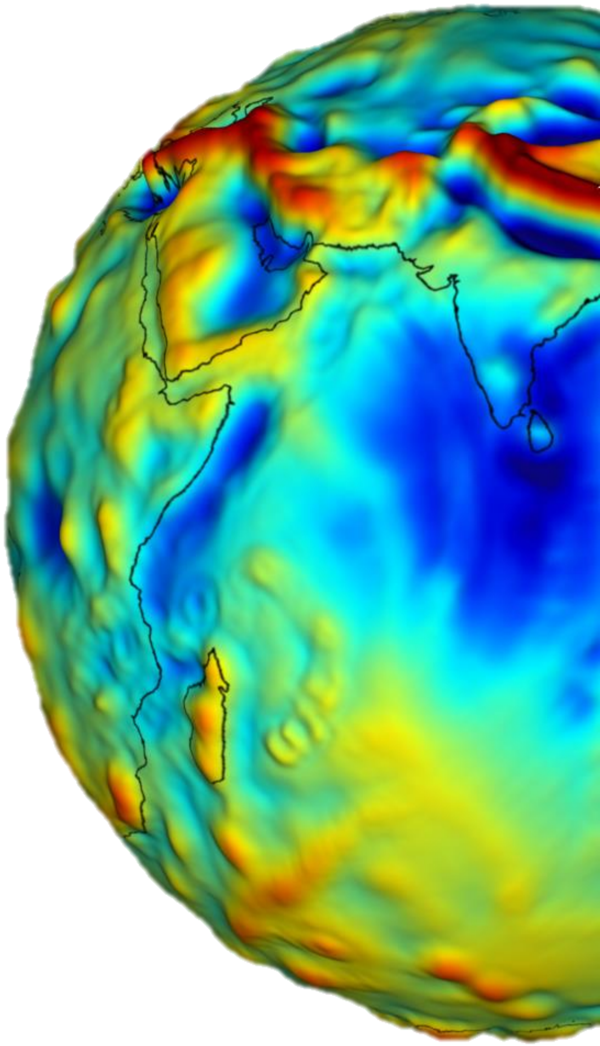
Gravity anomalies

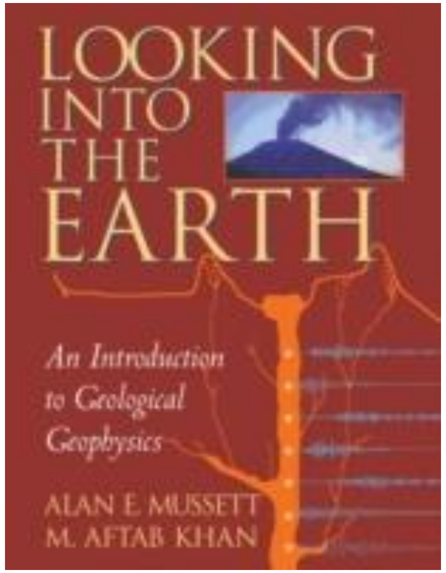


Åse Hestnes

01.11.2021

GEO-DEEP9300 course 2021

Picture: NASA



1. Introduction
2. What is gravity?
3. Gravity anomalies and corrections
4. Large-scale gravity and isostasy

Gravity surveying

- Measuring the variations in the Earth's gravitational field caused by differences in the density of subsurface rocks
- What is really measured is the variations of acceleration due to the gravity

When do we use gravity surveys

Source: NASA

- Changes in mass of ice caps
- Changes in water resources
- Ocean current transport
- Sea level change (T and mass changes)
- Atmosphere-ocean mass exchange
- Internal Earth forces (tectonics)

What is gravity?

- All things with a mass is attracted to each other
- Newton's law of attractive forces

$$F = G\frac{m_1 m_2}{r^2}$$

Where F=attractive force, G=gravitational constant ($\mathbf{6.672 \times 10^{-8}}\ m^3/Mg \times s^2$), m1 and m2 are small masses in tonnes, r is distance of separation in m

What is gravity?

- To measure gravity on Earth, we also need to consider its mass, M_E
- The attraction of M_E on a smaller mass m_s on Earth surface would be

$$F = G\frac{M_E m_s}{R_E^2}$$

Where F=attractive force, G=gravitational constant ($6.672 \times 10^{-8}\ m^3/Mg \times s^2$), and R_E is the radius of the Earth

What is gravity?

- We use the acceleration that the force on a surface mass produces

$$F = mass \times acceleration = m_s \times g$$

$$F = m_s g = G\frac{M_E m_s}{R_E^2} \rightarrow \boldsymbol{g} = \boldsymbol{G}\frac{\boldsymbol{M_E}}{\boldsymbol{R_E^2}}$$

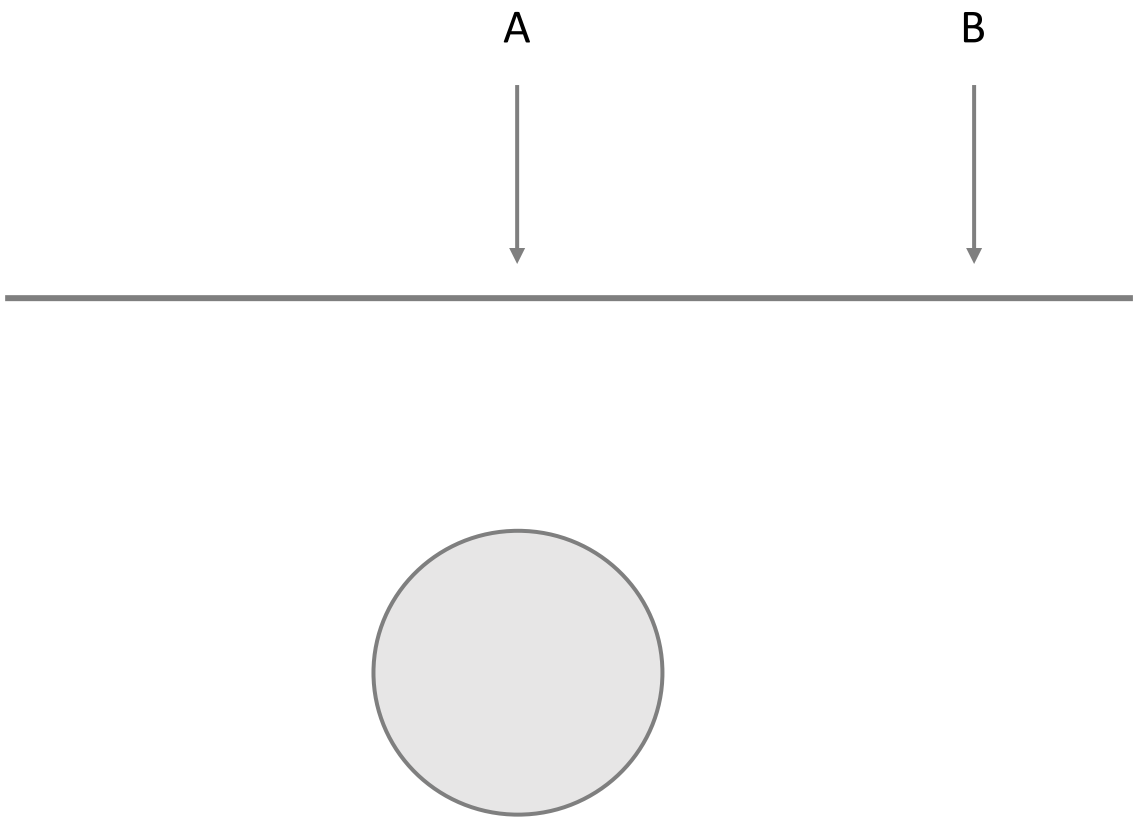
Where g=acceleration due to gravity, G=gravitational constant ($6.672 \times 10^{-8}\ m^3/Mg \times s^2$), M_E is the mass of the Earth and R_E is the radius of the Earth

