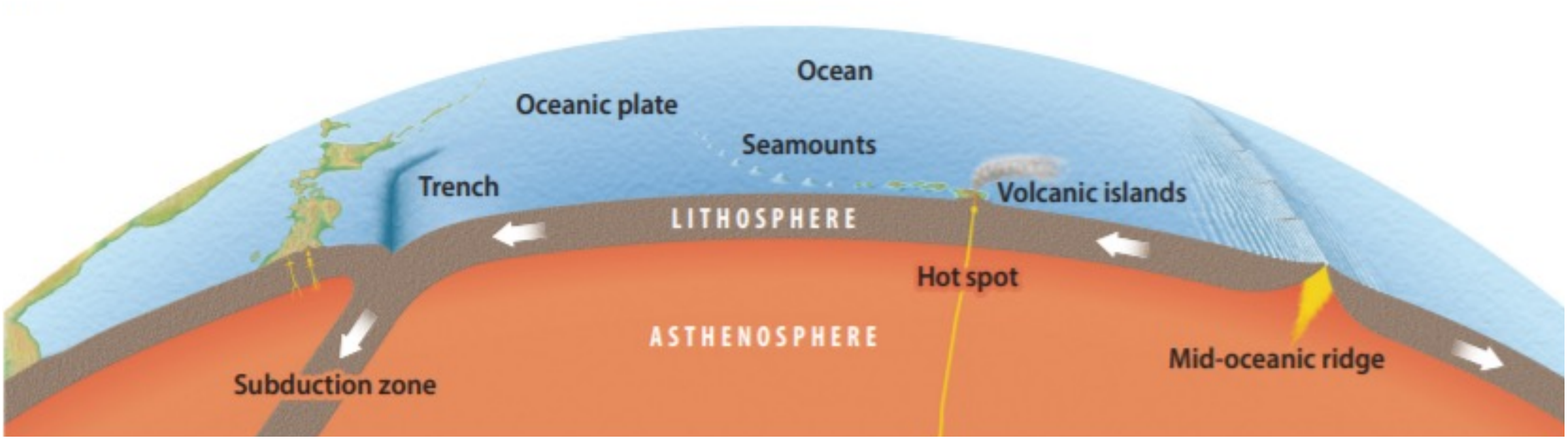
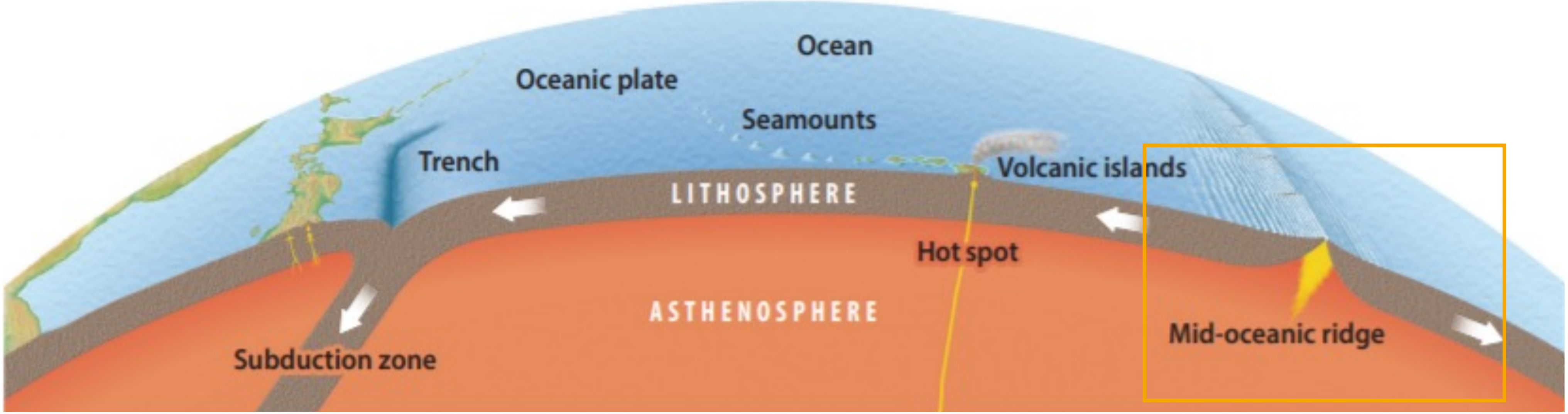
THE OCEANIC LITHOSPHERE



THE OCEANIC LITHOSPHERE

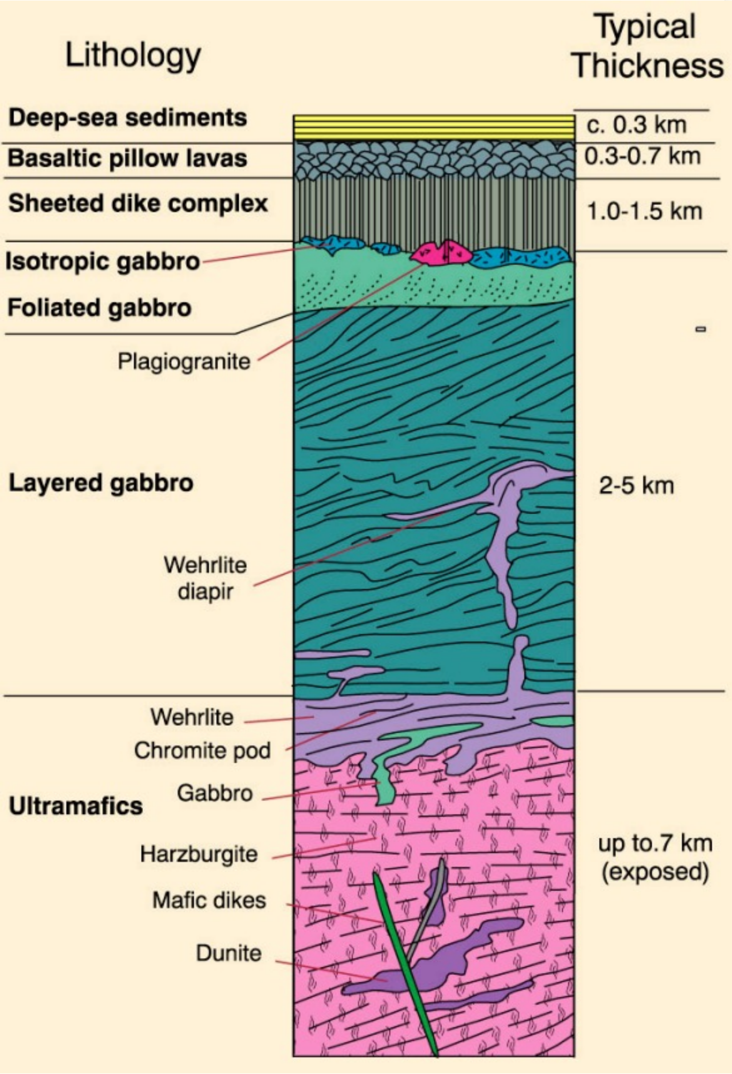
BIRTH



Structure of oceanic crust

- Layer 1 is pelagic sediments
- Layer 2 “sheeted complex” basaltic pillows, and their feeder dykes
- Layer 3 made of gabbros, some of them with a cumulative texture. Occasional “plagiogranites” (diorites to trondjhemites) are found, evidencing fractional crystallization
- Layer 4 is the peridotitic mantle, the top of it being peridotite cumulates (dunite), above “normal” mantle lherzolites or harzburgites, possibly with evidences for melting

- Common crystallization sequence:
- Ol (+/- Mg-Cr spinel)
- Ol +plag (+/- Mg-Cr spinel)
- Ol + plag + cpx

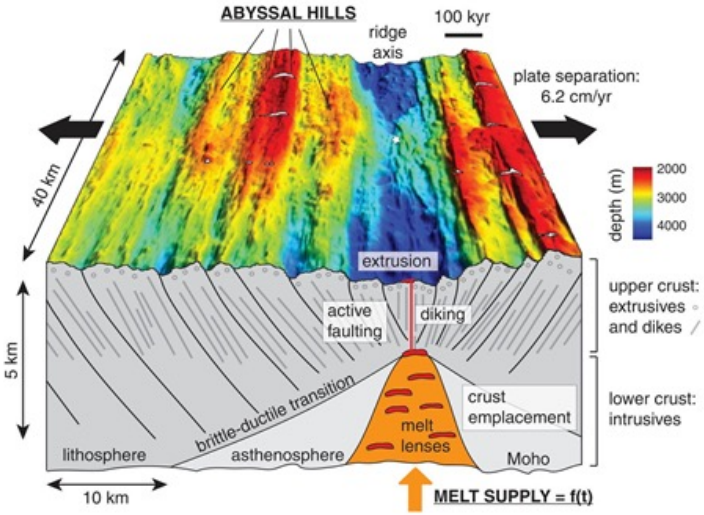


Mid-Ocean Ridges

- system of ridges (or rises) stands 1 to 3 km above the abyssal plain
- about 2000 km wide and forms a continuous globe-encircling submarine mountain range about 65,000 km long that covers approximately a third of the sea floor

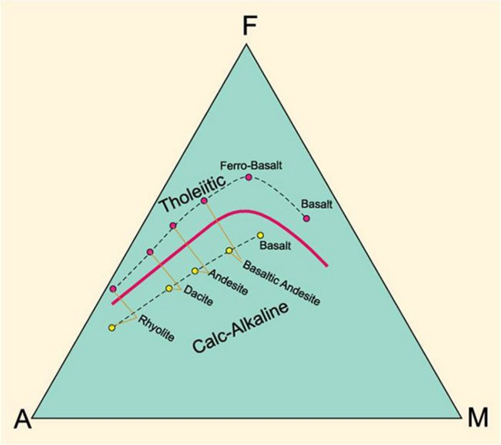
  - Data:
  - Geophysical
  - Petrographic
  - Chemical

- A molten zone is (seismically) observed under the ridges
- Petrology, geochemistry, field evidences (melt veins in peridotites) suggest melting of the mantle, immediately below the ridge (shallow melting of a Pg- or Sp-peridotite).



