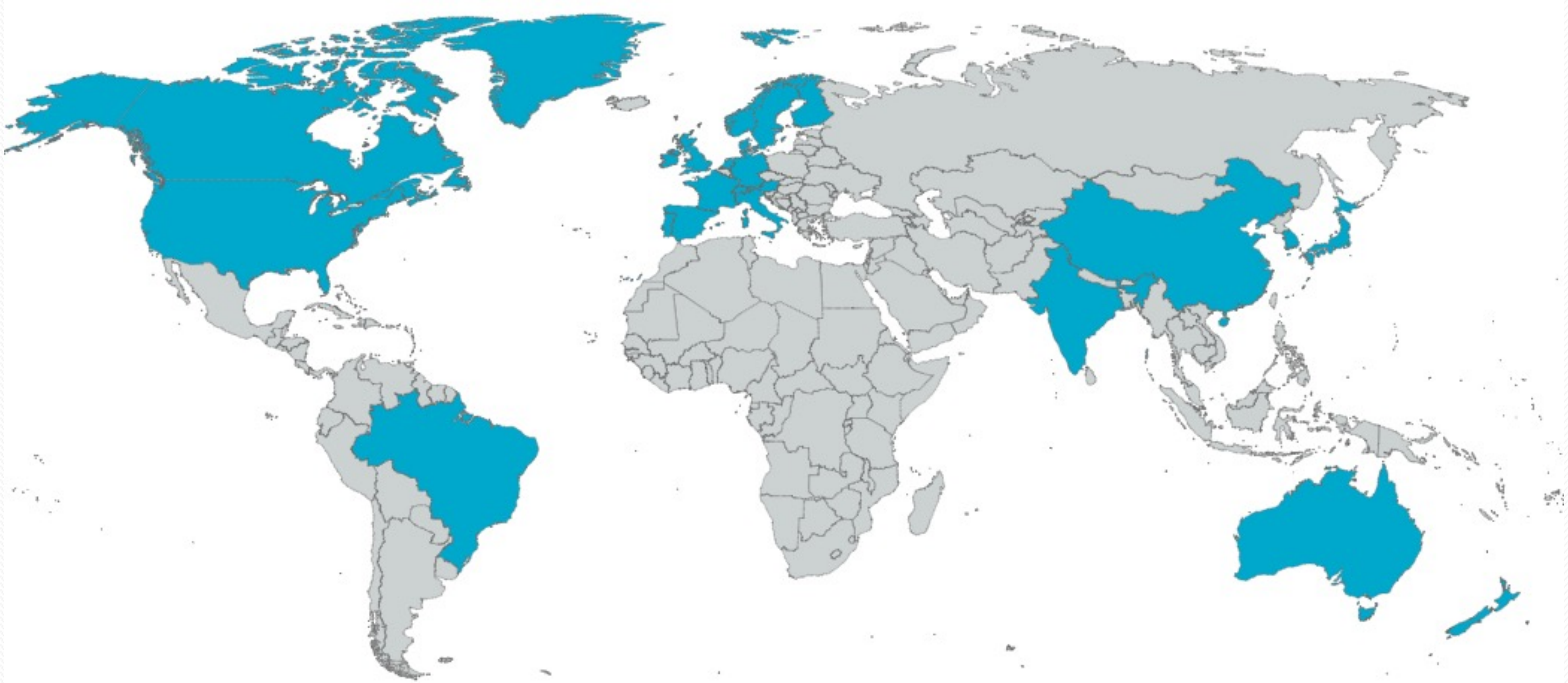
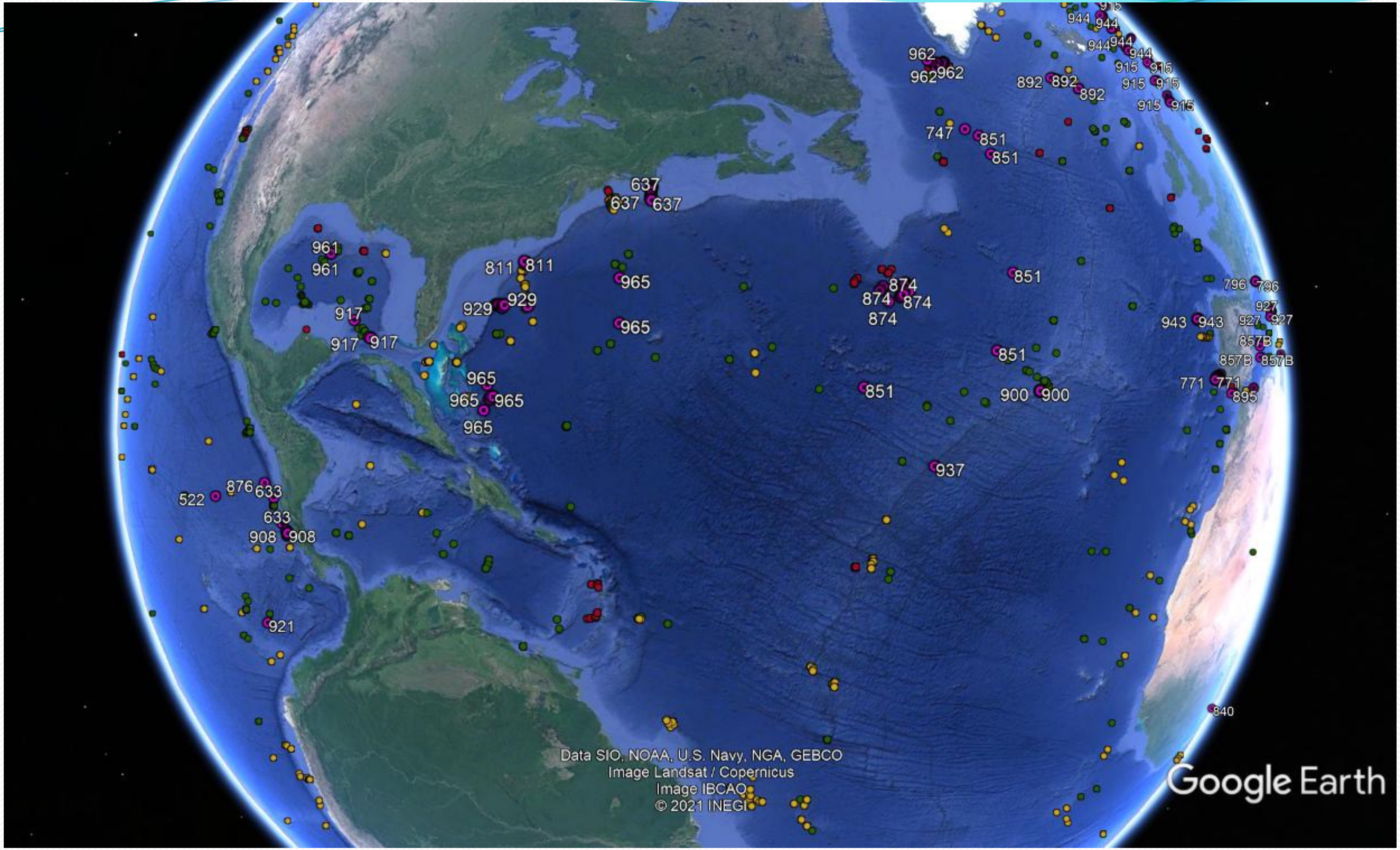
Deep Ocean drilling in lower crust and mantle: why should we go further?

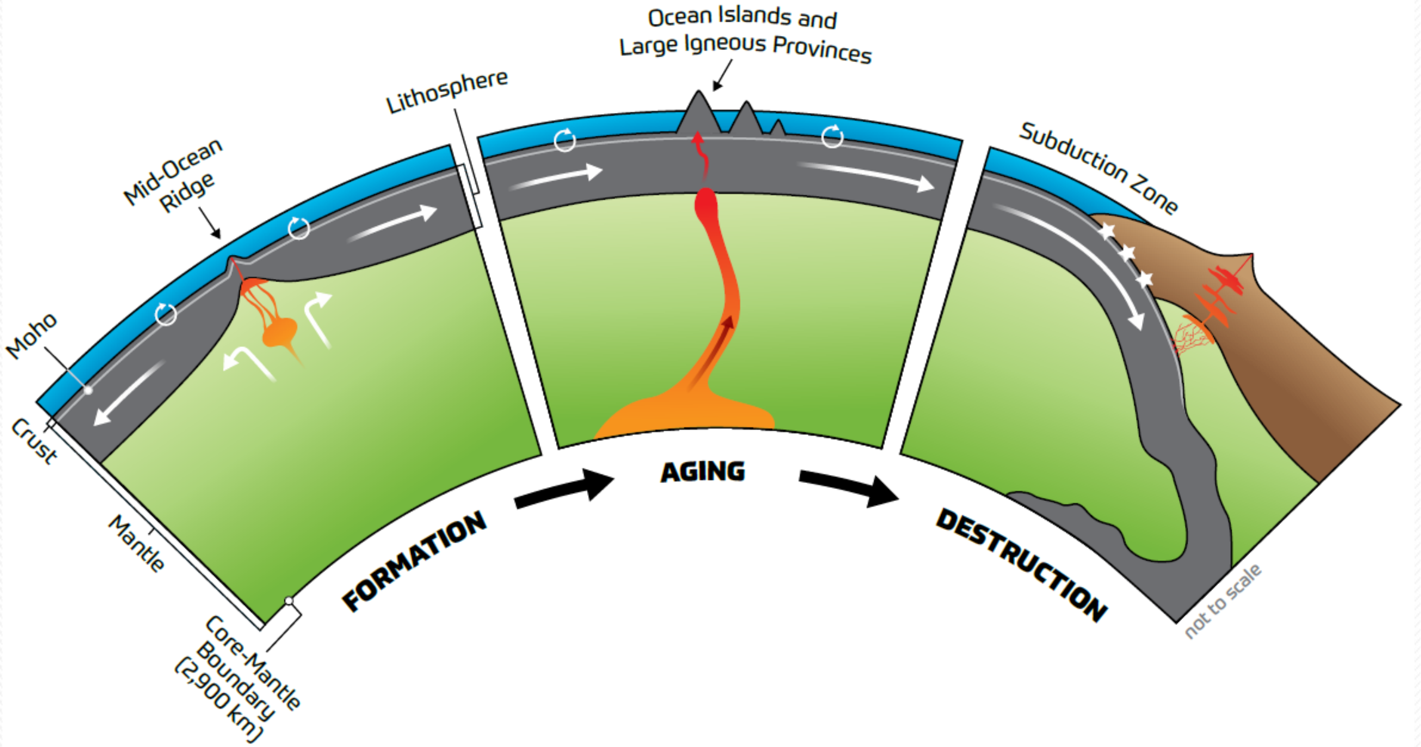
Alessio Sanfilippo
Dipartimento di Scienze della Terra e dell'Ambiente; Università di Pavia





https://www.iodp.org/resources/maps-and-kml-tools

Obj2-The Oceanic Life Cycle of Tectonic Plates



https://www.iodp.org/2050-science-framework

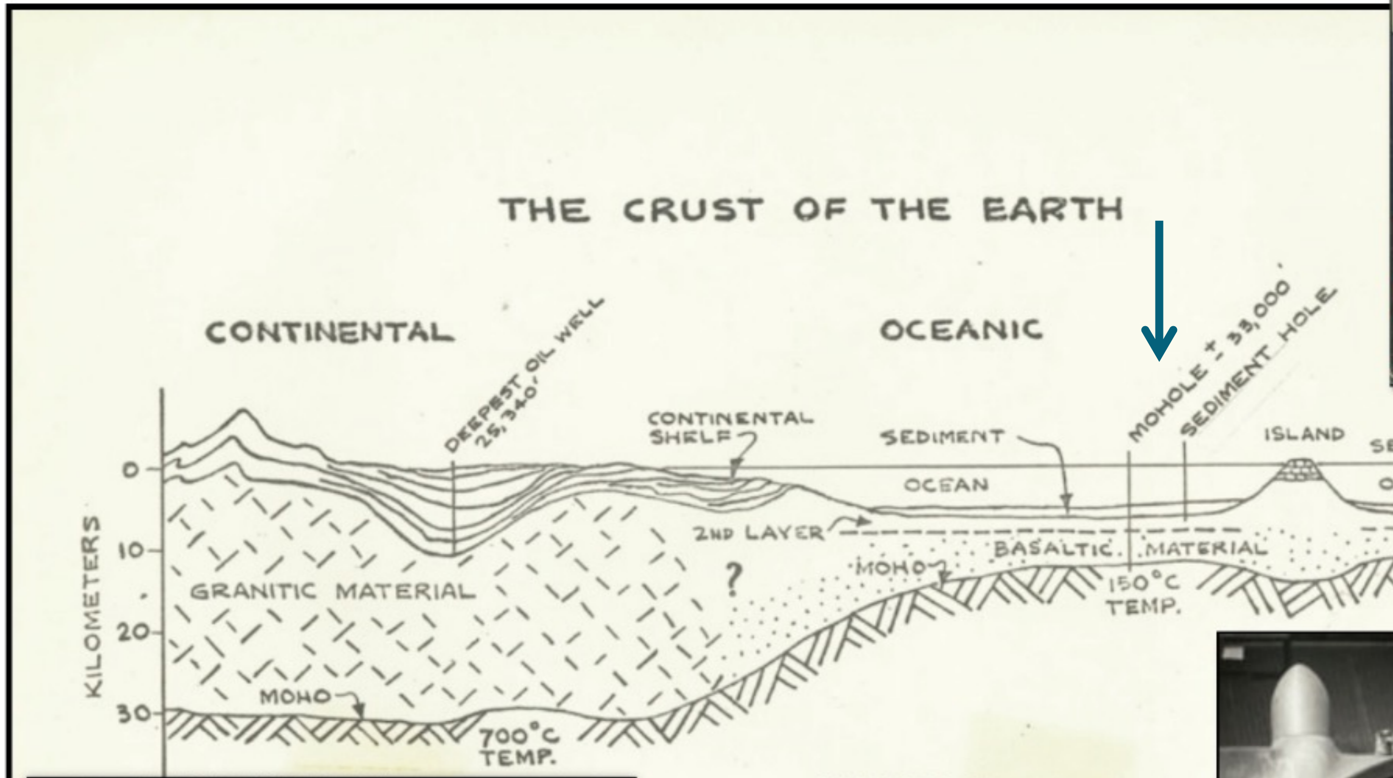
- Heat flux and global chemical cycles

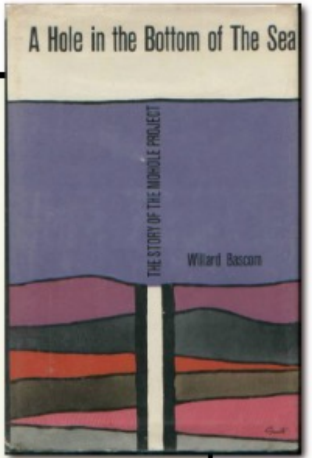
- Formation and destrcution of oceanic crust

