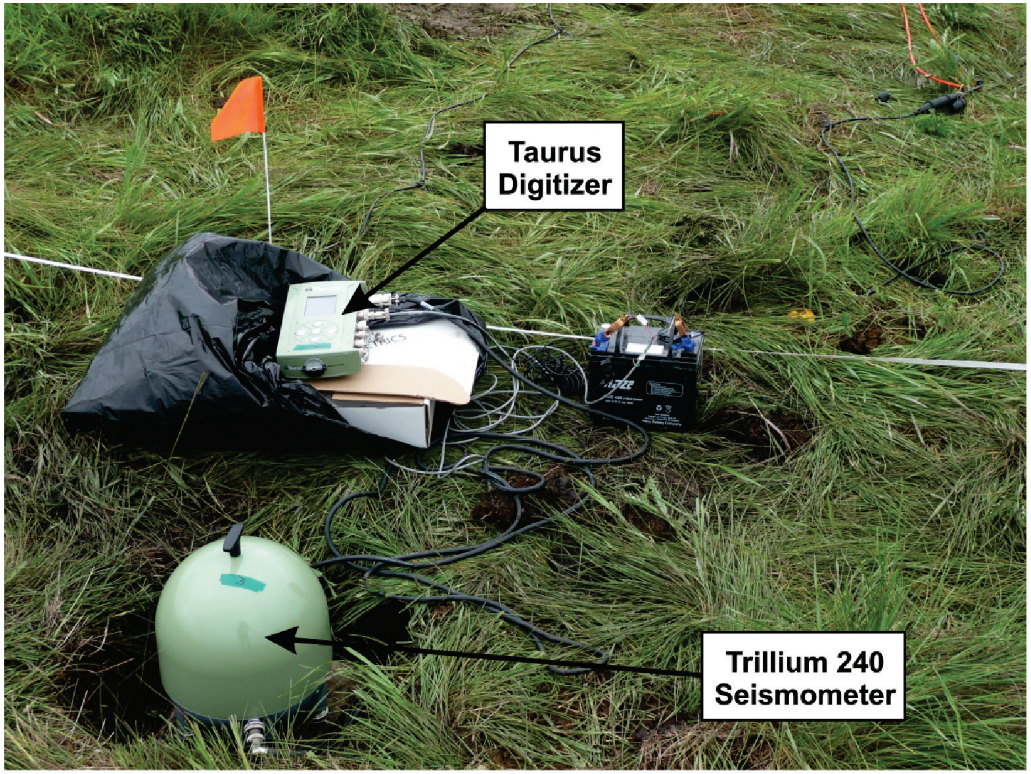
Quantitative estimation of elastic strain using broadband seismometers

