Geophysics 224
B6 Applications of gravity exploration

B6.1 Location of caves and man-made underground cavities

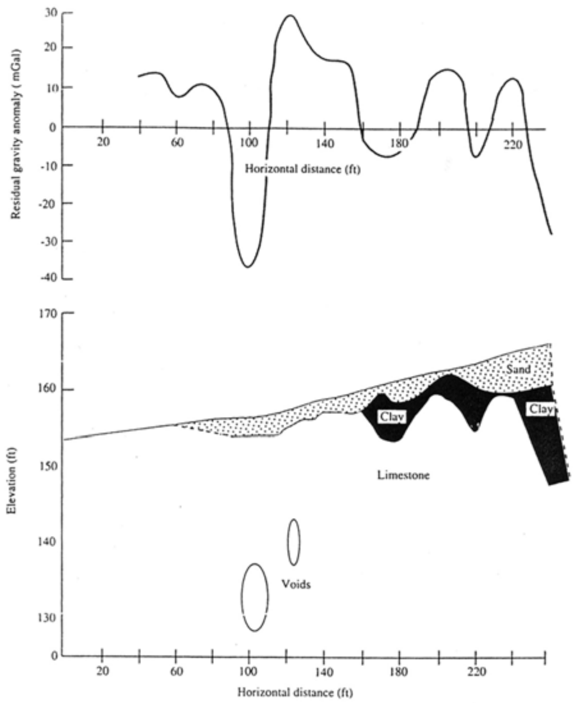


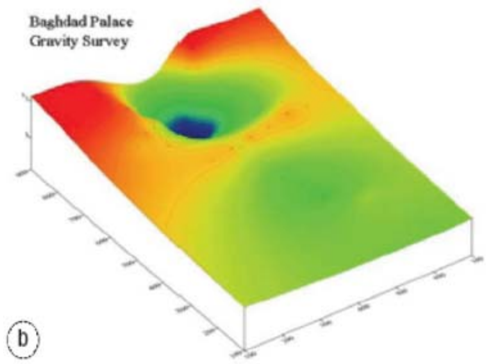
Figure 6-37 Gravity study at Medford Caves, Florida. (a) Profile from residual gravity map. (b) Geologic section determined from borehole information. Gravity highs correlate with limestone pinnacles and voids, and lows correlate with depressions in limestone occupied by clay deposits. (Modified from Butler, Dwain K., 1984, Microgravimetric and gravity gradient techniques for detection of subsurface cavities: Geophysics, v. 49, p. 1084–1096.)

●Cave location in karst terrain. Taken from Burger Figure 6-37. The caves produce a decrease in the Bouguer gravity anomaly.

● Sand and clay have a lower density than limestone. Note that the variable thickness of sand and clay can mask the effect of the voids.

● The -30 mgal anomaly looks very big for such a small cave! Can you verify the result with the formula for a cylinder?

● Microgravity was recently used by United Nations weapons inspectors to look for underground bunkers in certain Middle Eastern countries.



"Microgravity meters -- also called gravimeters -- measure minute differences in gravitational pull at one site versus another. Large underground voids, such as tunnels or weapons production facilities, slightly lower Earth's gravitational pull at the surface right above the voids. Gravimeters can detect these differences, indicating where such facilities might exist. According to a source familiar with the inspections, gravimeters operate too slowly to efficiently scan large areas. However, they work well within a single structure, such as a palace or a bunker, where single and/or multiple basements are suspected" (*Geotimes*, 2002)

Figures from an interesting article by Won *et al.*, (2004).

See also http://www.agiweb.org/geotimes/nov02/WebExtra112702.html

- Kearey Figure 6.30 Microgravity detection of cavities at the site of a proposed cooling tower for a power station. Note that contours are in gravity units (g.u.).

B6.2 Geotechnical studies

- Size and geometry of landfills. The contents of the landfill are usually lower in density than the rock that was removed. Burger Figures 6-38 and 6-39 show a study of a known landfill that was used to see what gravity anomaly was associated with a small landfill. Before and after air photos were used to estimate the depth of the landfill.

- What is the average density of this landfill?

- How accurate must the vertical surveying be for data that is accurate to 0.1 mgal?

