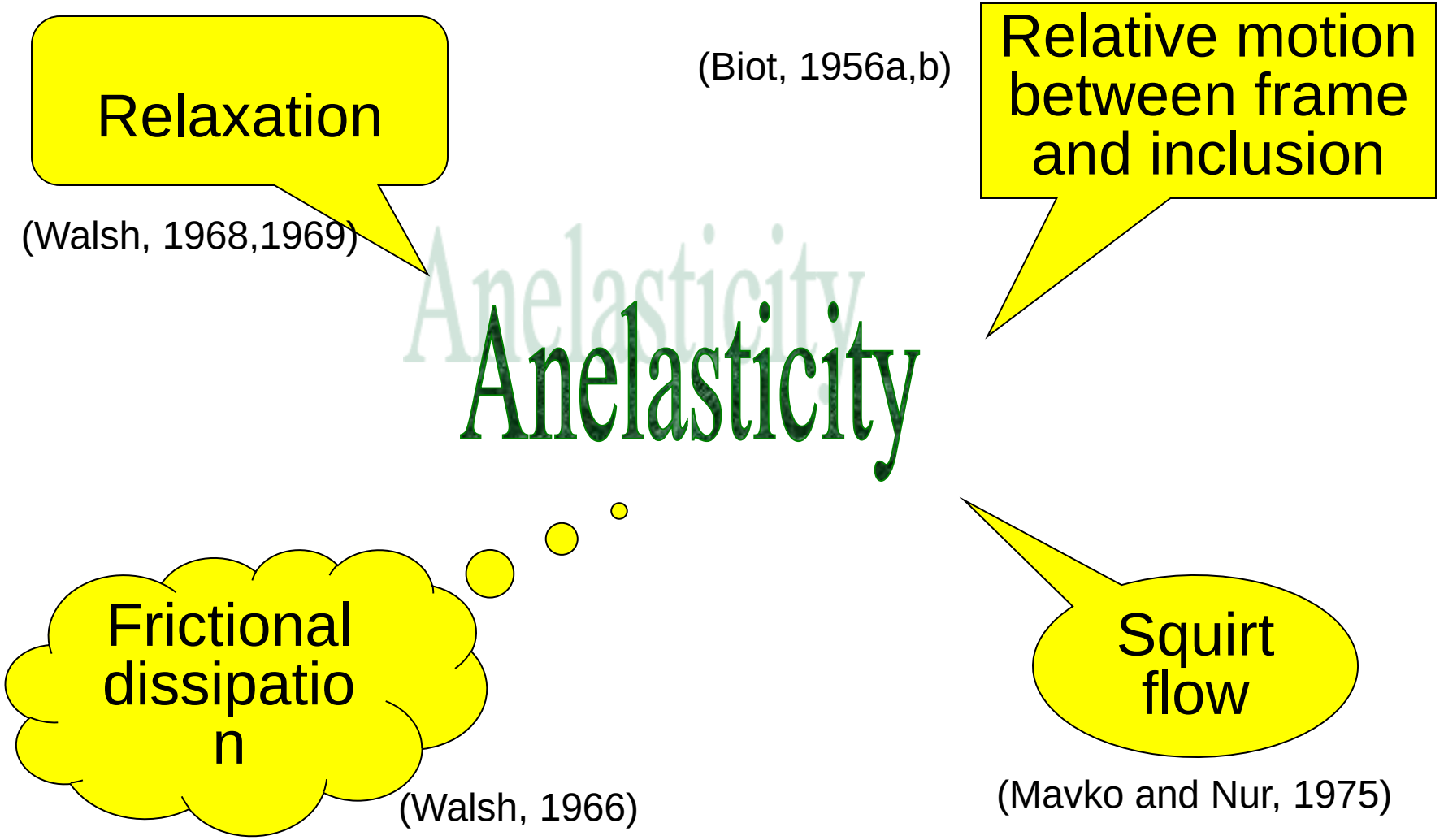
Outline

- General statement on attenuation
  - Causes of attenuation
  - Mechanisms of intrinsic attenuation
- Fundamental models (solid earth)
  - Waveforms from the lab
- Factor of attenuation in oils -- Viscosity
  - Factors that change viscosity
- A simple model which attributes attenuation to viscosity
  - Maxwell's model with dynamic solution
  - Effects on modulus, velocity and attenuation
- Fluid substitution
  - Effects of viscosity for a variety frequency bands
  - Comparison with Gassmann's equation
- Conclusions and remarks