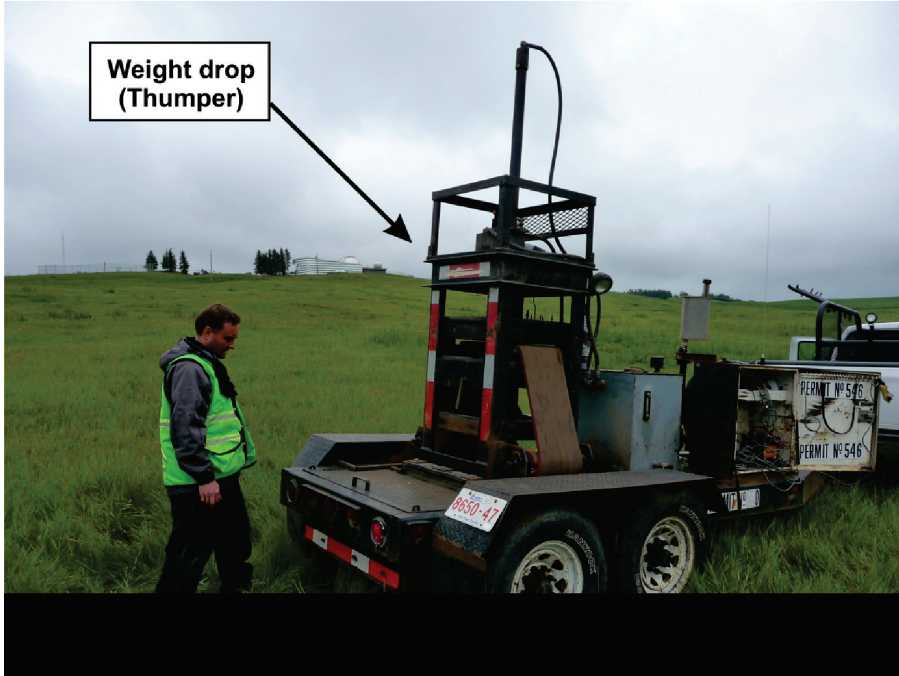


David W. Eaton, Adam Pidlisecky, Robert J. Ferguson and Kevin W. Hall

Department of Geoscience
University of Calgary

Talk Outline

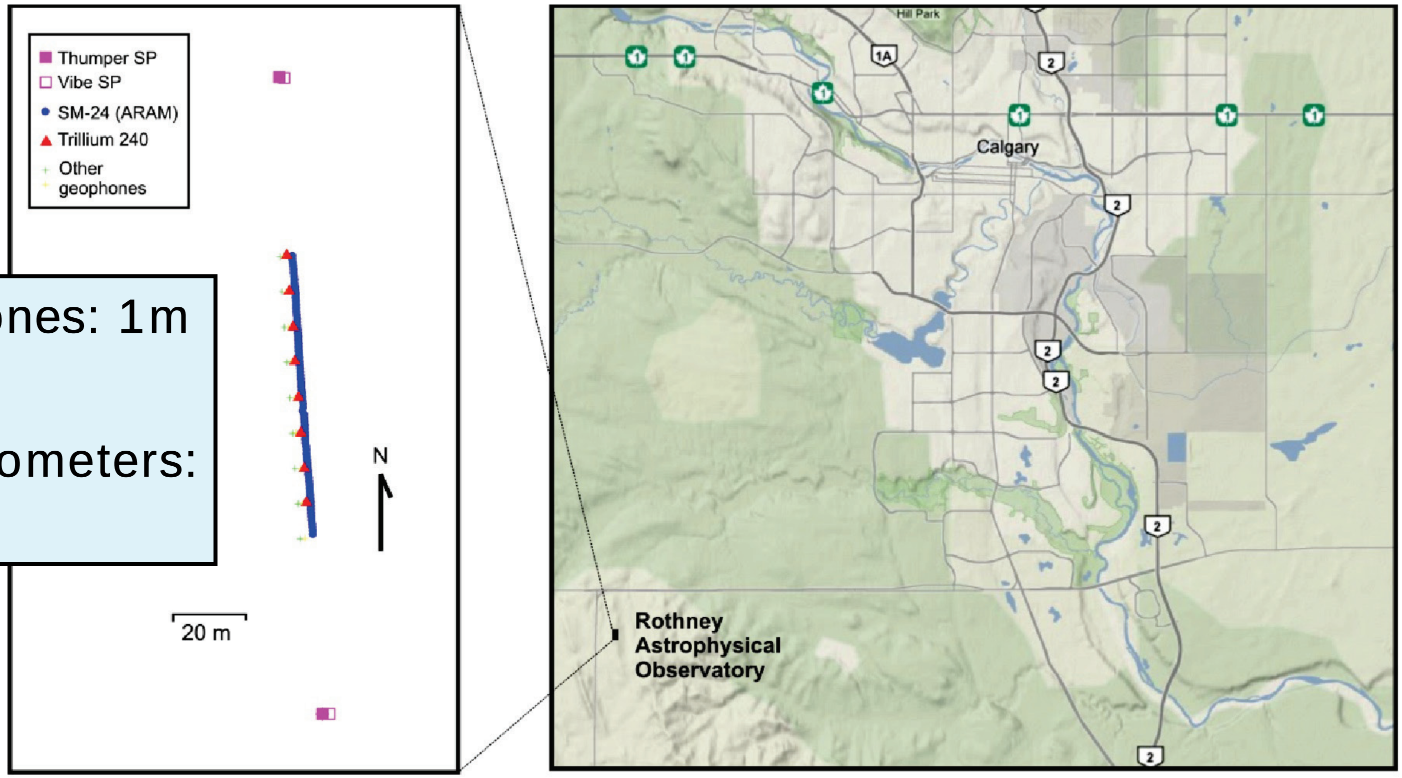
- Location and Purpose
- Theory: Elastic strain & Instrument response
- Observations: Seismometer & Geophone
- Quantitative strain estimate
- Where are the seismos now?



Location and Purpose

Field Site: RAO lands near Priddis, Alberta

- 3-C geophones: 1m spacing
- T240 seismometers: 10m spacing



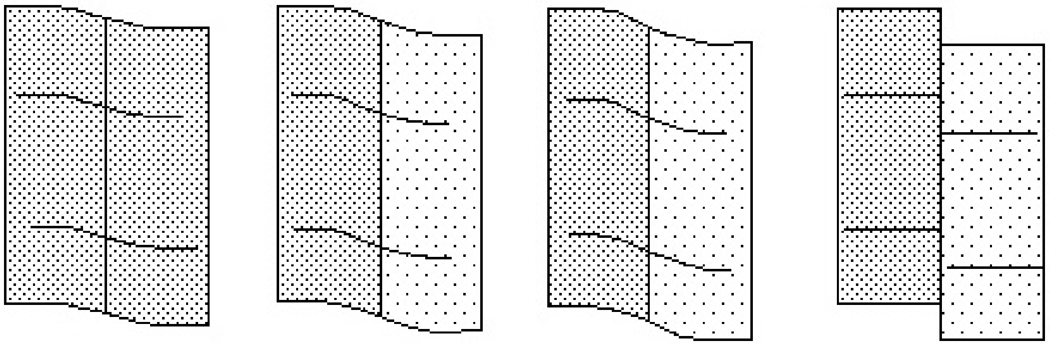
<u>Objective</u>: Determine absolute elastic strain, for geotechnical purposes.

