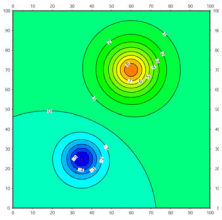
Gravity:
Corrections and analysis

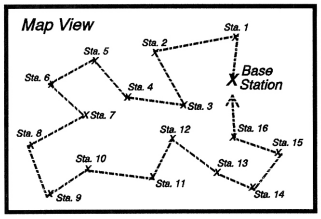


Reading:
- **Today: p22-39**
- **Next Lecture: p39-64**

Gravity corrections

Measure gravity variations at stations around loop

Correct for drift



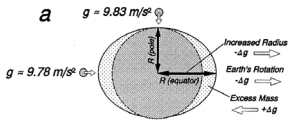
Observations still subject to extraneous effects unrelated to subsurface geology

➔ **Must make corrections…**

1. **Latitude correction**
2. **Free-air correction**
3. **Bouguer correction**
4. **Terrain correction**

Latitude correction

...correct for the spheroid

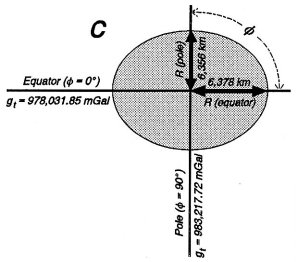


Geodetic Reference System (GRS-1967) formula

$$g_\phi = 9.780318(1 + 0.0053024\sin^2\phi - 0.0000059\sin^2 2\phi)$$ **m/s²**

For smaller scale studies we can simplify:

$$C_\phi = 8.12\sin 2\phi$$ **g.u./km-N-S**



Correction is greatest at mid-latitudes. For 0.1 g.u. accuracy need relative N-S distance to 12 m

Add or subtract?

Free-air correction

Accounts for the 1/r² decrease in gravity with distance from the center of the Earth, recall:

$$g = \frac{GM_E}{{R_E}^2}$$

We calculate:

$$C_F = 3.086h$$

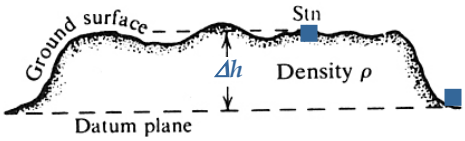
where *h* is the elevation in meters

For 0.1 g.u. accuracy stations elevation is needed to 4 cm.

Add or subtract?

Bouguer correction

Accounts for rock thickness between current and base station elevation



Treat the rock as an infinite horizontal slab:

$$C_B = 0.000419\Delta h\rho$$ where Δh is in m and ρ is in km/m^3

For 0.1 g.u. accuracy station elevation is needed to 9 cm

Add or subtract?

Terrain correction

When Bouguer correction is inadequate, also use terrain correction

Add or subtract?

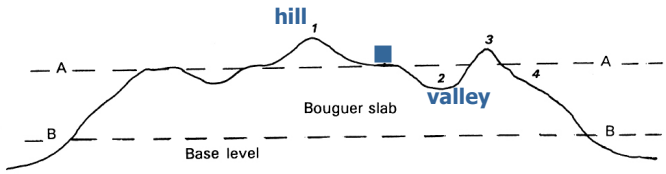


Fig. 2.6 Bouguer and terrain corrections. The Bouguer correction refers to the gravity effect of the intervening plate mass between station S and the base level B. The terrain correction takes into account the effects of topographic rises (1,3) and depressions (2,4).

Approaches to correction

Rectangular grid

Hammer segments … both use elevation differences between station and surround

Terrain correction

Hammer correction

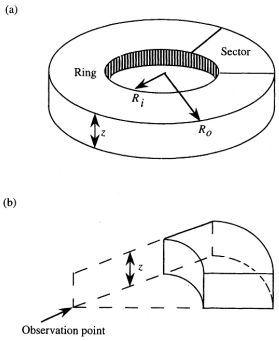


Figure 6-6 The basic approach to representing masses for the purpose of terrain corrections. (a) A cylindrical ring with inner radius R_i, outer radius R_o, and thickness z. A section of the ring is referred to as a *sector*. (b) A sector representing a topographic feature above the level of a gravity observation point.

