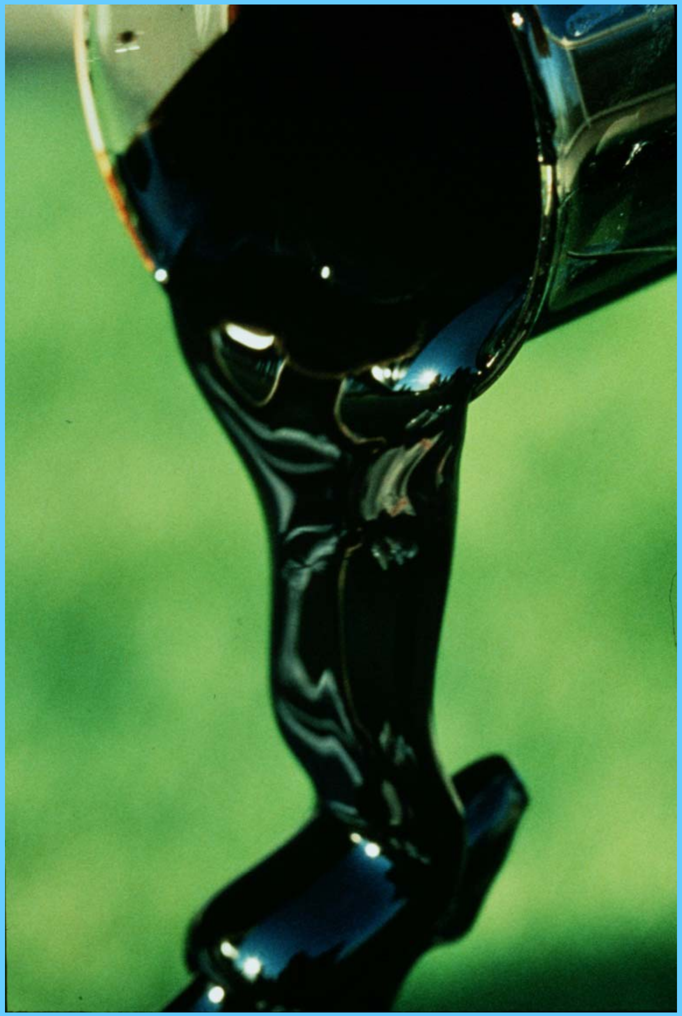
Experimental confirmation of "Reflections on Q"

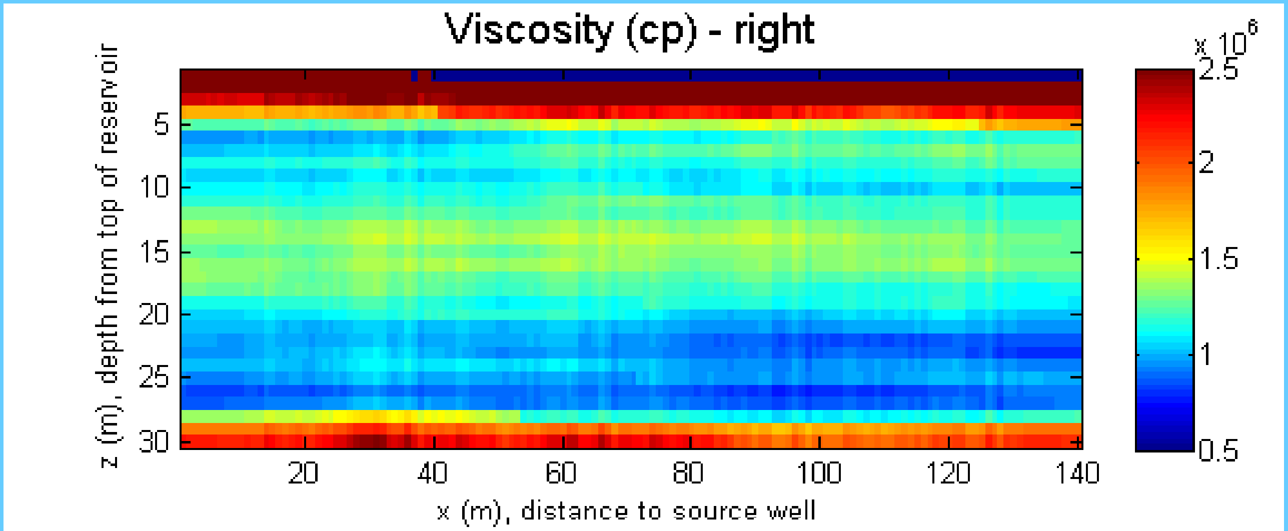
Larry Lines, Carl Sondergeld, Kris Innanen, Joe Wong, Sven Treitel and Tad Ulrych



