SUSTech Southern University of Science and Technology

南方科技大学 SOUTHERN UNIVERSITY OF SCIENCE AND TECHNOLOGY

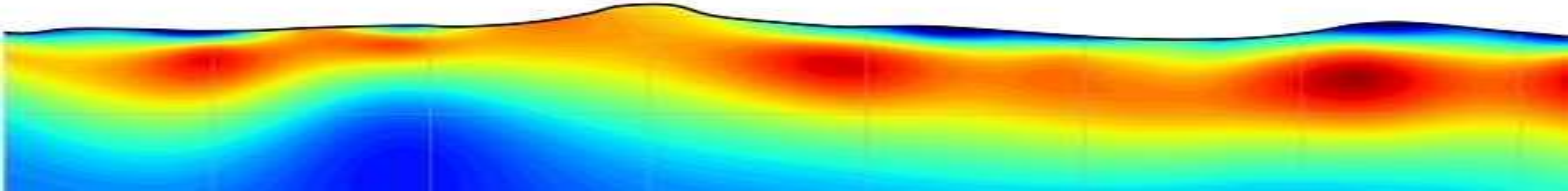
地球与空间科学系 DEPARTMENT OF EARTH AND SPACE SCIENCES

ESS302 Applied Geophysics II

Gravity, Magnetic, Electrical, Electromagnetic and Well Logging

Electromagnetic 2: GPR Applications

Instructor: Dikun Yang   Feb – May, 2019



Quiz

- True or false and why: While dc resistivity is only sensitive to the electrical resistivity, GPR data only response to the variation of electrical permittivity.

- Both dc resistivity and GPR can use electrical dipole sources. In a dc survey the dipole electrodes need to be in contact with the earth, but the GPR dipole source can be suspended in the air. Why?

- Which survey parameters determine the depth of investigation (DOI) in dc resistivity and GPR?

jupyter GPR_TBL4_DOI_Resolution (autosaved)

Logout

File Edit View Insert Cell Kernel Widgets Help Trusted Python 3

Run Code

- **Propagation Velocity:** $v = \sqrt{\dfrac{2}{\mu\varepsilon}} \left[\left(1 + \left(\dfrac{\sigma}{\omega\varepsilon} \right)^2 \right)^{1/2} + 1 \right]^{-1/2}$
- **Skin Depth:** $\delta = \sqrt{\dfrac{2}{\omega^2\mu\varepsilon}} \left[\left(1 + \left(\dfrac{\sigma}{\omega\varepsilon} \right)^2 \right)^{1/2} - 1 \right]^{-1/2}$

where $\omega = 2\pi f_c$ and f_c is the operating frequency. Here, we assume that the Earth is non-magnetic (e.g. $\mu = \mu_0$). The app
propagation velocity and skin depth at frequencies f_c = 25,100 and 1000 MHz.

Wave regime:

- **Propagation Velocity:** $v = \dfrac{c}{\sqrt{\varepsilon_r}}$
- **Skin Depth:** $\delta = 0.0053 \, \dfrac{\sqrt{\varepsilon_r}}{\sigma}$

Parameters for the App:

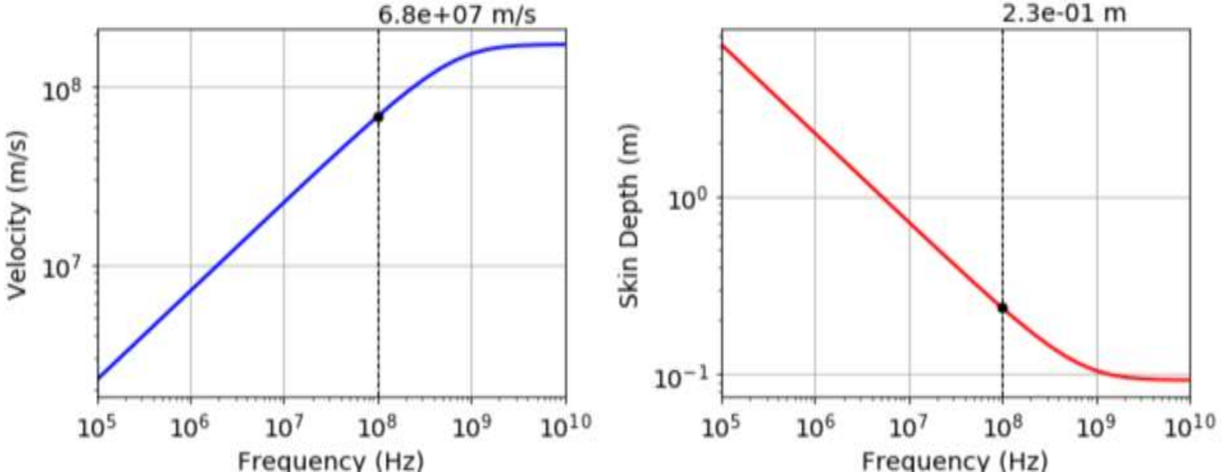
- *epsr*: Relative permittivity of the medium (unitless)
- *sigma*: Log (base 10) conductivity of the medium. *Note that sigma = -1.5 corresponds to a true conductivity of σ = 0.0316 S/m.*

In [4]:
```
AttenuationWidgetTBL()
```

ϵ_r 3

log(σ) -1.00

log(f) 8.00

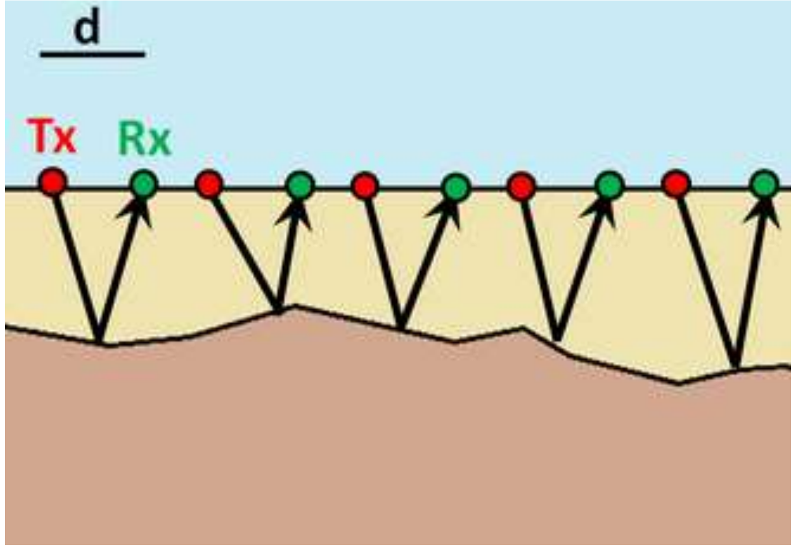


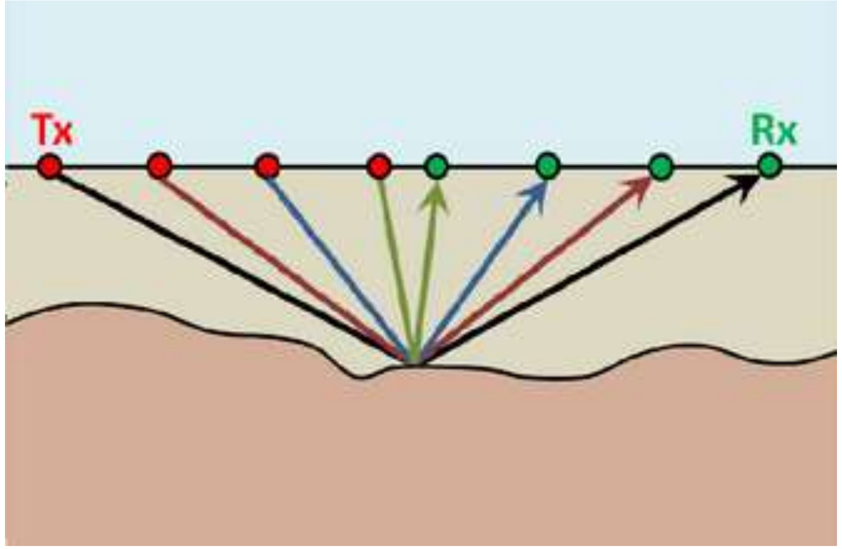
When velocity and skin depth change with frequency?

$$\delta \approx \begin{cases} 503\sqrt{\dfrac{1}{\sigma f}} & \text{for } \omega\varepsilon \ll \sigma \\ 0.0053\,\dfrac{\sqrt{\varepsilon_r}}{\sigma} & \text{for } \sigma \ll \omega\varepsilon \end{cases}$$

