# B6 Analysis techniques for gravity data

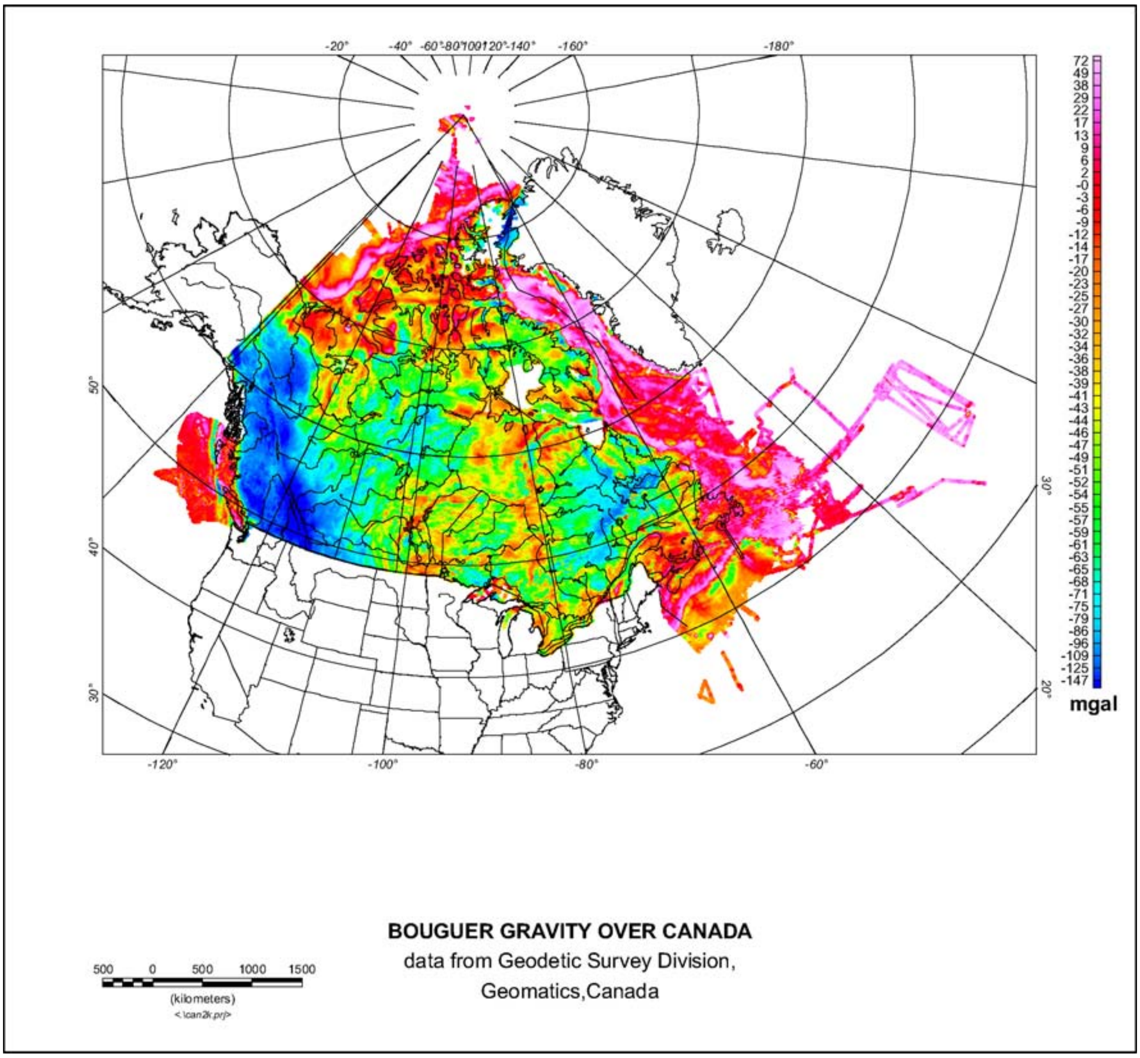
## B6.0 Bouguer anomaly maps

● Once the Free Air and Bouguer corrections have been made, the Bouguer anomaly should contain information about the subsurface density alone. The effect of latitude and elevation should have been removed

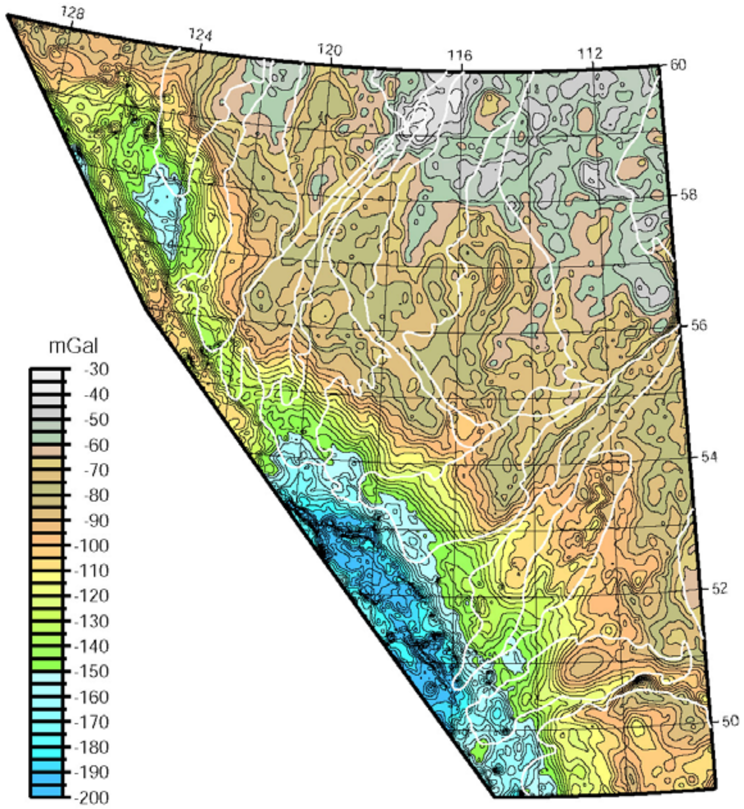
● A map of the Bouguer anomaly gives a good impression of subsurface structure in an area. We will look at examples for Canada and Alberta.