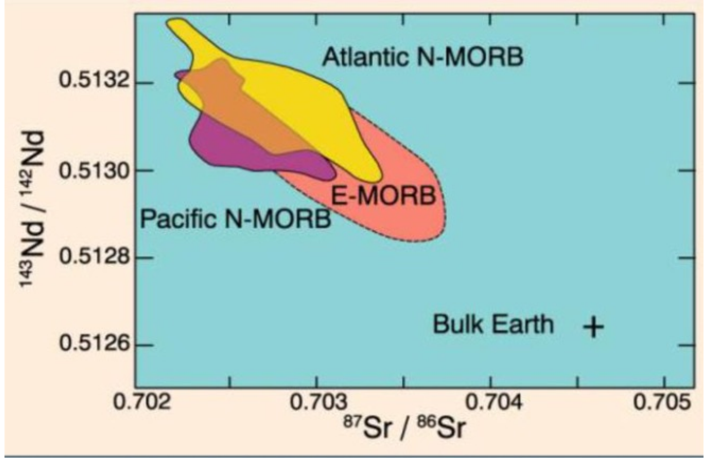
Olive, J-A., et al. (2015)

Petrology and Geochemistry of Mid-Ocean Ridges

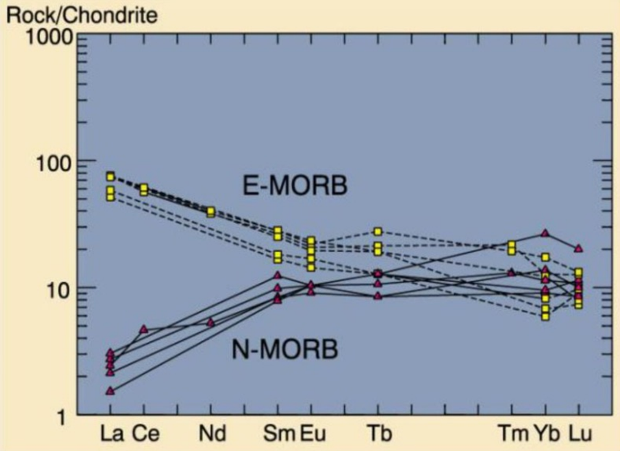


- Mostly tholeiitic basalts - small range of chemical compositions erupted to form the basaltic layer of the oceanic crust
- Tholeiitic magmas are sub-alkaline (they contain less sodium and potassium than other basalts) and can be distinguished from other basalts by the redox state of the magma from which they crystallized (tholeiitic parent magmas are reduced whereas calc-alkaline parent magmas are oxidized)
- Differenciation is demonstrated by major elements trends, consistent with the formation of Ol, Pg and Px
- Shallower melting (25% melting at <30 km = tholeiite)
- Greater % partial melting (30% melting at 60 km = tholeiite)
- This corresponds more or less to the observed petrologic sequence (dunites – gabbros)

Normal-MORB vs Enriched-MORB



Ito et al. 1897

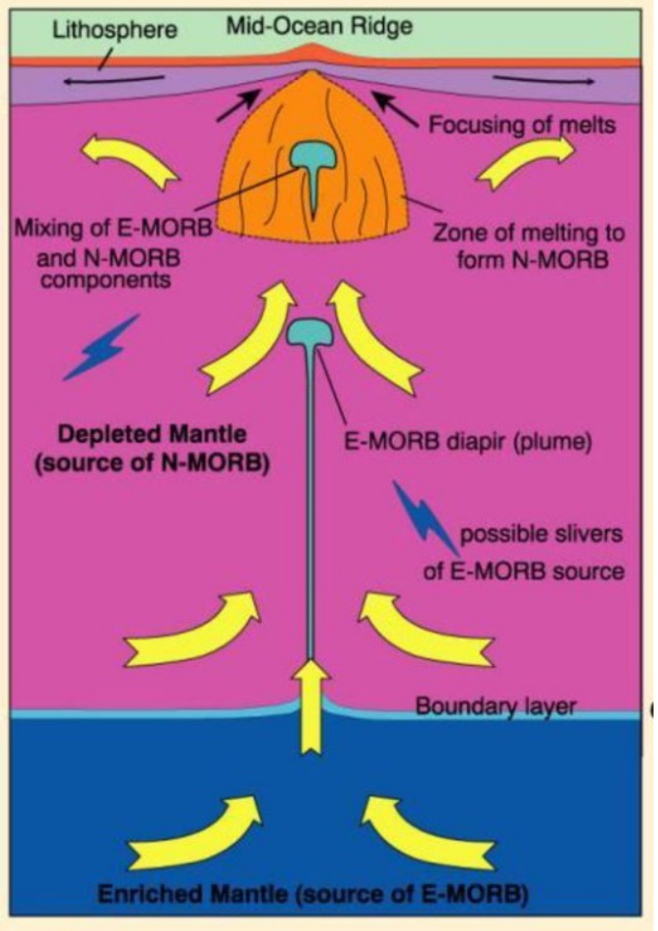


Schilling et l. 1983

E-MORB are richer in LREE and incompatible elements its such as K, Ba, La, Rb
-Iceland where the rate of magma production has caused volcanism

Origin of Mid-Ocean Ridges

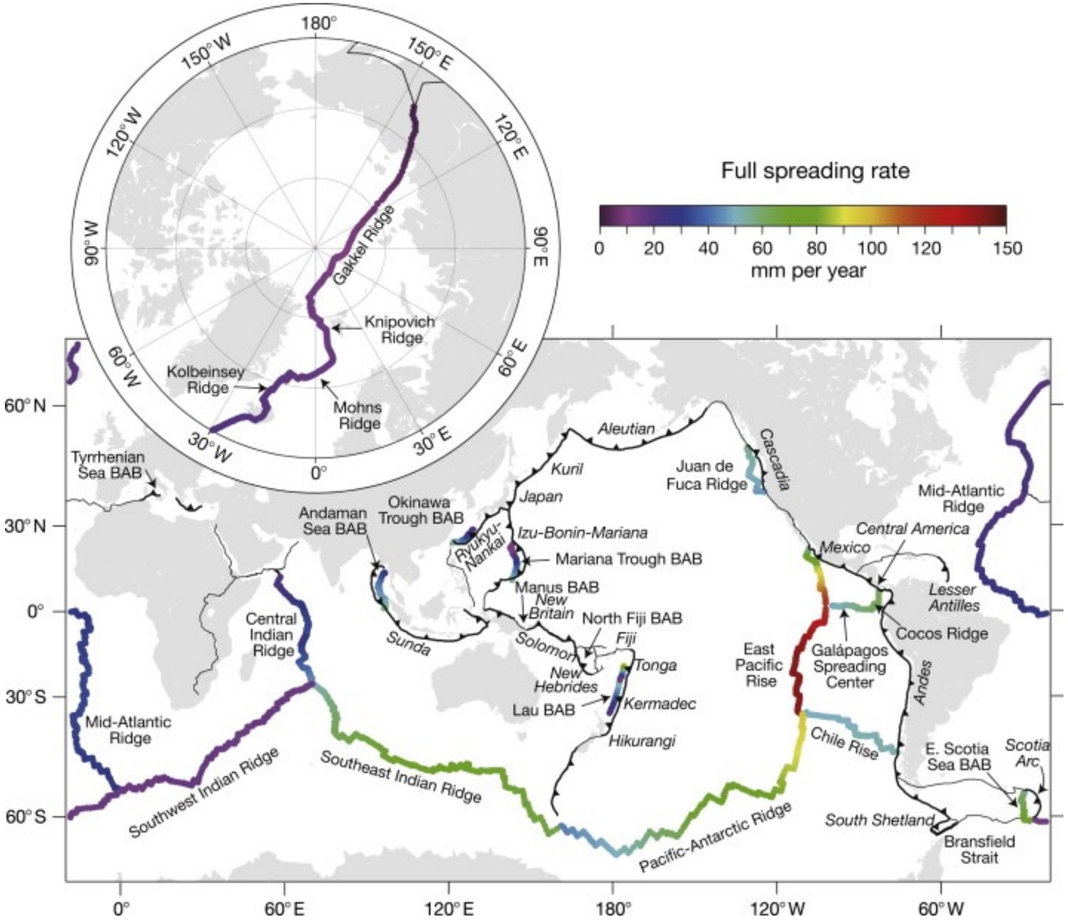
- This suggests several distinct sources; the deeper mantle, regarded as more enriched, is a good candidate for the source of E-MORBs
- Lower enriched mantle reservoir drawn up E-MORB plume initiation
- Probably minor influx of E-MORB type in a dominantly N type magma chamber at the ridge
- Mixing between the two more or less efficient (the more melt, the more efficient – so fast ridges are more mixed)



After Zindler et al. 1984

SEAFLOOR SPREADING RATES

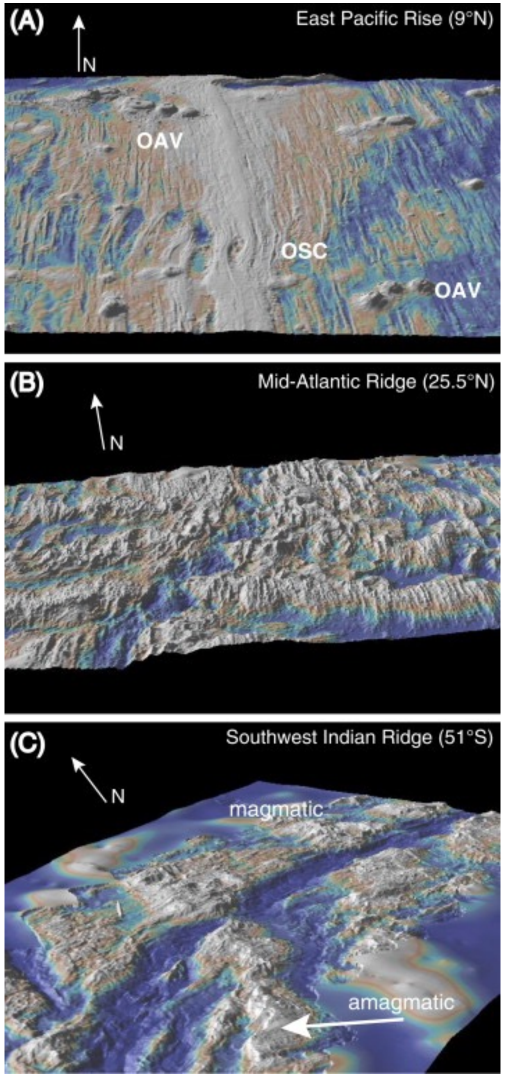
- defined by the relative rate of plate motion between the diverging plates and are subdivided
- spreading ridges:
- ultrafast (>12 cm a^{-1})
- fast (<12 to >8 cm a^{-1})
- intermediate (<8 to >5 cm a^{-1})
- slow (<5 to >2 cm a^{-1})
- ultraslow (<2 cm a^{-1})
- More than a third of mid-ocean ridges have a spreading rate of less than 20 mm a year



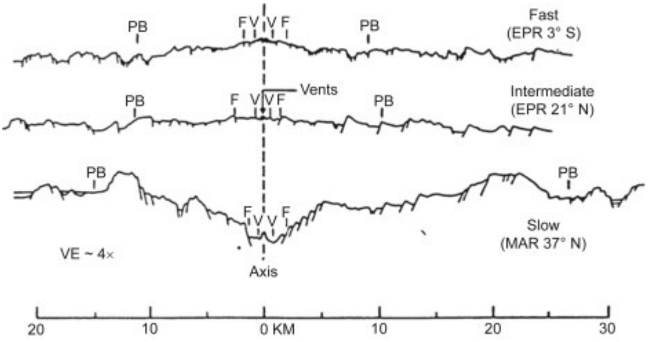
Bird (2003), Argus et al. (2011)

SPREADING RIDGES CLASSES

- Distinctive mid-ocean ridge morphologies
- Modern electromagnetic deep imaging have greatly improved our understanding of fast-spreading ridges
- substantially improved understanding
  of structures and evolution
- but have not been available for the ultraslow-spreading ridges



- bathymetry gently increases from the abyssal plain to the ridge or rise with an elevation increase of ~500 m



Macdonald, K.C., 1982

- neovolcanic zone is defined by a >10 km wide by 0.5–2.5 km deep axial graben, bound by inward dipping normal faults

