The Mid-lithosphere Discontinuities (MLDs): Observations, Origins, and Geodynamic Implications

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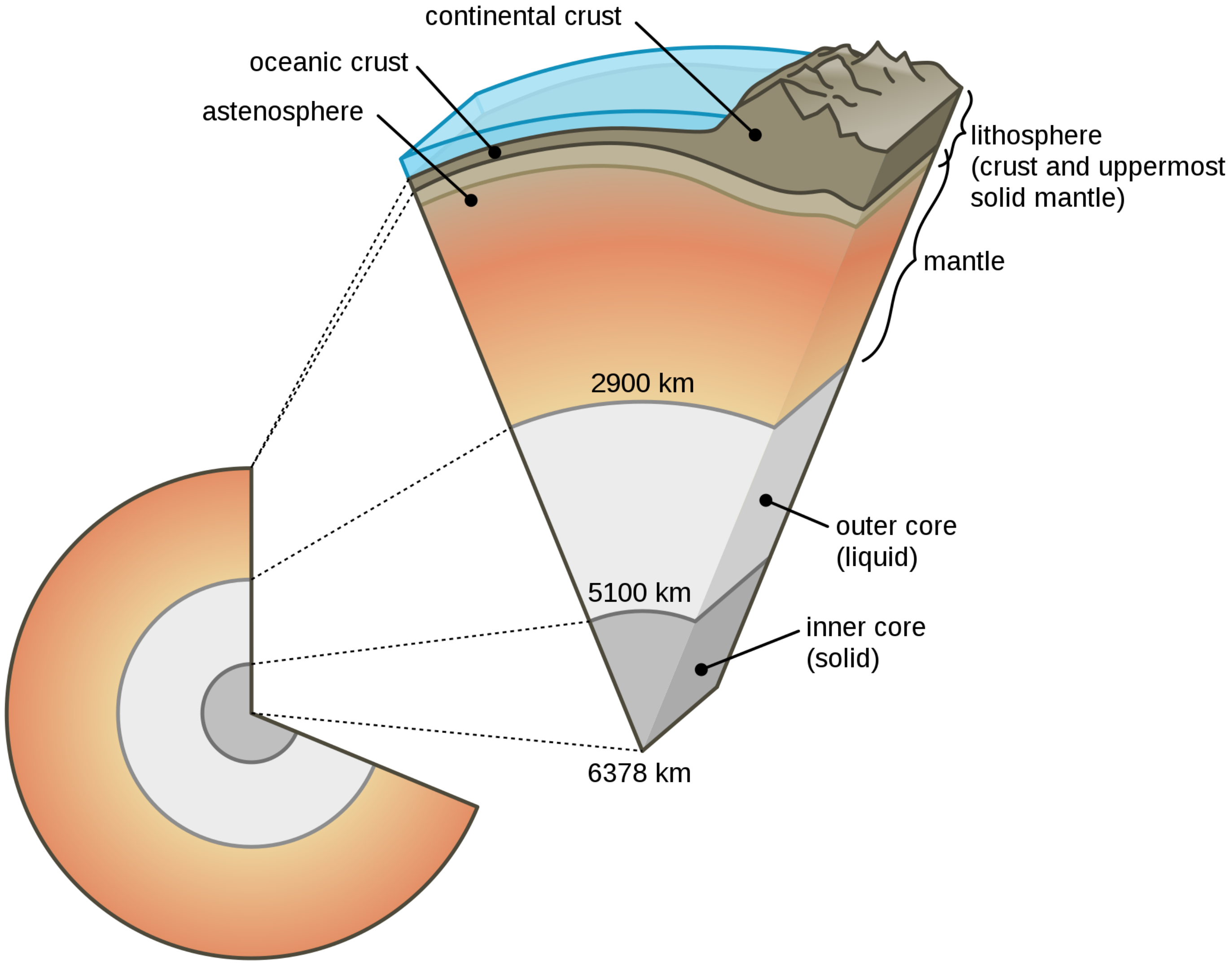
Lithosphere & Asthenosphere

◆ Lithosphere

- Earth's lithosphere includes the crust and the uppermost mantle, which constitutes the hard and rigid outer layer of the Earth;
- It is defined from its rigid mechanical properties, unlike the crust and mantle which are initially defined by their compositions.

◆ Asthenosphere

- Highly viscous, mechanically weak and ductile region of the upper mantle of the Earth.



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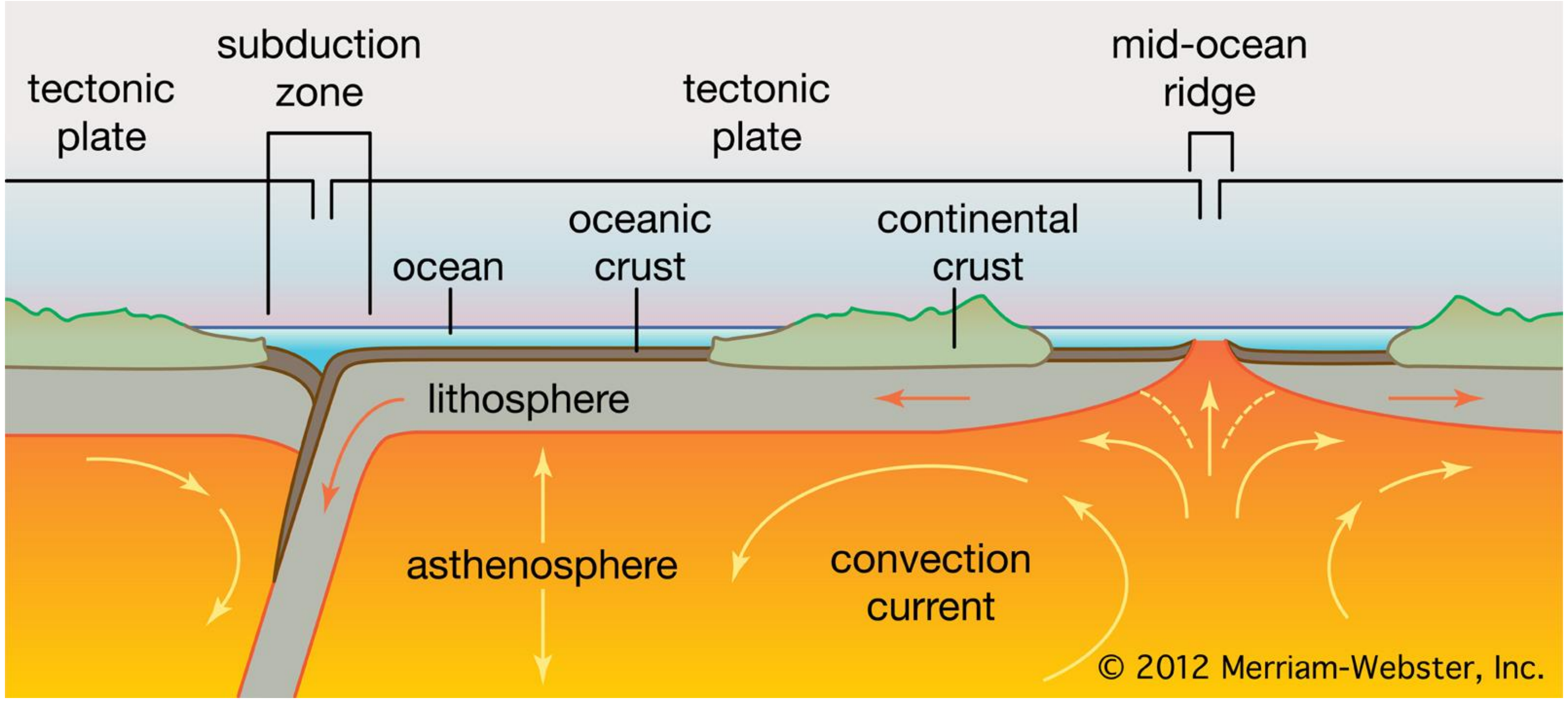
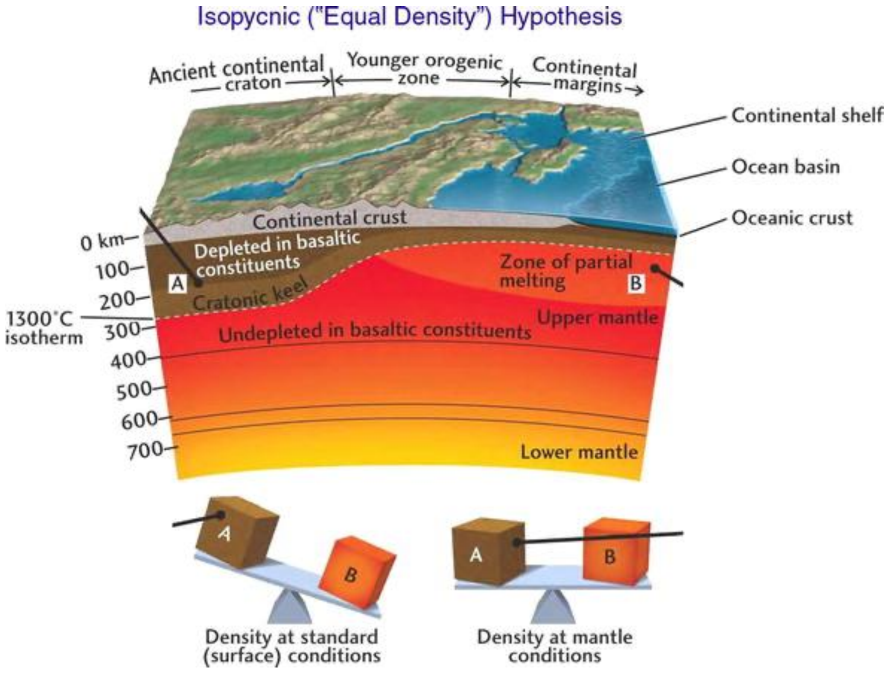
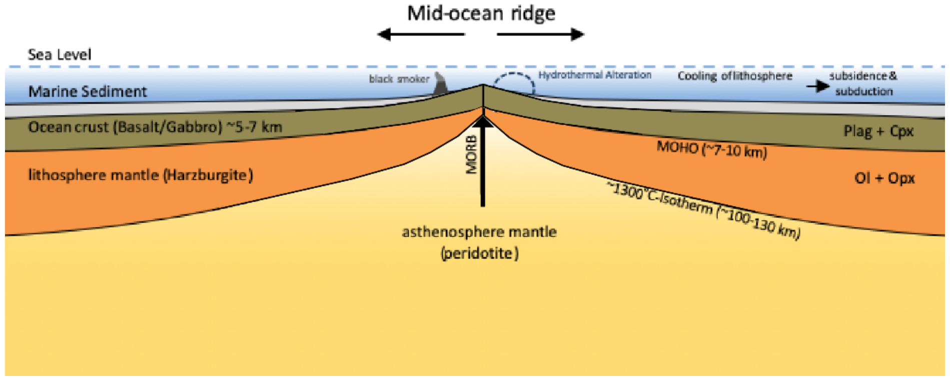


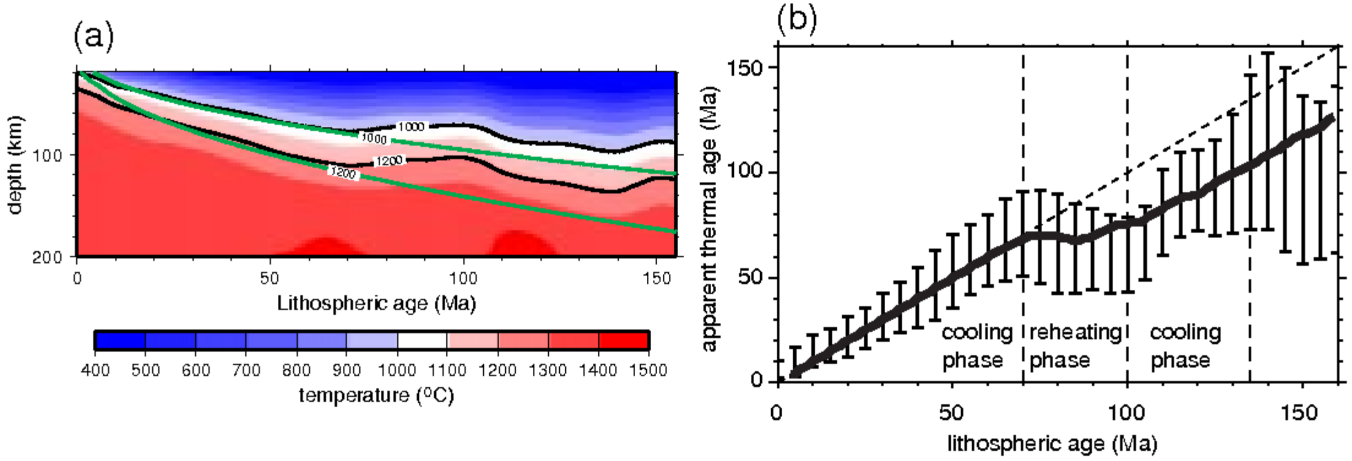
Lithosphere & Asthenosphere

- Continental lithosphere
  - The continental lithosphere consists of the continental crust and, typically, some non-convecting part of the underlying upper mantle;
  - the continental lithosphere is heterogeneous and its structure highly variable.



- Oceanic lithosphere
  - Oceanic lithosphere for the most part obeys comparatively simple thermal models;
  - Usually denser than continental lithosphere.





Lithosphere & Asthenosphere

◆ Lithosphere-asthenosphere boundary (LAB)

Definition in different discipline:

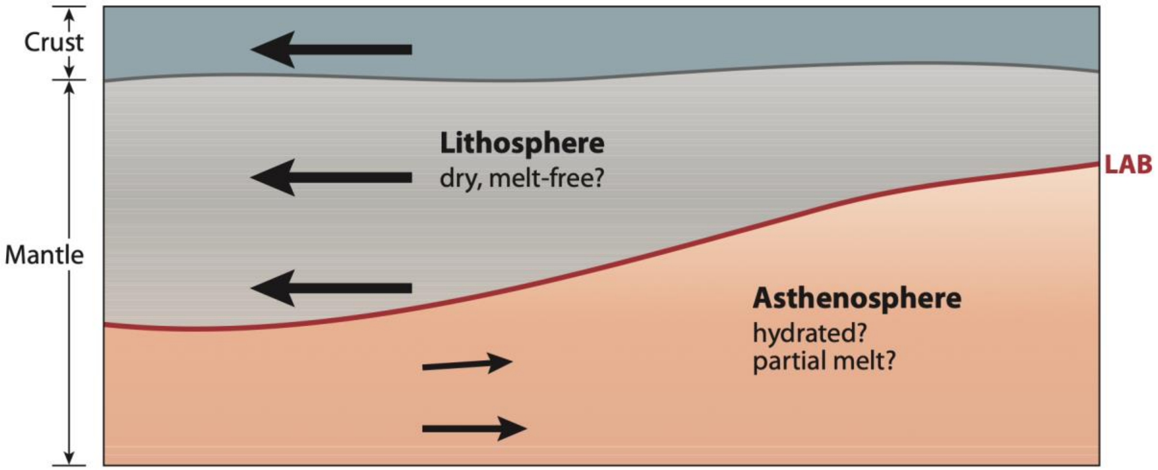
- Mechanical boundary layer (MBL)
  - The LAB separates the mechanically strong lithosphere from the weak asthenosphere. Earthquakes are primarily constrained to occur with … B is most shallow when using this definitio…
- Thermal boundary layer …
  - The lithosphere is unable … ntle beneath is much weaker. In this fran… tion vs. convection.
- Rheological boundary la…
  - Colder material in the lit… contributes to its lower viscosity.

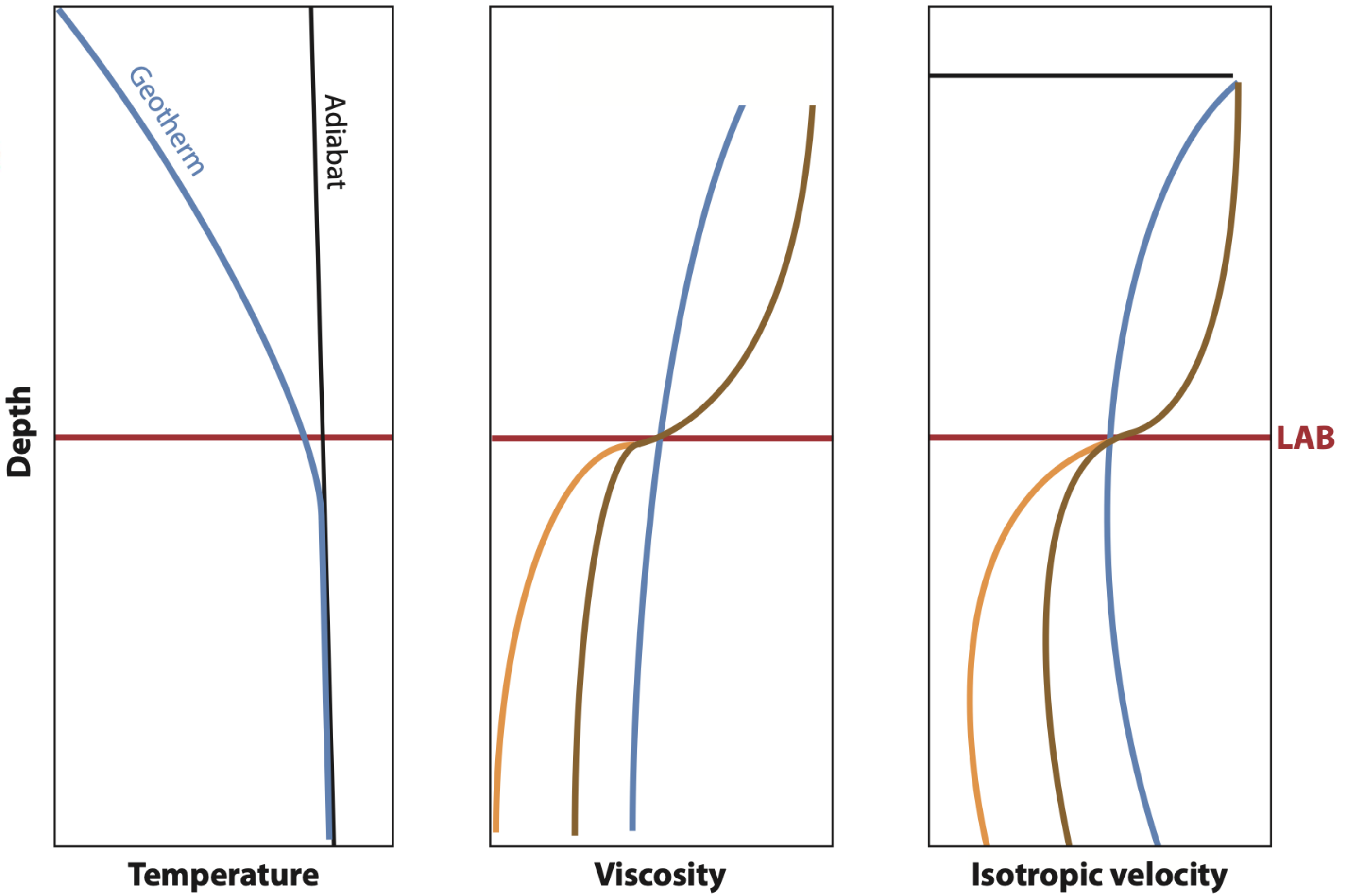
A xenolith is a rock fragment that becomes enveloped in a larger rock during the latter's development and solidification.

- Compositional boundary layer (CBL)
  - Lithospheric mantle is ultramafic and has lost most of its volatile constituents, such … water, calcium, and aluminum. Knowledge of this depletion is based upon the composition of mantle xenoliths.