● **Low (negative) values** of Bouguer anomaly indicate **lower density** beneath the measurement point.

● **High (positive) values** of Bouguer anomaly indicate **higher density** beneath the measurement point.




● What are the dominant features in the Bouguer anomaly map of Canada? How are these related to the distribution of mountain belts and sedimentary basins?




**Bouguer anomaly**

- What are the dominant features in the Bouguer anomaly map of Alberta? Sketch a profile from Fort McMurray to the Rockies and try and account for the main features observed above.

- White lines denote the boundaries of basement blocks. Details of this in B6.5

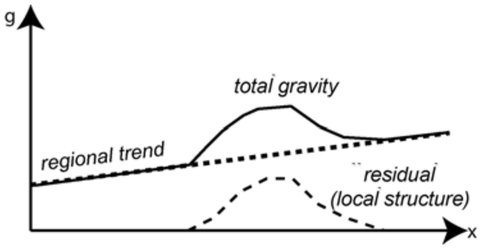
- Data and figure from : M. Pilkington et al, *Can. J. Earth Sciences*, 37, 1453-1471, 2000.

# B6.1 Regional and residuals

- Measured gravity depends on Earth structures ranging from scales of 1m to 10,000 km

- **Deeper** density structures produce gravity anomalies with a **long** spatial wavelength. For a body such as a sphere, this would be expressed as a large value for the half-width ($x_{½}$).

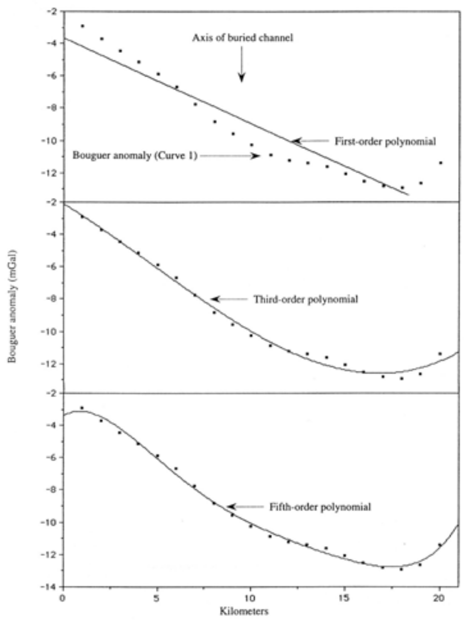
- Similarly **shallow** density structures produce gravity anomalies with **short** spatial wavelengths or small half-widths.




- Often the longer wavelength effects are called **regional trends**, while the shorter wavelength features are called **residuals** or **anomalies**. The distinction between the two is somewhat arbitrary.

- In **shallow gravity exploration**, we are generally interested in the short wavelength gravity anomalies. The long wavelength regional trends can make it difficult to analyse the short wavelength residuals. Thus we need to find a way to **remove the regional** trends and emphasize the anomaly more clearly.

- In other studies the regional trend could be the target of the study (one person's noise is another persons signal!)




- Regional trends may be computed by finding the straight line (or curve) that gives the best fit to the data. The regional trend is then subtracted from the measured Bouguer anomalies. However care is needed not to eliminate useful data during this process.

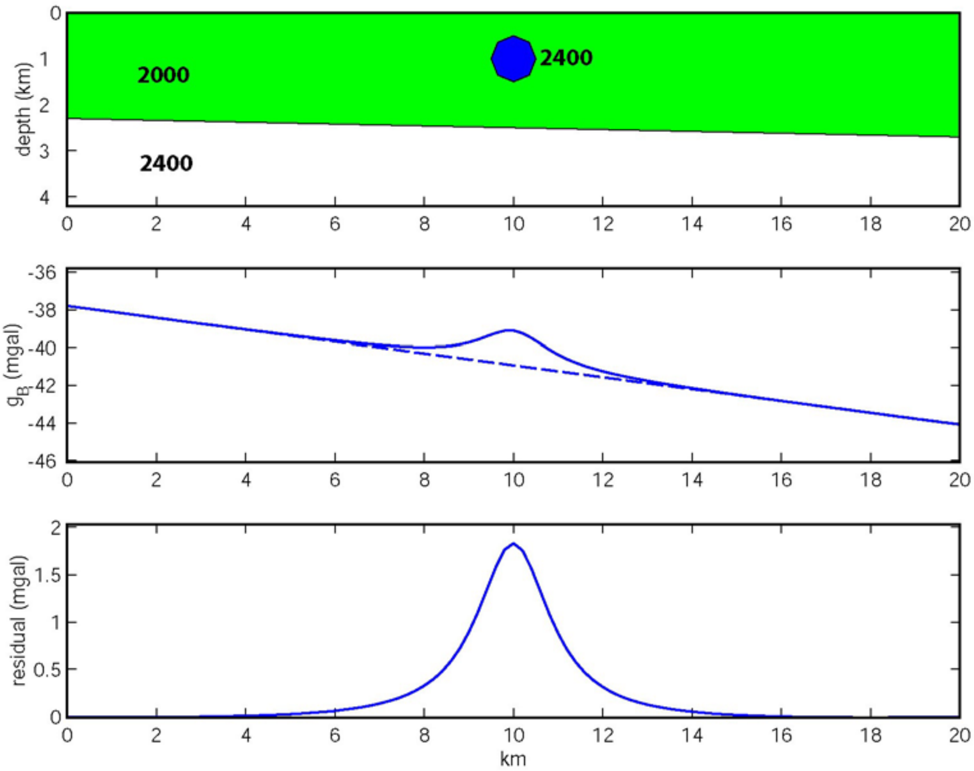
  In this example there is a gravity anomaly in the data at 10 km offset. If a linear trend is removed, then the anomaly at 10 km will be well recovered. A $3^{rd}$ order polynomial trend fits the data better, but also begins to fit the anomaly.