Plate tecnonics

The dream: project **Mohole**

1957



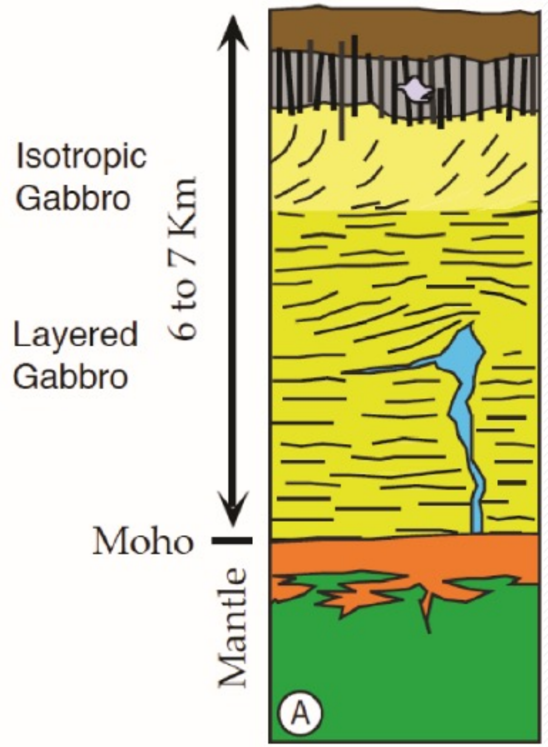


American Miscellaneous Society

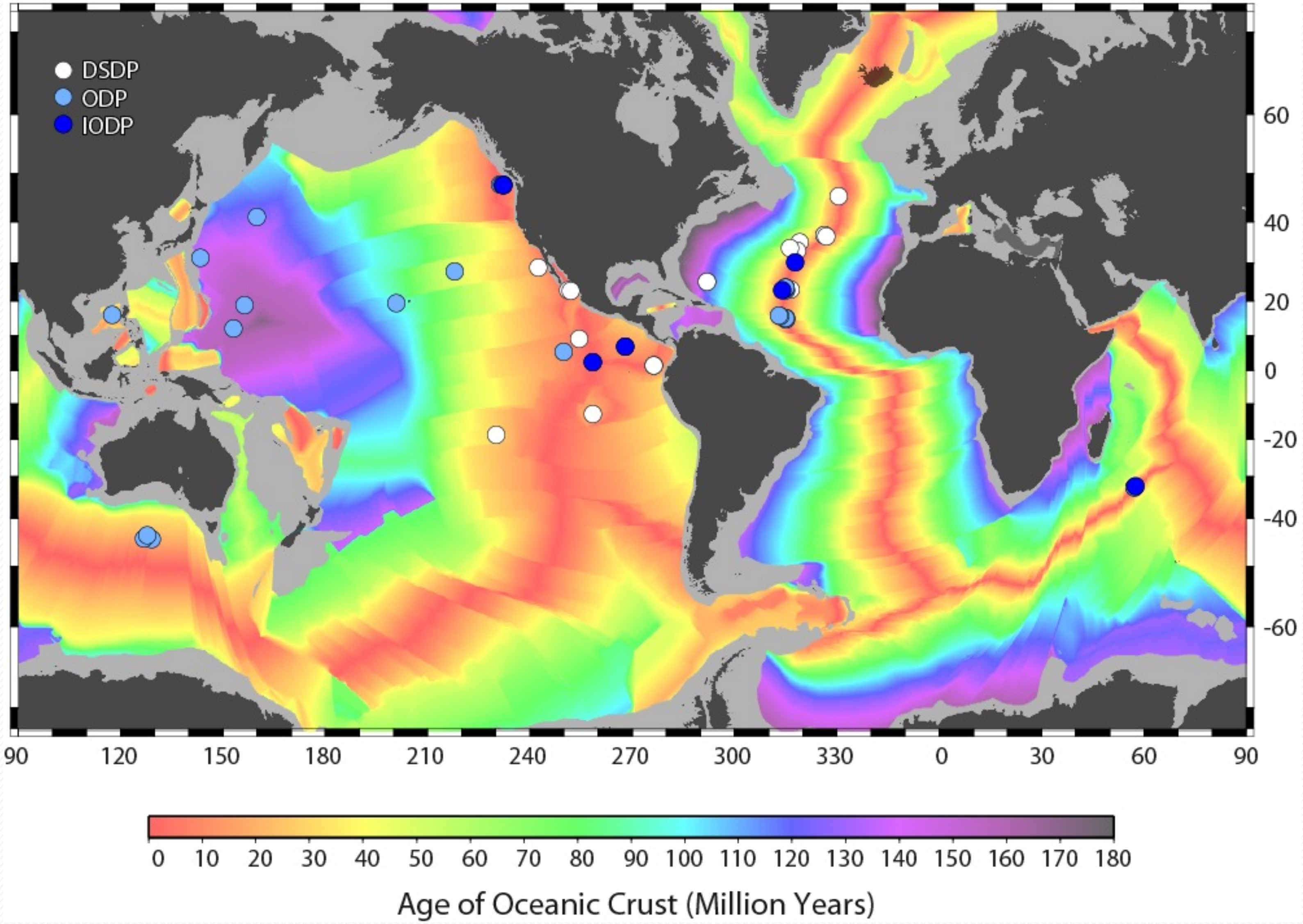
Deep drilling in the oceanic basement

DSDP *ODP* *IODP* *IODP* ***oggi***

1957 1968 1985 2004 2013



'Layered' oceanic basement



Deep drilling in the oceanic basement

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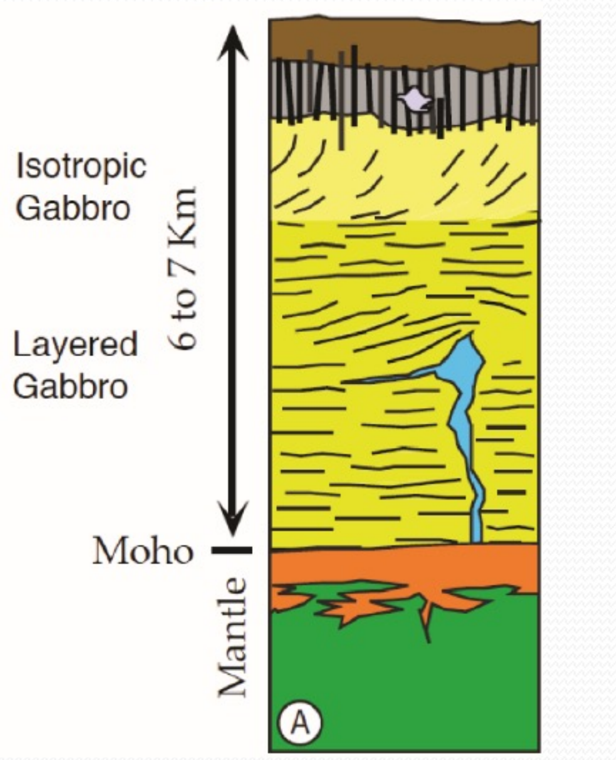
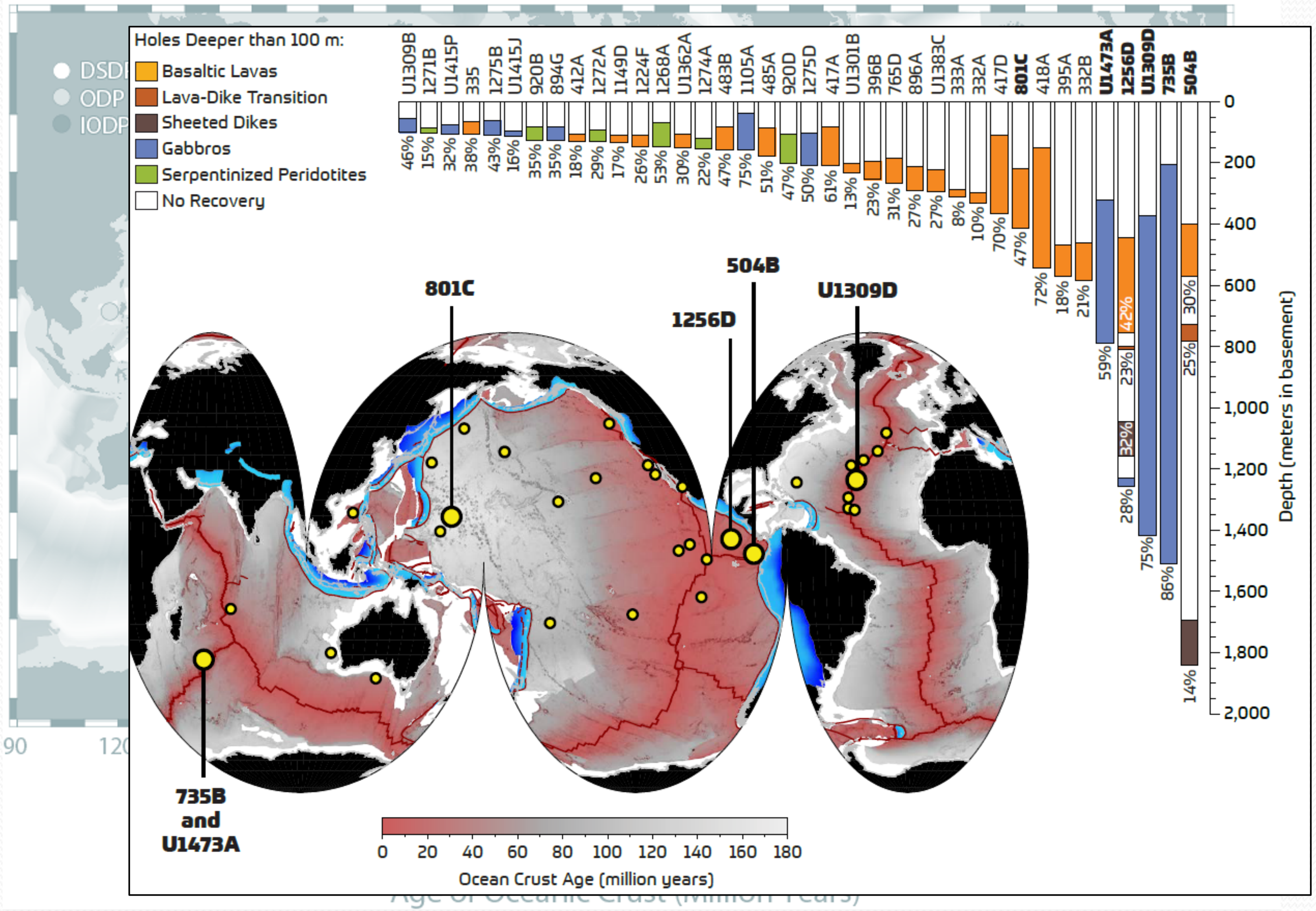


‘Layered’ oceanic basement

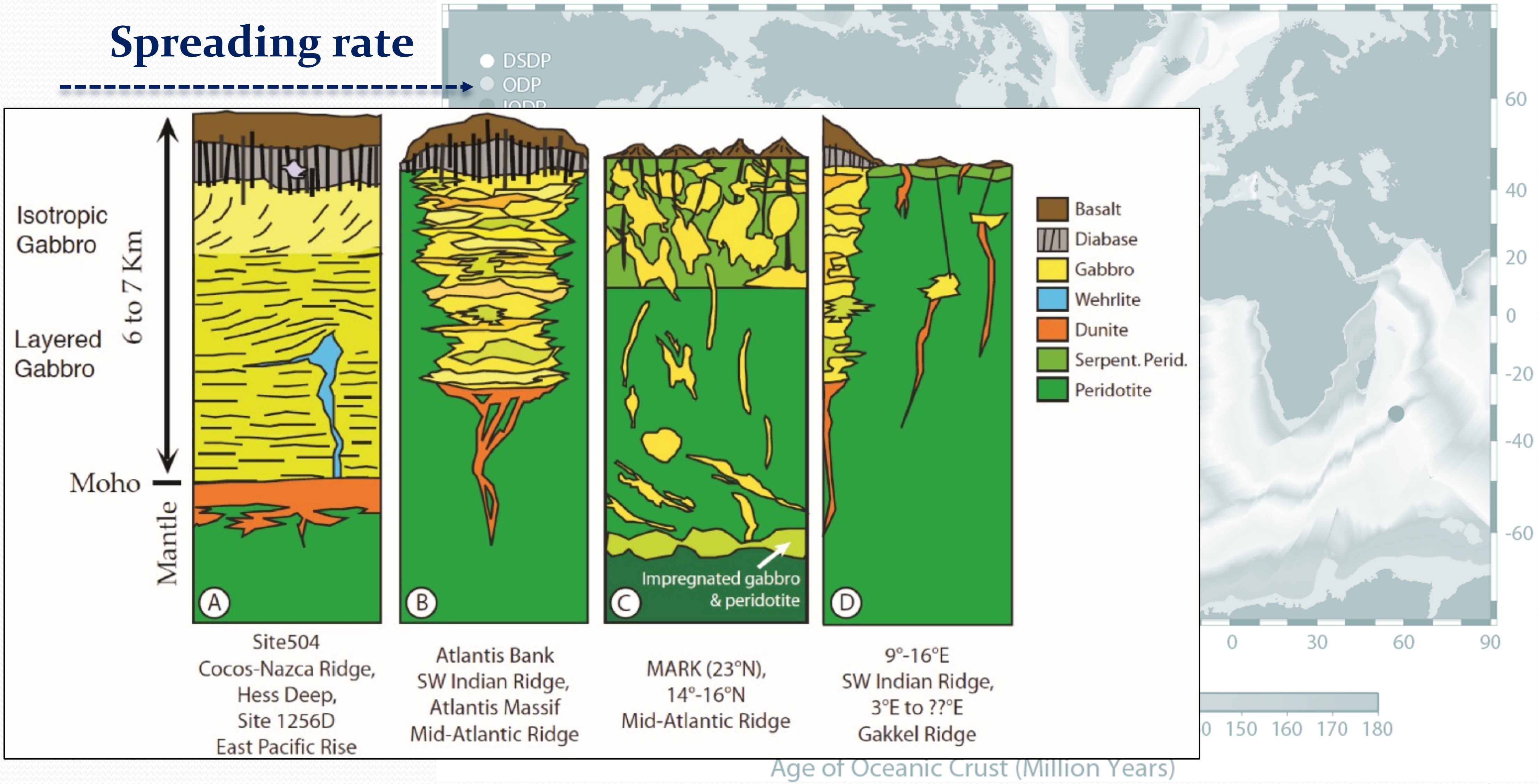


Deep drilling in the oceanic basement

DSDP *ODP* *IODP* *IODP* ***oggi***

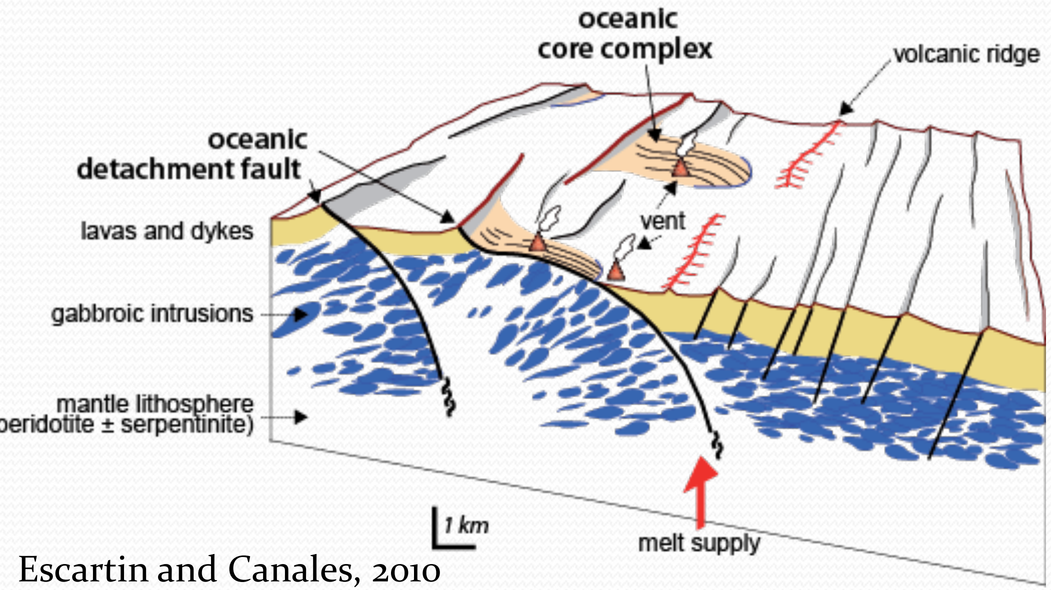
1957 1968 1985 2004 2013

Spreading rate

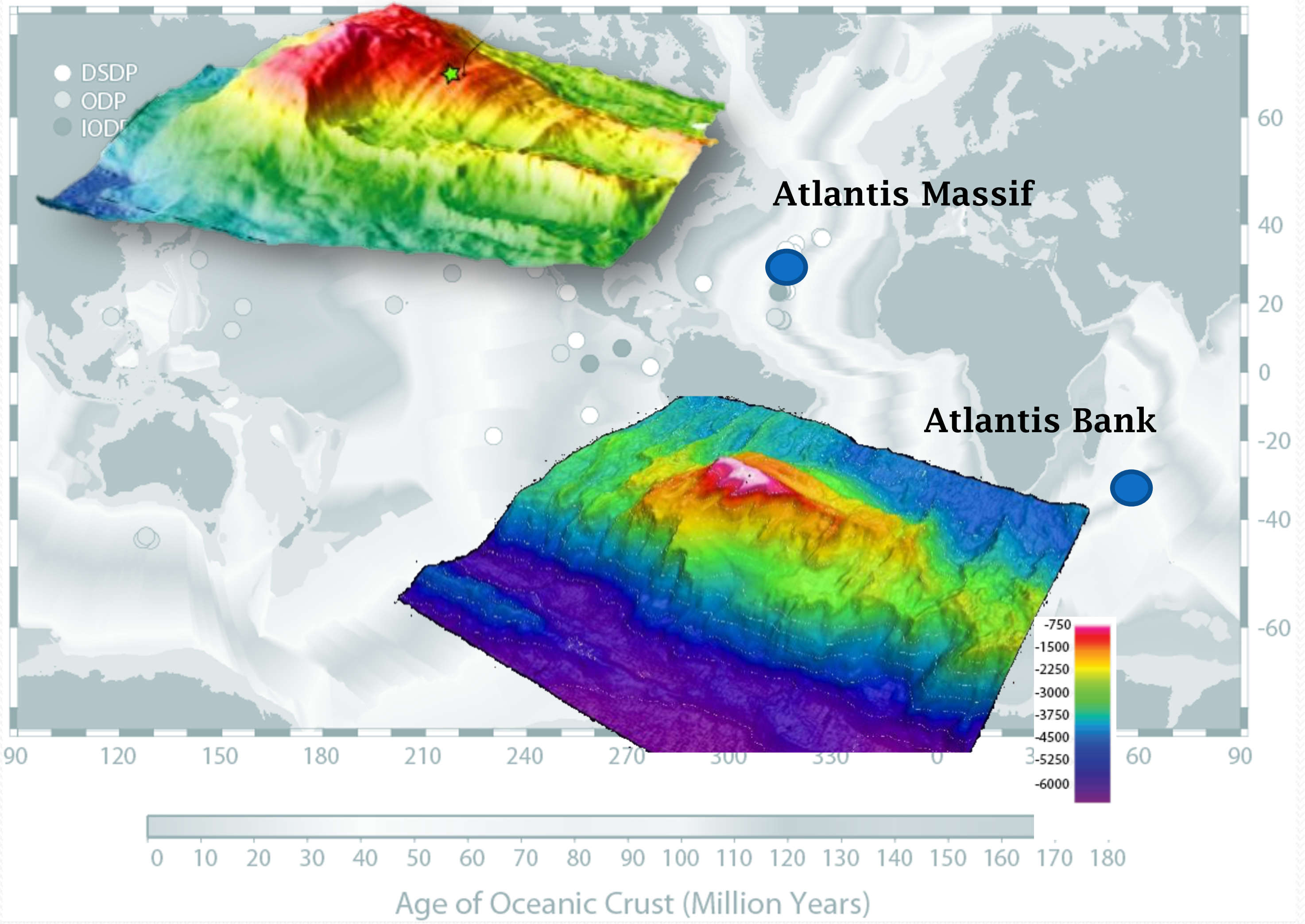


Deep drilling in lower crust

Oceanic Core Complex

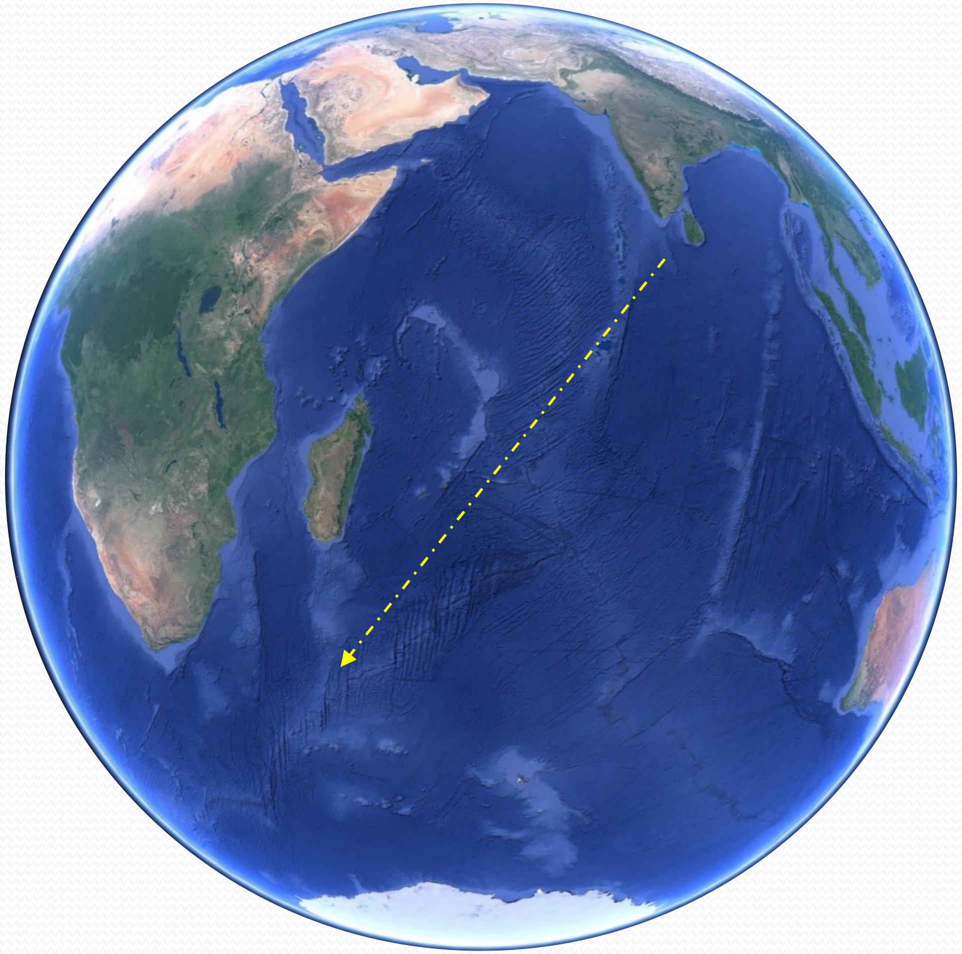


Escartin and Canales, 2010
AGU Chapman conference, Cyprus

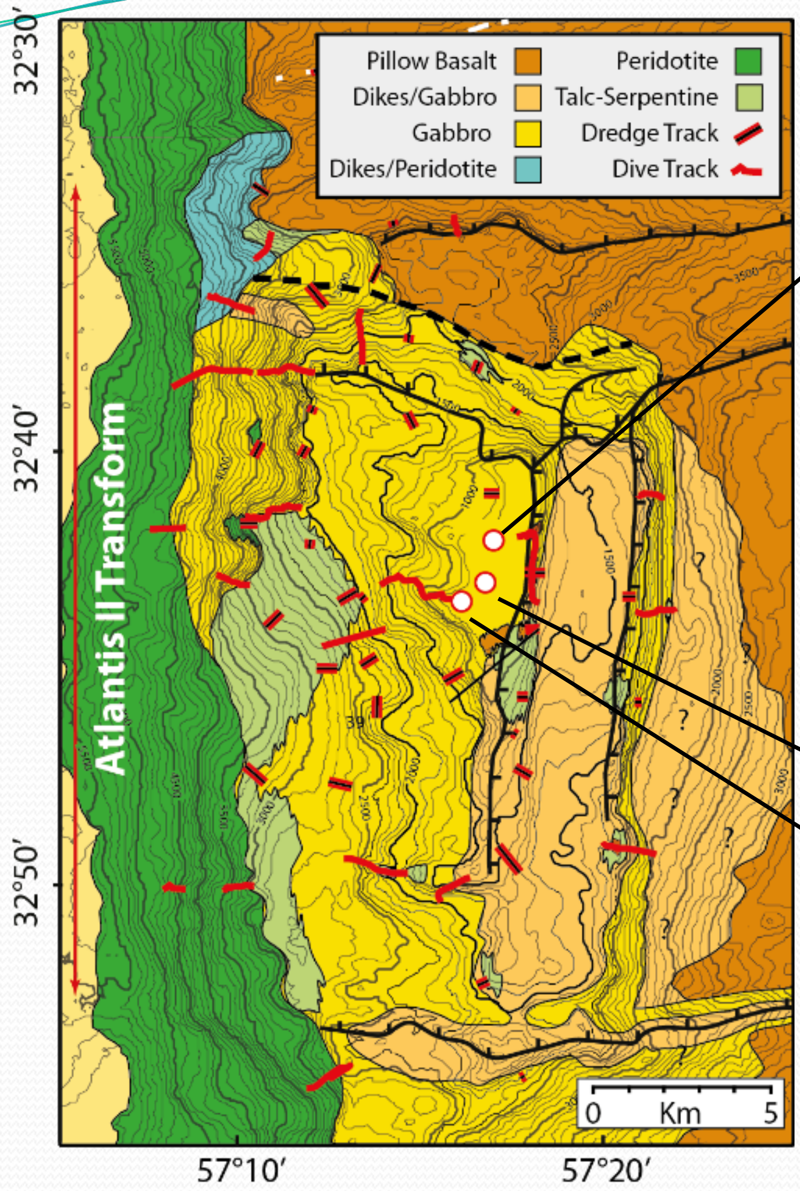


Tectonic windows where lower crustal and mantle rocks can be exposed by detachment faulting

