The LAB & asthenosphere

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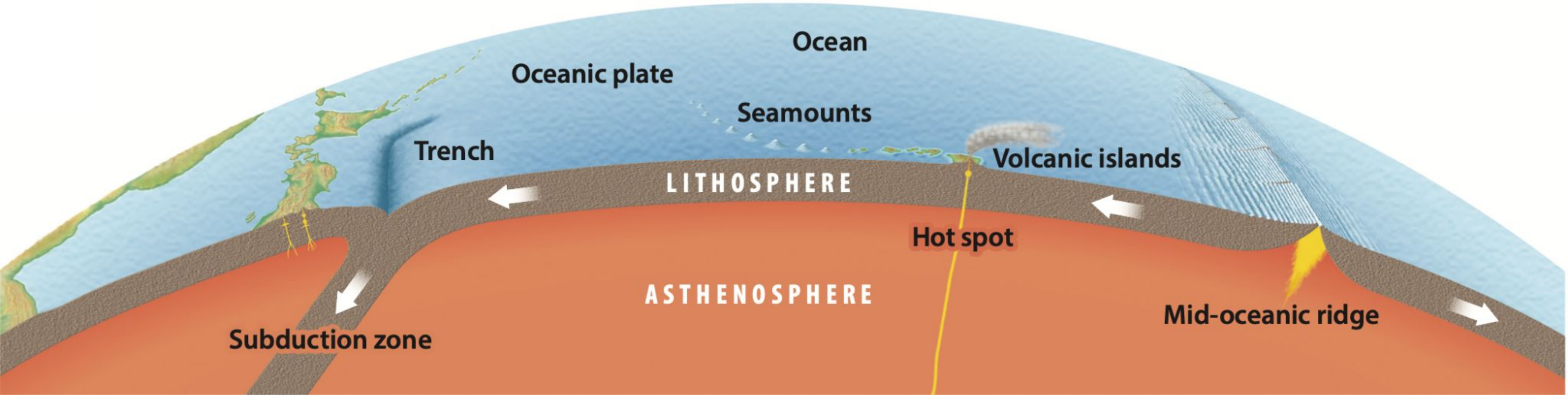


How do we know there is an asthenosphere?

Observation	**Method**
low velocity zone (G-discontinuity)	seismology (surface wave dispersion, ScS waves, seismic anisotropy)
fast isostatic rebound	GPS elevation measurements / isostasy studies
high-conductivity layer	resistivity/conductivity measurements?
GTR favors the presence of a weak layer	gravity-topography studies
consistent with plate motions	plate tectonic modelling

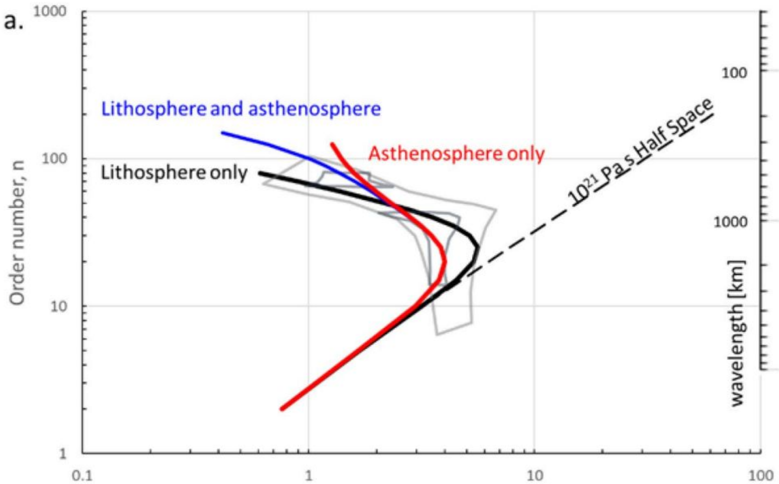
Isostatic evidence for an asthenosphere

Bulk mantle viscosity is inferred as roughly 10^21 Pa s (Peltier, 2021) with a radially varying rheology (van der Wal et al., 2015).

“This results in viscosity values below 10^19 Pa s for parts of West Antarctica at 95 km depth, increasing to almost 10^22 Pa s at 300 km depth” (van der Wal et al., 2015)