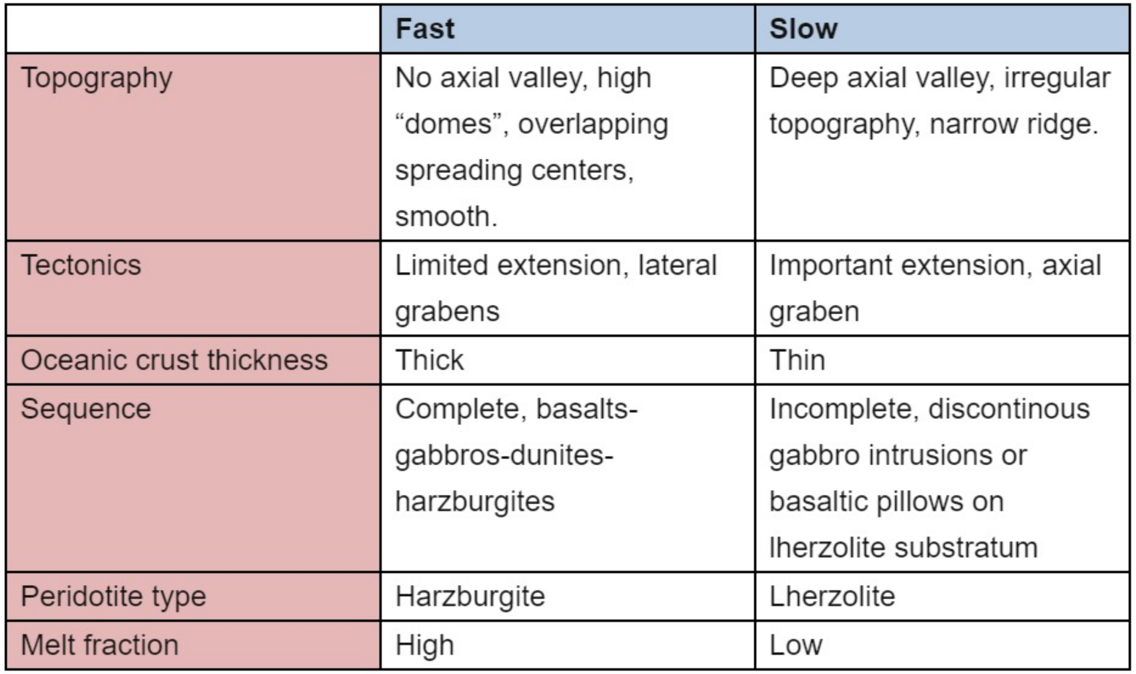
- ultraslow mid-ocean ridges accommodate relative plate motions by magmatic and amagmatic accretion processes

SPREADING RIDGES CLASSES

- Fast spreading correlates with high degree of melting, yielding lots of basalts and strongly depleting the residual mantle, which becomes harzburgitic
- Slow spreading .. is the reverse situation !

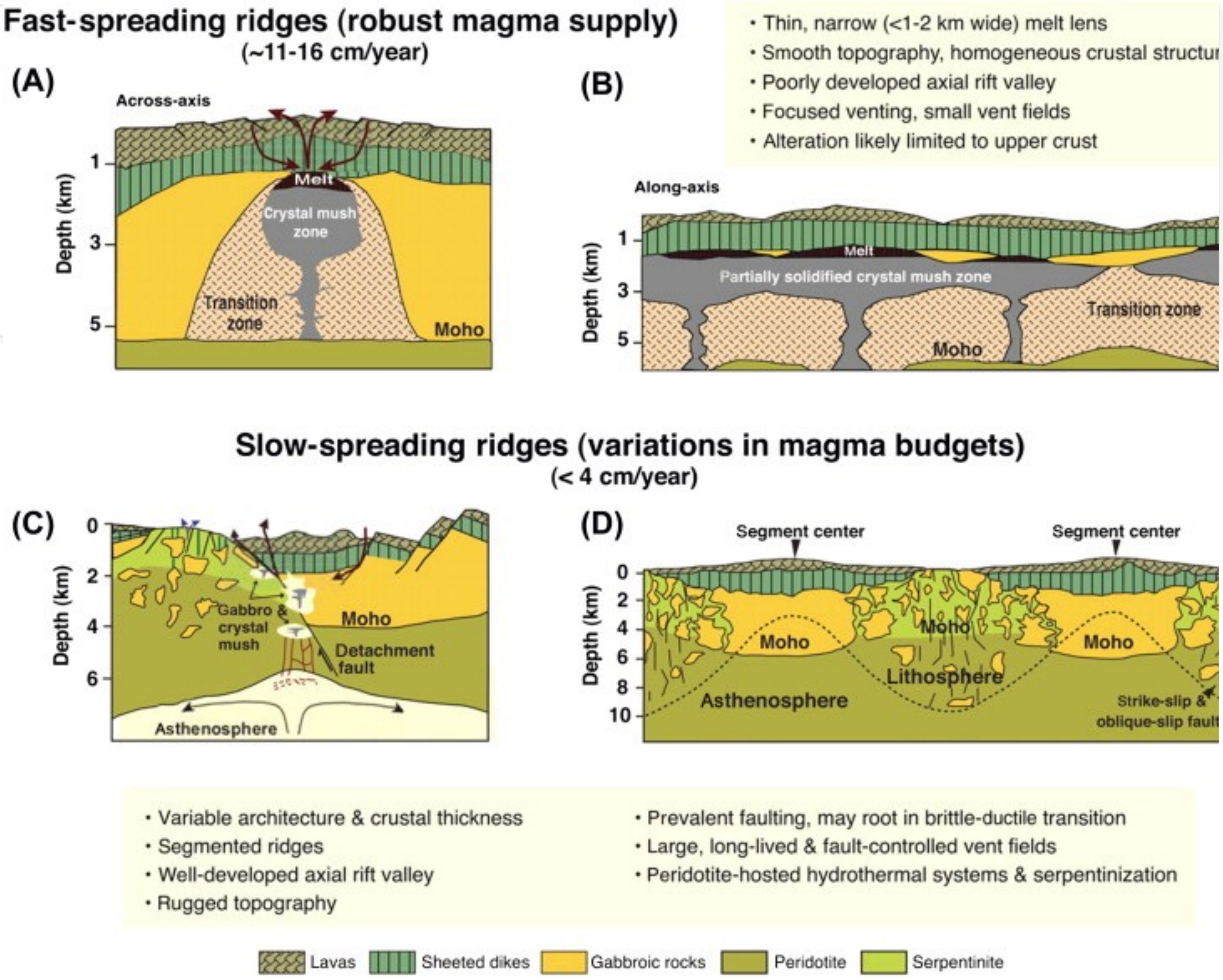
Two extreme cases:

- Harburgite Ophiolite Type
- Lherzolite Ophiolite Type



	Fast	**Slow**
Topography	No axial valley, high “domes”, overlapping spreading centers, smooth.	Deep axial valley, irregular topography, narrow ridge.
Tectonics	Limited extension, lateral grabens	Important extension, axial graben
Oceanic crust thickness	Thick	Thin
Sequence	Complete, basalts-gabbros-dunites-harzburgites	Incomplete, discontinous gabbro intrusions or basaltic pillows on lherzolite substratum
Peridotite type	Harzburgite	Lherzolite
Melt fraction	High	Low

FAST VS SLOW SPREADING CLASS



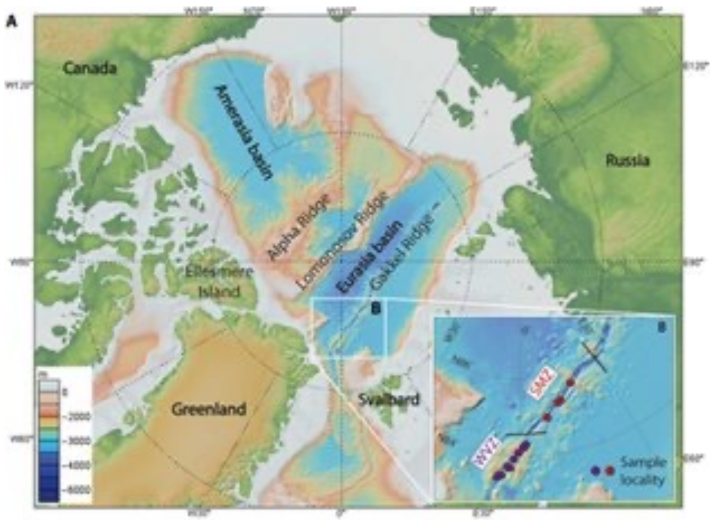
- Thin, narrow (<1-2 km wide) melt lens
- Smooth topography, homogeneous crustal structur
- Poorly developed axial rift valley
- Focused venting, small vent fields
- Alteration likely limited to upper crust

- Variable architecture & crustal thickness
- Segmented ridges
- Well-developed axial rift valley
- Rugged topography

- Prevalent faulting, may root in brittle-ductile transition
- Large, long-lived & fault-controlled vent fields
- Peridotite-hosted hydrothermal systems & serpentinization

Bach, W., 2010

ULTRA-SLOW SPREADING CLASS

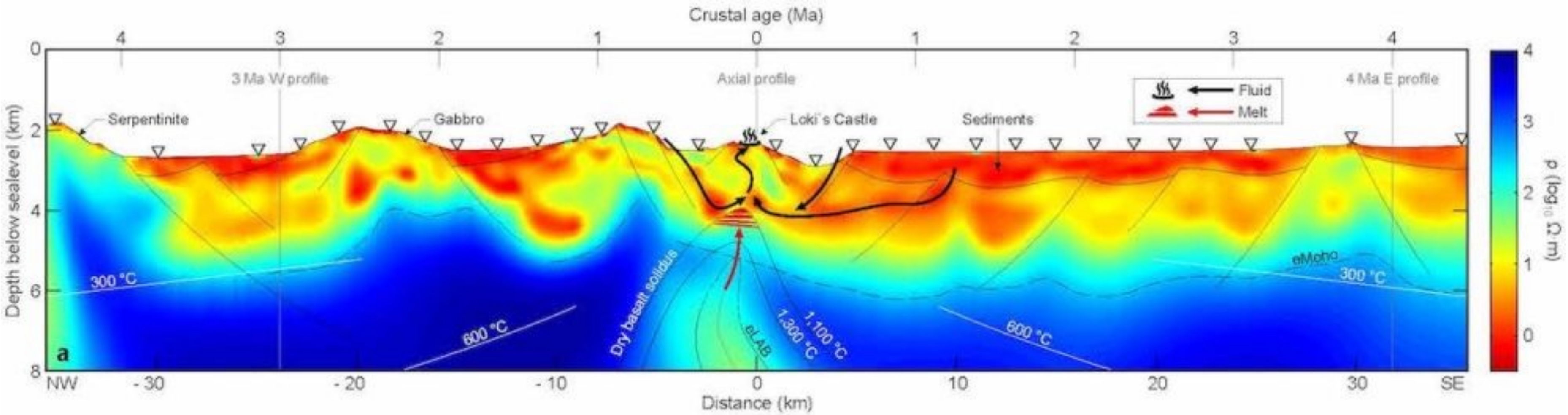


Richter, M., et al. 2020

- The ultraslow-spreading ridges consist of linked magmatic and amagmatic accretionary ridge segments
- The amagmatic segments are a previously unrecognized class of accretionary plate boundary structure
- Any orientation, with angles relative to the spreading direction ranging from orthogonal to acute
- These amagmatic segments sometimes coexist with magmatic ridge segments for millions of years to form stable plate boundaries, or may displace or be displaced by transforms and magmatic ridge segments as spreading rate, mantle thermal structure and ridge geometry change