Anelasticity

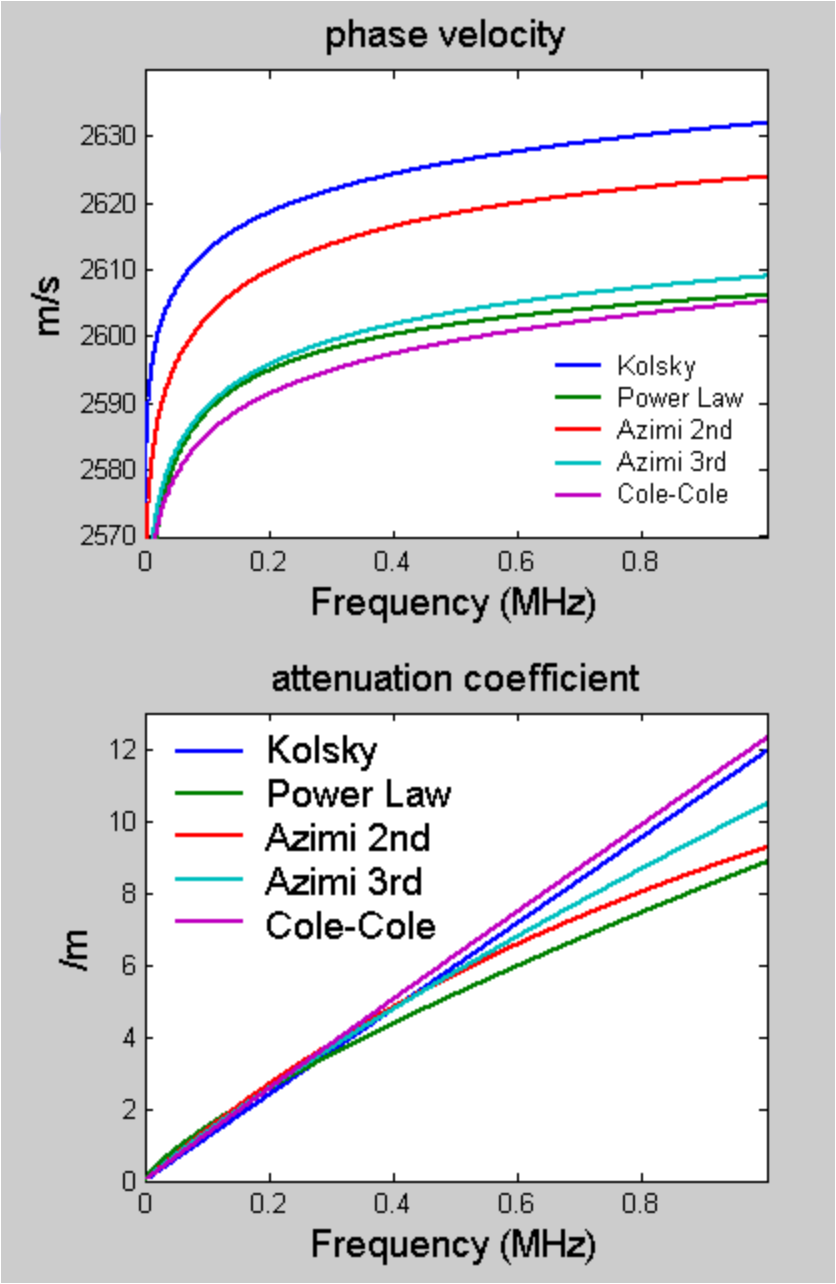
Mechanisms that cause attenuation



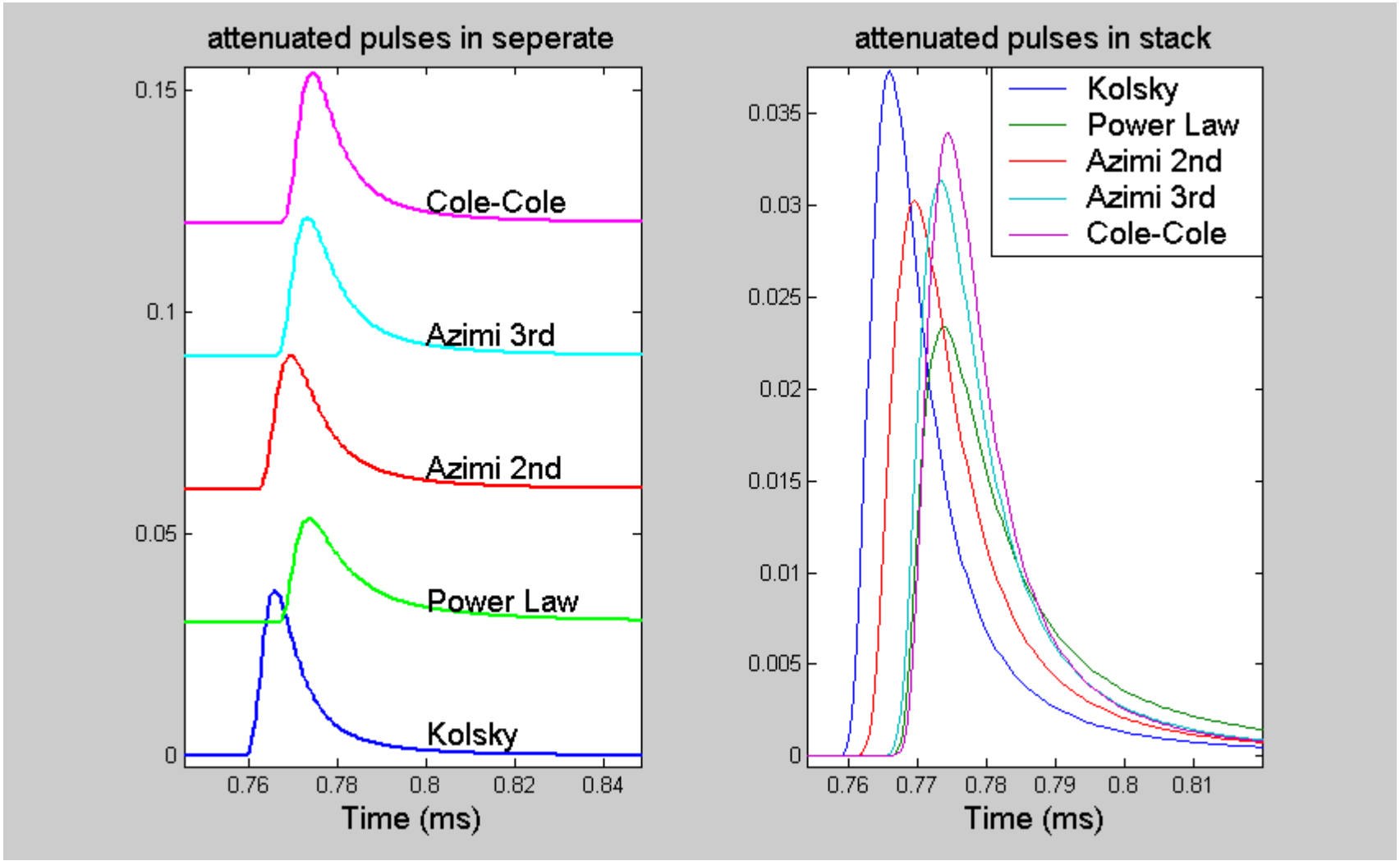
Mathematical models

A variety of models are proposed in literature to address attenuation and dispersion in rocks.

