Geophysics 325 B7 Applications of gravity exploration

B7.1 Location of caves and man-made underground cavities

- Cave location in karst terrain. Taken from Burger 6-37. Note that the variable thickness of lower density sand and clay can hide the effect of the voids.

- The -40 mgal anomaly looks very big for such a small cave. Can you verify the result with the formula for a cylinder derived in 325B3.4?
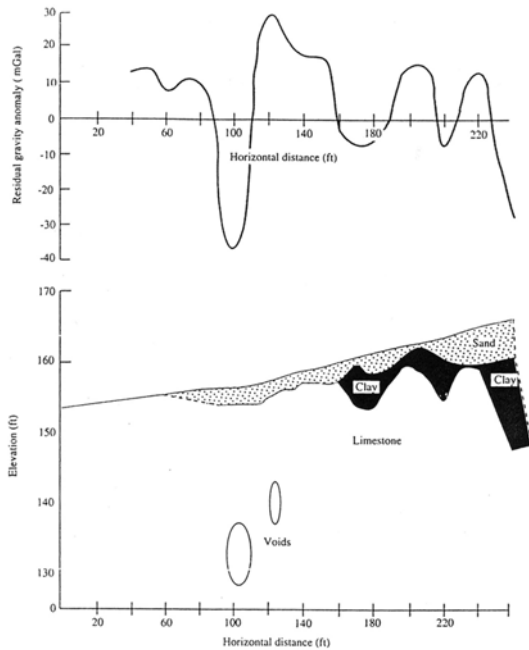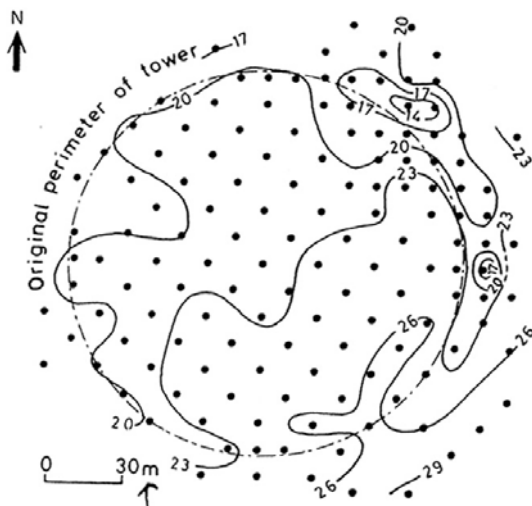
  Note 1 m = 3.28 feet

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.)

- 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.)

  1 gravity unit = 0.1 mgal

- In 2002 microgravity was being by U.N. weapons inspectors to look for underground bunkers in certain Middle Eastern countries. See details in *Geotimes*, December 2002.
http://www.agiweb.org/geotimes/nov02/WebExtra112702.html

Before

After

"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.

See also the Nov 17, 2002 *Edmonton Journal*, article "Saddam hiding arms in mosques".
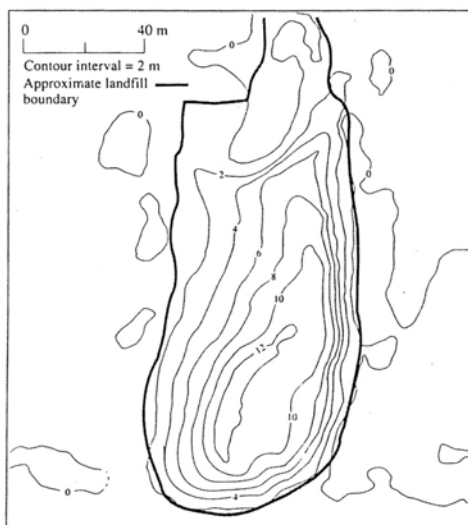
B7.2 Geotechnical studies

