GEOL 4714 Field Geophysics

Lab 5A: Gravity Data Interpretation Part I: Terrain Correction
Due in class

This first part of the lab is preparatory for the main lab. You are to determine the terrain correction for three gravity stations as assigned. The terrain corrections you calculate will be shared with everyone else via the web so that all can fully reduce their gravity data.

Terrain corrections

You are to make a table for your station listing the various rings and compartments, the mean elevation difference in each compartment, and the terrain correction for that compartment. It might be wise to write down the mean elevation in each compartment (beyond the B and C rings, which were variations from gravimeter in the field) for those compartments where all the terrain is above or below the station (for compartments that are split, you need to estimate the mean of the absolute value of the difference in elevation). You should also add the far field terrain correction from the map handed out with the lab materials to get the full terrain correction. See the partial example table on the page after the station locations.

Andrew Adams	A1	B7
Tom Bunn	A2	B6
Philip Cunnell	A3	B4
Tyson Eby	A4	B1
Maria Furtney	A6	B5
Dan Gleason	A7	S1
Rhiana Henry	B1	A6
Mariel Herzog	B2	A1
Taylor Hindman	B3	A2
Qibai Huang	B5	B7
Muhammad Bin Ismail	B6	A3
Robert Kowalsky	B7	A4
Myranda Prentiss	B8	A5
John Sterling	B5	A7
Ryan Thompson	A6	A2
Marshall Van Swaay	A7	B2

Station locations as surveyed (with a correction to bring the elevations into agreement with the topo map) are below and online. Italicized stations lack dGPS controlled elevations (W3, W8, RN2):

Name	Latitude N	Longitude E	Topo Map Elev (ft)	Topo map elev (m)
A1	39.98177746	-105.5851910	10215	3113.65
A2	39.9817542	-105.5873429	10184	3103.99
A3	39.981319	-105.5887106	10142	3091.34
A4	39.98120275	-105.5913966	10092	3075.91
A6	39.98022987	-105.5876082	10274	3131.49
A7	39.98022271	-105.5858273	10344	3152.76
B1	39.98183426	-105.5942317	10122	3085.11
B2	39.98350069	-105.5955638	10153	3094.57
B3	39.98423377	-105.5991752	10241	3121.58
B5	39.98766522	-105.5995512	10214	3113.27
B6-float	*39.98894498*	*-105.5958053*	*10159*	*3096.34*
B7	39.98687711	-105.5931338	10114	3082.84
B8	39.98623434	-105.5899523	10048	3062.73
BASE	39.98122612	-105.5788850	9992	3045.56

Example sheet:

compartment	Elevation (ft)	Station Elevation	Elevation difference	Terrain Correction (mGal)
		Ring B		
1			1 m	0.01
2			1 m	0.01
3			2 m	0.02
4			1 m	0.01
Ring B total				**0.05**
		Ring C		
1			5 m	0.01
2			3 m	0.00
3			6 m	0.01
4			2 m	0.00
5			2 m	0.00
6			0 m	0.00
Ring C total				**0.02**
		Ring D		
1	10031 ft	10020 ft	11 ft	0.00
2	10100 ft	10020 ft	80 ft	0.07
3	10095 ft	10020 ft	75 ft	0.06
4	10020 ft	10020 ft	0 ft	0.00
5	9980 ft	10020 ft	40 ft	0.02
6	10000 ft	10020 ft	20 ft	0.00
Ring D total				**0.15**
		Ring E …		
		…		
Ring B total				**0.05**
Ring C total				**0.02**
Ring D total				**0.15**
Ring E total				**0.35**
Ring F' total				**0.80**
Ring outer zone (map)				**4.80**
Total terrain Correction				**6.17**

GEOL 4714/5714 Field Geophysics

Lab 5A: Gravity Data Contour map
Map should be completed 24 October 2013

Lab Report Contents

Your lab report should include the following:

1. Your calculation of the inner zone terrain correction for the stations assigned you.
2. A spreadsheet showing your reduction of all the gravity data; units should be indicated when appropriate and columns should be clearly labeled.
3. A contoured map of the complete Bouguer anomaly for our data as well as the 2003, 2005, 2008-12 data (is online as a tab-delimited file). You can do this by hand or use Surfer (if you can find it) or use Matlab or some other contouring package (Aable, for instance, can do this). Some instructions for contouring in Matlab are online. If you use a software package, be sure your map has a single scale (for instance, a horizontal (east-west) kilometer should be the same length as a north-south kilometer).

For the second half of the lab next week, you will need a copy of your data (which is presumably a spreadsheet saved somewhere) and your map. Although your map is to be completed by the deadline, it will not be turned in.

