GG611
Structural Geology Section

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Lecture 5

Isotasy

Isostasy

- Refers to gravitational equilibrium
- Provides a physical rationale for the existence of mountains
- Based on force balance and buoyancy concepts

$$P = \int_0^h \rho(h) g(h) dh$$

P = pressure (convention: compression is positive here)

ρ = density

g = gravitational acceleration

For constant ρ and constant g,

$P = \rho g h$

http://en.wikipedia.org/wiki/File:Iceberg.jpg

Isostasy

- Assumes a “compensation depth” at which pressures beneath two prisms are equal and the material beneath behaves like a static fluid, where $P_1 = P_2$
- Flexural strength of crust not considered
- Gravity measurements yield crustal thickness and density variations
- Complemented by seismic techniques

http://en.wikipedia.org/wiki/File:Iceberg.jpg

Origin of Theory of Isostasy: da Vinci (from Jones, 1962)

The center of the world continually changes its position in the body of the earth fleeing towards our hemisphere. This is shown by the above-mentioned soil which is continually carried away from the declivities or sides of the mountains and borne to the seas; the more it is carried away from there the more it becomes lightened and as a consequence the more it becomes heavy where this soil is deposited by the ocean waves, wherefore it is necessary that such center changes its position.

That part of the surface of any heavy body will become more distant from the center of its gravity which becomes of greater lightness.

The earth therefore, the element by which the rivers carry away the slopes of the mountains and bear them to the sea is the place from which such gravity is removed it will make itself lighter and in consequence will make itself more remote from the center of gravity of the earth, that is from the center of the universe which is always concentric with the center of of the earth gravity of the earth.

The summits of the mountains in course of time rise rise continually.

Because the centre of the natural gravity of the earth ought to be in the center of the world, the earth is always growing lighter in some part and the part that is lighter pushes upwards and submerges as much of the opposite part as is necessary for it to join the center of its aforesaid gravity to the centre of the world; and the sphere of the water keeps its surface steadily equidistant from the center of the world.

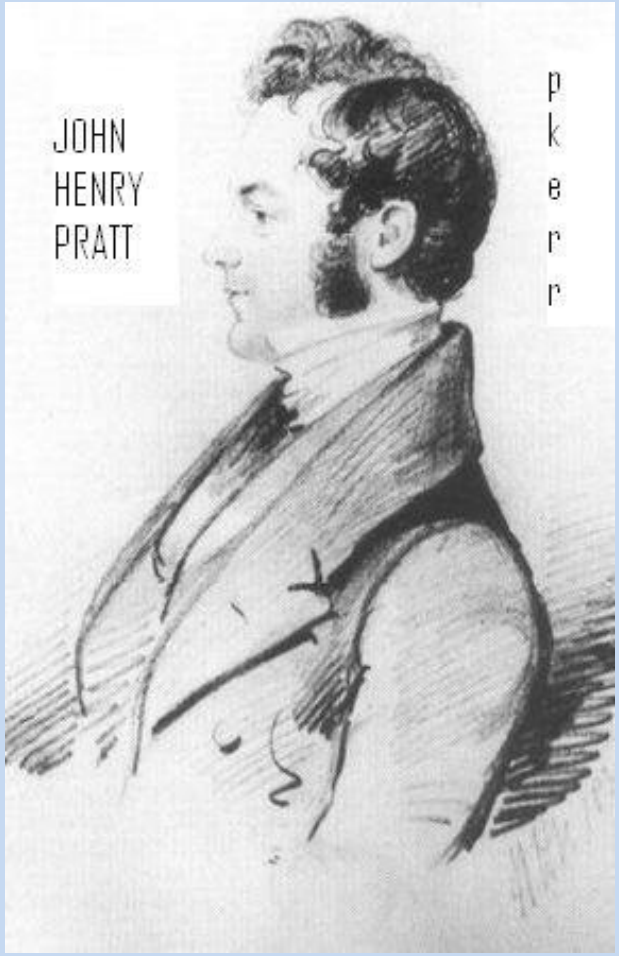
Origin of Theory of Isostasy

- Term coined by Clarence Edward Dutton (USGS) in 1889
- Post-1800 interest triggered by surveying errors in India
- Two main models: Pratt, Airy

https://en.wikipedia.org/wiki/Clarence_Dutton

John Henry Pratt (6/4/1809-12/28/1871)

