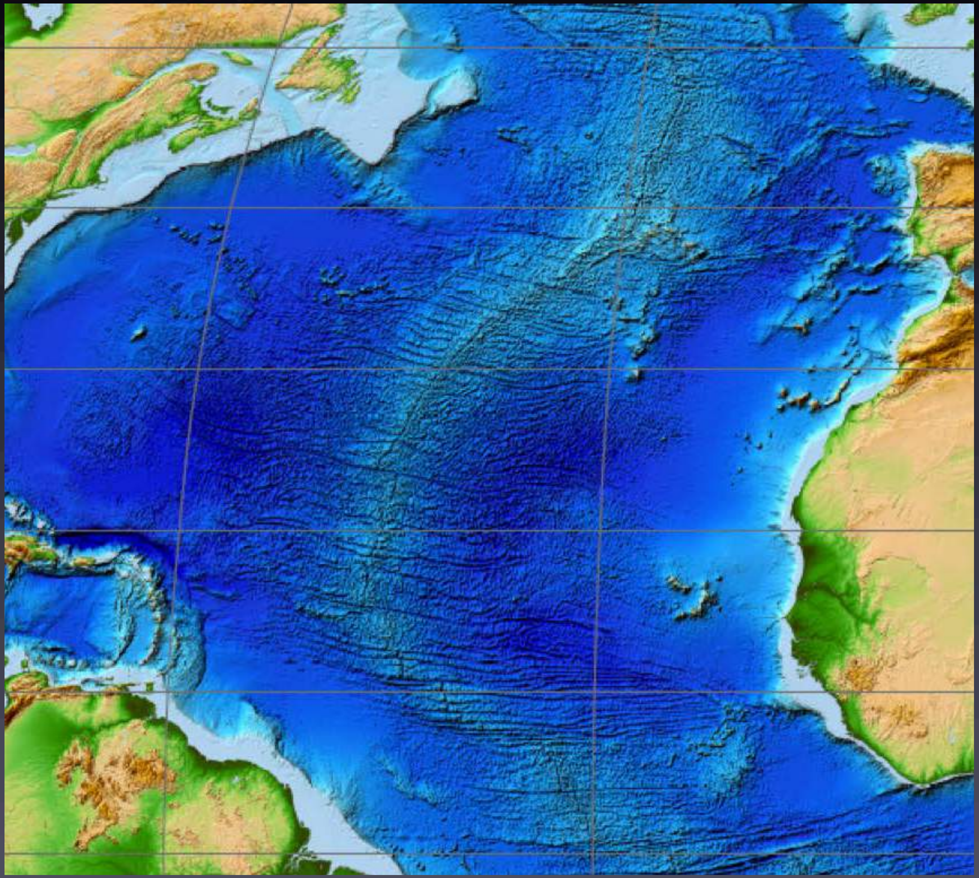
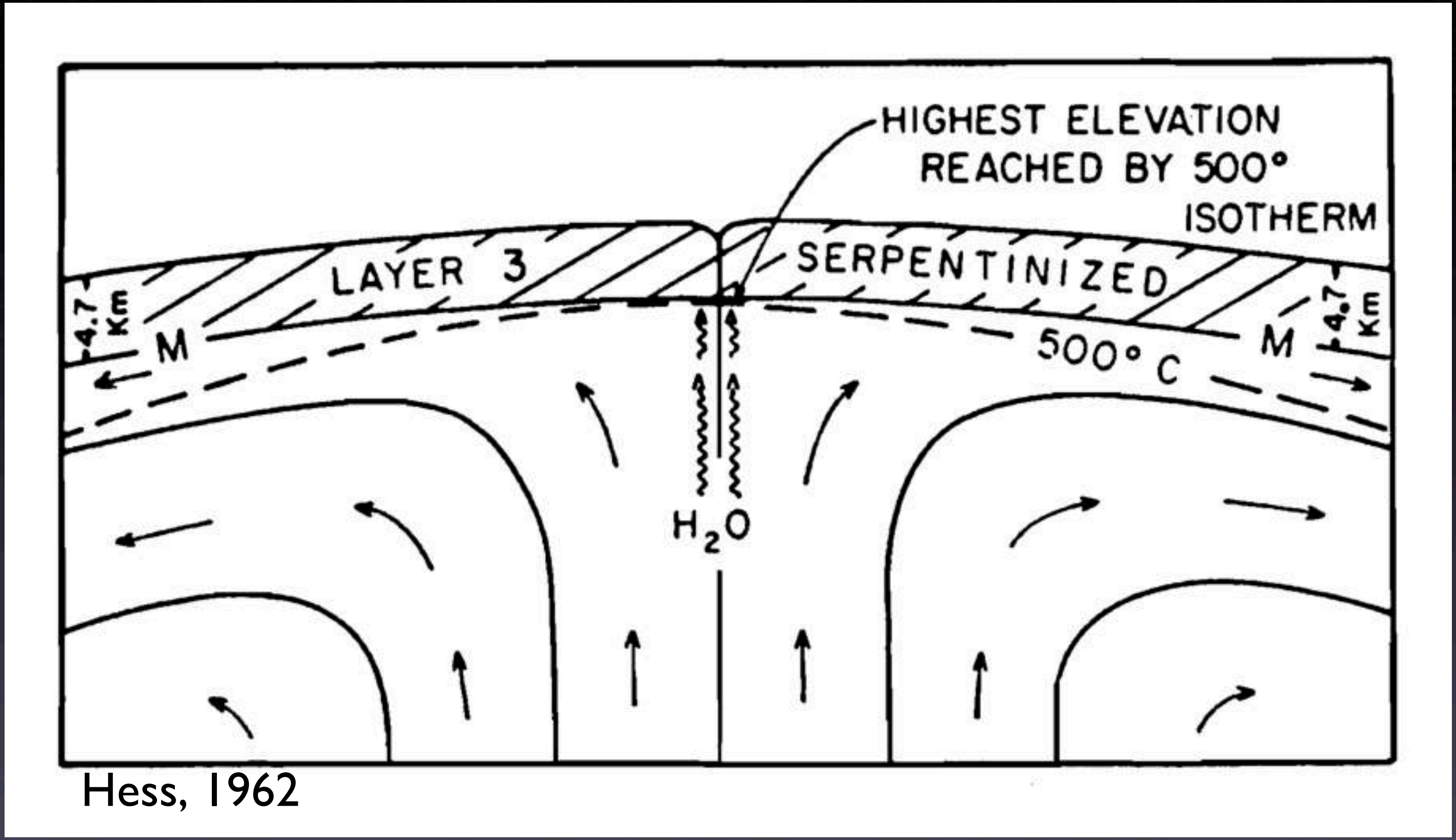
(my) Current understanding of plate divergence processes at mid-oceanic ridges (in 24 slides)