Lithosphere & Asthenosphere

◆ Lithosphere-asthenosphere boundary (LAB)



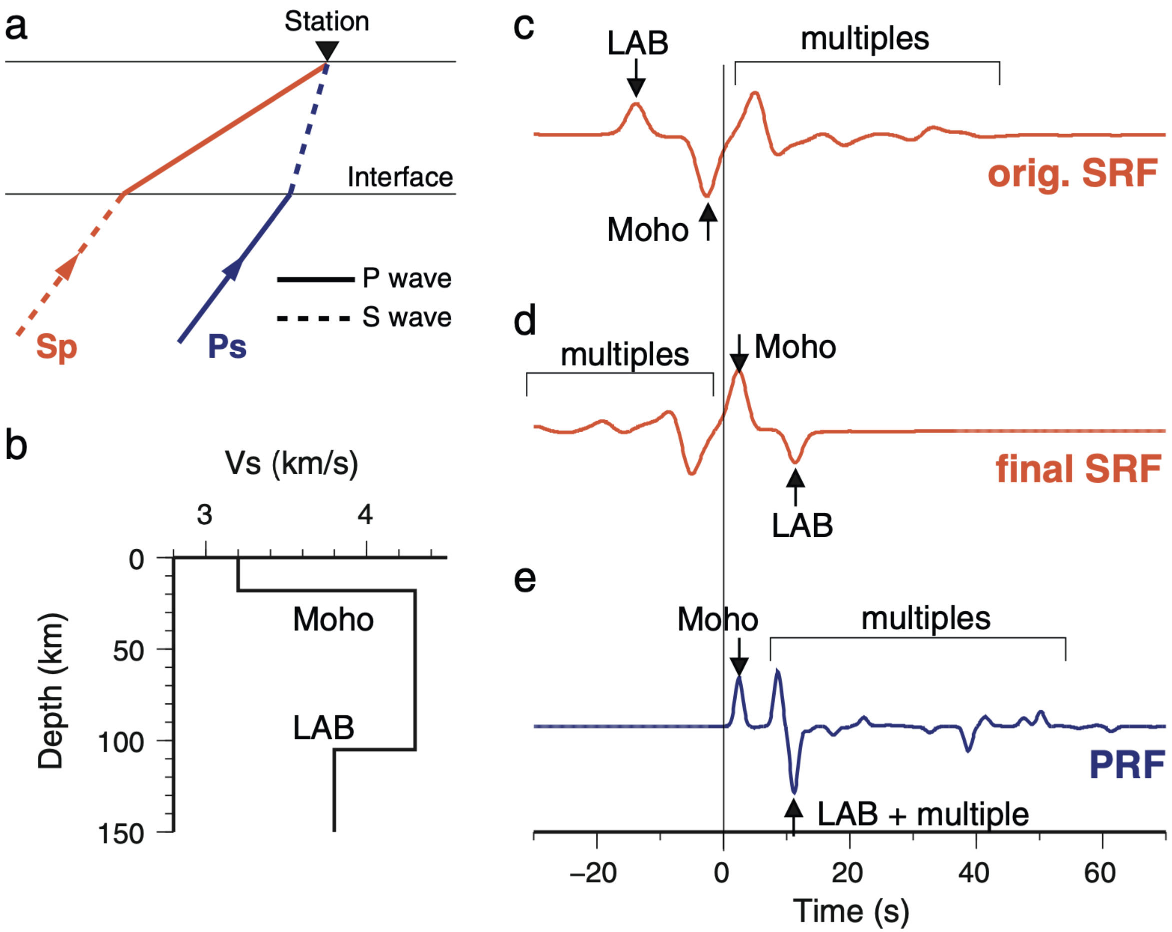


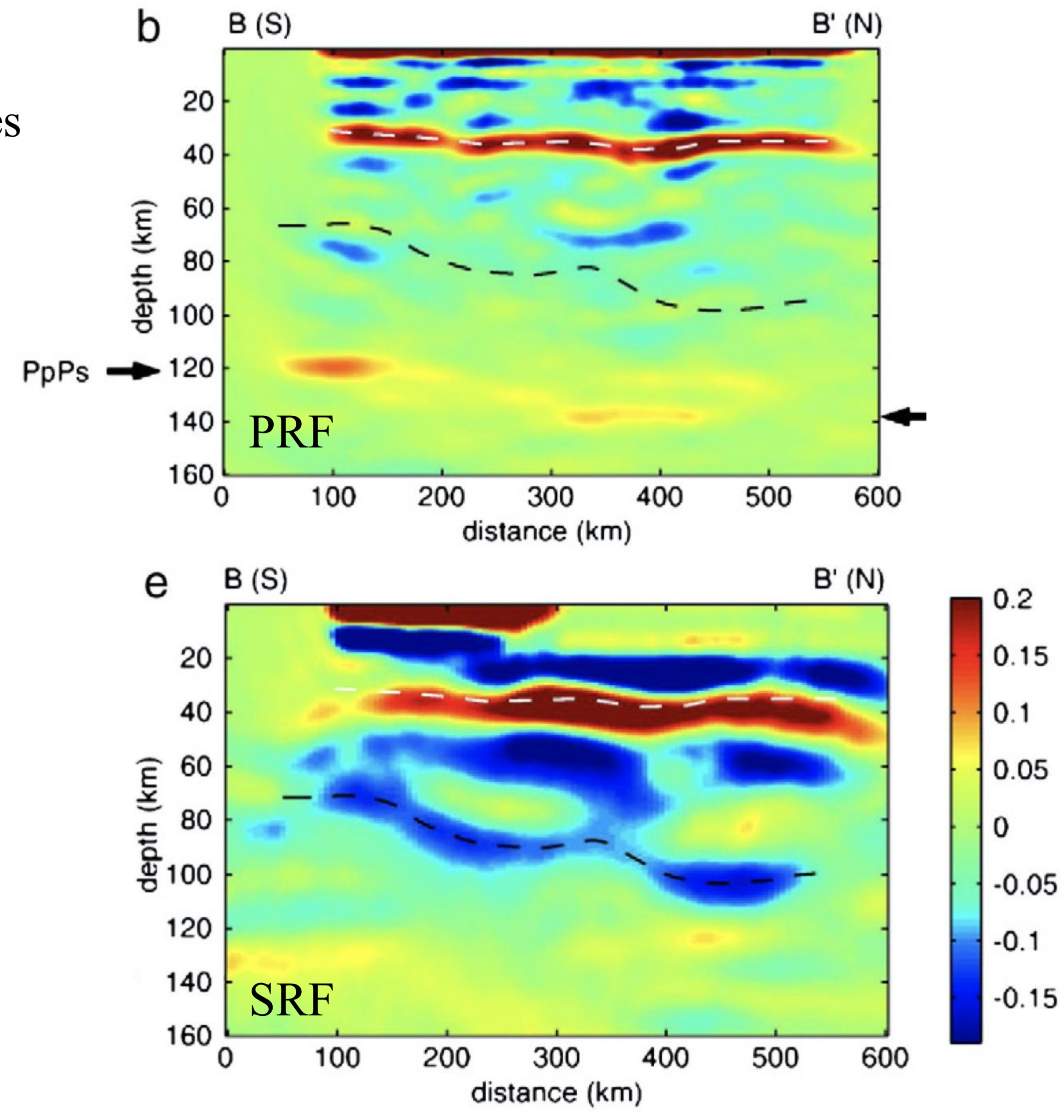
Blue: the geotherm in the left. Brown: the geotherm superimposed on a compositional difference at the LAB (dry lithosphere over hydrated asthenosphere). Orange: the latter case plus partial melt in the asthenosphere.

- Seismic LAB
  - Definition of seismic LAB originates from the seismic observations, i.e. a drop in seismic velocities;
  - Seismic LAB is more close to the TBL LAB, and generally deeper than CBL.

Seismic Observations of LAB

- Receiver function
  - SRFs are ideal for determining mantle structure since the faster converted Sp waves arrive before the primary S waves and are therefore distinct from any crustal multiples.





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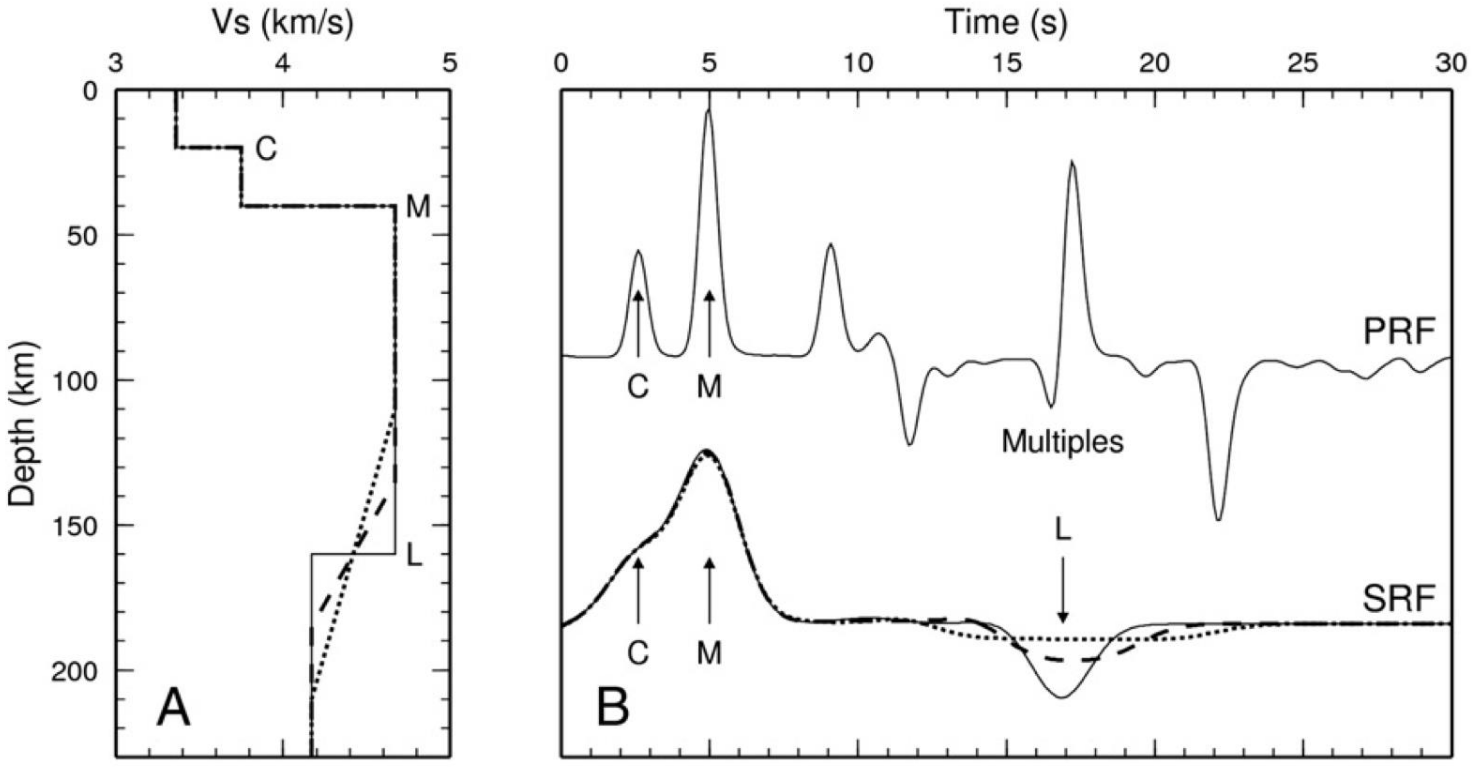
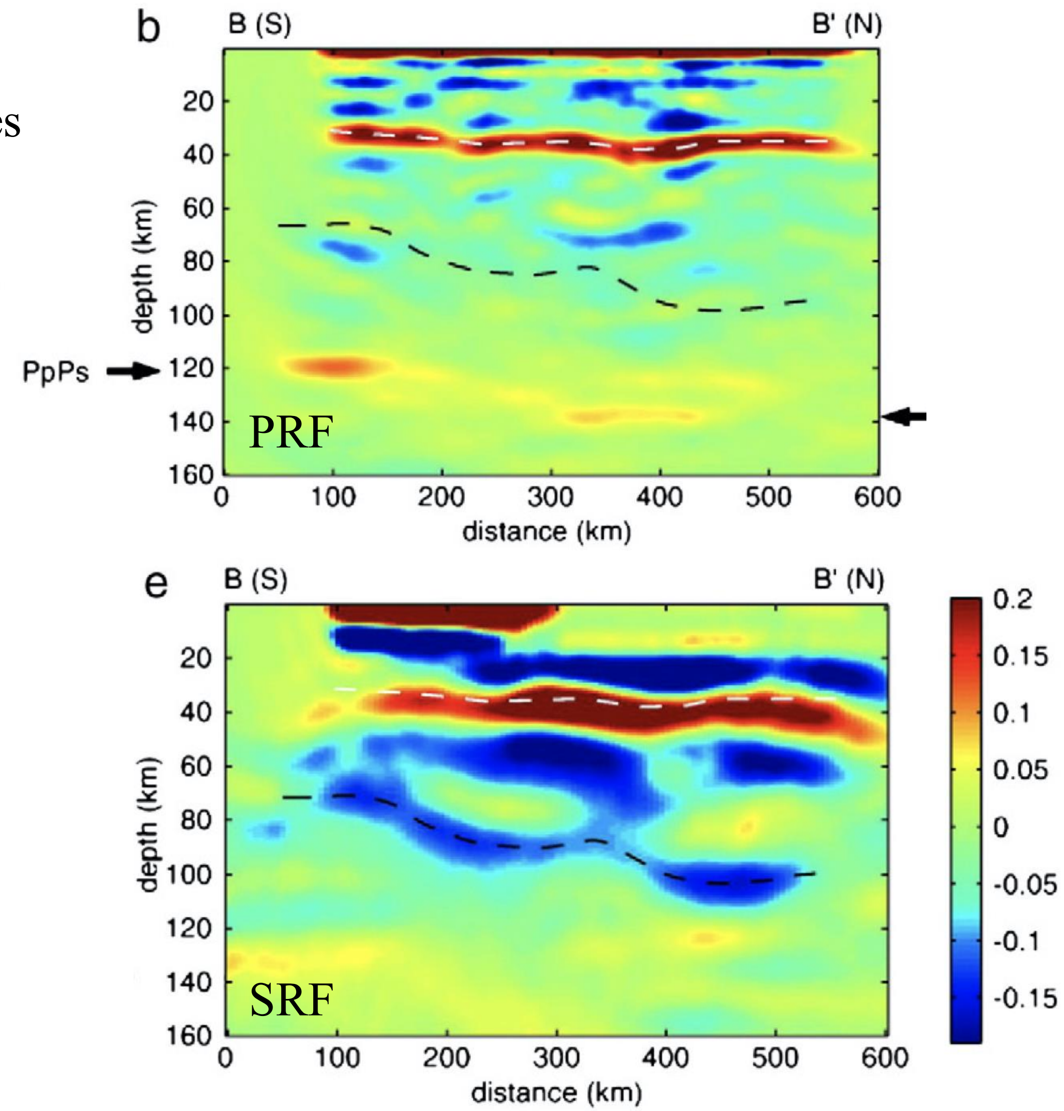
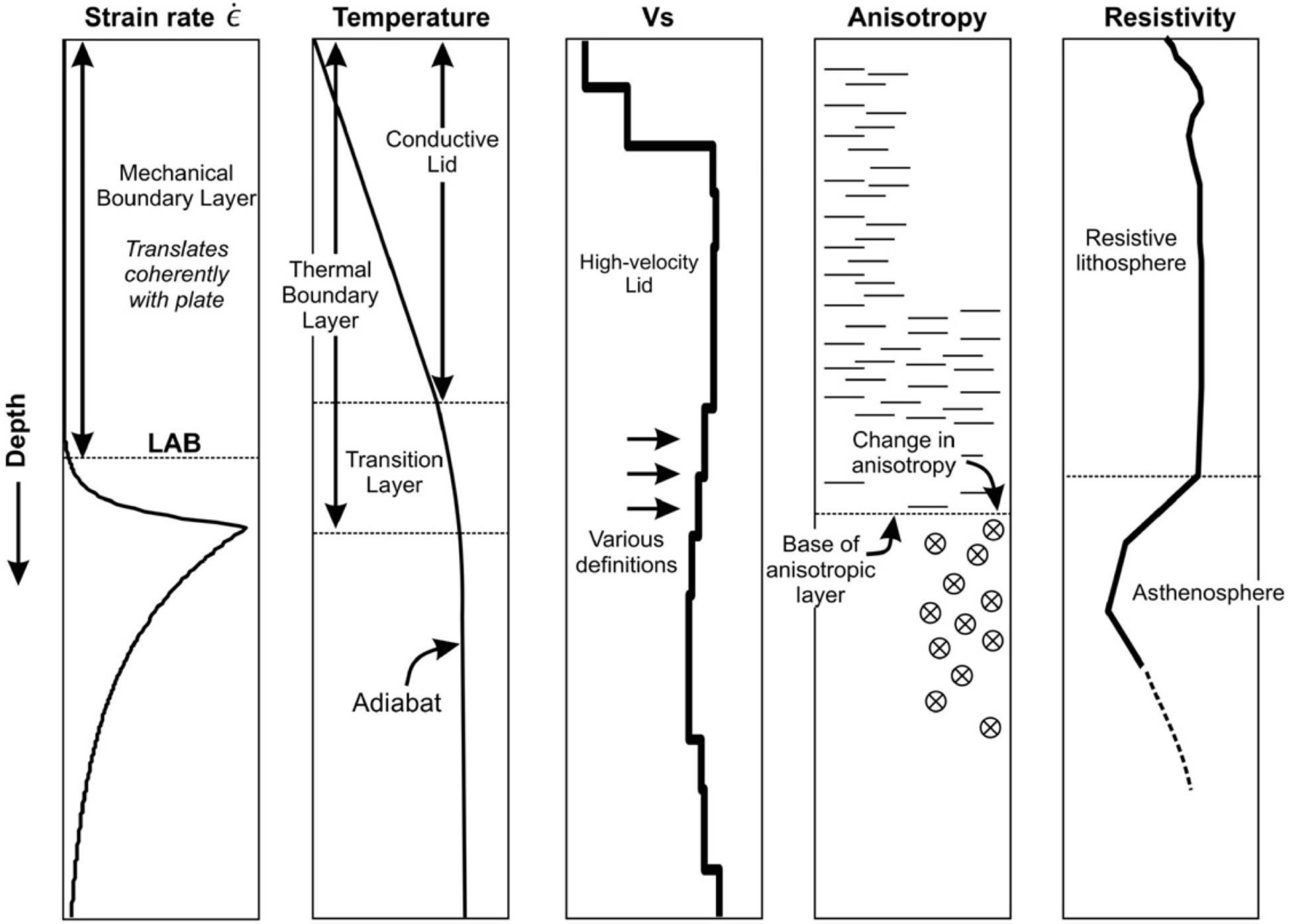




Seismic Observations of LAB

◆ Surface waves



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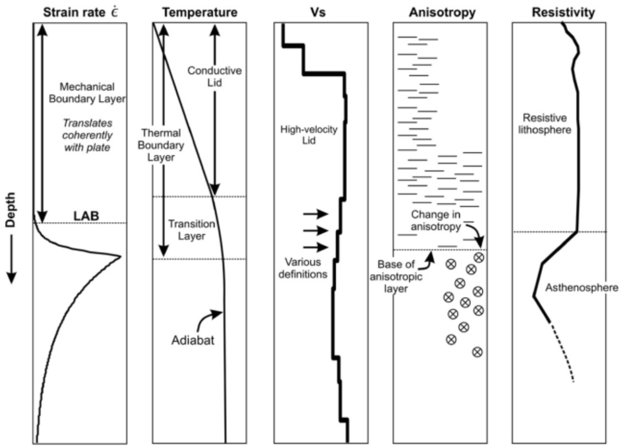

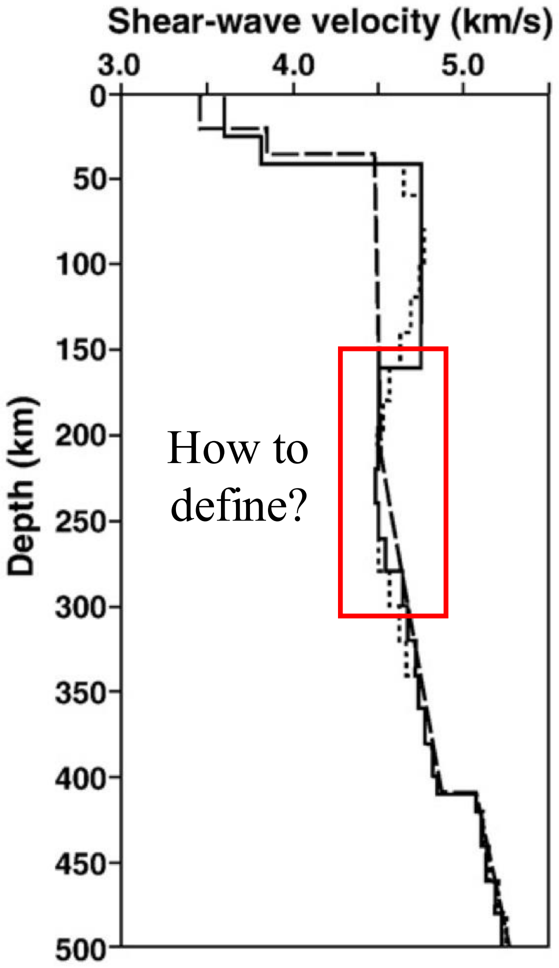

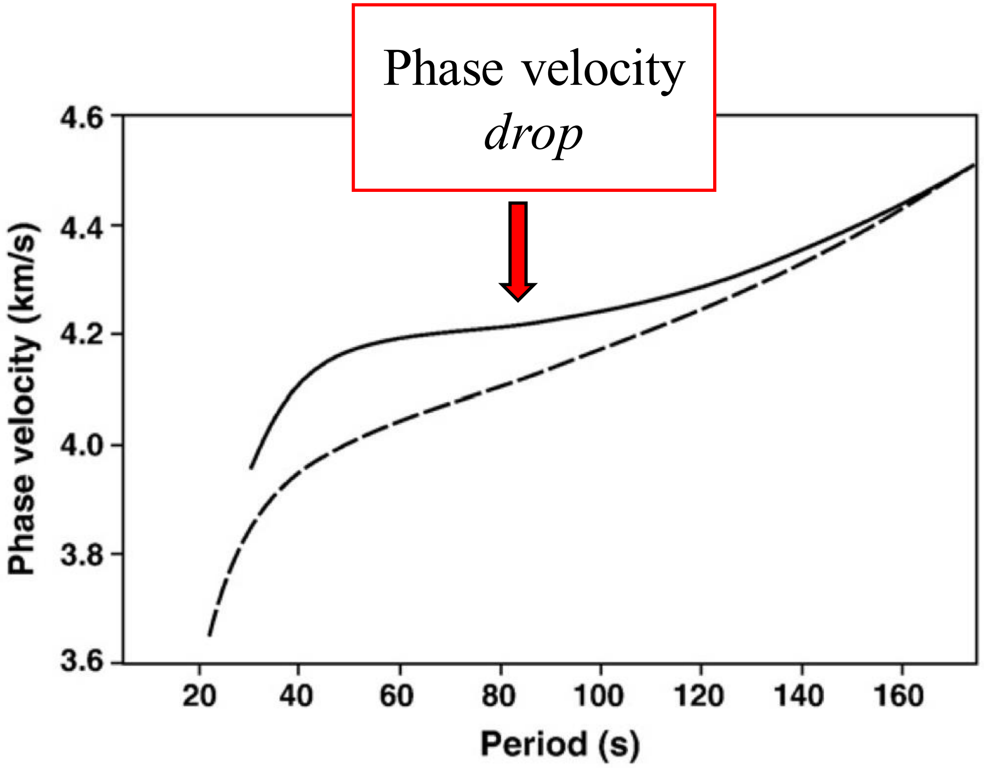

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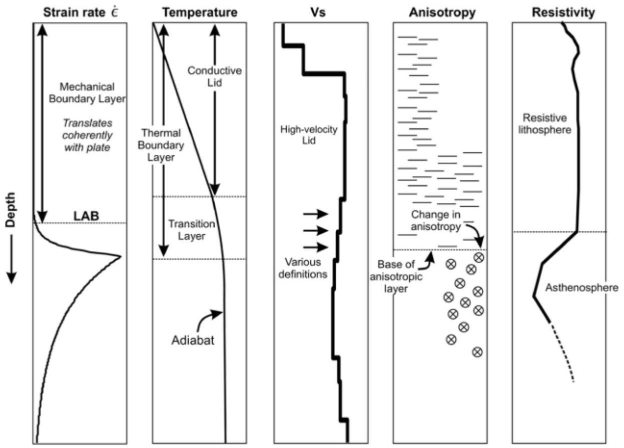

