# The Use of Radar Methods to Determine Moisture Content in the Vadose Zone

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Use surface and subsurface radar methods.

Imaged variation in dielectric constant $\kappa$
is linked to variation in moisture content $\Theta_w$

Two approaches:

1) radar image →1→ "map" of $\kappa$ →2→ map of $\Theta_w$
challenges: a) need improved radar image
b) →1→ inversion step
c) →2→ rock physics step

2) spatial variability in radar image = spatial variability in $\Theta_w$
challenges: a) need improved radar image
b) quantifying spatial variability
c) how best to use the information

## Improving the Radar Image

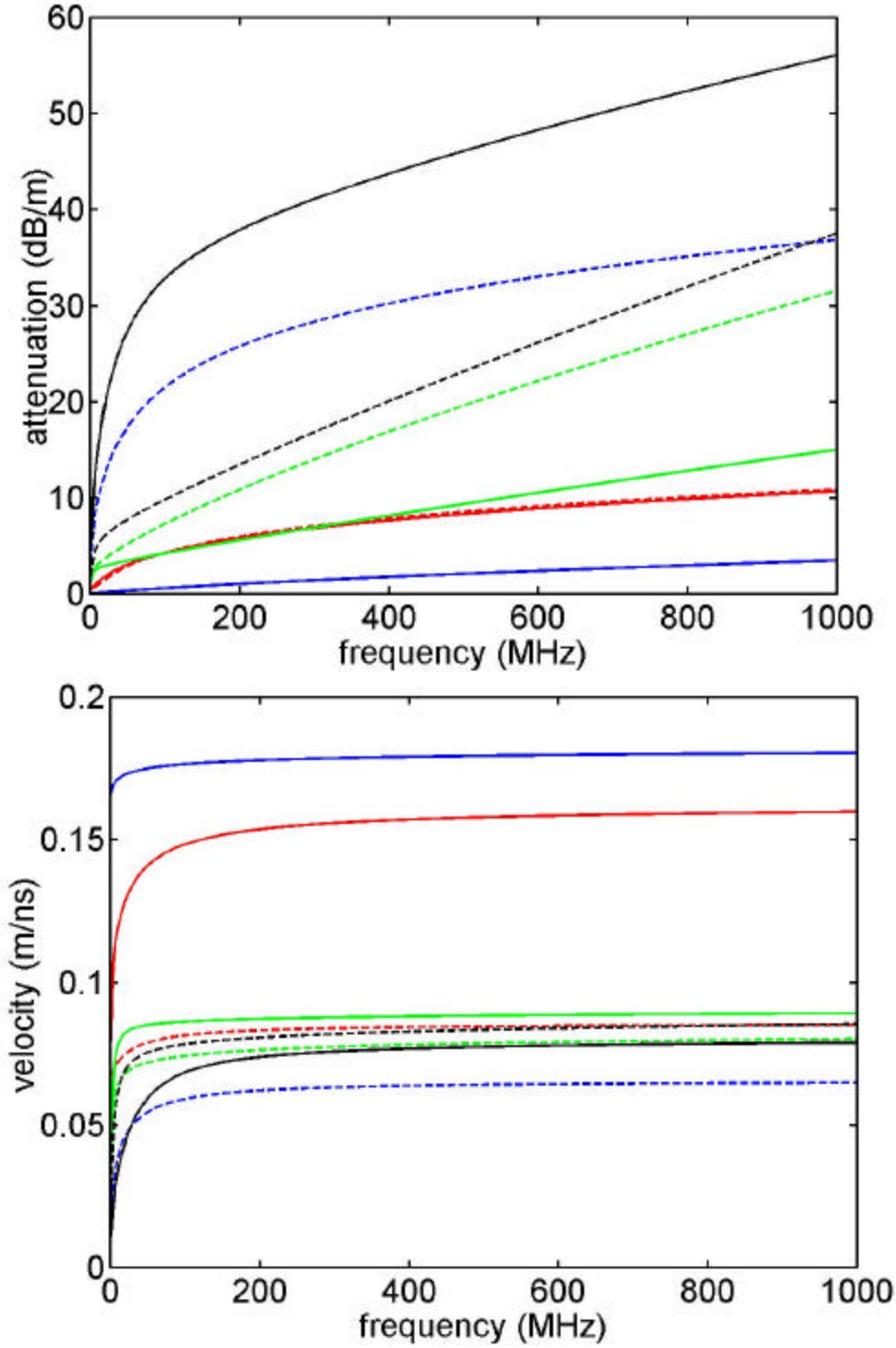
current research: correcting for frequency-dependent attenuation