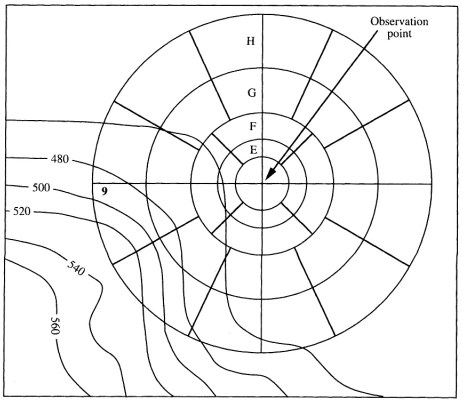


Figure 6-7 A terrain-correction template placed on a topographic map with the center at a gravity-observation point. Most contours are not shown for purposes of clarity. Only zones E, F, G, and H are illustrated.

Free-air anomaly

A gravity "anomaly" suggests the difference between a theoretical and observed value.

➔ Tie survey to base station where absolute gravity is known

Then the free-air anomaly is: $\Delta g_F = g_{obs} + C_F - g_\phi$

Have not corrected for topography

- **Onshore: anomaly map similar to topography**
- **Free-air anomaly mainly used for offshore**

Bouguer anomaly

Apply all the corrections:

$$\Delta g_B = \Delta g_{obs} + C_\phi + C_F - C_B + C_T$$

…watch the signs!

Smaller scale engineering/environmental surveys:

- **Not tied to absolute gravity**
- **Use corrections with accuracy necessary**

…determined by the size of the target signal

Field determination of density

Why do we need rock density?

Nettleton method: density profile

Other methods:

- The same problem can be formulated mathematically and solved by least squares
- Borehole logging

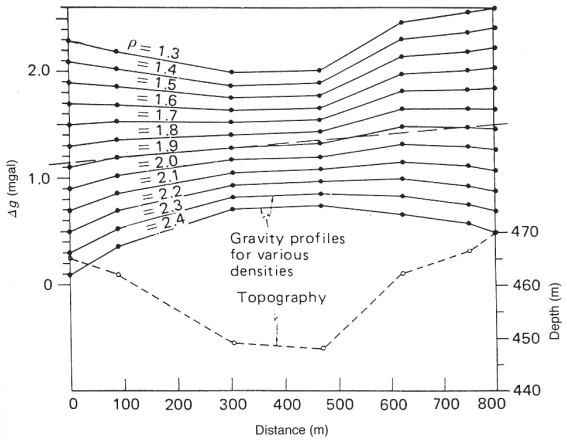


Fig. 2.8 A gravimetric method for measuring the surface density. The criterion for the actual density is that which gives a reduced gravity profile with no visible correlation with the topography. The indicated density of 1.9 g/cm³ (1900 kg/m³) is an average value for the topographic feature sampled. (Modified from Nettleton, 1971.)

Analysis and interpretation

Once we have made our gravity observations,
corrected for surface effects,
we attempt to deduce sub-surface structure

Considerations:

- **Anomaly profile (2D structure) or map (3D structure)?**

  If anomaly length > twice the width a 2D interpretation is OK

- **Ambiguity**

  There are an infinite number of structures that could generate the observations

- **Forward calculation**

  "Guess" at structure, calculate the anomaly and compare. Simple formula for depth and size of geometric shapes.

- **Inverse modeling**

  Directly invert for structure, choose constraints on the geometry …don't forget that ambiguity.