Theory

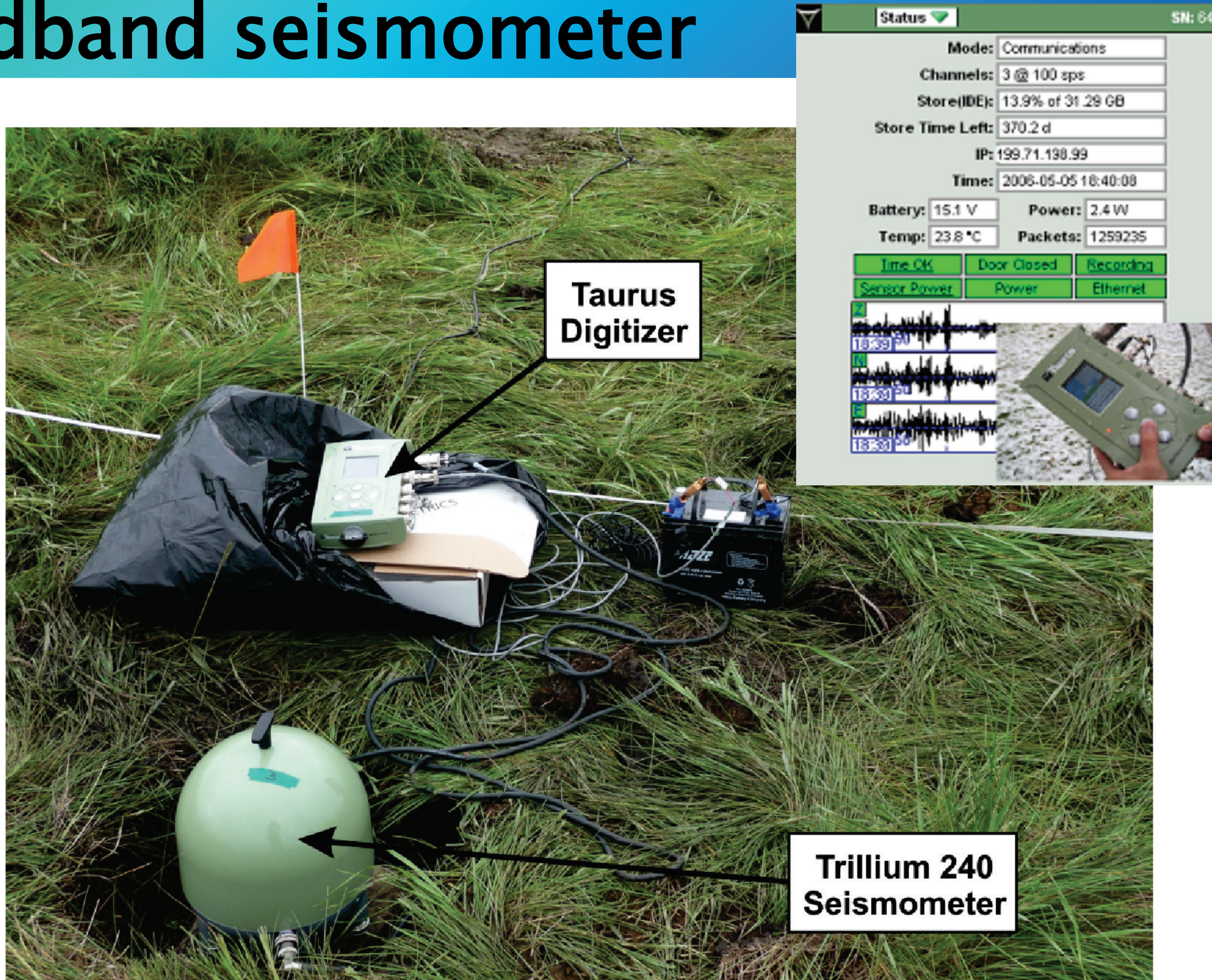
Strain Tensor

- Dimensionless measure of deformation in a continuum; proportional to stress in an elastic medium.
- Each element of **e** is calculated using spatial derivatives of the particle displacement, **u**.

$$e_{ij} = \frac{1}{2}\left(\partial u_i / \partial x_j + \partial u_j / \partial x_i\right)$$



Broadband seismometer



Seismic source

Instrument response

Broadband Seismometer

- Capacitive force-balance device
- Transfer-function characterized using poles (p_j), zeros (z_i) and sensitivity (K_S).

$$H_S(\omega) = K_S \frac{\sum_{i=1}^{N} \omega - z_i}{\sum_{j=1}^{M} \omega - p_j}$$

Nanometrics Trillium T240 Seismometer

Instrument response

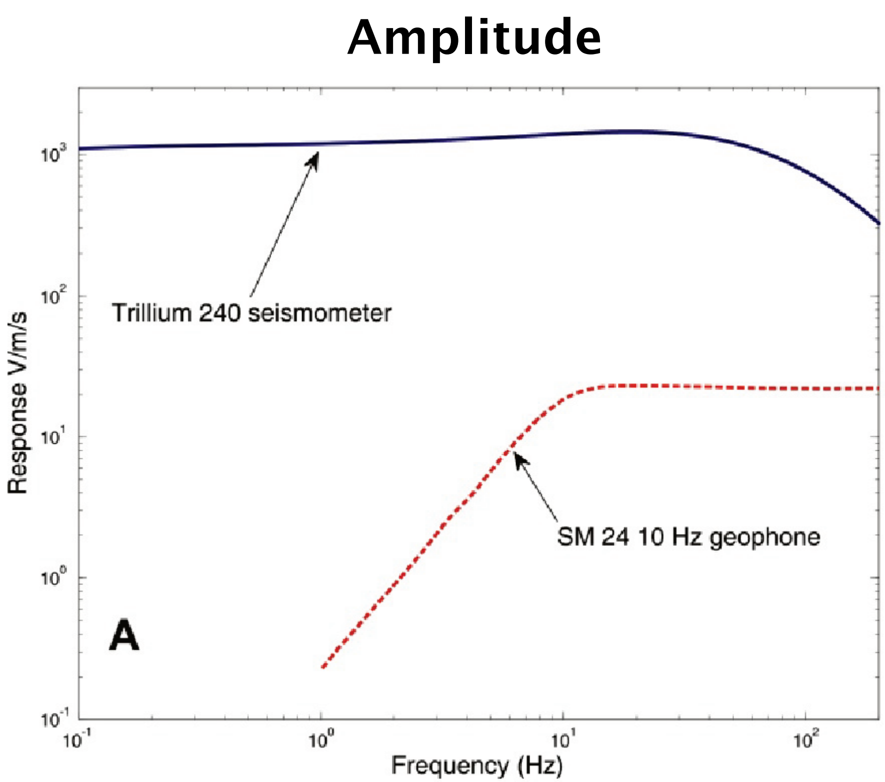
Geophones

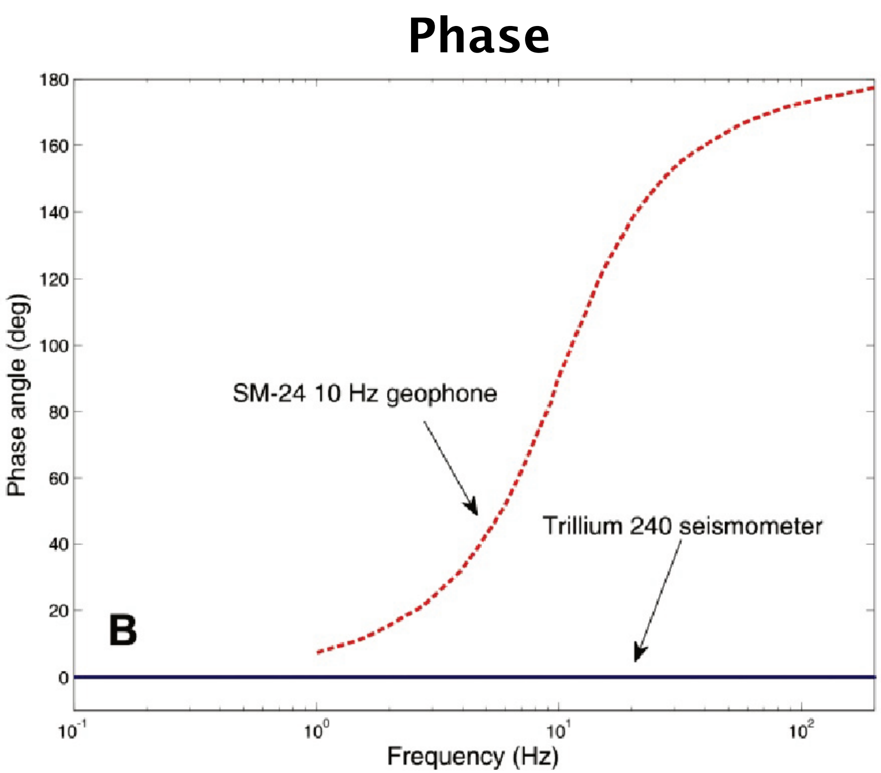
- Resonant mass-coil systems
- Transfer-function characterized using natural frequency (ω_N) and damping factor λ

$$H_g = K_g \frac{(\omega/\omega_N)^2}{-(\omega/\omega_N)^2 + 2j\lambda\omega/\omega_N + 1}$$