- Pratt, J.H., 1855, On the attraction of the Himalaya Mountains, and of the elevated regions beyond them, upon the Plumb-line in India. Philosophical Transactions of the Royal Society of London, v. 145, p. 53-100.
- British clergyman and mathematician
- Archdeacon of India



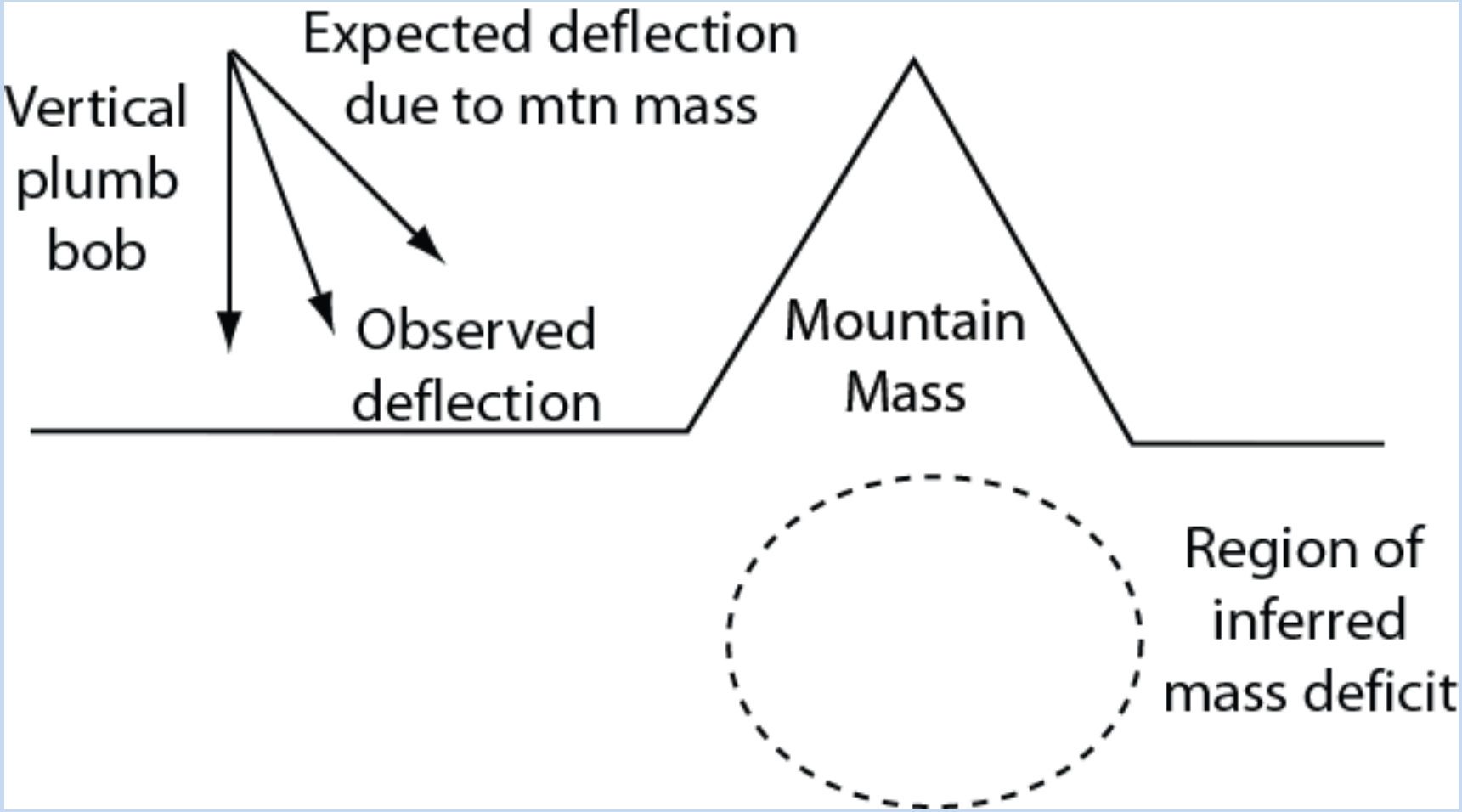
http://sphotos.ak.fbcdn.net/photos-ak-snc1/v2100/67/88/730660017/n730660017_5593665_6871.jpg