A journey towards the Moho:
IODP Expedition 360



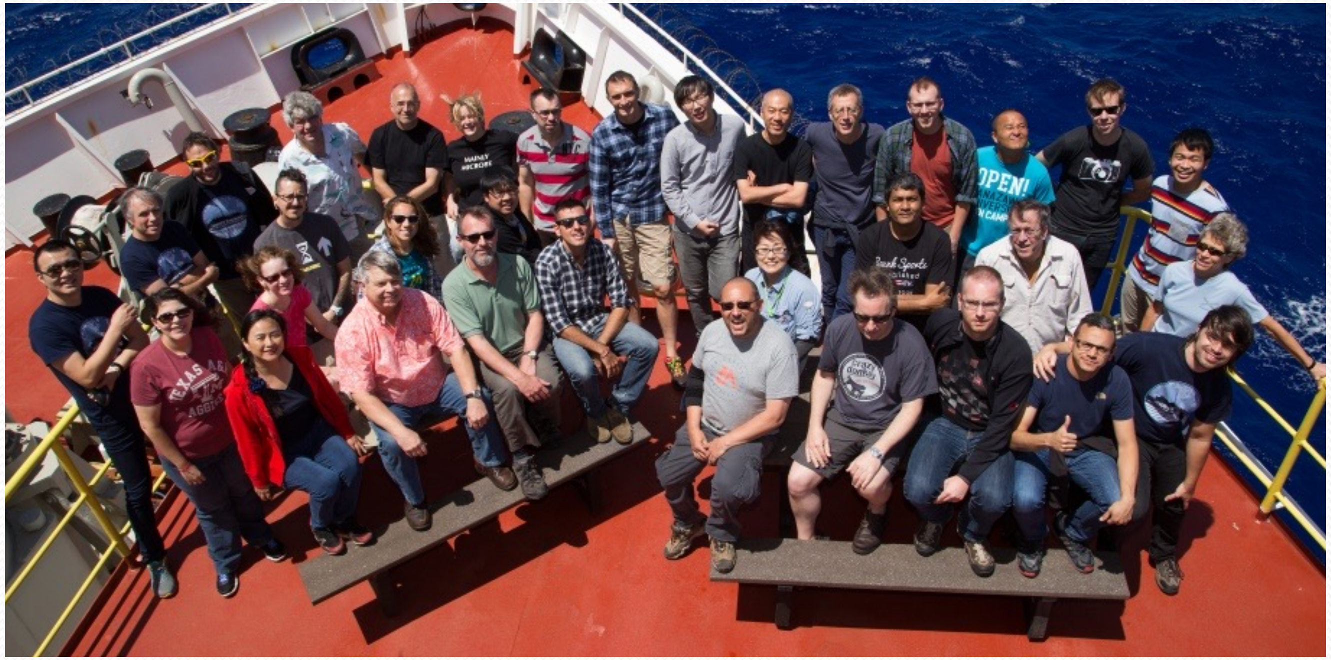
IODP Expedition 360



Dick et al. (2019) JGR

IODP Hole U1473A | IODP Expedition 360

MacLeod et al. (2017)



ODP Hole 1105A

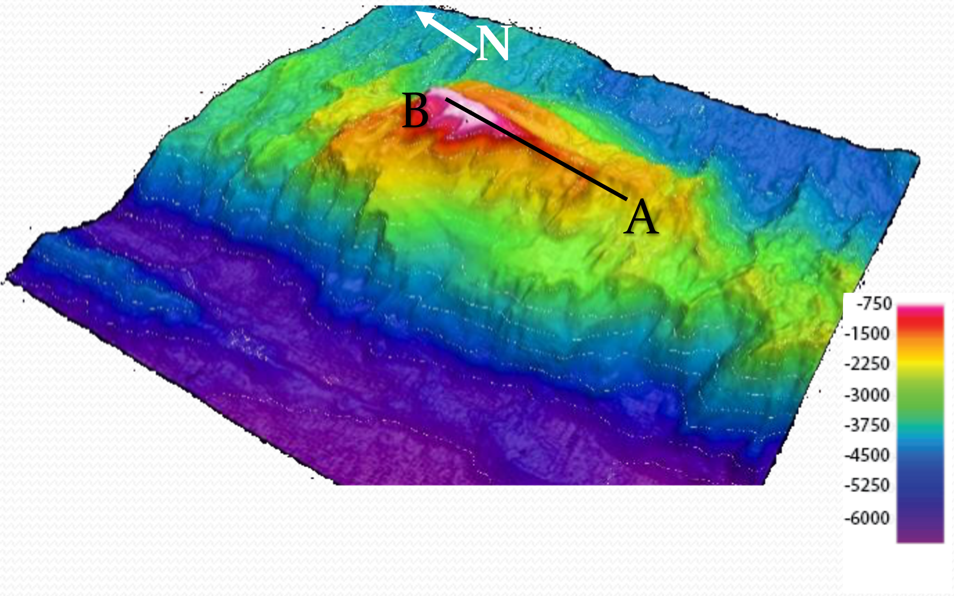
ODP Hole 735B

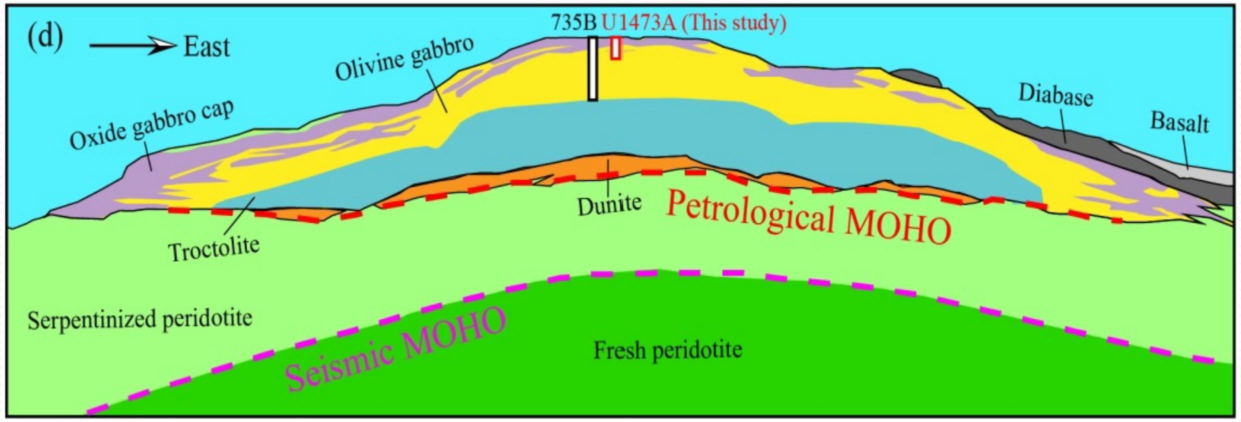
(Robinson et al., 1989; Dick et al., 2000)

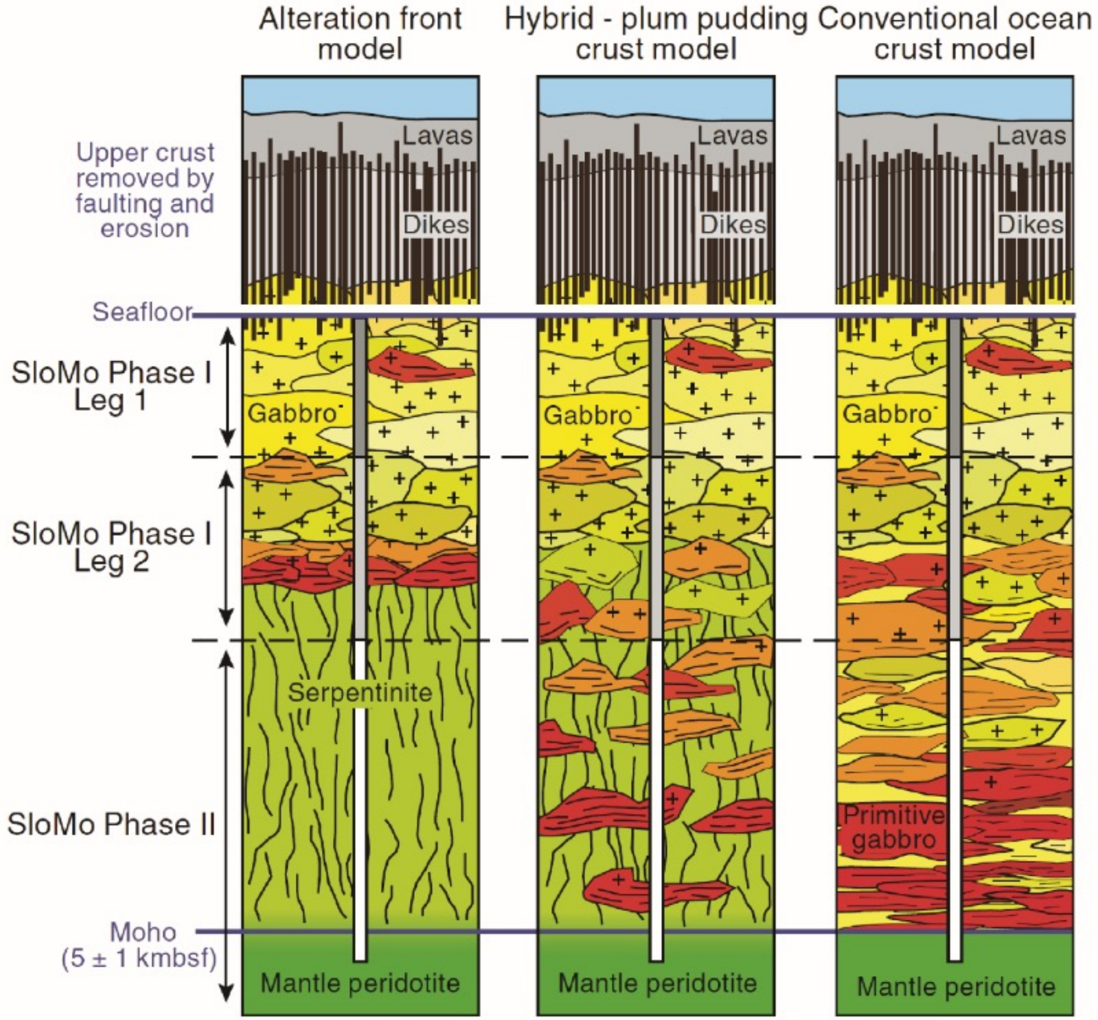
ODP Leg 118 and Leg 176

IODP Expedition 360

Atlantis Bank Oceanic Core Complex



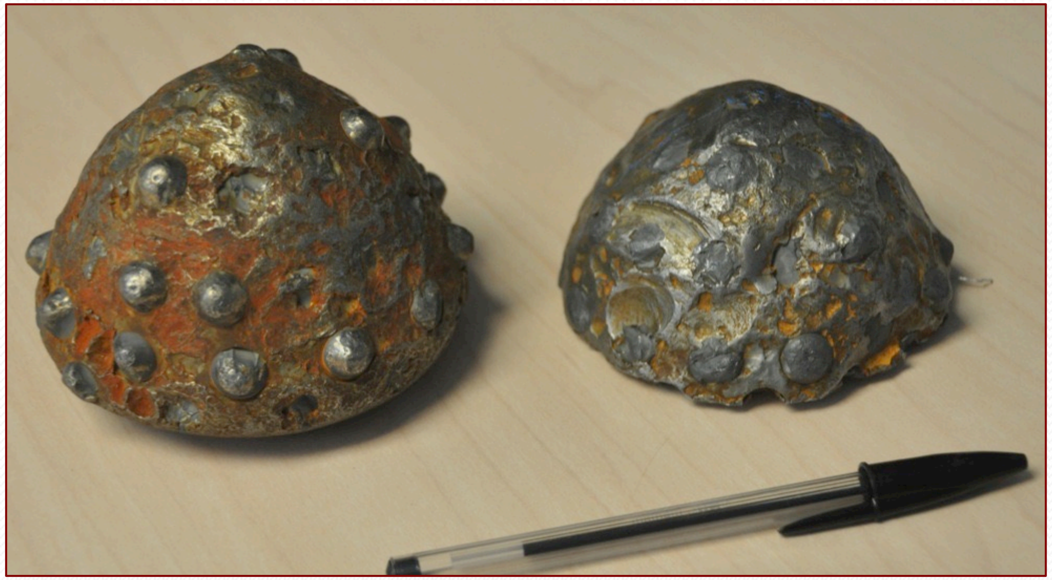




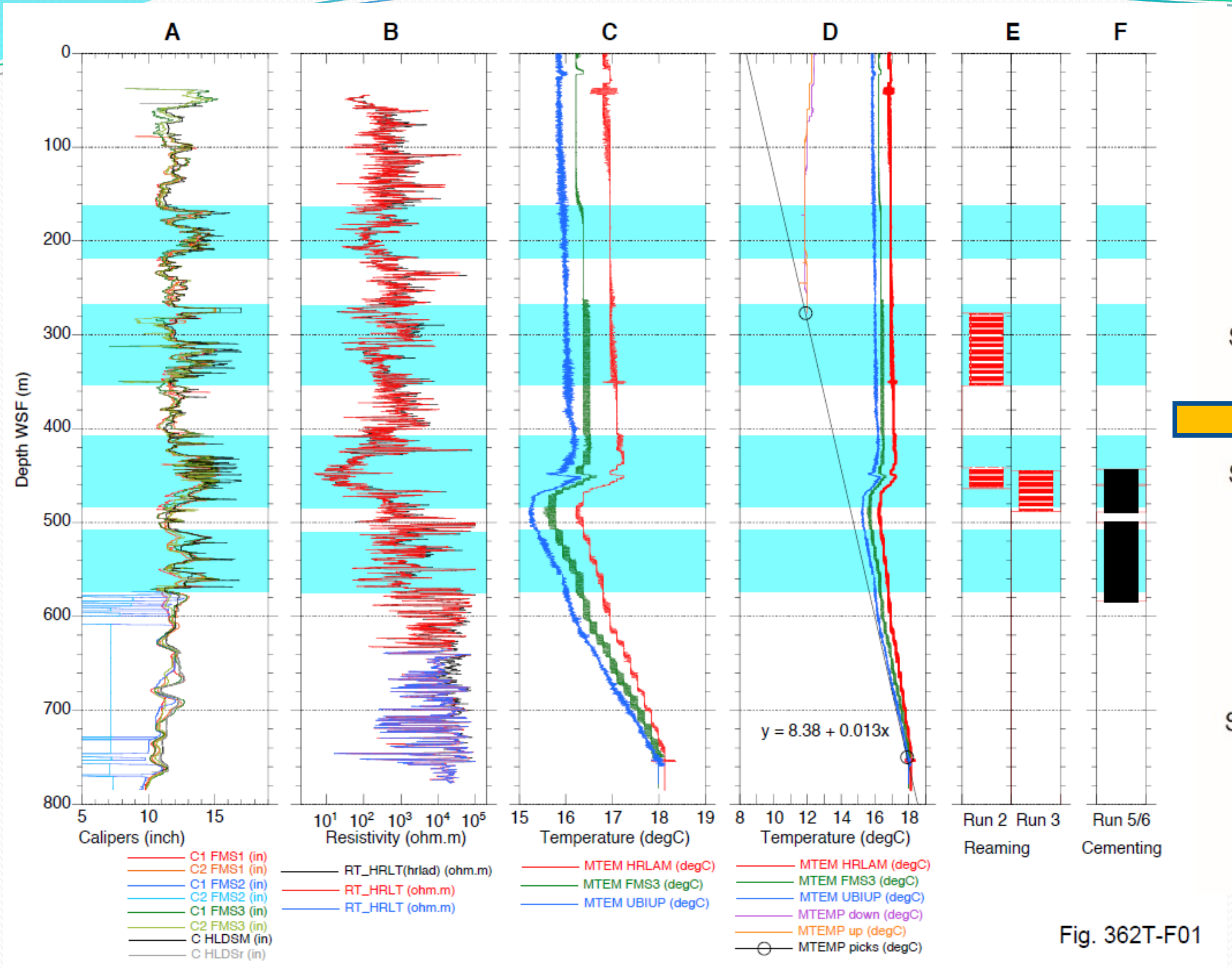
MacLeod et al.; Proc. IODP Exp 360. Vol 360

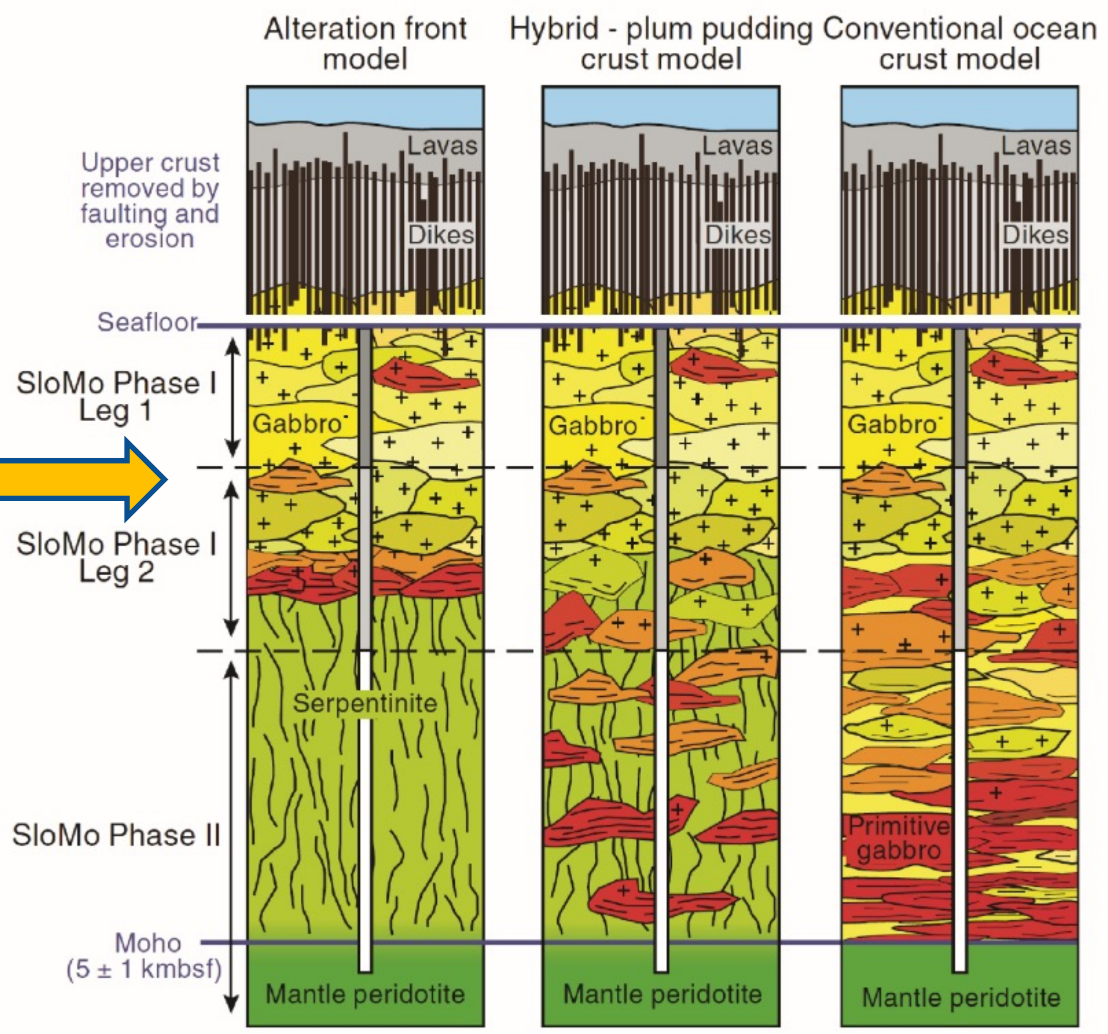
IODP Expedition 360

Zona di faglia a circa 400 mbsf



Towards the Moho?