- And $M_E = 5.97 \times 10^{24} kg = 5.97 \times 10^{21} Mg$
- Unit most often used is milliGals:

$$1mGal = 10 gravity\ units = 10^{-5} m/s^2 \sim 10^{-6} g$$

What is gravity?

$$g = G\frac{M_E}{R_E^2}$$



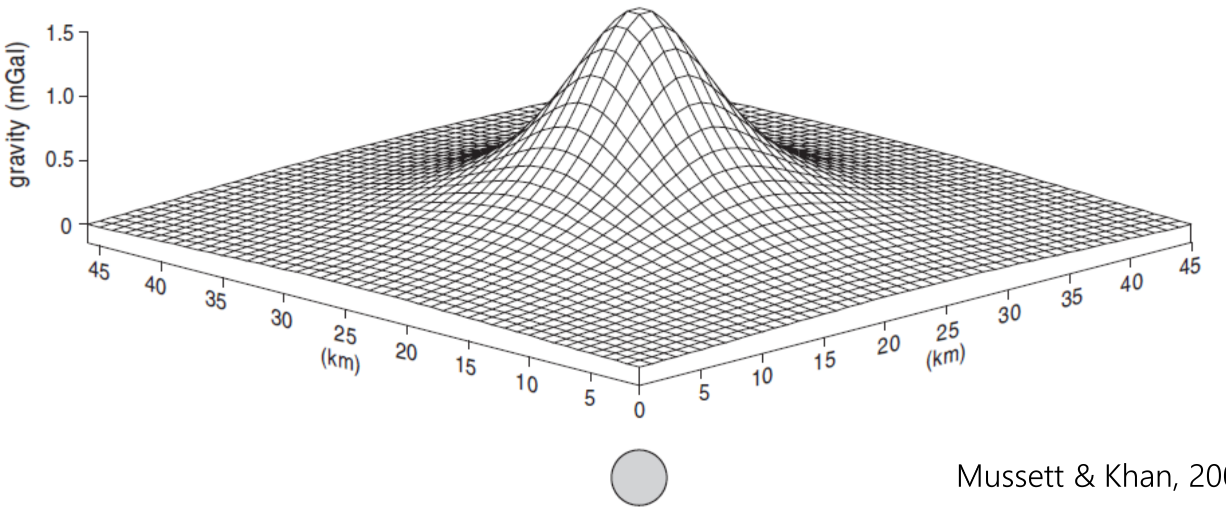
What controls *g*

- Variations and size of *g* will depend on density
- The signal on a subsurface body will vary with density, lateral density variations, extent, dept
- Average density of the Earth is 5.5 Mg/m3

	Density (Mg/m3)
Unconsolidated	
clay	1.5–2.6
sand, dry	1.4–1.65
sand, saturated	1.9–2.1
Sediments	
chalk	1.9–2.5
coal, anthracite	1.3–1.8
coal, lignite	1.1–1.5
dolomite	2.3–2.9
limestone	2.0–2.7
salt	2.1–2.6
sandstone	2.0–2.6
shale	2.0–2.7
Igneous and metamorphic	
andesite	2.4–2.8
basalt	2.7–3.0
gneiss	2.6–3.0
granite	2.5–2.8
peridotite	2.8–3.2
quarzite	2.6–2.7
slate	2.6–2.8
Minerals and ores	
barite	4.3–4.7
chalcopyrite	4.1–4.3
galena	7.4–7.6
haematite ore	4.9–5.3
magnetite ore	4.9–5.3
pyrite	4.9–5.2
sphalerite	3.5–4.0
Other	
oil	0.6–0.9
water	1.0–1.05

Gravity anomalies

… is the difference of *g* above or below its value in the surrounding area

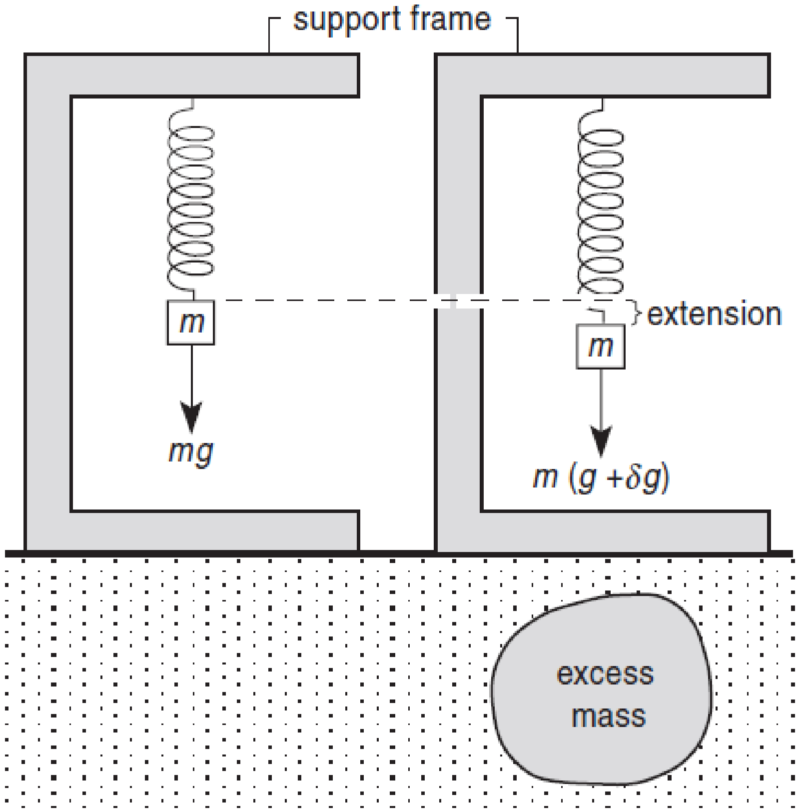


Mussett & Khan, 2000

Small-scale gravity

- Used to find subsurface bodies or structures, e.g. faults, ore, pipes, which density will differ from the surrounding density

