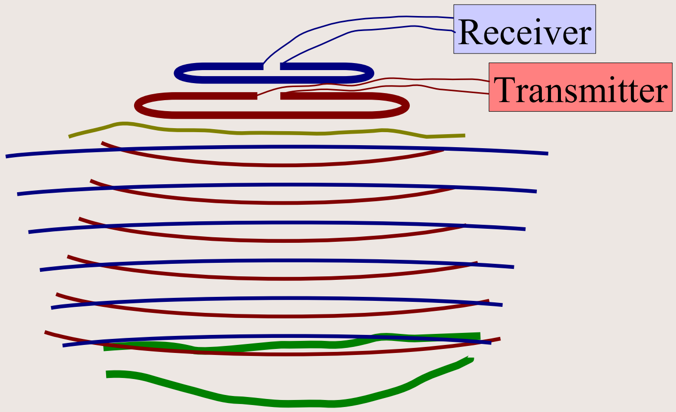
Ground-Penetrating Radar
(also Ground-Probing Radar, GPR)

- Similarities and dissimilarities to seismic
- Case histories

- Reading:
  - Reynolds, Chapter 12

GPR Principles

- Uses 30- 1000 MHz electromagnetic waves emitted in short “chirps” for probing
  - 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 susceptibility* (ε) and *conductivity* (σ).



Propagation and reflection of radio waves

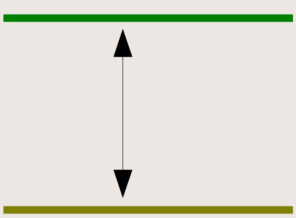
- Velocity: $$c = \frac{c_0}{\sqrt{\varepsilon \mu}} \approx \frac{c_0}{\sqrt{\varepsilon}}.$$
  - the fastest for the 'air' wave;
  - generally decreases with depth.

- Impedance: $$Z = \sqrt{\frac{\mu}{\varepsilon}} \approx \sqrt{\frac{1}{\varepsilon}} [Ohms].$$

- Amplitude reflection coefficient:

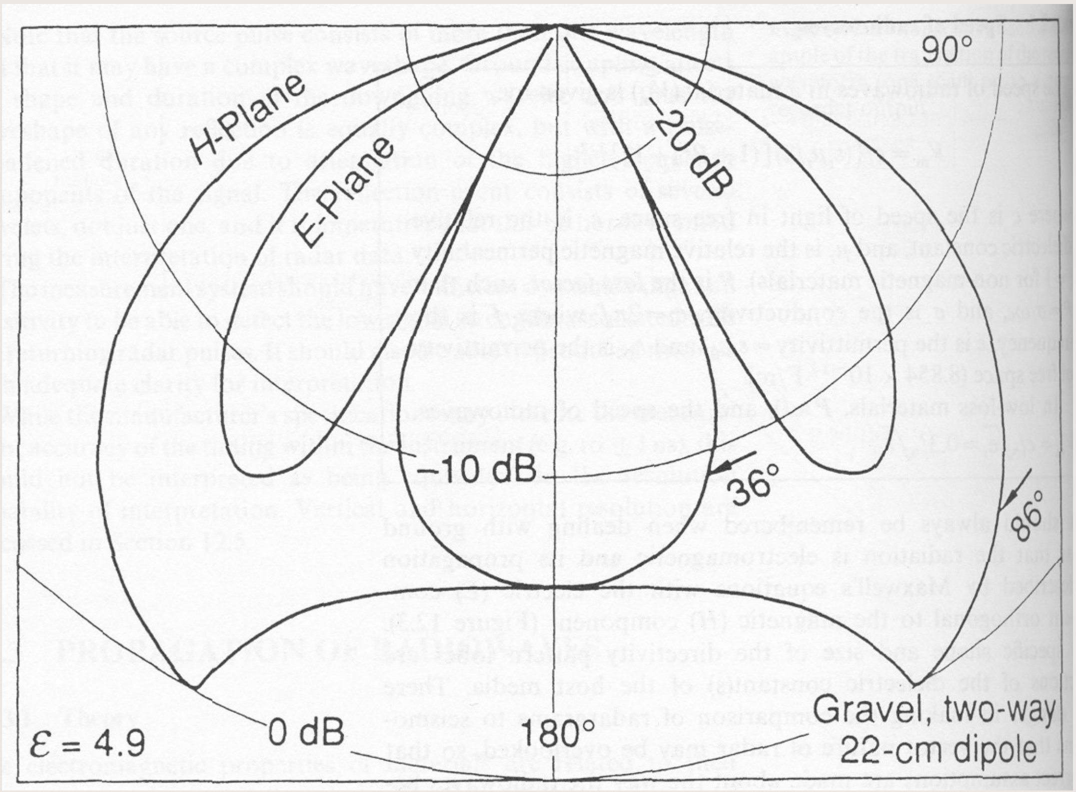
$$R = \frac{Z_2 - Z_1}{Z_2 + Z_1}.$$

- Two-way travel times:
  - Air: 6 ns/m;
  - Unsaturated sand: 12-18 ns/m;
  - Saturated sand: 18-27 ns/m.

