Physicochemical monitoring

Lecture 4

Learning outcomes

- Familiarity with subsurface monitoring methods

Site characterization

- Soil /geological characterization
- Pollutant characterization
- Water characterization
- Gas characterization
- Microbial characterization
- Source of the pollution

Site characterization

- Identify information gaps
- Will this require further investigation?
- What type of investigation?
- What kind of samples and how many?
- Sampling method-how obtained, preserved?
- Sample location and depth
- Which chemical analyses?
- Will there be a pilot study?

Gathering relevant data

- "Do we have enough information on this site to adequately characterize its contamination status?"
- History of the site, previous occupants, their activities
- Site visit: look for evidence of contamination
- Local geology and hydrogeology
- Presence and quality of water and GW
- Layout of site (above- and below-ground)
- Nearby pits and quarries
- Previous investigation of site
- Processes used on the site: raw materials, products, waste, disposal methods
- Nearby receptors: houses, water, parks

Pollutant linkage

- Source of impact
- Pathway of migration
- Potential receptor

- Decide if have enough information from existing data or if site investigation is necessary.

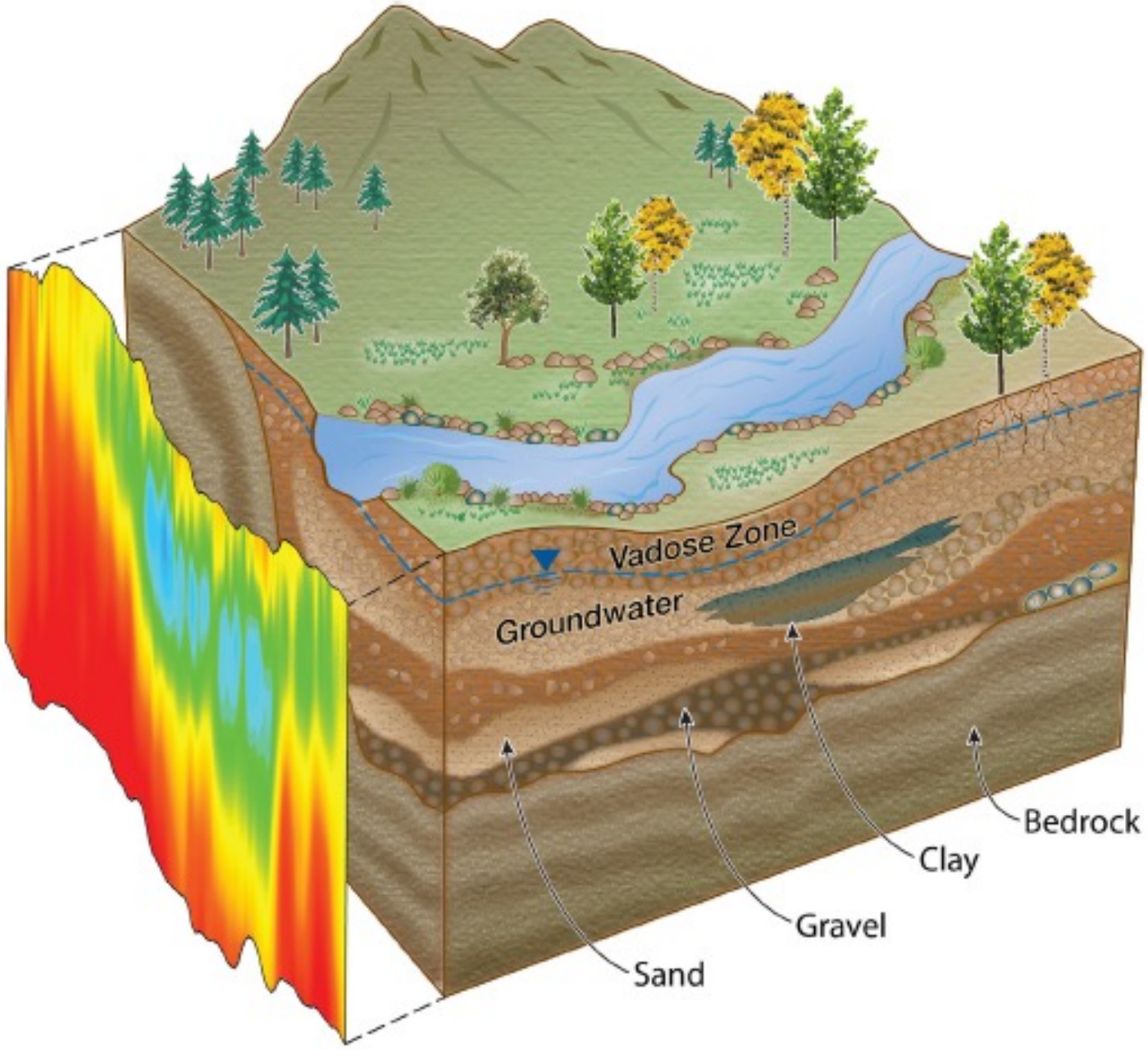
Investigative techniques

- Intrusive and nonintrusive
- Intrusive:
  - Obtain samples and involve disturbance of ground
- Nonintrusive:
  - Advantage of providing lots of data in a short time and with little disturbance
  - Disadvantage: require significant analysis

Nonintrusive techniques

Type of method	Geophysical method	Geophysical properties	Derived properties
Seismic	Seismic refraction	Elastic moduli and bulk density	Lithology, ice content, cementation state, pore fluid substitution
Gravity	Microgravity	Bulk density	Water content, porosity
Electrical	Direct Current (DC) resistivity	Electrical conductivity	Water and clay content, porewater conductivity
	Induced polarization (IP)	Electrical conductivity, chargeability	Water and clay content, porewater conductivity, surface area, permeability
	Self-potential (SP)	Electrical sources, electrical conductivity	Water flux permeability
	Electromagnetic induction (EMI)	Electrical conductivity	Water content, clay content, salinity
	Ground-penetrating radar (GPR)	Permittivity, electrical conductivity	Water content, stratigraphy, porosity

Electrical conductivity profile



Seismic refraction

Seismic refraction is used for investigating subsurface ground conditions utilizing surface-sourced seismic waves. The acquired data is computer processed and interpreted to produce models of the seismic velocity and layer thickness of the subsurface ground structure.

Practice: Weight drop and measure the seismic waves with geophone

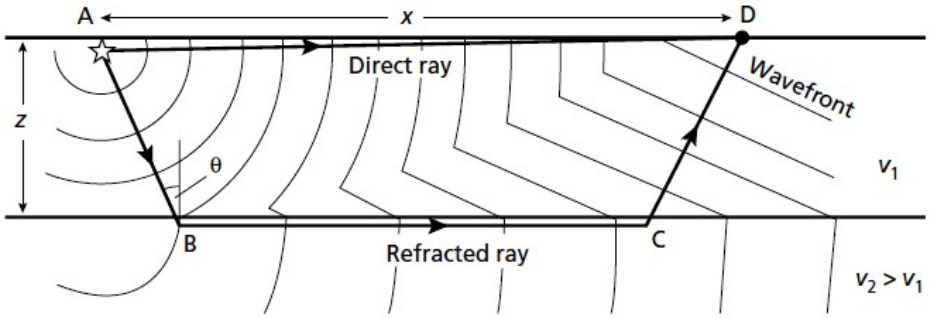
Where

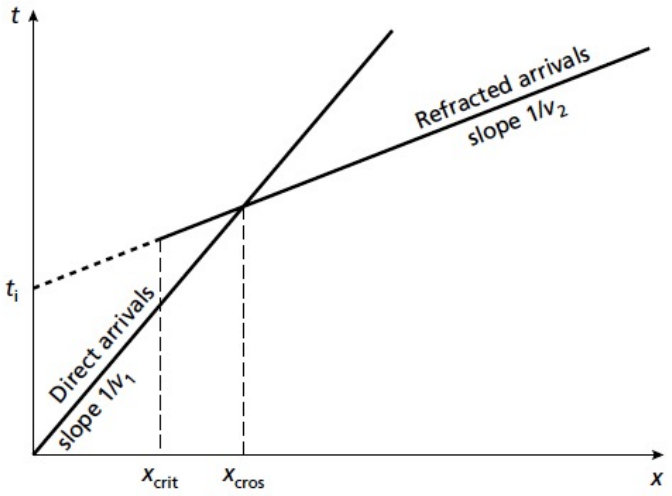
$$z=\frac{x_{cros}}{2}\left[\frac{v_2-v_1}{v_2+v_1}\right]^{1/2}$$

z= thickness of uppermost layer

x_{cros}= distance to point of intersection

v_1, v_2= velocity in layer 1, layer 2





- Obtain v1 and v2 from the plot of the time arrival at each geophone location
- Obtain x_{cros} from the plot (distance at which direct and refracted ray cross)
- Calculate z (thickness of the top strata)

Seismic refraction example

$$T = \left(\frac{D}{2}\right)\frac{\sqrt{(v_2 - v_1)}}{\sqrt{(v_2 + v_1)}}$$

Where

T = thickness of uppermost layer

D= distance to point of intersection

v_1, v_2= velocity of layer 1, layer 2

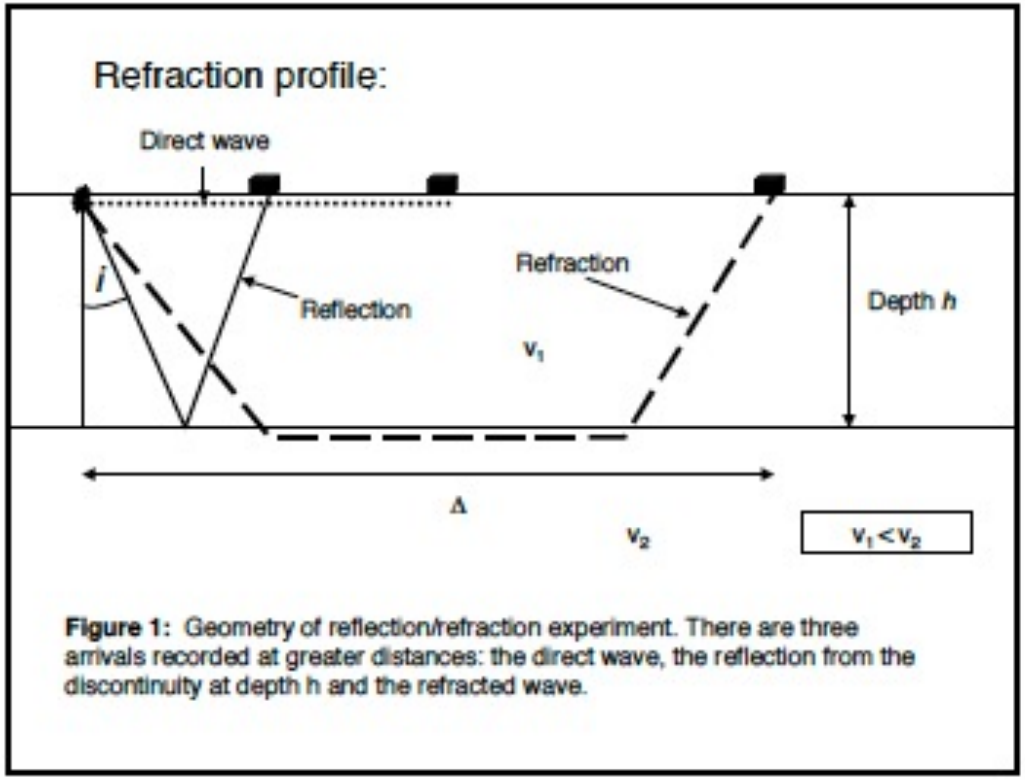


Figure 1: Geometry of reflection/refraction experiment. There are three arrivals recorded at greater distances: the direct wave, the reflection from the discontinuity at depth h and the refracted wave.