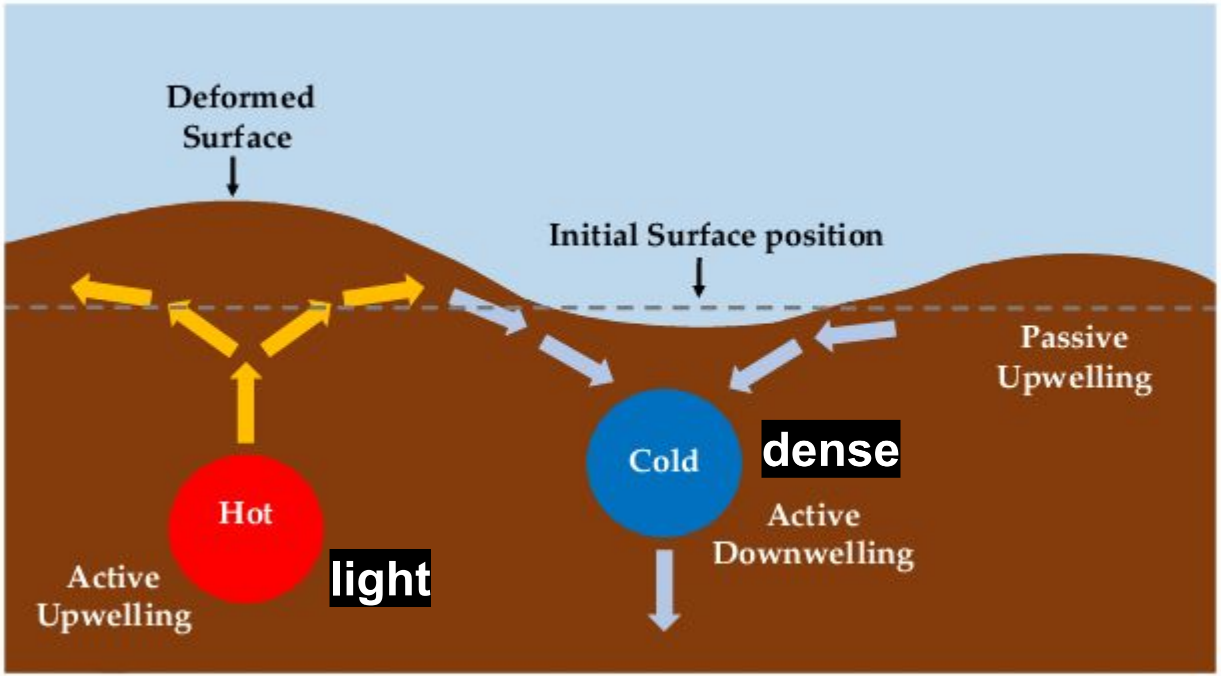
James et al. (2009) modelled the astenosphere viscosity in the range 3x10^18 - 4x10^19 Pa s given a thickness varying between 140-380 km - close to a subduction zone.

There is evidence of a thin but less viscous astenosphere between the lithospheric mantle and the lower mantle as shown in Glacio-Isostatic Adjustment studies (Cathles et al., 2023).