Measuring *g* on small scales - gravimeter



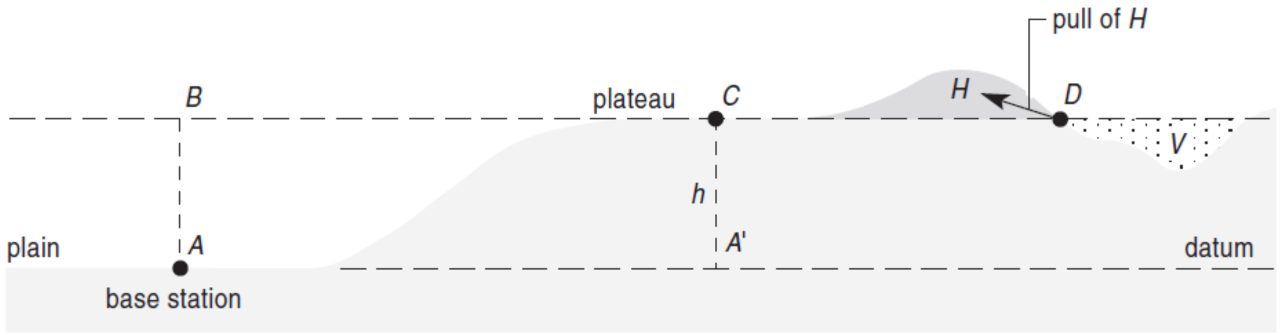
Mussett & Khan, 2000

Corrections

- Conversion of reading
- Drift
- Latitude
- Topographic corrections
  - Free-air correction
  - Bouguer correction
  - Terrain correction

→Bouguer anomaly

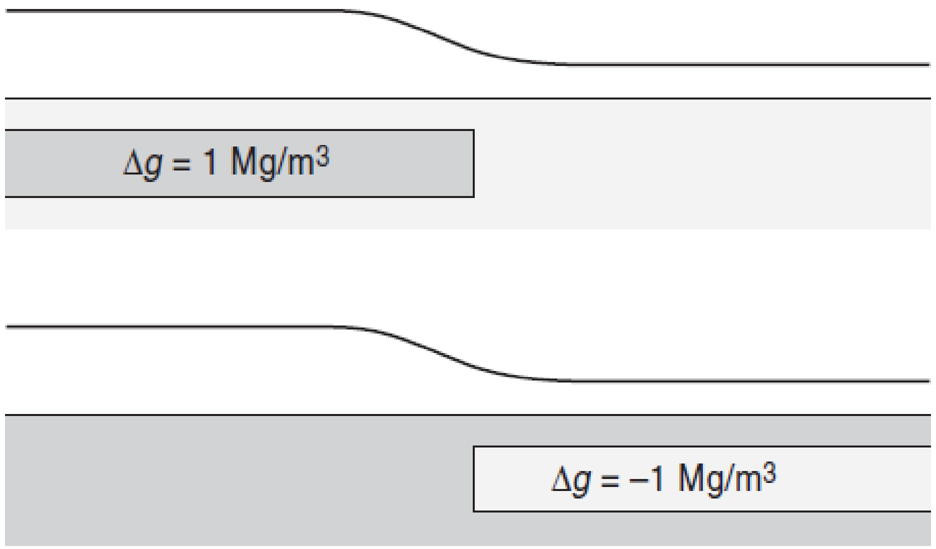
→Marine surveys – Free air anomaly



Mussett & Khan, 2000

Modelling and interpretation

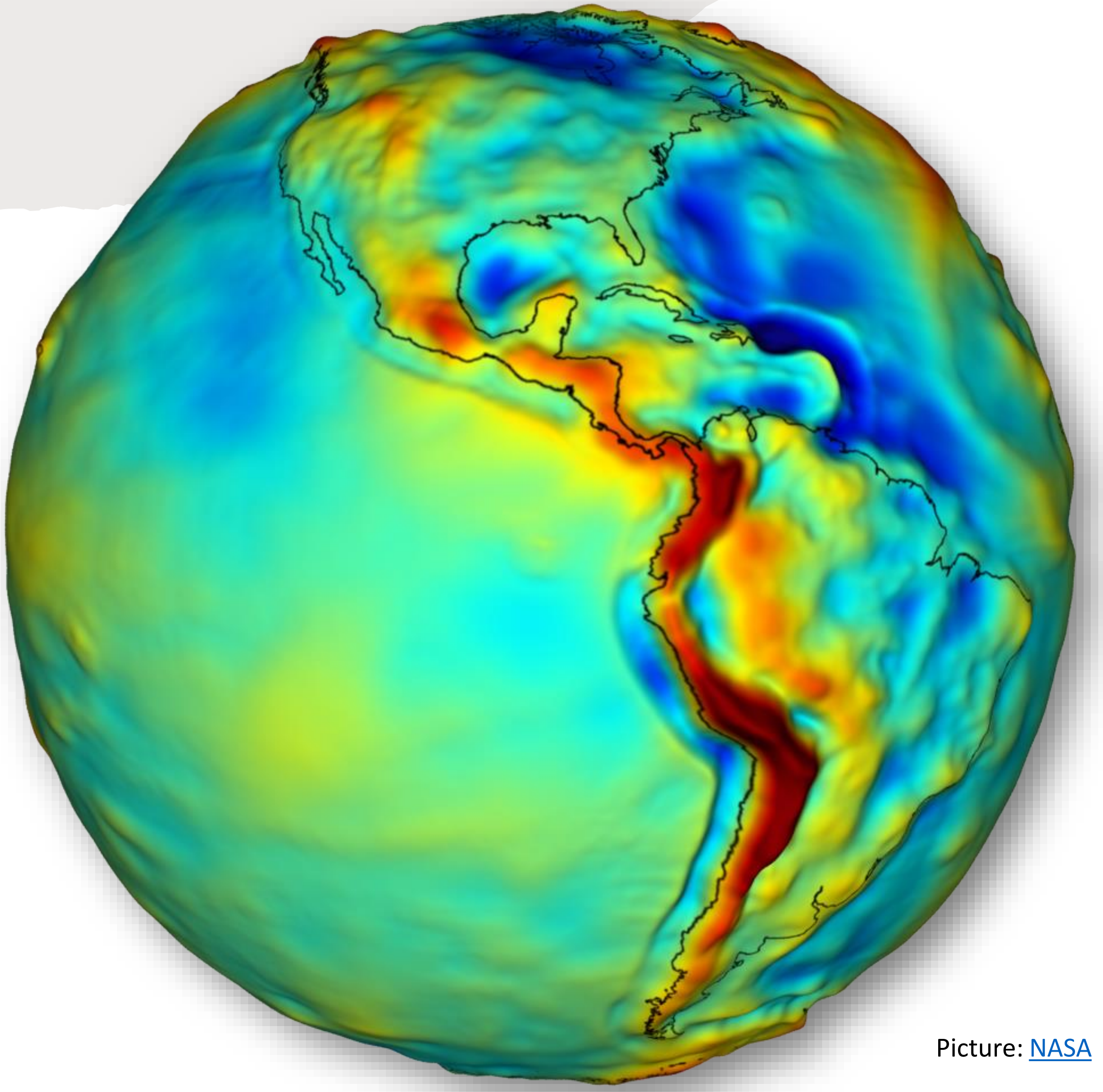
- Inversion models
  - Non-uniqueness
  - The dependence on density contrast