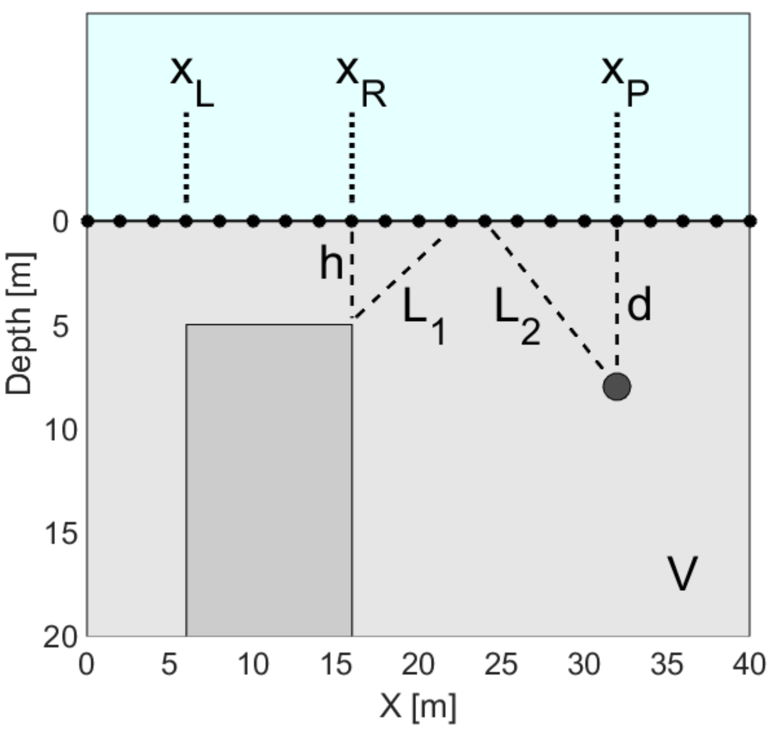
Common Offset

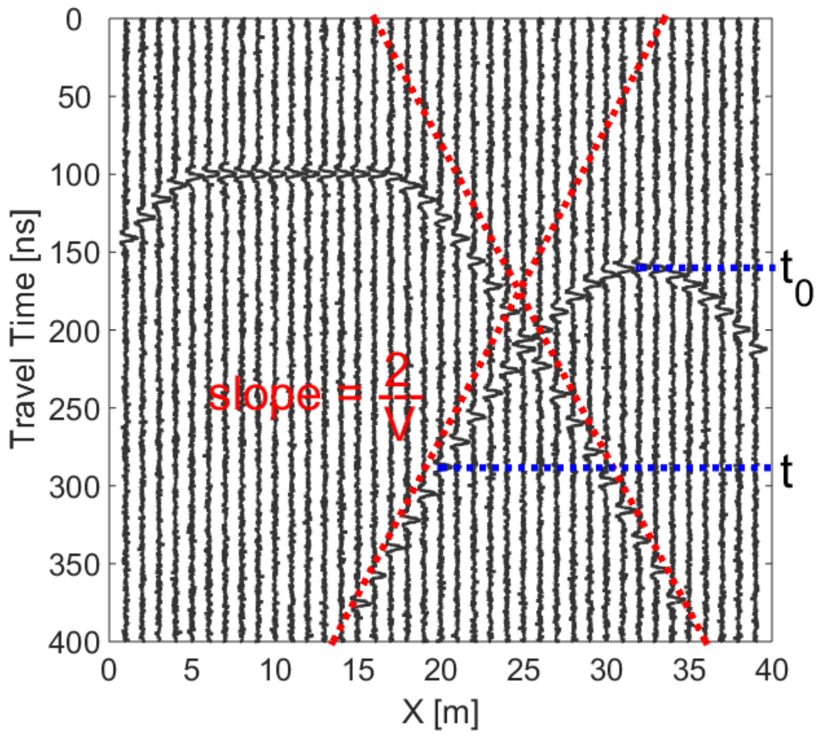
Common Midpoint





Zero Offset: Finding Buried Objects





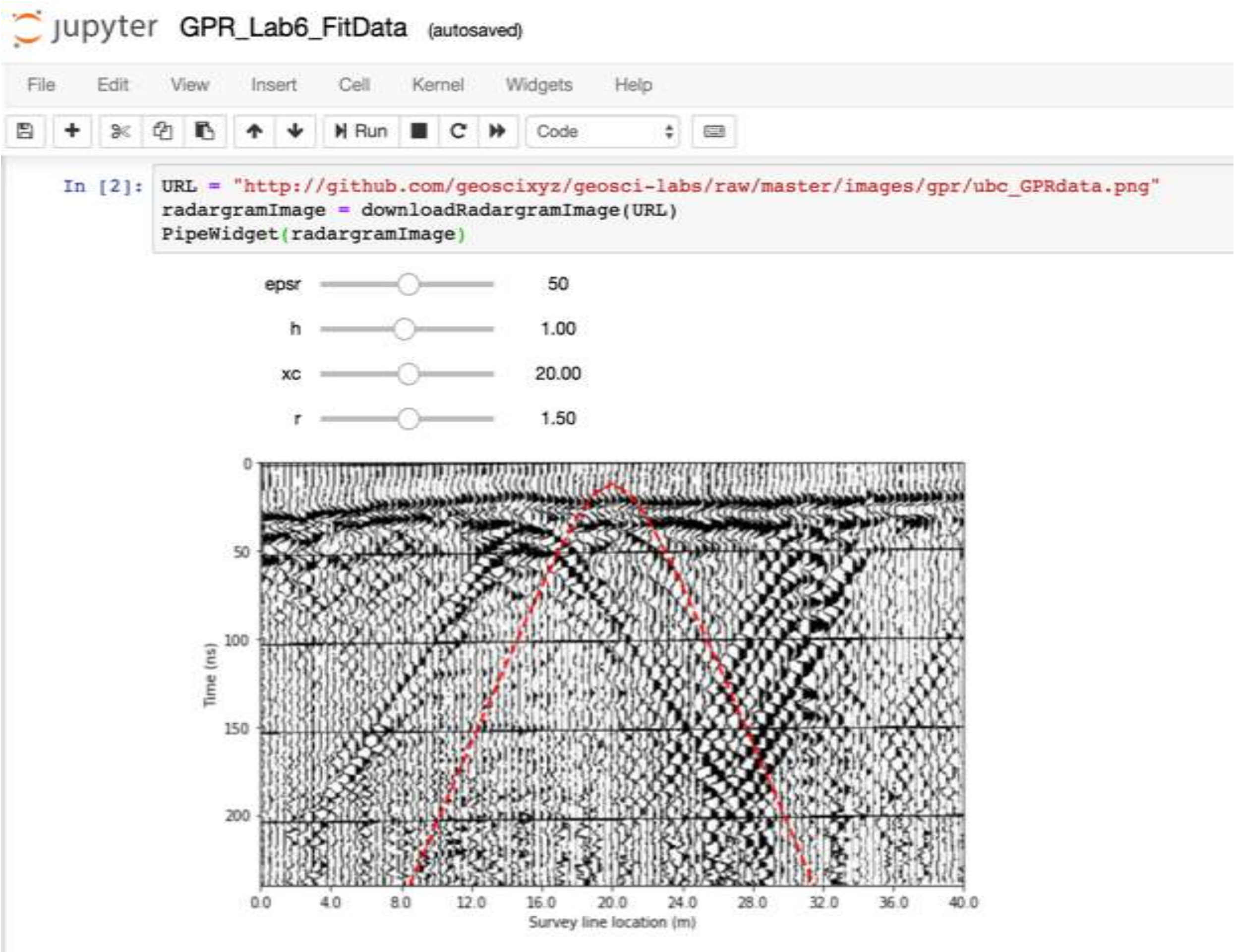
Two-way travel time for a point scatter

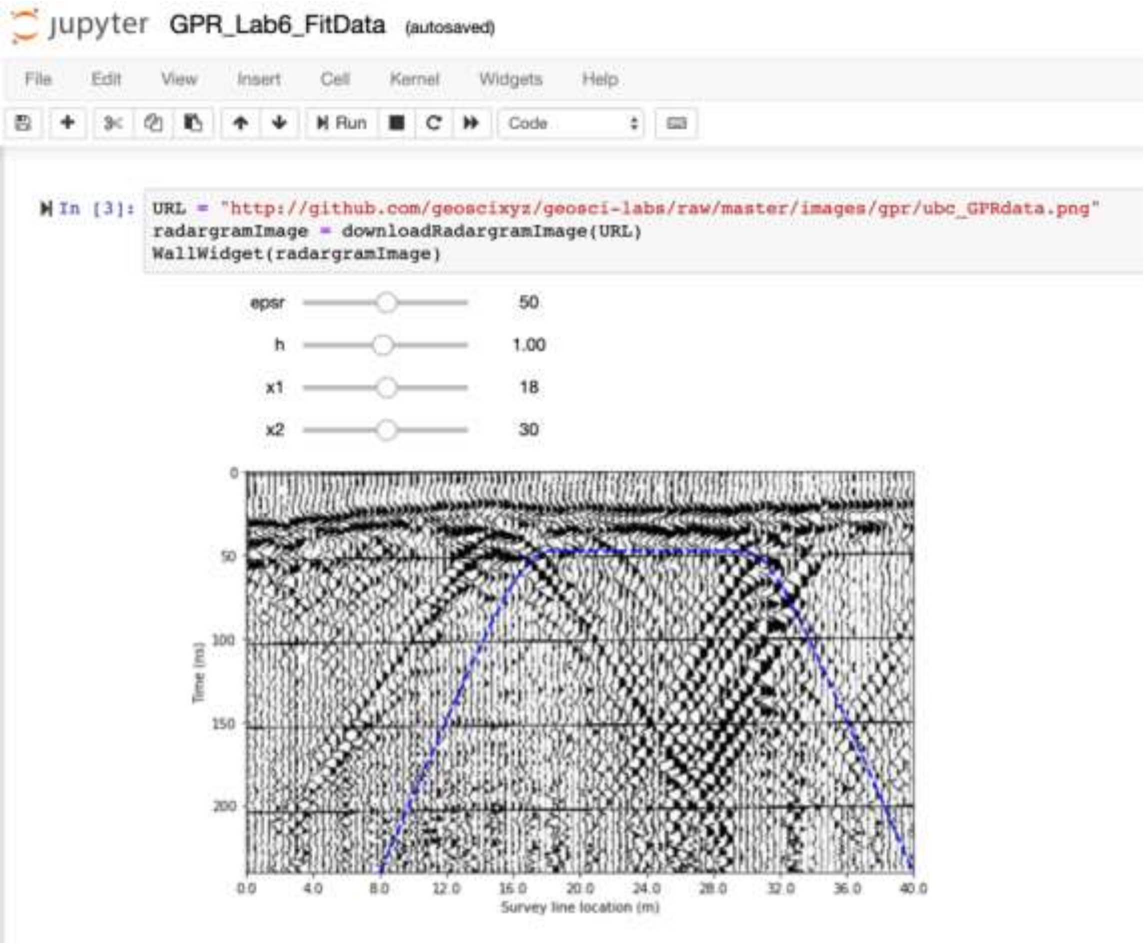
$$t_p = \frac{2L_2}{V} = \frac{2\sqrt{(x - x_p)^2 + d^2}}{V}$$

(1) Estimate the velocity *V*. Can you think of two methods?