  With $5^{th}$ order polynomial, nothing is left as a anomaly! Beware!

- Various techniques can be used to remove residuals and are effectively filtering techniques. More sophisticated analyses use formal filtering can be done after transforming to the Fourier domain.

**Example 1** :

**325 B6.1 Regional trends and residuals - example 1**



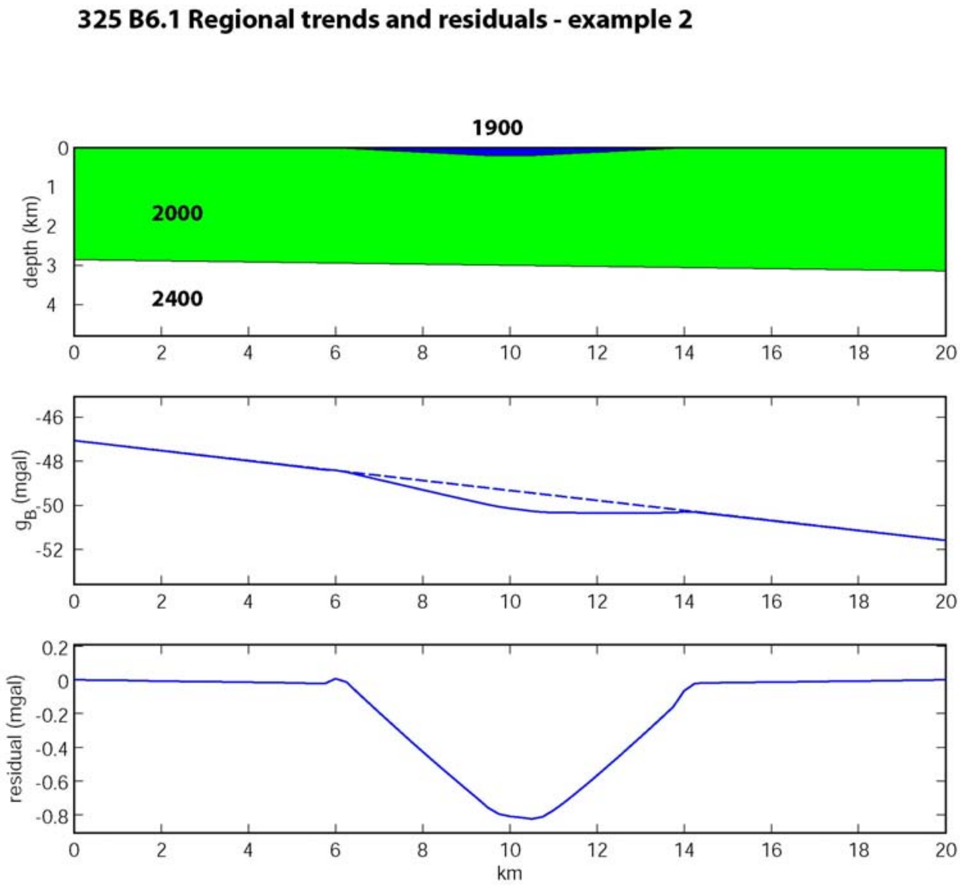

This shows two density structures

(a) higher density bedrock that dips to the right and which produces a slow decrease in $g_B$ from left to right.

(b) a shallow buried cylinder. It is difficult to determine the half-width of the anomaly due to the cylinder in the presence of the linear regional trend.