Mussett & Khan, 2000

Large-scale gravity

- Closely linked to the shape of the Earth
- Major use is to measure how far an area is from isostatic equilibrium



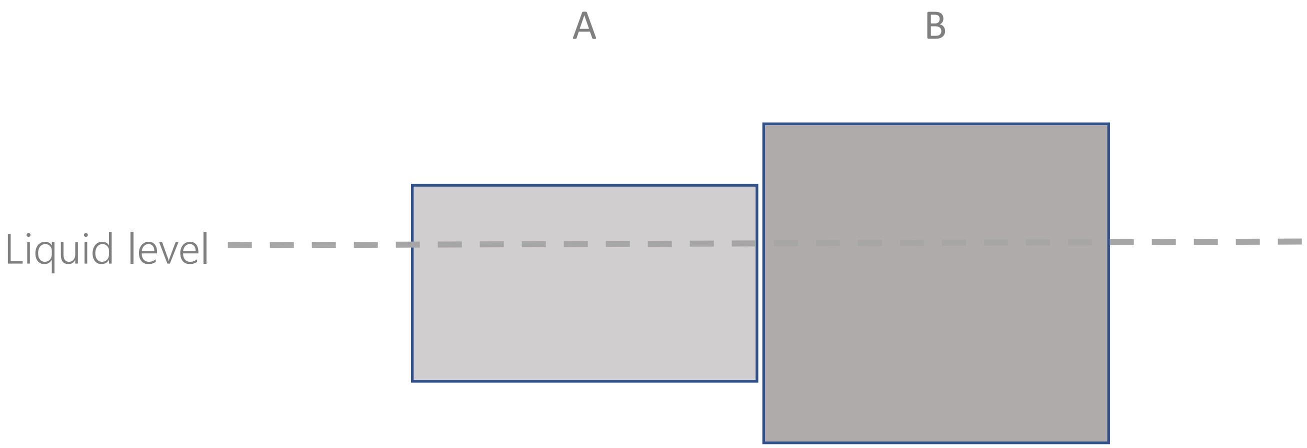
Picture: [NASA]

Isostasy

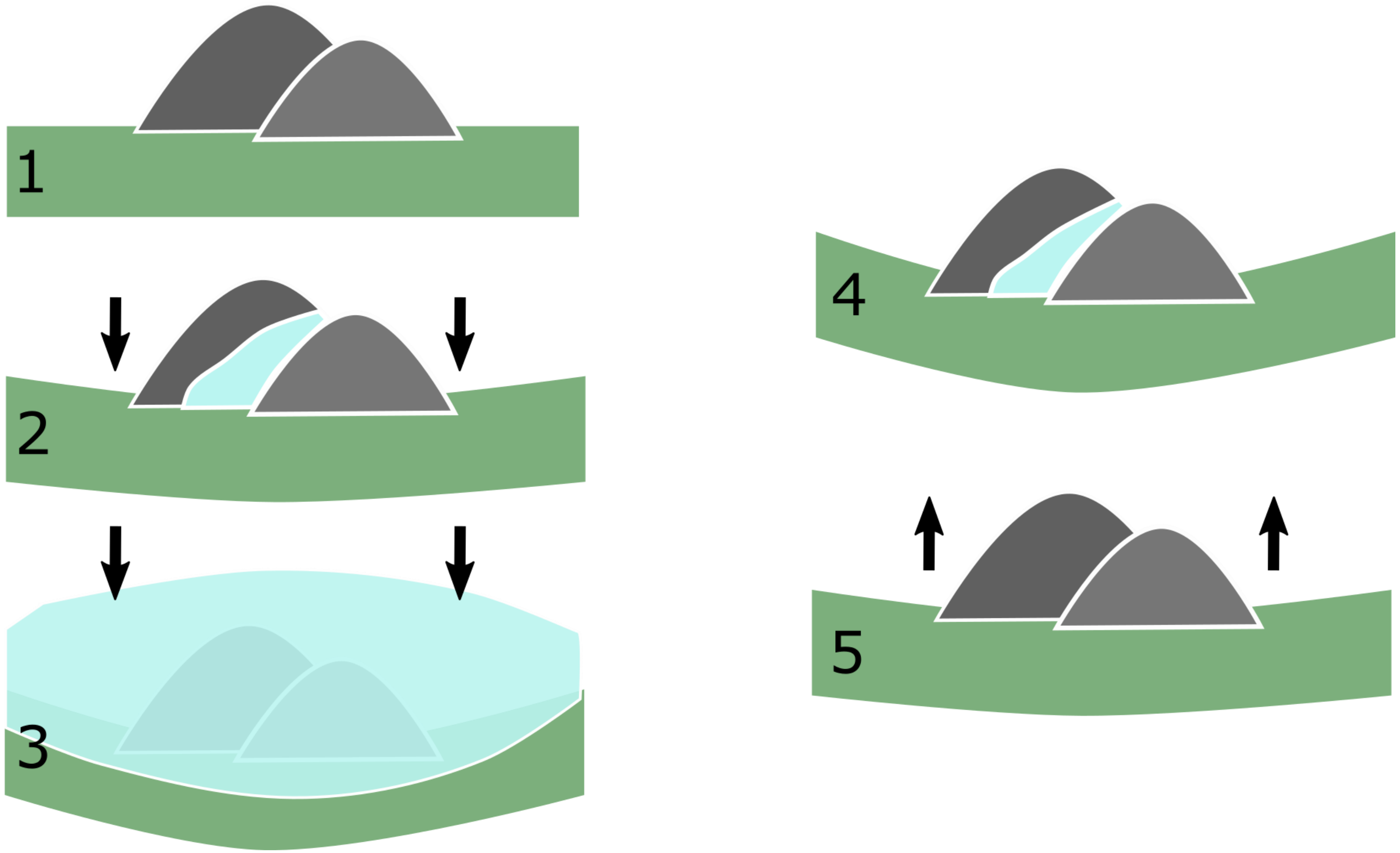
Gravitational equilibrium between the lithosphere and the mantle