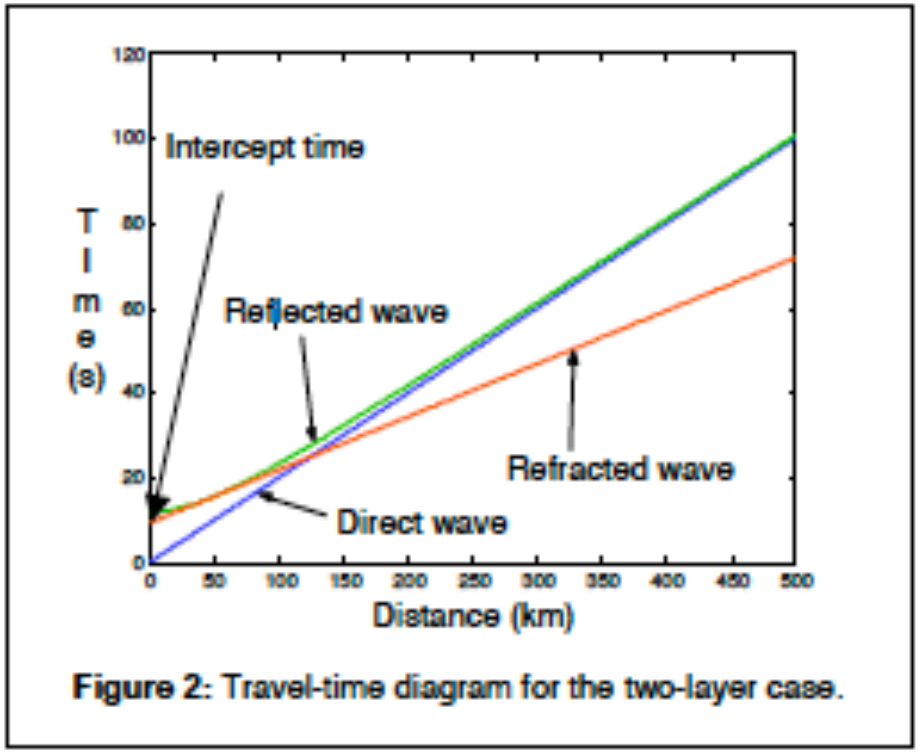


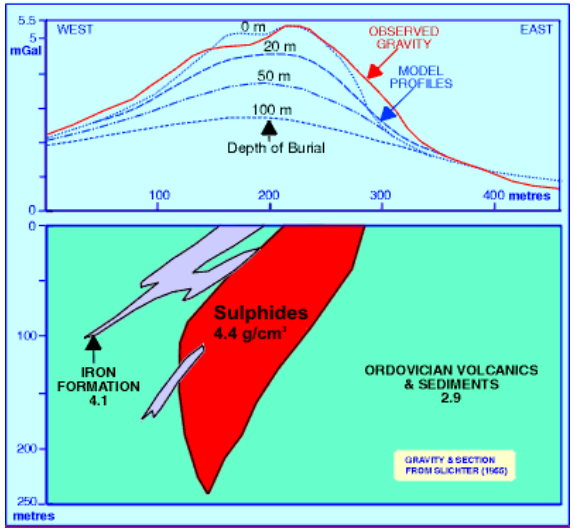
Figure 2: Travel-time diagram for the two-layer case.

Determine v1 from slope of direct wave and v2 from slope of refracted wave

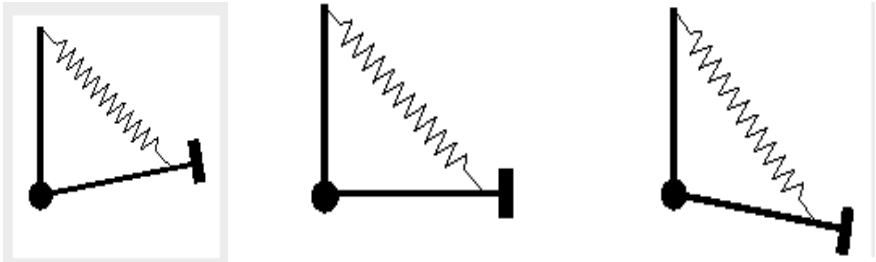
Geothermal resource mapping in Lausanne January 2023 using reflection seismic waves

Seismic refraction survey in Lausanne for geothermal energy locations in January 2023