Heavy oil production involves lowering oil viscosity. We describe this viscosity through Q estimation.

Recent Uses of Q in Estimation of Heavy Oil Viscosity

- Vasheghani (2011 PhD thesis) showed how Q-tomograms and BISQ rock physics could be used to map heavy oil viscosity between wells.
- The example below shows a viscosity tomogram for the Grand Rapids Formation between two Laricina wells in the Wabasca area of Northern Alberta.



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Further “Reflections on Q”

- Following the publication of the paper “Reflections on Q” by Lines, Vasheghani and Treitel (2008) in the CSEG Recorder we received input from several colleagues in the industry including David Aldridge, Chris Bird, Kris Innanen, Ed Krebes, Igor Morozov, Carl Sondergeld, and Joe Wong. This feedback led to further computations and experiments which answered some questions and raised others.
- We present the feedback, results and discussions in this talk.

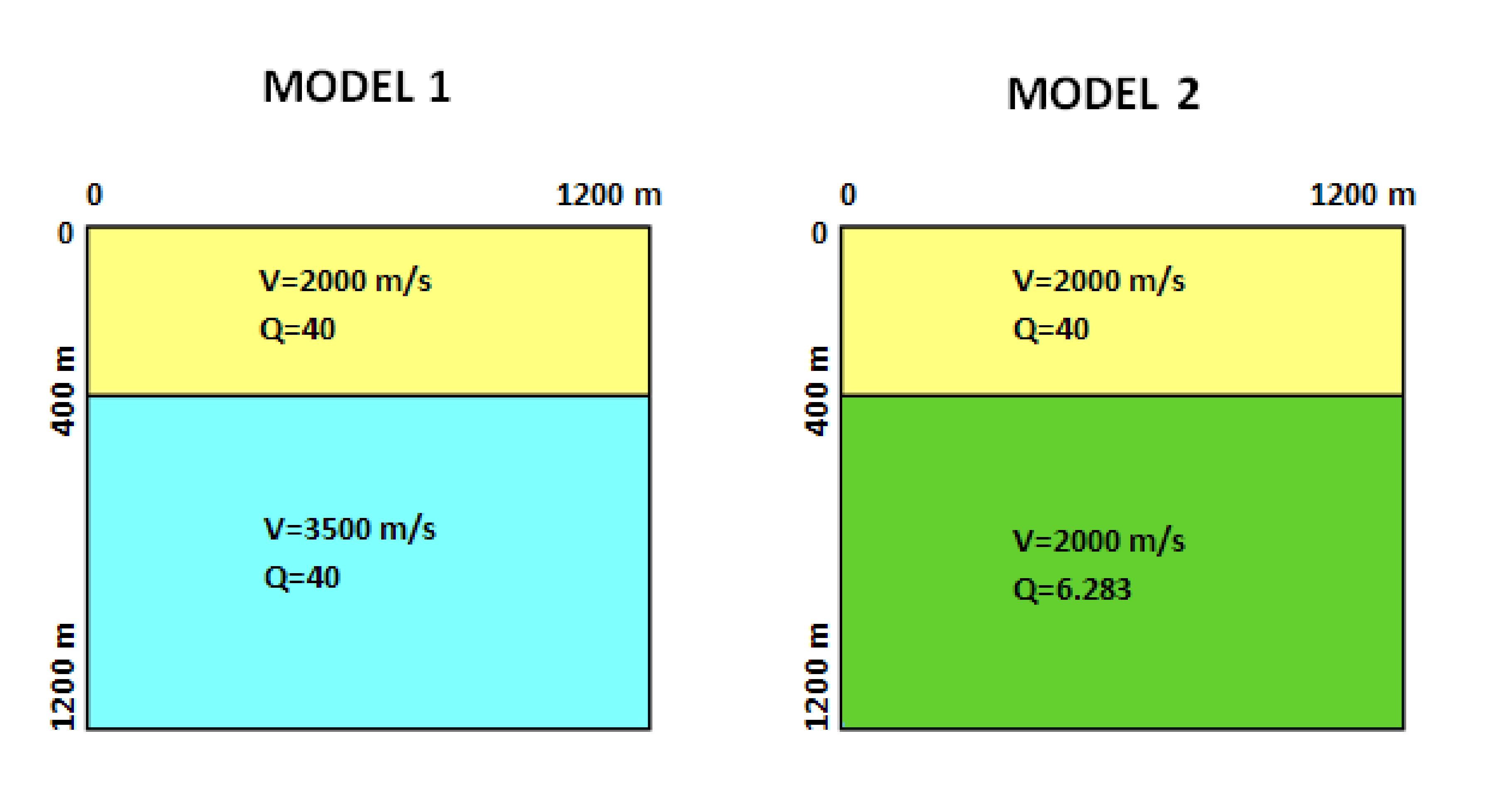
Further “Reflections on Q”