Isostatic equilibrium

The closer a region is to isostatic equilibrium, the smaller the variations of g will be



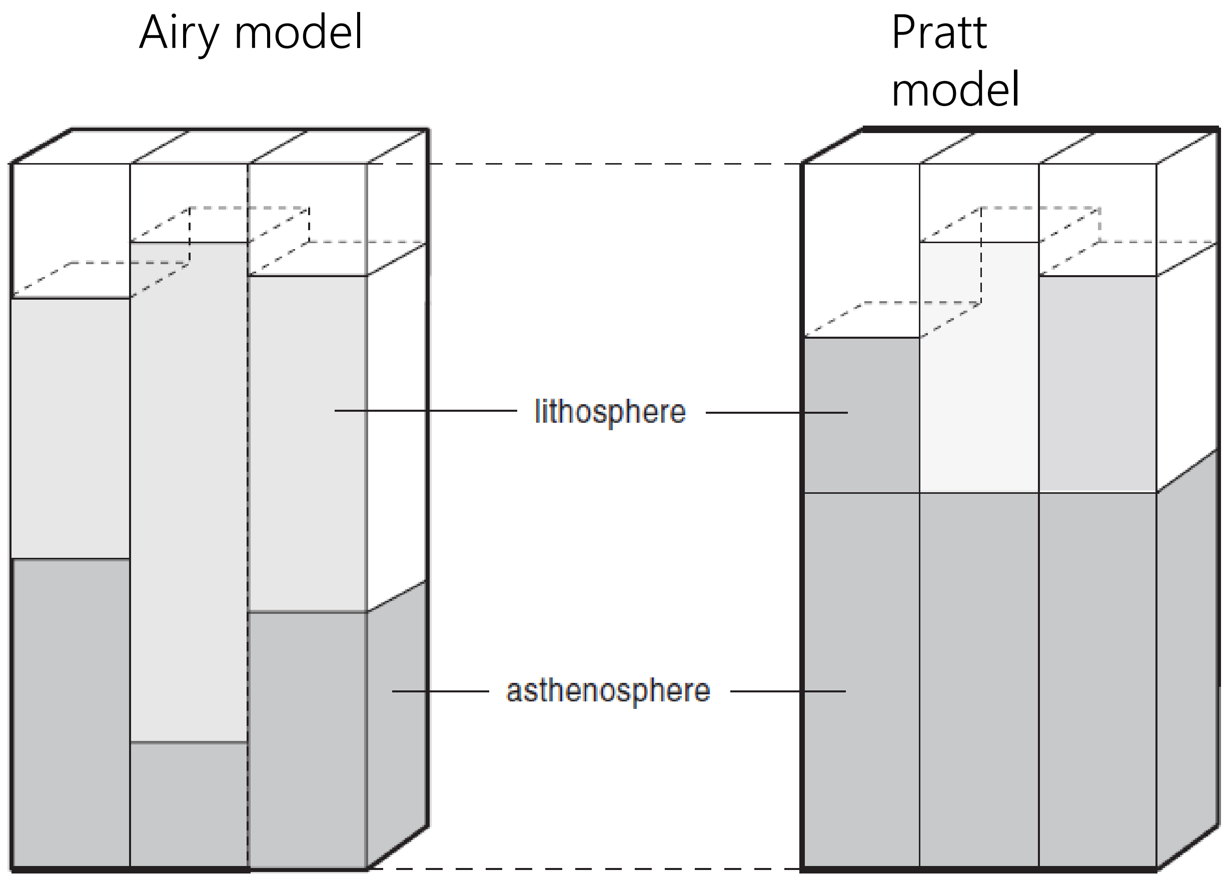
Isostasy and buoyancy



Airy and Pratt models of isostasy

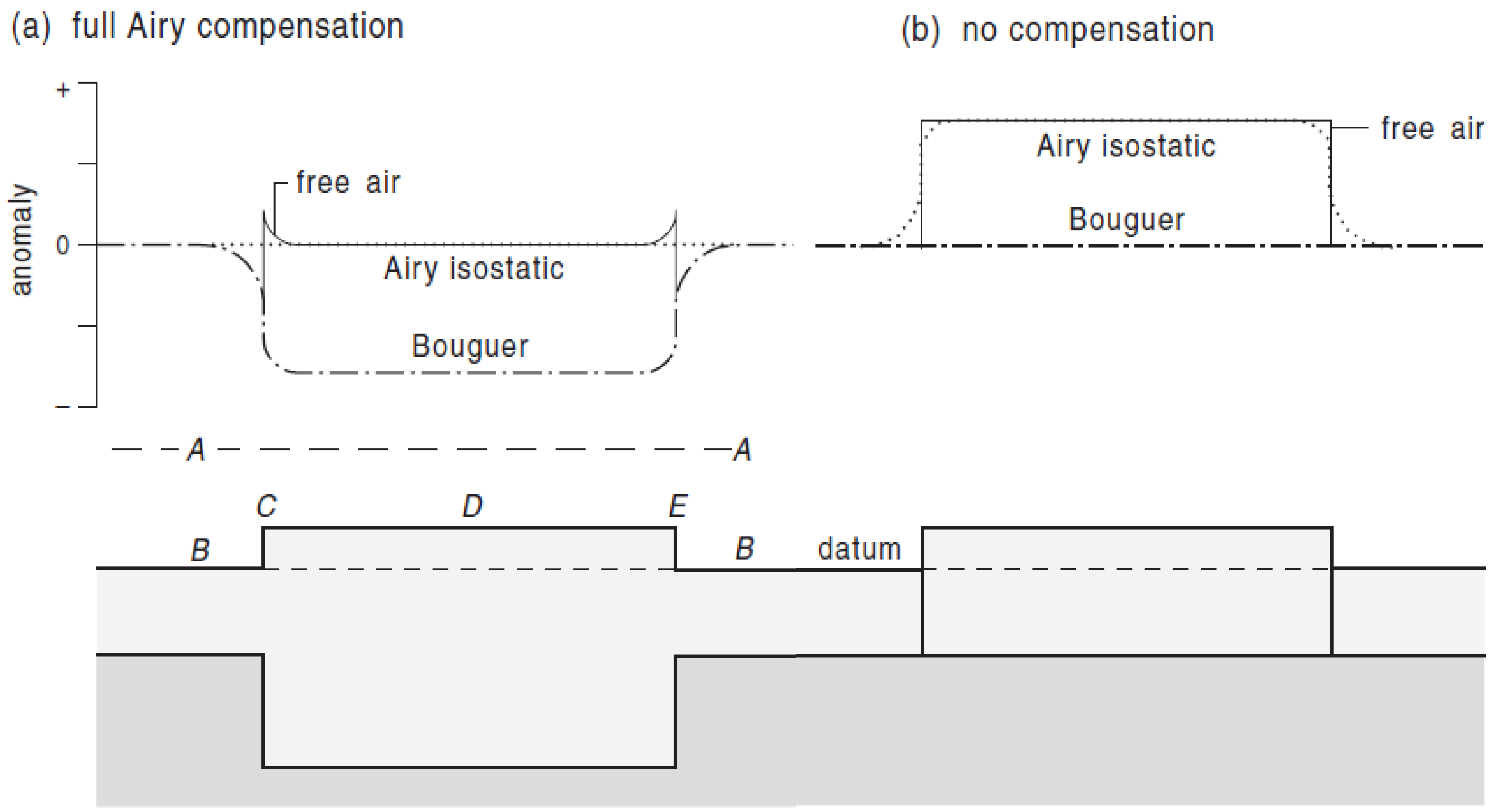
- Airy model
  - Same density
  - Different thickness
