GRAVITY AND ISOSTASY

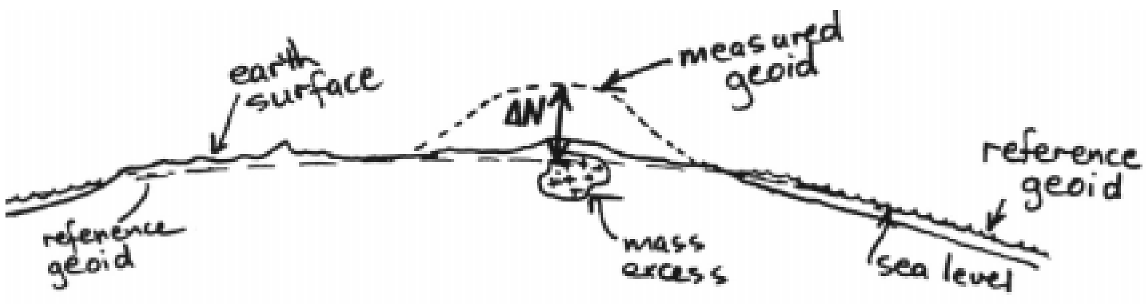
Gravity

The **Geoid** is the oblate spheroid -- the sea level surface over the entire Earth's surface

Physically, the Geoid is an equipotential surface for gravity (i.e. the surface for which the gravitational potential is constant over the entire globe)

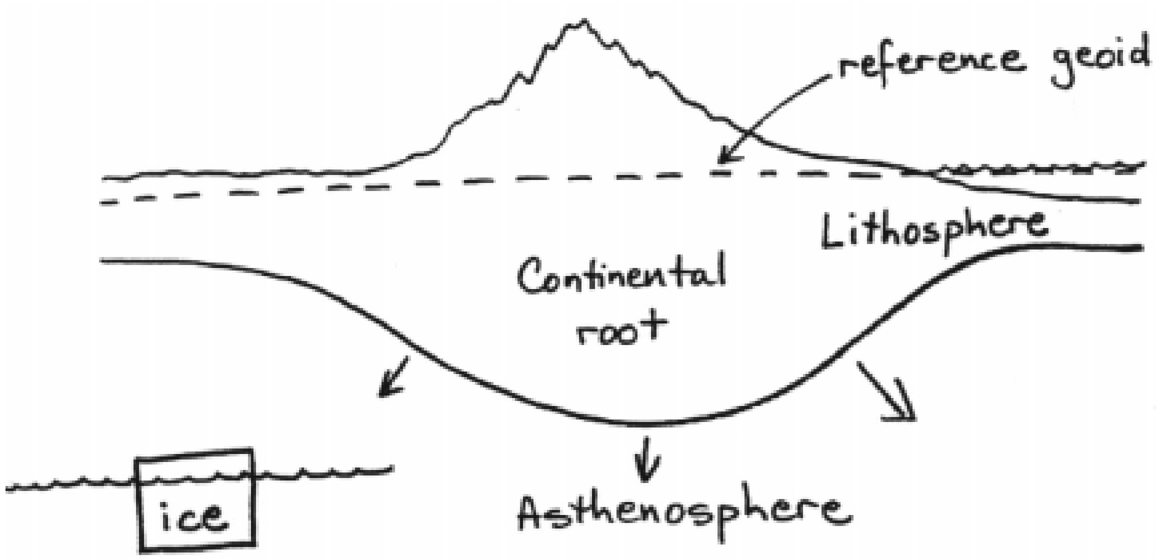
The reference geoid is the best fitting surface to the real geoid.

The difference between the reference geoid and the actual measured geoid at any point on the Earth is the geoid anomaly ΔN. This difference is due to variation in mass distribution in the Earth.



