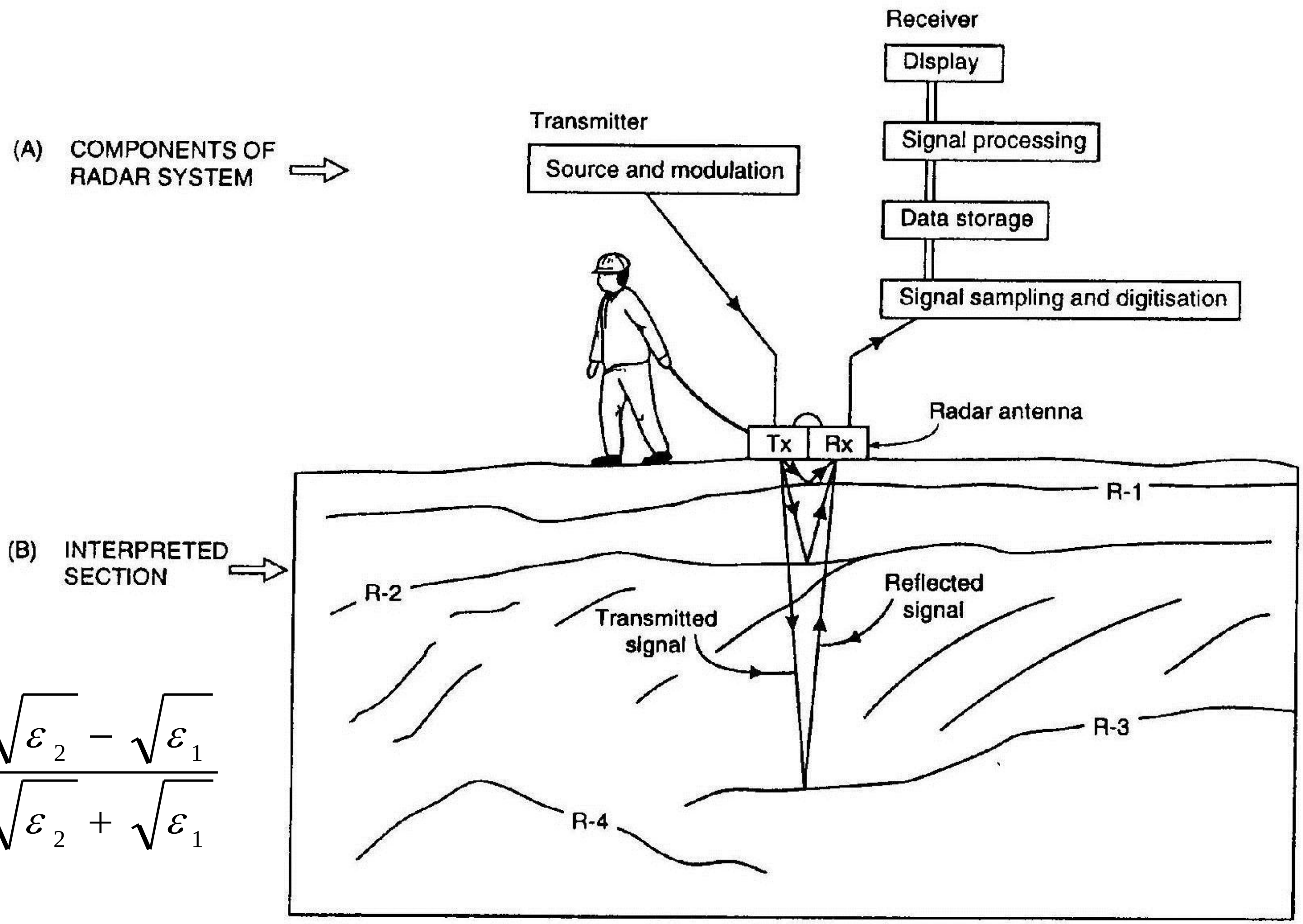
GPR Part II:

- Effects of conductivity
- Surveying geometries
- Noise in GPR data
- Summary notes with essential equations
- Some Case histories

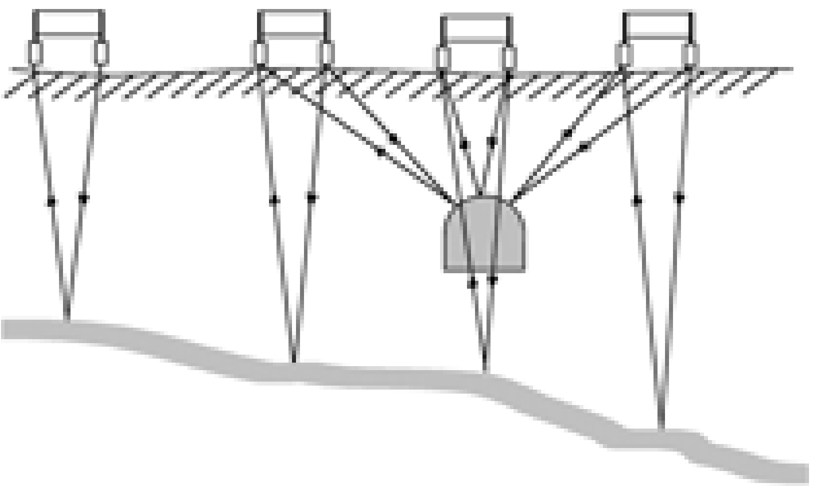
GPR Ground Penetrating Radar

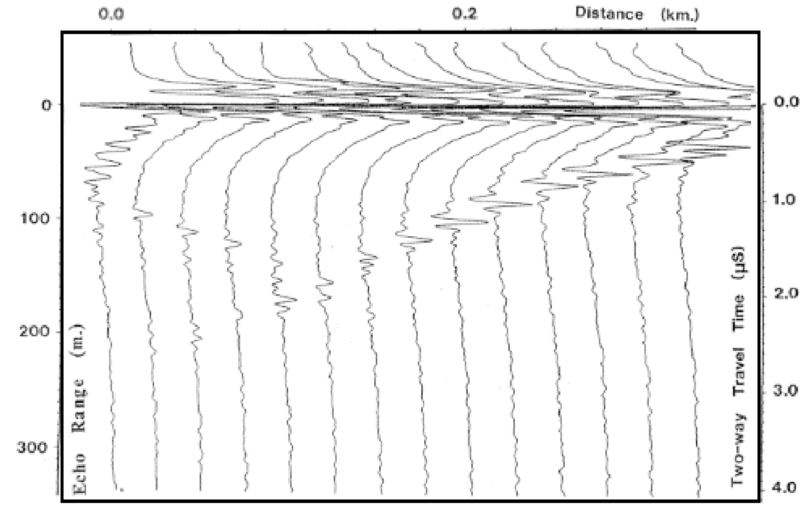


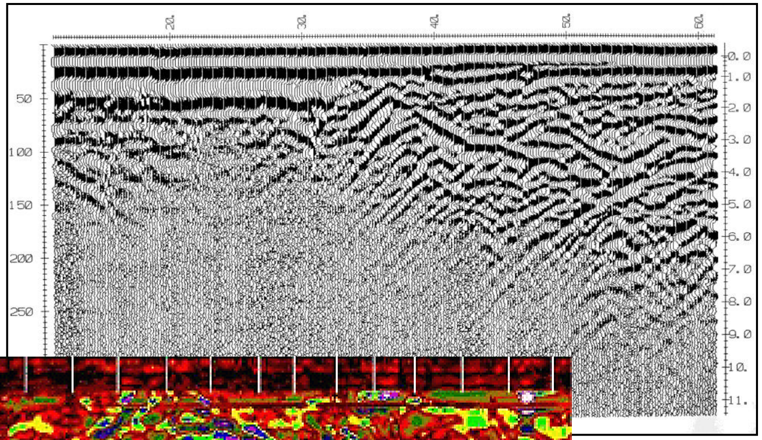
$$R = \frac{\sqrt{\varepsilon_2} - \sqrt{\varepsilon_1}}{\sqrt{\varepsilon_2} + \sqrt{\varepsilon_1}}$$

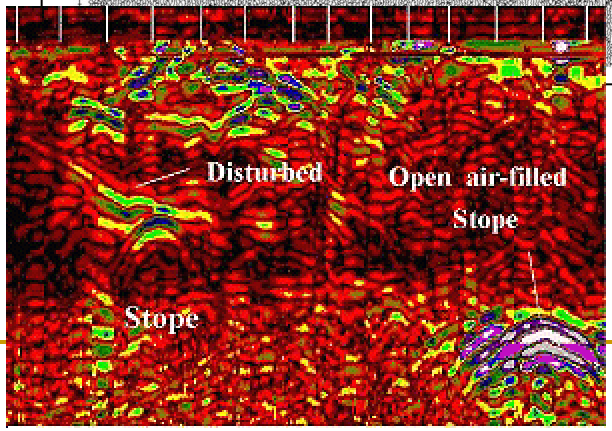
GPR data - echoes

- Essentially wiggle traces
  - Sometimes variable area
  - Sometimes as coloured bands

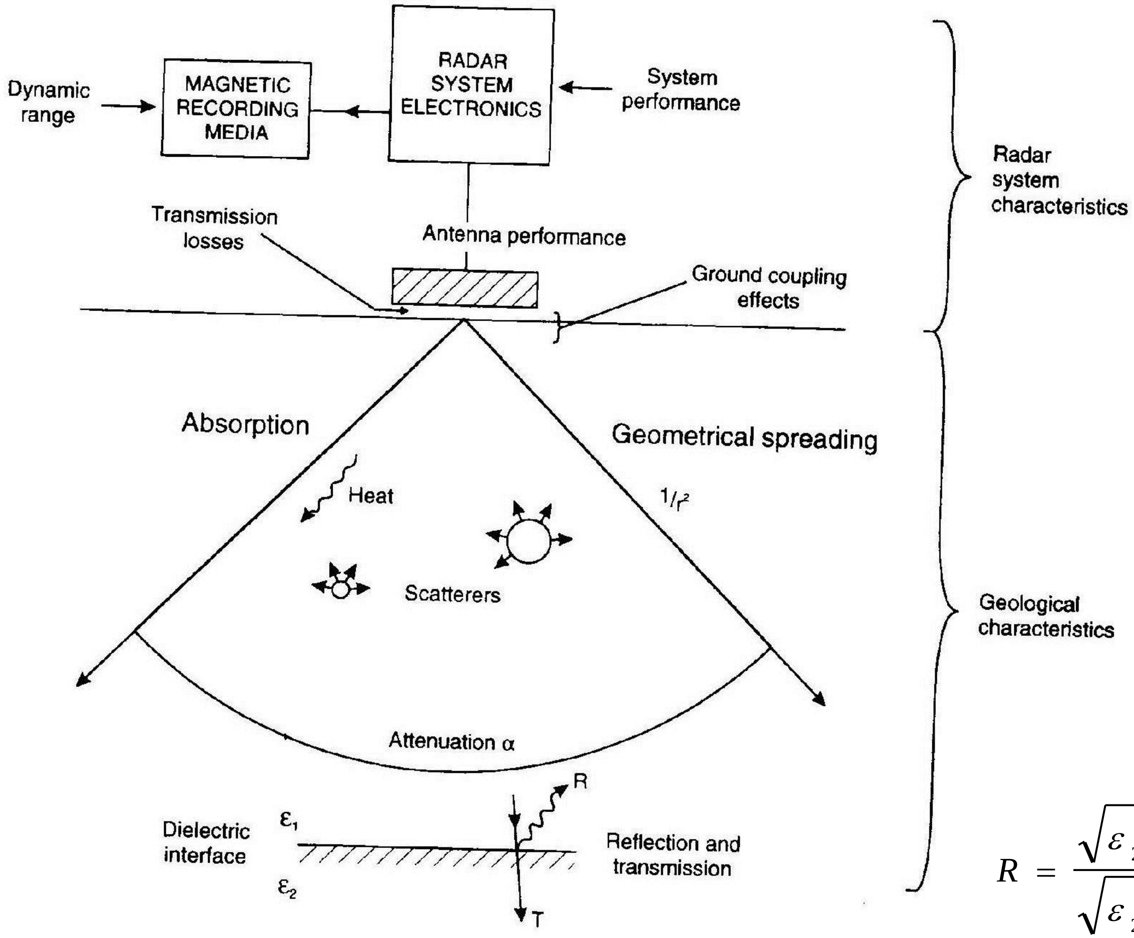








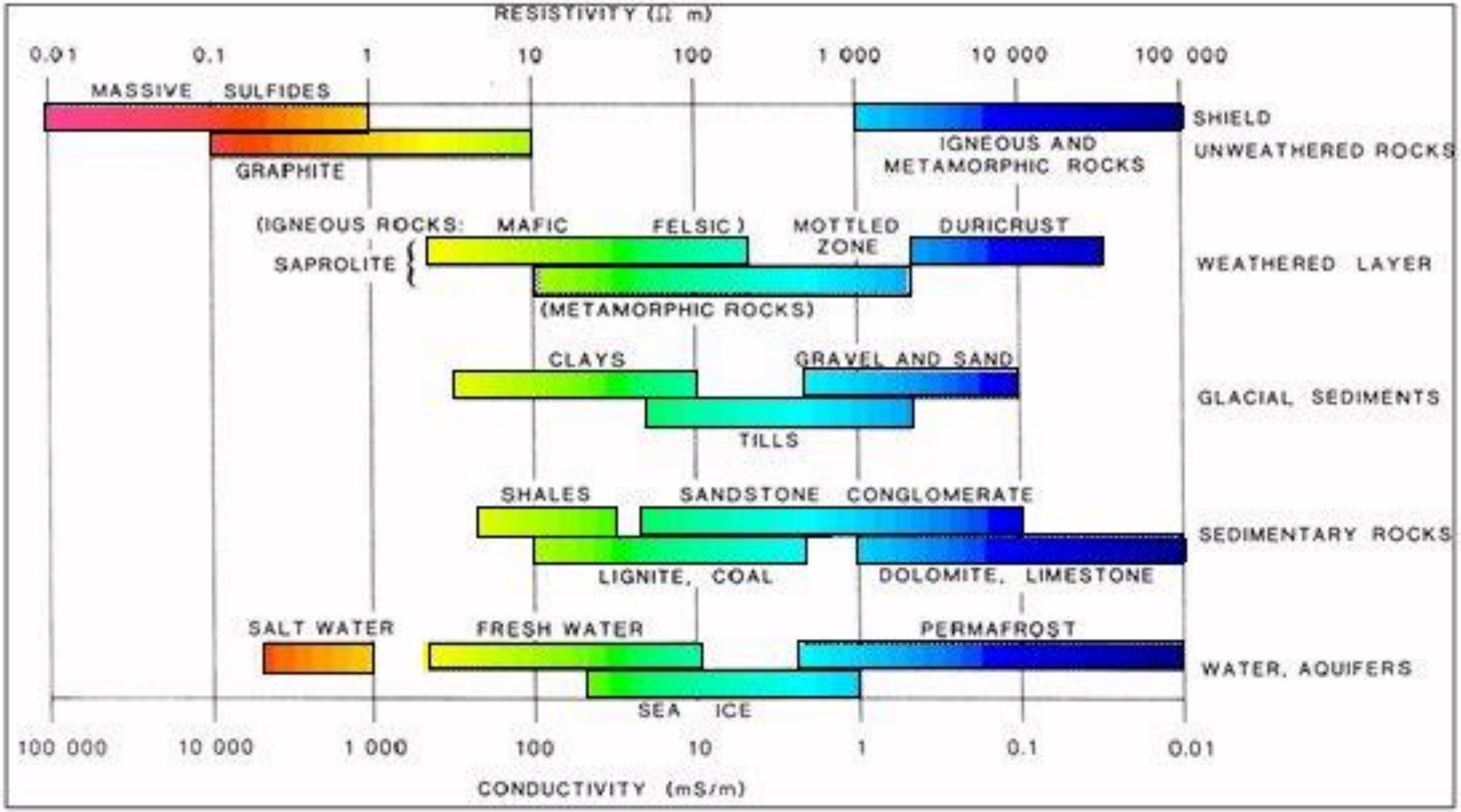
Attenuation of GPR signals



$$R = \frac{\sqrt{\varepsilon_2} - \sqrt{\varepsilon_1}}{\sqrt{\varepsilon_2} + \sqrt{\varepsilon_1}}$$

