جامعة الانبار

كلية العلوم -قسم الجيولوجيا التطبيقية

اسم المادة بالعربي: الجيوفيزياء الجهدية - الطريقة الجذبية

اسم المادة بالإنكليزي: Potential Geophysics- Gravity Method

عنوان المحاضرة: Indirect interpretation

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Indirect interpretation

In indirect interpretation, the causative body of a gravity anomaly is simulated by a model whose theoretical anomaly can be computed, and the shape of the model is altered until the computed anomaly closely matches the observed anomaly. Because of the inverse problem this model will not be a unique interpretation, but ambiguity can be decreased by using other constraints on the nature and form of the anomalous body. A simple approach to indirect interpretation is the comparison of the observed anomaly with the anomaly computed for certain standard geometrical shapes whose size, position, form and density contrast are altered to improve the fit. Two-dimensional anomalies may be compared with anomalies computed for horizontal cylinders or half-cylinders, and three-dimensional anomalies compared with those of spheres, vertical cylinders or right rectangular prisms. Combinations of such shapes may also be used to simulate an observed anomaly. Figure 6.20(a) shows a large, circular gravity anomaly situated near Darnley Bay, NWT, and Canada. The anomaly is radially symmetrical and a profile across the anomaly (Fig. 6.20(b)) can be simulated by a model constructed from a suite of coaxial cylinders whose diameters decrease with depth so that the anomalous body has the overall form of an inverted cone. This study illustrates well the non-uniqueness of gravity interpretation. The nature of

the causative body is unknown and so no information is available on its density. An alternative interpretation, again in the form of an inverted cone, but with an increased density contrast, is presented in Fig. 6.20(b). Both models provide adequate simulations of the observed anomaly, and cannot be distinguished using the information available. The computation of anomalies over a model of irregular form is accomplished by dividing the model into a series of regularly-shaped compartments and calculating the combined effect of these compartments at each observation point. At one time this operation was performed by the use of graticules, but nowadays the calculations are invariably performed by computers. A two-dimensional gravity anomaly may be represented by a profile normal to the direction of elongation. This profile can be interpreted in terms of a model which maintains a constant cross-section to infinity in the horizontal directions perpendicular to the profile. The basic unit for constructing the anomaly of a two-dimensional model is the semi-infinite slab with a sloping edge shown in Fig. 6.21, which extends to infinity into and out of the plane of the figure. The gravity anomaly of this slab Δg is given by

$$\begin{aligned}\Delta g = 2G\Delta\rho[&-\{x_1 \sin\theta + z_1 \cos\theta\} \\ &\times \{\sin\theta \log_e(r_2/r_1) + \cos\theta(\phi_2 - \phi_1)\} \\ &+ z_2\phi_2 - z_1\phi_1]\end{aligned}$$