- ☐ 1962-2018
  mid-ocean ridge processes (magmatism, tectonics, hydrothermalism) : discoveries, evolving concepts, new & old questions

- ☐ mid-ocean ridge research perspectives

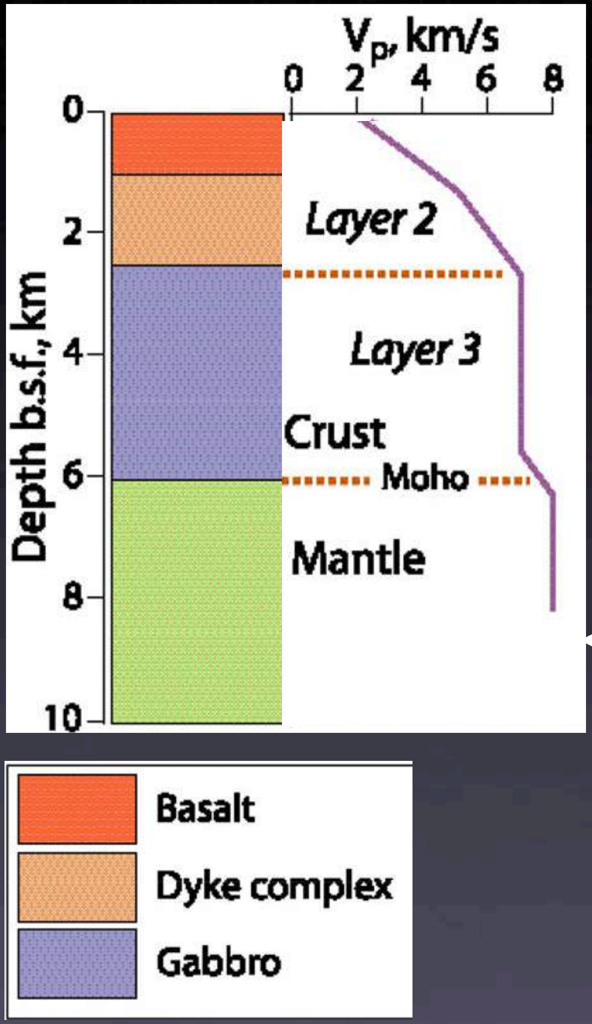
1962 : H. Hess (The History of Ocean Basins)