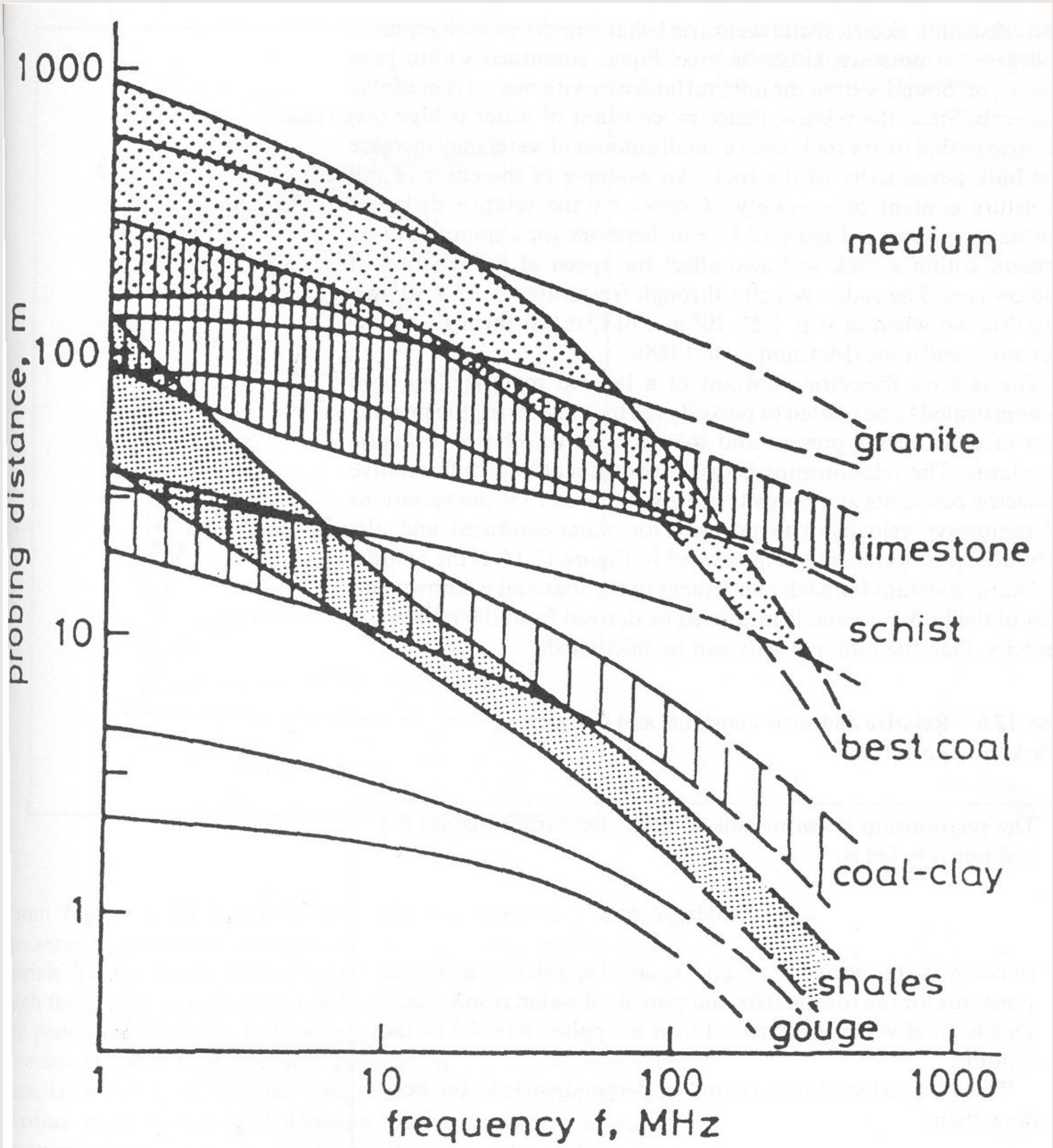


Antenna directivity patterns

- GPR antenna focuses energy in a beam directed downward;
- Receiver antenna has a similar sensitivity pattern.



