The use of Rapid Digital Computing Methods for Direct Gravity Interpretation of Sedimentary Basins

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Summary

A rapid digital computing method for the direct calculation of the shapes of two-dimensional sedimentary basins of known density contrast from their residual gravity anomalies is described. In conclusion an example of the use of the method in determining the shape of the Dumfries New Red Sandstone basin (South Scotland) is given.

1. Introduction

Two rapid computing methods for the interpretation of effectively two-dimensional gravity anomalies have recently been developed. The first method enables the calculation of the theoretical anomalies of specified two-dimensional shapes bounded by a connected polygonal series of straight lines. A programme similar in principle has already been developed and described by Talwani & others (1959) and therefore this method need not be described.

The second method enables the shapes of two-dimensional sedimentary basins to be obtained directly from the regionally corrected gravity anomalies profile. This is logically a development from the first method and is based on the principle of successive approximation for the removal of residuals. This method is described in the following account and in conclusion an example of its use is given.

2. Calculation of shapes of sedimentary basins

In general an observed gravity profile can be caused by an infinite number of different mass distributions. The consequent uncertainty in quantitative interpretation can sometimes, however, be reduced or even eliminated if certain assumptions may legitimately be made from our geological knowledge. One such set of circumstances whereby a unique interpretation is possible arises when a gravity anomaly can be entirely attributed to a sedimentary basin for which the density of the sediments in relation to the surrounding and underlying rocks is known. In practice it is possible to calculate the shape of the floor of such an effectively two-dimensional sedimentary basin from the regionally corrected gravity anomalies by a process of trial and error which can be readily adapted for rapid digital computing methods.

The method which has been developed depends on the division of the total width of the outcropping sedimentary basin into a series of two-dimensional strips which need not necessarily be of uniform width (the half width of the ith strip will be represented by w_i). The regionally corrected gravity anomaly observed at the centre point of each strip is obtained from the profile and will be denoted by $(A_{obs})_i$. The object is then to obtain the pattern of sediment thicknesses beneath the strips (in the form of two-dimensional rectangular blocks) which can account for all the values of A_{obs}.

The first approximation to the shape is obtained by the computer by assuming the thickness of sediments beneath each strip to be given by the thickness of a horizontal infinite slab (t_i) of the assumed density contrast needed to give $(A_{obs})_i$. The calculated values of gravity for this model $(A_{calc})_i$ are obtained by considering the sediments beneath each strip to be in the form of a two-dimensional rectangular block, depth t_i and width $2w_i$, and by summing the contributions of all the blocks for each position. Each individual calculation is based on the formula given by Heiland (1940, p. 152) for the gravitational attraction of a vertically sided two-dimensional block. The residual anomalies are obtained by subtracting the calculated values of the anomalies for the model from the observed values. To this stage an approximate model has been constructed, the exact anomalies over the model have been calculated and the residual anomalies, indicating the degree of misfit of the model, have been obtained by subtracting calculated from observed anomalies.

The succeeding stages of the calculation aim at progressive reduction and removal of the residuals by repeated alteration of t_i and recalculation of residuals. Each stage of the adjustment begins with the estimation of the alteration of the depth of sediments beneath each strip (t_i) by calculating the thickness of an infinite slab of the assumed density contrast needed to account for the corresponding residuals. Having approximately adjusted the shape in this way, the anomalies can be recalculated in either of two ways, both of which are used in the programme. The first method involves a complete recalculation of the anomalies for the new model as has been outlined above. The second method depends on the direct adjustment of the previous calculated values for the gravitational effect of the incremental thickness of sediments added or removed from the bases of the rectangular blocks: since an approximation can be conveniently used in this second method it is much faster.

A "flow diagram" for the programme, as prepared for the Ferranti Pegasus computer, is shown below (G representing the gravitational constant). The following paragraphs give a short explanation of the divisions of the programme.

The purpose of the *initial interlude* is to read into the computer the numerical information, suitably scaled and arranged. The main programme, following the initial interlude, is divided into two parts. *Part I* provides for an adjustment of the depths of the rectangular blocks in accordance with the residuals, followed by a full and rigorous recalculation of the gravitational effect of the adjusted model. The residuals are then recalculated. If desired the calculated depths and the corresponding residuals may be printed at this stage. *Part I* is used both at the beginning of the calculation when the approximation involved in Part II would introduce too great errors and also before printing the results.

Part II of the main programme similarly begins with the alteration of the depths of the rectangular blocks in accordance with their residuals. A complete recalculation of the theoretical anomalies is, however, avoided by calculating directly the gravitational effect of the increments and by adjusting the previous values by these amounts. An approximation to the effect of the incremental rectangular block can be made by assuming the mass to be concentrated uniformly over a two-dimensional plate. The errors are negligible under normal circumstances and in consequence Part II becomes four times faster than Part I. It has been

Read into computer numerical details for successive strips (position coordinate x, half width w, density and observed anomaly A_{obs}).

↓

Scale and place in main store, one strip per main store block.

↓

Make calculated depth, t, = 0 for each strip

↓

Make A_{calc} = 0 for each strip.