Sir George Biddell Airy (7/27/1801 - 1/2/1892

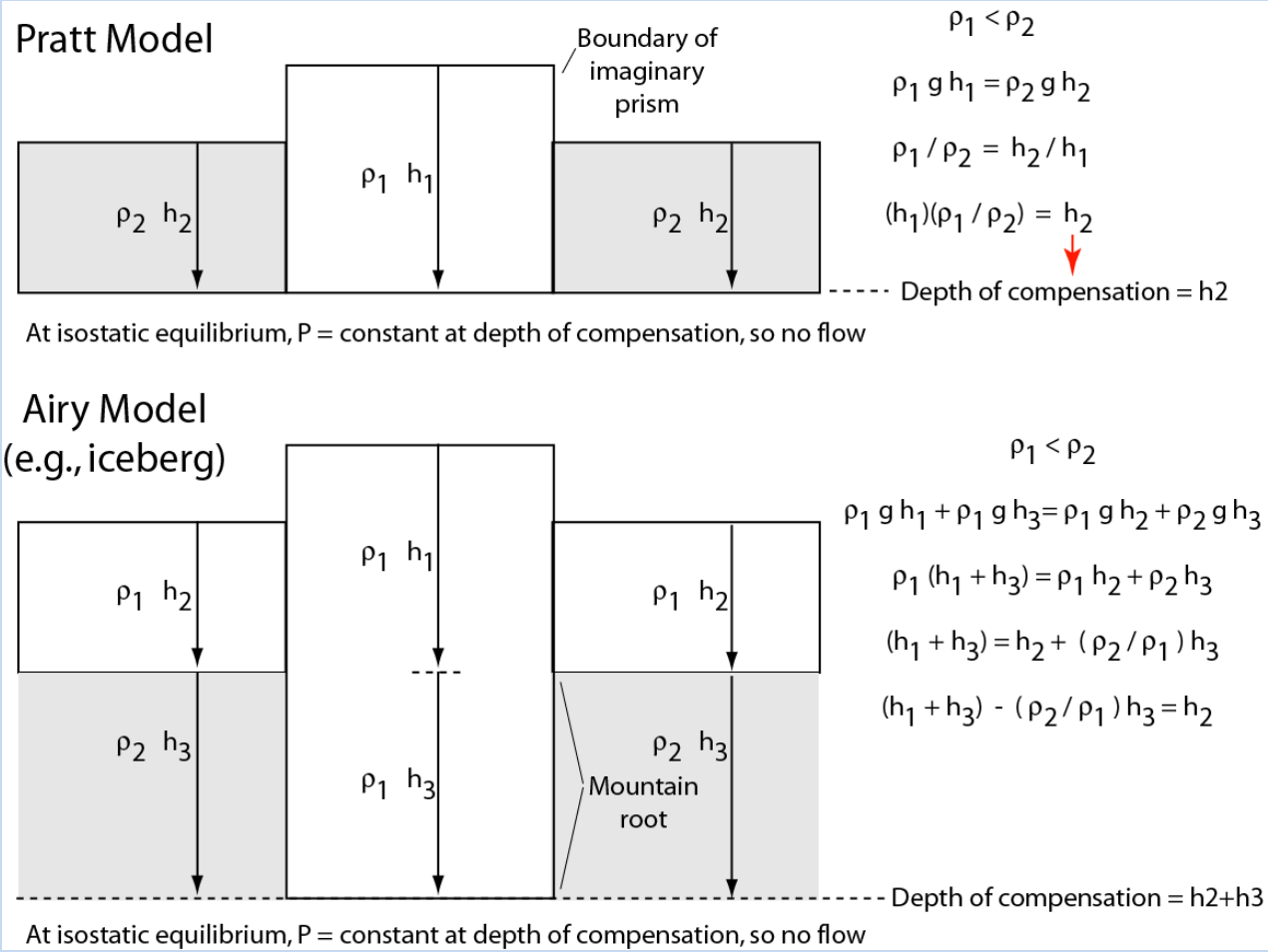
- Airy, G.B., 1855, On the computation of the Effect of the Attraction of Mountain-masses, as disturbing the Apparent Astronomical Latitude of Stations in Geodetic Surveys. Philosophical Transactions of the Royal Society of London. v. 145, p.101-104.
- British Royal Astronomer from 1835-1881
- Determined the mean density of the Earth from pendulum experiments in mines
- Contributor to elasticity theory (telescope deformation)
- Opponent of Charles Babbage from 1842 to ??