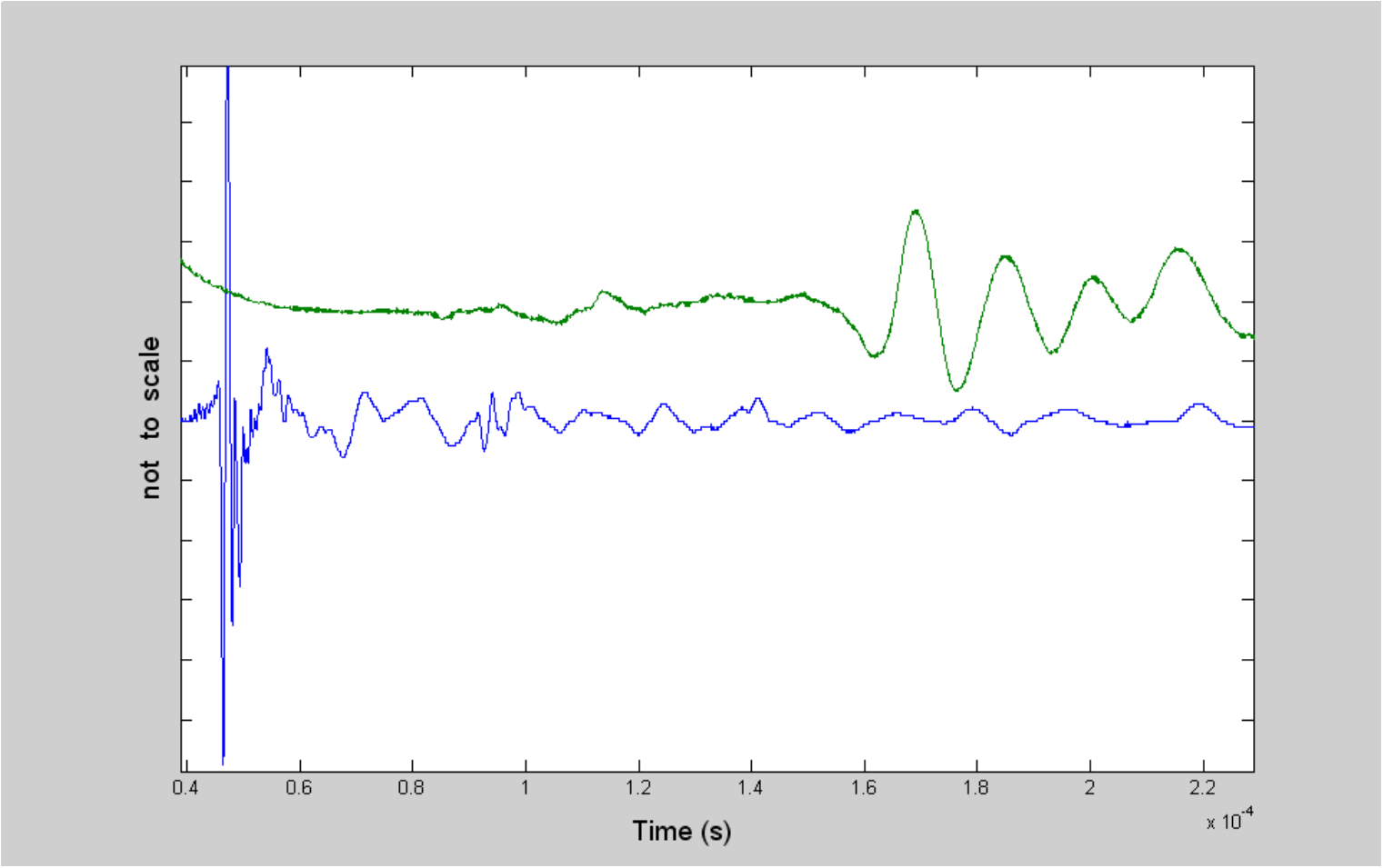
Most of them assume nearly linear relation between attenuation and frequency over a wide frequency range.



Recovered waveform at x = 2m



Waveforms in oil sands



Viscosity

Liquids (25 ° C)	**Viscosity** (Pa·s)
Ethanol*	1.074×10^{-3}
Acetone*	0.306×10^{-3}
Methanol*	0.544×10^{-3}
Water*	0.890×10^{-3}
Mercury*	1.526×10^{-3}
Sulfuric acid*	24.2×10^{-3}
Glycerol*	934×10^{-3}
Olive oil	81×10^{-3}
Molten polymers	10^{3}
Pitch	10^{11}
Glass	10_{40}

