Ground-Penetrating Radar

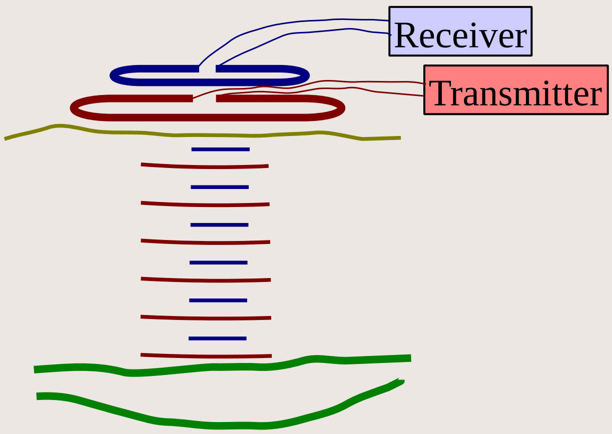
(also Ground-Probing Radar, GPR)

- Similarities and dissimilarities to seismic
- Case histories

- <u>Reading:</u>
  - Reynolds, Chapter 12

GPR Principles

- Uses 30-1000 MHz electromagnetic (radio) waves emitted in short “chirps” for probing the subsurface
  - Two dipole antennas as source and receiver
  - Automatically stacks series of pulses for noise reduction
- Directly produces a zero-offset section
  - Optionally, can also be used to produced a constant-offset or walkaway sections
- Sensitive to *dielectric permittivity* (ε) and *conductivity* (σ)
  - ε varies strongly for different materials (from 1 to max $\varepsilon \approx 80$ for water), which makes material contrasts reflective



Electric properties of materials

- Note ranges: green = lowest values, red = largest values

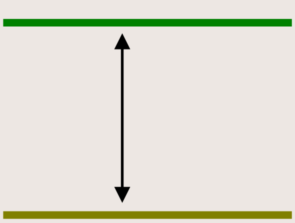
Material	Dielectric permittivity ε	Conductivity σ (mSiemens/m)	GPR wave velocity (m/ns)
Air	1	0	0.3
Distilled water	80	0.01	0.033
Fresh water	80	0.5	0.033
Sea water	80	3000	0.01
Dry sand	3 - 5	0.01	0.15
Saturated sand	20 - 30	0.1 - 1.0	0.06
Limestone	4 - 8	0.5 - 2.0	0.12
Shales	5 - 15	1 - 100	0.09
Silts	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
Concrete	7	0.001 – 0.01	0.08

Propagation and reflection of radio waves

- Velocity: $c = \frac{c_0}{\sqrt{\varepsilon\mu}} \approx \frac{c_0}{\sqrt{\varepsilon}}$
  - the fastest for the 'air' wave: $c_0 \approx 3 \cdot 10^8$ m/s
  - generally decreases with depth
- Impedance: $Z = \sqrt{\frac{\mu}{\varepsilon}} \approx \sqrt{\frac{1}{\varepsilon}}$ [Ohms]
- Reflection coefficient for amplitude:

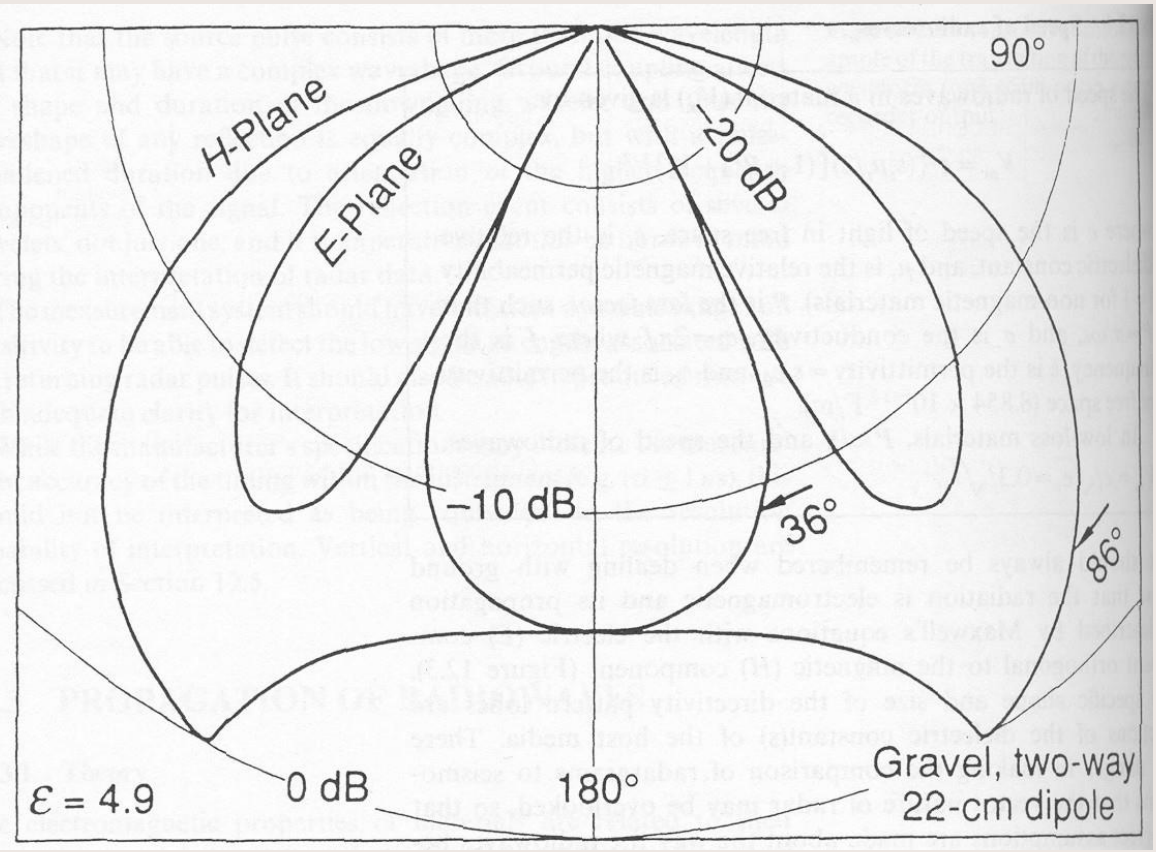
$$R = \frac{Z_2 - Z_1}{Z_2 + Z_1}$$

- Two-way travel times (see table in the preceding slide):
  - Air: 6 ns/m
  - Unsaturated sand: 12-18 ns/m
  - Saturated sand: 18-27 ns/m



