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# GEO-DEEP9300
# The lithosphere and the asthenosphere

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# GEO-DEEP9300: gain scientific knowledge

→ *What is the lithosphere and asthenosphere?*

→ *What do we know about them?*

→ *How do we know this?*

→ *What is still under debate? Which knowledge is missing?*

→ 3 parts:

- introduction to methodologies
- summary of current knowledge
- what to do next?

→ ***Gather, summarize and present information from litterature***

→ ***Propose what to do next***

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# GEO-DEEP9300: transferable skills

→ *Present yourself orally*
→ *Present orally a scientific topic*
→ *Work in groups*
→ *Interact with scientists with another background*
→ *Identify the limitations of current knowledge*
→ *Formulate a scientific proposal*
→ *Write a scientific document*

# Introduction of concepts

What is the lithosphere?

- A concept related to plate tectonics: **the rigid plate**
- Crust + lithospheric mantle
- LAB at the bottom

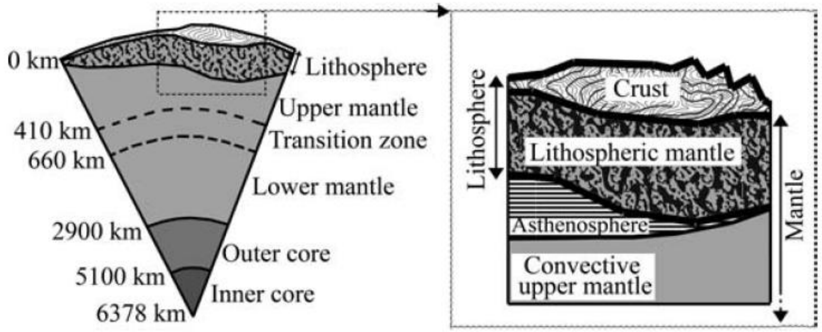
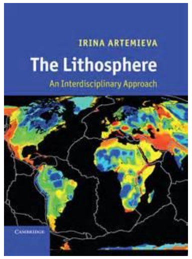



**Fig. 1.1** Schematic Earth section showing various layers, not to scale (left). Zoom on the lithosphere (right).

From Artemieva:




What is the asthenosphere?

- What is below the lithosphere: **a less rigid region**

# Role of lithosphere in plate tectonics

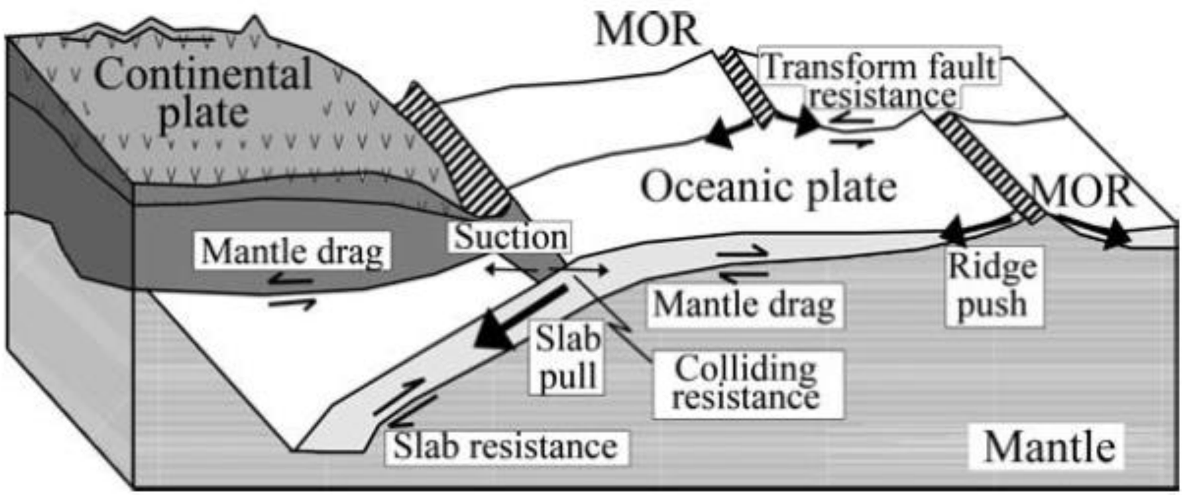



**Fig. 9.28** Sketch of major plate tectonic forces acting on the lithospheric plates (after Forsyth and Uyeda, 1975). MOR = mid-ocean ridge.

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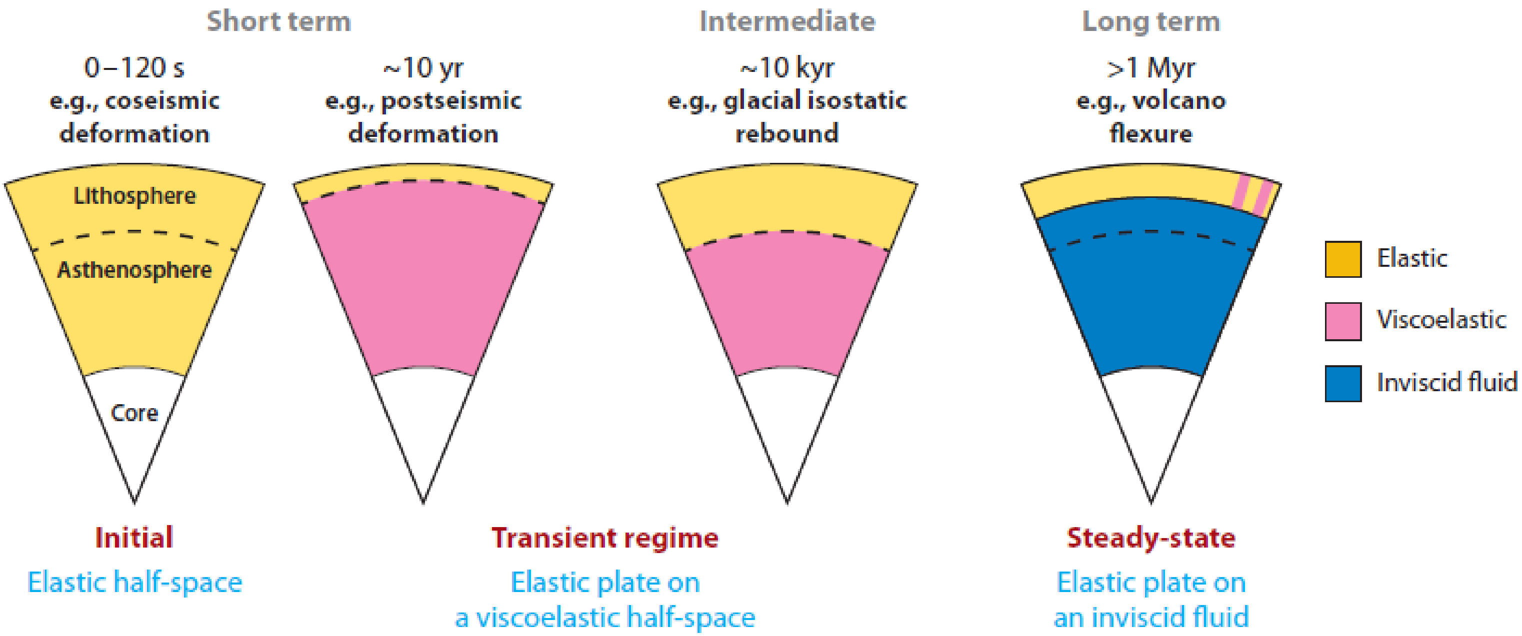
# The importance of time scale in the concept of rigidity




*From Watts et al., 2013*

# Rigidity

Rigidity **at geological scales**

- Can we measure rigidity?
- Other parameters which are proxy for rigidity?
- What is the physics/chemistry behind differences in rigidity?