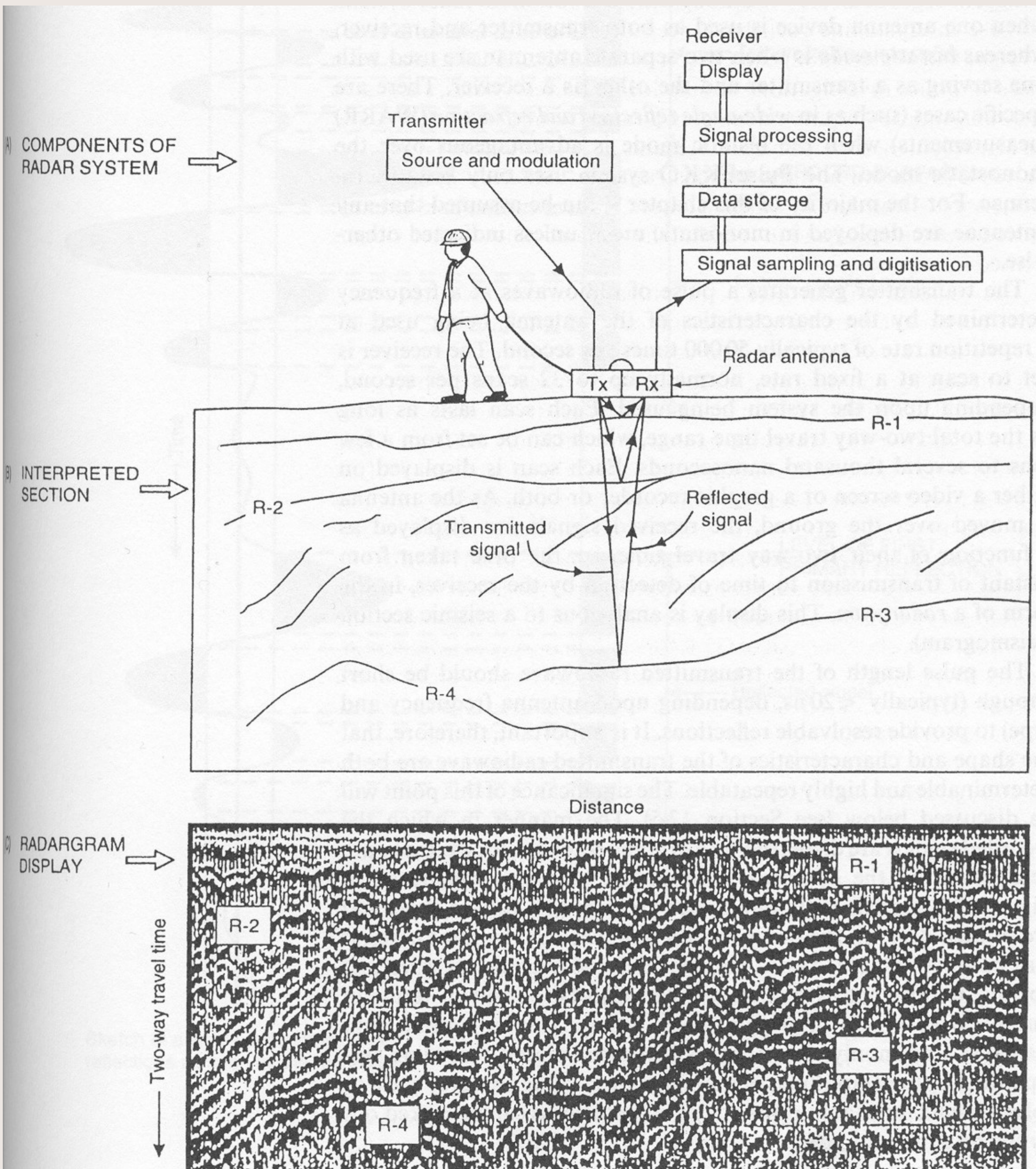
Depth penetration of GPR waves



Relation to Reflection Seismics

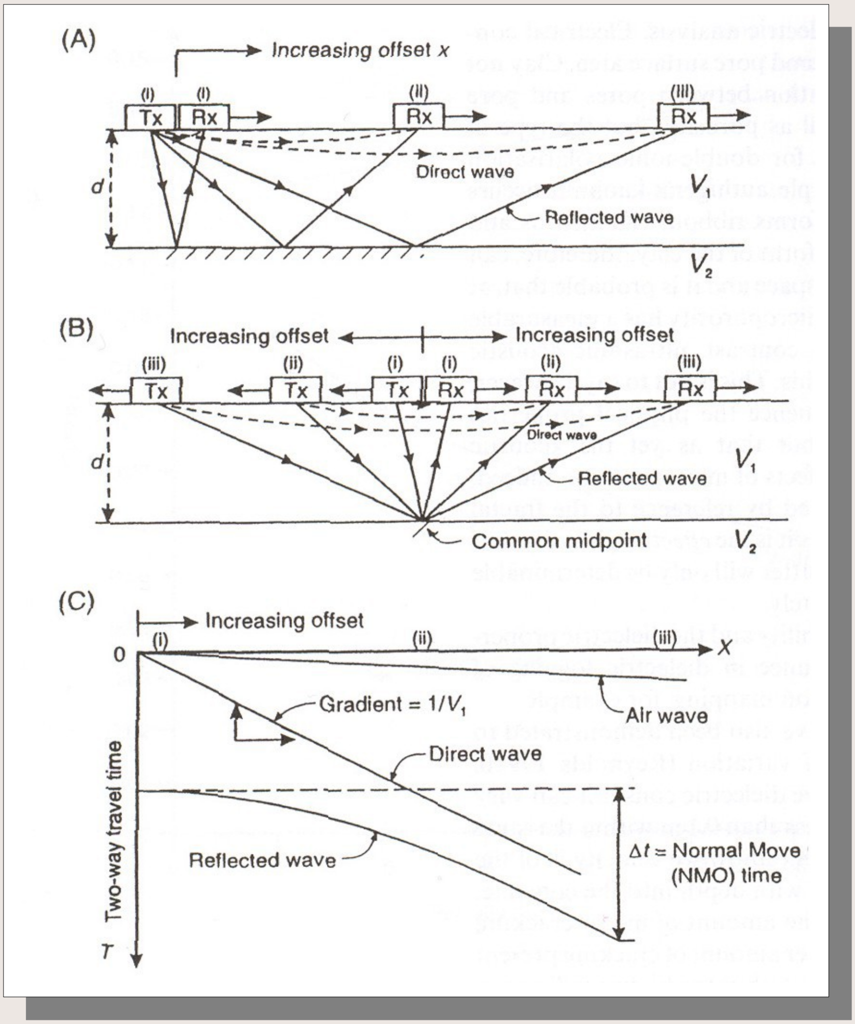
- Similarities:
  - Processing procedures (filtering, stacking, migration);
  - Appearance of the zero-offset section;
  - Resolution-frequency relationships;
  - Interpretation techniques.
- Differences:
  - Nanoseconds (*ns*) instead of milliseconds (*ms*);
    - Sub-meter vertical resolution and ~10-100 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 a valuable complementary technique to shallow seismics.

GPR operation



GPR acquisition modes

- 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

- 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
  - Detection and mapping of Roman Roads, etc. Location of post-holes, etc.
  - Pre-excavation mapping
  - Detection of voids (crypts, etc.)
  - Location of graves
- Forensic science:
  - Location of buried targets (*e.g.* bodies and bullion)