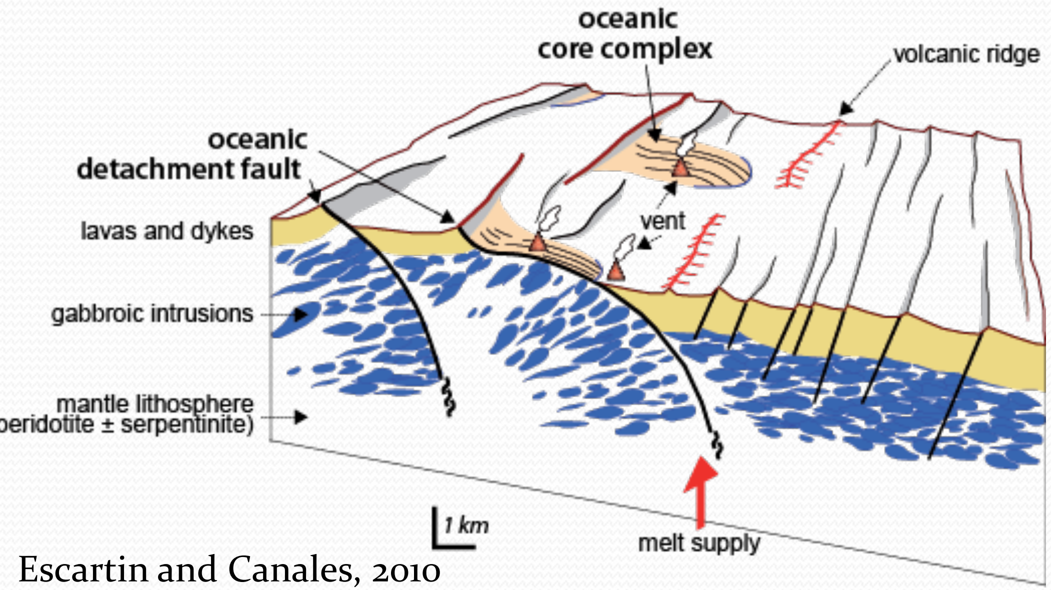




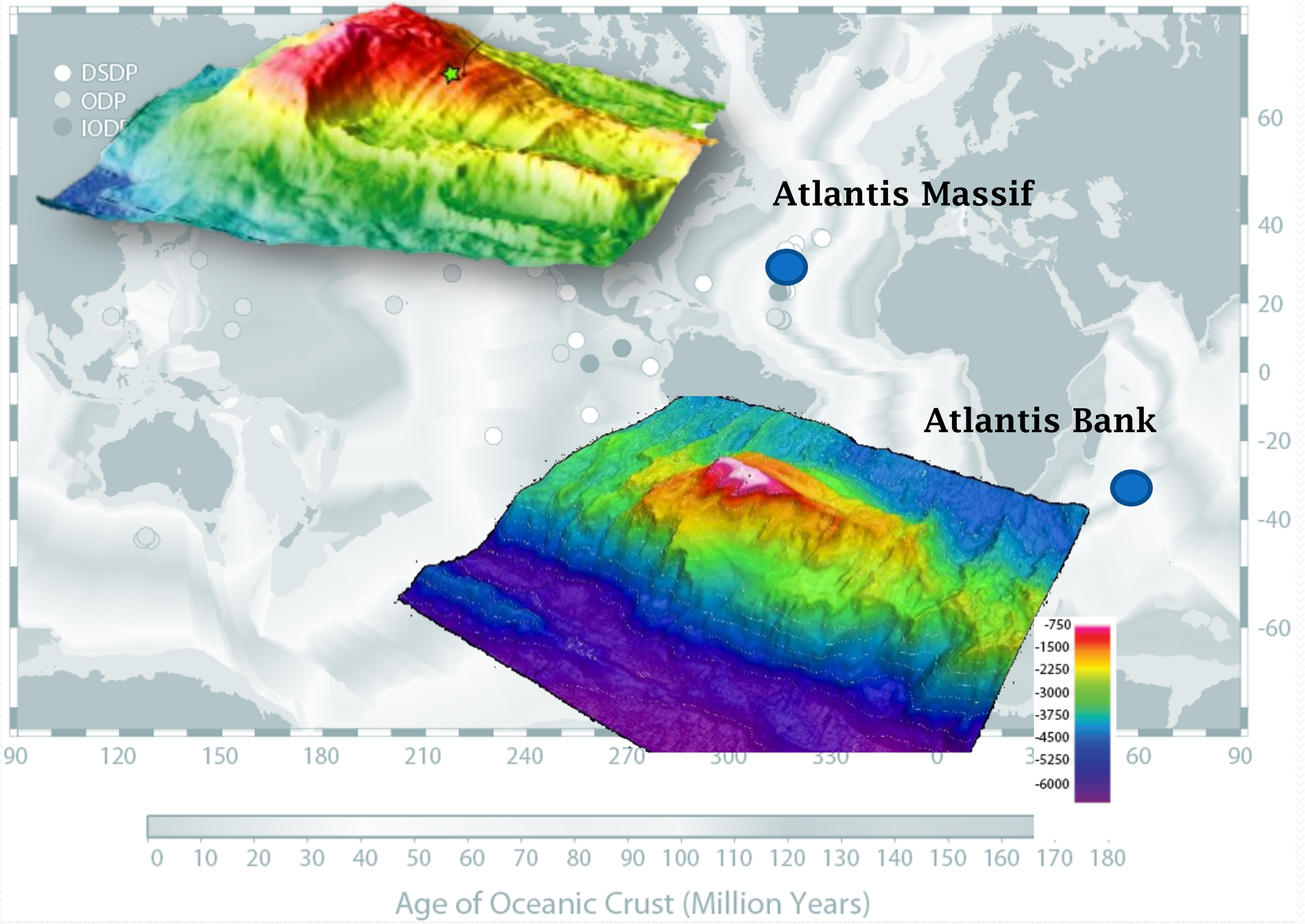
Expedition IODP 362T. Hole U1473A remediation operations

Deep drilling in lower crust

Oceanic Core Complex

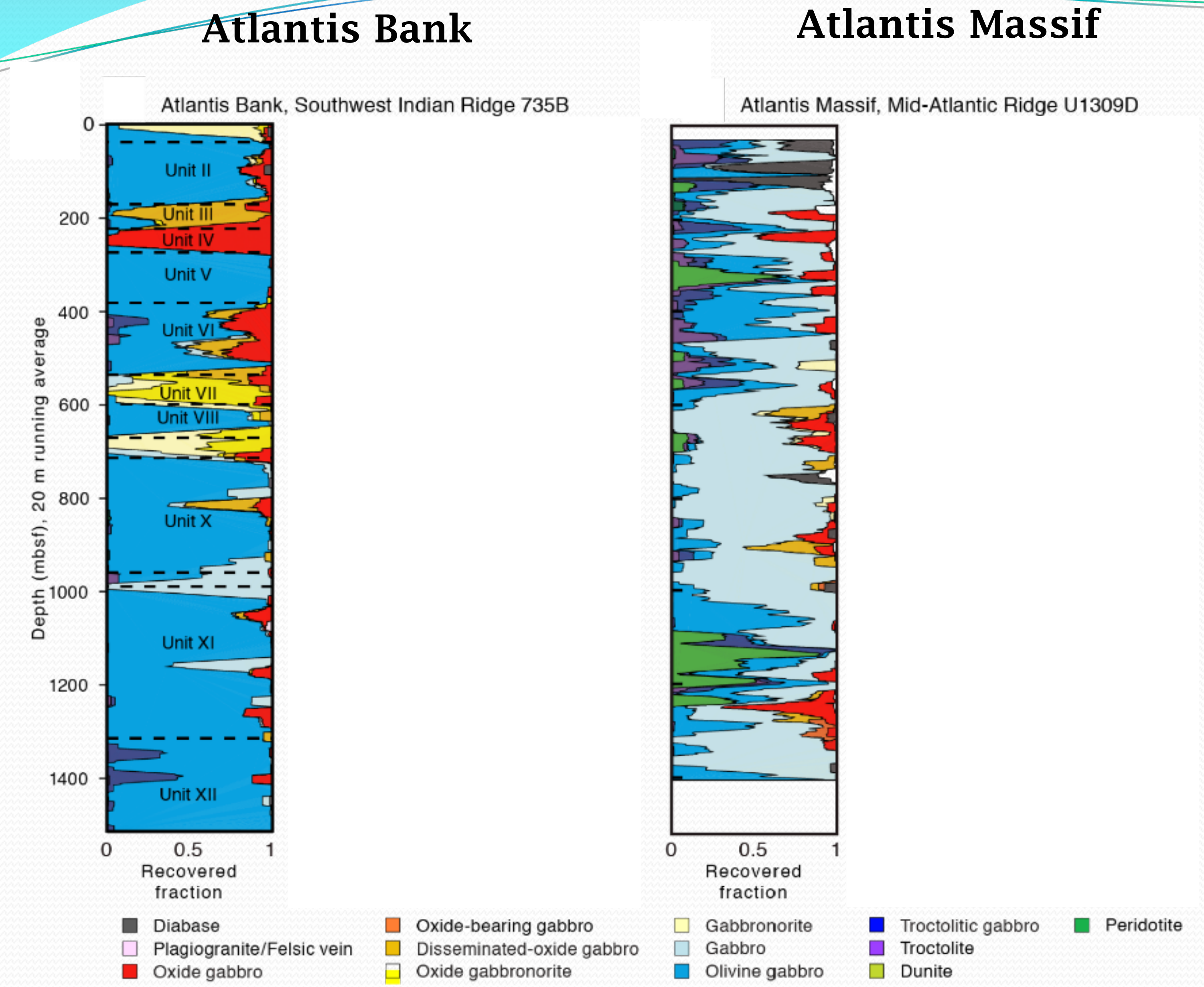


Escartin and Canales, 2010
AGU Chapman conference, Cyprus

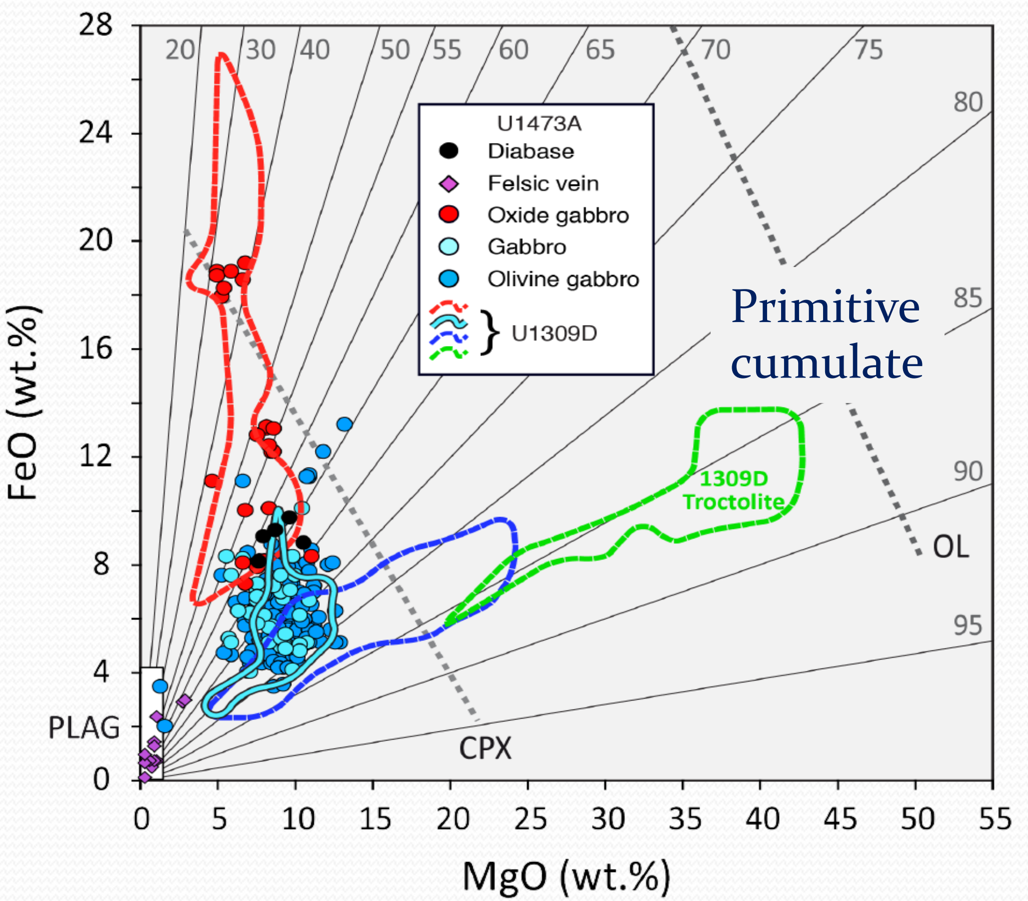


Tectonic windows where lower crustal and mantle rocks can be exposed by detachment faulting

Deep drilling in lower crust

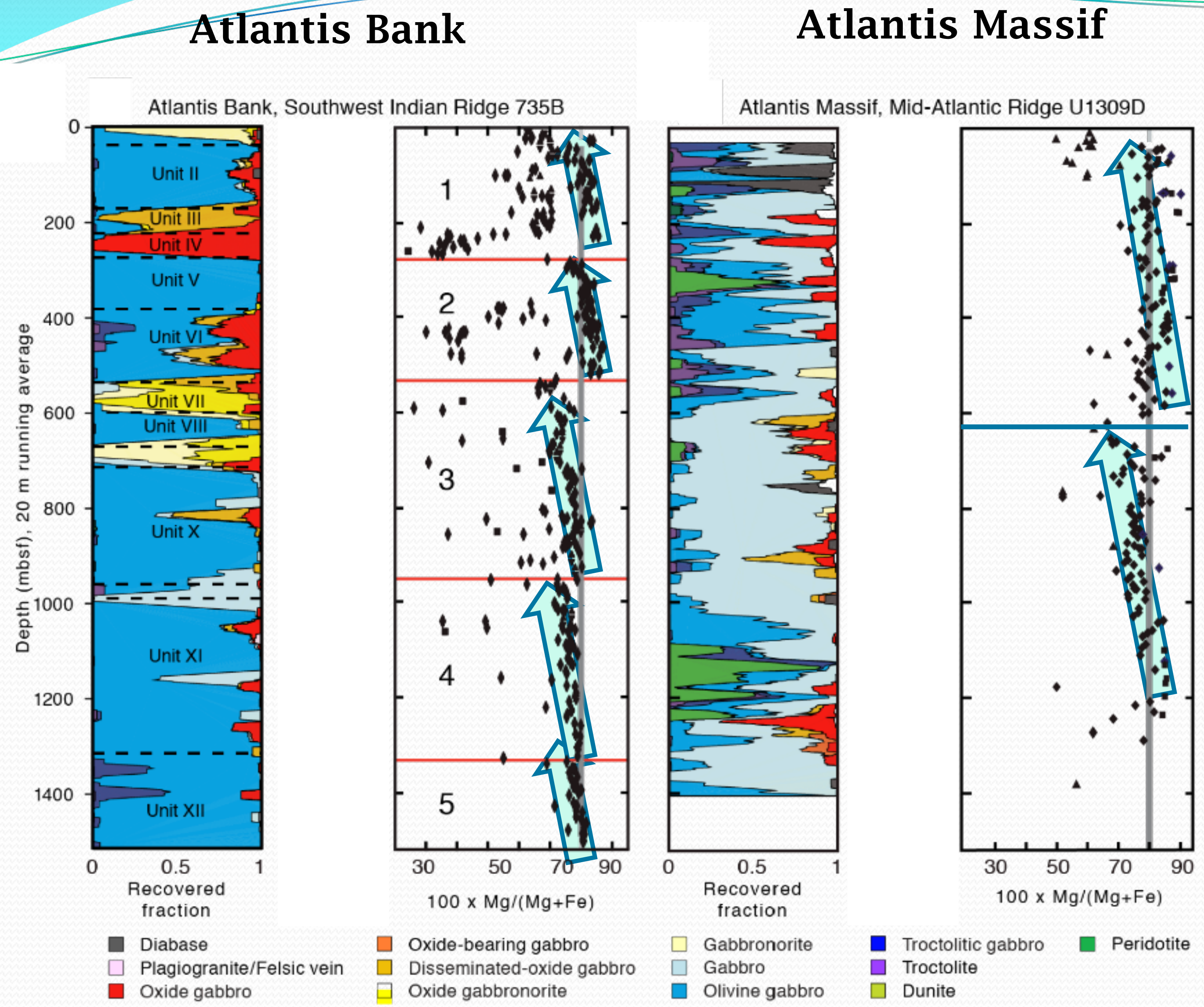


- ✓ Extreme lithological heterogeneity, evolved lithologies randomly distributed and lack of magmatic layering



Modified from MacLeod et al., 2017. Proceedings IODP Expedition 360. Vol. 360

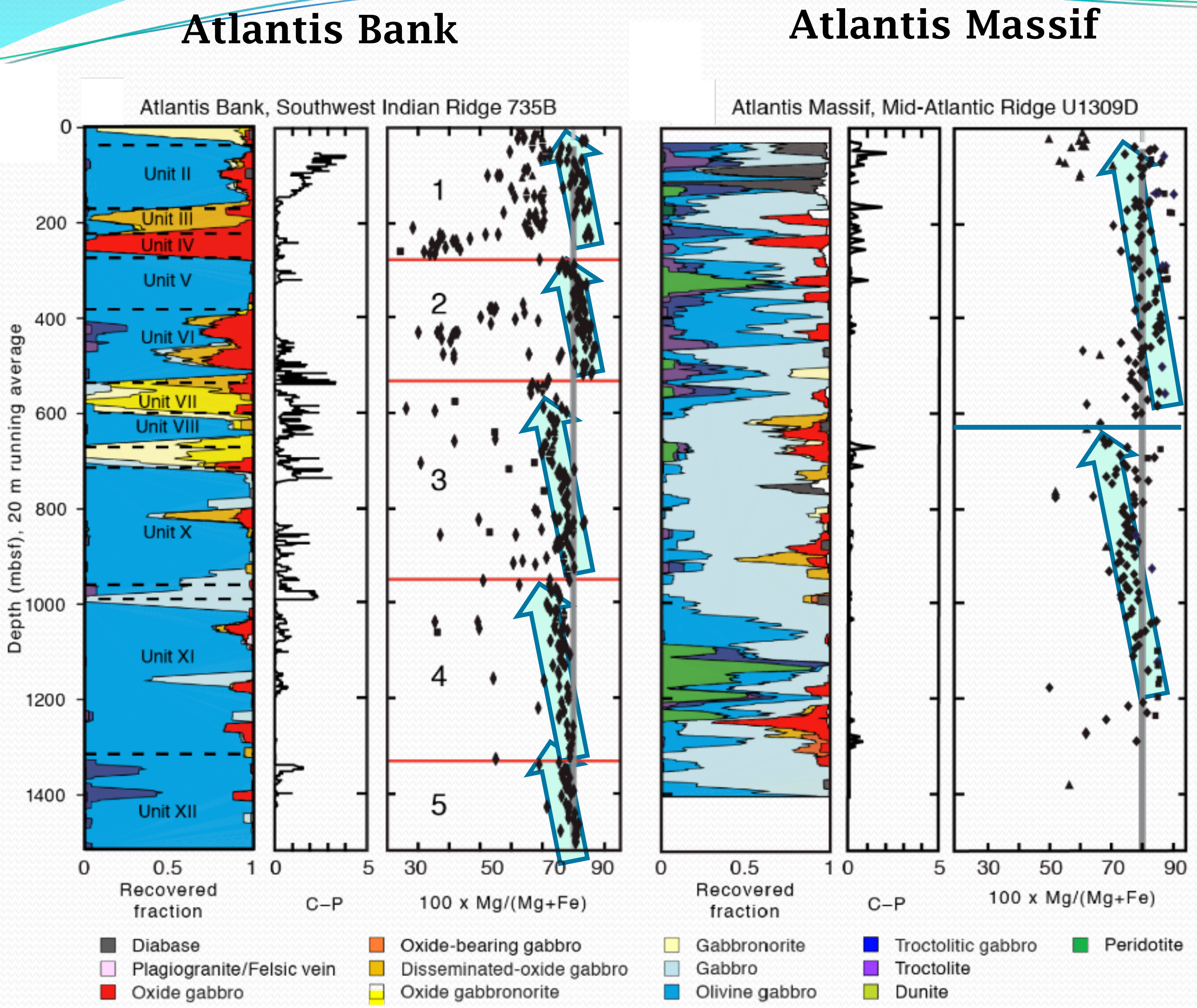
Deep drilling in lower crust



- ✓ Extreme lithological heterogeneity, evolved lithologies randomly distributed and lack of magmatic layering
- ✓ Geochemical cycles evolving upwards