frequency-dependent attenuation causes significant wavelet dispersion

high frequencies are attenuated faster than lower ones during propagation of the radar wavelet – causes the pulse to broaden as it propagates through the earth

in the GPR image, this is displayed as a characteristic blurriness that increases with depth

prevents accurate qualitative interpretation and inversion




Attenuation and velocity calculated as a function of frequency for a variety of geologic materials whose dielectric permittivities have been fitted using the Cole-Cole formula: sandy soil, sandy soil (saturated), clay soil (dry), clay soil (30 wt% water), limestone saturated with brine, sandstone saturated with brine.

*Correcting for Wavelet Dispersion*

- seismic processing method known as inverse Q filtering

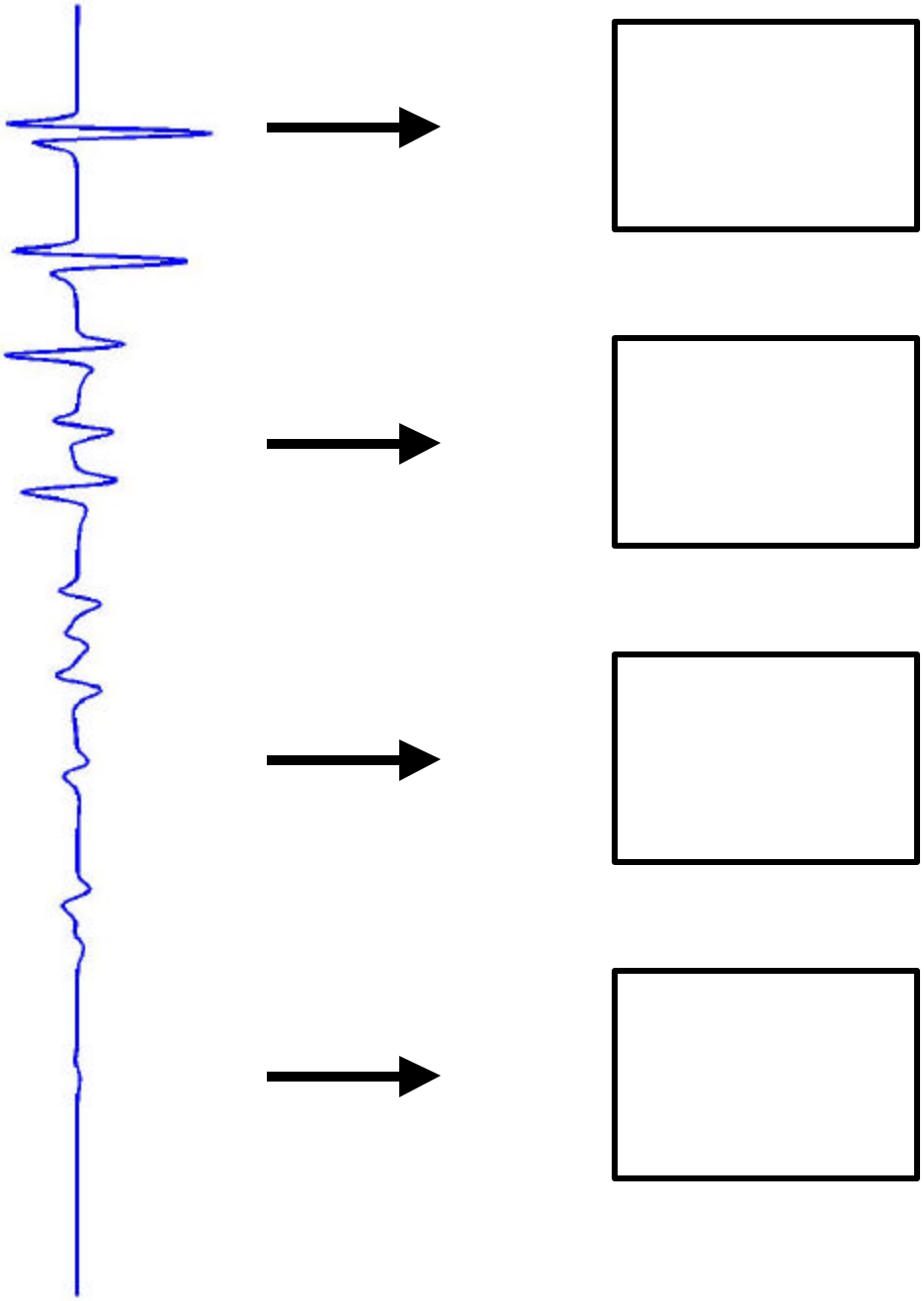
- must first determine Q in the subsurface