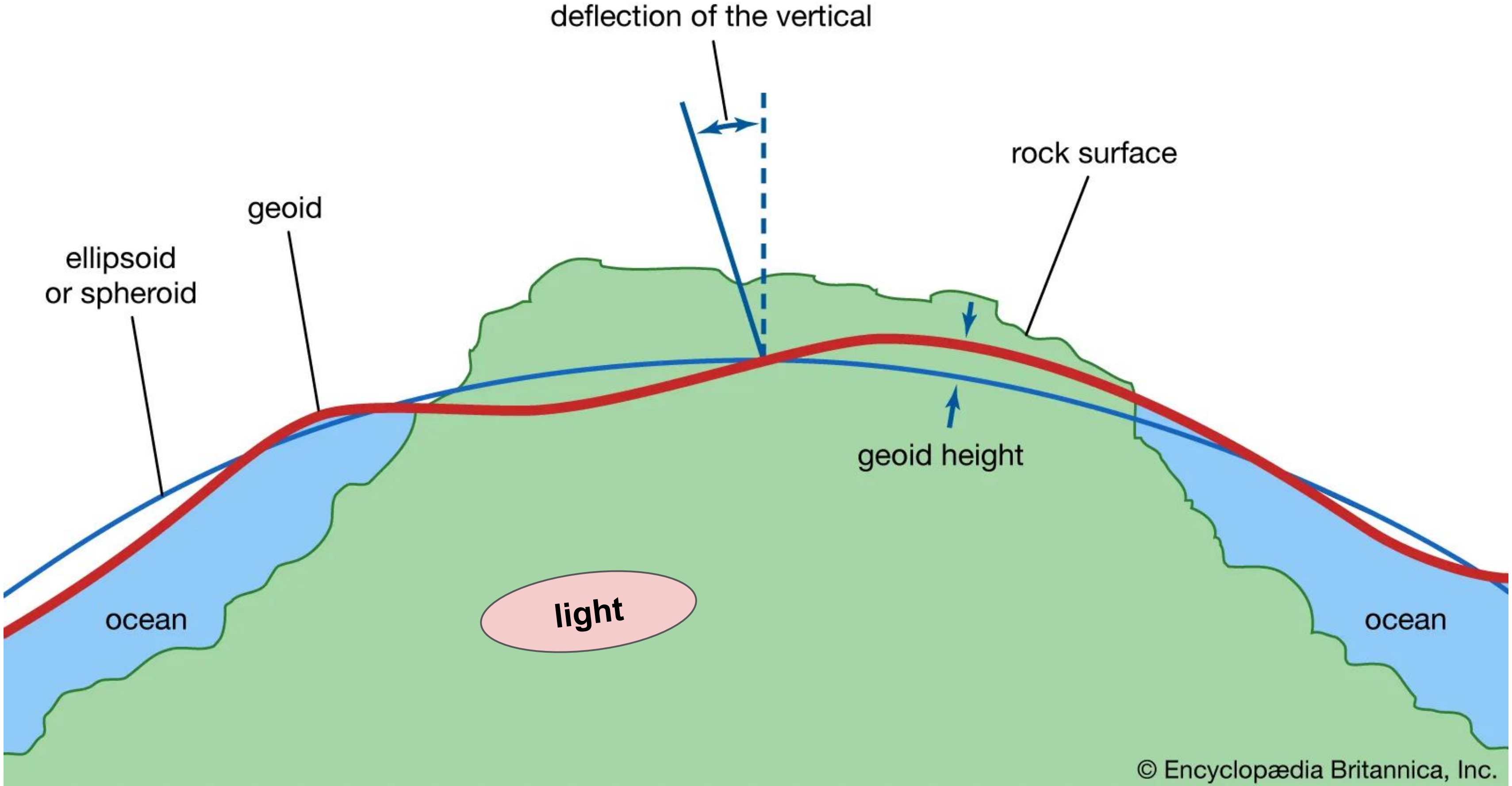


Isostatic rebound of small scale loads are observed significantly faster (1 ka) than models using the bulk mantle viscosity (50 ka) (Cathles et al., 2023).
The misfit can be modelled by three different scenarios, but a less viscous layer beneath the lithospheric mantle can be inferred in several other ways.

Dynamic topography



Geoid signal = topography + interior density variations



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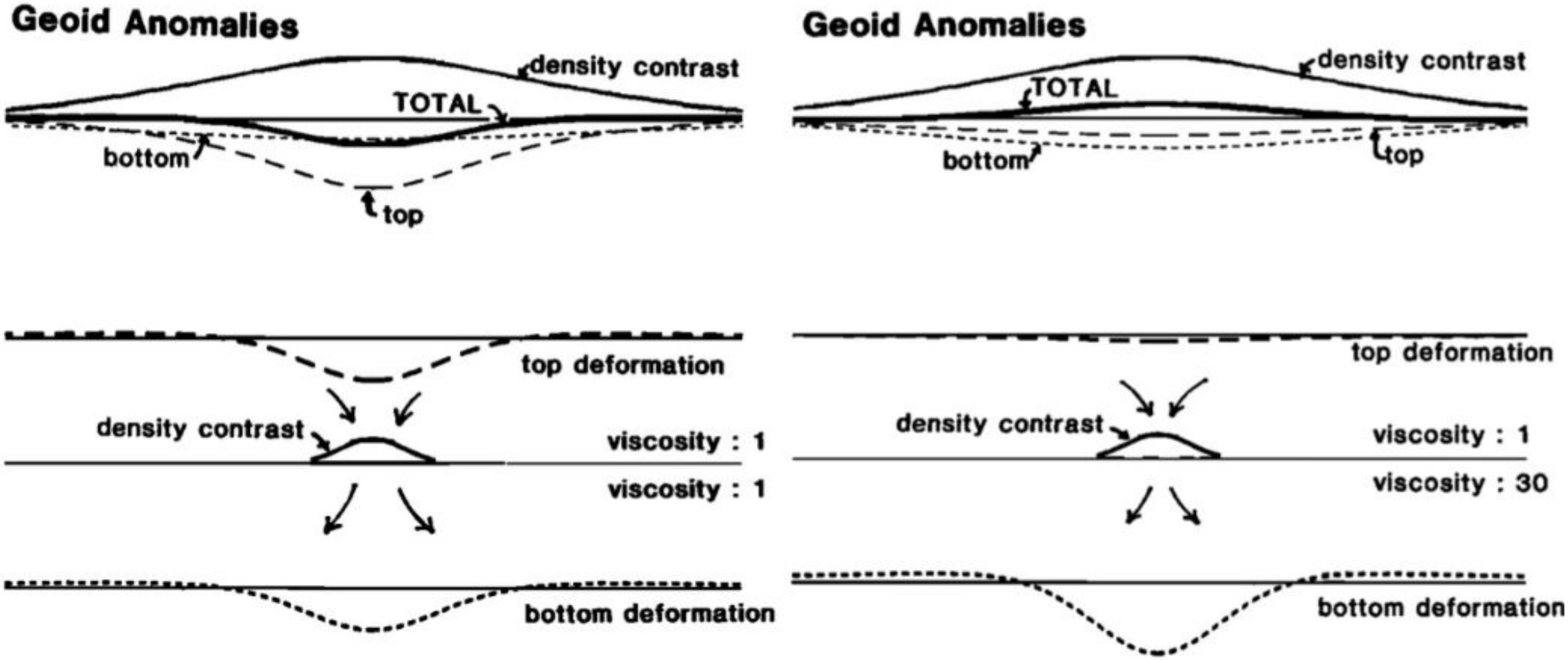
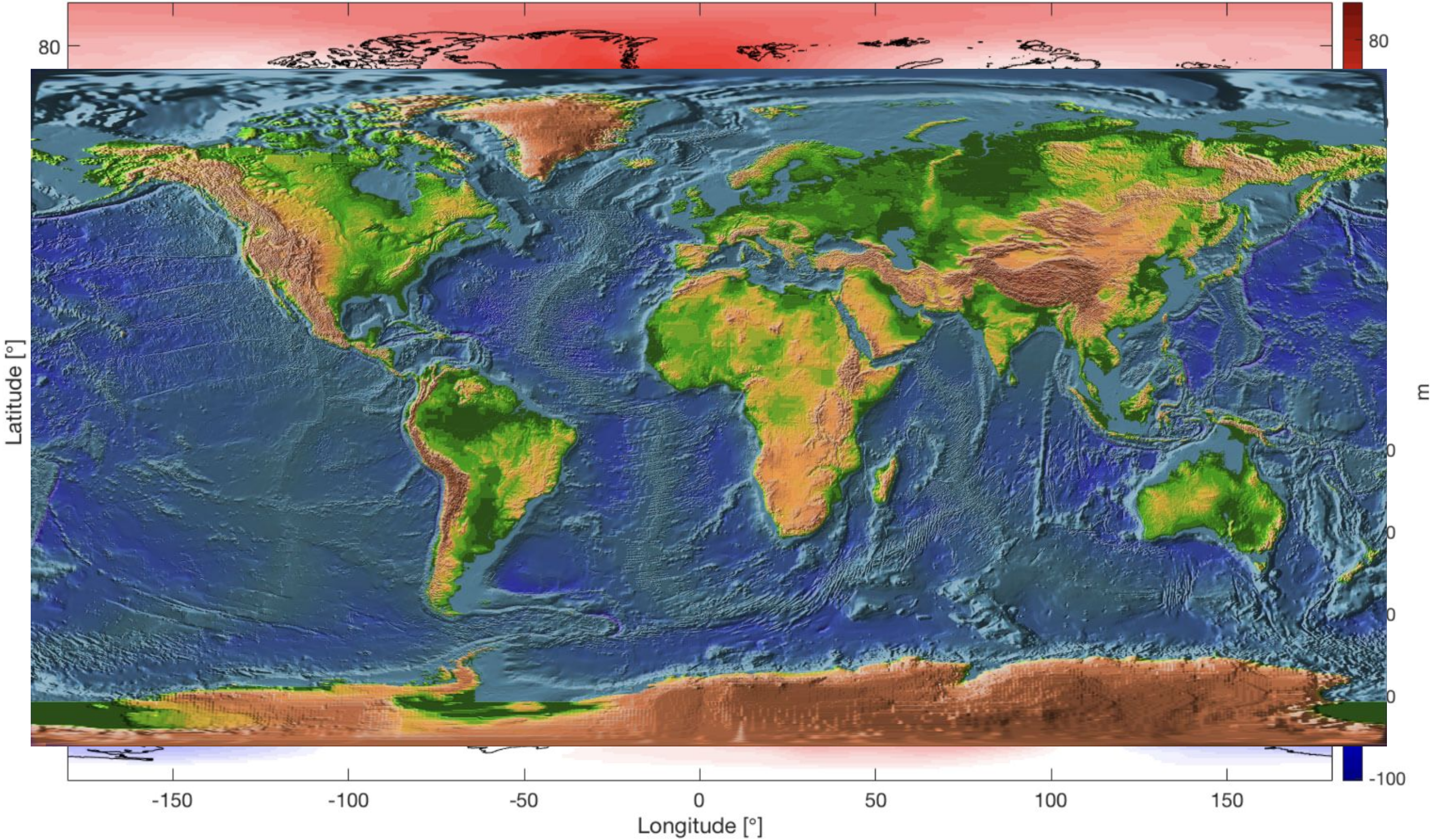
Geoid & dynamic topography



