Paper

Automated Density Profiling over a 35 Metre Ridge

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Abstract

Automated density profiling can be used to analyse real data errors, and to anticipate the effect of errors. The best possible density-profiling precision can also be predicted for any given topographic cross-section. Although the terrain correction is by-passed in the automatic process, it is useful to display this quantity, as its size is a function of steepness and height, and therefore an indicator of the likely effectiveness of density profiling.

Density profiling over ridges less than 50 m high is feasible provided there are no perturbations in the gravity field, and the cross-sectional shape is known accurately. A comprehensive density-profiling analysis is demonstrated for a 35 metre ridge.

Introduction

Density profiling is fundamental to gravity exploration because it can provide accurate bulk-density information for large rock masses while at the same time being instrumental in removing from gravity observations the topographic anomaly caused by the air-rock interface. Nettleton's (1939) original profiling concept was a strictly graphical one, and although mathematical alternatives have been sought, the graphical display method is still the most effective device, as it allows a subjective evaluation of whether the correct conditions for obtaining a density estimate apply.

In the present paper, the automated method of Anfiloff (1976) is used to produce Bouguer density profiles over a 35 m ridge. The same topographic cross-section is also used to produce synthetic density profiles to aid in the analysis of the real data. The effects of introducing elevation and positional errors are also demonstrated.

Automated Density Profiling

A set of Nettleton's density profiles can be produced automatically from the principal facts (i.e. station number, observed gravity, elevation and coordinates) of any gravity survey along a traverse, if the following conditions are satisfied:

1. The traverse must cut elongate topographic features at right angles, and avoid non-elongate features.
2. There must be sufficient stations to provide an accurate cross-section of topography along the entire traverse.
3. The traverse must consist of reasonably straight segments.

Figure 1 shows the result of processing a gravity traverse which crosses a 35 m ridge. A set of actual Bouguer profiles is computed for densities in the range 1.8 – 2.6 g/cm^3, and at the same time, a set of synthetic density profiles is produced to show what perfect data would have given if the ridge had a nominal density of 2.2 g/cm^3. A long traverse may cross a large number of ridges, each of which is capable of producing a bulk-density determination which can be applied to the interpretation. Even if a ridge is too small to produce a reliable bulk density, it should not be avoided, because the resulting gap in the traverse could prejudice the delineation of the gravity field.

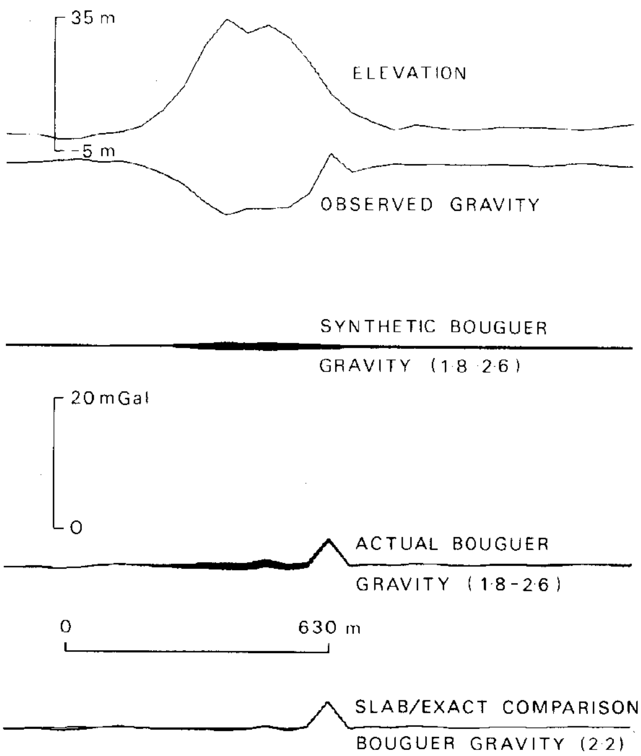

FIGURE 1

Density profiles and other pertinent profiles produced by computer directly from principal facts. The terrain correction is equal to the divergence between the exact and slab-computed Bouguer profiles. The large error spike is removed by deleting the offending station.