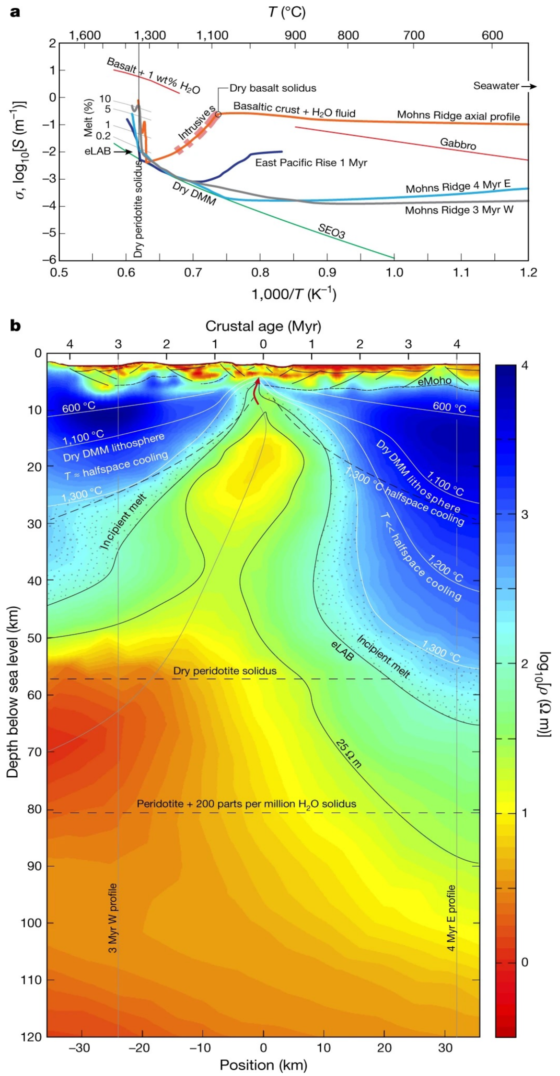
Passive or active ridge system

- lithospheric plate on the eastern side of the ridge was much thicker and colder than on the western side of the ridge
- asymmetric thickness along mid-ocean ridges means there must be a dynamic system and that overpressure pushes magma up from the deep mantle??
- Eurasian plate, which is slowly moving southwards. In contrast, the North American plate is moving nearly west
- because you have asymmetric plate movement at the surface –asymmetric structures below the ridge



Mohns Ridge, combining controlled source electromagnetic and magnetotelluric data *Johansen, S.E. et al., (2019, Nature)*

Arrows in the red areas at the top of the section show circulation patterns of seawater through the oceanic crust, which helps enrich the water with metals before it emerges from the ridge in a black smoker



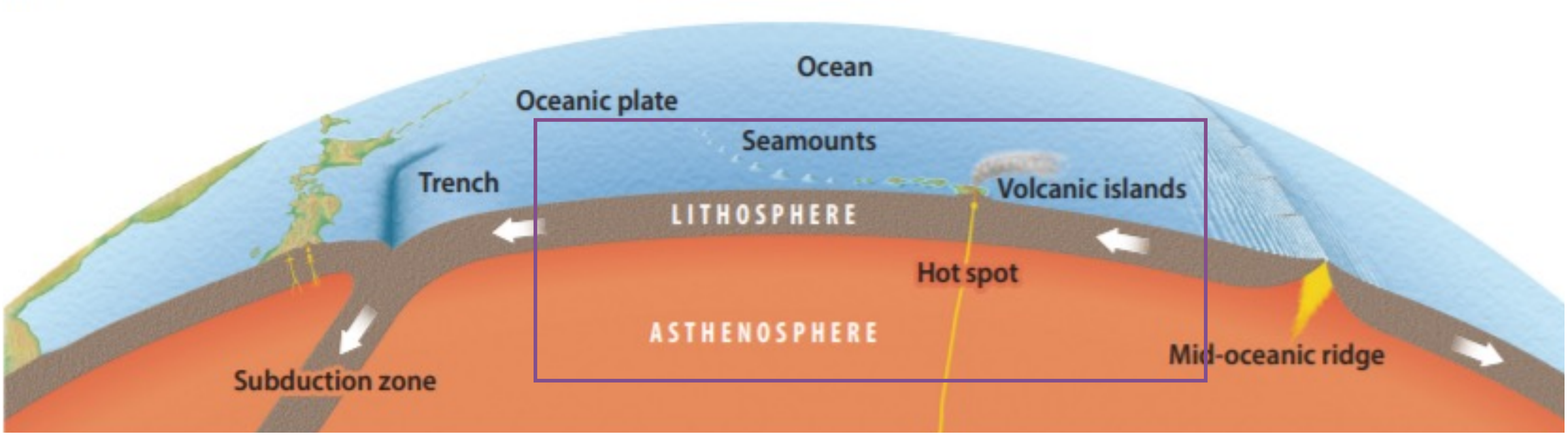
Johansen, S.E. et al., (2019, Nature)

- lithosphere on the right, or eastern side of the ridge, is much thicker than the lithosphere on the left, or western side of the ridge.

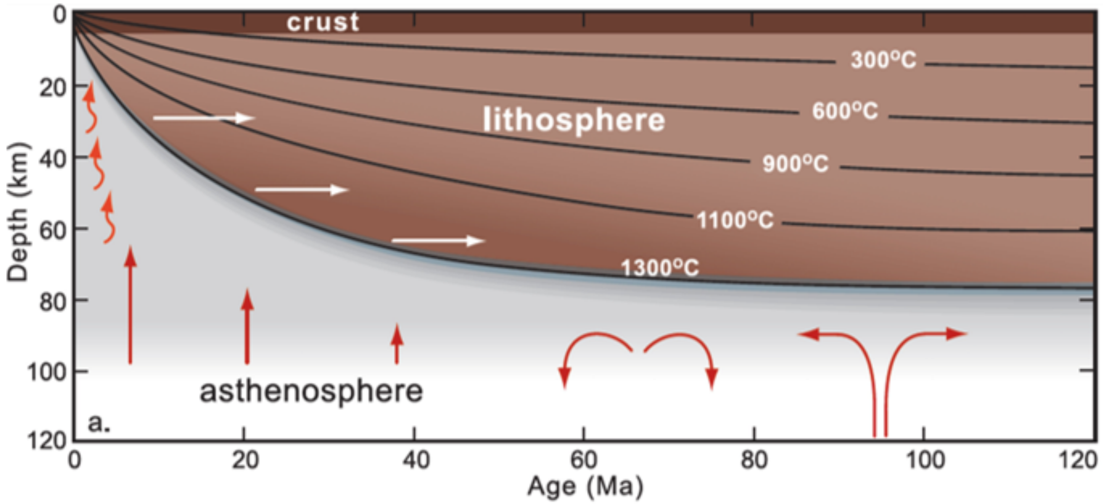
- inversion images show mantle upwelling focused along a narrow, oblique and strongly asymmetric zone coinciding with asymmetric surface uplift.
- electrical LAB (eLAB) may represent a rheological boundary defined by a minimum melt content
- model in which crustal thickness is directly controlled by the melt-producing rock volumes created by the separating plates is more likely
- fluid convection extends for long lateral distances, exploiting high porosity at mid-crustal levels. The magnitude and long-lived nature of such plumbing systems could promote venting at ultraslow-spreading ridges

THE OCEANIC LITHOSPHERE

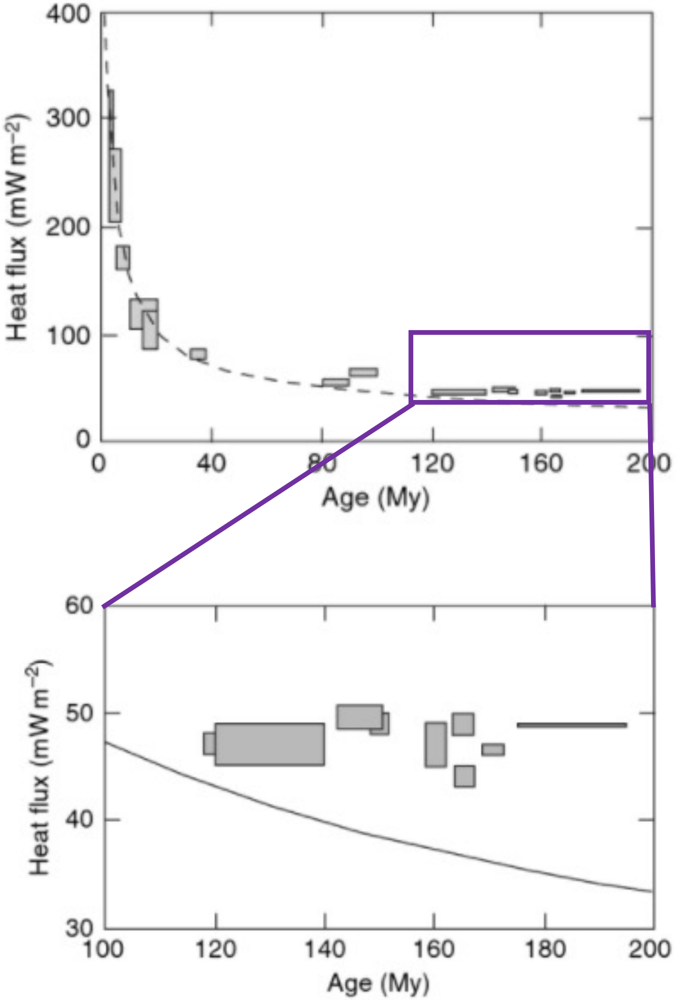
EVOLUTION



Evolution



Davies & Chapman, 2020



Jaupart & Mareschal, 2007

Thermal structure

Thickness(a), ΔT, k, α

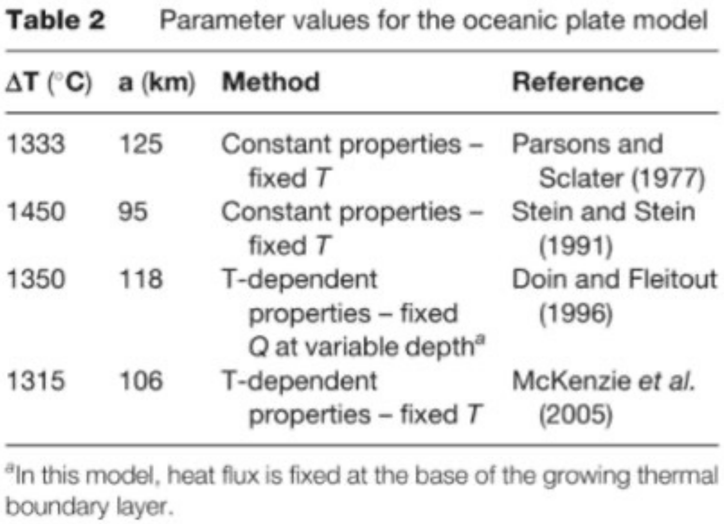
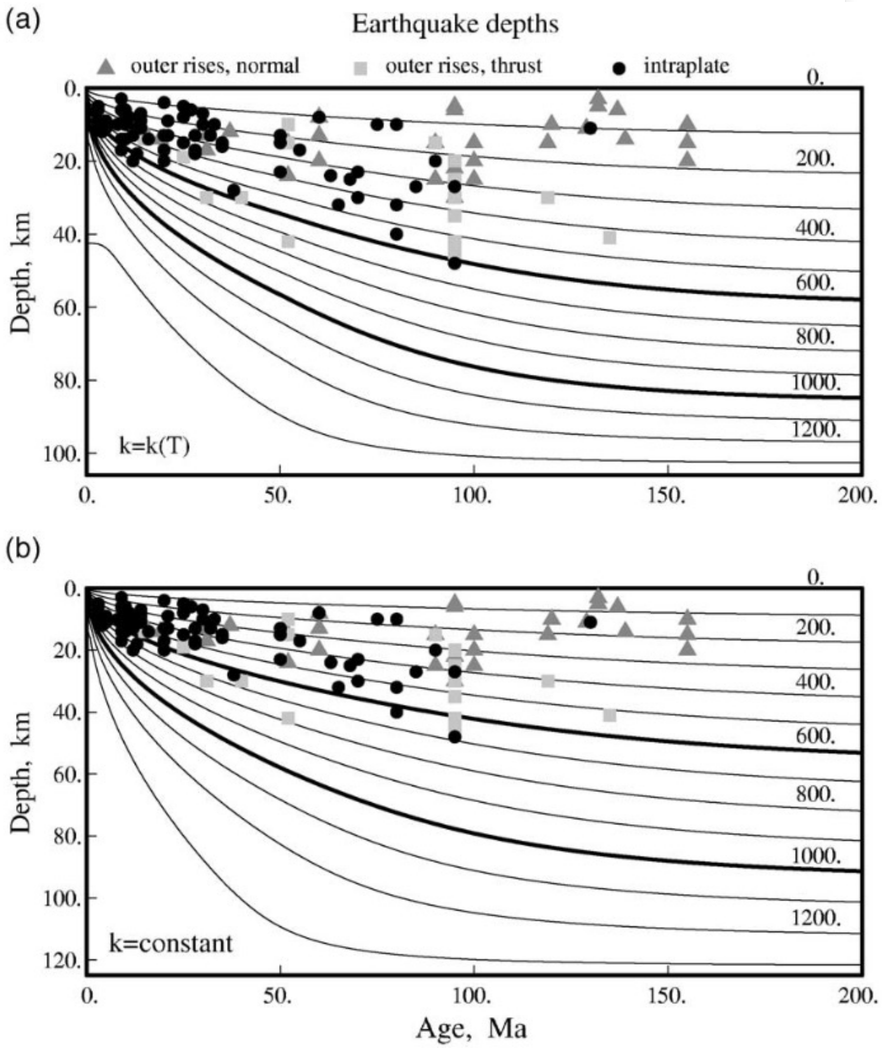