**Temperature**: a major parameter

→ Lithosphere = thermal boundary layer (LAB: 1300°C)

  → Cold

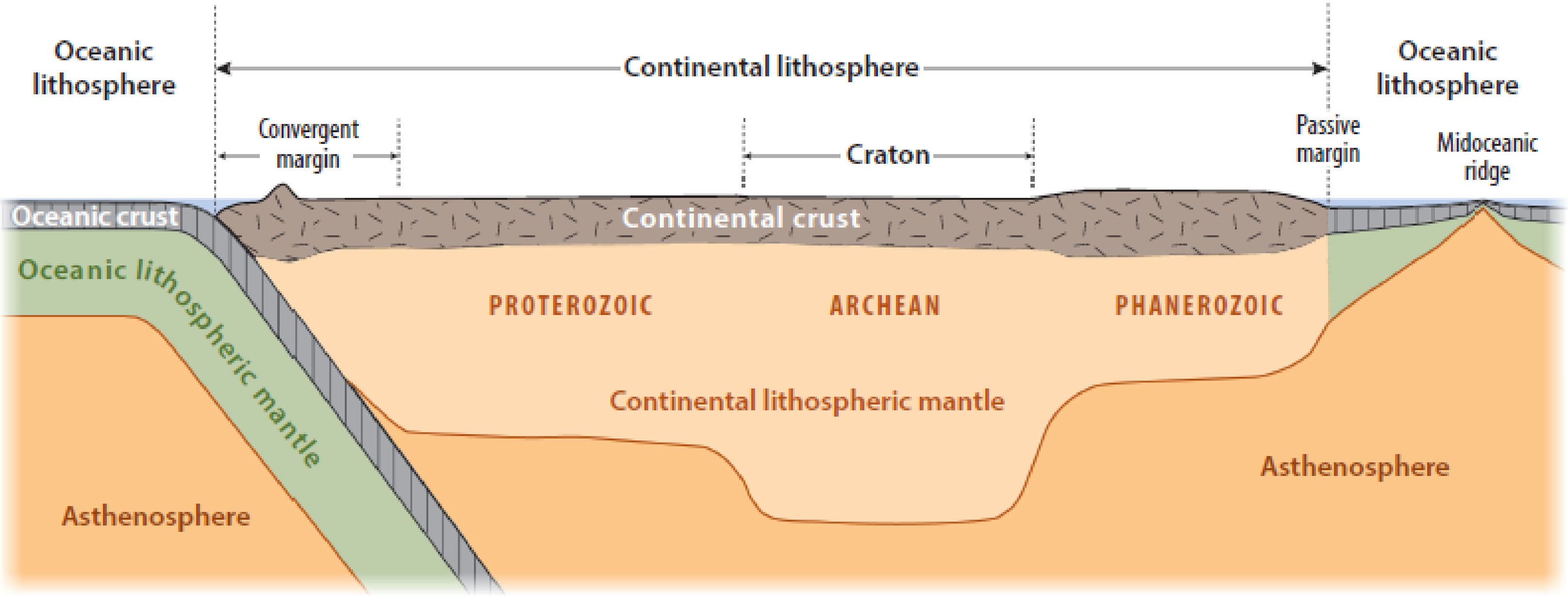
  → Heat conduction

→ How to measure temperature? Directly or proxys.

**Composition:** differentiation processes

→ Lithosphere = chemical boundary layer

# The lithospheres and asthenosphere(s)




*From Hawkesworth et al., 2017*

# Defining the base of the lithosphere and of the boundary layers

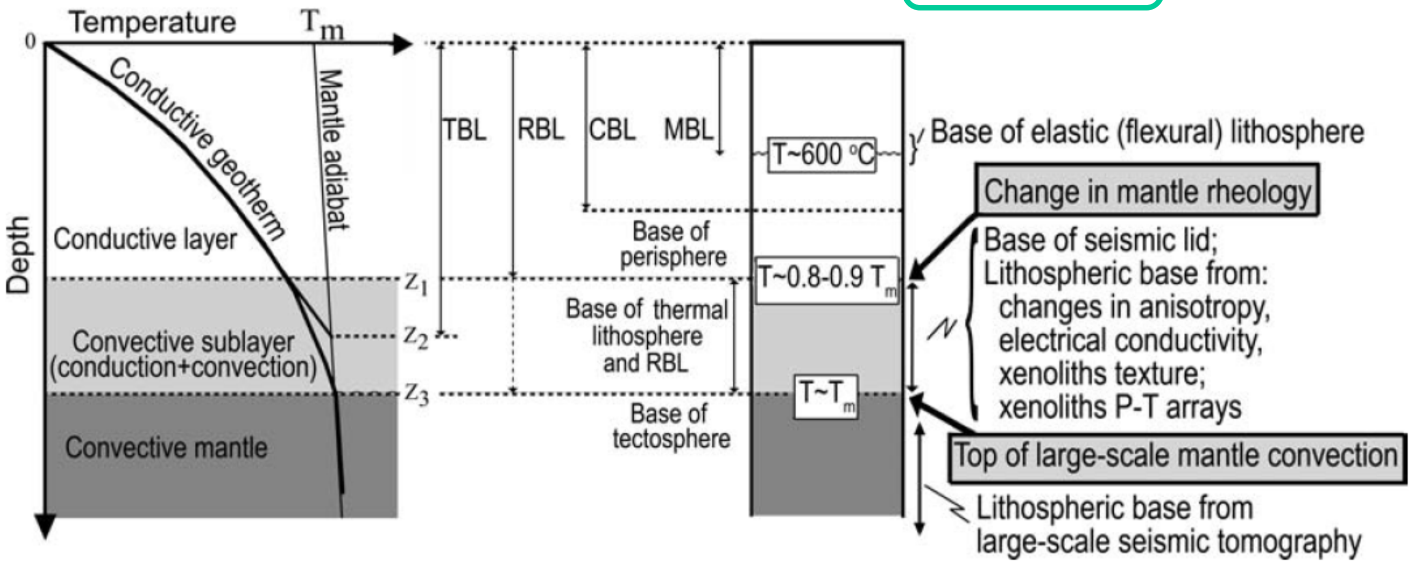



**Fig. 1.4** Sketch illustrating relations between the conductive boundary layer and the convective mantle, on one side, and various approaches to define the base of the lithosphere, on the other side. The layer above depth $Z_1$ has a purely conductive heat transfer; in the transitional "convective boundary layer" between depths $Z_1$ and $Z_3$ the heat transfer mechanism gradually changes from convection to conduction. The base of the conductive boundary layer (or TBL) is between depths $Z_1$ and $Z_3$. $Z_2$ corresponds to the depth where a linear downward continuation of the geotherm intersects with mantle adiabat $T_m$ that is representative of the convective mantle temperature profile. Thermal models commonly estimate $Z_2$, while large-scale seismic tomography images $Z_3$. The difference between $Z_2$ and $Z_3$ can be as large as 50 km, leading to a significant systematic difference in lithosphere thickness estimates based on seismic tomography and thermal data. Most practical definitions (except for chemical boundary layer and perisphere) are based on temperature-dependent physical properties of mantle rocks, and many lithosphere definitions correspond to the depth where a dramatic change in mantle rheology (viscosity) occurs. Layers RBL, TBL, CBL, and MBL are rheological, thermal, chemical, and mechanical boundary layers. Vertical dimensions are not to scale.

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# Definitions related to measurement methods