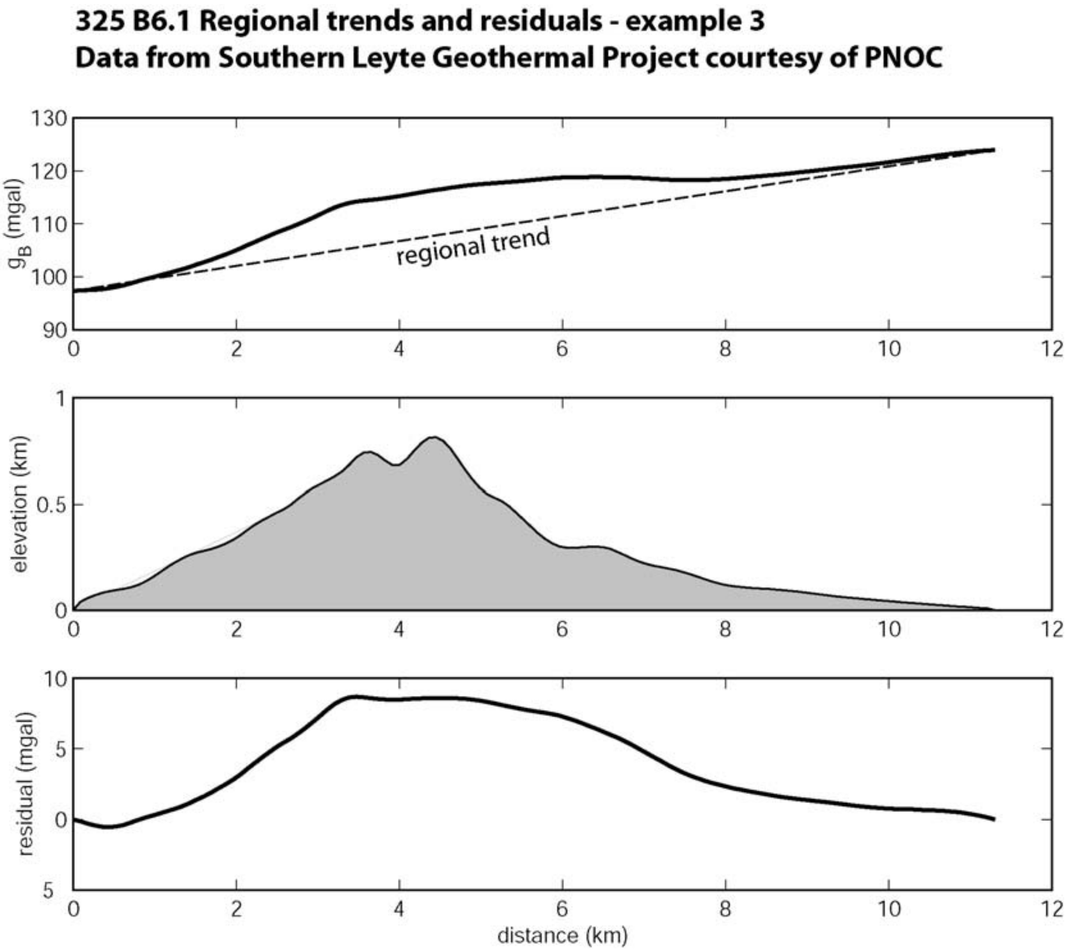
The dotted line denotes the regional trend, and is obtained by finding the best-fitting straight line to the data. When the regional trend is subtracted from $g_B$ the anomaly of the cylinder is much easier to interpret.

**Example 2**:




This features the same dipping bedrock and a shallow, low density river channel. Again, removal of the regional trend makes the effect of the river channel much clearer.

**Example 3**:

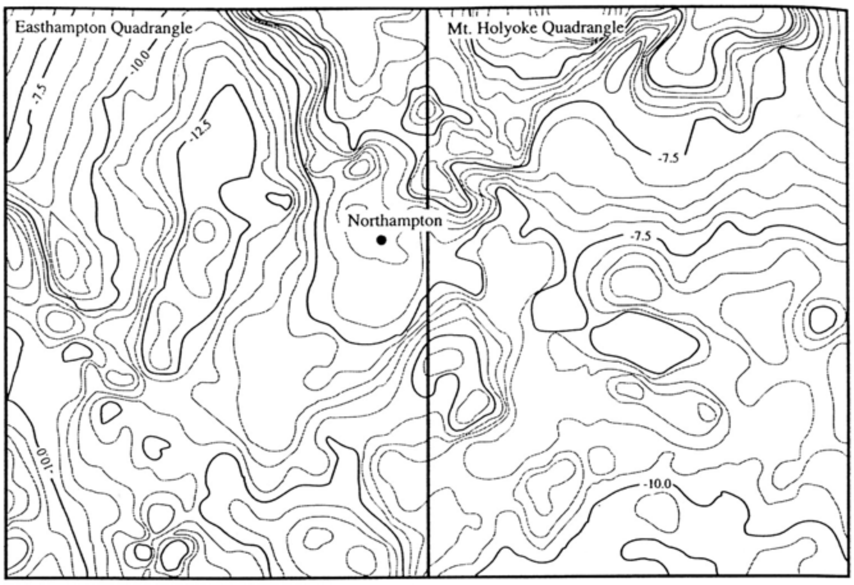



Real gravity data collected in a geothermal exploration project in the Philippines.

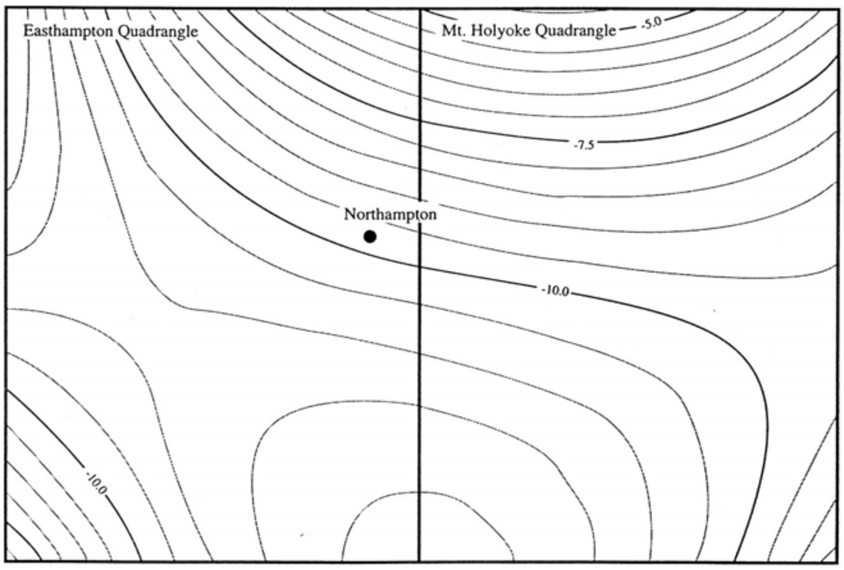
The Free Air and Bouguer corrections for these data were discussed in B4.