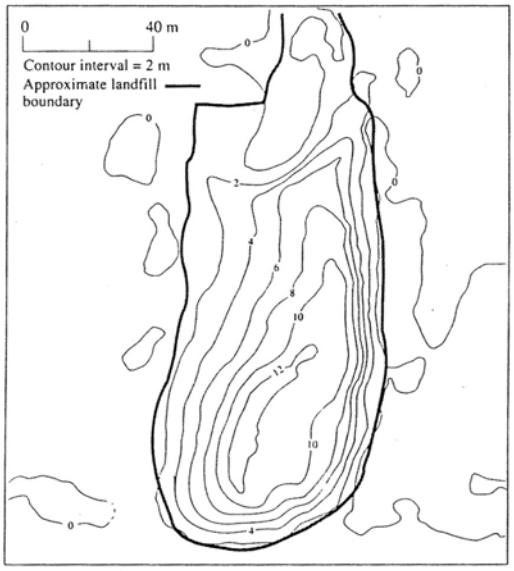


Figure 6-38 Isopach map of the Thomas Farm landfill, northwestern Indiana. (Modified from Roberts, R. L., Hinze, W. J., and Leap, D. I., 1990, Application of the gravity method to investigation of a landfill in the glaciated midcontinent, U.S.A. *in* Ward, Stanley H., ed., Geotechnical and environmental geophysics; Volume 2: Environmental and groundwater: Society of Exploration Geophysicists Investigations in Geophysics No. 5, p. 253–266.)

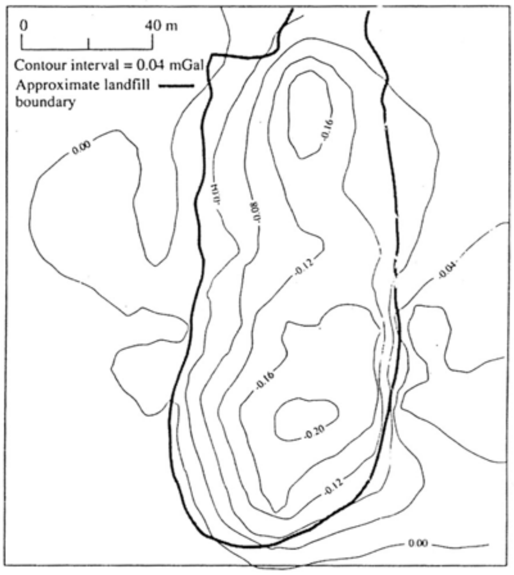


Figure 6-39 Residual gravity anomaly map of the Thomas Farm landfill, northwestern Indiana. (Modified from Roberts, R. L., Hinze, W. J., and Leap, D. I., 1990, Application of the gravity method to investigation of a landfill in the glaciated midcontinent, U.S.A. *in* Ward, Stanley H., ed., Geotechnical and environmental geophysics; Volume 2: Environmental and groundwater: Society of Exploration Geophysicists Investigations in Geophysics No. 5, p. 253–266.)

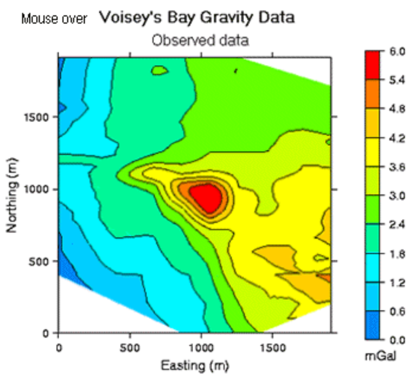
- Other applications of gravity exploration in hydrogeology. Kearey Figures 6.28 and 6.29 show how gravity data were used to detect buried river channels containing aquifers near Antofagasta in Northern Chile. The gravity data do not detect the aquifers directly, but locate structures that contain the aquifers.

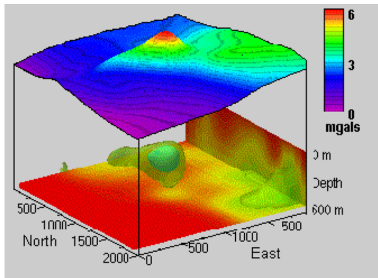
- Depth to bedrock studies

B6.3 Mineral exploration

Ore bodies are often higher density than the host rock and can produce positive gravity Bouguer anomalies. Gravity can be used to estimate the excess mass of an ore deposit, using Gauss's theorem. While non-uniqueness prevents the spatial distribution being uniquely determined, the **total excess mass** can be estimated reliably (see Kearey 6.10.3).

The example below comes from Voisey's Bay, Labrador. This massive sulphide deposit has a pronounced positive gravity anomaly. Note that **gravity inversion** is an automated procedure that determines a density model that fits the measured gravity data. An inversion is a solution of the inverse problem, and non-uniqueness must be taken into account.