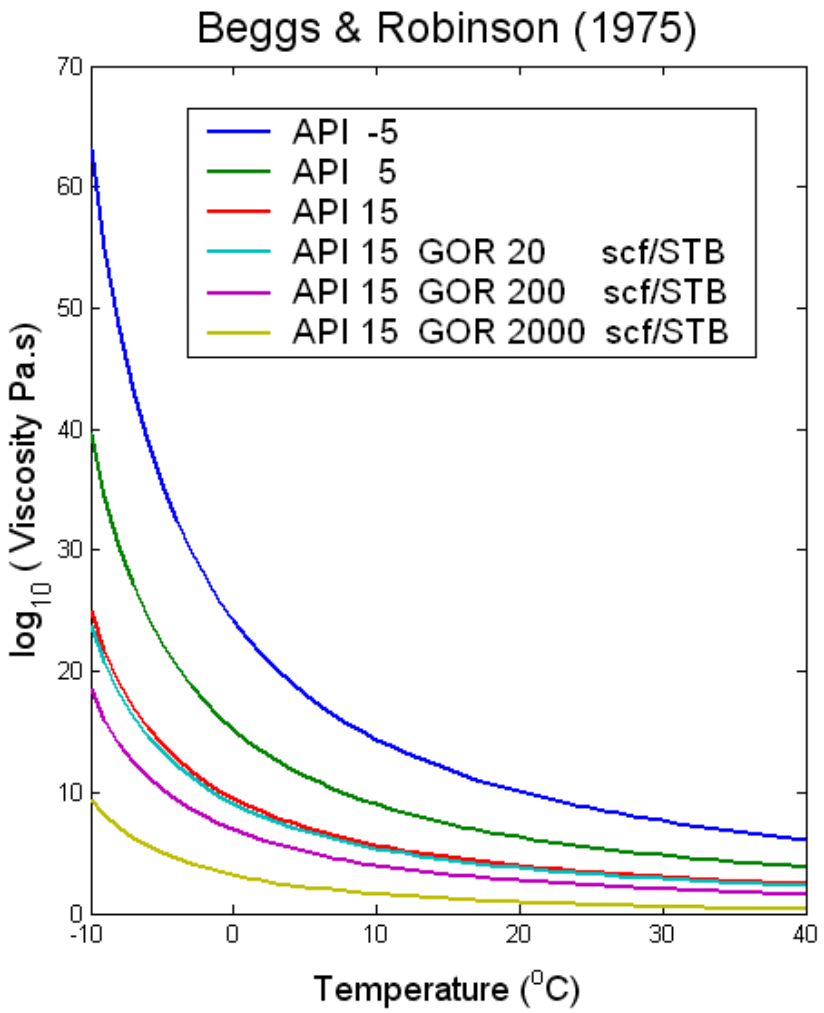
*Data from CRC Handbook of Chemistry and Physics, 73rd edition, 1992-1993

The rest data from Wikipedia online: en.wikipedia.org

What changes viscosity?

- Viscosity is influenced by pressure and GOR, but primarily, it's a function of API and termperature.

- Beggs and Robinson's relation is one of the most commonly used relation shown at the right handside



Maxwell's Model

- Constitutive equation:

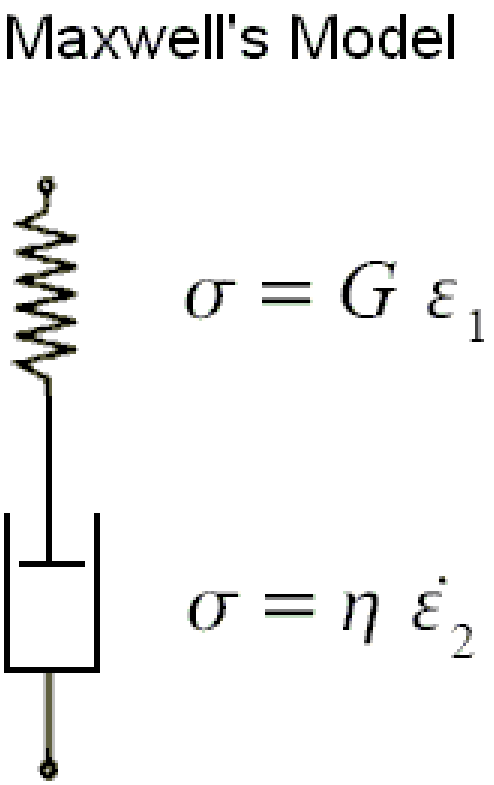
$$\frac{\dot{\sigma}}{G} + \frac{\sigma}{\eta} = \dot{\varepsilon}$$

- Solution:

$$\sigma(t) = -\int_{-\infty}^{t} G(t-t')\,\dot{\varepsilon}(t')\,dt'$$

- Relaxation time:

$$\tau_s = \frac{\eta}{G}$$



Dynamic Spectroscopy (I)

- The dynamic response of the model to an oscillating strain rate could provide indication to attenuation

$$\dot{\varepsilon}(t) = \dot{\varepsilon}_0 cos(wt)$$

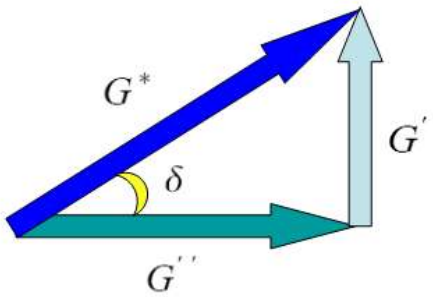
- Plug harmonic oscillation into constitutive equation, we get the solution:

$$\sigma(t) = -A\cos(\omega t - \delta)$$

$$A = \sqrt{G'^2 + G''^2}\,\frac{\dot{\varepsilon}_0}{\omega}$$

$$\delta = \arctan\left(\frac{G'}{G''}\right)$$

- The phase shift is between the applied stress and resultant strain rate



Dynamic Spectroscopy (II)

- Complex shear modulus with harmonic solution:

