## Gravity method

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The Gravity surveys investigate the subsurface geology based on the variation of the earth’s gravity field produces by density differences of the subsurface geologic structures. Gravity survey is based on the Isaac Newton’s (1643-1727) Universal Law of Gravitation, which states that the force **F** between two masses **m**1 and **m**2 is equal

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| --- | --- |
|  | **(1.)** |

Provide that the dimension of those two masses are small comparing with distance **r**.

**G** is the universal gravitational constant that first determined by an experiment performed by Henry Cavendish and has been repeated many times using modern instruments to obtain the value

6.673 × 10-8 (g/cm3)/s2

If **M** is the mass of the earth and **R** is the radius, then gravitational attraction of the earth on a small mass **m** assuming that the earth is homogenous and spherical is:

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| --- | --- |
|  | **(1.)** |

Therefore the gravity is **g=GM/R**2, which will be constant. However the earth’s ellipsoidal shape, irregular surface relief, different rock types and rotation cause the gravity to be variable.

The gravitational filed is most usefully expressed as scalar Gravitational Potential **U**.

|  |  |
| --- | --- |
|  | **(1.)** |

The c.g.s. unit of gravity is milligal (mGal) which 1 mGal=10-3 Gal and 1 mGal=10-3 cm/s2. . (1gal= 1cm/s2)

Note that the Equipotential surfaces can be defined on which **U** is constant. Therefore, the sea-level surface, or geoid is the most easily recognised equipotential surface, which is everywhere horizontal and orthogonal to the direction of the gravity.

### Gravity Corrections

### Drift and Tide corrections

Drift correction accounts for time-dependent mechanical changes of the Gravimeter and tide correction accounts for the time-varying gravitational attraction of the sun and moon that may reaches amplitude of 0.3 mGal (Telford et. al. 1990).

For digital gravitymeter Drift correction is carried out by repeated readings at one location for one day or more, and therefore, the drift is the slope of the best-fit line.

However, Drift in non-digital gravitymeter can be corrected by closing the gravity loop at certain time interval repeated at the base station.

## Gravity Data Reductions

Gravity values vary from place to place. Some of those variations have obvious causes such as earth flattening and rotation, variation in the distance from the earth’s centre, and the fact that there would appear to be more mass beneath a high gravity site than a lower one, causing the gravity values measured at these sites to differ.

By correcting for the above factors, (a process referred to as “reduction”) the remaining changes of gravity values will only depend on the density contrast relating to geological features or structures

### Latitude correction

Variation of gravity with latitude is due to the none-spherical shape of the earth and the angular velocity variations from zero at the pole to its maximum at the equator (Kearey and Brooks 1991). Rotation generated centripetal acceleration causes the gravity to increase from equator to the pole. And effect that is partly counteracted by the larger radius at the equator than the pole. Never the less these remains a net increase of approximately 5186 mGal from equator to pole. Also the radius at the equator is longer than at the pole which is partly counteracted by the increased mass at the equator, but still caused the gravity to increase from the equator to pole the net result of the above two factors is approximately 5186 mGal increase of gravity at the pole with respect to the equator.

The latitude correction is determined by the Clairaut’s formula:

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| --- | --- |
|  | (1.4) |

This formula relates gravity to latitude on the reference spheroid, where **G**lat is the theoretical gravity value at the latitude of the gravity reading. **G**equatoris the gravity value at the equator**. K**1and **K**2 are constants dependent on the shape and speed of rotation of the earth. The resulting **G**lat should be subtracted from the observed value to correct for the latitude variation

The Gravity formula was modified at least three times in this century in 1930, 1967 and 1984. In 1930 the first international accepted reference ellipsoid was established and its parameters were used for the 1930 International Gravity Formula:

|  |  |
| --- | --- |
| **G**lat**=978049.0(1+0.0052884sin2(lat)-0.0000059sin2 (2xlat))** | **(1.5)** |

However, by calculating more precise geodetic parameters from satellite observations the 1930 gravity formula was modified to the 1967 Geodetic Reference System Formula (GRS67)

|  |  |
| --- | --- |
| **G**lat**=978031.846(1+0.005278895 sin2(lat)+0.000023462 sin4(lat))** | **(1.6)** |

This formula is simplified to the following form:

|  |  |
| --- | --- |
| **G**lat**=978031.846(1+0.0053024sin2(lat)-0.0000059sin2 (2xlat))** | **(1.7)** |

In 1979 the International Association of Geodesy (IAG) adopted the Geodetic Reference System 1980 (GRS80) which led the World Geodetic System 1984 (WGS84) and a theoretical gravity formula approximated by:

|  |  |
| --- | --- |
| **Glat=978032.67714(1+0.00193185138639sin2(lat)/(1-0.00669437999013sin2(lat))1/2** | **(1.8)** |

In summary Results of measurements of gravity (g) presented as *deviations* from mean value of gravity, the normal gravity or theoretical gravity

**Glat is called Normal gravity gn or theoretical gravity**

Average gravitational acceleration on the surface of the earth, gn

gn depends on latitude

gn greatest at the poles

gn least at the equator

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### The elevation corrections

Three corrections explained below, account for the elevation of the gravity readings: Free-air, Bouguer and terrain corrections.

