# 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.

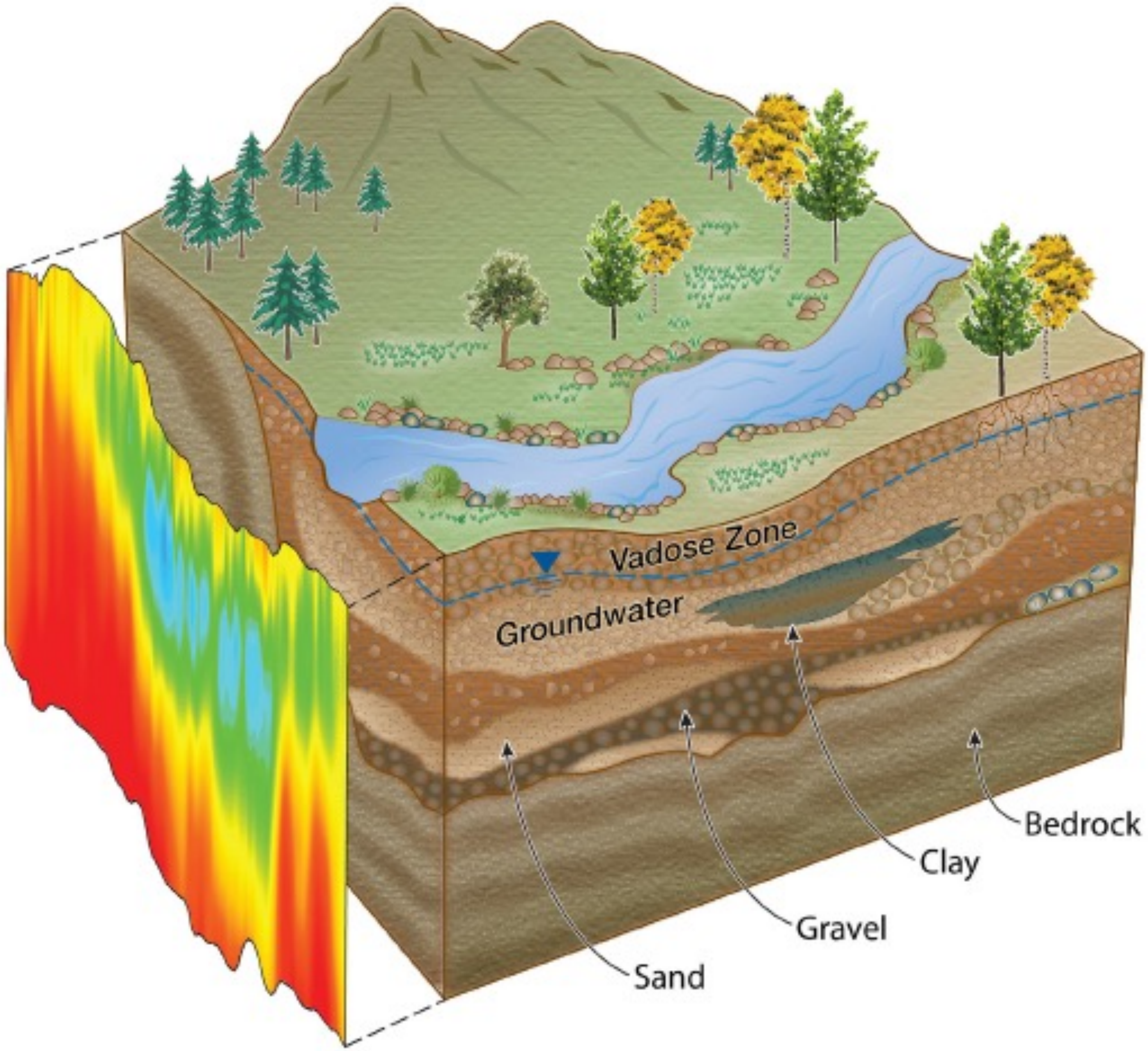
# Investigative techniques

- 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 |
|---|---|---|---|
| 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 |
| | Ground-penetrating radar (GPR) | Permittivity, electrical conductivity | Water content, stratigraphy, porosity |
| | Electromagnetic induction (EMI) | Electrical conductivity | Water content, clay content, salinity |
| Seismic | Seismic refraction | Elastic moduli and bulk density | Lithology, ice content, cementation state, pore fluid substitution |
| Gravity | Microgravity | Bulk density | Water content, 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

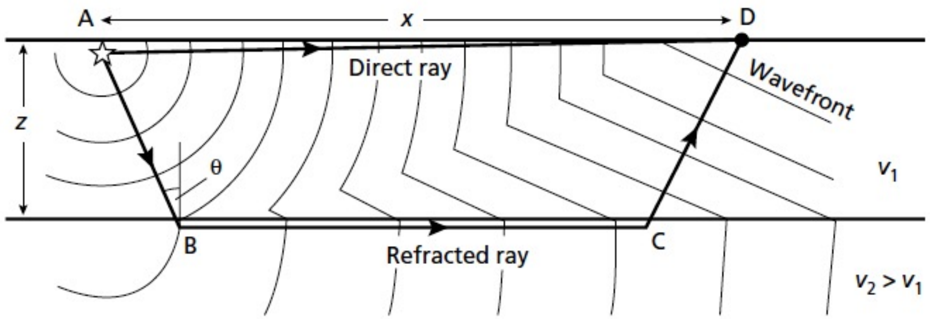
$$z=\frac{x_{cros}}{2}\left[\frac{v_2-v_1}{v_2+v_1}\right]^{1/2}$$

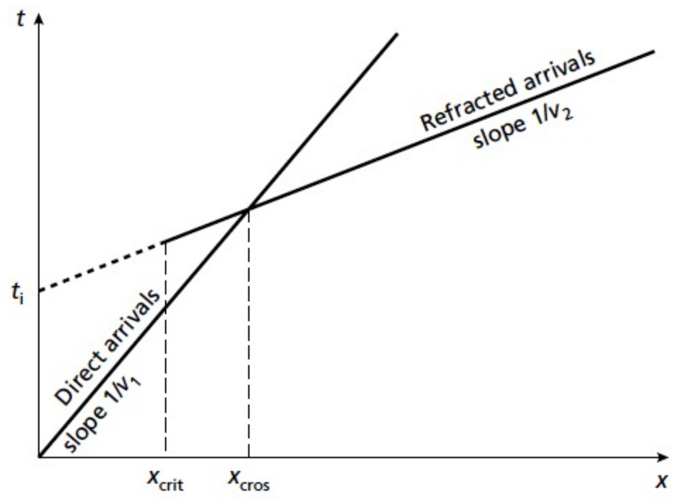
Where

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

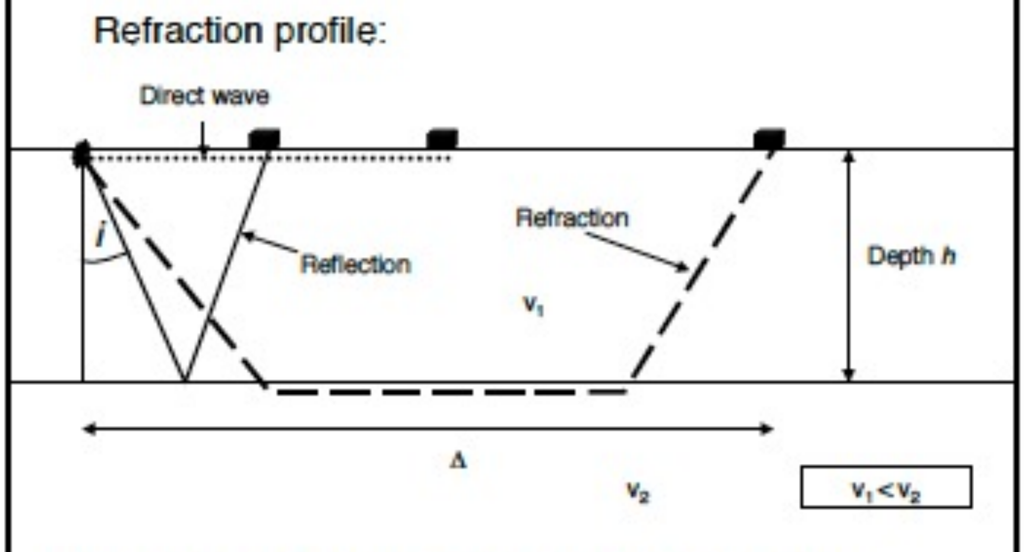



**Figure 1:** Geometry of reflection/refraction experiment. There are three arrivals recorded at greater distances: the direct wave, the reflection from the discontinuity at depth h and the refracted wave.