Buried sphere

Analytic expressions for simple geometric shapes

e.g. a buried sphere

$$\Delta g_z = \frac{4\pi G R^3 \Delta\rho}{3z^2} \frac{1}{\left[1+\left(x^2/z^2\right)\right]^{3/2}}$$

Depth rule

$$z = 1.302 x_{1/2}$$

Note: it is only the density **contrast** that is important

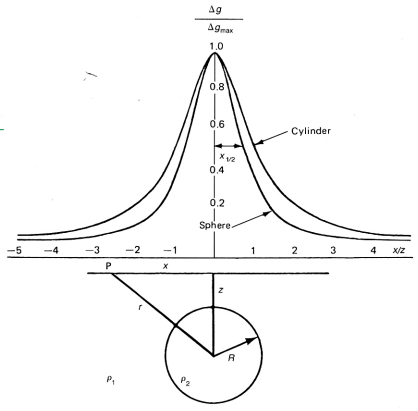
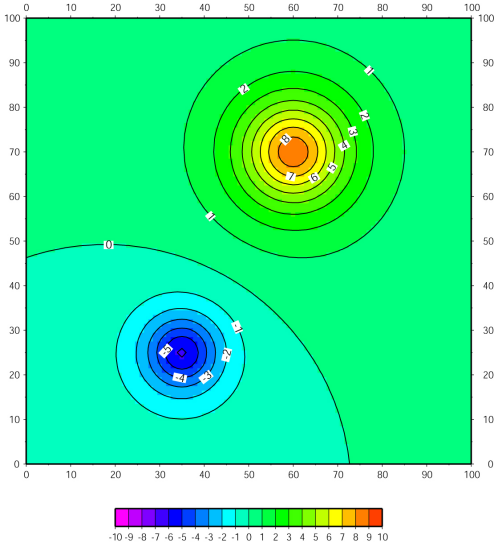


Fig. 2.13 Horizontal variation in gravity due to a sphere and a horizontal cylinder, both of radius R and density contrast ($\Delta\rho = \rho_2 - \rho_1$). The maximum anomaly occurs at $x=0$ and falls to its half-value at $x = x_{1/2}$.

Gravity anomaly map



Simple shape anomalies

Table 2.2 *Simple mass shapes used to approximate geological structures. Formulas for calculating their gravity anomalies are listed. Depth rules (where applicable) are given in terms of the 'half-width' ($x_{1/2}$) or some other characteristic of the anomaly (see Figs. 2.13 and 2.14).*

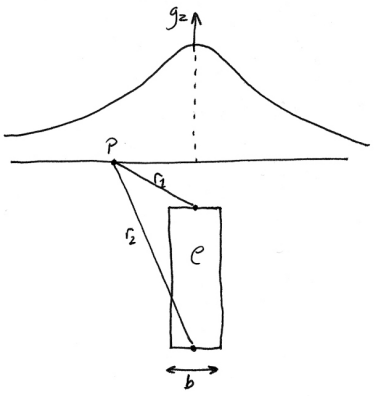
Geometrical form	Geological structure	Gravity formula	Depth rule
Sphere	compact bodies, salt domes	$\Delta g = \frac{4\pi GR^3\Delta\rho}{3z^2}\frac{1}{[1+(x^2/z^2)]^{3/2}}$	$z = 1.305x_{1/2}$
Horizontal cylinder (infinite strike)	ridges, valleys, tunnels	$\Delta g = \frac{2\pi GR^2\Delta\rho}{z}\frac{1}{[1+(x^2/z^2)]}$	$z = 1.0x_{1/2}$
Narrow cylinder (infinite depth extent)	volcanic necks, plugs	$\Delta g = \pi GR^2\Delta\rho/(x^2+z_1^2)^{1/2}$	$z_1 = 0.58x_{1/2}$
Vertical sheet (infinite strike)	thin dikes	$\Delta g = 2Gb\Delta\rho\left[\frac{\ln(x^2+z_2^2)^{1/2}}{\ln(x^2+z_1^2)^{1/2}}\right]$	$z_1 \approx 0.4x_{1/2}$ (empirical, for $z_2 \geq 5z_1$)
Horizontal slab (semi-infinite)	near-vertical faults	$\Delta g = 2Gt\Delta\rho\phi$	$z = 1.0x_{\frac{1}{2}}$
Infinite slab (Bouguer slab)	sedimentary basins, plutons, ice caps	$\Delta g = 2\pi Gt\Delta\rho$	$t = \Delta g/2\pi G\Delta\rho$
Finite rectangular prism	basement blocks, topographic features	(see Eq.(2.21))	
Finite cylinder	small cavities, sinkholes	(see Appendix B)	