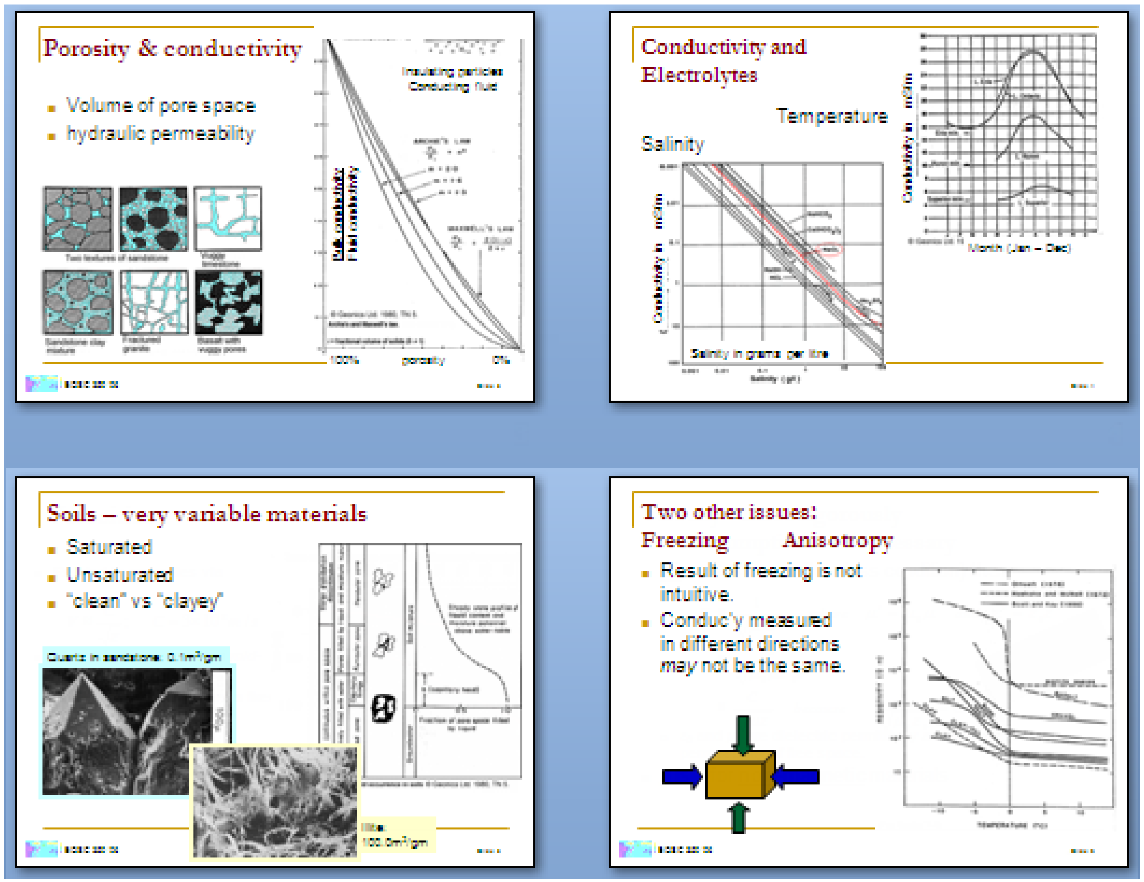
Consider conductivity – GPR point of view

- 7 orders of magnitude
- Matrix materials mainly insulators
- Therefore fluids and porosity are key



From Second week of term

Many reasons why geology ←→ conductivity is complicated …



Attenuation of GPR signals

- The strength of the EM radiation gets weaker the further away from the source

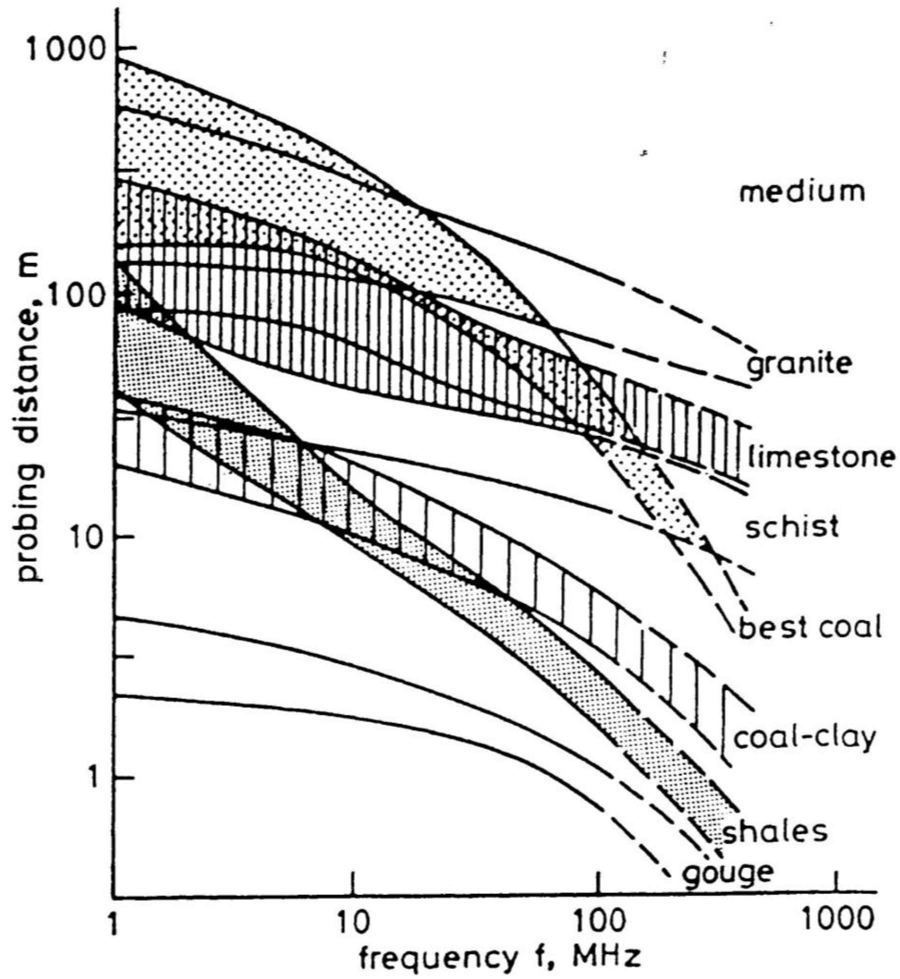
- The concept of “skin depth” is the distance at which the signal has decreased to 1/e (that is ~37%)

$$\delta = \left(5.31\sqrt{\varepsilon_r}\right)/\,\sigma \quad \text{meters}$$

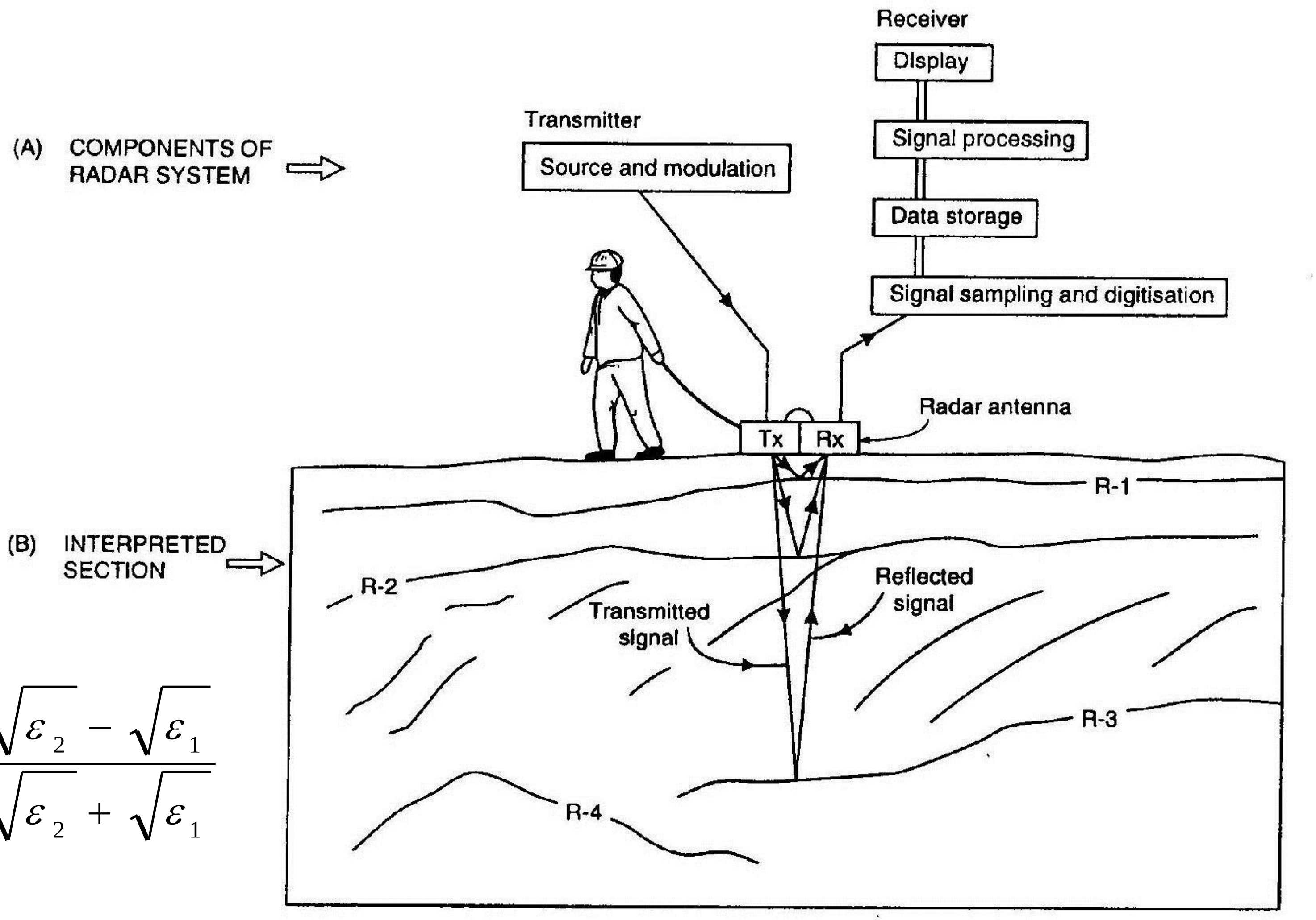
Conductivity in mS/m (milli-Semens per meter)

GPR probing distance

Keep in mind that GPR probing distance is highly dependent on the amount of moisture/water content of the material



Summary: GPR Ground Penetrating Radar



$$R = \frac{\sqrt{\varepsilon_2} - \sqrt{\varepsilon_1}}{\sqrt{\varepsilon_2} + \sqrt{\varepsilon_1}}$$

Di-electric constant, conductivity, velocity

- Water has is extremely important
- **Attenuation** of radar signals is most affected by σ..

Table of relative dielectric permittivity (e_R), electrical conductivity (σ), and velocity.			
Material	e_R	σ (mSeimens/m)	V avg (m/ns)
Air	1	0	.3
Distilled water	80	0.01	0.033
Fresh water	80	0.5	0.033
Sea water	80	3000	0.01
Dry sand	3- 5	0.01	0.15
Saturated sand	20-30	0.1-1.0	0.06
Limestone	4-8	0.5-2.0	0.12
Shales	5-15	1-100	0.09
Silts	5-30	1-100	0.07
Clays	5-40	2- 1000	0.06
Granite	4-6	0.01-1.0	0.13
Dry salt	5-6	0.01-1.0	0.13
Ice	3-4	0.01	0.16

Attenuation of GPR signals

- Wave velocity $V \approx \frac{C}{\sqrt{\varepsilon}}; \quad C = 3 \times 10^{8} m/s$
- Reflection coefficent $R = \frac{\sqrt{\varepsilon_2} - \sqrt{\varepsilon_1}}{\sqrt{\varepsilon_2} + \sqrt{\varepsilon_1}}$
- Refraction $\frac{\sin \theta_1}{v_1} = \frac{\sin \theta_2}{v_2}$
- Skin Depth Conductivity in mS/m (milli-Semens per meter $\delta = \left(5.31\sqrt{\varepsilon_r}\right)/\sigma$

GPR Readings

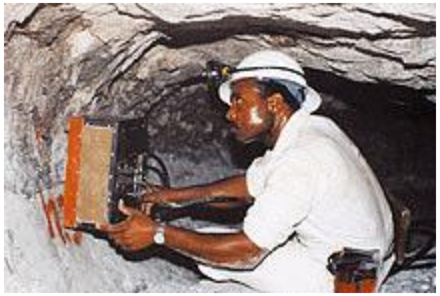
- GPG section 3.g

Field operations

- Most common mode of operation
  - Common offset (distance between Tx and Rx is fixed)
  - Sometimes processed as zero offset (coincident source and receiver)

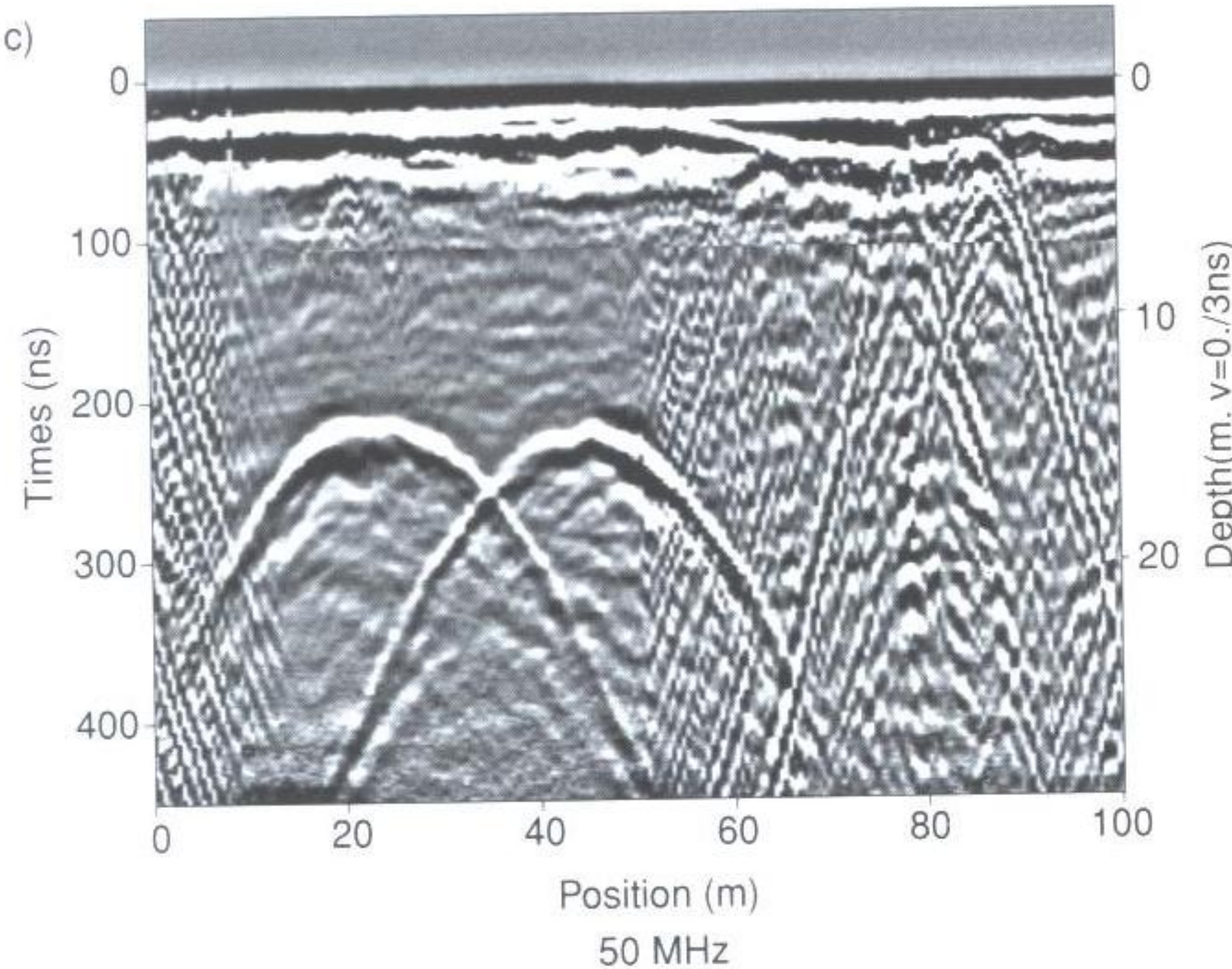
Common (fixed) offset systems

- Small scale, but expensive equipment.