Modified from MacLeod et al., 2017. Proceedings IODP Expedition 360. Vol. 360

Deep drilling in lower crust

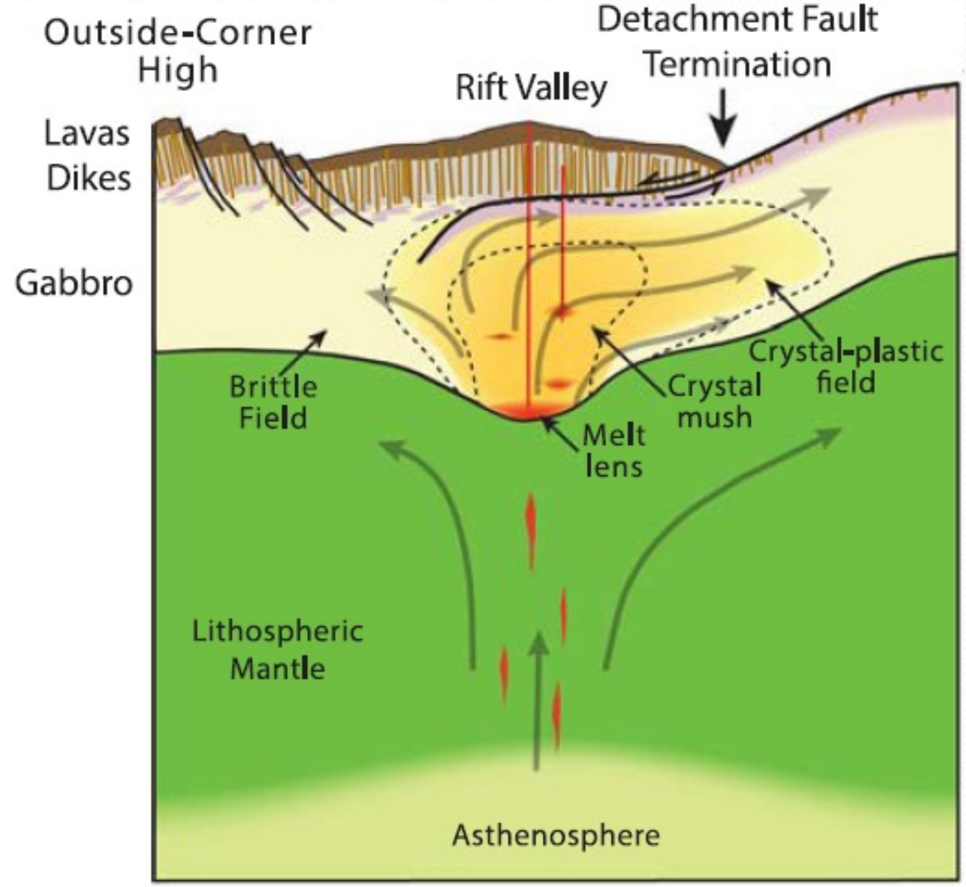


- ✓ Extreme lithological heterogen
  evolved lithologies randomly d
  and lack of magmatic layering
- ✓ Geochemical cycles evolving up
- ✓ Crystal-plastic deformation
  ranging from hyper-solidus
  to amphibolite facies conditions
  (>1100° – 700°C)

Modified from MacLeod et al., 20
Expedition 360. Vol. 360

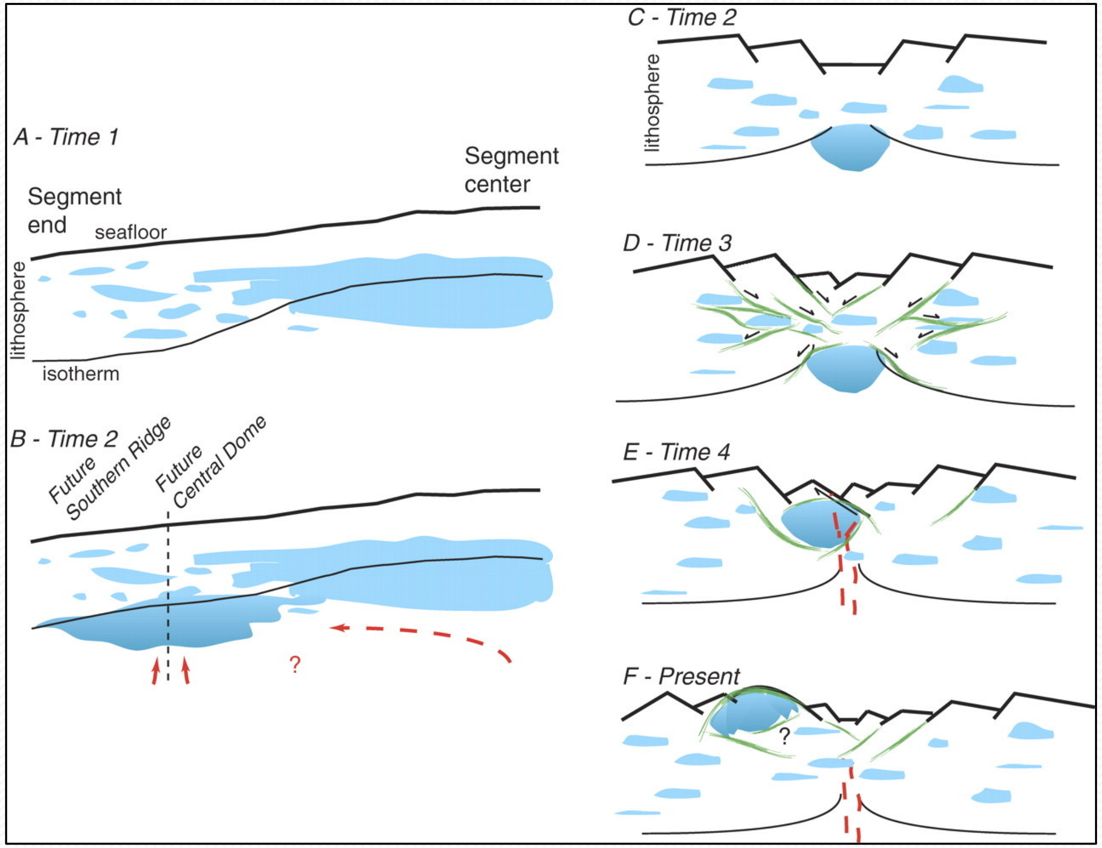
Deep drilling in lower crust

Atlantis Bank (660 km²)



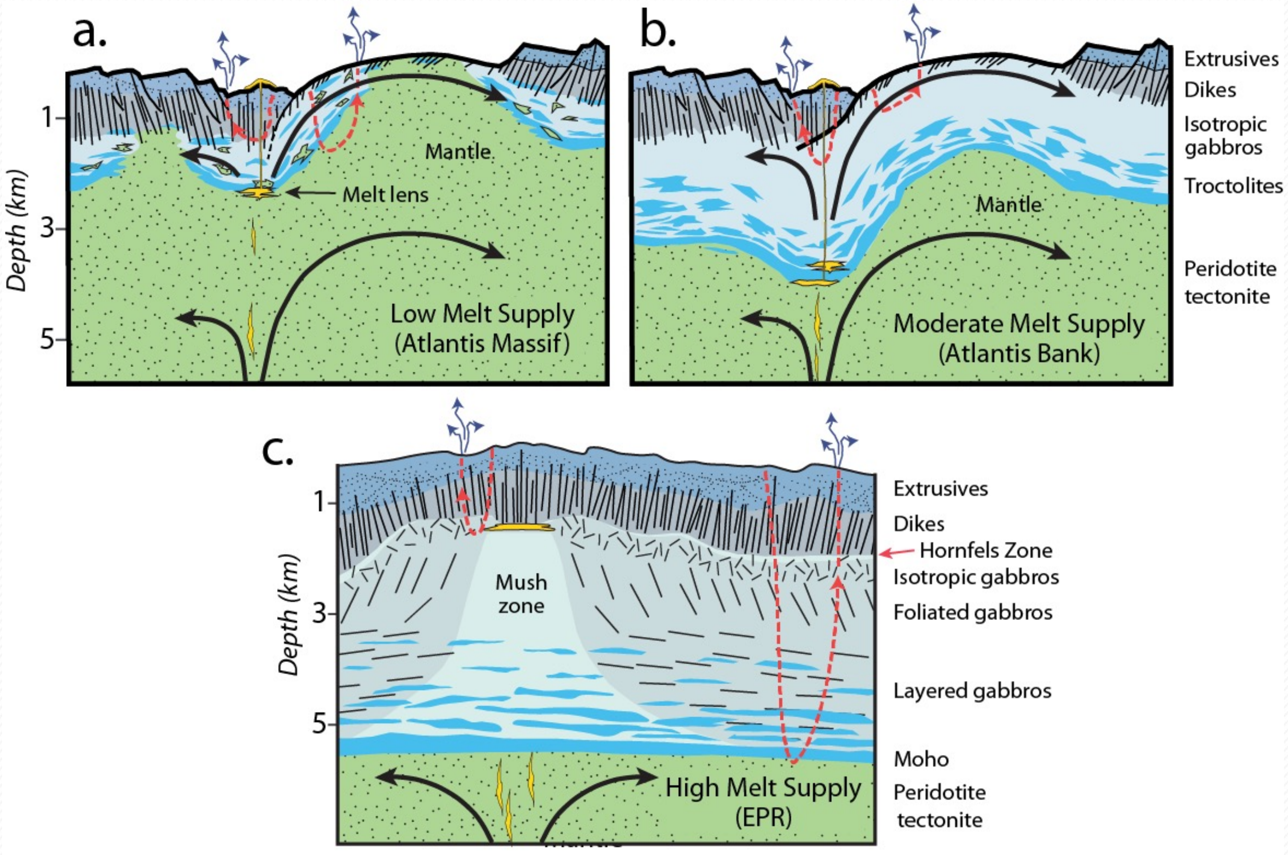
Dick et al. 2019, JGR

Atlantis Massif (100 km²)



Ildefonse al. 2007, Geology

Towards a new model of seafloor accretion?



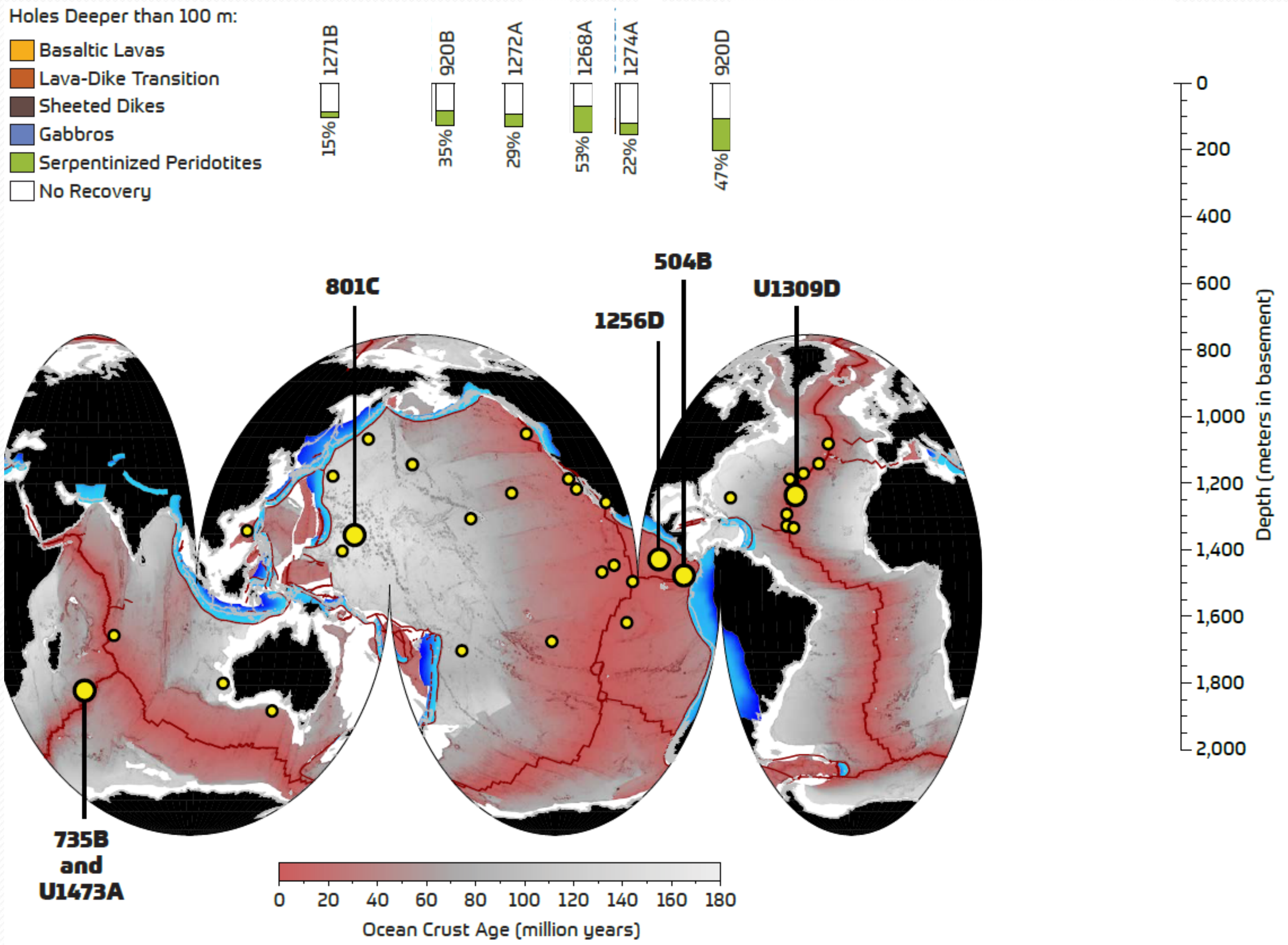
from Sanfilippo et al. IODP Proposal 971-Full2
(modified after Dick and Koepke)

Difference in

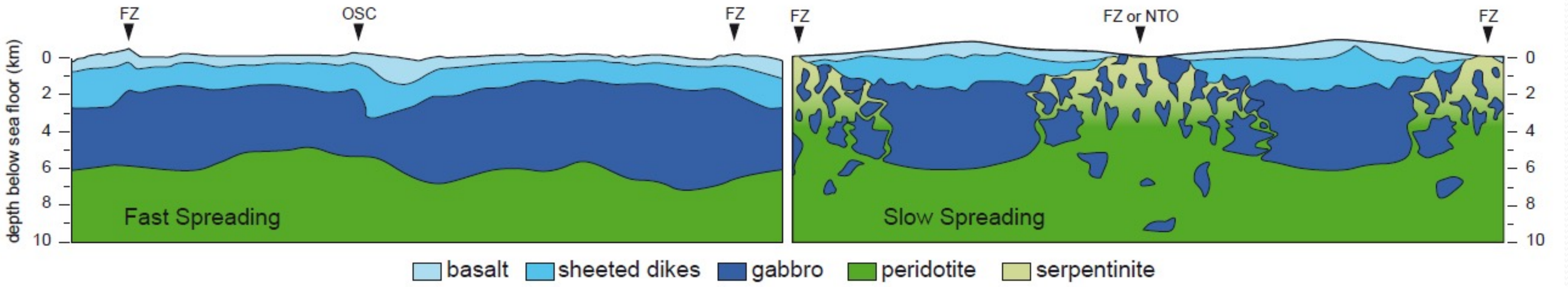
- **Thermal regime**
- **Postcumulus processes**
- **Deformation style and intensity**
- **Alteration and hydrothermalism**
- **Geo-biology**

Can be potentially explained by a **general** accretionary process fundamentally dependent on regional variations in ***melt supply***

Deep drilling in the mantle



Deep drilling in the mantle



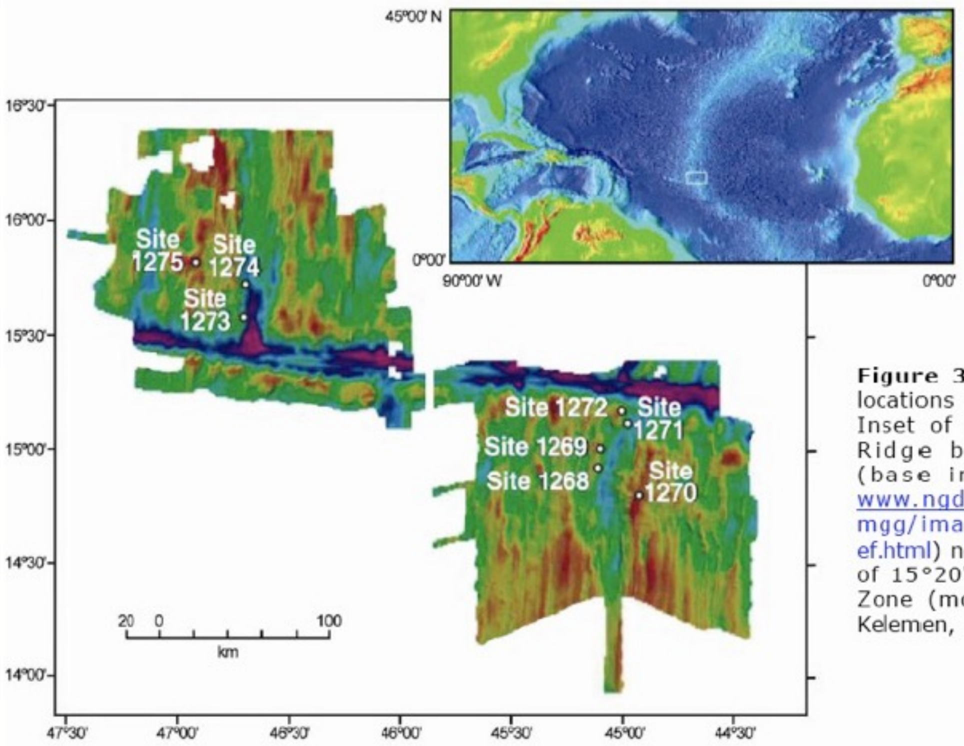
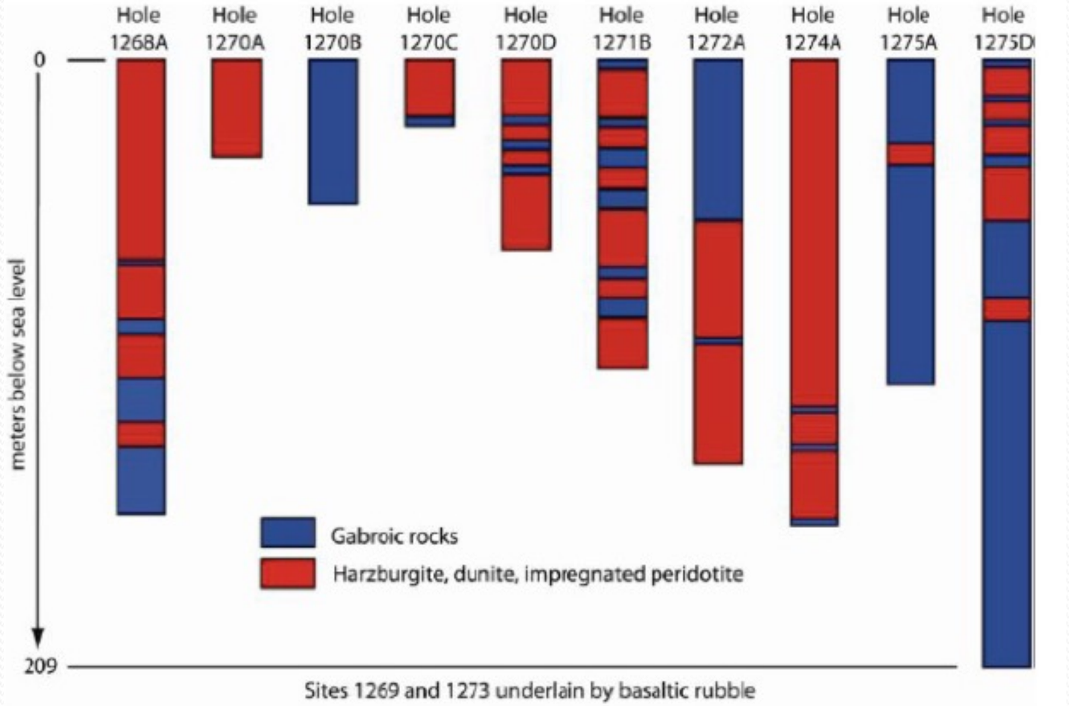


Figure 3.1 Drill site locations for Leg 209. Inset of Mid-Atlantic Ridge bathymetry (base image from www.ngdc.noaa.gov/mgg/image/2minrelief.html) noting location of 15°20' N Fracture Zone (modified from Kelemen, et al., 2004).