I/O Sensor SM-24 10 Hz 3-component geophones

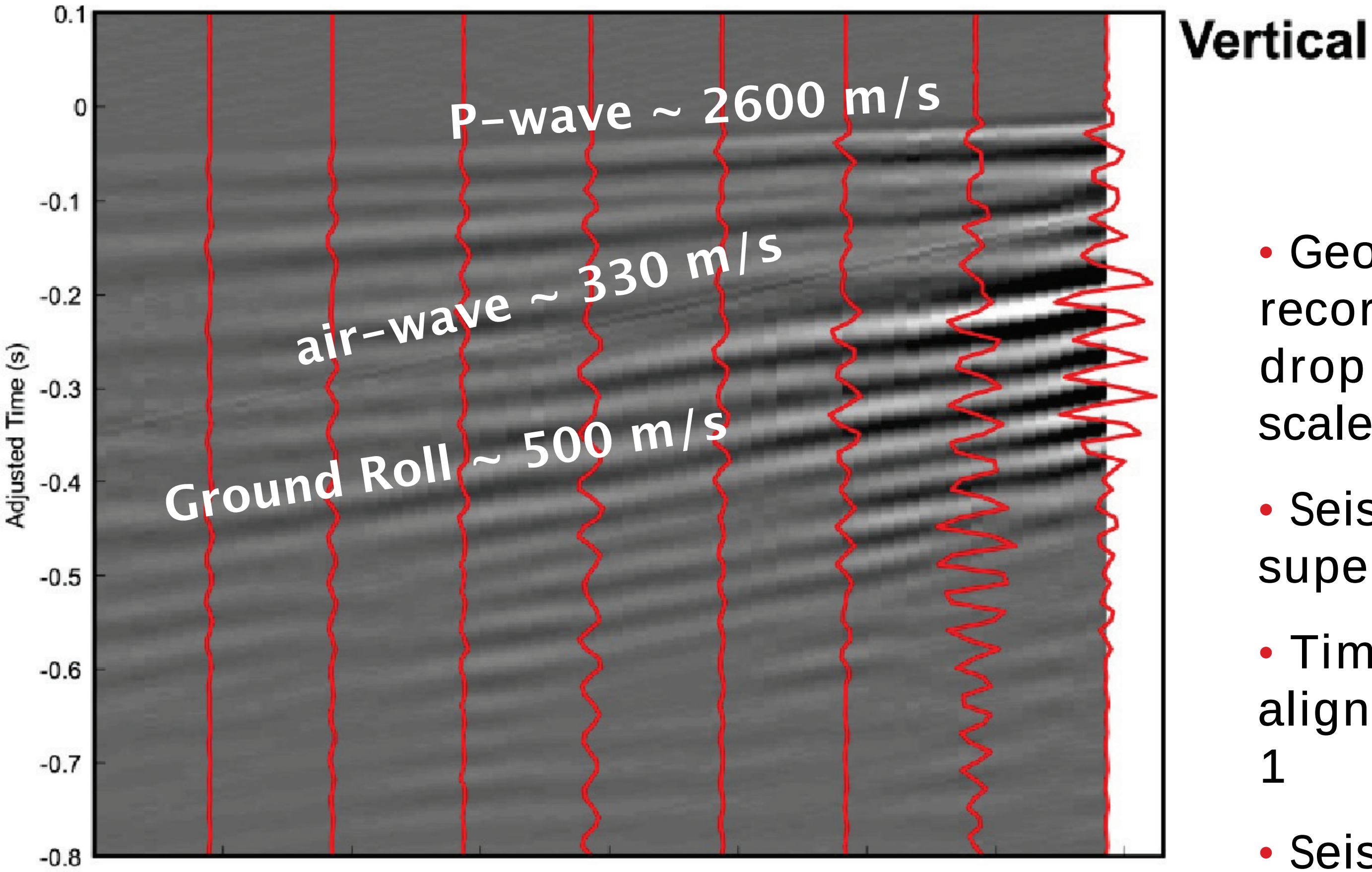
Instrument Response





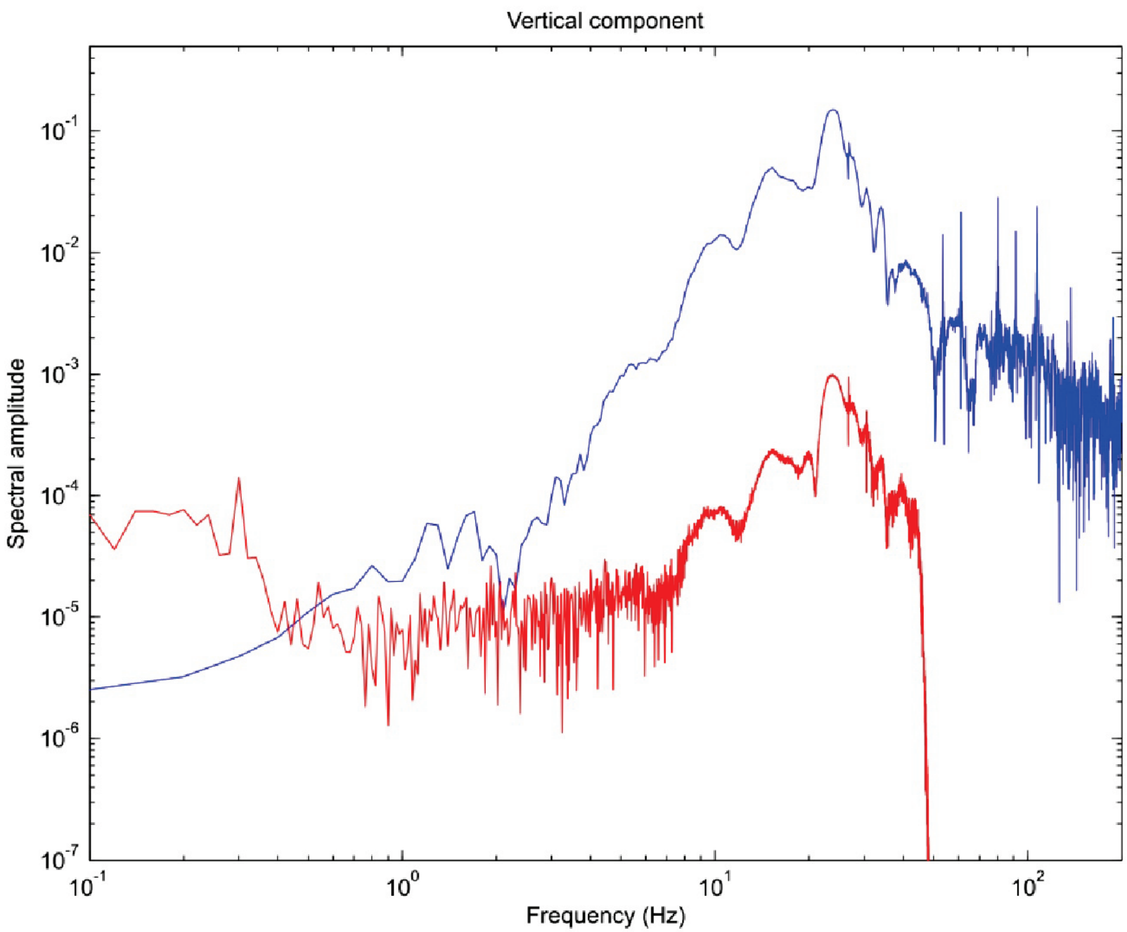
Both seismometers and geophones measure ground velocity, not displacement.

Raw Data



