جامعة الانبار

كلية العلوم -قسم الجيولوجيا التطبيقية

اسم المادة بالعربي: الجيوفيزياء الجهدية - الطرق الكهربائية

اسم المادة بالإنكليزي: Potential Geophysics- Gravity Methods

عنوان المحاضرة: Gravity Data Corrections

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Gravity Data Corrections

Before the results of a gravity survey can be interpreted it is necessary to correct for all variations in the Earth's gravitational field which do not result from the differences of density in the underlying rocks. This process is known as gravity reduction (LaFehr 1991) or reduction to the geoid, as sea-level is usually the most convenient datum level.

Drift correction

Correction for instrumental drift is based on repeated readings at a base station at recorded times throughout the day. The meter reading is plotted against time (Fig. 6.10) and drift is assumed to be linear between consecutive base readings. The drift correction at time t is d, which is subtracted from the observed value. After drift correction the difference in gravity between an observation point and the base is found by multiplication of the difference in meter reading by the calibration factor of the gravimeter. Knowing this difference in gravity, the absolute gravity at the observation point gobs can be computed from the known value of gravity at the base. Alternatively, readings can be related to an arbitrary datum, but this practice is not desirable as the results from different surveys cannot then be tied together.

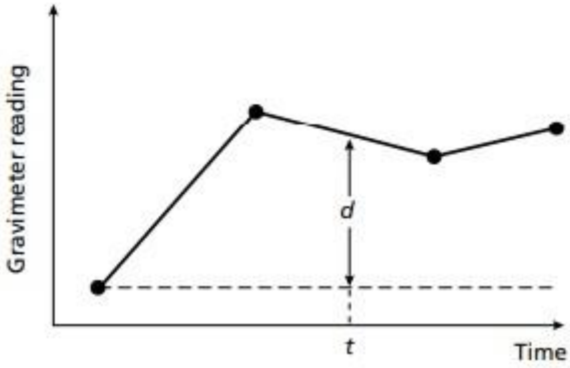

Fig. 6.10 A gravimeter drift curve constructed from repeated readings at a fixed location. The drift correction to be subtracted for a reading taken at time *t* is *d*.

Latitude correction

Gravity varies with latitude because of the non-spherical shape of the Earth and because the angular velocity of a point on the Earth's surface decreases from a maximum at the equator to zero at the poles (Fig. 6.11(a)).The centripetal acceleration generated by this rotation has a negative radial component that consequently causes gravity to decrease from pole to equator. The true shape of the Earth is an oblate spheroid or polar flattened ellipsoid (Fig. 6.11(b)) whose difference in equatorial and polar radii is some 21km. Consequently, points near the equator are farther from the center of mass of the Earth than those near the poles, causing gravity to increase from the equator to the poles. The amplitude of this effect is reduced by the differing subsurface mass distributions resulting from the equatorial bulge, the mass underlying equatorial regions being greater than that underlying Polar Regions

The net effect of these various factors is that gravity at the poles exceeds gravity at the equator by some 51860gu, with the north–south gravity gradient at latitude f being 8.12sin2ϕgukm-1 . Clairaut's formula relates gravity to latitude on the reference spheroid according to an equation of the form

$$g_\phi = g_0(1 + k_1 \sin^2 \phi - k_2 \sin^2 2\phi)$$

An alternative, more accurate, representation of the Gravity Formula 1967 (Mittermayer 1969), in which the constants are adjusted so as to minimize errors resulting from the truncation of the series, is

$$g_\phi = 9\,780\,318.5\,(1 + 0.005278895 \sin^2 \phi + 0.000023462 \sin^4 \phi)\ \text{gu}$$

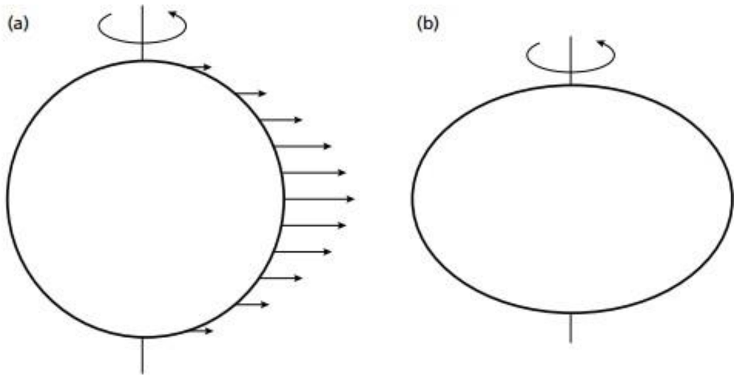

Fig. 6.11 (a) The variation in angular velocity with latitude around the Earth represented by vectors whose lengths are proportional to angular velocity. (b) An exaggerated representation of the shape of the Earth. The true shape of this oblate ellipsoid of revolution results in a difference in equatorial and polar radii of some 21 km.

This form, however, is less suitable if the survey results are to incorporate pre-1967 data made compatible with the Gravity Formula 1967 using the above relationship. The value $g\phi$ gives the predicted value of gravity at sea-level at any point on the Earth's surface and is subtracted from the observed gravity to correct for latitude variation.