Hess, 1962

« Mid-ocean ridges represent the rising limbs of mantle-convection cells..... Convective flow comes right through to the surface, and the oceanic crust is formed by hydration of mantle material .... The water to produce serpentine of the oceanic crust comes from the mantle.... »

1962-1972 : MAGMATISM



- mid-ocean ridges are volcanic chains
- the mantle melts as it rises to the ridge*
- the ocean crust is made of basaltic rocks

Vine and Matthews, 1963
Green and Ringwood, 1967….
Several geophysical (heat flow, gravity, seismics, magnetics) and sampling cruises…….

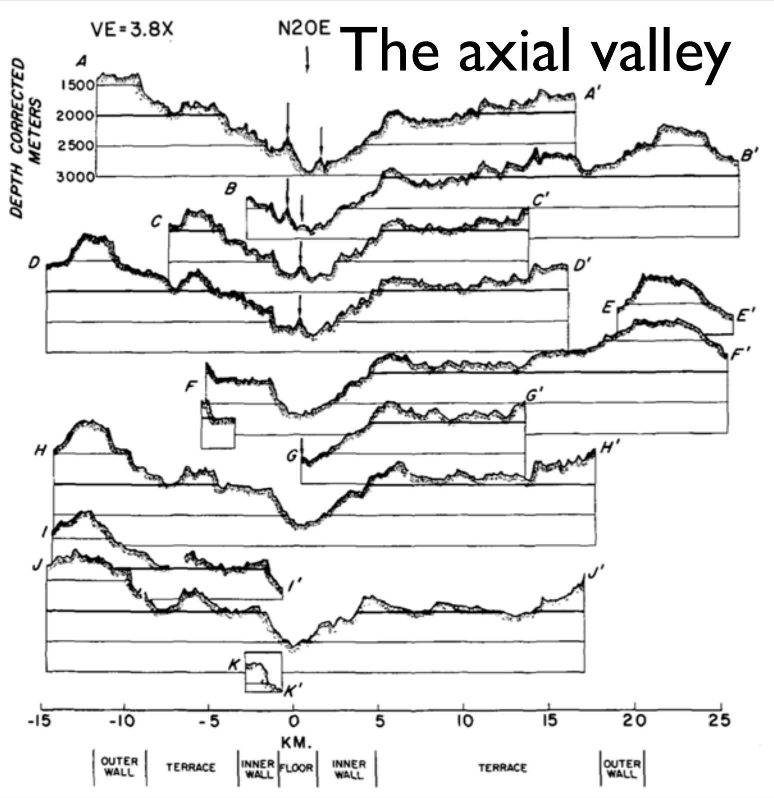
….The 1972 Penrose field conference on ophiolites

* in the 80s and 90s ridge melting models, predicting parent MORB composition and crustal thickness as a function of mantle composition and temperature (McKenzie, Grove, White, Langmuir….)