- 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 the paper by Futterman (1962), wherever there is attenuation (finite-Q), there will be dispersion. Therefore, Q reflections would be frequency dependent.

Further “Reflections on Q”

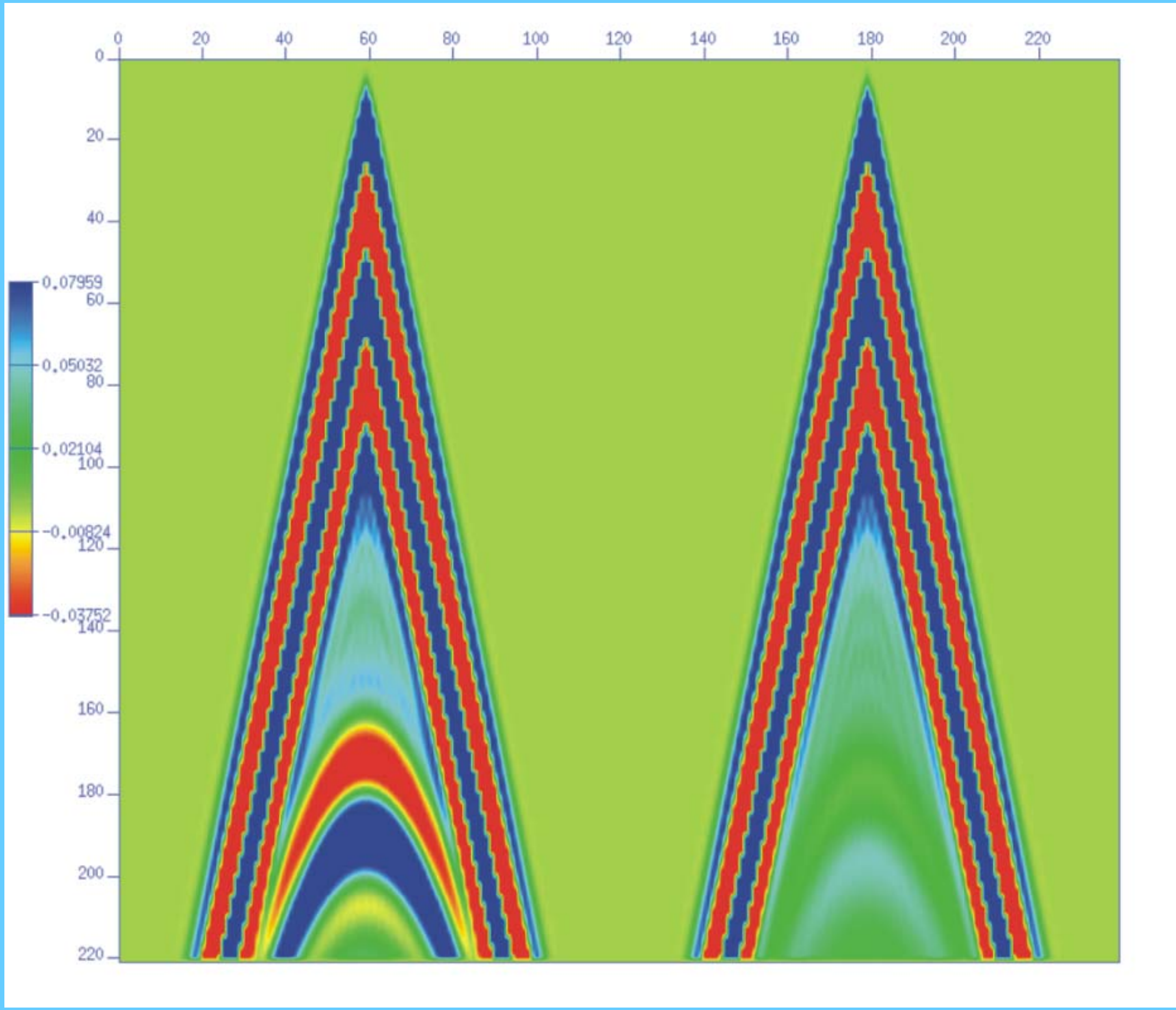
- Q-reflections were described through theory and lab measurements by Bourbie (1983 PhD