Gravimetric methods

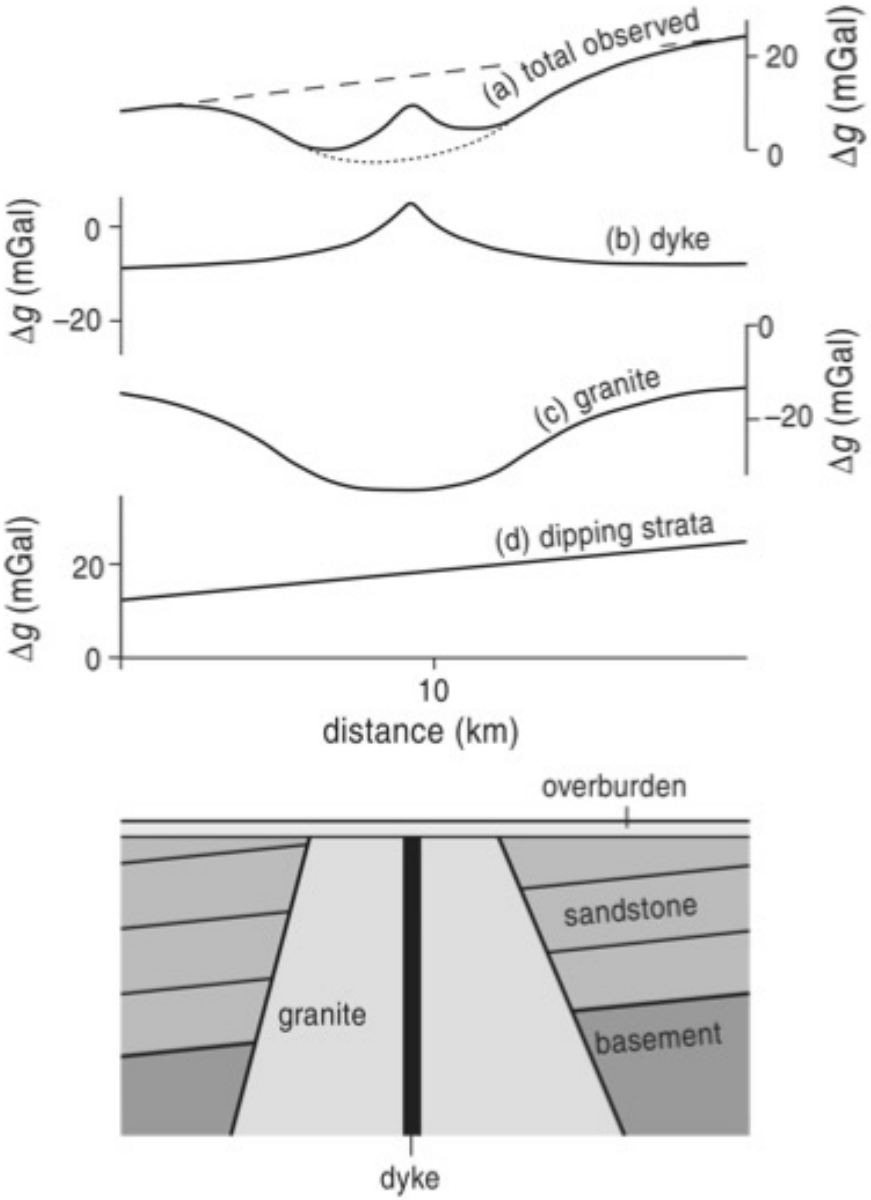


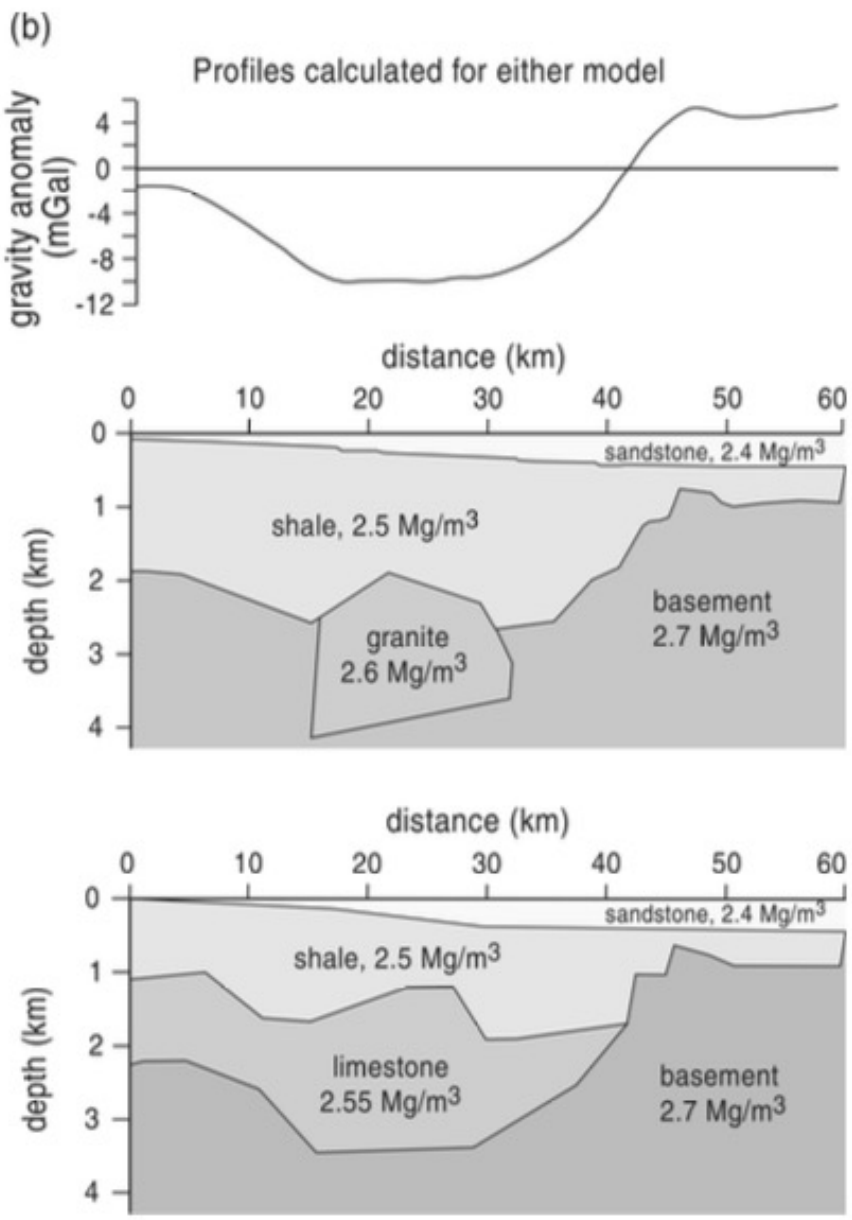
- **Microgravimetry** deals with Earth's gravity. A measured deviation from the 'normal' distribution of gravity allows to draw conclusions on density inhomogeneities in the subsurface.
- Gravity is measured with gravimeters: pendulum in fall experiment or superconducting gravitometers. Small mass suspended on an extremely sensitive spring: can measure 10^{-8} to 10^{-9} of the gravity at the Earth's surface.



- Measurements are carried out as relative values: gravity changes between two points is measured.
- Units of Gals (which equals 1 centimeter per second squared)

Gravimetric methods: examples





Problem= non-unique interpretation

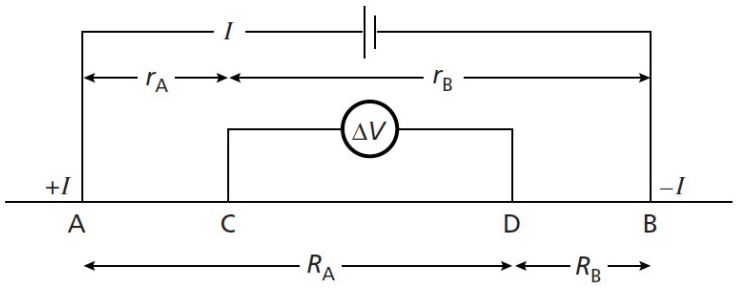
Electrical methods

Electrical: Involve making measurements using electrodes with galvanic or capacitive contact with the subsurface. Plot scale (<10 m) acquisition.

Direct Current (DC) resistivity
Induced polarization (IP)
[Self-potential (SP)]
[Electromagnetic induction (EMI)]
Ground-penetrating radar (GPR)

Electrical methods

DC resistivity: apply a direct current (DC) between electrodes and measure current (I) and voltage (U) by varying the distance between electrodes.



$$\rho = \frac{2\pi\Delta V}{I\left\{\left(\frac{1}{r_A}-\frac{1}{r_B}\right)-\left(\frac{1}{R_A}-\frac{1}{R_B}\right)\right\}}$$

Electric resistivity ρ= k* U/I

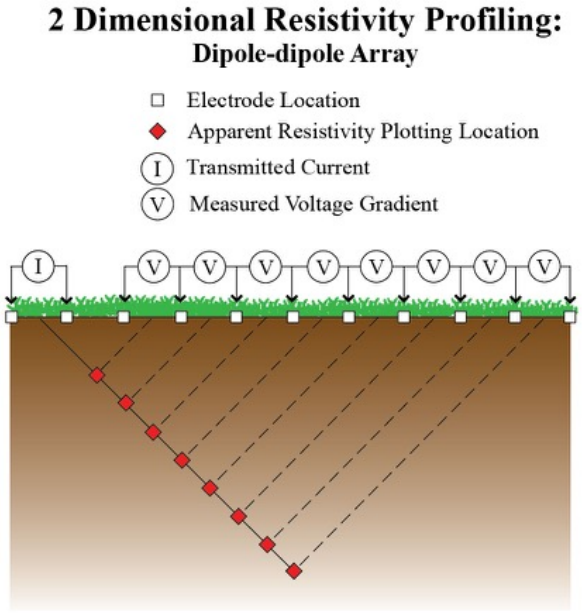
ρ_a= Ohm.m

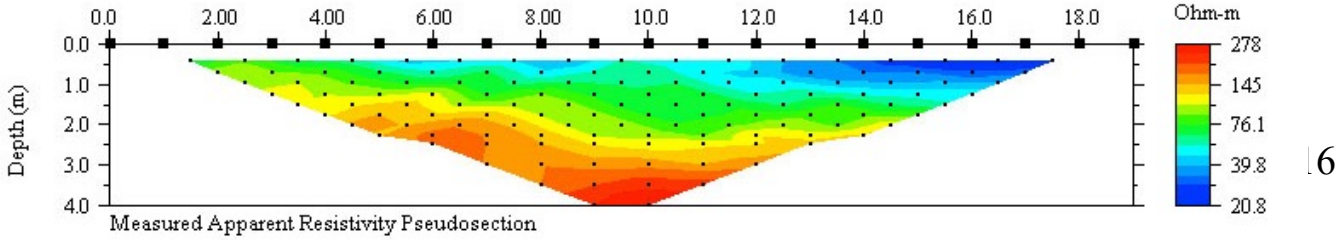
Voltage= V

Current= A

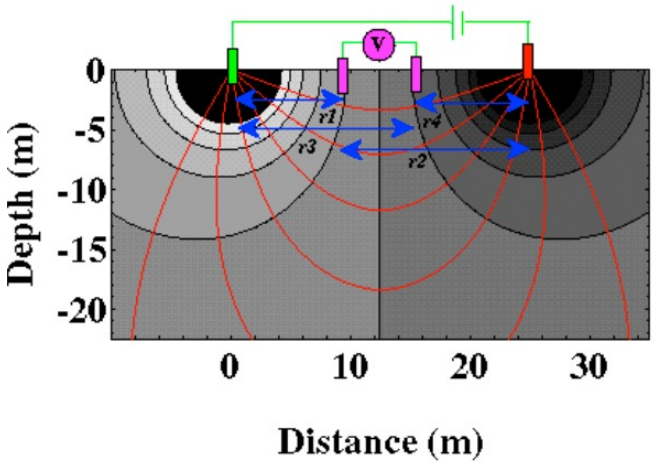
k is dependent on the electrode positions

Resistivity is different from resistance because it is independent of geometry





Electrical methods= example



$$\rho_a = \frac{2\pi\Delta V}{i}\left[\frac{1}{\left(\frac{1}{r_1}-\frac{1}{r_2}-\frac{1}{r_3}+\frac{1}{r_4}\right)}\right]$$

ΔV=10V
r1=15m
r2= 50m
r3= 40m
r4=10m
i= 10 A

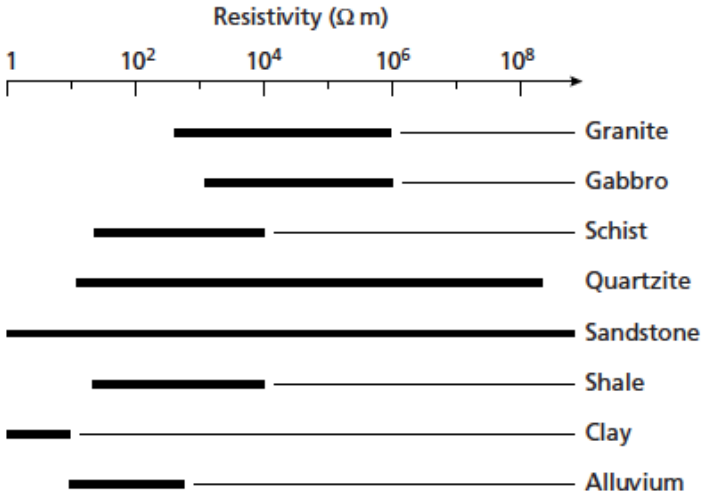
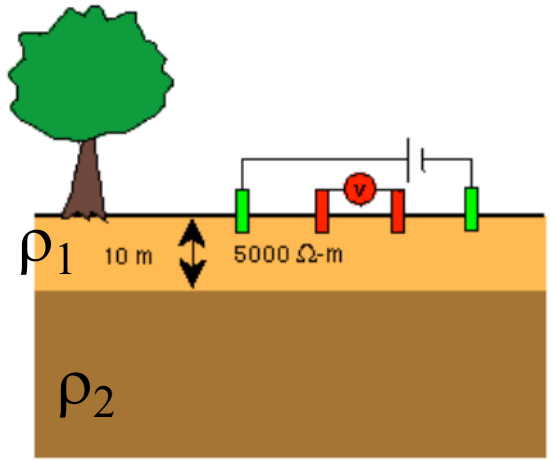


Fig. 8.2 The approximate range of resistivity values of common rock types.

Electrical methods= example



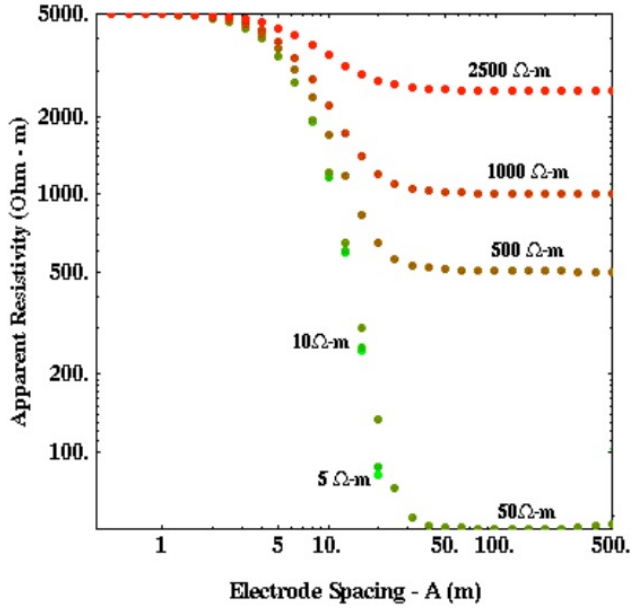
Wenner array= equidistant

Resistivity methods may be used to map lateral subsurface changes and near-vertical features (e.g., fracture zones) and to determine depths to geoelectric horizons (e.g. depth to saline water).