- Pratt model
  - Different density
  - Blocks float at same level

- For both – height stay unchanged



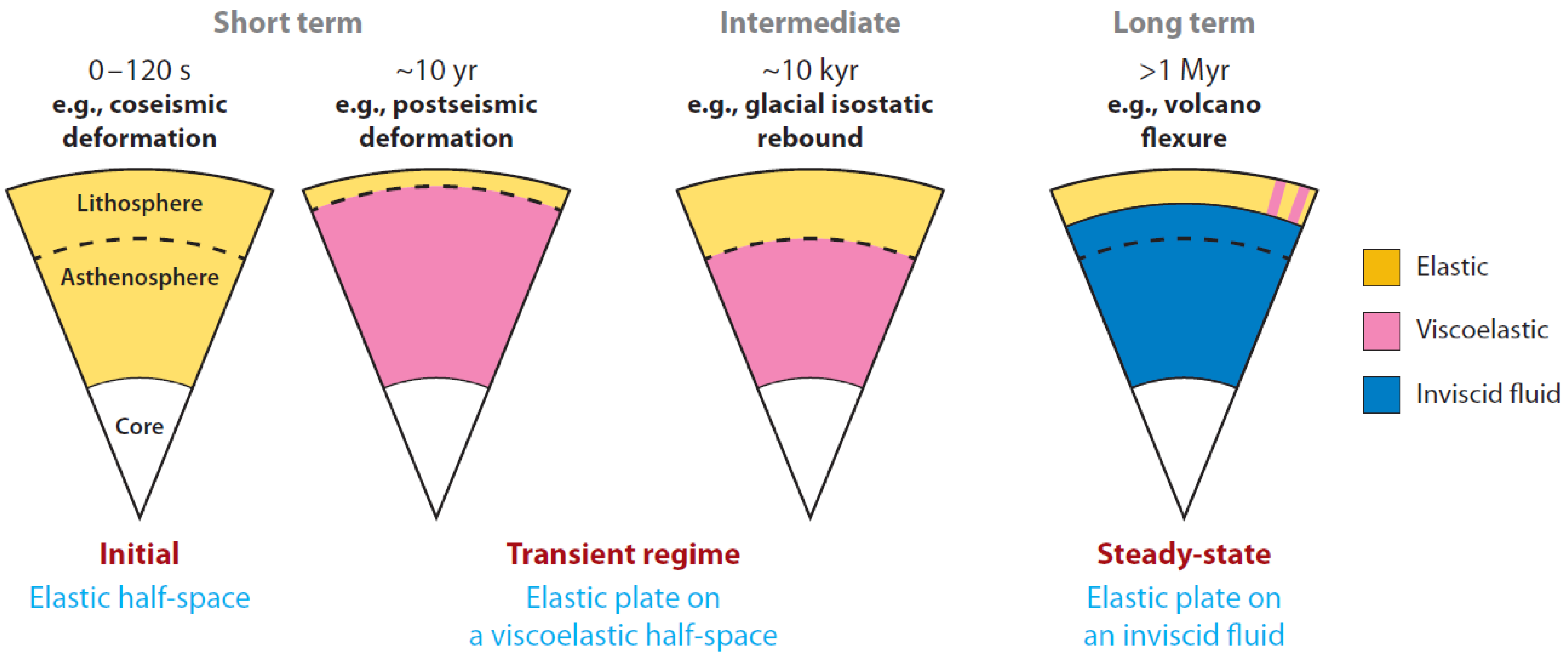
Mussett & Khan, 2000

The isostatic anomaly



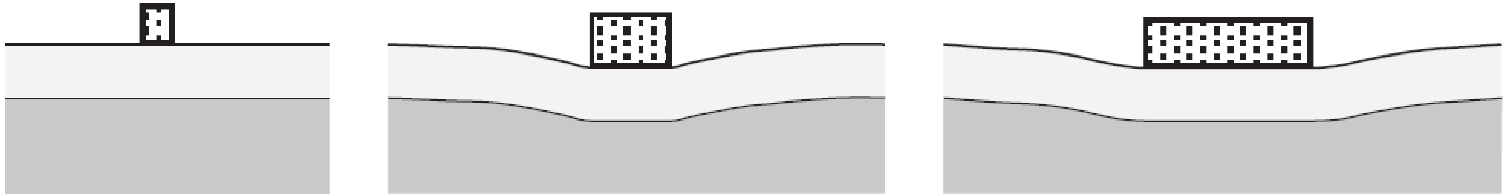
Mussett & Khan, 2000

How can the mantle change by load?