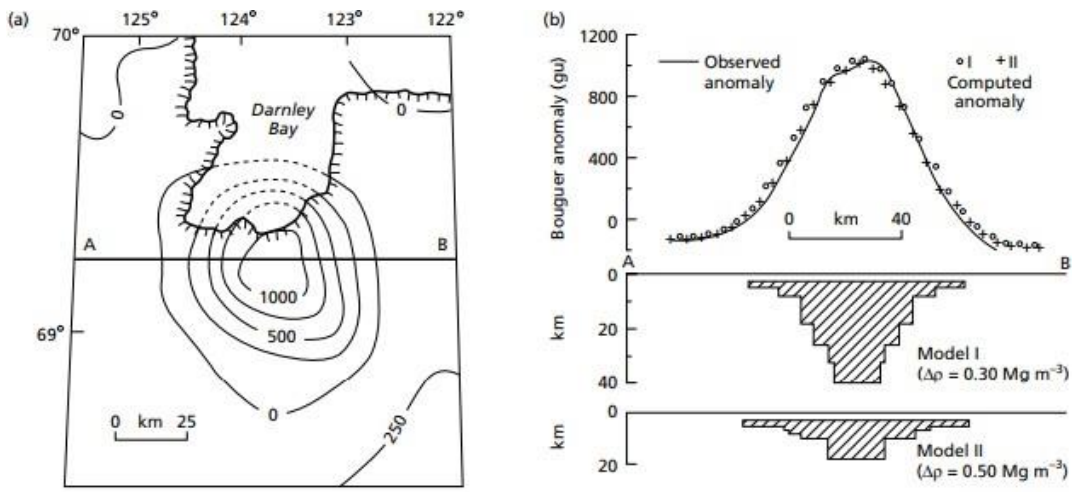


Fig. 6.20 (a) The circular gravity anomaly at Darnley Bay, NWT, Canada. Contour interval 250 gu. (b) Two possible interpretations of the anomaly in terms of a model constructed from a suite of coaxial vertical cylinders. (After Stacey 1971.)

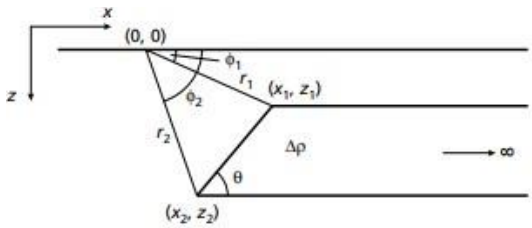


Fig. 6.21 Parameters used in defining the gravity anomaly of a semi-infinite slab with a sloping edge.

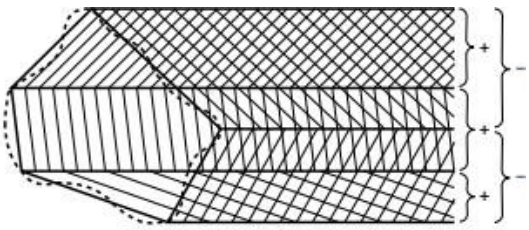


Fig. 6.22 The computation of gravity anomalies of two-dimensional bodies of irregular cross-section. The body (dashed line) is approximated by a polygon and the effects of semi-infinite slabs with sloping edges defined by the sides of the polygon are progressively added and subtracted until the anomaly of the polygon is obtained.

where Δr is the density contrast of the slab, angles are expressed in radians and other parameters are defined as in Fig. 6.21 (Talwani et al. 1959).To calculate the anomaly of a two-dimensional body of irregular cross-section, the body is approximated by a polygon as shown in Fig. 6.22. The anomaly of the polygon is then found by proceeding around it summing the anomalies of the slabs bounded by edges where the depth increases and subtracting those where the depth decreases.

Figure 6.23 illustrates a two-dimensional interpretation, in terms of a model of irregular geometry represented by a polygonal outline, of the Bodmin Moor granite of southwest England. The shape of the uppermost part of the model is controlled by the surface outcrop of granite, while the density contrasts employed are based on density measurements on rock samples. The interpretation shows unambiguously that the contacts of the granite slope outwards. Ambiguity is evident, however, in the interpretation of the gravity gradient over the northern flank of the granite. The model presented in Fig. 6.23 interprets the cause of this gradient as a northerly increase in the density of the granite; a possible alternative, however, would be a northerly thinning of a granite body of constant density contrast.

ranite body of constant density contrast. Two-dimensional methods can sometimes be extended to three-dimensional bodies by applying end-correction factors to account for the restricted extent of the causative body in the strike direction (Cady 1980).The end-correction factors are, however, only approximations and full three-dimensional modelling is preferable. The gravity anomaly of a three-dimensional body may be

calculated by dividing the body into a series of horizontal slices and approximating each slice by a polygon (Talwani & Ewing 1960). Alternatively the body may be constructed out of a suite of right rectangular prisms.

