CREWES

Reflections on Q

Larry Lines

Fereidoon Vasheghani

Outline

- Definition of Q
- Reflections due to Q
- Motivation for Q estimation
- Q versus Viscosity
- Conclusions

Definition of Q, quality factor

- Solution to wave equation for damped harmonic oscillation

$$A(x,t) = A_0 e^{i(k' x - \omega t)}$$

with complex wavenumber, $k' = k + i\alpha$

$$A(x,t) = A_0 e^{-\alpha x} e^{i(kx - \omega t)}$$

where α is the absorption coefficient.

Definition of Q, the quality factor

- Relation of Q to absorption and wavelength (Toksoz and Johnston, 1981)

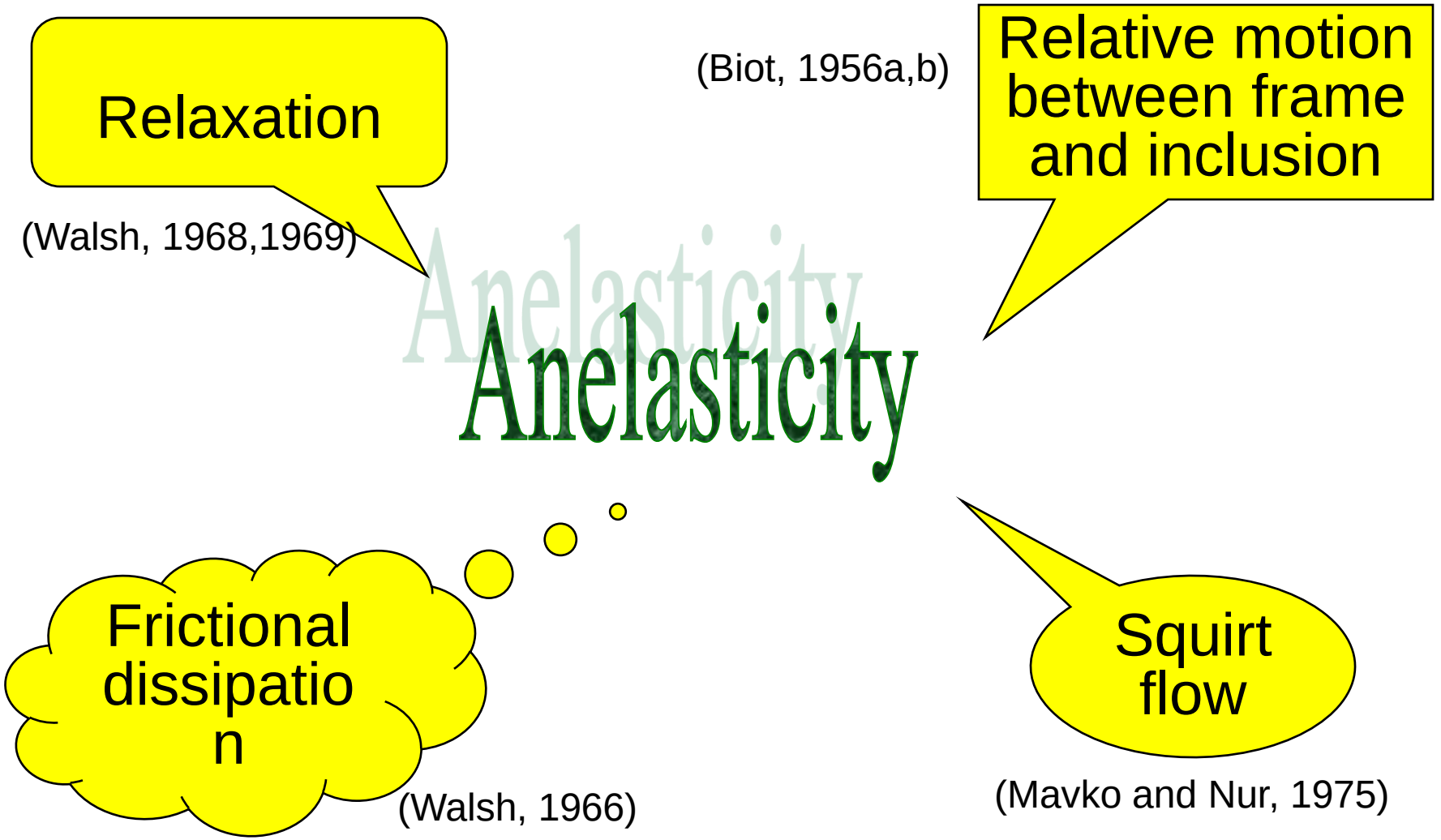
$$\frac{1}{Q(\omega)} = \frac{1}{2\pi}\frac{\Delta E}{E} = \frac{1}{2\pi}\frac{\Delta(A^2)}{A^2} = \frac{1}{\pi}\frac{\Delta A}{A}$$