Table 2 Parameter values for the oceanic plate model

ΔT (°C)	a (km)	Method	Reference
1333	125	Constant properties – fixed *T*	Parsons and Sclater (1977)
1450	95	Constant properties – fixed *T*	Stein and Stein (1991)
1350	118	T-dependent properties – fixed *Q* at variable depth[a]	Doin and Fleitout (1996)
1315	106	T-dependent properties – fixed *T*	McKenzie *et al.* (2005)

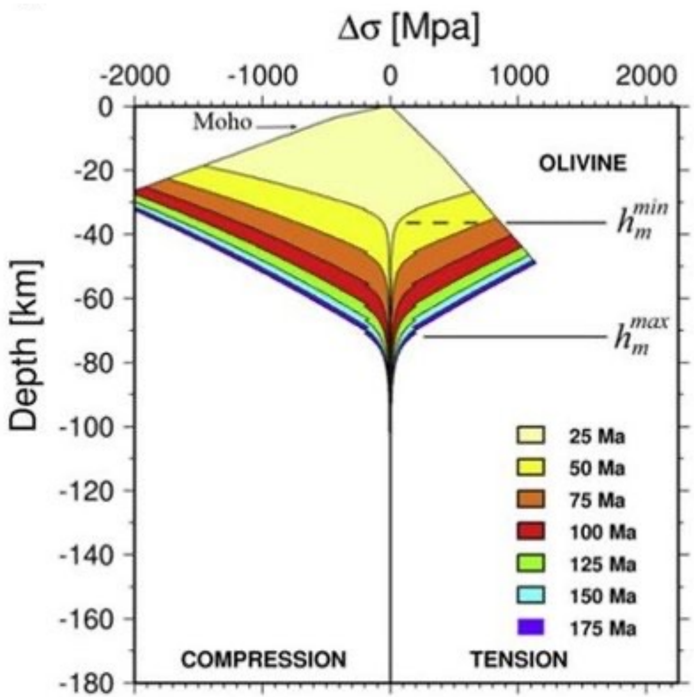
[a] In this model, heat flux is fixed at the base of the growing thermal boundary layer.

Jaupart & Mareschal, 2007

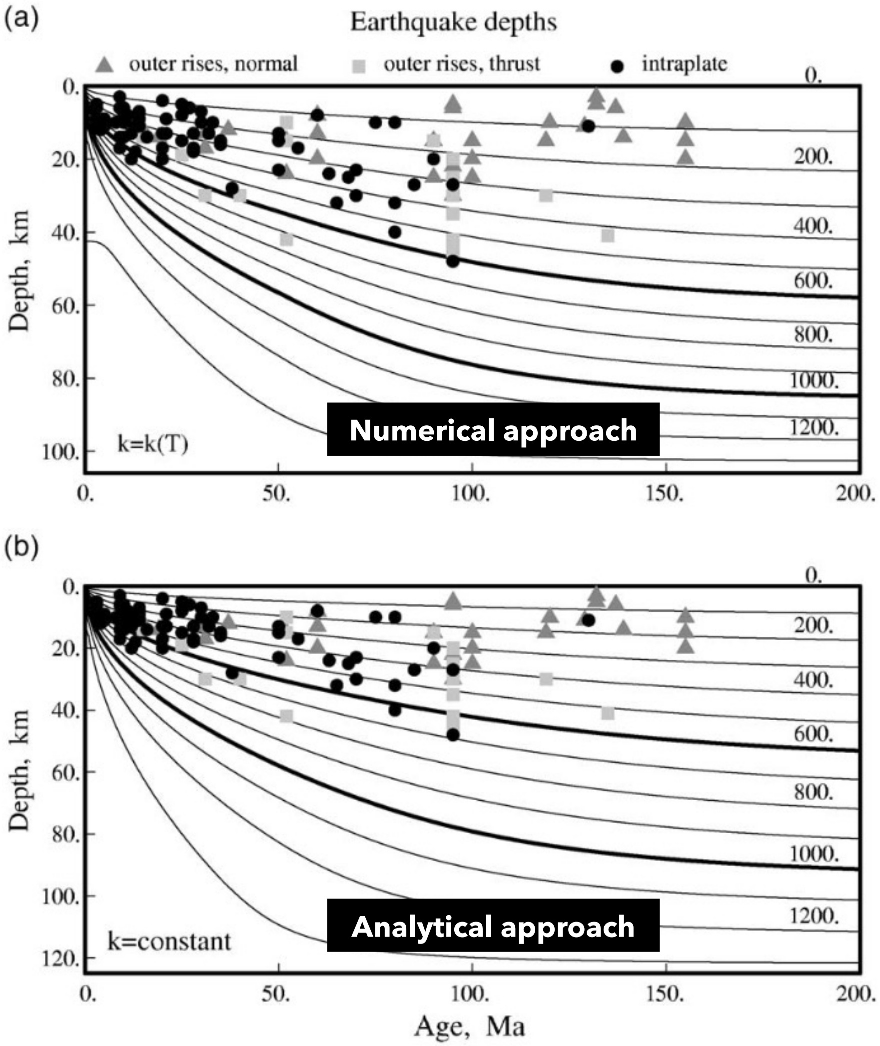


McKenzie et al. 2005

Mechanical structure



Burov, 2011



Numerical approach

Analytical approach

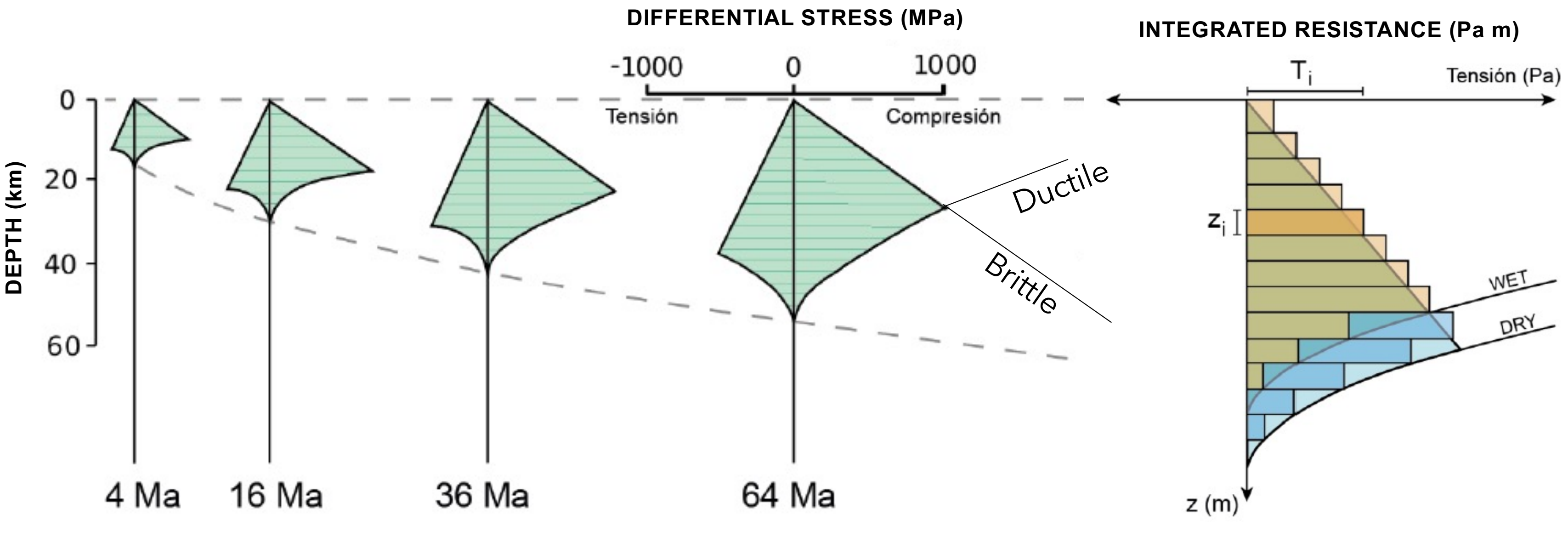
McKenzie et al. 2005

Rheology

$$\Delta\sigma = \left(\frac{\dot{\varepsilon}}{A_m}\right)^{\frac{1}{n}} \cdot e^{\left[\frac{Q}{nRT}\right]} \quad para\ \Delta\sigma > 200\ MPa\ (Ley\ de\ Power)$$

$$\Delta\sigma = \sigma_d\left(1-\sqrt{\frac{RT}{Q}}\cdot ln\left(\frac{\dot{\varepsilon}_d}{\dot{\varepsilon}}\right)\right) \quad para\ \Delta\sigma < 200\ MPa\ (Ley\ de\ Dorn)$$

Burov, 2011



Based on Goetze & Evans 1979

Intraplate volcanism

- Thermal rejuvenation
- Crustal thickening
- Decreased elastic thickness
- Topography anomaly