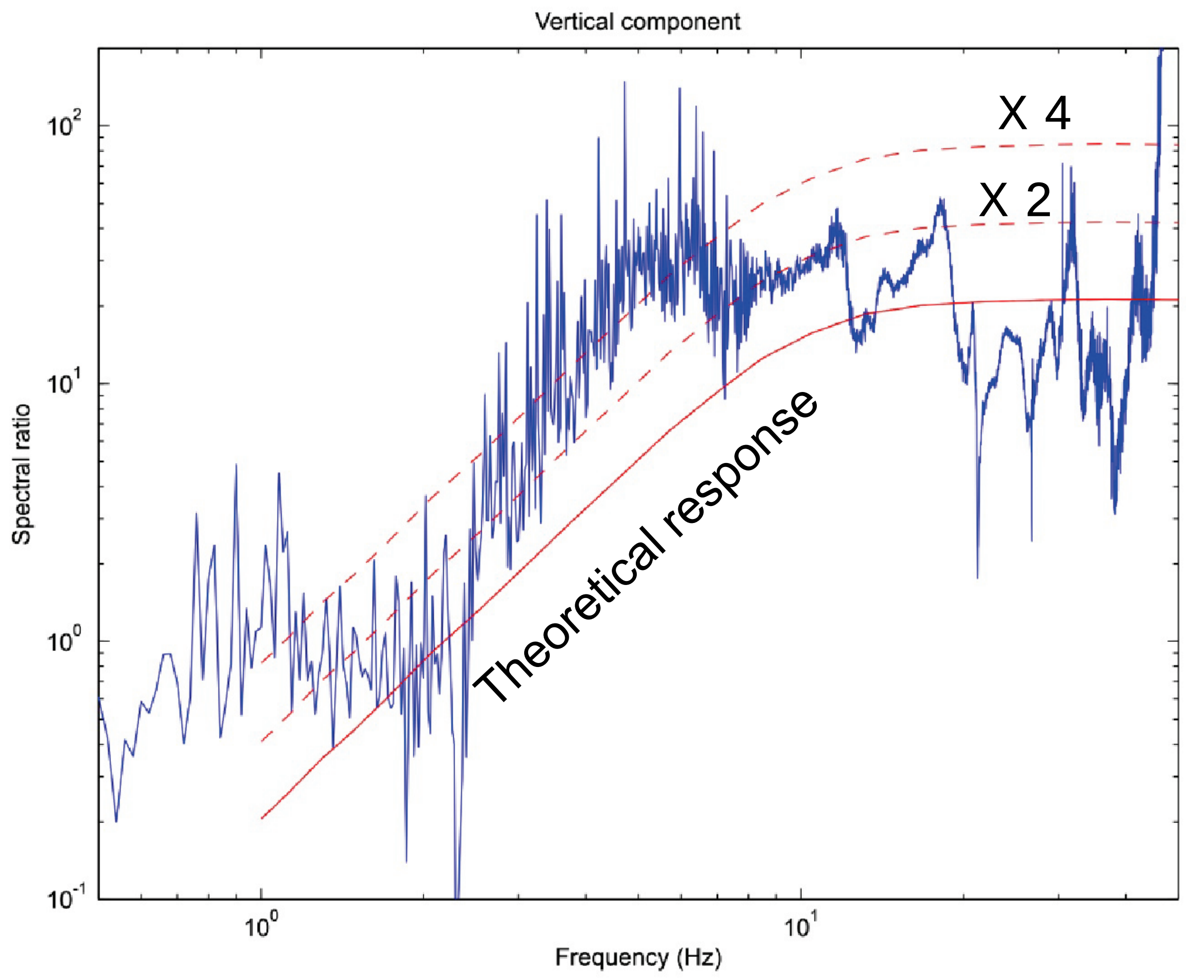
- Geophone (ARAM) record from weight-drop source (gray scale image)
- Seismometer traces superimposed (red)
- Time adjusted to align P wave on trace 1
- Seismometer amplitudes show greater variability - likely due to variable coupling