$where\, \Delta E$ is the energy change over one wavelength

$$\frac{1}{Q(\omega)} = \frac{1}{\pi}\frac{A_0(1-e^{-\alpha\lambda})}{A_0} \cong \frac{\alpha\lambda}{\pi}$$

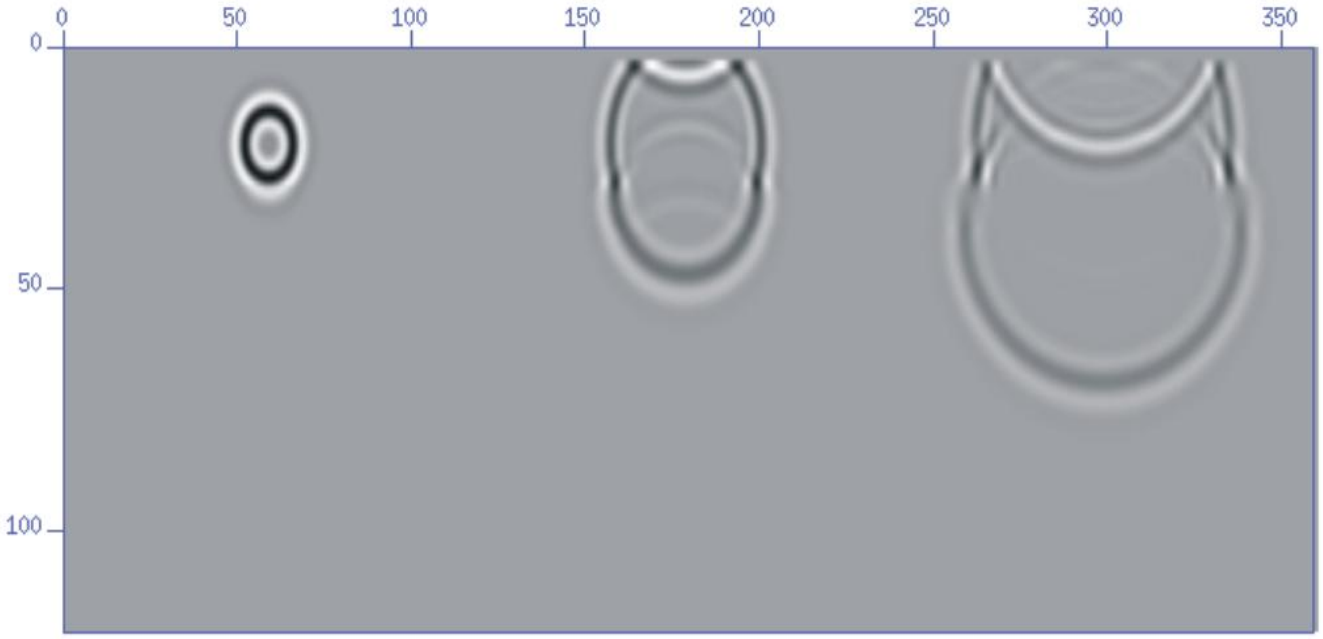
$$Q(\omega) \cong \frac{\pi}{\alpha\lambda}$$

Mechanisms that cause attenuation (Qi and Schmitt)