Note:
Δg is the gravity anomaly (m/s^2) due to a density contrast $\Delta\rho$ (kg/m^3); $G = 6.672\times10^{-11}$ (SI units); x, z, R, respectively, denote horizontal distance along the profile, depth to center or median plane of the source, and its radius (Fig. 2.13); $x_{1/2}$ is the half-width of the anomaly (defined in Fig. 2.13); z_1, z_2 are, respectively, depth to the top and bottom of the source; ϕ is the angle from the horizontal of the point of observation to the median plane of the semi-infinite slab (Fig. 2.14); x_0 is the horizontal distance over which the fault anomaly falls from $0.5\Delta g_{max}$ to $0.25\Delta g_{max}$ (Fig. 2.14); t is thickness (depth extent) of the slab; b is horizontal thickness of the vertical sheet.

2D vertical column

Gravity anomaly due to a two dimensional vertical column:

$$\Delta g_z = 2G\Delta\rho b \ln\left(r_2 / r_1\right)$$



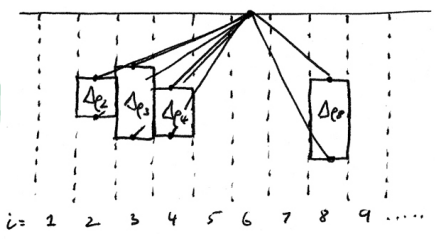
2D vertical columns

Gravity anomaly due to a two dimensional vertical column:

$$\Delta g_z = 2G\Delta\rho b \ln\left(r_2 / r_1\right)$$

Gravity anomaly due to a series of vertical columns:

$$\Delta g_z = 2G\sum_i \Delta\rho_i b_i \ln\left(r_i^2 / r_i^1\right)$$



Gravity Anomalies: 2D forward calculation

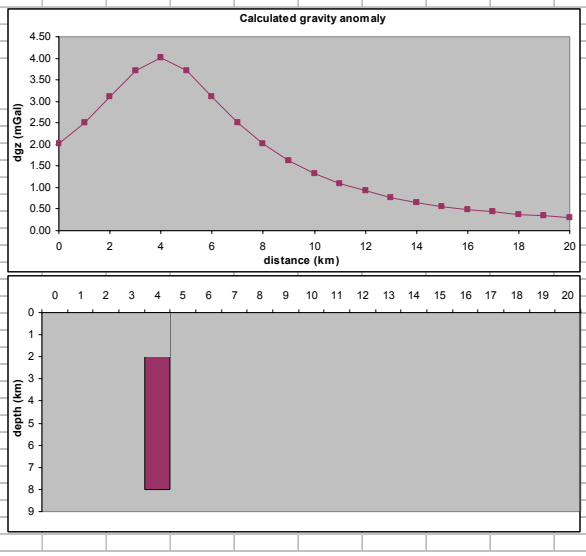
for rectangular parallelepipeds with greater vertical extent than horizontal

see Dobrin and Savit eq 12-34

Define density structure

Adjust bold numbers...