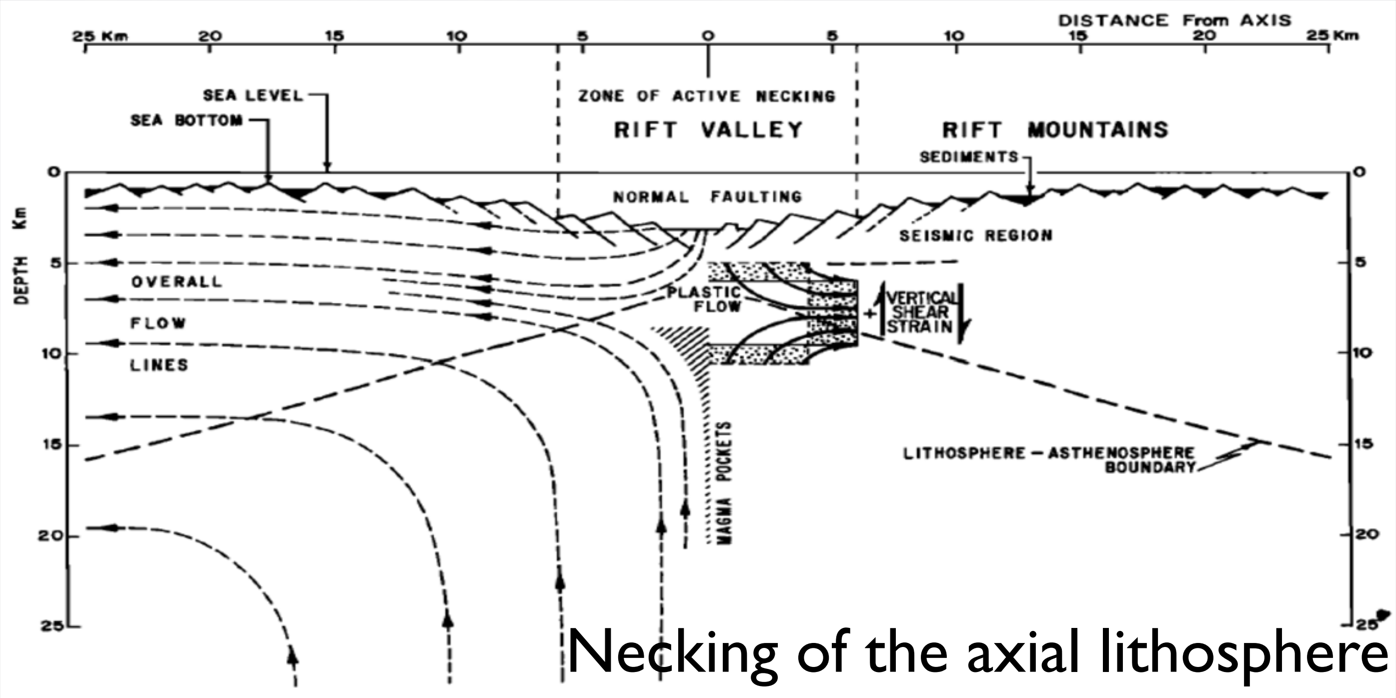
1973-1978 (the FAMOUS years)
TECTONICS

the Mid-Atlantic Ridge has an axial valley produced by tectonic extension of the AXIAL LITHOSPHERE

