RESEARCH REPORT

Geophysics Gravity Field Trip

October 23, 2012

Measurement of Gravity & Calculation of Density

along a lava flow and mountain profile in the Reykjavik area.

Figure 1 Field Gravity Surveying

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A. **Introduction.**

Geophysical applications recognize gravitational acceleration of a mass due to the attraction of another mass. The mean value of gravity at Earth’s surface is 9.80 m/s$^2$, or 980,000 mgal. Geological structures cause small changes in the acceleration of gravity, measured in milligal precise to about a millionth of a gal, or microgal. Measurements of gravity along a profile are proven to be a useful tool for estimating the density of material in the Earth. The mean density of the Earth may be calculated by dividing the Earth’s mass by its volume, resulting in 5515 kg m$^{-3}$, about double the crustal rock density. Thus, the Earth’s density must increase with depth (Lowrie 1997).

The Sun and Moon’s gravitational forces deform the Earth’s shape, resulting in tides of the solid body of the Earth, the atmosphere and ocean (Lowrie 1997). Gravity instruments can detect gravity differences of 0.01 mgal and the combination of the Sun and Moon’s acceleration at the Earth’s surface can be up to 0.3 mgal, two-thirds from the Moon and one-third from the Sun. Latitude, elevation and the geoid reference affect gravity measurements, thus must be acknowledged in calculations for gravity and density.

![Figure 2 Potsdam Gravity Potato, image from space with gravity field in effect (GeoSciences 2011)](image)

The mean density of a mountain can be estimated using gravity data over a profile and Nettleton’s method. This method determines different rock density values from calculated Bouguer and terrain corrections, with the best estimate being the least correlation between elevation and Bouguer anomalies.

B. **Location.**

The field gravity survey was conducted along a profile in the southeastern area of Reykjavik, Iceland at approximately 64 N 21 W. The first three gravity measurements were along a low-lying lava flow at about 72.5m above sea level (m.a.s.l.). The following four gravity measurements were over a fairly steep hill to 140.7 m.a.s.l., then down to 40.4 m.a.s.l. at Vifilsstadavatn Lake. The week prior to the day gravity measurements were taken, there were significant earthquake swarms occurring in Northern Iceland, although this day was fairly calm, with no significant local seismicity and an overcast day.
Figure 3 First three gravity measurements A, B and C in lava field

<table>
<thead>
<tr>
<th>Point</th>
<th>lat. (deg. N)</th>
<th>long. (deg. W)</th>
<th>Elevation (m a.s.l.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>64,06752</td>
<td>21,88393</td>
<td>72</td>
</tr>
<tr>
<td>B</td>
<td>64,06686</td>
<td>21,88712</td>
<td>73,4</td>
</tr>
<tr>
<td>C</td>
<td>64,06782</td>
<td>21,88161</td>
<td>72,8</td>
</tr>
<tr>
<td>D</td>
<td>64,0703</td>
<td>21,87569</td>
<td>140,7</td>
</tr>
<tr>
<td>E</td>
<td>64,07281</td>
<td>21,87476</td>
<td>110,3</td>
</tr>
<tr>
<td>F</td>
<td>64,07434</td>
<td>21,87023</td>
<td>49</td>
</tr>
<tr>
<td>G</td>
<td>64,07482</td>
<td>21,86924</td>
<td>43,4</td>
</tr>
</tbody>
</table>

Figure 4 map profile of 7 gravity measurement sites

Figure 5 map profile of 7 gravity measurement sites
C. Methods.

Instruments used:

During the field work a total of 7 stations were measured (without including the measurements at the reference station at the start and the end of the survey). The equipment used consisted of an analogue gravity meter, the La Costa & Romberg gravity meter (G-445), as well as a GPS NetR9 (SN-5209K82800) to measure the elevation and location of each survey point.