Elevation corrections

Correction for the differing elevations of gravity stations is made in three parts. The free-air correction (FAC) corrects for the decrease in gravity with height in free air resulting from increased distance from the Centre of the Earth, according to Newton's Law. To reduce to datum an observation taken at height h (Fig. 6.12(a)),

$$\text{FAC} = 3.086h\ \text{gu}\ (h \text{ in metres})$$

The FAC is positive for an observation point above datum to correct for the decrease in gravity with elevation. The free-air correction accounts solely for variation in the distance of the observation point from the centre of the Earth; no account is taken of the gravitational effect of the rock present between the observation point and datum. The Bouguer correction (BC) removes this effect by approximating the rock layer beneath the observation point to an infinite horizontal slab with a thickness equal to the elevation of the observation above datum (Fig. 6.12(b)). If r is the density of the rock, from equation (6.8)

$$BC = 2\pi G\rho h = 0.4191\rho h \text{ gu}$$
$$(h \text{ in metres, } \rho \text{ in Mg m}^{-3})$$

On land the Bouguer correction must be subtracted, as the gravitational attraction of the rock between observation point and datum must be removed from the observed gravity value. The Bouguer correction of sea surface observations is positive to account for the lack of rock between surface and sea bed. The correction is equivalent to the replacement of the water layer by material of a specified rock density ρ_r. In this case

$$BC = 2\pi G(\rho_r - \rho_w)z$$

where z is the water depth and ρ_w the density of water. The free-air and Bouguer corrections are often applied together as the combined elevation correction. The Bouguer correction makes the assumption that the topography around the gravity station is flat. This is rarely the case and a further correction, the terrain correction (TC), must be made to account for topographic relief in the vicinity of the gravity station. This correction is always positive as may be appreciated from consideration of Fig. 6.12(c).The regions designated A form part of the Bouguer correction slab although they do not consist of rock.

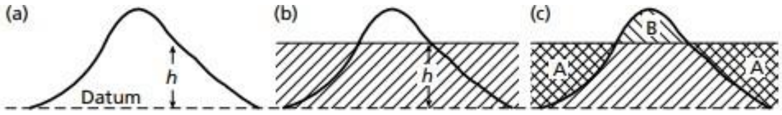

Fig. 6.12 (a) The free-air correction for an observation at a height h above datum. (b) The Bouguer correction. The shaded region corresponds to a slab of rock of thickness h extending to infinity in both horizontal directions. (c) The terrain correction.

Consequently, the Bouguer correction has overcorrected for these areas and their effect must be restored by a positive terrain correction. Region B consists of rock material that has been excluded from the Bouguer correction. It exerts an upward attraction at the observation point causing gravity to decrease. Its attraction must thus be corrected by a positive terrain correction. Classically, terrain corrections are applied using a circular graticule known, after its inventor, as a Hammer chart (Fig. 6.13), divided by radial and concentric lines into a large number of compartments. The outermost zone extends to almost 22km, beyond which topographic effects are usually negligible.The graticule is laid on a topographic map with its centre on the gravity station and the average topographic elevation of each compartment is determined. The elevation of the gravity station is subtracted from these values, and the gravitational effect of each compartment is determined by reference to tables constructed using the formula for the gravitational effect of a sector of a vertical cylinder at its axis. The terrain correction is then computed by summing the gravitational contribution of all compartments. Table 6.1 shows the method of computation. Such operations are time consuming as the topography of over 130 compartments has to be averaged for each station, but terrain correction is the one operation in gravity reduction that cannot be fully automated. Labour can be reduced by averaging topography within a rectangular grid. Only a single digitization is required as the topographic effects may be calculated at any point within the grid by summing the effects of the right rectangular prisms defined by the grid squares and their elevation difference with the gravity station. This operation can effectively correct for the topography of areas distant from the gravity station and can be readily computerized. Such an approach is likely to be increasingly adopted as digital elevation models for large regions become available (Cogbill 1990). Correction for inner zones, however, must still be performed manually as any reasonable digitization scheme for a complete survey area and its environs must employ a sampling interval that is too large to provide an accurate representation of the terrain close to the station. Terrain effects are low in areas of subdued topography, rarely exceeding 10gu in flat-lying areas. In areas of rugged topography terrain effects are considerably greater, being at a maximum in steep-sided valleys, at the base or top of cliffs and at the summits of mountains. Where terrain effects are considerably less than the desired accuracy of a survey, the terrain correction may be ignored. Sprenke (1989) provides a means of assessing the distance to which terrain corrections are necessary. However, the usual necessity for this correction accounts for the bulk of time spent on gravity reduction and is thus a major contributor to the cost of a gravity survey.

