Geophysics science

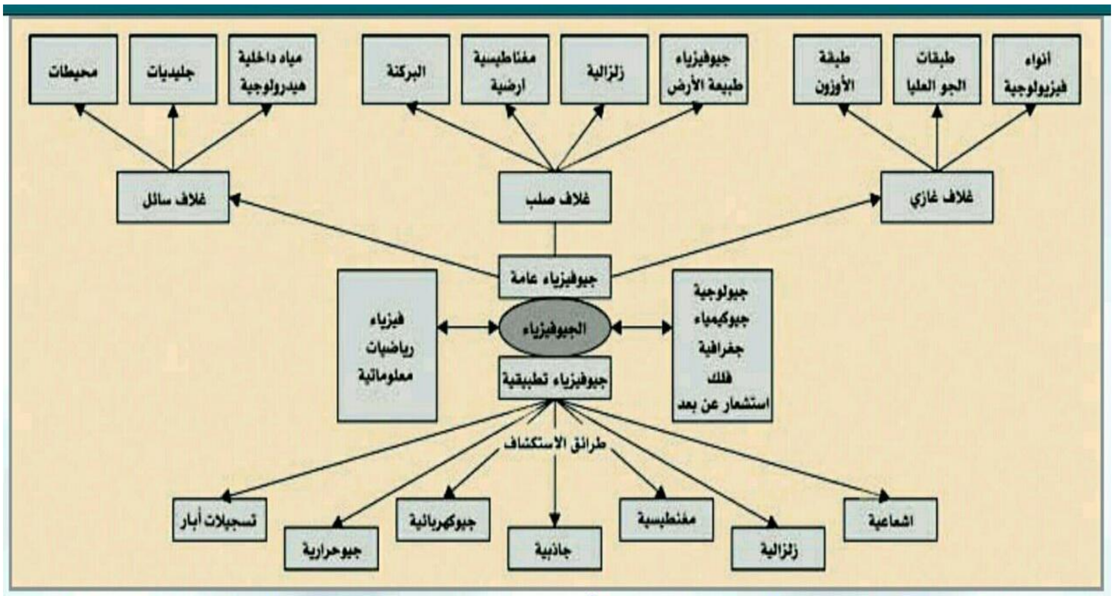
Introduction

Geophysics is the **application** of physics to the study of the **Earth**. The rocks **does not** differ only by their studied field geologists or petrologists, they also differ by their chemical and **physical properties**. Hence as the rocks differ according to their origin, structure, texture, etc. they also differ by their density, The advantage of geophysics is زMagnetization, resistivity, etc image hidden structures and features inaccessible that it is able to measurements on to direct observation and inspection. That from the surface we can deduce what is in the depth. Moreover, we can on traverses or even make a grid and hence obtain a measure profile view, map or even a 3d image of a Subsurface.

Geophysics science

It’s one of the earth`s sciences which interesting to study the earth **through** determining the variations in physical property for earth`s layers.

It’s **depend** on geology and physics science, Diagram (1) show the relationship between it and other sciences.



■ شكل (١) علاقة علم الجيوفيزياء بالعلوم الأخرى، ومجالات بحث الجيوفيزياء العامة، والطرق الجيوفيزيائية المستخدمة في الاستكشاف.

Classification of Geophysics science

Depending on the **kinds of study**, geophysics science

Classify to:

1- **Physics of the earth**

It's using all physics science (like: gravity& magnetic) to study the earth from surface to the core.

2- Applied geophysics

It's measuring the lateral, vertical (or both) variations in physical property for bodies and structure geology bored in different depths under earth near to surface, and called geophysical methods, Diagram (2).

geophysical methods may be applied to a wide range of investigations from studies of the entire Earth to exploration of a localized region of the upper crust for engineering or other purposes.

Depending on the **nature of measuring,** geophysical methods classify to:

•**Passive Method:** its measure the natural fields of the Earth, e.g. gravity and magnetic methods.

•**Active Method:** It's measure the induced field by transmitting a signal into the subsurface and record what comes back, e.g. seismic arrivals – earthquakes.

Diagram (2) Shown Applied Geophysical methods

Physical properties of Earth

The **object** of geophysics is detecting the presence of subsurface structures or bodies and determine their size, shape, depth, **by** variations (different) in physical properties table (1):

Method	physical property
Gravity	Density
Magnetic	Magnetic susceptibility and remanence
Seismic	Seismic velocity
Electrical Resistivity	Electrical conductivity
Induced polarization	Electrical capacitance
Self-potential	Electrical conductivity
Electromagnetic	Electrical conductivity and inductance

Table (1): geophysical methods and its physical properties

Geophysical methods applications

Exploration for fossil fuels (oil, gas, coal) S, G, M, (EM)

Exploration for metalliferous mineral deposits M, EM, E, SP, IP, R

Exploration for bulk mineral deposits (sand and gravel) S, (E), (G)

Exploration for underground water supplies E, S, (G), (Rd)

Engineering/construction site investigation E, S, Rd. (G), (M)

Archaeological investigations Rd, E, EM, M, (S)

G, gravity; M, magnetic; S, seismic; E, electrical resistivity; SP, self-potential; IP, induced polarization; EM, electromagnetic; R, radiometric; Rd, ground-penetrating radar.

5- Gravity method

Gravity method measure variations in the earth`s gravitational field caused by differences in the density of sub-surface rocks. Figure (1).

1-Application of gravity survey:

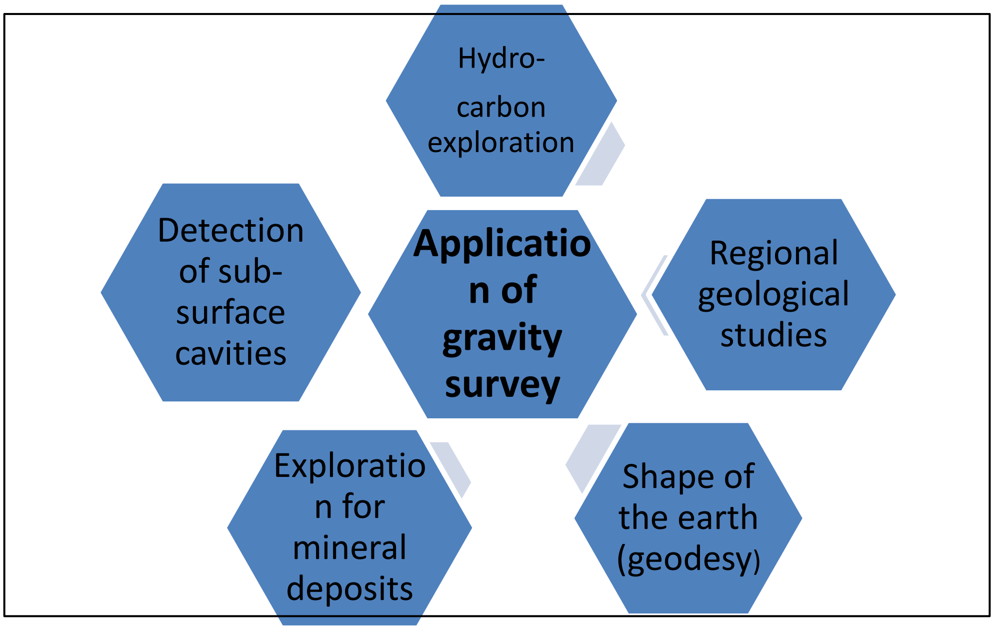


Diagram (3) shown Applications of gravity survey

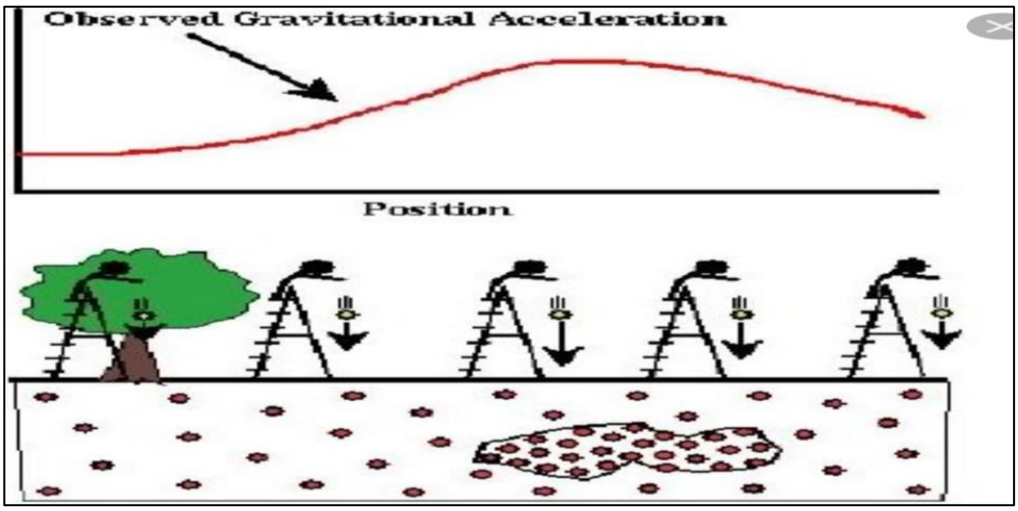


Figure (1): gravity survey

2- Basic theory of method

1- **Newton's Law of Gravitation:** The basis of the gravity survey method is **Newton's Law of Gravitation**, which states that(the force of attraction ***F*** between two masses **m1** and **m2**, is directly proportional to the product of two masses and inversely proportional to the square of the distance ***R*** between them), is given by

$$F = \frac{G * M * m}{R^2} \ldots\ldots 1$$

(G) Gravitational constant = 6.67 * 10^{-11} $m^3 kg^{-1} s^{-2}$

R is the Earth's radius

m is the mass of body

M is the mass of the Earth

2- Newton's Second Law of Motion

if we let a body drop vertically from high building, its have a accelerated velocity equal 9.8 m/sec for every minute.so the body will accept a velocity with increasing time, that called gravity acceleration (g).

States that(the force of attraction **(*F*)** IS equal to mass **(m)** × gra,k,,… vity acceleration (g)).

***F* = m×g** …………2

g is the gravity acceleration of the earth

By combined eq. 1 & 2 can obtain simple relationship:

$$F = \frac{G \times M \times m}{R} = m \times g$$

$g = \frac{G \times M}{R}$.............3

Whereas the gravitational acceleration **g** is a **vector quantity**, having both magnitude and direction (vertically downwards).

The **gravitational potential U,** due to a point mass m, at a distance r from m, is the **work done** by the gravitational force in moving a unit mass from infinity to a position r from m.

The gravitational potential **U** is **a scalar**, having magnitude only.

$U = \frac{G\ M}{r} \ldots\ldots 4$

The first derivative of U in any direction gives the component of gravity in that direction. Consequently, a potential field approach provides computational flexibility. Equipotential surfaces can be defined on which U is constant.

Theoretically acceleration duo to gravity should be **constant** over the earth.in reality, **gravity varies** from place to place because the earth has the **shape** of flattened sphere, **rotates** and has an **irregular surface** topography and **variable mass** distribution.

NOT: the Newton Laws calculate the earth gravity values depends on mass and radius of the earth.

3- Theoretical International Gravity Formula (I. G. F.)

The Earth is inhomogeneous and it rotates. Rotation causes the Earth to be an **oblate spheroid**. The polar radius of the Earth is **22 km less** than the equatorial radius, which means that **g** is ~ 0.4% less at equator than pole. At the equator, g is ~ 5300 mGal (milliGals), and a person would weigh ~ 1 lb less than at the pole. this results a different in gravity values about (5 Gal) and it is very big values in gravity explorations

The best fitting spheroid is called the reference **spheroid**, and gravity on this surface is given by the International Gravity Formula (the IGF), 1967:

$$\mathbf{g_{Ø} = 9.780318(1+ 0.005302 \sin^2 Ø - 0.0000059 \sin^2 2Ø)}$$

$g_{Ø}$ = earth gravity on latitude (gal, mgal)

Ø = latitude on degree

The **geoid** is an equipotential surface corresponding to mean sea level. On land it corresponds to the level that water would reach in canals connecting the seas, the geoid is a **conceptual surface**, which is warped due to absence or presence of attracting material. It is warped up on land and down at sea, Figure (2).

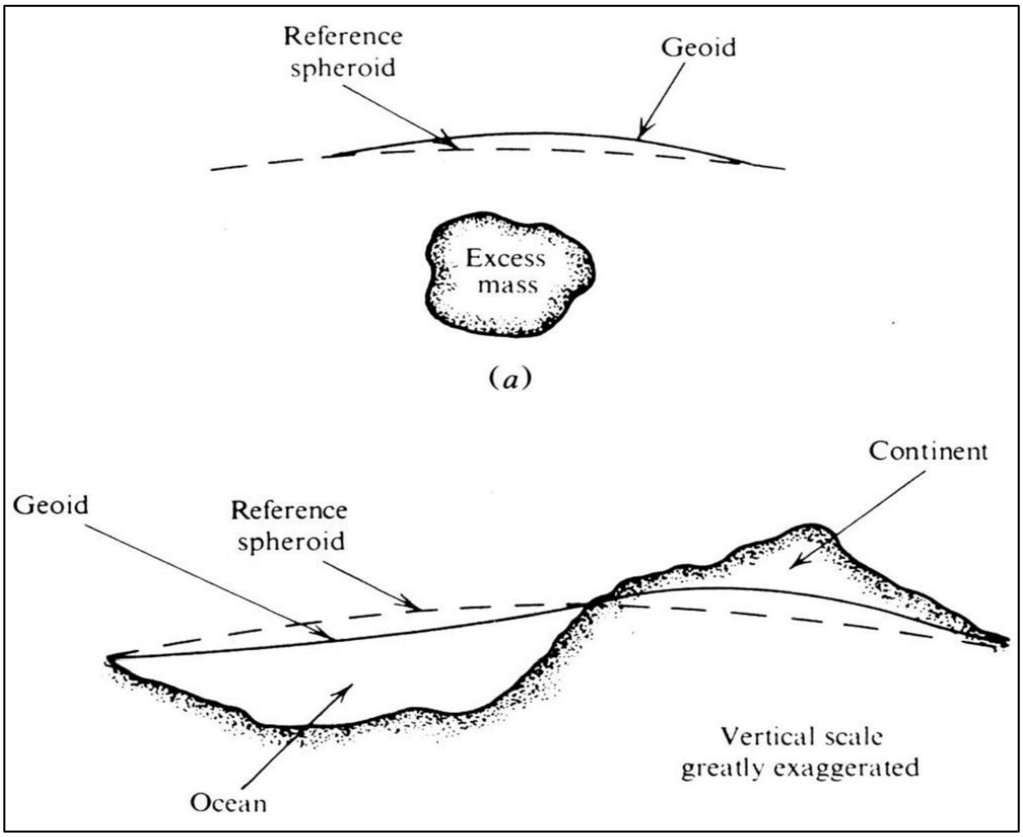


Figure (2) The relationship between the geoid, the spheroid, topography and anomalous mass

3- Units of gravity

The mean value of gravity at the Earth's surface is about

9.8 (m/sec^2 or gal).Variations in gravity **caused by density variations** in the subsurface are of the order of $100mms^{-2}$.This unit of the micrometer per second is referred to as the gravity unit (gu).

Unit of gravity is the 1**miligal** equivalent to **10gu**.

($1mgal = 10^{-3}gal = 10^{-3}cms^{-3}$).

Normal value of **g** at the surface of the Earth:

$g_E = 9.8\ m/s^2 = 980\ cm/s^2 = 980$ Gal = 980,000 mGal = 9800 g.u.

4- Geological factors affecting density

Density is the important physical property use in gravity exploration. Rocks in crust have varies in density ranging between **(1.5 – 3.5)kg/m^3**.

Gravity surveying is sensitive to variation in rock density that appear as a **gravity anomaly**, so an appreciation of the density will aid the interpretation of gravity data.