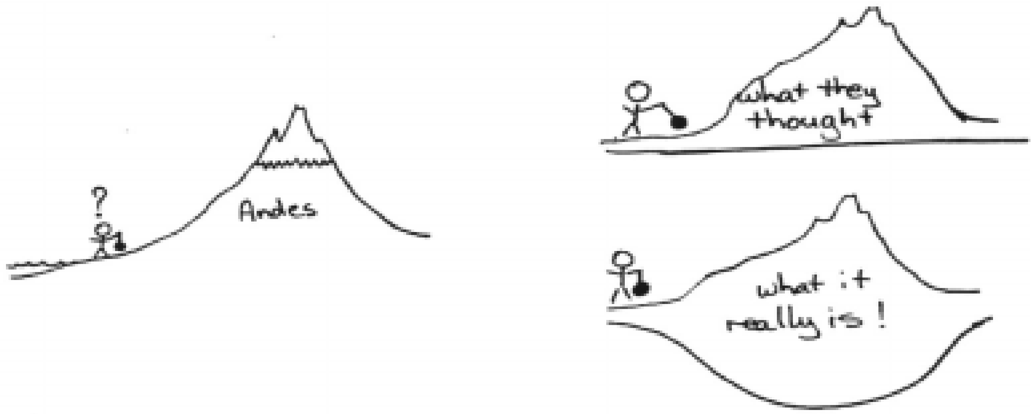
Isostasy

Isostasy is the application of Archimedes principle to the upper layers of the Earth. The continents "float" on a denser mantle substructure. As with icebergs, a large blob above the Earth's surface (major mountain ranges) corresponds to a deep local penetration of crust into the mantle.



The History

Isostasy found its origins in 1735 during the French academy expedition lead by Pierre Bouguer to Peru.
According to the size and hence mass of the Andes, there should be a significant gravitational attraction due to the sheer mass of rock:

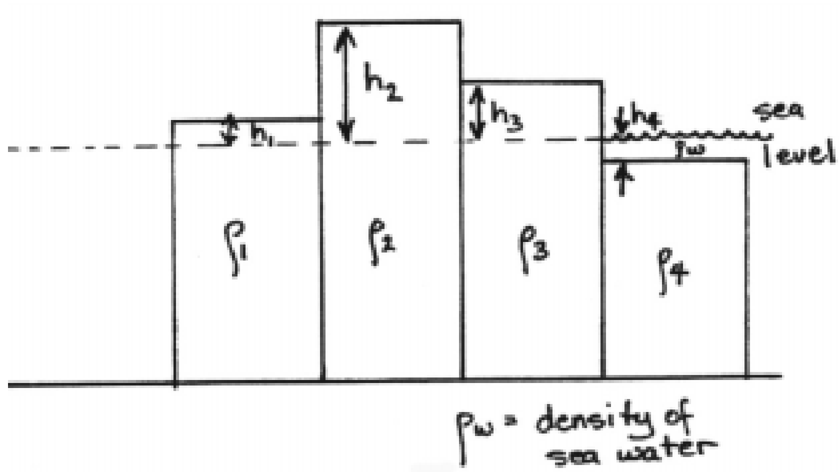


The magnitude of the observed results were much less than predicted from their model (a large mountain chain sitting on the normal rigid crust - no plate tectonics here)

Their observations could only be explained if there was a significant low density root (mass deficiency) under the Andes

In 1855, 2 different hypotheses were proposed to account for the observations of the French expedition.

1. Pratt's Hypothesis: ssumes that the density within the various columns within the crust-upper mantle, above the <u>depth of compensation</u> (that depth below which pressure in the Earth is hydrostatic) varies laterally, depending on topography



$$\rho_1 > \rho_3 > \rho_2$$

Acording to this model, the following conditions must hold (for unit cross sectional area columns):