(2) Calculate the depth of burial *d* or *h*

Exercise: “Curve-fitting” Inversion

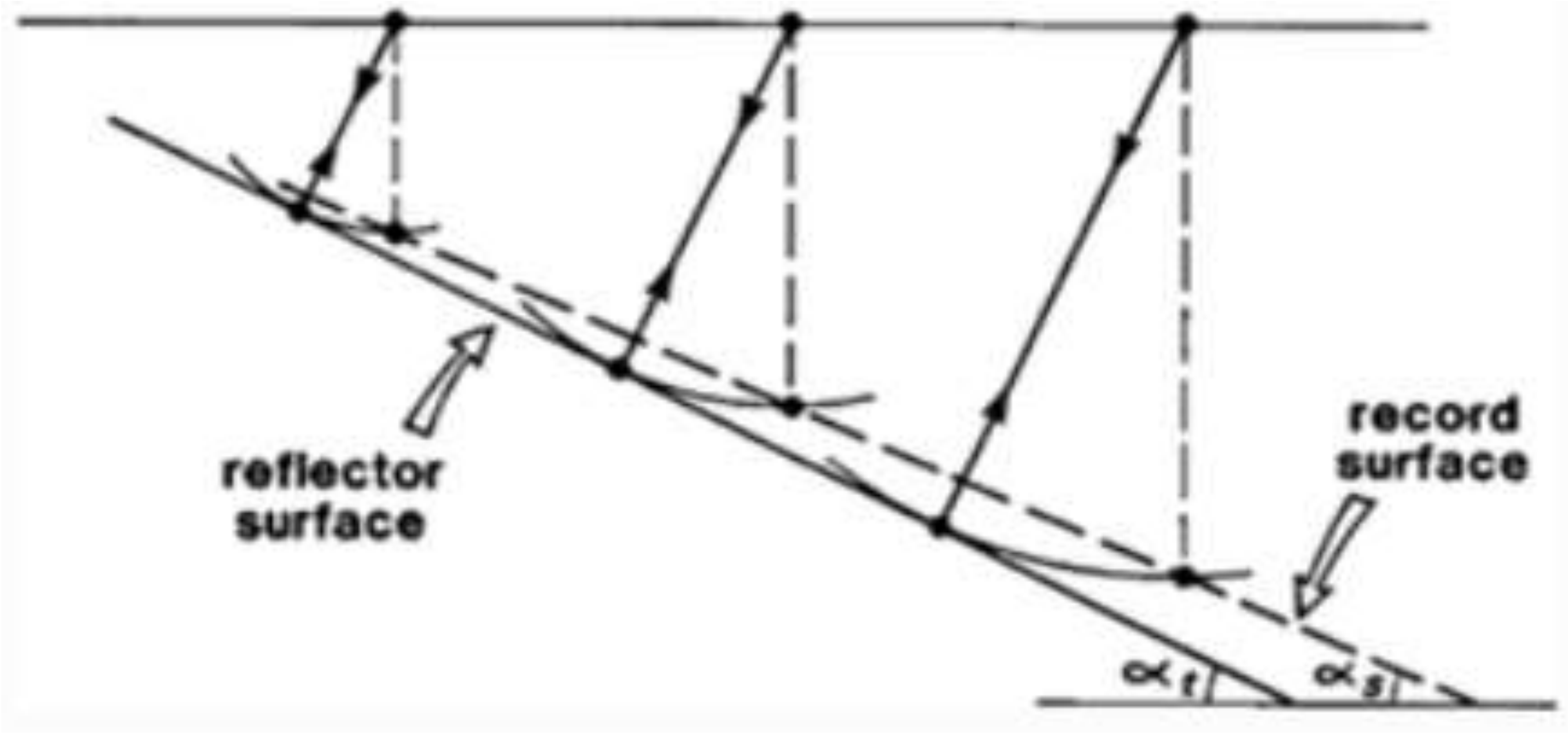




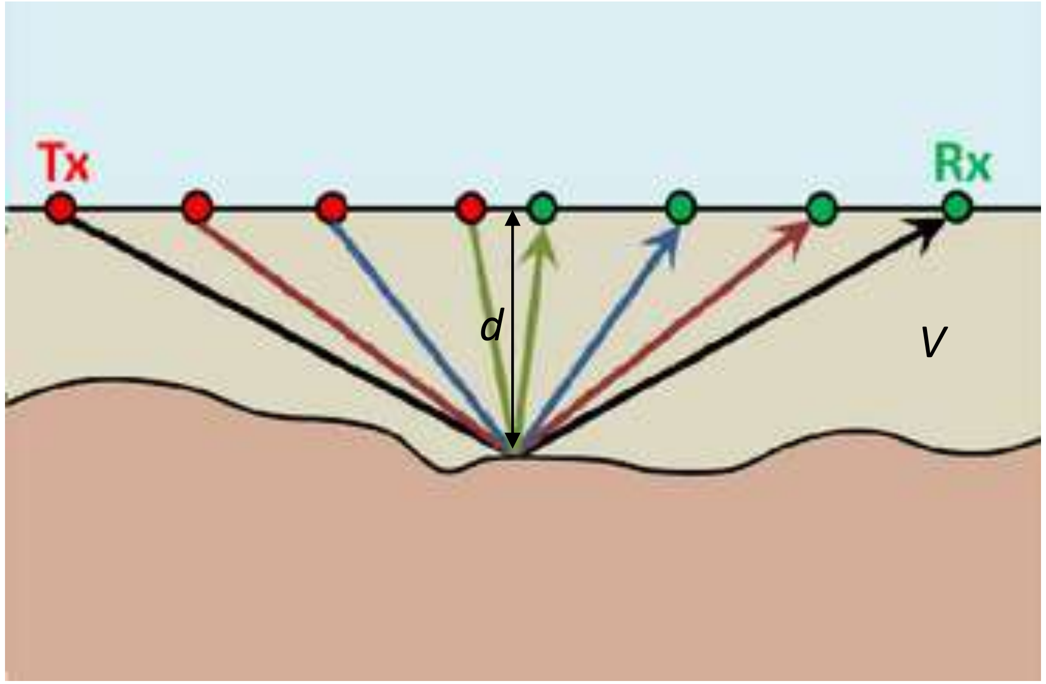
Jupyter Notebook at geosci-labs/notebooks/gpr/GPR_Lab6_FitData.ipynb