Gravity data processing involves several steps, outlined below. After making terrain corrections, we will use Microsoft Excel (or any other spreadsheetish application of your choice) to make a spreadsheet of our gravity data and correct for instrument drift, latitude, and elevation. Once you have the gravity anomalies, you may then interpret them with GravMag. (Note that in printing out your table, there are options in Excel and some of the other programs for repeating specific columns and/or rows on all printed pages).

Steps of gravity data processing:

0. Make inner zone terrain corrections using the tables and Hammer zone overlay and map distributed in class. The results should be in a table with the elevation difference in each compartment and the contribution to the terrain correction from that compartment all indicated.

1. In Excel or Surfer, **Make a table** of gravity readings (average the three or five readings made at each station), including station name, dial reading, time (in minutes), survey information (latitude, longitude, elevation, and distance north and east of base and elevation above or below base).

2. **Dial correction**: multiply the observed value by the meter constant in order to convert from meter units to milligals.

CUB meter 235: 1.05527 between 2800 and 2900; USGS meter 64: 1.04205 between 2800 and 2900

3. **Tide correction:** Enter the value from the table of tide corrections for each measurement. These are added to the dial-corrected values from step 2 values to make a set of tide corrected values g_{tc}.

4. **Drift correction:** You can make a plot of readings at the base station as a function of time, linearly interpolate between the points, and subtract this value from subsequent readings as a function of time. The algebra is simple, though. The form of the drift correction is:

$$g_{dc}(t) = g_{tc}(t) - b_0 - (b_e - b_0)\frac{t - t_0}{t_e - t_0}$$

where g_{tc} is the dial- and tide-corrected reading at time t (can be at any station), t is time of the reading (in minutes or hours or fractional days—just be consistent), b_e is average base station reading at time t_e at the end of the day (also dial- and tide-corrected) and b_0 is the average base station reading at beginning of the day at time t_0. Note that this reduces our reading to be relative to the base and so should be well within 100 mGal.

A check on the drift correction is that all drift corrected base station readings should be identical and zero. (In tables of past experiments, the "raw" column is usually g_{dc}).

5. **Latitude correction**. Gravity varies with latitude because the earth is not a perfect sphere and the polar radius is smaller than the equitorial radius, also, the effect of centrifugal acceleration is different at the poles versus the equator. Thus gravitational acceleration is larger at the poles than at the equator, a relationship that is fully expressed as g=978031.85[1+0.005278895sin$^2\phi$ - 0.000023462sin$^4\phi$] mGal, where ϕ is latitude. The derivative with respect to latitude is (90.11008-0.800987sin$^2\phi$)sin2ϕ in mGal/degree latitude. At 40°N, the variation is 88.4152 mGal per degree, which is 0.00079439 mGal per meter. Thus the latitude corrected gravity g_{lc} is

$g_{lc} = g_{dc}$ - (ΔN) • 0. 79439 (mGal/km)
(make sure you get the sign right, if a station is SOUTH of the base station it is negative (-) NORTH)

Recall from lab 1:
latitude difference in meters
= latitude difference in decimal degrees x 111,300 m/deg

longitude difference in meters
= longitude difference in decimal degrees x 85,300 m/deg (near 40° N)

6. **Free air correction**: a high station has gravity that is too low (farther from center of Earth, so gravity is lower), so the free air correction is added to data to produce the free air anomaly (FAA):

$$\text{FAA} = g_{lc} + \Delta z \bullet 0.3086\ (\text{mGal/m})$$

The value resulting from removal of the free air correction is the free air anomaly (FAA). Δz is the difference in elevation relative to an appropriate reference; for us the reference is the base station.

7. **Bouguer correction:** corrects for excess mass between the reading elevation and your datum elevation (excess mass makes the gravity reading higher), is subtracted from data and produces the simple Bouguer anomaly (SBA):

$$\text{SBA} = \text{FAA} - 0.04193\ (\text{mGal cm}^3/\text{g/m}) \bullet 2.67\ (\text{g/cm}^3) \bullet \Delta z$$

8. **Terrain correction**: The presence of terrain always reduces the value of gravity. Add the total terrain correction to your simple Bouguer anomaly and then subtract the terrain correction for the base (TBA for us) to get the complete Bouguer anomaly relative to the base.