http://www.computerhistory.org/babbage/georgeairy/img/5-2-1.jpg

Isostasy and Gravity Measurements

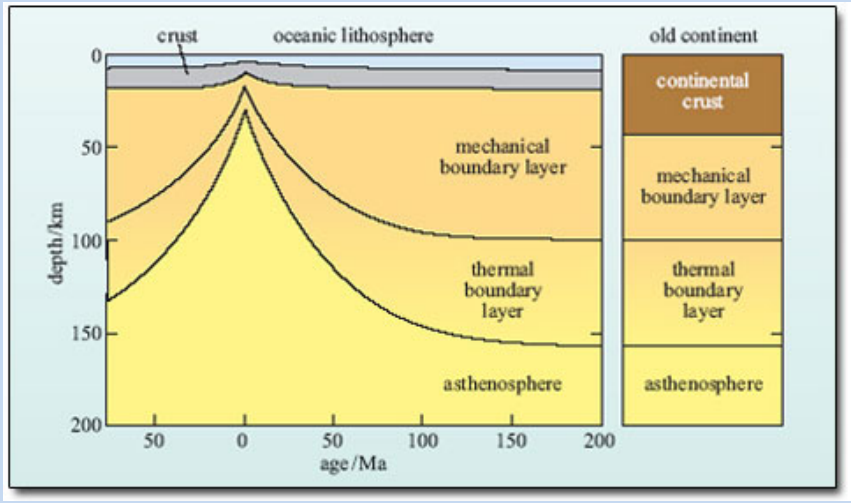


Comparison of Isostatic Models



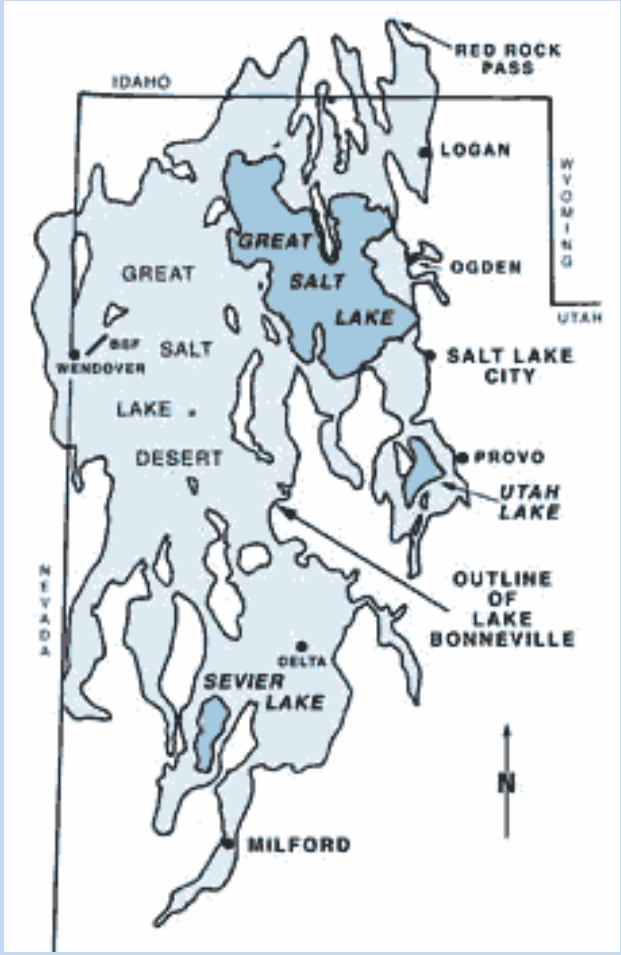
Thermal Isostasy (e.g., Turcotte and Schubert, 2002)

- Oceanic crust thickens and increases in density as it cools with time
- Oceanic crust thickens and increases in density with distance from ridge
- Depth to seafloor increases with distance from ridge



http://openlearn.open.ac.uk/file.php/2717/!via/oucontent/course/414/s279_1_014i.jpg

Isostatic Rebound: Lake Bonneville



http://geology.utah.gov/online/pi-39/images/pi39-01.gif

Shorelines of Lake Bonneville
Tilt Away from Lake

http://k43.pbase.com/g6/93/584893/2/79634985.GXiIakLZ.jpg

Estimates of mantle viscosity and lithospheric plate thickness from Lake Bonneville (Bills and May, 1987)