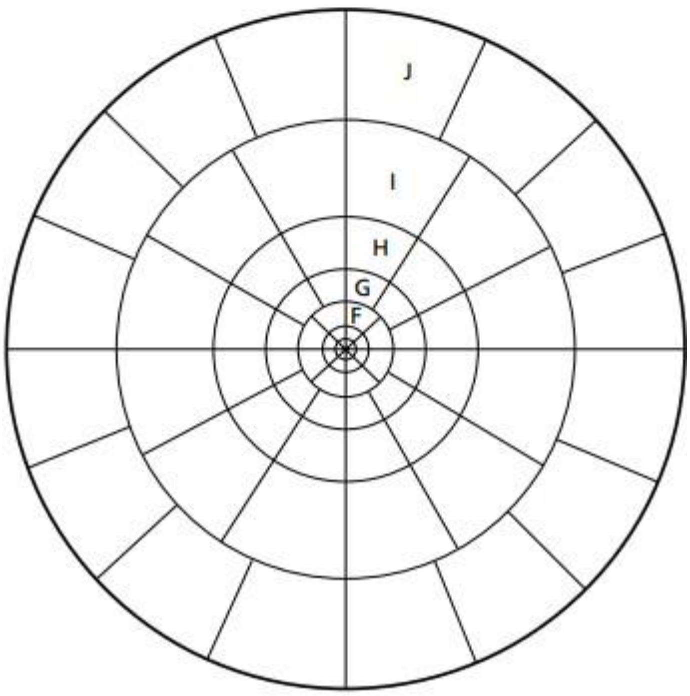

Fig. 6.13 A typical graticule used in the calculation of terrain corrections. A series of such graticules with zones varying in radius from 2 m to 21.9 km is used with topographic maps of varying scale.

Table 6.1 Terrain corrections.

Zone	r_1	r_2	n	Zone	r_1	r_2	n
B	2.0	16.6	4	H	1529.4	2614.4	12
C	16.6	53.3	6	I	2614.4	4468.8	12
D	53.3	170.1	6	J	4468.8	6652.2	16
E	170.1	390.1	8	K	6652.2	9902.5	16
F	390.1	894.8	8	L	9902.5	14740.9	16
G	894.8	1529.4	12	M	14740.9	21943.3	16

$$T = 0.4191\frac{\rho}{n}\left(r_2 - r_1 + \sqrt{r_1^2 + z^2} - \sqrt{r_2^2 + z^2}\right)$$

where T = terrain correction of compartment (gu); ρ = Bouguer correction density (Mg m^{-3}); n = number of compartments in zone; r_1 = inner radius of zone (m); r_2 = outer radius of zone (m); and z = modulus of elevation difference between observation point and mean elevation of compartment (m).

Tidal correction

Gravity measured at a fixed location varies with time because of periodic variation in the gravitational effects of the Sun and Moon associated with their orbital motions, and correction must be made for this variation in a high precision survey. In spite of its much smaller mass, the gravitational attraction of the Moon is larger than that of the Sun because of its proximity. Also, these gravitational effects cause the shape of the solid Earth to vary in much the same way that the celestial attractions cause tides in the sea. These solid Earth tides are considerably smaller than oceanic tides and lag farther behind the lunar motion. They cause the elevation of an observation point to be altered by a few centimeters and thus vary its distance from the center of mass of the Earth. The periodic gravity variations caused by the combined effects of Sun and Moon are known as tidal variations. They have maximum amplitude of some 3gu and a minimum period of about 12h. If a gravimeter with a relatively high drift rate is used, base ties are made at an interval much smaller than the minimum Earth tide period and the tidal variations are automatically removed during the drift correction. If a meter with a low drift rate is employed, base ties are normally made only at the start and end of the day so that the tidal variation has undergone a full cycle. In such a case, a separate tidal correction may need to be made. The tidal effects are predictable and can be computed by a small computer program.

Free-air and Bouguer anomalies

The free-air anomaly (FAA) and Bouguer anomaly (BA) may now be defined

$$FAA = g_{obs} - g_{\phi} + FAC\ (\pm EC)$$

$$BA = g_{obs} - g_{\phi} + FAC \pm BC + TC\ (\pm EC)$$

The Bouguer anomaly forms the basis for the interpretation of gravity data on land. In marine surveys Bouguer anomalies are conventionally computed for inshore and shallow water areas as the Bouguer correction removes the local gravitational effects associated with local changes in water depth. Moreover, the computation of the Bouguer anomaly in such areas allows direct comparison of gravity anomalies offshore and onshore and permits the combination of land and marine data into gravity contour maps.These may be used, for example, in tracing geological features across coastlines. The Bouguer anomaly is not appropriate for deeper water surveys, however, as in such areas the application of a Bouguer correction is an artificial device that leads to very large positive Bouguer anomaly values without significantly enhancing local gravity features of geological origin. Consequently, the free-air anomaly is frequently used for interpretation in such areas. Moreover, the FAA provides a broad assessment of the degree of isostatic compensation of an area (e.g. Bott 1982). Gravity anomalies are conventionally displayed on profiles or as contoured (isogal) maps. Interpretation of the latter may be facilitated by utilizing digital image processing techniques similar to those used in the display of remotely sensed data. In particular, colour and shaded relief images may reveal structural features that may not be readily discernible on unprocessed maps (Plate 5.1a). This type of processing is equally appropriate to magnetic anomalies (Plate 5.1b; see for example Lee et al. 1990).

References

Kearey, P. An Introduction to Geophysical Exploration. Department of Geology University of Leicester, Michael Brooks, 2002.