- using surface GPR data: examine the frequency content of the GPR signal at all times down a trace using the wavelet transform

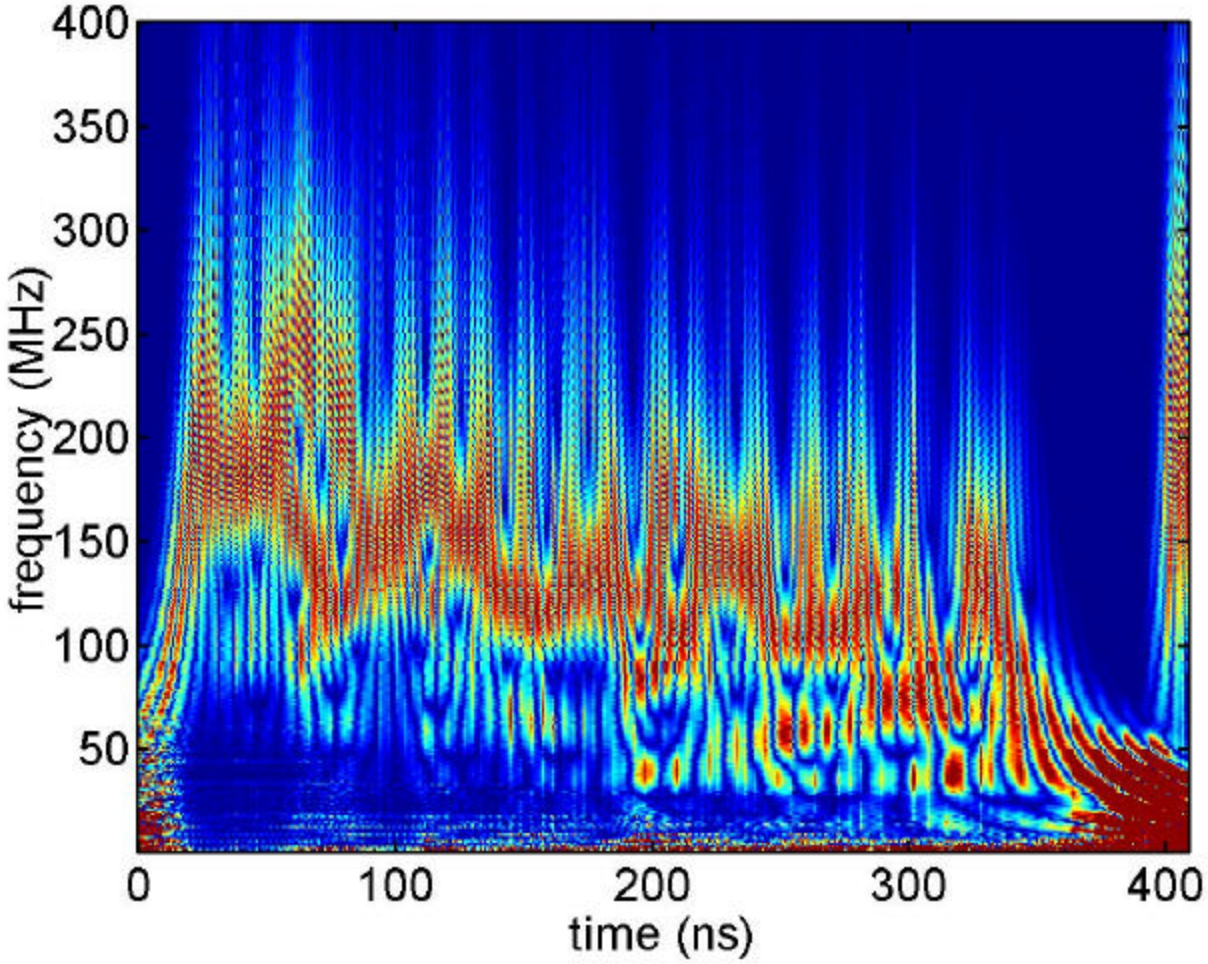
-high frequencies are attenuated faster than lower ones, so the dominant frequency content shifts to lower frequencies

