جامعة الانبار

كلية العلوم -قسم الجيولوجيا التطبيقية

اسم المادة بالعربي: الجيوفيزياء الجهدية - الطريقة الجذبية

اسم المادة بالإنكليزي: Potential Geophysics- Gravity Method

عنوان المحاضرة: Interpretation of gravity anomalies

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Interpretation of gravity anomalies

The inverse problem

The interpretation of potential field anomalies (gravity, magnetic and electrical) is inherently ambiguous. The ambiguity arises because any given anomaly could be caused by an infinite number of possible sources. For example, concentric spheres of constant mass but differing density and radius would all produce the same anomaly, since their mass acts as though located at the center of the sphere. This ambiguity represents the inverse problem of potential field interpretation, which states that, although the anomaly of a given body may be calculated uniquely, there are an infinite number of bodies that could give rise to any specified anomaly. An important task in interpretation is to decrease this ambiguity by using all available external constraints on the nature and form of the anomalous body. Such constraints include geological information derived from surface outcrops, boreholes and mines, and from other, complementary, geophysical techniques (see e.g. Lines et al. 1988).

Regional fields and residual anomalies

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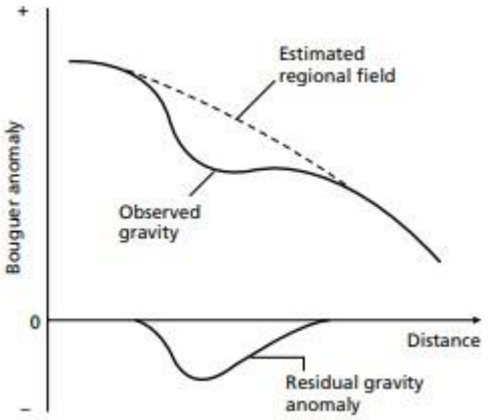

Fig. 6.17 The separation of regional and residual gravity anomalies from the observed Bouguer anomaly.

Regional fields and residual anomalies

Bouguer anomaly fields are often characterized by a broad, gently varying, regional anomaly on which may be superimposed shorter

wavelength local anomalies (Fig. 6.17). Usually in gravity surveying it is the local anomalies that are of prime interest and the first step in interpretation is the removal of the regional field to isolate the residual anomalies. This may be performed graphically by sketching in a linear or curvilinear field by eye. Such a method is biased by the interpreter, but this is not necessarily disadvantageous as geological knowledge can be incorporated into the selection of the regional field. Several analytical methods of regional field analysis are available and include trend surface analysis (fitting a polynomial to the observed data, see Beltrão et al. (1991)) and low-pass filtering (Section 6.12). Such procedures must be used critically as fictitious residual anomalies can sometimes arise when the regional field is subtracted from the observed data due to the mathematical procedures employed.

It is necessary before carrying out interpretation to differentiate between two-dimensional and three-dimensional anomalies. Two-dimensional anomalies are elongated in one horizontal direction so that the anomaly length in this direction is at least twice the anomaly width. Such anomalies may be interpreted in terms of structures which theoretically extend to infinity in the elongate direction by using profiles at right angles to the strike. Three-dimensional anomalies may have any shape and are considerably more difficult to interpret quantitatively. Gravity interpretation proceeds via the methods of direct and indirect interpret.

Direct interpretation

Direct interpretation provides, directly from the gravity anomalies, information on the anomalous body which is largely independent of the true shape of the body. Various methods are discussed below.

Limiting depth

Limiting depth refers to the maximum depth at which the top of a body could lie and still produce an observed gravity anomaly. Gravity anomalies decay with the inverse square of the distance from their source so that anomalies caused by deep structures are of lower amplitude and greater extent than those caused by shallow sources. This wavenumber–amplitude relationship to depth may be quantified to compute the maximum depth (or limiting depth) at which the top of the anomalous body could be situated.

a) Half-width method. The half-width of an anomaly ($x_{1/2}$) is the horizontal distance from the anomaly maximum to the point at which the anomaly has reduced to half of its maximum value (Fig. 6.18(a)). If the anomaly is three-dimensional, the initial assumption is made that it results from a point mass. Manipulation of the point mass formula allows its depth to be determined in terms of the half-width

$$z = \frac{x_{1/2}}{\sqrt{\sqrt[3]{4} - 1}}$$

Here, z represents the actual depth of the point mass or the centre of a sphere with the same mass. It is an overestimate of the depth to the top of the sphere, that is, the limiting depth. Consequently, the limiting depth for any three-dimensional body is given by

$$z < \frac{x_{1/2}}{\sqrt{\sqrt[3]{4} - 1}}$$

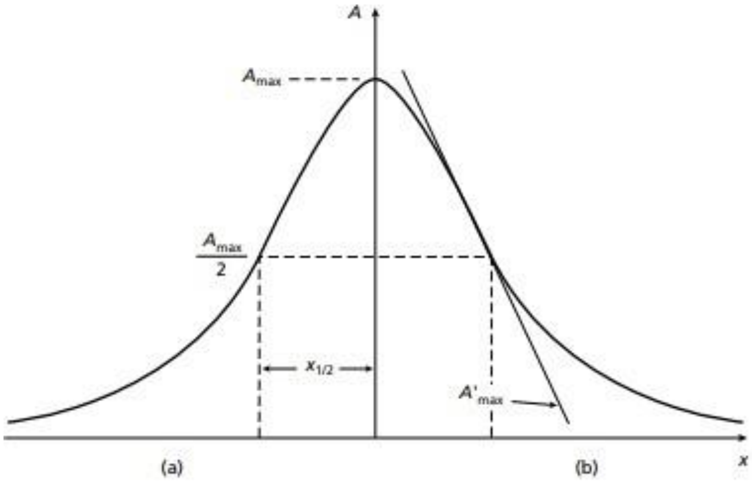

Fig. 6.18 Limiting depth calculations using (a) the half-width method and (b) the gradient–amplitude ratio.