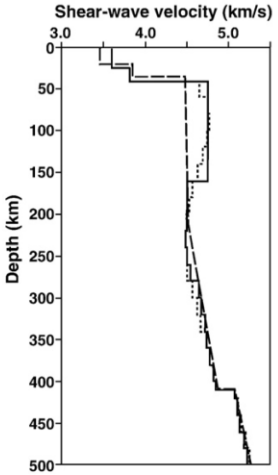

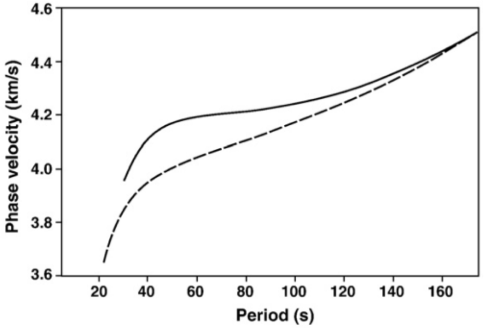

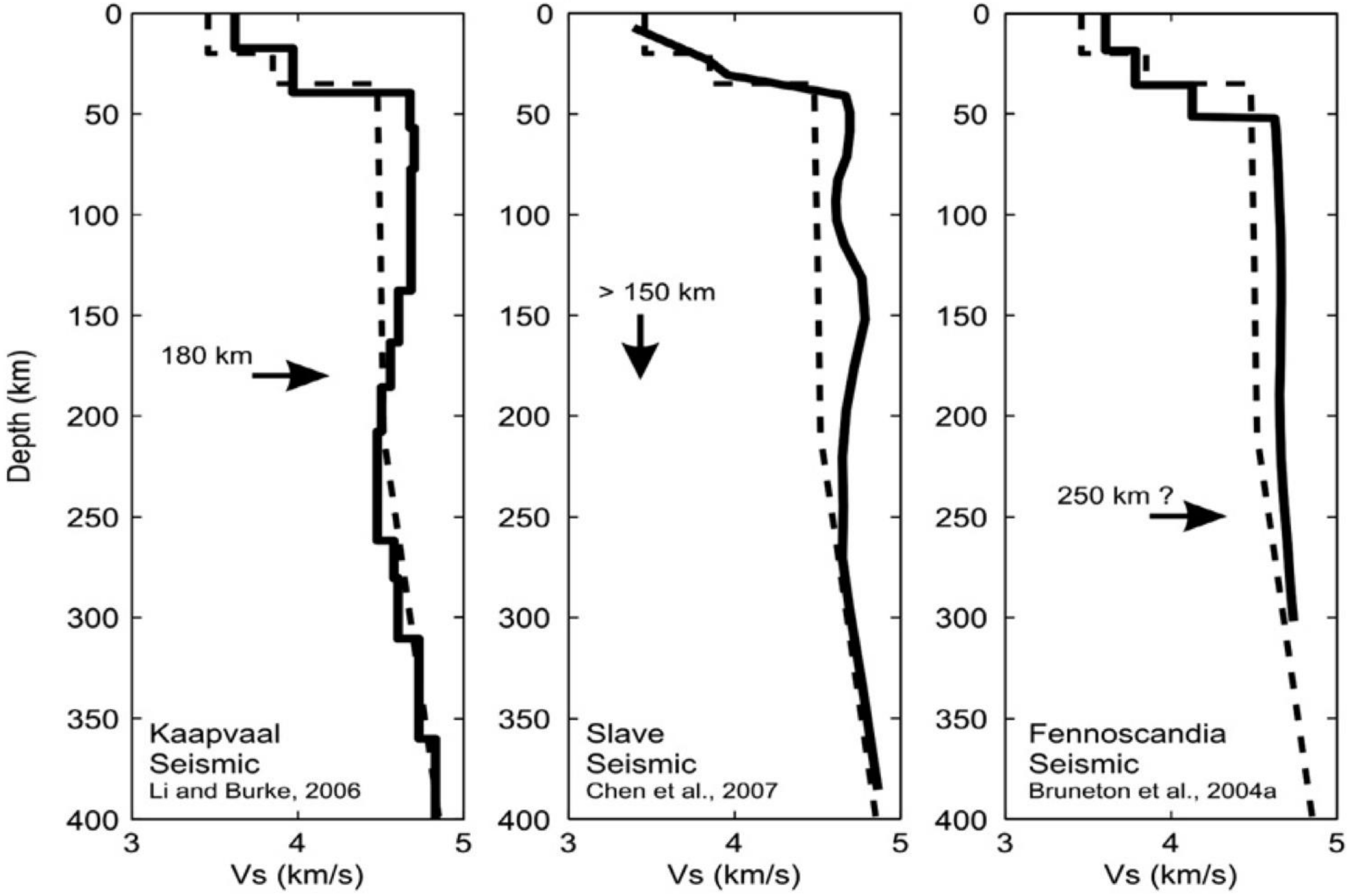

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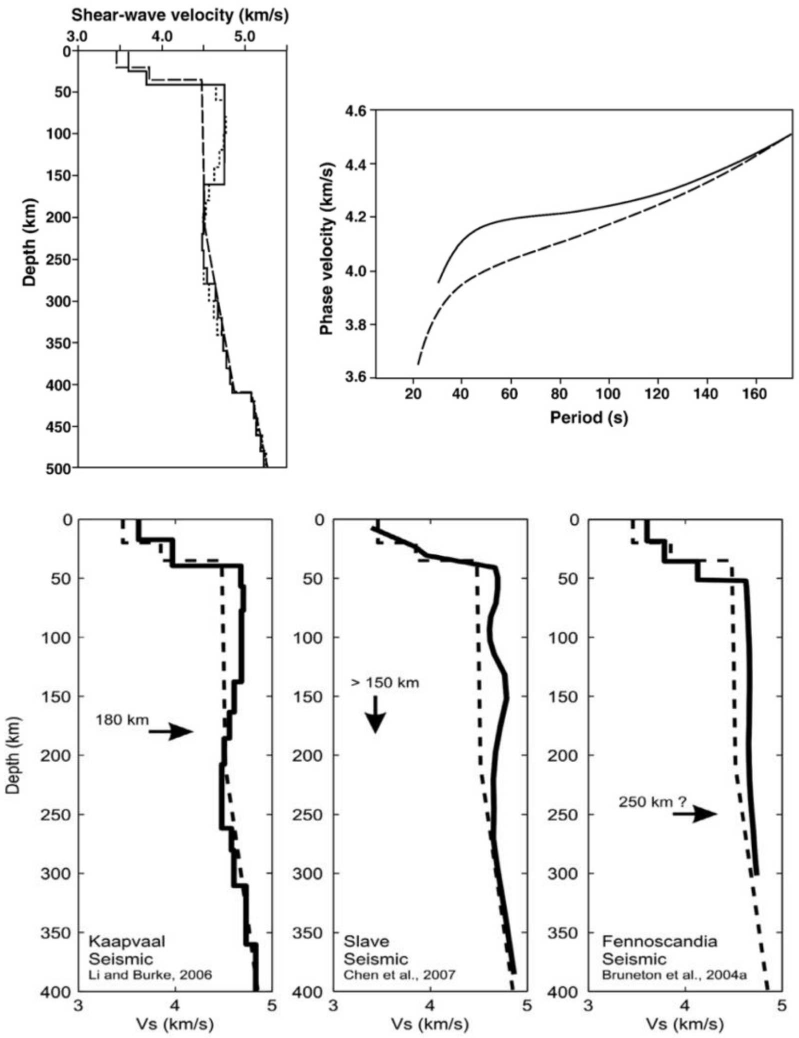
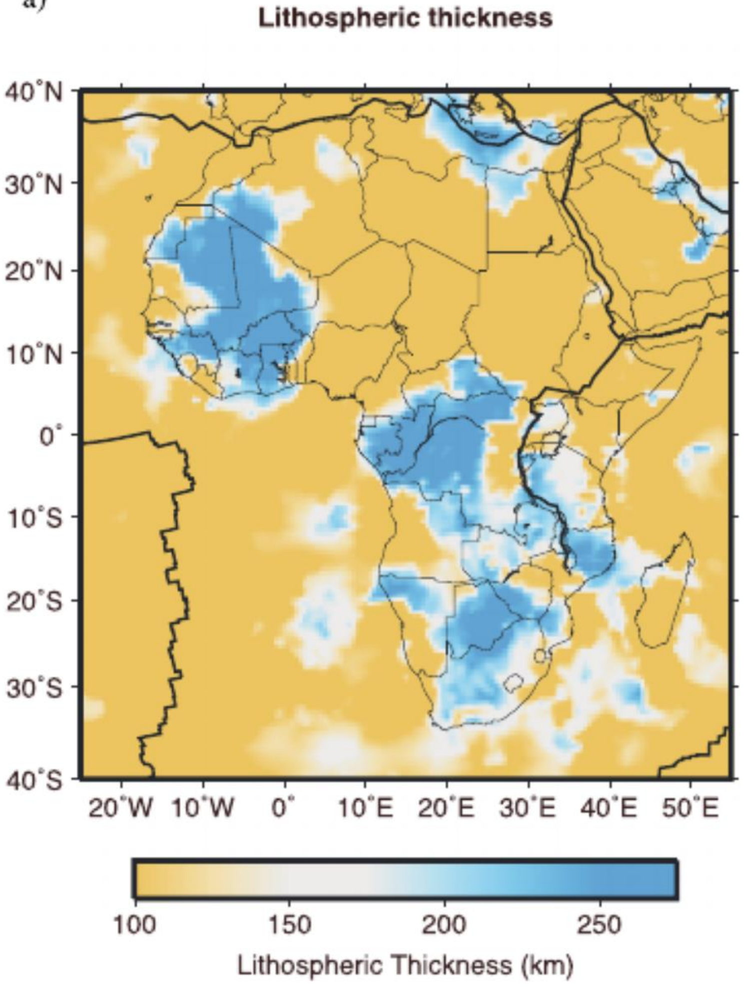


a)



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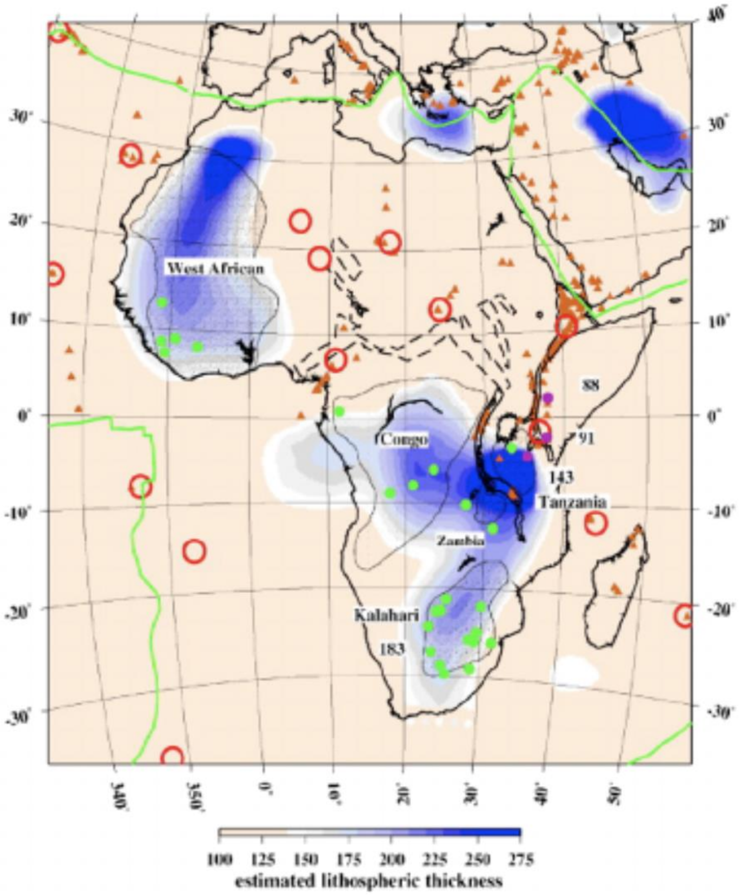


Mid-lithosphere Discontinuity (MLD)

From LAB to MLD

- Because the seismic observations to the LAB and MLD are similar, it is hard to distinguish between them;
- Since the different definition of LAB, people in the past tend to interpret MLD as LAB;
- We first need to have a clear LAB (hard), and then we can determine the MLD.

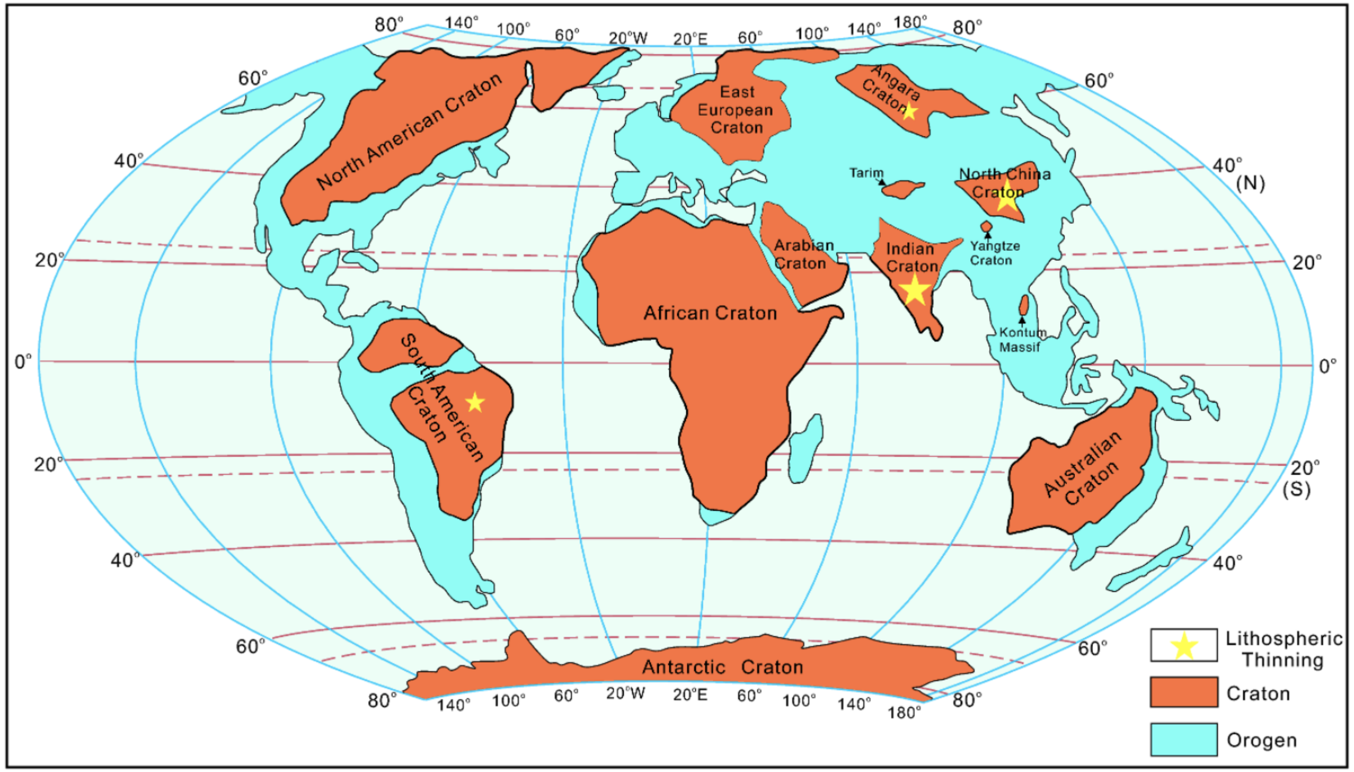
Facts

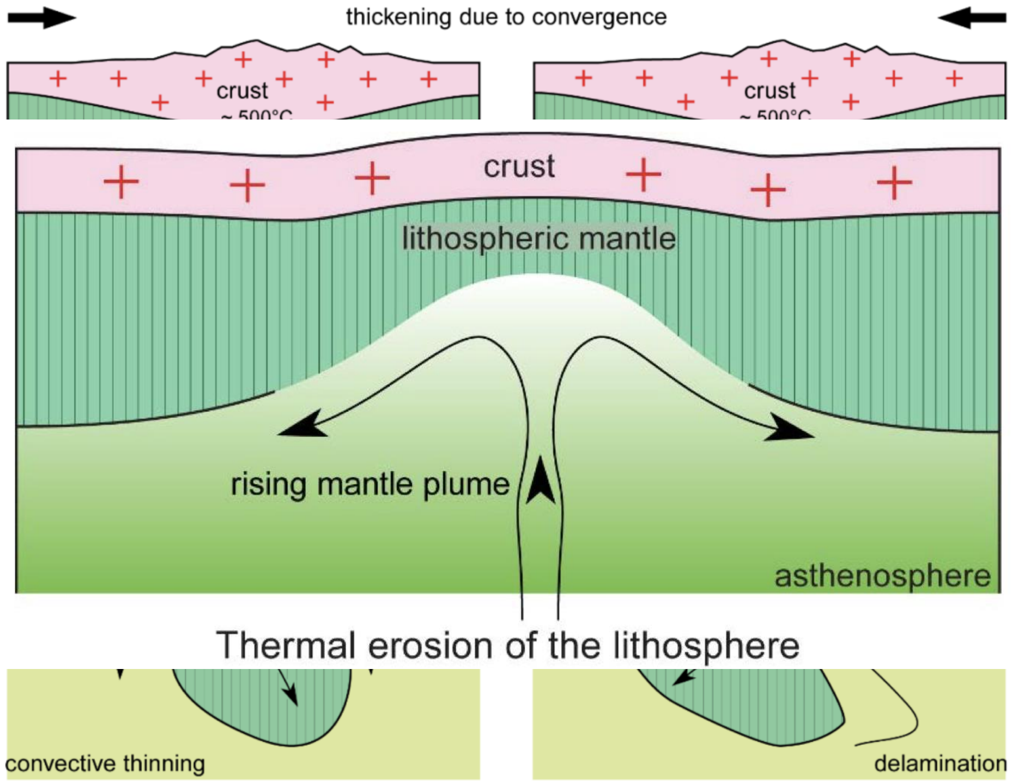
- MLD is more common at craton regions, and sometimes has a weaker velocity reduction, but a ~10% velocity reduction is also possible;
- Velocity structure from Moho to MLD are very complex, sometimes with multiple layers.

Cratons usually have the deepest LAB in the world, so MLD can be easily distinguished.

Mid-lithosphere Discontinuity (MLD)

- Cratons
  - Stable: With the exception of minor magmatic activity from the deep mantle, there is hardly any tectonic deformation, magmatic activity in cratons.