DC Resistivity is commonly used to…

- delineate aggregate deposits for quarries
- estimate depth to bedrock
- estimate depth to water table
- detect and map geologic features

ρ1



ρ2

ρ2

ρ2

ρ2

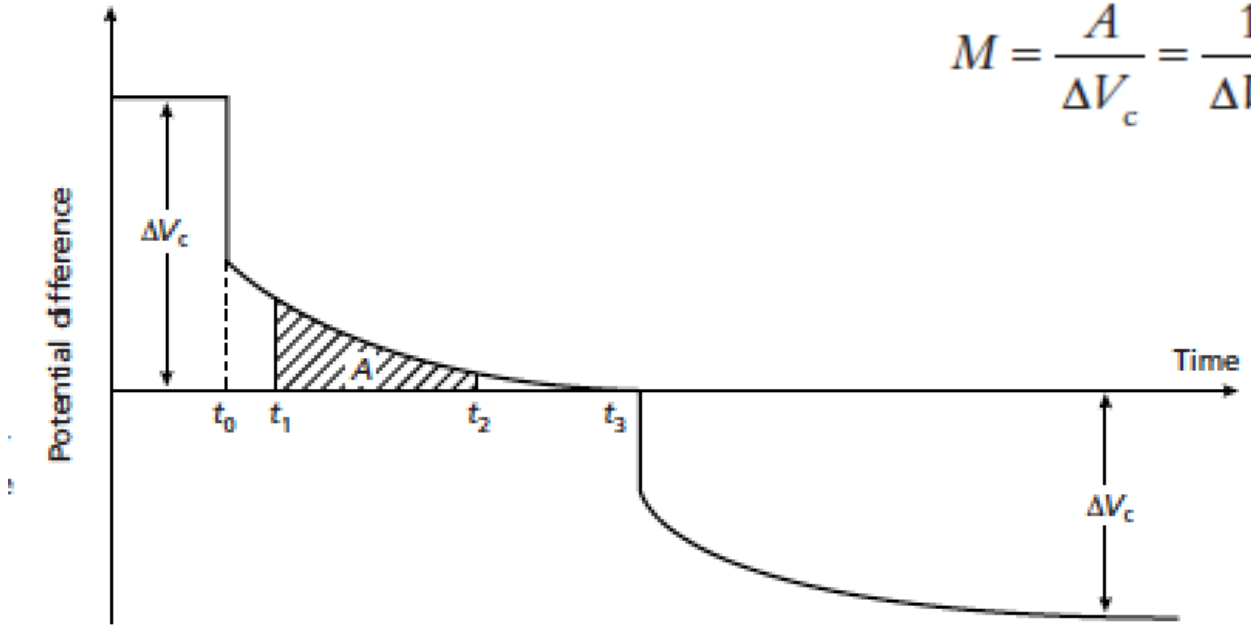
Possible curves depending on value of ρ_2

Electrical methods

Induced polarization

- Induced polarization due to ground acting as a capacitor and stores electric charge and becomes electrically polarized
- Measurement of apparent resistivity (ρ_A) at low-frequency variable AC source is known as frequency-domain IP surveying
- Apparent resistivity decreases as the frequency increases (because the capacitance of the ground inhibits the passage of DC but transmits AC with increasing efficiency as frequency rises)
- At time t_0, the current is switched off and the measured potential difference, after an initial large drop from the steady-state value ΔV_c, decays gradually to zero. A similar sequence occurs when the current is switched on at time t_3. A represents the area under the decay curve for the time increment t_1-t_2.
- Measurement of chargeability as a function of time
- Chargeability (M) and conductivity related to resistivity

$$M = \frac{A}{\Delta V_c} = \frac{1}{\Delta V_c}\int_{t_1}^{t_2} v(t)\,dt$$

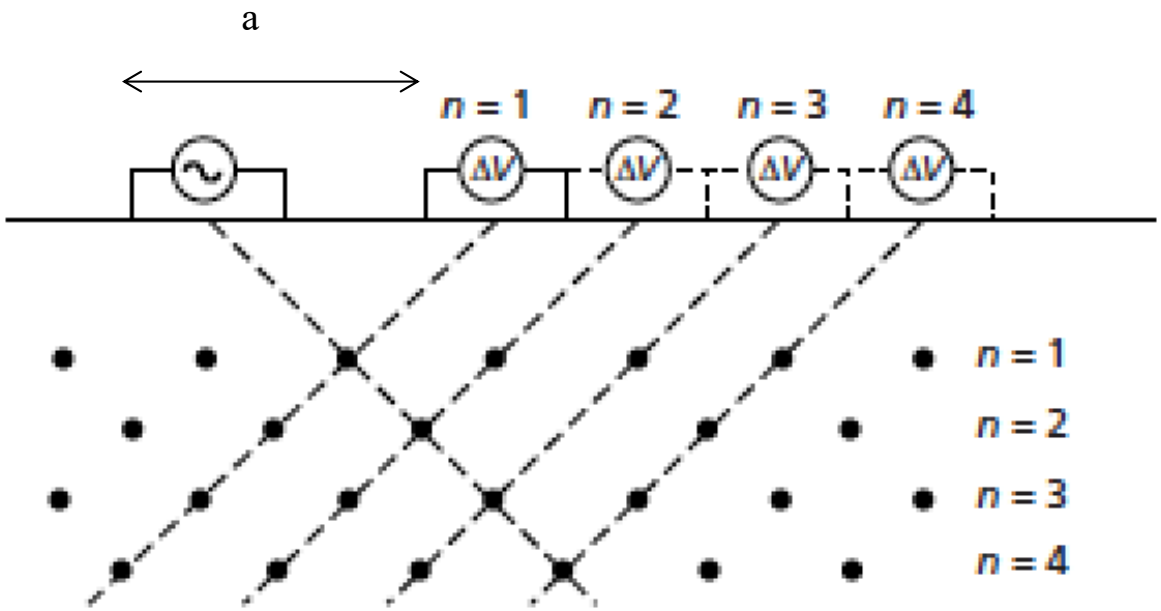


Electrical methods

Induced polarization

- Produce pseudosections with apparent resistivity values plotted at the intersections of lines sloping at 45° from the centers of the potential and current electrode pairs
- Move electrodes to measure the next point.

$$\rho_A = \frac{V}{I}\pi an(n+1)(n+2)$$



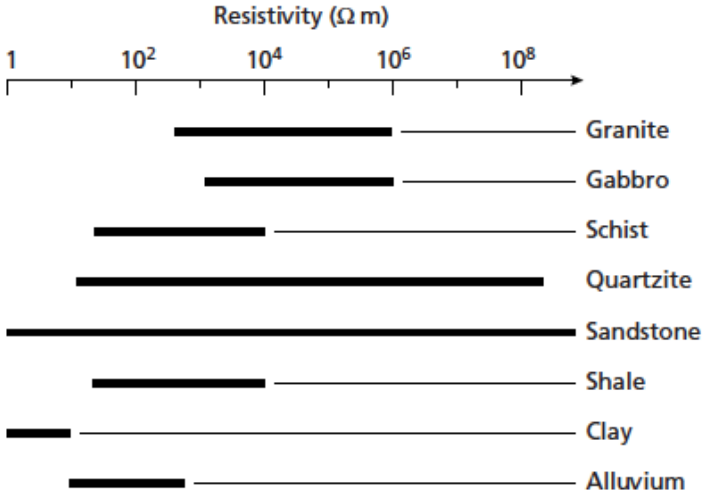
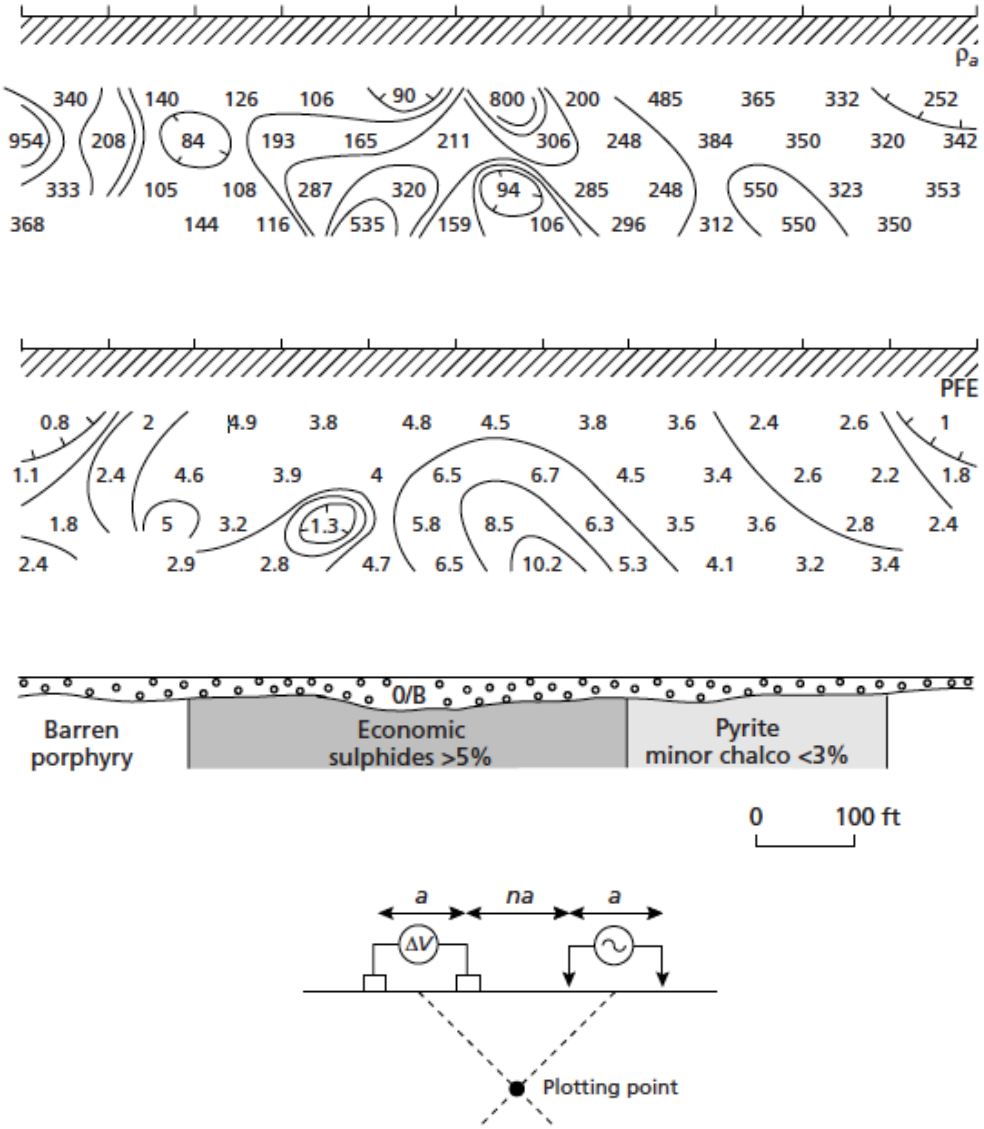


Fig. 8.2 The approximate range of resistivity values of common rock types.