Migration

Zero offset survey along lines

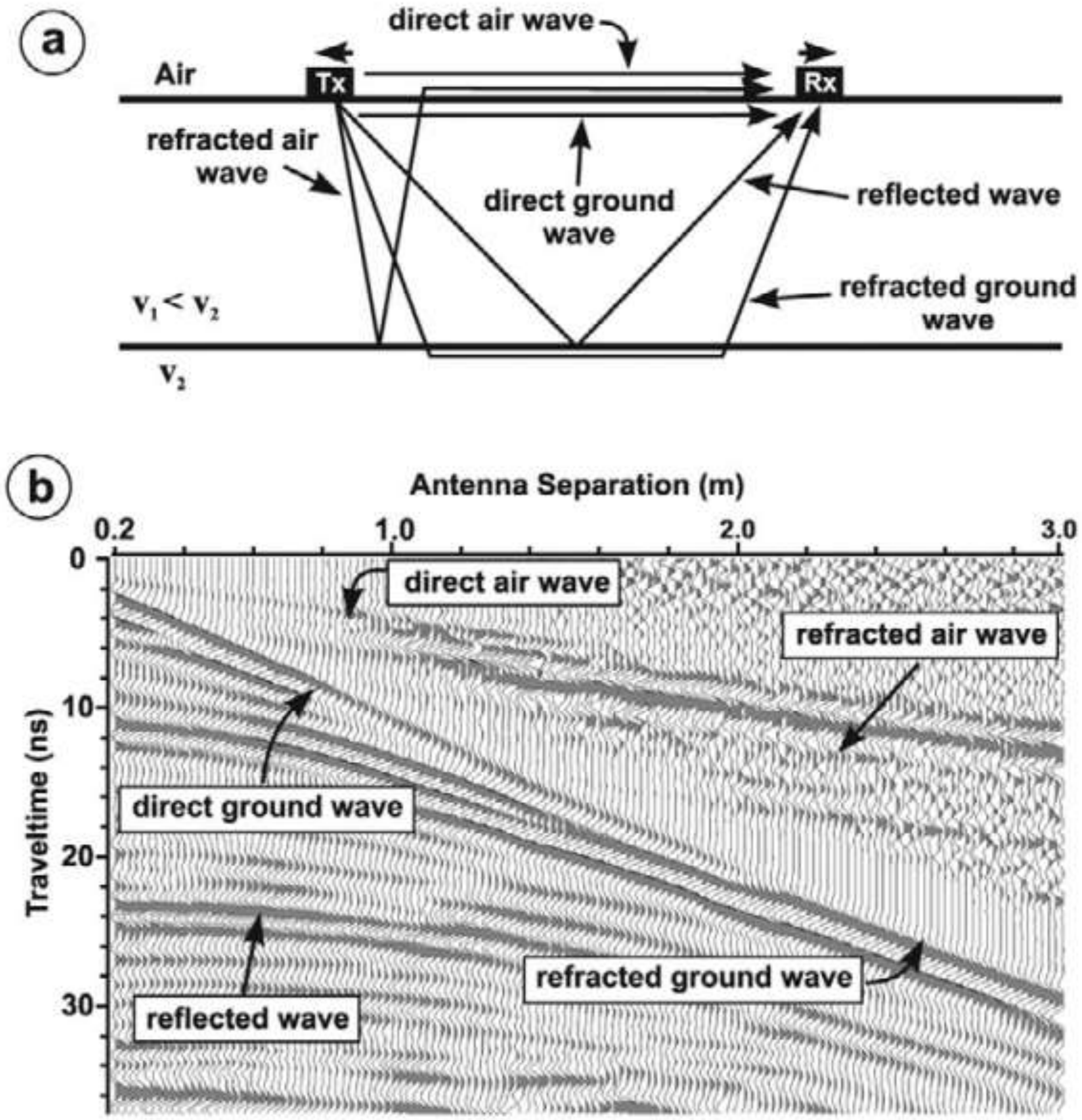


Common Midpoint



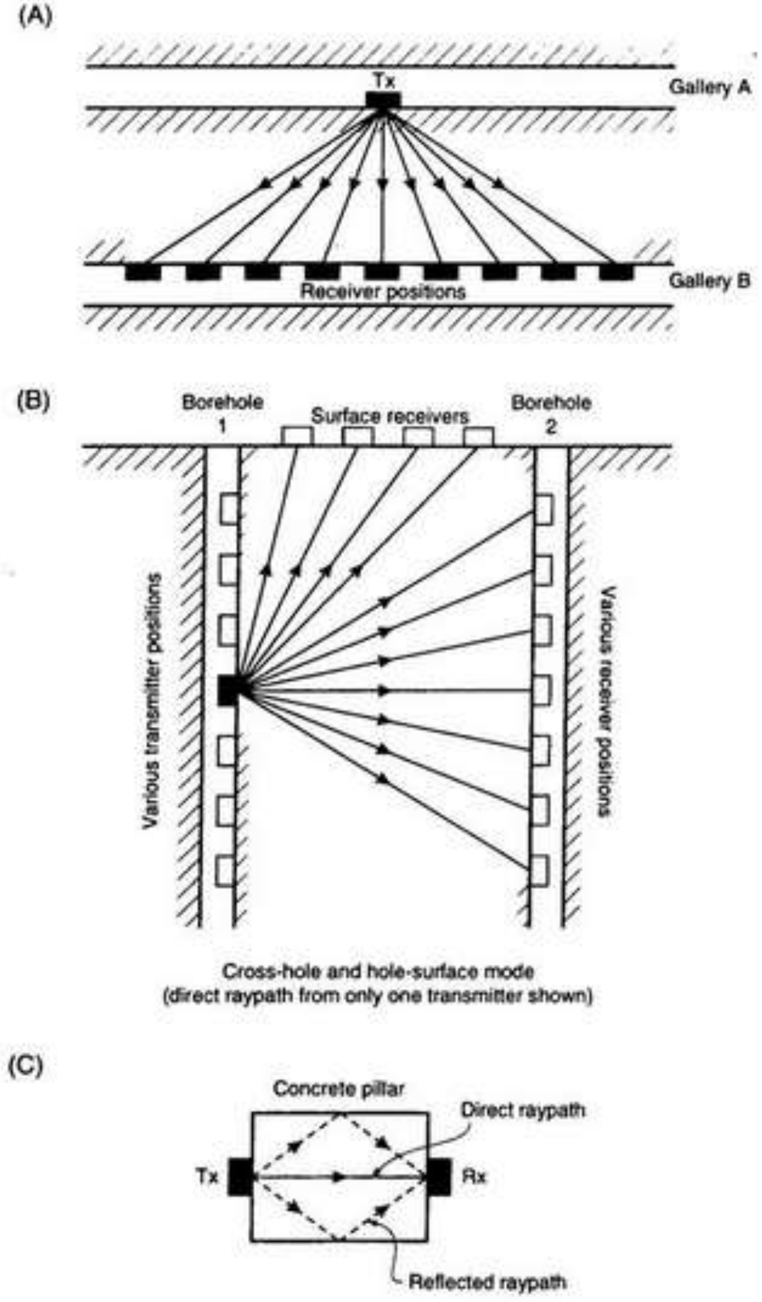
$$t = \frac{2\sqrt{x^2 + d^2}}{V}$$

Solve for *V* and *d*



Transillumination Surveys

- Tx and Rx are placed on opposing sides of a target.
- Sometimes many Tx and Rx
- Used for:
  - Structural integrity of mine shafts
  - Borehole surveys
  - Finding internal structures within objects

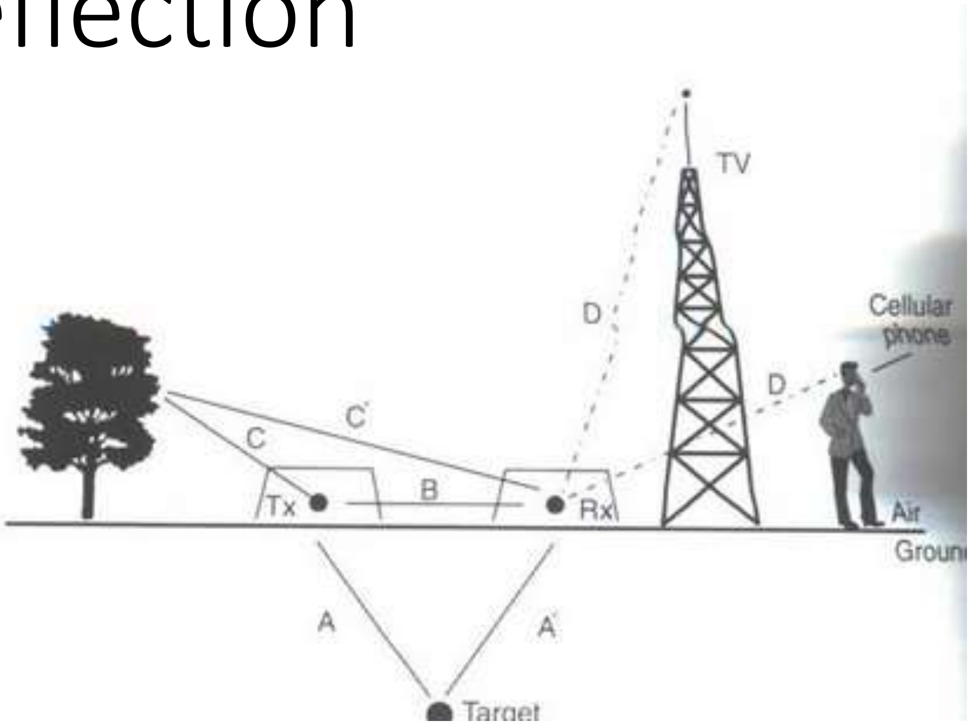


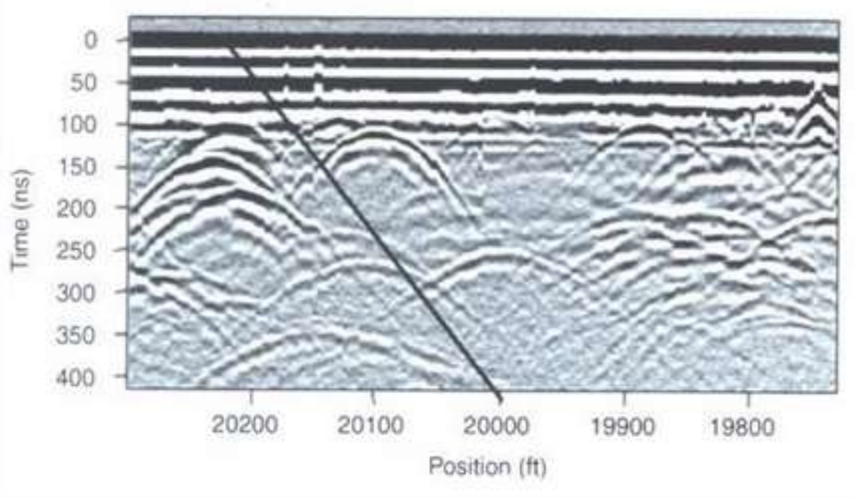
Q: If higher frequencies give better resolution, what does that say about pulse width?

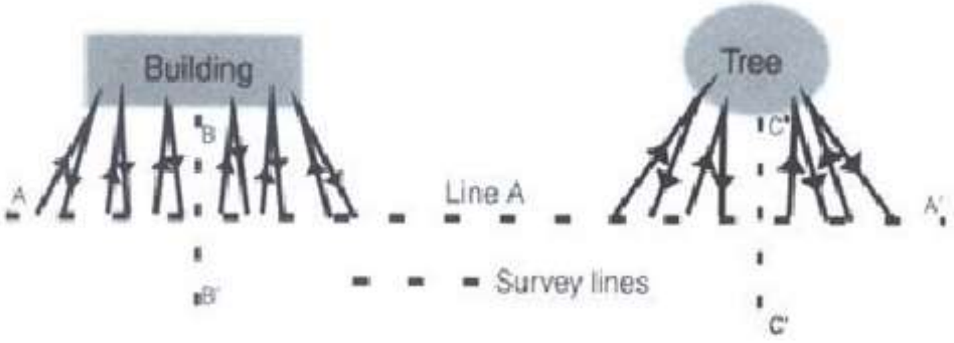
$$f_c = \frac{1}{\Delta t}$$

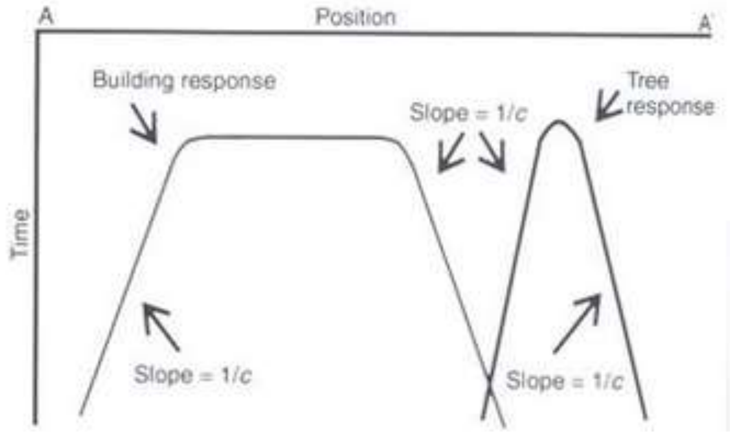
Q: What are some things you want to know before choosing an operating frequency?

Noise – External Radiowave or Above Ground Reflection

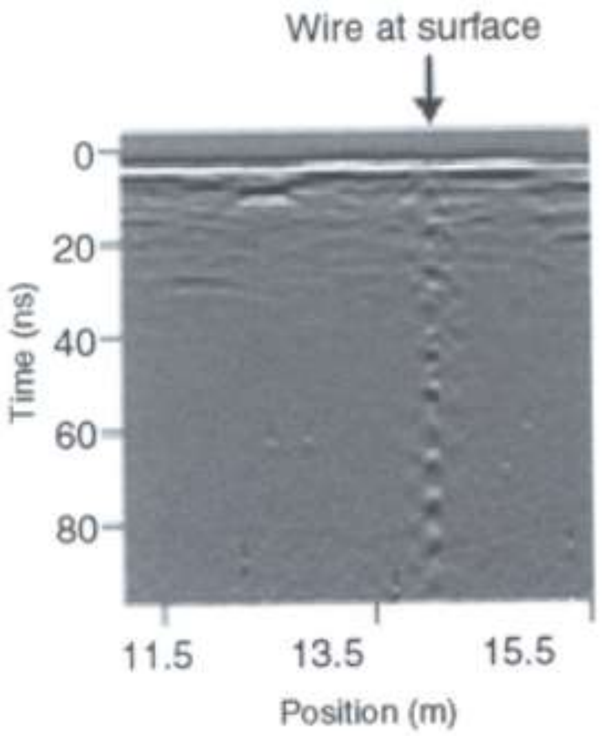








Noise - “Ringing”