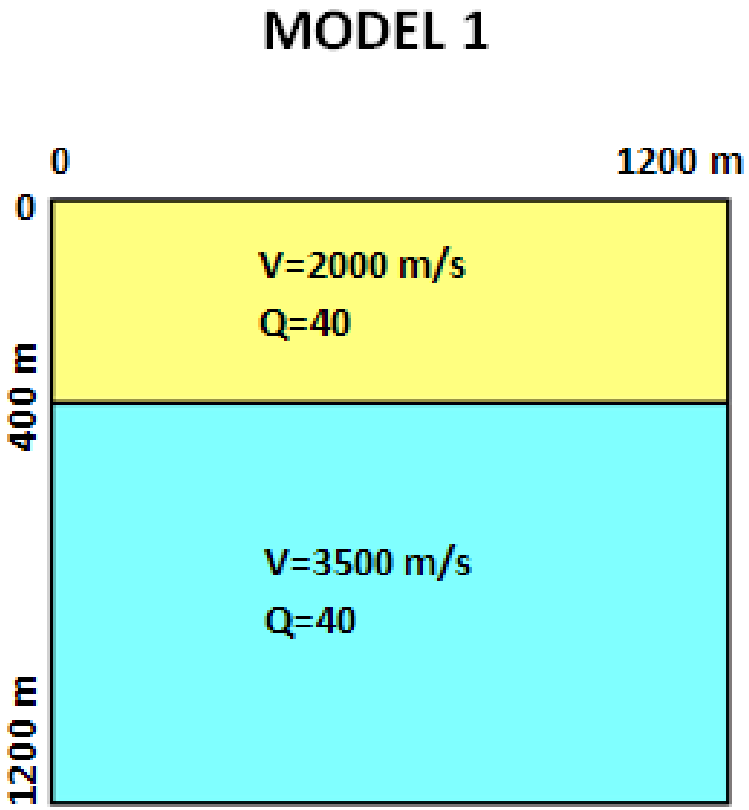


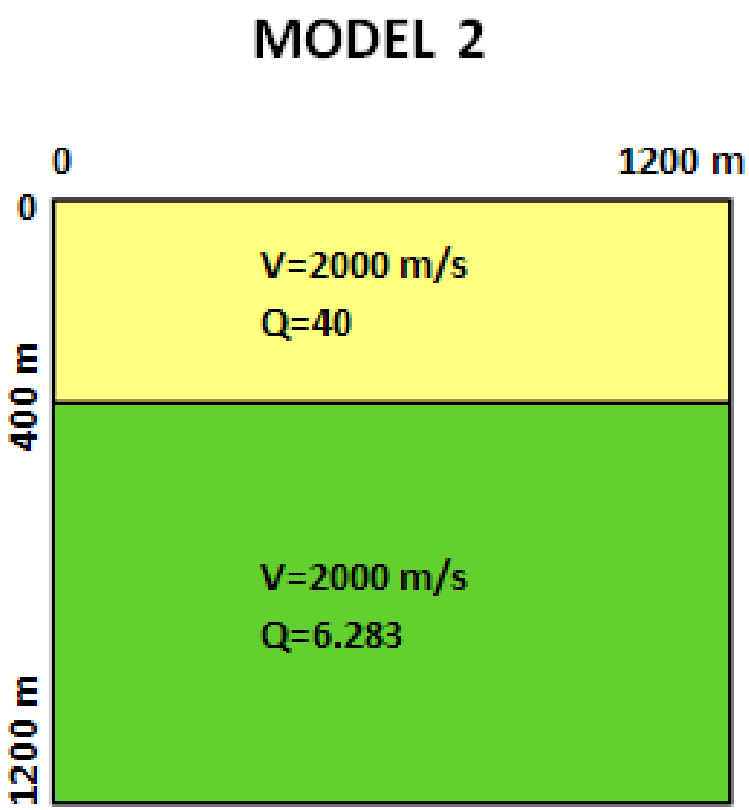
Finite-difference modeling using Carcione's modeling codes

- Finite-difference codes (Fortran 90) from Carcione (2007) can b used to model the effects of Q.