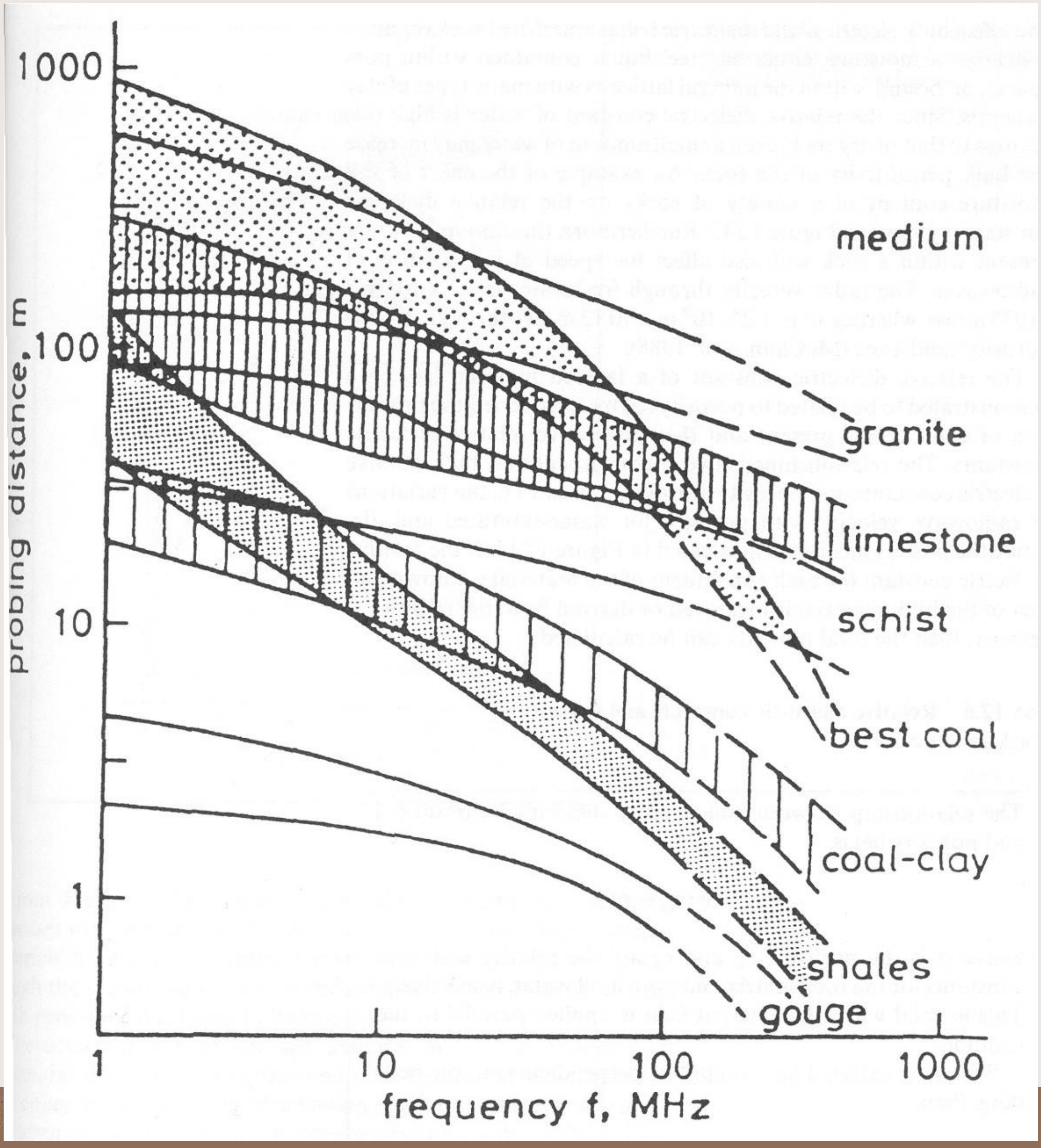
Antenna directivity

- GPR antenna focuses energy in a beam directed downward
- Receiver antenna has a similar sensitivity pattern
- These properties of antennas favor reflection imaging



Depth penetration of GPR waves

- GPR wave penetration strongly depends on the conductivity (presence of clays, saline fluids) within the subsurface



Depth resolution

- As with seismic waves, vertical resolution limit of GPR equals $\delta z = \lambda/4$
  - Therefore, δz is proportional to wave velocity and inversely proportional to frequency
  - These are approximate estimates. In practice, δz may be larger or smaller depending on the signal/noise ratio and signal bandwidth

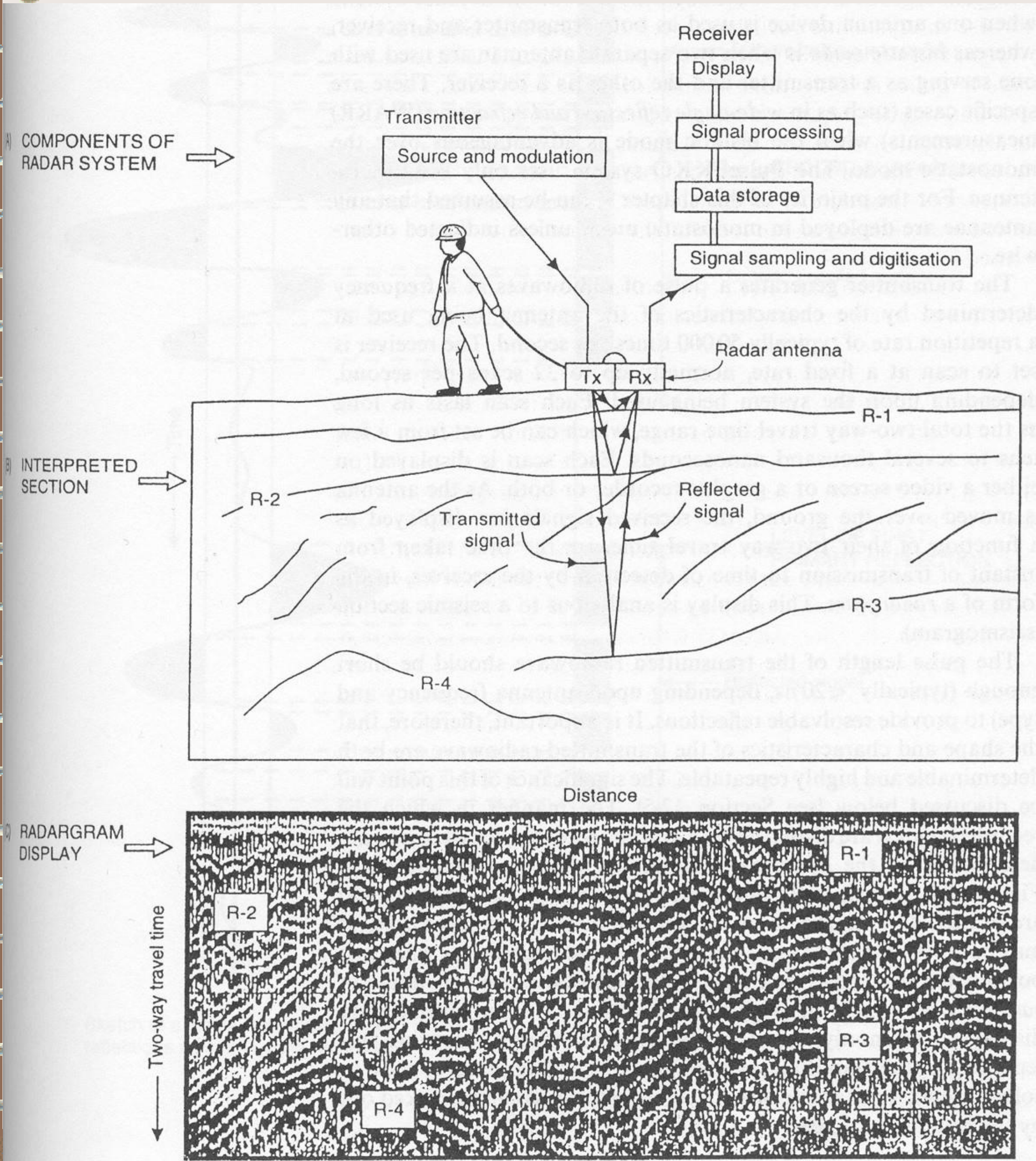
Material	Dielectric permittivity ε	δz at f_c = 100 MHz (cm)	δz at f_c = 500 MHz (cm)
Air	1	75	15
Water	80	8.5	1.5
Dry sand	3 - 5	43 - 33	8 - 6
Saturated sand	20 - 30	17 - 13	3.5 - 3
Limestone	4 - 8	75 - 53	15 - 10
Shales	5 - 15	65 - 40	13 - 8
Silts	5 - 30	67 - 27	13 - 5
Clays	5 - 40	66 - 24	13 - 5
Granite	4 - 6	75 - 60	15 - 12
Dry salt	5 - 6	67 - 60	13 - 12
Ice	3 - 4	85 - 75	17 - 15
Concrete	7	55	11