● The above examples are for a single profile. However, regional trends are usually removed from Bouguer anomaly data defined on a grid (i.e. a Bouguer anomaly map)

The regional trend of real gravity data collected on a 2-D grid is shown in Burger 6-27 and 6-28




(a) Measured Bouguer anomaly data




(b) 3rd order trend surface that gives best fit to data

## B6.2 Half width techniques

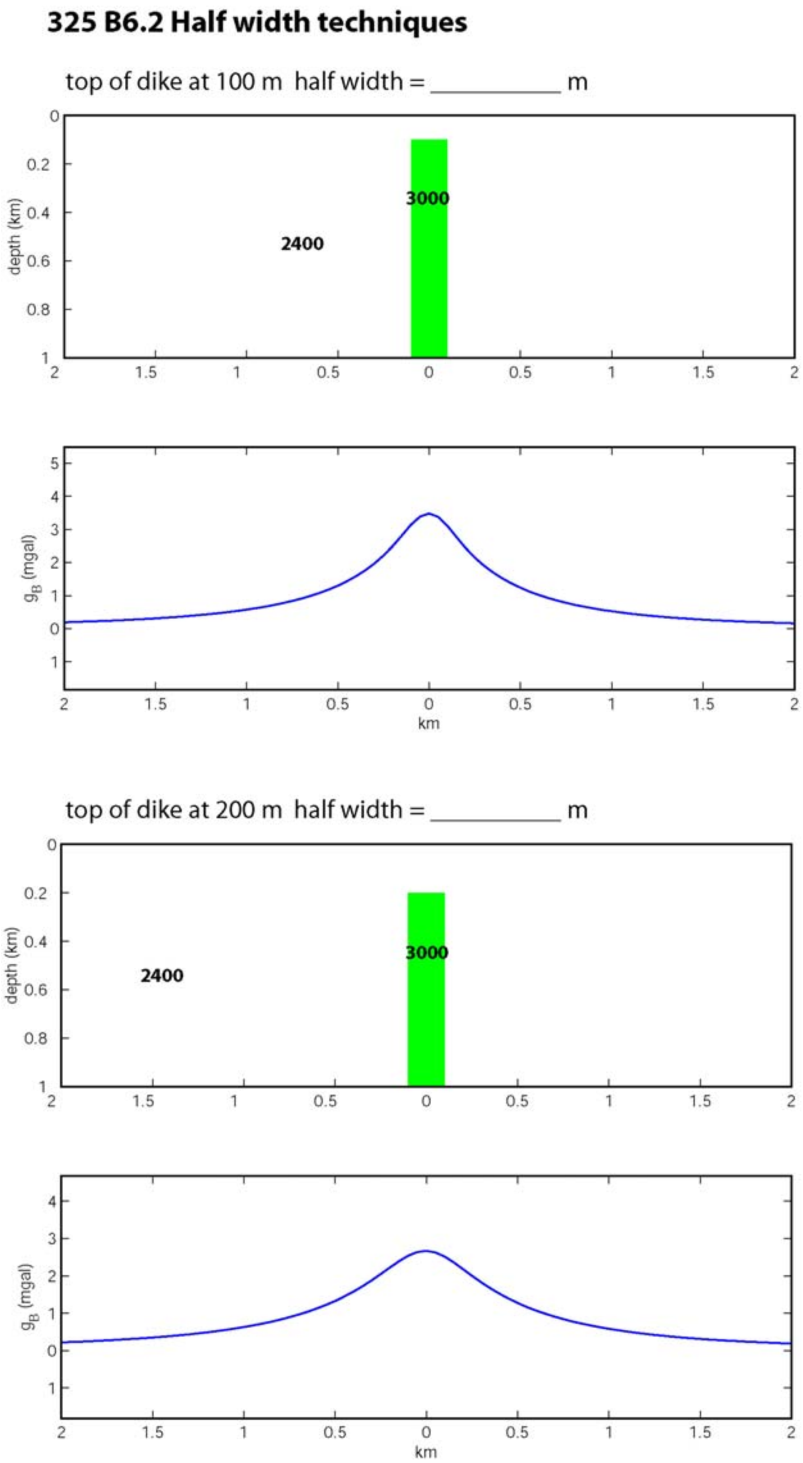
- For a number of shapes the width of the anomaly can give an approximate depth to the density anomaly.

  *e.g.* sphere : depth of centre = half-width

  cylinder : depth of centre = 1.304 *x* half-width

  In these cases the ratio half-width / depth is constant for a range of depths.

- However in some cases this is not so. Consider the vertical dikes shown below.



Anticline (*Geophysics*, **12**, 43, 1947)

# AMBIGUITY IN GRAVITY INTERPRETATION

D. C. SKEELS

## ABSTRACT

It is shown that contrary to what is stated and implied in much of the literature, gravity data cannot, of themselves, be interpreted uniquely. It is shown by means of a two-dimensional example that for a given anomaly and a given density contrast a wide range of possible interpretations can be made, at various depths, and that whereas there is a maximum depth for the solution the minimum depth is zero. Other examples are given to show that depth rules based upon the assumption of geometrical shapes may give results very much in error when applied to actual anomalies. Nor does the method of interpretation by vertical gradients allow us to make an unique interpretation, or to distinguish deep from shallow anomalies as has been claimed. It is shown that we do not escape the ambiguity by using second derivative quantities such as gradient and curvature, and that, in fact, gravity and its derivatives are related by a corollary of Green's theorem. This theorem provides an analytical proof of ambiguity not only for the case of gravity data but for magnetic data as well.