The scale of presentation plays an important role in the subjective evaluation of gravity data. The profiles in Fig. 1 were originally plotted at a scale of 5 mgal/cm, the scale normally used by this writer for the routine display of gravity profiles. At this scale, a 35 m ridge produces little separation in the Bouguer profiles, and experience then tells that even small errors or perturbations in the gravity field will nullify a density determination. The separation, which is an indicator of the precision achievable, is a function of steepness and size, and cannot be readily estimated in advance of a survey. Consequently, when contemplating profiling over a particular feature, it may be useful to produce synthetic density profiles, using an approximate cross-section.

Another indicator of steepness and size is the amount of terrain correction applicable. The terrain correction is the difference between the 'exact' Bouguer profile as computed using the automatic terrain modelling process, and the approximate profile produced using the Bouguer slab formula. Although the correction is made redundant by the modelling process, it is useful to know how large it is because its size is an indicator of whether density profiling is likely to provide an accurate estimate of topographic density. In the past, steep topography was often avoided because it involved tedious manual terrain corrections, and the most reliable sources of bulk-density information were not therefore utilised. Since topographic density is most forthcoming in steep topography, it follows that a gravity field over steep topography tends to be less ambiguous than elsewhere.

The actual data in Fig. 1 show a large spike in the observed gravity, while the synthetic density profiles form a set about the 2.2 g/cm^3 profile. The spike is obviously out of character with the rest of the data and can be removed as an error, although it could, strictly speaking, represent a dense shallow body. The identification of error spikes in elevation and gravity data can be facilitated by the production of actual and synthetic density profiles for comparison. Primarily, the synthetic profiles show what a given topographic cross-section would have produced if it had a uniform density, and if the gravity observations were perfect. Thus, errors in the shape of the topographic cross-section are accommodated in the synthetic profiles, but not in the actual ones.

If the true gravity field is assumed to be broader than the width of a one-station error spike, the elevation and gravity measurements can be expected to vary predictably, and isolated errors can be traced. A spike in the elevation profile which is not matched by an opposite spike in the observed gravity will usually represent an error in elevation. However, an elevation spike may be partly offset by a gravity spike, resulting in a smaller spike whose shape will be different in each density profile. Locating the error then requires checking the original data, or perhaps even remeasuring a gravity interval. If both elevation and gravity are known to be correct, the spike may represent a local lack of two-dimensionality. However, if all the data are known to be correct, the gravity spike must represent a density irregularity associated with the topographic spike. In most cases, if some of the quantities are established, others can be deduced by analysing the density profiles.

In Fig. 2, the large spike shown in Fig. 1 has been removed, and the profiles plotted at an enlarged scale. The remaining errors are now magnified, and the actual Bouguer profiles show a series of narrow perturbations. The prominent 0.7 mgal spike near the centre of the ridge coincides with inflexions in the elevation profile, but has a constant shape in the density profiles, implying an error in the measured gravity. The generally disturbed nature of the actual density profiles shows that a bulk-density determination cannot be made to any worthwhile degree of accuracy by any method. Yet a statistical correlation method would give a density value. Such mathematical substitutes for density profiling will always give a density estimate, but even when an estimate appears reasonable, its validity is by no means guaranteed. Density profiling is the only means of establishing whether a reliable estimate can be made, and by the very nature of the principle involved, the most reliable estimates are those which can be deduced directly from the shape of the profiles. The synthetic profiles in Fig. 2 show that a separation of 0.1 g/cm^3 in the profiles involves about 0.15 mgal of gravity. Consequently, in the absence of perturbing gravity effects, a normal survey with a precision of ±0.03 mgal would give a bulk density accurate to about ±0.02 g/cm^3.