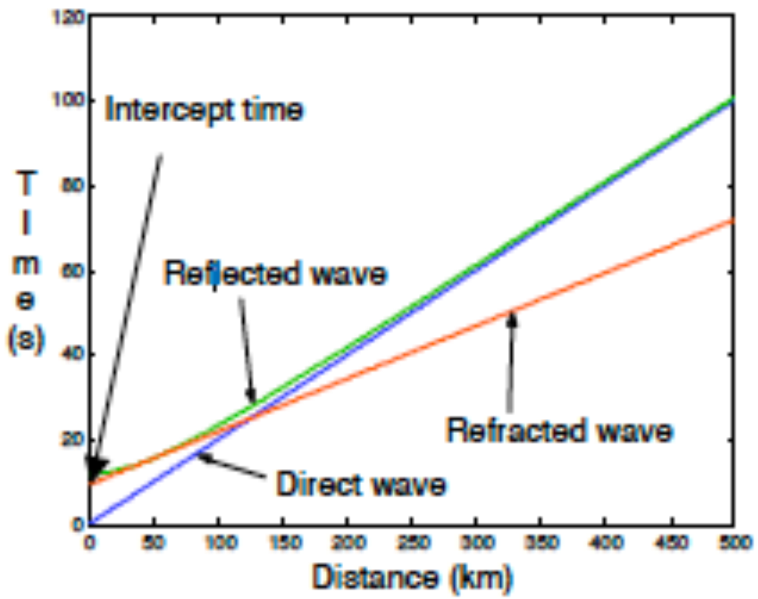


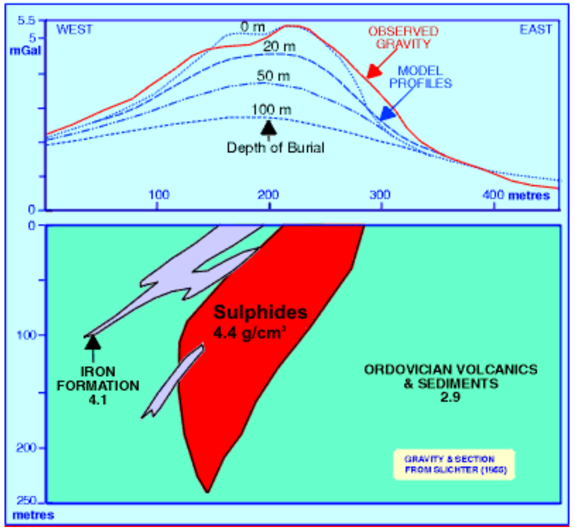

**Figure 2:** Travel-time diagram for the two-layer case.

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

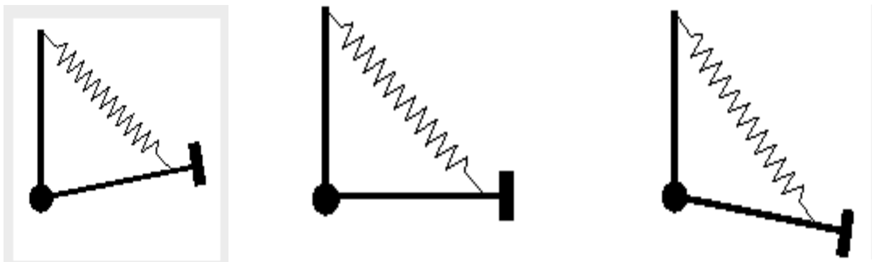
# Geothermal resource mapping in Lausanne January 2023 using reflection seismic waves