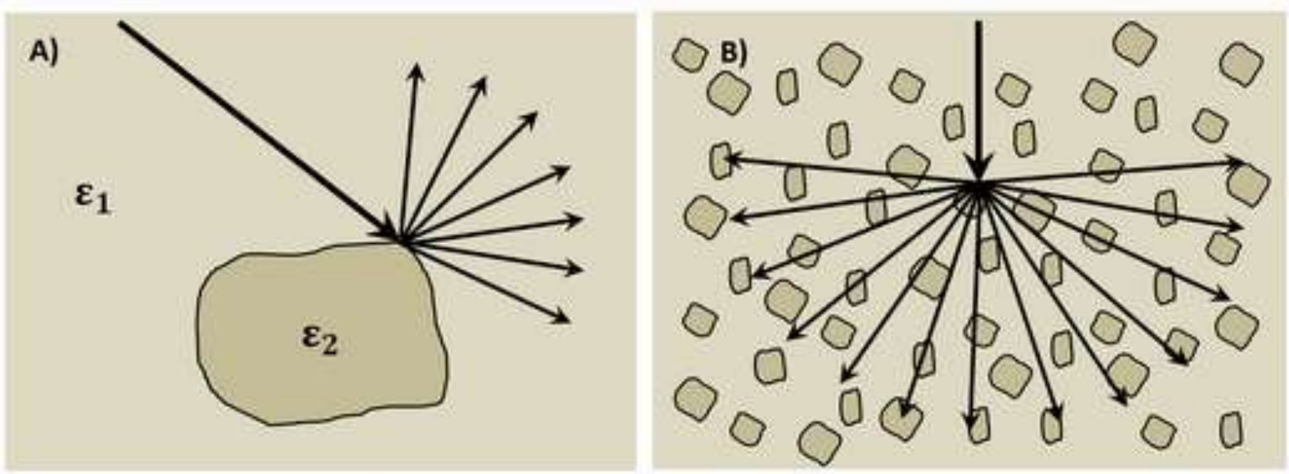
Wire below surface

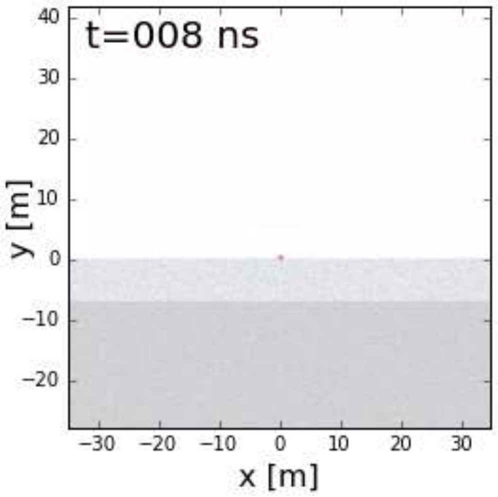
2 nearby objects

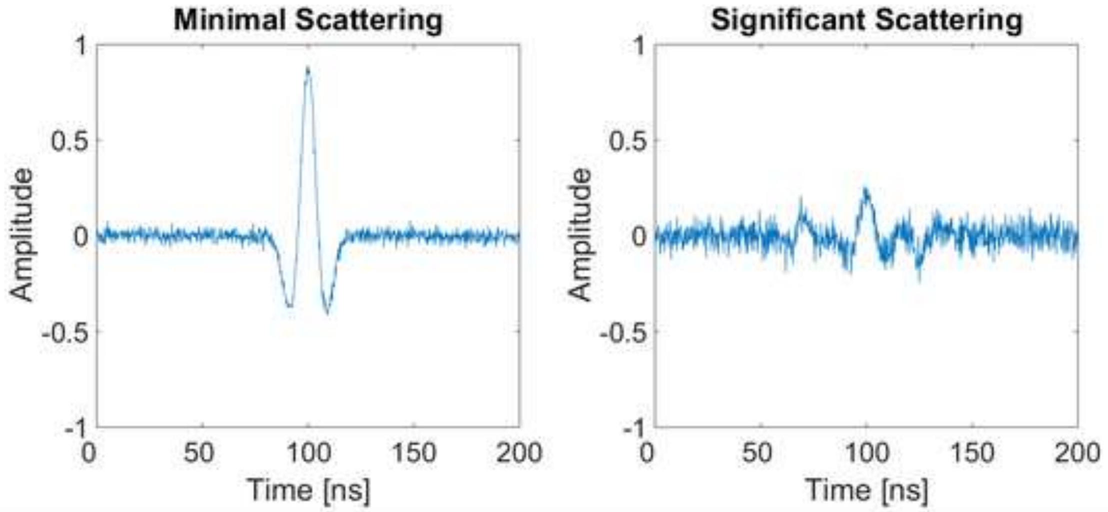
- Caused when signals reverberate in regular fashion

- Signal repeatedly bounces within a layer or between objects.

Noise – Scattering

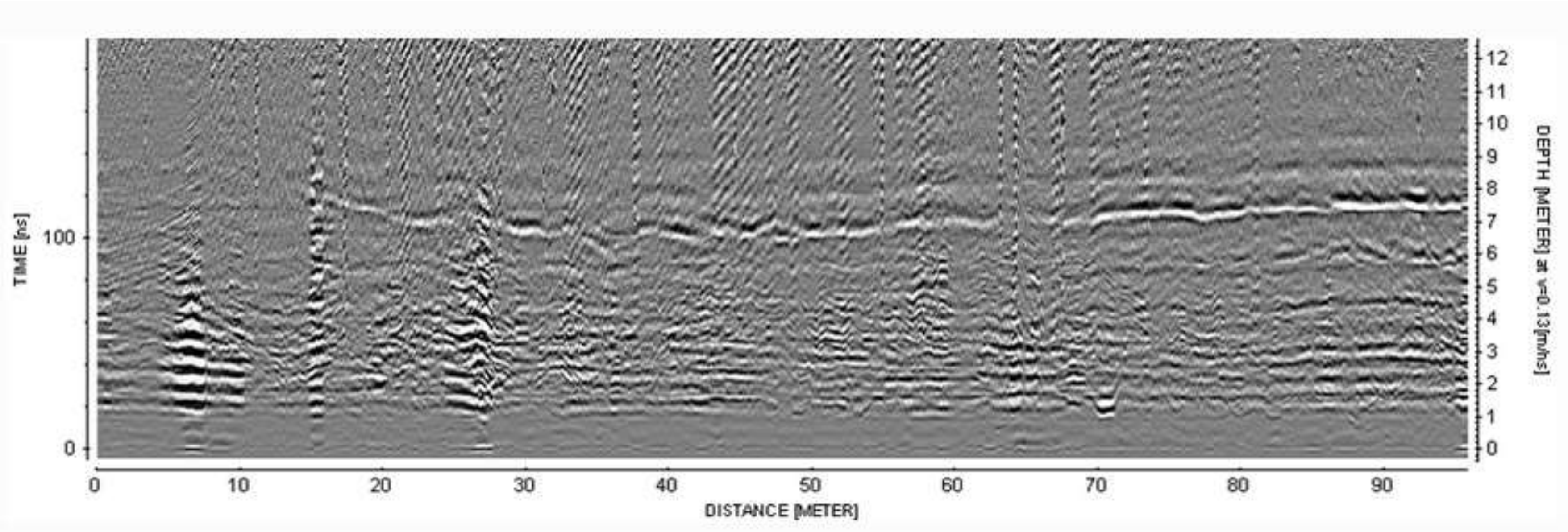






- Deviations in signal path due to localized non-uniformities.
- Reduces amplitude of usable signal and increases noise.

Processing – Time-depth Conversion

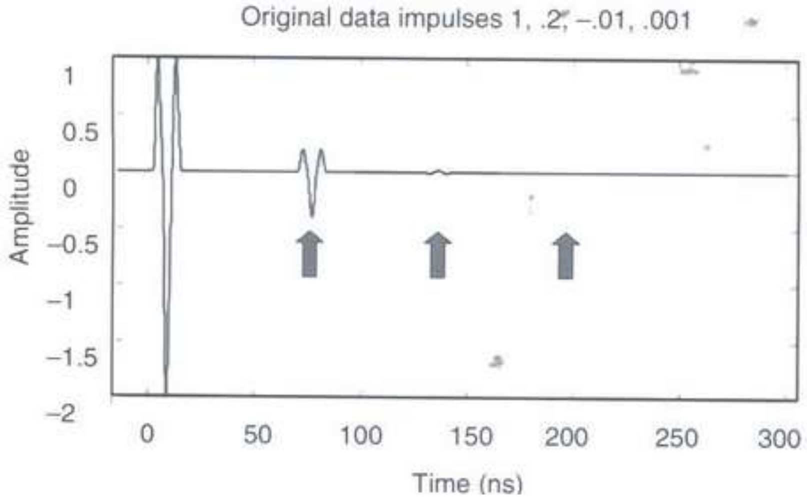


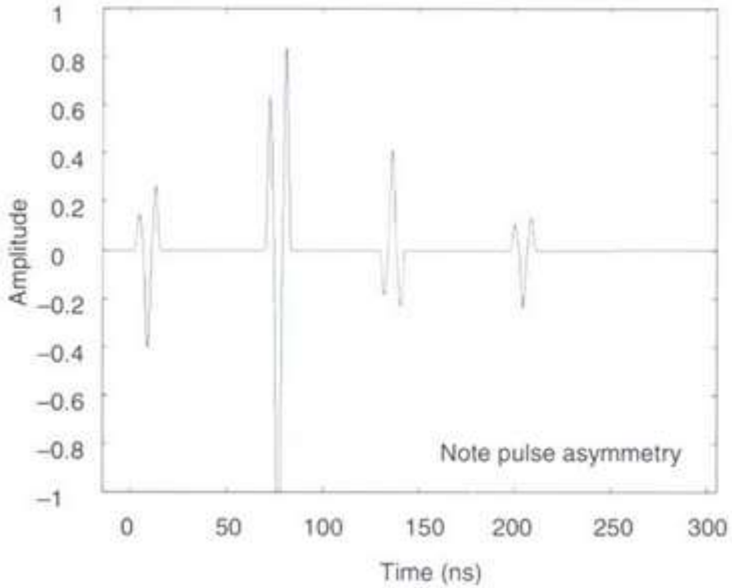
Apparent depth:

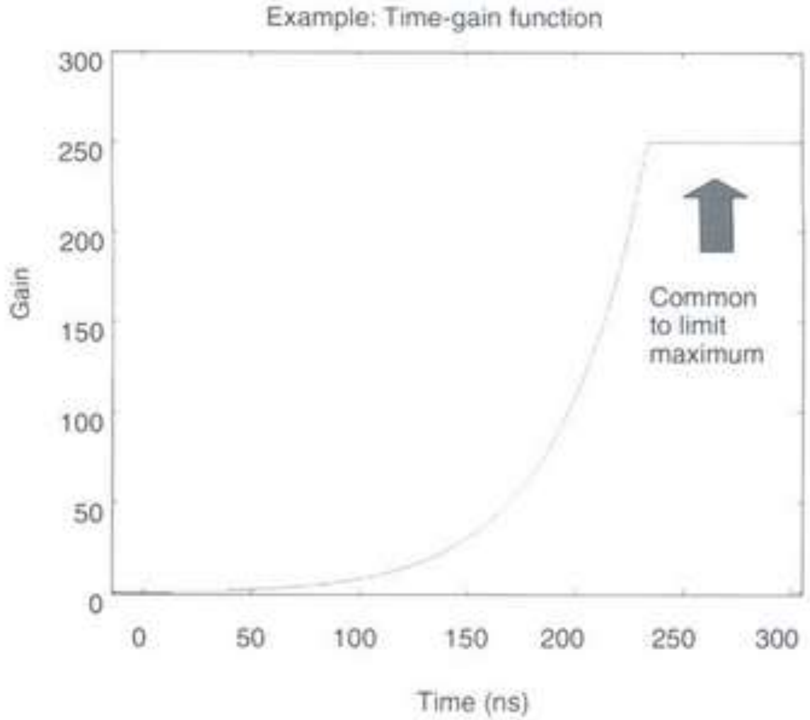
$$d_a = \frac{Vt}{2}$$

- Vertical axis usually 2-way travel time [ns]
- Get velocity first, then get an apparent depth

Processing – Gain Correction

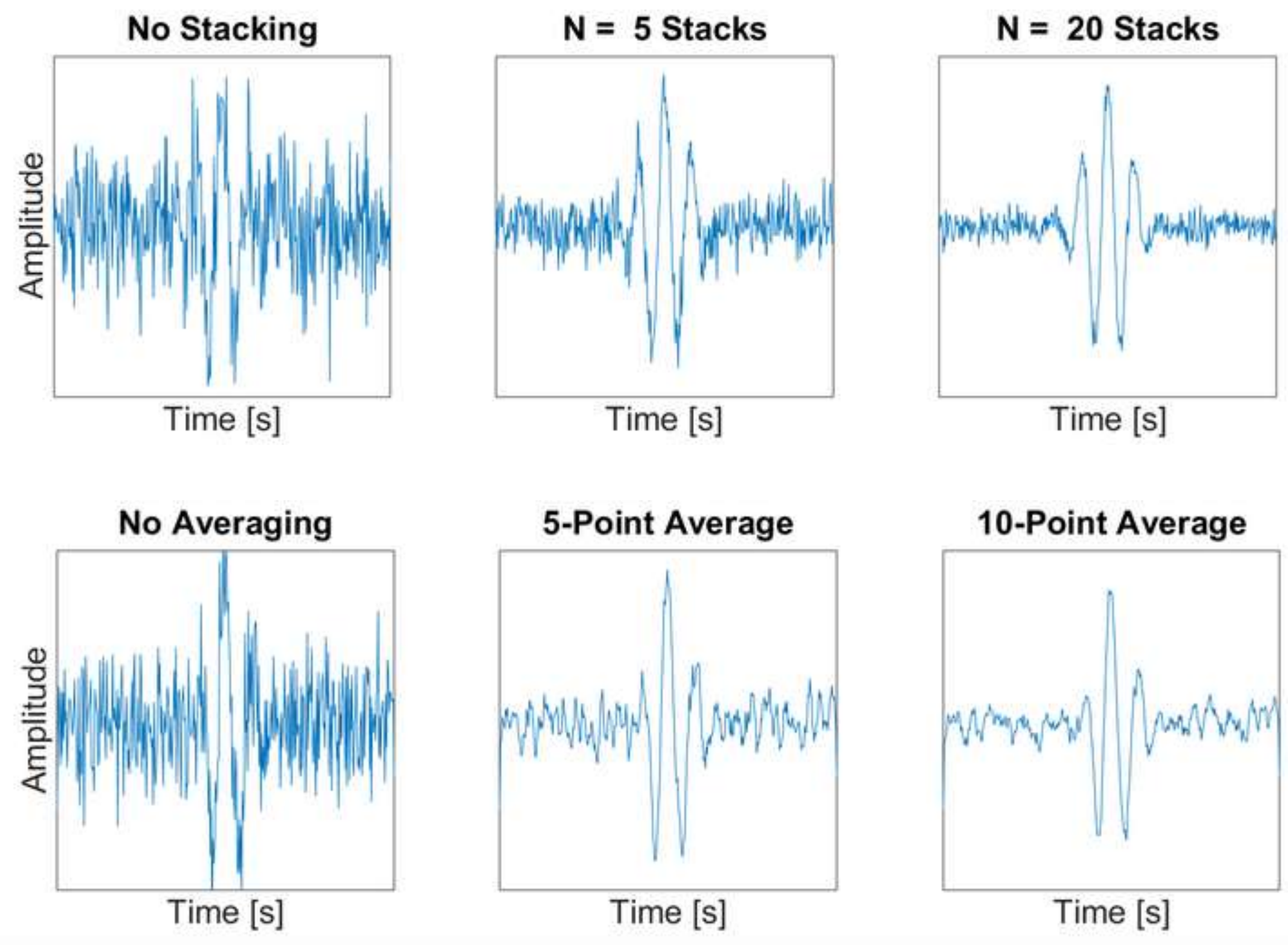






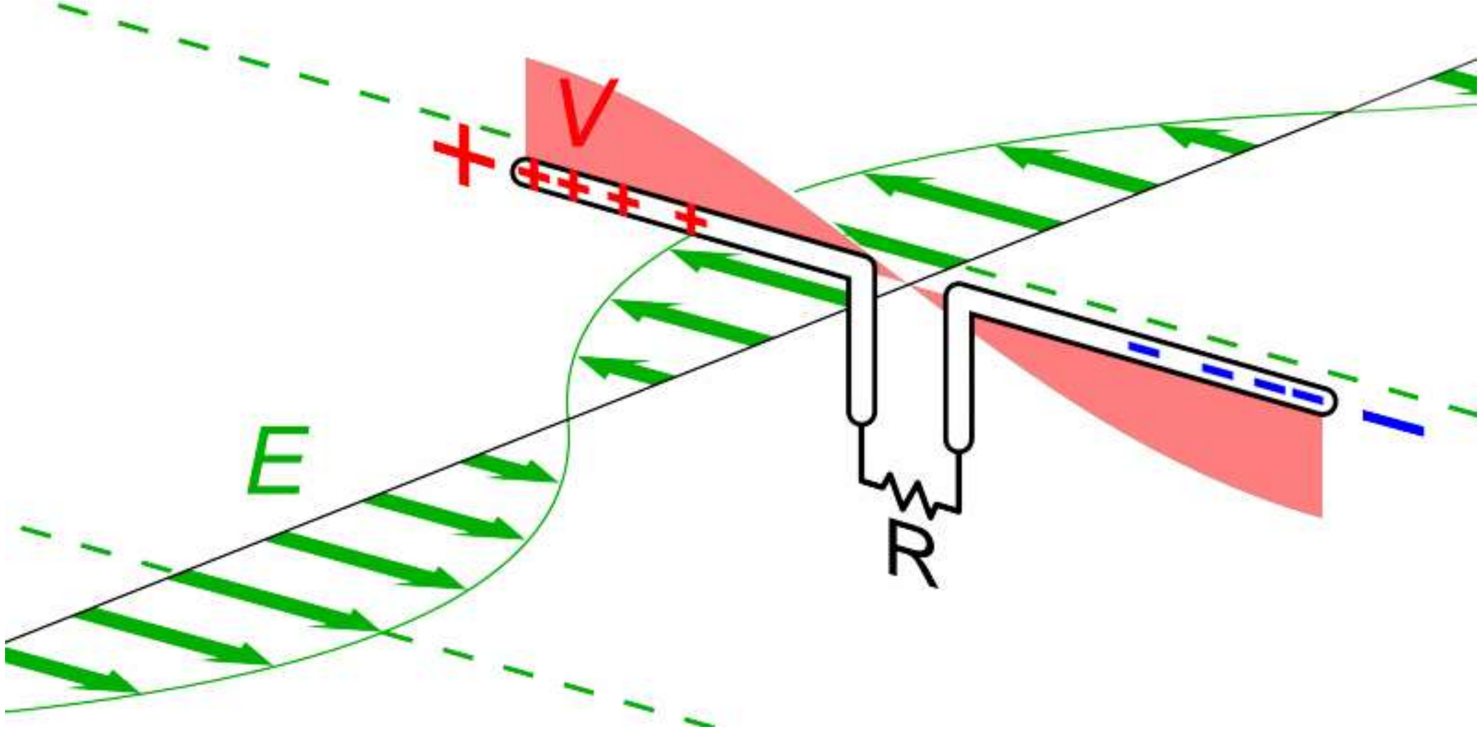
- Multiply raw data by a gain factor so that late signals can be recognized.
- Gain factor generally counteracts exponential decay in amplitude

Processing – Stacking and Averaging



- Data from repeated shots are averaged (stacked)
- Stacking reduces the amplitude of incoherent noise
- Wavelet signal is smooth whereas incoherent noise is random
- Smoothing decreases amplitude of random noise relative to returning signals.