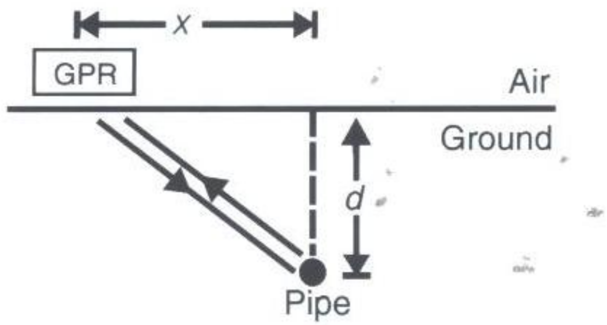


GPR Frequencies : 100 MHz,

Two underground tunnels, (Common Offset data)



Burried objects



GPR Traveltime

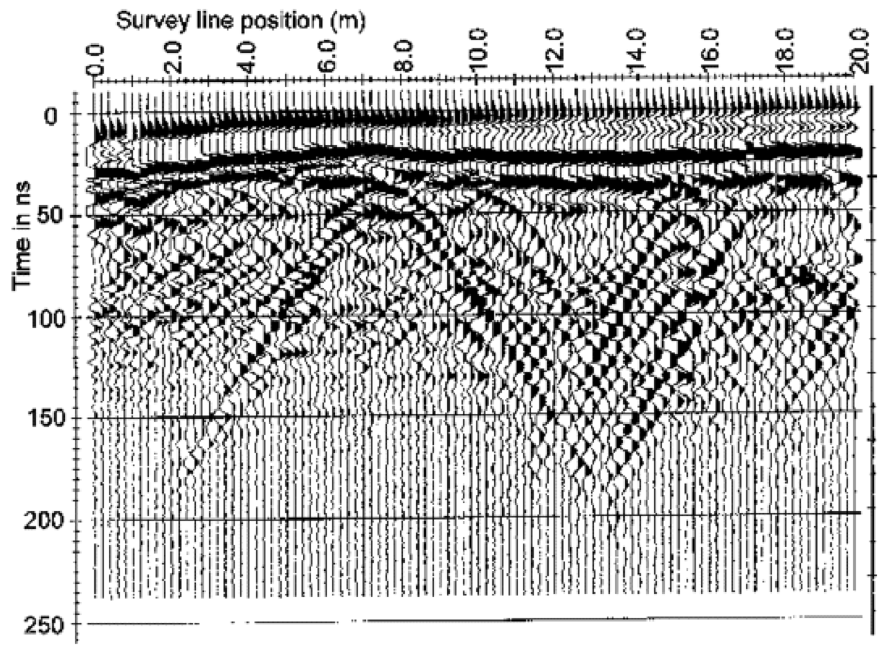
$$T = \frac{2\,(x^2+d^2)^{1/2}}{v}$$

or

$$T = \left(\frac{4x^2}{v^2} + T_0^2\right)^{1/2}$$

where

$$T_0 = \frac{2d}{v}.$$

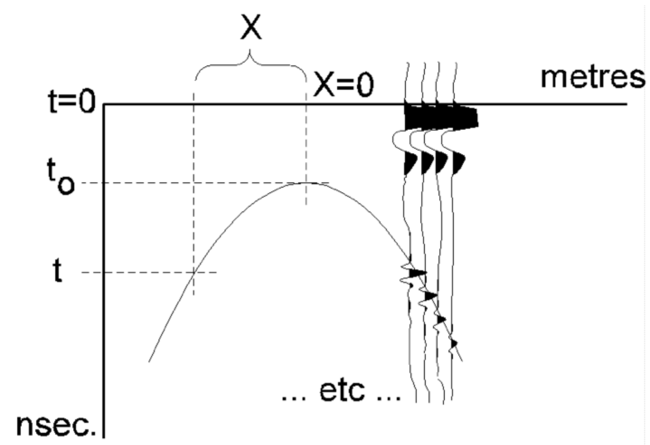


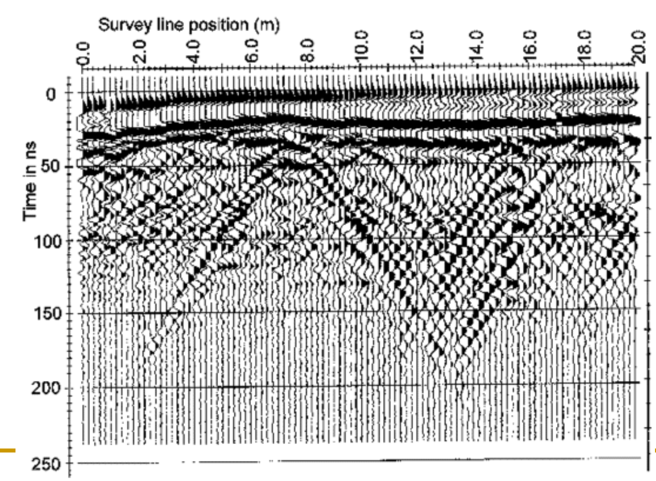
Velocity from hyperbolic patterns

- Geometry of travel time distance curve can be solved for velocity.

- Useful so long as velocity is uniform for all signals used.

$$V^2 = \frac{4x^2}{t^2 - t_0^2}$$



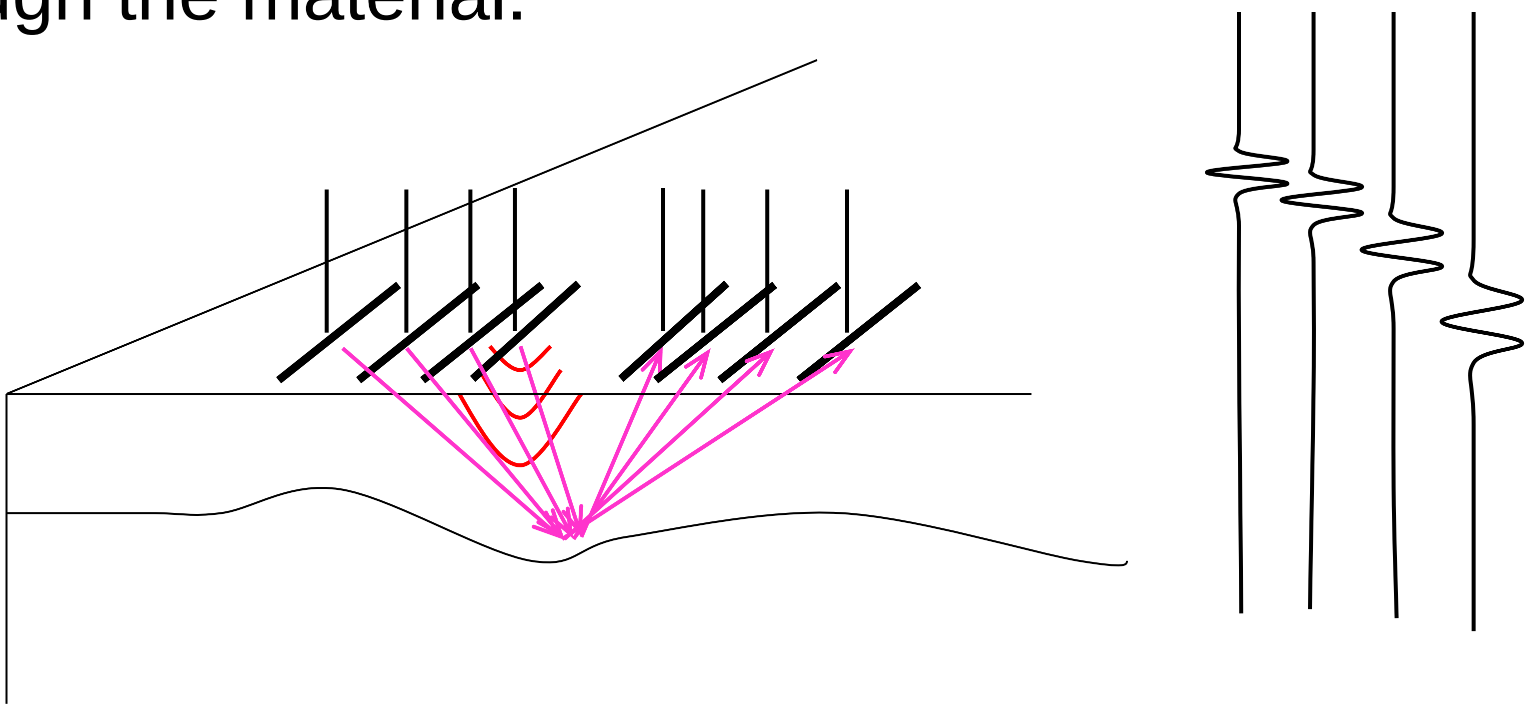


Other systems: Separate Tx and Rx

- Common offset surveys
- Common midpoint surveys

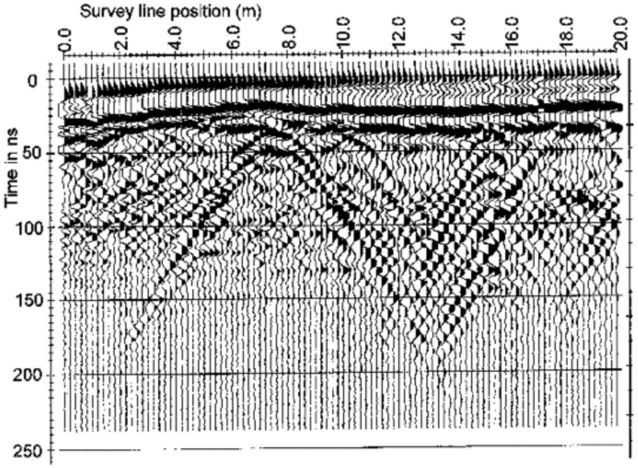
Field measurement of velocity

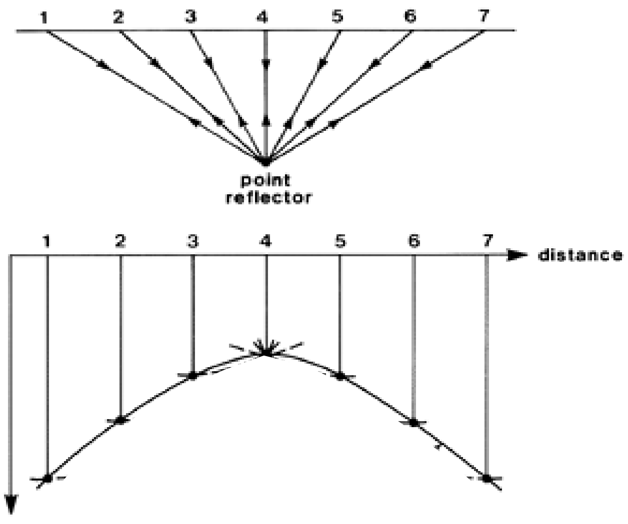
- Common midpoint
- Fix all contributors to travel time except path length through the material.



Buried objects and hyperbolas

- Energy is emitted in all directions from antennas.
- But, plotting shows traces "vertically".





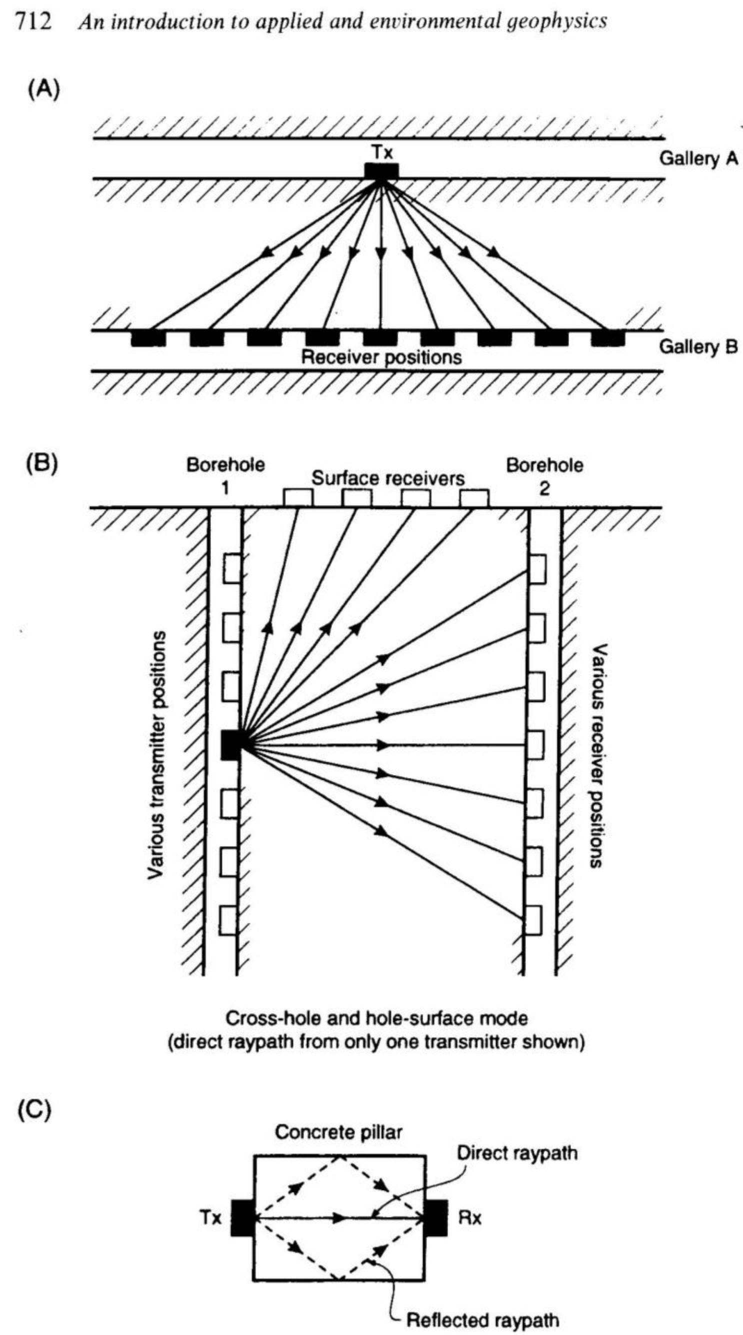
$$V^2 = \frac{4x^2}{t^2 - t_0^2}$$

Field operations: Other modes

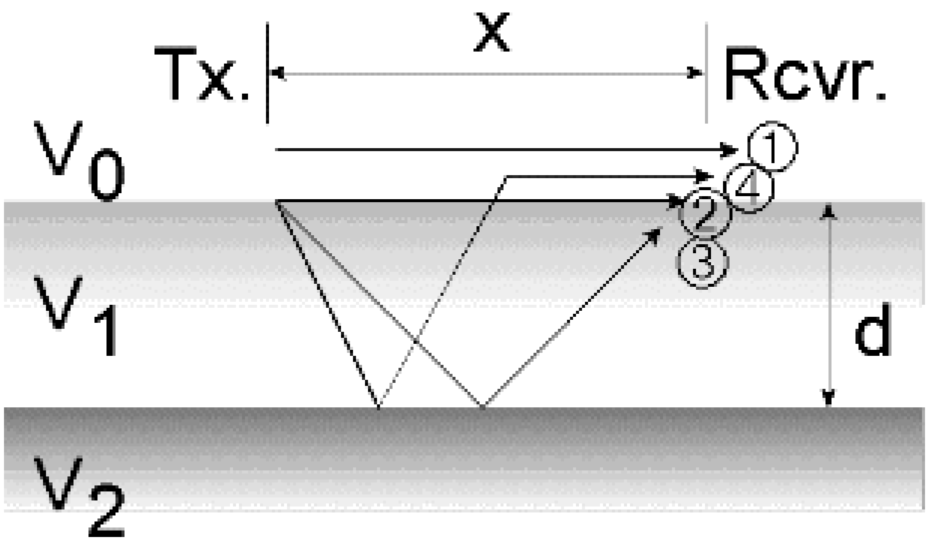
- Transillumination Tx and Rcvr on opposite sides of the target.
  - Used for concrete structure testing, some in-mine work.