$$\rho_i(D + h_i) = \text{constant (continental)}$$

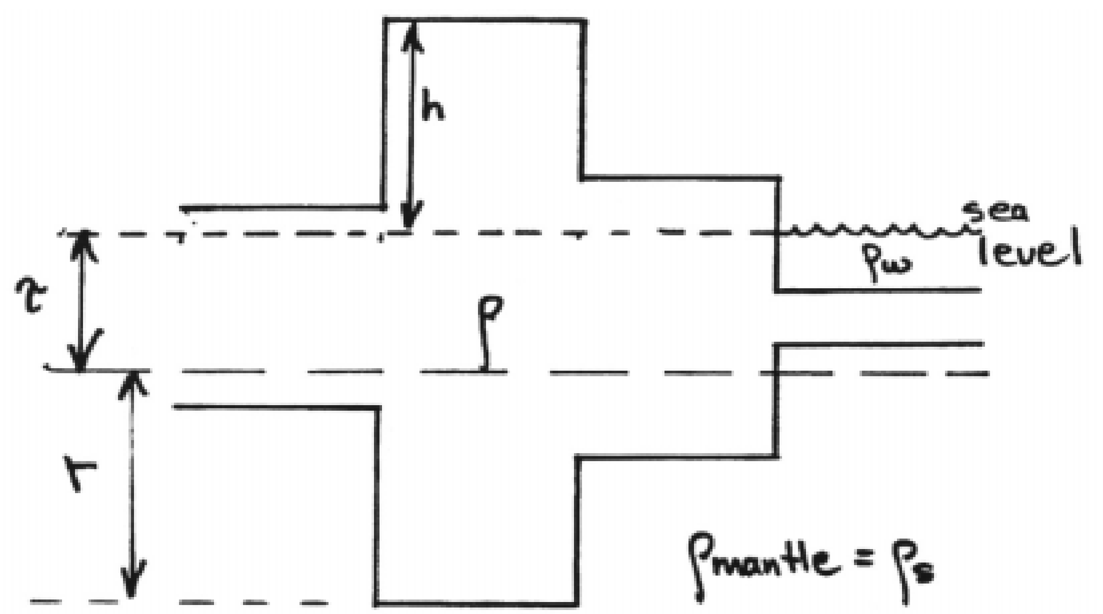
$$\rho_i(D - h_i) + \rho_w h_i = \text{constant (oceanic)}$$

i.e. all columns above have the same total mass

Note: in Pratt's model, mountains must be made of low density rocks and plains of higher density rocks

2. Airy's hypothesis

Unlike Pratt, Airy assumed that the uppermost layer of the Earth has a uniform density ρ, with each column floating in a substratum (the mantle) of density ρ_s, at a depth which is dictated by the length of the column and Archimedes Principle of Buoyancy. Thus compensation occurs as a result of variation in thickness of the uniform density "crustal" layer - high regions are underlain by a thicker than normal crust (crustal root).



The condition for equilibrium is:

$$h_p = r(\rho_s - \rho)$$

where r is the depth of the root below a chosen sea level crustal standard section of depth τ. The value of τ cannot, in practice, be determined uniquely from gravity data alone.

Gravity Anomalies

1. Bouguer anomaly - This anomaly corrects for the gravitational attraction of the rock above sea level and the height of the point of measurement, treating it as a slab of uniform thickness. The Bouguer anomaly is best for looking at local and regional gravity anomalies.

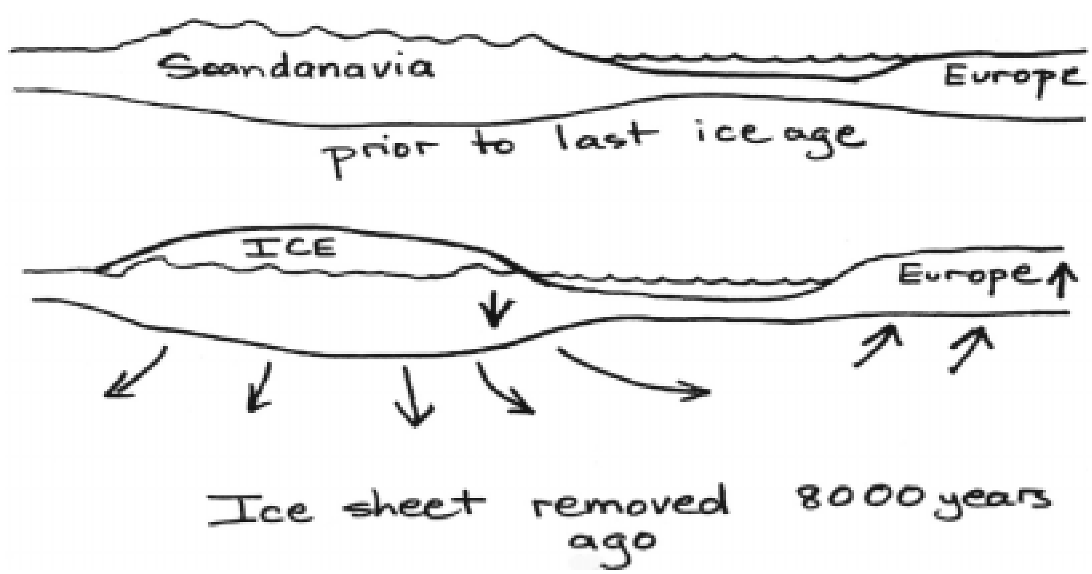
2. Free air anomaly - This anomaly corrects for the variation in gravity with height above the spheroid. The higher the altitude, the larger the FAC needed to correct for altitude. The free air anomaly is best for looking at anomalies in the oceans and at continental margins.