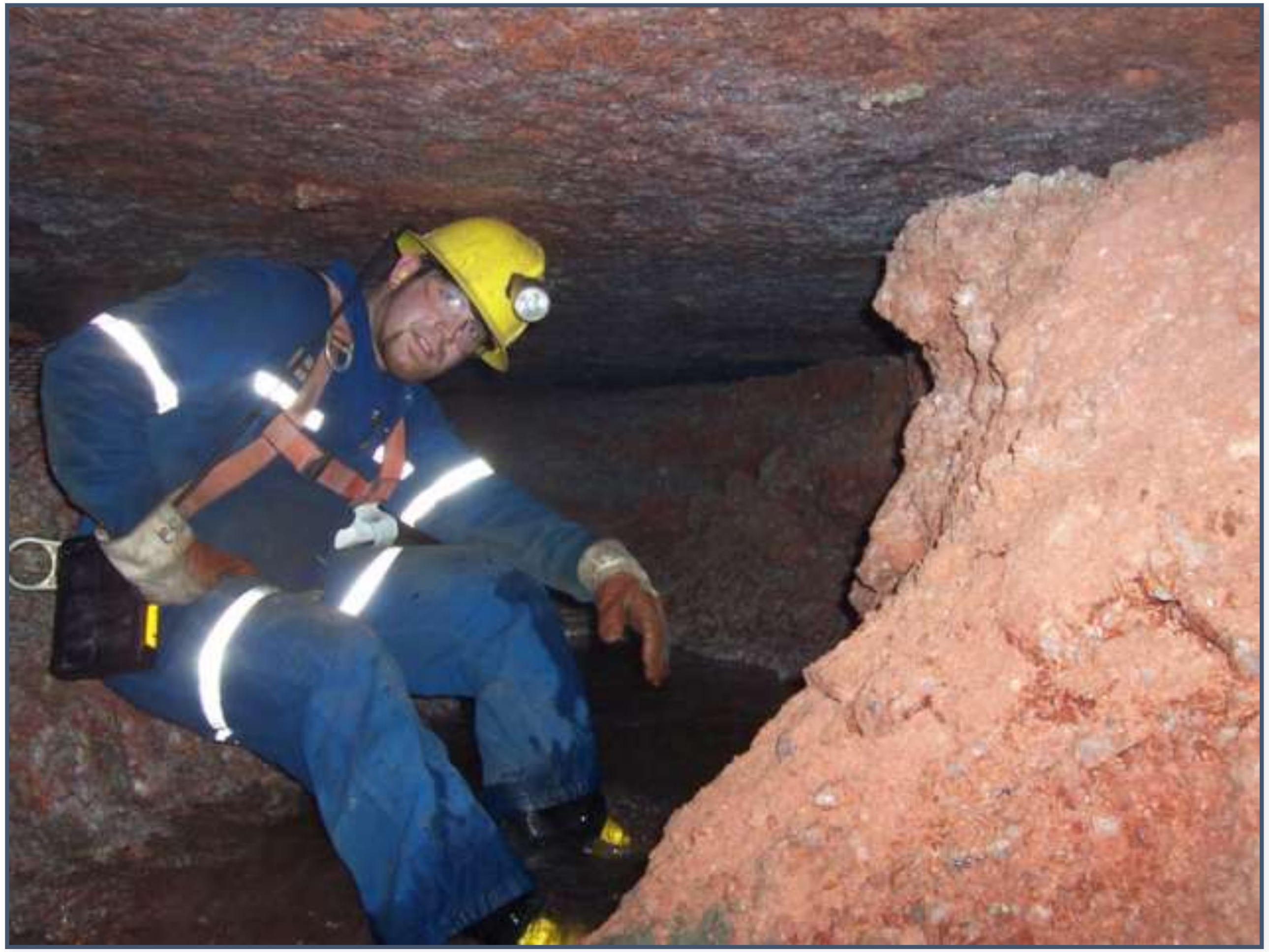
GPR Antenna



Half-wave dipole antenna: Length is determined by the intended wavelength (or frequency) of operation

GPR Antenna

Water Hazard in Potash Mine

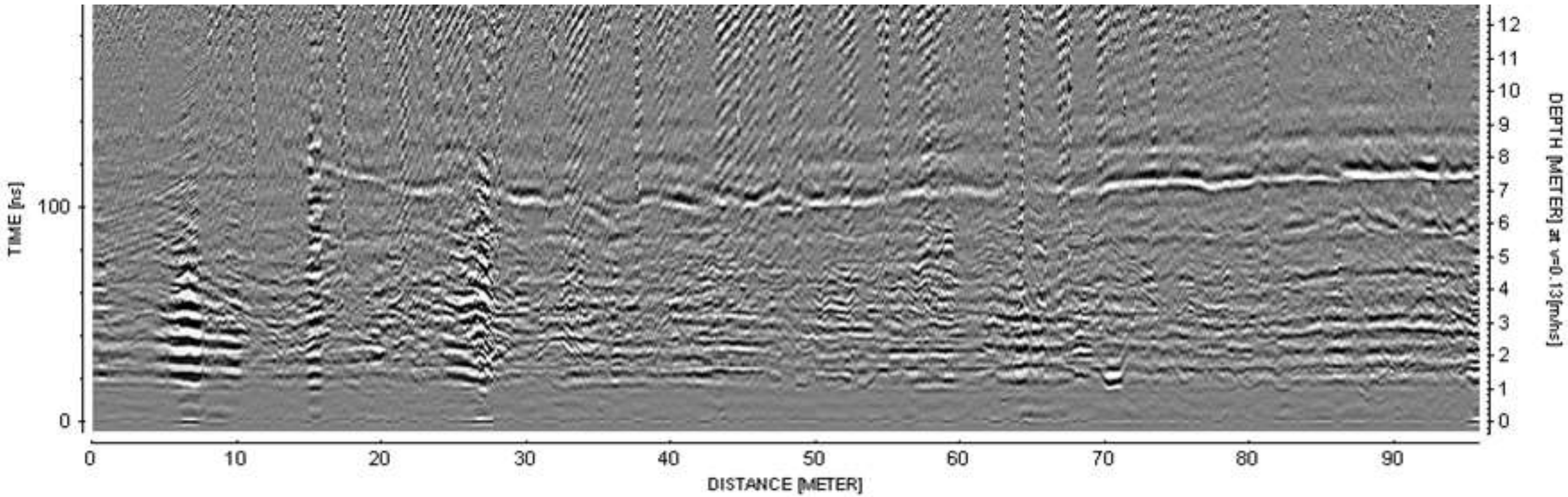


- Water was leaking into the potash mine

→ Reducing structural integrity of mine shafts

→ Want to know where water is and its source

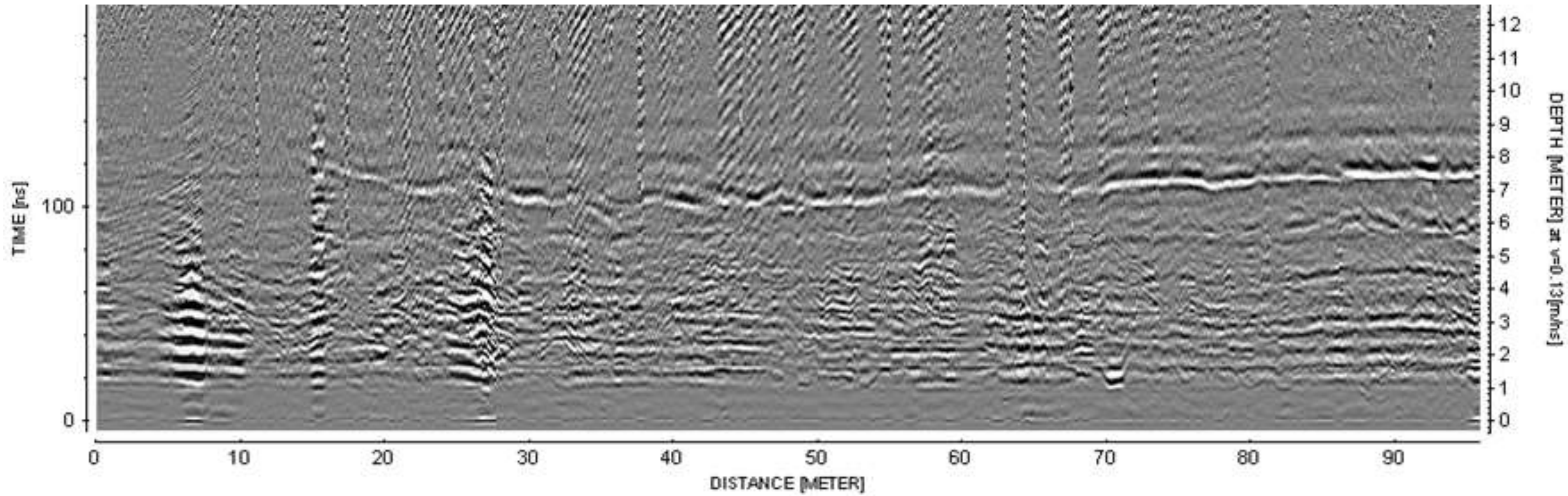
→ Water infiltration produces a strong reflector



- Zero offset GPR survey performed.

- Arrival time to depth conversion performed

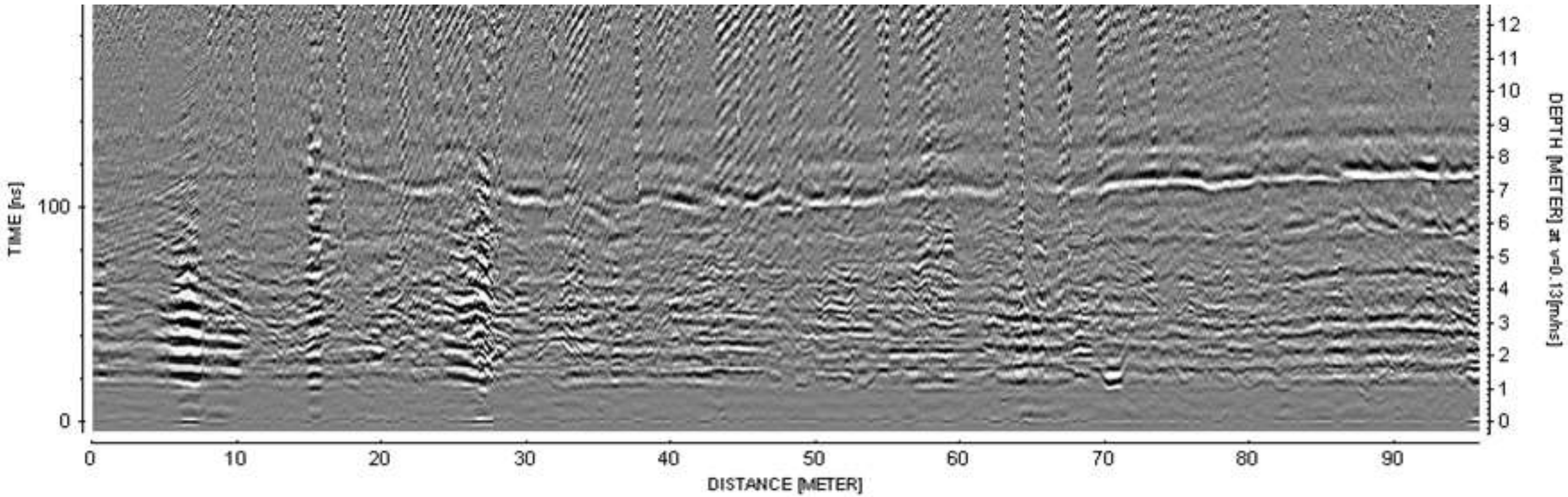
  Q: Without a direct ground wave measurement or hyperbola to obtain propagation speed, how could they do conversion?