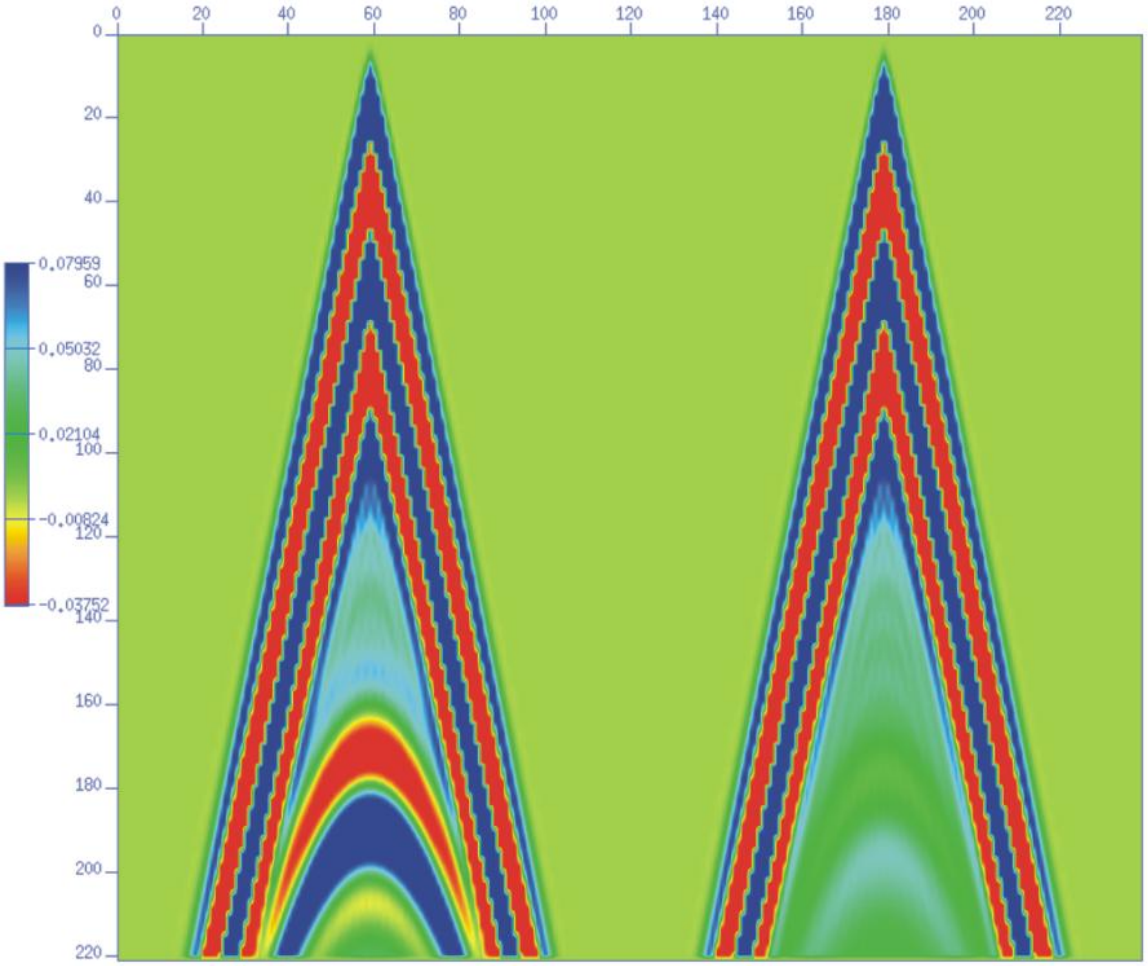
Models to illustrate reflections due to impedance and Q contrasts





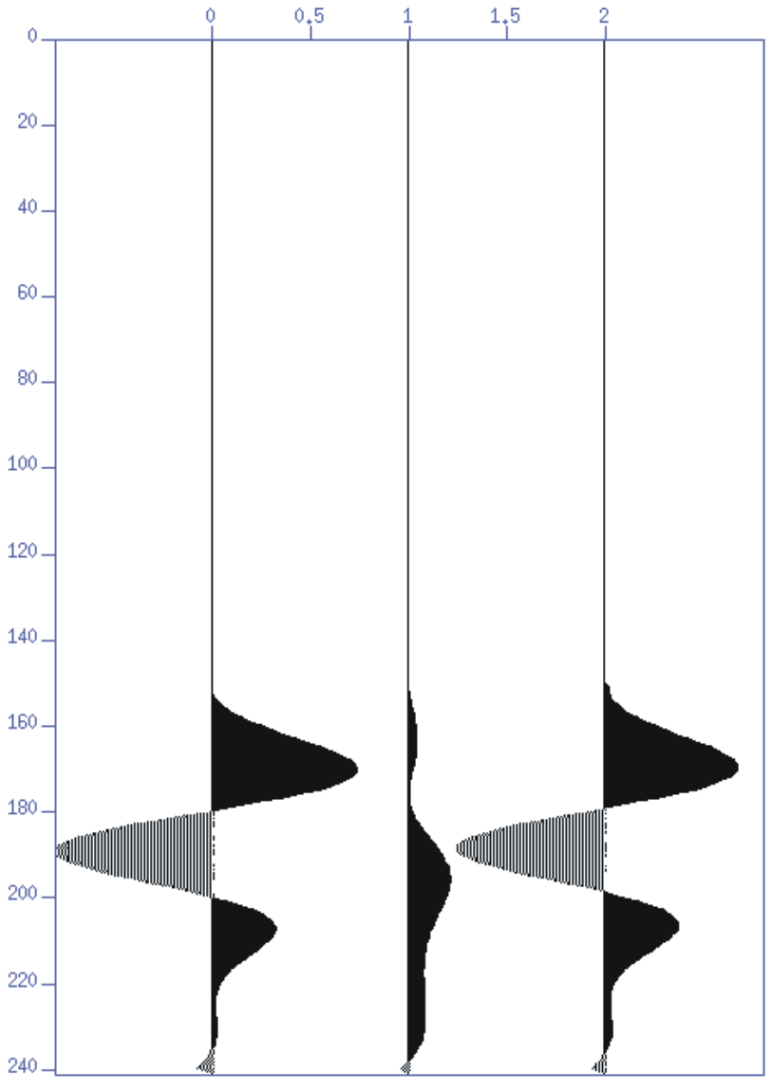
Reflection seismograms for models 1 and 2.