thesis, Stanford) and later published by Bourbie and Nur (1984 JGR).

Reflections on Q Revisited



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
- From "Reflections on Q" by Lines et al. (2008).

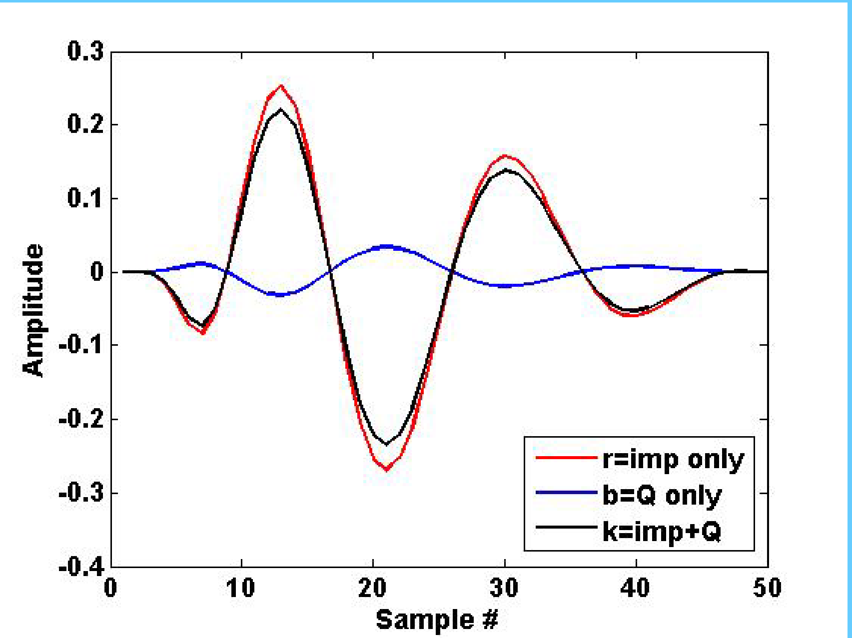


The reflection coefficients for pressure (P-waves at normal incidence) use a complex impedance as described by White (1965).