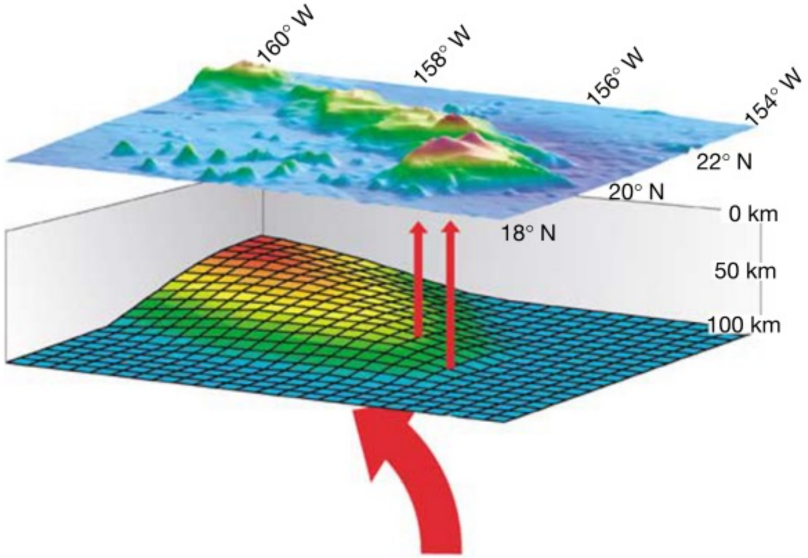
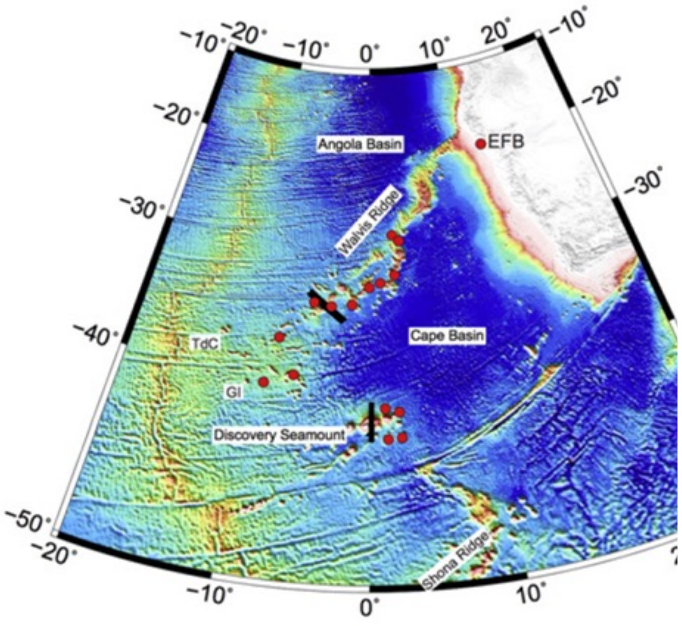
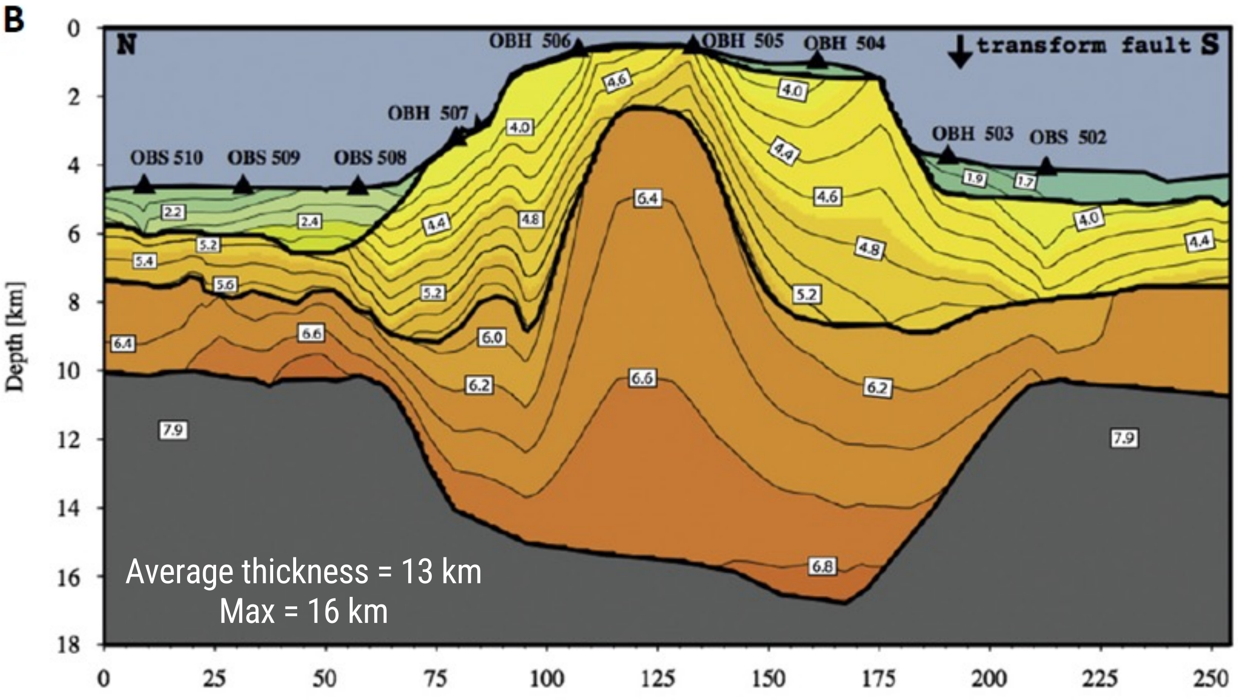


Figure 3 Sketch of the obtained lithosphere–asthenosphere boundary below the Hawaiian island chain.