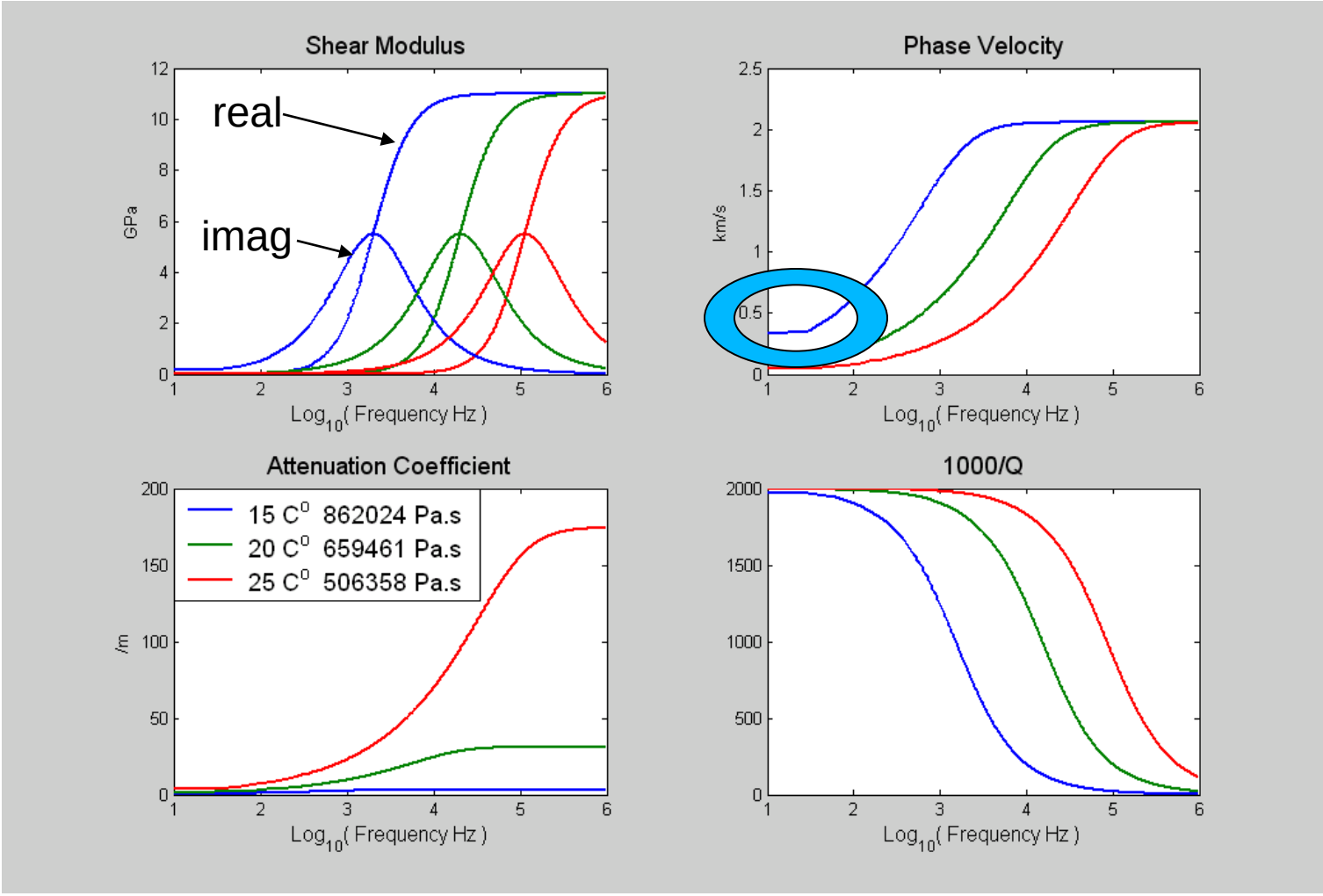
$$G^*(w) = G' + iG'' = G_\infty \frac{w^2 {\tau_s}^2}{1 + w^2 {\tau_s}^2} + iG_\infty \frac{w\tau_s}{1 + w^2 {\tau_s}^2}$$

with relaxation time: $\tau_s = \frac{\eta}{G_\infty}$

- Phase velocity and attenuation can be calculated via a complex wavenumber k:

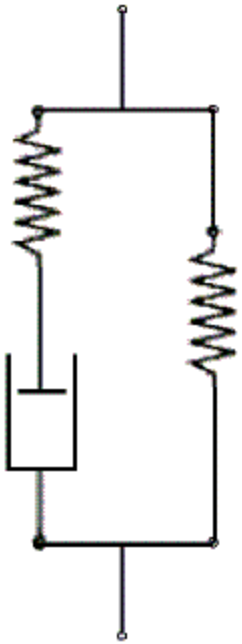
$$k = \frac{\omega}{v} = \frac{\omega}{c(\omega)} - i\,\alpha(\omega) \quad \begin{cases} c = \dfrac{\omega}{\Re(k)} \\ \alpha = -\Im(k) \end{cases}$$

Viscosity and frequency bands



Fluid substitution (I)

Standard linear model (SLM)