$$R_{12} = \frac{\rho_2 v_2 \left[1 + \dfrac{i}{2Q_2}\right] - \rho_1 v_1 \left[1 + \dfrac{i}{2Q_1}\right]}{\rho_2 v_2 \left[1 + \dfrac{i}{2Q_2}\right] + \rho_1 v_1 \left[1 + \dfrac{i}{2Q_1}\right]}$$

Observations

- Impedance only contrast (Model 1) has displacement reflection coefficient R=-0.27.
- Q-contrast only has R=-.0015-0.0335i found by substituting for Q values in reflection coefficient formula (Lines et al., 2008).
- Figure below from Ulrych shows reflections for impedance contrast only, Q contrast only and combined Q and impedance contrast for normal incidence

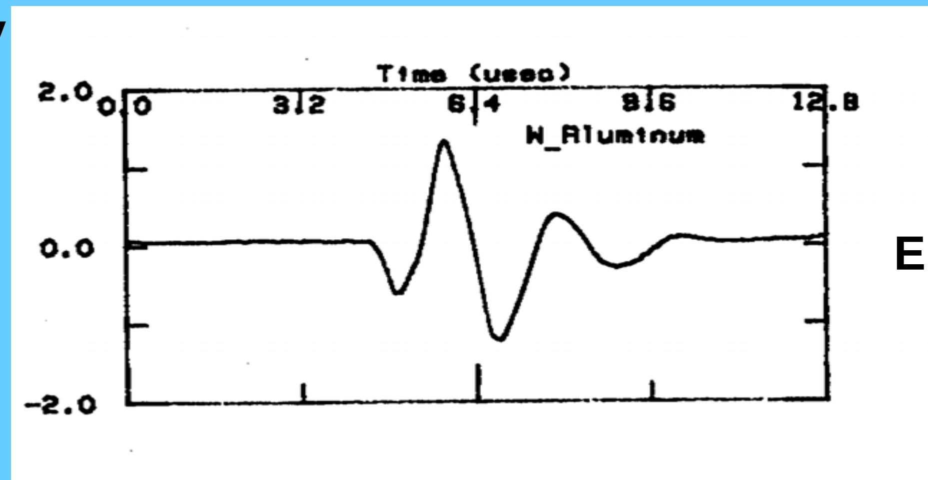


Lab Measurements from Sondergeld (2010)

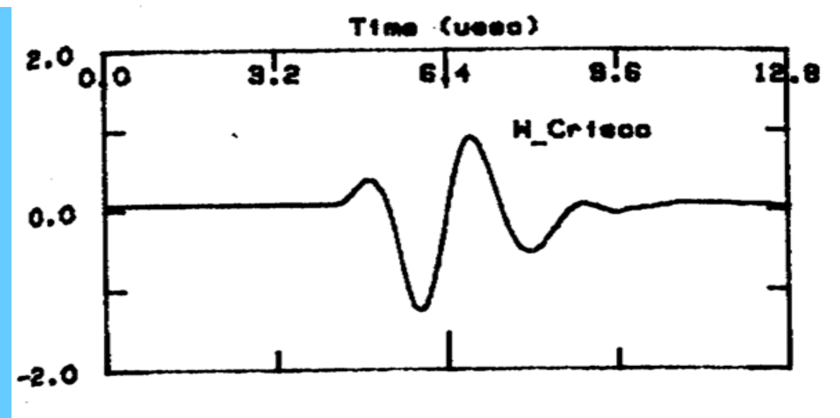
- The lab measurements from Sondergeld show reflections for water-aluminum (large impedance contrast) and water-crisco (low impedance contrast, large Q contrast).
- The wave shapes are very similar to those from Ulrych's calculations for impedance-contrast and Q-contrast! However, the amplitudes are significantly larger than anticipated.