- Note ranges: green = lowest values, red = largest values

Relation to Reflection Seismics

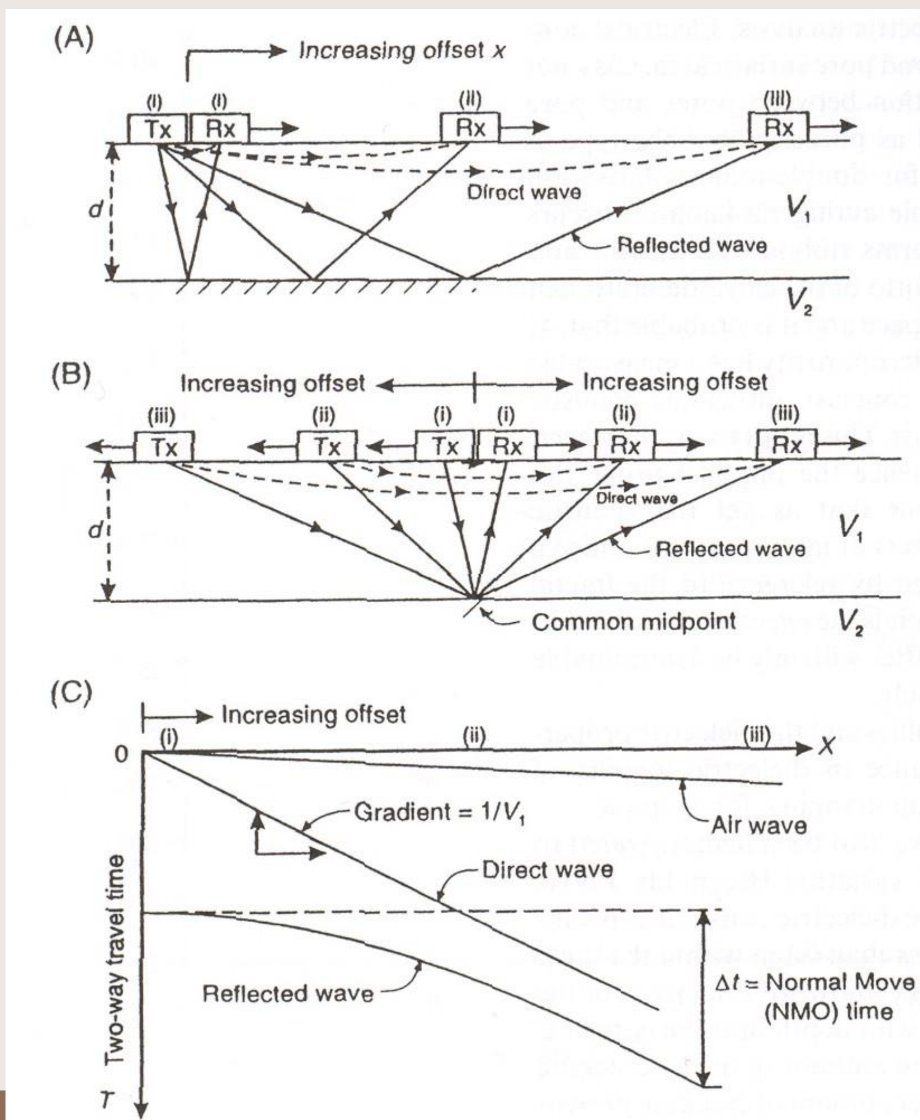
- Similarities:
  - Processing procedures (filtering, stacking, migration)
  - Appearance of the zero-offset section
  - Resolution-frequency relationships
  - Interpretation techniques
- Differences:
  - Nanoseconds (*ns*) instead of milliseconds (*ms*)
    - Sub-meter vertical resolution and ~10-100 m penetration
  - Electrical properties instead of acoustic impedance
    - Very sensitive to buried metallic objects
  - Velocities decrease with depth
    - Rays bend *toward* the vertical
    - Free-air arrival is the *fastest*
    - Faster attenuation
    - Large velocity contrasts
  - Sub-meter resolution
- Thus, GPR is a valuable complementary technique to shallow seismics

GPR operation



GPR acquisition styles

- Zero-offset (collocated source and receiver antennas)
  - Most typical in GPR work
  - Inexpensive 3-D surveys
- Wide-angle or expanding CMP surveys to measure velocities



GPR applications

- Generally, any cases where the subsurface is *not* too conductive but targets have different electric properties
- Geological:
  - Detection of natural cavities and fissures
  - Subsidence mapping
  - Mapping sand body geometry
  - Mapping of superficial deposits
  - Soil stratigraphy mapping
  - Glacial geological investigations
  - Mineral exploration and resource evaluation
  - Peat thickness mapping and resource evaluation Permafrost investigations
  - Location of ice wedges
  - Fracture mapping in rock salt
  - Location of faults, dykes, coal seams, etc.
  - Geological structure mapping
  - Lake and riverbed sediment mapping

GPR applications (cont)

- Environmental:
  - Contaminant plume mapping
  - Mapping and monitoring pollutants within groundwater Landfill investigations
  - Location of buried fuel tanks and oil drums
  - Location of gas leaks
  - Groundwater investigations
- Glaciological:
  - Ice thickness mapping
  - Determination of internal glacier structures
  - Ice movement studies
  - Detection of concealed surface and basal glacier crevasses Mapping water conduits within glaciers
  - Determination of thickness and type of sea and lake ice Sub-glacial mass balance determination
  - Snow stratigraphy

GPR applications (cont)

- Engineering and construction:
  - Road pavement analysis
  - Void detection
  - Location of reinforcement (rebars) in concrete
  - Location of public utilities (pipes, cables, etc.)
  - Testing integrity of building materials
  - Concrete testing
- Archaeology:
  - Location of buried structures
  - Pre-excavation mapping
  - Detection of voids (crypts, etc.)
  - Location of graves
- Forensic science:
  - Location of buried targets (*e.g*. bodies and bullion)

