# Mineral Exploration & Mining

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# Exploration Methods

Direct exploration methods:

- Mapping
- Drilling

Geochemical exploration methods:

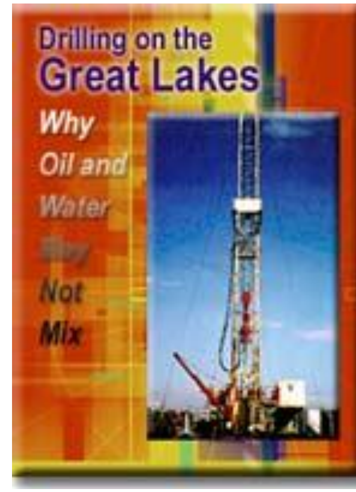
- soil sampling
- stream sampling.

Geophysical exploration techniques used for finding hydrocarbons, coal and metals:

- seismic reflection and refraction,
- gravity surveys,
- magnetic survey using proton magnetometer,
- electrical resistivity
- down hole logging surveys.

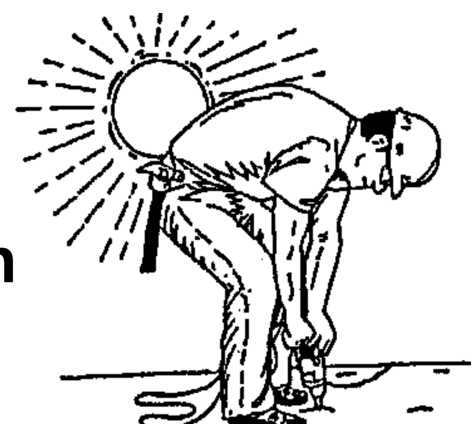
# Direct exploration methods:

- **There are 2 main methods:**
  - **Drilling**
  - **Mapping**




## Drilling

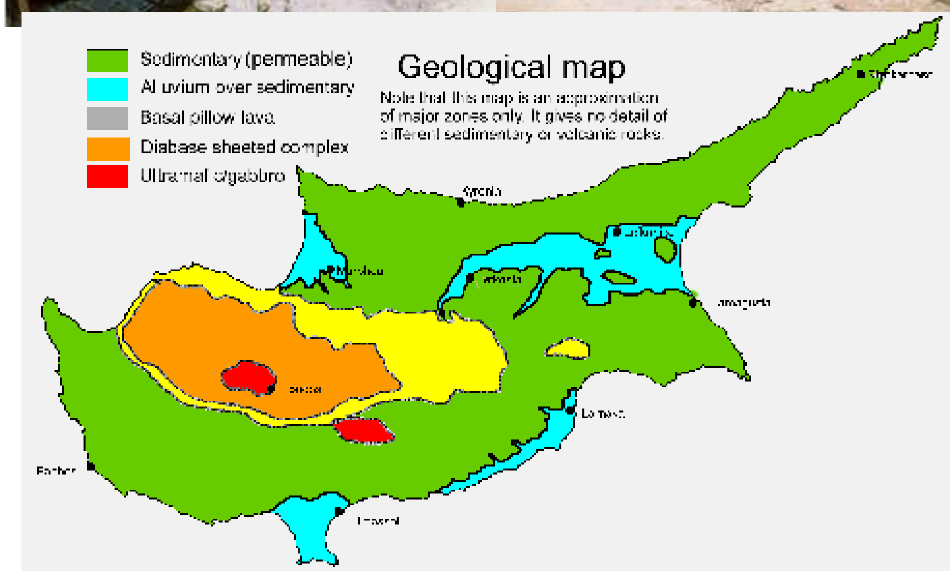
- **Drilling in an area is often the only way of being absolutely sure what is underground.**
- **The geochemical and geophysical methods will give a clue.**
- **Analysing the samples and noting the depths at which rocks occur can help decide whether an ore is worth minin**



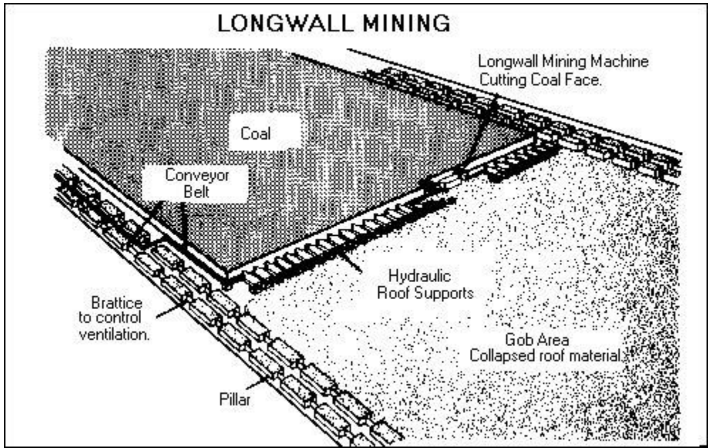
# Direct exploration methods 2

## Mapping

- **If rocks are exposed at the surface then mapping them can give a clear indication of the geology not only on the surface but also underground.**
- **You may be able to work out an underground cross section.**



- **It is usual for a whole array of techniques to be used together in order to finally decide:**
  - Where an ore or resource is.
  - How much there is.
  - The grade of the resource.
  - Any geological problems.
  - Whether it is worth exploiting.




# Surface Guide

Most of the mineral deposits portray surface signature like favorable stratigraphy and host rocks, weathering effects of metallic and nonmetallic mineralization, presence of earlier mining and smelting remnants, shear zone, lineaments, etc., that can be identified by experienced eyes.

- Host Rock & Stratigraphy: The existence and identification of favorable stratigraphy and complimentary host rocks are the essential prerequisites to initiate any exploration program for a specific mineral or group of minerals.
- Weathering: Weathering and leaching of near-surface metallic deposits is an indicator of probable existence of mineral deposit down depth.
- Old Workings: One can find ancient mine debris around open pits with wooden wall supports, entry system to shallow and greater depth for underground mining, abandoned underground gallery with wooden ladder and platform, in situ potholes rock grinder at surface for ore dressing, smelting furnaces, enormous heaps of slag and retorts reused for wall making, ruined places of worship and deserted township in and around the ancient mine-smelting sites.

# Surface Guide

FIGURE 3.1 Ancient entry system to underground mine at shallow depth of orebody without any plunge during the 3rd and 2nd millennium BC at Khetri copper belt, Rajasthan, India.

FIGURE 3.6 Ancient cylindrical distillation clay retorts from the smelting site at Zawar mine area, India.

FIGURE 3.4 Ancient potholes at surface used for crushing, grinding and concentration of rich zinc ore are still preserved at Rajpura-Dariba mine, India.

# Direct Exploration

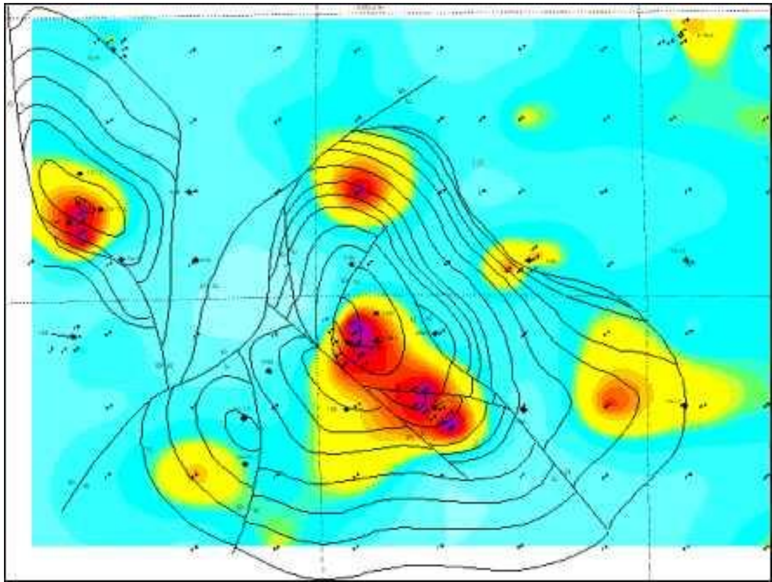
- Topographic Survey
- Geological Map

**Surface Map:** Surface maps are prepared by taking traverses on the surface at various intervals and plotting the records like rock types and all other observations including strike, dip, plunge, etc..