Induced polarization

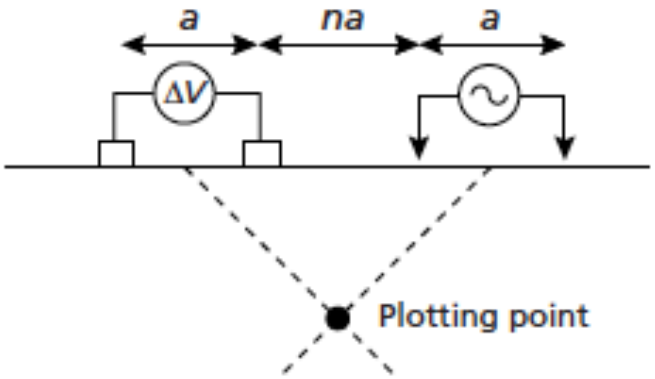
Dipole-dipole configuration

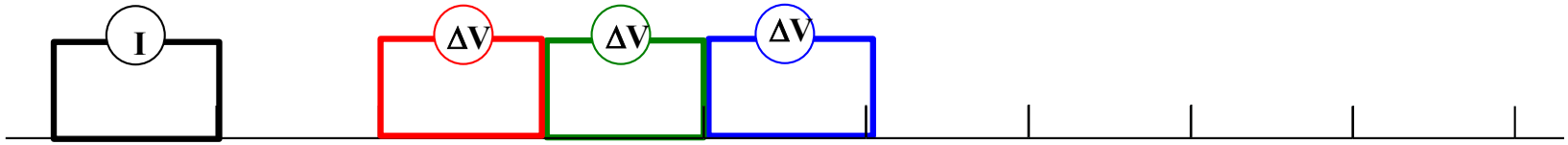


- Often measure percentage frequency effect (PFE) and metal factor (MF)
- $\rho_{0.1}$ and ρ_{10}= apparent resistivities at measuring frequencies of 0.1 and 10 Hz.

$$PFE = \frac{(\rho_{0.1} - \rho_{10})}{\rho_{10}} * 100$$

$$MF = 2\pi * 10^5 * \frac{(\rho_{0.1} - \rho_{10})}{\rho_{0.1} * \rho_{10}}$$


a
na
a
ΔV
Plotting point


I
ΔV
ΔV
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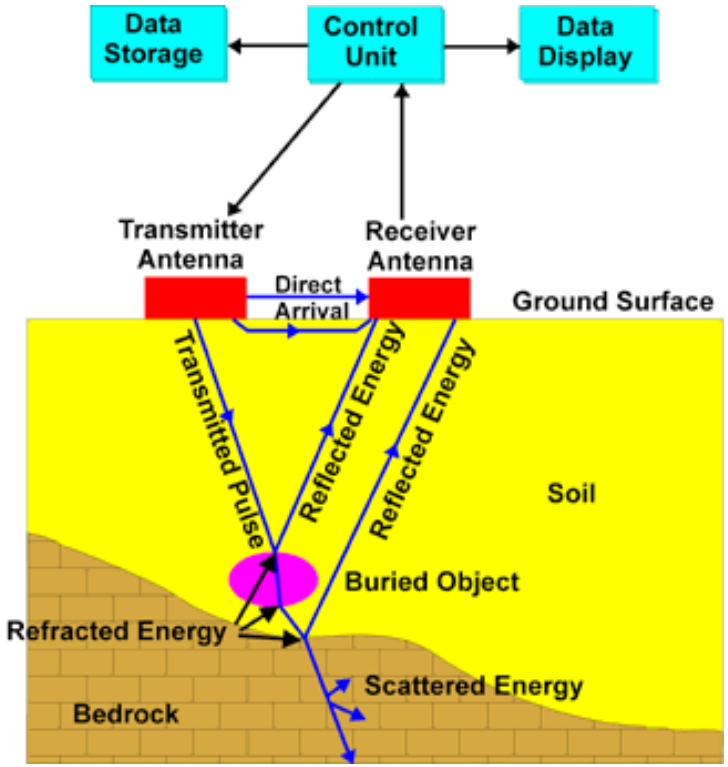
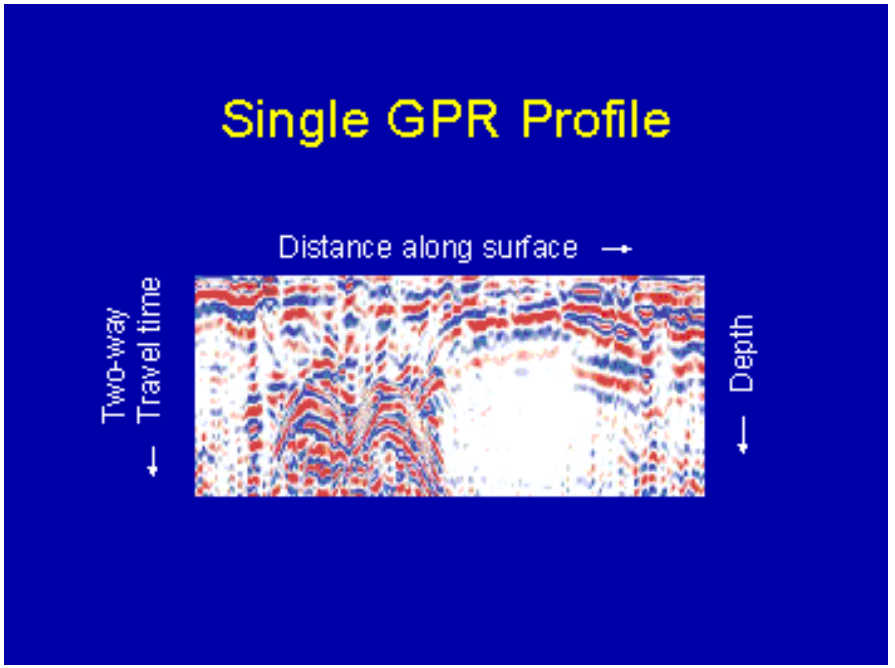
Ground-penetrating radar

- Ground penetrating radar (GPR): used to detect buried tanks, pipes, voids
- Require expert processing of signal
- Possible to distinguish between water and LNAPL- thickness of hydrocarbon layer





Intrusive methods

- Trial pits and trenches-
  - –Large, requires excavator-
  - –Allows detailed examination of ground conditions

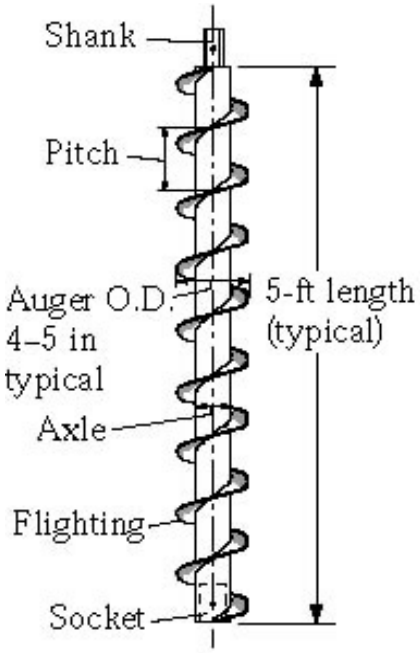
- Drilling:
  - – Auger drilling
  - – Rotary drilling
  - – Direct Push drilling
  - – Sonic drilling

- *In situ* tests: determining characteristics of the subsurface without collecting samples and analyzing them in laboratory
  - –Standard penetration test
  - –Cone penetrometer test