**1-Free-air Correction:**



By assuming the earth is a sphere and not rotating, the theoretical gravity value on the earth surface would be calculated by this formula:

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| --- | --- |
| **g=GM/R2** | **(1.9)** |

By given **G**=6.673×10-8  (g/cm3)/s2, **M**=5.97 × 1027 gram and **R**=6.37 × 108 cm, the gravity **g**=981.7854494(Gal)=981785.45 mGal, if the radius is increased by one meter (i.e. if elevation increases) the gravity will decrease to **g**=981785.14 mGal. Which means that the gravity will decrease by 0.31 mGal by moving the 1 meter higher. Due to the rotating nature of the earth the formula (1.9), is actually more complicated, and the changes truly approximately 0.3086 mGal/m. so the Free Air Correction (FAC) is a correction that accounts for the variations caused by variation in the distance to the centre of the earth.

***In summary Free-air correction***

* With increasing elevation, the distance to the centre of the earth *increases* - as a result the value of g *decreases*
* gradient in g with height is 0.3086 mGal/m
* a correction is applied, the free-air correction = 0.3086h mGal

with h in metres above sea level

* Free-air correction *added* to gravity value

The Free Air Correction is applied by subtracting from **G**lat the change of gravity resulting from moving **h** abovethe normal ellipsoid. This change can be determined by multiplying **h** by 0.3086 mGal/m. The Free Air Correction (FAC) would be:

|  |  |
| --- | --- |
| **FAC=0.3086h,** where **h** in meter | **(1.10)** |

Applying this correction to the observed gravity readings (**g**obs) results in the Free-air gravity anomaly formula (1.11)

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| --- | --- |
| **FAA=g**obs**-(g**lat**-0.3086h)** | **(1.11)** |

where **g**lat and **g**obs are in mGal and **h** in meter. The Free-air anomaly usually reflects the topography and can be used to check the data reliability.

##### 2-Bouguer Correction

This correction accounts for the landmass beneath the gravity site between the surface of the site and the sea level. It is accomplished by approximating the rock layer beneath the gravity site to an infinite horizontal slab with a thickness equal the elevation of the gravity site above sea level,

The gravity effect of an infinite landmass with a thickness **h** and density ***p*** is:

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| **Gravity attraction of slab = 2πG*p*h.** | **(1.12)** |

If the density is in grams per cubic centimetre and the thickness in meters, the gravity attraction of the slab is = 2×3.1416×6.673 ×10-8 ***p*h** =0.04193***p*h** mGal/m

The Bouguer correction is applied in an opposite sense to the free air correction. While the Free Air Correction is added when the gravity station above the datum (usually the see level) to correct for the decrease in gravity with elevation. The Bouguer correction is subtracted when the station is above the datum to remove the gravitational attraction of the rocks between the gravity station and the datum and vice versa.

Applying a latitude-dependent flattening and rotation correction, a Free air correction and Bouguer correction for each gravity reading yields in the Bouguer gravity anomaly or the simple Bouguer gravity anomaly **SBGA**:

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| --- | --- |
| **SBGA=g**obs**–(g**lat**-0.3086h+0.04193*p*h)** | **(1.13)** |

Values of **g**obs and **g**lat are given in mGal, **h** in meters, and ***p*** in grams per cubic centimetre, with ***p*** representing an average density for the earth crust.

* In summary After the free-air correction the effect of mass above sea level must be corrected for.



* In the Bouguer correction the gravitational effect of an infinite slab/plate of thickness h and density ***p***  is *subtracted* from the gravity value
* The Bouguer correction does not take *variations* in topography into effect

**3-Terrain Correction**



Because valleys and hills affect the gravity reading, further correction are made by adding mass to the infinite Bouguer slab to correct for hills and removing mass to correct for valleys. In order to account for the gravity relief in the vicinity of the gravity station. Such correction is always positive and therefore added to the gravity reading whatever the location of the station on top of hill or bottom of valley.

Terrain effect is maximum in areas of strong relief and minimum in flat or nearly flat areas. The most widely use technique to calculate the terrain correction is the Hammer chart developed by Sigmund Hammer. The Hammer chart is time consuming, however digital topographic data can be used more expeditiously in computer programs to calculate the terrain correction. Applying the terrain correction **TC** on the observed gravity data results in formula of the Complete Bouguer Gravity Anomaly **CBGA**:

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| --- | --- |
| **CBGA=g**obs **–(g**lat**-0.3086h+0.04193*p*h-TC)** | **(1.14)** |

where **TC**, **g**obsand **g**latare in mGal,***p*** in gram per cubic centimetre and **h** in meter.

**In summary Terrain corrections**

* the Bouguer plate is not a good approximation to the terrain where there is considerable topography. Mountains - sideways and uppward pull
* Valleys - act in the same way as a mountain - removes downwards pull
* tables of correction values used to account for terrain effects
* Terrain corrections **TC** *added* to the gravity value

**Free-air anomalies**

* correlated with total mass under point of measurement
* if total mass high **FAA**  positive
* if total mass low **FAA**  negative
* when averaged over large areas (> few hundred km diameter)
* **FAA** 0
* On a large scale the mass of the rock column is everywhere similar - demonstrates isostasy

**Bouguer anomalies**

* The best type of anomaly to study variations in density of the crust and uppermost mantle
* On a large scale Bouguer anomaly mirrors the topography
* For most areas: -400 mGal <**SBGA** < 400 mGal
* In most cases:
  + **SBGA** positive on sea
  + **SBGA**  negative on land