Spectral comparison



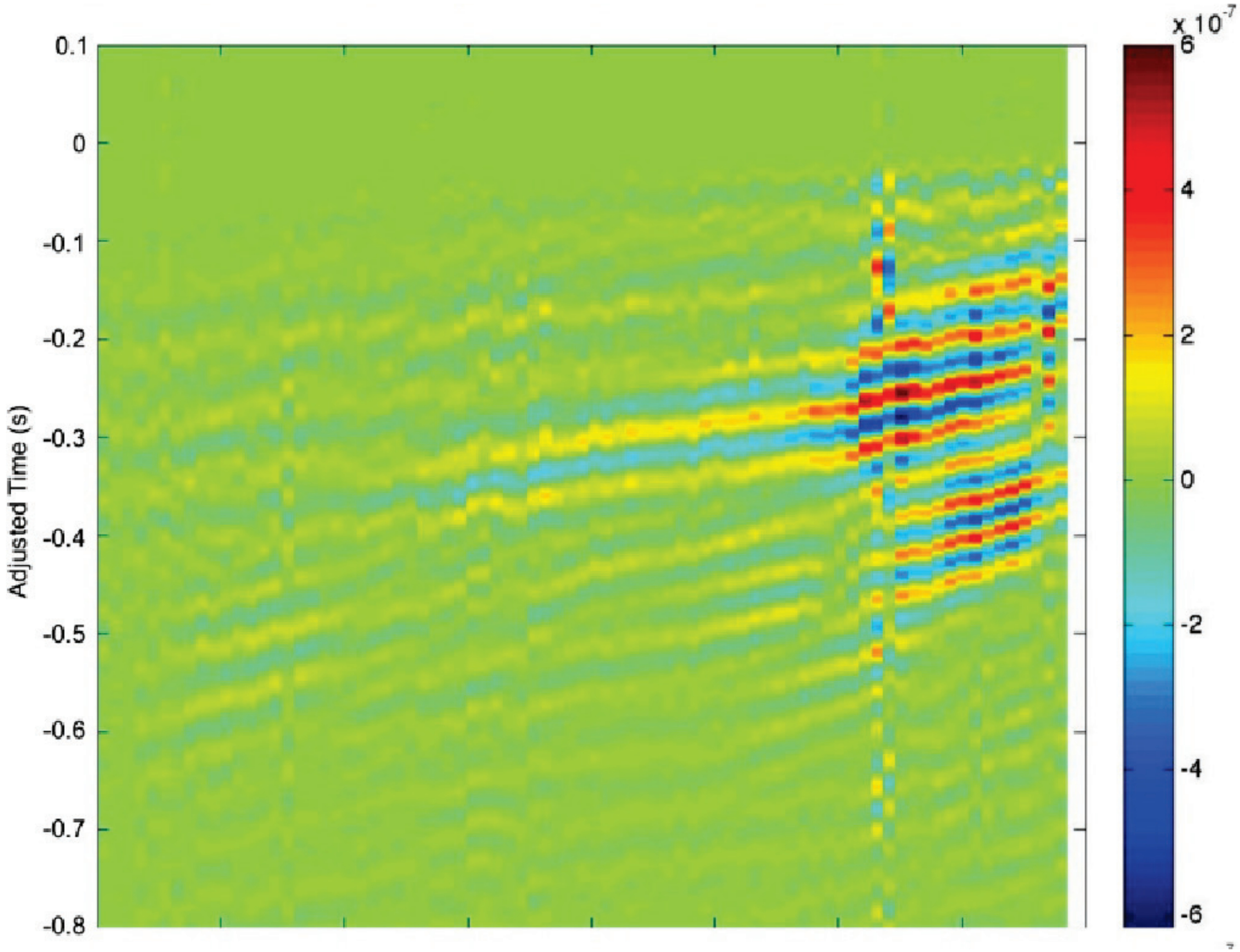
- Fourier spectra (FFT) from a single trace, with equal number of time samples
- Seismometer instrument response was deconvolved
- Seismometer spectrum cut off at high end by anti-alias filter
- Low-frequency increase reflects microseismic noise peak (oceans)

Empirical geophone response



- Average spectral ratio (8 geophone-seismometer pairs)
- Shape is generally correct, but higher than expected amplitude below corner