Intraplate volcanism

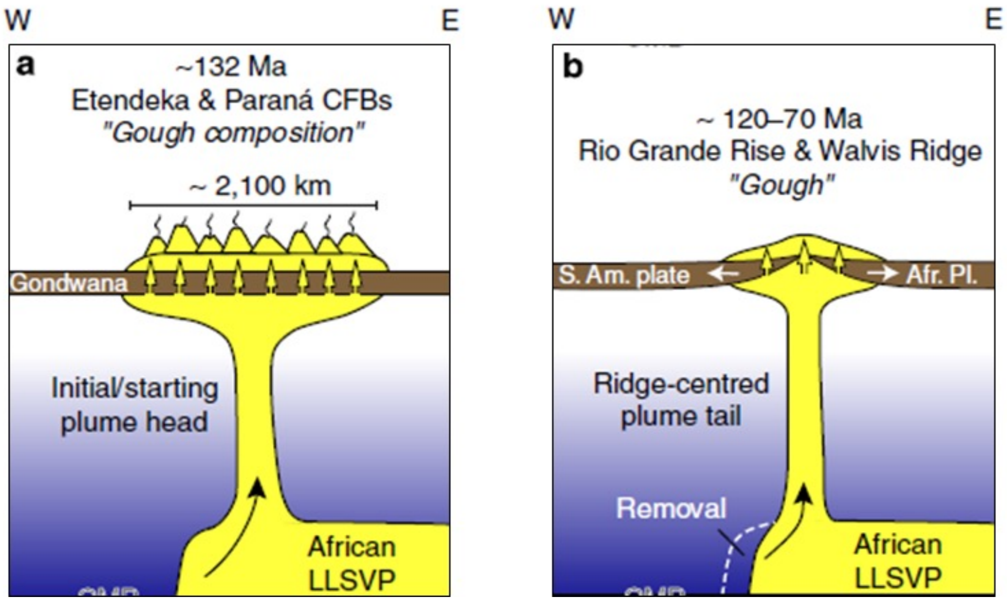


Jokat & Reents 2017

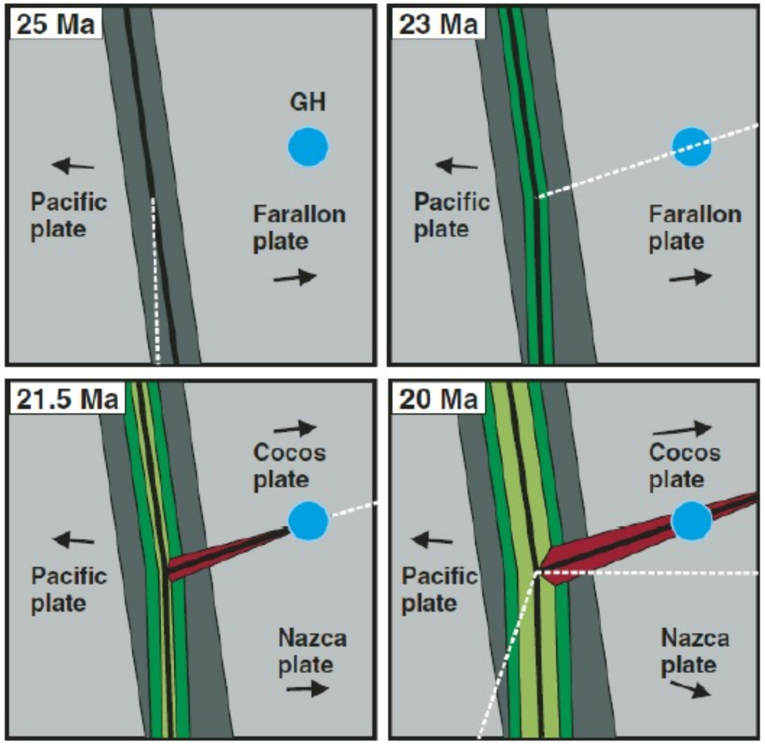


Average thickness = 13 km
Max = 16 km

Relevance

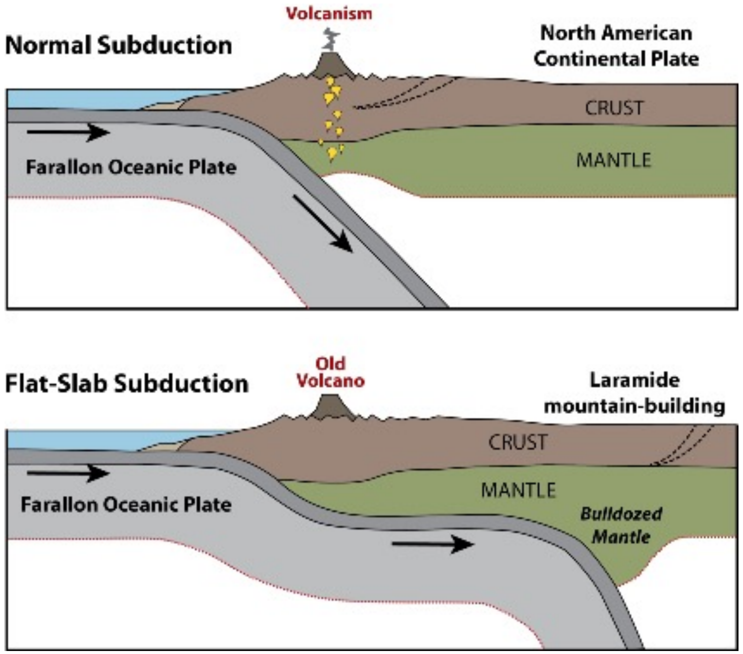


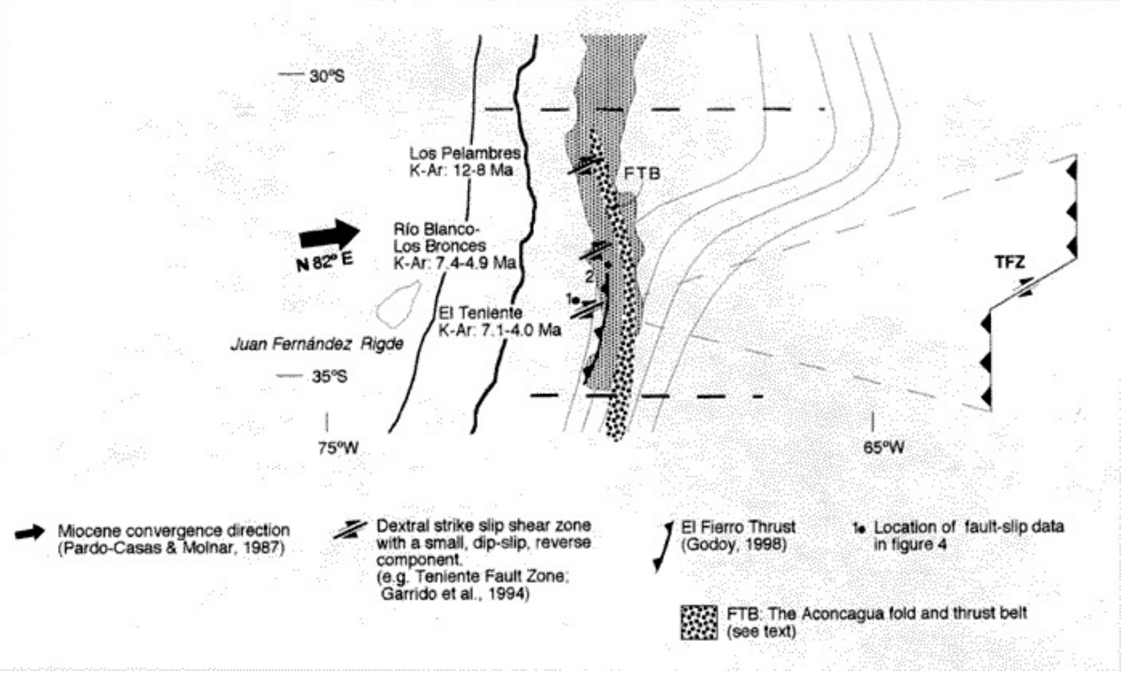
Hoernle et al., 2015



Barckhausen et al., 2008

Relevance

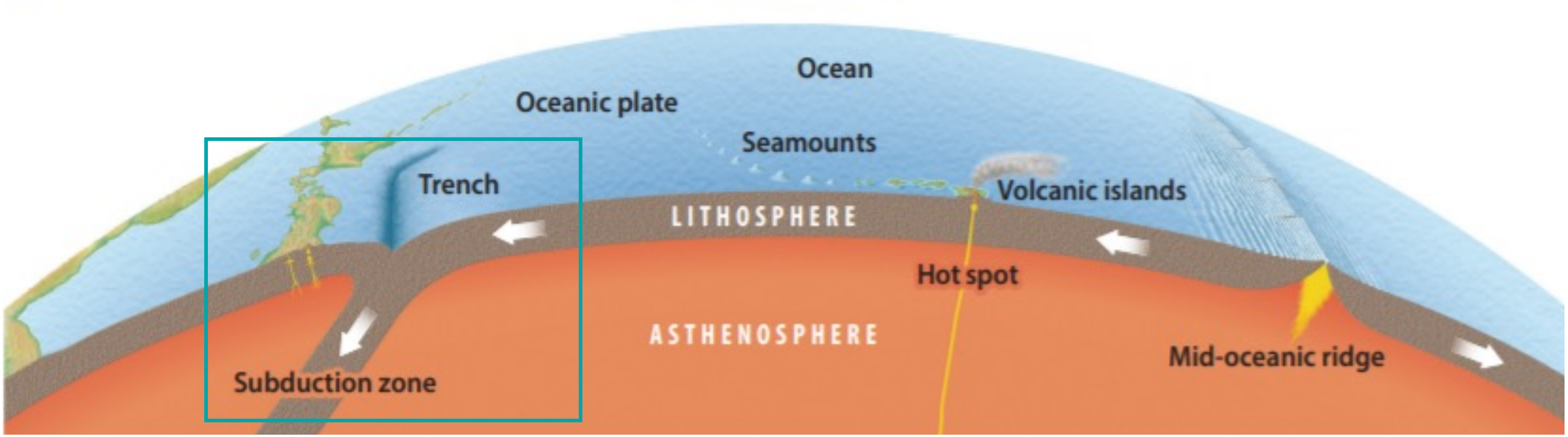




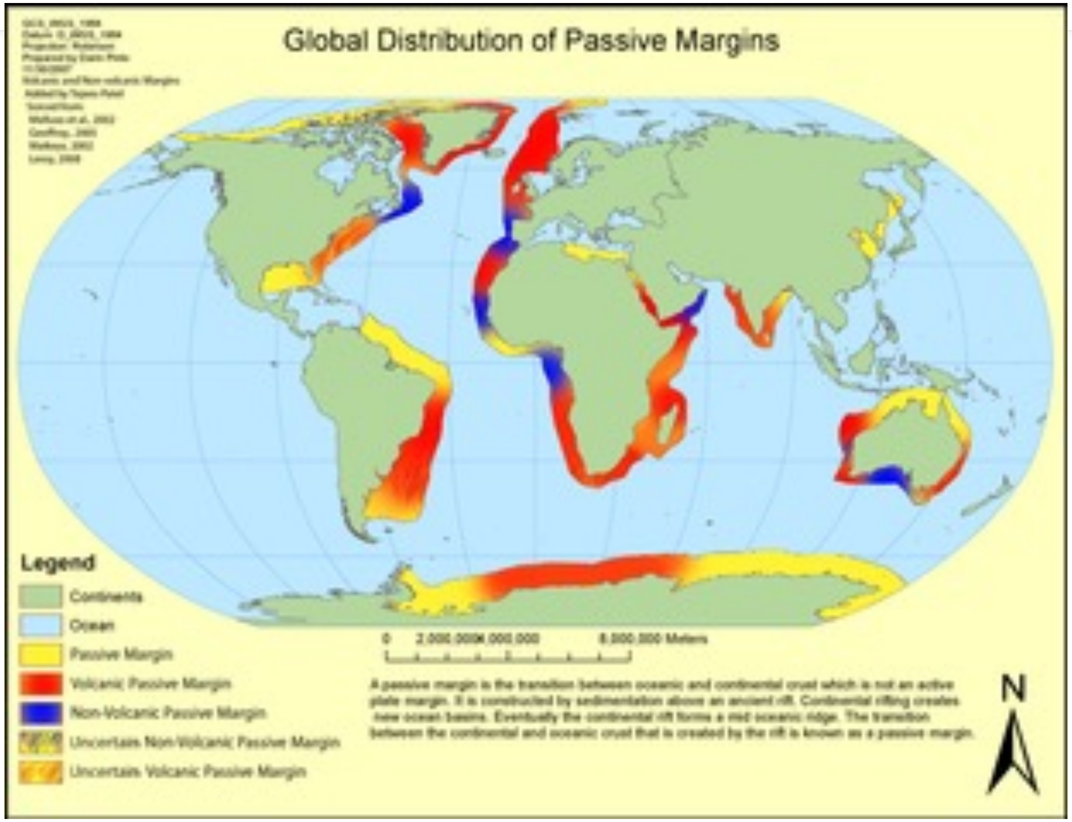
Wessel & Kroenke 2008

THE OCEANIC LITHOSPHERE

SUBDUCTION

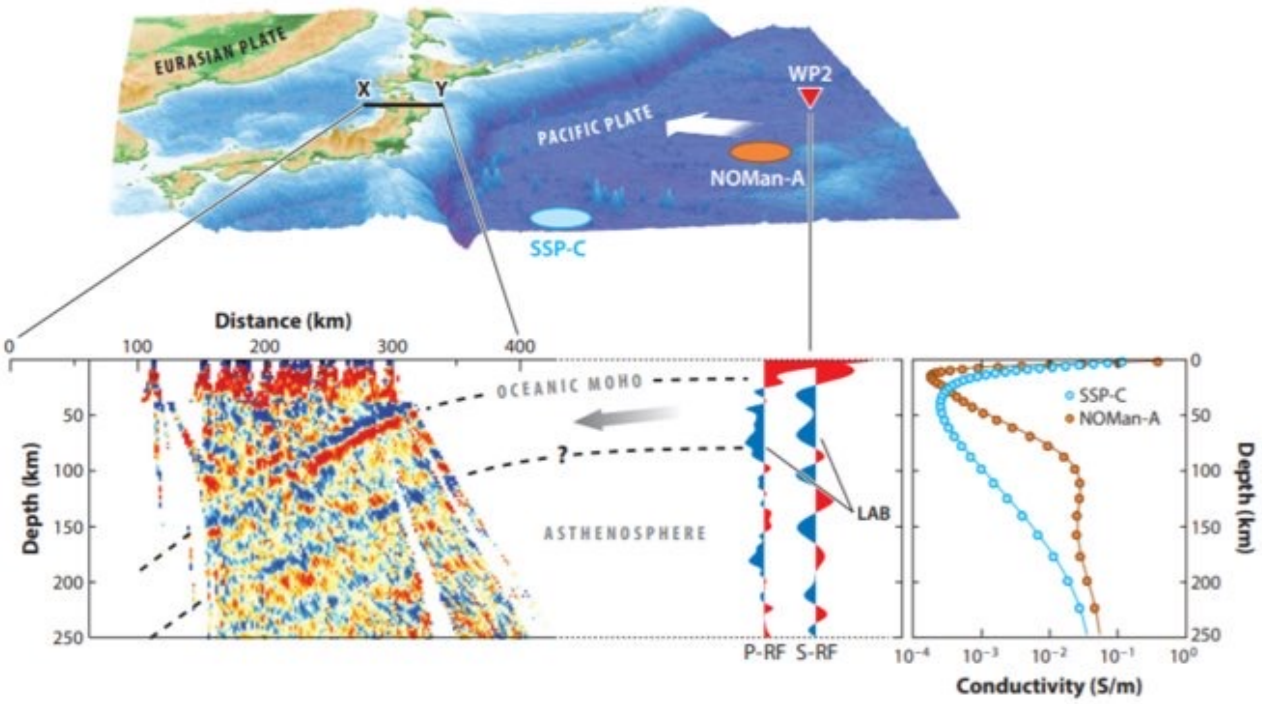


Passive margins



A passive margin is the transition between oceanic and continental crust which is not an active plate margin. It is constructed by sedimentation above an ancient rift. Continental rifting creates new ocean basins. Eventually the continental rift forms a mid oceanic ridge. The transition between the continental and oceanic crust that is created by the rift is known as a passive margin.

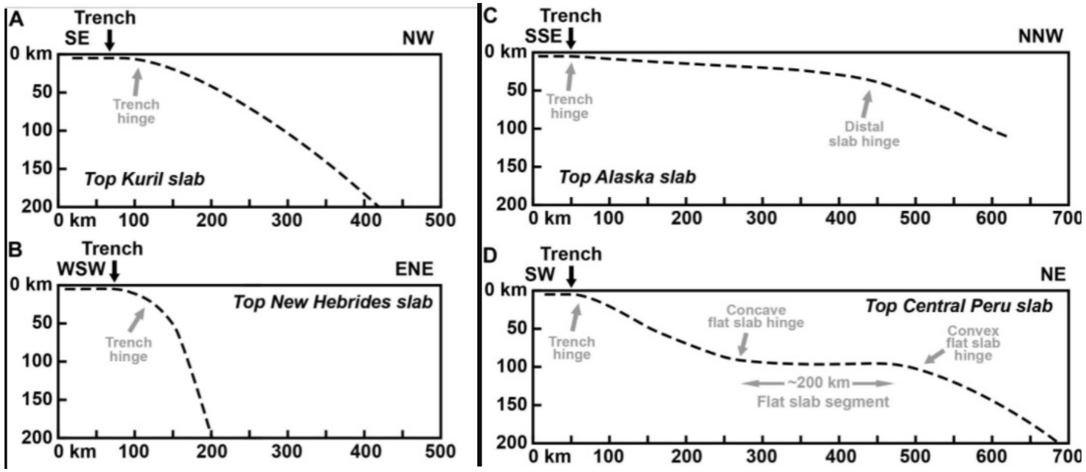
Greater network coverage



Subducting systems allow us to map and study the oceanic lithosphere with a greater array of geophysical networks

