224 B4. Instrumentation and field procedures

224B.4.1 Instrumentation for gravity exploration - gravimeters

4.1.1 Absolute measurements of g

A range of devices can be used including reversible pendulum and free fall devices. They are generally more expensive and slower to operate than a mass-on-a-spring gravimeter.

For details of instrumentation	http://www.microgsolutions.com/
Application to tectonics in BC	http://www.pgc.nrcan.gc.ca/geodyn/abs_grav.htm
	http://www.pgc.nrcan.gc.ca/geodyn/cascadia.htm

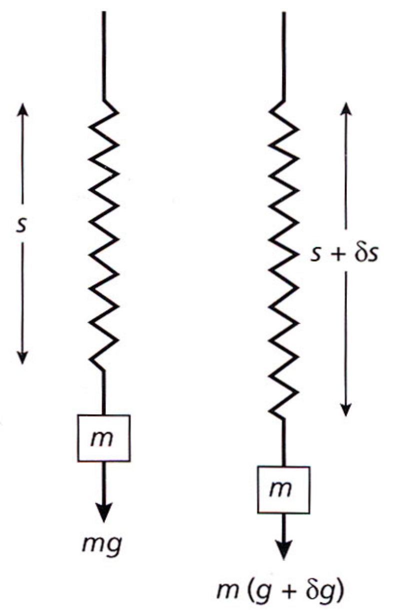
4.1.2 Relative measurements of g (measure differences in g)

Since we have seen that it is the **differences** in gravity that is generally more important than absolute values, we do not need absolute measurements of gravity at every survey location. Often relative gravity measurements can be made over a survey area, and then tied to an absolute value by using the relative gravimeter at a location that was previously surveyed with an absolute gravimeter.

(a) *Portable pendulum*

Accuracy around 0.25 mgal when popular in the 1930's

(b) Mass-on-a-spring gravimeters



The mass experiences a force of $F = mg$ and the spring stretches an amount s. Hooke's Law states that

$$F = ks = mg$$

where k is a measure of the stiffness of the spring (the spring constant). If the gravimeter is then taken to a location where the acceleration of gravity is stronger by an amount δg, then the spring will stretch a little bit more, δs.

$$k(s+\delta s) = m(g+\delta g)$$

Subtracting these two equations gives

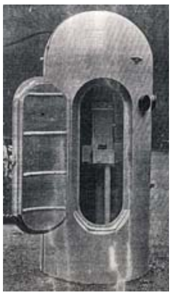
$$\delta g = \frac{k\delta s}{m}$$

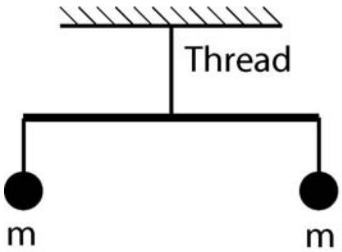
δs can be very small, so various engineering features are used to amplify the movement. Typical accuracy is 0.01 mgal. What change in elevation produces 0.01 mgal?

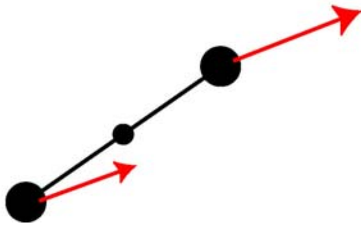
Two widely used gravimeters are:

- ●LaCoste-Romberg gravimeter (http://www.lacosteromberg.com)
- ●Worden gravimeter (http://www.gravityservices.com/meter.htm)

4.1.3 Gravity gradient measurements (dg/dx)

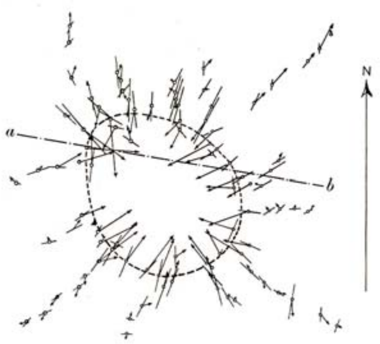


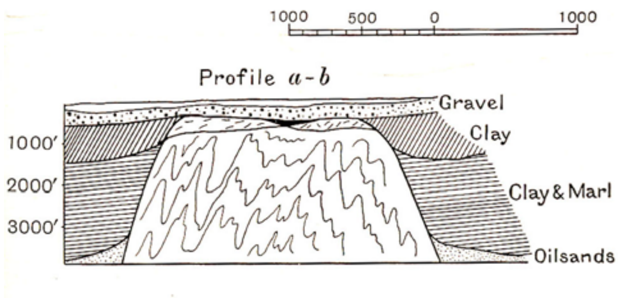




These were initially made with torsion balances. In a torsion balance, two masses are suspended from a beam. The force required to twist the thread is determined by calibration. The horizontal pull of gravity will tend to orient the beam so it points towards or away from concentrations /deficits of mass. The Cavendish torsion balance allowed measurements of *G* to be made. An alternative design was developed by Baron von Eötvös in Hungary in the later 19th century and was used in **the first geophysical discovery of oil** in the early years of the 20th century.