- downshift in the dominant frequency of the GPR wavelet with time can be used to calculate Q

# Change in Wavelet Character Down A Dispersive GPR Trace

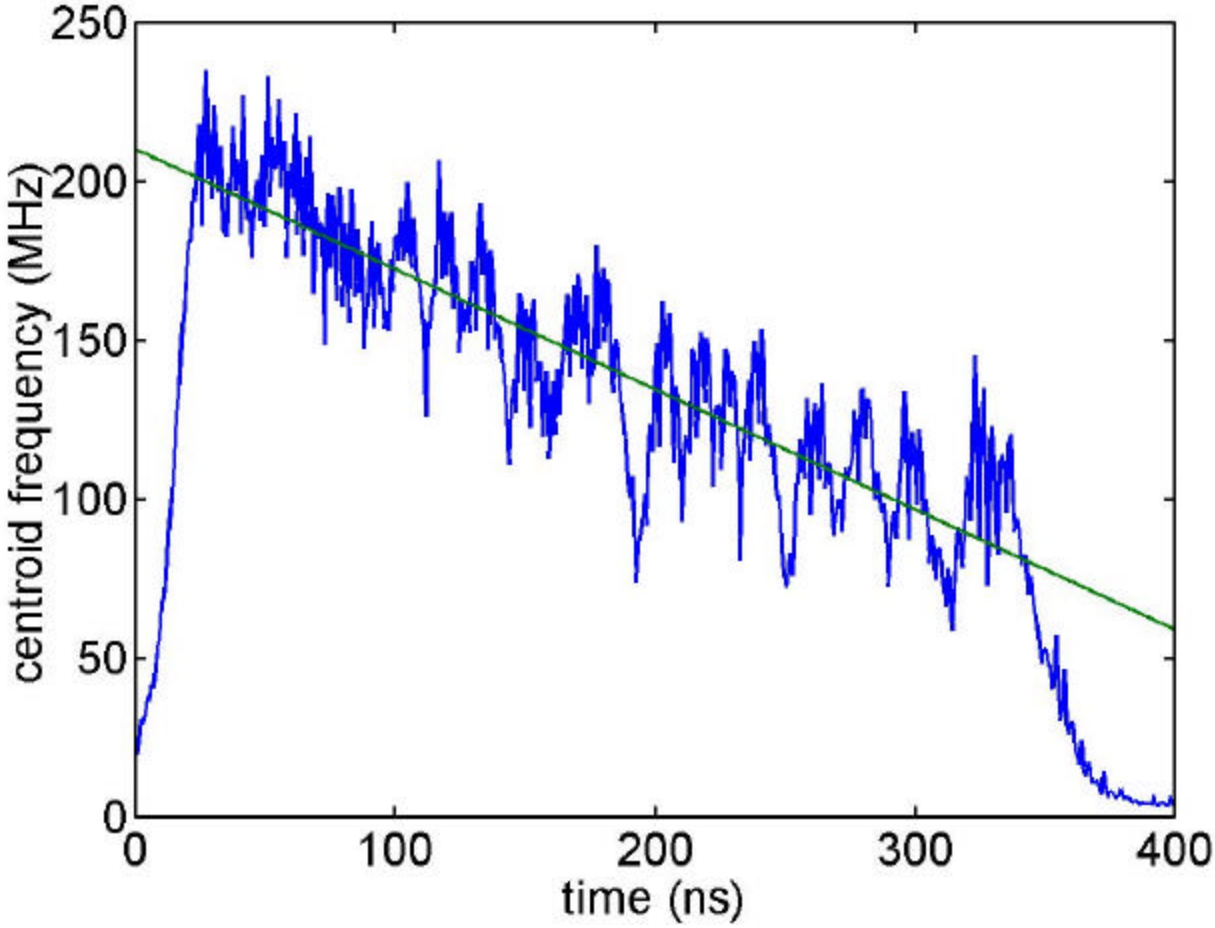