GPR equipment
Systems with shielded antennas

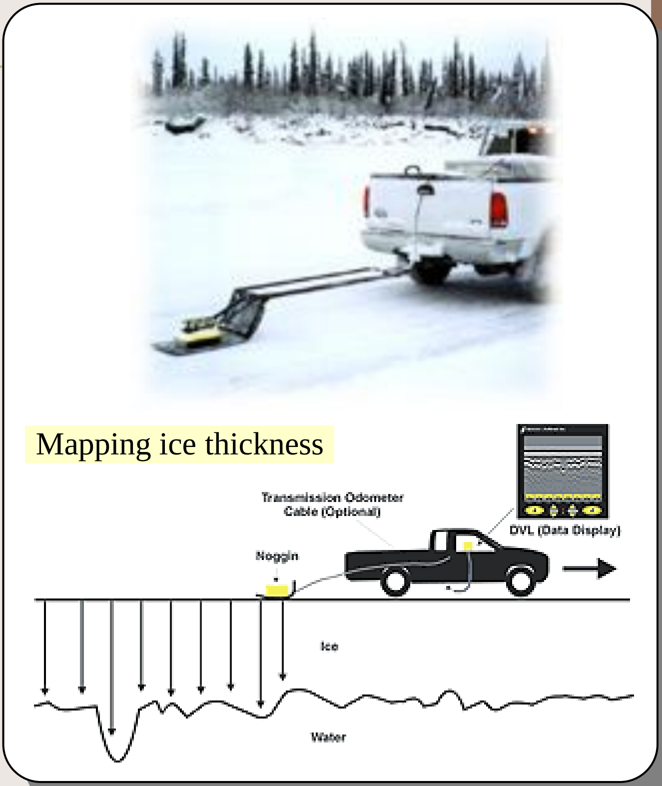
PulseEKKO RockNoggin

PulseEKKO 1000

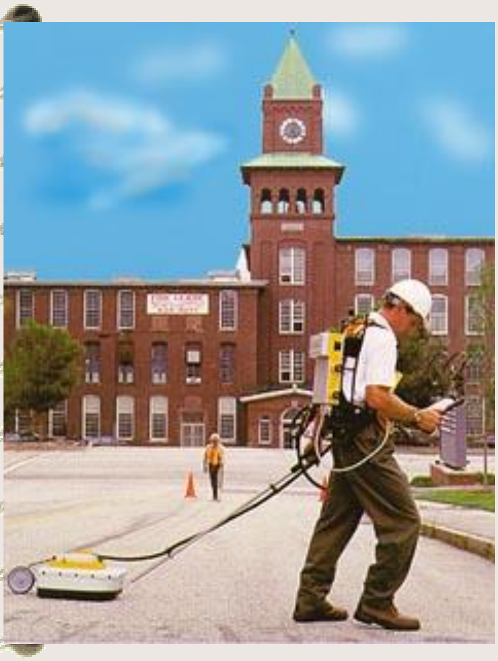
PulseEKKO 100

GPR applications


Archeology



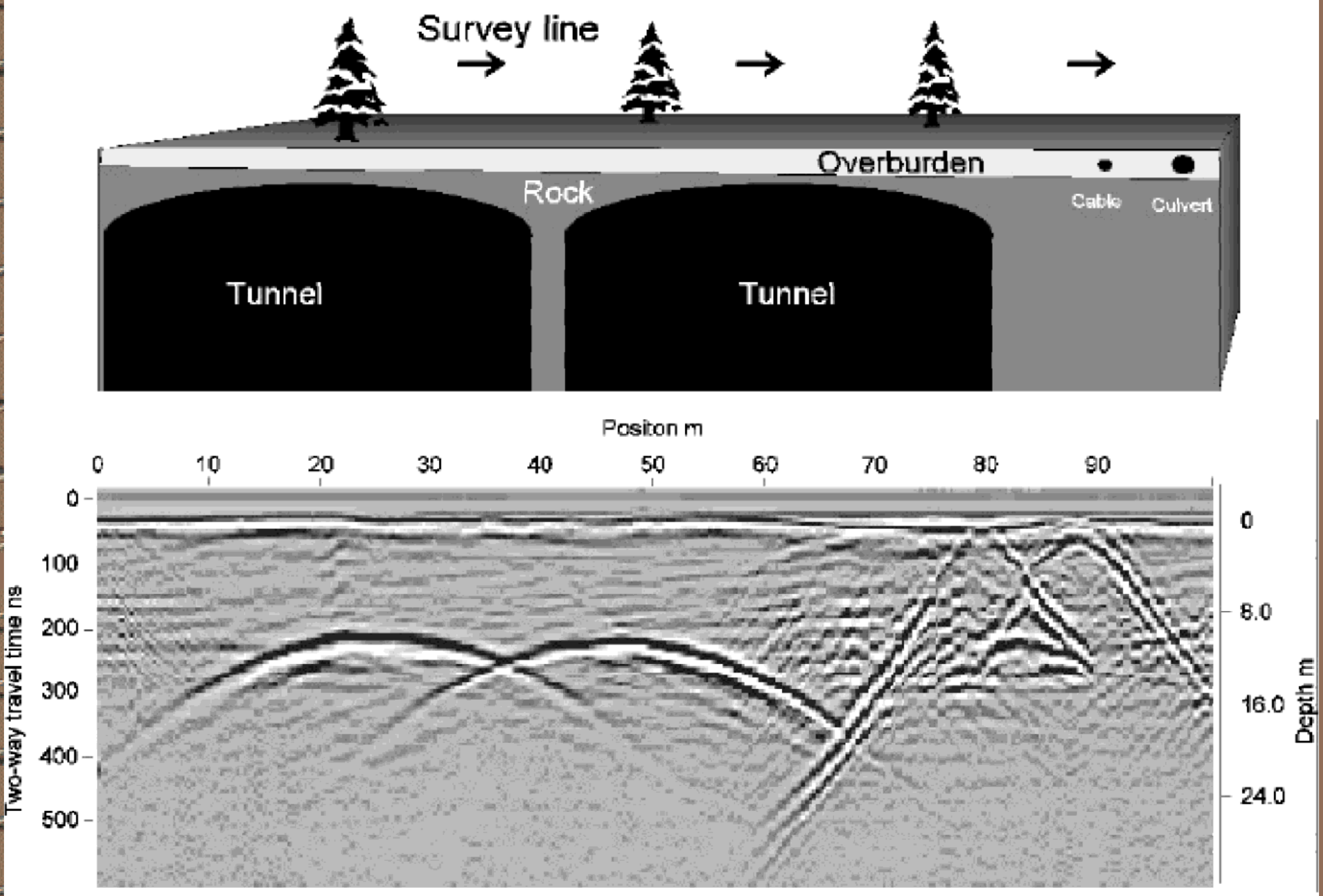
Mapping ice thickness




SnowNoggin

Case history: Engineering

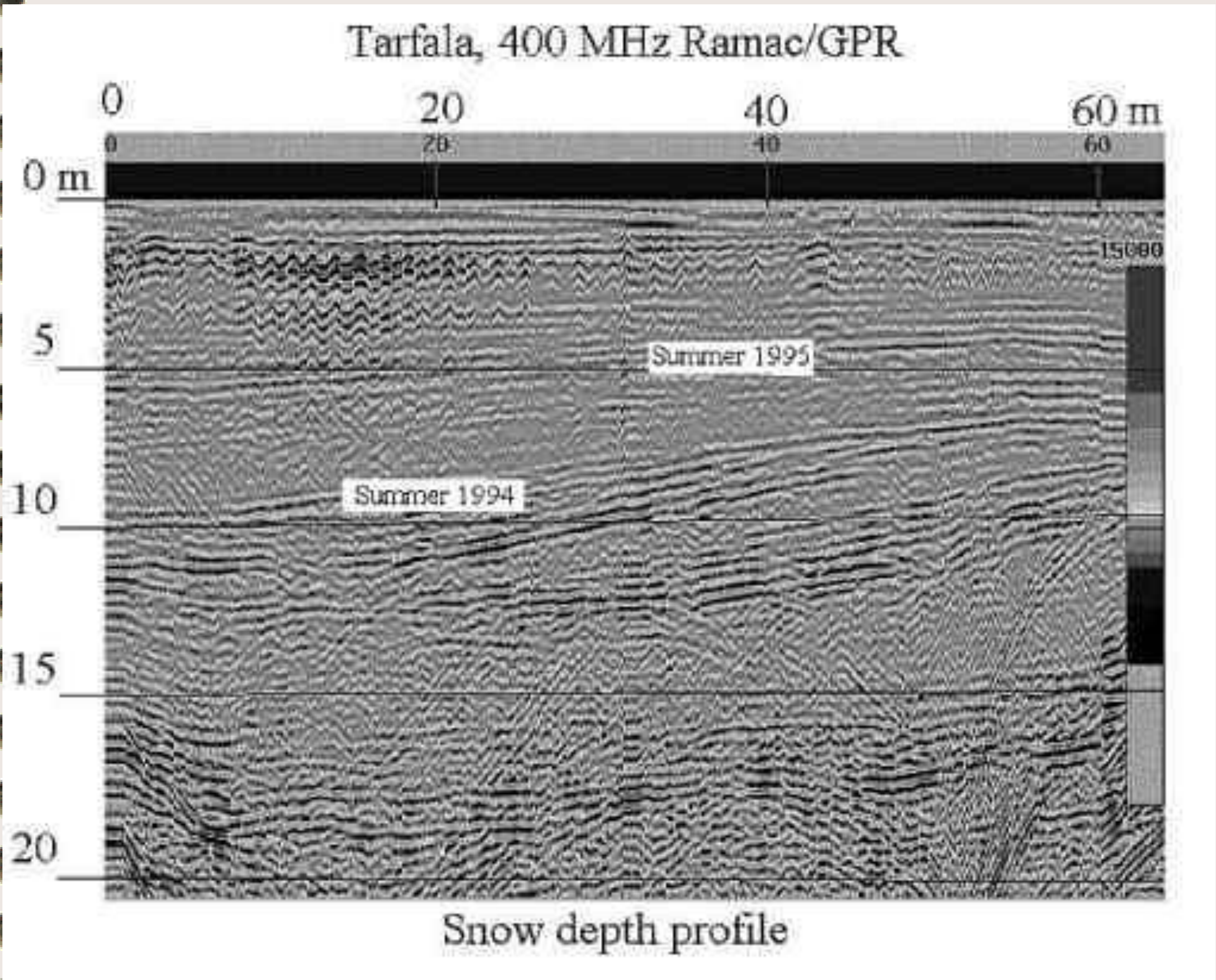
- Detecting tunnels (Sweden)



