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 produce a constant-offset or walkaway sections.
- Sensitive to dielectric susceptibility ($\varepsilon$) and conductivity ($\sigma$).
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 \textit{toward} the vertical;
    - Free-air arrival is the \textit{fastest};
    - Faster attenuation;
    - Large velocity contrasts.
  - Sub-meter resolution.

Thus, GPR is 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

Mapping ice thickness

Archeology

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 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 permeability.
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