The torsion balance was quite effective at locating salt domes, owing to the lower density of the salt compared to the surrounding sedimentary rocks. The torsion balance required a light-proof and wind proof chamber to house the instrument.





Figures from *Applied Geophysics*, Eve and Keys, Cambridge University Press, 1928

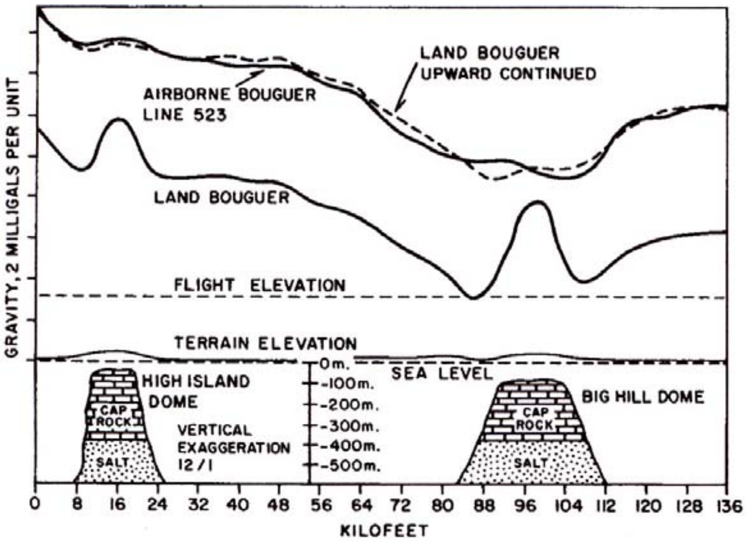
4.1.4 Marine gravity surveys

Conventional gravity measurements can be made by stopping the ship and lowering a gravimeter to the sea floor for each measurement. However, this is very time consuming, especially in deep water.

To measure gravity on a moving ship, the gravimeter is placed on a **gyroscopically stabilized platform** and for each measurement, **g** is measured for several minutes. The acceleration due to the waves is equally positive and negative and thus the average value is due to the acceleration of the Earth. This steady **velocity** of the ship must also be accounted for through the Eötvös correction. Typical accuracy of marine gravity data is around 1 mgal.

4.1.5 Airborne gravity surveys

The problems encountered in marine gravity surveys are even more severe in airborne exploration (turbulence can produce an acceleration greater than **g)** and velocities are higher. However, airborne measurements are excellent at covering large, roadless areas very easily. In contrast to marine surveys, the acceleration of the aircraft can be independently measured through accurate measurements of aircraft elevation as a function of time. The acceleration of aircraft can be computed and then removed from the acceleration recorded on board.



From, Sigmund Hammer, Airborne gravity is here, *Geophysics*, 1983. Note that:

- **Upward continuation** is a mathematical method that uses gravity data at one elevation to compute the gravity data that would be measured at a **higher elevation**.
- Gravity measured at 300 m elevation in a helicopter agrees with the upward continuation of the surface gravity measurements (land Bouguer).
- By moving further away from the target, small features such as the (higher density) cap rock are not detected. This is a consequence of the inverse square law.

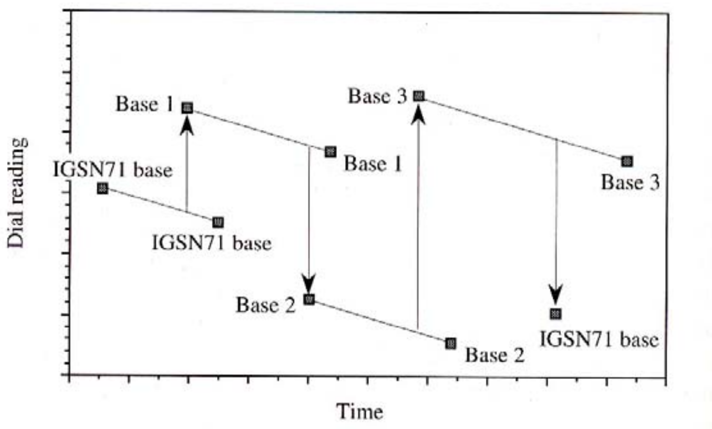
224 B.4.2 Instrument drift and tidal effects