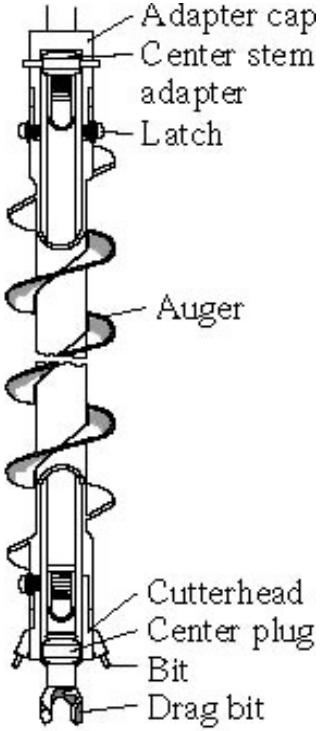
- Monitoring wells
- Soil gas surveys

Drilling techniques

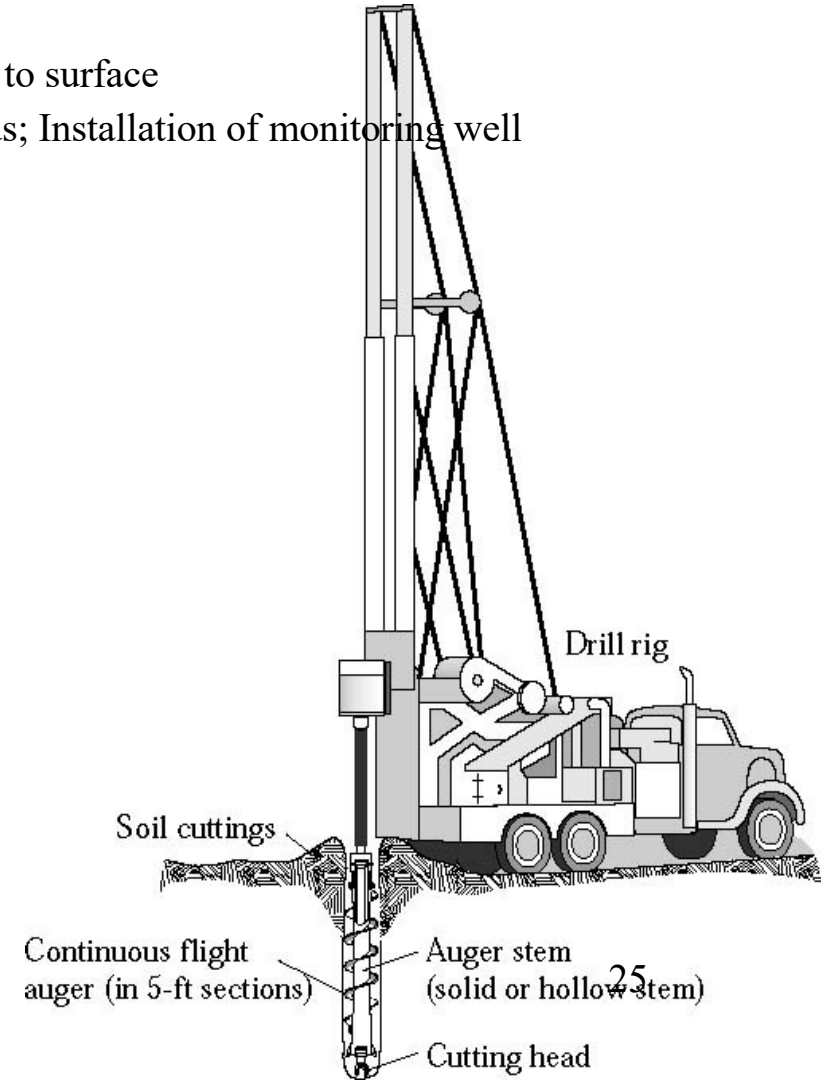
- Drilling techniques have three fundamental requirements:
  - A method or tool to advance the borehole
  - A method or tool to carry the cuttings to the surface
  - A method to maintain borehole stability
- Auger drilling:
  - Continuous flight auger
  - Rotate the auger and cutting bit
  - Cutting bit loosens the soil and the auger flights carry cutting to surface
  - Hollow stem auger: sampling in the center as drilling proceeds; Installation of monitoring well through inside of auger



(a) Solid-stem auger

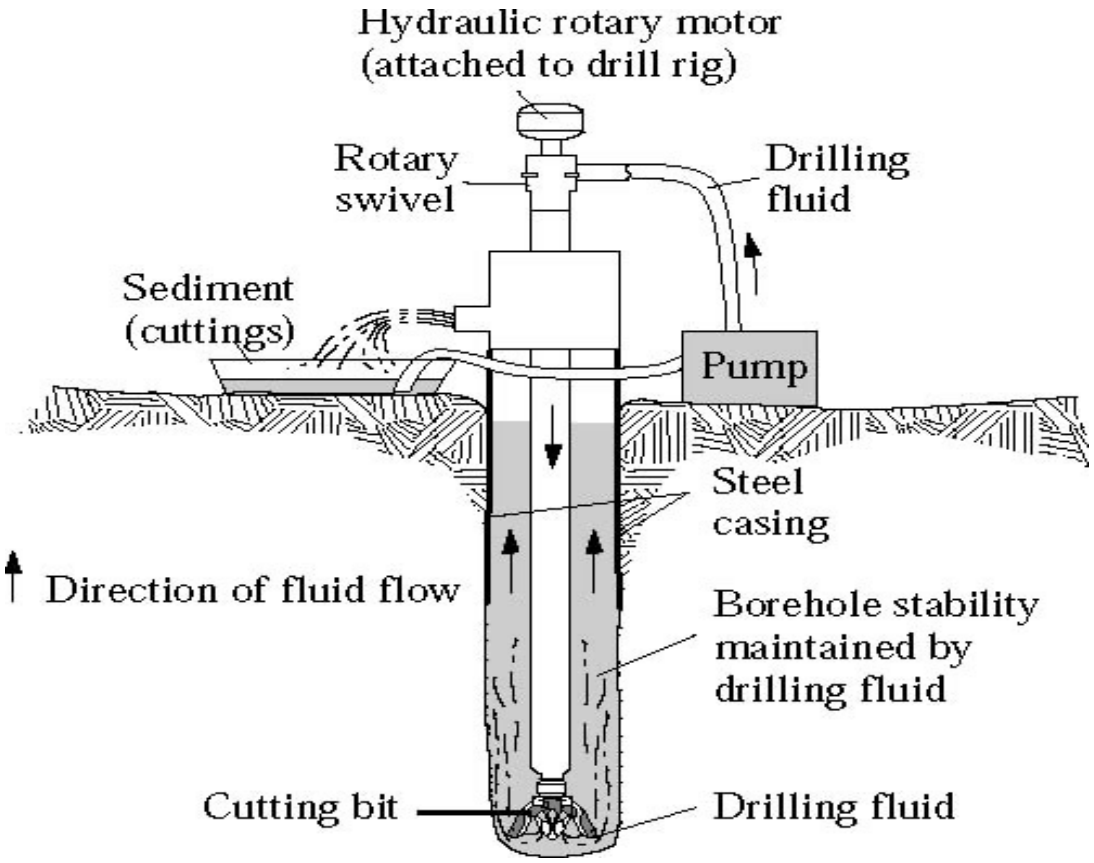


(b) Hollow-stem auger



Drilling techniques

- Rotary drilling:
  - Cutter head is rotated in the presence of drilling fluid
  - Cutting bit loosens material and drilling fluid carries cuttings to surface
  - Use steel casing to maintain borehole stability



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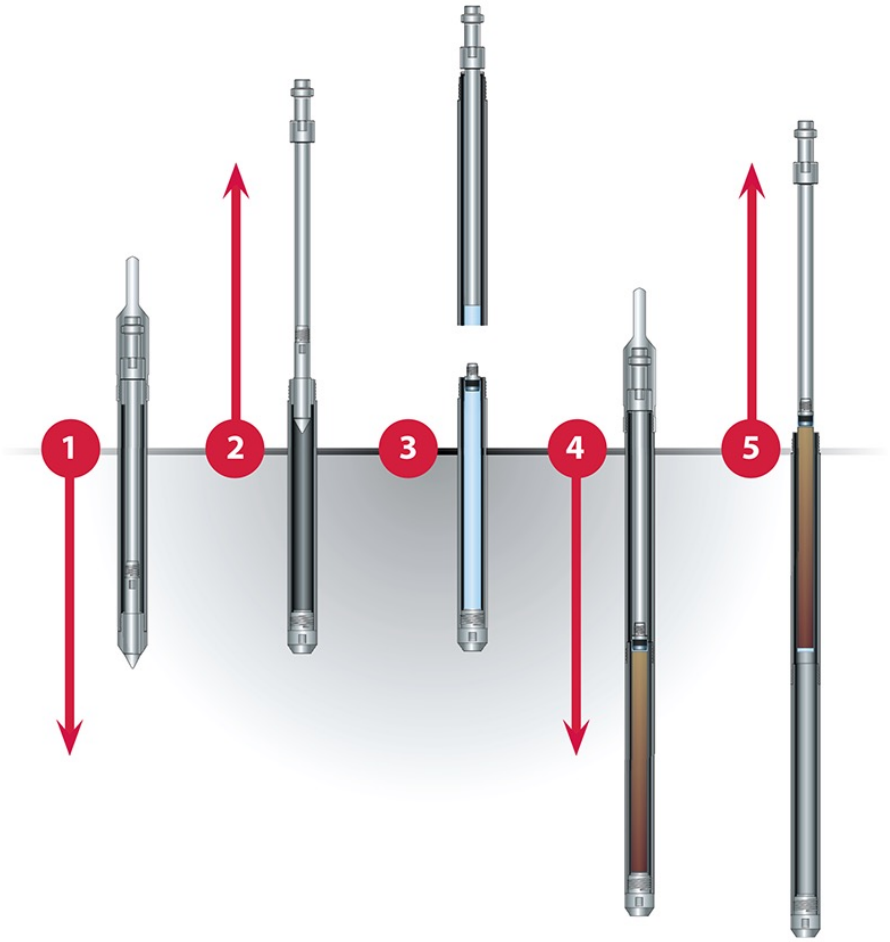
- Rotary drilling:
  - Cutter head is rotated in the presence of drilling fluid
  - Cutting bit loosens material and drilling fluid carries cuttings to surface
  - Use steel casing to maintain borehole stability

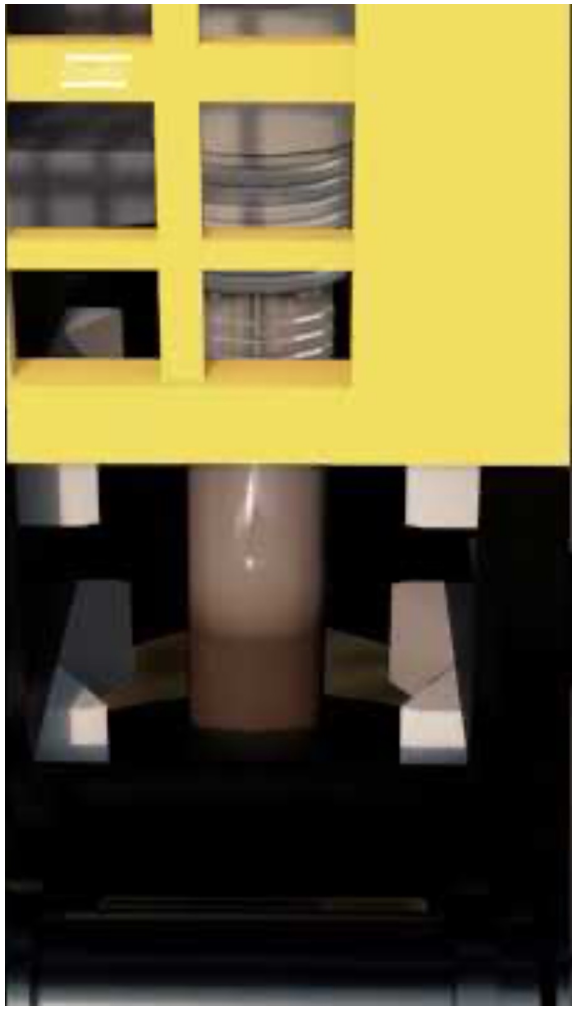
Drilling techniques

- Direct push drilling:
  - A drill with a hollow stem is pushed into the ground
  - A core is collected into a central tube
  - The core is removed by sliding out of the drilling tube



Drilling techniques

- Sonic drilling:
  - Advanced drilling technique
  - Oscillator within the drill head generates high frequency resonant energy
  - Resonant energy combined with rotational movement
  - Soil particles around the drill string and bit loose structure (liquefy) providing lubrication
  - Drill string moving 150 times per second
  - Relatively fast
  - (for rocks, need lubrication because no liquefaction)



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STEP 1: CORE BARREL ADVANCEMENT

The core barrel is advanced using sonic frequencies. When necessary, this step can be performed using no fluids, air, or mud.