Transillumination

Placing a transmitter and receiver on opposite sides of the object of interest



Ray paths are used to interpret all GPR waves



- Direct air wave (1)
- Direct ground wave (2)
- Reflected wave (3)
- Critically refracted wave(4)

Eq'ns for signal travel times

① Direct air wave: $t(x) = x/V_0$.

② Direct ground wave: $t(x) = x/V_1$.

③ Reflected wave: $t(x) = \frac{\sqrt{x^2 + 4d^2}}{V_1}$.

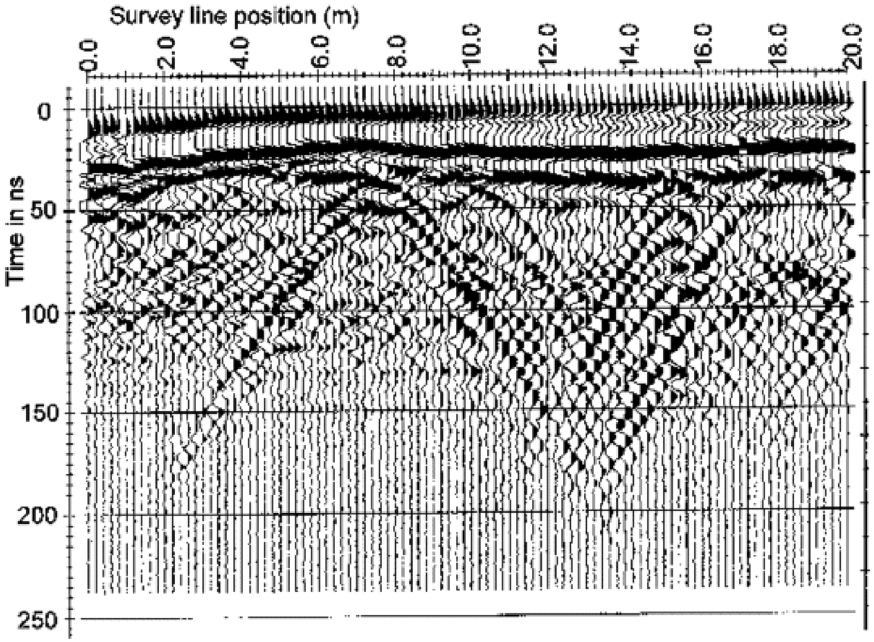
④ Critically refracted wave:

$t(x) = x/V_0 + const$

Important: Understand how to get the travel time and velocity for the "reflected wave"

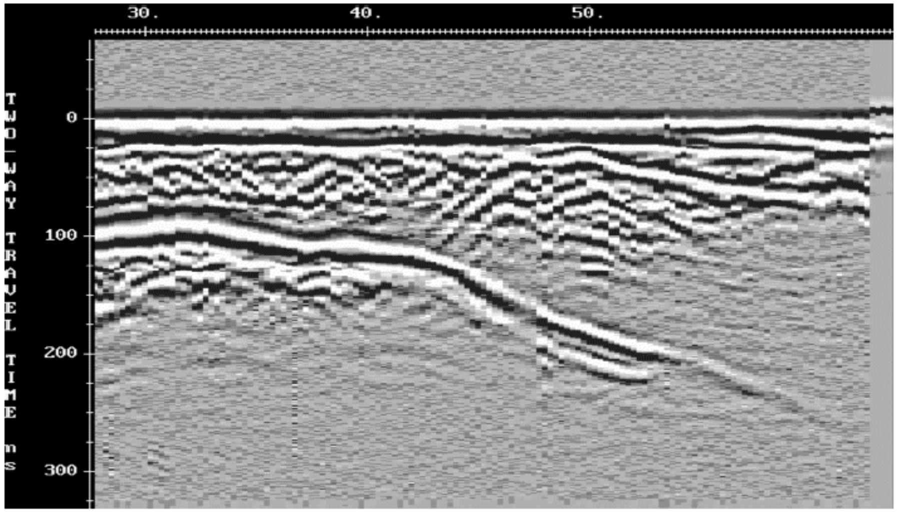
Typical GPR common offset response patterns

- Air/ground wave
- Layers
- Objects
  - Small **hyperbolas**
  - What if objects are "large"
- Scattering
  - **Texture** of ground response.
  - Attenuation rates



Common-offset data

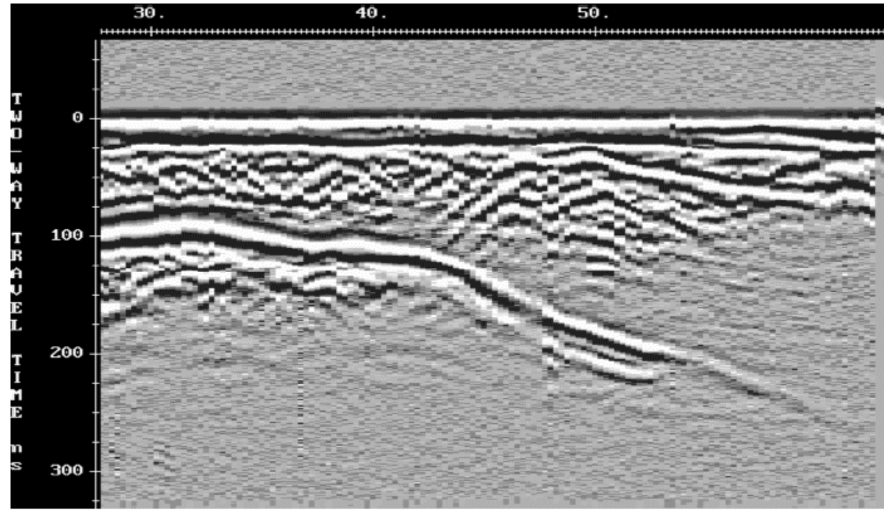
- What are we seeing?
- Data: consider:
  - X-axis ?
    - Parameter?
    - Units?
  - Y-axis ?
    - Parameter?
    - Units?
  - Axis direction ?



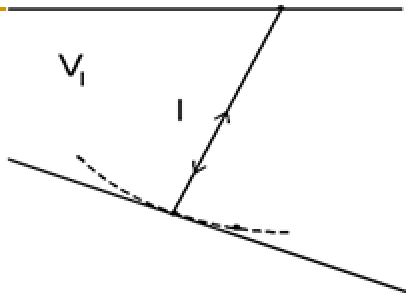
- Geology: consider
  - What was measured?
  - What's visible?
    - Lines
    - Patterns
    - Fading
  - What causes features?

Typical GPR common offset response patterns

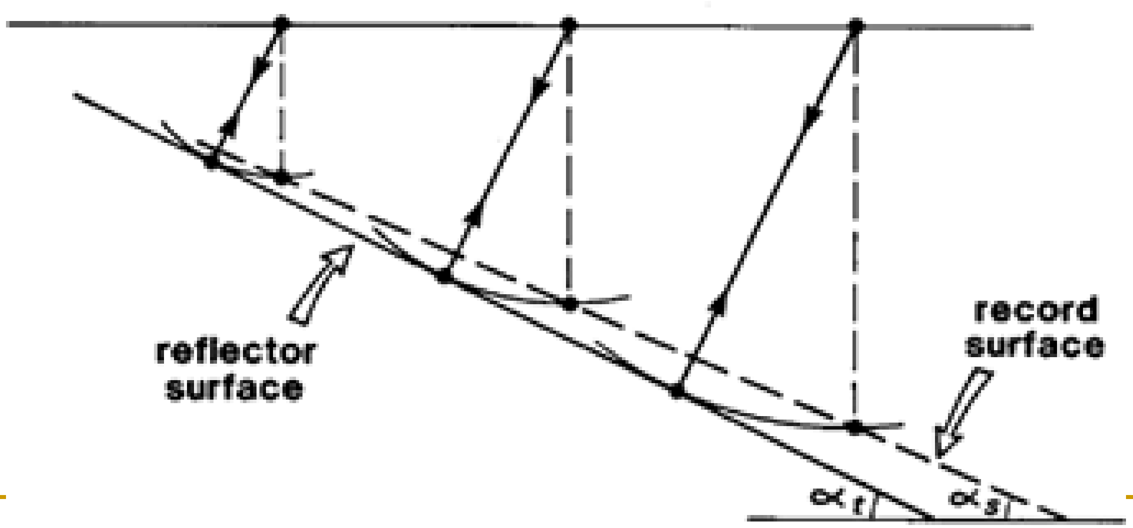
- Air/ground wave
- Layers:
  - Not always flat
- Scattering
  - **Texture** of ground response.
  - Attenuation rates



Dipping layers

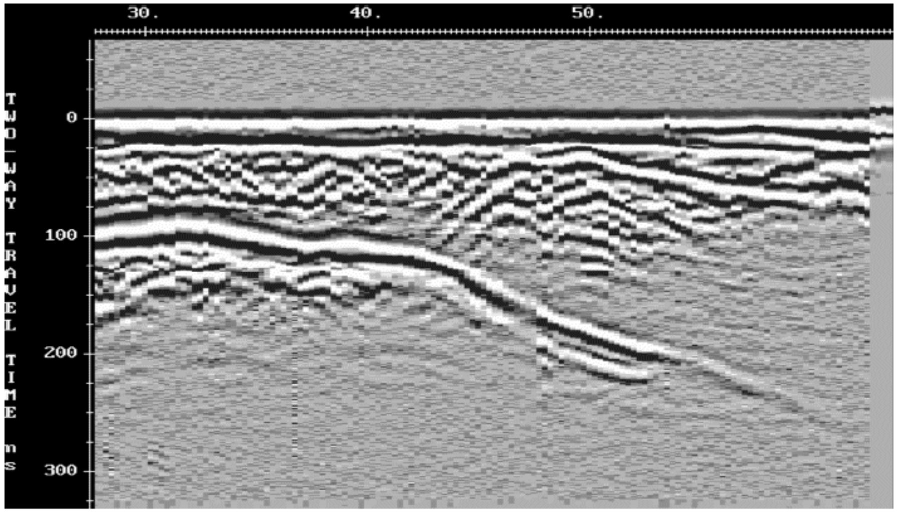


- Reflection direction is perpendicular to reflecting surface.
- Therefore 2WTT yields a <u>distance</u> not a depth.
- Slopes on raw reflection data will always be <u>less</u> than reality.
- Correct via “migration” – circular arcs are simplest.

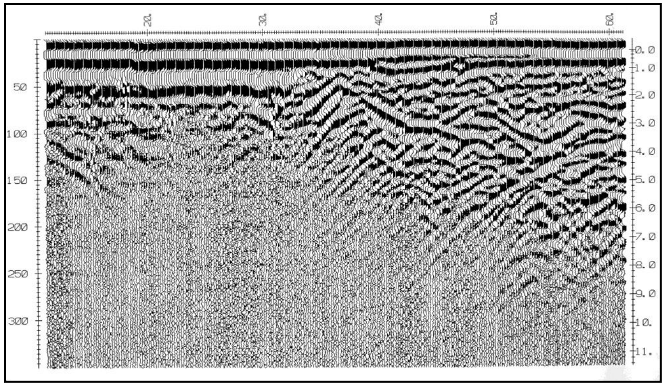


Typical GPR common offset response patterns

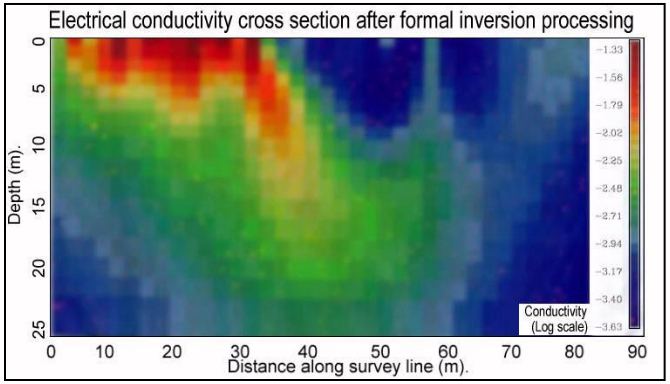
- Air/ground wave
- Layers:
  - Not always flat
- Scattering
  - **Texture** of ground response.
  - Attenuation rates



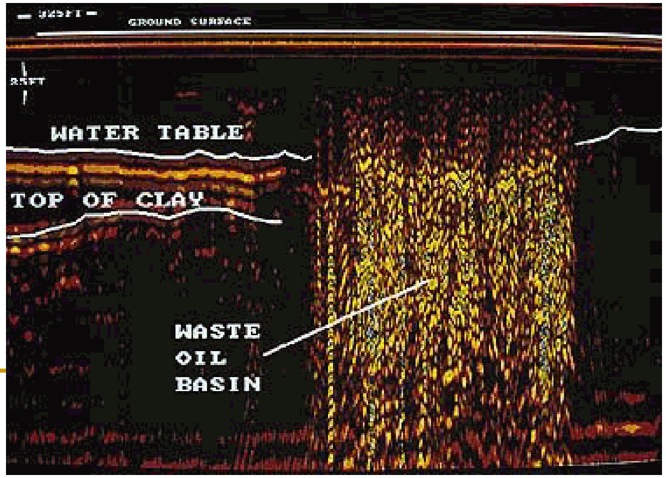
Attenuation and scattering



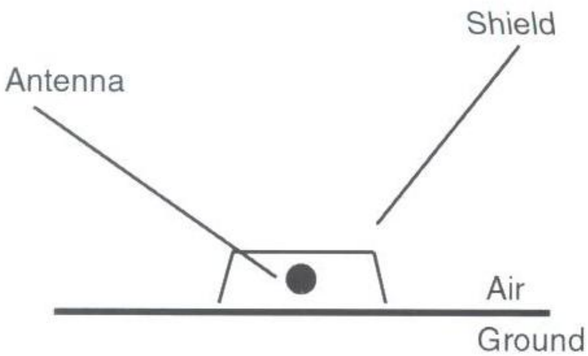
- We said earlier that conductivity controls signal attenuation (ie penetration depth).



- Information from texture and penetration depth is often very useful.