GPR equipment

PulseEKKO 1000

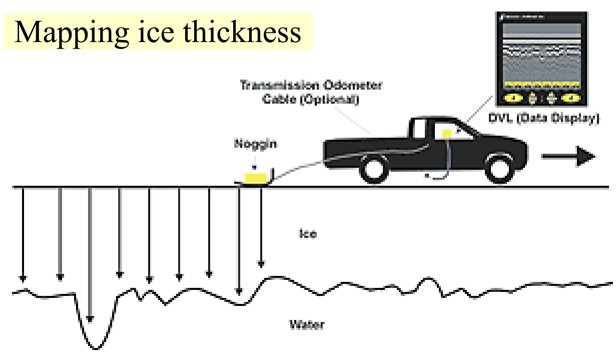
PulseEKKO RockNoggin

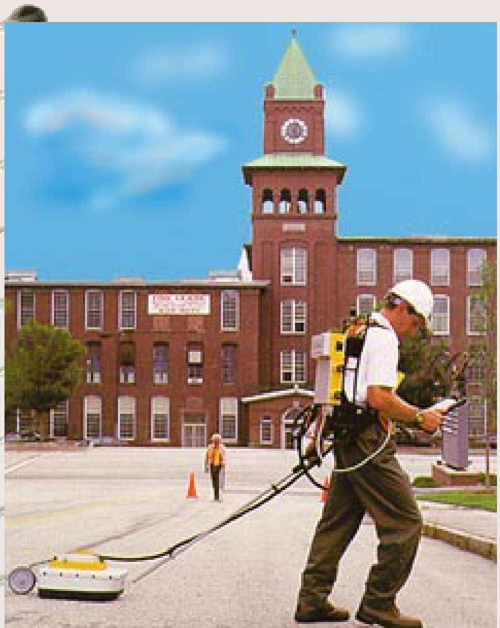
PulseEKKO 100

GPR applications

Archeology

Mapping ice thickness

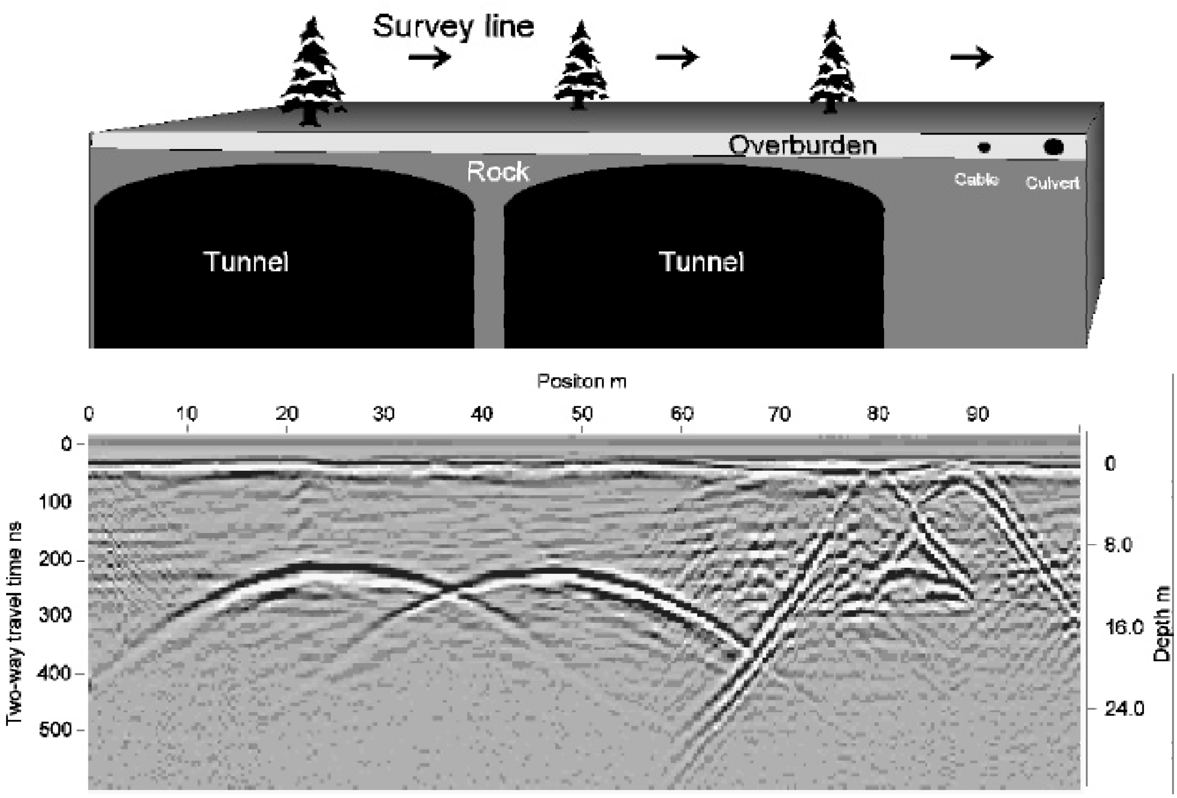




SnowNoggin

Case history: Engineering

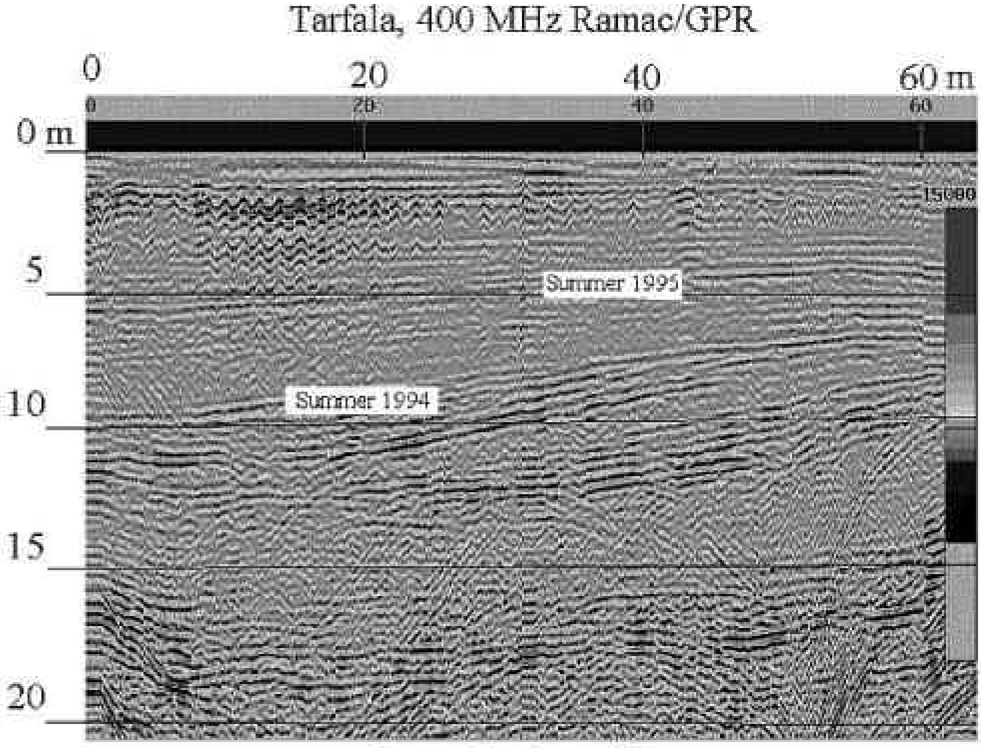
- Detecting tunnels (Sweden)