coulum center (km)	density contrast (g/cm3)	top (km)	bottom (km)	error check
0	**0.5**	**0**	**0**	OK
1	**0.5**	**0**	**0**	OK
2	**0.5**	**0**	**0**	OK
3	**0.5**	**0**	**0**	OK
4	**0.5**	**2**	**8**	OK
5	**0.5**	**0**	**0**	OK
6	**0.5**	**0**	**0**	OK
7	**0.5**	**0**	**0**	OK
8	**0.5**	**0**	**0**	OK
9	**0.5**	**0**	**0**	OK
10	**0.5**	**0**	**0**	OK
11	**0.5**	**0**	**0**	OK
12	**0.5**	**0**	**0**	OK
13	**0.5**	**0**	**0**	OK
14	**0.5**	**0**	**0**	OK
15	**0.5**	**0**	**0**	OK
16	**0.5**	**0**	**0**	OK
17	**1**	**0**	**0**	OK
18	**0.5**	**0**	**0**	OK
19	**0.5**	**0**	**0**	OK
20	**0.5**	**0**	**0**	OK



Gravity Anomalies: 2D forward calculation

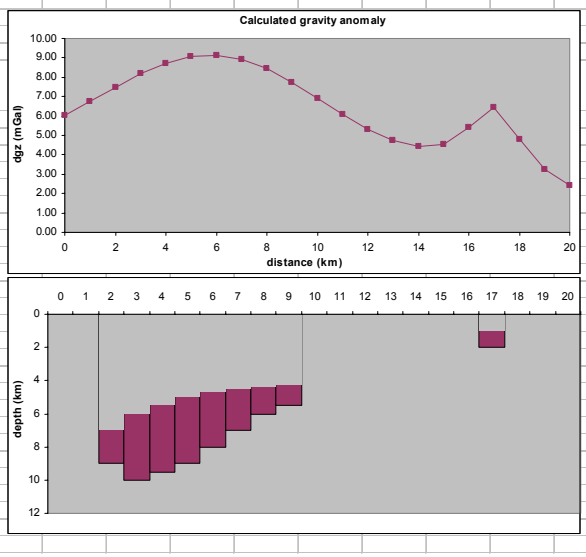
for rectangular parallelepipeds with greater vertical extent than horizontal

see Dobrin and Savit eq 12-34

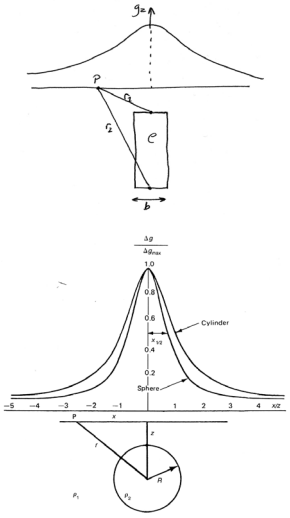
Define density structure

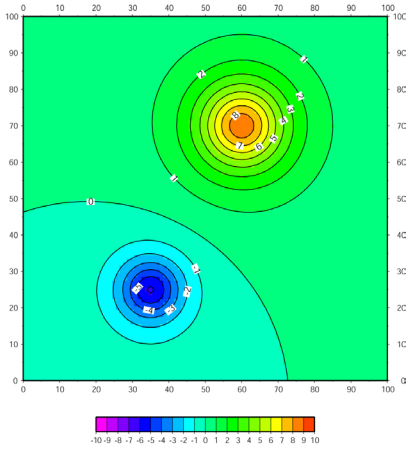
Adjust bold numbers...

coulum center (km)	density contrast (g/cm3)	top (km)	bottom (km)	error check
0	**0.5**	**0**	**0**	OK
1	**0.5**	**0**	**0**	OK
2	**0.5**	**7**	**9**	OK
3	**0.5**	**6**	**10**	OK
4	**0.5**	**5.5**	**9.5**	OK
5	**0.5**	**5**	**9**	OK
6	**0.5**	**4.7**	**8**	OK
7	**0.5**	**4.5**	**7**	OK
8	**0.5**	**4.4**	**6**	OK
9	**0.5**	**4.3**	**5.5**	OK
10	**0.5**	**0**	**0**	OK
11	**0.5**	**0**	**0**	OK
12	**0.5**	**0**	**0**	OK
13	**0.5**	**0**	**0**	OK
14	**0.5**	**0**	**0**	OK
15	**0.5**	**0**	**0**	OK
16	**0.5**	**0**	**0**	OK
17	**1**	**1**	**2**	OK
18	**0.5**	**0**	**0**	OK
19	**0.5**	**0**	**0**	OK
20	**0.5**	**0**	**0**	OK