- **50-Mhz GPR locates two tunnels at 11 meters depth**
- **GPR locates a cable and culvert**
- **GPR defines overburden thickness**

Case history: Glaciology

- Measuring snow depth on Storglacierien, a small polythermal glacier in northern Sweden.
- Snow thickness were estimates by identifying summer ice surfaces

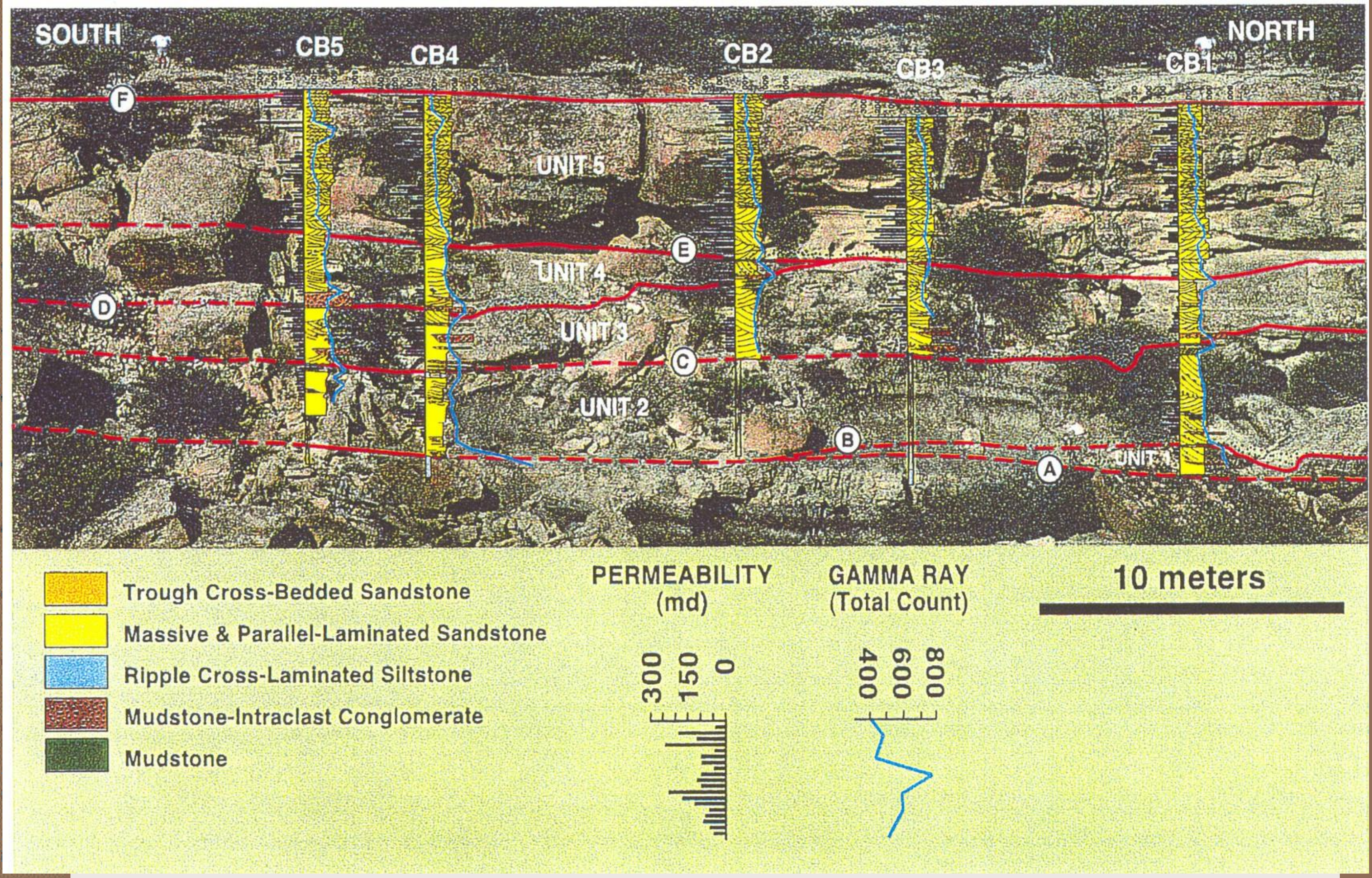


From http://www.terraplus.com/gpr_case_study.htm

Case history:

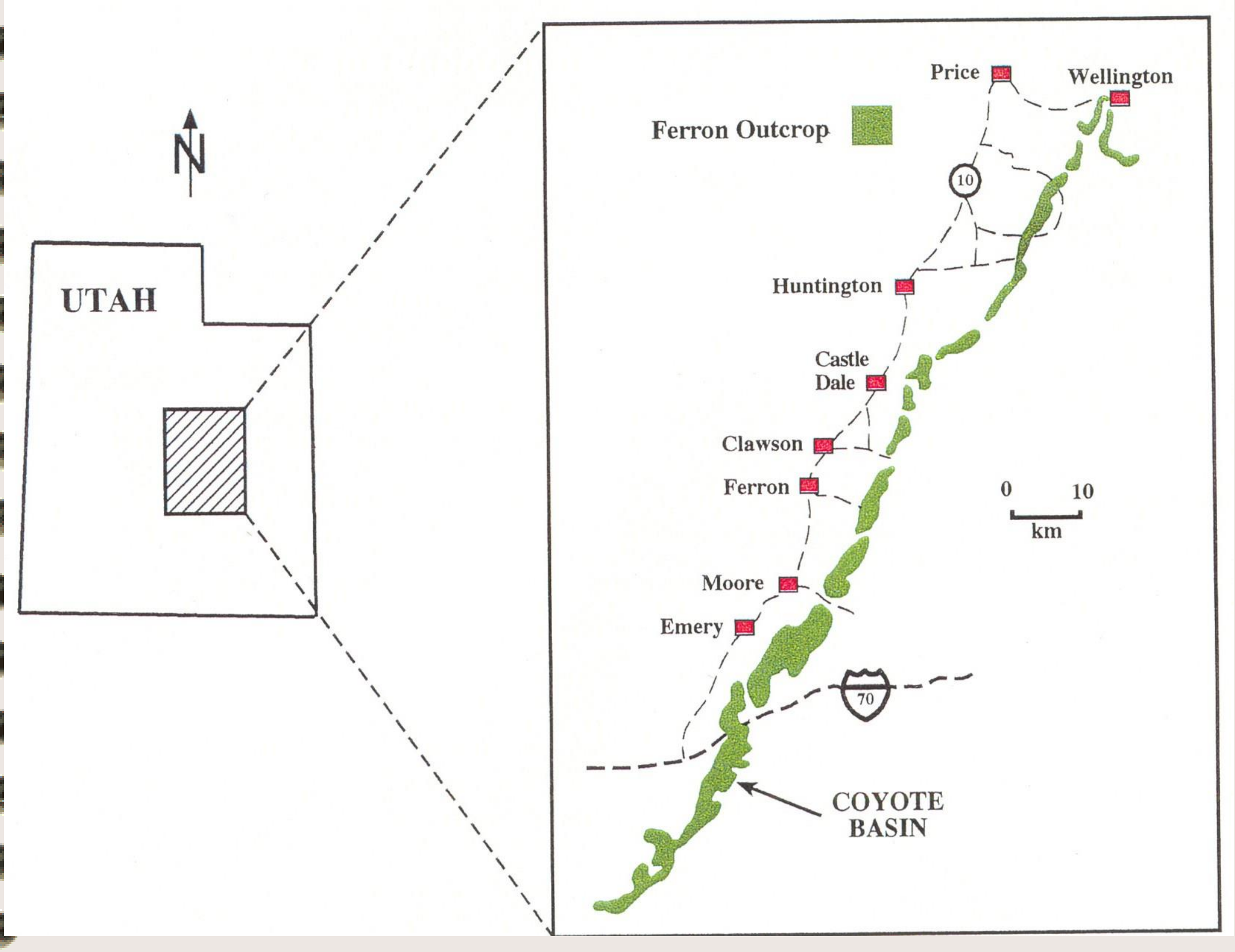
3D characterization of a clastic reservoir analog (*Szerbak et al.*, 1999)