3D Inversion of gravity: Voisey's Bay Ovoid Ore Body
- Observed gravity data on top of recovered density contrast.
- Isosurfaces at 0.2 g/cc (inside) and 0.4 g/cc.

More information : *http://www.geop.ubc.ca/ubcgif/casehist/voisey/intro.html*

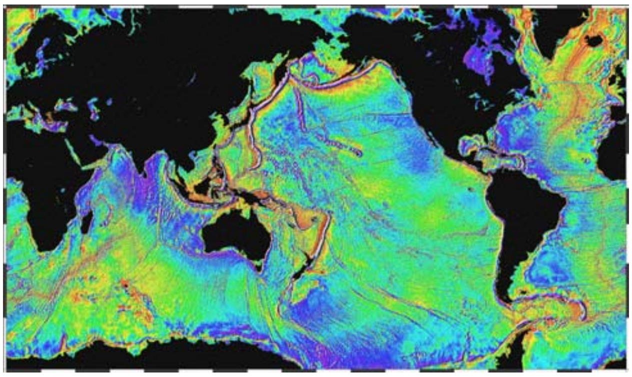
B6.4 Hydrocarbon exploration

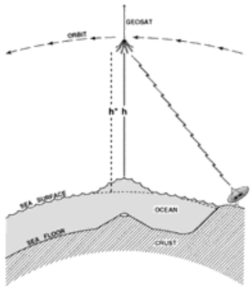
Torsion balances were used in the 1920's in the first discovery of an oil deposit in the United States with a geophysical method (Nash Dome, Louisiana). The torsion balance was quite slow and was rapidly replaced by pendulums in the 1930's.

Applications of gravity exploration in hydrocarbon exploration include:

- **Reconnaissance surveys** to map the thickness and extent of sedimentary basins. Can also locate buried rift structures and basement faults. Generally basins are gravity lows. Reef trends can sometimes be identified.

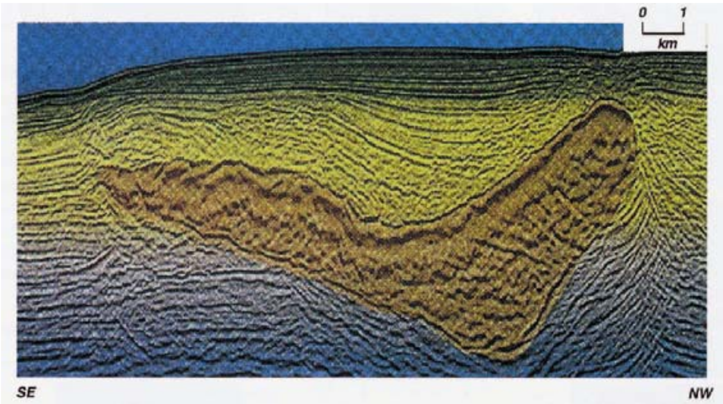
  In addition to surface and airborne gravity data, **satellite gravity data** has contributed to exploration in offshore areas.





Figures from: http://topex.ucsd.edu/marine_grav/mar_grav.html

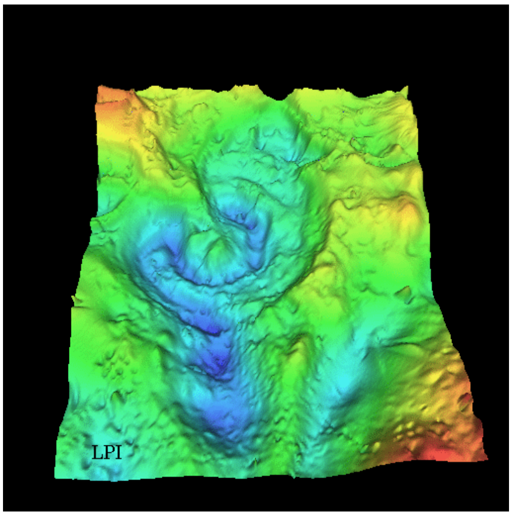
● **Salt structures**. Salt has a lower density than surrounding sedimentary rocks, and gravity data can be used to characterize the geometry of salt layers and domes. Locating the **base of a salt body** is difficult with seismic reflection data, and alternative geophysical methods are being used. In combination with seismic reflection data, gravity can be used to give a joint interpretation. This can include hypothesis testing of a velocity model. Since gravity data is usually available on a grid, it can be used to extrapolate features between, or beyond, seismic coverage.



●Continental scale data gravity databases can also be used. More effective when regional features due to isostatic effects are removed (*Chapin*, 1998 in volume edited by *Gibson and Millegan*, 1998).