Geoid-topography ratios

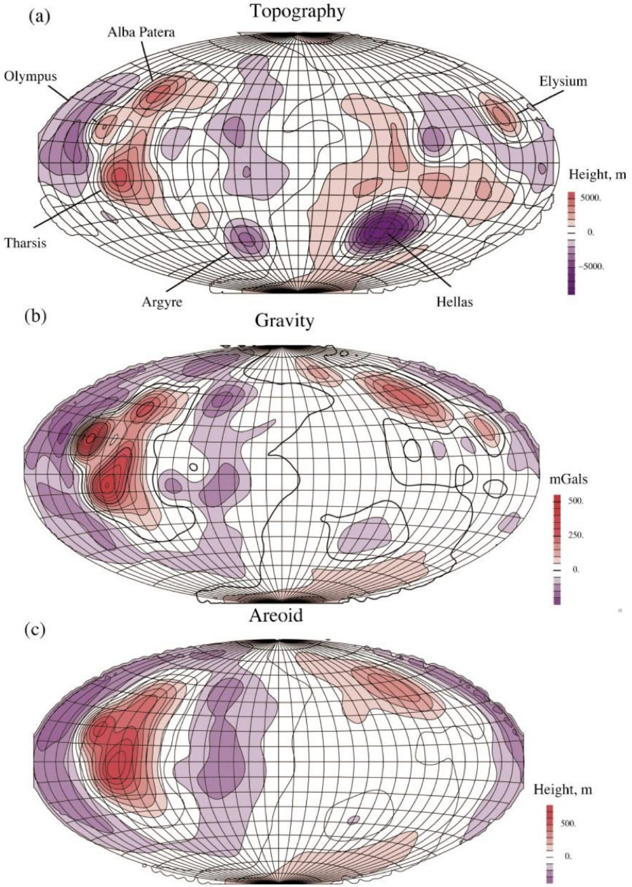


Geoid-topography ratios

McKenzie et al. (2002)

→ geoid-topography ratios (GTR)

(1D) Compare to convection calculations to obtain a thermal structure



- 🟥 Seismology
- 🟪 Isostasy
- 🟩 Conductivity
- 🟨 Gravity/ topography
- 🟦 Plate tectonic modelling

What’s the nature of the asthenosphere?