- **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

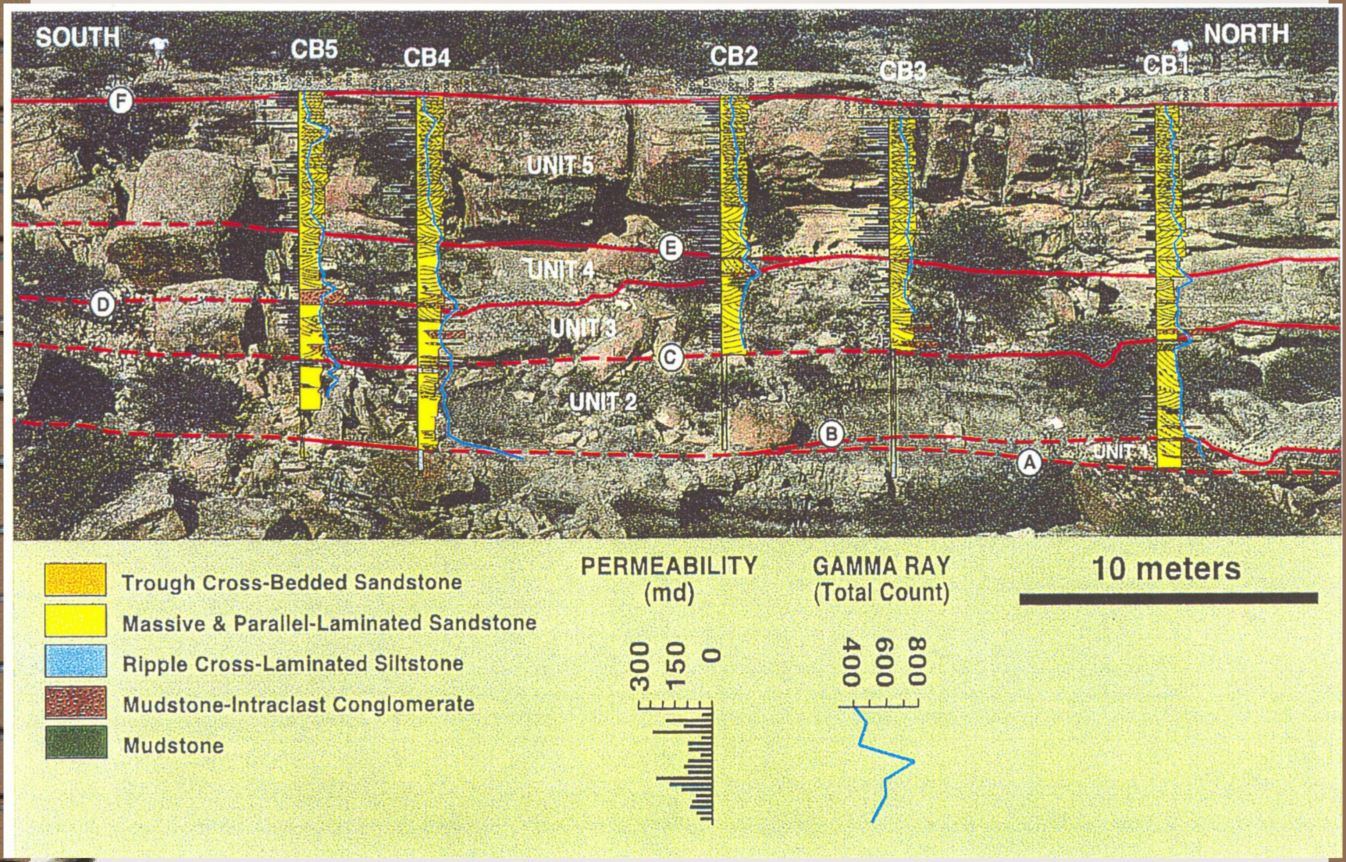


Snow depth profile

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

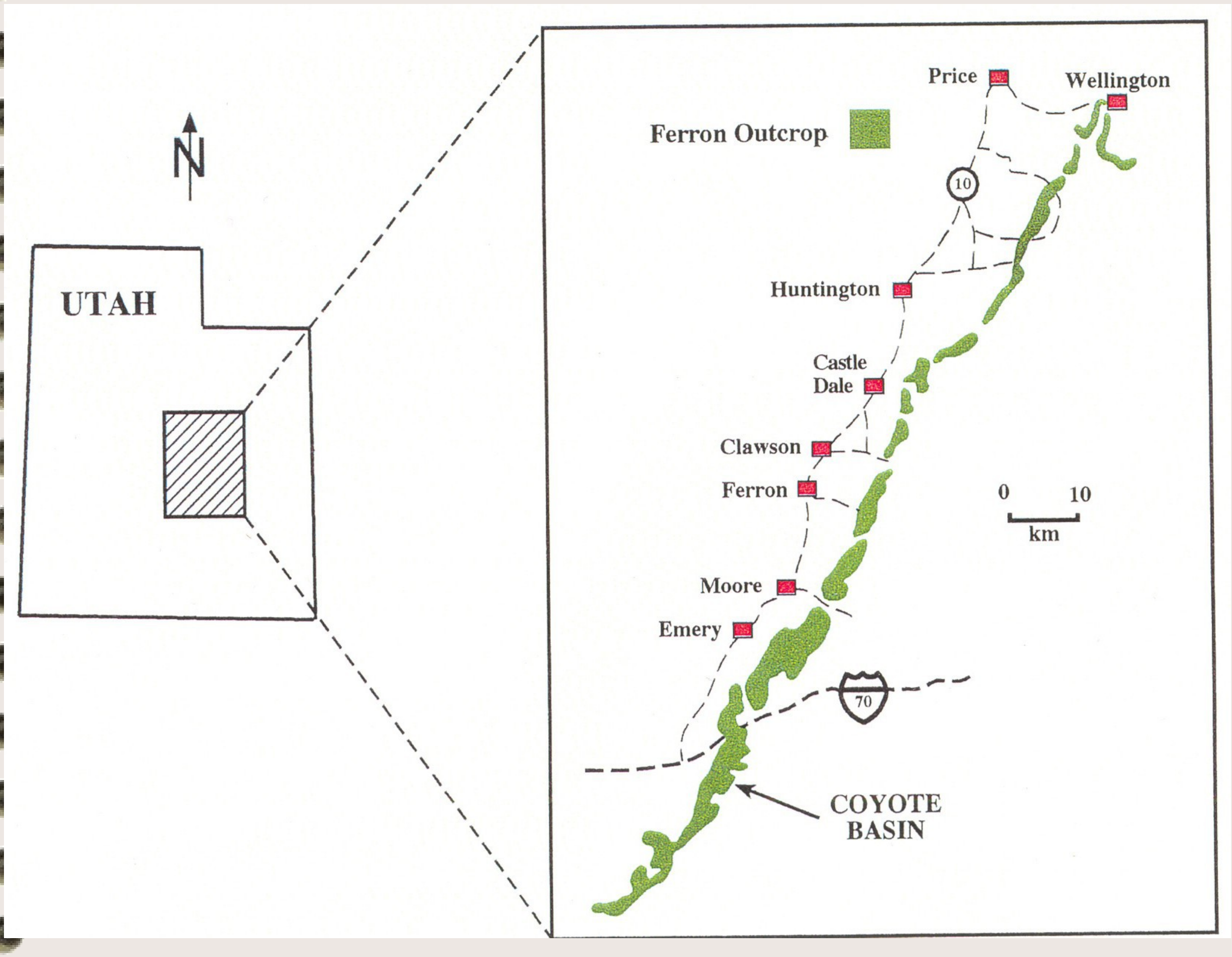
Case history:
3D characterisation of a clastic reservoir analog (*Szerbak et al., 1999*)

- Mapping outcrop;
- 3-D GPR cube adjacent to the outcrop;
- Correlation with well data;
- Geostatistics of permeability/velocity/depth relationships.
- Inversion for permeabilty.