**Underground Mapping:** The surface geology related to lithology, structure and mineralization can be correlated for down-depth continuity with subsurface features as the mine progresses through service and stope development.

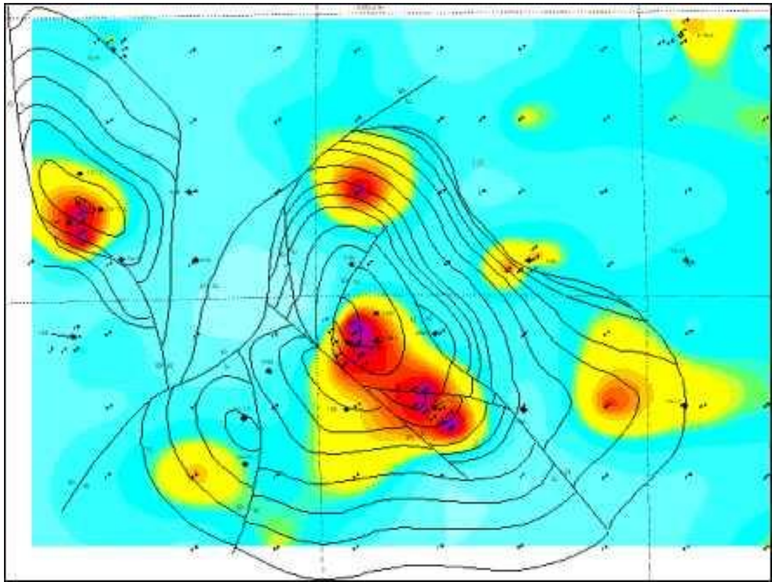
# Geochemical Exploration Methods

- There are only really two:
  - Soil surveys/sampling
  - Water surveys/sampling
- Soil surveys give an indication of the chemistry of the underlying rocks (that have been weathered).
- If on a slope the rock will be further up slope from the soil.



# Geochemical Exploration Methods 2

- **With stream sampling the chemistry of the water will be influenced by the rock it flows over.**
- **The concentration of an element will be highest just downstream from the ore.**
- **The concentration will then decrease as the water gets diluted further downstream.**



# Geochemical Exploration

## Elemental Dispersion

Traces of metallic elements are usually found in soil, rocks, and groundwater in the proximity of an orebody.

The geochemical envelope, which is an expression of alteration and zoning conditions surrounding metalliferrous deposit, is called "primary dispersion halo."

The formation of primary halo is synchronous to the mineralization.

The halos are either enriched or depleted in several elements as a result of introduction or redistribution related to ore-forming processes.

"Secondary dispersion halo" is the dispersed remnants of mineralization caused by surface processes of chemical and physical weathering and redistribution of primary patterns.

# Geochemical Exploration

## Pathfinder Elements

"Pathfinder" or "indicator" elements are characteristic parameter in geochemical prospecting. These are relatively mobile elements due to physicochemical conditions of the solutions in which they are found or in volatile state (gaseous).

**TABLE 4.1** Common Pathfinder Elements in Geochemical Exploration

| Type of deposits | Pathfinder elements |
|---|---|
| Gold, silver, gold-silver-copper-cobalt-zinc and complex sulfide ores | As |
| Copper-zinc-lead-silver and complex sulfide deposits | Hg, Zn |
| Wolframite-tin deposits | Mo |
| Porphyry copper, barium-silver deposits | Mn, Mo, Au, Te |
| Platinum-Palladium in mafic-ultramafic rocks | Cu-Ni-Cr-Pd |
| Uranium (all types) | Rn, Cu, Bi, As |
| Sulfide deposits | $SO_4$ |

# Geochemical Exploration

## Background & Threhold Value

"**Background**" values are characterized by the normal range of concentration of elements in regional perspective rather than localized mineral occurrences. It is significant to establish the background value of the area against which the anomalies due to economic mineral accumulations, if any, can be identified.

"**Threshold**" value is defined as the probable upper or lower limit of the background value at some statistically precise confidence level. Any sample that exceeds this threshold is considered as possibly anomalous and belongs to a separate population.

# Geochemical Exploration

## Orientation Survey

In practice, a first round "orientation survey" is conducted in every new area to draw detail work plan that adequately distinguish anomaly from background value. The important parameters to be considered in combination during orientation survey are:

(a) host rock environment,

(b) identify criteria that influence dispersion,

(c) possible local contamination if any,

(d) effect of topography,

(e) best sample medium,

(f) optimum sample interval,

(g) depth of soil sample,

(h) size fraction,

(i) analysis of group of elements,

(j) anomaly enhancement and

(k) analytical techniques for establishing the background and threshold value.

# Geochemical Exploration

## Analytical Methods

- ICP-MS
- XRF
- SEM-TEM
- EPMA
- AAS

## Geochemical Methods

1. Pedo-geochemical (soil survey),
2. Consolidated weathered cover prospecting,
3. Litho-geochemical (rock survey),
4. Drift or till geochemical survey,
5. Stream sediment survey,
6. Hydro-geochemical survey,