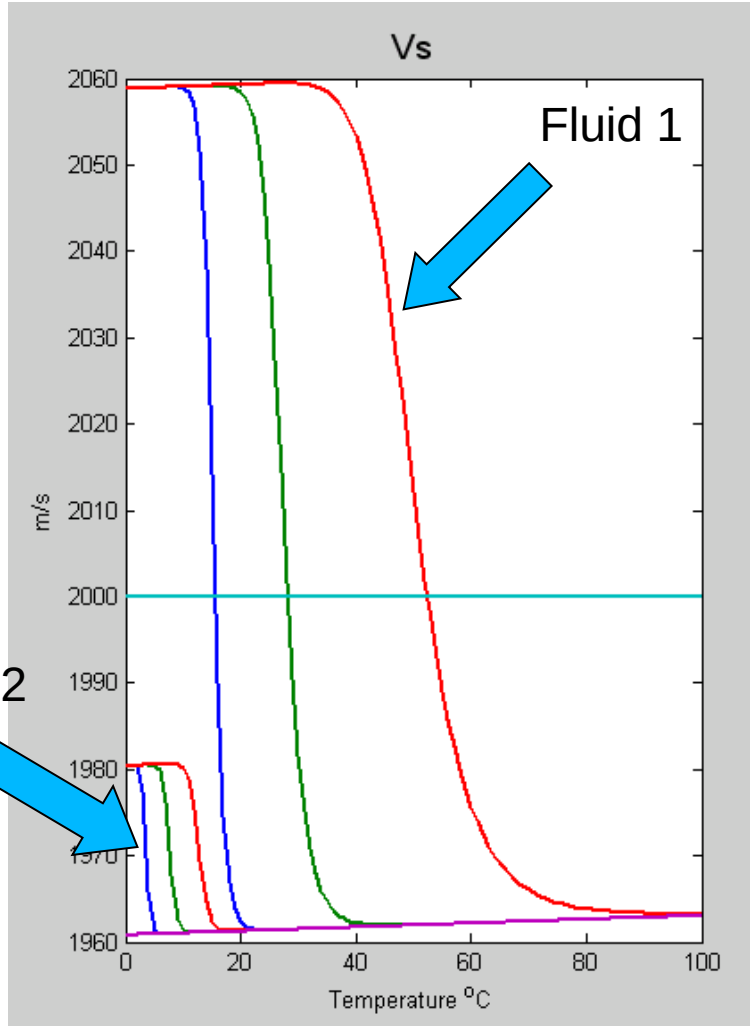


Two fluids with different viscosities and shear moduli are tested.

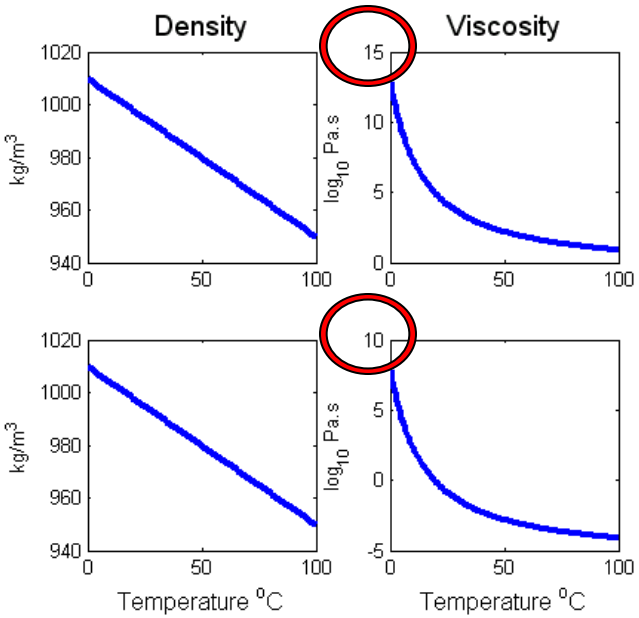
Parameters used are listed below:

$$\phi = 0.1$$
$$\rho_s = 2.5\ g/cc$$
$$G_{s\infty} = 10\ GPa$$
$$G_{1\infty} = 1\ GPa\ (fluid\ 1)$$
$$G_{2\infty} = 0.2\ GPa\ (fluid\ 2)$$

Fluid substitution (II)