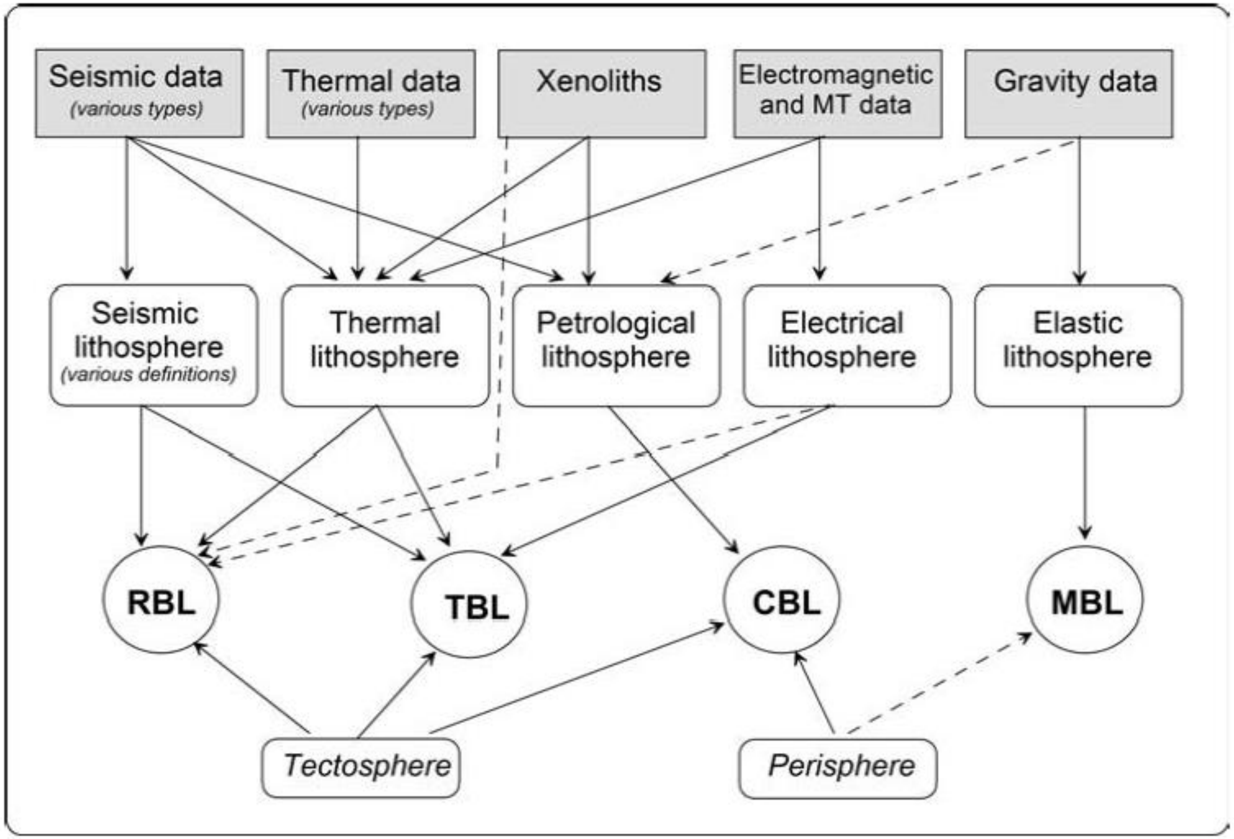
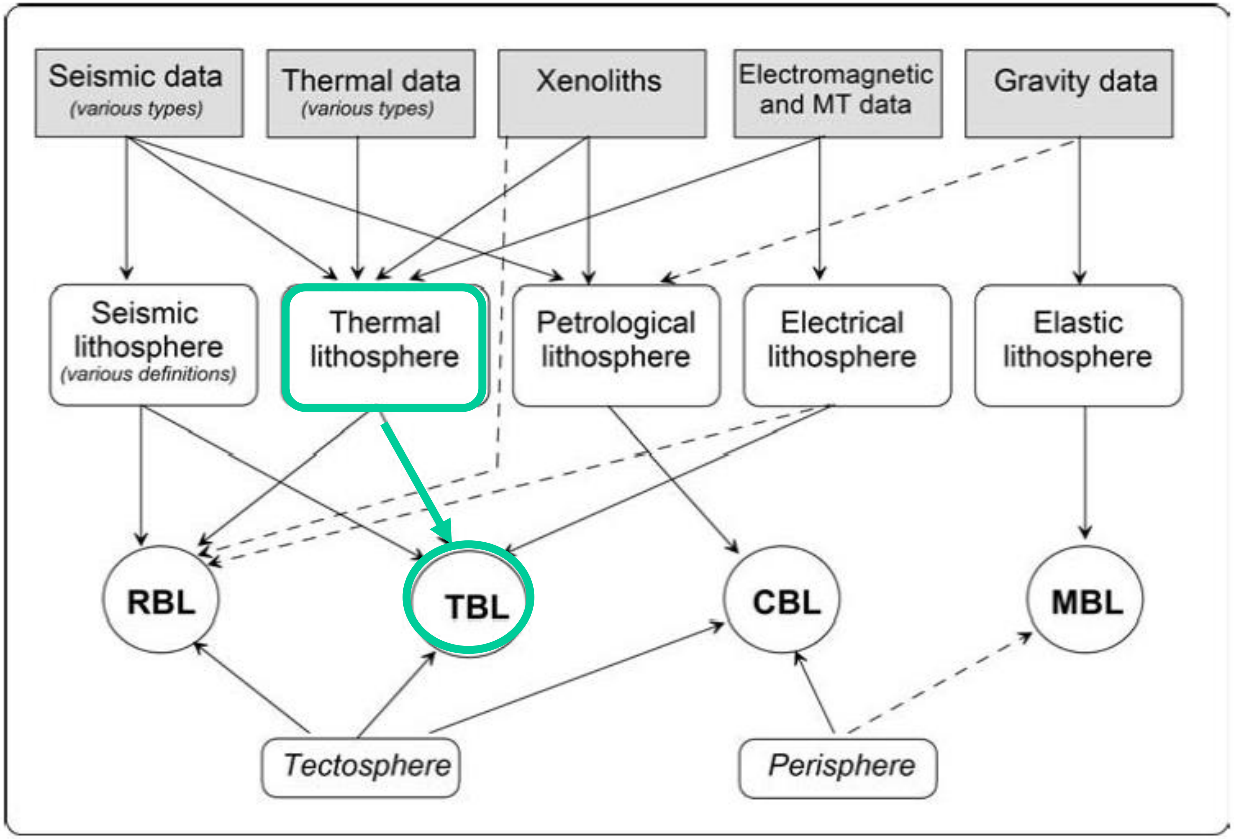



**Fig. 1.5** Correspondence between different lithosphere definitions and links with other related definitions. RBL, TBL, CBL, and MBL are rheological, thermal, chemical, and mechanical boundary layers. See discussion in text.

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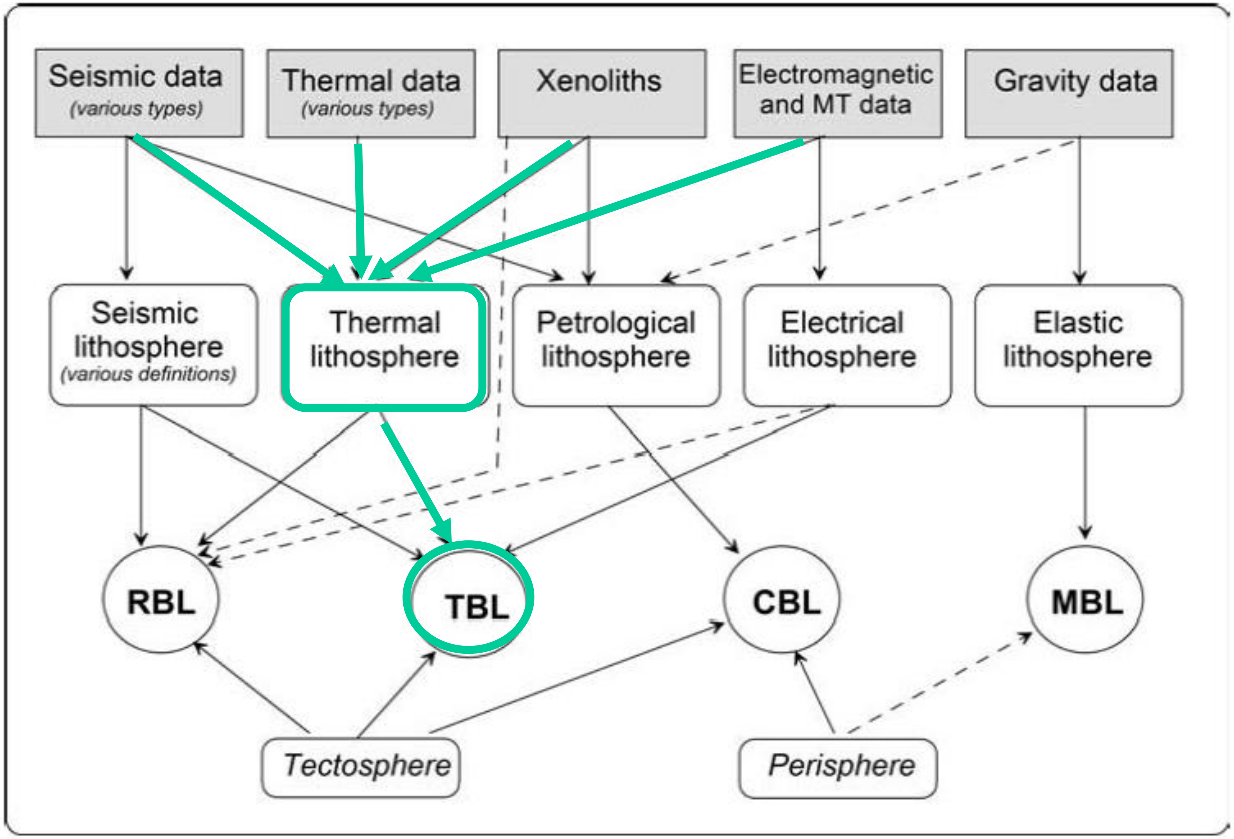