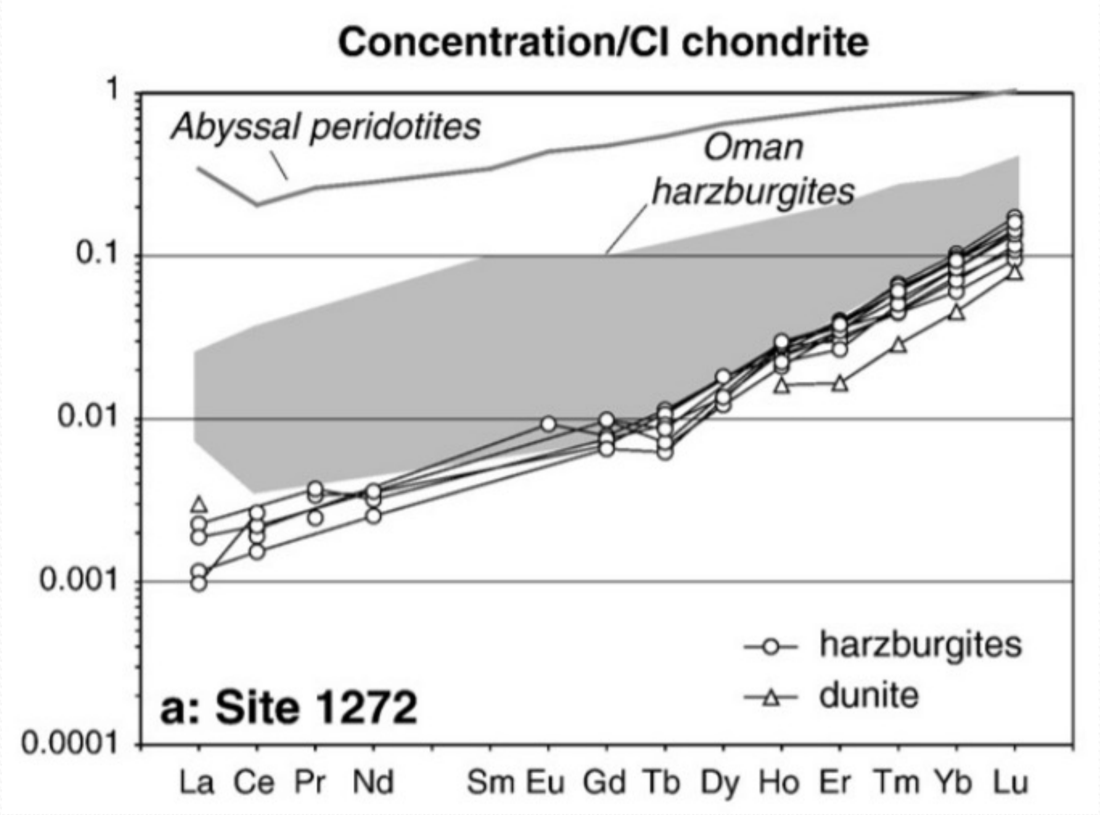


Leg 209, Preliminary Report, Kelemen et al., 2004

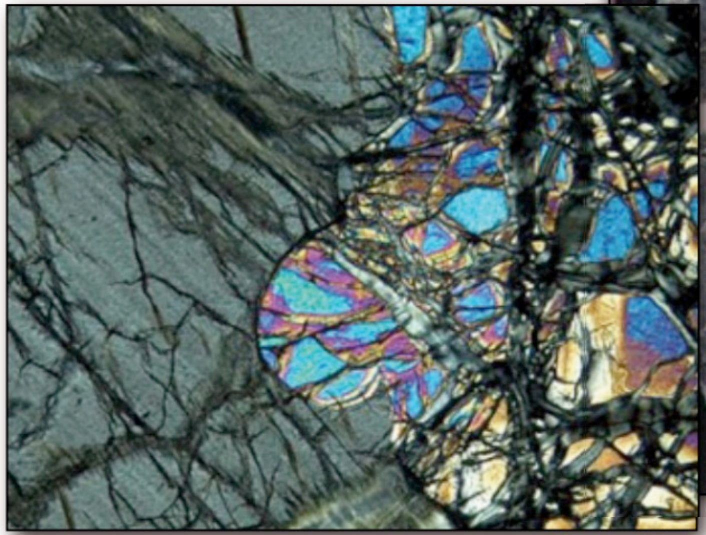
Deep drilling in the mantle

Leg 209 peridotites: a window in the **depleted mantle**

- Peridotiti fortemente impoverite (e.g., Godard et al., 2008; Suhr et al., 2008)
- *Re depletion ages* etremamente antiche – fino a 2 Ga (Harvey et al., 2006)

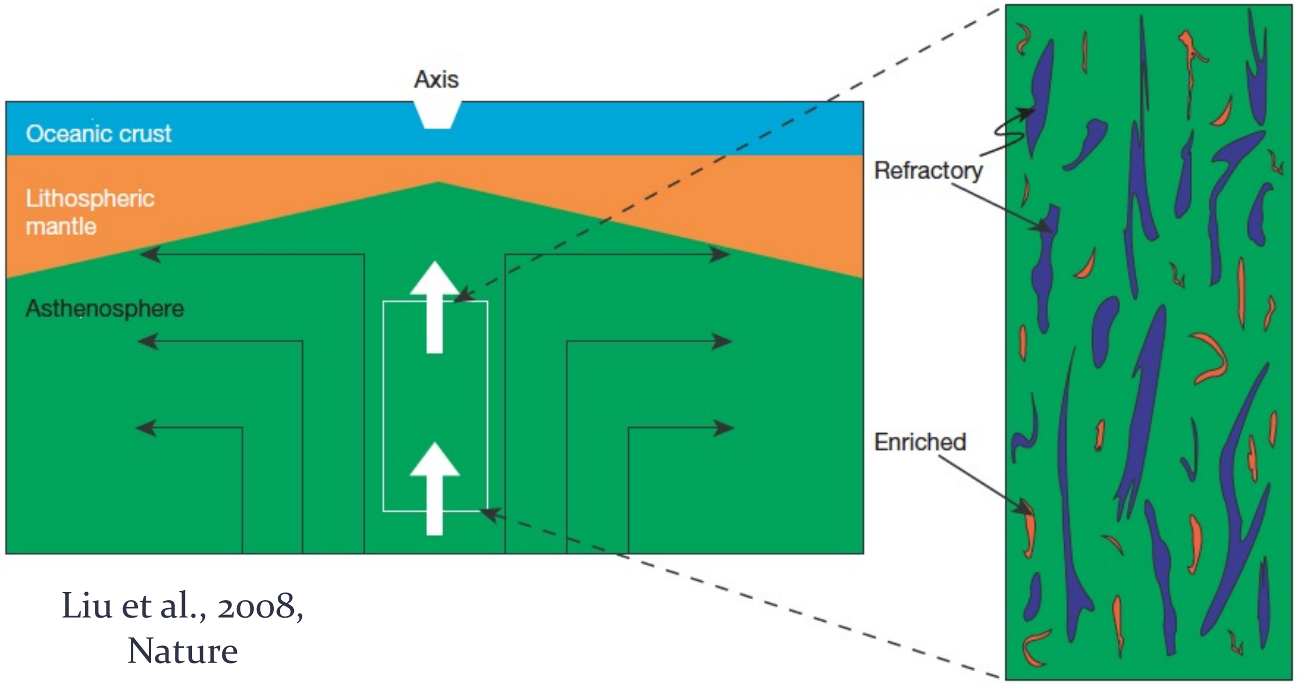


Godard et al., 2008, EPSL

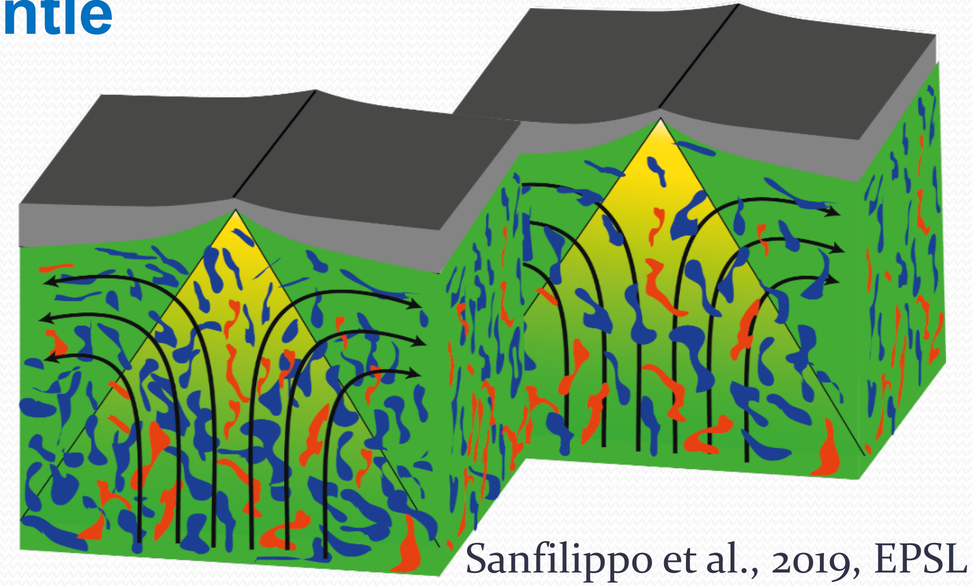


Deep drilling in the mantle

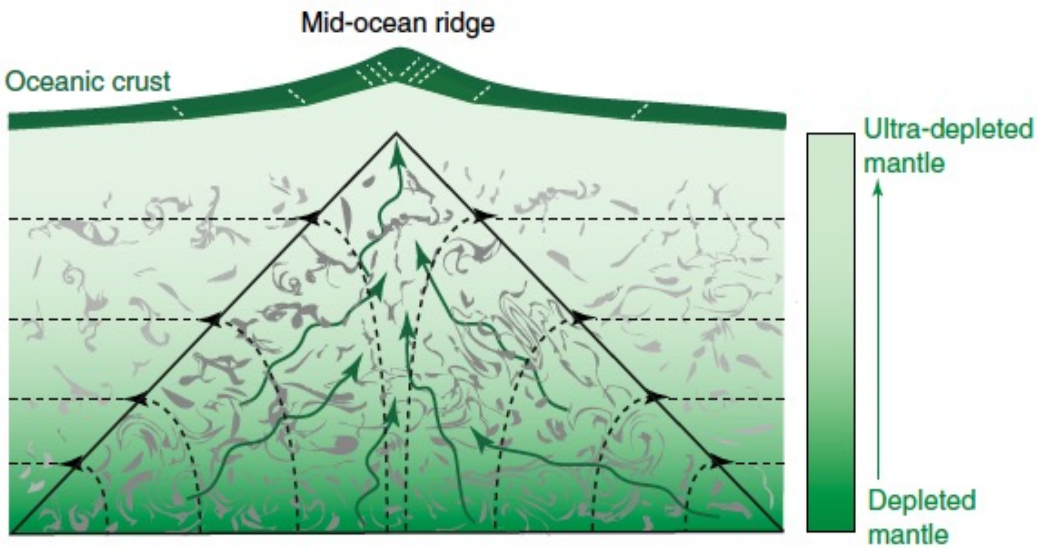
Leg 209 peridotites: a window in the **depleted mantle**



Liu et al., 2008, Nature



Sanfilippo et al., 2019, EPSL



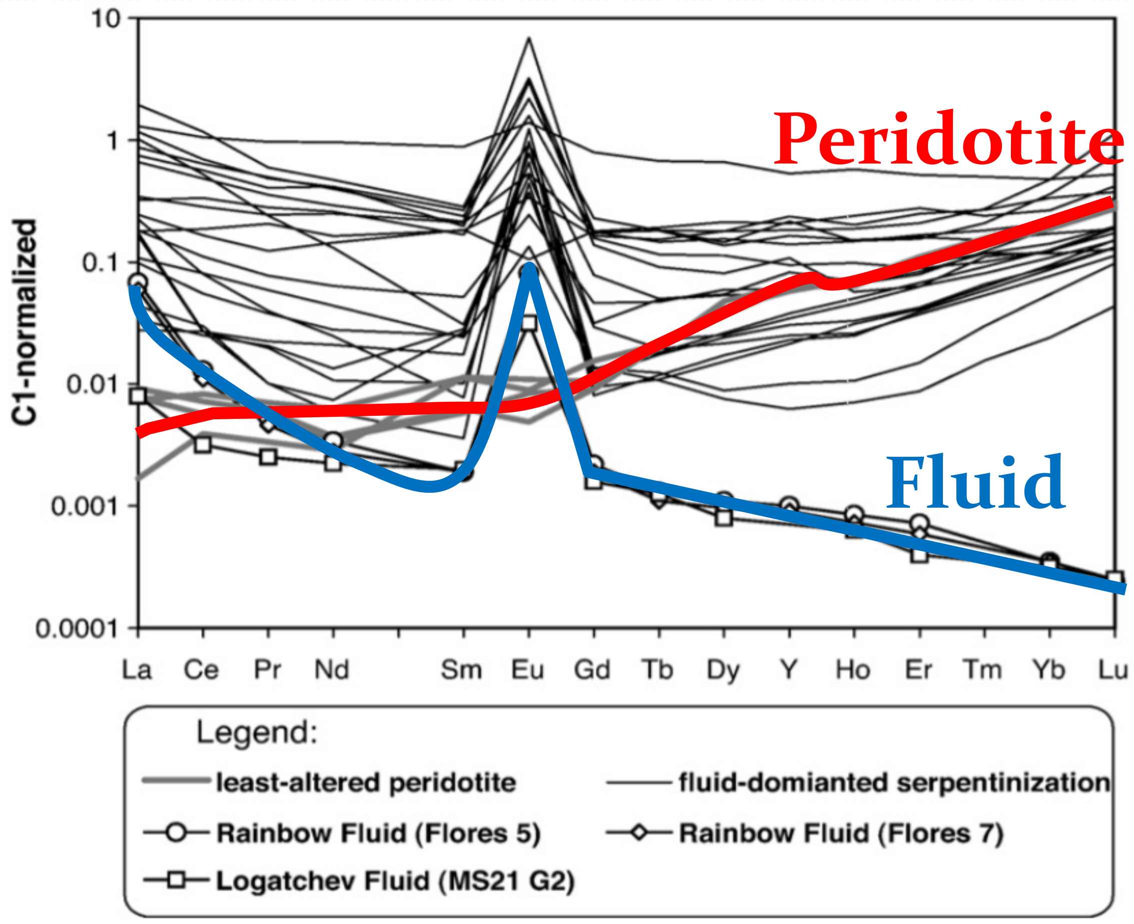
Stracke et al., 2019, NatGeosc

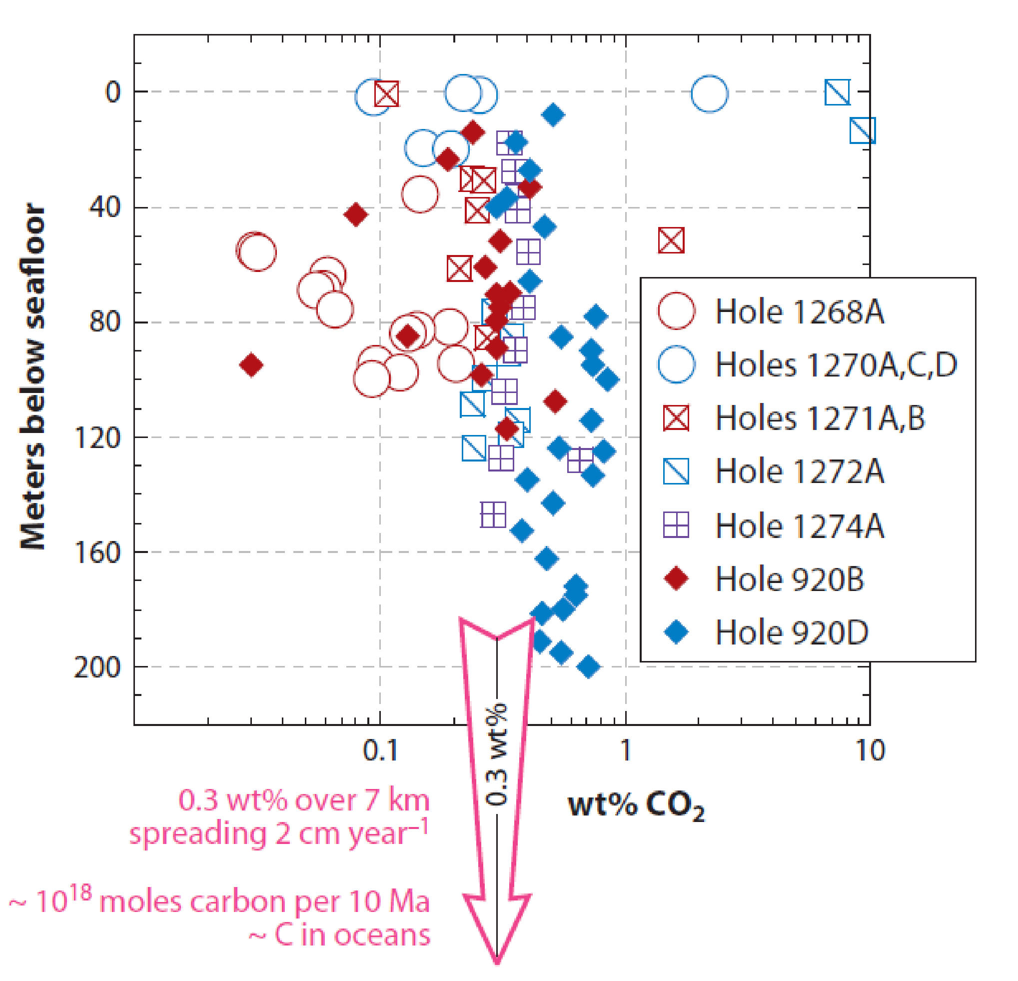
"The Earth's mantle is more depleted than previously thought…"

Stracke et al., 2011; Salters et al., 2011; Byerly and Lassiter, 2014; Mallick et al., 2015; Day et al., 2017; Sanfilippo et al., 2019; Stracke et al., 2019; Willig et al, 2020; Sanfilippo et al., 2021…