There were many ways to measurements density:

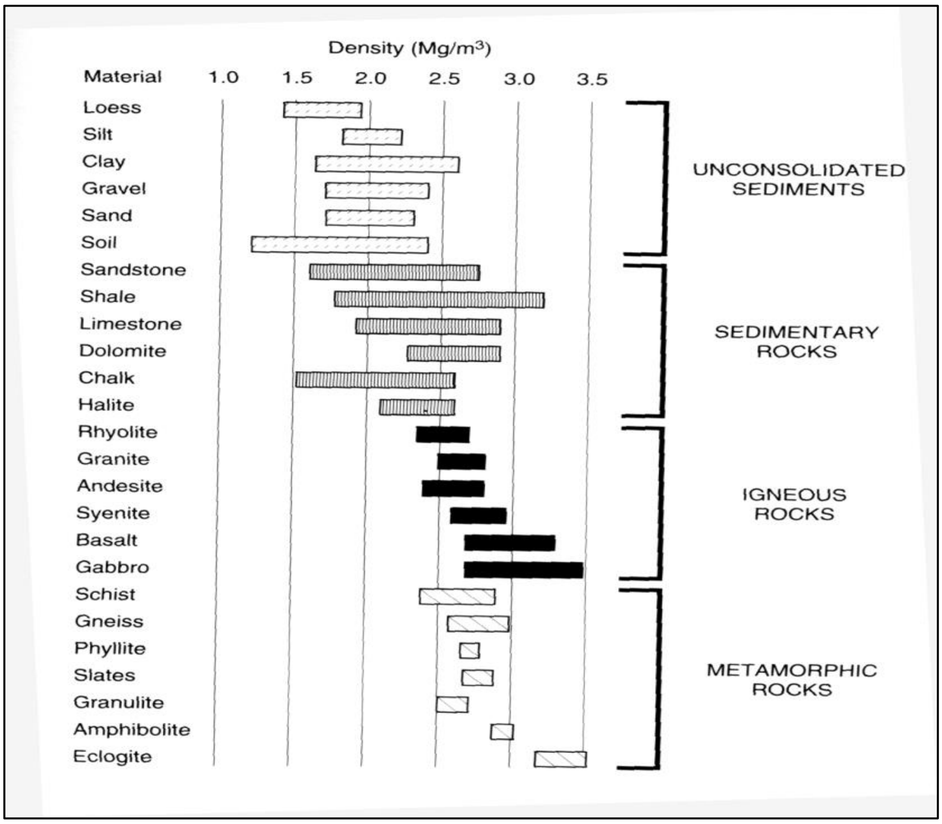
a- Direct measurement (laboratory).
b- Borehole record.
c- Gamma-gamma logger.
d- Nettleton's method.

Factors affected to density rocks

1- Unconsolidated. Dep.: composition, porosity, saturation.
2- Sedimentary R.: comp., age, depth, cementation.

3- Igneous R.: comp., grain size, fractures.
4- Metamorphic R.: comp., metamorphic degree, fractures.

Porosity and **pore fluid** are most important factors **affected** on rocks density.



Table(2) :show kinds of rocks and there densities

Similarity in rock densities can make it difficult to distinguish

<u>5-Measurements of gravity</u>

First: Measurement of gravity on land:

1- On the Earth's surface.

2- In boreholes.

Second: Measurement of gravity on moving platforms:

1 -Sea surveys.

2 -Air surveys.

3-Space measurements.

Measurement of gravity on the Earth's surface:

The Gravity value (g) measured of two ways:

1- Weight drop, pendulum in **one station (Base st.)** and get Absolute value, its difficult and requires complex apparatus and a lengthy period of observation, it obtained by reference to the International Gravity Standardization Network (IGSN) of 1971, in a network stations.

2- Mass on a spring in **many stations** and get Relative value**.**

Relative value is the differences of gravity values between stations in gravity surveying which show inhomogeneous medium due to subsurface bodies**. it** is simpler and is the standard procedure in gravity surveying.

Modern instruments for gravity measurements are known as **Gravimeter** is basically spring balances carry a constant mass. Variations in the weight of the mass caused by variations in gravity which effect on the length of the spring to vary and give a measure of the change in gravity, this measurements called **(gravity data)**.Its small size, easy to used, carry, rapid measurement, and high accuracy reach to 0.001 mgal**.** Figure (3)

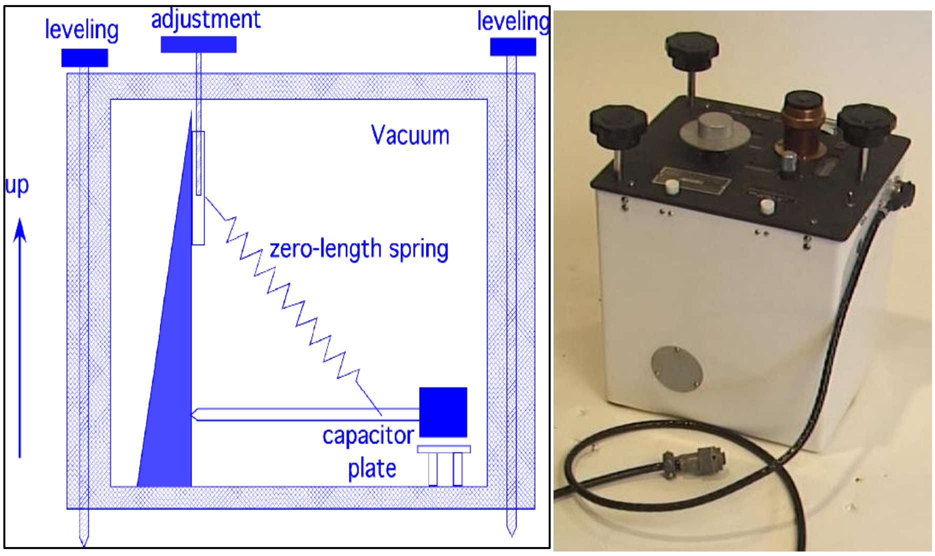


Figure (3): Principle of the La Coste and Romberg gravimeter

The **calibration constants** of gravimeters may **vary with time** and should be checked periodically. The most common procedure is to take readings at two or more locations where absolute or relative values of gravity are known.

6-Gravity Method Technique

It’s oldest of geophysical methods, most commonly used, **because** it’s easy measurements and low cost and highly accuracy. These technique consist three stage:

First stage: the preparations

Second stage: field work

Third stage: interpretation & conclusion

1- Aim of the search : ores of mineral ،type rocks ،structure geology ،Gravity surveying.
2- Topography map.
3- Sellecte the instruments & make measurements.
4- Previous studies.
5- Suitable time.

Second stage: field work

Its consisted **Data acquisition** & **Data Corrections**.

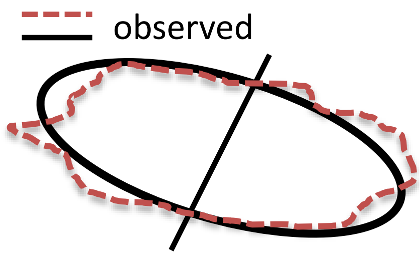
Field preparation in gravity survey before Data acquisition

1- Constant calibration.
2- Drift of the gravimeter.
3- Earth tides.
4- Survey design.
5- Establish base station.
6- Determine elevation of station.
7- Make the measurements.

Gravity data corrections

Measurements of gravity must multiplied by an instrumental calibration factor to get observed gravity value **(g_{obs}).**

Before interpreted the results, the data have to be corrected to a common datum. Such as sea level **(geoid)**, in order to remove the effects of geological bodies.



The corrections of gravity data are:

1-Drift correction: Gravimeter readings change (drift) with times as a result of elastic creep in the springs, producing an apparent change in gravity at station. The drift is usually estimated from repeated readings on the base station.