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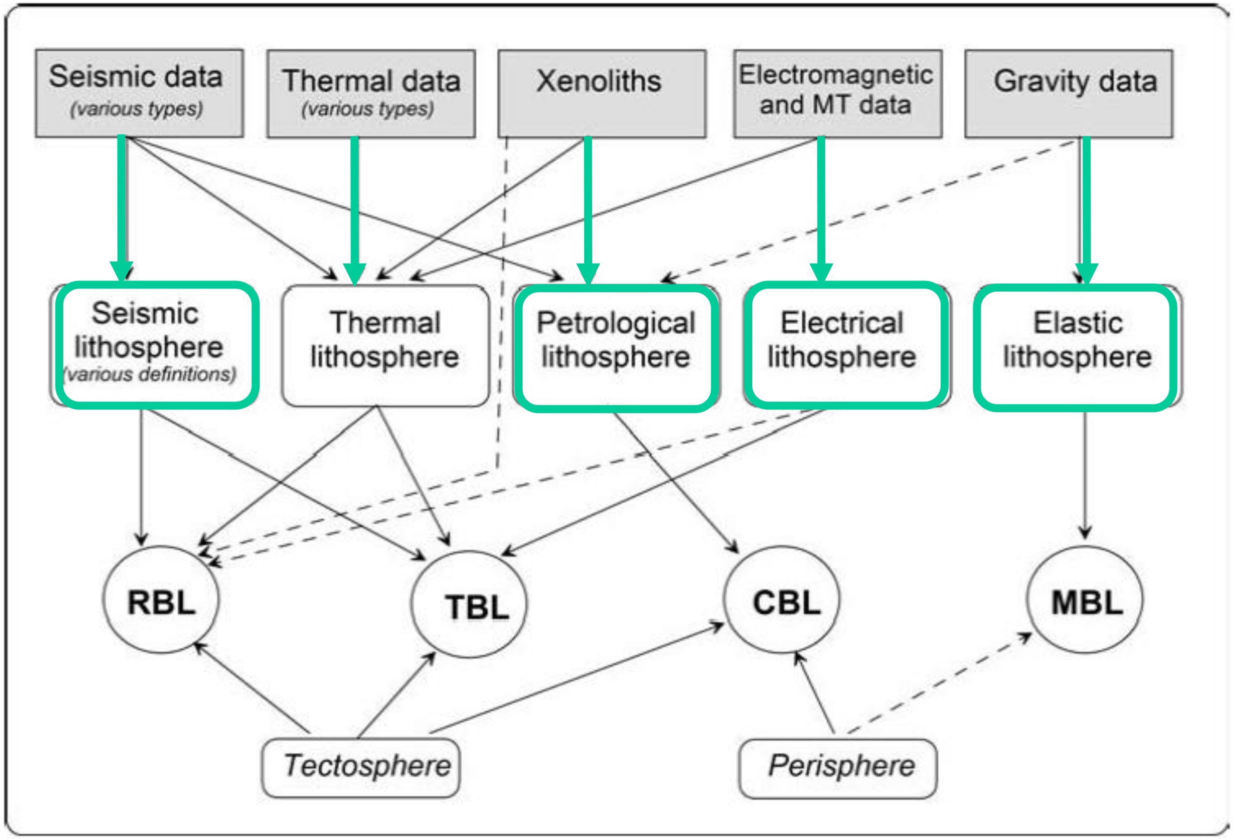


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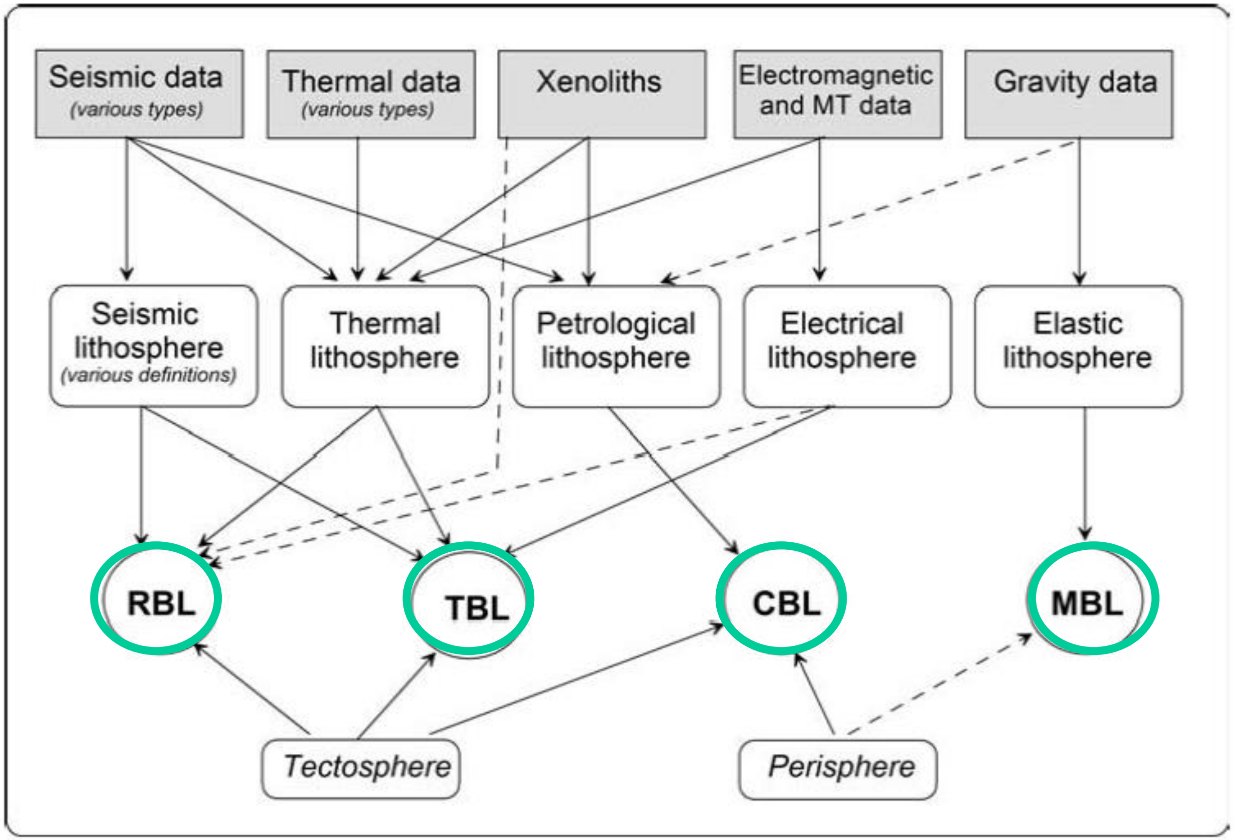


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# Questions on formation and evolution