- 🟥 A low velocity zone
- 🟪 A low viscosity zone (quick response)
- 🟨 Weak layer?
- 🟦 A low viscosity zone (lubricant)

What’s the nature of the LAB?

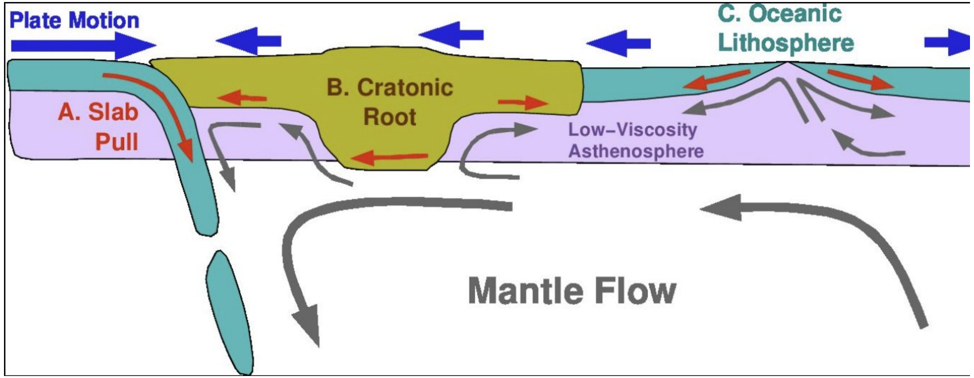
- 🟥 G-discontinuity
- 🟩 Jump in electrical conductivity
- 🟨 Lower boundary of elastic lithosphere
- 🟦 Interface of plate - mantle coupling

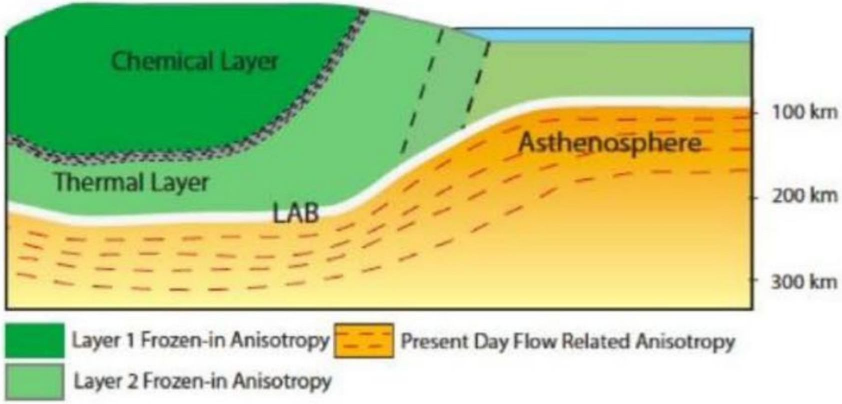
Asthenosphere boundaries

Upper boundary: lithosphere-asthenosphere boundary (LAB)

Lower boundary: very unknown and poorly constrained!

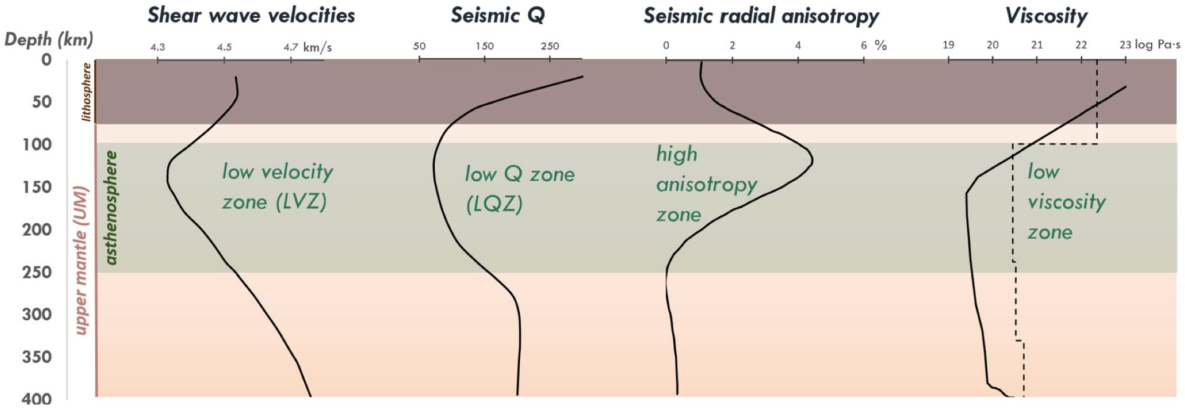
Does is follow thickening of the lithosphere or is it constant?