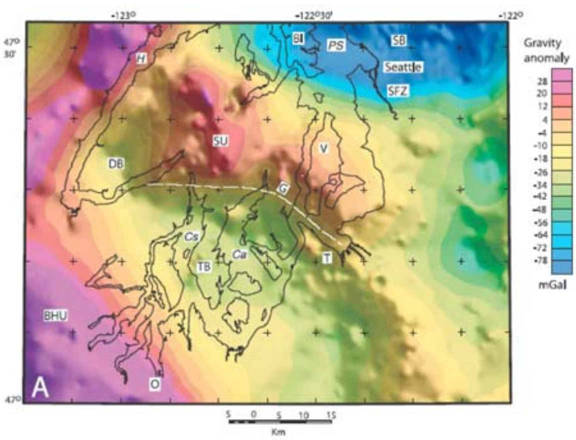
B6.5 Regional scale studies of lithospheric structure

- **Impact craters** : The Chicxulub Impact crater in Mexico was initially discovered from Bouguer anomaly data. The ringed shaped gravity low is caused by a basin that is filled with lower density sedimentary rocks that were deposited in the crater after the impact. The Bouguer gravity high in the centre is due to crystalline basement rocks that rebounded immediately after impact. In Lab 2 we will interpret these gravity data and estimate the thickness of the basin.



- **Isostacy** : Gravity measurements have also led to the concept of isostacy. Based on observations by Pierre Bouguer in South America (1735), and George Airy and John Pratt in India (1800's) who noted that pendulums were not deflected as much as expected by large mountain ranges. These observations can be interpreted to show that these mountains and plateau are supported by a **low density root**. This is very similar to the way that an iceberg floats in seawater, where most of the ice is below sea level.

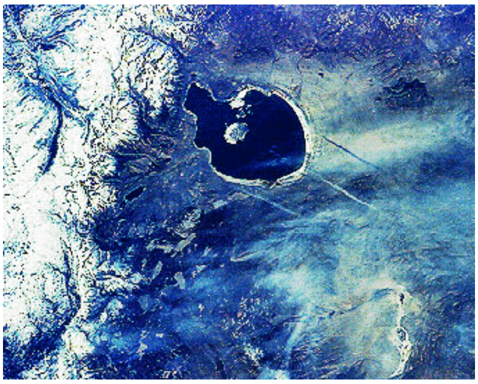
- **Basin structure and earthquake hazards**: The Seattle Fault forms the Southern edge of the Seattle Basin, and may have caused M=7 earthquakes in the recent geological past. In Lab 2 we will model gravity data that have been used to study the geometry of this fault. In this study data were collected along the shore of Lake Washington. This allows measurements to be made at a constant elevation and removes the need for Bouguer or Free Air corrections to be made.

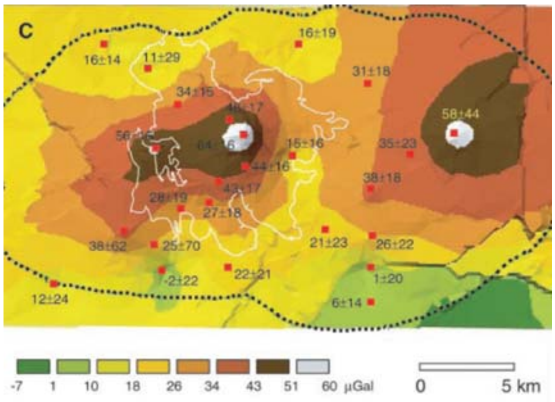


Modelling of these gravity data also provides a useful illustration of the inherent **non-uniqueness** associated the interpretation of gravity data.

B6.6 Temporal variations in gravity

Time variations in gravity have been observed on active volcanoes as magma intrudes prior to an eruption. What could cause an increase or decrease in gravity in such a case?





The data above were collected at Long Valley Caldera, California. It is not clear if this will provide a useful tool for predicting eruptions. Typical changes are of the order of 50 µgal.

Data analysis requires that time variations **in elevation** must also be accounted for. Why is this important?

References

M. Battaglia *et al*, Magma intrusion beneath Long Valley Caldera confirmed by temporal changes in gravity, *Science*, **285**, 2119-2122, 1999.

Geologic Applications of gravity and magnetics: Case Histories, edited by R.I. Gibson and P.S. Millegan, Society of Exploration Geophysicists, 1998.

Gravity and magnetic methods at the turn of the millennium, *Geophysics*, **66**, 36-37, 2001.

Won, I., et al., Geophysics and weapons inspection, The Leading Edge, 658-662, July, 2004