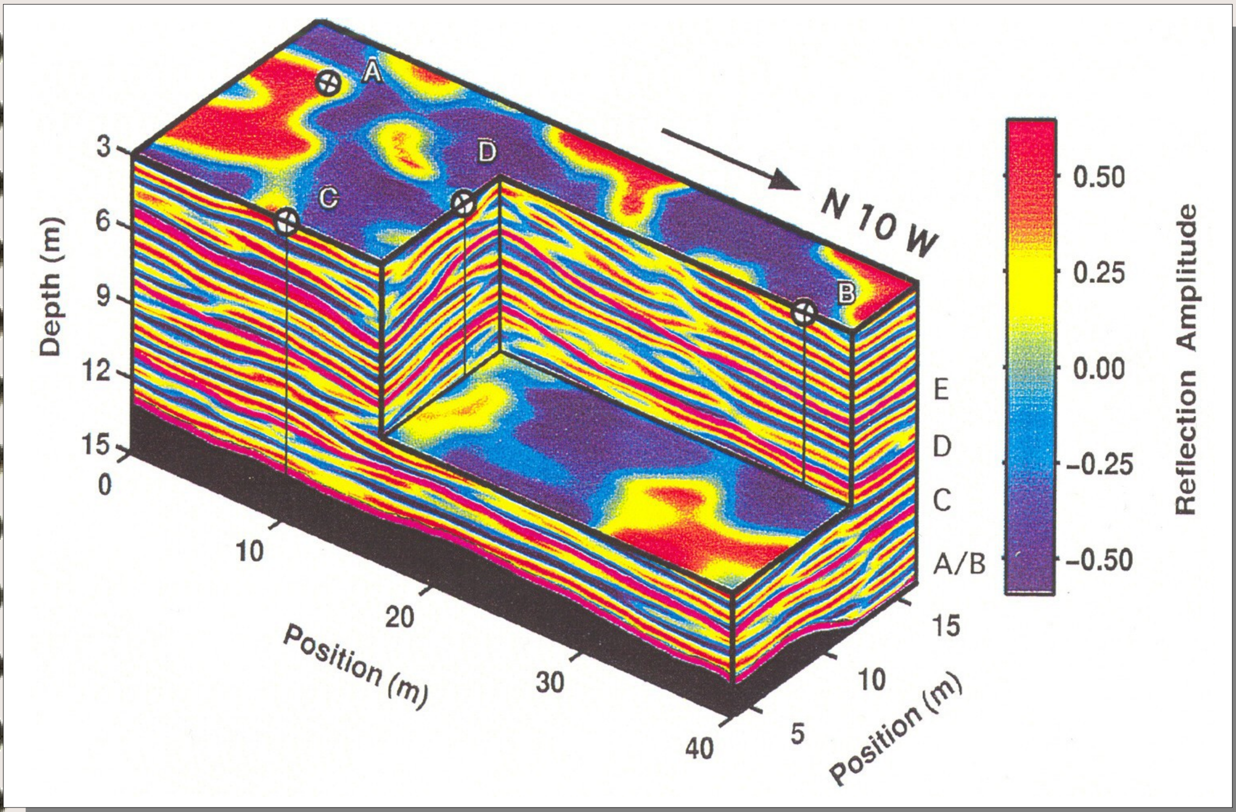
Case history (cont 0):
location map

- Coyote basin, UT



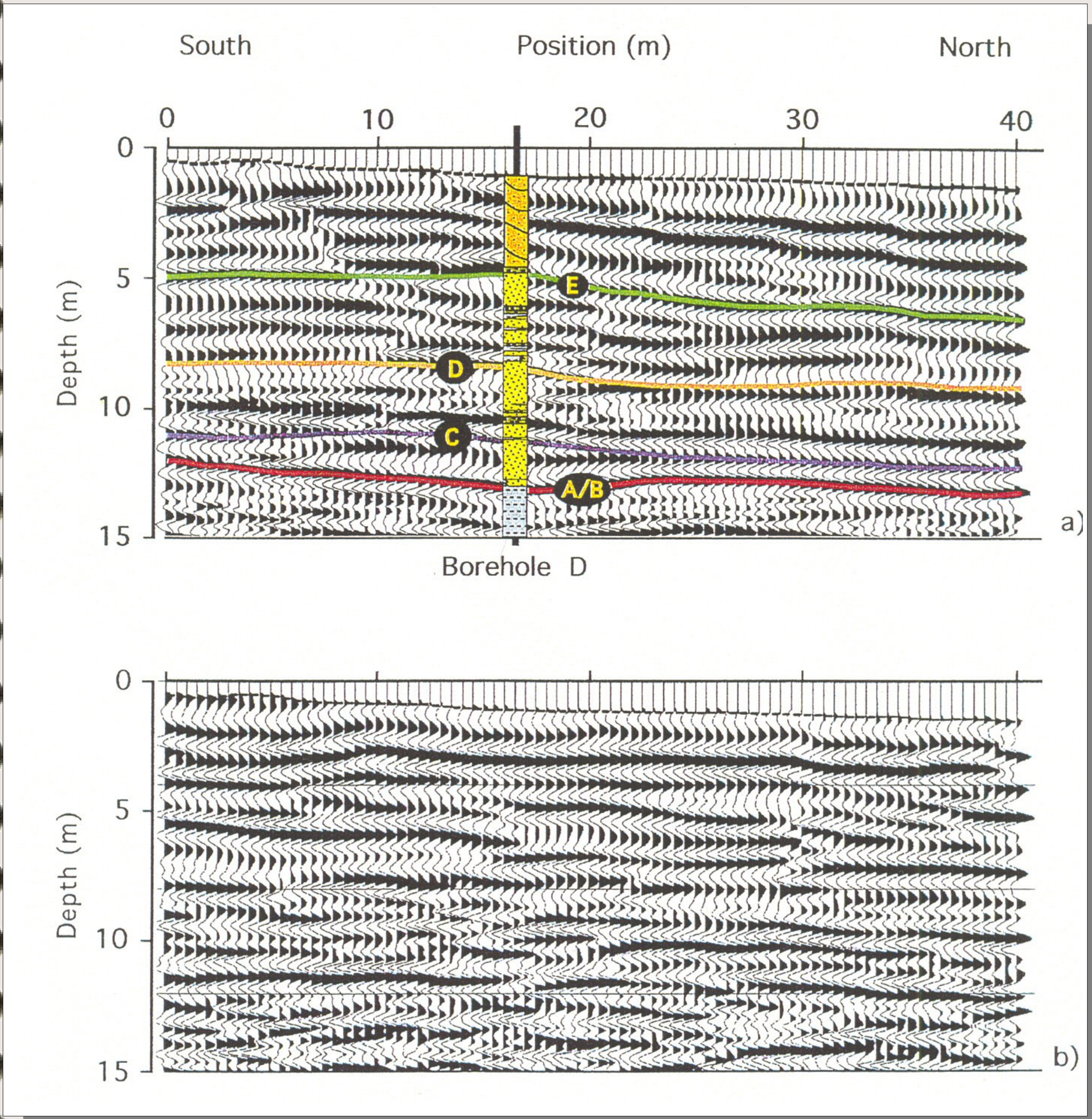
Case history (cont. 1)
(*Szerbak et al., 1999*)

- 3D radargram



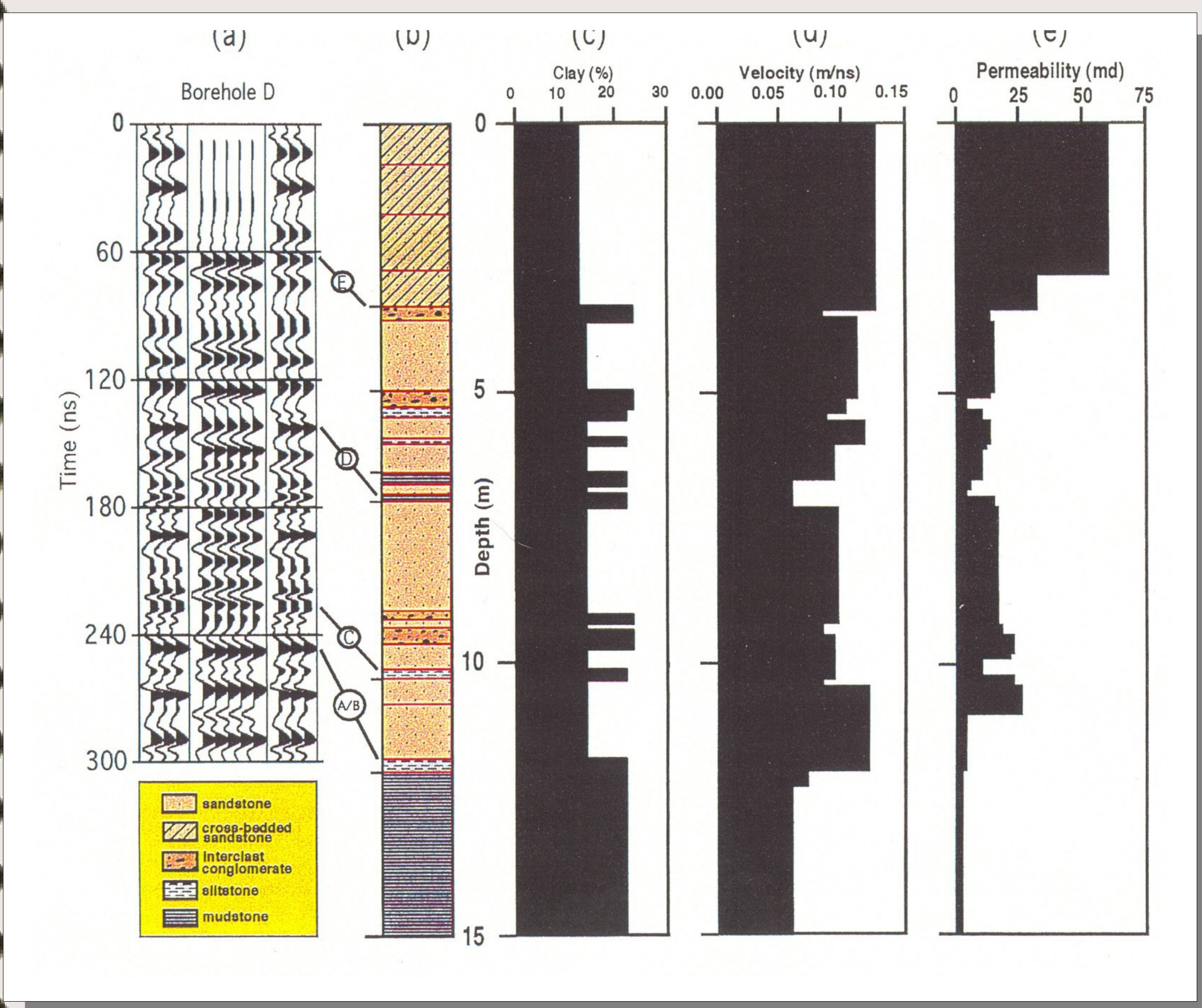
Case history (cont. 2)
(*Szerbak et al., 1999*)