Needham and Francheteau, 1974
Macdonald et al., 1975

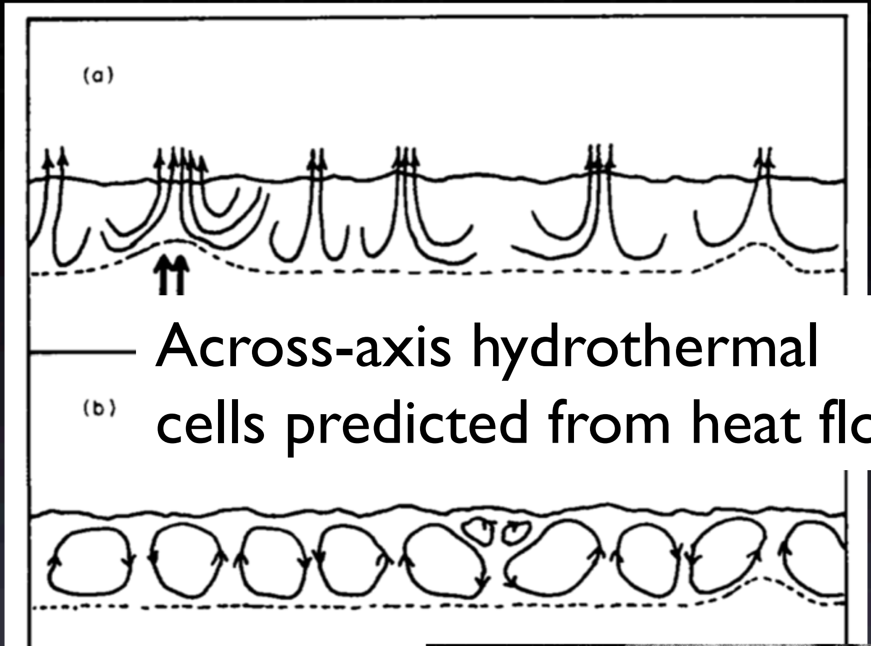

The axial valley

Tapponnier and Francheteau, 1978


Necking of the axial lithosphere

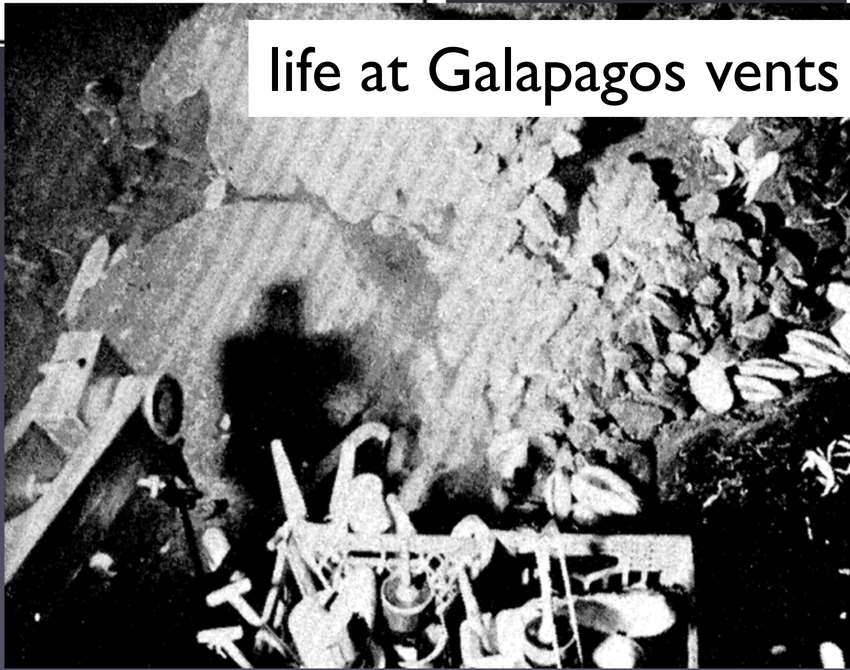
1972-1979 : HYDROTHERMALISM

Chemiosynthetic life, heat and chemical transfers from solid Earth to Ocean



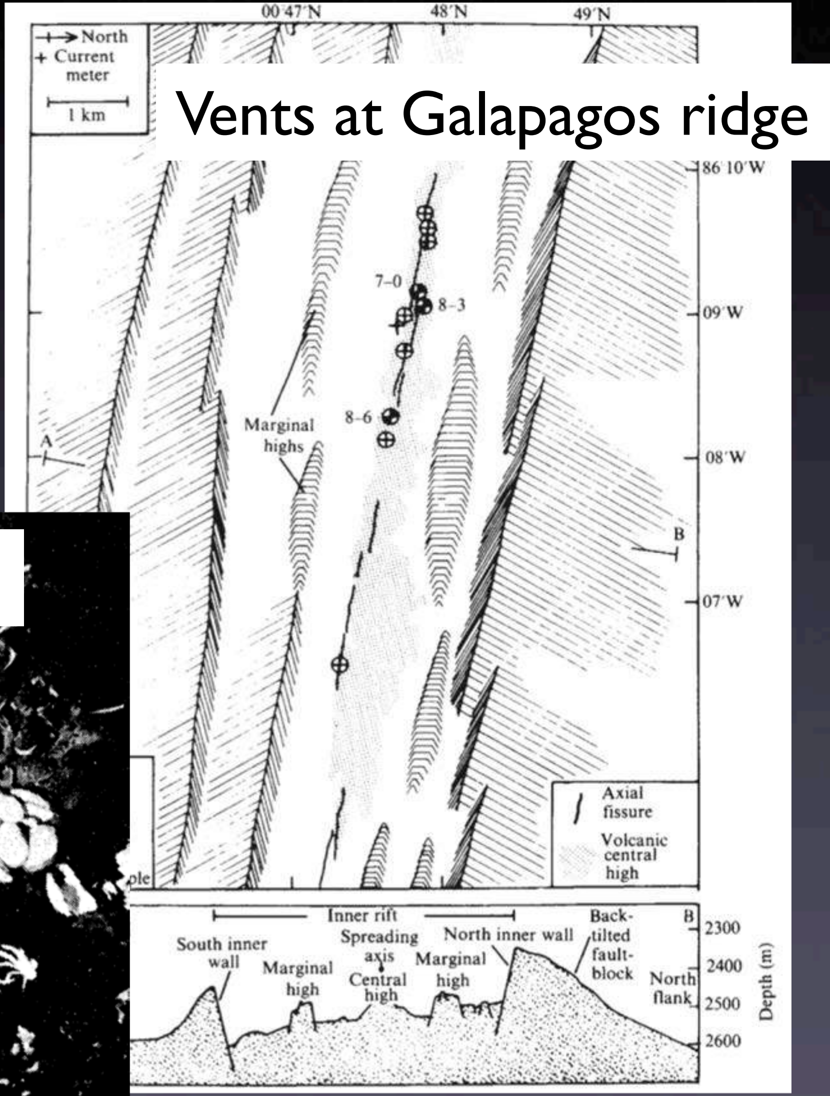
Across-axis hydrothermal cells predicted from heat flow