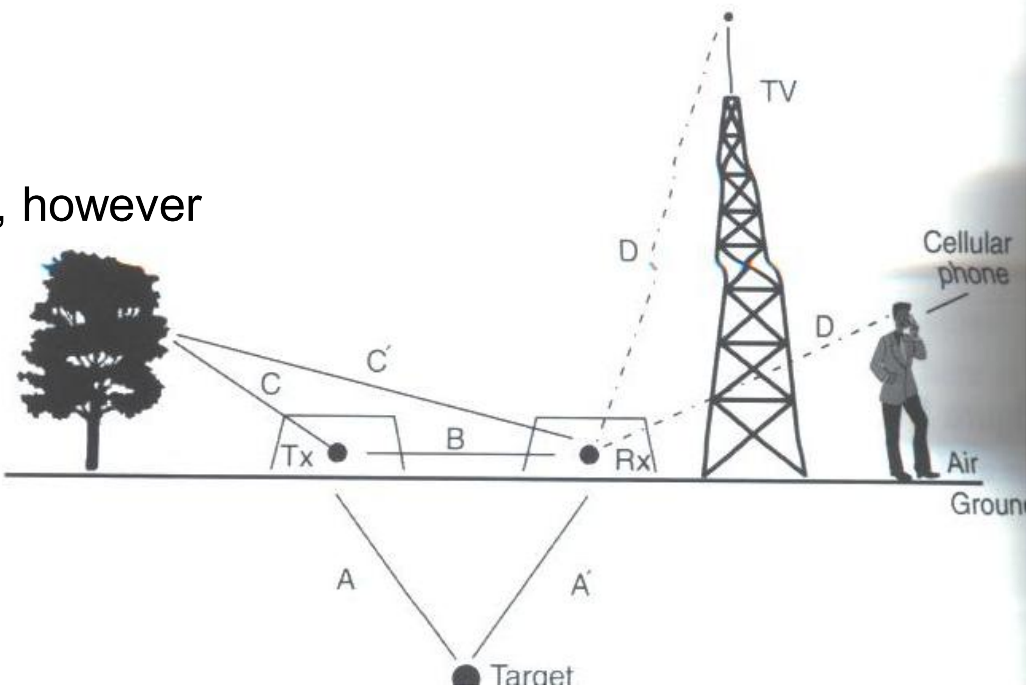


GPR noise sources



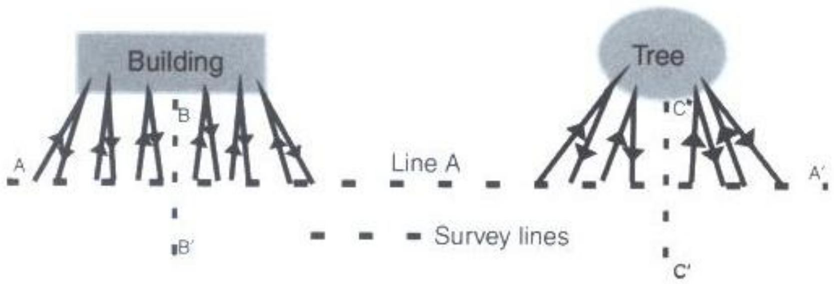
Many noise sources

- Radio waves in the air
- Reflections from objects
- Reflections from near surface debris
- “ringing”
- GPR antennas are “shielded”, however noise is still an issue

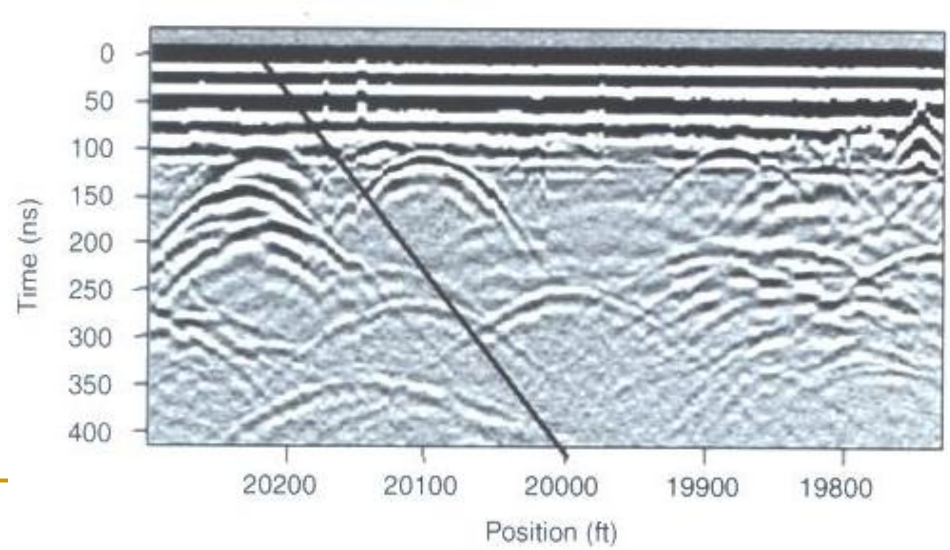


Reflections from Objects

- Nearby objects can reflect the radar waves

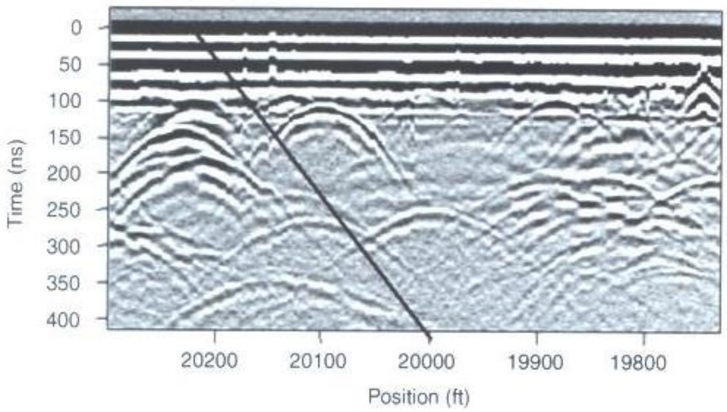


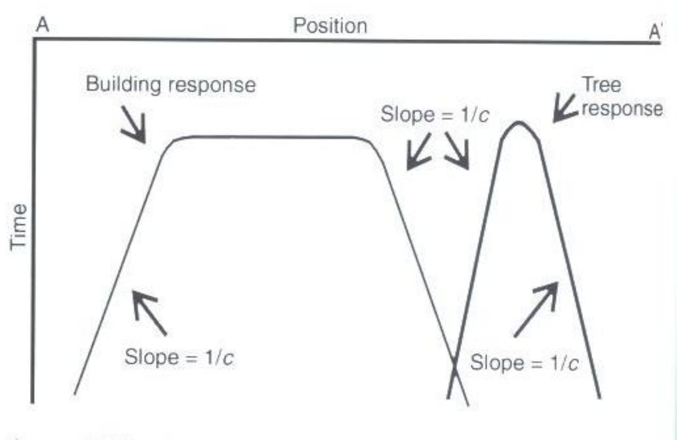
- Example: most reflections in this image after 100ns are due to trees:



Reflections from objects

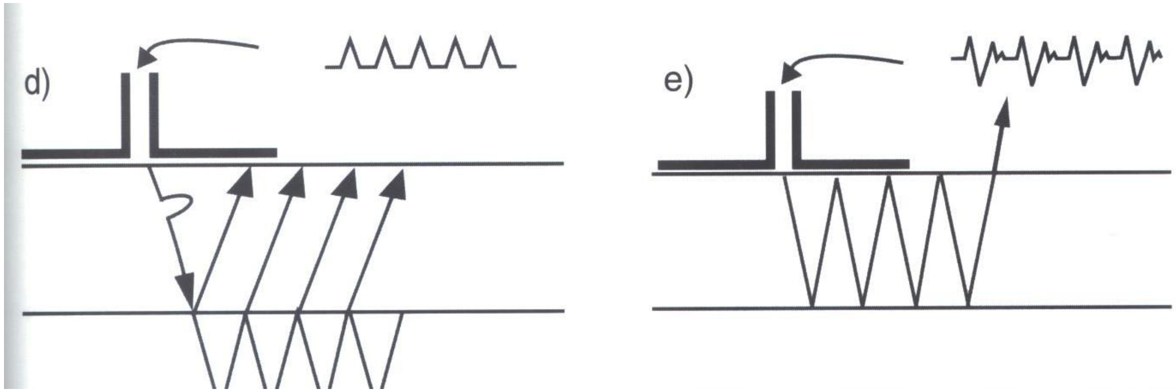
- We know that the signals are travelling through the air (at the speed of light)





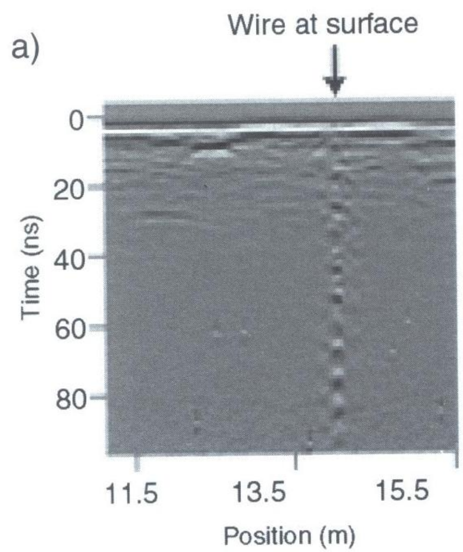
Noise source: “Ringing”

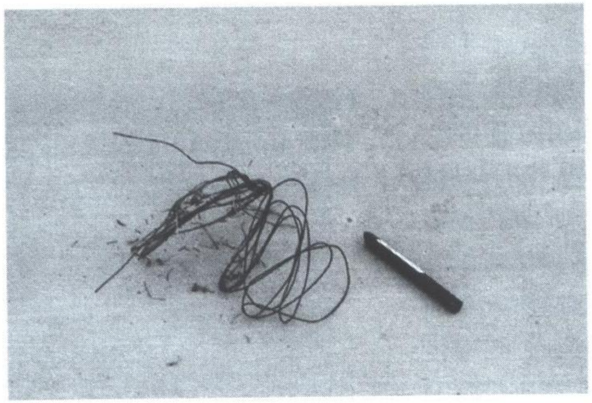
- Signals that reverberate in a regular fashion
- Created when GPR signal repeatedly bounches within an object, or between objects (analogy: a ringing bell)

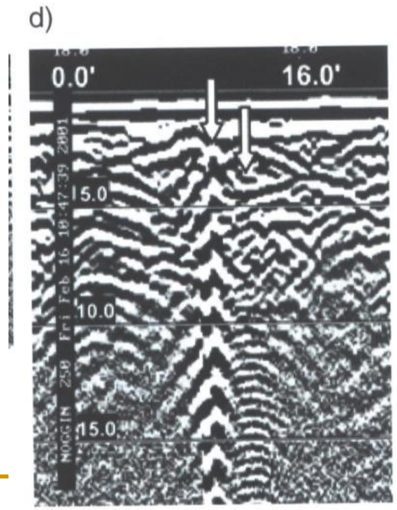


“Ringing” example

- A small piece of wire was burried beneath the surface







Two metal objects side-by-side. Note the two different “ringing” frequencies

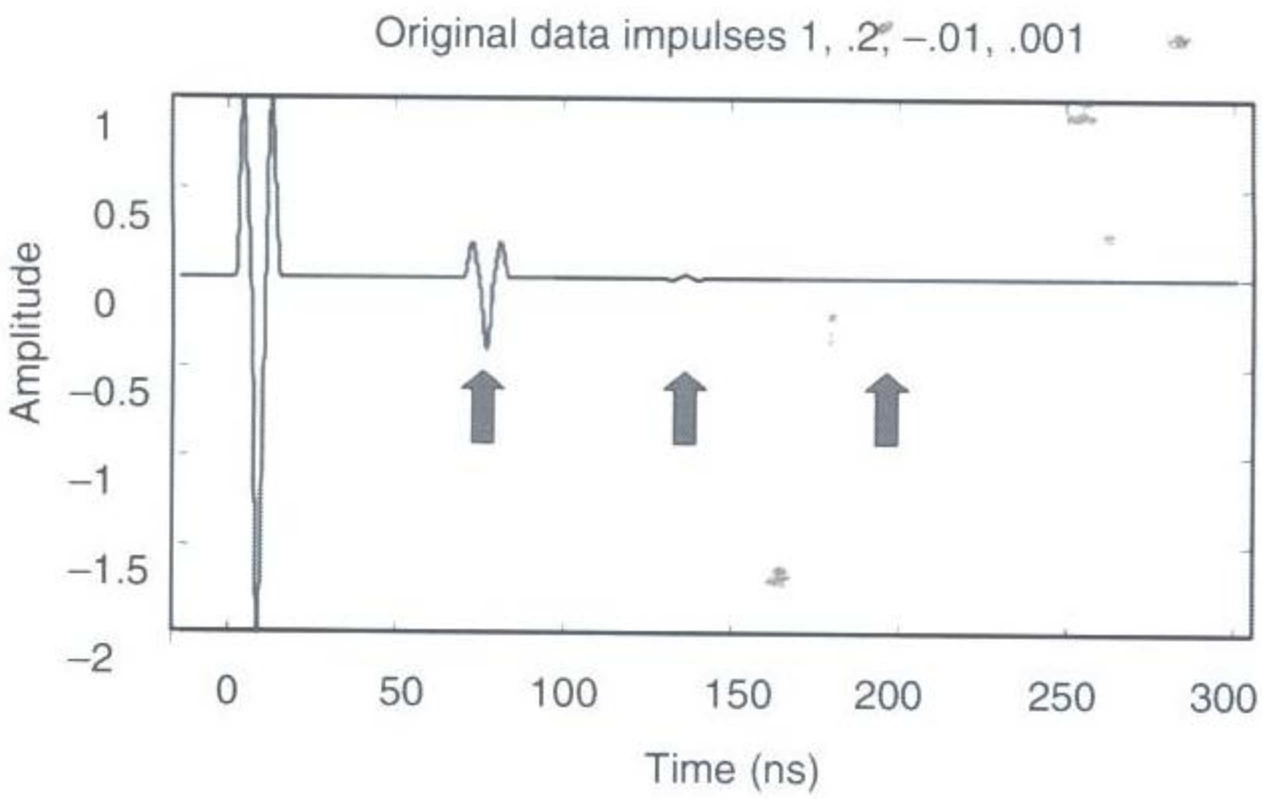
Gain and stacking

- As we can see, the signals in GPR can become quite small later in time

- To overcome this, “gain” is applied, in which the incoming signal is amplified by a factor. The gain factor then increases with time in a systematic fashion