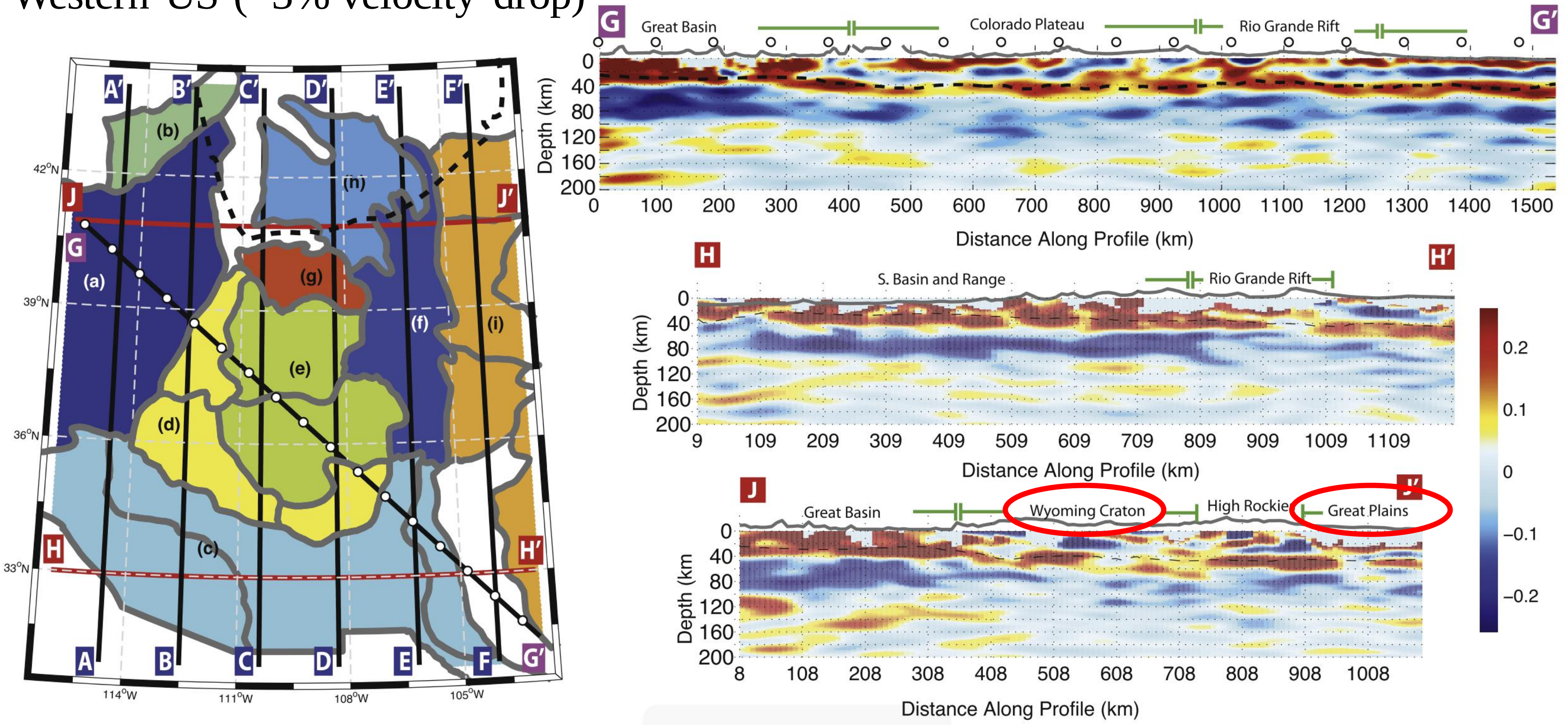




Mid-lithosphere Discontinuity (MLD)

- ◆ Observations
  - ➢ Western US (~3% velocity drop)

(Lekic and Fischer, 2014)

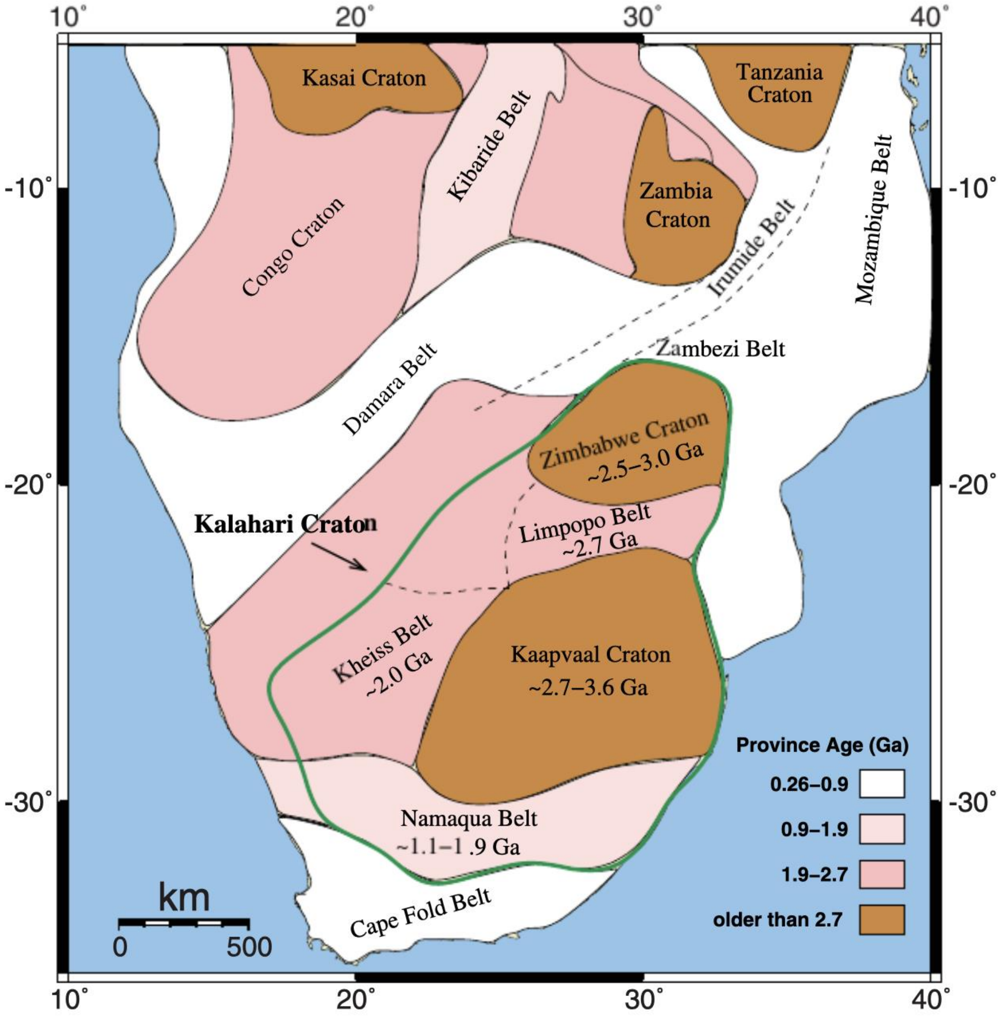


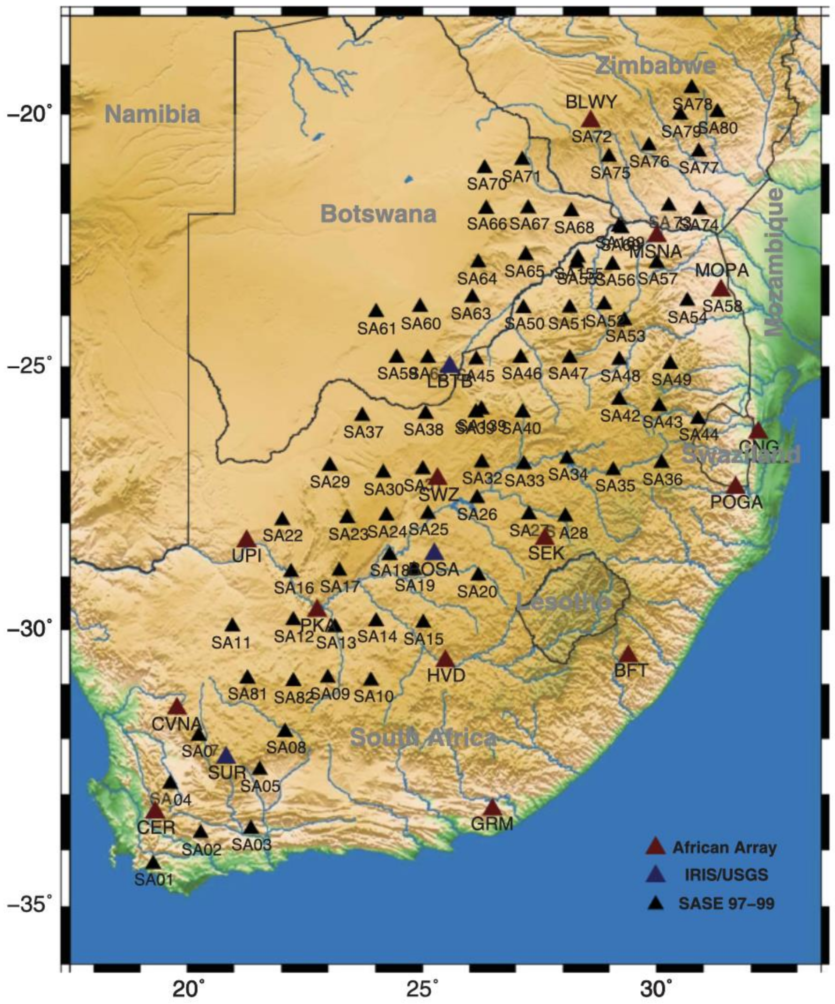
The authors state that - “The negative phase (blue) is less straightforward to interpret; beneath the Great Basin, Southern Basin and Range, the Snake River Plain, the High Rockies and the western and southern margins of the Colorado Plateau, is consistent with a seismically-defined LAB; beneath the Wyoming Basin, the central and northern Colorado Plateau, and the Great Plains craton it likely represents mid-lithospheric discontinuity/ies.”

Mid-lithosphere Discontinuity (MLD)

- Observations
  - Kalahari Craton – South Africa

(Sodoudi et al., 2013)





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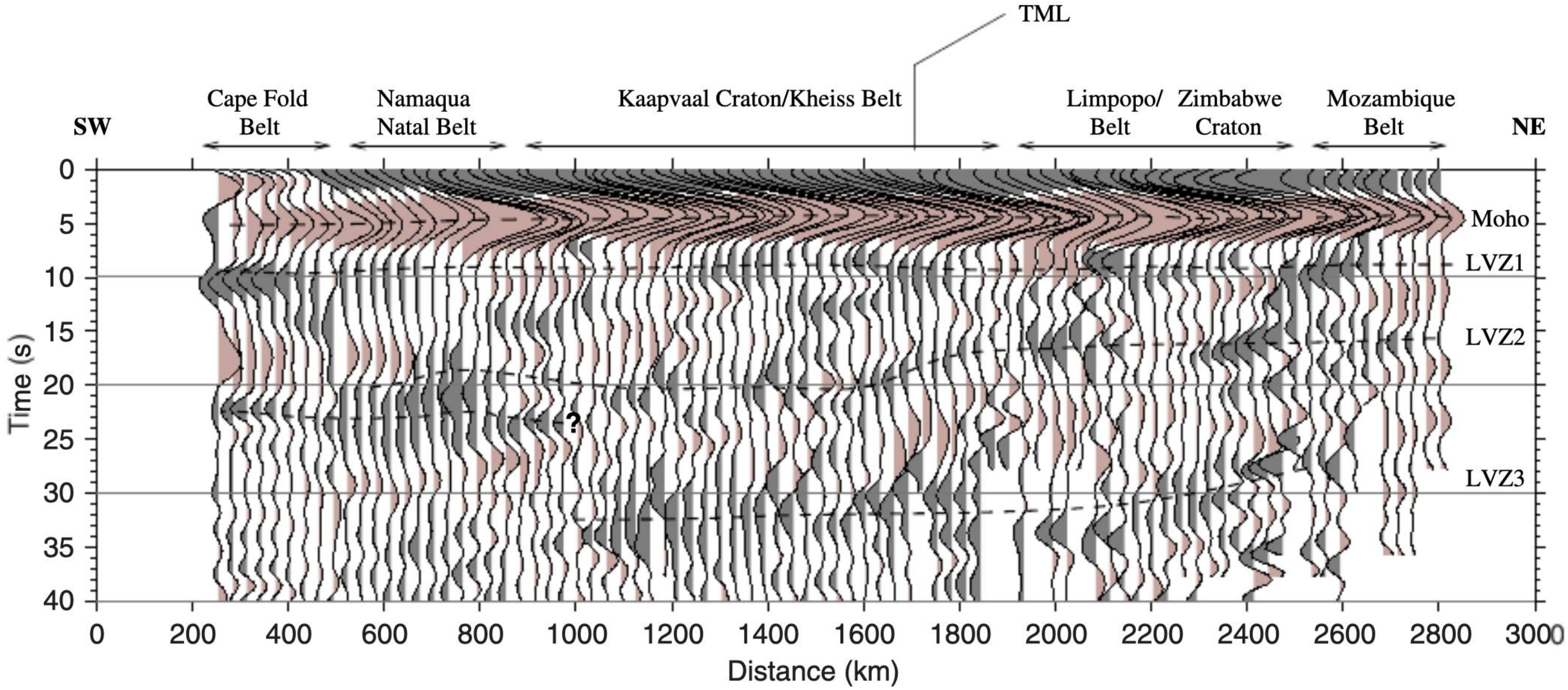
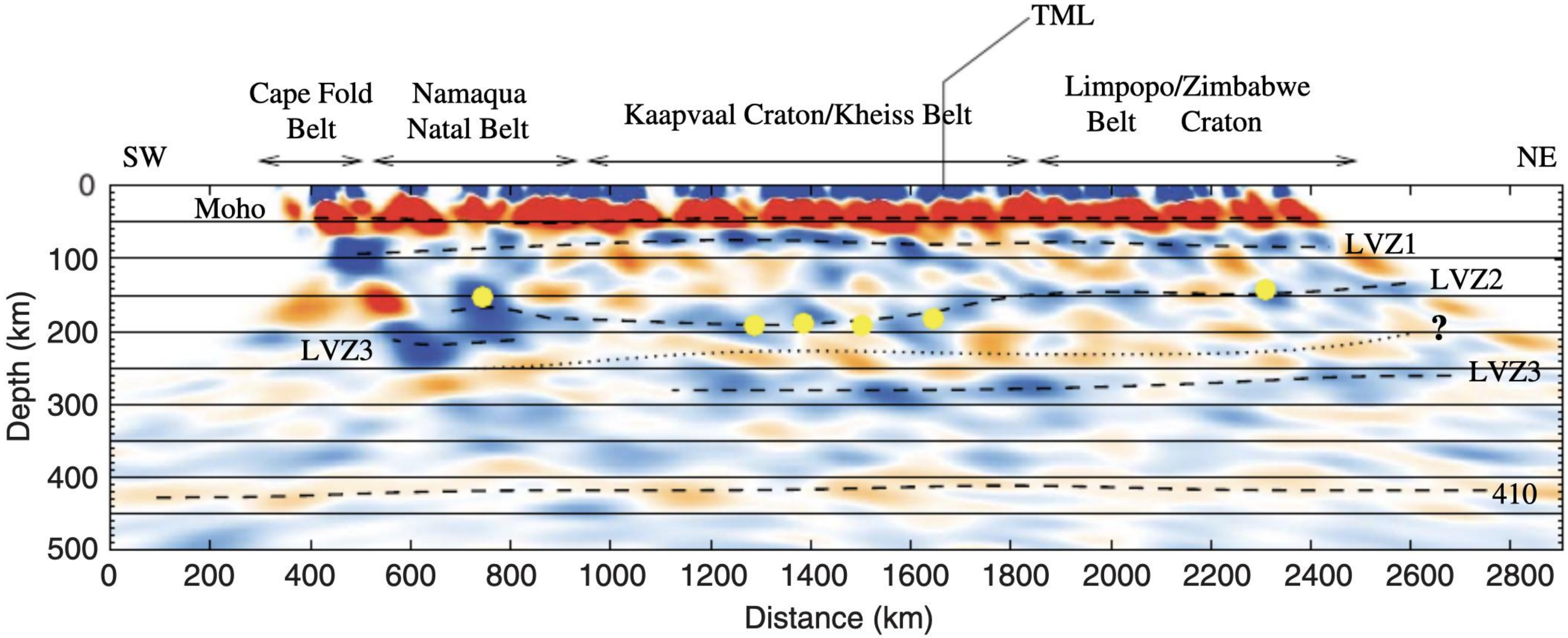


Mid-lithosphere Discontinuity (MLD)

- Observations
  - Kalahari Craton – South Africa (~3-5% velocity drop)

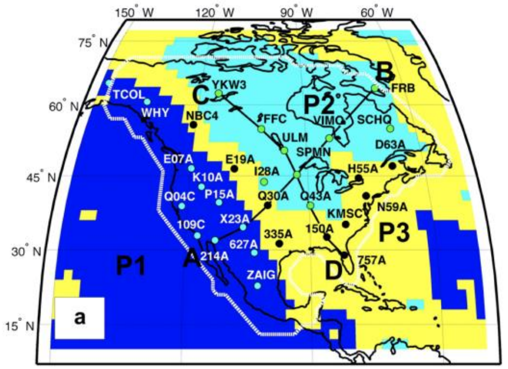
(Sodoudi et al., 2013)

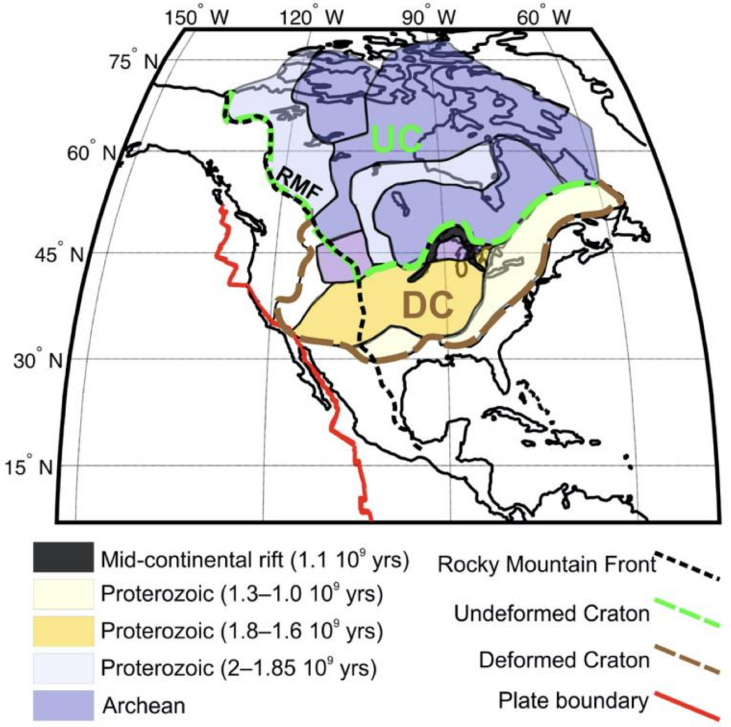


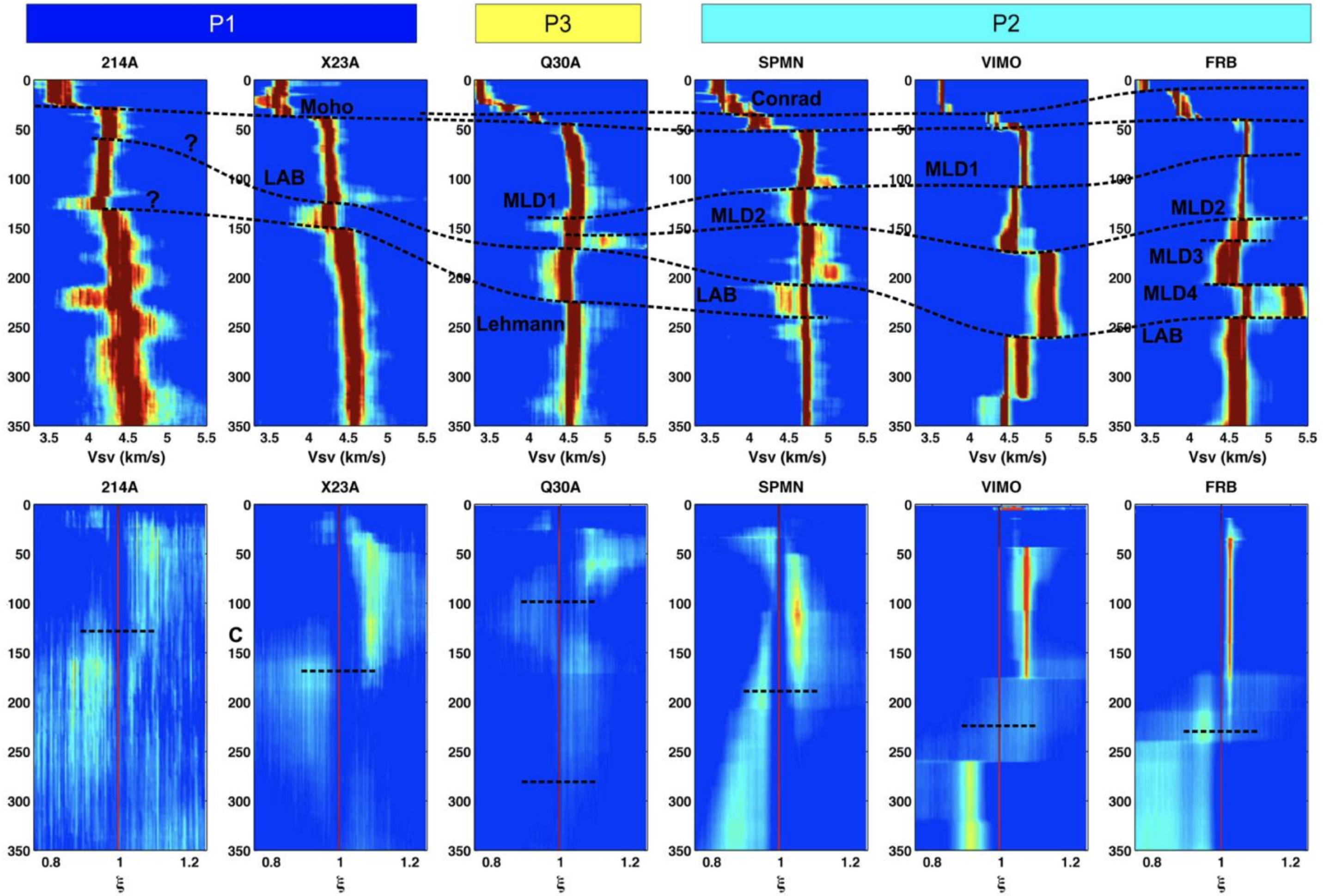
The migrated SRFs show evidence for an irregularly stratified and thick lithosphere beneath the Kalahari Craton, containing three consecutive negative velocity contrasts: LVZ1 at 85 km, LVZ2 at 150-200 km, and LVZ3 at 260–280 km depth.