Instrument drift

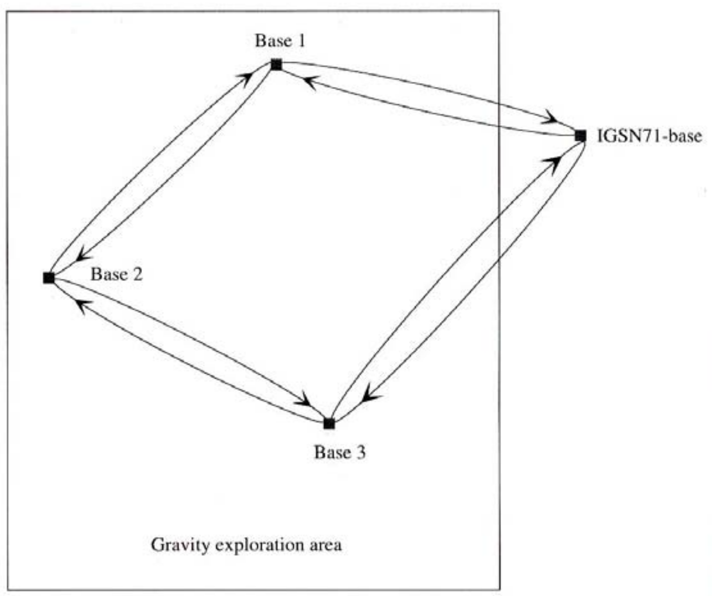
If repeated gravity measurements are made at the **same location** with a relative gravimeter, the answer will **change over time**.

Occasionally, this is due to changes in the density of the Earth. However, it is usually due to the spring in the gravimeter stretching over time. This effect can be removed by establishing a **base station** that is visited repeatedly during the survey.

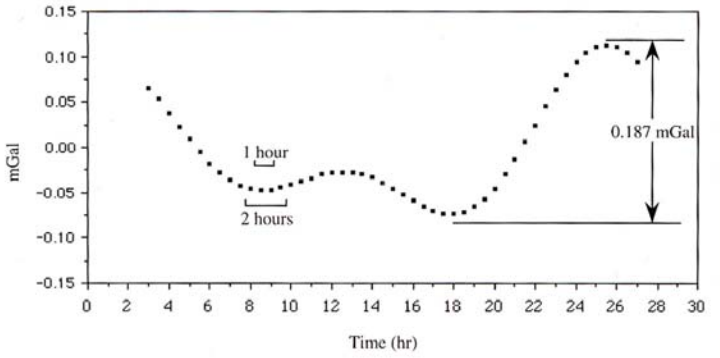
This problem arises because the gravimeter cannot be in two places at once. For example, when the first measurement is made at Base 1, we would like to know the gravity measurement that would be made at the same time at IGSN71 base. This cannot be done, so linear time variation is assumed between the two measurements at the IGSN71 base. This allows us to calculate the difference in gravity measurements (dial reading) between Base 1 and IGSN71 base. Note that the Dial reading is a relative measure of **g** (mgal).



(1) IGSN71 g = 981,000 mgal (absolute)
(2) Difference between IGSN71 and Base 1 is 9 mgals (relative)
(3) Thus, at Base 1, g 981,009 mgals (absolute)



Tidal effects
In additional to instrument drift, gravity measurements made at the same location will vary with time due to tidal effects. This is dominantly due to the gravitational pull of the sun and moon. The magnitude can generally be predicted accurately and removed from the measured gravity data



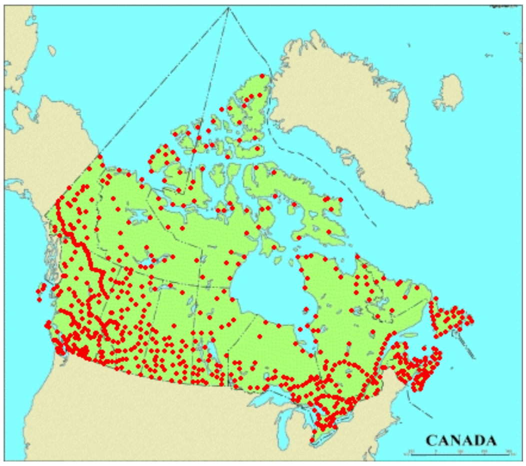
224B.4.3 Gravity survey procedures

- Collect gravity data on a 2-D **grid** and repeat measurements at cross-over points where lines intersect. This will give a good idea of the **repeatability** of the measurements.