However a model calculation is performed, indirect interpretation involves four steps:

1. Construction of a reasonable model.

2. Computation of its gravity anomaly.

3. Comparison of computed with observed anomaly.

4. Alteration of model to improve correspondence of observed and calculated anomalies and return to step 2.

The process is thus iterative and the goodness of fit between observed and calculated anomalies is gradually improved. Step 4 can be performed manually for bodies of relatively simple geometry so that an interpretation is readily accomplished using interactive routines on a personal computer (Götze & Lahmeyer 1988). Bodies of complex geometry in two- or three-dimensions are not so simply dealt with and in such cases it is advantageous to employ techniques which perform the iteration automatically. The most flexible of such methods is non-linear optimization (Al-Chalabi 1972). All variables (body points, density contrasts, and regional field) may be allowed to vary within defined limits. The method then attempts to minimize some function F which defines the goodness of fit, for example

$$F = \sum_{i=1}^{n} \left(\Delta g_{\mathrm{obs}_i} - \Delta g_{\mathrm{calc}_i} \right)^2$$

where Δg_{obs} and Δg_{calc} are series of n observed and calculated values.

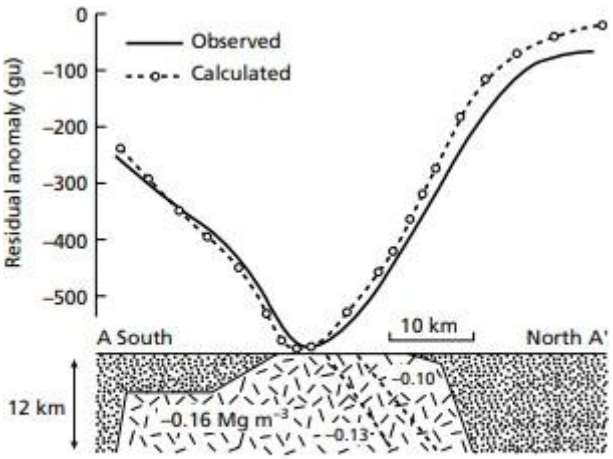
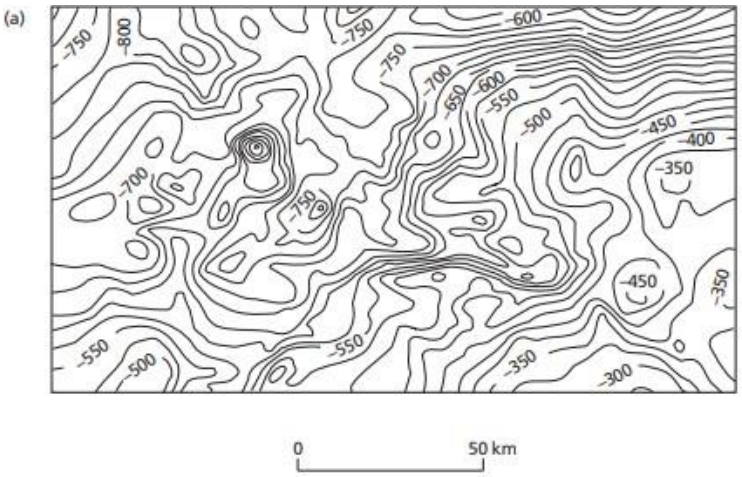


Fig. 6.23 A two-dimensional interpretation of the gravity anomaly of the Bodmin Moor granite, southwest England. See Fig. 6.27 for location. (After Bott & Scott 1964.)

The minimization proceeds by altering the values of the variables within their stated limits to produce a successively smaller value for F for each iteration. The technique is elegant and successful but expensive in computer time. Other such automatic techniques involve the simulation of the observed profile by a thin layer of variable density. This equivalent layer is then progressively expanded so that the whole body is of a uniform, specified density contrast. The body then has the form of a series of vertical prisms in either two or three dimensions which extend either above, below or symmetrically around the original equivalent layer. Such methods are less flexible than the non-linear optimization technique in that usually only a single density contrast may be specified and the model produced must either have a specified base or top or be symmetrical about a central horizontal plane.