- 7. Vegetation survey

# Geochemical Exploration
## Geochemical Methods

7. Vegetation survey

(a) Geobotany,

(b) Biogeochemical,

8. Geo-zoological/homo-geochemical survey,

9. Atmo-geochemical (vapor survey),

10. Electro-geochemical survey,

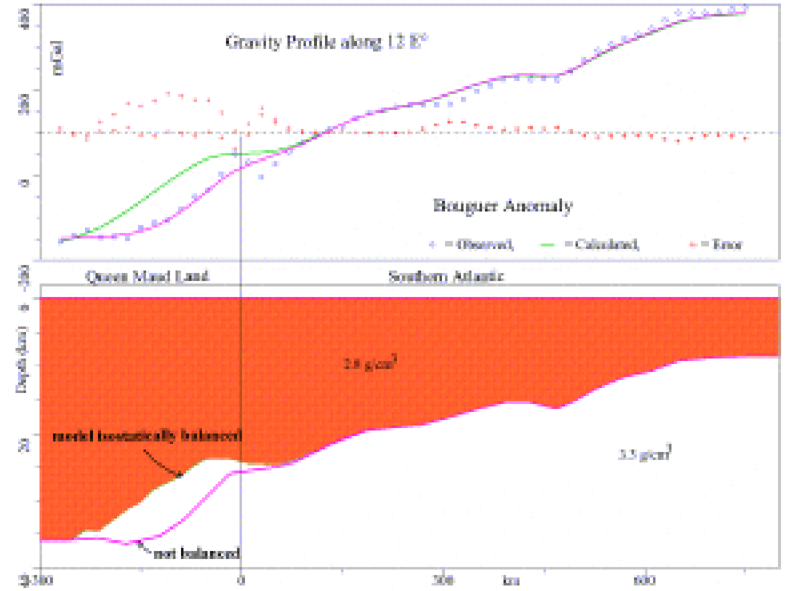
11. Radiogenic isotope geochemistry,

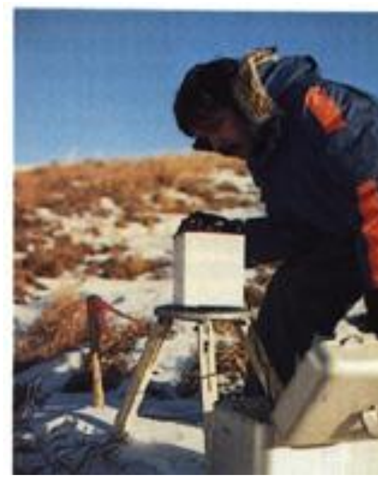
12. Heavy mineral survey,

13. Polymetallic-polynodule survey.

# Gravity Surveys

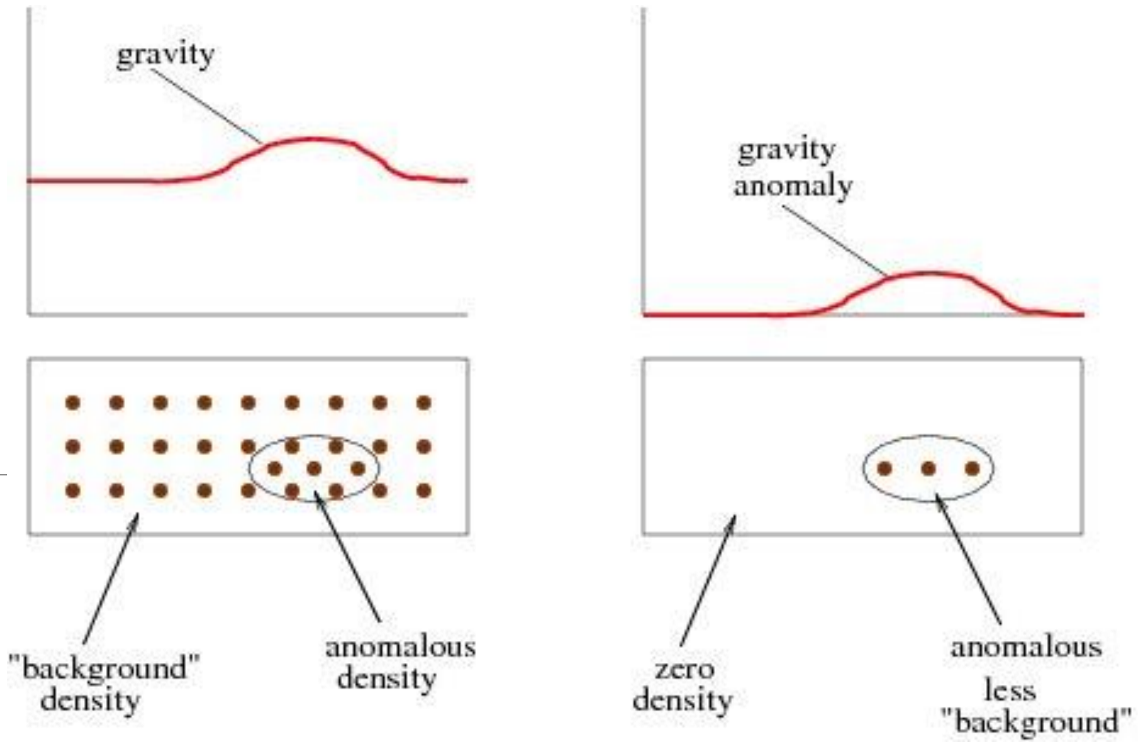
- **These use a gravimeter that measure the gravity at a given point.**
- **These can be carried in planes, ships or carried by hand.**
- **If there are denser rocks below (ores) they will give a positive gravity anomaly.**
- **If there are less dense rocks (salt/halite) there will be a negative anomaly.**



# Practical issues

The shape of the gravity anomaly depends not on the absolute density, but on the density contrast, i.e. the difference between the anomalous density and the "background density".



# Practical issues

Here's a list of densities associated with various earth's materials:

| material | $1000\ kg/m^3$ |
|---|---|
| sediments | 1.7-2.3 |
| sandstone | 2.0-2.6 |
| shale | 2.0-2.7 |
| limestone | 2.5-2.8 |
| granite | 2.5-2.8 |
| basalt | 2.7-3.1 |
| metamorphic | 2.6-3.0 |

Note that:

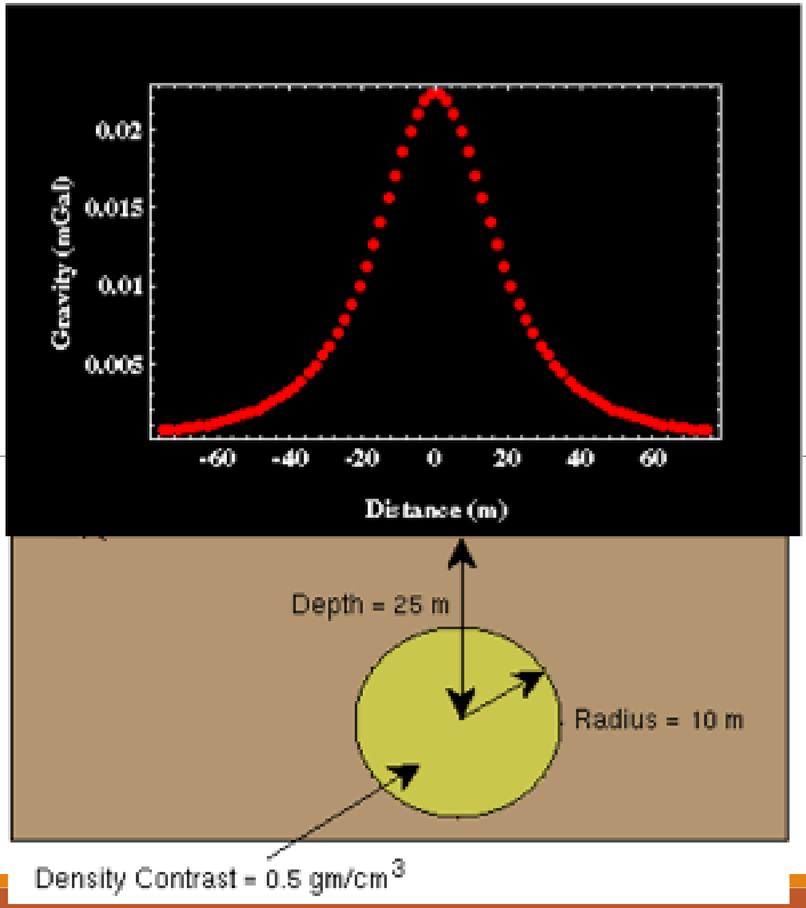
- Density differences are quite small, up to $800\ kg/m^3$.
- There's considerable overlap in the measured densities.

# Practical issues

Consider the variation in gravitational acceleration due to a spherical ore body with a radius of 10 meters, buried at a depth of 25 meters below the surface, and with a density contrast of 500 kg per meter cubed.

The maximum anomaly for this example is 0.025 mGal.

(keep in mind that 9.8 $m/s^2$ is equal to 980,000 mGal !!!)



# Practical issues

- Owing to the small variation in rock density, the spatial variations in the observed gravitational acceleration caused by geologic structures are quite small

- A gravitational anomaly of 0.025 mGal is very small compared to the 980,000 mGals gravitational acceleration produced by the earth as a whole. Actually, it represents a change in the gravitational field of only 1 part in 40 million.

- Clearly, a variation in gravity this small is going to be difficult to measure.

# Practical issues

How is gravity measures:

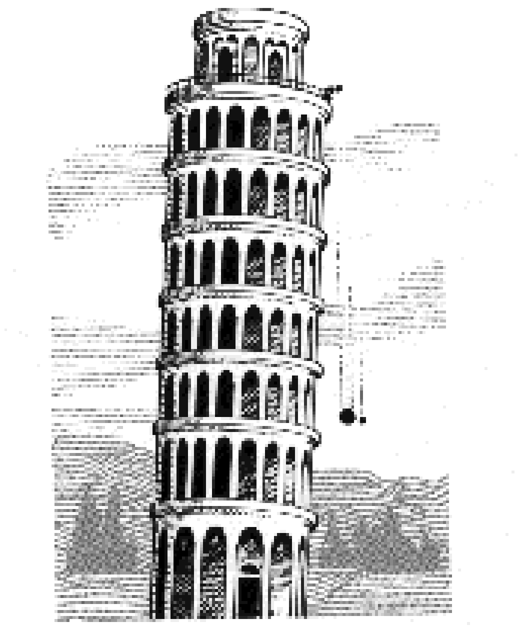
- Falling objects
- Pendulum
- Mass on a spring

## Practical issues

Falling objects:

The distance a body falls is proportional to the time it has fallen
squared. The proportionality constant is the gravitational
acceleration, g:

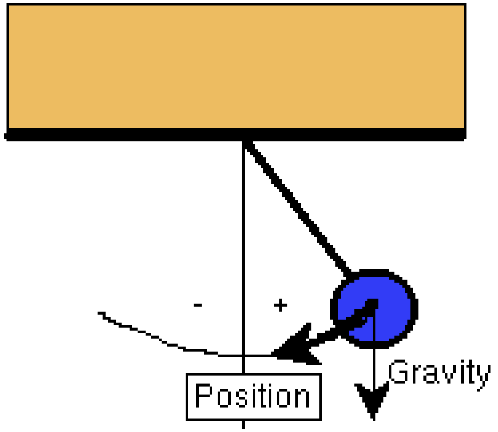
$$g = \text{distance} / \text{time}^2 \ .$$



To measure changes in the gravitational acceleration down to 1 part in 40 million using an instrument of reasonable size, we need to be able to measure changes in distance down to 1 part in 10 million and changes in time down to 1 part in 10 thousands!! As you can imagine, it is difficult to make measurements with this level of accuracy.