A similar approach is adopted for a two-dimensional anomaly, with the initial assumption that the anomaly results from a horizontal line mass (equation (6.7)).The depth to a line mass or to the canter of a horizontal cylinder with the same mass distribution is given by

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

For any two-dimensional body, the limiting depth is then given by

$$z < x_{1/2}$$

(b) Gradient–amplitude ratio method. This method requires the computation of the maximum anomaly amplitude (Amax) and the maximum horizontal gravity gradient (A¯ max) (Fig. 6.18(b)).Again the initial assumption is made that a three-dimensional anomaly is caused by a point mass and a two-dimensional anomaly by a line mass. By differentiation of the relevant formulae, for any three-dimensional body

$$z < 0.86 \left| \frac{A_{max}}{A'_{max}} \right|$$

and for any two-dimensional body

$$z < 0.65 \left| \frac{A_{max}}{A'_{max}} \right|$$

(c) Second derivative methods. There are a number of limiting depth methods based on the computation of the maximum second horizontal derivative, or maximum rate of change of gradient, of a gravity anomaly (Smith 1959). Such methods provide rather more accurate limiting depth estimates than either the half-width or gradient–amplitude ratio methods if the observed anomaly is free from noise.

Excess mass

The excess mass of a body can be uniquely determined from its gravity anomaly without making any assumptions about its shape, depth or density. Excess mass refers to the difference in mass between the body and the mass of country rock that would otherwise fill the space occupied by the body. The basis of this calculation is a formula derived from Gauss' theorem, and it involves a surface integration of the residual anomaly over the area in which it occurs. The survey area is divided into n grid squares of area Δ_a and the mean residual anomaly Δ_g found for each square. The excess mass M_e is then given by

$$M_e = \frac{1}{2\pi G}\sum_{i=1}^{n}\Delta g_i \Delta a_i$$

Before using this procedure it is important that the regional field is removed so that the anomaly tails to zero. The method only works well for isolated anomalies whose extremities are well defined. Gravity anomalies decay slowly with distance from source and so these tails can cover a wide area and be important contributors to the summation. To compute the actual mass M of the body, the densities of both anomalous body (ρ_1) and country rock (ρ_2) must be known:

$$M = \frac{\rho_1 M_e}{(\rho_1 - \rho_2)}$$

The method is of use in estimating the tonnage of ore bodies. It has also been used, for example, in the estimation of the mass deficiency associated with the Chicxulub crater, Yucatan (CamposEnriquez et al. 1998), whose formation due to meteorite or asteroid impact has been associated with the extinction of the dinosaurs

Inflection point

The locations of inflection points on gravity profiles, i.e. positions where the horizontal gravity gradient changes most rapidly, can provide useful information on the nature of the edge of an anomalous body. Over structures with outward dipping contacts, such as granite bodies (Fig. 6.19(a)), the inflection points (arrowed) lie near the base of the anomaly. Over structures with inward dipping contacts such as sedimentary basins

(Fig. 6.19(b)), the inflection points lie near the uppermost edge of the anomaly.

Approximate thickness

If the density contrast Δρ of an anomalous body is known, its thickness t may be crudely estimated from its maximum gravity anomaly Δg by making use of the Bouguer slab formula

$$t = \frac{\Delta g}{2\pi G \Delta \rho}$$

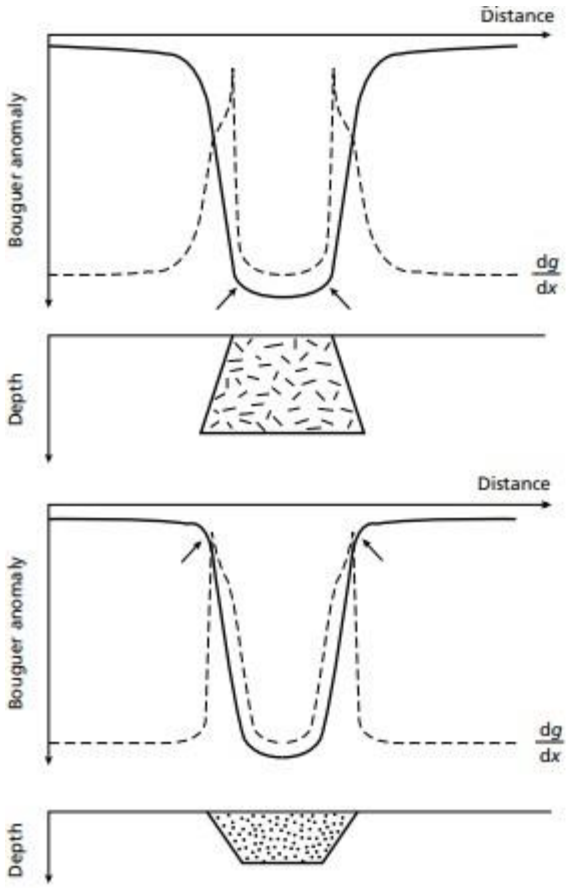

Fig. 6.19 Bouguer anomaly profiles across (a) a granite body, and (b) a sedimentary basin. The inflection points are marked with an arrow. The broken lines represent the horizontal derivative (rate of change of gradient) of the gravity anomaly, which is at a maximum at the inflection points.

This thickness will always be an underestimate for a body of restricted horizontal extent.The method is commonly used in estimating the throw of a fault from the difference in the gravity fields of the upthrown and downthrown sides. The technique of source depth determination by Euler deconvolution, described in Section 7.10.2, is also applicable to gravity anomalies (Keating 1998).

References

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