# Wavelet Transform Time-Frequency Representation of a Dispersive GPR Trace



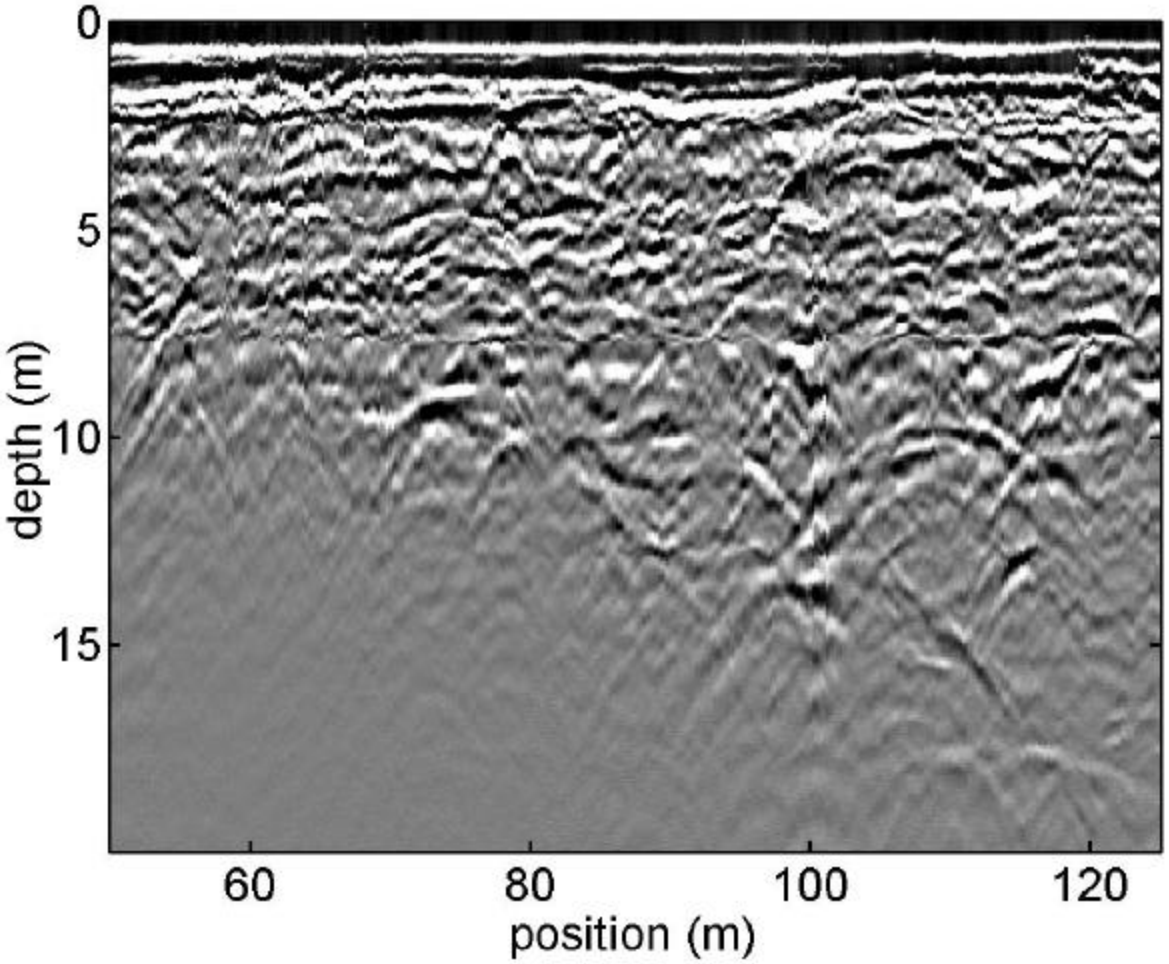

- note downshift in dominant frequency with time due to frequency-dependent attenuation