- Calibrating the GPR image using boreholes



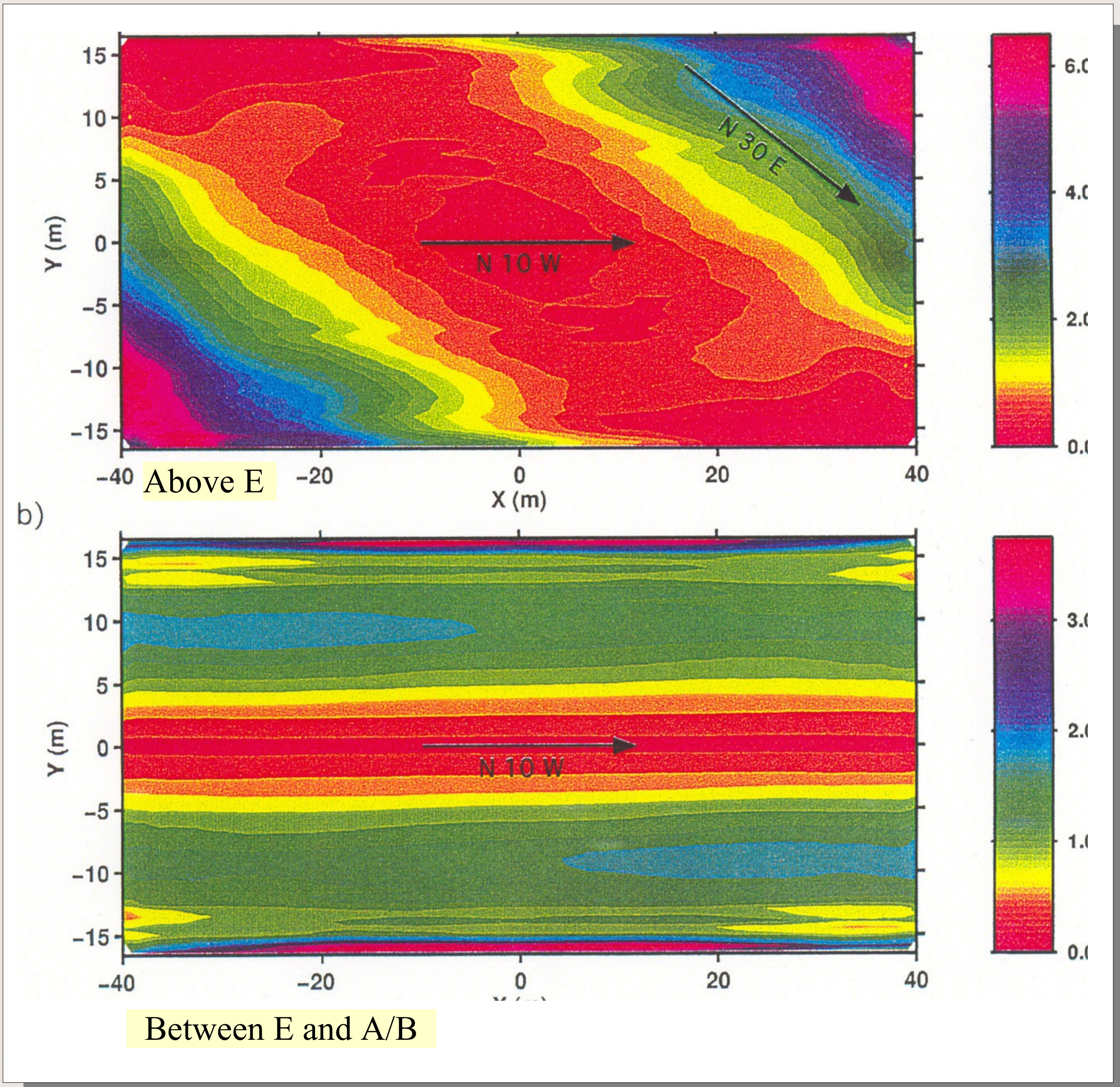
Case history (cont. 3)
(*Szerbak et al., 1999*)