Pendulum measurements:

The period of oscillation of the pendulum, T, is proportional to one over the square root of the gravitational acceleration, g. The constant of proportionality, k, depends on the pendulum length:




$$T = 2\pi\sqrt{\frac{k}{g}} \quad .$$

Here too, in order to measure the acceleration to 1 part in 50 million requires a very accurate estimate of the instrument constant k, but k cannot be determined accurately enough to do this.

# Practical issues

But all is not lost:

• We could measure the period of oscillation of a given pendulum by dividing the time of many oscillations by the total number of oscillations.

• By repeating this measurement at two different locations, we can estimate the variation in gravitational acceleration without knowing k.

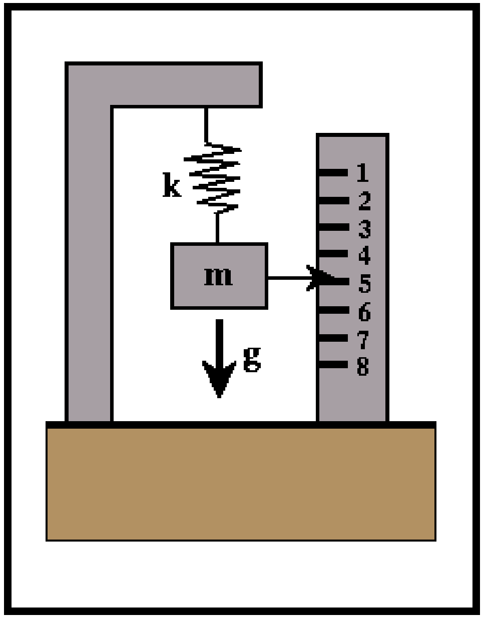
Mass on a spring measurements:

The most common type of gravimeter used in exploration surveys is based on a simple mass-spring system.

According to Hook's law:

$$X = mg / k ,$$

with k being the spring stiffness.

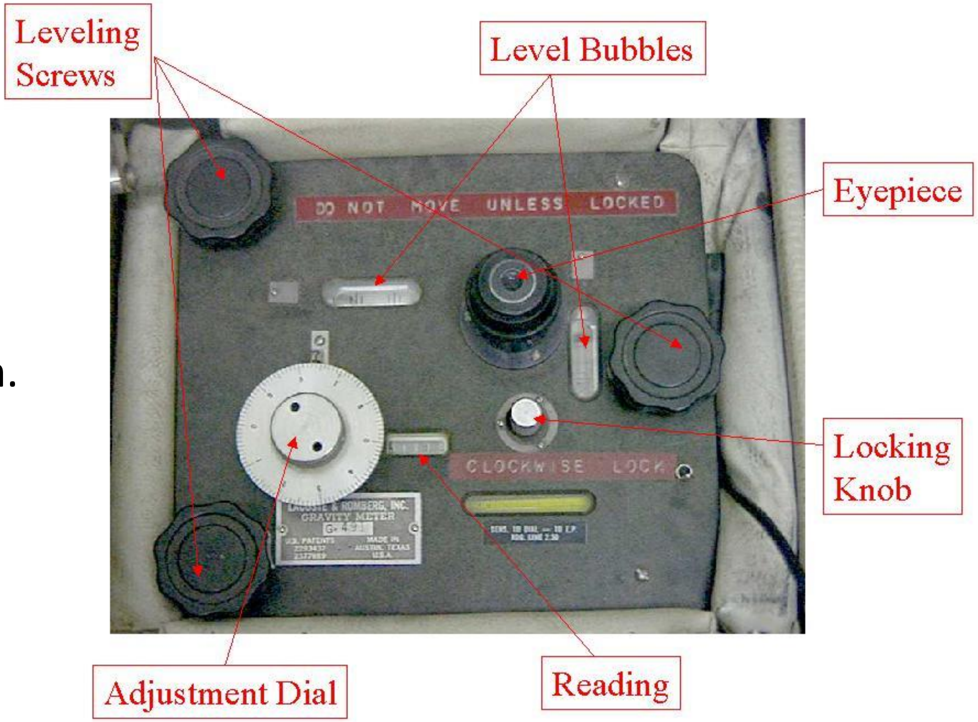


## Practical issues

• Like pendulum the measurements, we can not determine k accurately enough to estimate the absolute value of the gravitational acceleration to 1 part in 40 million.

• We can, however, estimate variations in the gravitational acceleration from place to place to within this precision.

Under optimal conditions, modern gravimeters are capable of measuring changes in the Earth's gravitational acceleration down to 1 part in 1000 million.



# Practical issues

Various undesired factors affect the measurements:

- Temporal (time-dependent) variations:

1. Instrumental drift
2. Tidal effects

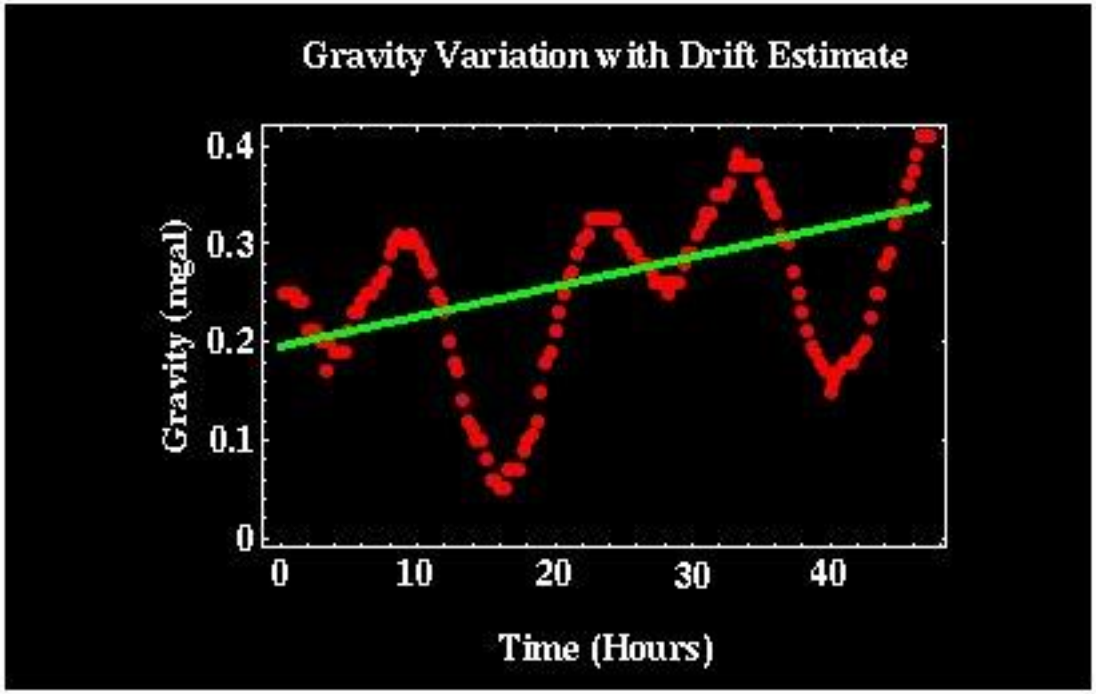
- Spatial variations:

1. Latitude variations
2. Altitude variations
3. Slab effects
4. Topography effect

Instrumental drift:

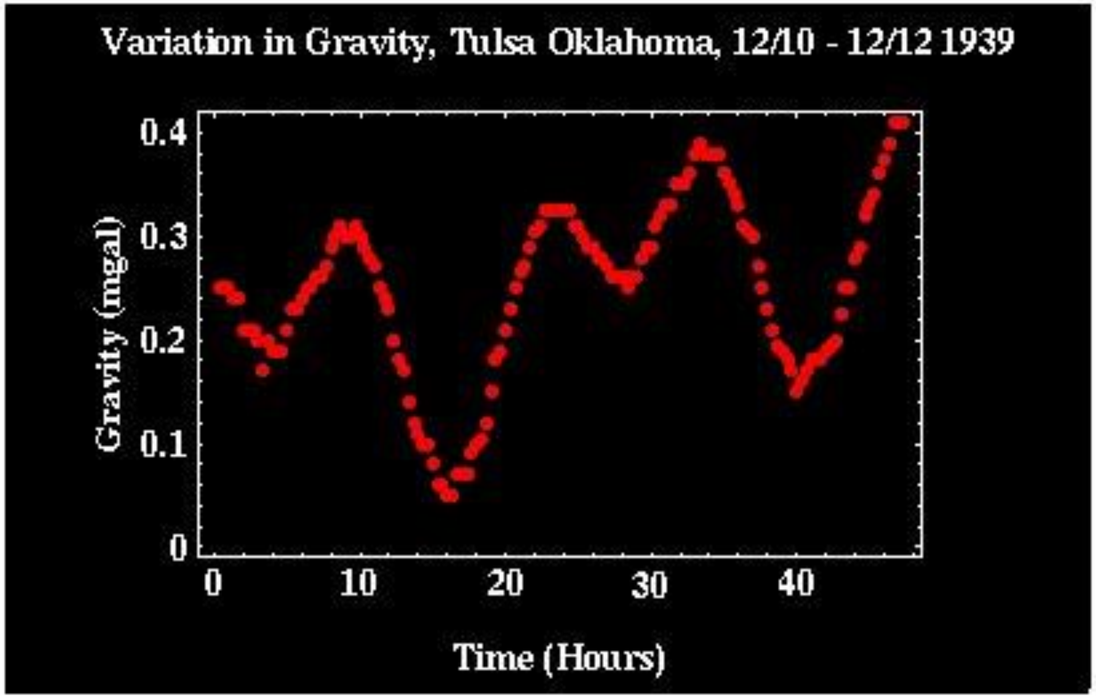
The properties of the materials used to construct the spring change with time. Consequently, gravimeters can drift as much as 0.1 mgal per day.

What causes the oscillatory changes superimposed on the instrumental drift?



Tidal effect:

In this example, the amplitude of the tidal variation is about 0.15 mGals, and the amplitude of the drift appears to be about 0.12 mGals over two days. These effects are much larger than the example gravity anomaly described previously.



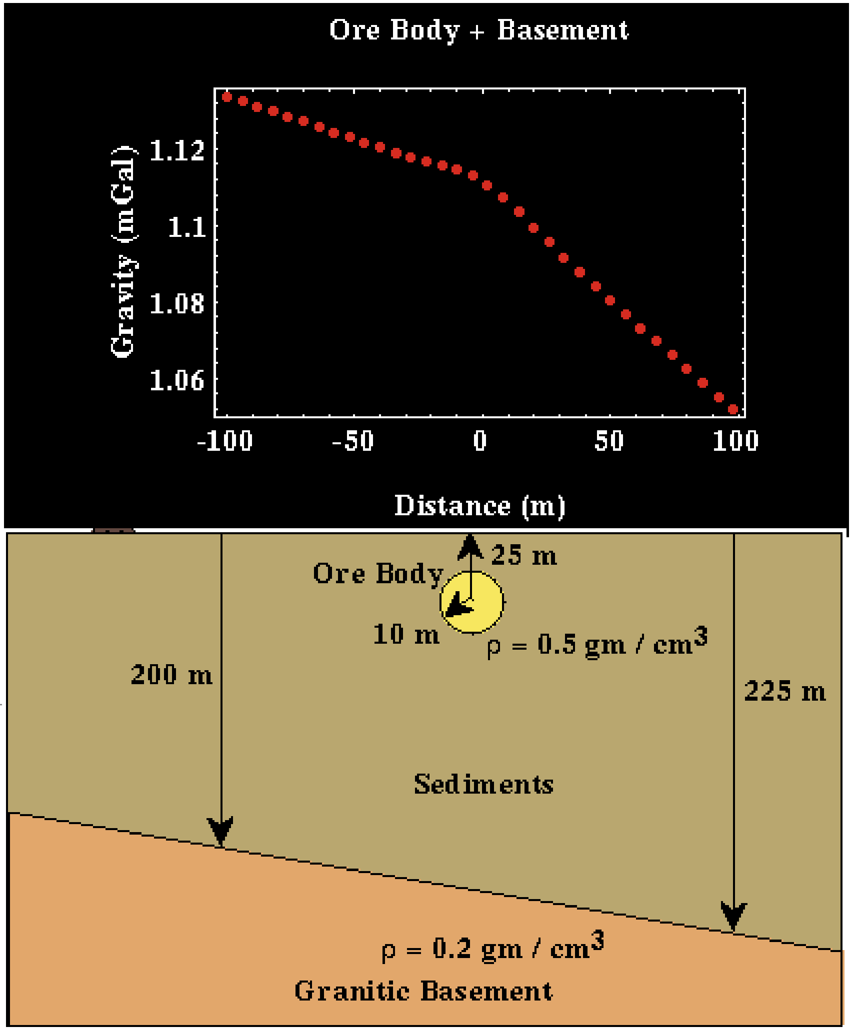
# Practical issues

• Since changes caused by instrumental drift and tidal effects do not reflect the mass distribution at depth, they are treated as noise.

• Strategies to correct for instrumental drift and tidal effects are discussed in:
www.earthsci.unimelb.edu.au/ES304/MODULES/GRAV/NOTES/tcorrect.html

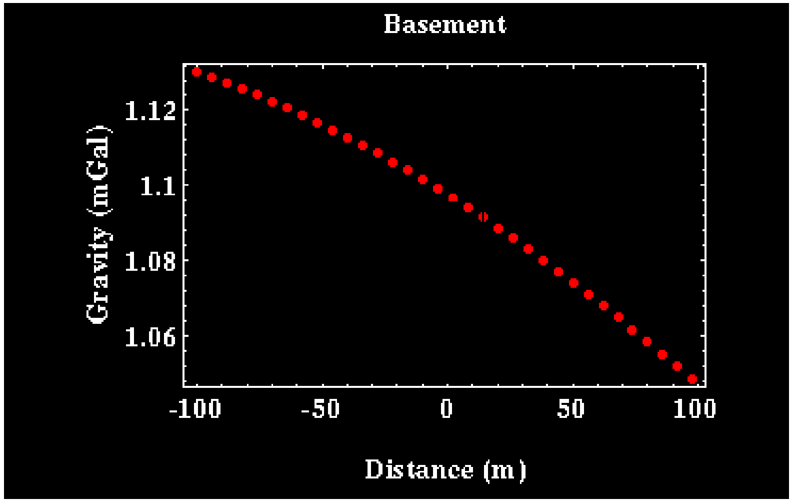
Regional and local (or residual) gravity anomalies:

Consider a spherical ore body embedded in a sedimentary unit on top of a (denser) Granitic basement that is dipping to the right.



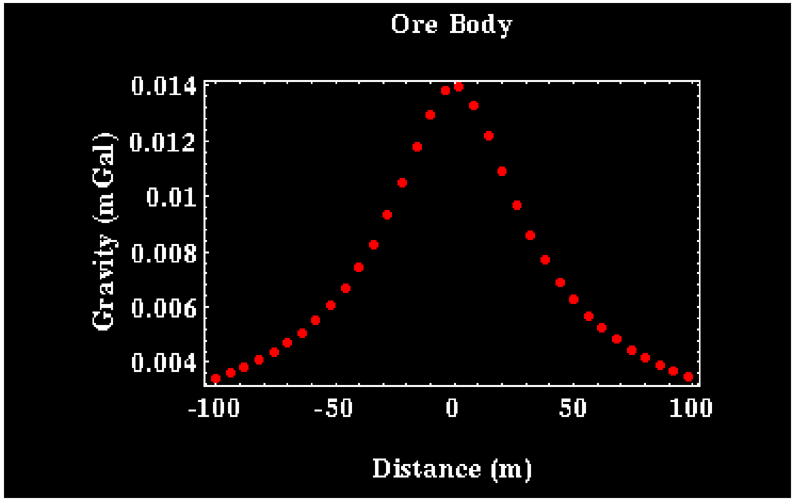
# Practical issues

The strongest contribution to the gravity is caused by large-scale geologic structure that is not of interest. The gravitational acceleration produced by these large-scale features is referred to as the regional gravity anomaly.