Deep drilling in the mantle

Leg 209 peridotites: fluid alteration and **global cycles**



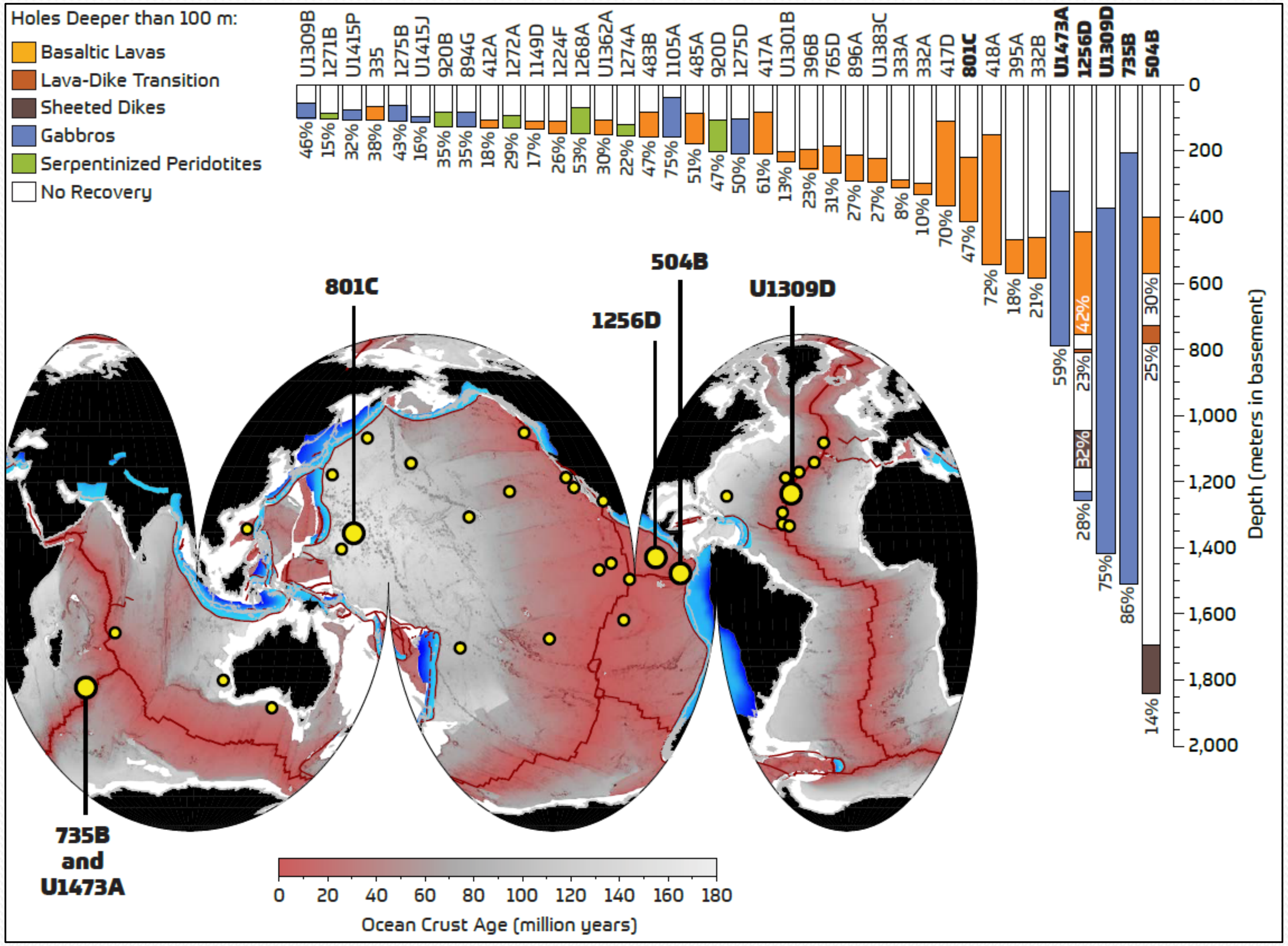


Paulick et al., 2006, ChemGeol

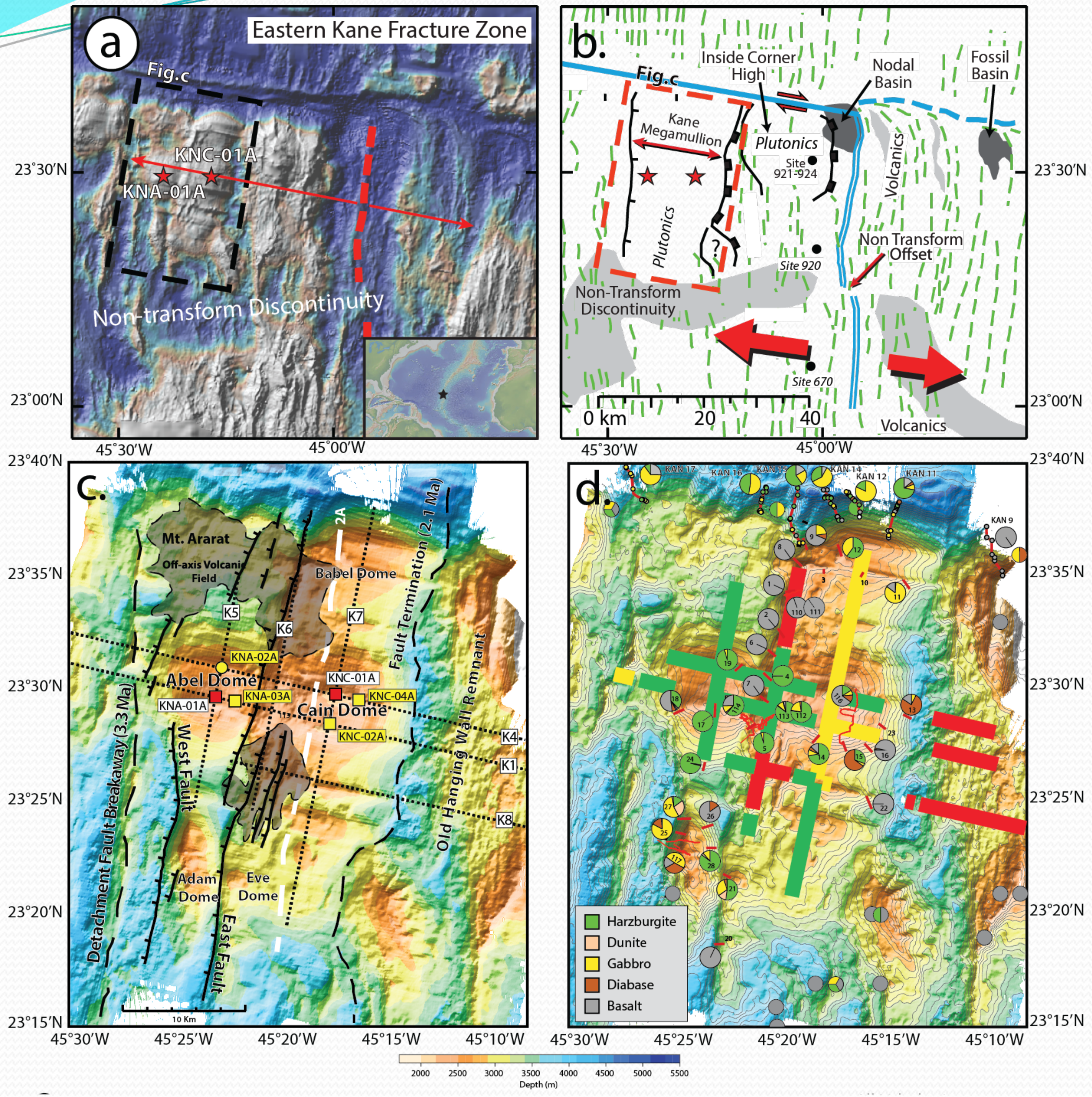
Kelemen et al., 2011, Ann.Rev.EPS.

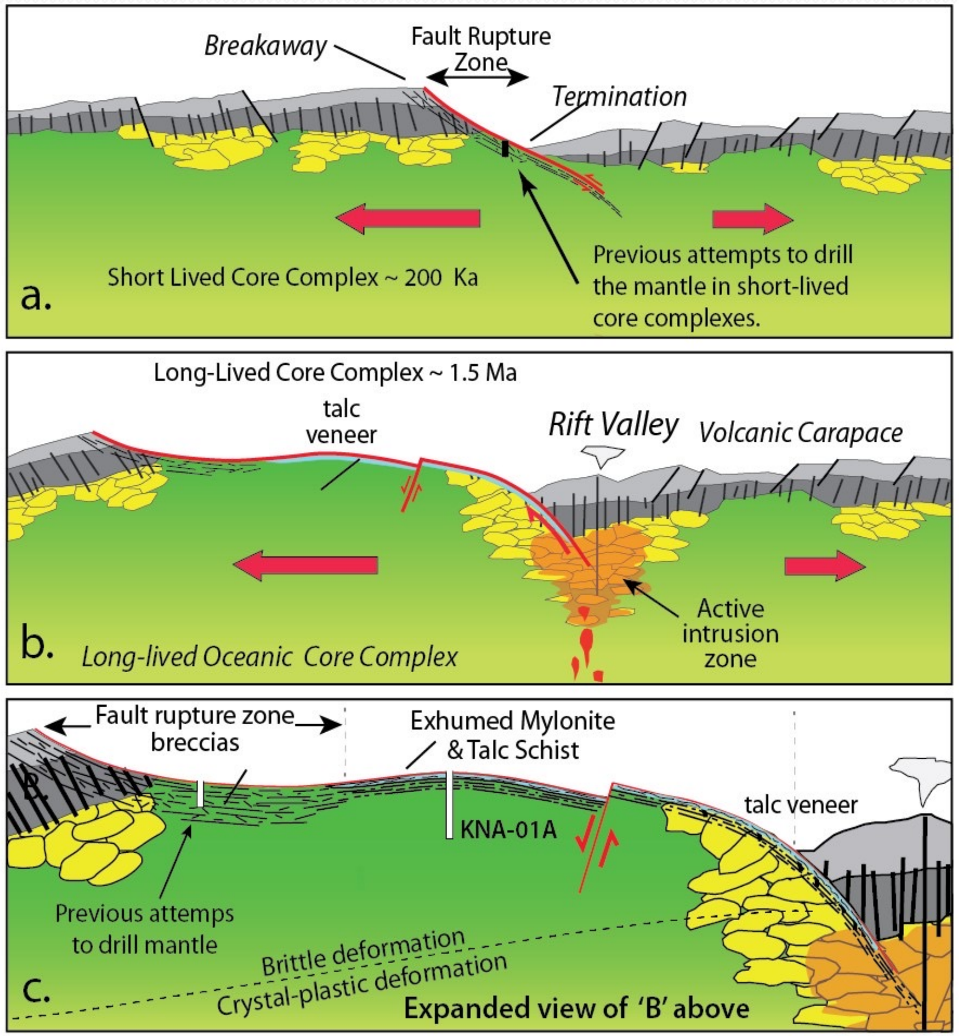
Deep drilling in the lower crust and mantle

Mantle composition, crustal accretion, fluid alteration and **global cycles**



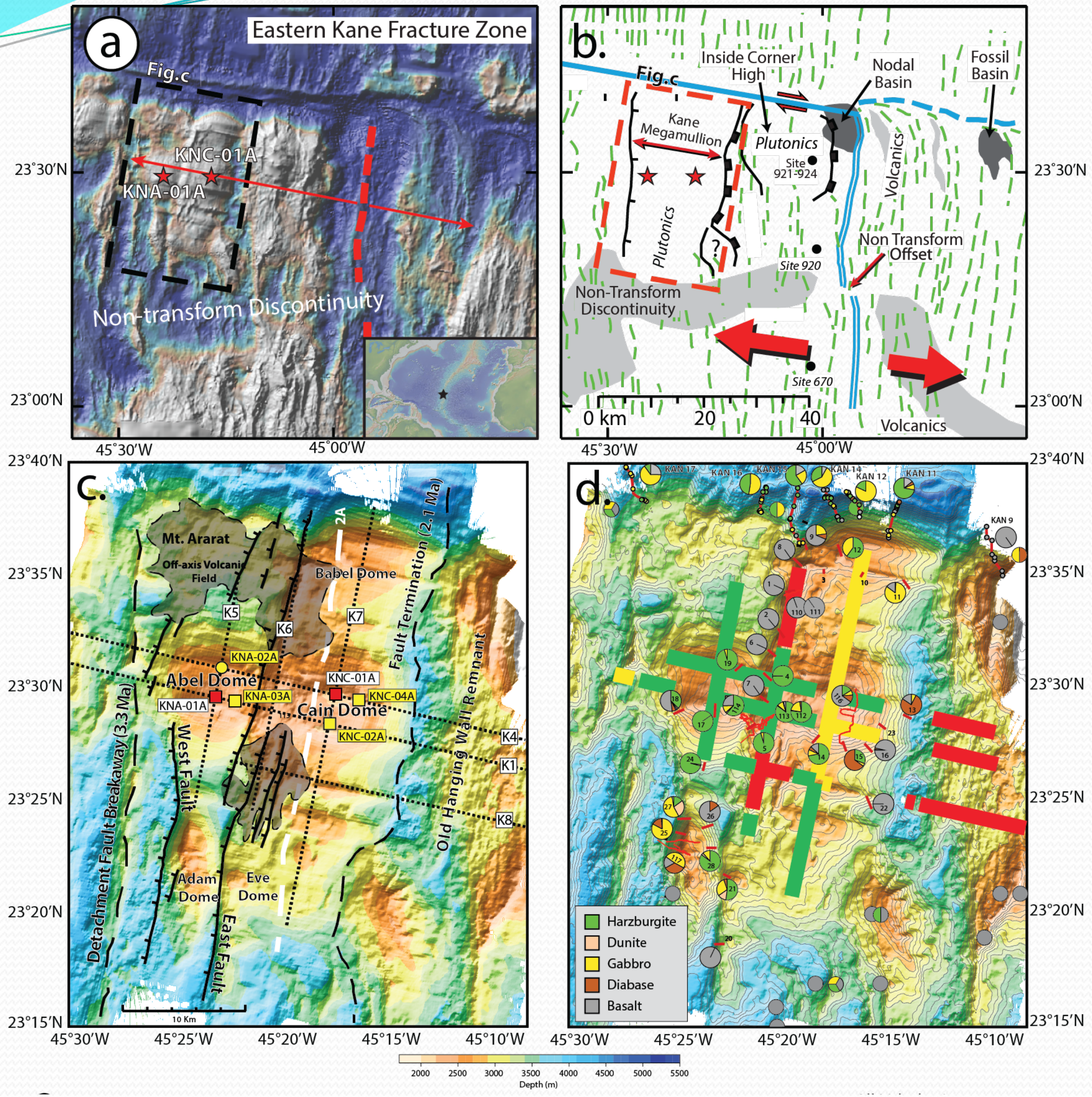
Next step: Kane OCC lower crust and mantle

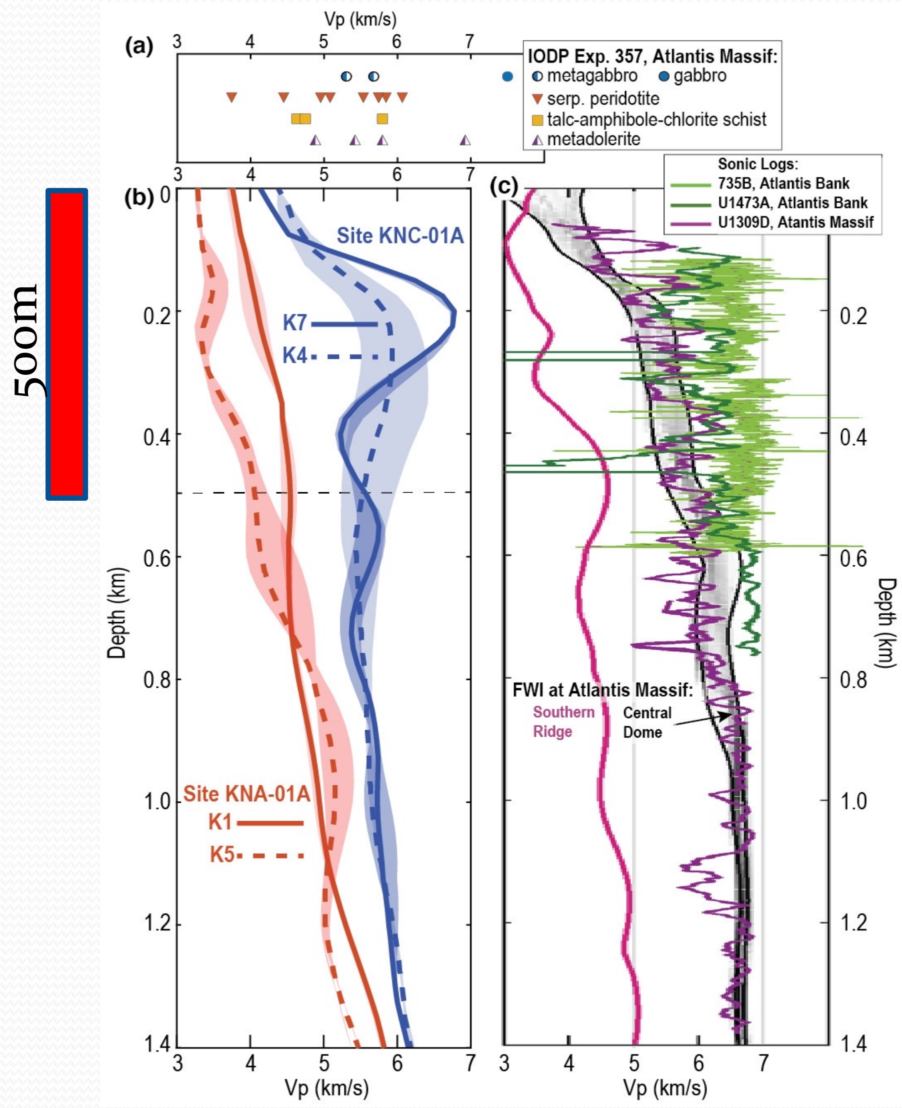




IODP Proposal 971-Full2; Sanfilippo et al.