Lister, 1972



life at Galapagos vents

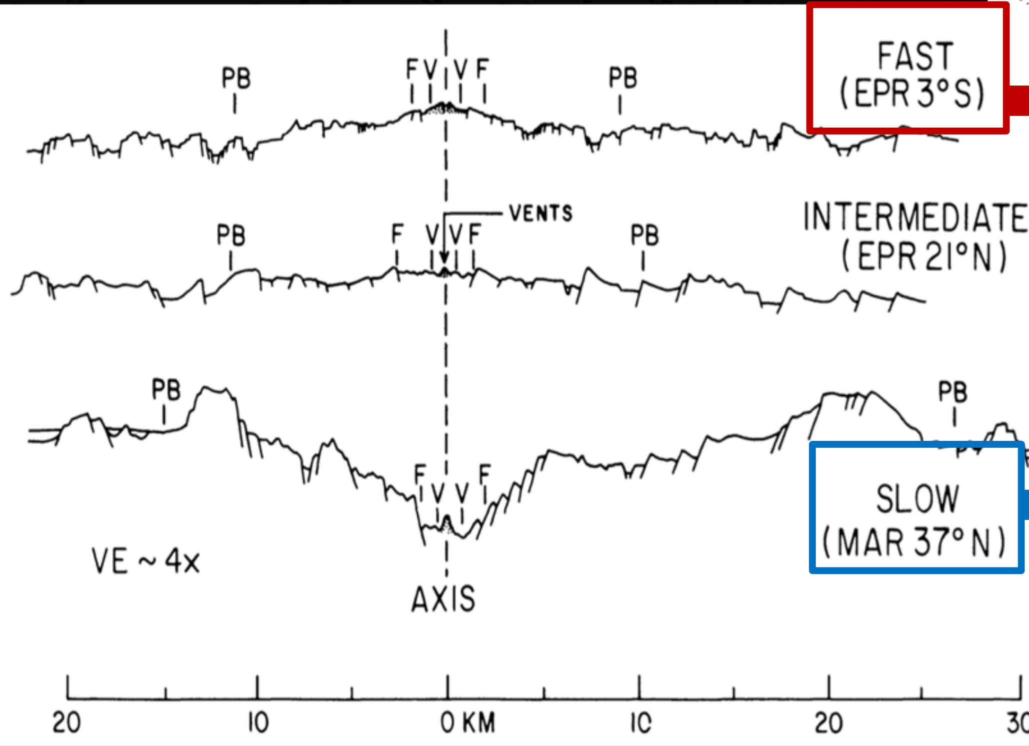
Corliss et al., 1979



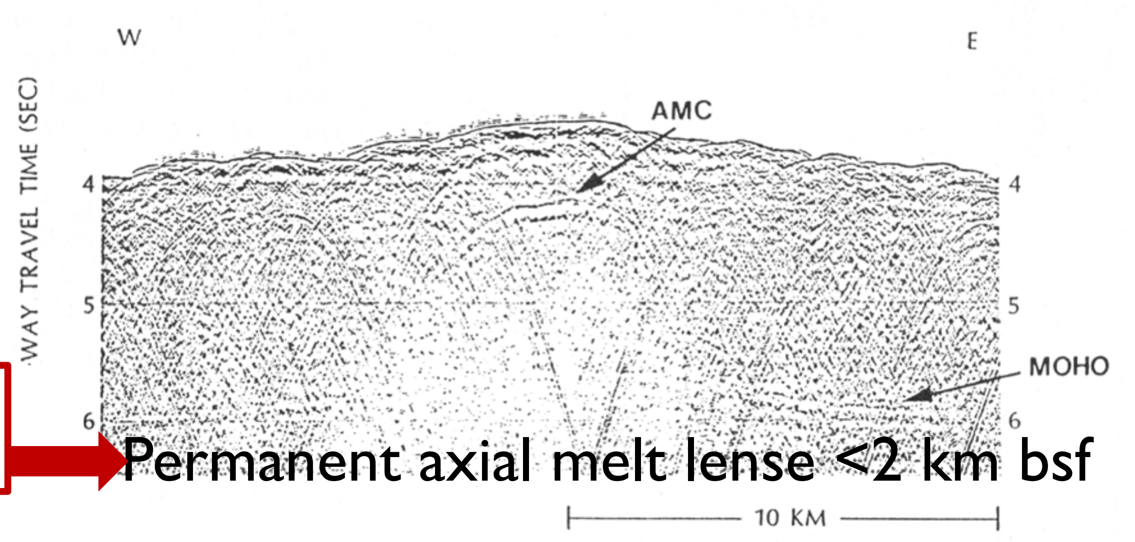
Vents at Galapagos ridge

Weiss et al., 1977

1978-1990 : spreading rate control on axial topography and axial lithosphere thickness