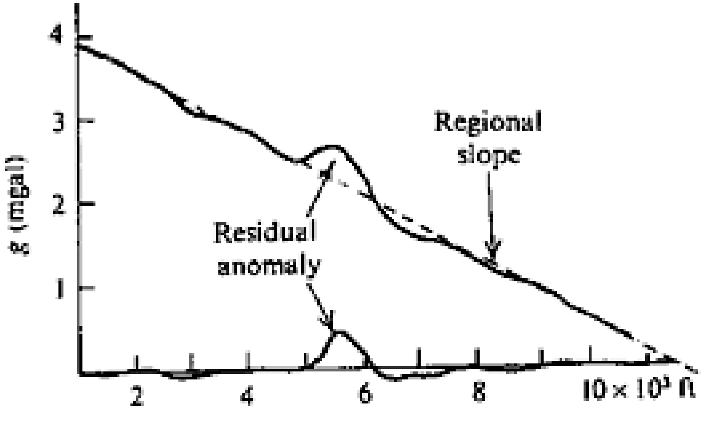
# Practical issues

The second contribution is caused by smaller-scale structure for which the survey was designed to detect. That portion of the observed gravitational acceleration associated with these structures is referred to as the local or the residual gravity anomaly.



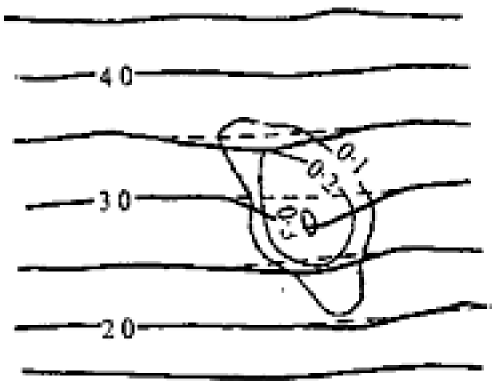
There are several methods of removing unwanted regional gravity anomalies. Here's an example for a graphical approach:

Smoothing in 1 dimension




(a)

Smoothing in 2 dimensions




(b)

Variations in gravity around the globe are inferred from satellite orbit.

The balance between the gravitational attraction and the centrifugal force is written as:

$$\gamma \frac{M_E m}{r^2} = \frac{mV^2}{r} \quad .$$

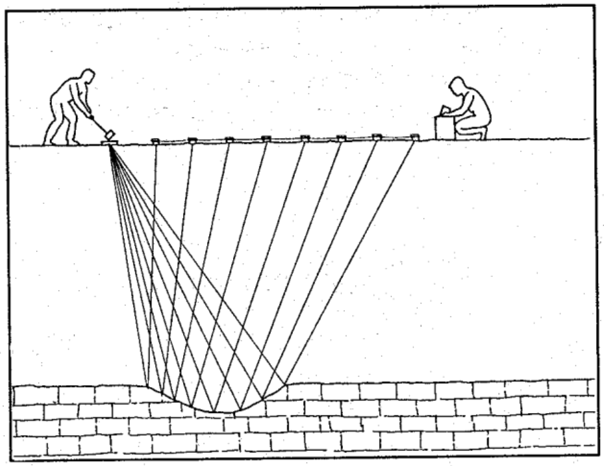
This leads to:

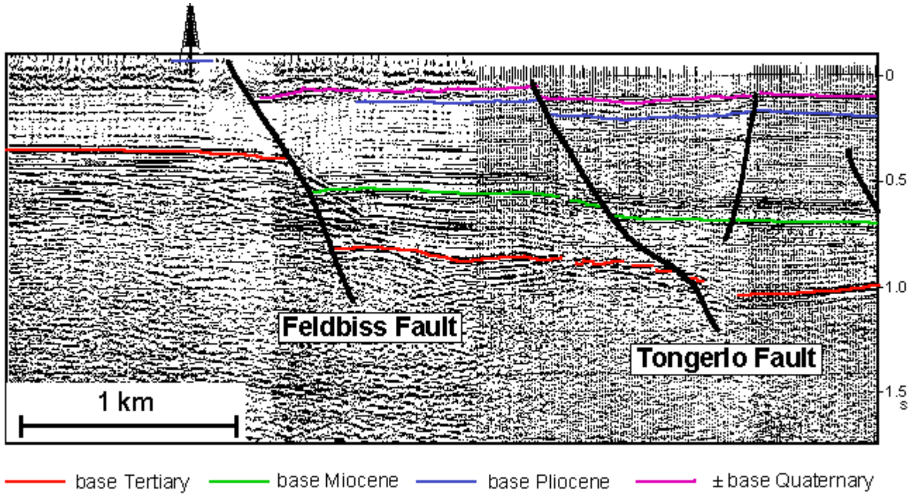
$$M_E = \frac{r^3}{\gamma}\left(\frac{2\pi}{T}\right)^2 \quad ,$$

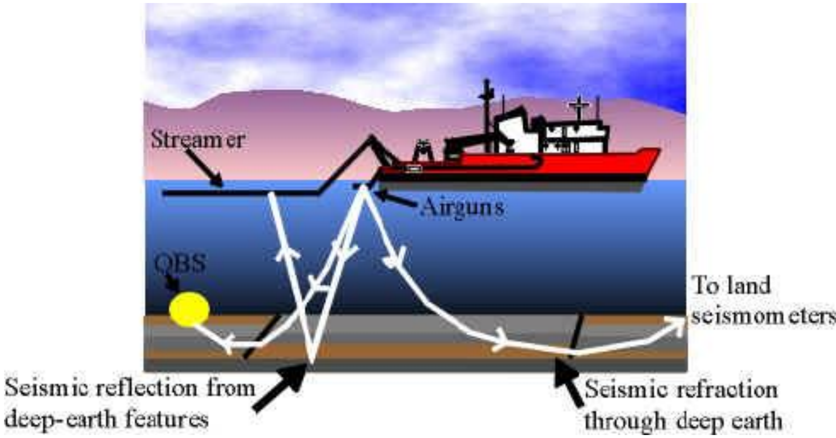
where T is the satellite's period, $2\pi r$ / V .

# Seismic Reflection

- This technique is used extensively in oil exploration as well as for metal ores.
- The travel time is noted.
- This survey is important for oil & gas exploration