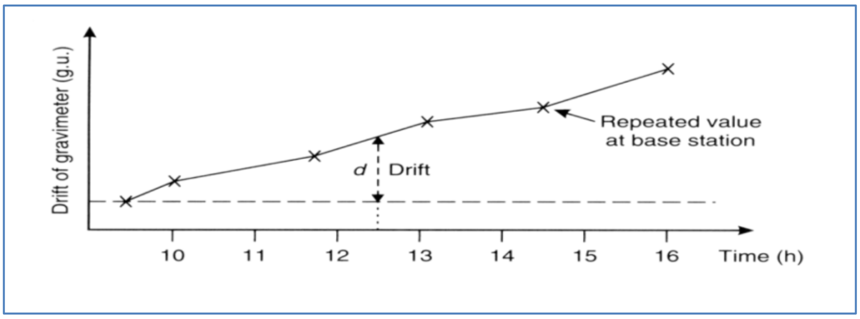


Figure (4): Drift Curve

2- Tidal correction: The tidal correction accounts for the gravity effect of Sun, Moon and large planets. Modern gravity meters compute the tide effects automatically.

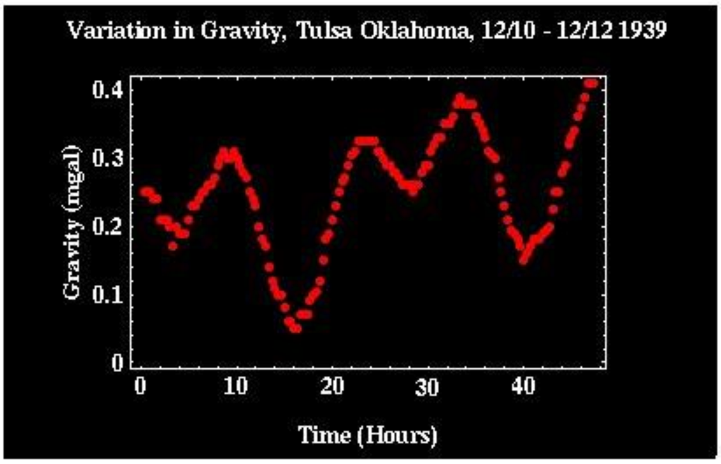


Figure (5): variation in gravity by tide effects

3- Latitude correction. : Because the earth is not spherical, where the equator radius is bigger than pole radius in about 22 Km, this different make a changes in gravity measurements. It is clear that the changes only in the N–S direction, not in the W–E. Correction made by subtracting the theoretical gravity data using (IGF) International Gravity Formula from the observed value (g_{obs}).

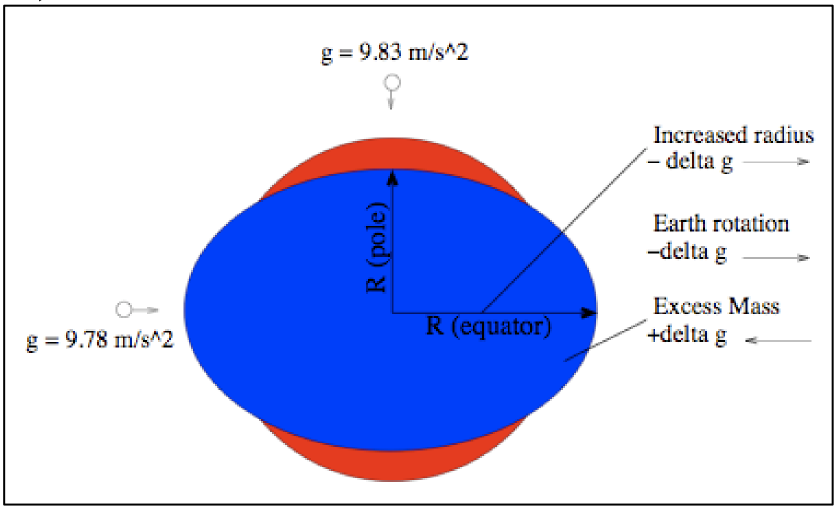


Figure (6): the diameters of earth

$g_{\text{ø}}$ = 978031.8(1 + 0:0053024 $\sin^2$ Ø _ Ø 0:0000059 $\sin^2$ .2Ø) mGal

g_e = 978 gal ; g_p = 983 gal

L.C have (+) value if the gravity survey line move towards equator line because gravity decrease.

L.C have (-) value if the gravity survey line moved towards poles because gravity increase.

5- Free- air correction

The gravity value is decrease with height increasing over sea level because increasing of distance from earth center. A value of 0.31 mgal/m.

To calculate the value of F.A.C = ± 0.3086 *Δh mgal

F.A.C = + if the station was over sea level

F.A.C = - if the station was under sea level.

6- Bouger correction

It's used to account for the rock mass between the measuring station and sea level.

B.C= ± 0.04191 * ρ * Δh

B.C= + if the station was under the sea level

B.C= - if the station was over the sea level

The free-air cor. and bouger cor. are commonly combined into one term (**elevation correction**):

$g_E = g_{f.a.c} - g_B$

= (3.086-0.4192* ρ) *h **mgal**

Where ρ in (**Mg.m^{-3}**) : h in (**m**)

6- Terrain Correction

Bouger cor. assumes an approximation to a semi-infinite horizontal slab of rock between the measuring station and sea level. It makes no allowance for **hills and valleys** and this is why the terrain correction is necessary. The topography (excess mass or mass deficiency) have **force** which **resolved** into horizontal and vertical components, in **two case** will **reduced** the gravity measurement so this correction requires **added** to gravity data.

To calculate this cor. must use **Hammer chart**, it's consist of a series of segmented concentric rings, it's overlaid on a topographic map with same scale , and the **average elevation** of each segment of the chart is estimated. It's range of chart is extend to 50 Km.

Terrain cor.= K* ρ * $\sum h$

7- Bouger Anomaly

It’s the gravity anomaly results of **difference** between observed values in **g.st. , duly corrected,** and gravity value in **base station**.