Seismic Wave Propagation

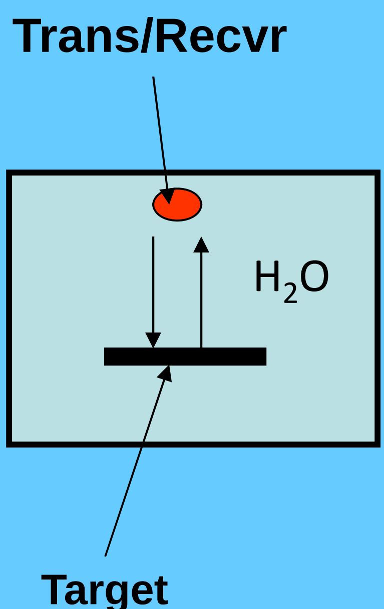
Reflection: anelasticity



Elastic



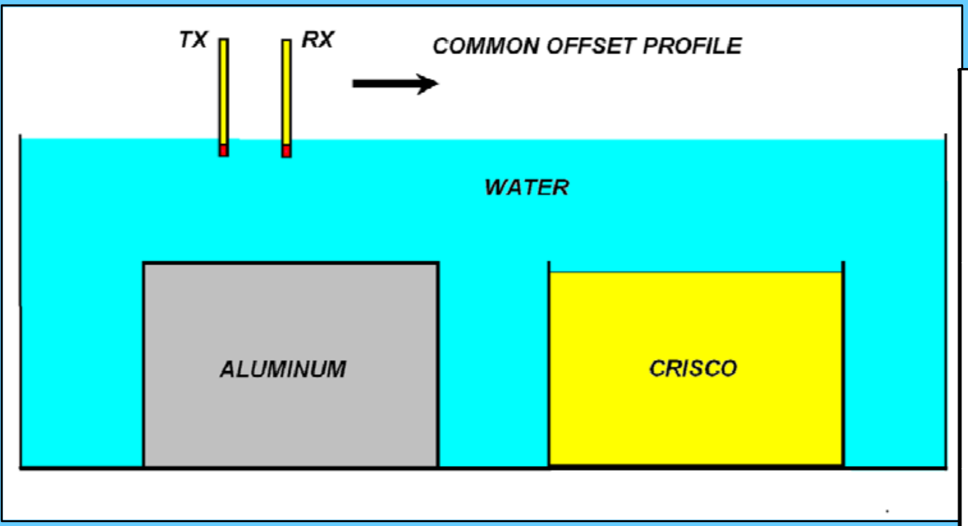
Anelastic

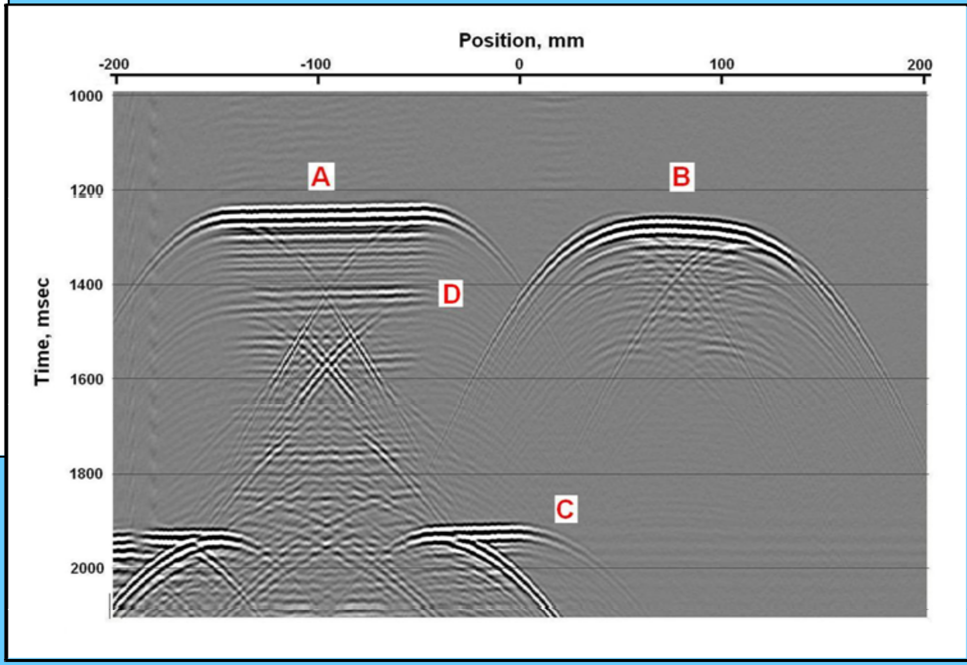


material	density	Vp	Zp	Rp
water	1	1.47	1.47	0
aluminum	2.65	6.39	16.93	-0.84022
crisco	0.98	1.49	1.46	0.003413

Joe Wong's Lab Measurements at CREWES Confirmed Sondergeld's Experiments

- In 2011, Joe Wong conducted a series of experiments to test Sondergeld's results. This is described by Joe in an accompanying CREWES talk