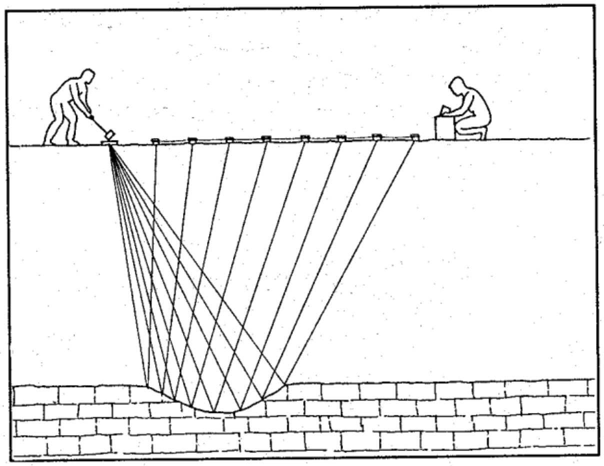



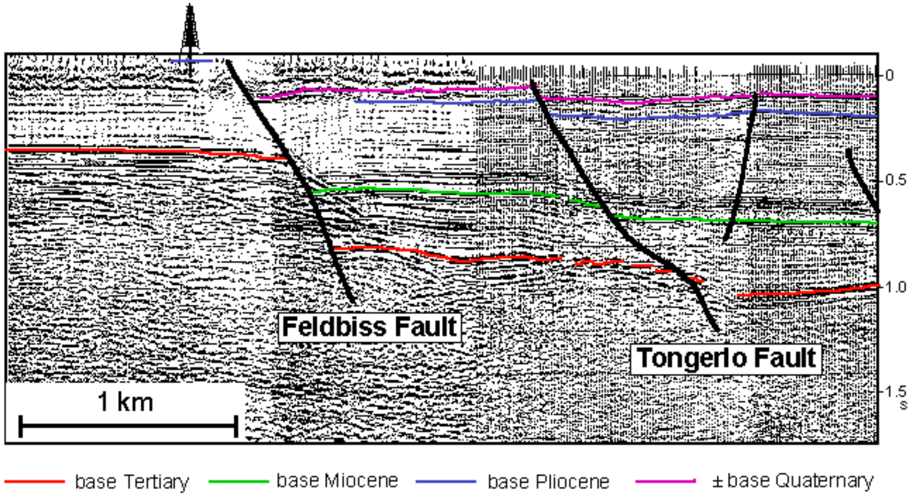


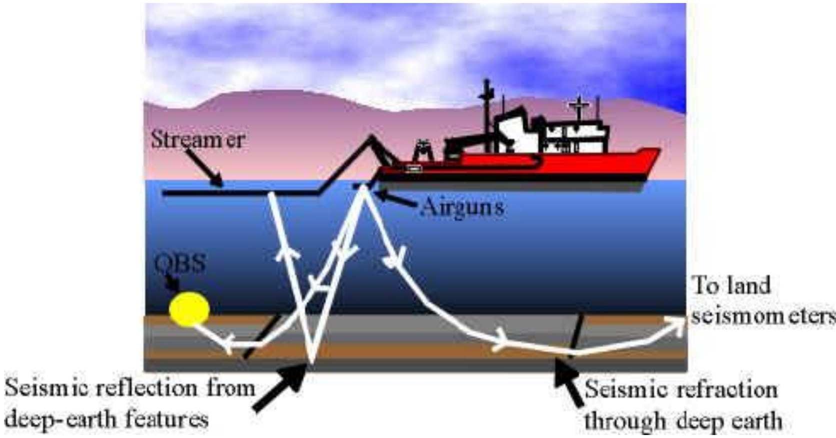



# Seismic Reflection

- The seismic reflection method works by bouncing sound waves off boundaries between different types of rock.
- The reflections recorded are plotted as dark lines on a seismic section.

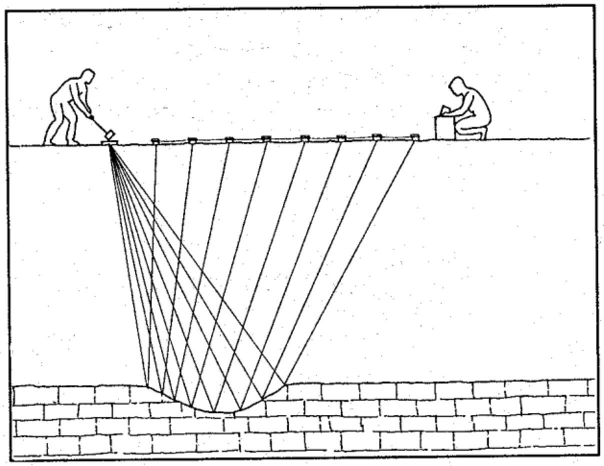



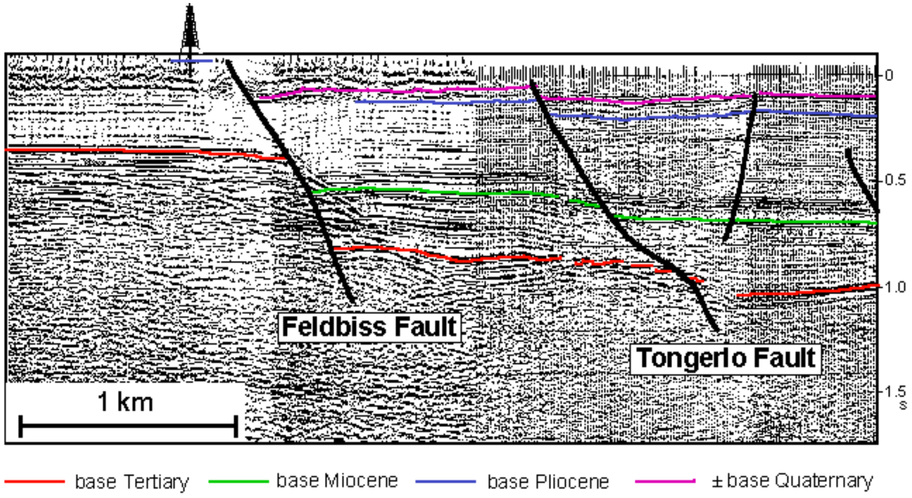


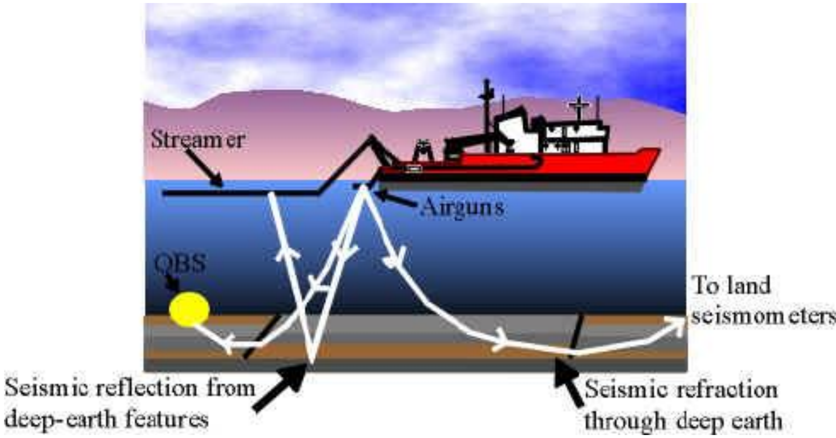



# Seismic Reflection

- This can be done on land or at sea.
- It can show up oil traps and dipping beds.
- It shows up rocks with contrasting densities so ores show up well as well as less dense rocks like salt.

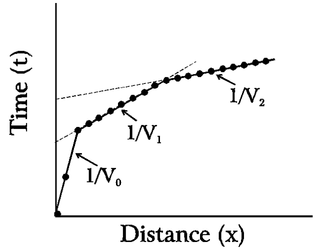



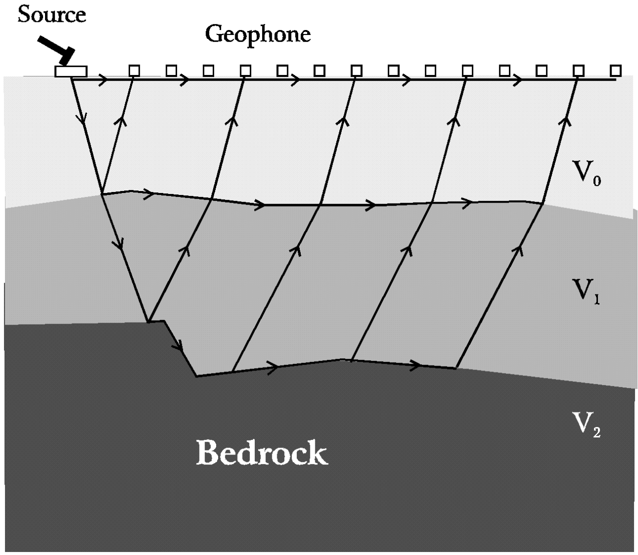


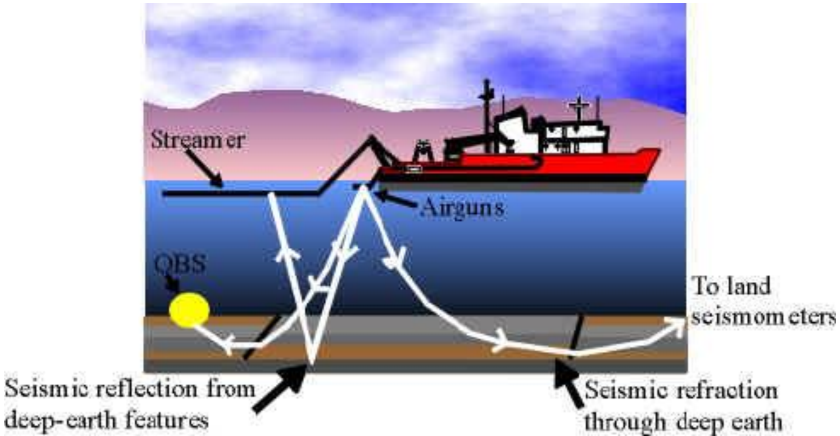



# Seismic Reflection

- This is basically the same as seismic reflection but this time the waves are refracted through the layers before returning to the surface.
- These waves hit the boundary between 2 rocks and then travel along the boundary before returning to the surface.