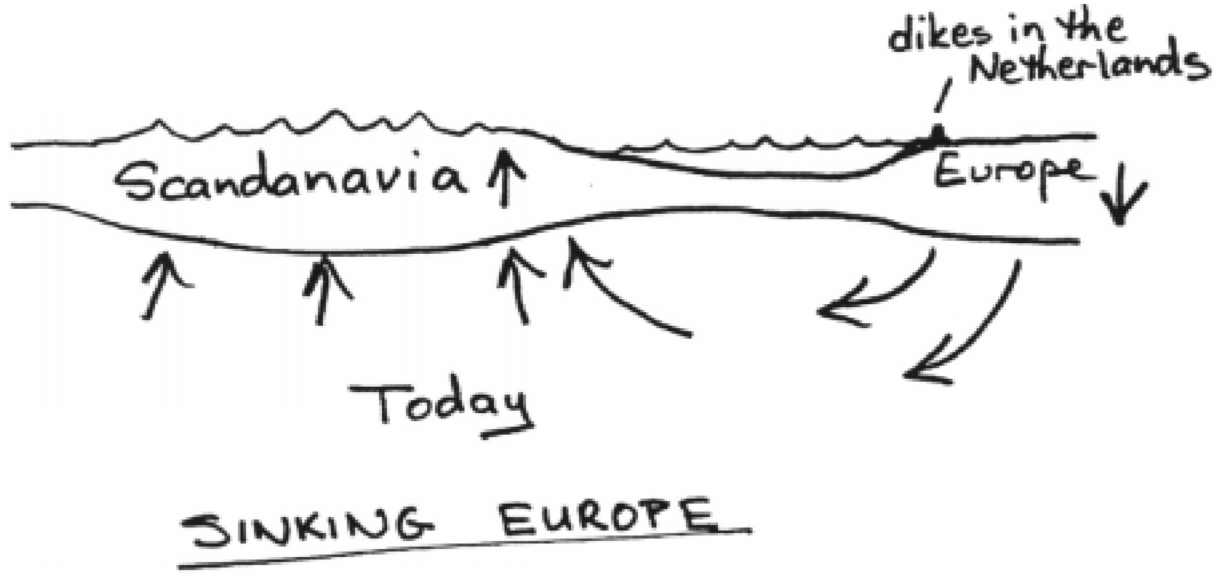
3. Isostatic anomaly - The isostatic anomaly can be derived using either Pratt's or Airy's hypothesis and corresponds to the deviation of the crustal structure from floating statically in the upper mantle. The isostatic anomaly improves on the other 2 anomaly models by taking into consideration the root structure under the crustal structure (mountain range) but that is also a problem as we often don't know what the root looks like.

Isostatic compensation is the sinking or rising of the crustal block until it is floating freely in the mantle. If a crustal block is fully isostatically compensated, it is said to be in isostatic equilibrium.

For a mountain range in isostatic equilibrium, (i.e. it is happy where it is, so that it is neither sinking nor rising)

Subducting plates at oceanic trenches are **not** isostatically compensated.





Interpretation of Isostatic and Free Air Anomalies

The Free Air and Isostatic anomalies give values close to zero for isostatically compensated crust. Terrestrial gravity measurements typically have Free Air and Isostatic anomalies near zero (satellite gravity measurements confirm this), anomalies less than ± 10 mgal, indicating that the Earth's crust is approximately at isostatic equilibrium.

For the crust to remain in isostatic equilibrium during the rapid surface geological activity, such as erosion and tectonic deformation, the crust must be able to sink into and rise out of the mantle more rapidly than these processes. This sinking and rising requires that the upper mantle (asthenosphere) plastically deforms to make room for or replace the crust as it moves. In turn the crust itself must deform by a combination of plastic flow and brittle fracture as it bends and flexes.

From the rate of movement of the crust as isostatic compensation occurs, we can estimate that the strength of the crust and upper mantle during isostatic motion is somewhere in the range 10 - 100 bars (10 - 100 atm). This number is in agreement with the measured stress drop of earthquakes.