- Source depth= 250m
- Source offset = 600m
- Receiver depths = 260m
- Lateral receiver spacing =10 m
- Wavelet peak delayed 20 ms from onset
- Note that both model responses have reflections at about 165 ms



Zero offset traces for models 1, 2, and a 3rd model which includes the contrast of both models .

- Zero offset traces for model 1 (impedance contrast 1), model 2 (Q contrast only) and model 3 (combination of both models 1 and 2).
- Impedance contrast reflections are dominant



Observations

- Reflections are dominantly caused by impedance (density*velocity) contrasts, but in the case of constant impedance, reflections could be caused by Q-contrast alone.
- The Q reflections are phase-shifted from those due to impedance contrast.
- As a consequence of Futterman (1962), wherever there is attenuation (finite-Q), there will be dispersion. Therefore, Q reflections would be frequency dependent.
- What are the reflection coefficients for impedance and Q contrast boundaries?

Solving the boundary conditions for normally incident P or SH waves gives the following displacement reflection coefficients.

$$R = \frac{\rho_1 v_1 \left[1 + \frac{i}{2Q_1}\right] - \rho_2 v_2 \left[1 + \frac{i}{2Q_2}\right]}{\rho_1 v_1 \left[1 + \frac{i}{2Q_1}\right] + \rho_2 v_2 \left[1 + \frac{i}{2Q_2}\right]}$$

Observations

- Q contributions to the reflection coefficients are phase shifted by 90 degrees compared to impedance contributions.
- For most rocks, the Q reflection contributions would be much smaller than the impedance contributions.
- Also, it would be rare for a rocks to have the same impedance and significant Q contrasts.
- Use of the spectral ratio method or centroid method on VSPs are probably more reliable methods for estimating Q from seismic data.

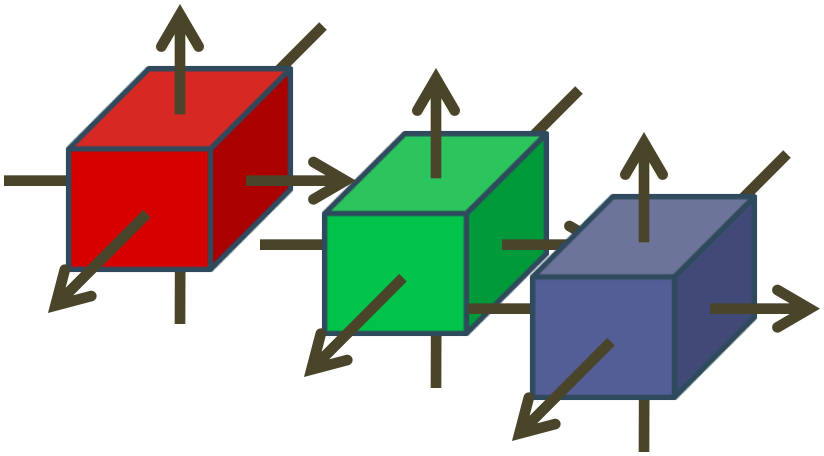
Questions

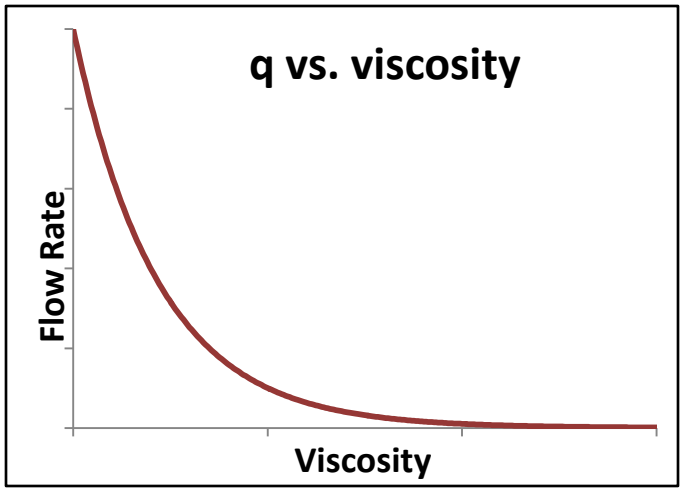
- Why are we interested in Q anyhow?
- That is, why did Larry spend his (abbreviated) sabbatical visiting rock physics labs at U of A, CSM and Stanford?