Upward continuation methods are employed in gravity interpretation to determine the form of regional gravity variation over a survey area, since the regional field is assumed to originate from relatively deep-seated structures. Figure 6.24(a) is a Bouguer anomaly map of the Saguenay area in Quebec, Canada, and Fig. 6.24(b) represents the field continued upward to an elevation of 16km. Comparison of the two figures clearly illustrates how the high-wavenumber components of the observed field have been effectively removed by the continuation process. The upward continued field must result from relatively deep structures and consequently represents a valid regional field for the area. Upward

continuation is also useful in the interpretation of magnetic anomaly fields (see Chapter 7) over areas containing many near-surface magnetic sources such as dykes and other intrusions. Upward continuation attenuates the highwavenumber anomalies associated with such features and enhances, relatively, the anomalies of the deeperseated sources. Downward continuation of potential fields is of more restricted application. The technique may be used in the resolution of the separate anomalies caused by adjacent structures whose effects overlap at the level of observation. On downward continuation, high-wavenumber components are relatively enhanced and the anomalies show extreme fluctuations if the field is continued to a depth greater than that of its causative structure. The level at which these fluctuations commence provides an estimate of the limiting depth of the anomalous body. The effectiveness of this method is diminished if the potential field is contaminated with noise, as the noise is accentuated on downward continuation. The selective enhancement of the low- or highwavenumber components of potential fields may be achieved in a different but analogous manner by the application of wavenumber filters. Gravitational and magnetic fields may be processed and analysed in a similar fashion to seismic data, replacing frequency by wavenumber. Such processing is more complex than the equivalent seismic filtering as potential field data are generally arranged in two horizontal dimensions, that is, contour maps, rather than a single dimension. However, it is possible to devise two-dimensional filters for the selective removal of high- or low-wavenumber components from the observed anomalies. The consequence of the application of such techniques is similar to upward or downward continuation in that shallow structures are mainly responsible for the high-wavenumber components of anomalies and deep structures for the low wavenumbers. However, it is not possible fully to isolate local or regional anomalies by wavenumber filtering because the wavenumber spectra of deep and shallow sources overlap. Other manipulations of potential fields may be accomplished by the use of more complex filter operators (e.g. Gunn 1975, Cooper 1997).Vertical or horizontal derivatives of any order may be computed from the observed field. Such computations are not widely employed, but second horizontal derivative maps are occasionally used for interpretation as they accentuate anomalies associated with shallow bodies.



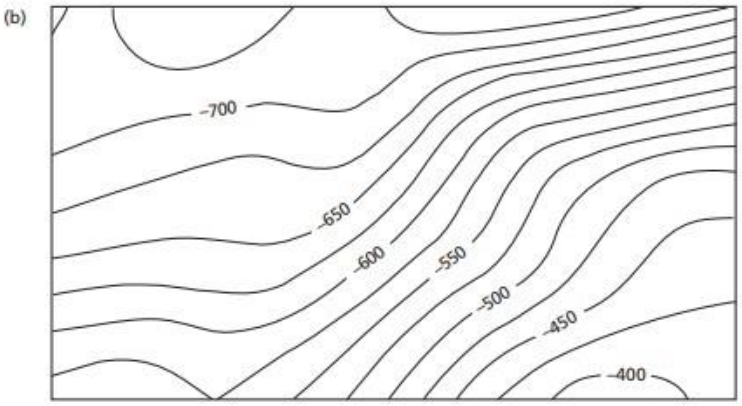


Fig. 6.24 (a) Observed Bouguer anomalies (gu) over the Saguenay area, Quebec, Canada. (b) The gravity field continued upward to an elevation of 16 km. (After Duncan & Garland 1977.)