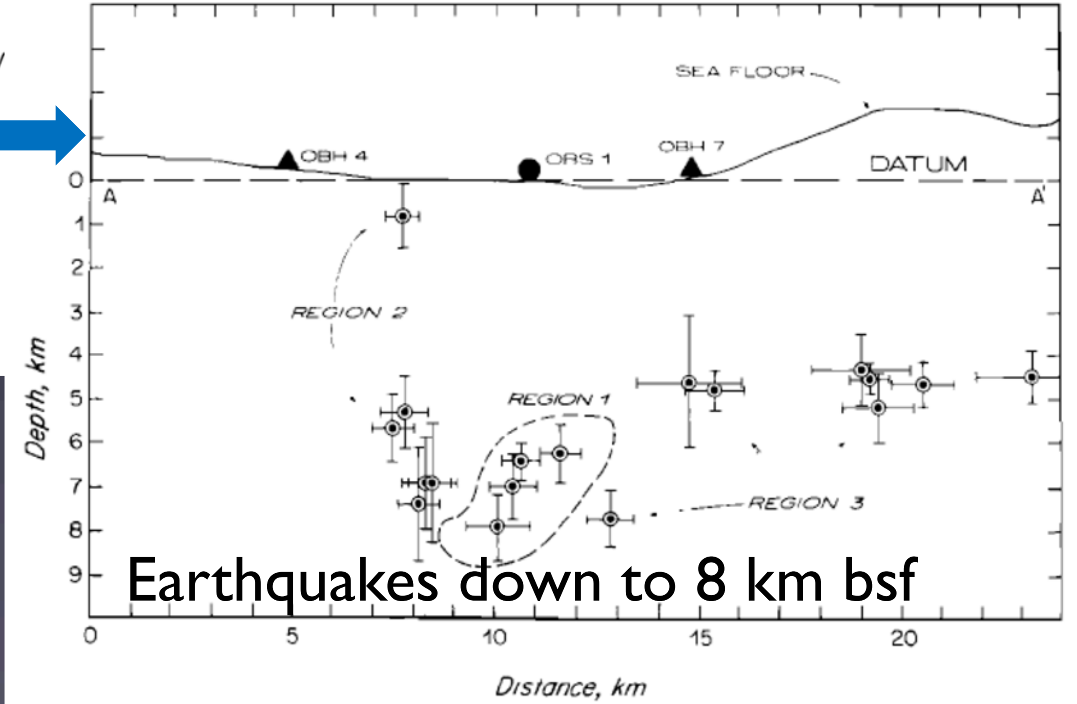


Macdonald, 1982



Permanent axial melt lense <2 km bsf

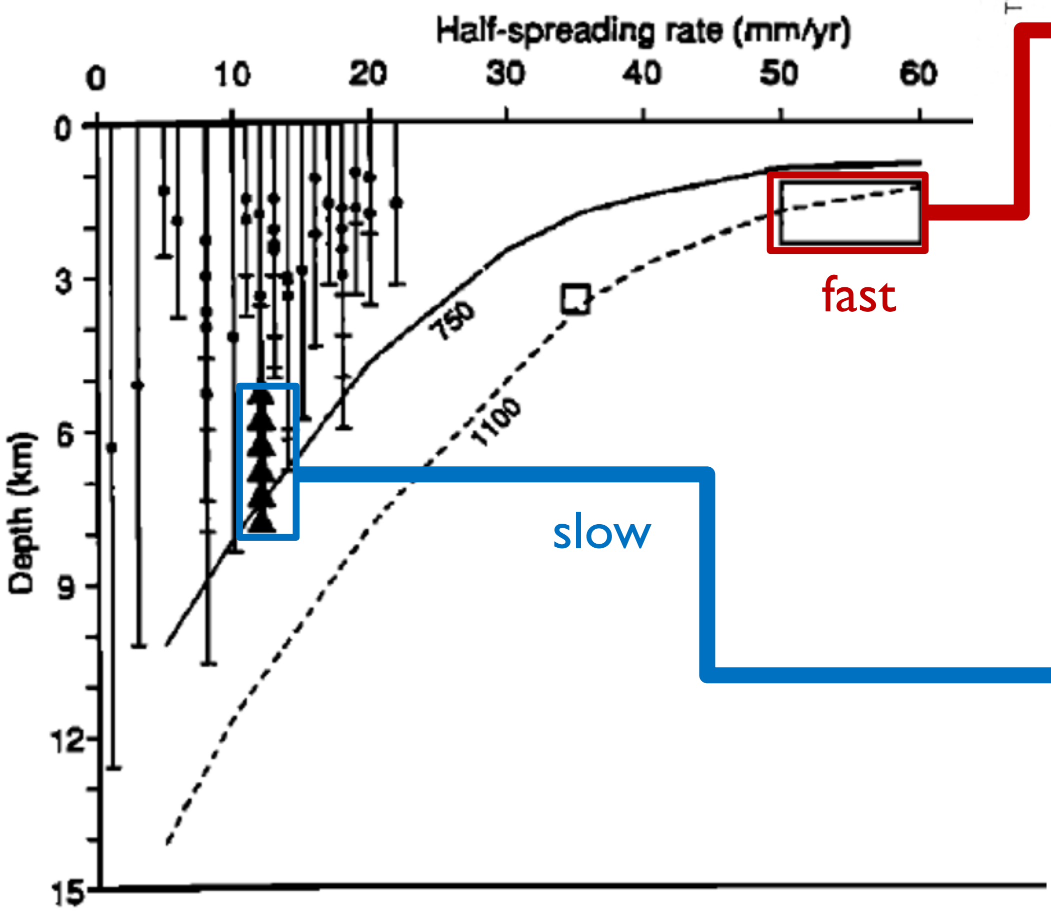
Detrick et al., 1987 / East Pacific Rise 9°N



Earthquakes down to 8 km bsf

Toomey et al., 1985 / Mid-Atlantic Ridge 23°N