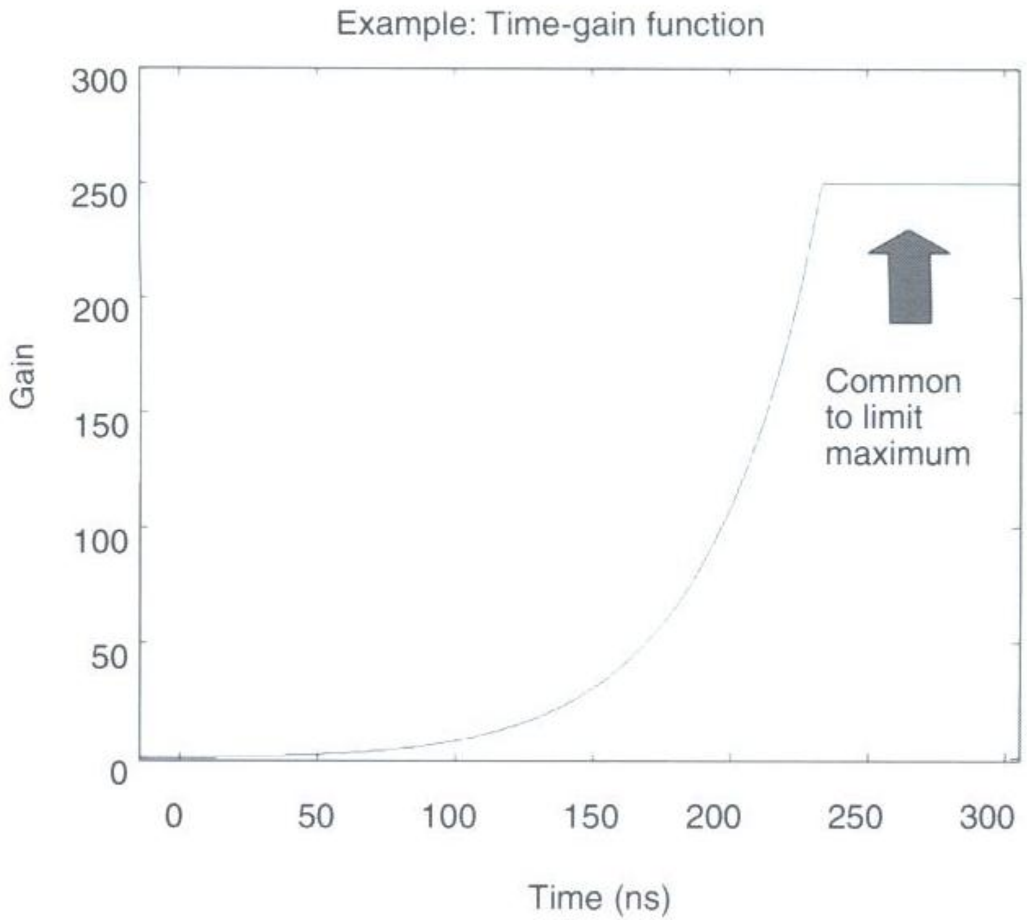
Gain example

- Original data



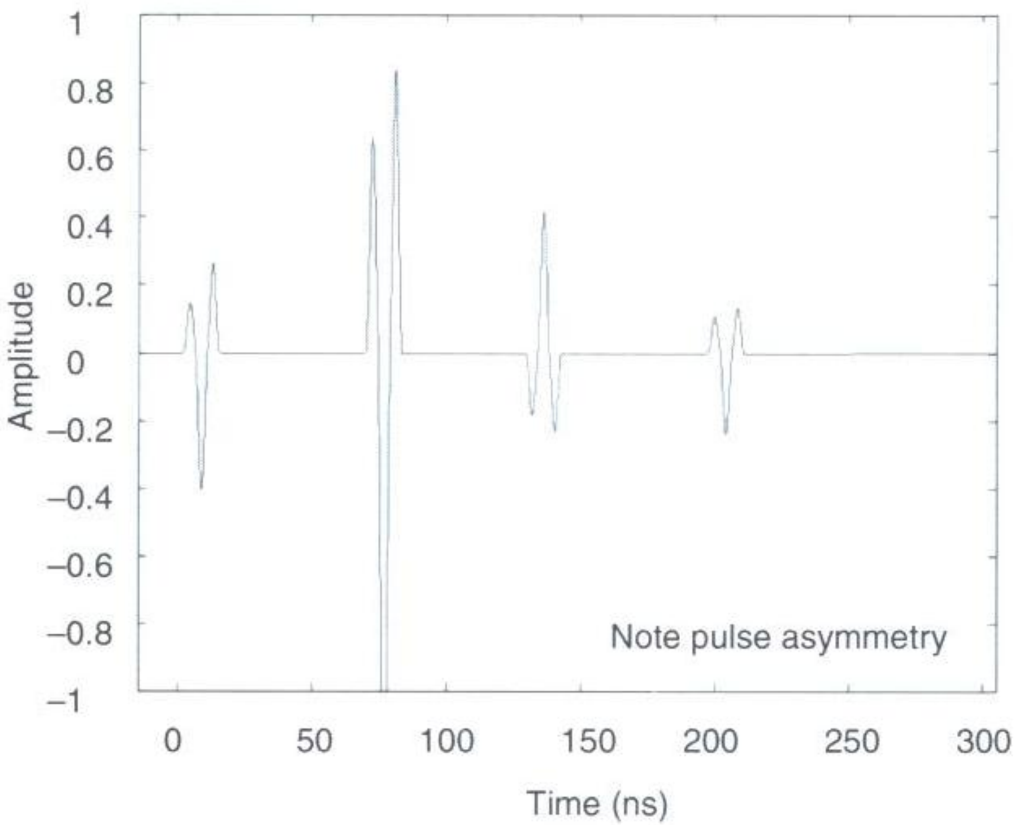
Gain example

- Gain function

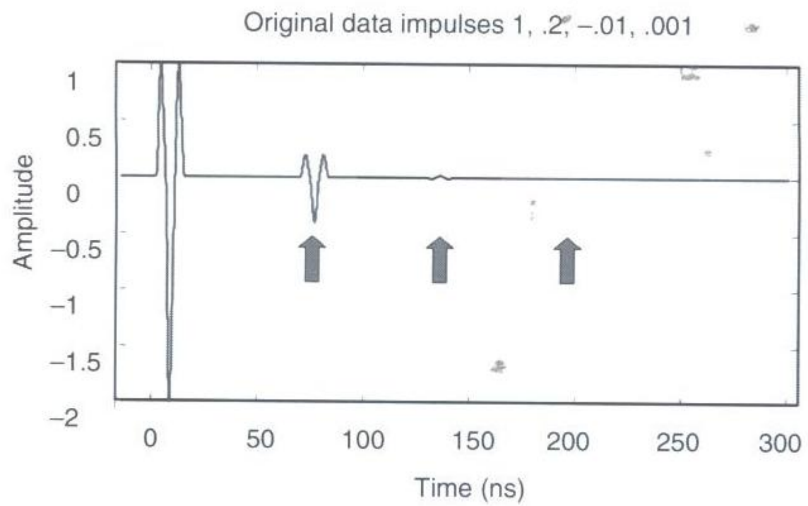


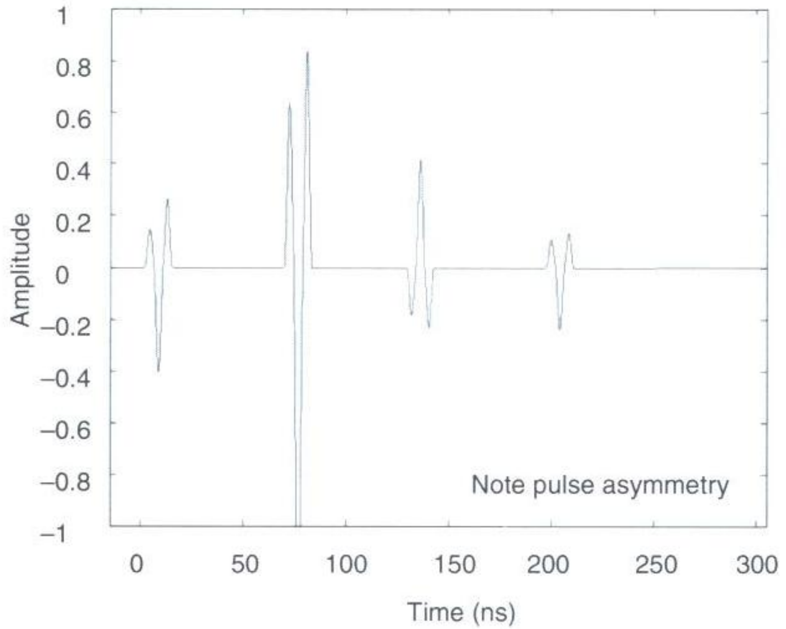
Gain example

- Processed “amplified” data:



Comparison


Original data impulses 1, .2, −.01, .001
Amplitude
1
0.5
0
−0.5
−1
−1.5
−2
0
50
100
150
200
250
300
Time (ns)


Amplitude
1
0.8
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
−0.8
−1
0
50
100
150
200
250
300
Time (ns)
Note pulse asymmetry

Stacking/noise suppression

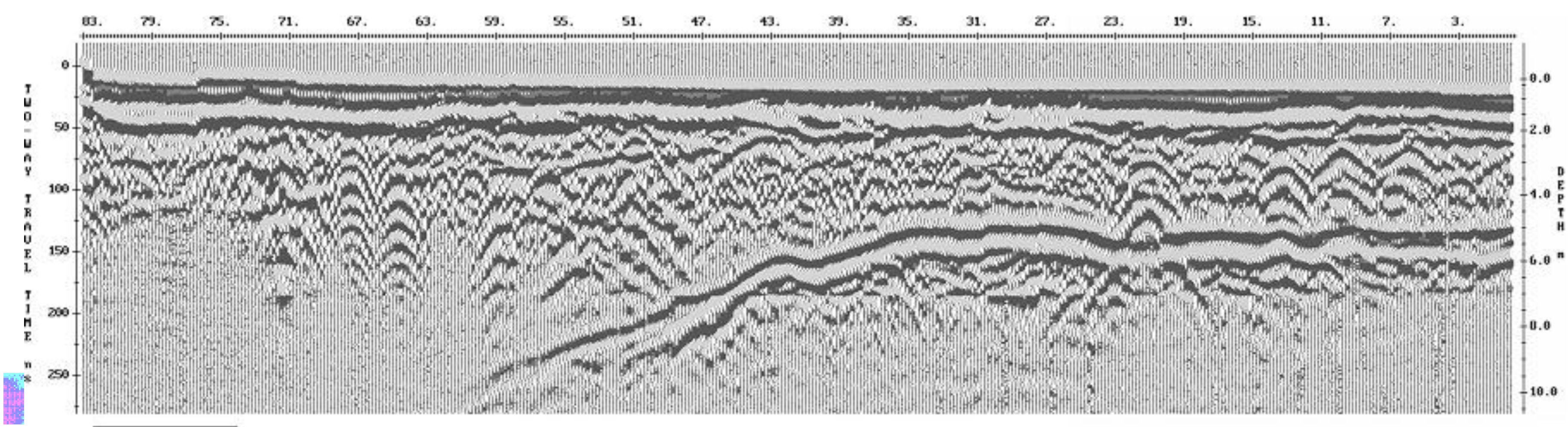
- Various strategies can be employed:
  - Stacking of individual readings
  - Smoothing of individual traces
  - Averaging of neighboring traces
    - Tends to emphasize horizontal structure

Typical GPR common offset response patterns and questions

- General characteristics
  1. Max. two way travel time (2wtt) recorded.
  2. Survey line length.
  3. Station (trace) spacing.
  4. Identify a single trace.
  5. Surface signals.
     A) Sketch it's waveform shape.
  6. Where are the "Latest" visible signals?
     A) Did they record long enough traces?
  7. What is their 2wtt?
  8. What is the time of the earliest useful signals?
  9. Guesstimate error bars on identifying 2wtt.

- Geologic features:
  10. More conductive / less conductive ground
  11. 1 shallow reflecting horizon (called a reflector). What is it saying about geology?
  12. 1 deeper reflector. What is it saying about geology?
      A) Sketch the shape of the signal being reflected.
  13. Guesstimate *V*, and resulting depths to lower interface.
  14. What is the maximum dip of the interface?
  15. Any possible "objects" (boulders, pipe lines etc.)?
  16. Region where very near surface materials appear variable.

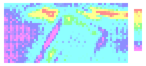
METRES



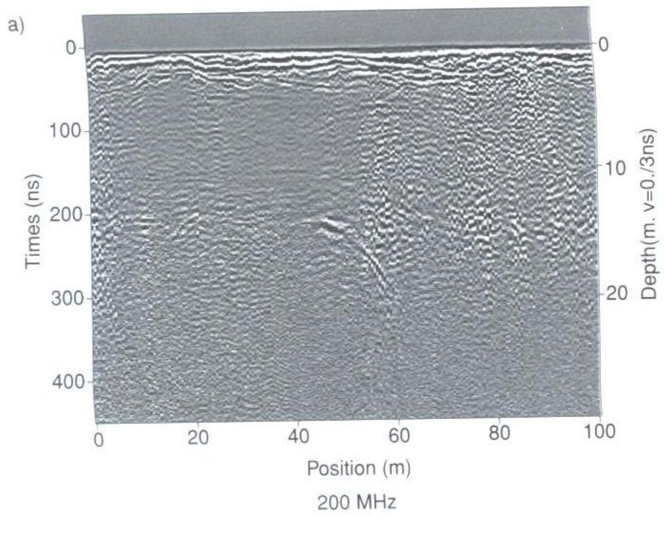
Case Histories:

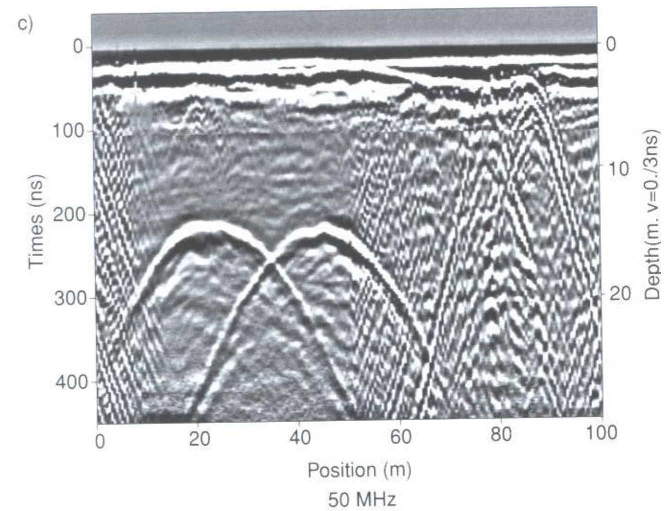
- http://www.sensoft.ca/

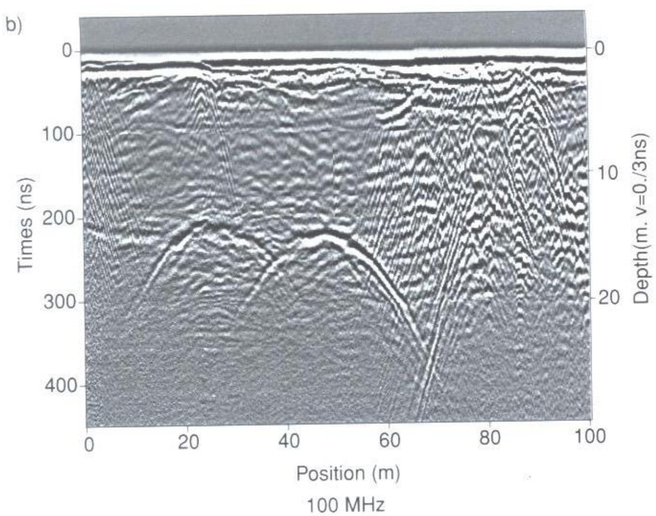
- My hand notes on GPR (basic useful equations to understand GPR signatures and resolution)



GPR Frequencies





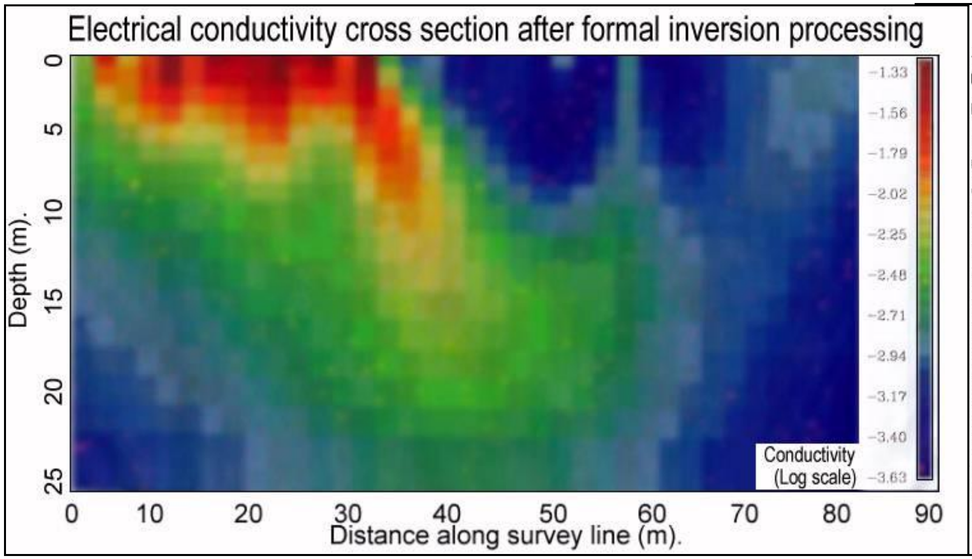


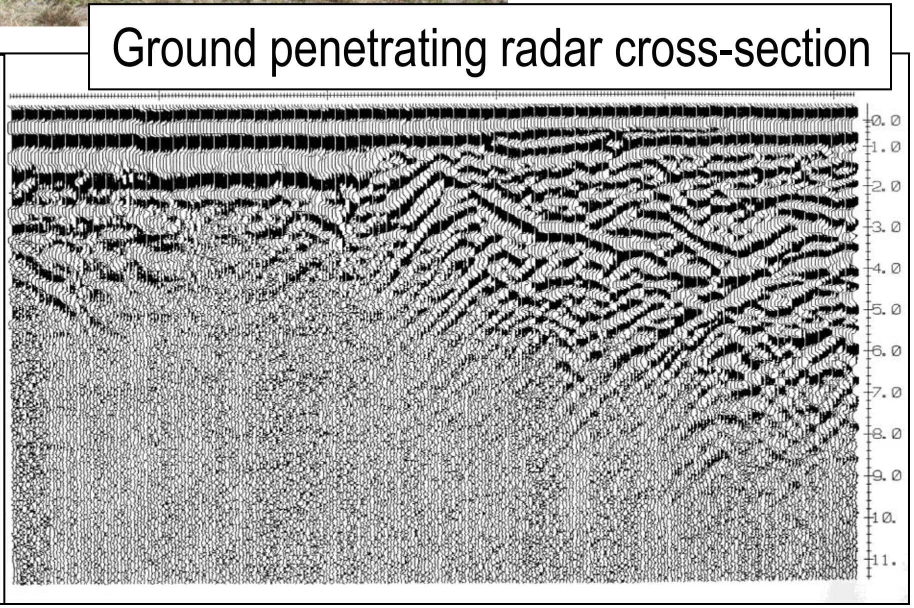
Same survey using 200 Mhz, 100 Mhz, 50 Mhz GPR center frequencies