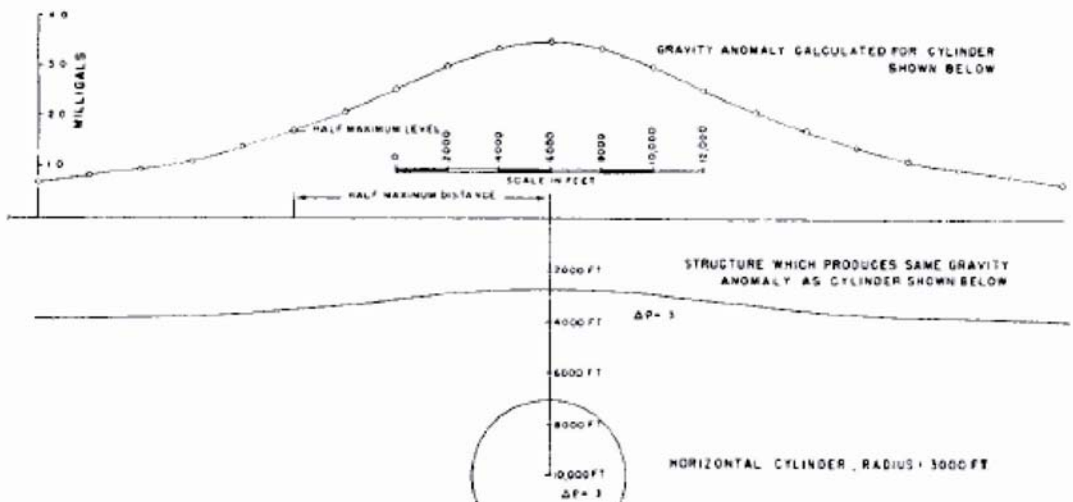



FIG. 5. Gravity effect of a horizontal cylinder and a broad anticline at much shallower depth which will produce an identical effect.

## B6.3 Gauss's theorem

Consider a buried ore body, with excess mass ΔM. Gauss's theorem states that

$$\int_S g.dS = 4\pi G \Delta M$$

Consider the surface 'S' as a hemisphere with 'S1' = upper surface on the Earth's surface. And 'S2' = surface of hemisphere, radius *r*.

$$\int_S g.dS = \int_{S1} g.dS + \int_{S2} g.dS = \int_{S1} g.dS + \frac{G\Delta M}{r^2} 2\pi r^2 = \int_{S1} g.dS + 2\pi G \Delta M$$

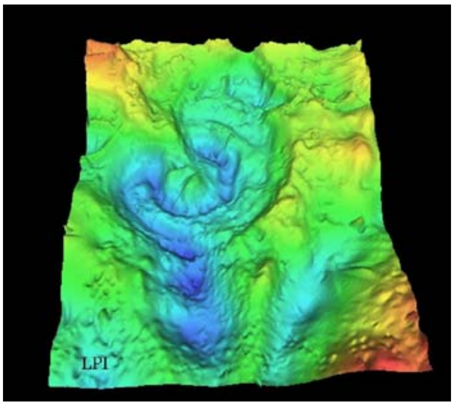
Thus

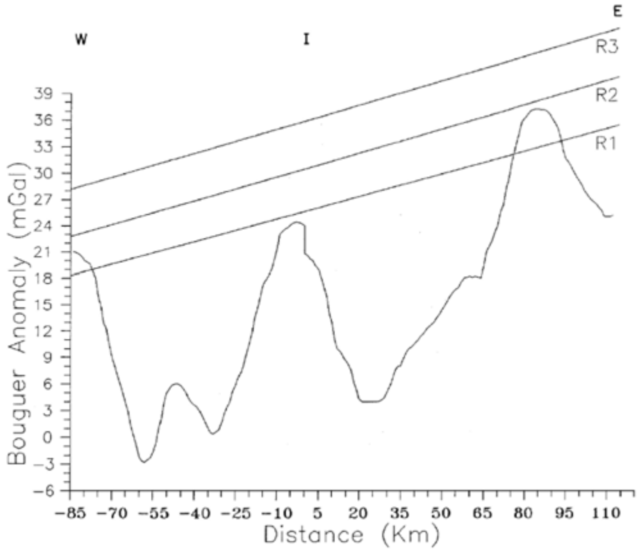
$$\int_{S1} g.dS + 2\pi G\Delta M = 4\pi G \Delta M \quad \text{and} \quad \int_{S1} g.dS = 2\pi G \Delta M$$

Excess mass can be computed as, $\Delta M = \frac{1}{2\pi G}\int_{S1} g.dS$

The right hand side of this equation could be computed from measurements of **g** on a grid of points on the Earths surface. It is important that the measurements extend well away from the ore body.

**Example**: Data from the Chicxulub Impact Crater in Mexico




The gravity anomaly consists of a series of ring shaped anomalies. The ring shaped gravity low can be seen at -55 km and +35 km in the figure above. This gravity low is due to a **mass deficit** that occurred when basement rock was excavated during the impact and replaced by lower density crater fill. The relative high value in the centre (distance -10 km in figure above) is due to an **uplift in the basement rocks** in the seconds after the impact that was essentially a rebound.


Total mass deficit can be estimated by applying Gauss's Theorem and integrating over a surface 'S' that is a circle centred at the impact point. The mass deficit estimate clearly depends on the radius to which the integration is extended. A value of 2 10e+12 tonnes is consistent with integration to the crater rim.