***Where does the lithosphere come from?***

***How old is it?***

***Definition of the age of the lithosphere?***

**** the age of crustal differentiation from the mantle (ex: oceanic lithosphere),***

**** the age of the last major tectono-thermal event (ex: continental lithosphere).***

***Does it evolve with geological time?***

**Oceanic/continental regions: ≠ geological history**

**≠ roles in plate tectonics**

**→ ≠ lithospheres**

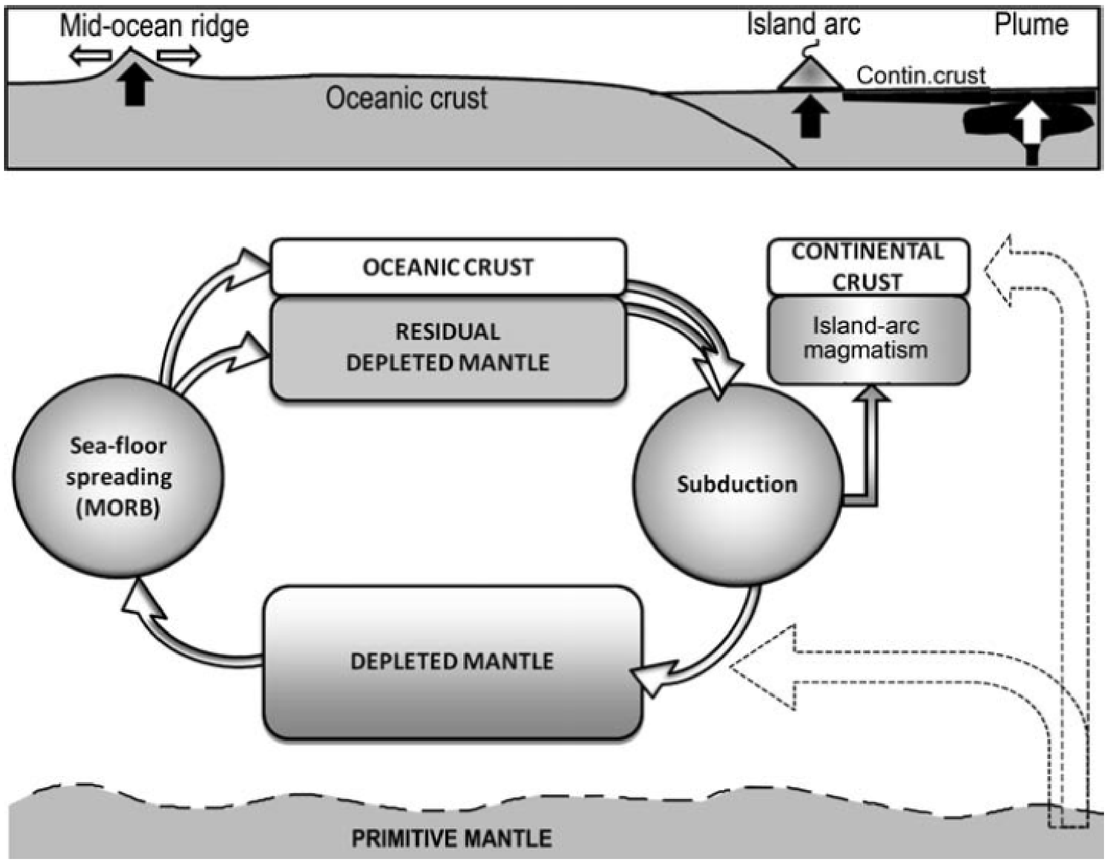



**Fig. 9.10** Sketch illustrating major processes of crustal growth and recycling. Upper mantle is depleted as compared to the primitive mantle, primarily by extraction from it of the continental crust (dotted arrows); this key concept in mantle geochemistry is based on the complementary pattern of trace-element abundances (Fig. 9.9). Melting of the depleted mantle and extraction from it of mid-ocean ridge basalts (MORB) produces the oceanic crust (the melt) and the residual depleted mantle (the residue) which are chemically complementary. A significant amount of the oceanic crust and the associated residual depleted mantle is recycled back into the depleted mantle in the subduction zones. However, island-arc magmatism brings some of the most highly incompatible trace elements back to the near-surface environment, thus playing an important role in formation of the continental crust.

# Questions on formation and evolution

***Lithosphere = crust + mantle***

***Differenciation: 2 complementary chemical bodies***

→ Relation to chemical boundary layer

***Relation between crustal age and lithospheric mantle age?***

→ Dating based on analysis of samples: easier for crust than mantle

Broad correlation in age → same melting event

But some exceptions: young/old and old/young

# Age of the continental lithosphere

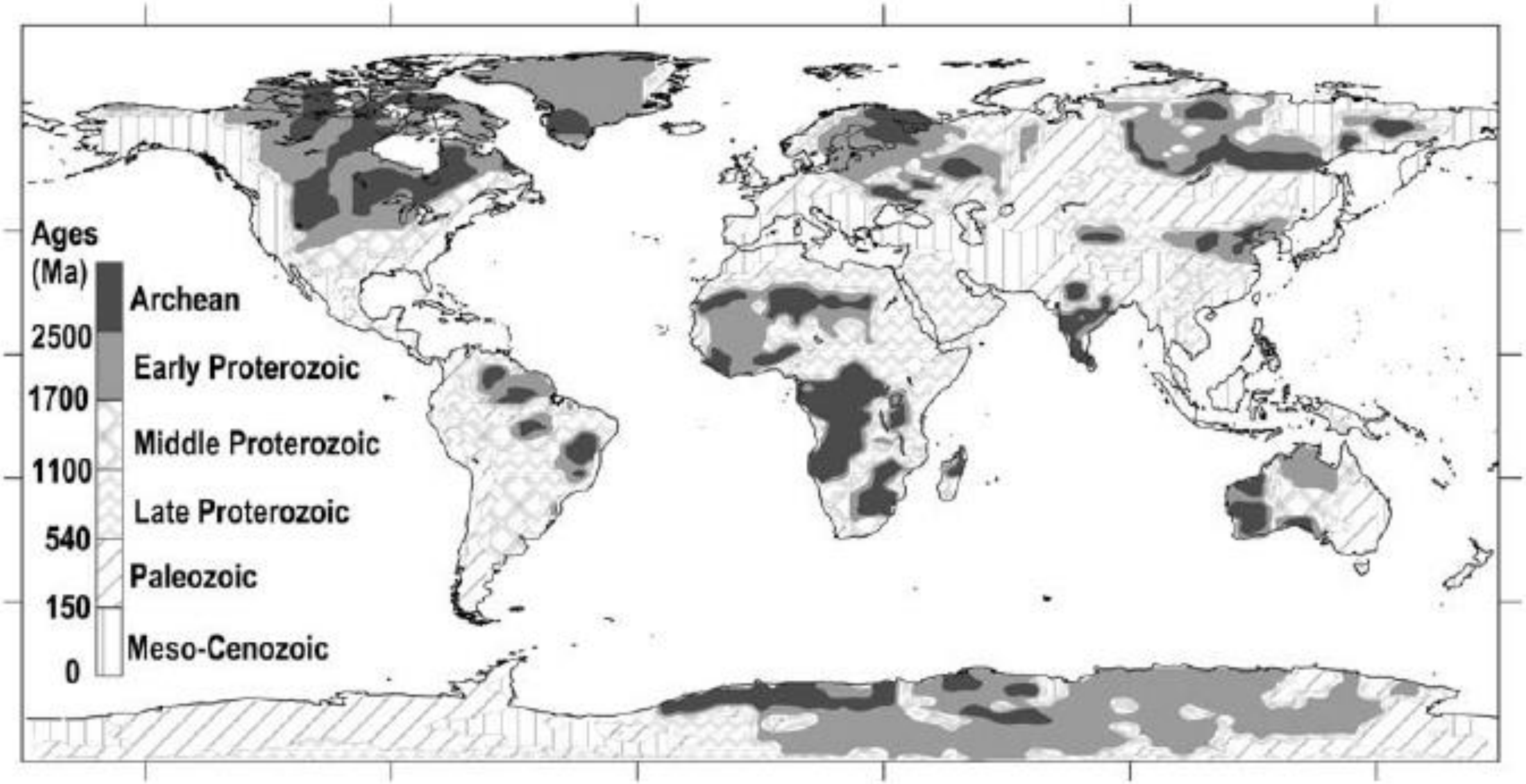



Fig. 2.16 Tectono-themal age of the continental lithosphere (after Artemieva, 2006; www.lithosphere.info).

Based on crustal age

# Different differenciation at early stages

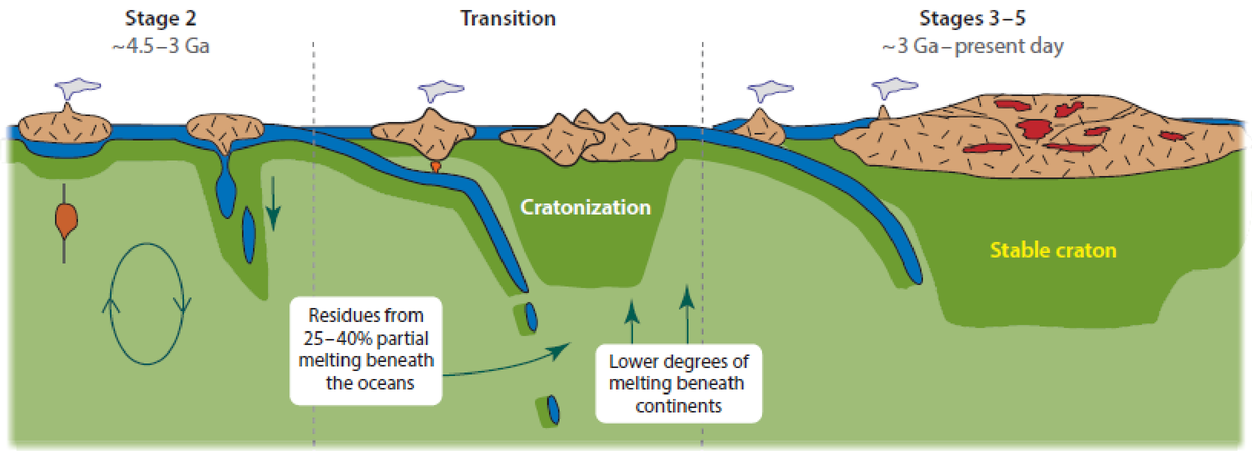



**Figure 9**

Schematic depiction of changing tectonic processes controlling the evolution of the lithosphere from an early Earth dominated by nonplate processes (stage 2) to one in which plate tectonics is the main mechanism for the generation and recycling of lithosphere (stages 3–5). These changes are a response to the secular cooling of the mantle and the consequent increase in lithospheric strength and rigidity. The mantle xenolith record suggests that they represent residues (from relatively shallow partial melting of hot mantle beneath the oceans), which subsequently accreted beneath continents. In contrast, the mafic crust that is the source of Archean tonalite-trondhjemite-granodiorites has relatively low Lu/Hf and Sm/Nd ratios, implying lower degrees of partial melting.