Initial Interlude

↓

→For each strip:

(a) Find $A_{obs} - A_{calc}$ (residual).

(b) Calculate thickness (δt) of uniform slab giving residual : $\delta t = (A_{obs} - A_{calc})/2\pi G\rho$.

(c) Make $t' = t + \delta t$.

(d) Make $A_{calc} = 0$.

↓

Return to main store on completion.

↓

→Bring first/next strip block into computing store.

↓

Calculate incremental contribution of rectangular two-dimensional block corresponding to strip to gravitational attraction at centre of each strip and add to A_{calc} for each.

↓

Test if calculation for last strip completed. If not jump as shown.

Main Programme (Part I)

↓

Print calculated depths and corresponding residual anomalies ($A_{obs} - A_{calc}$) for sucsive strips.

Print Programme

↓

Set counter = n (n = 8 is suitable).

↓

→For each strip calculate residual anomaly ($A_{obs} - A_{calc}$) and corresponding thickness of infinite uniform slab as above.

↓

→Bring first/next strip block into computing store.

↓

Calculate incremental contributions to all A_{calc}, assuming mass of incremental thickness to be uniformly concentrated over layer of negligible thickness. Add each increment to corresponding A_{calc}.

↓

Test if calculation for last strip completed. If not jump as shown

↓

Subtract one from counter, $n' = n - 1$.

Main Programme (Part II)

↓

Test if $n' = 0$

↓ = 0

Jump.

Flow diagram for the programme.

found convenient to repeat Part II eight times before re-entering Part I in preparation for printing.

In practice it has been found that usually about ten stages of successive approximation (one of Part I followed by eight of Part II followed by one of Part I) are sufficient to reduce the residuals well below the level of observational error. Less rapid convergence is usually an indication of an observational error or a local disturbing effect. It has been found that a calculation of ten stages for a sedimentary basin subdivided into ten strips takes about three minutes on the Ferranti Pegasus computer used. The time is proportional to the square of the number of strips.

The programme, including subroutines, occupies about forty blocks (each containing eight words) of the main store. In addition each strip uses one main store block. Since the Pegasus main store contains 640 blocks there is no problem over storage space.

3. An application of the method

The method has been used to obtain the shapes of the floors of two New Red Sandstone basins near Dumfries in the south of Scotland. The interpretation of the gravity survey of this region is being published elsewhere (Bott & Masson-Smith 1960) but the interpretation of the profile across the Dumfries trough is reproduced here as an example of the use of the method. The New Red Sandstone rocks are about 0·4 g/cm^3 lower in density than the surrounding Silurian rocks. Both the observed gravity profile (corrected for the regional effect) and two interpretations, based on different assumptions of density distribution, are shown in Figure 1 below.

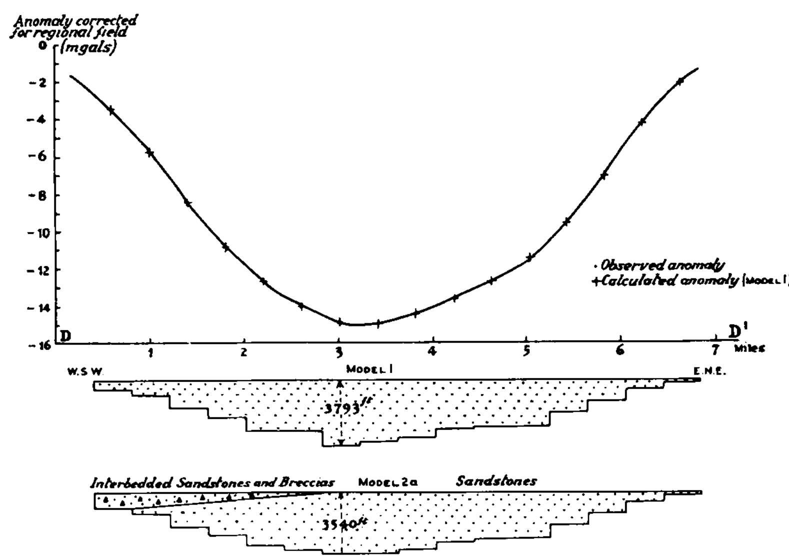

FIG. 1.—The interpretation of the gravity profile across the Dumfries New Red Sandstone basin. Model 1 has been calculated for an assumed uniform density contrast of 0·4 g/cm^3 and the calculated anomalies are shown as crosses on the profile.

Model 2 takes into account certain denser breccias which are assumed to be distributed as shown and to have a density of 0·2 g/cm^3 lower than the Silurian rocks. The residuals are negligible apart from one value of 0·3 mgal where convergence is poor.

Fuller details of the interpretation are given in the above-mentioned paper, where interpretations with varying strip widths are also shown.

4. Possible extensions of the method

It is thought that the method could fairly readily be adapted to basins of finite length by the use of end-effect corrections. A disadvantage is that the final shape needs to be expressed in terms of rectangular blocks but it is feasible that a similar programme could be developed for a polygonal outline to the floor.

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