# Centroid Frequency vs. Time

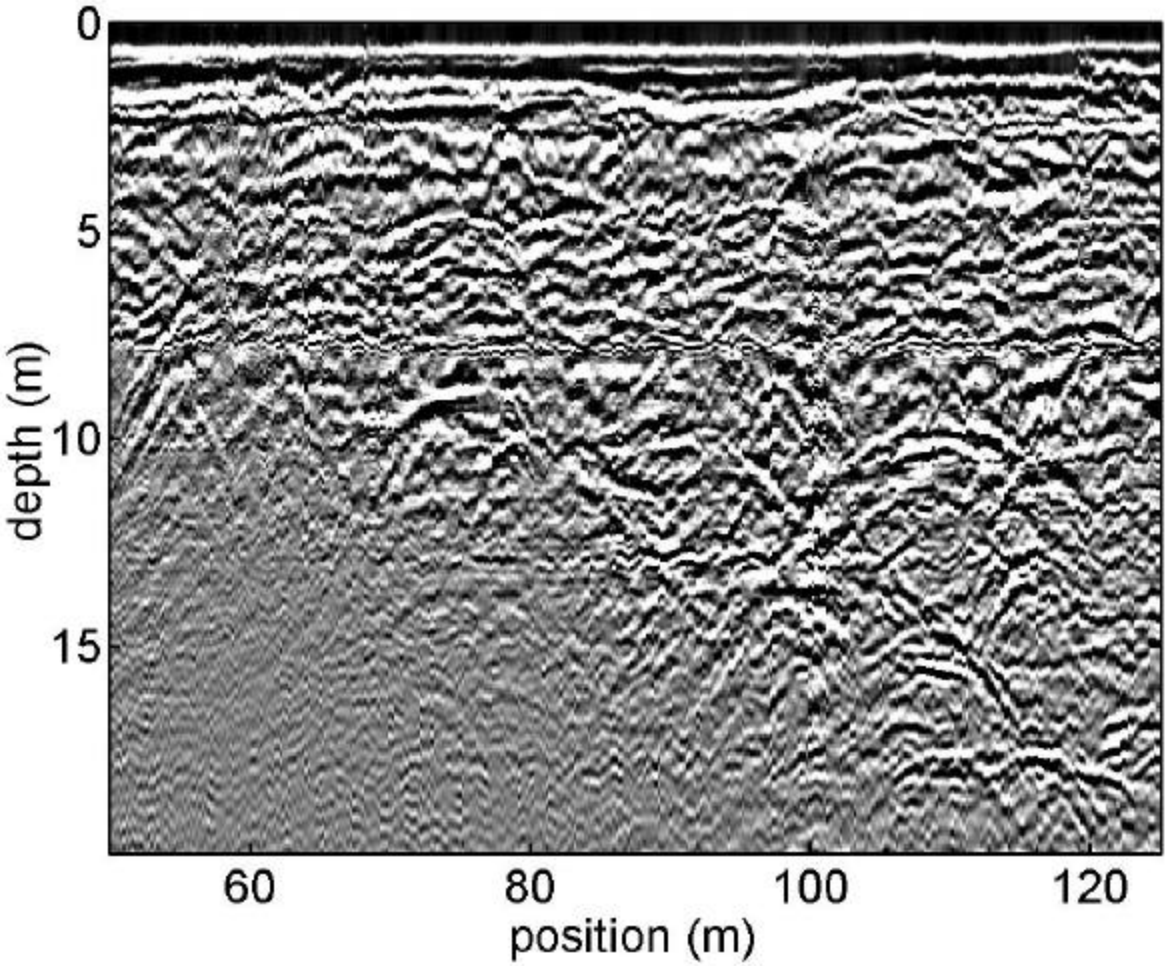



$$Q \alpha \left( \frac{\Delta f}{\Delta t} \right)^{-1}$$

# 100 MHz GPR Data from Langley, BC
# No Correction for Wavelet Dispersion



# Corrected for Wavelet Dispersion



to do : 1) use subsurface radar data to improve processing of surface radar data

- the use of borehole radar methods in combination with surface-based methods would permit much more accurate determination of Q (radar attenuation tomography)

- knowledge of Q in the subsurface could aid in quantitative interpretation e.g. to map changes in moisture content

note:
do we need boreholes?
“subsurface” = borehole OR
??cone-based measurements??