Mid-lithosphere Discontinuity (MLD)

- Observations
  - Northern US (multiple MLDs)







(Calò et al., 2016)

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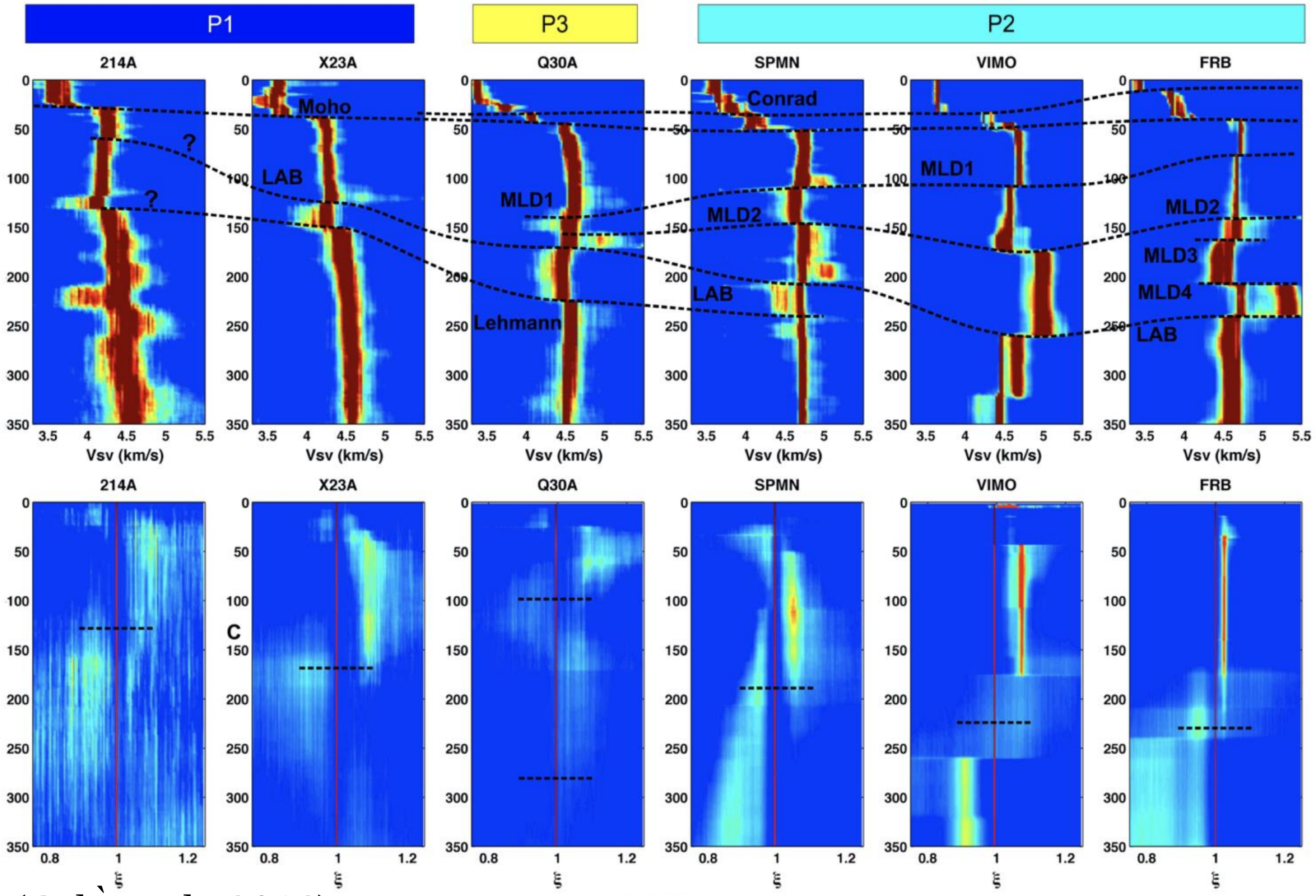
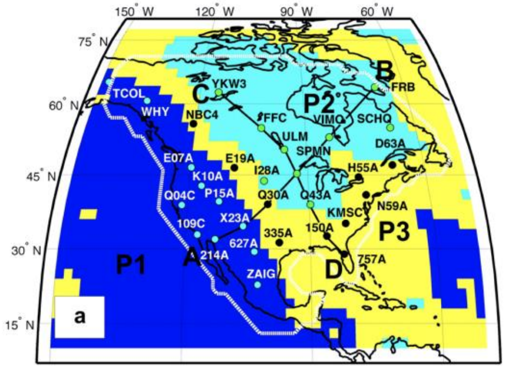
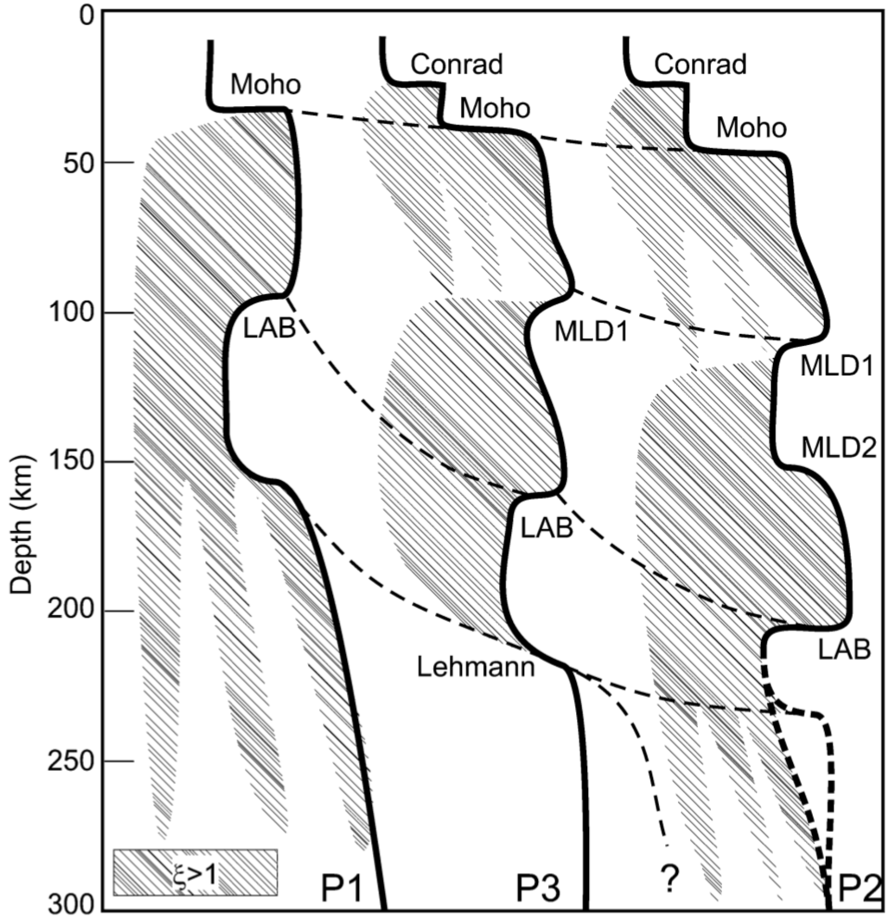


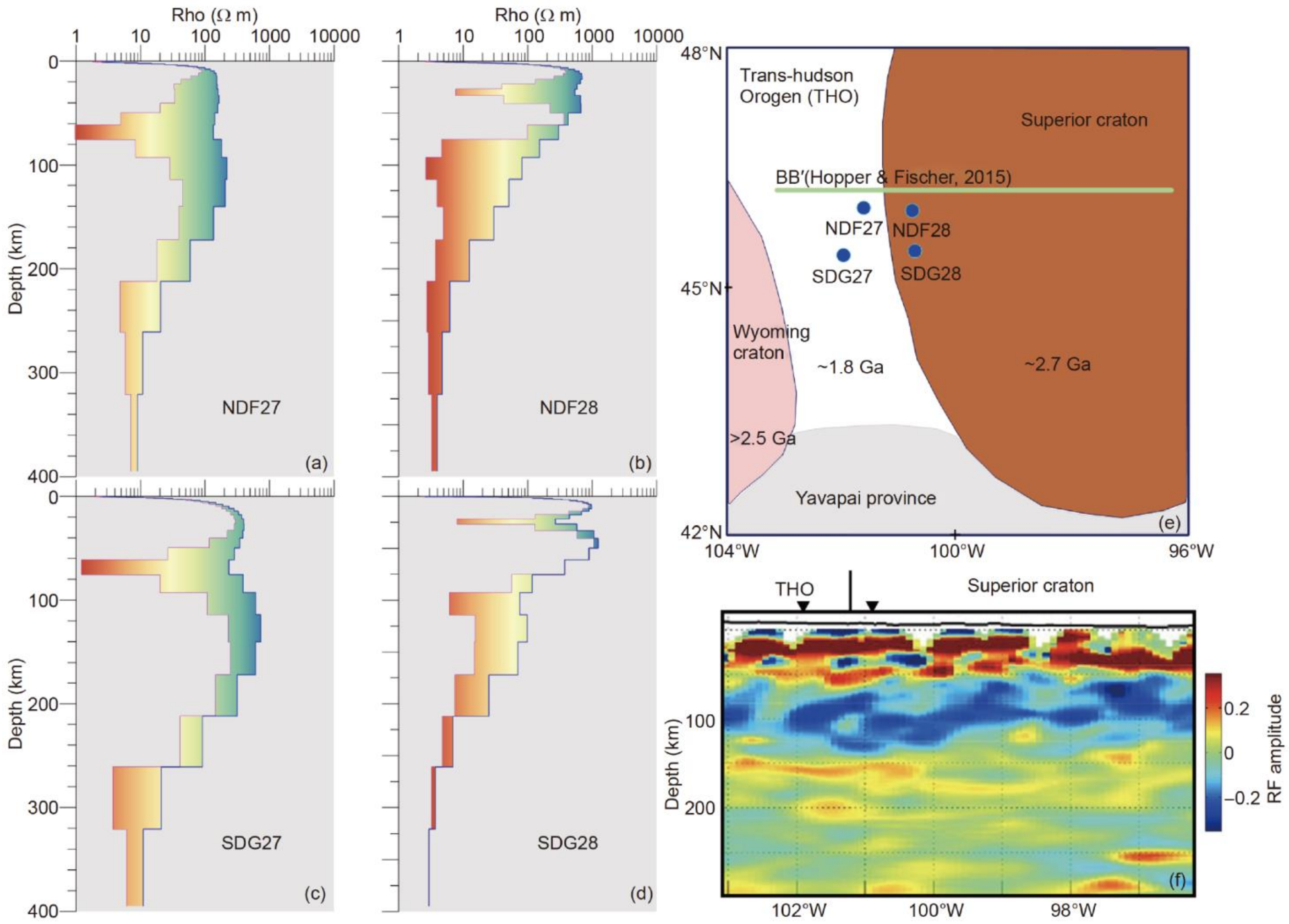




(Calò et al., 2016)

Mid-lithosphere Discontinuity (MLD)

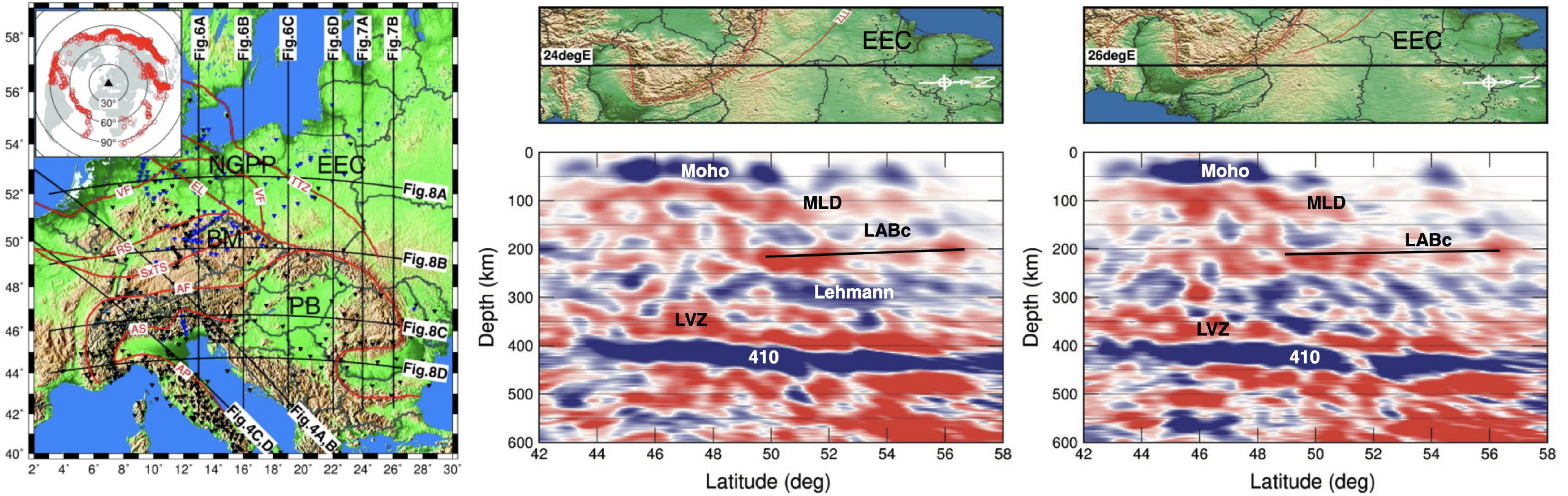
- Observations
  - Northern US (magnetotelluric (MT) observation)



(Xu et al., 2019)

Mid-lithosphere Discontinuity (MLD)

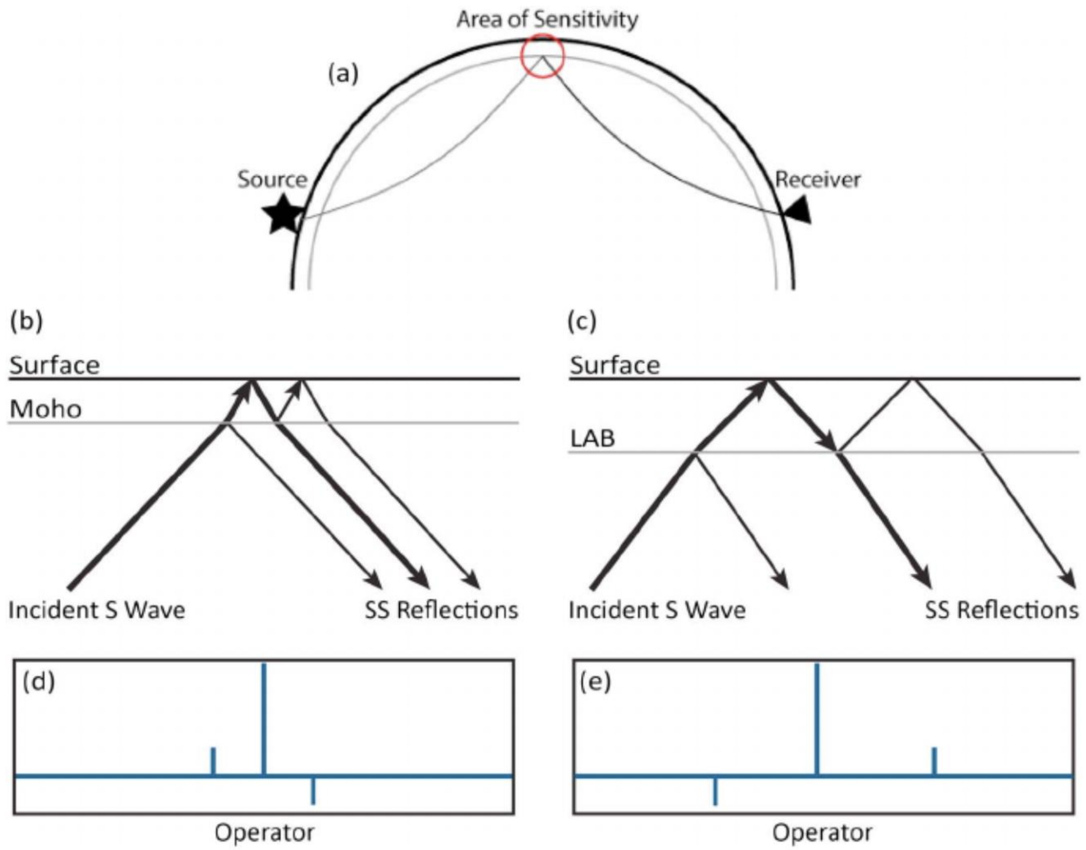
- Observations
  - Europe (connection between LAB and MLD?)

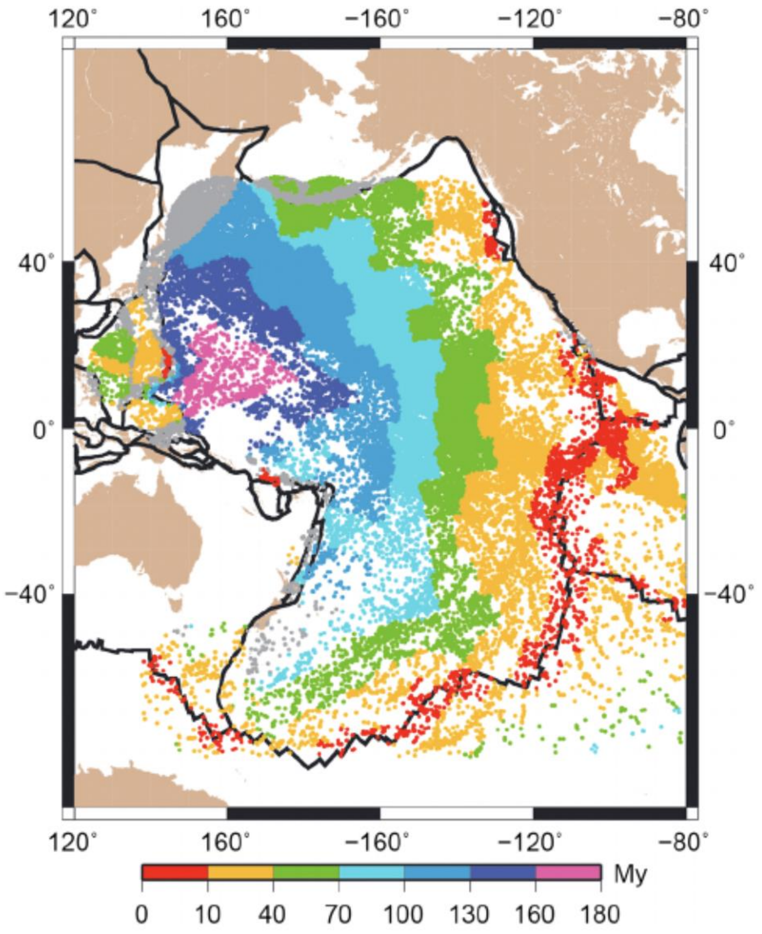


(Kind et al., 2017)

Mid-lithosphere Discontinuity (MLD)

- Observations
  - Pacific (Oceanic lithosphere)
    - Using SS precursors from 24 years of teleseismic data





(Tharimena et al., 2016)

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◆ Observations

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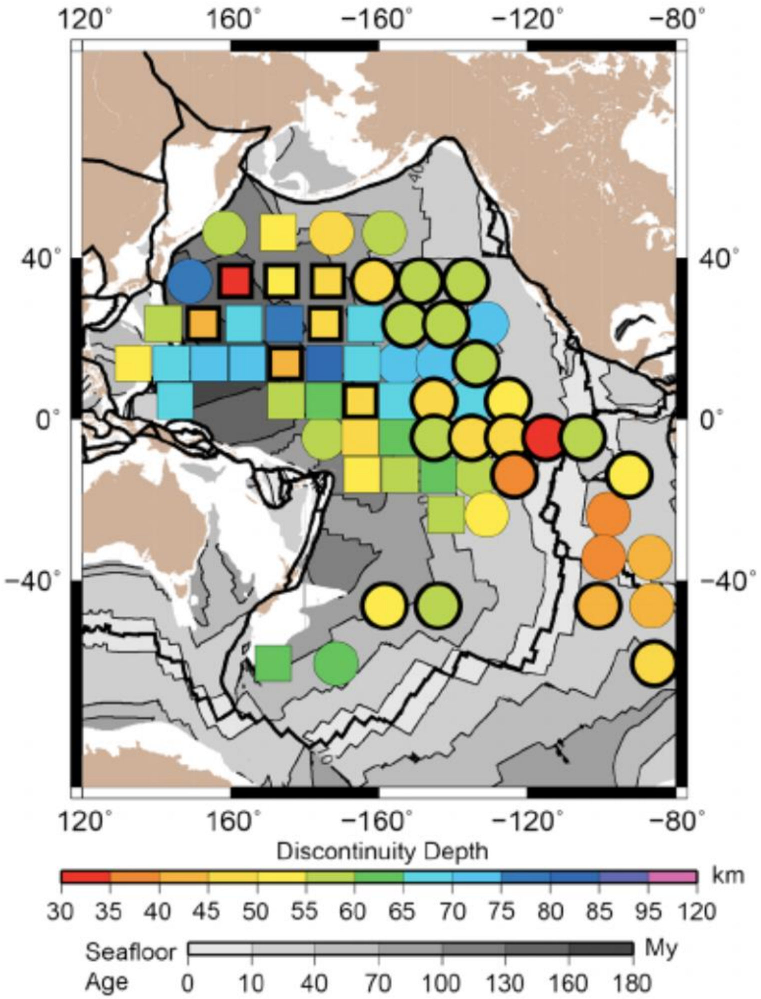