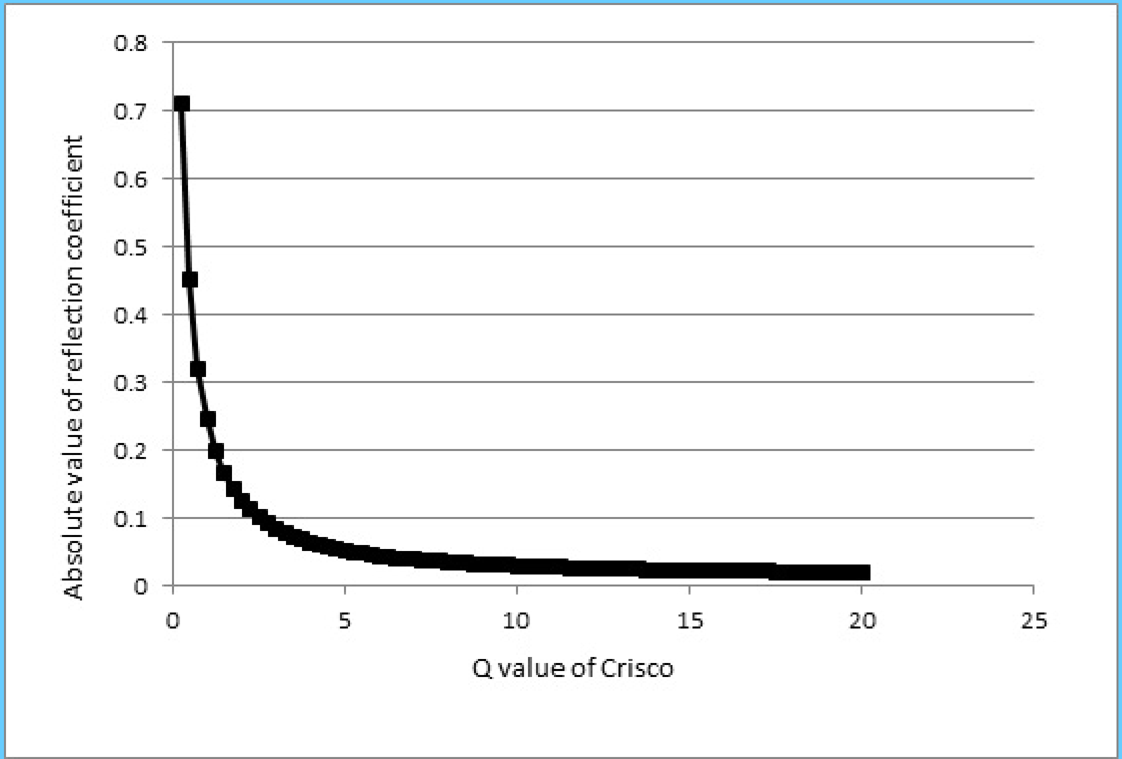


Observations

- The good news is that theory, numerical modeling and lab measurements all show that seismic reflections can arise at interfaces with almost zero contrast in the real part of impedance (density*velocity) contrasts, but with only Q-contrasts.
- However, the story is not quite complete. The measured amplitudes for the water/Crisco reflections are about as large water/aluminum amplitudes.

Observations

How do we account for the large amplitudes from the water/Crisco reflection? Matching the amplitudes requires a Q value for Crisco that is unrealistically low (less than 2). If we include dispersion effects, this also requires a Q for Crisco that is very low or a frequency-effect term that is unrealistically large.



Observations

If we include dispersion effects, this also requires a Q for Crisco that is very low or a frequency-effect term that is unrealistically large. Bourbie and Nur (1984) propose a reflection coefficient formula that includes dispersion effects in addition to contrasts in complex impedance.