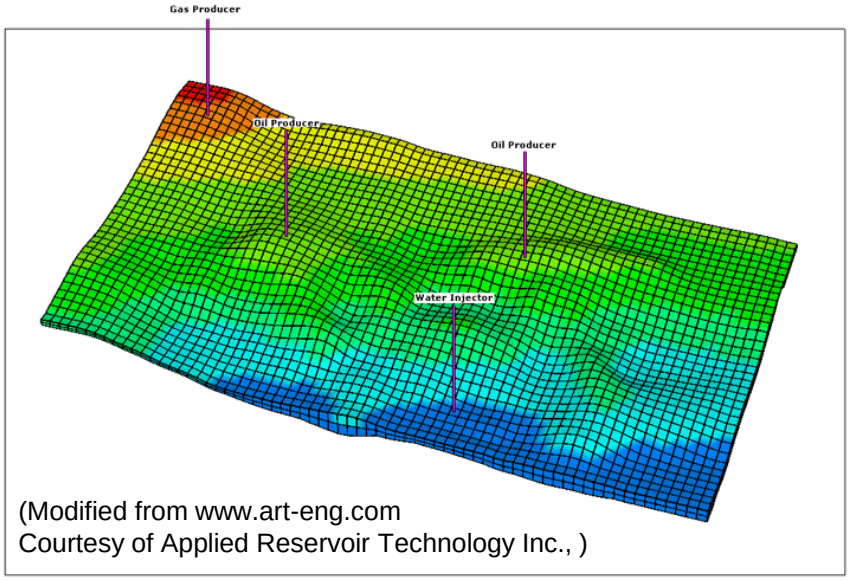
Reservoir Engineering Importance
(ref. Vasheghani, 2008)