Strain components

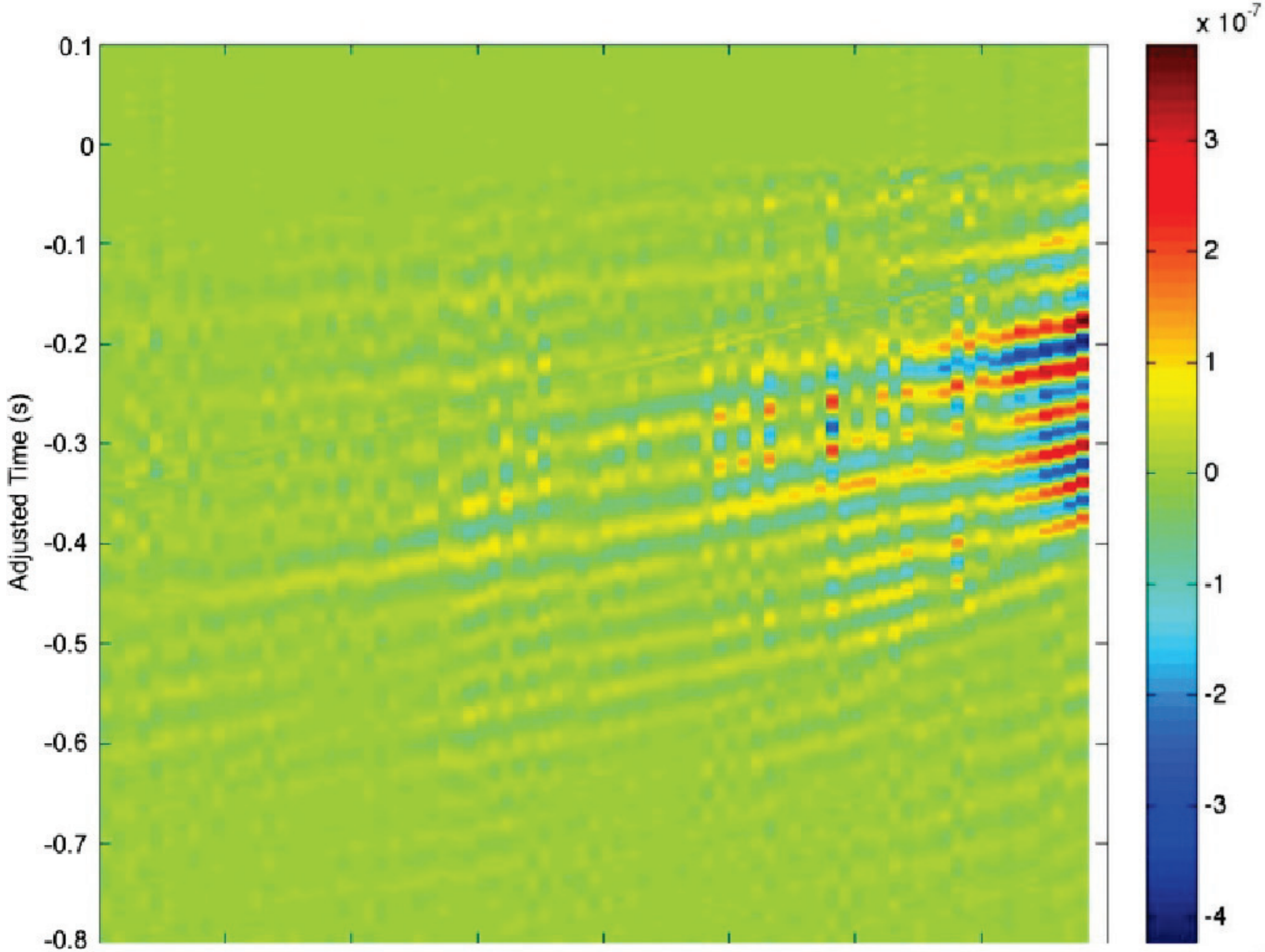


du_r/dr

1. Normalize by geophone response
2. Convert to displacement by numerical integration
3. Compute r-derivative along line

Longitudinal strain - expect to see P and Rayleigh wave

Strain components

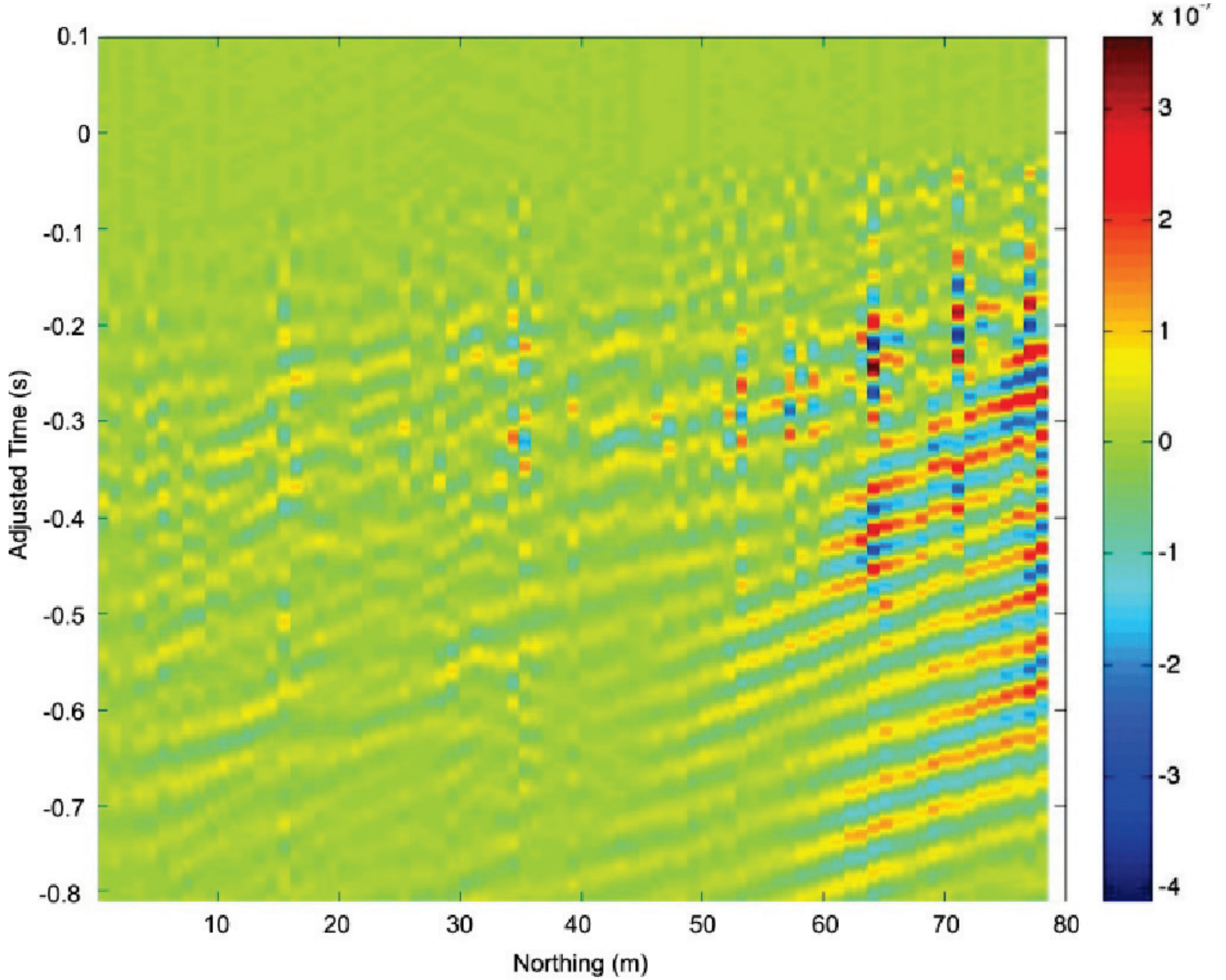


du_z/dr

1. Normalize by geophone response
2. Convert to displacement by numerical integration
3. Compute r-derivative along line

Part of SV shear strain - expect to see Rayleigh, SV wave

Strain components



du_t/dt

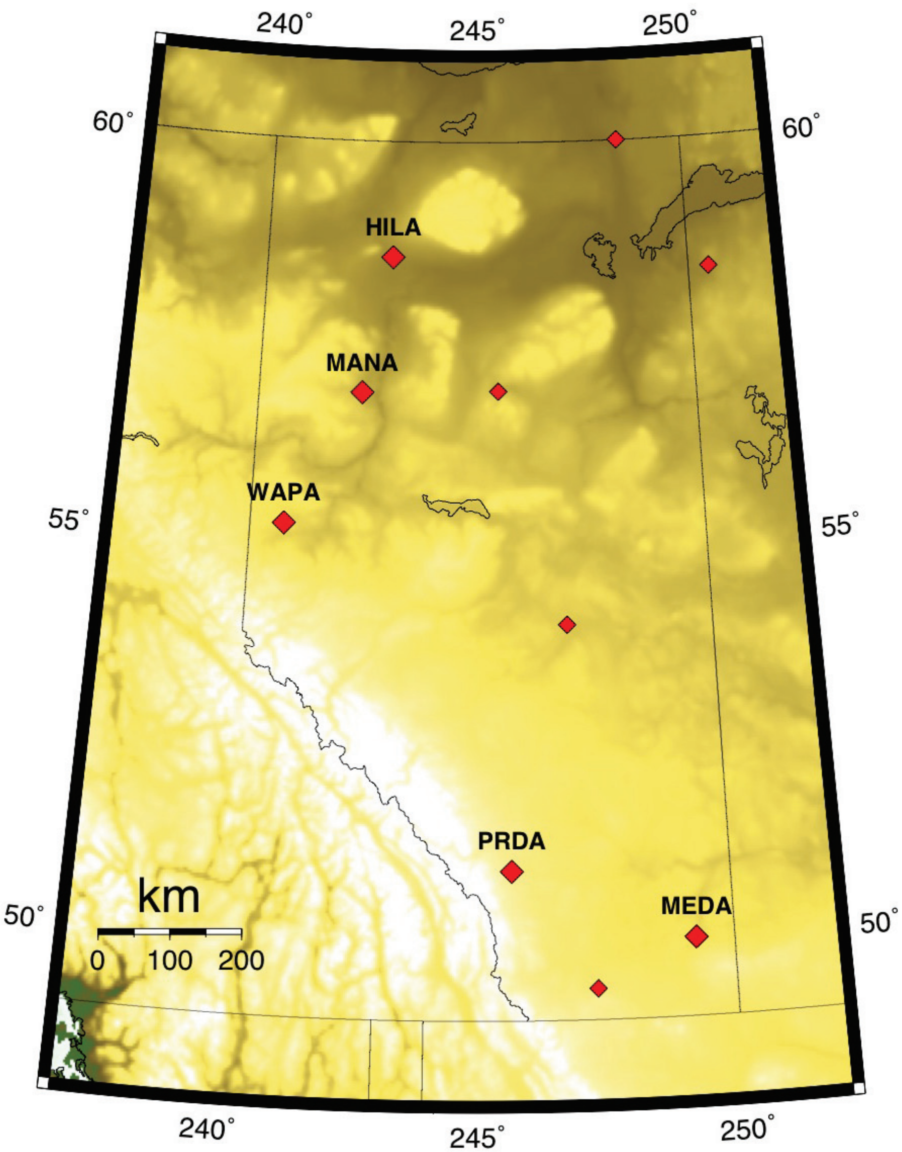
1. Normalize by geophone response
2. Convert to displacement by numerical integration
3. Compute r-derivative along line

Part of SH shear strain - expect to see Love, SH wave

Conclusions

- Empirical geophone spectral response agrees with theory (based on geophone specs) within a factor of ~ 4