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

# Gravimetric methods

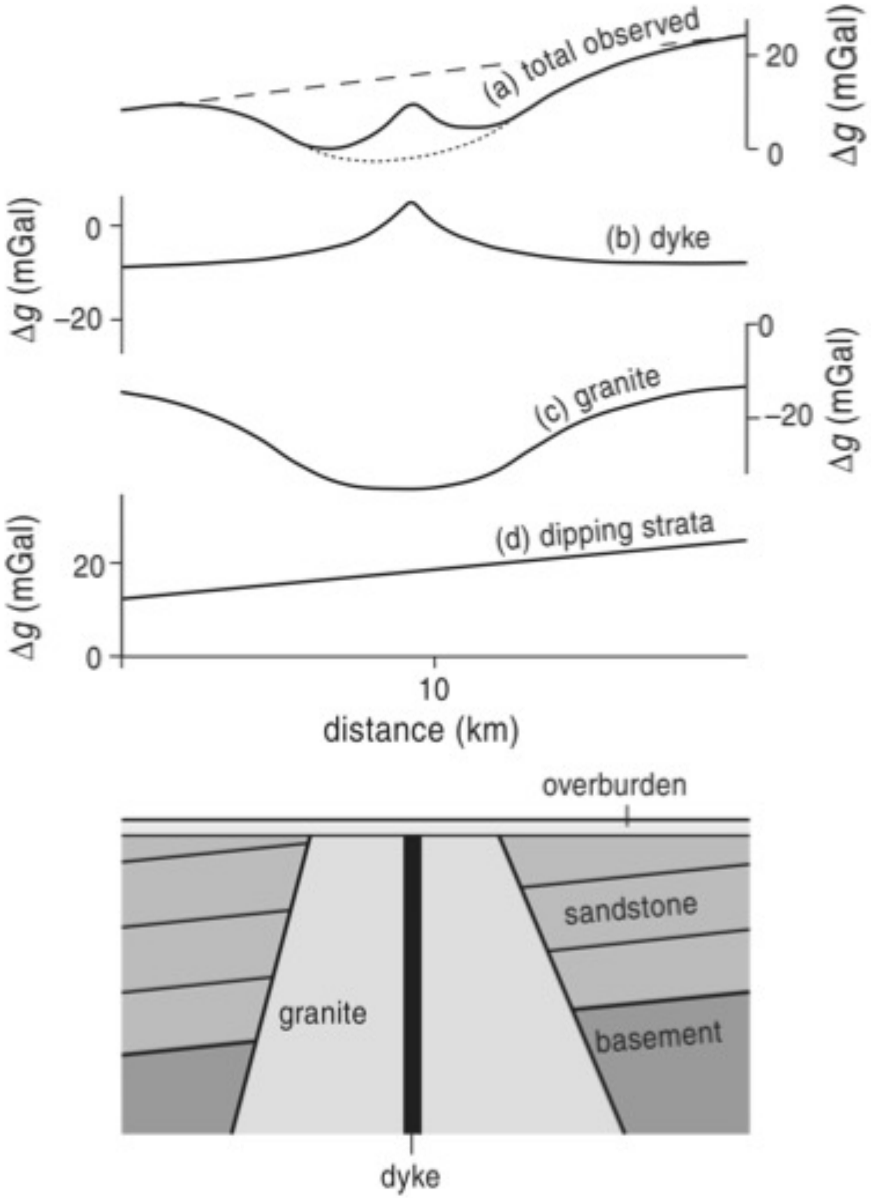


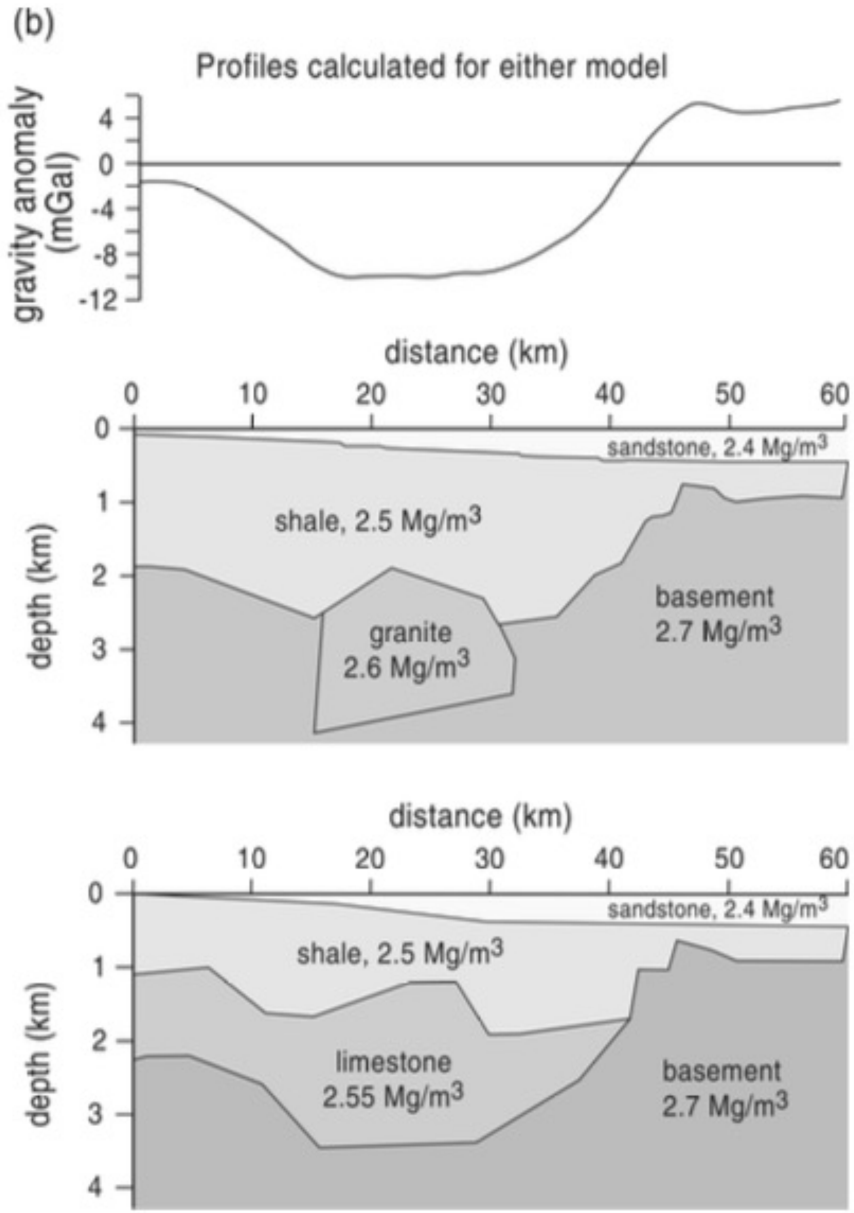

- **Microgravimetry** deals with Earth's gravity. A measured deviation from the 'normal' distribution of gravity allows to draw conclusions on density inhomogeneities in the subsurface.
- Gravity is measured with gravimeters: pendulum in fall experiment or superconducting gravitometers. Small mass suspended on a 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

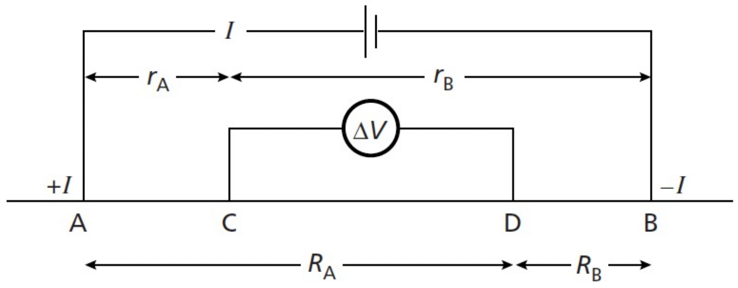
**Electrical**: Involve making measurements using electrodes with galvanic or capacitive contact with the subsurface. Plot scale (<10 m) acquisition.

DC resistivity
Induced polarization
(Self-potential)
Electromagnetic
Radar

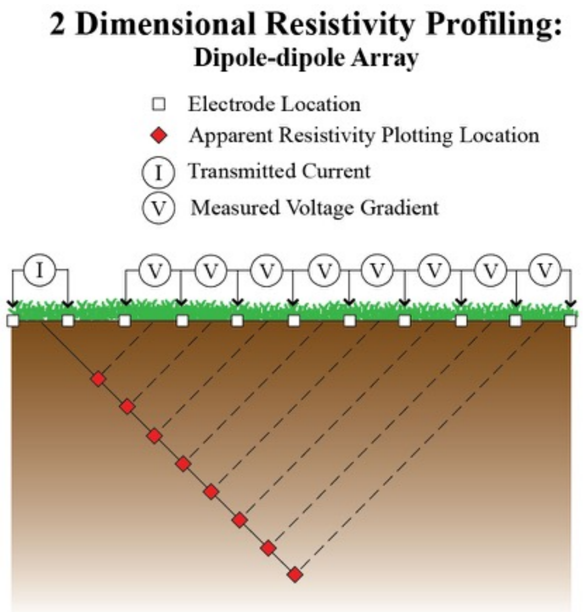
# Electrical methods

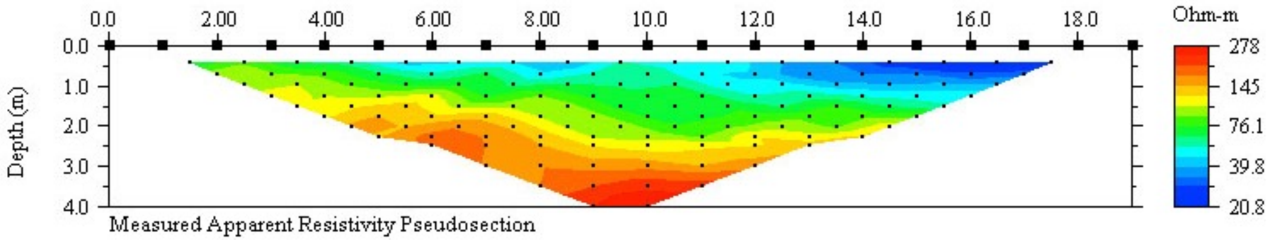
**DC resistivity**: apply a direct current (DC) between electrodes and measure current (I) and voltage (U) by varying the distance between electrodes.

Electric resistivity ρ= k* U/I
$\rho_a$= Ohm.m
Voltage= V
Current= A
k is dependent on the electrode positions
Resistivity is different from resistance because it is independent of geometry

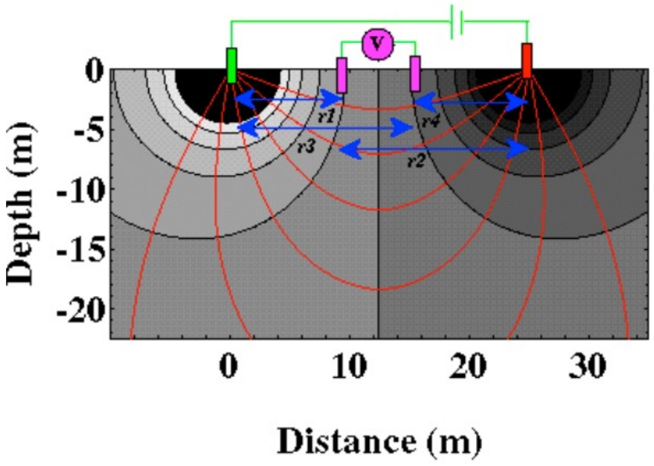



$$\rho = \frac{2\pi \Delta V}{I\left\{\left(\frac{1}{r_A}-\frac{1}{r_B}\right)-\left(\frac{1}{R_A}-\frac{1}{R_B}\right)\right\}}$$



# Electrical methods= example




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

$\Delta V$=10V
r1=15m
r2= 50m
r3= 40m
r4=10m
i= 10 A

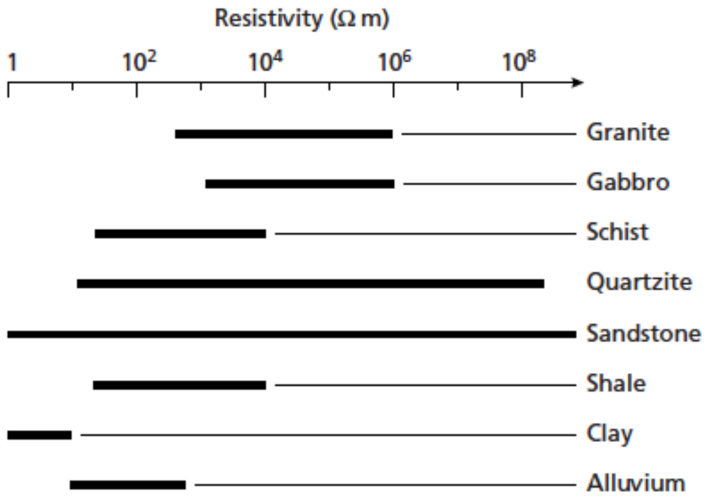
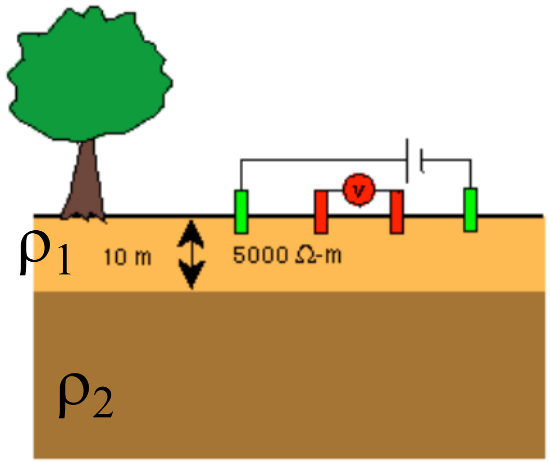
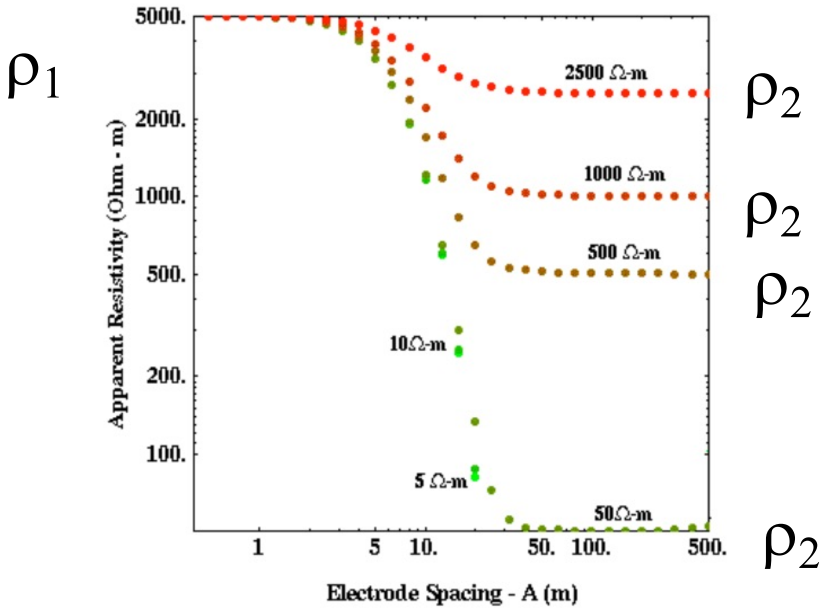