$$B.A = g_{obs} + \sum (corr.) - g_{B.s}$$

$$B.A = (g_{obs} + C.L \pm F.A.C \pm B.C + T.C) - g_{B.}$$

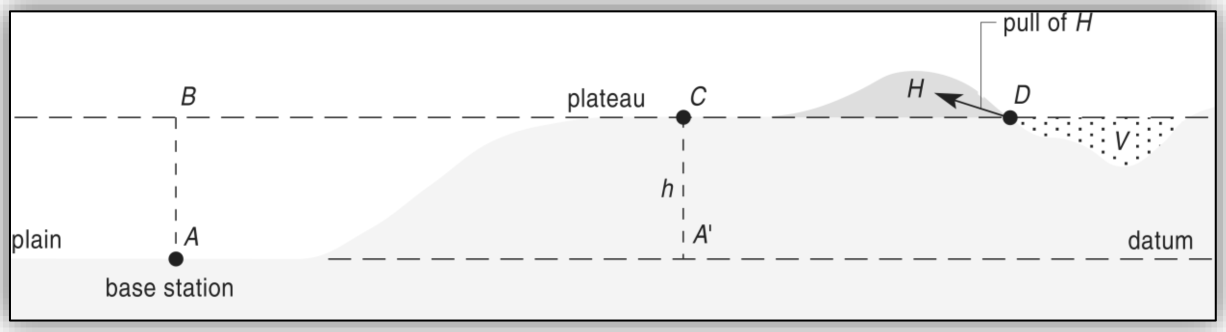


Figure (7) : Bouger anomaly corrections

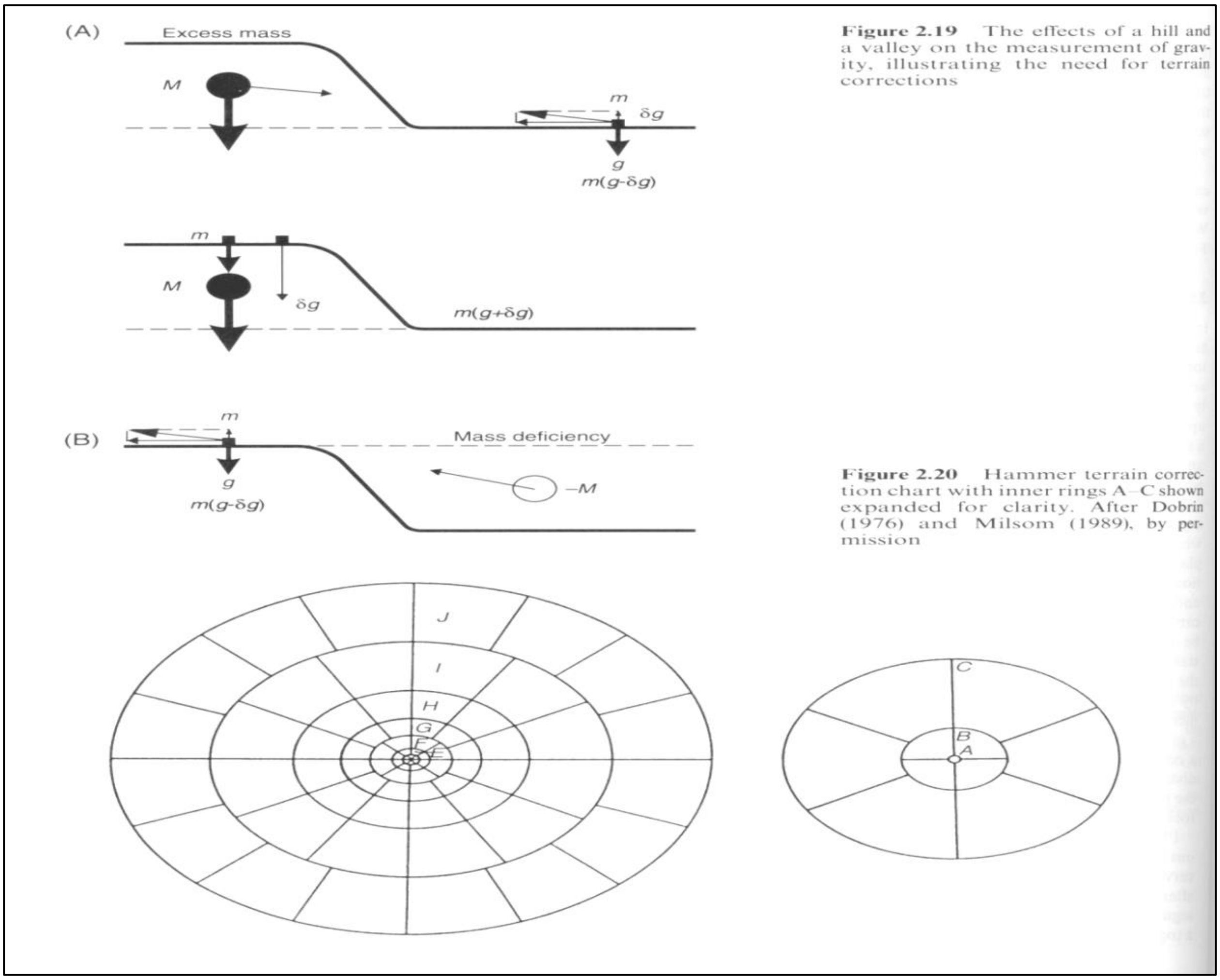


Figure (8): Hammer chart

Local & Regional Anomaly

Local Anomaly. Is a small gravity an. Results from small mass or from lateral variations in density or from structure bodies near surface, gave sharp anomaly. Shallow anomalies are important to mineral exploration.

Regional anomaly is a large gravity anomaly (miles) may be caused by large-scale geologic bodies, variations in basement density or isostatic roots, gave smooth anomaly. deep anomalies are important for oil exploration. These must be removed to enable local anomalies to be interpreted.

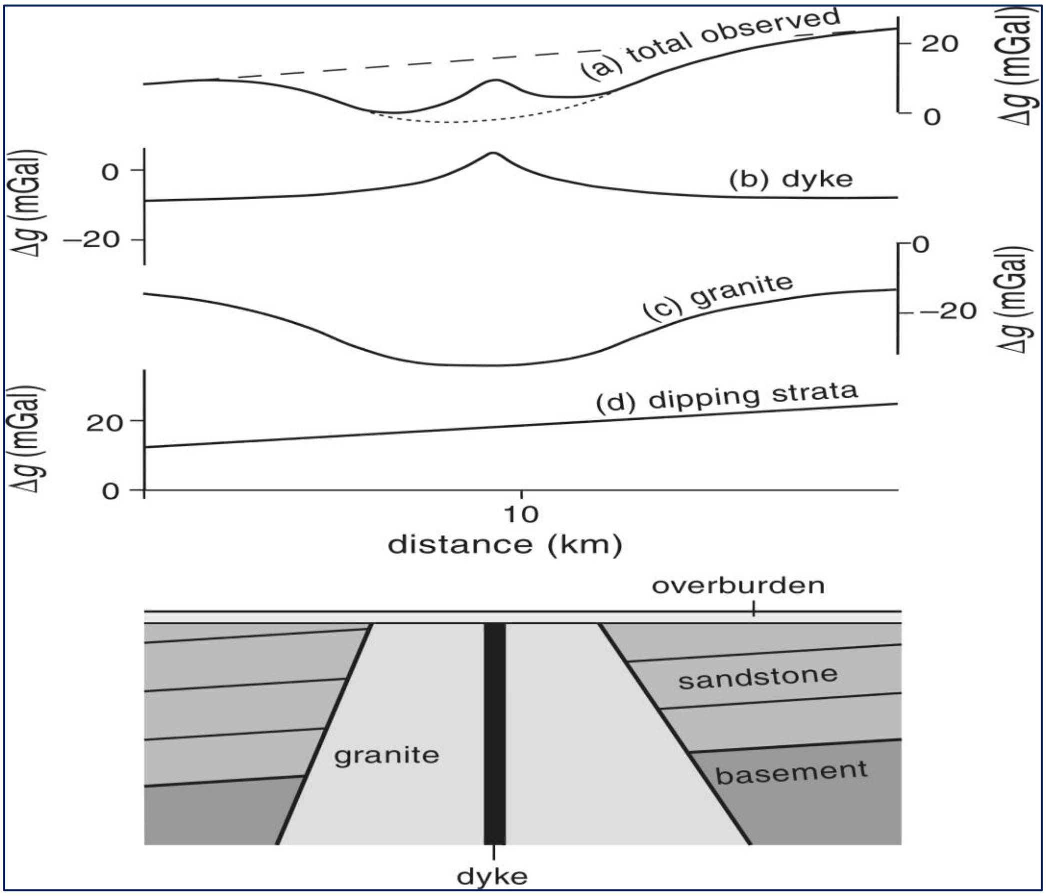


Figure (9): Illustration of regional and residual anomalies.
If we are looking for the dyke, then the anomalies due to the dipping strata and granitic pluton are not relevant to our research and we would like to remove them from the data to easy Interpretation.

There are methods to isolate local an. From regional an.:

1-graphical method

A- Sketching in estimated regional trends by eye on **a profile**.

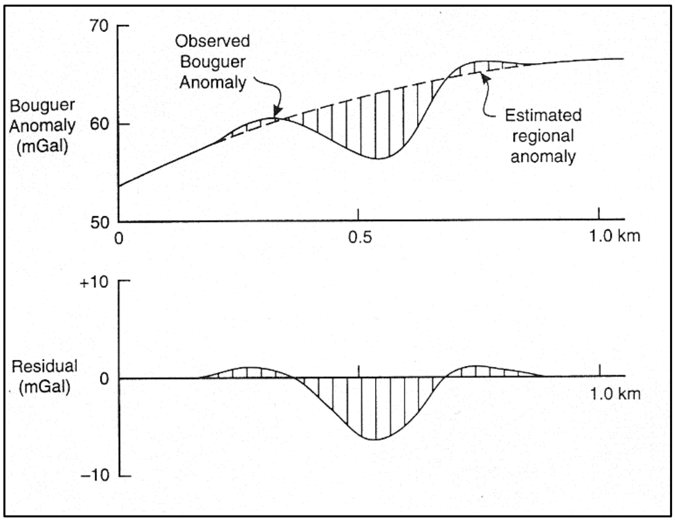


Figure (10): profile method to isolate

B- Calculating the residual an. From estimated the isog

al on a **map** (smoothing) .

Residual (local) an. = Bouger (Observed) an. – Regional an.