Next step: Kane OCC lower crust and mantle

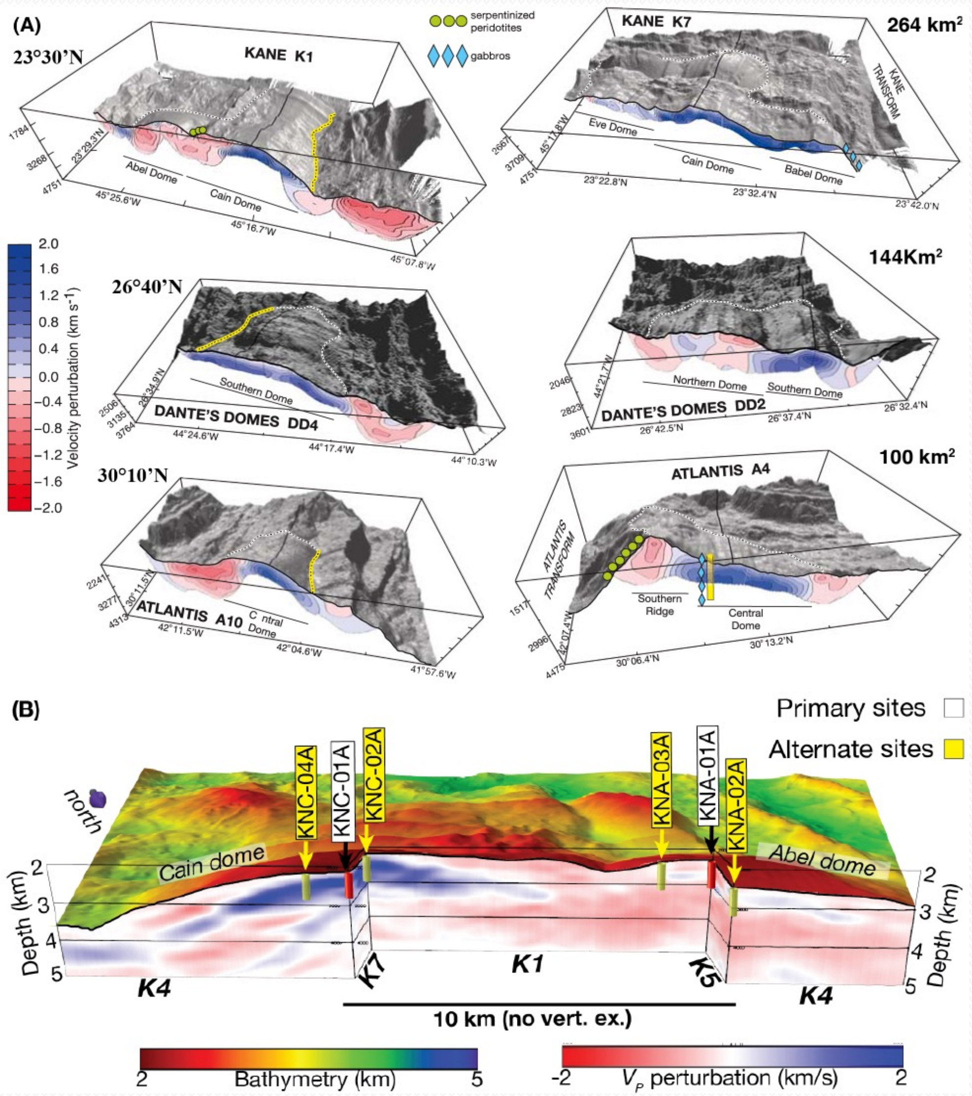


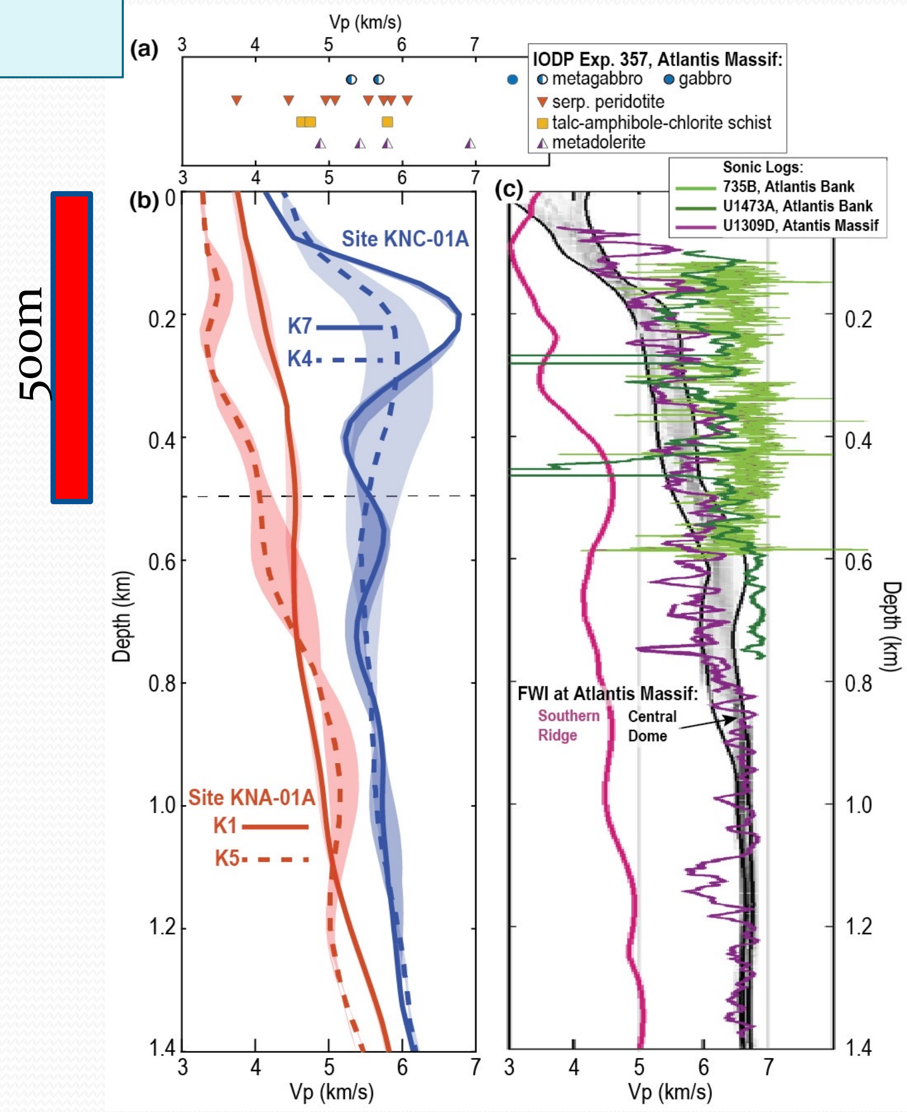


IODP Proposal 971-Full2; Sanfilippo et al.

Next step: Kane OCC lower crust and mantle

Objective 1: Test the seismic and geologic interpretations of the Kane OCC sub-surface structure

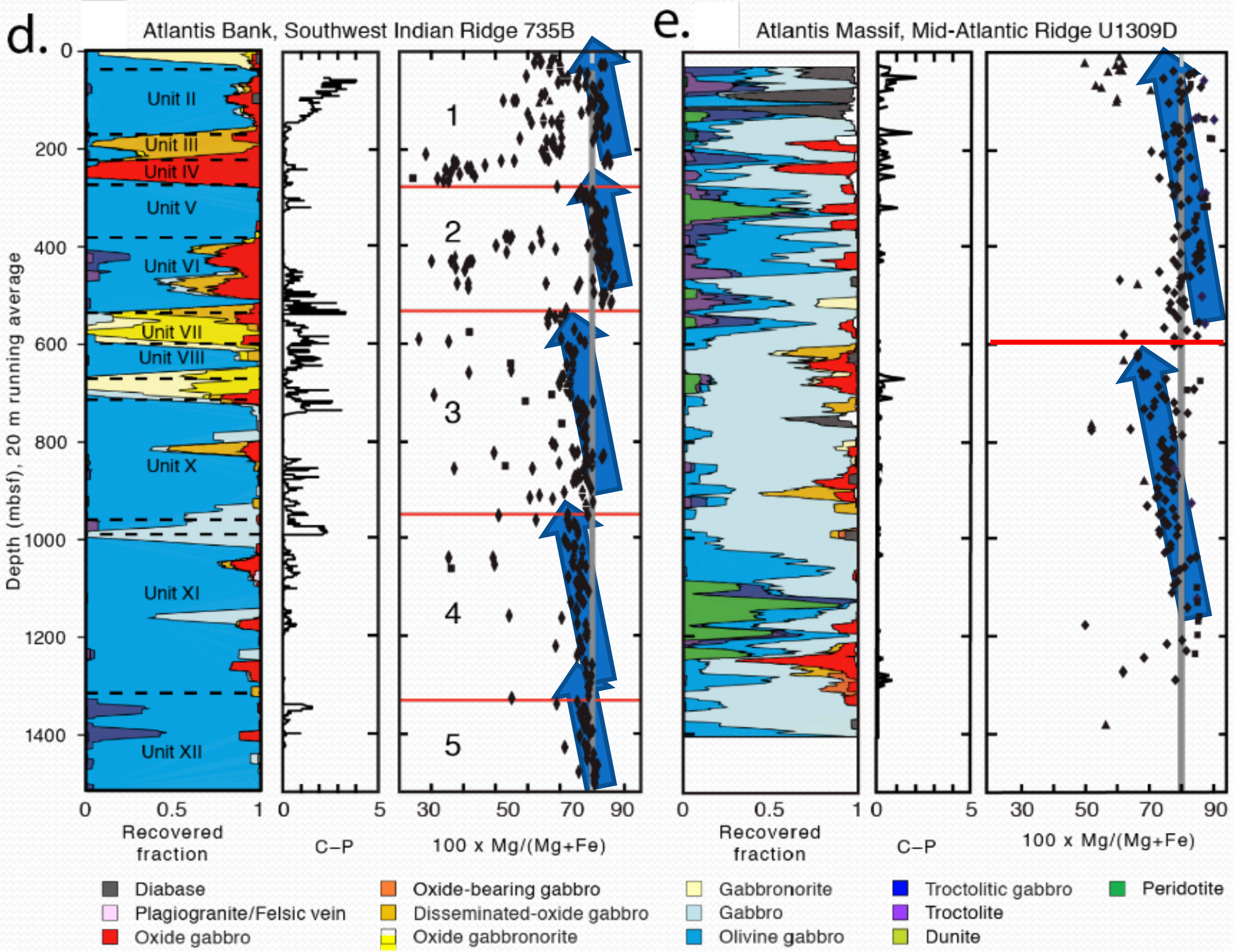


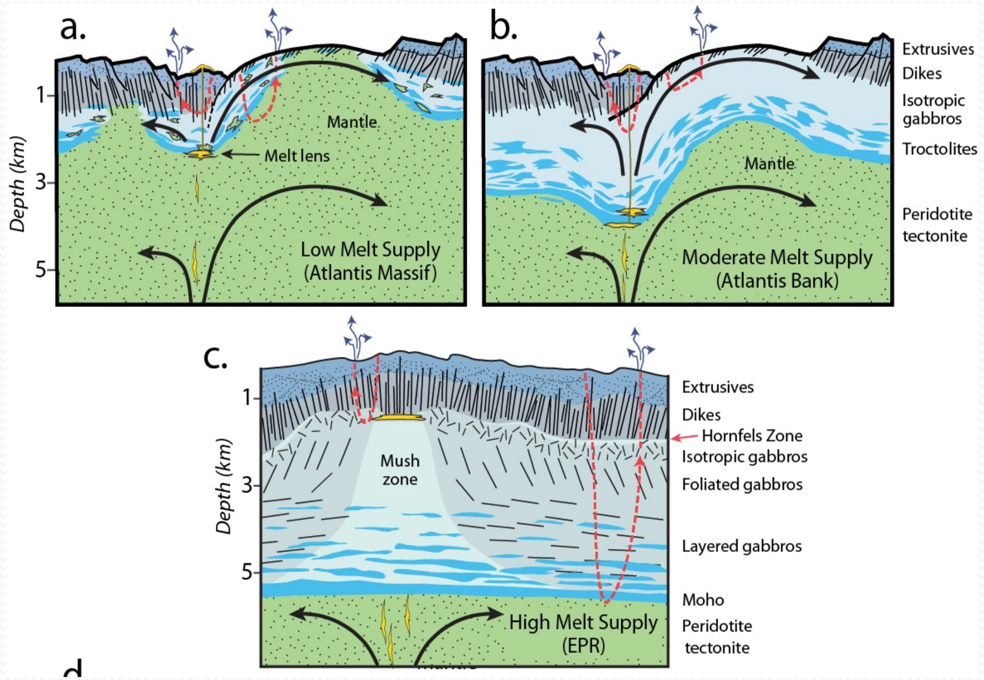


IODP Proposal 971-Full2; Sanfilippo et al.

Next step: Kane OCC lower crust and mantle

Objective 2: Test the variability of crustal architecture with decreasing melt flux in 3D

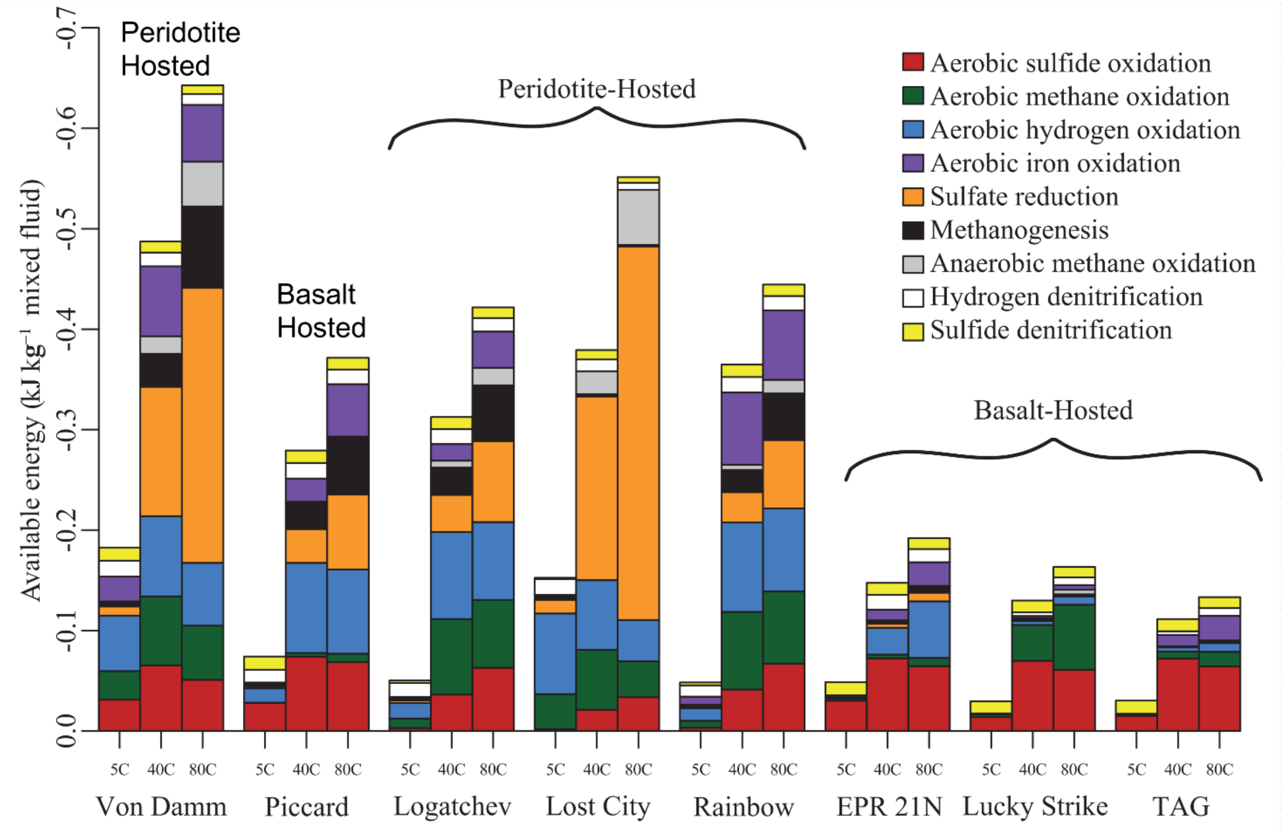


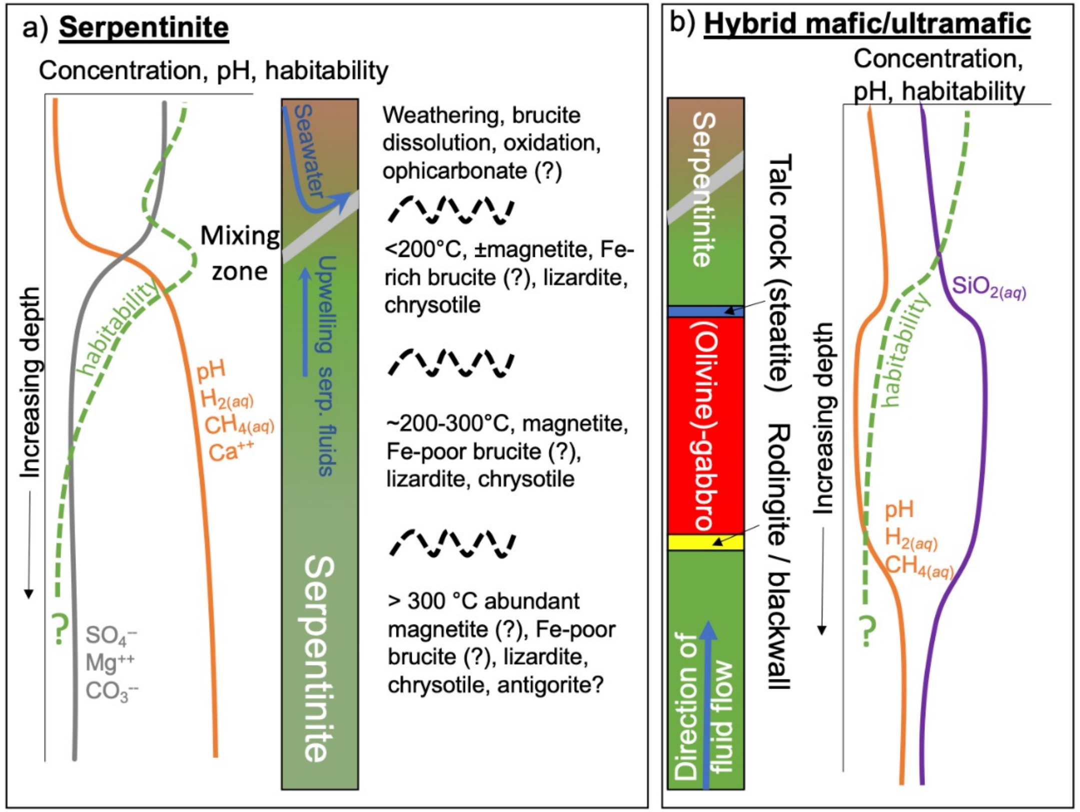


IODP Proposal 971-Full2; Sanfilippo et al.

Next step: Kane OCC lower crust and mantle

Objective 3: Examine hydrothermal alteration processes in lower crustal and mantle lithologies as a function of depth and temperature

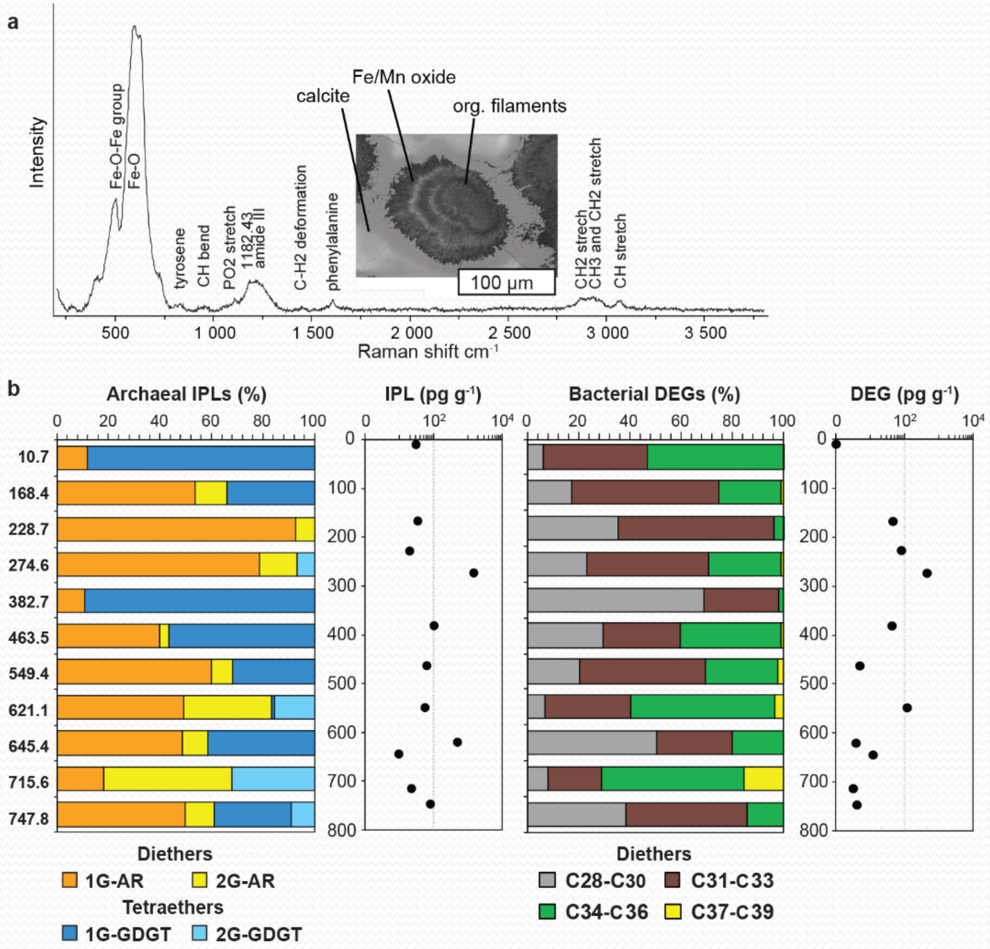




IODP Proposal 971-Full2; Sanfilippo et al.

Next step: Kane OCC lower crust and mantle

Objective 4: Explore heterotrophic and chemolithoautotrophic lifestyles in the lower oceanic crust and upper mantle



Li et al., 2020, Nature

Ginny Edgcomb and Chris MacLeod sampling the most promising cores during Expedition 360

Why should we go further?

Deep drilling allows us to investigate the interconnected magmatic, tectonic, hydrothermal, and microbial processes active in seafloor spreading and during the evolution of oceanic lithosphere that are responsible for the unique characteristics of more than 50% of Earth's solid surface.