G-discontinuity (seismicity)

- Seismic velocity layering
    - High-velocity layer, low velocity zone
- Three mechanisms
    - Presence of melts?
    - Variations in seismic velocity, grain size
    - Seismic anisotropy



Ramirez et al. (2023)

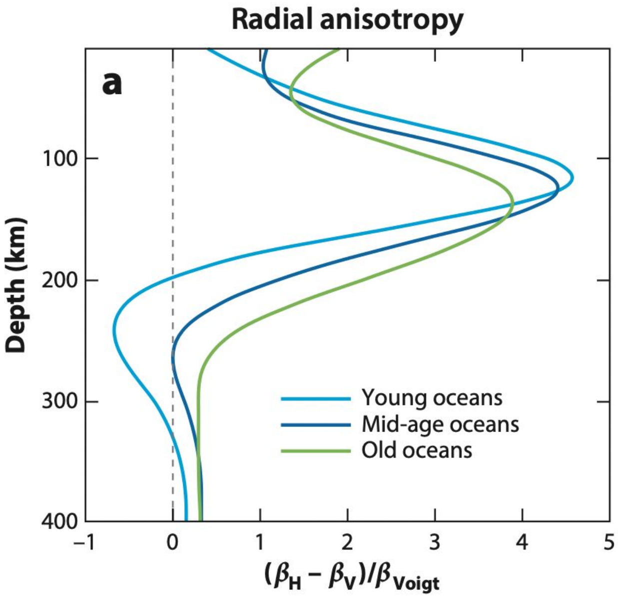
Seismic anisotropy

Understanding Lithosphere and Asthenosphere

Shear motion → LPO of olivine (highly anisotropic)

Radial anisotropy, strong in the LVZ

Azimuthal anisotropy



How sharp is the LAB?

ScS reverberation analysis

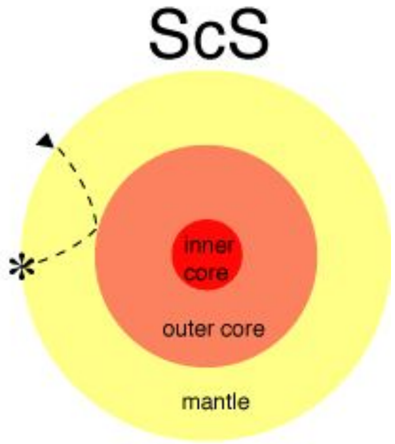
- Reflections from discontinuities

G-discontinuity central Pacific (Parmentier et al., 2015) is relatively sharp

- <30 km thick
- 6 % velocity decrease

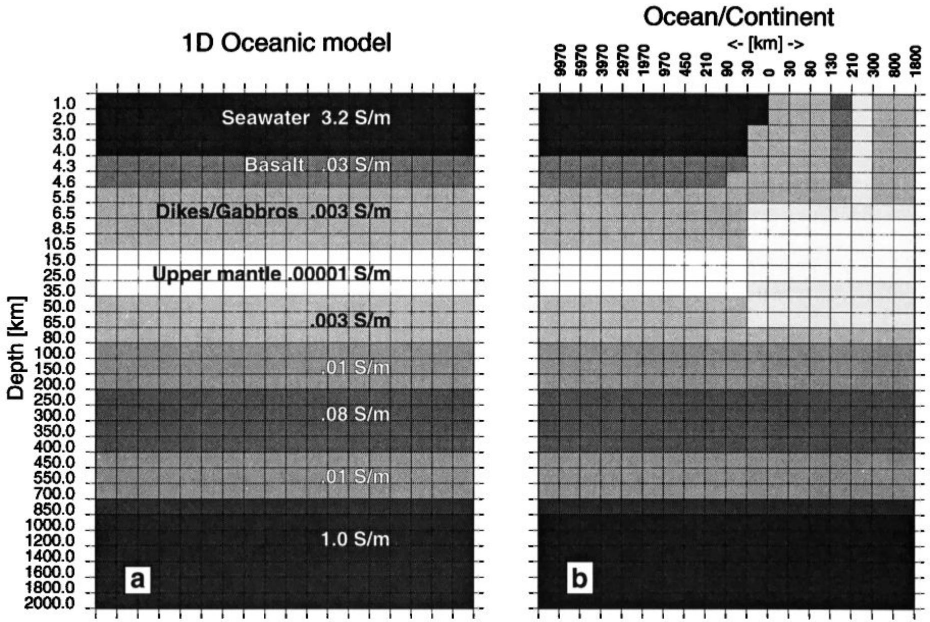
G-discontinuity oceanic region (Kawakatsu & Utada, 2017)