*From Hawkesworth et al., 2017*

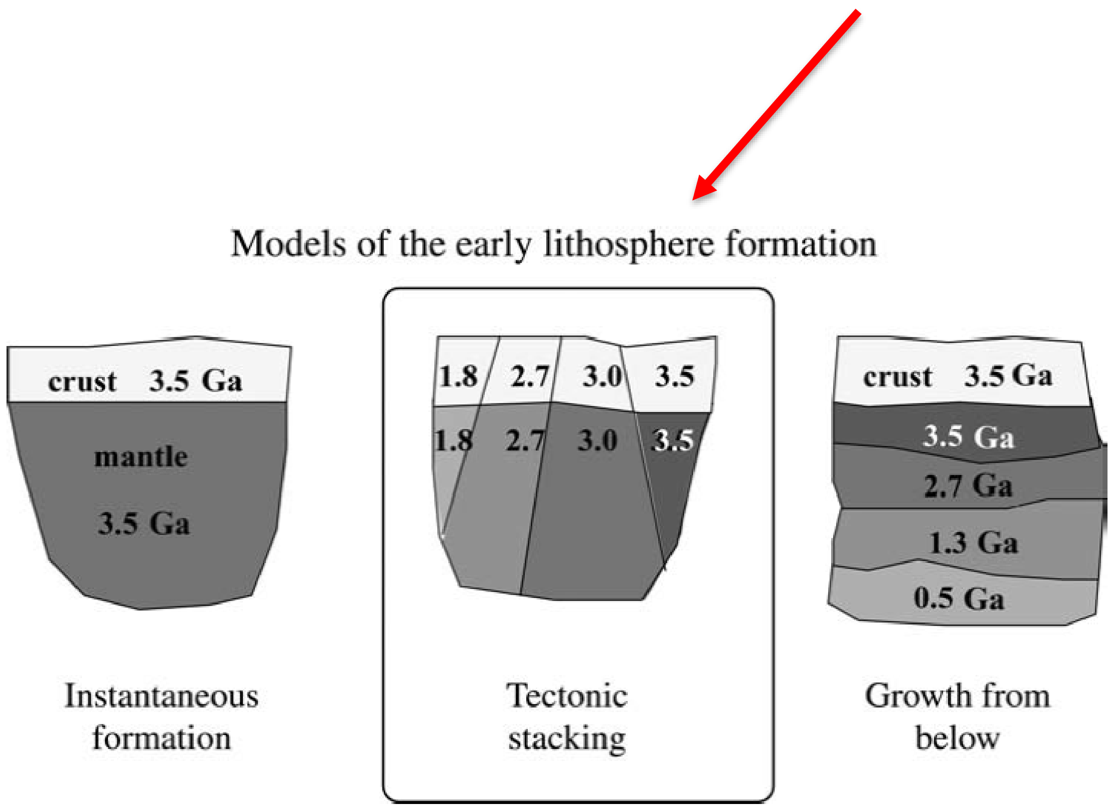



**Fig. 9.8** Sketch of three end-member models of lithospheric growth in the early terranes. Numbers – possible representative ages in Ga. The depth distribution of lithospheric ages constrained by isotope analysis of xenolith data does not support models of instantaneous or gradual lithospheric growth from below. The model of tectonic stacking of Archean terranes with similar ages of the crust and the lithospheric mantle is the one supported by the existing data.

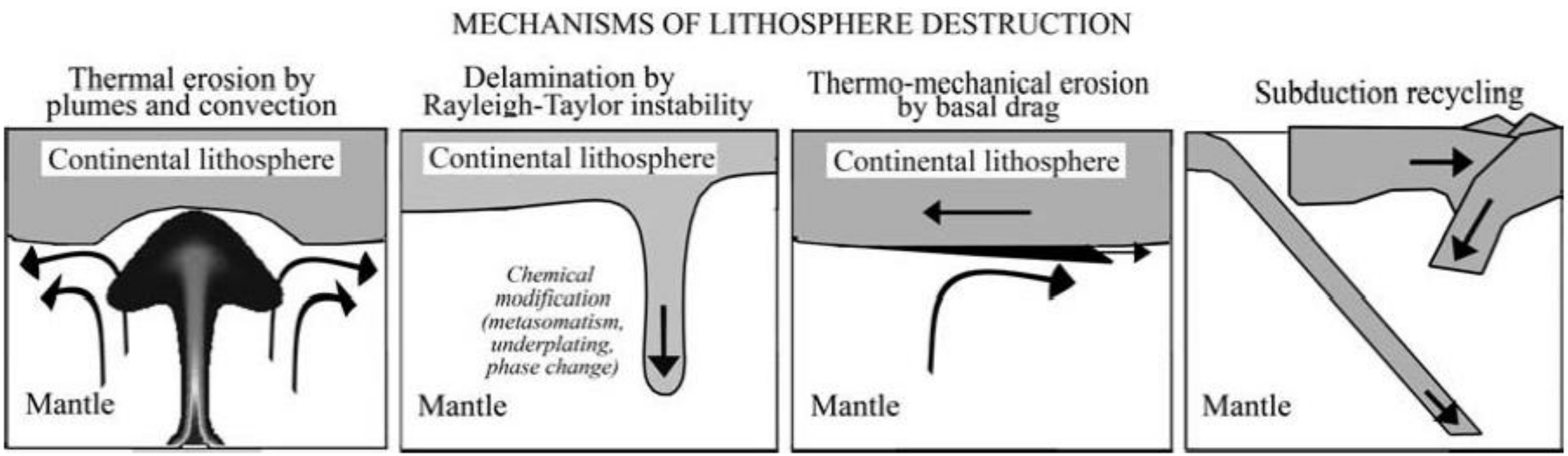
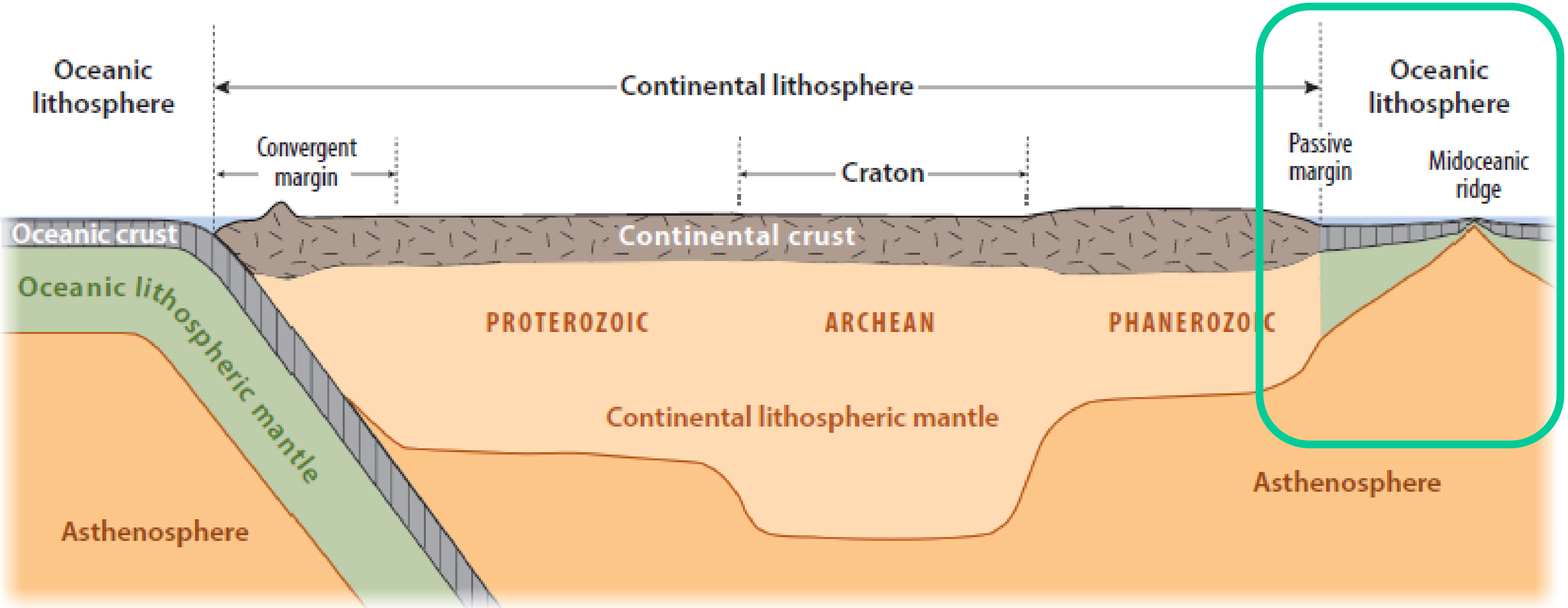