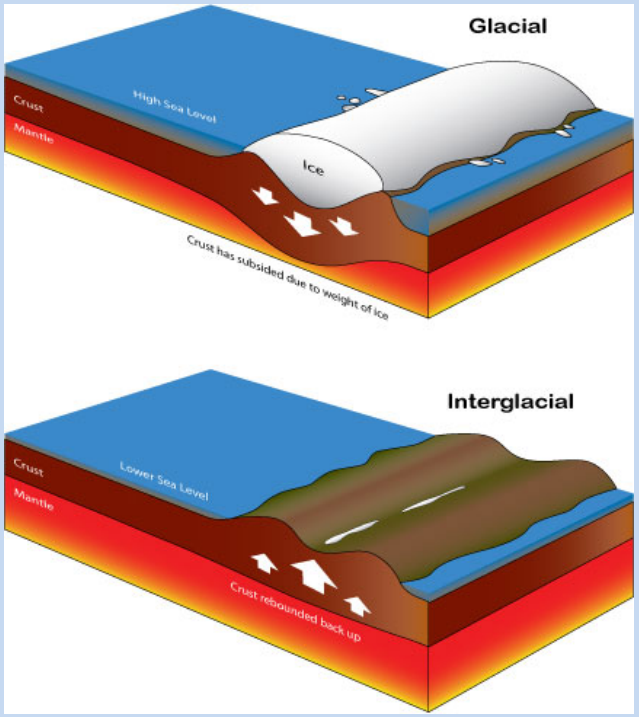
- Model: Elastic plate over a viscoelastic channel
- Viscosity: $1.2 \pm 0.2 \times 10^{20}$ Pa•sec
- Elastic plate thickness: 23±2 km