**Fig. 8.2** The approximate range of resistivity values of common rock types.

# 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

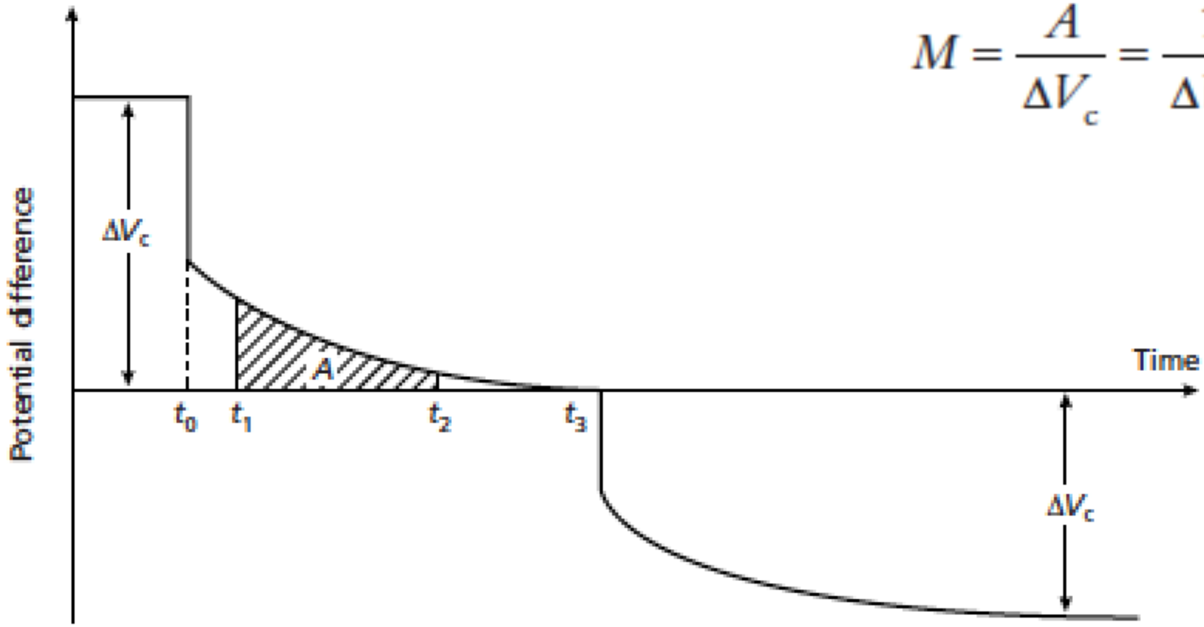
Possible curves depending on value of $\rho_2$

**Induced polarization**

# Electrical methods

- Induced polarization due to ground acting as a capacitor and stores electric charge and becomes electrically polarized
- Measurement of apparent resistivity ($\rho_A$) 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 $\Delta V_c$, 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

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

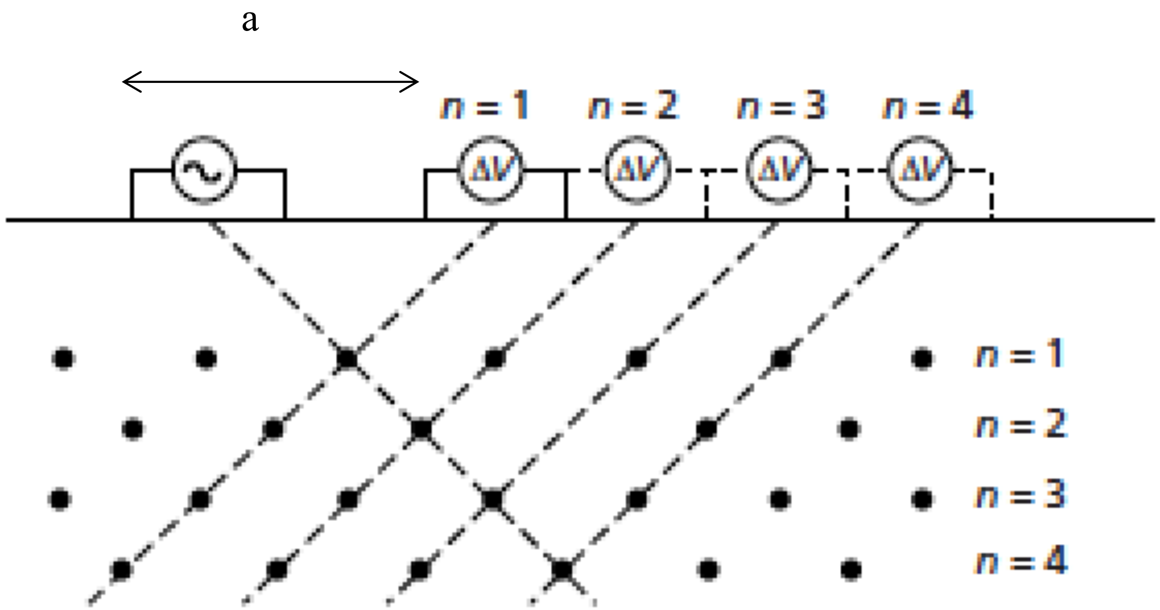


**Induced polarization**

# Electrical methods

- 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.