**Fig. 9.23** Sketch illustrating major mechanisms of lithosphere destruction.

# The formation and evolution of the oceanic lithosphere

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# The oceanic lithosphere

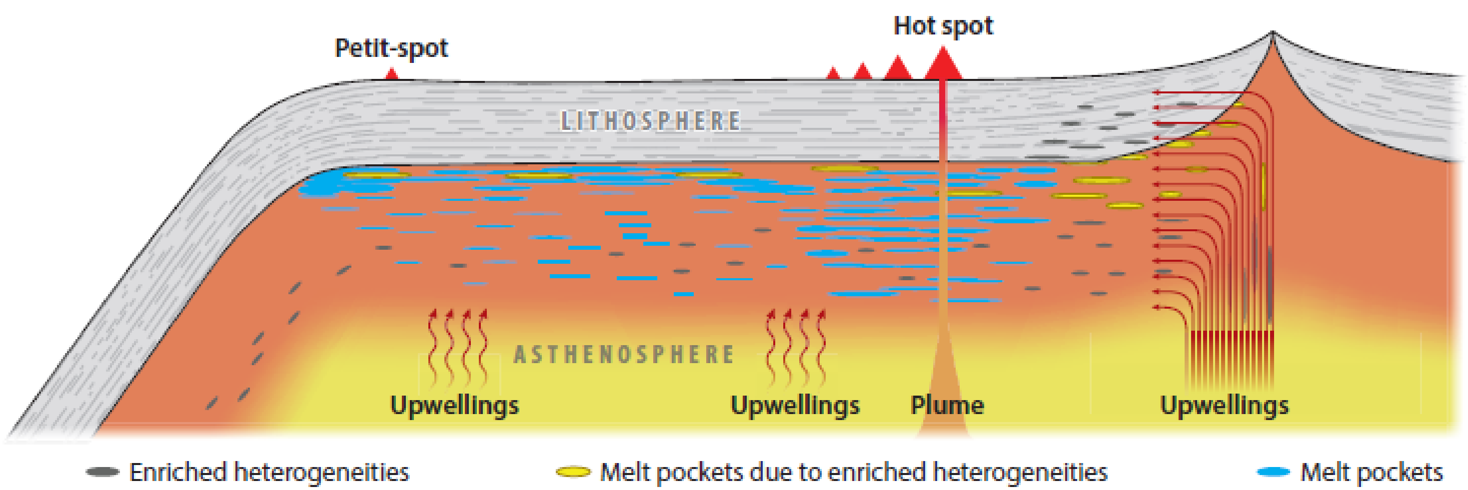



**Figure 13**

Diagram showing the synthesis made in Section 5: near ridges, enriched heterogeneities (*dark gray lenses*) develop melt pockets in the shallow parts of the low-velocity zone (LVZ) (*yellow lenses*) that will be stretched horizontally due to strong corner flow (Hirschmann 2010); other mantle upwellings will also introduce heat or volatiles in the LVZ to induce melting (*light blue lenses*) that will be also stretched horizontally to make connected networks (millefeuille asthenosphere; Kawakatsu et al. 2009). When these stretched melts solidify due to the plate cooling (underplating), laminar heterogeneities are accumulated at the base of lithosphere (e.g., Kennett & Furumura 2015).

*From Kawakatsu and Utada, 2017*

# The asthenosphere and Lithosphere-Asthenosphere Boundary (LAB)

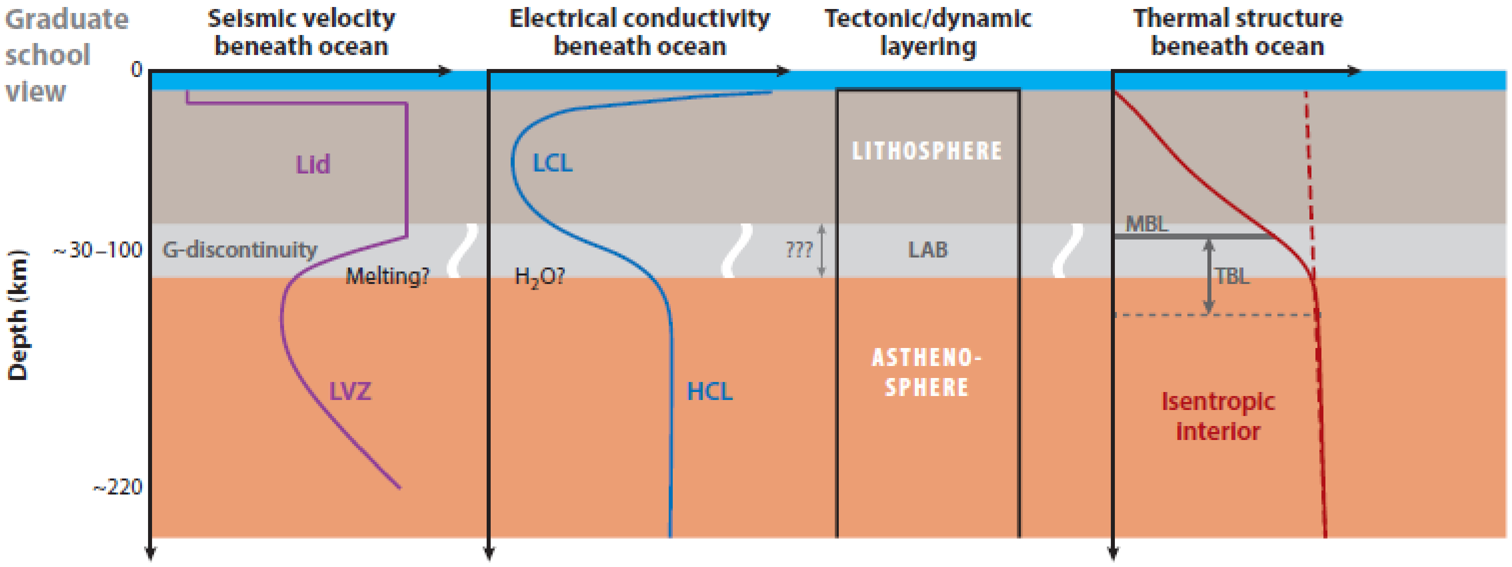



**Figure 1**

(*Top*) High school and (*bottom*) graduate school textbook views of the oceanic lithosphere–asthenosphere system. Abbreviations: HCL, high-conductivity layer; LAB, lithosphere–asthenosphere boundary; LCL, low-conductivity layer; LVZ, low-velocity zone; MBL, mechanical boundary layer; TBL, thermal boundary layer. Top panel adapted from *Basic Earth Science*, revised edition, Keirinkan ~~Press~~.