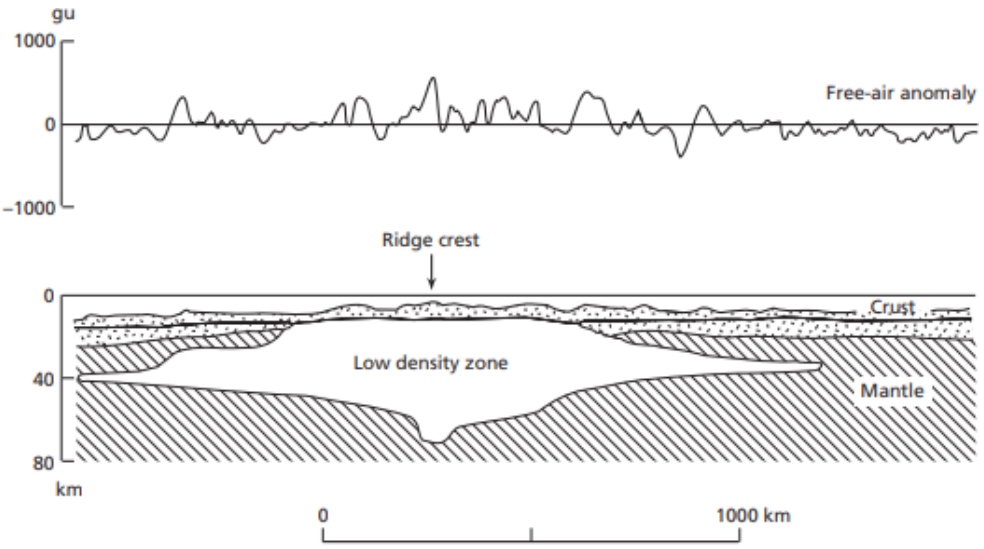


Fig. 6.25 Free-air anomaly profile across the mid-Atlantic ridge. (After Talwani *et al.* 1965.)

Applications of gravity surveying

Gravity studies are used extensively in the investigation of large- and medium-scale geological structures (Paterson & Reeves 1985). Early marine surveys, performed from submarines, indicated the existence of large positive and negative gravity anomalies associated with island arcs and oceanic trenches, respectively; subsequent shipborne work has demonstrated their lateral continuity and has shown that most of the major features of the Earth's surface can be delineated by gravity surveying. Gravity anomalies have also shown that most of these major relief features are in isostatic equilibrium, suggesting that the lithosphere is not capable of sustaining significant loads and yields isostatically to any change in surface loading. Figure 6.25 shows the near-zero freeair anomalies over an ocean ridge which suggest that it is in isostatic equilibrium. The gravity interpretation, which is constrained by seismic refraction results, indicates that this compensation takes the form of a zone of mass deficiency in the underlying mantle. Its low seismic velocity and the high heat flow at the surface suggest that this is a region of partial melting and, perhaps, hydration. Gravity surveying can also be used in the study of ancient suture zones, which are interpreted as the sites of former plate boundaries within the continental lithosphere. These zones are often characterized by major linear gravity anomalies resulting from the different crustal sections juxtaposed across the sutures (Fig. 6.26). On the medium scale, gravity anomalies can reveal the subsurface form of igneous intrusions such as granite batholiths and anorthosite massifs. For example, gravity surveys in southwest England (Bott et al. 1958) have revealed a belt of large-amplitude, negative Bouguer anomalies overlying a region of outcropping granites (Fig. 6.27). Modelling of the gravity anomalies (Fig. 6.23) has led to the postulation of a continuous batholith some 10–15km thick underlying southwest England (see e.g. Brooks et al. 1983). Studies such as these have provided important constraints on the mechanism of emplacement, composition and origin of igneous bodies. Similarly, gravity surveying has been extensively used in the location of sedimentary basins, and their interpreted structures have provided important information on mechanisms of basin formation. The gravity method was once extensively used by the petroleum industry for the location of possible hydrocarbon traps, but the subsequent vast improvement in efficiency and technology of seismic surveying has led to

the demise of gravity surveying as a primary exploration tool. In commercial applications, gravity surveying is rarely used in reconnaissance exploration. This is because the method is relatively slow to execute, and therefore expensive, due to the necessity of accurately determined elevations and the length of the reduction procedure. Gravity methods do find application, however, as a follow-up technique used on a target defined by another, more cost-effective method. An important application of this type in mineral exploration is the determination of ore tonnage by the excess mass method described in Section 6.10.3. Gravity surveying may be used in hydrogeological investigations to determine the geometry of potential aquifers. Figure 6.28 shows a Bouguer anomaly map of an area near Taltal, Chile (Van Overmeeren 1975).The region is extremely arid, with groundwater supply and storage controlled by deep geological features.The gravity minima revealed by the contours probably represent two buried valleys in the alluvium overlying the granodioritic bedrock. Figure 6.29 shows an interpretation of a profile over the minima.