Watts et al. 2013

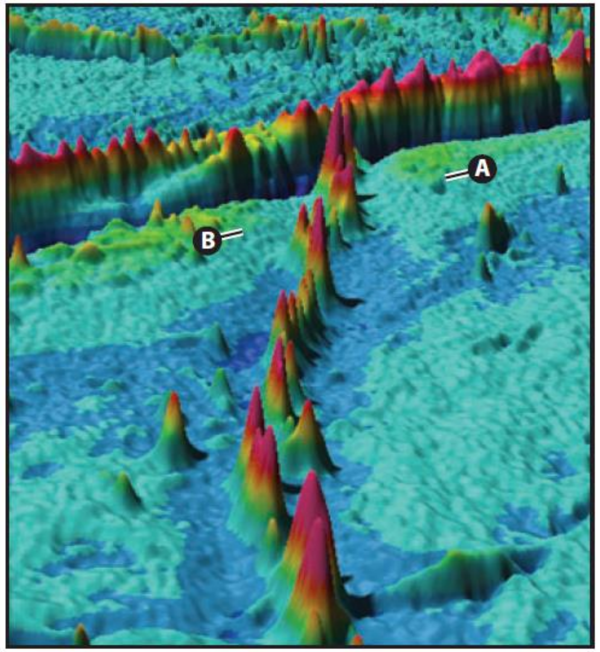
Flexural deformation

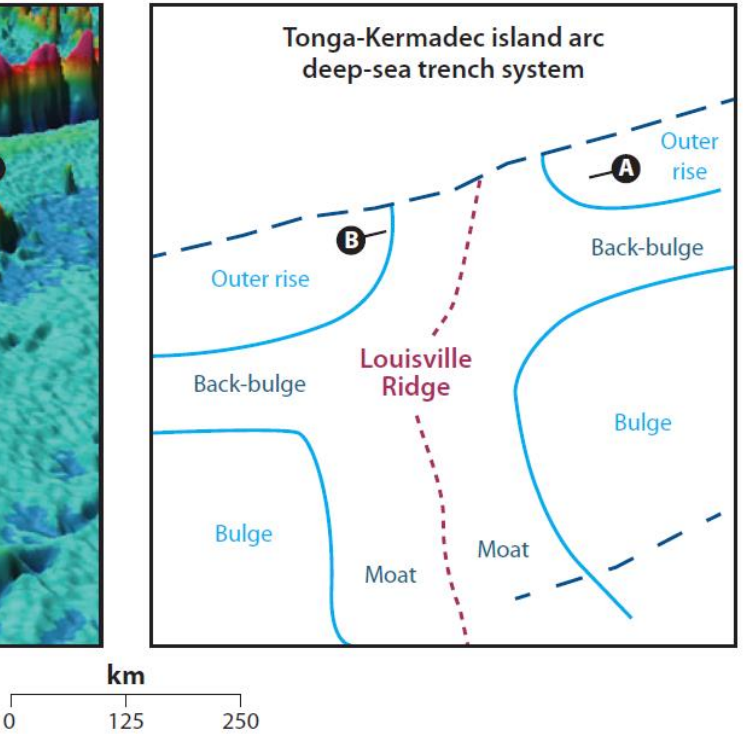


Mussett & Khan, 2000

- Small loads supported by the strength of the lithosphere
- Larger loads are supported by a combination of the lithospheres strength and buoyancy
- The largest weights (mountains, ice sheets, sedimentary basins) are mainly supported by the buoyancy