Kawakatsu, and Utada, 2017

Variation in Slab Dip angle

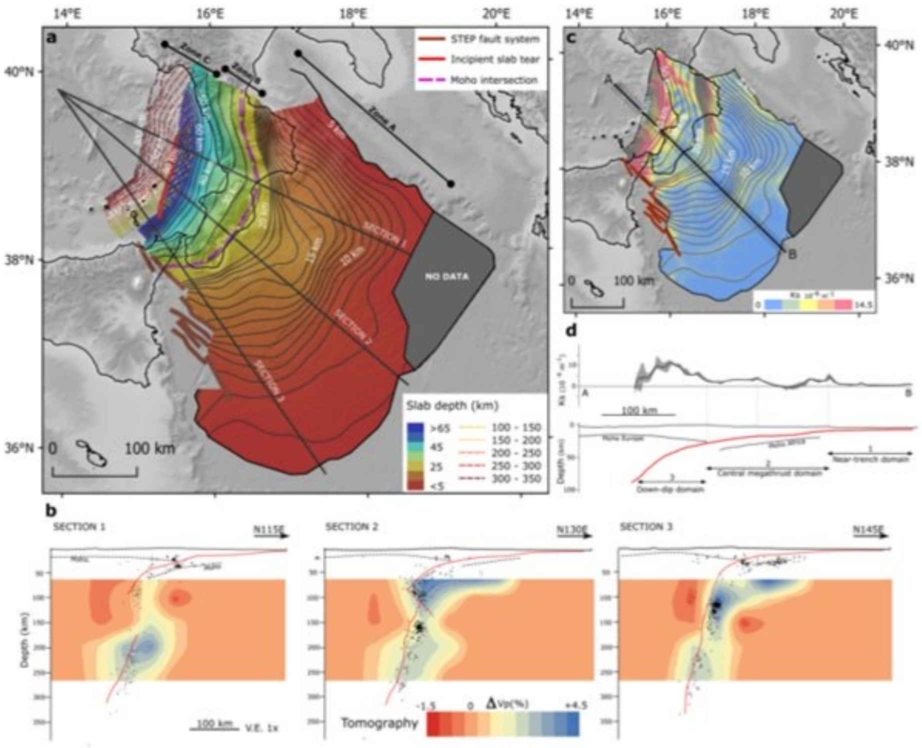


Variation in slab dip angle is something that is seen around the world, through tomography, anisotropy, and seismicity

Some potential reasons:
- Wedge Suction
- Based on the width of the SZ
- Plumes (unlikely)
- Forced Slab Rollback
- Age of plate and composition

Schellart, 2020

Slab tear

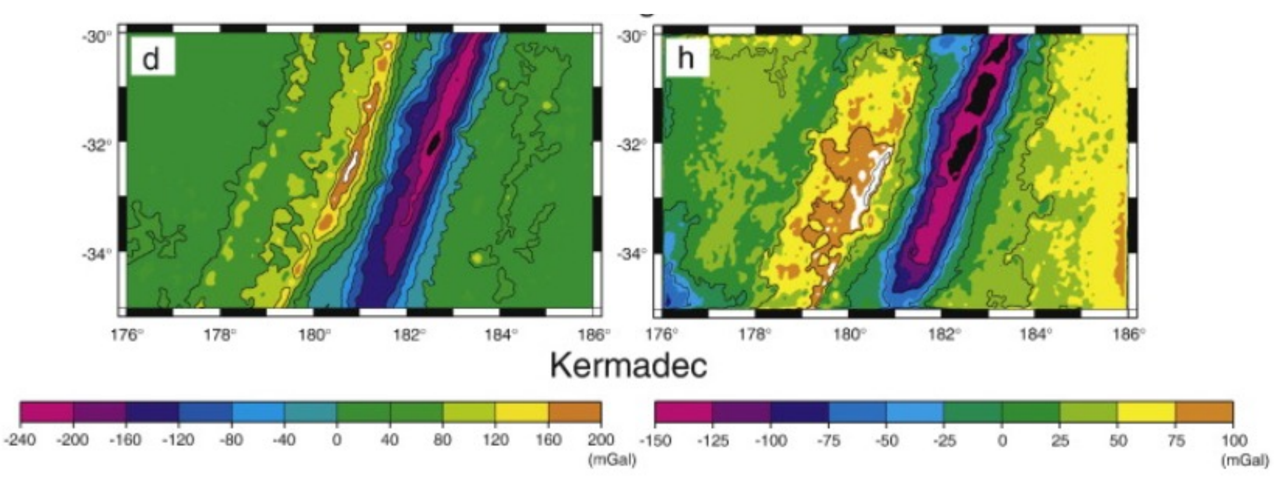


Slab Tear or Subduction-Transform Edge Propagator (STEP) faults are thought to be caused by a combination of localised collisional events and variations in slab velocities

Also the potential cause of transform faults at collisional boundaries

Maesano, 2017

Gravity anomalies



Large negative anomaly zones either within or above the subducting system may be influenced by:
- Parital melt of the downgoing slab
- Difference in the age and thermal strucutre in the slabs
- Serpentinization of the mantle material
- anomalous crustal structure beneath the arc and forearc

Kim et al., 2009

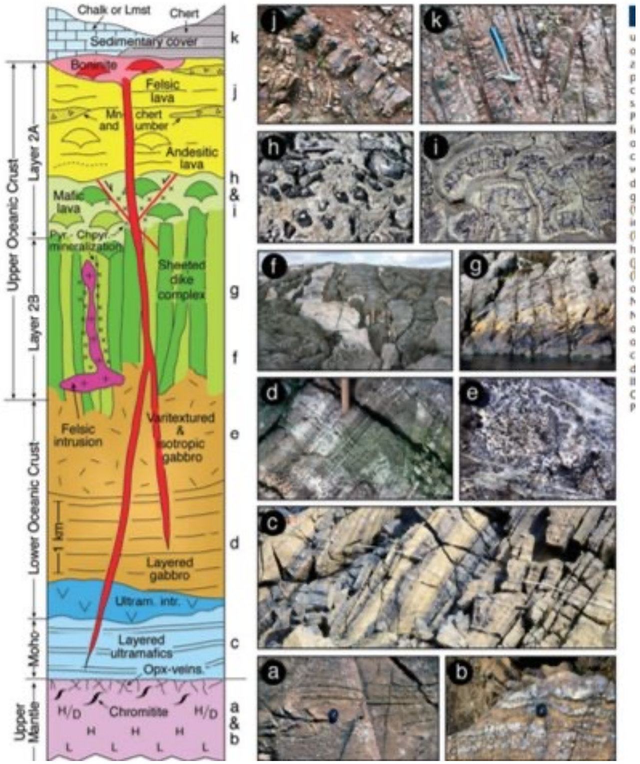
Subduction rocks and minerals

Blueschist

Eclogite

Serpentinite

Ophiolites

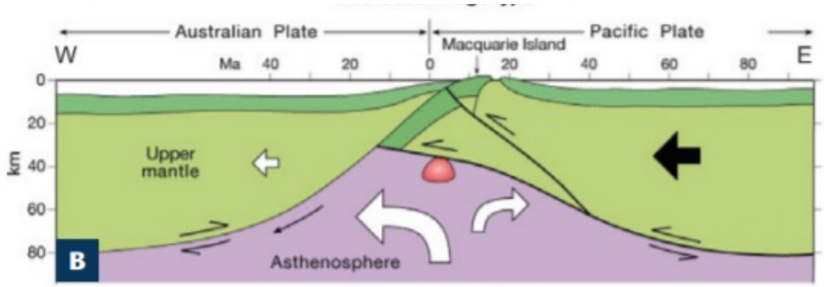


Oceanic crust and upper mantle that have been emplaced on the surface

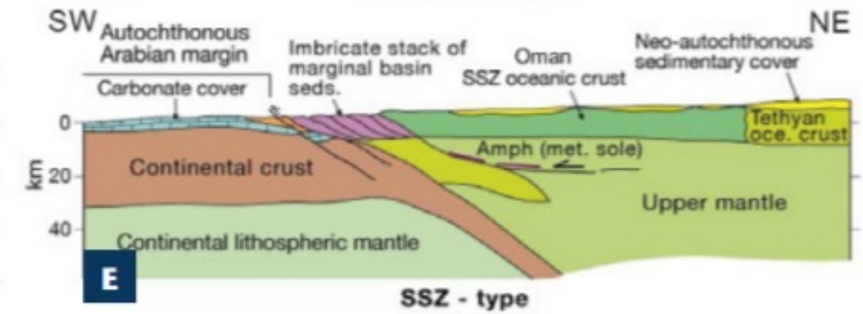
Used as our best approximation of the compositional and structural make-up of the oceanic lithosphere

Dilek and Furnes, 2014

Ophiolite emplacement

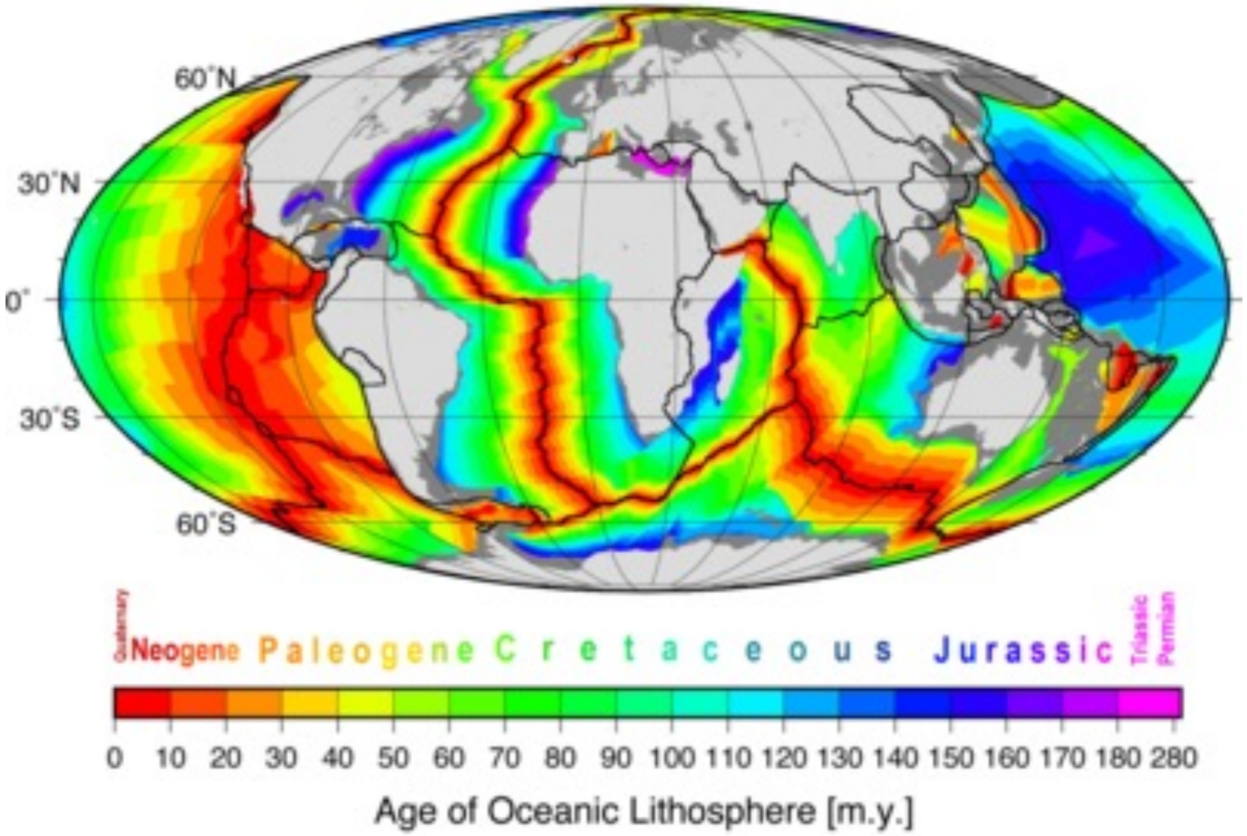


Mid-ocean ridge type



SSZ - type

Dilek and Furnes, 2014



Muller, R.D., et al., 2008

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