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



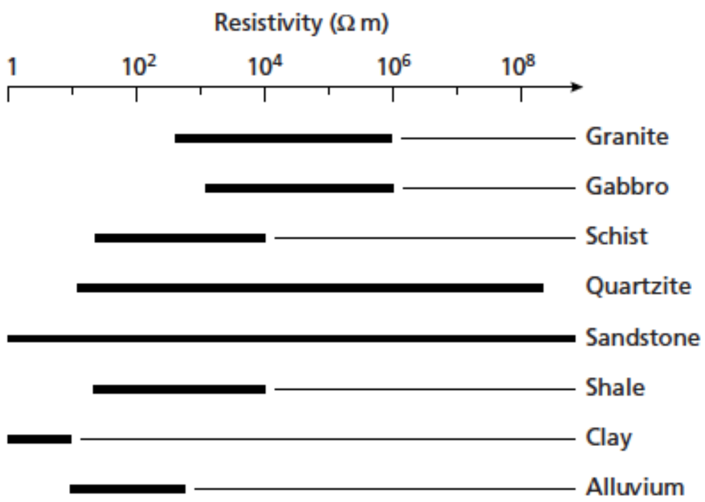
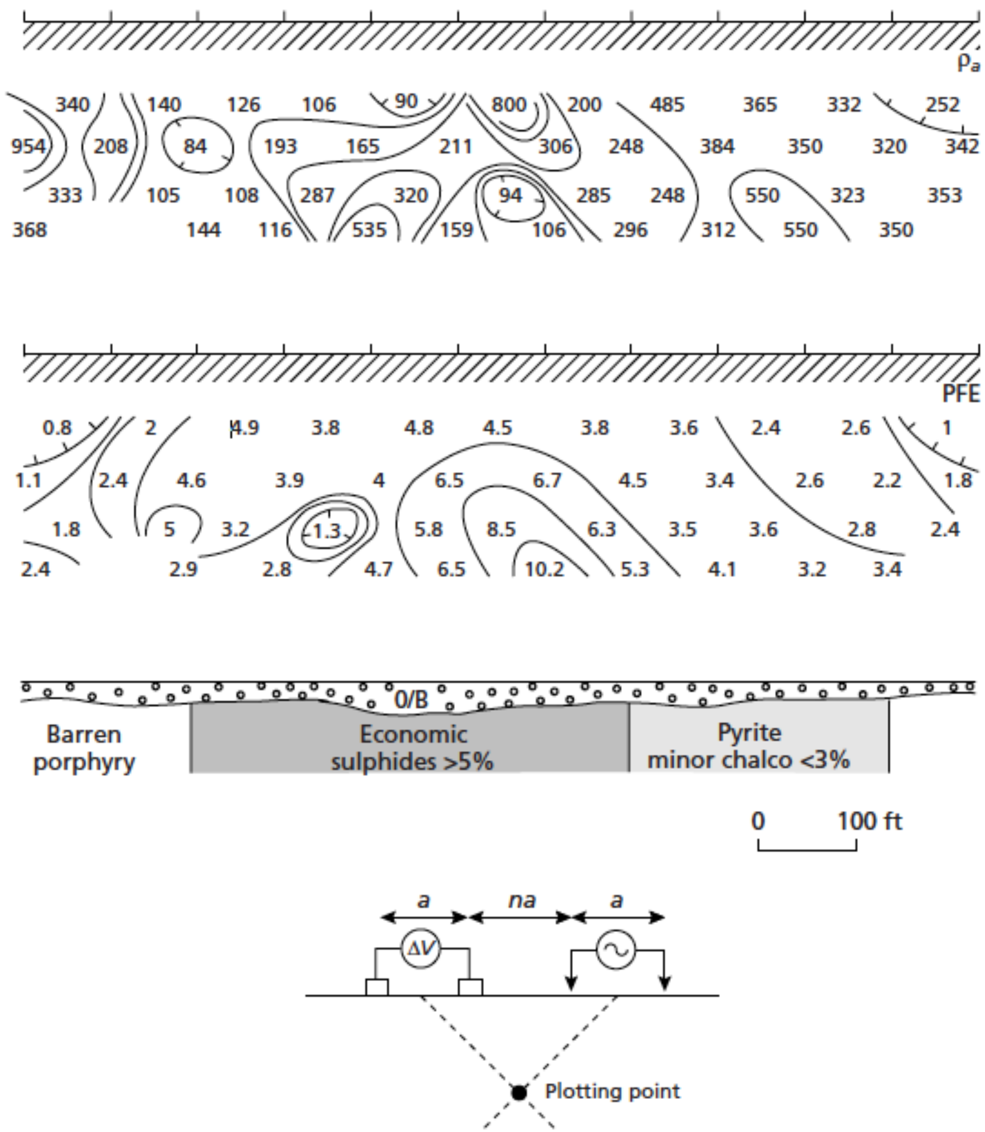




**Fig. 8.2** The approximate range of resistivity values of common rock types.

# Induced polarization

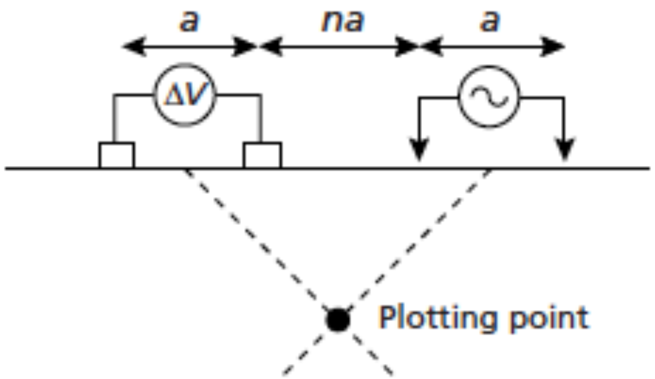
Dipole-dipole configuration

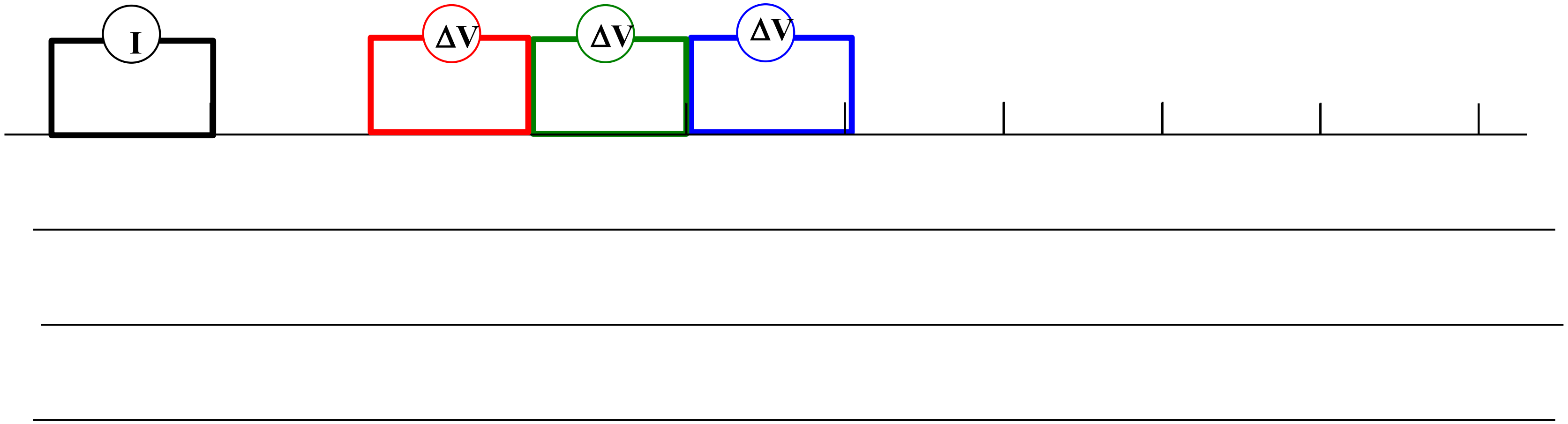



- Often measure percentage frequency effect (PFE) and metal factor (MF)
- $\rho_{0.1}$ and $\rho_{10}$= apparent resistivities at measuring frequencies of 0.1 and 10 Hz.

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

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


a
na
a
ΔV
Plotting point


I
ΔV
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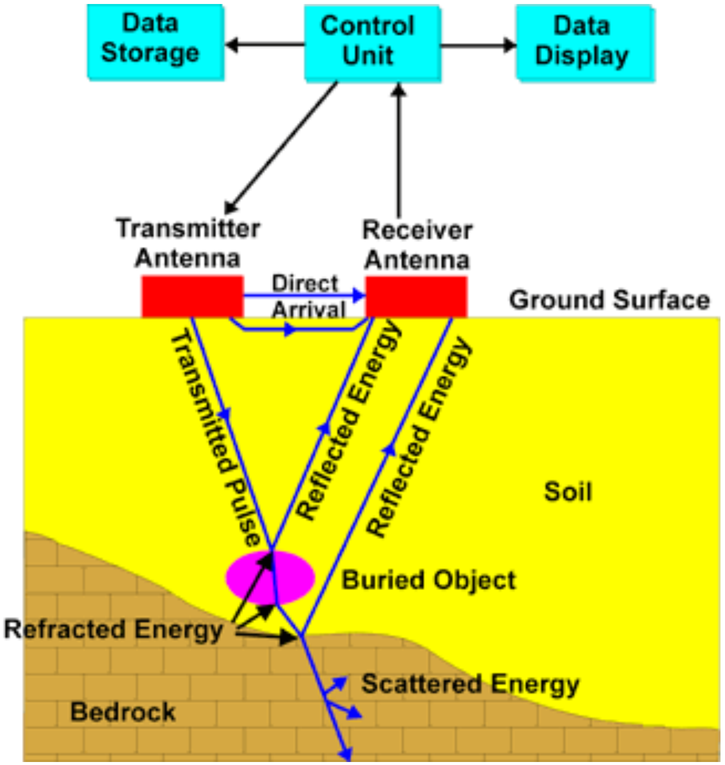
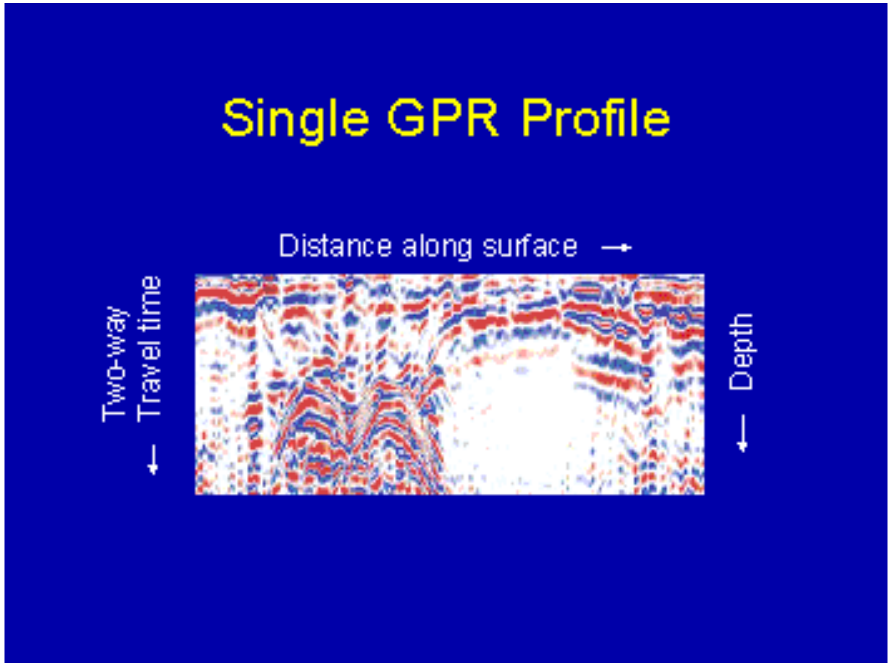
ΔV