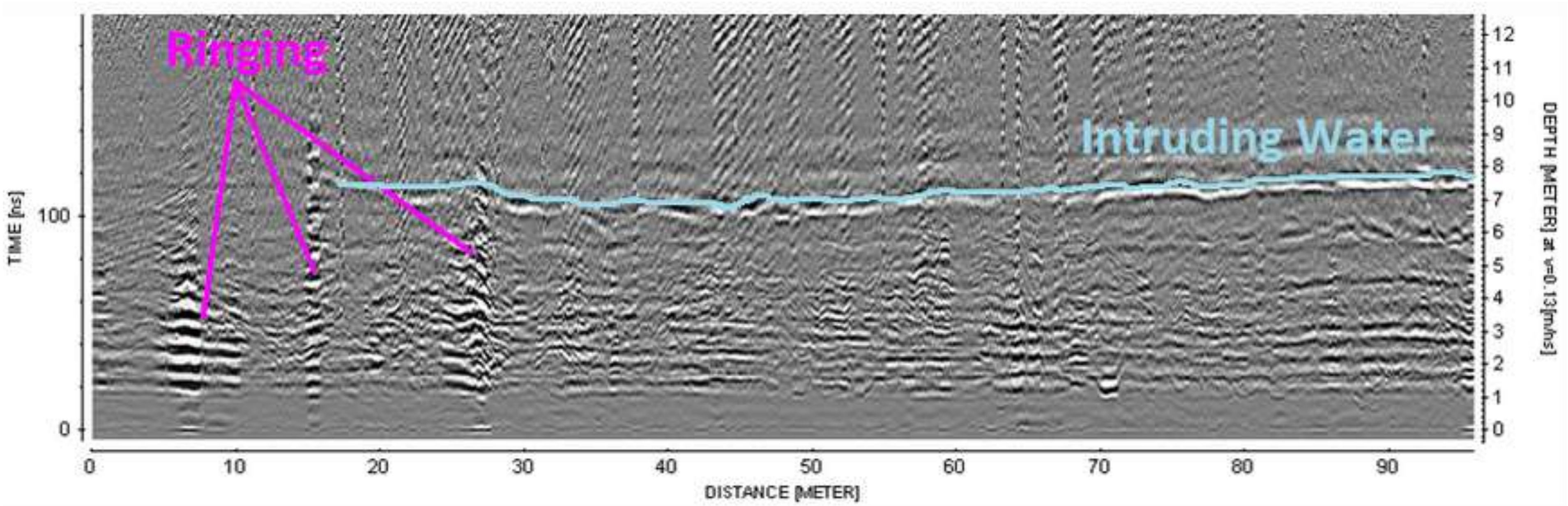
A: Potash in an anhydrite mineral.

From known physical properties, V ~ 0.13 m/ns

Apparent depth $d_a = V t / 2$



Q: What kinds of features do you see in the data?



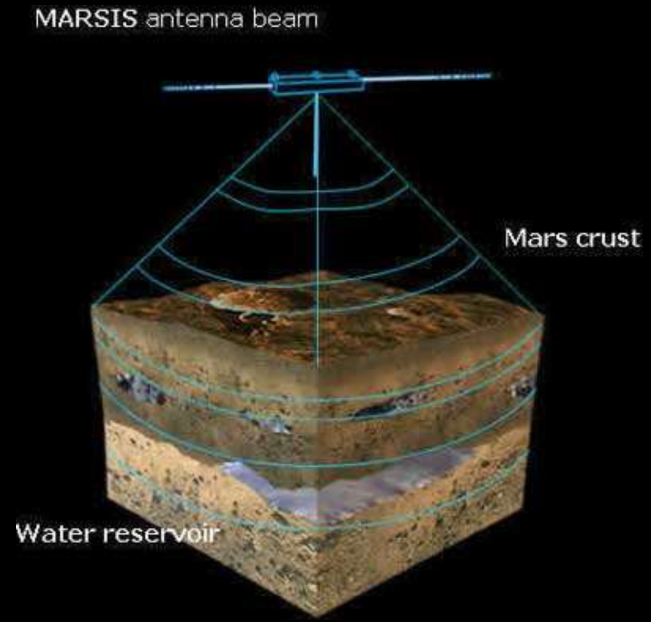
- Strong reflector from intruding water (7 - 8 m into the wall)
- Water is delineated and seems to be coming from the right
- Ringing from mine infrastructure

GPR on SUSTech Campus

On SUSTech campus: search for buried power cables

- Frequency range: 100M to 1G Hz
- Depth of penetration: within 100 m
- High frequency: good resolution but shallow
- Low frequency: poor resolution but deep
- Good reflectors: water (ε_r = 81), metal (ε_r = infinity)

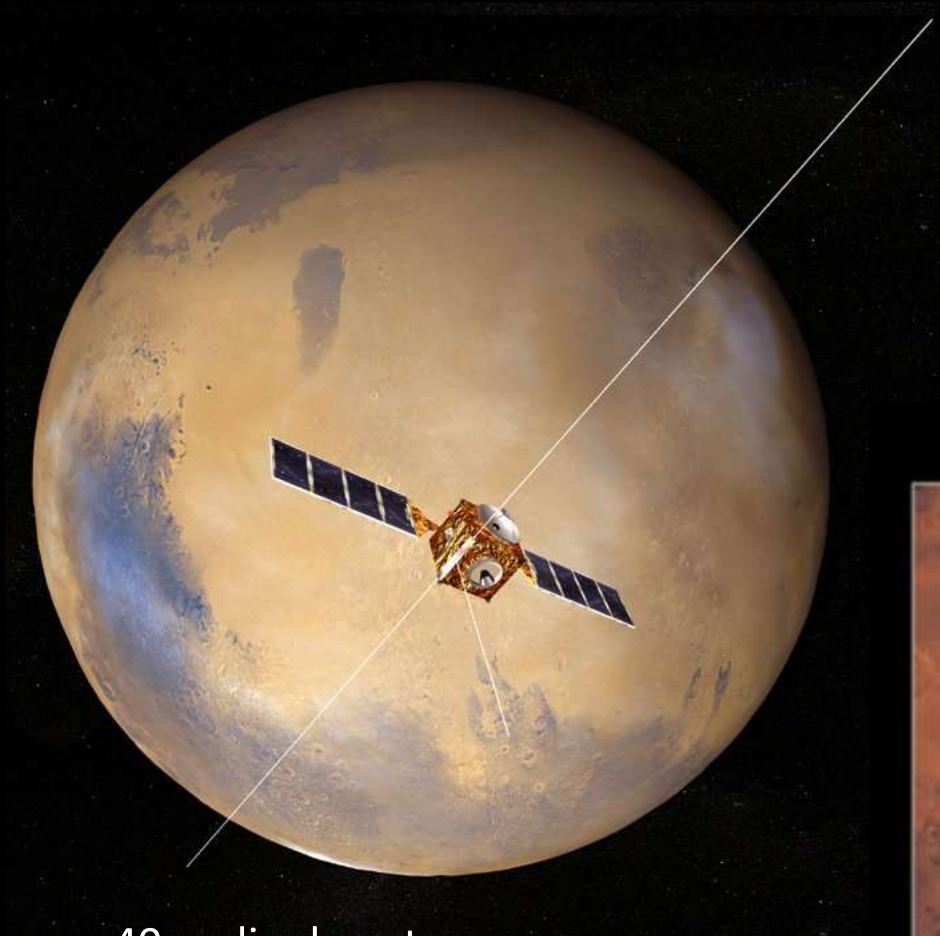
Mars Radar

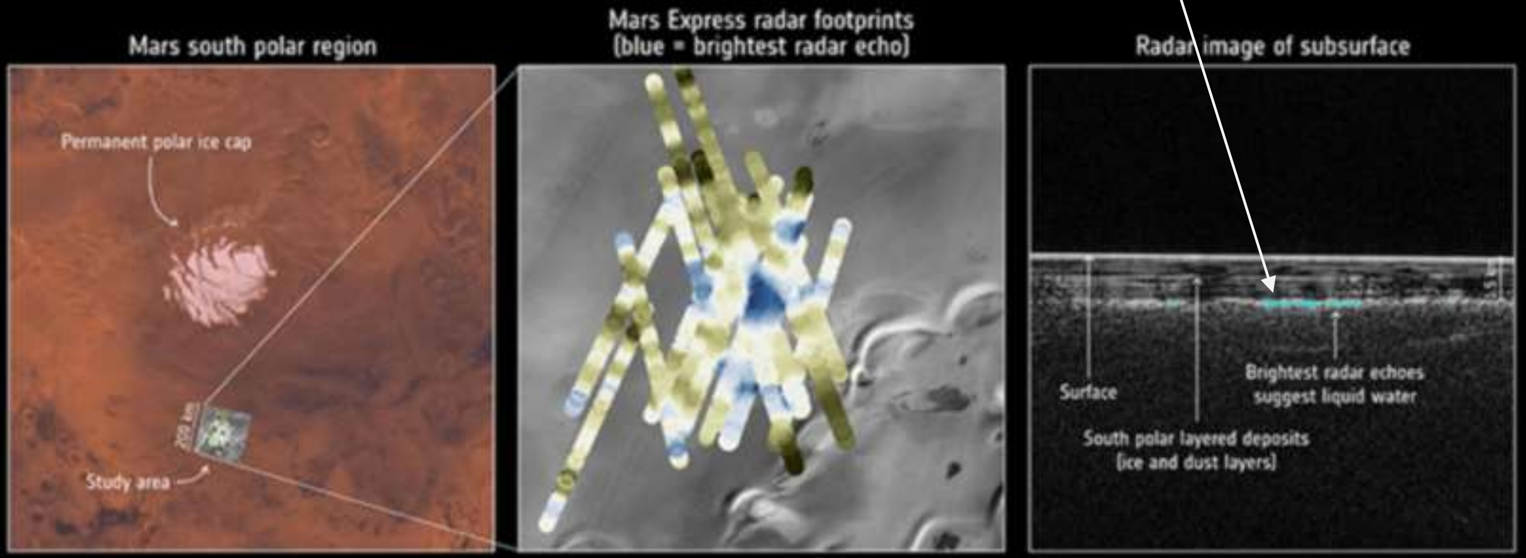


<u>M</u>ars <u>A</u>dvanced <u>R</u>adar for <u>S</u>ubsurface
and <u>I</u>onosphere <u>S</u>ounding

MARSIS mission

Liquid water beneath ice cap





40 m dipole antenna
1.8 ~ 5.0 MHz

Summary

- GPR survey types
- GPR data analysis: velocity and depth
- GPR data processing
- GPR noise in practice
- GPR instruments: Antenna
- Applications: Water gushing in potash mines, MARS radar, Searching pipes on SUSTech campus.