Flexural deformation

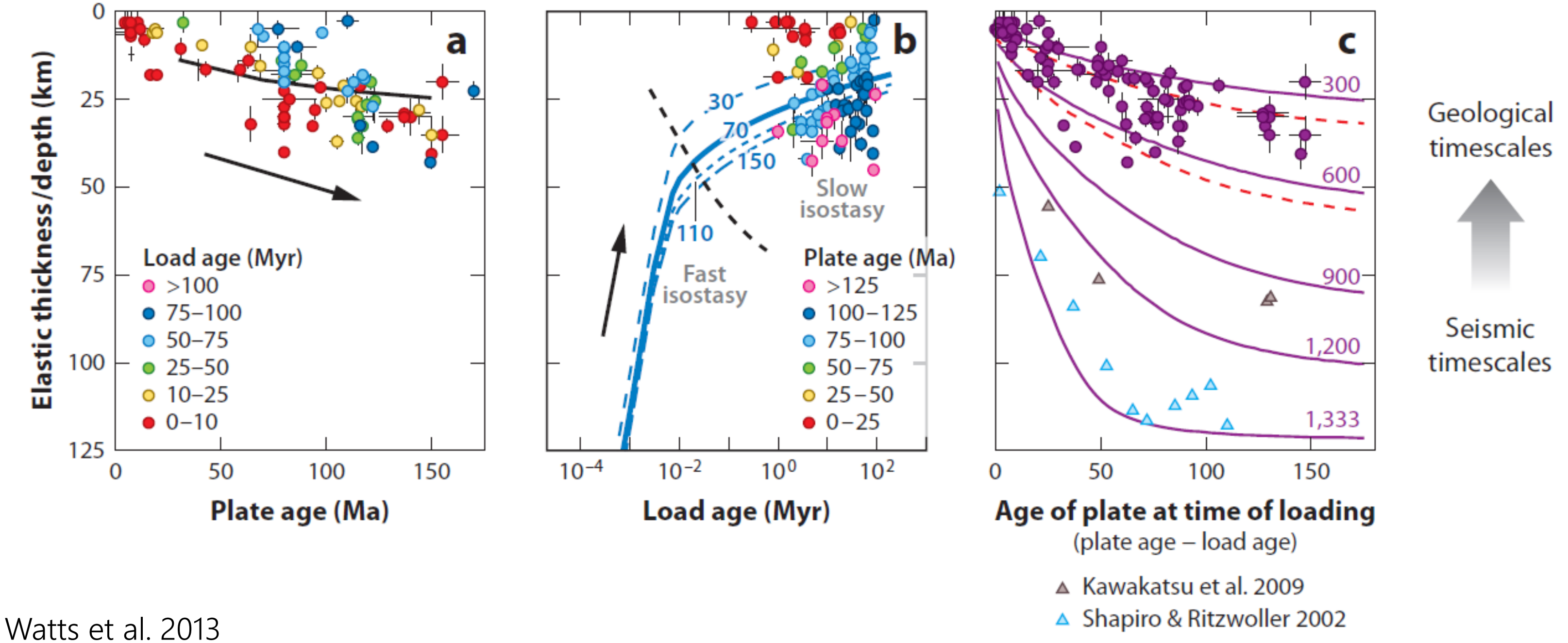




Free-air anomaly. Watts et al. 2013

Elastic thickness, T_e

Proxy for the strength of the lithosphere

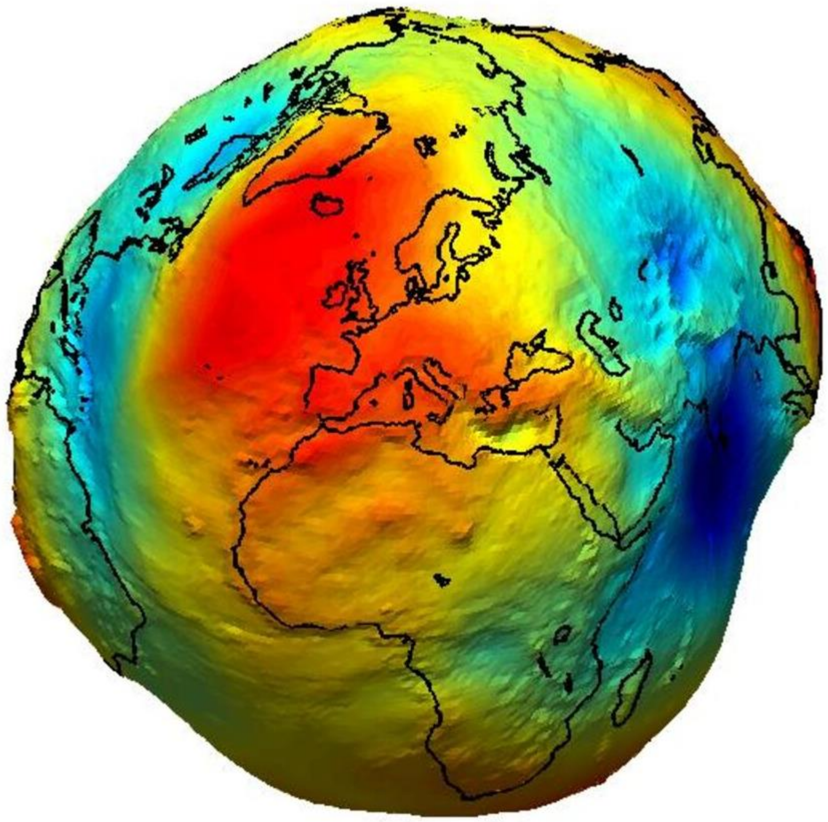


Watts et al. 2013

→ T_e decrease with load age and increase with plate age

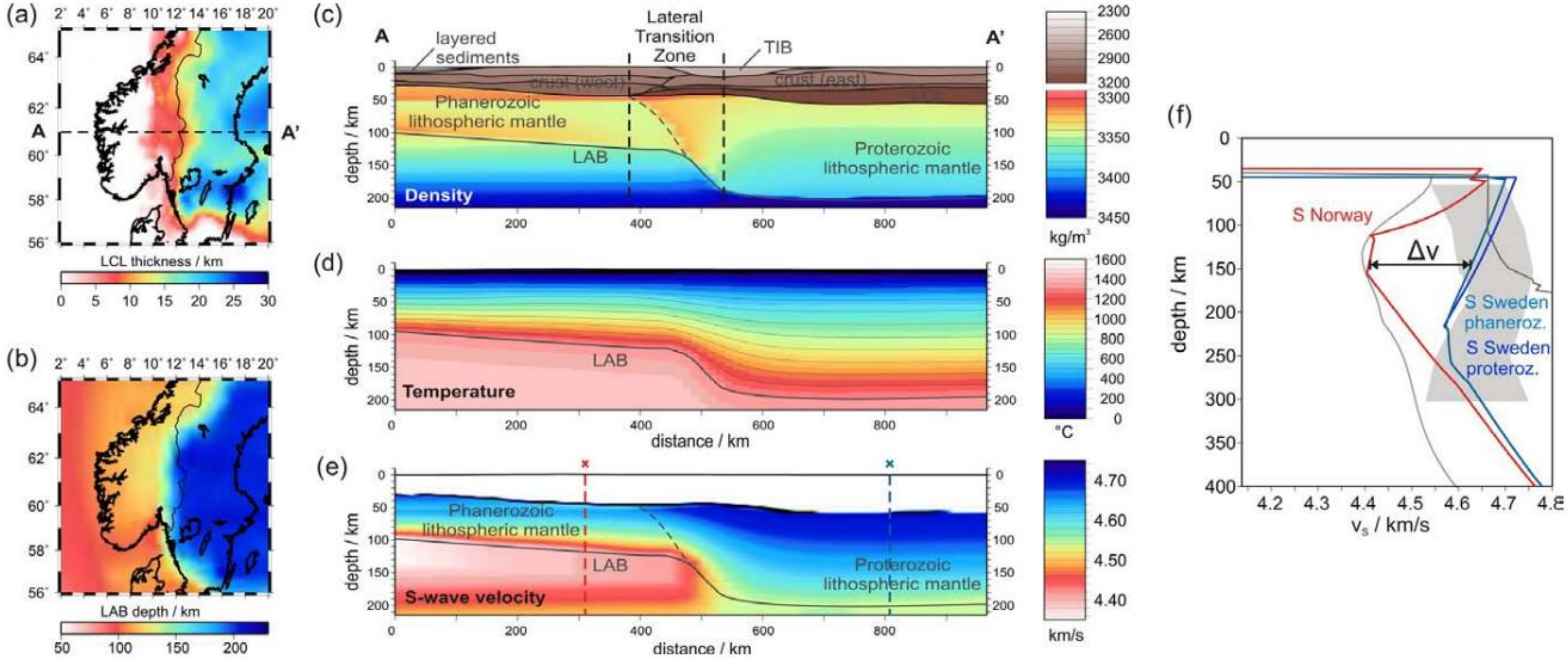
Geoid

- Geoid – the surface of equal gravitational potential of a hypothetical ocean at rest
- GOCE – Gravity field and steady-state Ocean Circulation Explorer
  - Measuring Earth’s gravity gradients at satellite height
  - Will retain the lithospheric and underlying density signals



GOCE, ESA

Integrated forward modeling



Gradmann et al. 2013