- **Darcy's Law, q=flow rate**

$$q = \frac{kA}{\mu}\frac{\partial P}{\partial x}$$





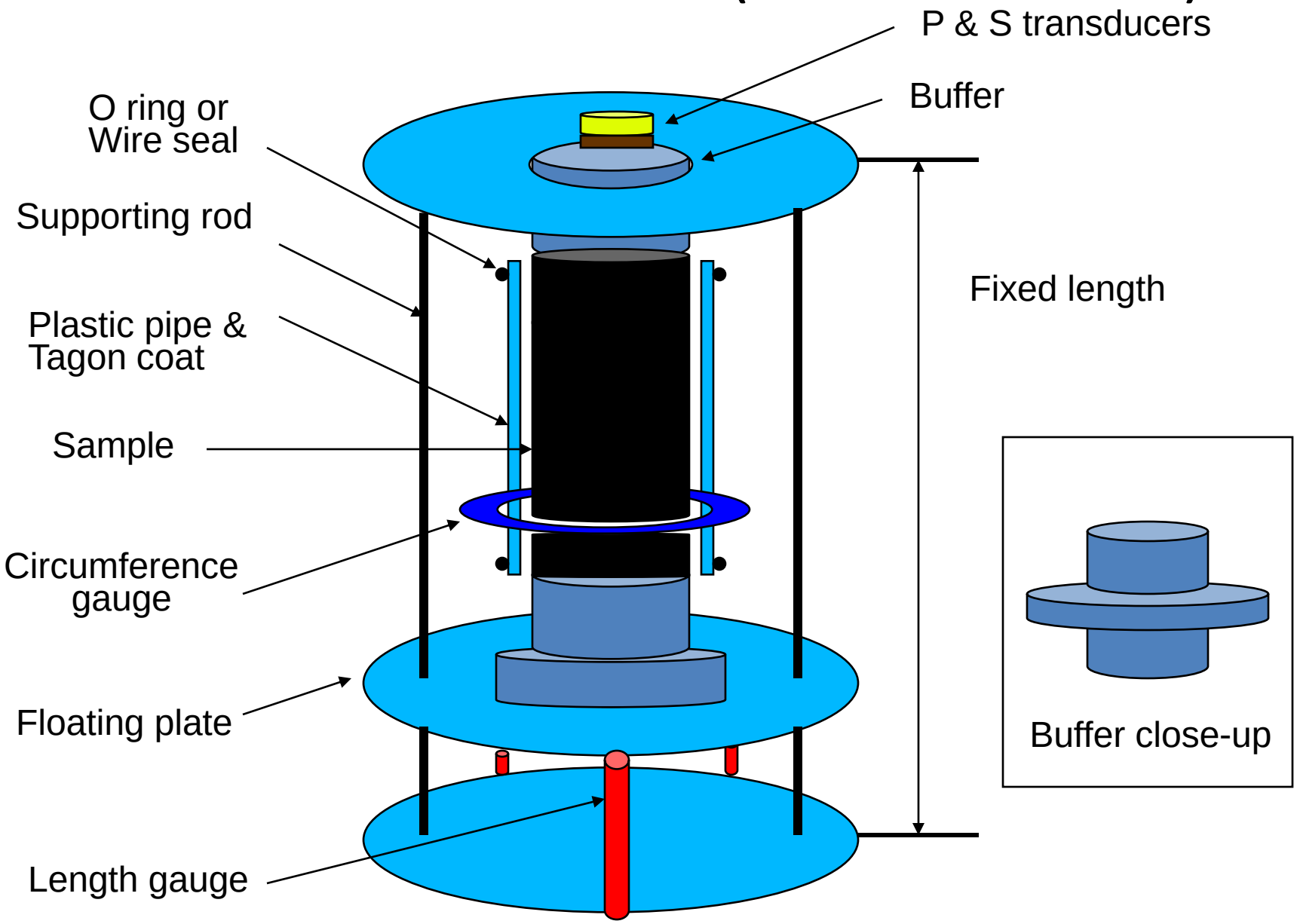


(Modified from www.art-eng.com
Courtesy of Applied Reservoir Technology Inc.,)

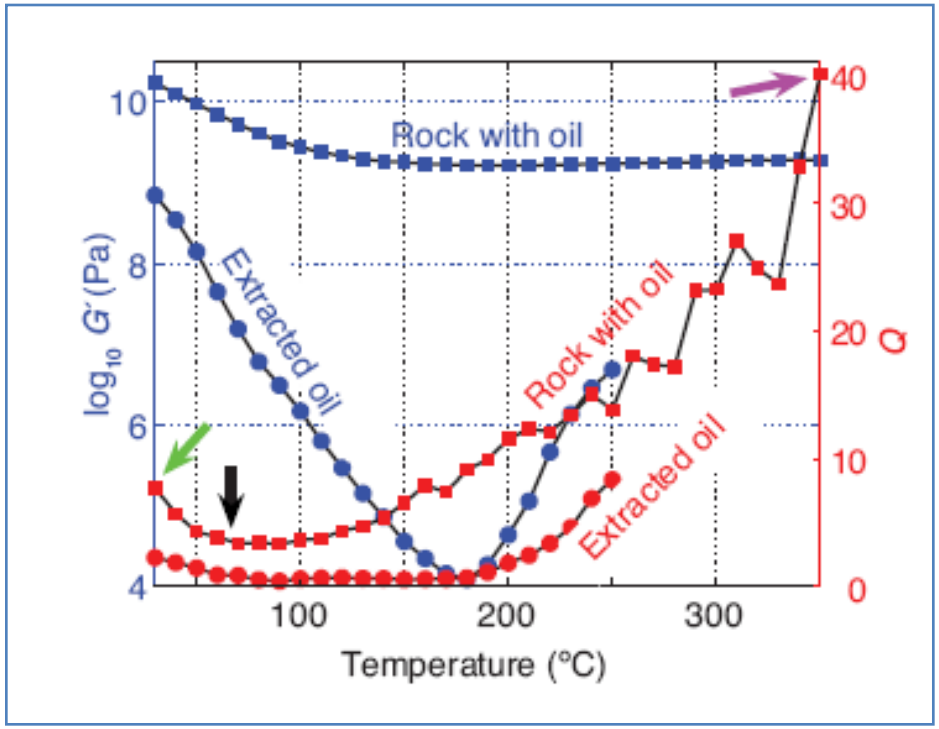
Most important points of the talk

- The viscosity, μ, is a very important parameter in reservoir modeling of heavy-oil field production.
- Q is related to viscosity
- If we can estimate Q (or Q changes) from seismic data, we may be able to significantly improve our reservoir models.