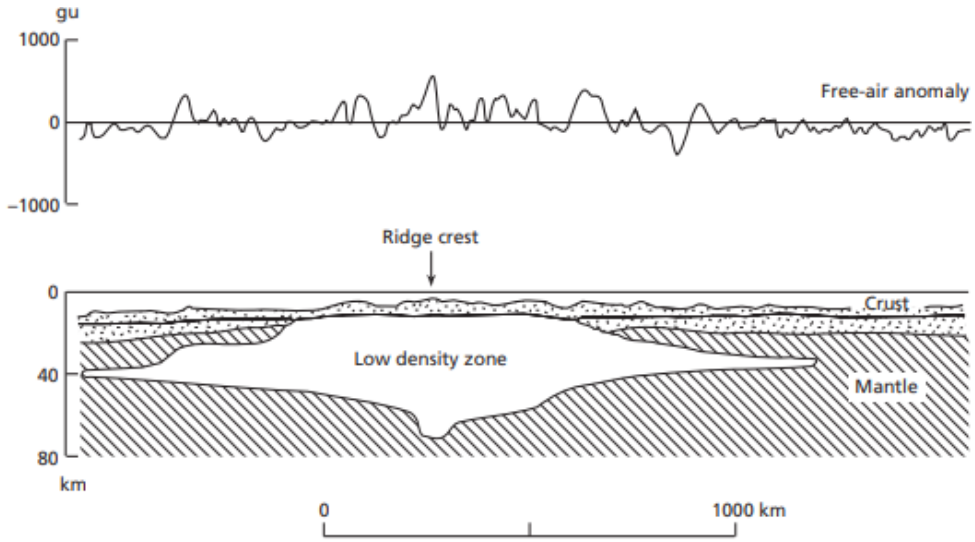


Fig. 6.25 Free-air anomaly profile across the mid-Atlantic ridge. (After Talwani *et al.* 1965.)

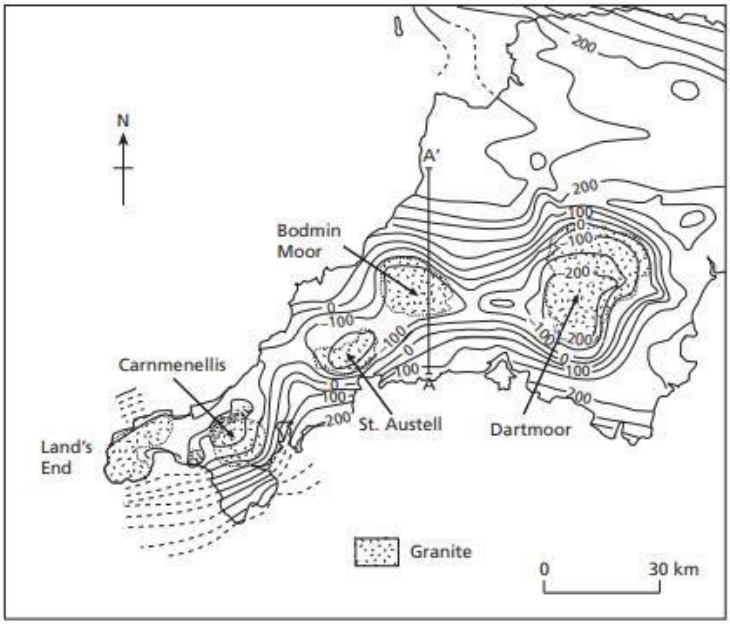


Fig. 6.27 Bouguer anomaly map of southwest England, showing a linear belt of large negative anomalies associated with the zone of granite outcrops. Contour interval 50 gu. (After Bott & Scott 1964.)