As an example, consider the reduction of CU1 from 2000.
The first base reading (averaged from 5 readings) was 2852.021 with the CU meter at an average time of 15:02 on 9/26/00. The last base reading of the day was 2852.035 at 18:25 on the same day. Using the CU meter constant of 1.0553, these become 3009.738 and 3009.753 mGal. The tide correction at 15:02 is 0.024 mGal and at 18:25 is -0.098 mGal, so the two base readings corrected for tides are 3009.762 and 3009.655. So the drift rate (change in the base reading with time) was (3009.655 – 3009.762)/(18:25-15:02) = -0.107 / (3:23) = -0.107/3.3833 hours = -0.03163 mGal/hour (we are saving some extra digits to prevent calculation errors through premature truncation). This means that the reading we would expect at the base would be 3009.738 - 0.03163*(*t* – 15:02). For CU1, the measurement averaged to 2823.329 meter units and was made at 16:14. Multiplying by our meter constant of 1.0553, the measurement is 2979.459 mGal. The tidal correction at 16:14 was -0.035 mGal, so the corrected reading was 2979.424 mGal. The base reading at 16:14 should be (from our equation) 3009.700 mGal, so the drift corrected value is 2979.424-3009.700 = -30.276 mGal.

Station CU1 was 0.342 km north, -2.131 km east, and 125.19 m above the base station. From the latitude correction equation, we find we should subtract 0.273 mGal because we are to the north of the base, we should add 38.635 mGal because of the elevation difference, and thus we get a **free air anomaly** of 8.086 mGal. We now use the equation for the Bouguer correction to subtract -0.04193 x 2.67 x (125.19m) to get a **simple Bouguer anomaly** of –5.929 mGal. Now we add in the terrain correction of 6.06 and subtract the base's terrain correction of 5.15 to get a **complete Bouguer Anomaly** of -5.02 mGal.

Mapping gravity

You now should have latitude, longitude, and complete Bouguer anomalies for all the 2013 data as well as the older data. Separate instructions on how you might contour this in Matlab are available online; you can also contour by hand if desired. The easiest way to make a contour map with correct scales is to convert latitude and longitude to distance north and east from the base (in km). You did this already (at least distance north) in order to make the latitude correction for each point. You can add a latitude and longitude marker by simply converting a specific latitude and/or longitude to distance north and east of base and marking those lines. Your contour maps should also show where the control points are (the points where gravity was measured).

Terrain Correction Worksheet p. 1
Station Name: ________________________ Name: __________________________

compartment	Elevation (ft)	Station Elevation	Elevation difference	Terrain Correction (mGal)
		Ring B		
1				
2				
3				
4				
Ring B total				
		Ring C		
1				
2				
3				
4				
5				
6				
Ring C total				
		Ring D		
1				
2				
3				
4				
5				
6				
Ring D total				

compartment	Elevation (ft)	Station Elevation	Elevation difference	Terrain Correction (mGal)
Ring E				
1				
2				
3				
4				
5				
6				
7				
8				
Ring E total				
Ring F'				
1				
2				
3				
4				
5				
6				
7				
8				
Ring F' total				
…				
Ring B total				
Ring C total				
Ring D total				
Ring E total				
Ring F' total				
Ring outer zone (map)				
Total terrain Correction				

GEOL 4714 Field Geophysics

Lab 5B: Gravity Profile & Interpretation
Report due 5 November 2013

Lab Report Contents

1. Choose a profile through the gravity data and show the position of this profile on your map. Justify why you pick a particular profile to model.
2. Make a simple estimate of the likely depth extent and density contrast of the density anomaly producing the gravity anomaly, showing how you derived this estimate.
3. Project your data onto your profile. Provide a table showing the distance along your profile, the distance normal to your profile, and the gravity point name and complete Bouguer value.
4. Interpret the gravity anomaly along your profile. You might recall that the primary geologic item of interest is the dense rocks of the ores in the area and make your interpretation with this in mind. You might want to refer to the geologic map on the website.

Modeling the gravity anomaly

First you will need to decide on the location of a profile to model. This is not a trivial decision. To use a 2-D program like **GravMag**, you will want the profile to go perpendicular to contours somewhere where you have a significant amount of data. You obviously would prefer it to cross some interesting aspect of your field area.

You have distances north and east from the base. To place these on our profile, you would want the distance along your profile. Decide what the orientation of the profile is. You can convert the north and east coordinates to along and perpendicular to a profile θ degrees from north using

Along = north * cos(θ) + east * sin(θ)

Perpendicular = -north * sin(θ) + east * cos(θ)

Where east and north are in kilometers (or meters). Ideally this should be in your spreadsheet for the gravity calculation. You can (and should) use the perpendicular distance to limit the data included in your profile: identify a point directly on your profile and note its perpendicular distance in your spreadsheet. Decide on how wide a swath should be included in your gravity profile. Ideally, this should not extend out so far that you are including areas where the contours on your map are deviating significantly from being perpendicular to your profile. You then only want to include points with perpendicular distances differing from your reference station by this amount or less. For instance, if your station on the profile had a perpendicular distance of -1.25 km, and you felt that points within 500 m of the profile should be included, you would then only include points with a perpendicular distance between -1.75 and -0.75 km. A data table with the positions of the points used and their gravity values should be in your report.