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.)
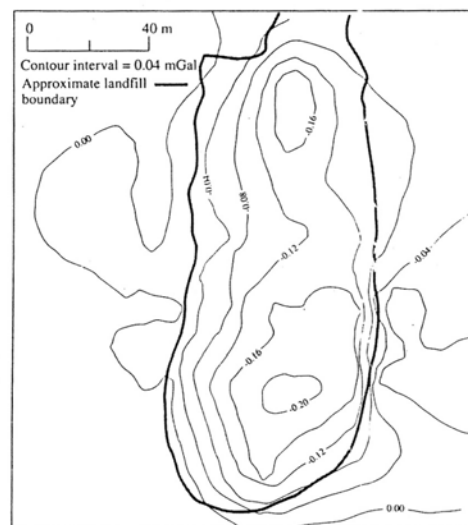

Figure 6-39 Residual gravity anomaly map of the Thomas Farm landfill, northwestern Indiana. (Modified from Roberts, R. L., Hinze, W. ., and Leap, D. I., 1990, Application of the gravity method to investigation of a landfill in the glaciated midcontinent, U.S.A. *in* Ward, Stanley H., ed., Geotechnical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

- Size and geometry of landfills. The contents of the landfill are usually lower in density than the rock that was removed. Burger 6-38 and 6-39. In this case the geometry of the landfill was known, but it provides a test case to show that abandoned landfills might be detected with this method.

- What is the average density of this landfill?

● How accurate must the vertical surveying be for the Bouguer anomaly data to be accurate to 0.1 mgal?

● Other applications in hydrogeology. Kearey figures 6.28 and 6.29 show gravity detection of buried river channels containing aquifers near Antofagasta in Northern Chile. Note how the depth to bedrock is proportional to the Bouguer anomaly.

In this example, coincident seismic refraction data were also collected. The seismic data will image the bedrock as a high velocity refractor.
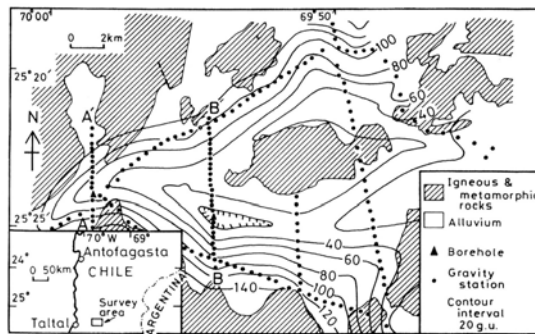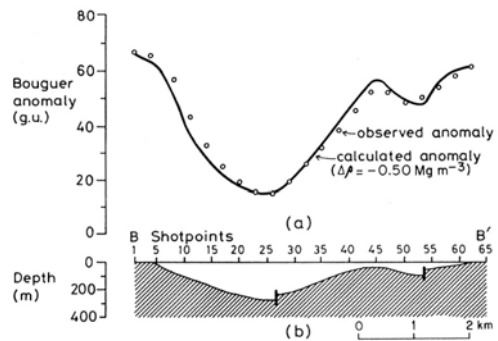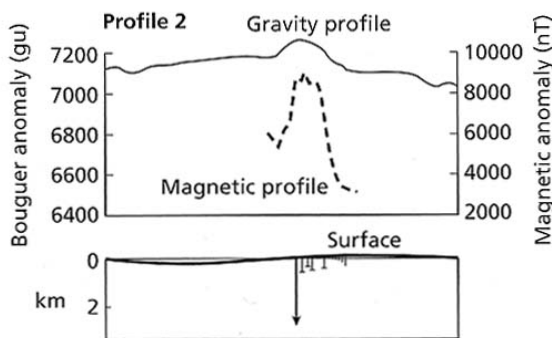

Fig. 6.28 Geological map of an area near Taltal, Chile, showing location of gravity and seismic refraction profiles and contoured Bouguer anomalies. (After Van Overmeeren 1975.)