- <40 km thick
- velocity reduction



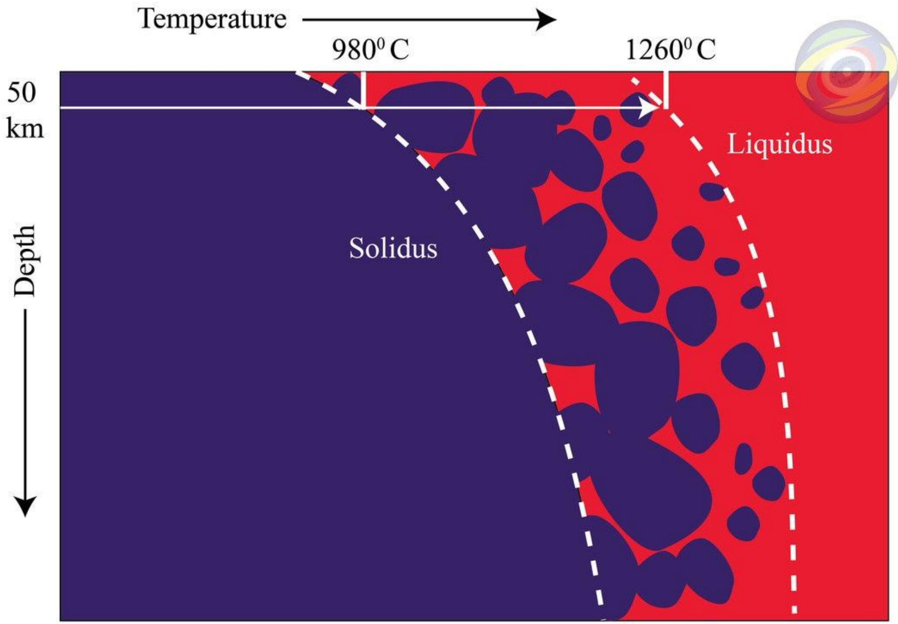
Water content

- Magnetotelluric investigation (Lizarralde et al., 1995)
- Conductive zone between 150km and 400km depth. Water?
- More recent studies disagree (Yoshino et al., 2006; Reychert et al., 2020)



Partial melts

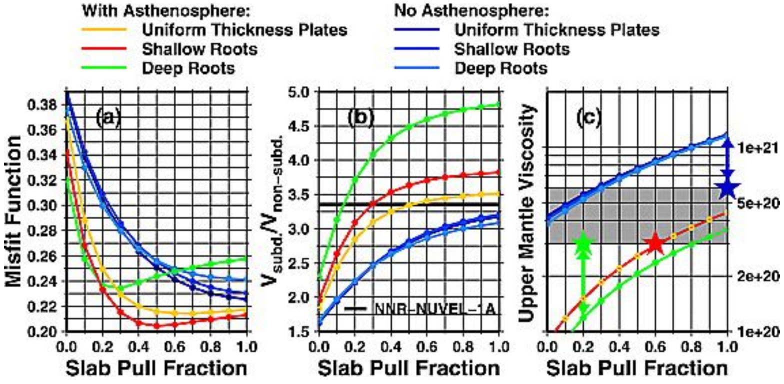
- Water content would move the solidus to lower temperatures, could explain high conductivity zone
- Small amounts of partial melt may explain velocity jump from seismic observations.
    - Rychert et al. (2020),
      Sakamaki et al. (Nature, 2013)

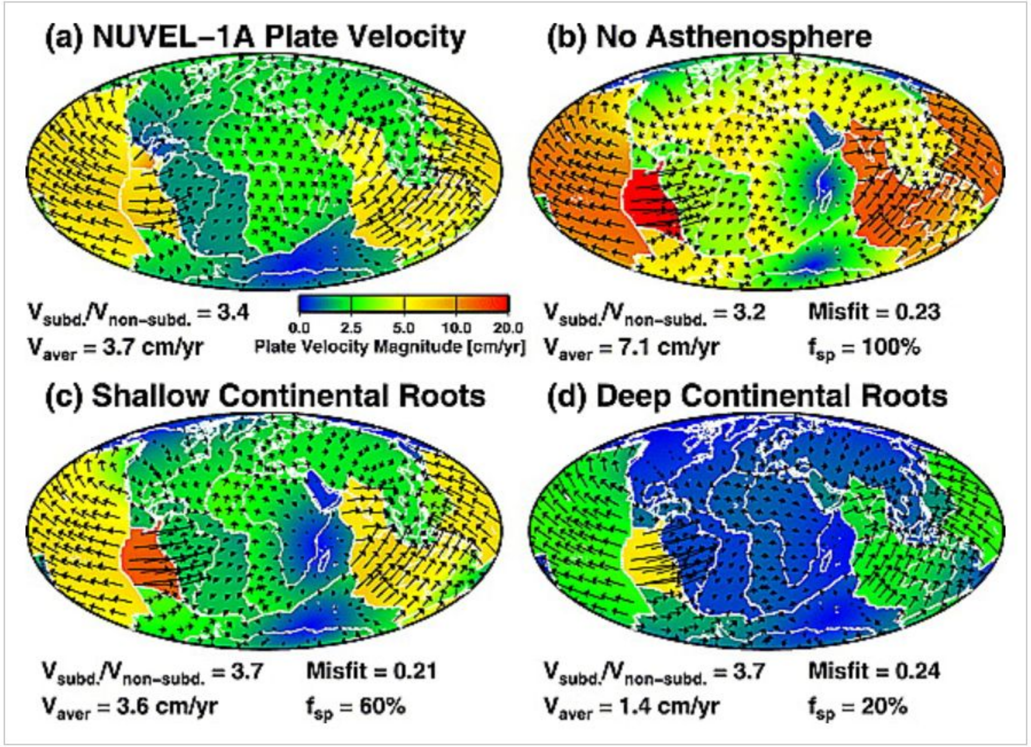


Interactions between plate and mantle

- *Even the deepest continental roots are underlain by a low-viscosity layer*
- *With anchoring roots, predicted plate motions differ from the observations*