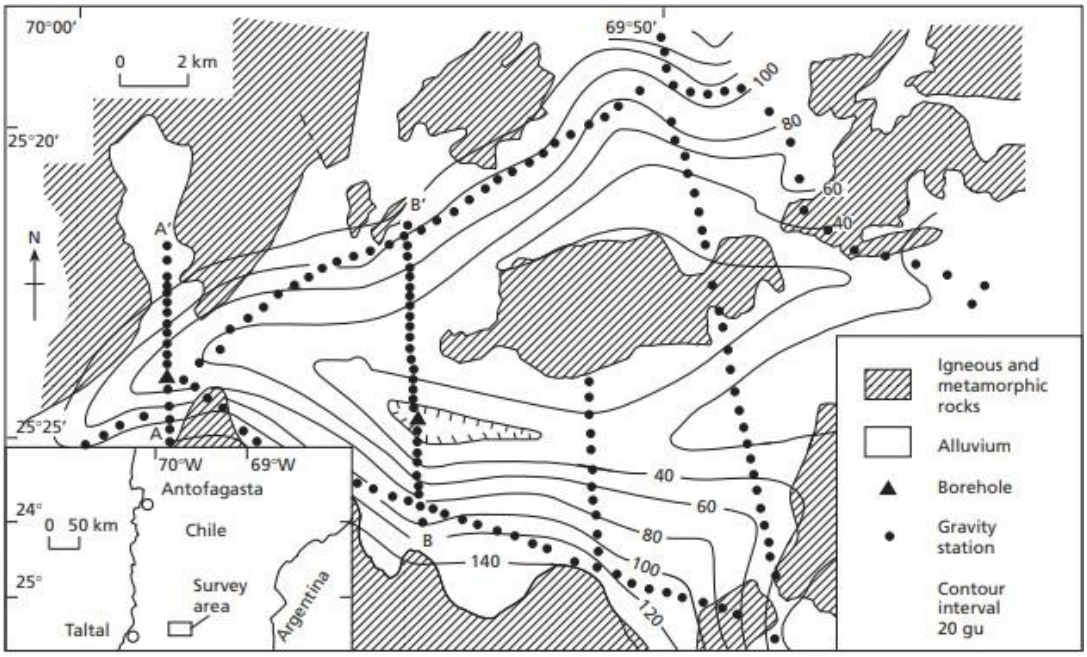


Fig. 6.28 Geological map of an area near Taltal, Chile, showing location of gravity stations and contoured Bouguer anomalies. (After Van Overmeeren 1975.)

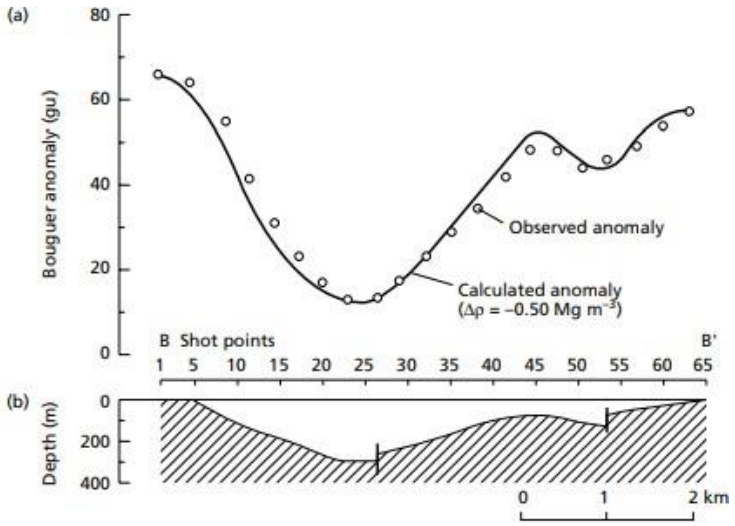


Fig. 6.29 Profile B–B′, Taltal area, Chile (see Fig. 6.28 for location). (a) Observed Bouguer anomaly and calculated anomaly for a model with a density contrast ($\Delta\rho$) of $-0.50\ \mathrm{Mg\,m^{-3}}$. (b) Gravity interpretation. (After Van Overmeeren 1975.)

References

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