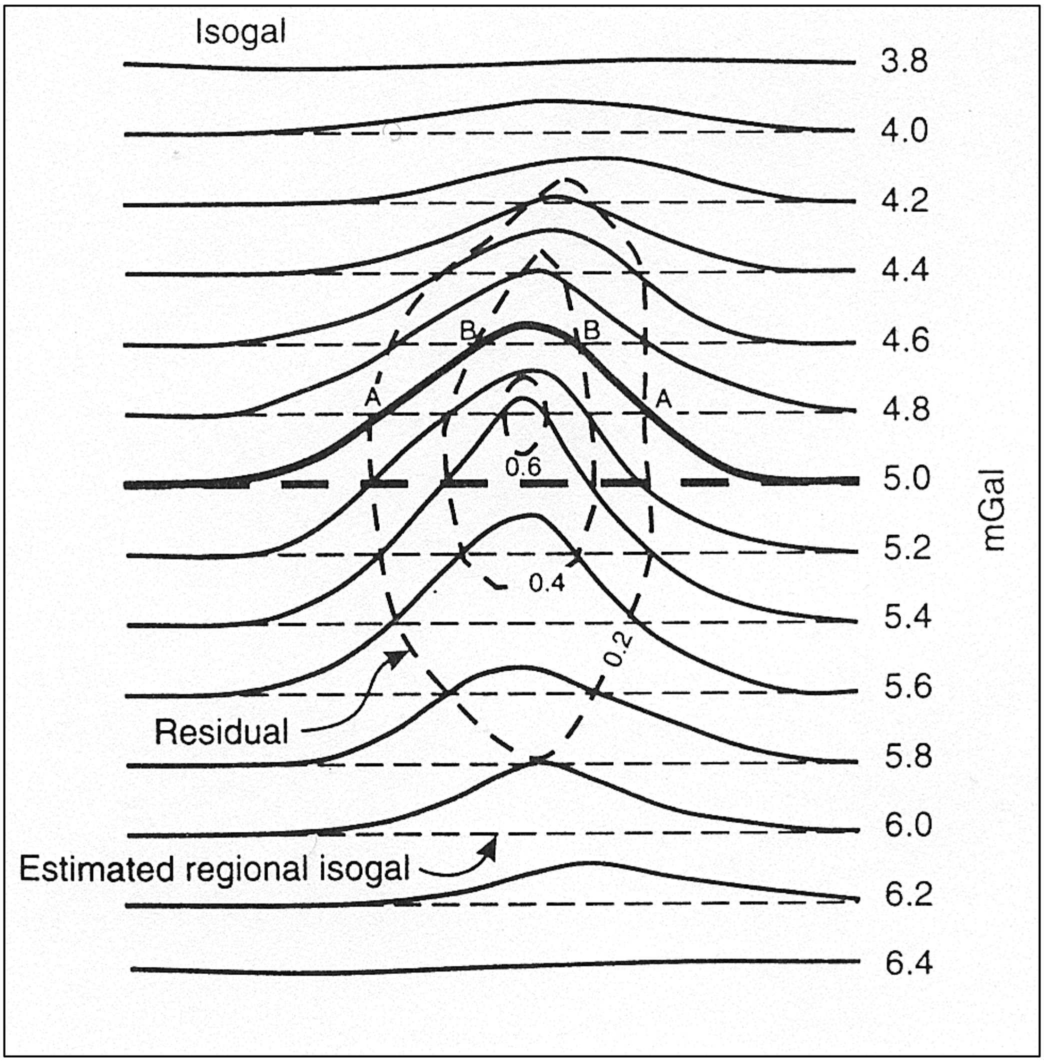


Figure (11): gravity map

2- Analytical method: It’s a **numerical processes** on data make the isolated is accusable without need the experiences handing in other methods.it need stations in systematic distribution on map then apply many analytical methods on it.

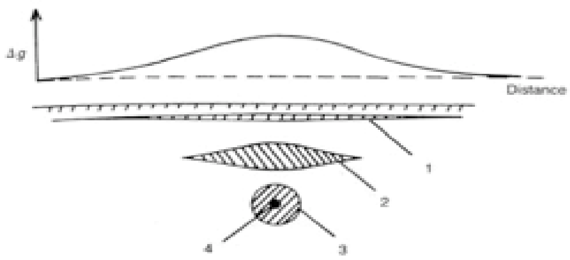
<u>**The ambiguity of surface gravity anomalies**</u>

The same gravity anomaly may be explained by different anomalous bodies, having different shapes and located at different depths:

Near surface very elongated body

Shallow elongated body

Deep sphere



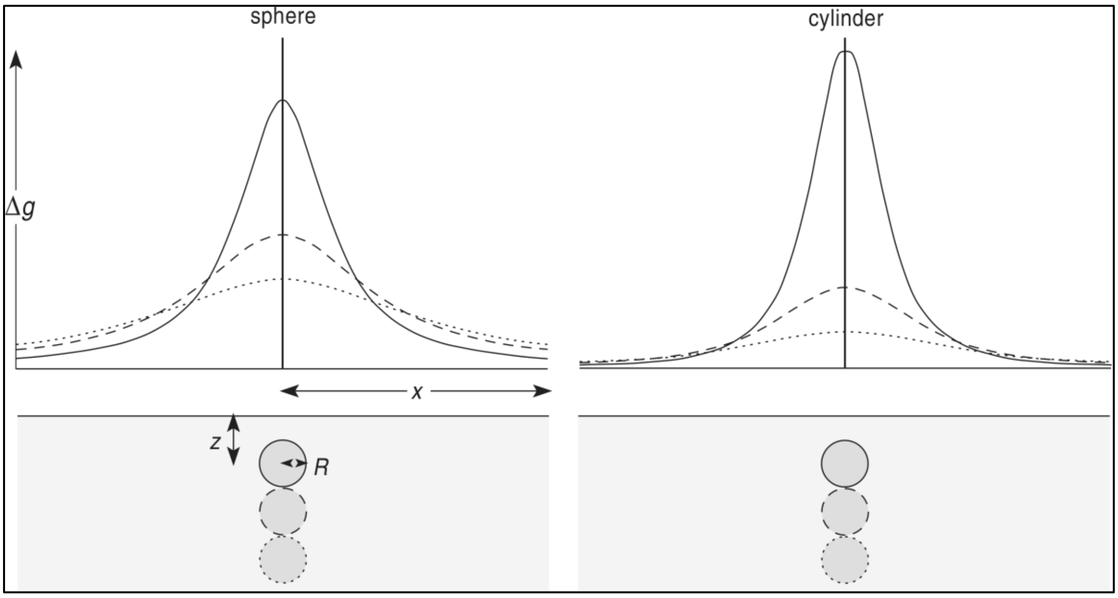


Figure (12): Anomalies of a sphere and a horizontal cylinder at different depths. (Musset and Khan 2000)