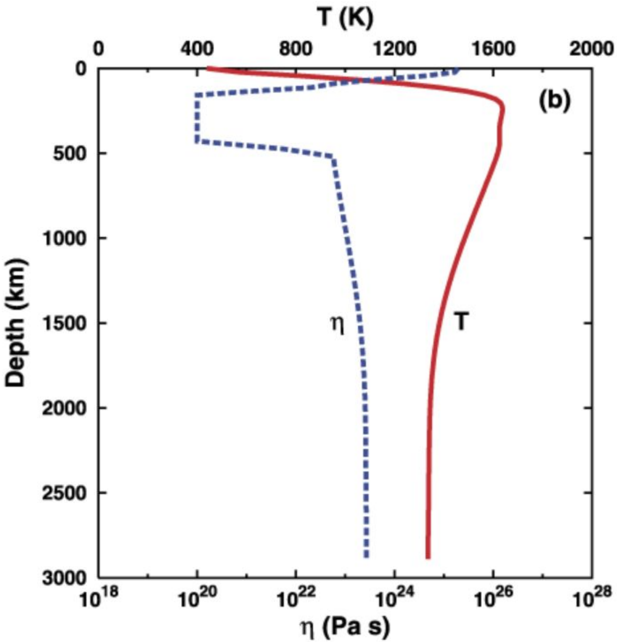
(van Summeren et al.,2012)

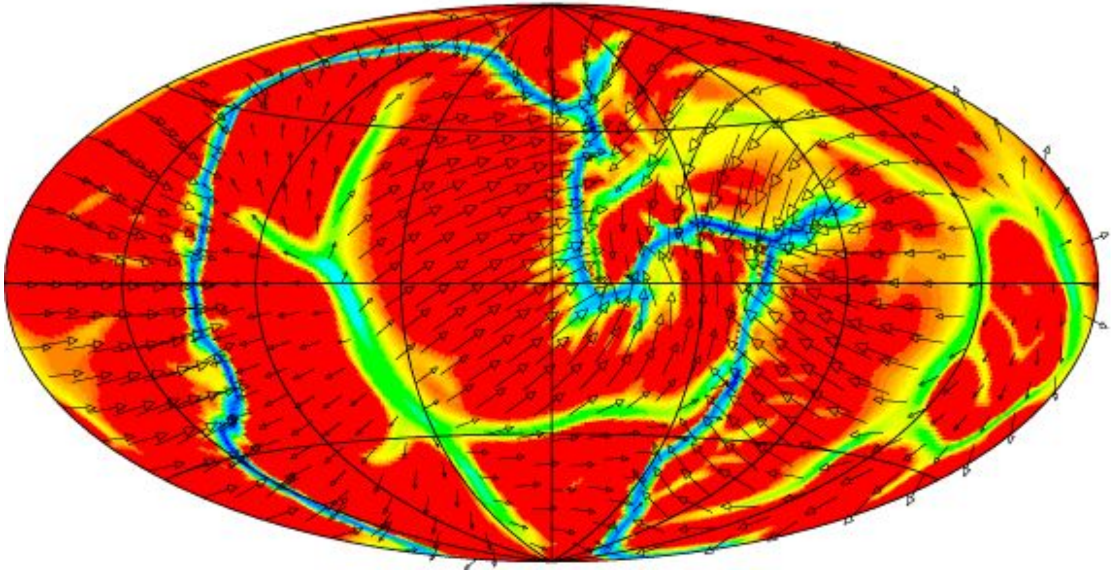




Interactions between plate and mantle

"combining a pronounced LVZ and a plastic yield stress to allow localized weakening of the cold thermal boundary layer results in a distinctly plate tectonic style of convection, with ~30% toroidal surface motion for the 3-D case. Recycling of water into the upper mantle at subduction zones is a plausible cause of Earth's LVZ, whereas Venus is dry and lacks both an LVZ and plate tectonics." **(Richards et al., 2001)**





Seismology
Isostasy
Conductivity
Gravity/ topography
Plate tectonic modelling

Do other planets have an asthenosphere?

Mercury: relatively thin mantle. Whole mantle asthenosphere? Or no asthenosphere? Unconstrained viscosity structure.

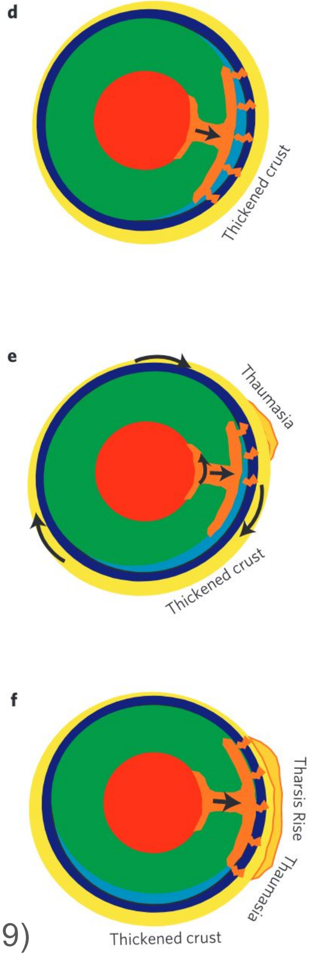
Venus:

+ tectonic features a result of ‘asthenospheric currents’ (Sukhanov, 1986)
- GTR discrepancy with Earth can be explained by lack of low viscosity zone (Smrekar & Phillips, 1991)

Mars:

+ crustal dichotomy could be explained by endogenic process of long wavelength mantle flow early in its history (Zhong & Zuber, 2001)
+ often modelled with an asthenosphere (Taylor et al. 2020; Schools, 2020)

Large uncertainties due to limited data availability!



Zhong (Nature, 2009)

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