Two underground tunnels, with a rock texture on the scale of 30 cm

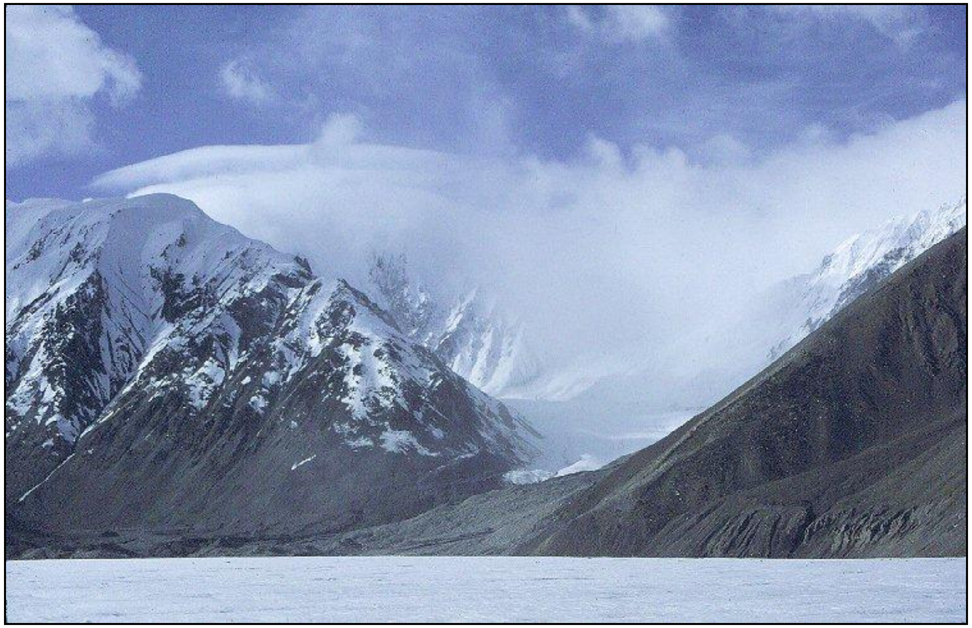
Wave-length of the GPR signal should be much larger than the wavelength of the "clutter"

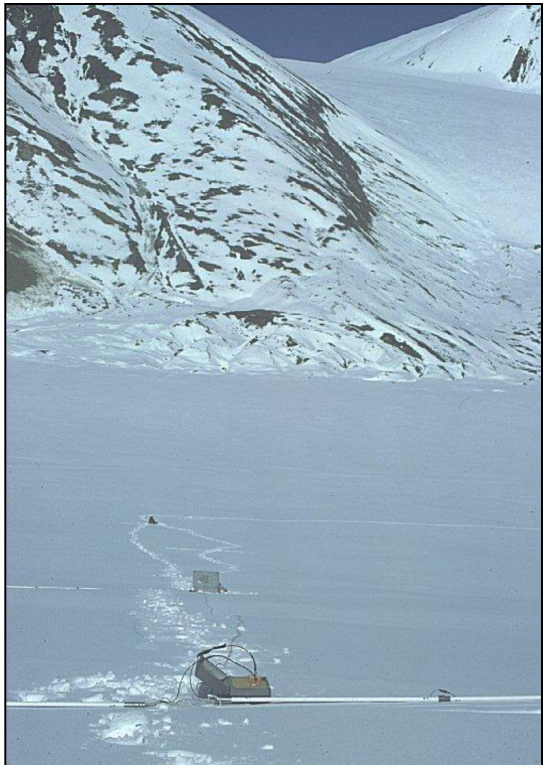
Egs: Ground water studies

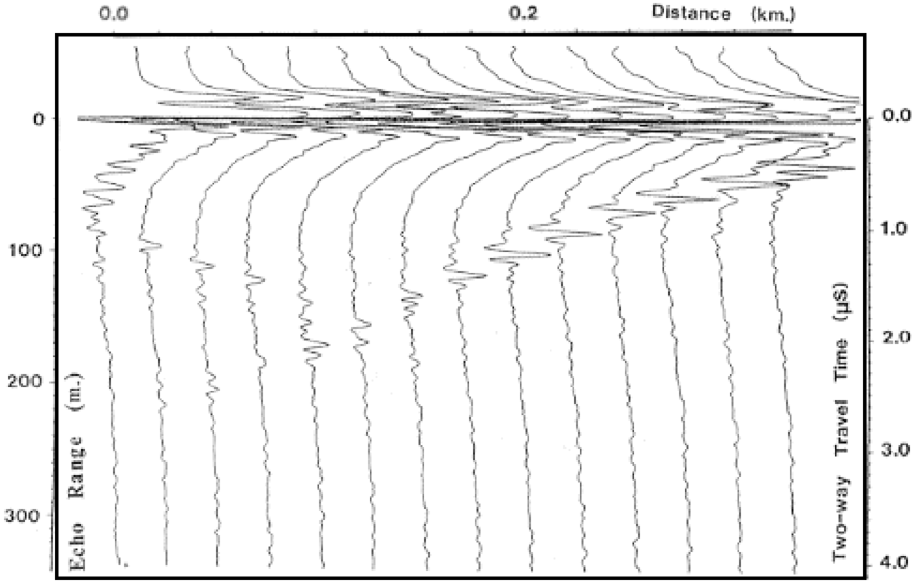


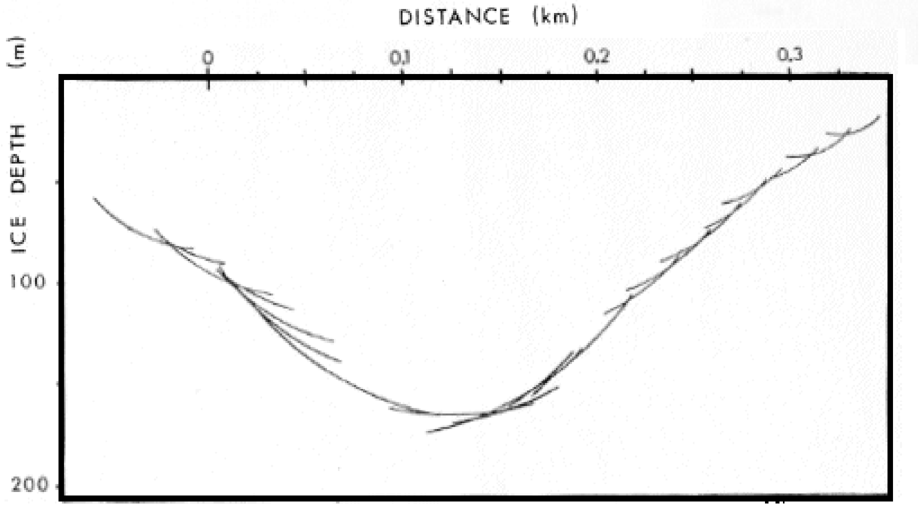


Egs: GPR on Glaciers









GPR on glaciers

"Cold" ice is nearly transparent to radio waves.

- Glaciers are where GPR was first successfully employed
  - Accidental behaviour of aircraft radar altimeters
  - Very cold (Antarctic) ice
  - Originally analogue (not digital) systems

- Digital systems are more recent (late 1980's) owing to very high speeds involved. Electronics is sophisticated.
  - Total travel times < ¼ microsecond
  - Samples of < nanosecond (a billionth of a second)

GPR: Some study points

- What are the physical properties of interest? What are the connections with the EM waves?
- What are the equations for velocity and attenuation,
  - What was assumed?   About frequencies? About conductivity? Magnetic permeability?
- What are the modes of data acquisition, how do they differ, and why are they used?
  - Common offset, versus common midpoint
- How are velocities obtained? How are depths obtained? What are the data?

GPR: Some study points

- What are important features to look for when interpreting radargrams?
- How does the frequency of the transmitter control the GPR wavelet and what is the connection with resolution?

Wednesday : GPR Quiz

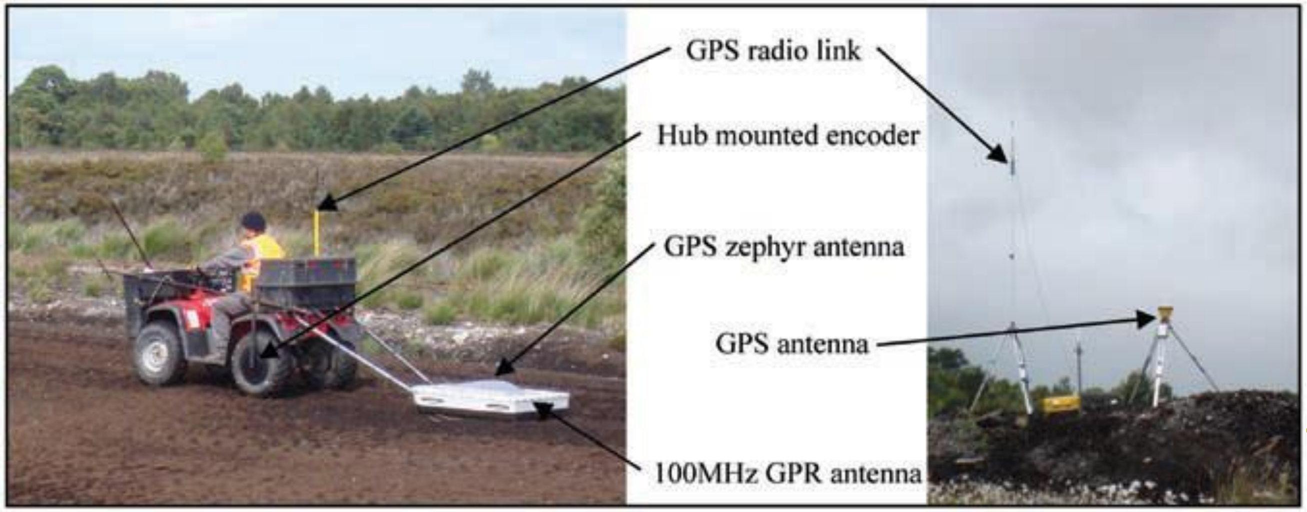
- Friday Nov 5   TBL
- Advances in long-range GPR systems and their application to mineral exploration geotechnical and static correction problems by Jan Francke and Vince Utsi

Other Case Histories

- Mapping Peat Thickness (CH3)

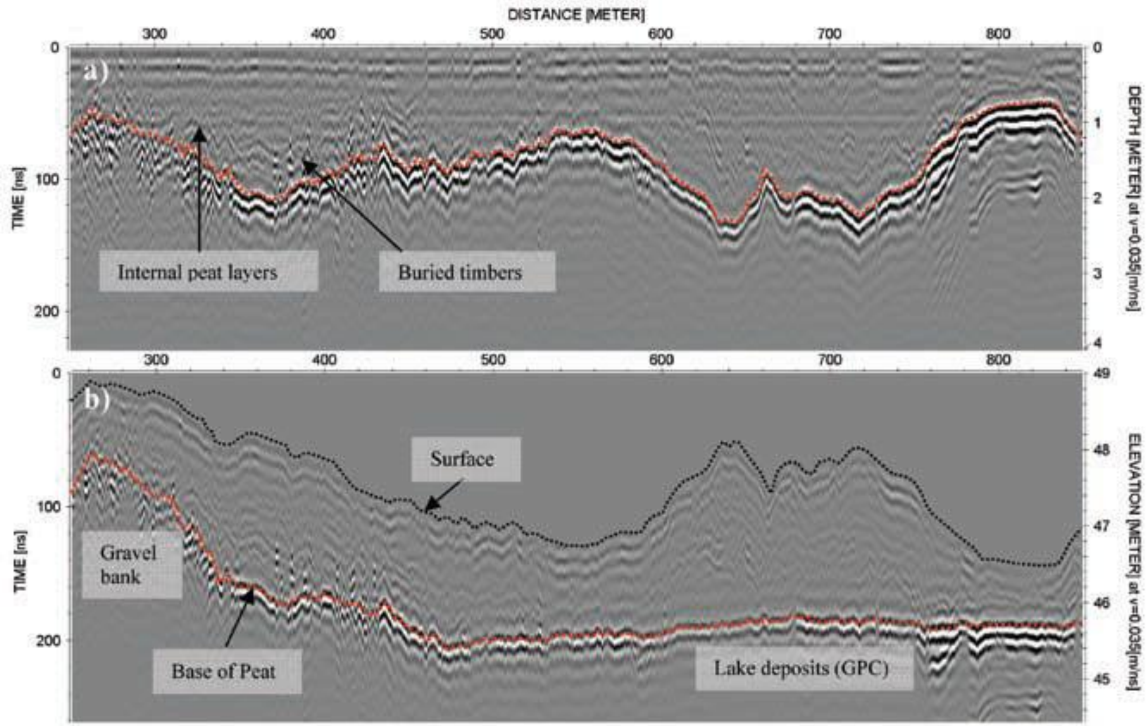
CH3: Mapping Peat Thickness

- **Setup:** Bog material in raised bogs is used for energy production. Need to map out thickness of the bog over 35,000 Ha.
- **Properties**: Peat is a porous carbon material with large water content (they need to dry it before using). Region below is listed as lake deposits. Possibly a difference is water content and texture and this may provide a difference in dielectric permittivity.
- **Survey**: GPR (Ground Penetrating Radar) Towed 100MHz antenna, with RTK GPS for positional accuracy. (20mm)
- **Data:** Profiles collected every 60 m and plotted as distance-time sections.



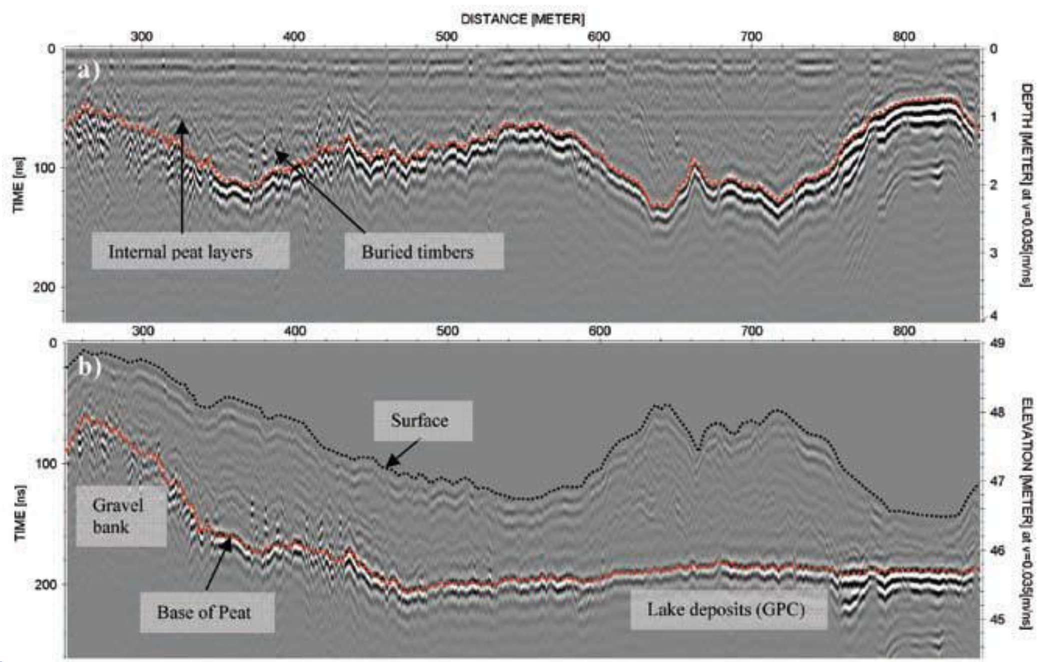
CH3: Mapping Peat Thickness

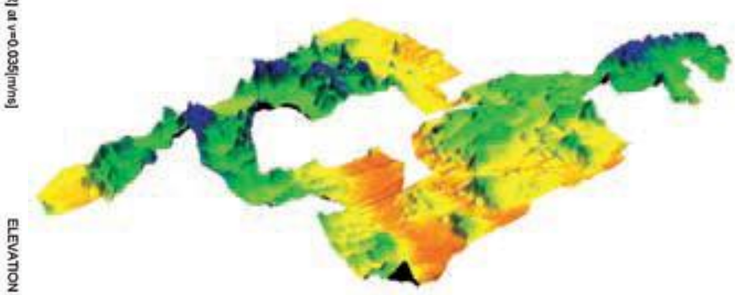
- **Data:** Profiles collected every 60 m and plotted as distance-time sections.
- **Processing:** Processed to remove topography effects and identify correlated reflection events.
- **Interpretation:** Peat augur (borehole device) was used to calibrate the data. The base of the peat was identified at various checkpoints and then the associated reflector interpolated throughout the section. The thickness of the peat is provided in ms.



CH3: Mapping Peat Thickness

- **Interpretation:** Peat augur (borehole device) was used to calibrate the data. The base of the peat was identified at various checkpoints and then the associated reflector interpolated throughout the section. The thickness of the peat is provided in ms. The 2D sections are interpolated and presented as a 3D image. (Picture)
- **Synthesis**: Survey results are listed as being invaluable in the future planning of the remaining peat resources.