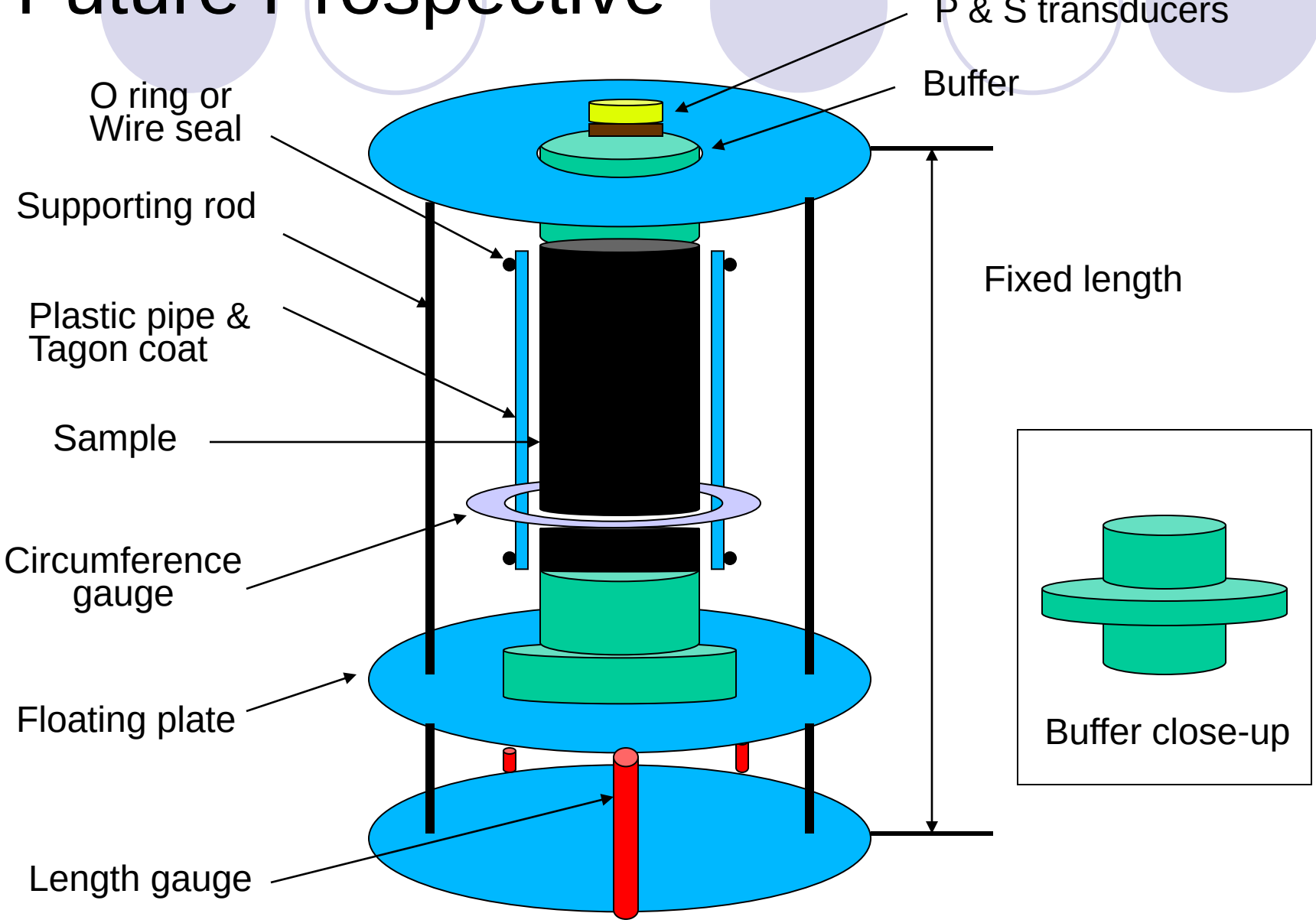
SLM 200 Hz
SLM 20 kHz
SLM 1 MHz
Dry Rock
Gassmann



Fluid 1

Fluid 2

Future Prospective



Conclusions & remarks (I)

- Viscosity is the major mechanism that causes intrinsic attenuation in oil related materials
- Increasing viscosity shifts shear modulus, phase velocity and dissipation to lower frequency. These variables remain a constant at viscosity extremes, while change greatly at intermediate viscosity.
- Alpha is low and varies little under high viscosity while at low viscosity, alpha increases greatly as frequency goes up.

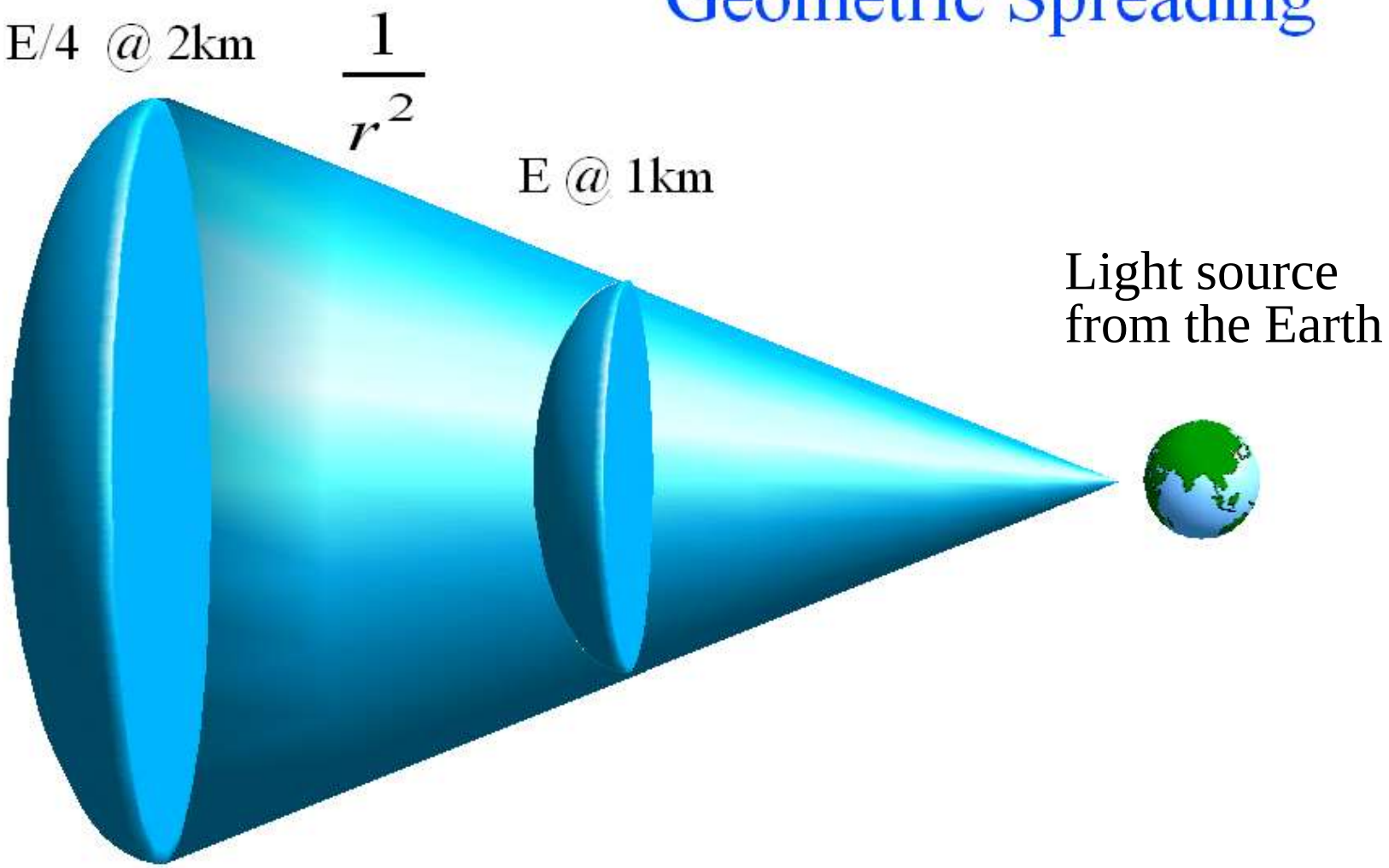
Conclusions & remarks (II)