http://k43.pbase.com/g6/93/584893/2/79634985.GXiIakLZ.jpg

Isostasy and relative sea level change

Loss of ice sheets from continents causes isostatic rebound

Uplifted shorelines, Nunavut, Canada

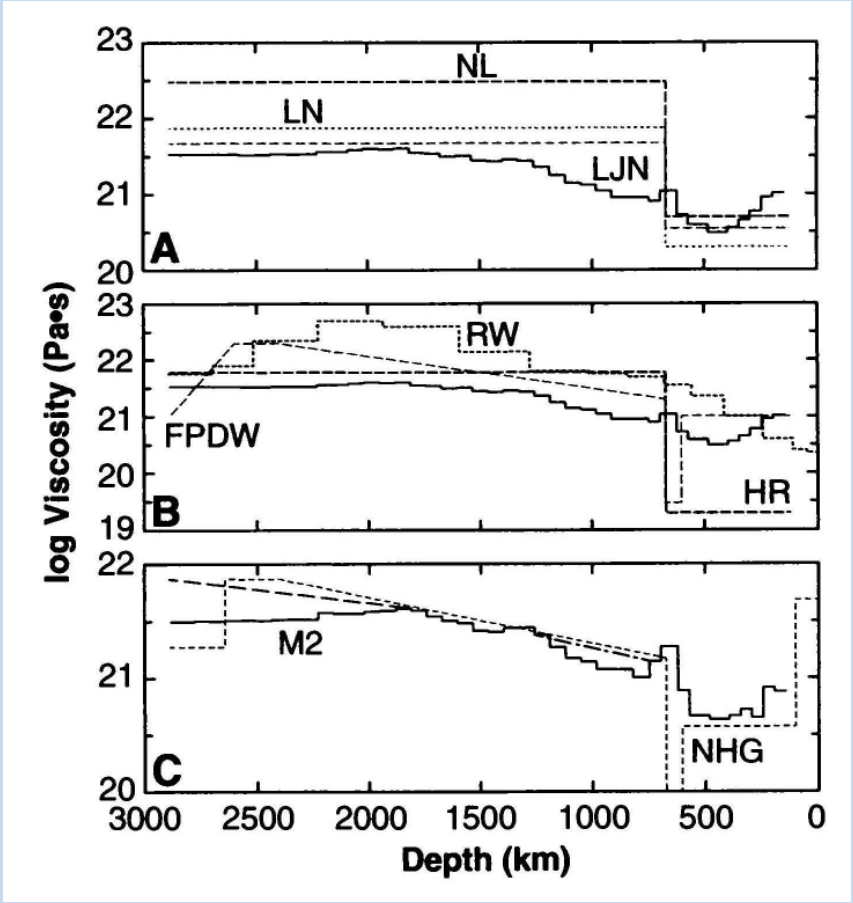


https://en.wikipedia.org/wiki/Post-glacial_rebound

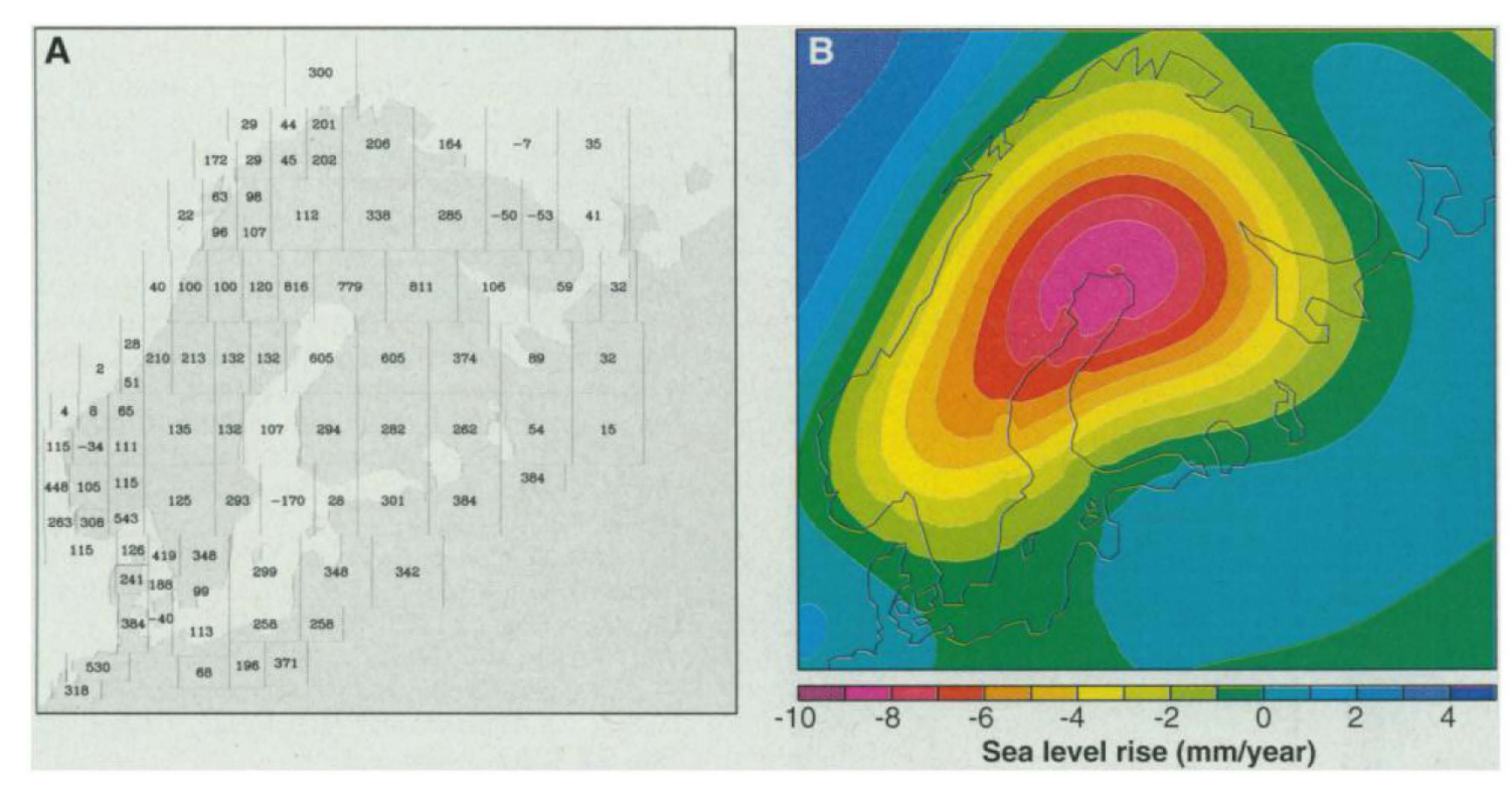
http://www.bgs.ac.uk/discoveringGeology/climateChange/general/images/isostaticUplift.jpg

Estimates of mantle viscosity from global isostatic data (Peltier, 1996)

- Model: Spherically symmetric viscoelastic
- Data: Post-glacial relative sea levels histories



Adjustments to ICE-4G LGM ice thickness model and relative sea level rise in Fennoscandia accounting for global isostatic data



From Peltier (1996)

Estimates of relative sea level rise (Peltier, 1996)

- Transfer of mass from continents to oceans causes isostatic adjustment
- Isostasy needs to be accounted for in estimating sea level rise
- Corrected relative sea level change rates are model-dependent