You should get an idea of the likely depth extent and magnitude of your anomaly. There is a decent discussion of simple techniques in section 6.7 of your text. Probably the easiest to apply is the half-maximum technique. Note that the size of the anomaly is from min to max, not height above our arbitrary zero. Apply this to your chosen anomaly to get an estimate of the depth of the midpoint of your anomaly, $z_{1/2}$. You might then use the equation for the gravity anomaly from a slab (eqn 6.24) of $g = 2\pi G(\rho z) = 0.04193(\Delta\rho z)$ in mGal for density contrast measured in g/cc and thickness (z) in meters. If you use double your midpoint depth as your thickness, you have a crude lower bound on the density of your body. All this can be done from a map or a profile. Note that you should have a pretty good idea of the total magnitude of the anomaly, so even if your profile does not include this new data far from the anomalies around Caribou Hill, you should be looking to fit the overall magnitude of the anomaly.

You can now use the GravMag code to model the gravity signal observed. You should include appropriate values from the older surveys (2003, 2005, and 2008-2012). **Note that the density entered for a body is its contrast with the surrounding rock.** Thus if you thought the body might have a density of 2.9 g/cc and the surrounding rock 2.67 g/cc, you would enter 0.23 g/cc (or 230 kg/m^3) as the density of the body. You should probably enter the "background" gravity value (value you expect where there is no anomaly) in the "Add to calculated" box in the gravity data window.

You probably should start with a simple box with its top at or just below the surface, its thickness derived from your simple analysis of the possible thickness of the body, and its density contrast the value estimated from application of the infinite slab equation. If you have gradients on both sides of your anomaly, place the edges of the box under those edges; if on one side, place one edge under that gradient and put the other edge far away. You should try adjusting the density of your anomaly to better fit the overall amplitude of the anomaly (the density calculated for an infinite sheet is going to be smaller than that from a finite sized anomaly). Determine then the best fit with such a rectangle. Try halving the density of the body and doubling its thickness; will this fit your gravity values as well? How about doubling the density and halving the thickness? You might try moving the top and bottom of the rectangle up and down. Note you can use the “Use Mean Offset” button to allow for a background change you are not modeling, and the RMS misfit can serve as a guide to how well you are fitting the data. Discuss your observations in your report.

(You could consider the second derivative technique of section 6.7.2 in the text as a possible means of making an estimate of the shape of a starting quadrilateral).

After finding your best rectangle, try changing the dip on one side of the rectangle. Try and find a dip that is too shallow to fit your data and, if possible, one that is too steep. This bounds the dip of one edge of your anomaly. The results of this should be in your report (ideally a graphic showing the two dips tried and either the RMS misfits associated with them or plots of the observed and calculated values).

Finally, see if you can get a better fit by moving the four corners independently. If you wish to explore somewhat more complex shapes, feel free, but be sure to report the results of your simple calculations, the best rectangle results and the constraints on the one edge of the anomaly.

Note that you do not want your body to extend above your gravity points! In the latest versions of GravMag, the points are shown in the section plot as x's. Clicking the "Show All" button will expand the view to include all points. If you enter the elevations of the gravity stations relative to sea level, note that points will be quite high; if relative to the field base, some will be negative. Depending on your profile, it is possible that you will want or need to match the top edge of the anomaly to topography.

Extra information: This is not necessary to complete the lab, but can be of interest and you can use it if you wish. There is a component of the gravity field that is produced by the isostatic mechanisms supporting the range. While the exact gravity contribution depends on the assumption of how the range is supported, there is a standard correction applied by many geophysicists termed the isostatic correction and it is often helpful in removing these log wavelength gravity anomalies when examining a small area (another approach, described in the text as well, is removing a low-order polynomial fit from the data). The resulting anomaly is termed the isostatic anomaly. In the vicinity of Caribou, the isostatic correction is nearly linear, working out to be about 0.84 mGal/km heading N75°E. So to obtain the isostatic anomaly, a point X 1 km to N75°E from a point Y should have 0.84 mGal subtracted from its complete Bouguer anomaly. It turns out for most of Caribou that this tends to add to the magnitude of the gravity anomaly because we have positive values in the southwest and lower values in the northeast.