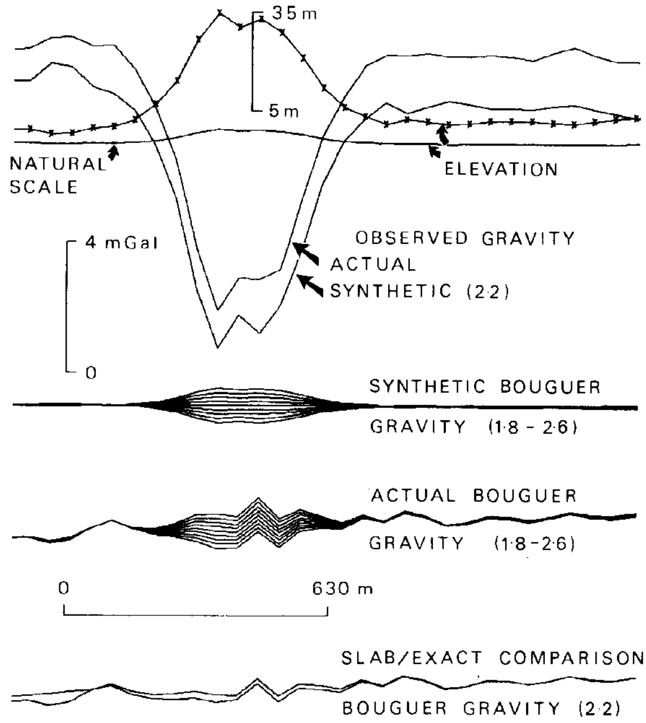

FIGURE 2

Enlarged profiles showing multiple spikes caused by density irregularities and possible data errors. The actual Bouguer profiles are not suitable for a density determination, but the synthetic profiles show that in an ideal situation a useful density value can be obtained.

Error Tolerance Analysis Using Synthetic Density Profiles

The perturbed nature of the actual density profiles in Fig. 2 is reminiscent of a series of barometric levelling errors of up to 3 m. Errors in barometric levelling can be random or systematic, but even random errors can cause large spikes if a positive error in one station is followed by a negative

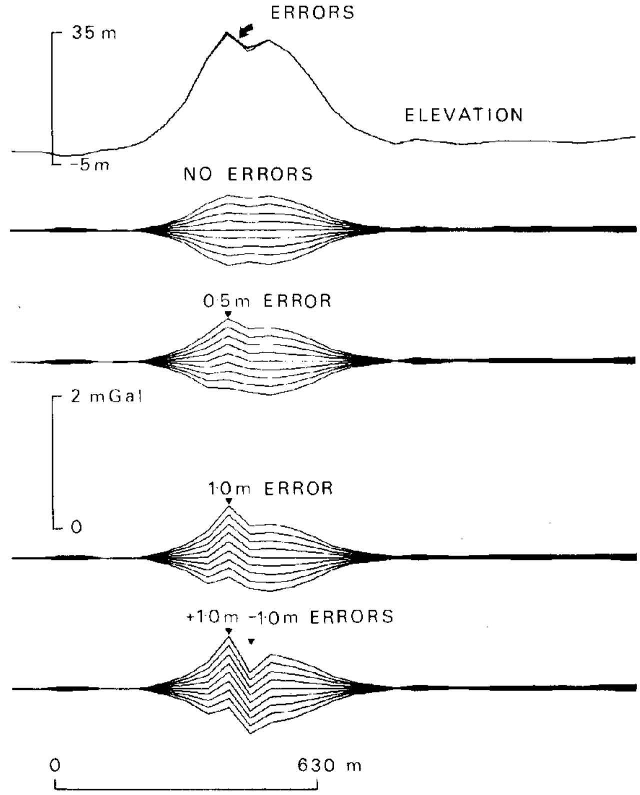

FIGURE 3

Demonstrating the theoretical effects of elevation errors on the density-profiling process.