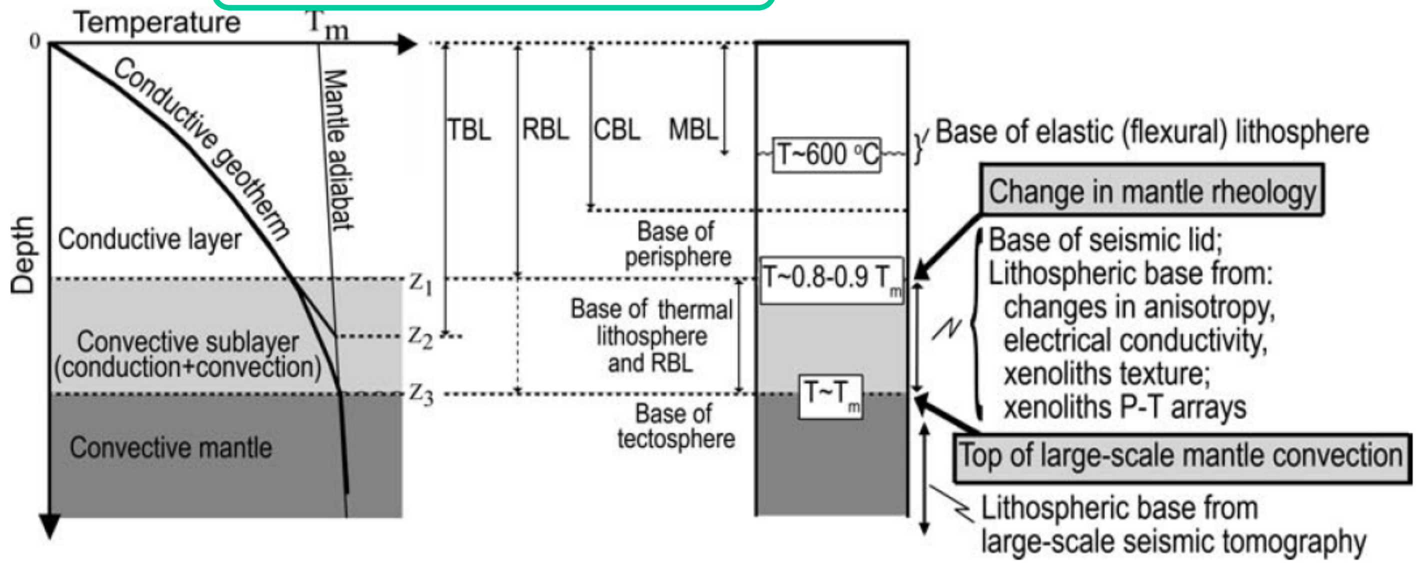
*From Kawakatsu and Utada, 2017*

Transitional nature of the LAB?

→ Definition of the lithosphere

Oceanic/continental differences?

# Defining the base of the lithosphere and of the boundary layers

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# Conclusion

*Understanding the nature, role and evolution of the Lithosphere-asthenosphere requires a pluridisciplinary approach.*

*We hope to give you an introduction to this in this course.*

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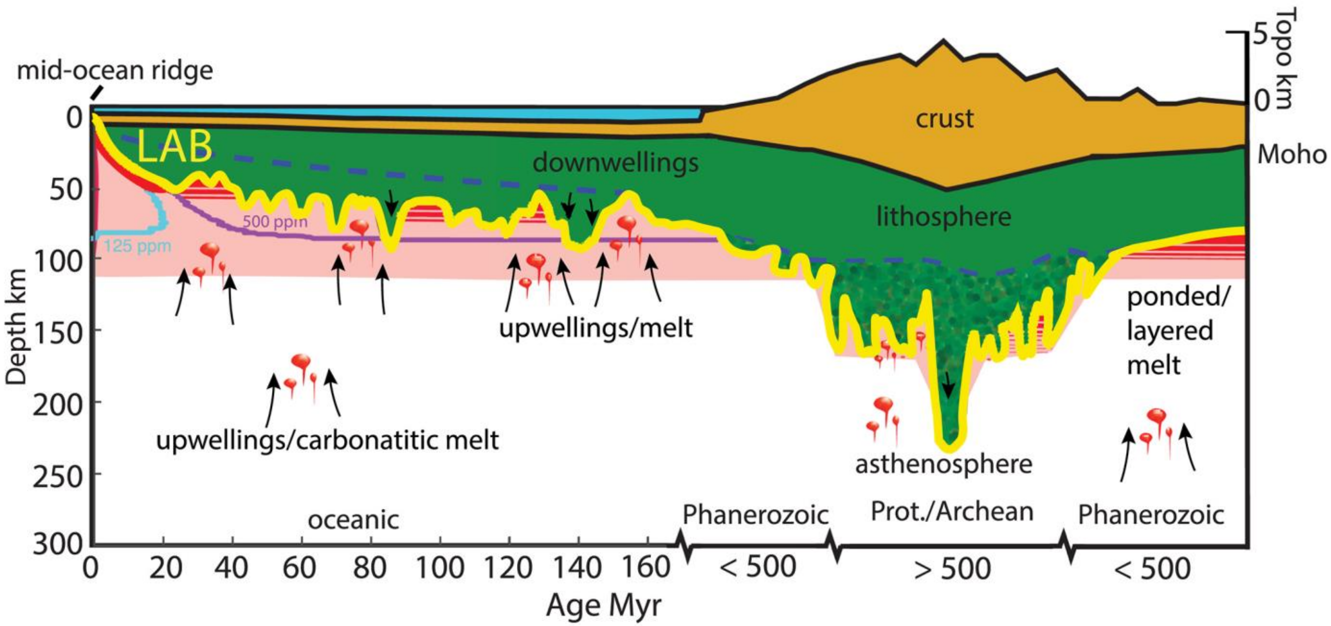


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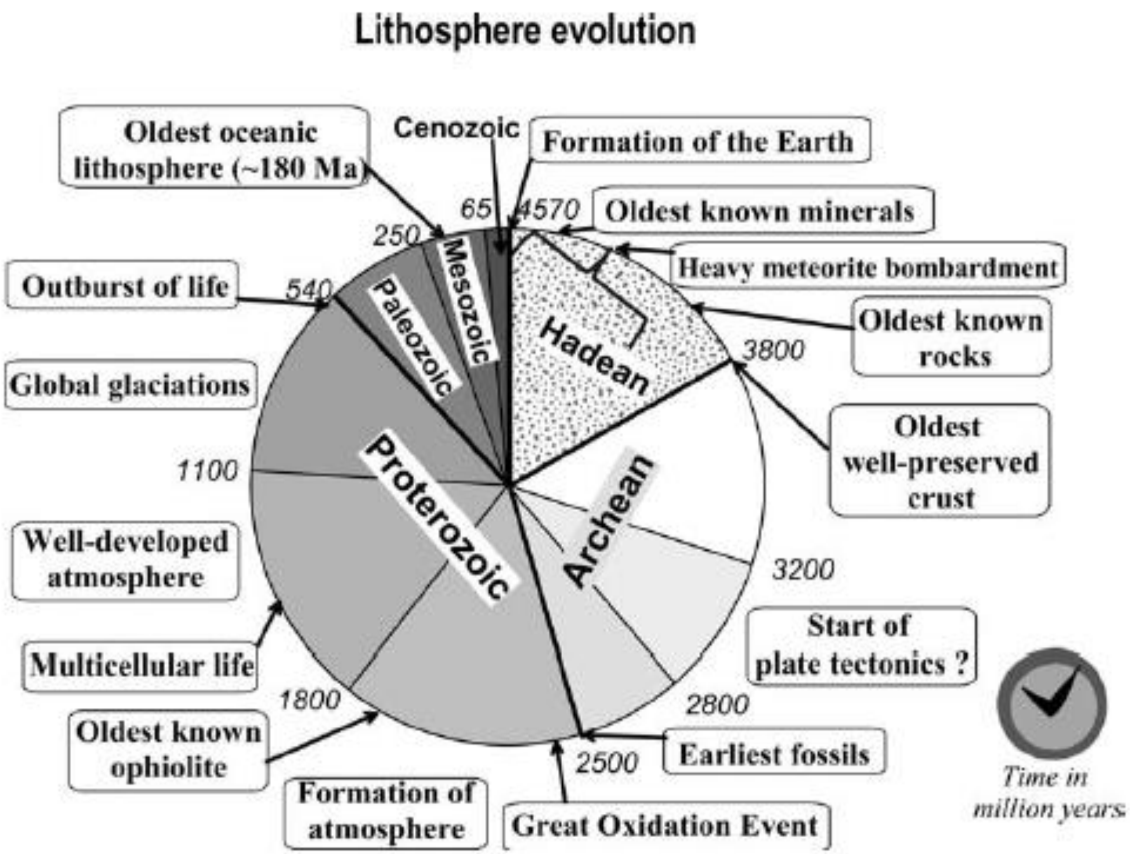


Fig. 2.14 Sketch illustrating major events in lithosphere evolution.

# Age of the continental lithosphere (based on crustal age)