## Inversion of Surface Radar Data

Approach 1:
radar image →1→ "map" of $\kappa$ → 2→
map of $\Theta_W$

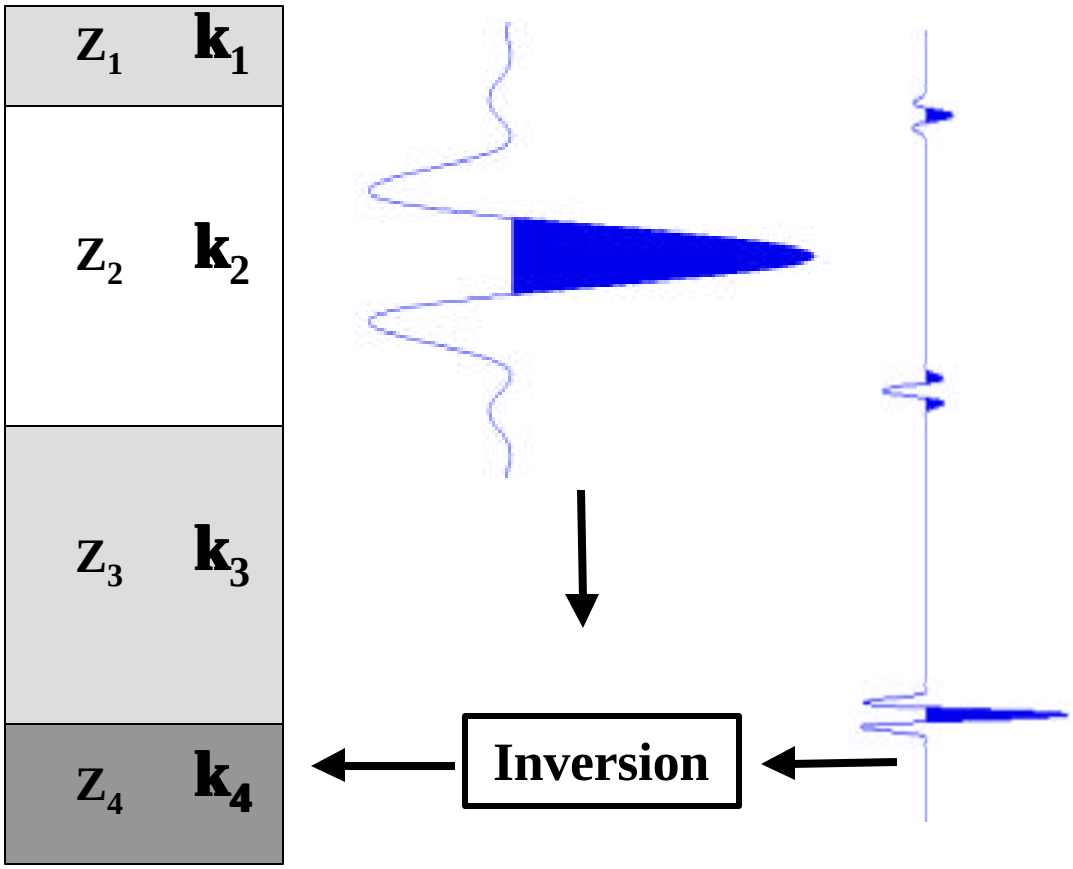
**→1→ = inversion step**

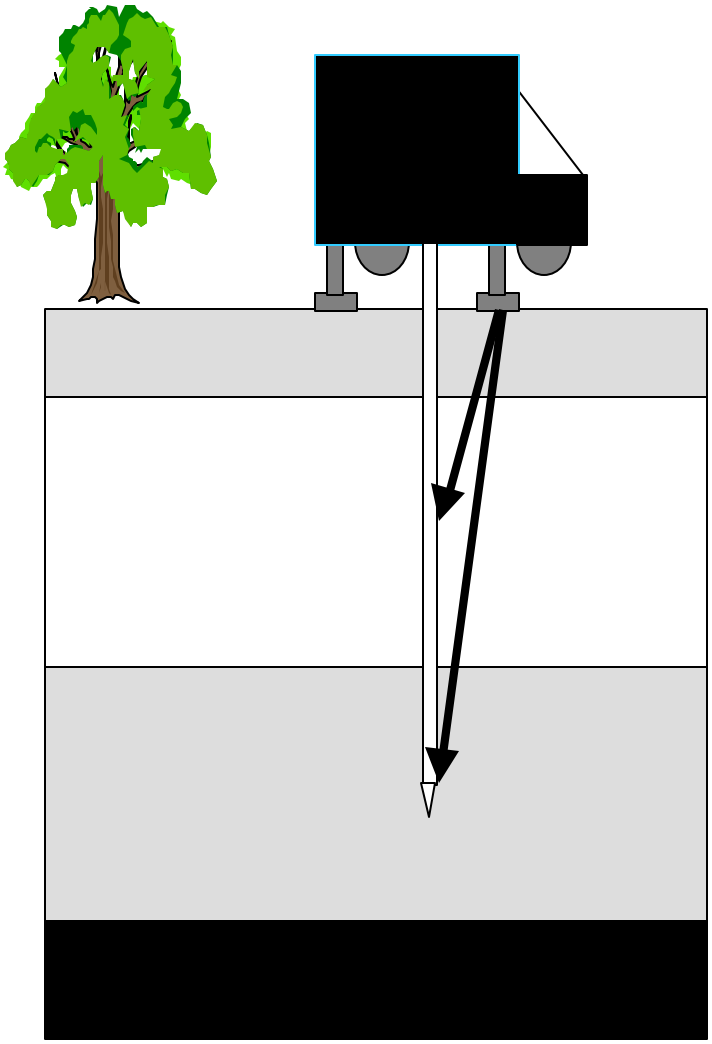
inversion: extracting a model of the subsurface from the measured geophysical data

current research:
have developed a Bayesian approach that incorporates seismic velocity data from cone penetrometer measurements to invert shallow seismic shear-wave data
(Jarvis and Knight, 1998)