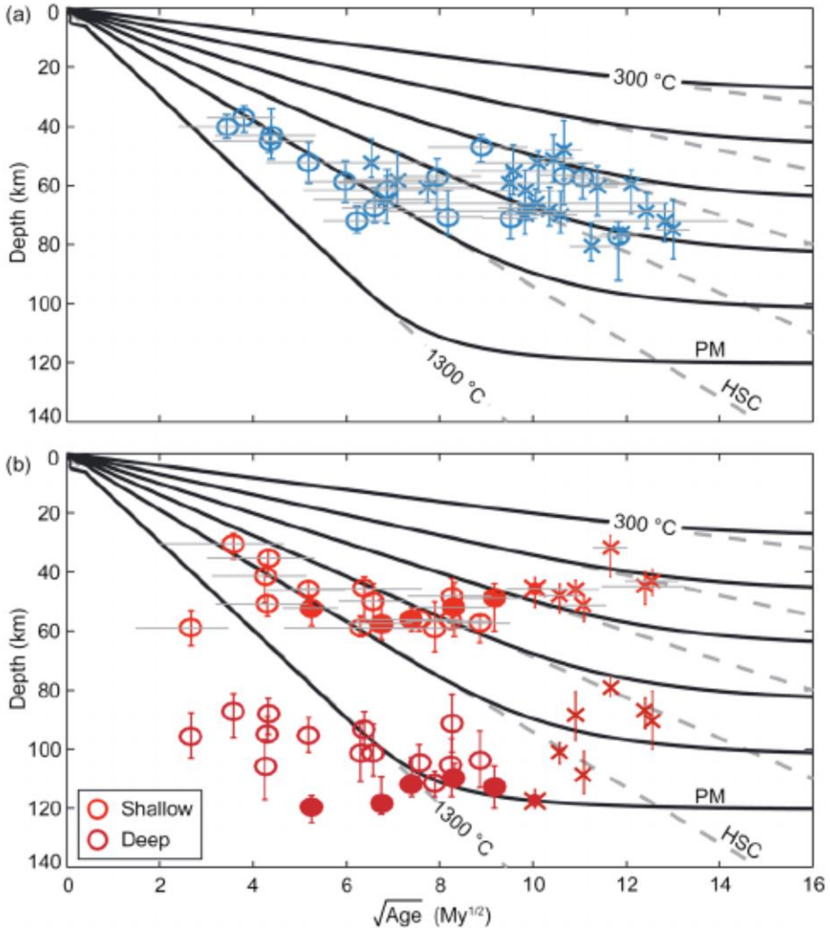

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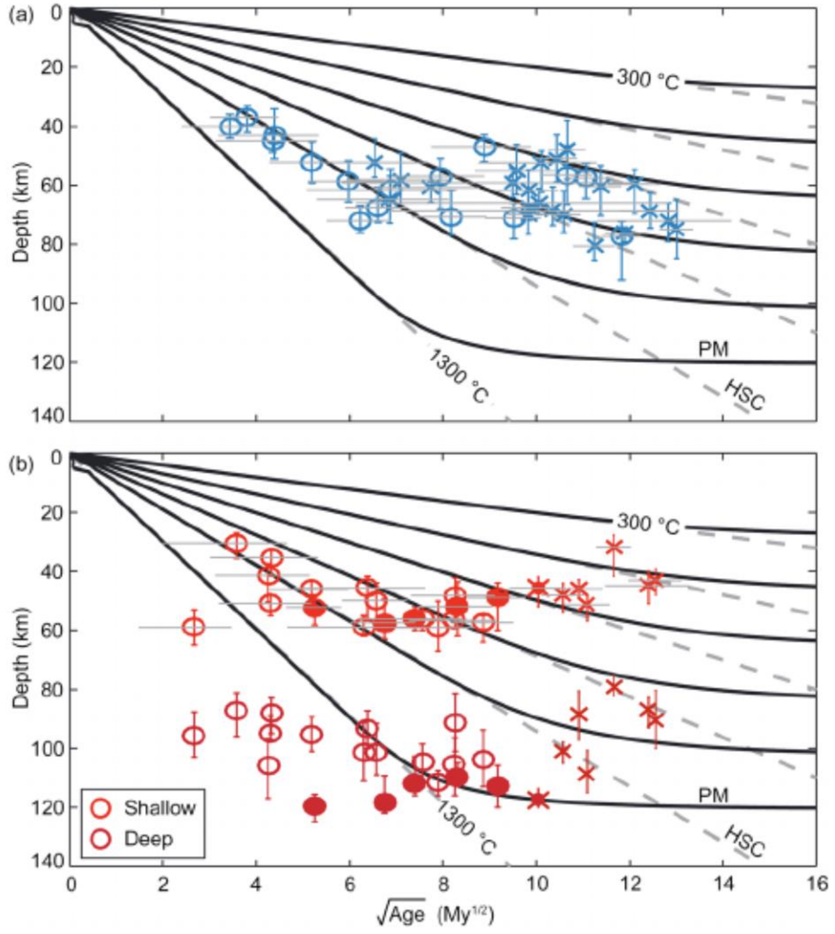
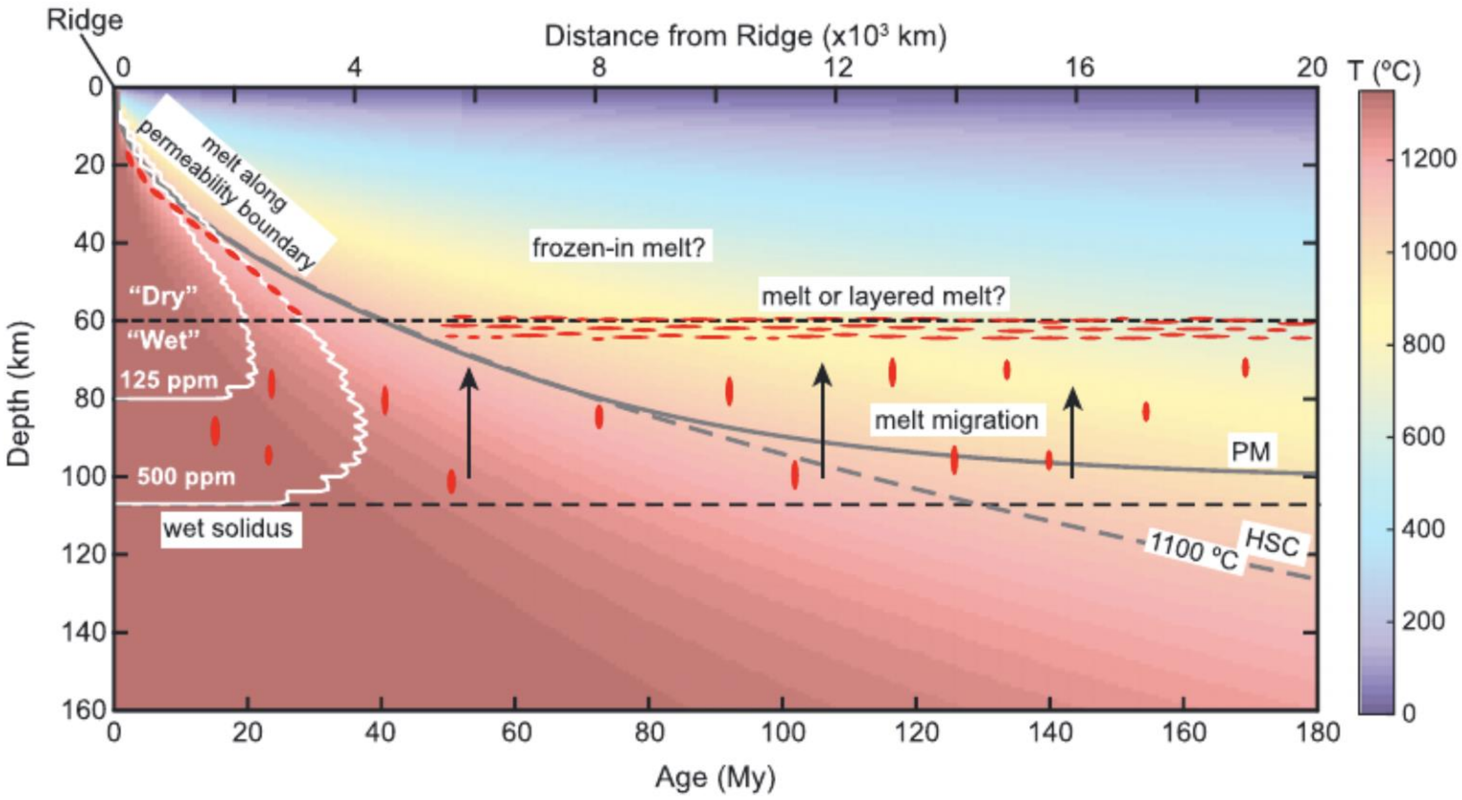
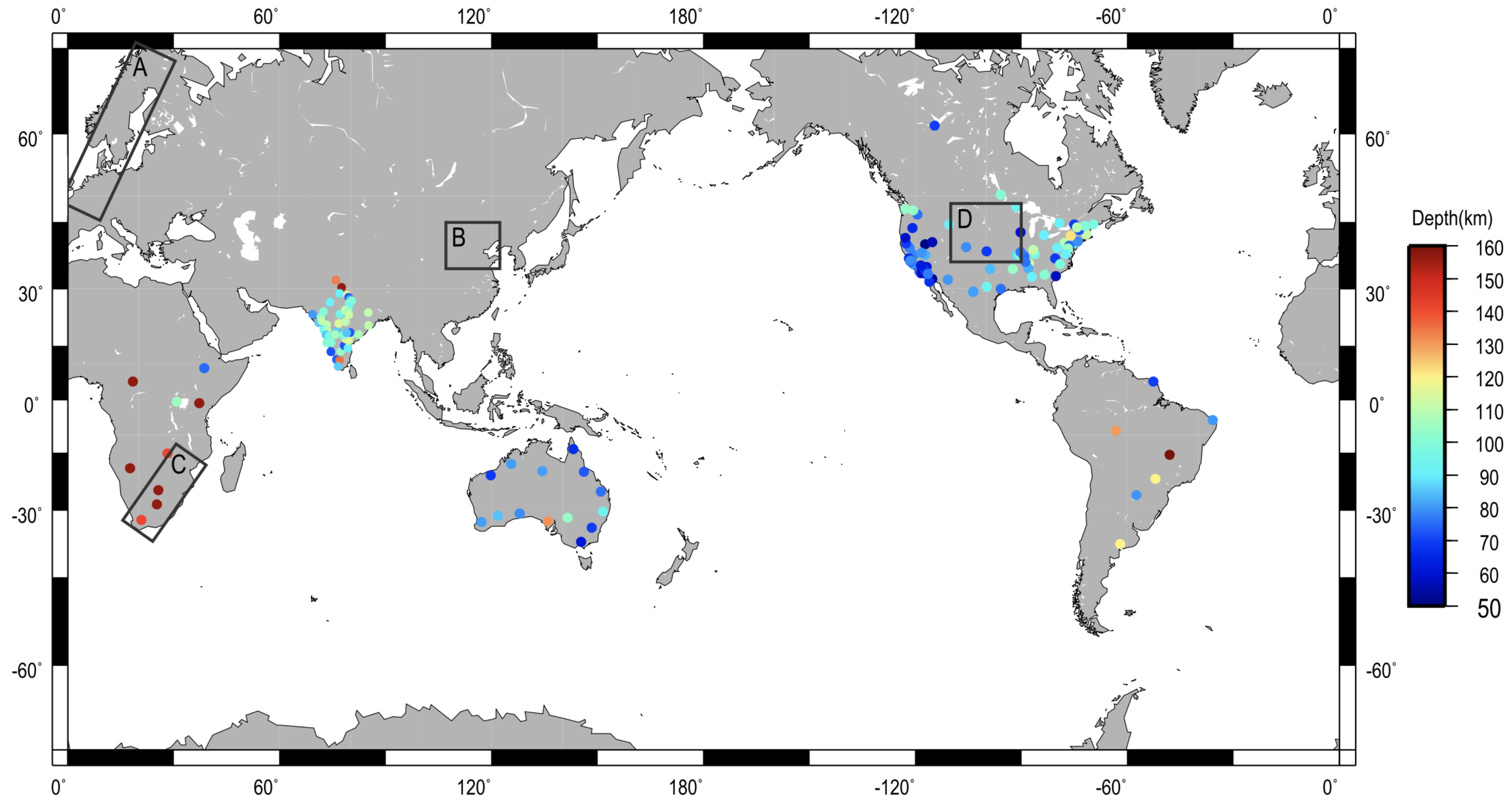




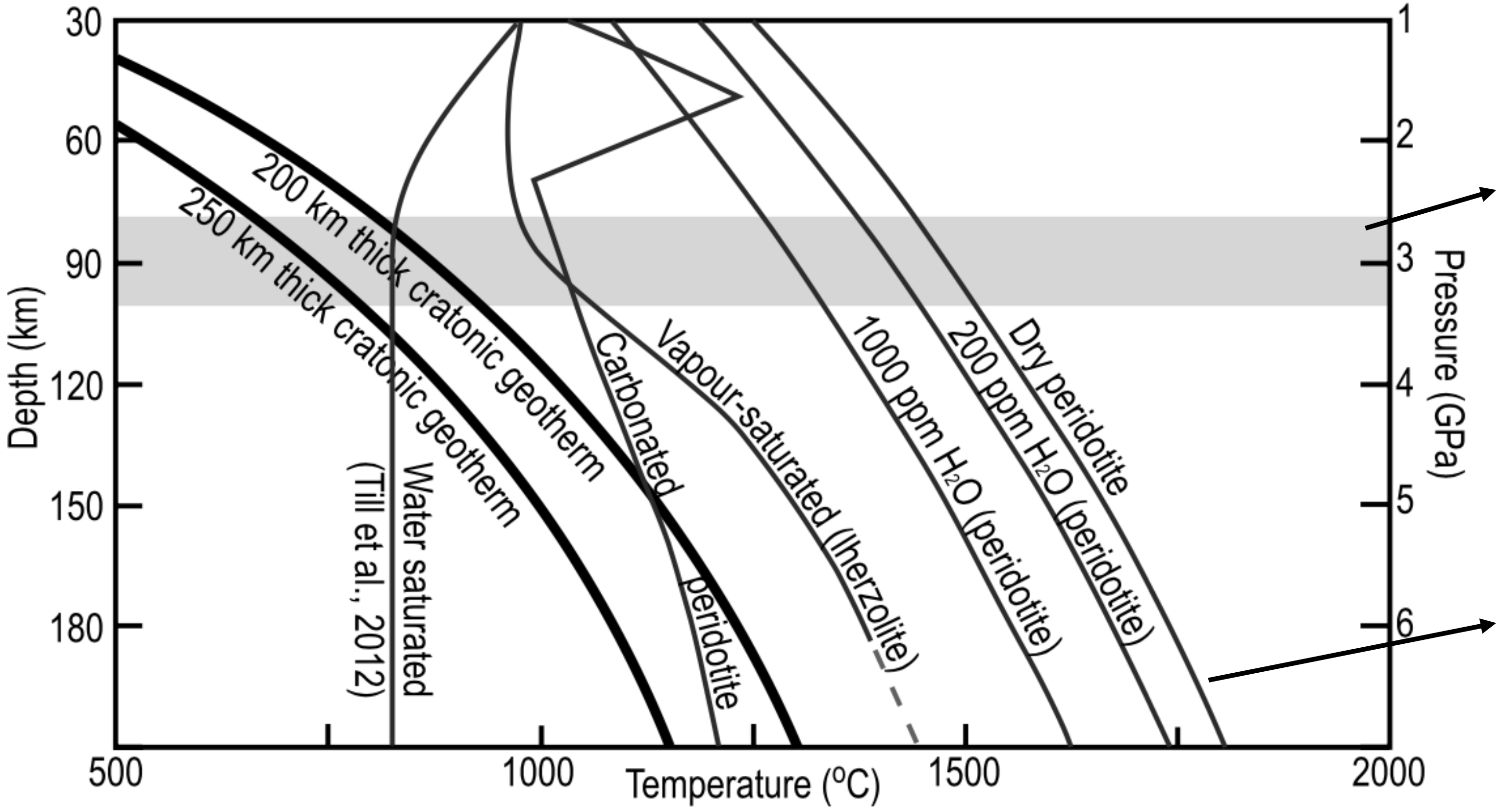
Mid-lithosphere Discontinuity (MLD)

- ◆ Observations
  - ➢ Others



Mid-lithosphere Discontinuity (MLD) – Origins

- Thermal causes
  - Seismic velocities are reduced in the presence of partial melt;
  - A layer of partial melt?



Typical MLD depths

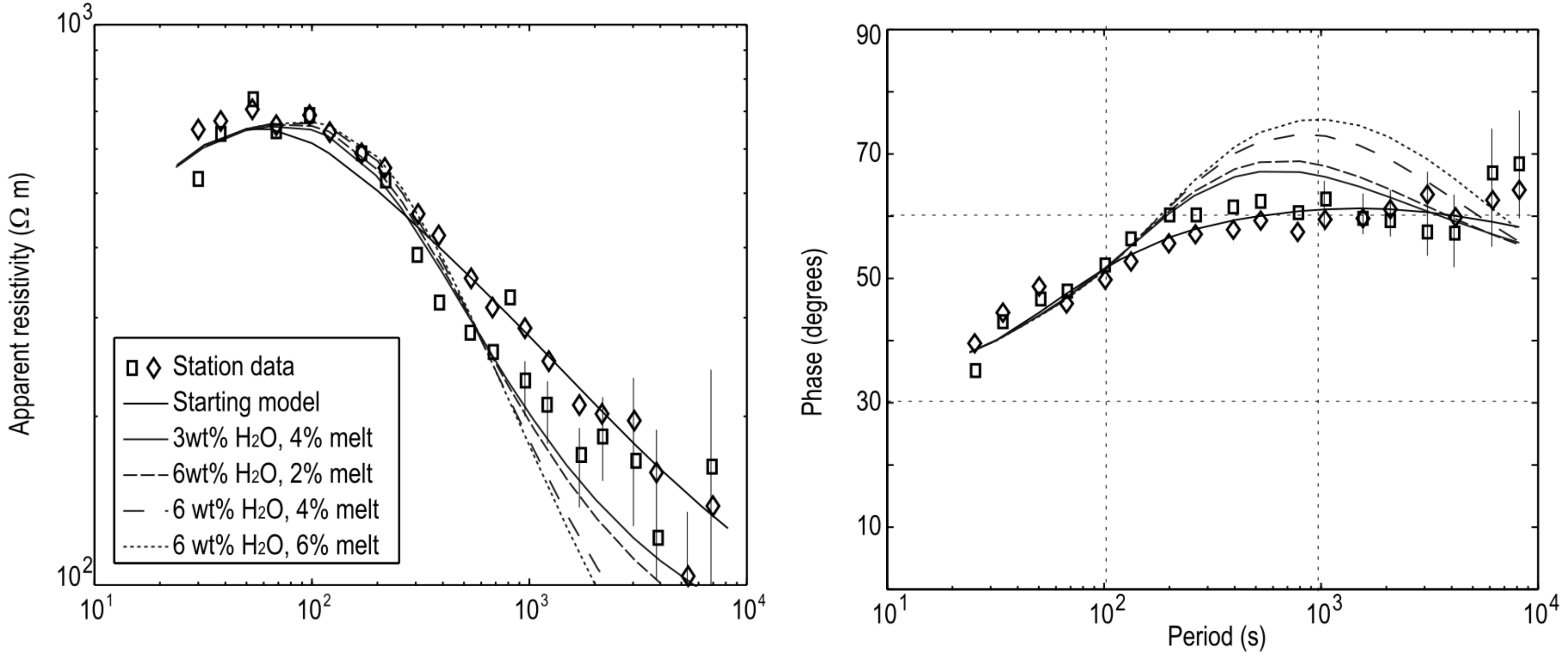
Solidus for different mantle rocks

Partial mantle layer at MLD depths is only possible in water-rich environment

Mid-lithosphere Discontinuity (MLD) – Origins

◆ Thermal causes

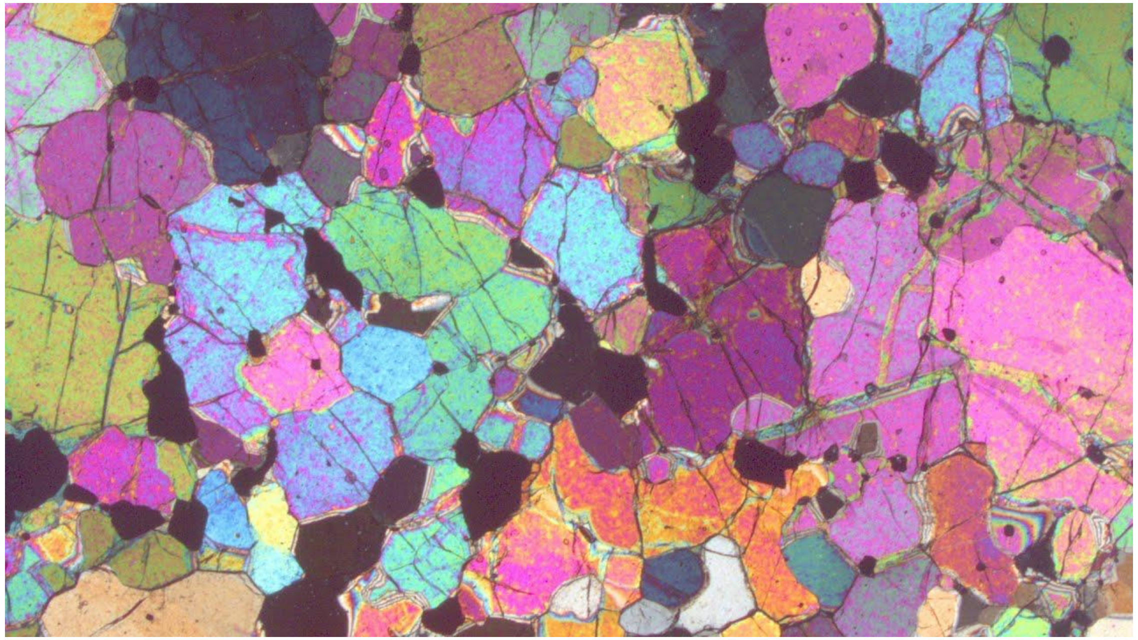
- Seismic velocities are reduced in the presence of partial melt;
- A layer of partial melt?
- Synthetic test on magnetotelluric (MT) data of Kaapvaal Craton (~150 km deep MLD at BOSA station)