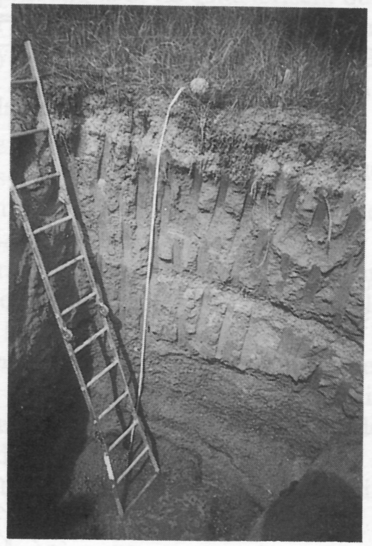
# Ground-penetrating radar

- 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

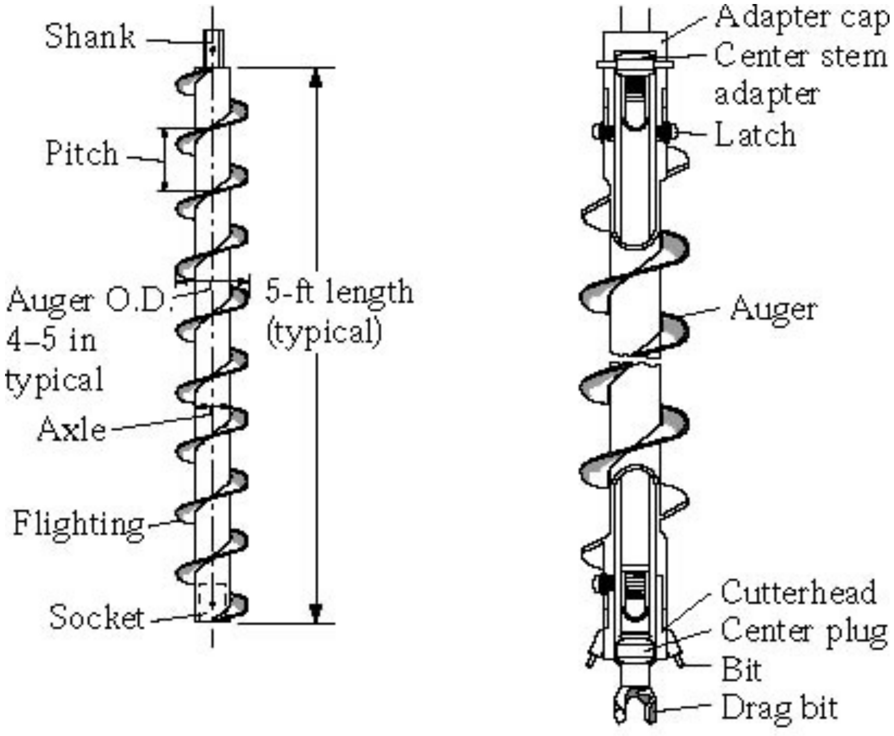
- Drilling:
  - – Auger drilling
  - – Rotary drilling
  - – Direct Push drilling
  - – Sonic drilling