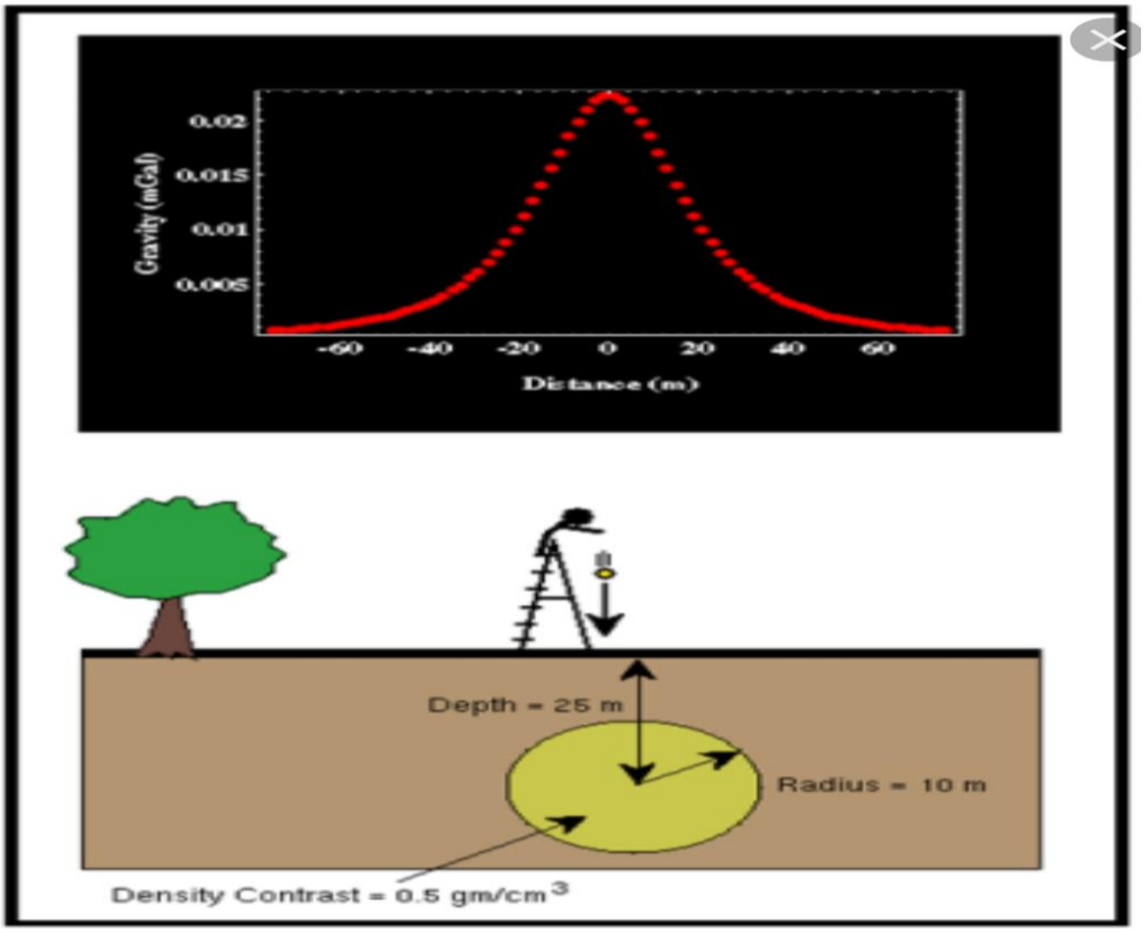
An important task in interpretation is to decrease this ambiguity by using geological information derived from surface outcrops, boreholes and mines.

<u>Third stage: interpretation & conclusion</u>

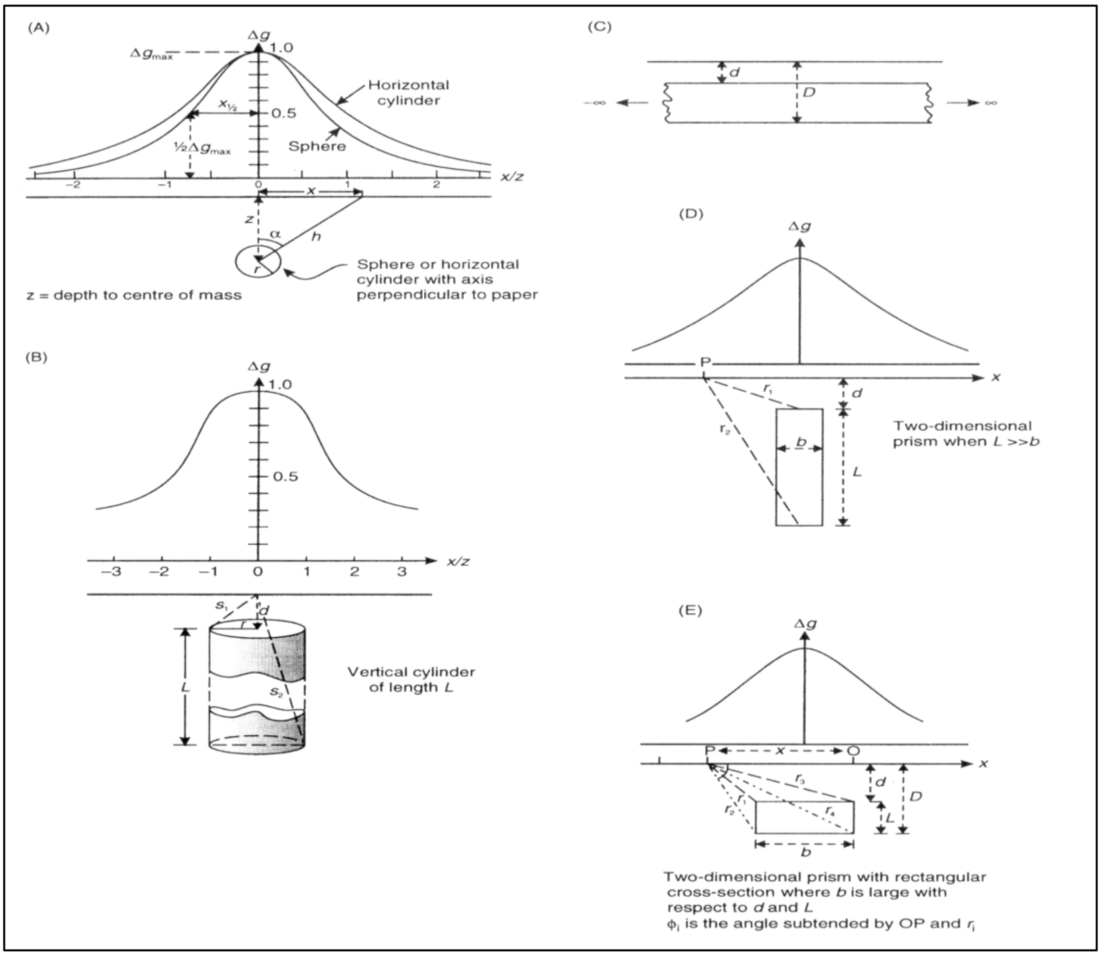
The result of isolation processing is the gravity **anomaly of the target** (goal), which draw as a map. it's **caused** by structure geology, lithology formation or ore body. There are two kinds of interpretation:

A- **Quantitative Intr**.: It explains the extension of residual an. And its average gradient, and describe the shape of anomaly (sphere, cylinder, prism), arraignment, the amplitude (2D or 3D) and its direction.

B- Qualitative Inter.: itsdepends on analytical and mathematical equations applied on residual anomaly to identify through it the quantitate values like (depth, size, radius), and made models of body causes the anomaly if it (fold, fault & infinite slab).



Gravity (mGal)
0.02
0.015
0.01
0.005
-60
-40
-20
0
20
40
60
Distance (m)
Depth = 25 m
Radius = 10 m
Density Contrast = 0.5 gm/cm3



(A)
Δg
1.0
Δg max
0.5
½Δg max
Horizontal cylinder
Sphere
x/z
z = depth to centre of mass
Sphere or horizontal cylinder with axis perpendicular to paper
(B)
Δg
1.0
0.5
x/z
Vertical cylinder of length L
(C)
d
D
-∞
∞
(D)
Δg
Two-dimensional prism when L >>b
(E)
Δg
Two-dimensional prism with rectangular cross-section where b is large with respect to d and L
ϕi is the angle subtended by OP and ri

Box 2.19A Depth estimates for given geometric forms

Form	Formula	Notes
Sphere	$z = 1.305x_{1/2}$ $d = z - r$	z is depth to centre of mass d is depth to top of sphere of radius r $r^3 = \|\Delta g_{max}\| z^2/(0.028\delta\rho)$ from Box 2.18
Horizontal cylinder	$z = x_{1/2}$ $d = z - r$	z is depth to cylinder axis d is depth to top of cylinder of radius r $r^2 = \|\Delta g_{max}\| z/(0.042\delta\rho)$ from Box 2.18
Vertical cylinder	$z = 1.732x_{1/2}$	z is depth to top end of cylinder (overestimates z)
Thin dipping sheet	$z \approx 0.7x_{1/2}$ $z \approx x_{1/2}$	z is depth to top of sheet When $z \approx$ dip length of sheet When $z \gg$ dip length of sheet *When length of sheet is very large or sheet dips at less than 60°, no solution is possible*
Thick prism	$z = 0.67x_{1/2}$ $z = 0.33x_{1/2}$	z is depth to prism top = prism width, and depth to prism base is twice width When depth to prism base is 10 times prism width *In both cases, estimates of z are unreliable*