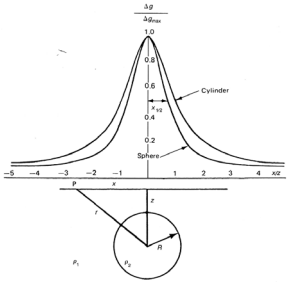
Ambiguity - I

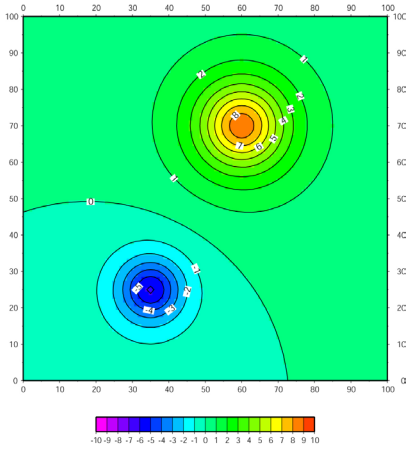




Ambiguity - II

$$\Delta g_z = \frac{4\pi G R^3 \Delta\rho}{3z^2} \frac{1}{\left[1+\left(x^2/z^2\right)\right]^{3/2}}$$





Gravity Anomalies: 2D forward calculation

for rectangular parallelepipeds with greater vertical extent than horizontal

see Dobrin and Savit eq 12-34

Define density structure

	Profile 1				*Profile2*			
	Adjust bold numbers...				**Adjust bold numbers...**			
coulum center (km)	density contrast (g/cm3)	top (km)	bottom (km)	error check	density contrast (g/cm3)	top (km)	bottom (km)	error check
0	**0.3**	**0**	**0**	OK	**0.9**	**0**	**0**	OK
1	**0.3**	**4**	**4.4**	OK	**0.9**	**0**	**0**	OK
2	**0.3**	**4**	**4.4**	OK	**0.9**	**0**	**0**	OK
3	**0.3**	**4**	**4.3**	OK	**0.9**	**0**	**0**	OK
4	**0.3**	**4**	**4.3**	OK	**0.9**	**0**	**0**	OK
5	**0.3**	**4**	**4.4**	OK	**0.9**	**0**	**0**	OK
6	**0.3**	**4**	**4.4**	OK	**0.9**	**0**	**0**	OK
7	**0.3**	**4**	**4.5**	OK	**0.9**	**0**	**0**	OK
8	**0.3**	**4**	**4.6**	OK	**0.9**	**0**	**0**	OK
9	**0.3**	**4**	**4.7**	OK	**0.9**	**0**	**0**	OK
10	**0.3**	**4**	**4.8**	OK	**0.9**	**8**	**12**	OK
11	**0.3**	**4**	**4.7**	OK	**0.9**	**0**	**0**	OK
12	**0.3**	**4**	**4.6**	OK	**0.9**	**0**	**0**	OK
13	**0.3**	**4**	**4.5**	OK	**0.9**	**0**	**0**	OK
14	**0.3**	**4**	**4.4**	OK	**0.9**	**0**	**0**	OK
15	**0.3**	**4**	**4.4**	OK	**0.9**	**0**	**0**	OK
16	**0.3**	**4**	**4.3**	OK	**0.9**	**0**	**0**	OK
17	**0.3**	**4**	**4.3**	OK	**0.9**	**0**	**0**	OK
18	**0.3**	**4**	**4.4**	OK	**0.9**	**0**	**0**	OK
19	**0.3**	**4**	**4.4**	OK	**0.9**	**0**	**0**	OK
20	**0.3**	**0**	**0**	OK	**0.9**	**0**	**0**	OK