Drilling techniques

- Sonic drilling:
  - Advanced drilling technique
  - Oscillator within the drill head generates high frequency resonant energy
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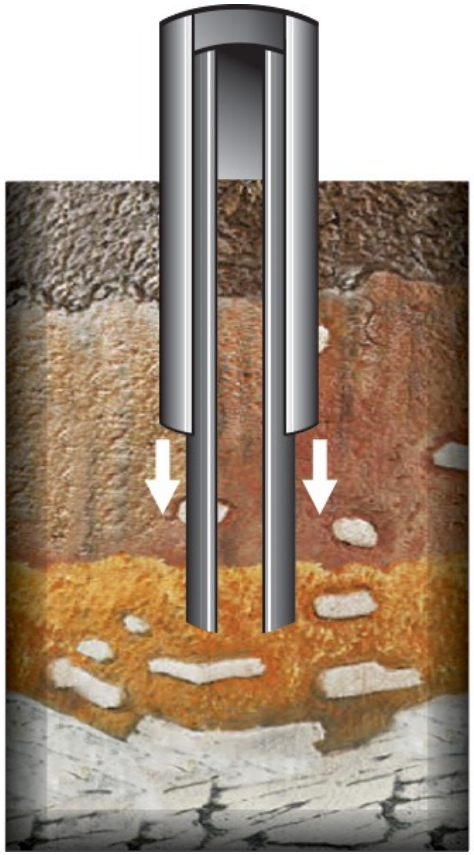

STEP 2: CASING OVERRIDE

After the core barrel is in place, casing is sonically advanced over the core barrel, protecting the bore hole's integrity in loose unconsolidated ground.

Drilling techniques

- Sonic drilling:
  - Advanced drilling technique
  - Oscillator within the drill head generates high frequency resonant energy
  - Resonant energy combined with rotational movement
  - Soil particles around the drill string and bit loose structure (liquefy) providing lubrication
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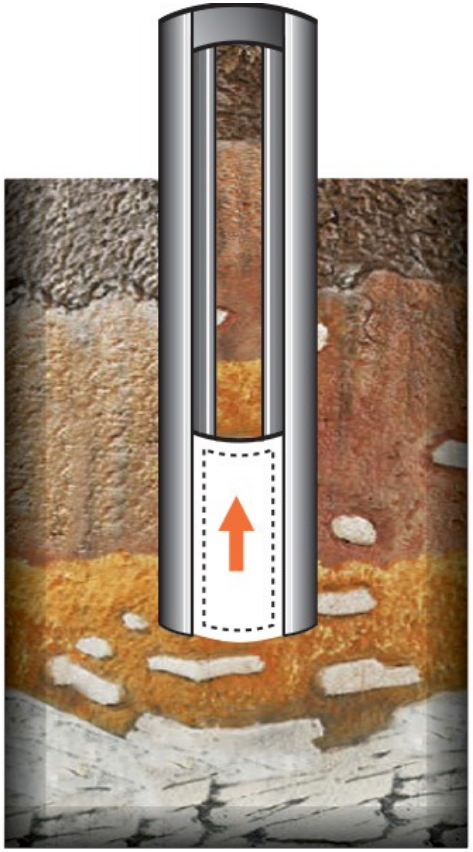


STEP 3: CORE RETRIEVAL

The core barrel is retrieved, producing a relatively undisturbed sample with near 100% core recovery.

Drilling techniques

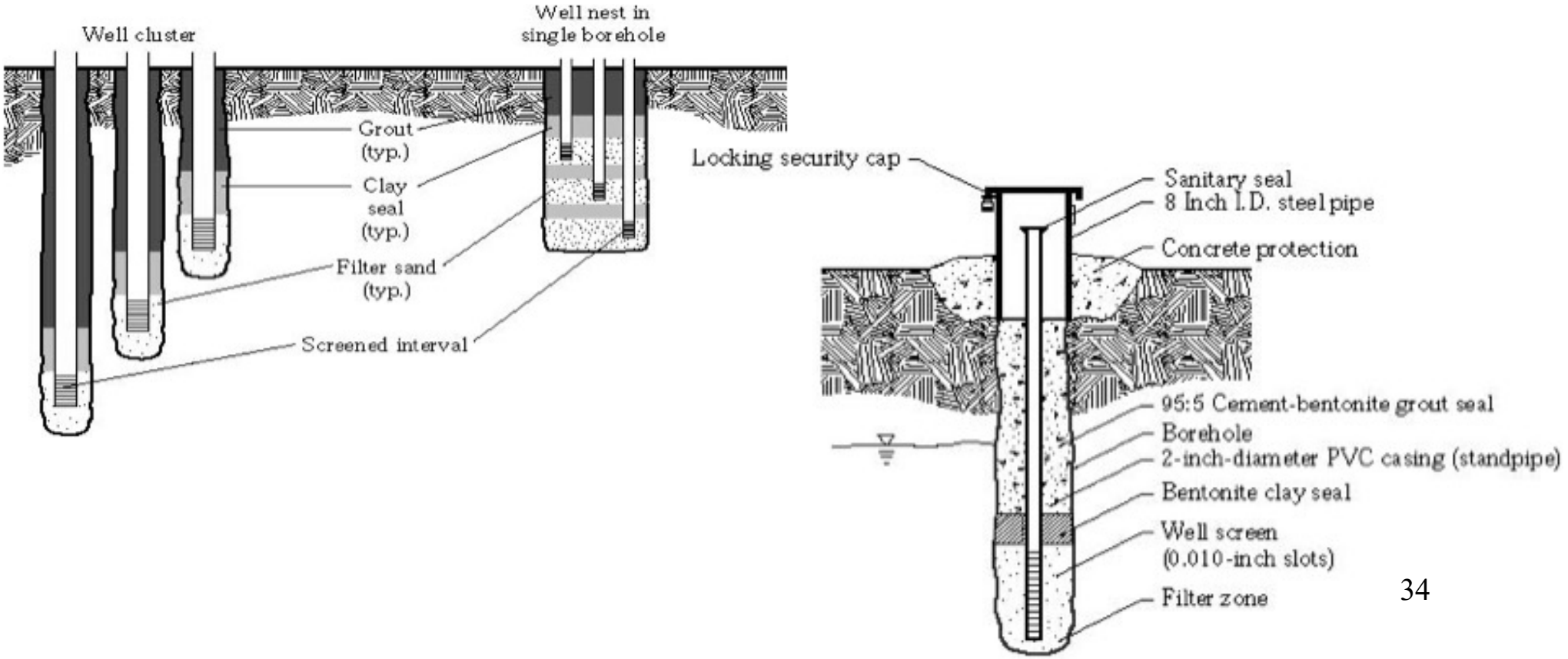
- Sonic drilling:
  - Advanced drilling technique
  - Oscillator within the drill head generates high frequency resonant energy
  - Resonant energy combined with rotational movement
  - Soil particles around the drill string and bit loose structure (liquefy) providing lubrication
  - Drill string moving 150 times per second
  - Relatively fast
  - (for rocks, need lubrication because no liquefaction)

STEP 4 - REPEAT CORE ADVANCEMENT

Steps 1 through 3 are repeated to depth, producing a continuous core sample through unconsolidated formations with less than 1% deviation.

Monitoring wells

- Monitoring wells allow the retrieval of groundwater from specific depths
- Riser pipe: sealed except at screened interval (sampled depth)
- Filter zone (sand or gravel pack): permit free flow of water from formation to screen without fines (prevent clogging)
- Seal the screen zone with bentonite (clay)
- Vented cap (no rain or surface water)
- Depth dependent sampling: Either multiple or nested wells



Soil gas surveys

- Conducted to provide quantitative information to assess risk associated with unsaturated zone
- Low cost alternative to groundwater sampling and help identify the boundaries of plume
- Measure vapor phase in void space in unsaturated soil
- Most effective for contaminants with high vapor pressure and low solubility
- In situ measurements of collecting gas in bag or analyze in laboratory

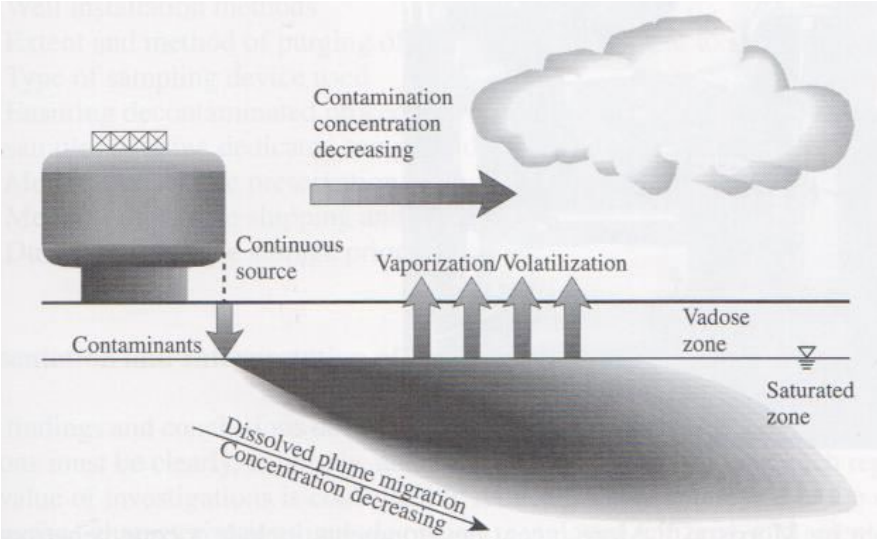


FIGURE 15-30
Principle of soil gas surveys.