B7.3 Mineral exploration

● Ore bodies are generally high density and generally produce positive Bouguer anomalies. See Example in Kearey Figure 7-28. The iron ore deposit was coincident with the deep well at the centre of the profile.

Note that the magnetic data gives additional confirmation that the target is an ore body.

● We can estimate **total excess mass** of an ore deposit using Gauss' theorem.While non-uniqueness prevents the spatial distribution being uniquely determined, the **total excess mass** can be estimated (see Kearey 6.10.3).

● Example 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. One way to do this is fix the density contrast for the target and allow the inversion to compute the shape.
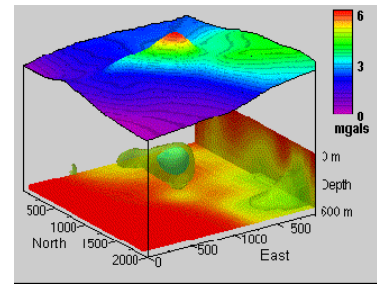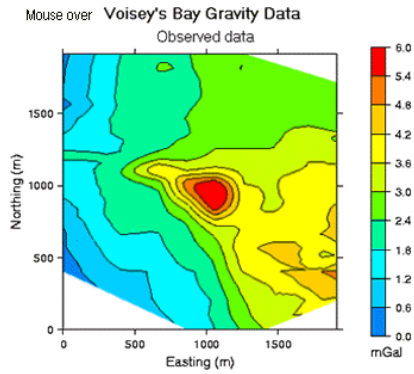
3D Inversion of gravity: Voisey's Bay Ovoid Ore Body
- Observed gravity data on top of recovered density contrast.
- Isosurfaces at 0.3 g/cc (inside) and 0.4 g/cc.

More information look at the WWW pages of the UBC Geophysical Inversion Facility at : *http://www.geop.ubc.ca/ubcgif/casehist/voisey/intro.html*

B7.4 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). Data collection with the torsion balance was quite slow and it was replaced by pendulums in the 1930's.


Some applications of gravity exploration in hydrocarbon exploration

● Reconnaissance surveys to find the thickness of sedimentary basins and the locations of buried rift structures. Generally basins are gravity lows. Reef trends can sometimes be identified.

●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).