Practical methods:

- Measure of the gravity at the reference point in Askja (eastern entrance on south side), at the start and end of measurements.
- At each survey point we measure with the gravity meter; we note the reading and the time. After, this data will be processed to have the gravitational acceleration observed at each point with the correction due to drift and tidal forces already done.
- We obtain the elevation as well as the latitude and longitude of each point with the GPS; calculations done by instructors using GPS software.
- At each station we estimate the terrain correction with the Hammer Chart for zones B and C, by looking at the height difference between the survey point and the surroundings and then looking up the result in the table (Appendix 1). For other zones the correction was provided by the instructors.
Theoretical methods:

- After processing of the data collected on the field we obtain: the $g_{\text{observed}}$, the latitude and longitude, the elevation and the terrain correction at each point.
- We use all this information to calculate $g_{\text{Bouguer}}$ for some initial density, then equation (1) is used to calculate $g_{\text{Bouguer}}$ for other values of density. We show on a graph the profile of $g_{\text{Bouguer}}$ for several different values of density and the curve that shows the least correlation with the topography is considered to be the true mean density of the rocks.

Figure 6 gravity survey site C between lava field and upcoming mountain profile. Terrain corrections done in periphery.

D. Gravity measurements corrections
From the equation (1), we need to correct the observed gravity field for variations occurring on the Earth system, between the Earth and other objects.

\[ g_{\text{obs}} \] – Gravity readings observed at each gravity station after corrections have been applied for instrument drift and earth tides.

Latitude correction – Correction subtracted from \( g_{\text{obs}} \) that accounts for Earth’s elliptical shape and rotation.

\[ g(\lambda) = g_e (1 + \alpha \sin^2(\lambda) + \beta \sin^4(\lambda)) \]

Free-air correction - accounts for gravity variations caused by elevation differences in the observation locations.

\[ \delta g_{\text{FA}} = 0.3086h \]

Bouguer correction - The Bouguer correction is a first-order correction to account for the excess mass underlying observation points located at elevations higher than the sea level or the geoid. Conversely, it accounts for a mass deficiency at observation points located below sea level.

\[ \delta g_{\text{FA}} = 2\pi G\rho h \]

Terrain correction - accounts for variations in the observed gravitational acceleration caused by variations in topography near each observation point. It is linearly dependent on the density \((\delta T/\rho_0)\)

### Calculations and results

<table>
<thead>
<tr>
<th>Survey points</th>
<th>lat. (deg. N)</th>
<th>lon. (deg. W)</th>
<th>m a.s.l.</th>
<th>( g_{\text{obs}} )</th>
<th>TC (0 m - 50 km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>64,06752</td>
<td>21,88393</td>
<td>72</td>
<td>982242,59</td>
<td>0.33</td>
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<tr>
<td>2</td>
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<td>0.58</td>
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<tr>
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<td>21,86924</td>
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<td>982249,09</td>
<td>0.57</td>
</tr>
</tbody>
</table>
Fig. g observed profile (field reading corrected for instrument drift and tides).

Example of calculation (Appendix 2)

Survey point 4:

\[ \text{g}_{\text{Bouger}} = \]

Results
Discussion of results.

Figure 7 near gravity survey site B in lava field

Figure 8 near gravity survey site D at top of mountain

Figure 9 near gravity survey site E coming down mountain profile to the lake

F. Discussion of results.
G. References.


Google Map. Aerial topographical map of Reykjavik, Iceland.


Appendix.
Appendix A: Table with terrain corrections for Hammer zones B – M

<table>
<thead>
<tr>
<th>g obs</th>
<th>( g (\lambda) = )</th>
<th>( \delta g_{FA} = 0.3086h )</th>
<th>( 2\pi G h )</th>
<th>( \delta T/\rho_0 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>mGal</td>
<td>( g_e (1 + \alpha \sin^2(\lambda) + \beta \sin^4(\lambda)) )</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>982242.59</td>
<td>982222.4206</td>
<td>22.2192</td>
<td>0.003018794</td>
<td>0.000163239</td>
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<tr>
<td>982242.45</td>
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<td>0.003077493</td>
<td>6.19373E-05</td>
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<td>982242.46</td>
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</tbody>
</table>

Appendix B: Table with corrections calculations.