- Correlation with clay and permeability data



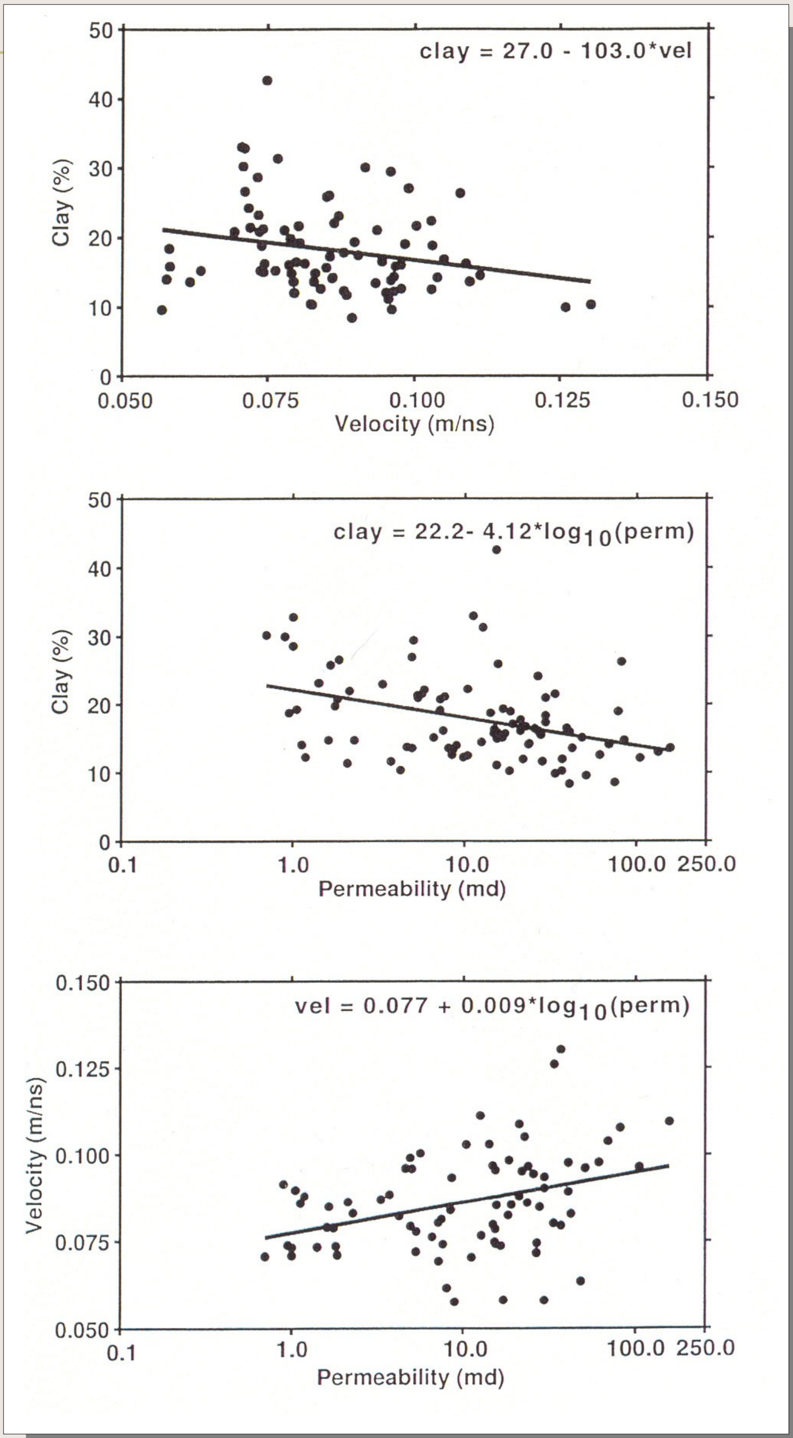
Case history (cont. 4)
(*Szerbak et al., 1999*)

- Velocity distribution correlation functions.



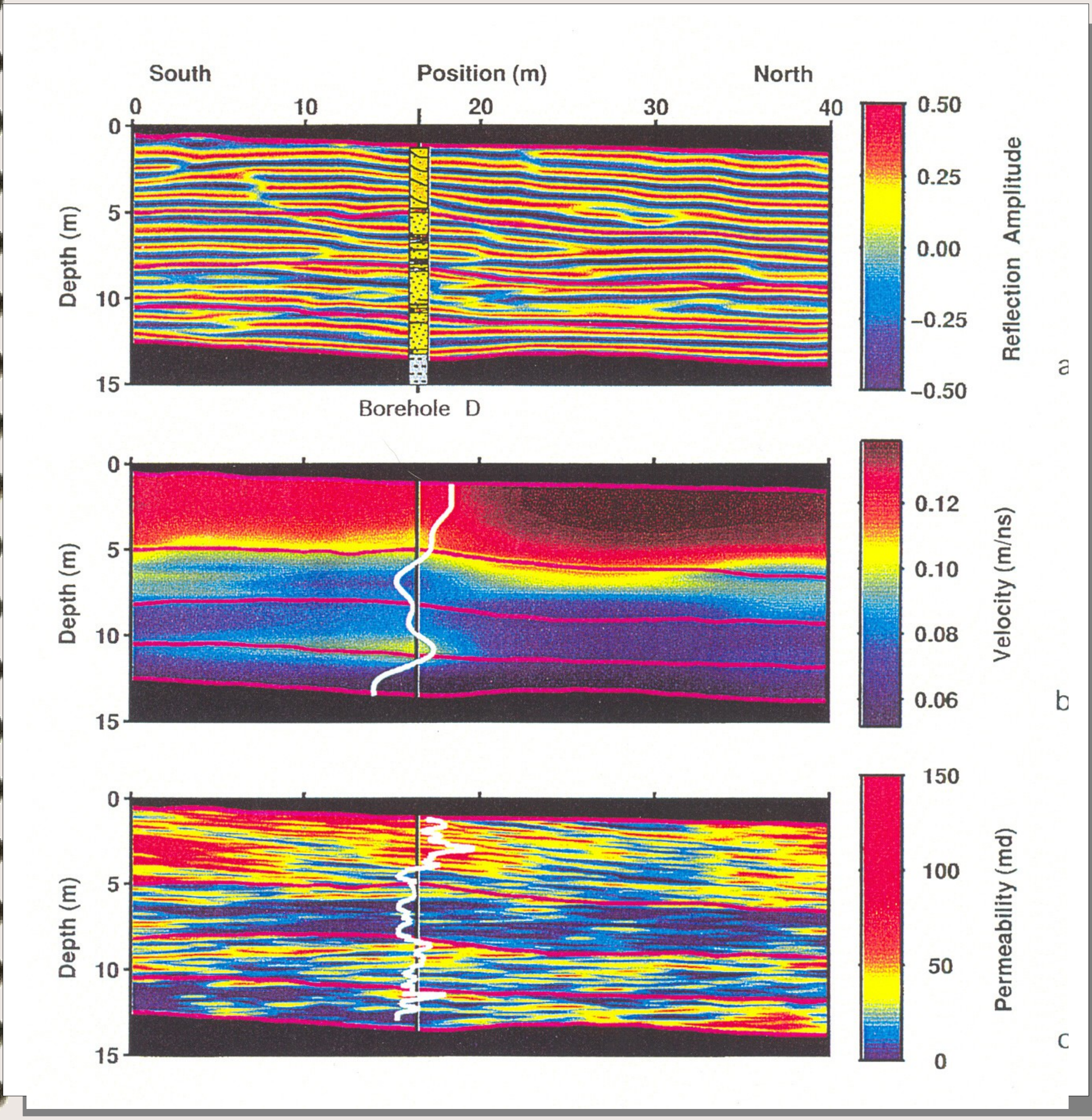
Case history (cont. 5)
(*Szerbak et al., 1999*)

- Statistical relationships between permeability, clay content, and *velocity*.



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