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

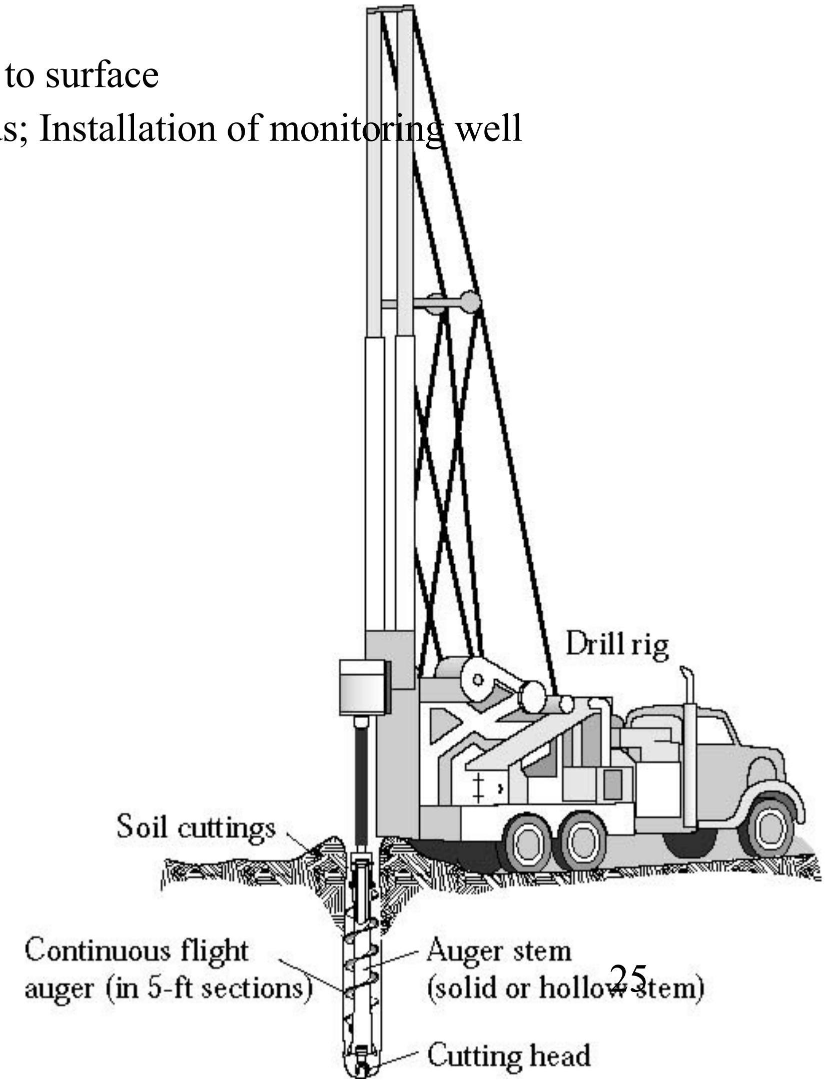
- Monitoring wells
- Soil gas surveys

# 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

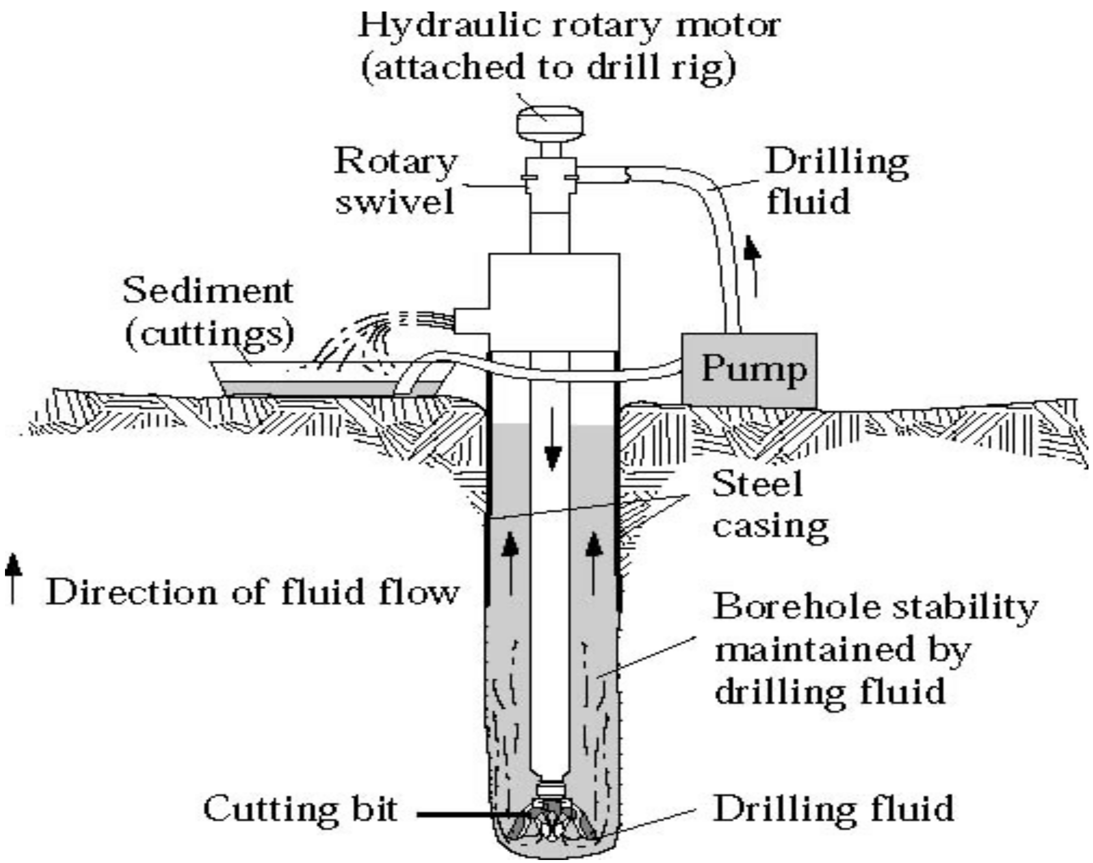



(a) Solid-stem auger (b) Hollow-stem auger



# 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

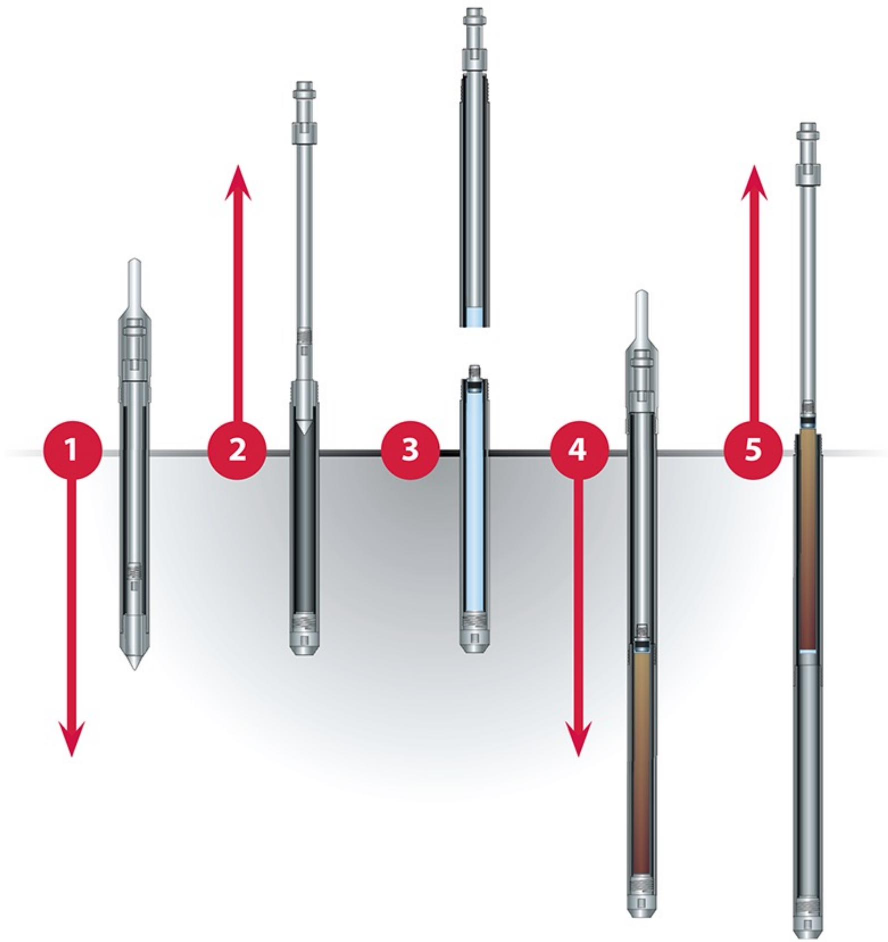


# Drilling techniques

- 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

# 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)

**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
  - Resonant energy combined with rotational movement
  - Soil particles around the drill string and bit loose structure (liquefy) providing lubrication
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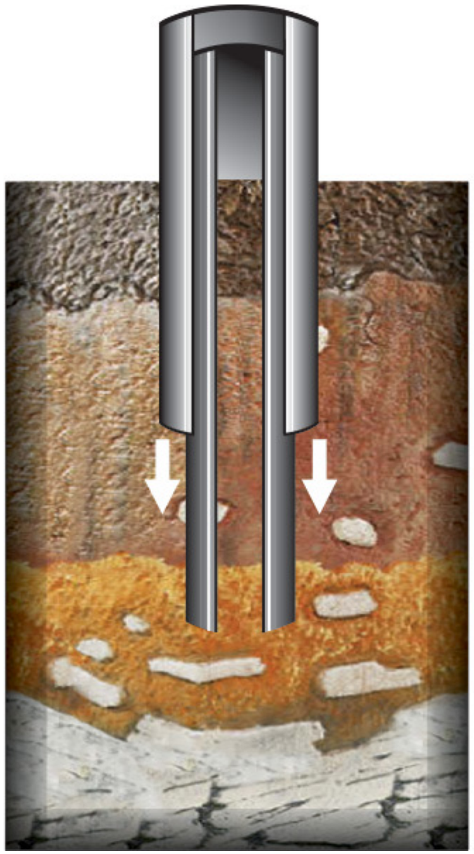


**STEP 2: CASING OVERRIDE**

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
  - Drill string moving 150 times per second
  - Relatively fast
  - (for rocks, need lubrication because no liquefaction)

**STEP 3: CORE RETRIEVAL**

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

# Drilling techniques

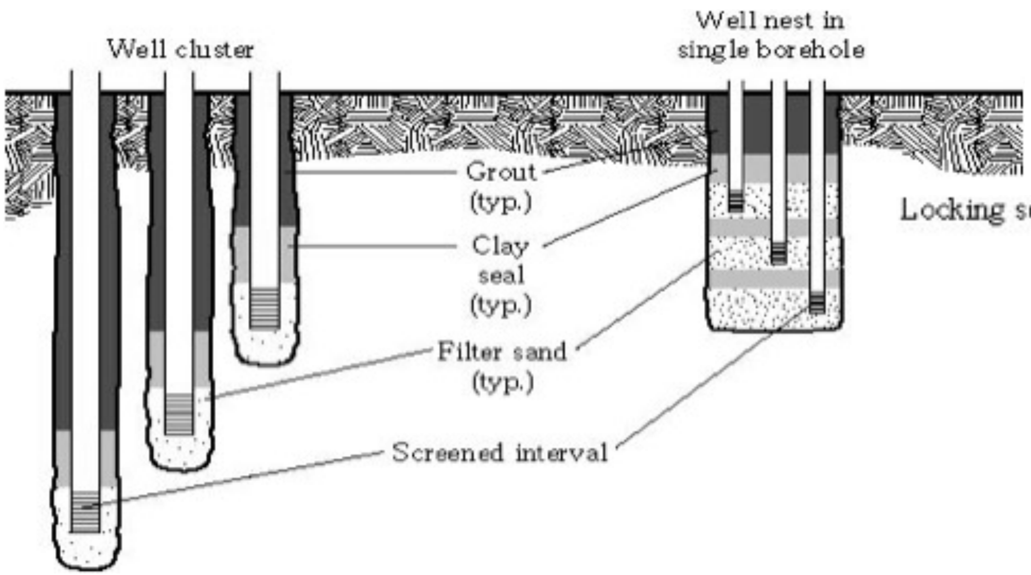
- Sonic drilling:
  - Advanced drilling technique
  - Oscillator within the drill head generates high frequency resonant energy
  - Resonant energy combined with rotational movement
  - Soil particles around the drill string and bit loose structure (liquefy) providing lubrication
  - Drill string moving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