- Integration of multiple geophysical approaches:
  - Mapping outcrop
  - 3-D GPR cube adjacent to the outcrop
  - Well logging and sampling
  - Geostatistics of permeability/velocity/depth relationships
  - Inversion for permeabilty



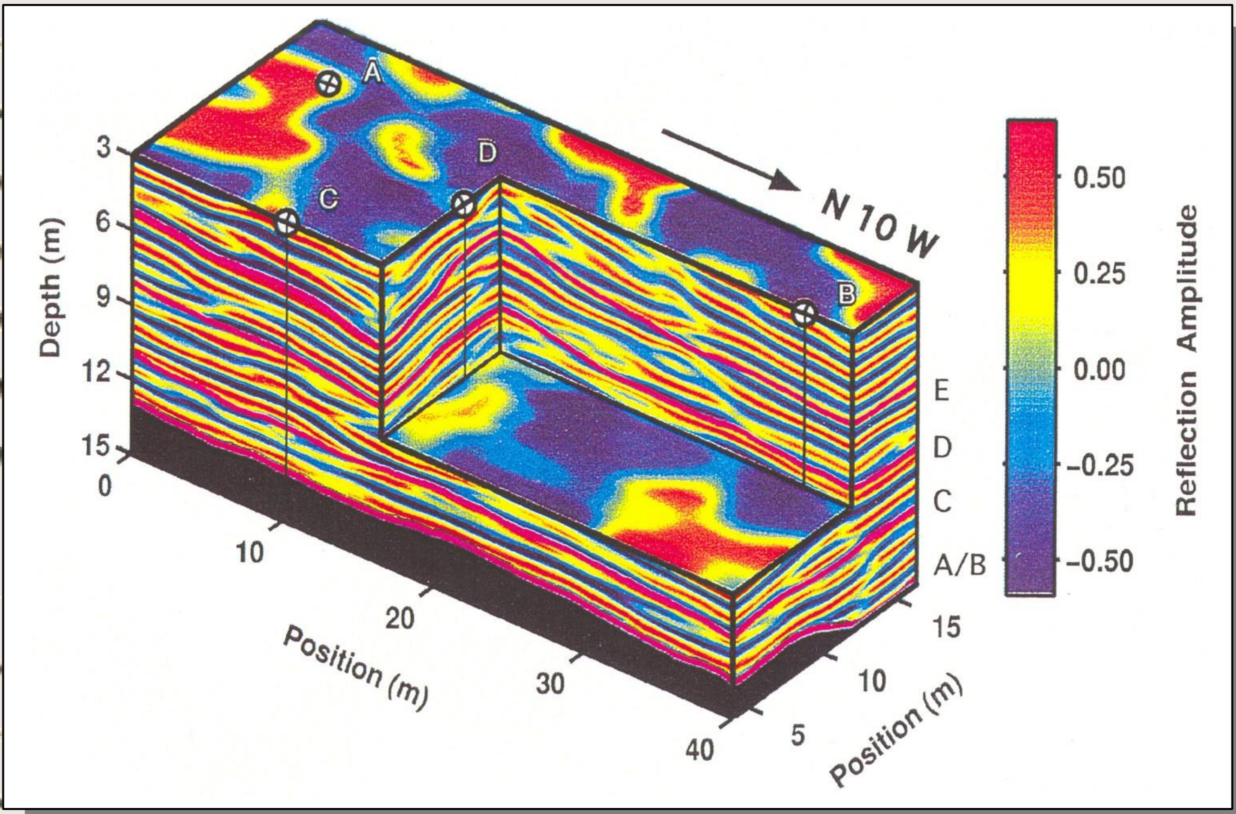
Case history (cont 0):
location map

- Coyote basin, UT



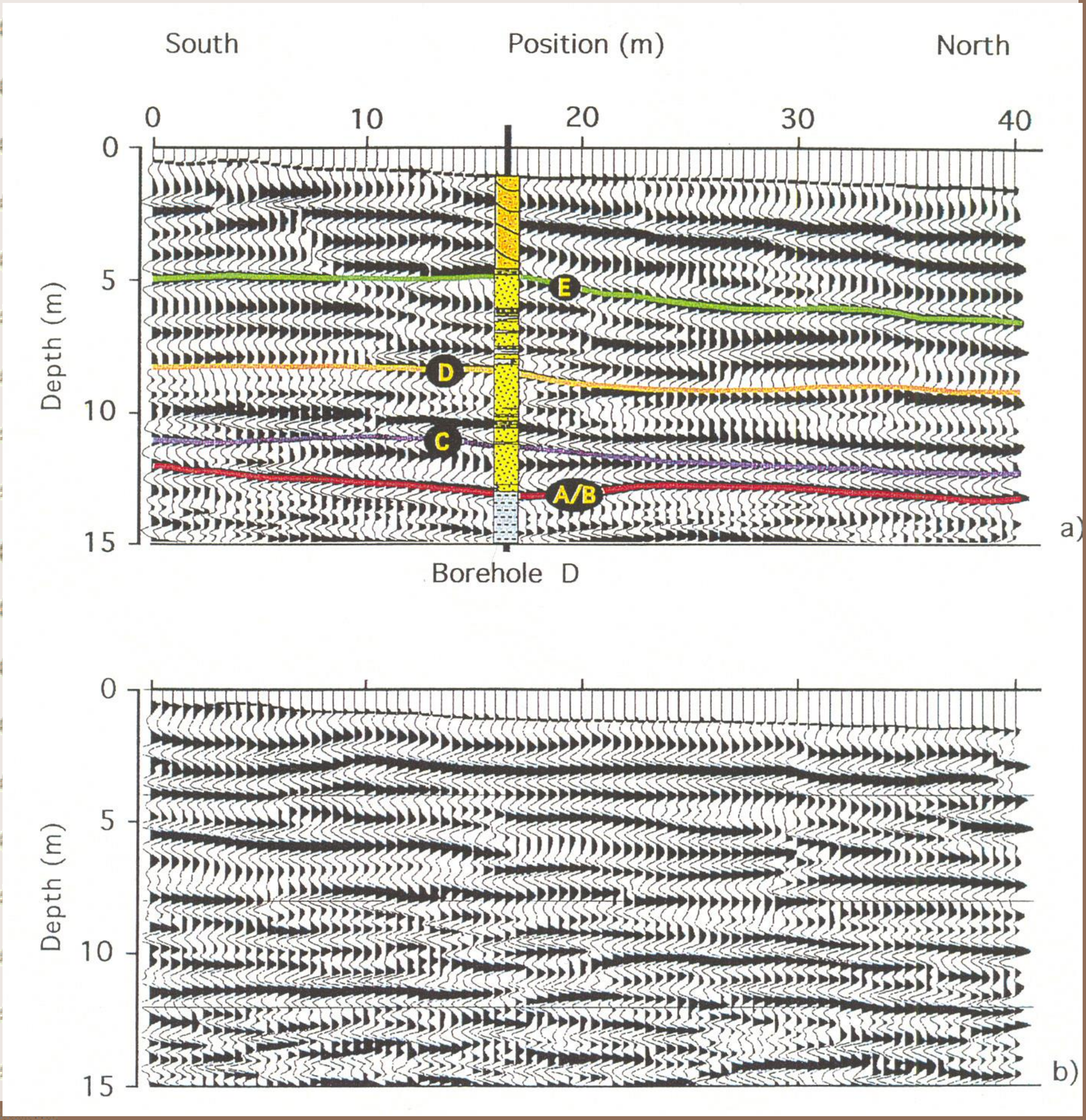
Case history (cont. 1)
(*Szerbak et al.*, 1999)