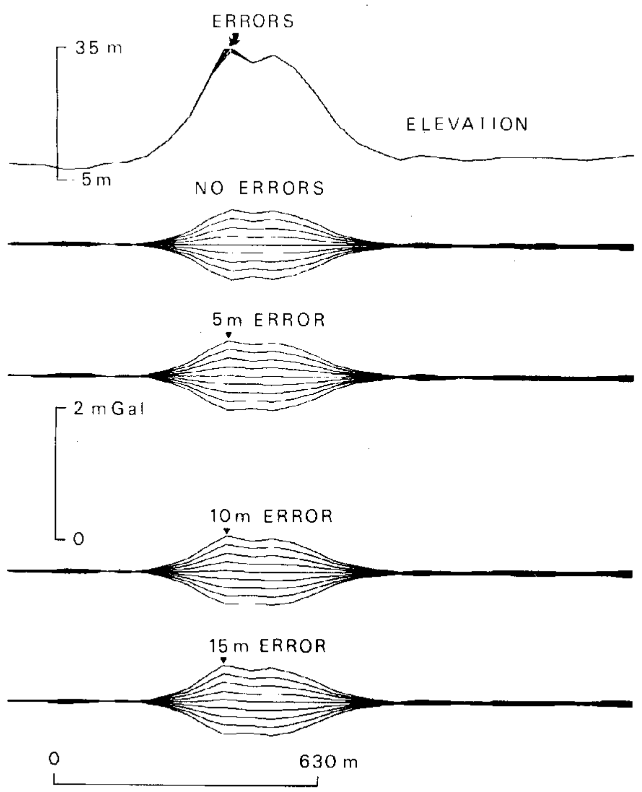

FIGURE 4

Demonstrating the theoretical effects of horizontal position errors on the density-profiling process.

error in the next. Consequently, quoted 'root mean-square' (r.m.s.) errors for barometric levelling are unlikely to give an adequate indication of the real effect of errors.

The error tolerance acceptable for density profiling will depend on the size and steepness of the topographic feature, and can be evaluated by introducing errors into the synthetic density-profiling process. Figures 3 and 4 show the theoretical effect of errors in elevation and horizontal coordinates, using the same topographic feature as in Fig. 2. The procedure involves computing a synthetic gravity profile from the topography for a nominal rock density, then reducing this profile using the same topography, but with one station modified to introduce an 'error' into the cross-section. This procedure is equivalent to accurately carrying out a gravity survey over a topographic feature the cross-section of which has been incorrectly determined.

The density profiles in Figs 3 and 4 are plotted at twice the enlargement of those in Fig. 2. The top set in Fig. 3 involves no cross-sectional errors. The next two sets involve 0.5 and 1.0 m errors in elevation. The bottom set shows the substantial dislocation in the density profiles caused by two elevation errors of +1.0 and −1.0 m in adjacent stations. Although the r.m.s. error in this case is 1.0 m, the dislocation in the density profiles is far greater than for a single 1.0 m error, demonstrating as mentioned earlier, the inadequacy of the r.m.s. value. In Fig. 4, errors have been introduced into the horizontal coordinate of one of the stations. The three bottom sets of profiles show the effect of displacing one of the stations 5, 10 and 15 m to the left of its true position. The resultant distortion in the profiles is hardly noticeable until the displacement reaches 15 m. The effect of horizontal errors is far less than vertical errors because the 'free-air' gravity effect does not apply to the former. Horizontal errors are more serious for steeper topography because they then produce a larger change in the vertical component of gravitational attraction.

Conclusions

The automated density-profiling process can be manipulated in various ways. Producing synthetic density profiles from a topographic cross-section is important for error analysis, and for investigating the suitability of topographic features for density determinations. A ridge 35 m high can produce an accurate bulk density if the gravity field is not perturbed by anomalous bodies. The analytical methods described here can be applied to whole traverses provided the topographic features crossed are reasonably elongate.

Acknowledgment

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References

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