Figures from : O. Campos et al, Gauss's theorem, mass deficiency at Chicxulub crater and the extinction of the dinosaurs, *Geophysics*, **63**, 1585-1594, 1998)

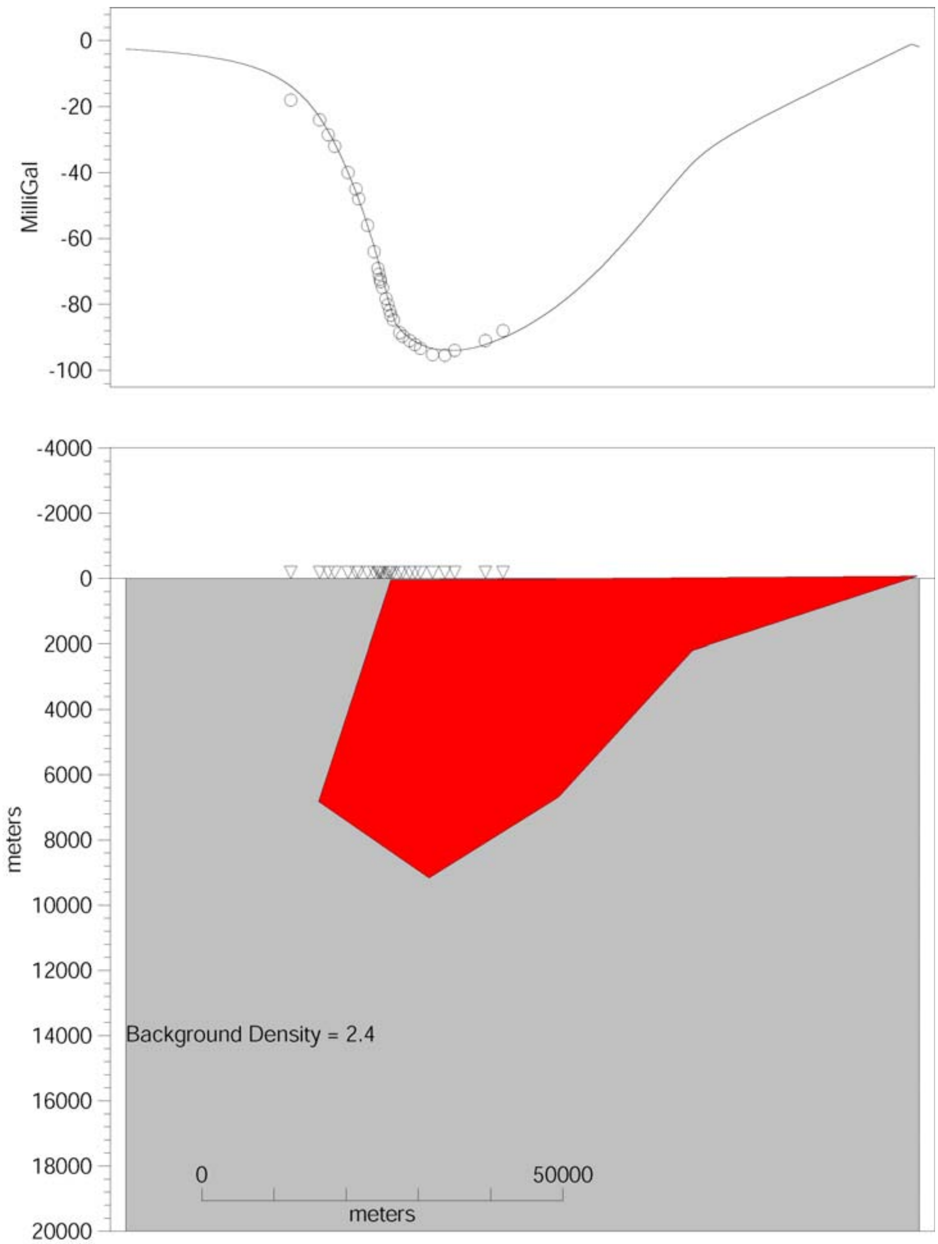
## B6.4 Two dimensional numerical modelling on a computer

● Computer software allows us to model completely general structures very quickly.

● The *Gravmodeler* package is used on field school data in Geophysics 437

● The simple MATLAB code discussed in 325B3.5 was used for most figures in this section of the course.

● Example of data from Seattle basin and Seattle fault. Illustration of non-uniqueness in gravity interpretation.