- 3D radargram



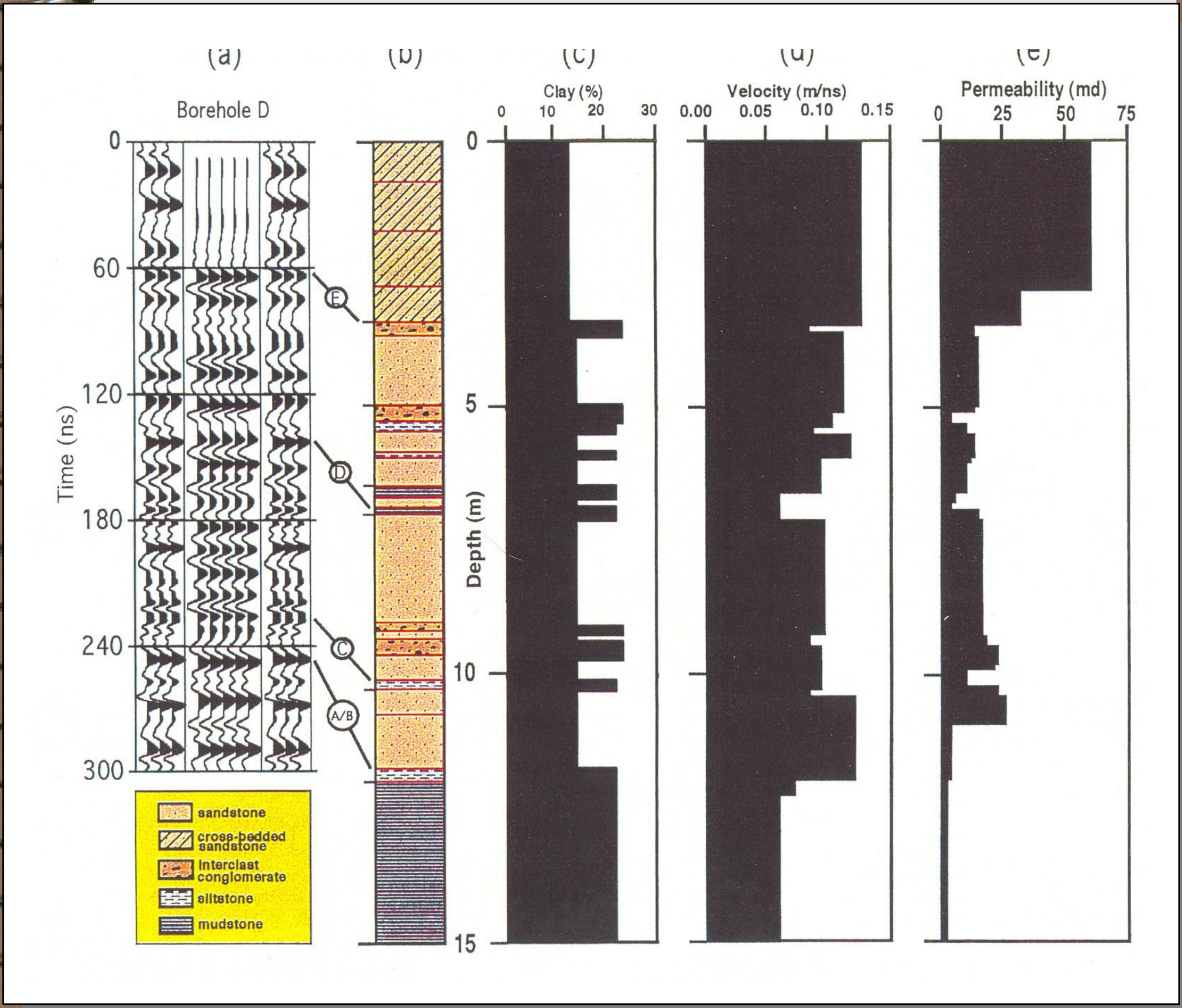
Case history (cont. 2)
(*Szerbak et al.*, 1999)

- Calibrating the GPR image using boreholes



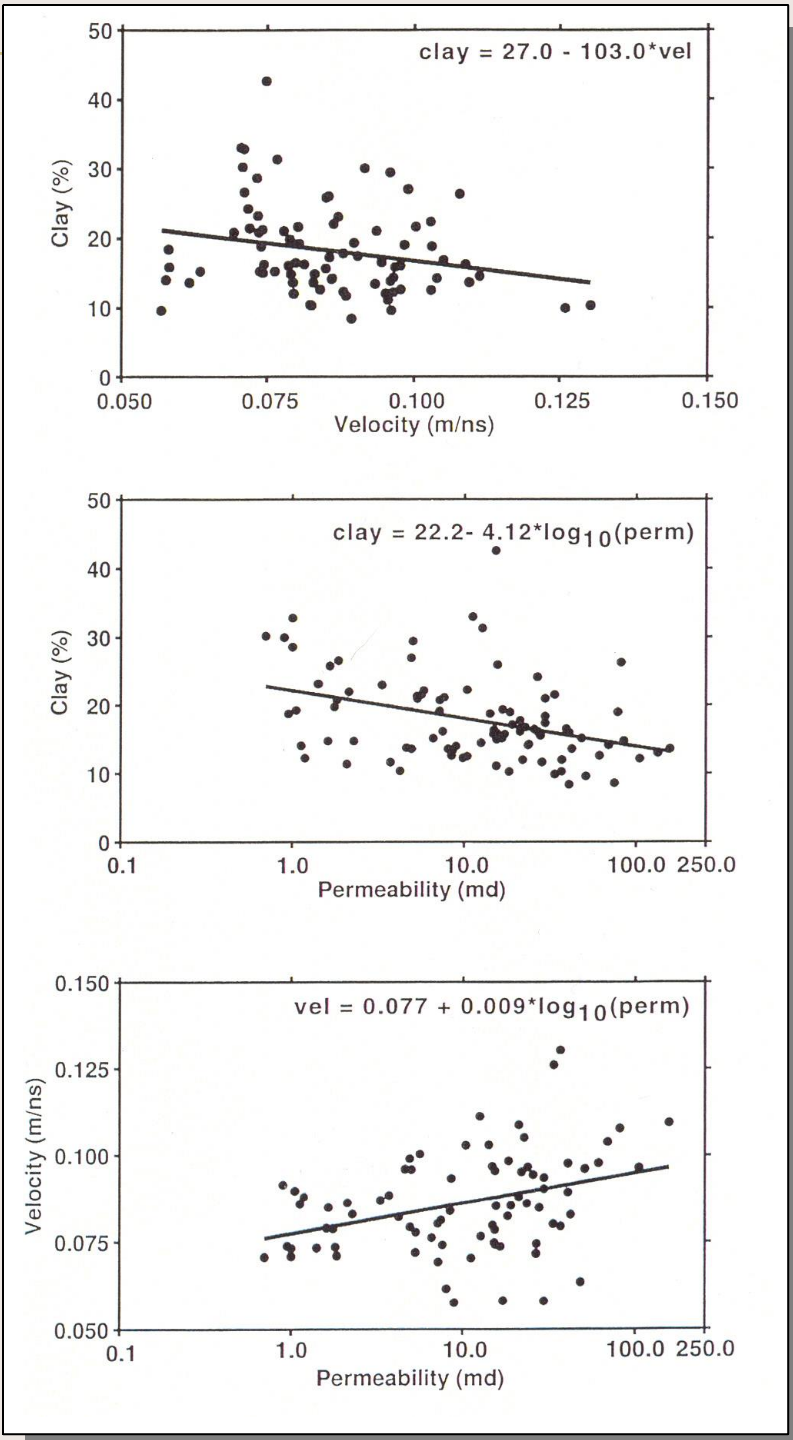
Case history (cont. 3)
(*Szerbak et al.*, 1999)