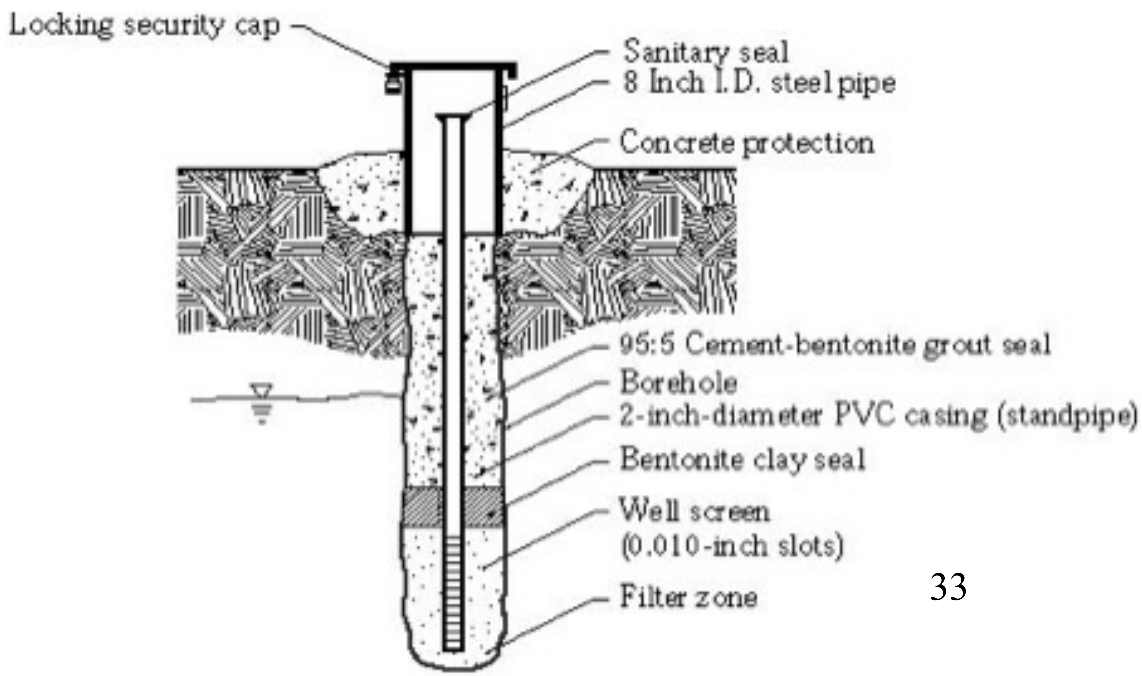
**STEP 4 - REPEAT CORE ADVANCEMENT**

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

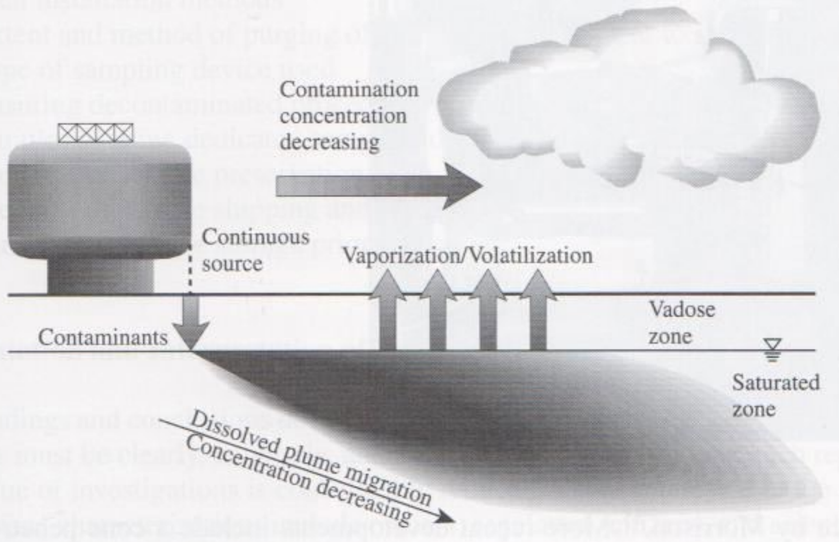



**FIGURE 15-30**
Principle of soil gas surveys.

**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

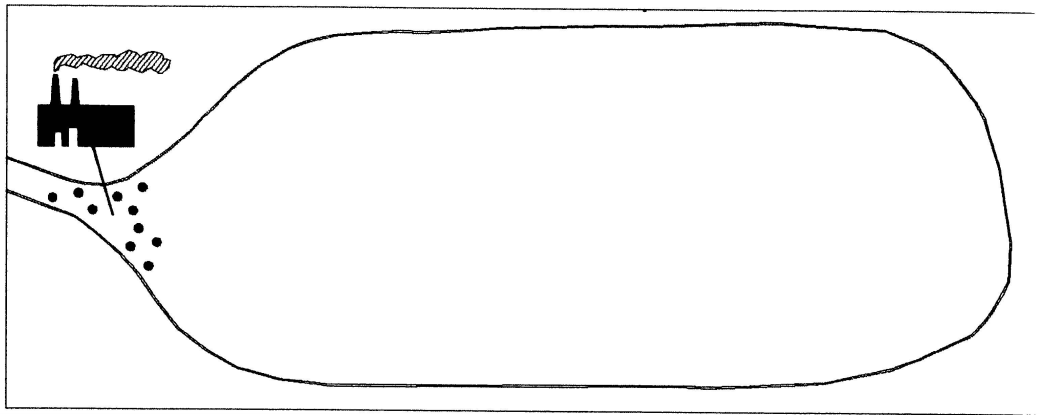
# Soil characterization

- 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

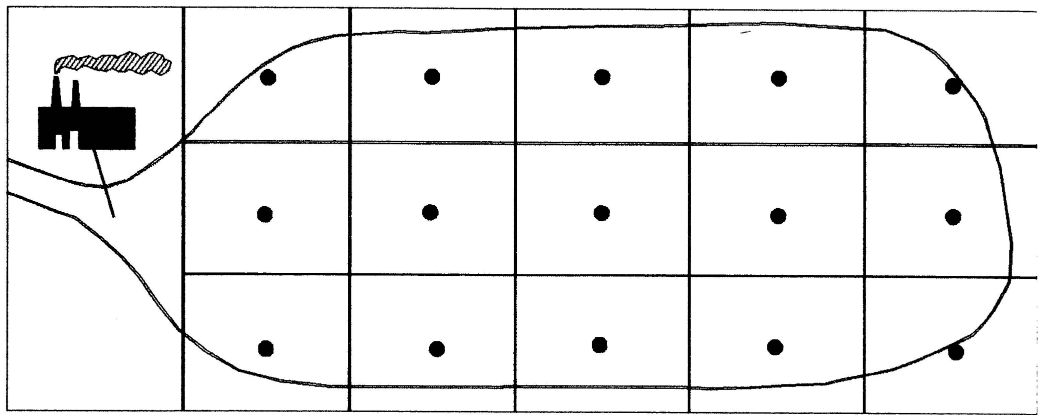
- Random sampling:
  - Identified at random
  - Avoid systematic error
- Nontargeted sampling:
  - Regular pattern of sample locations
  - Reliability of interpolation depends on homogeneity of site
  - If regular patterns on site (ditches at regular interval), sampling pattern should not coincide with topography
- Targeted sampling:
  - locations based on conceptual model of pollutant source
  - Examples: storage tanks, pipes, drains, pits, documented spill areas

# Sampling

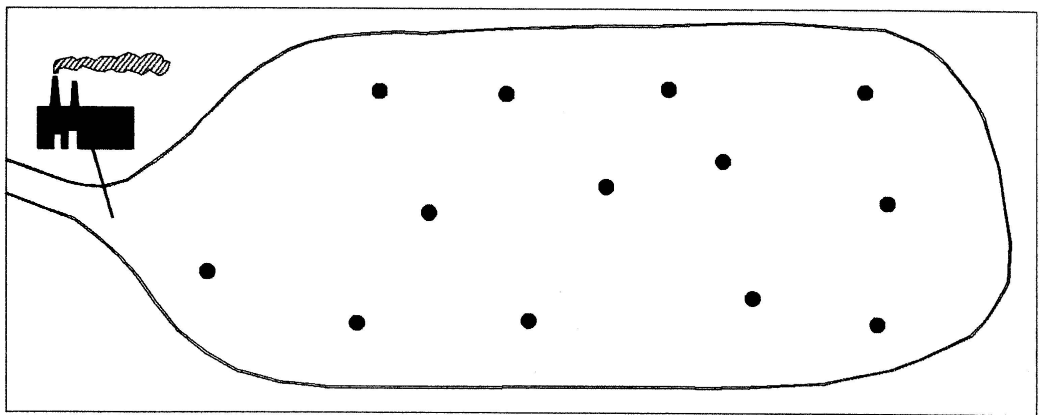
Targeted



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