$$R' \approx R + \frac{1}{2\pi}\left(\frac{1}{Q_2} - \frac{1}{Q_1}\right)\log\left|\frac{\omega}{\omega_0}\right| .$$

However matching this model to the data also requires an unreasonably small value of Q and/or an unreasonably large $\log\left|\frac{\omega}{\omega_0}\right|$ term.

Observations

- How do we account for this somewhat unexpected large amplitude?
- Matching the amplitudes requires a Q value for Crisco that is unrealistically low (less than 2). If we include dispersion effects, this also requires a Q for Crisco that is very low or a frequency-effect term that is unrealistically large.

Conclusions and Further Questions

- Theory, numerical modeling and lab measurements all show that seismic reflections can arise from contrasts in the attenuation properties (1/Q values) of materials
- We are having difficulty in accounting for the large amplitude of the Q reflections with realistic material properties.
- How does this relate to real life fluid saturated rocks and does it have future applications?

References

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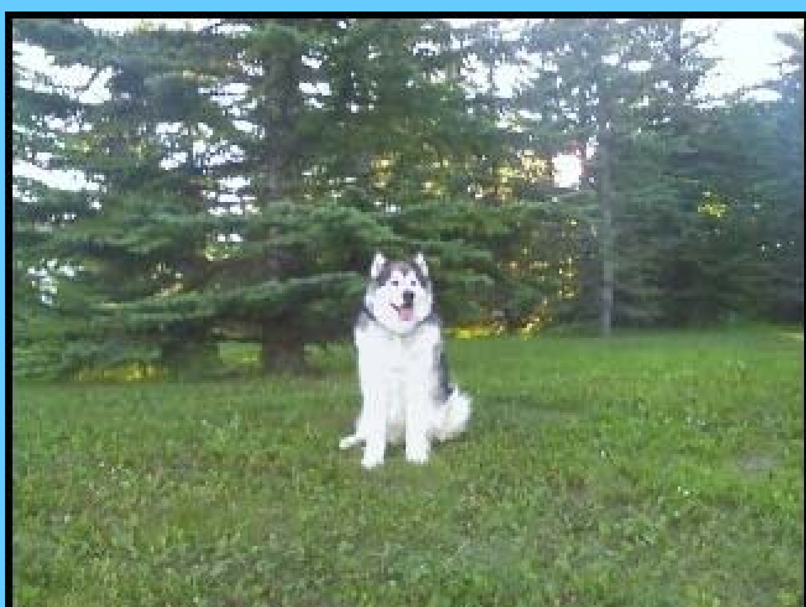

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