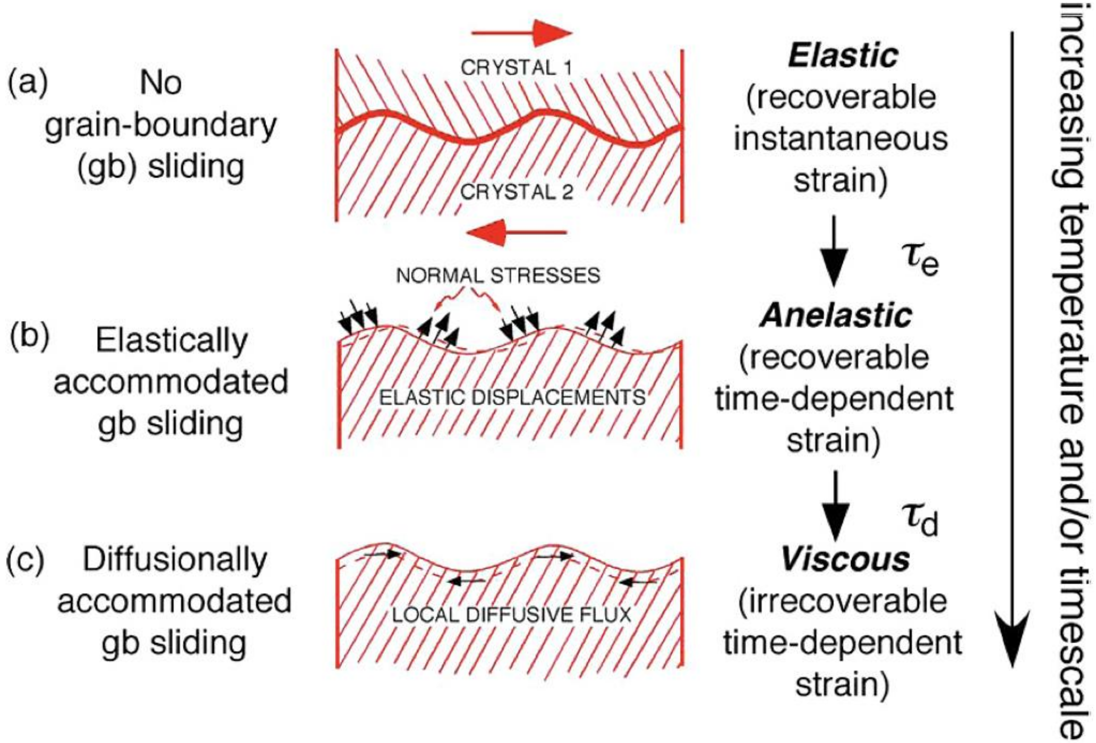


A partial melt layer is not responsible for the deep MLD at BOSA.

Mid-lithosphere Discontinuity (MLD) – Origins

- Thermal causes
  - Elastically accommodated grain-boundary sliding (EAGBS)
  - Velocity drop when material transit from elastic to anelastic;
  - A point in this transition applied stresses produce elastically-accommodated movement on grain boundaries due to their low effective viscosities.
  - Frequency and temperature dependent. EAGBS happens at ~1000°C at seismic frequencies.





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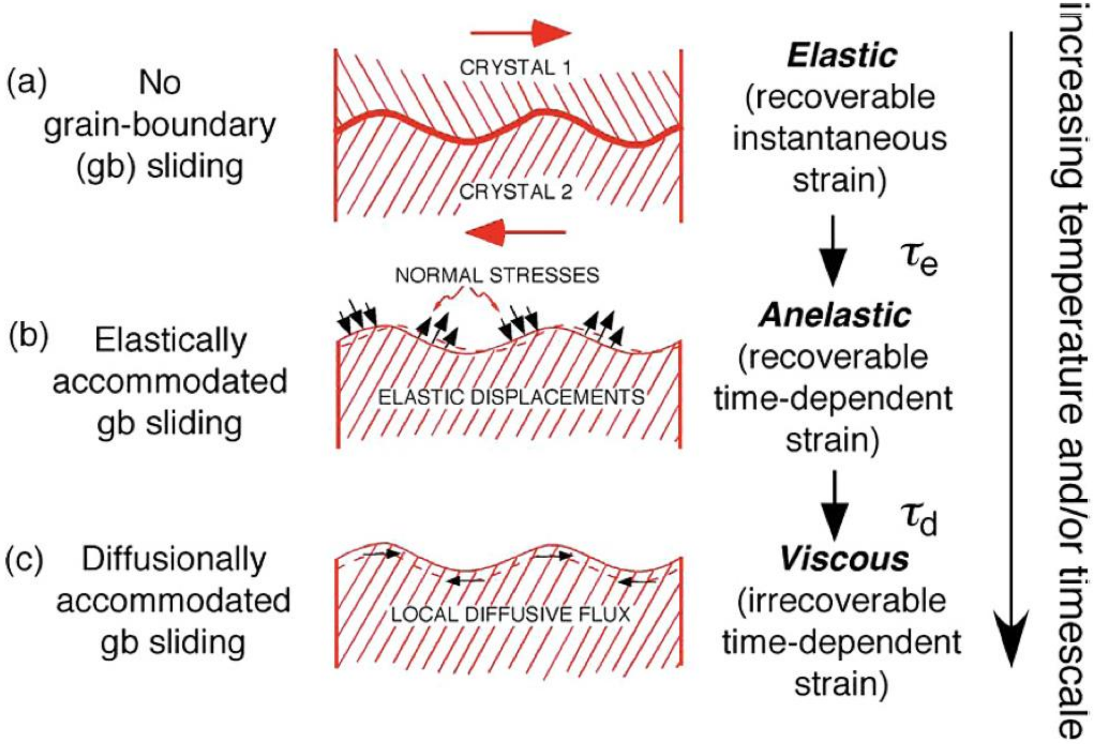

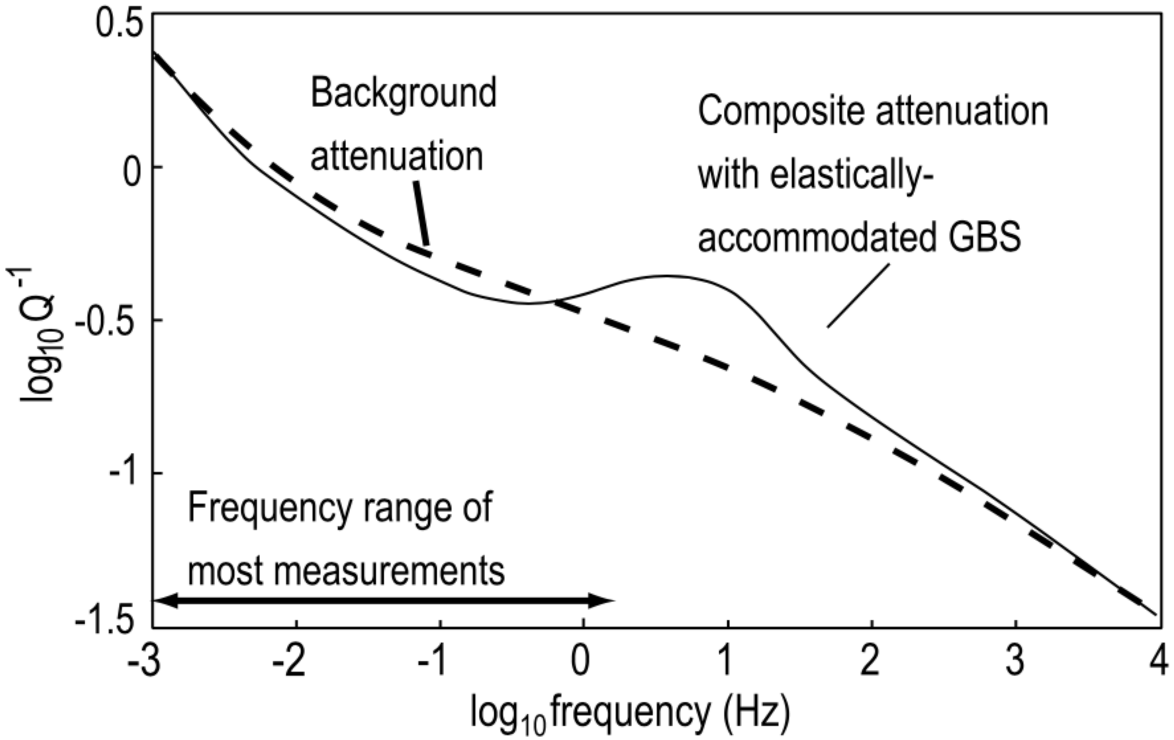

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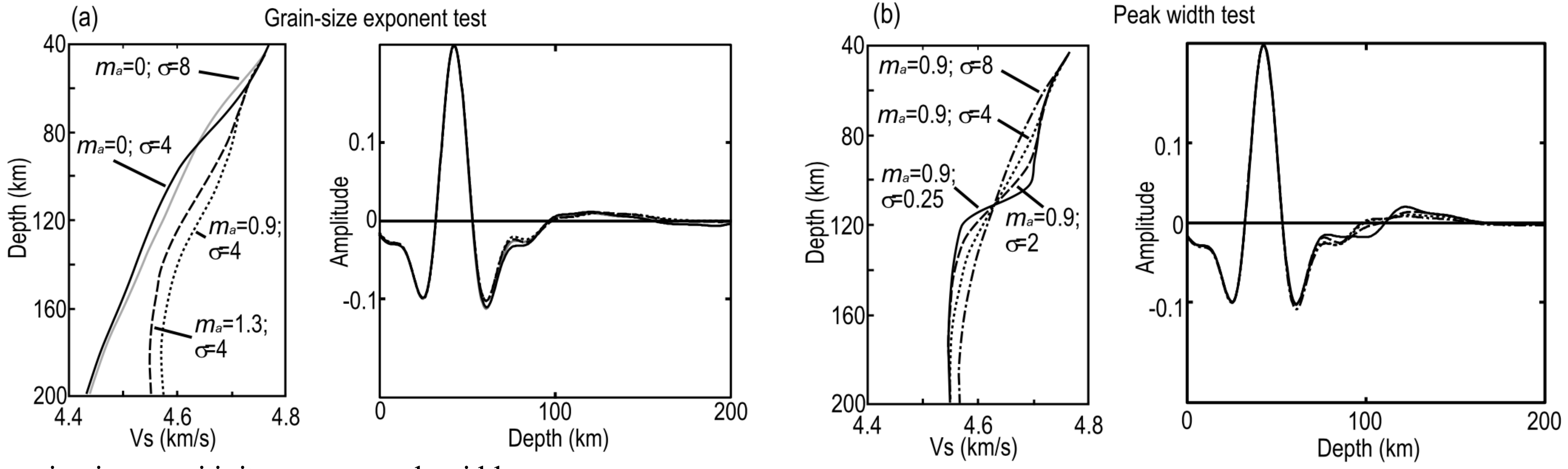
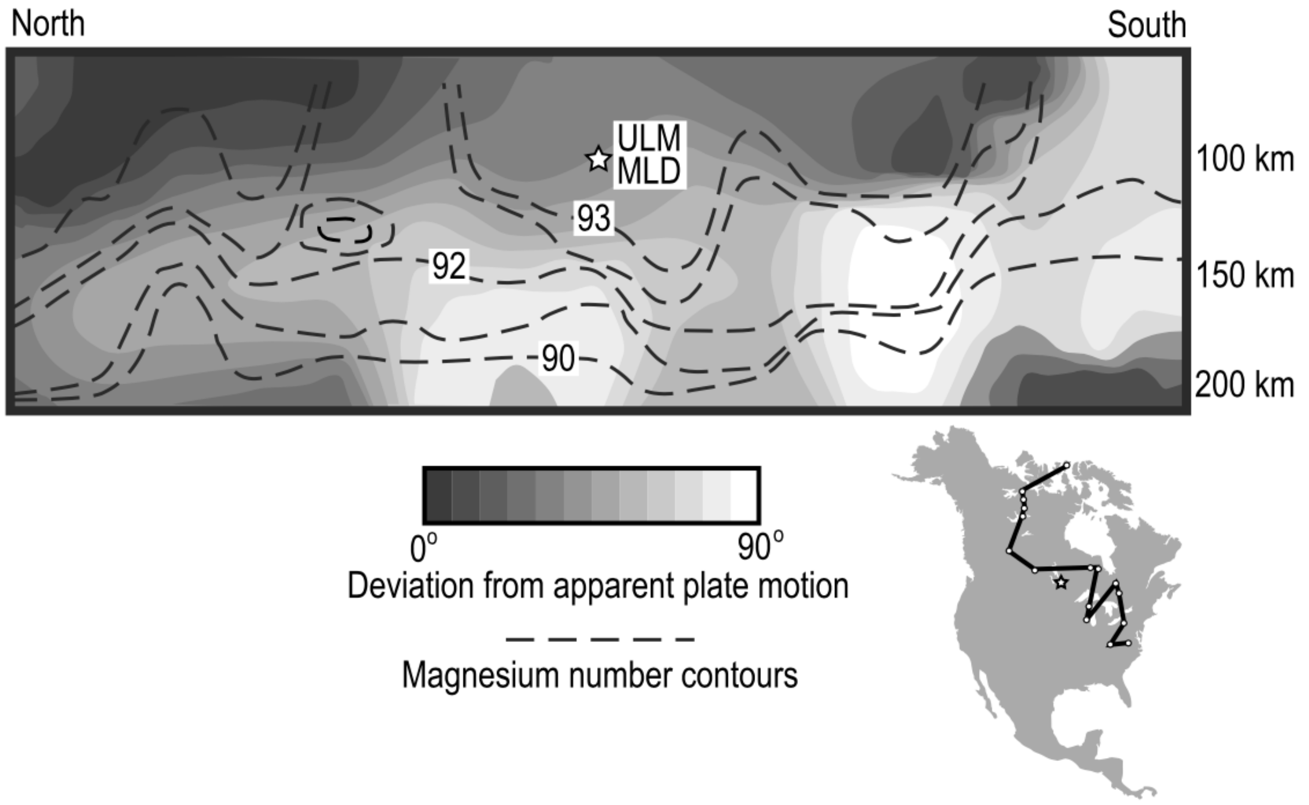


m_a: grain-size sensitivity σ: peak width

EAGBS alone cannot produce MLD

Mid-lithosphere Discontinuity (MLD) – Origins

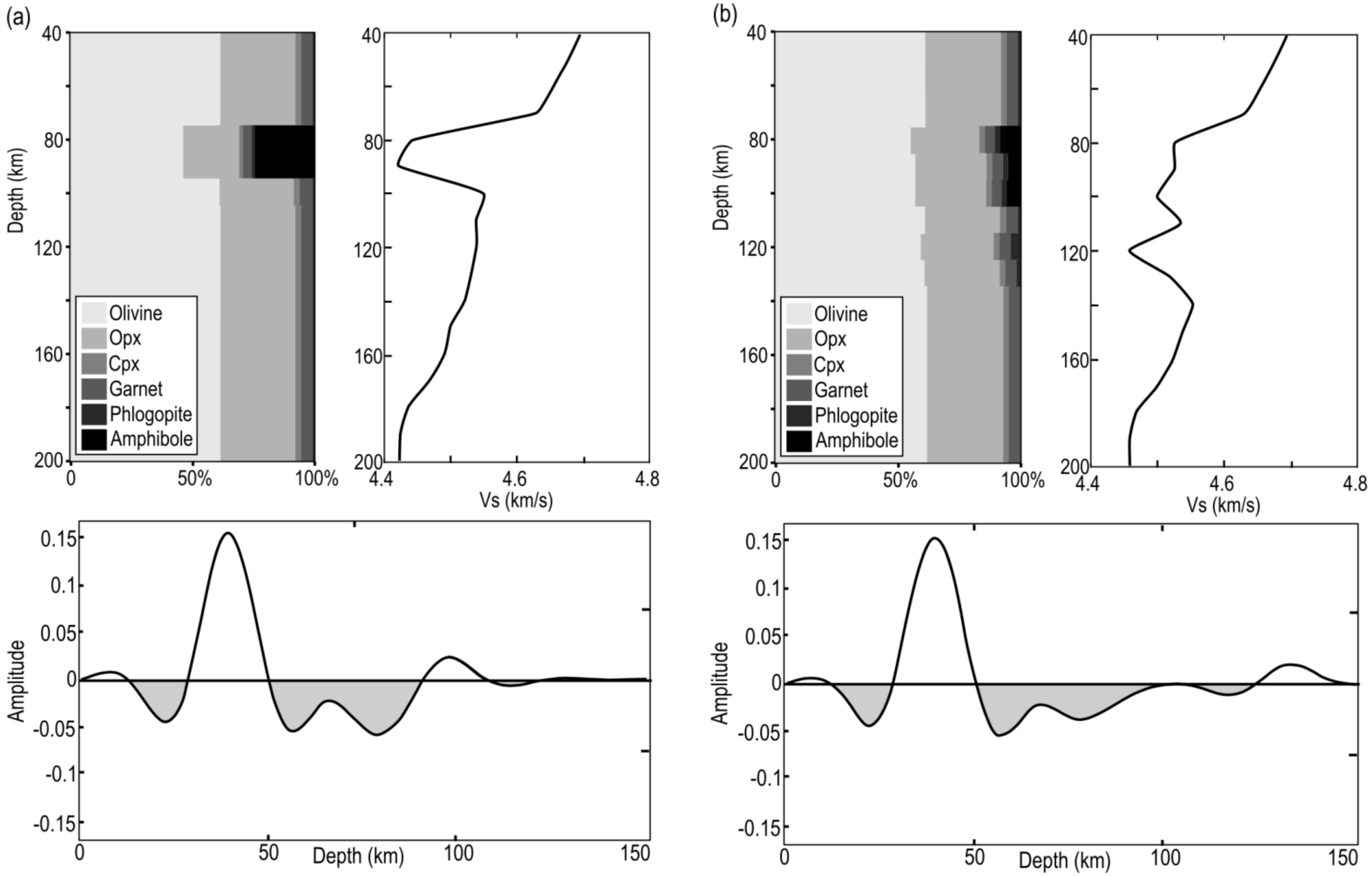
- Compositional cause
  - Major element change in lithospheric mantle peridotite: Mg#;
  - Mg# = 100 Mg / (Mg + Fe);
  - Mg# drop 5 → velocity drop ~2%.



Mantle xenoliths therefore do not support a change in Mg# as the MLD cause.