- Set up a series of base stations to remove instrument drift and tidal effects from data. These should be visited several times a day.

- We can obtain **absolute** gravity measurements from a **relative** gravimeter by making measurements at **pre-surveyed stations** where the absolute values is already known.

  A network of these stations has been established across Canada and is called the **Canadian Standardized Gravity Network** (CGSN).



  Details can be found at
  http://www.geod.nrcan.gc.ca/index_e/products_e/passiveNetworks_e/cgsn_e/cgsn_e.html

- Details of a base station at the International Airport are listed on the following page and can be found at:

  http://www.geod.nrcan.gc.ca/database7/grav/sd/stage/95001993EN.html
  Here the value is 981117.890 mgal Next time you have time to spare waiting for a flight, see if you can find the benchmark.

Natural Resources Canada / Ressources naturelles Canada

Canada

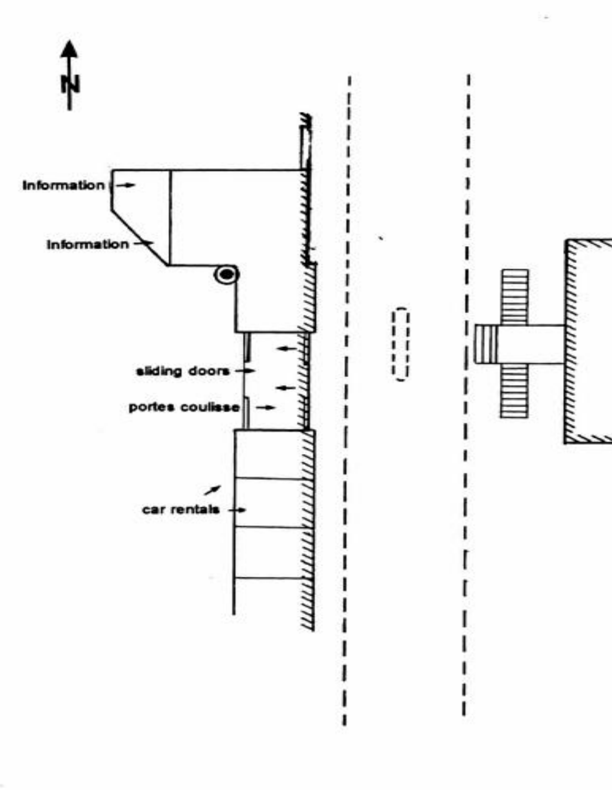
Canadian Gravity Standardization Network (CGSN)

STATION IDENTIFICATION (IGNS71)	STATION COORDINATES (SCALED)
EDMONTON **ALB** **9500-1993** **Gravity: 981117.890 mgal** **Last Inspection: 08/1996**	**Latitude :** N 53° 18' 29" **Longitude :** W 113° 35' 1" **Elevation :** 723 m

STATION INFORMATION AND LOCATION

The station is located in the Terminal of the Edmonton International Airport at Nisku. It is on the floor, in the corner, E of the Information counter on the ground floor of the terminal building. The station is monumented by an aluminum disc.

SKETCH:



DISTANT VIEW:

CLOSE-UP VIEW:

Geodetic Survey Division, Ottawa
http://www.geod.nrcan.gc.ca/index_e/products_e/passiveNetworks_e/cgsn_e/cgsn_e.html

- Often several survey crews needed for each gravimeter crew. It is vital to know the elevation of each measurement location. Differential GPS is sometimes good enough, but levelling may be needed.

- Marine and airborne surveys. Ground is covered much more quickly than with land-based methods, but in general observations made further away from potential targets.

- Satellite gravity: Cannot actually measure acceleration while the satellite is in free fall. However, from detailed observations of the orbit, or by measuring the altitude of the satellite above the Earth's surface, subsurface density structure can be inferred.

Sources of error in gravity data

(a) Vertical position	0.3 mgal per m
(b) Horizontal position	0.0008 mgal per m north-south
(c) Inadequate or incorrect terrain corrections	~ 1 mgal or more
(d) Instrument drift	0.5 mgal per month

(e) Incorrect density used in Bouguer correction

e.g. change in elevation = 100 m, density error 0.1 g cm $^{-3}$ gives an error of 0.42 mgal