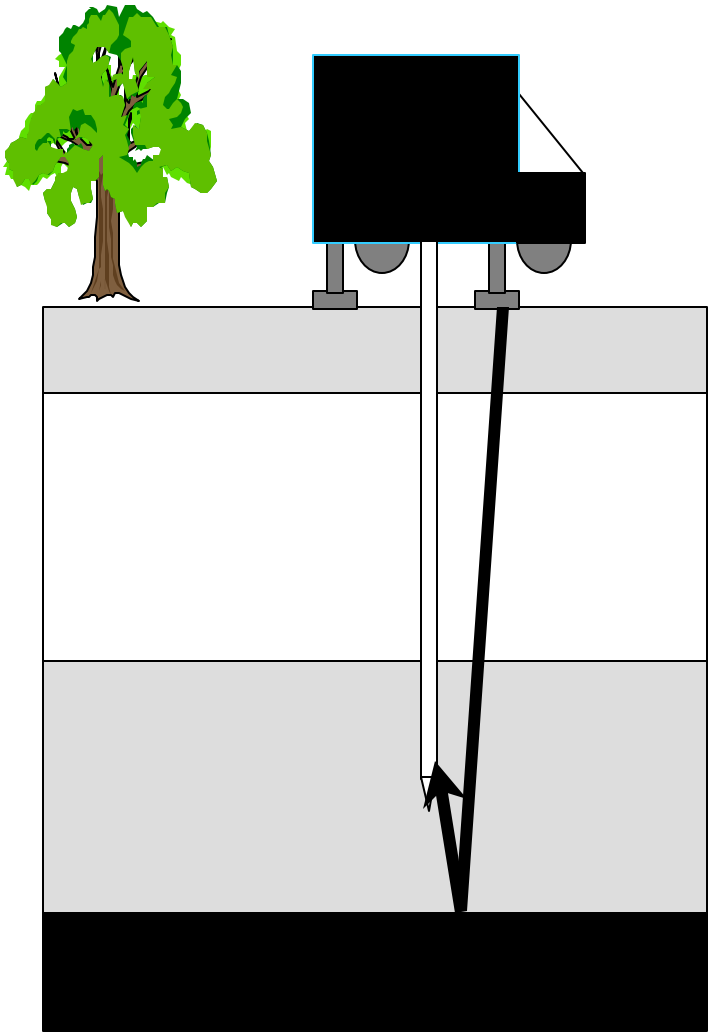
# Inversion

| | | | | |
|---|---|---|---|---|
| **Subsurface Property Variation** | **+** | **Wavelet** | **=** | **Recorded Trace** |





1) Determining velocity structure from first arrivals



1) Determining velocity structure from first arrivals
2) Imaging reflections deeper than the maximum cone depth

to do:

use a similar Bayesian approach, incorporating subsurface radar data, to invert surface radar data

## Rock Physics Step

"map" of $\kappa$ $\rightarrow 2 \rightarrow$ map of $\Theta_W$

commonly assumed:
sampled region of the subsurface is homogeneous

IFF homogeneous – can use simple models

BUT heterogeneity can result in large errors if these models used
(Chan and Knight, WRR, 1999)

to do : develop inversion method to accommodate uncertainty in structure and predict uncertainty in $\Theta_W$

*in summary* -
Approach 1:

radar image →1→ "map" of $\kappa$ →2→ map of $\Theta_W$

challenges:

need improved radar image

1→ = inversion step

2→ = rock physics step

To best address all three challenges – need subsurface sampling using borehole or perhaps cone measurements.

<u>Approach 2</u>

spatial variability in radar image

= spatial variability in $\Theta_w$

challenges:

need improved radar image

quantifying spatial variability

how best to use the information

quantifying spatial variability:

have developed/used geostatistical framework

(Rea and Knight, WRR, 1998)

BUT – results clearly show scale-dependence tied to resolution of radar image

This affects Approach 1 and 2 – focus of new research.