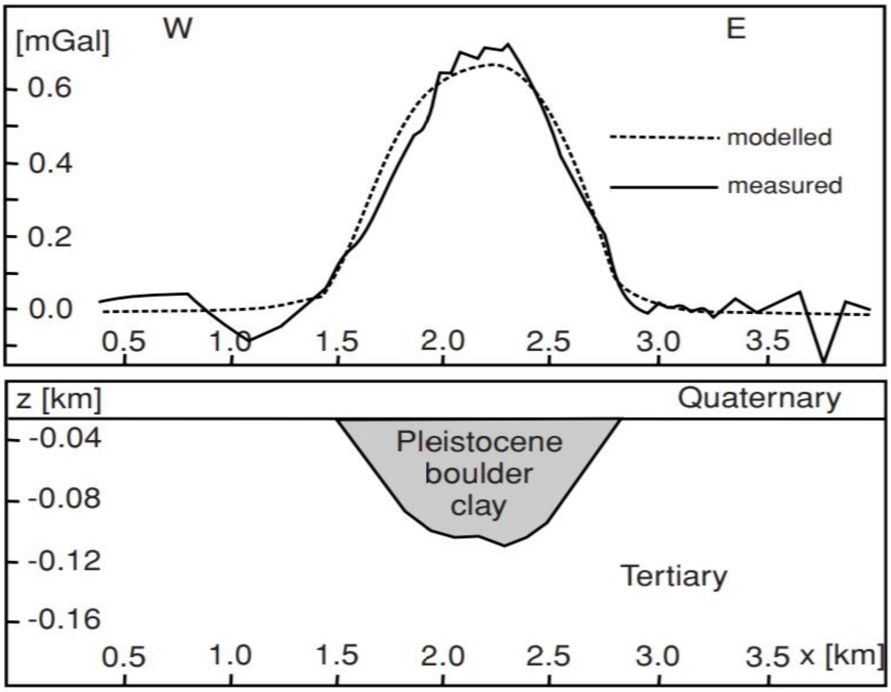
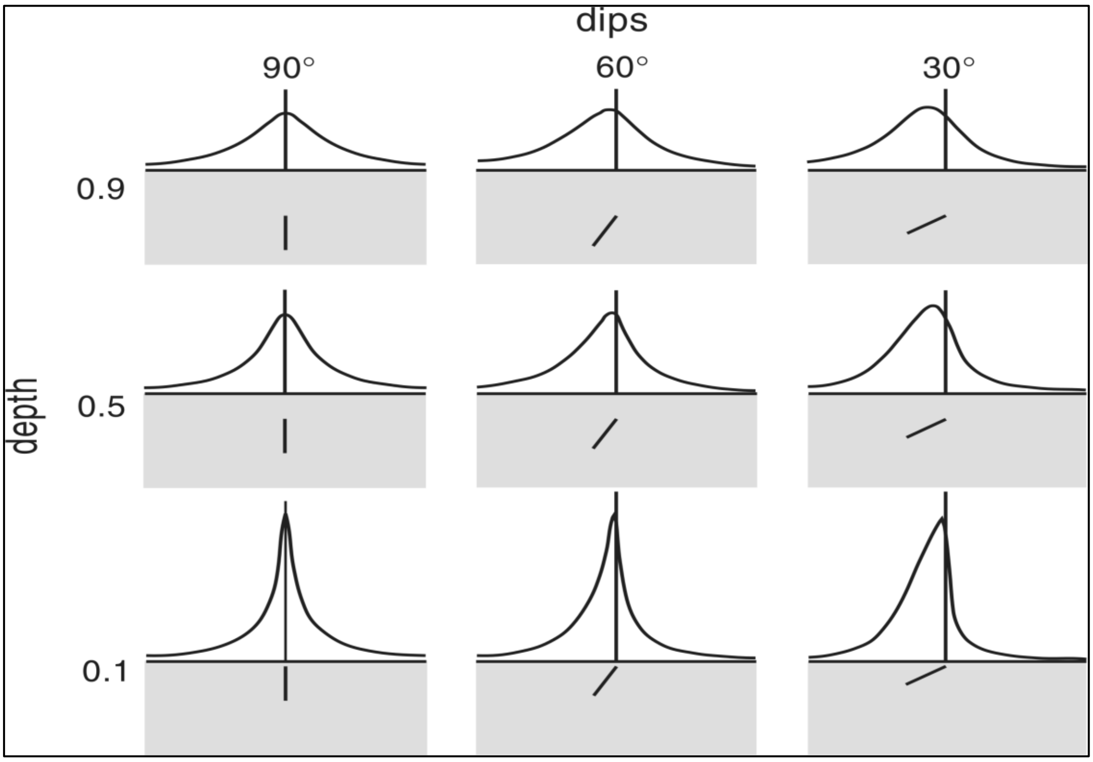
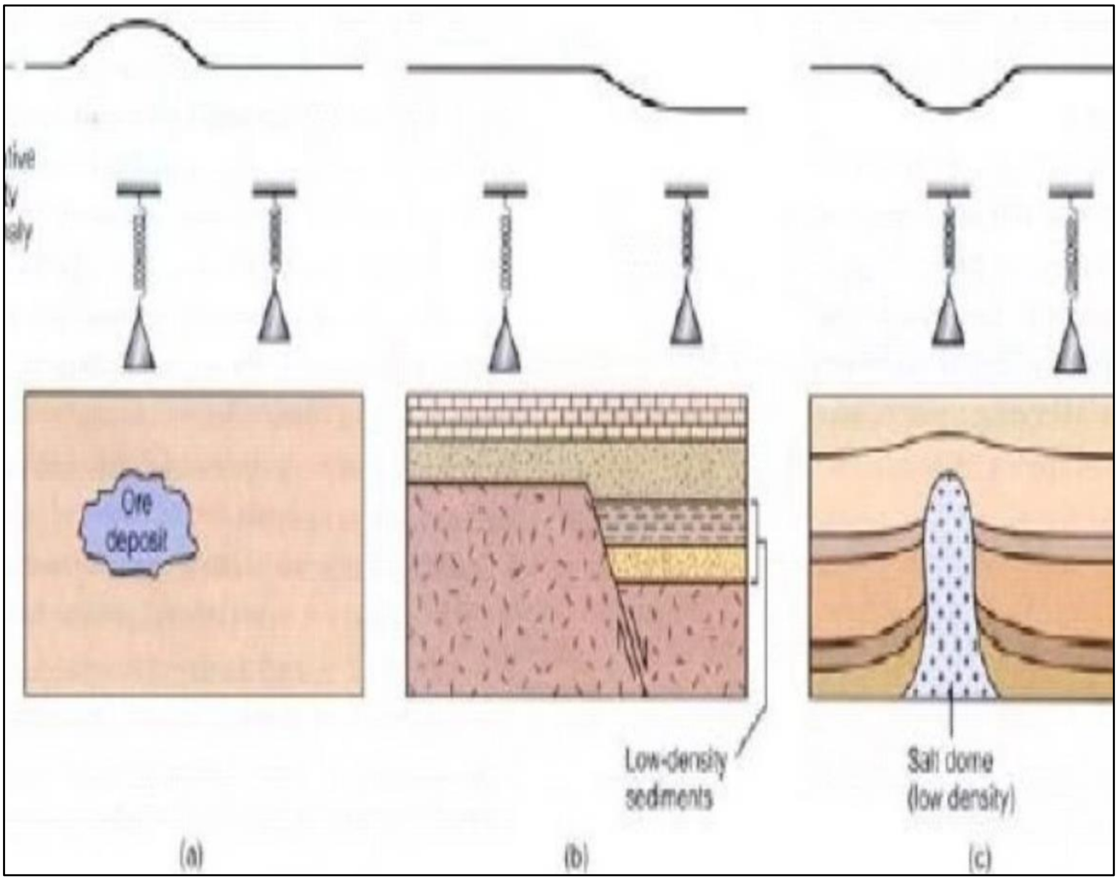


Figure 2.65 Gravity profile across the Trave valley, Germany, with the location of the valley based on a seismic reflection survey. After Gabriel (2006), by permission.



Anomalies of narrow sheets at different depths and dips. (Musset and Khan 2000)



Examples of gravity anomaly for different structure cases