LAB 3

DETERMINING THE TERRAIN DENSITY

Correcting for the attraction of the topography is an important step in modeling gravity and it requires an accurate estimate of the terrain density. The error in the computed attraction of the topography must be less than the design error in the gravity survey. The required error limit in the terrain density is found by taking a differential of the Bouguer formula

$$\Delta g_b = 2\pi G h \Delta\rho$$

where Δg_b is the error in the Bouguer correction, and h is the maximum elevation change over the survey.

1) Estimate the required accuracy you need in the terrain density to match the planned survey accuracy of $\pm .02 mgal$. Do this again using whatever number you got from your repeats.

There are numerous ways to estimate the terrain density: **Nettleton, Parasnis, scatterplot and covariance.** All of the techniques rely on the assumption that gravity from subsurface sources does not correlate with the topography. This is rarely a perfectly safe assumption to make, because often topography has a subsurface control. The only situation in which it topography would probably not have subsurface control is if topography is controlled by erosion only. Even in this case, erosion might have a subsurface control. There are two things you can do to minimize this problem. First, concentrate your attention on the shortest scale features in topography and gravity. Second, do the analysis for terrain density on stations that are not near the target of interest.

All of the techniques also use one or both of the following criteria.

a) *The correct terrain density will result in the 'smoothest' Bouguer gravity,*
b) *and the least correlation between Bouguer gravity and topography.*

A Free Air gravity anomaly will correlate positively with topography, (plot your free air gravity profile and elevation profile together on the same sheet and you will see an obvious correlation) because of the attraction of the topography. Since a Free Air anomaly is a Bouguer anomaly done with zero Bouguer density, it follows that using too low a terrain density will result in Bouguer anomalies that positively correlate with topography. Similarly, if too large a Bouguer density is used, a negative correlation between gravity and topography results.

It is good practice to ignore the large scale trends in both gravity and topography when performing any of the terrain density ana lyses, because the regional trend in gravity may bias the results. You can do this by eye with the Nettleton technique, but not with the scatterplot and covariance methods. Alternatively, you could remove a linear trend from both elevation and free air gravity before doing any of the terrain density ana lyses. The easiest way to do this is to least squares fit a line to your free air gravity profile (or a plane to a grid) and subtract this from the free air gravity. If you plot this detrended FA gravity it will just fluctuate about a mean value, but display no trend. Detrend the topography in the same way, that is, fit and remove a straight line. Of course the regional trend in the free air gravity may be due entirely to the regional trend in topography, in which case you would not be improving things by removing a trend as suggested above. It will help to look at the regional Bouguer map to see what the underlying regional trend is. If it is small, in the sense that the regional change in Bouguer gravity is much smaller than the change in gravity produced by the trend in topography, you may be best off not to remove the trend in FA and elevations. If the *Bouguer* trend is well defined, and its estimate does not depend too much on the terrain density used to calculate it, the best thing to do may be to subtract the Bouguer trend from the free air gravity profile or grid, before doing a terrain density analysis.

The Parasnis method is the simplest way to estimate the terrain density. If change in elevation is the only factor affecting Free Air gravity, then Free Air gravity should increase linearly with elevation. Therefore, a plot of Free Air gravity vs elevation should be a straight line with slope proportional to density.

$$\frac{g_{FA}}{h} = 2\pi G\rho$$

$$\text{or} \quad \frac{g_{FA}}{h} = \frac{0.1119}{2.67}\rho$$

$$\text{or} \quad \rho = \frac{g_{FA} \times 2.67}{h \times 0.1119}$$

Here, g_{FA} is in mgal, h is in m, and ρ is in gm/cm^3. Of course, if elevation is not the only thing affecting Free Air gravity, then there may be considerable scatter of values about a straight line. Furthermore, if Bouguer gravity and elevation correlate, the slope and estimated terrain density will be biased as well.

2) Estimate the terrain density using this method. Cross-plot h and g_FA*2.67/0.1119

3) If you want to concentrate on the short scale features try taking the first differences of the Free Air gravity and the elevations. You need to have your data listed in order along a profile for this. Plot the Free Air first differences against the elevation first differences. This is a first order derivative of the above equation, so each ratio is an estimate of the slope. The mean value of all of these estimates is the mean slope, or, if you scale x and y as above ie. $slope = 0.1119 \times \rho_{terrain}/2.67$, then the mean value of all the estimates is the density. Because you are taking first differences of neighbouring stations, the elevation differences are never large, so the accuracy of the resulting terrain density will not be as good as for the other techniques, however, it is biased towards the small scale topography, which is what you want.

better plot Dg/Dh*2.67/0.119

A Nettleton profile is done by plotting the topography along with a series of Bouguer anomalies calculated with Bouguer densities that bracket the expected value. A visual inspection indicates which densities are too high or too low. The smoothness of the plots can also be assessed and factored into the decision.

4) Perform a Nettleton profile analysis on the 'road' gravity data.

A scatterplot is a plot of Bouguer gravity vs topography. A positive correlation indicates that the density used in the Bouguer correction is too small, and a negative correlation means the terrain density is too large. As with Nettleton, the density is adjusted until the least correlation is judged to result. Sometimes this is done by plotting free air vs elevations and fitting a straight line. The slope of the straight line is then proportional to the terrain density. The scatterplot method relies mostly on the least correlation criterion and very little on the smoothness or least variance criterion. It is also more difficult to factor in considerations like relying more on the small horizontal scale variations. Its one advantage over Nettleton is that it can be used with gridded data as easily as with profiles.

5) Perform a scatterplot analysis on the same data.

The covariance method is actually a least variance method. Minimizing the variance in the Bouguer anomalies, as a function of the terrain density, leads to:

$$\rho = \frac{\sum_i \Delta g_i h_i}{2\pi G \sum_i h_i^2}$$

where i is a station number, and g and h are free air anomalies and elevations (See the class notes for a derivation). The covariance method (really only least variance) relies only on the least variance criterion, and does not take advantage of least correlation, nor does it allow a weighting towards the smaller horizontal scales. Like the scatterplot it works well with gridded data, and one can easily exclude areas that might give a biased result.

6) Perform a covariance analysis on the same data.

7) Repeat one of these exercises without removing a trend from either free air or elevations. Why is the result different?

8) How accurately do you think you have estimated the terrain density in each of these cases?

The terrain density can also be estimated directly by modeling, for example, with GMSYS. This approach is perhaps the strongest, because all of the methods described above use the Bouguer slab formula to model the attraction of the topography, whereas with modeling you can easily do a 2D or 3D terrain correction.