● Satellite gravity data has contributed to exploration in offshore areas (e.g. Black Sea, Gulf of Mexico, Western Australia).
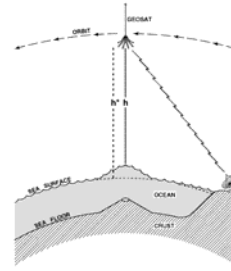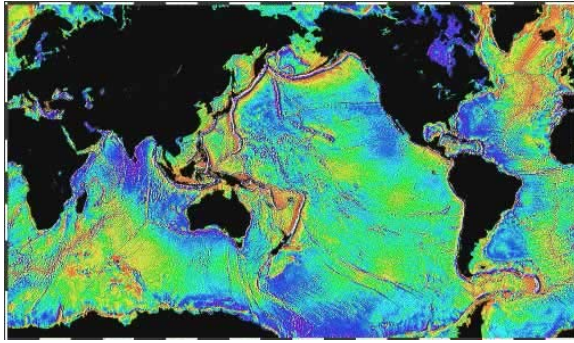
Details of satellite gravity are found in 325B5.2 and at
http://topex.ucsd.edu/marine_grav/mar_grav.html
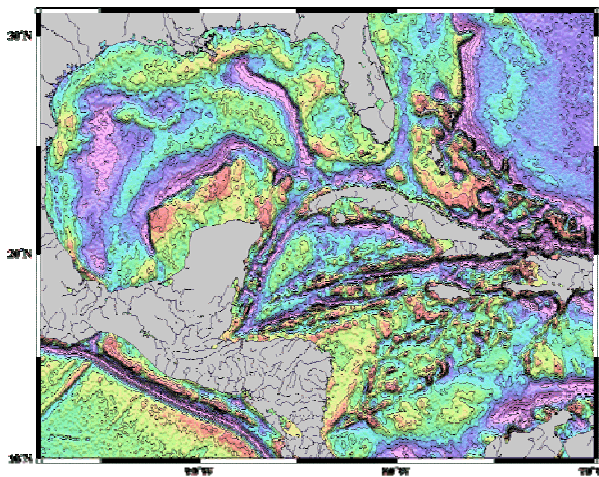
- In combination with seismic reflection data, gravity can be used to give a joint interpretation. This can include hypothesis testing of a velocity model. Since gravity data is usually available on a grid, it can be used to extrapolate features between, or beyond, seismic coverage.
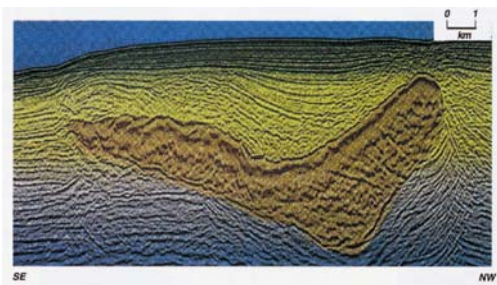
- Sub-salt imaging. Salt is often found in a sub-horizontal layer and seismic data cannot easily determine the depth to the base of the salt layer. Gravity data (and also gravity gradient data) can give additional constraints.
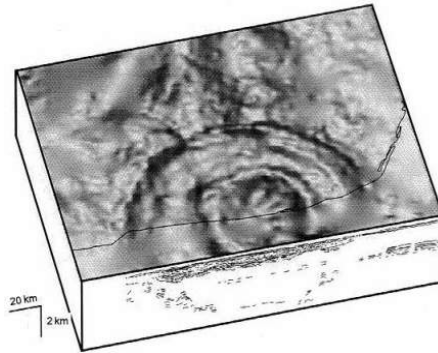
References

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.
http://www.lacosteromberg.com

B7.5 Regional scale studies of lithospheric structure

● 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. The figure above also shows seismic reflection data collected offshore. The combination of gravity and seismic reflection exploration can be a powerful one.

● Gravity measurements led to the concept of **isostacy**. This has shown that some mountains and plateau are supported by a crustal root, similar to the way that an iceberg floats in seawater with most of the ice is below sea level. See 325B8

● **Time variations** in gravity measurements have been observed on active volcanoes as magma intrudes prior to an eruption (*e.g.* Long Valley Caldera, California). A number of factors can change the measured gravity and include (1) intrusion of igneous rocks, (2) changes in surface elevation and (3) a redistribution of groundwater.
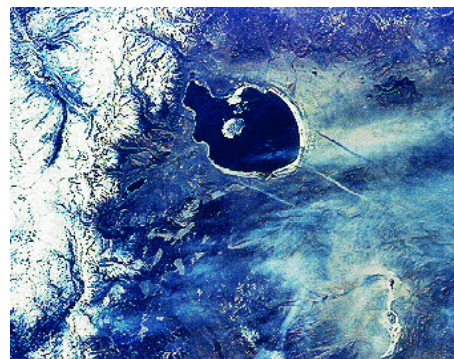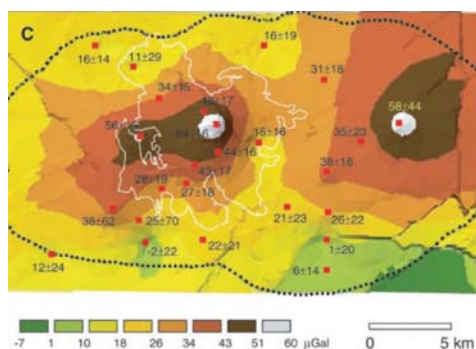
● It is not clear if this will provide a useful tool for predicting eruptions. Typical changes are of the order of 50 μgal.

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