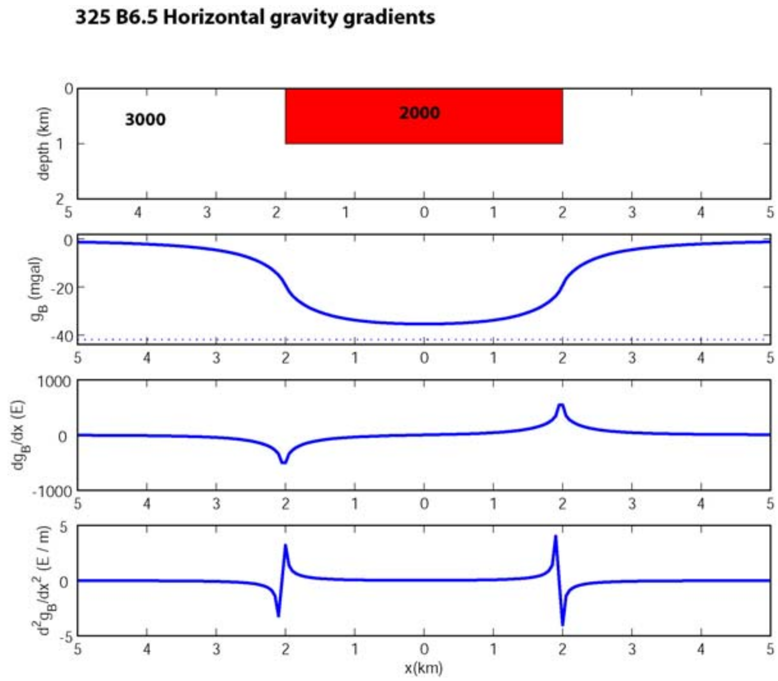


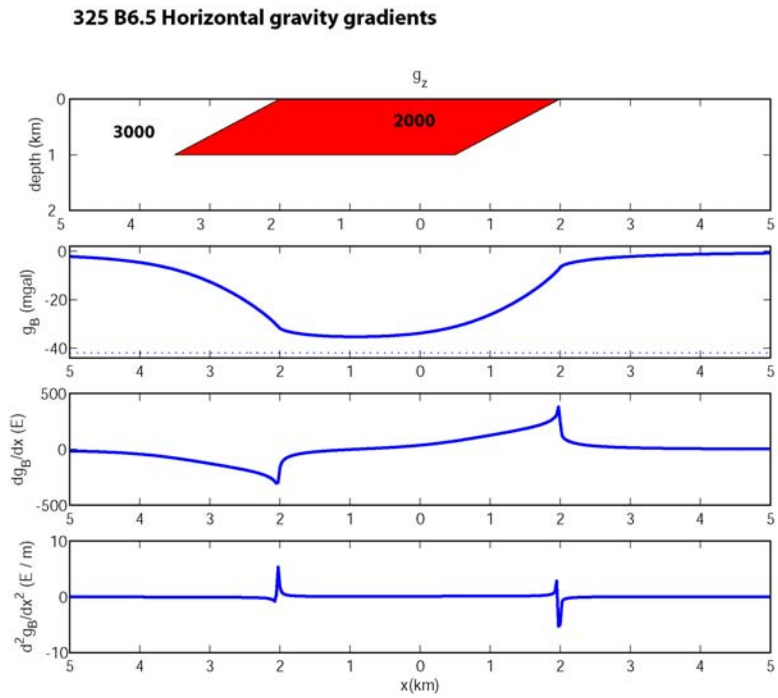
## B6.5 Horizontal derivatives of gravity data

- Taking the horizontal derivatives of the Bouguer anomaly emphasizes **changes** in the horizontal gradient.

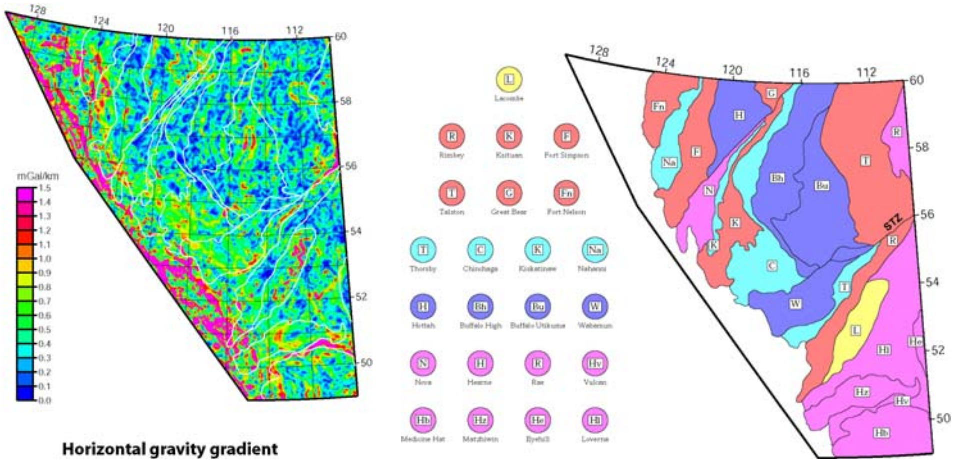
- This is also another way of removing (or suppressing) the regional trends in the data.

- Application to the basin example is shown below. Note that the edges are well defined in both the first and second horizontal derivatives of the gravity gradient.

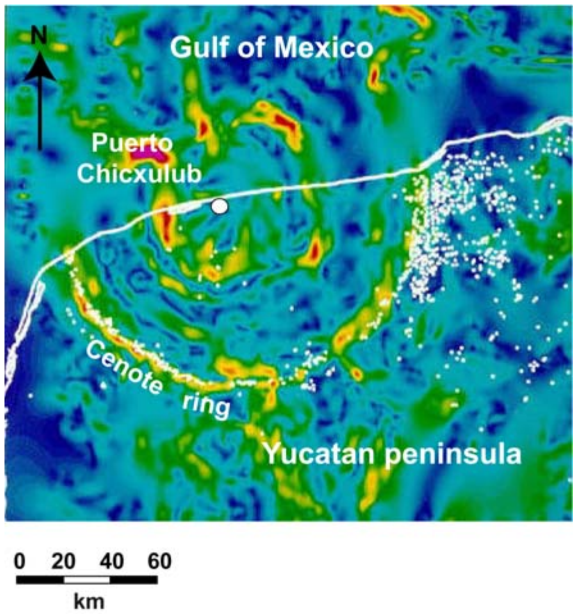


● Data for the Alberta Basement example. Note that the gradient emphasizes the edges of basement features.




● The horizontal gradients of the Bouguer gravity anomaly data from the Chicxulub impact structure defines the edges of the structure very clearly. Data from Alan Hildebrand, University of Calgary.




● Noise in field data can make this procedure unstable, so smoothing may be needed

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