- Ultrasonic, sonic and seismic frequencies have distinct difference. Coincidence occurs at viscosity and frequency extremes.

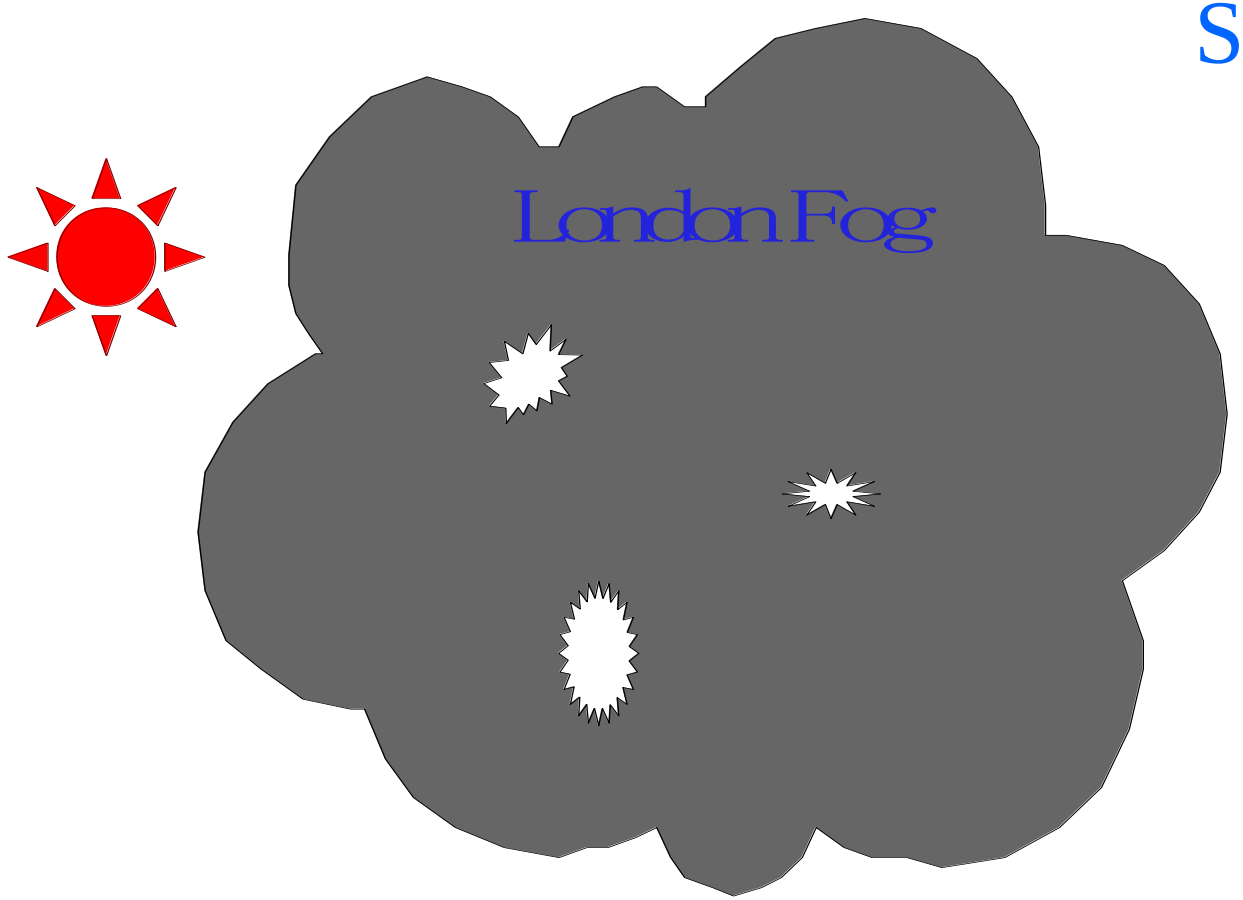
- Gassmann's equation predicts low viscosity fluid well, but when high viscosity liquid such as heavy oil is involved, it has to be adapted to yield better fit to lab results

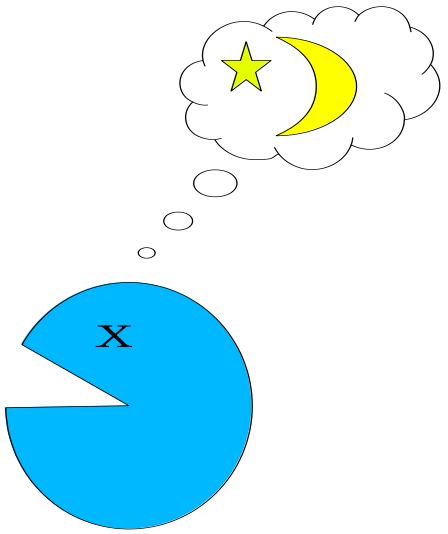
Acknowledgement

Geometric Spreading



Scattering





Multipathing