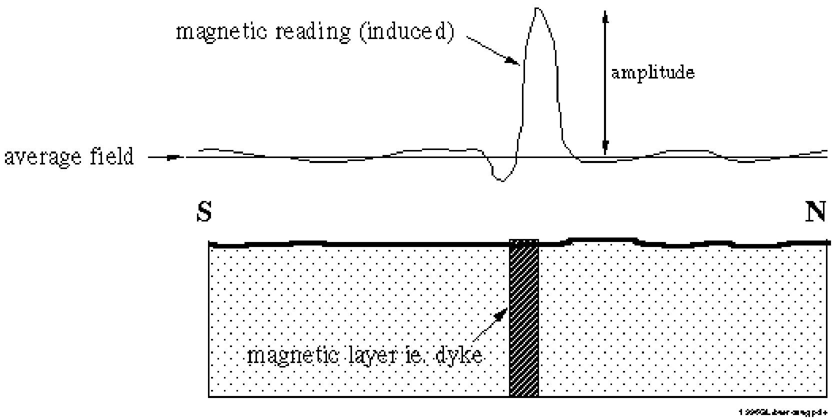



# Magnetic survey using a proton magnetometer

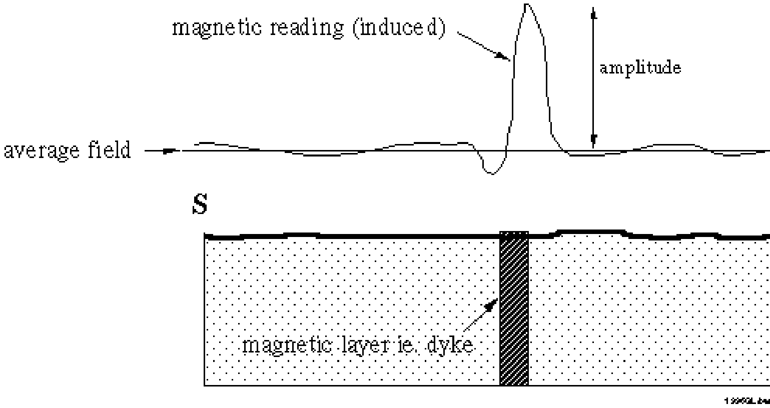
- They are fast, provide a great deal of information for the cost and can provide information about the distribution of rocks occurring under thin layers of sedimentary rocks, useful when trying to locate orebodies

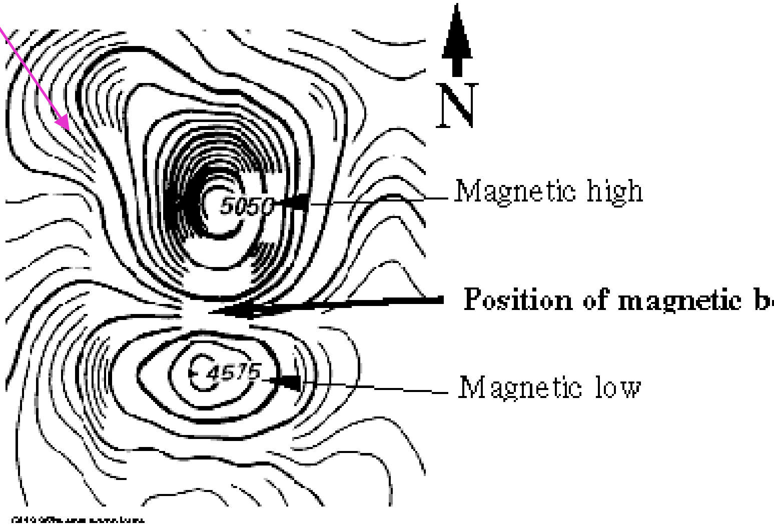



- Aeromagnetic surveys are taken from a moving plane.
- A magnetometer is the instrument used to measure the intensity of the magnetic field at a particular place.

# Magnetic survey using a proton magnetometer 2

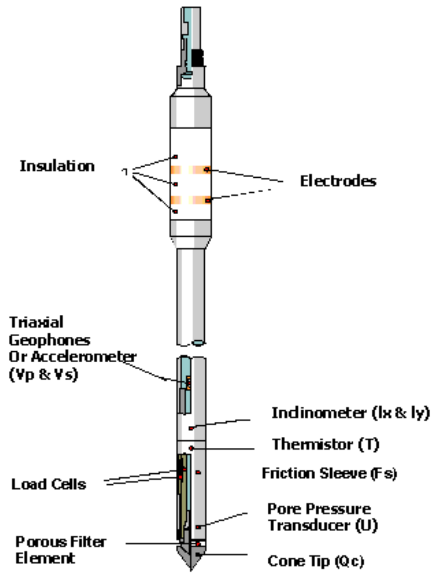
- The data for a survey can be plotted as a contour map using lines which join points of equal "magnetic" value.
- From these maps geoscientists can locate magnetic bodies (even if they are not outcropping at the surface), interpret the nature of geological boundaries at depth, find faults etc.

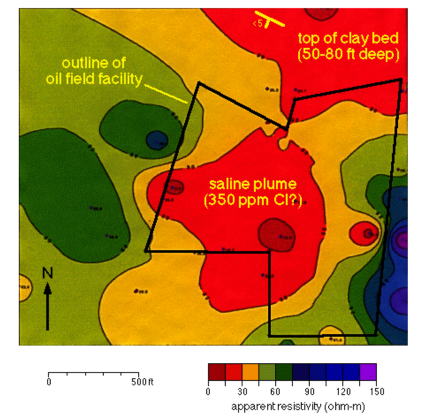


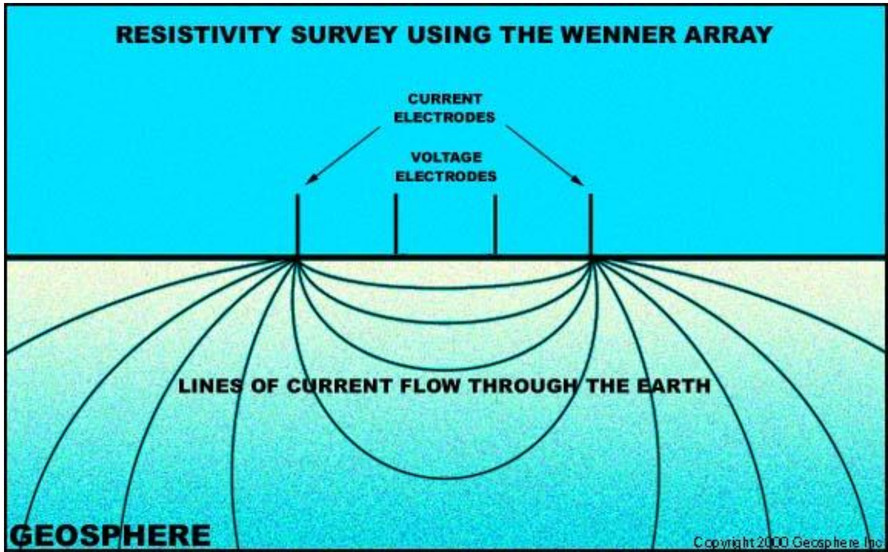

# Resistivity

- Electrical conductivity (resistivity) can be measured by applying a current directly into the ground through a pair of electrodes.
- A voltage difference measured across a second electrode pair provides the necessary information to calculate the **apparent earth resistivity**.
- The depth of investigation depends on the electrode separation and geometry, with greater electrode separations yielding resistivity measurements to greater depths.




Contour map of apparent resistivity in vicinity of oil field facility corresponding to a Schlumberger electrode spacing (AB/2) of 100 ft. Contour map is representative of hydrology and geology at a depth of 50-80 feet. Interpretations are supported by well data and computer models of resistivity data.



# Down hole logging surveys.

- **In the oil industry many types of geophysical survey can be carried out by placing instruments down the exploration borehole.**
- **See page 35 of the oil book.**
- **Such things as:**
  - Resistivity
  - Sound wave velocity
  - Gamma ray radiation
- **These give clues about:**
  - Porosity and permeability
  - Dip of beds
  - Fluid pressures