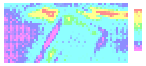


Other Case Histories

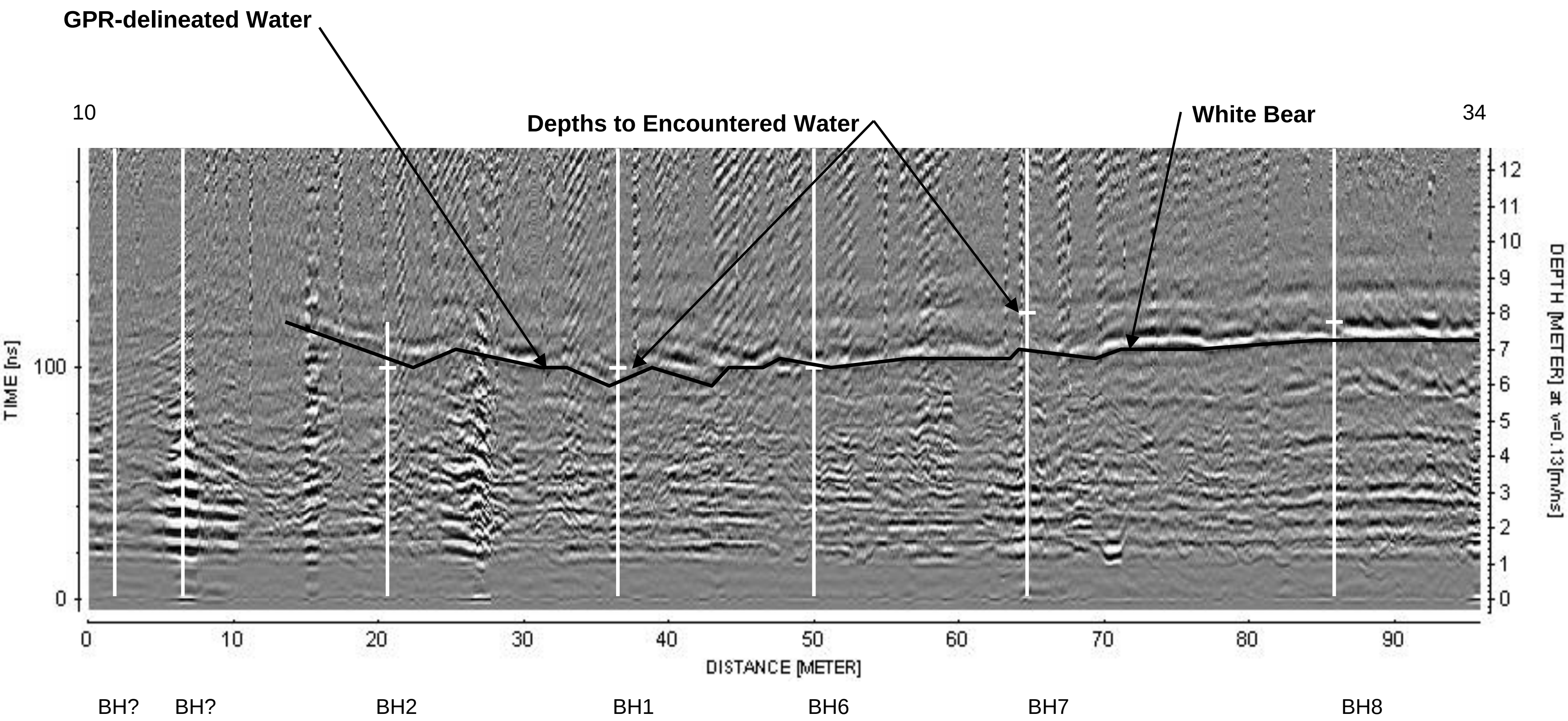
- Potash mine to find water. (Comparison with Electrical Resistivity Imaging ERI)

UNDERGROUND GEOPHYSICS

GPR AND ELECTRICAL RESISTIVITY IMAGING



GPR USED TO DELINEATE WATER ABOVE BACK



No Water Encountered

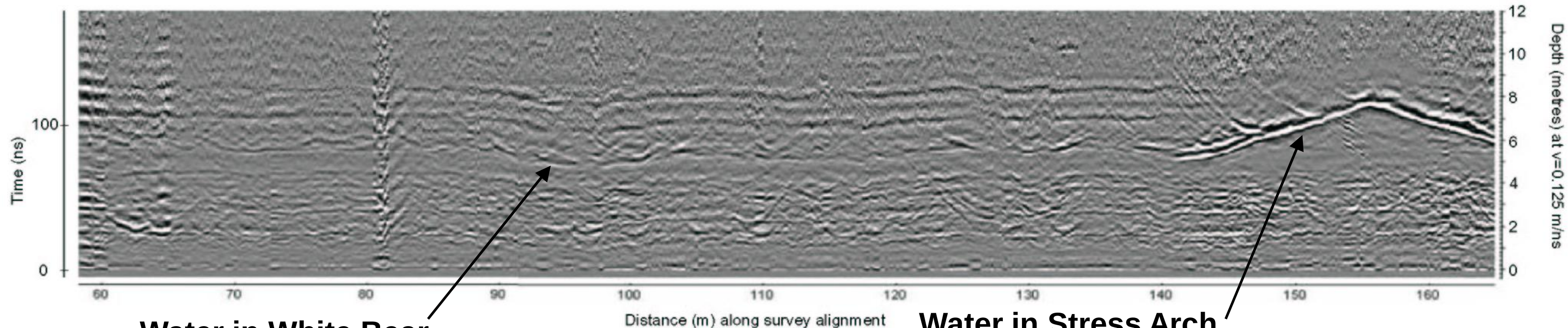
1. Distances are based on approximate 4 m spacing between wall markings which are indicated by the numbers (e.g. 321**).**

ERI IN UNDERGROUND DRIFTS USED TO DELINEATE WATER ABOVE BACK

GPR AND ERI PROFILES

FIGURE 1

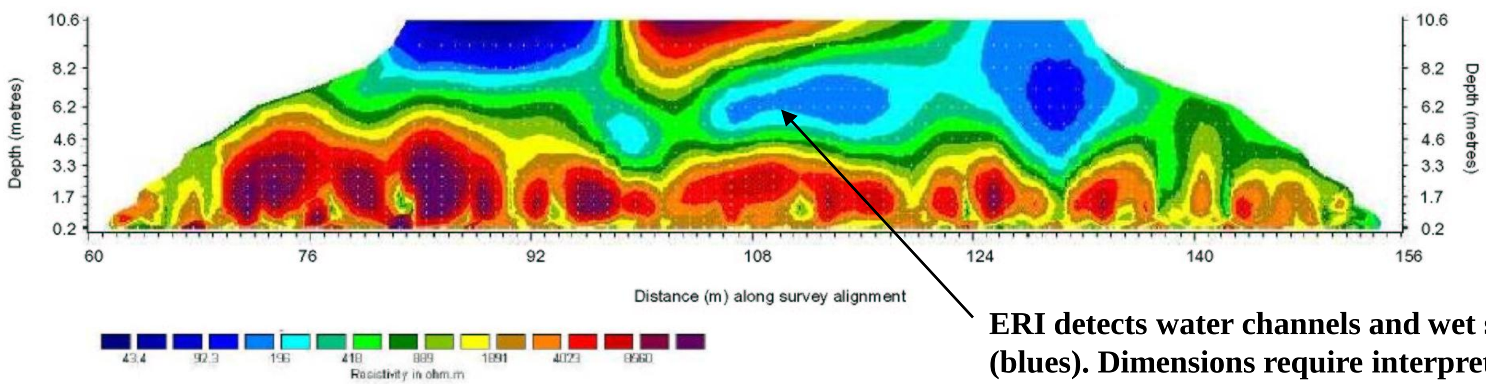
GPR Profile



Water in White Bear

Water in Stress Arch

Electrical Resistivity Model

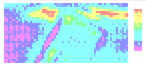


ERI detects water channels and wet salt (blues). Dimensions require interpretation.

NOTES

1. Figure is not to scale.
2. Unit electrode spacing is 1.0 metre.

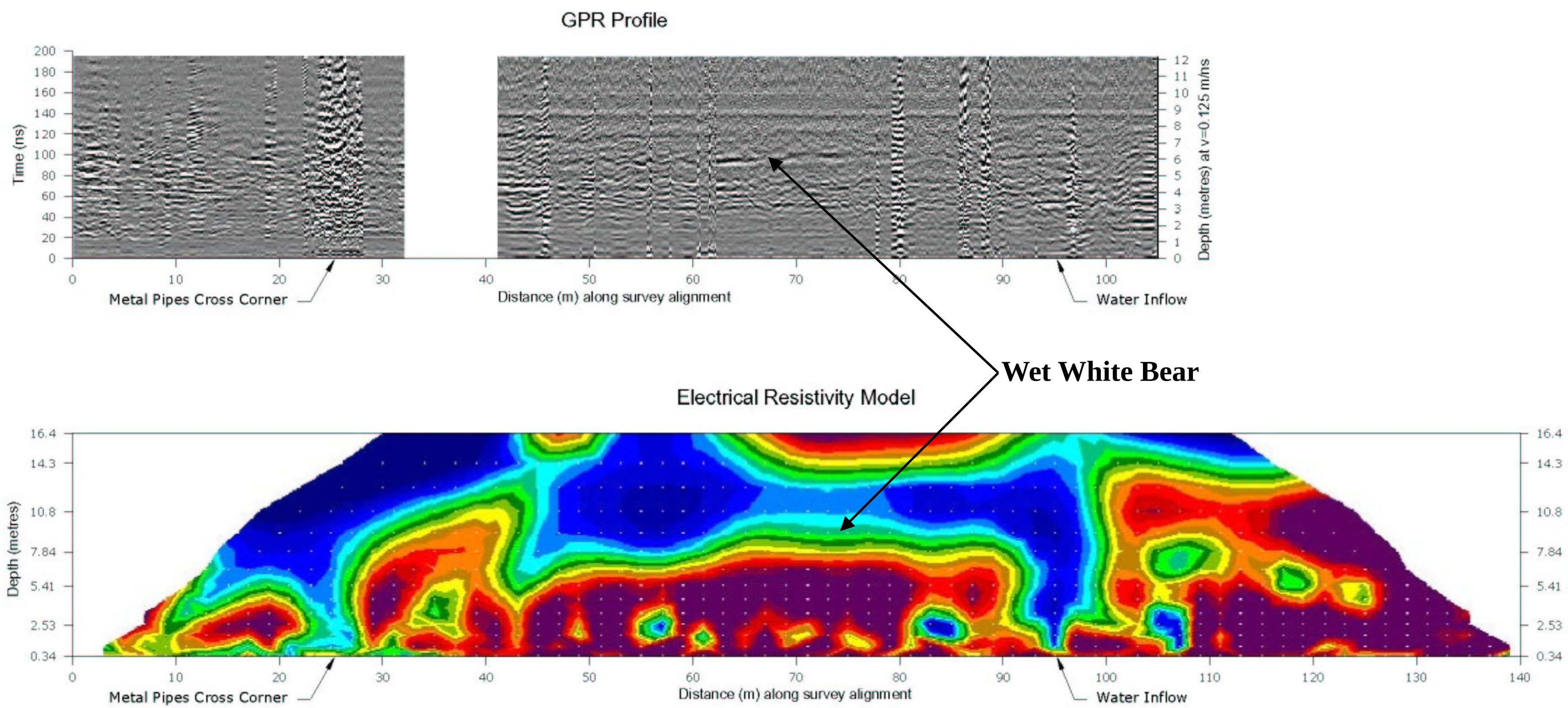
O:/ACTIVE/2003/

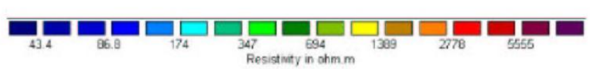


ERI USED TO DELINEATE WATER CHANNEL ABOVE BACK

GPR and ERI PROFILES AT WATER INFLOW

FIGURE 3



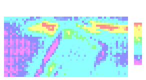


Water inflow (1 m from nearest electrode) is delineated by ERI profiling. Metal pipes extend along drift but rust must insulate them from providing a low resistance flow path.

O:\ACTIVE_2003\

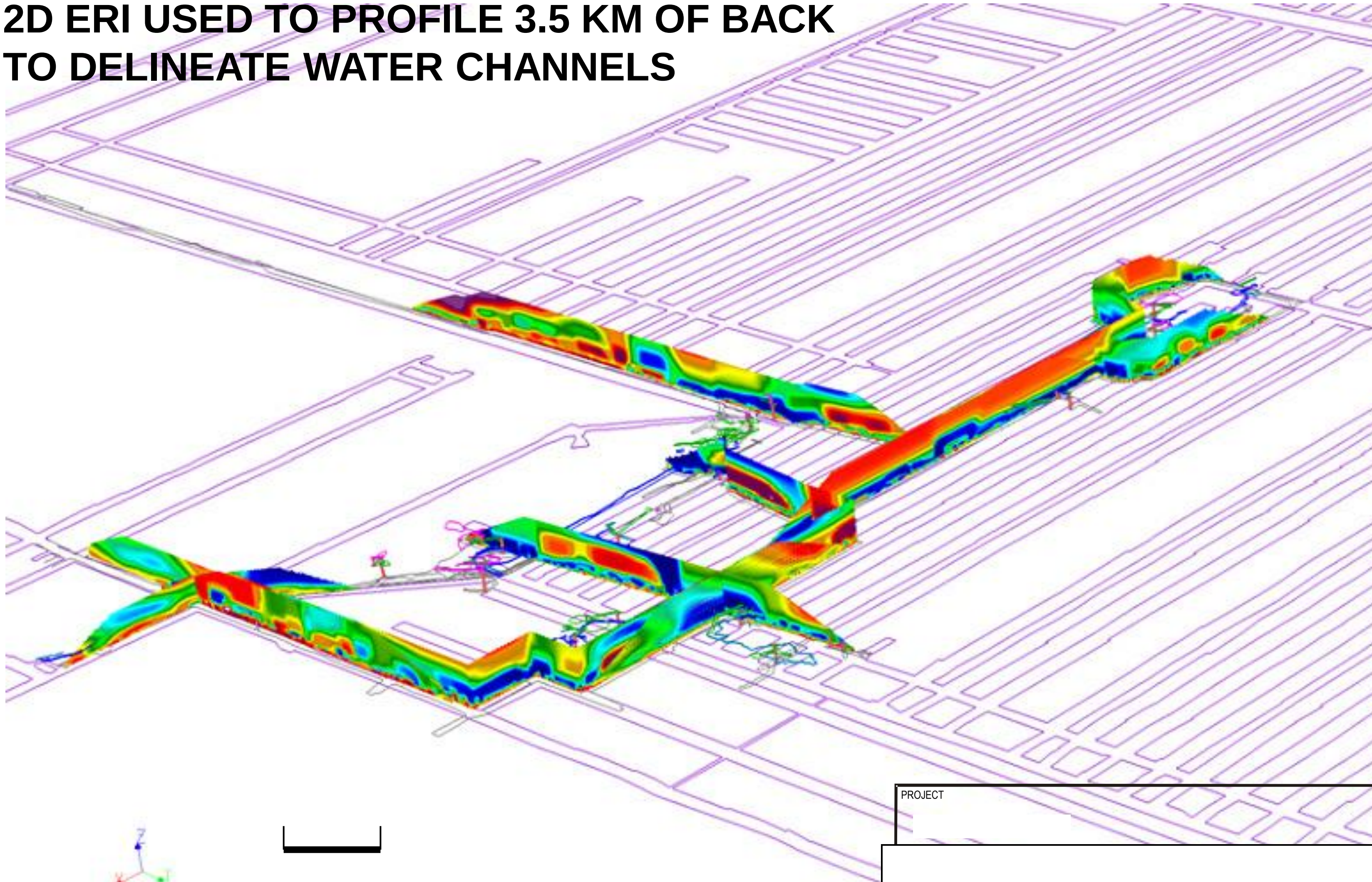
NOTES

1. Figure is not to scale.
2. Unit electrode spacing is 2.0 metre.



REVISION DATE: BY: FILE:

2D ERI USED TO PROFILE 3.5 KM OF BACK TO DELINEATE WATER CHANNELS



100 metres Approximate Scale

PROJECT