- Correlation of GPR results with clay and permeability data



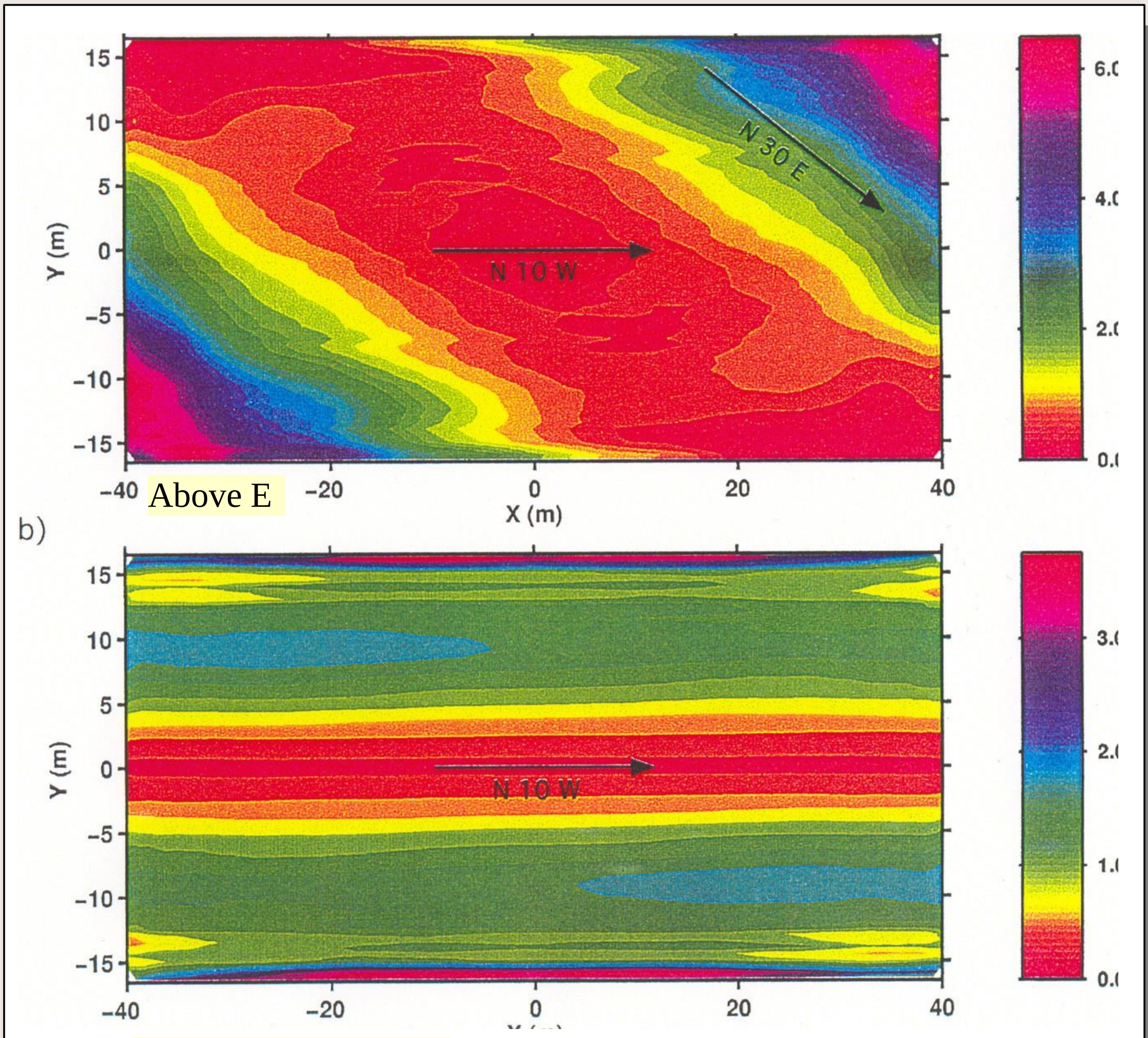
Case history (cont. 5)
(*Szerbak et al.*, 1999)

- Statistical relationships between permeability, clay content, and *velocity*
- Correlations are identified (lines in the plots) and used as proxies for relations between physical properties



Case history (cont. 4)
(*Szerbak et al.*, 1999)

- Velocity distribution correlation functions.

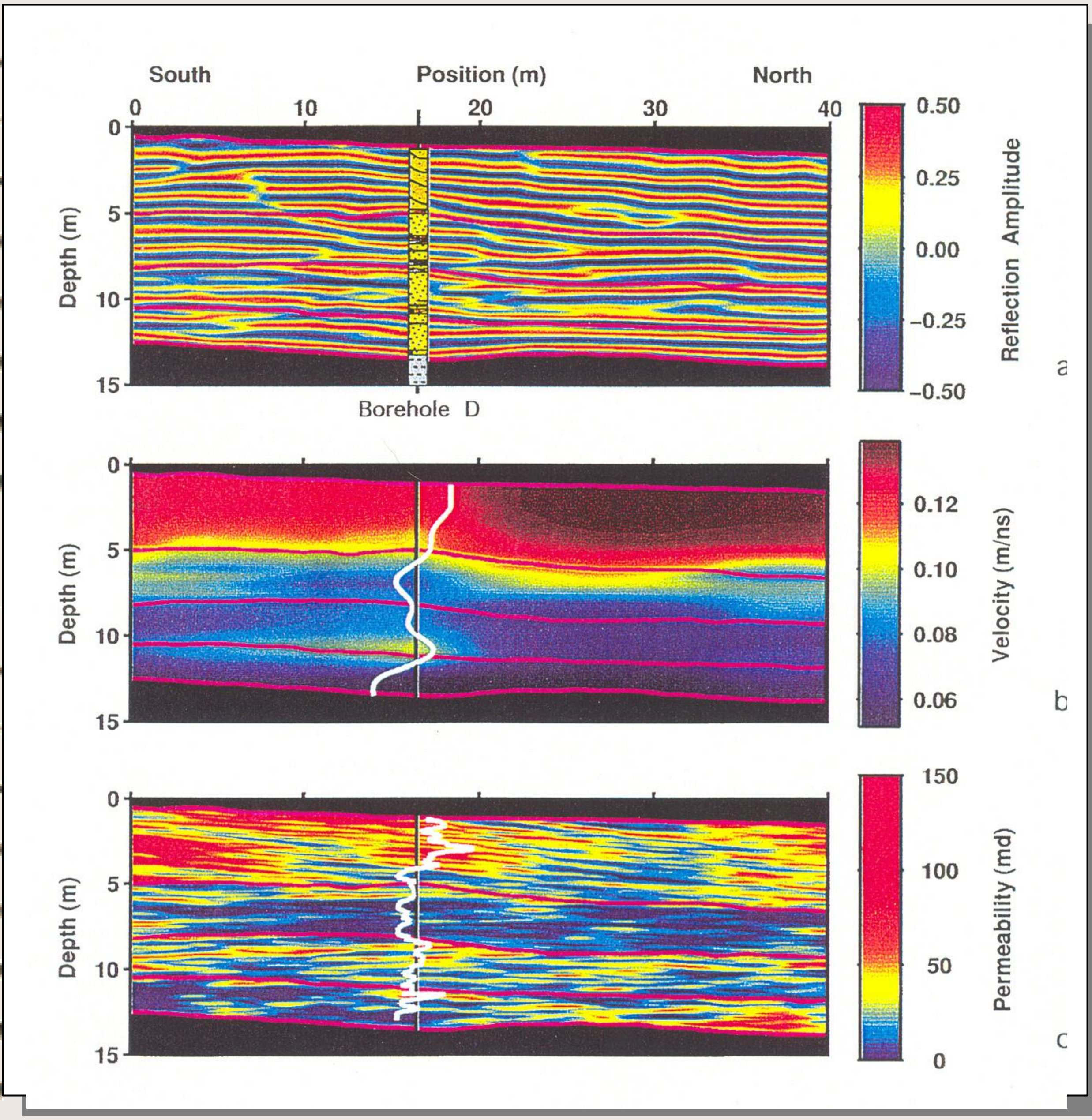


Above E

Between E and A/B

Case history (cont. 6)
(*Szerbak et al.*, 1999)

- Final reflectivity, velocity, and permeability models



Case history (cont. 7)
(*Szerbak et al.*, 1999)

- 3D permeability cube