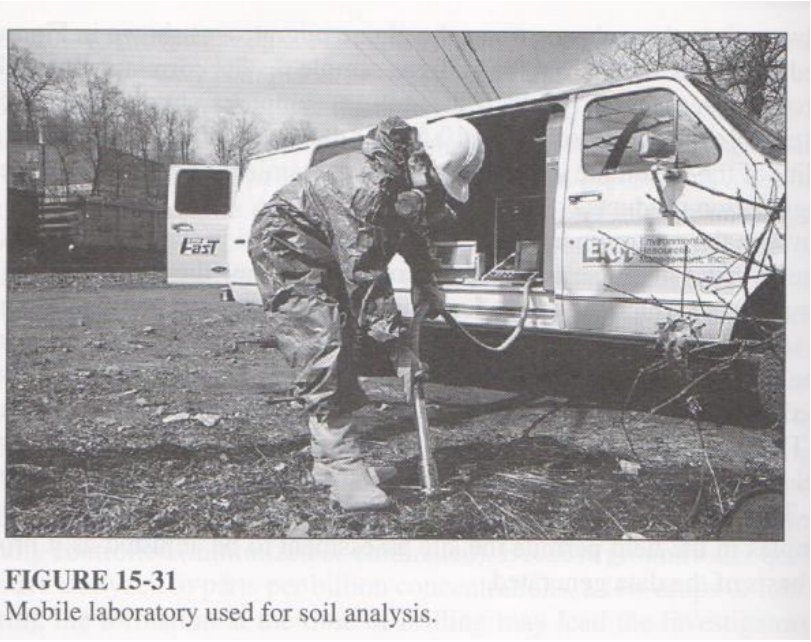


FIGURE 15-31
Mobile laboratory used for soil analysis.

Gas characterization

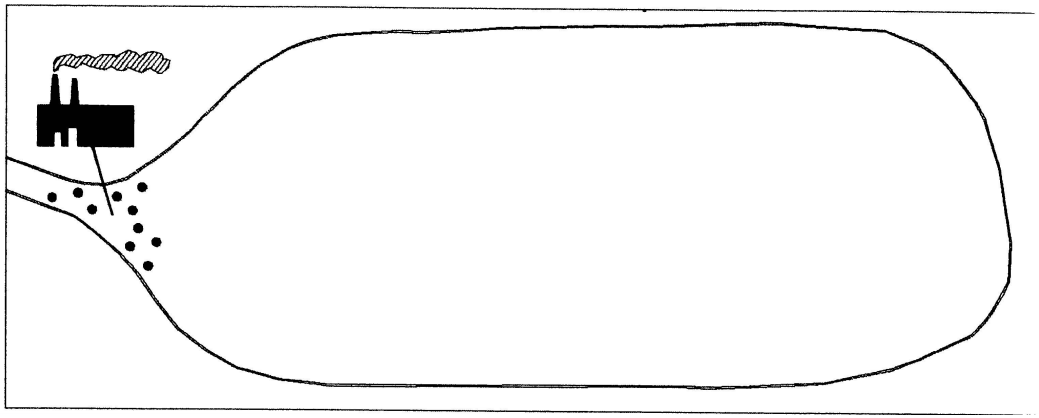
- Soil gases migrate in ground in all directions
- Vapor from VOCs have varying concentrations in the soil gas above different parts of plume
- Collected for analysis in lab or directly in field
- Spiked samples vary depending on soil porosity and weather
- Can accumulate when confined (e.g., wet ground conditions)
- Used to identify position of plume
- Sample by activated carbon tubes, gas syringe, sampling bag
- Monitor soil gas profile during drilling of borehole

Soil characterization

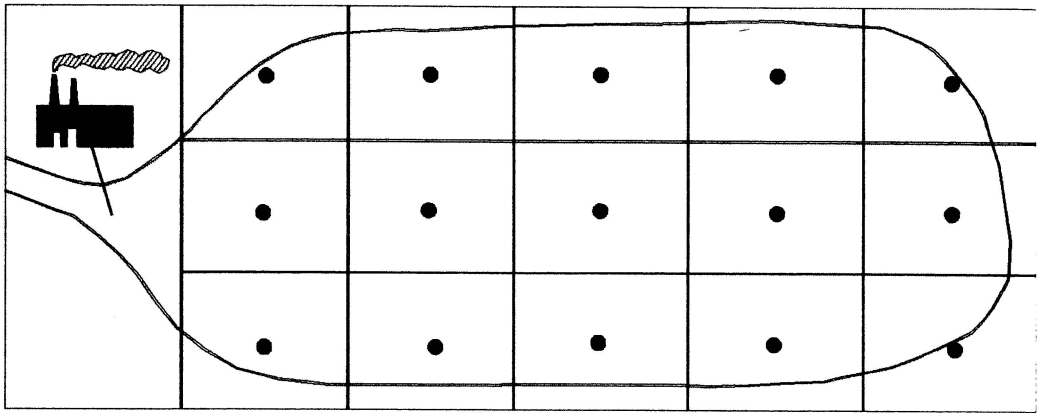
- Labeling system very important to quality of results (sampling date, site, project, ID, depth)
- Issues:
  - sample spacing determined by conceptual model or empirically
  - Cross-contamination: proper cleaning of sampling tool
  - Representative sampling
- Random sampling:
  - Identified at random
  - Avoid systematic error
- Nontargeted sampling:
  - Regular pattern of sample locations
  - Reliability of interpolation depends on homogeneity of site
  - If regular patterns on site (ditches at regular interval), sampling pattern should not coincide with topography
- Targeted sampling:
  - locations based on conceptual model of pollutant source
  - Examples: storage tanks, pipes, drains, pits, documented spill areas

Sampling

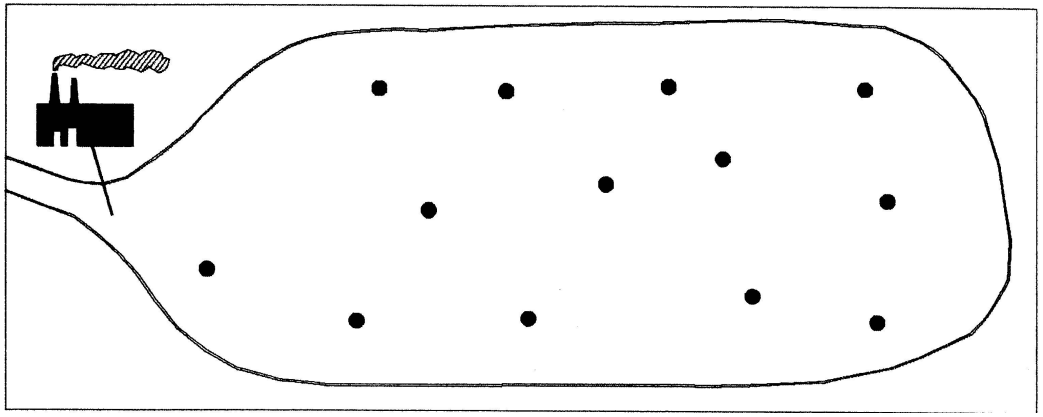
Targeted



Non-targeted

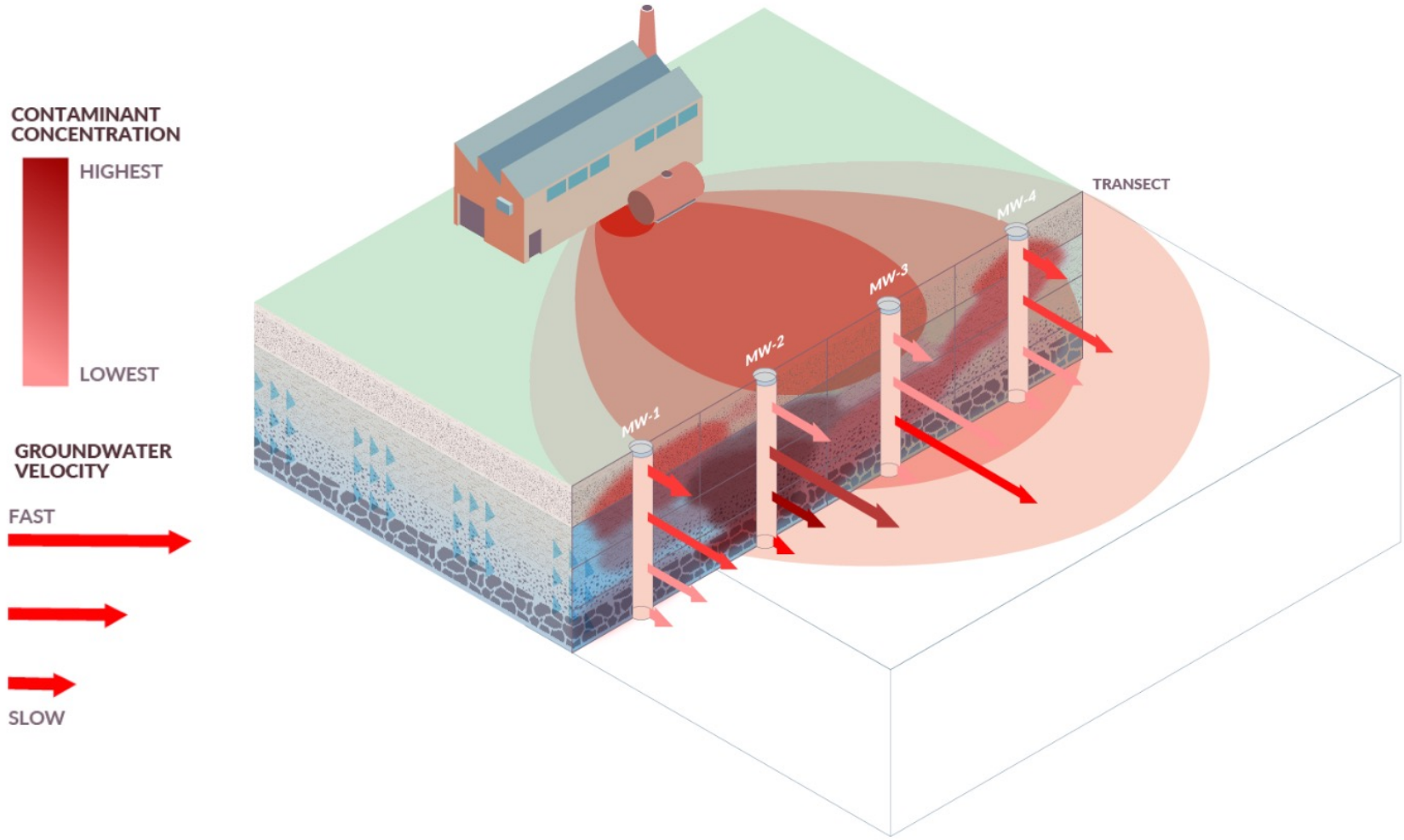


Random



In situ chemical analyses

Equipment	Measurement	Phase
Colorimetric kits	Specific ions (metals, nitrate) or functional groups (phenol, hydrocarbon)	Water
Enzymatic tests	Groups of organic compounds (PCBs, PAHs)	Water
GC (gas chromatography)	Organic molecules	Gas, water
Photoionization detectors (PIDs)	VOCs	Gas
pH, conductivity, T, DO, Eh	Physicochemical properties	Water
UV fluorescence	Petroleum hydrocarbons	soil

Novel technologies

- In-well contaminant flux measurement