Mid-lithosphere Discontinuity (MLD) – Origins

- Compositional cause
  - Hydrous minerals: amphibole & phlogopite (the mineral can stably presence at upper mantle P/T)



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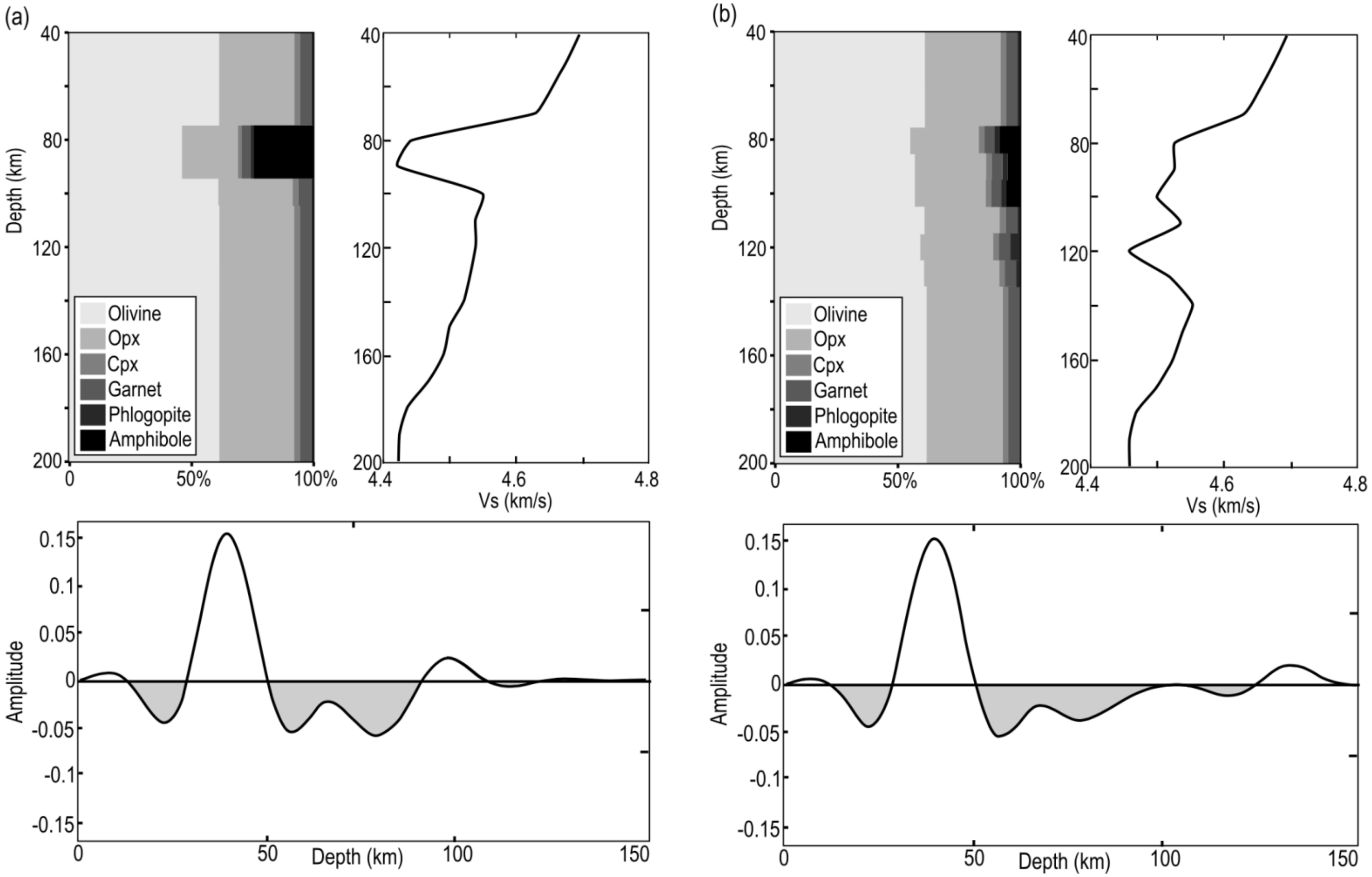
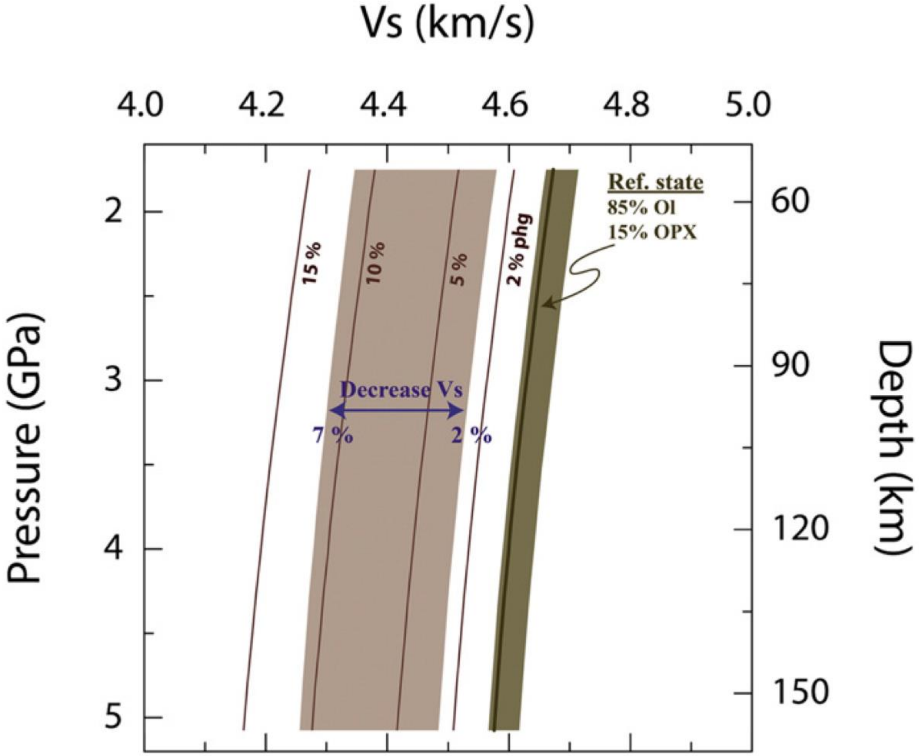
  - Hydrous minerals: amphibole & phlogopite (the mineral can stably presence at upper mantle P/T)

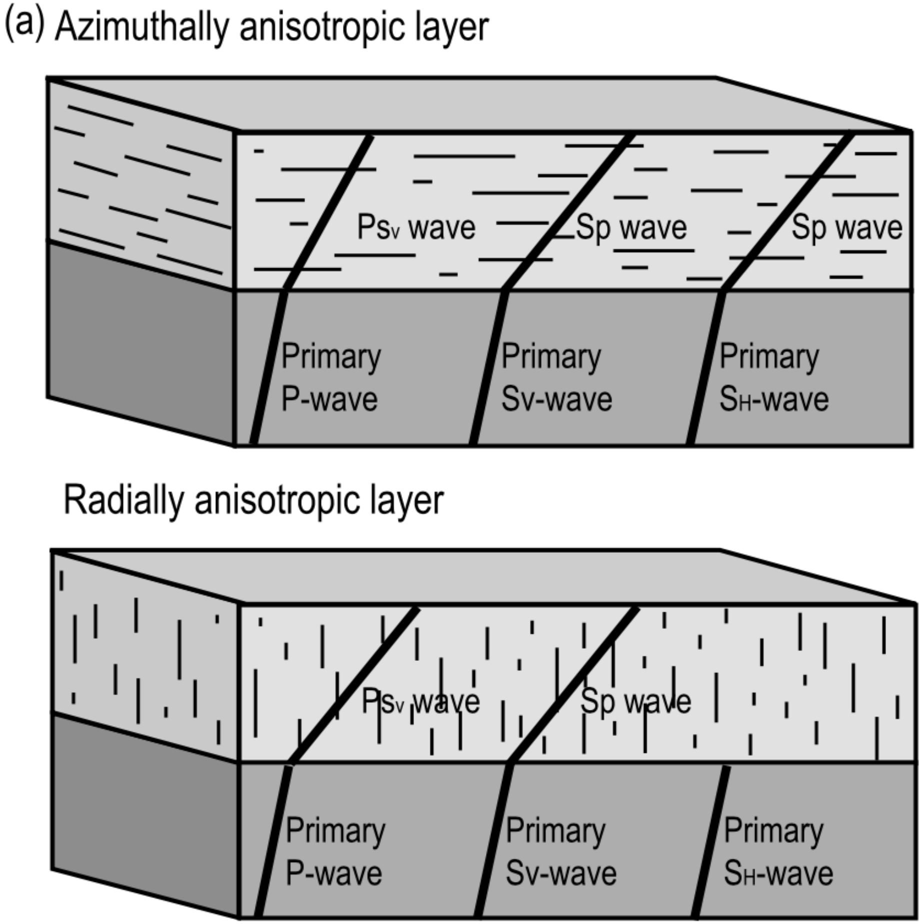


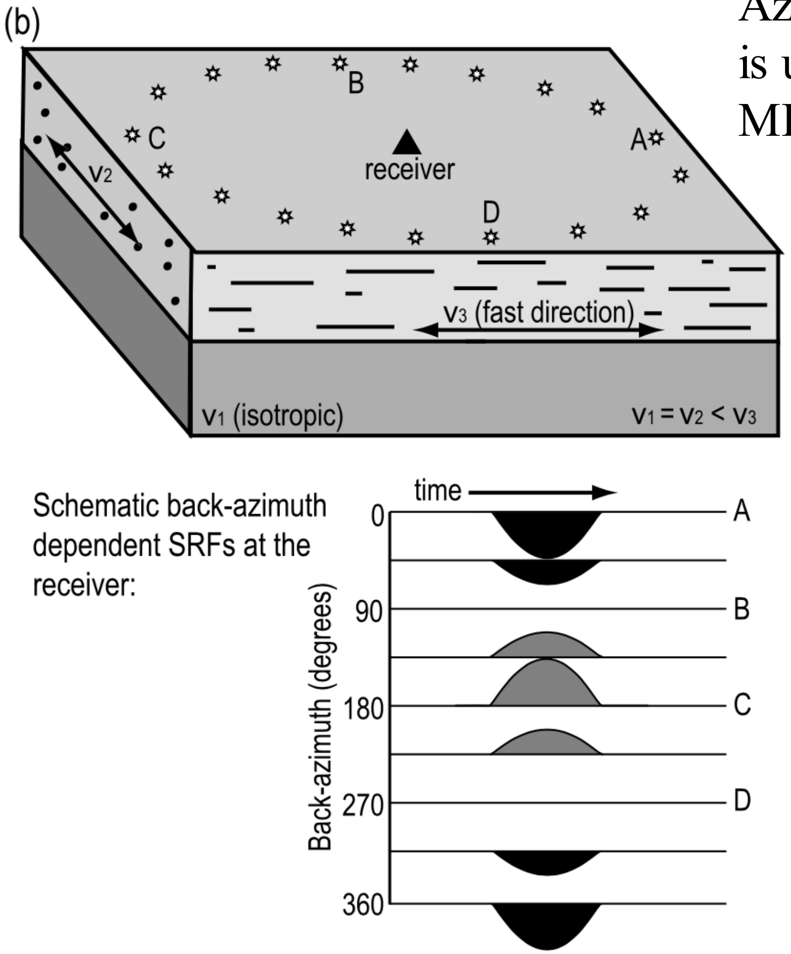


Xenolith data suggest that this may not occur ubiquitously, cannot explain all the MLD worldwide.

Mid-lithosphere Discontinuity (MLD) – Origins

- Anisotropic cause
  - A change from stronger to weaker radial anisotropy with depth?



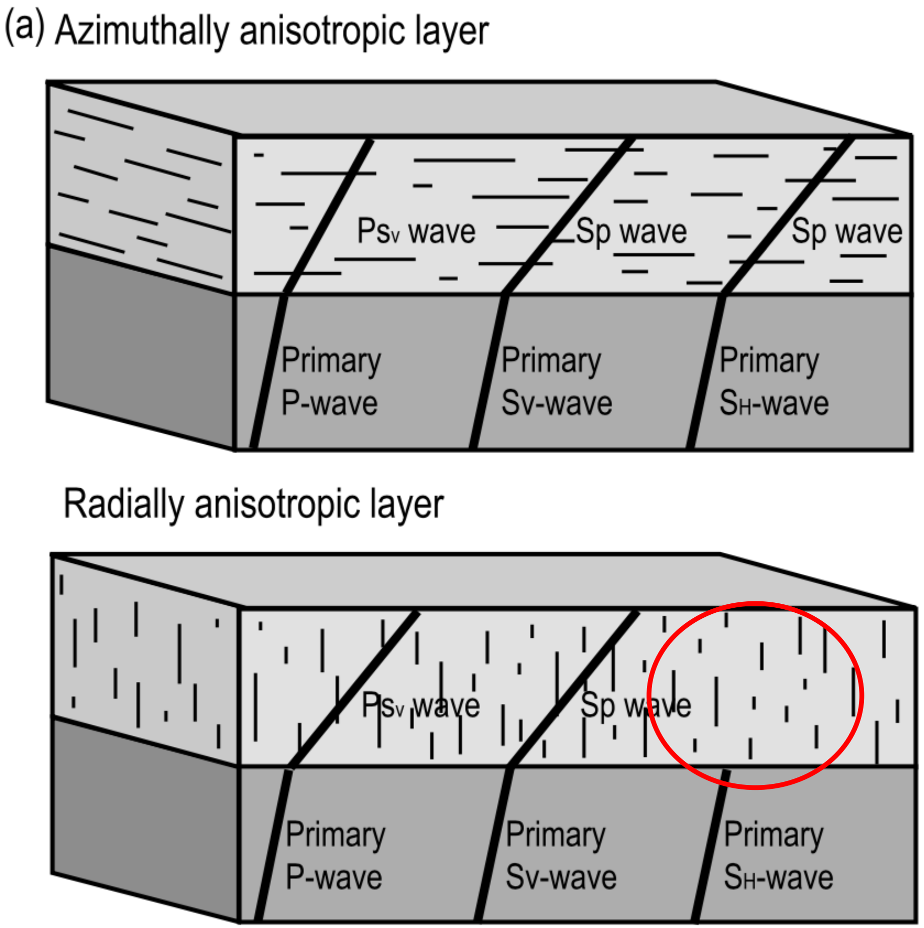


Azimuthal anisotropy is unlikely to produce MLD globally.

Mid-lithosphere Discontinuity (MLD) – Origins

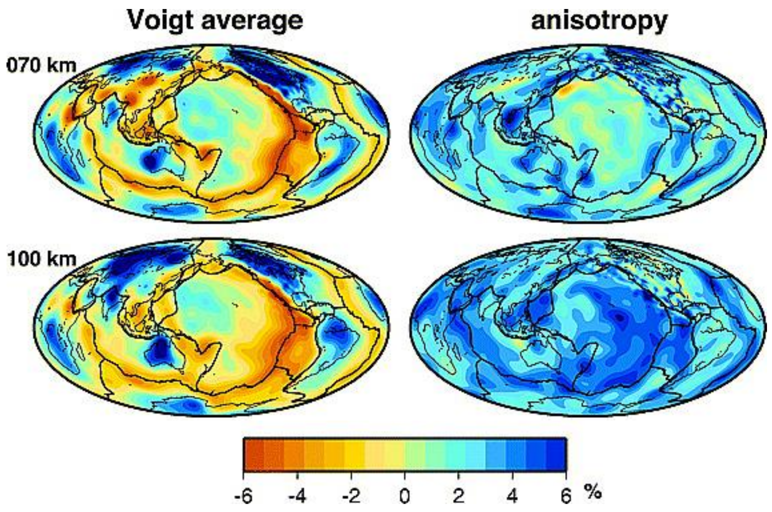
◆ Anisotropic cause

➢ A change from stronger to weaker radial anisotropy with depth?



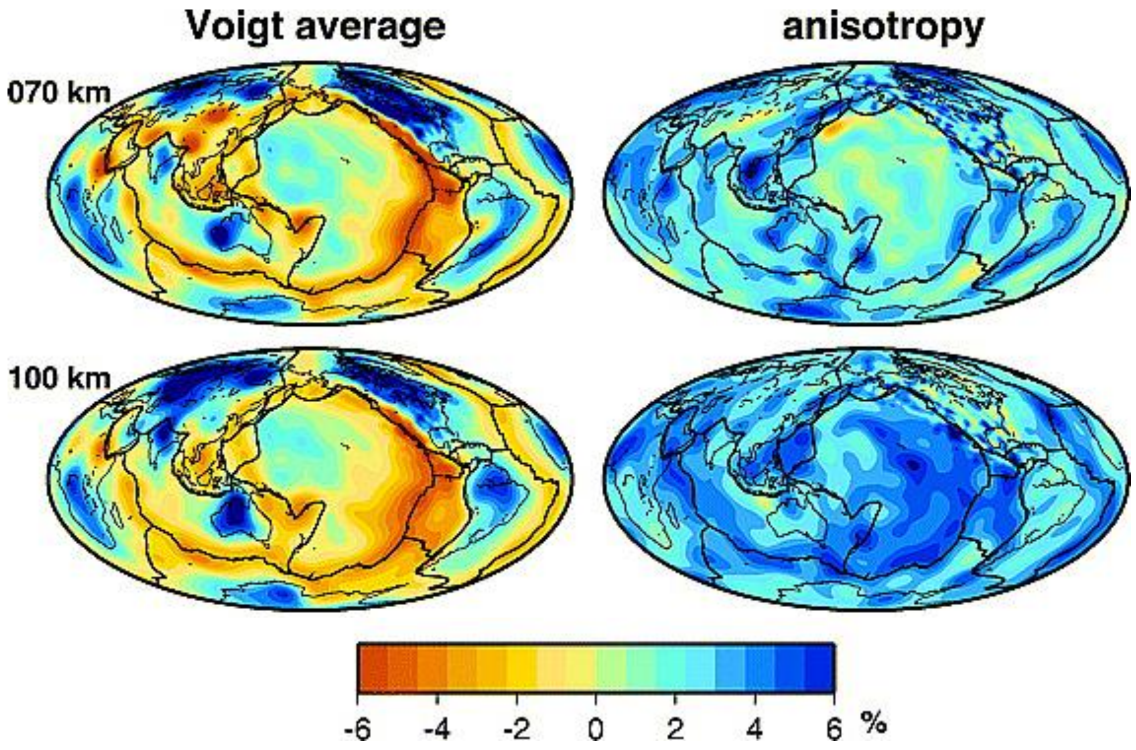
It is possible to produce consistent negative SRF phases in radial anisotropy cases (Ford, 2013).

However, such radial anisotropic media are uncommon. Instead, positive radial anisotropy (Vsh > Vsv) is often observed.



Mid-lithosphere Discontinuity (MLD)

- Geodynamic implications?
  - Any connections with the oceanic lithosphere?



- Frozen LAB
  - A dynamic LAB

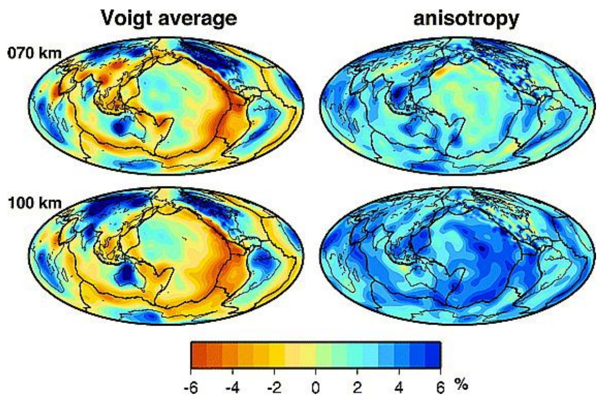
Mid-lithosphere Discontinuity (MLD)

◆ Geodynamic implications?

➢ Any connections with the oceanic lithosphere?

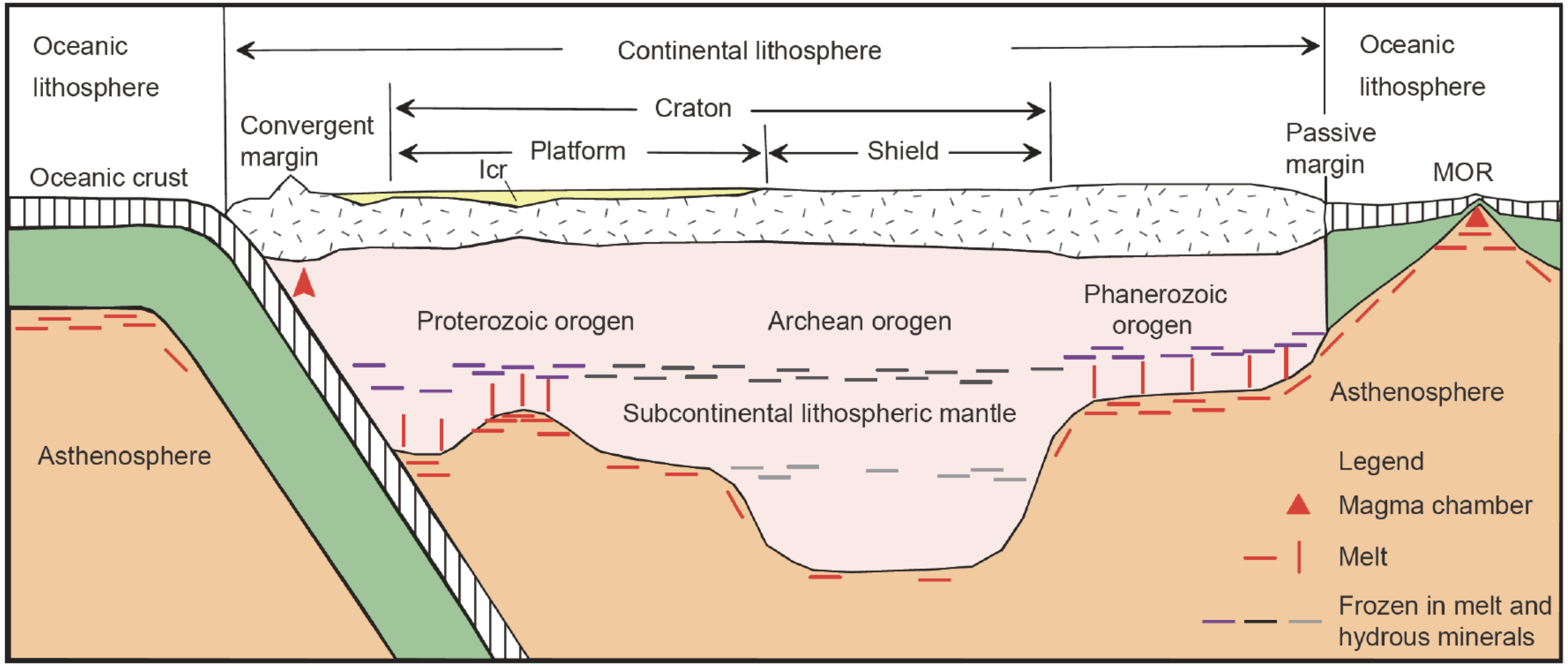
◆ Frozen LAB

➢ A dynamic LAB



Continental lithosphere developed from the oceanic lithosphere?

1. Ceased subduction zone in the plate boundary, e.g. Wyoming craton, Junggar terrain;
2. A trapped oceanic lithosphere; e.g. Mediterranean sea;
3. Passive margins; i.e. around Atlantic ocean;
4. Come from the cooled magma shell before plate tectonic onset.



Cools down and LAB grows deeper

MLD may represent the lower boundary of plate motion in cratons, rather than the LAB??

Thanks