- High degree of variability in seismometer signal is likely due to variable ground couple; this precluded robust calculation of off-line derivatives, needed to complete horizontal strain calculation
- Inferred peak strain of order ~ 10^{-7} for ground roll produced by weight drop
- Future work will require very careful installation of seismometers to enable accurate calibration of the full strain tensor (or just go with the geophone response!)

Seismic Stations



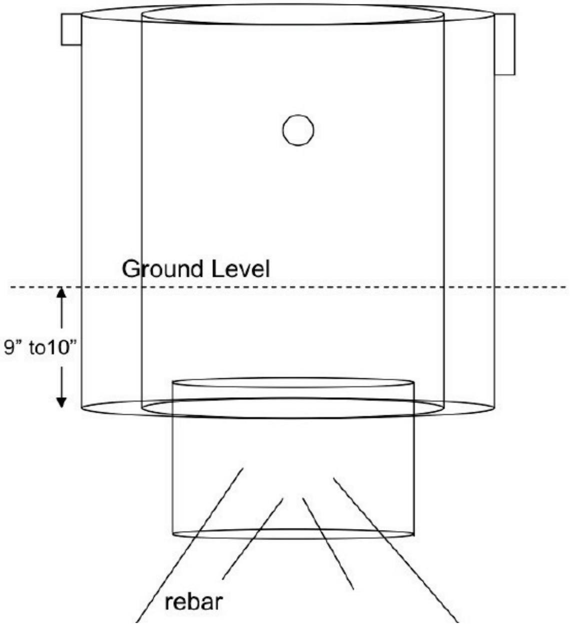
Alberta Telemetered Seismograph Network

- 5 (of 9) sites installed in October-November
- Remaining sites scheduled for installation in 2010
- Wireless internet used for real-time link with Canadian National Seismograph Network

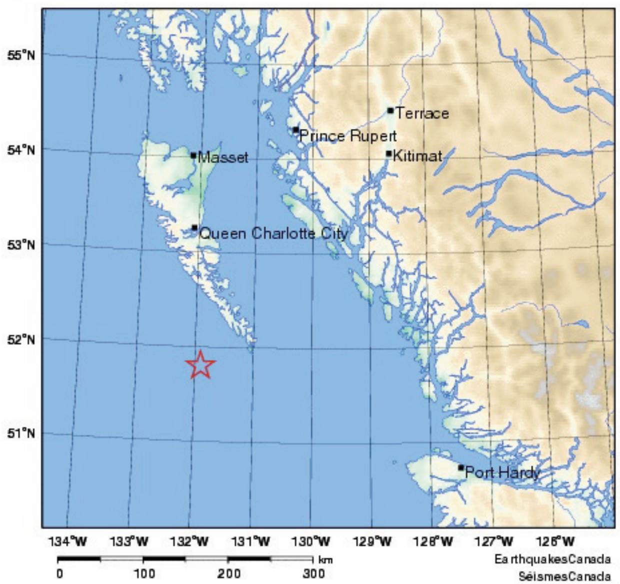
Seismic Stations

Site construction

- Concrete pier
- Thermal insulation
- AC power



M 6.5 Earthquake, Queen Charlotte Islands



Largest Canadian earthquake since 2004 occurred this week (Tuesday morning)