Q lab measurements (Qi and Schmitt)



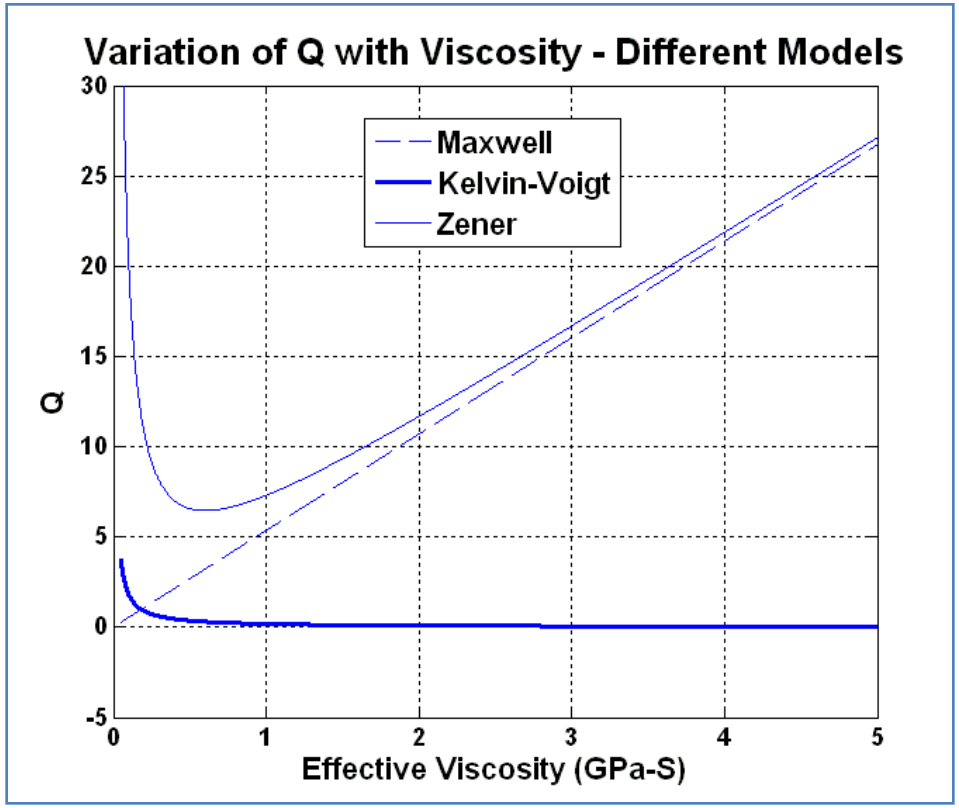
Q vs. Viscosity and Temperature

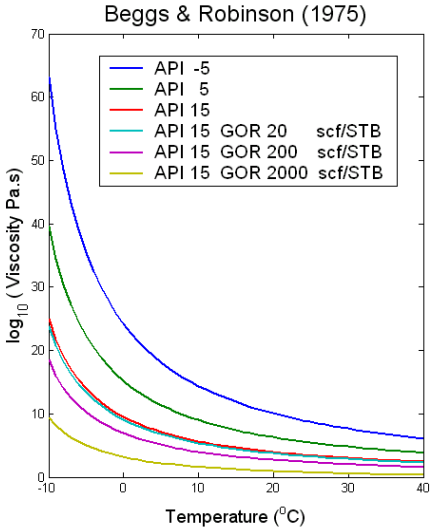


(from Behura et al., 2007).

- Frequency of signal: 12.6 Hz.
- Q at room temperature for the Uvalde carbonate rock with 25% porosity is about 5.
- With increasing temperature, Q reaches a minimum of around 4 and increases to a value of 40 at about 350°C.

Q vs. Viscosity and Temperature





- Frequency of signal: 25 Hz.

CHORUS
Consortium for Heavy Oil Research by University Scientists

Conclusions

- Reflections can be caused by Q contrast, but there are probably better methods for estimating Q, such observations of VSP spectral amplitude ratios and centroids.
- Reliable viscosity estimation is essential for reservoir modeling of heavy-oil fields.
- Estimates of Q can be related to viscosity.

Acknowledgements

The authors would like to thank

- Sven Treitel, TriDekon Inc.
- AICISE, CHORUS, CREWES, and NSERC
- Kit Crowe, formerly of Amoco Research, who demonstrated Q-reflections in theory and observations.
- Doug Schmitt (U of A), Mike Batzle (CSM), and Gary Mavko (Stanford), Pat Daley, and Arnim Haase (U of C) for discussions on Q and viscosity.
- All those who listened attentively to our ideas.