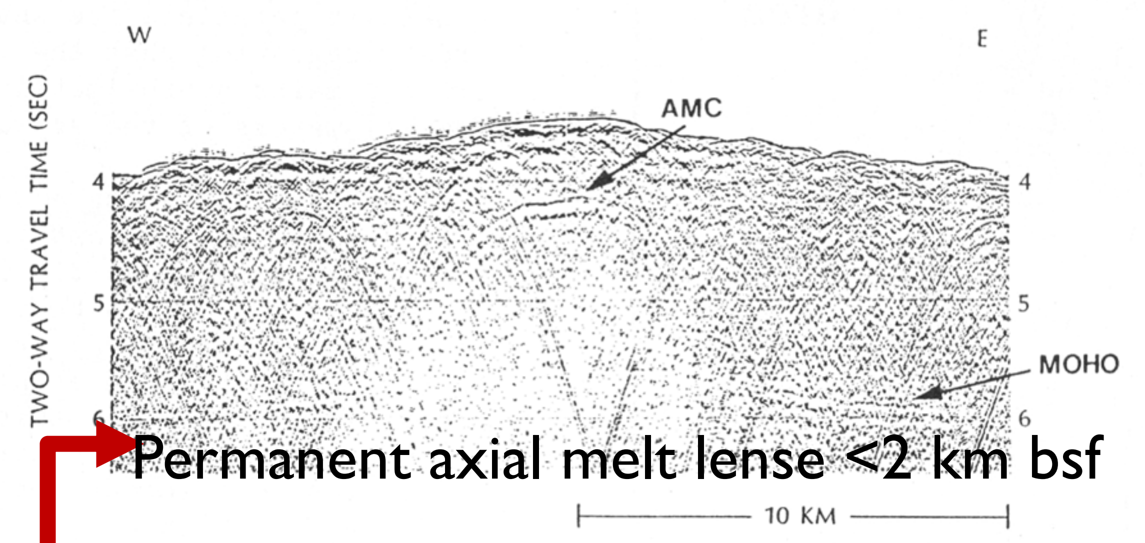
1978-1990 : spreading rate control on axial topography and axial lithosphere thickness



fast

slow

Chen and Morgan, 1990



Permanent axial melt lense <2 km bsf

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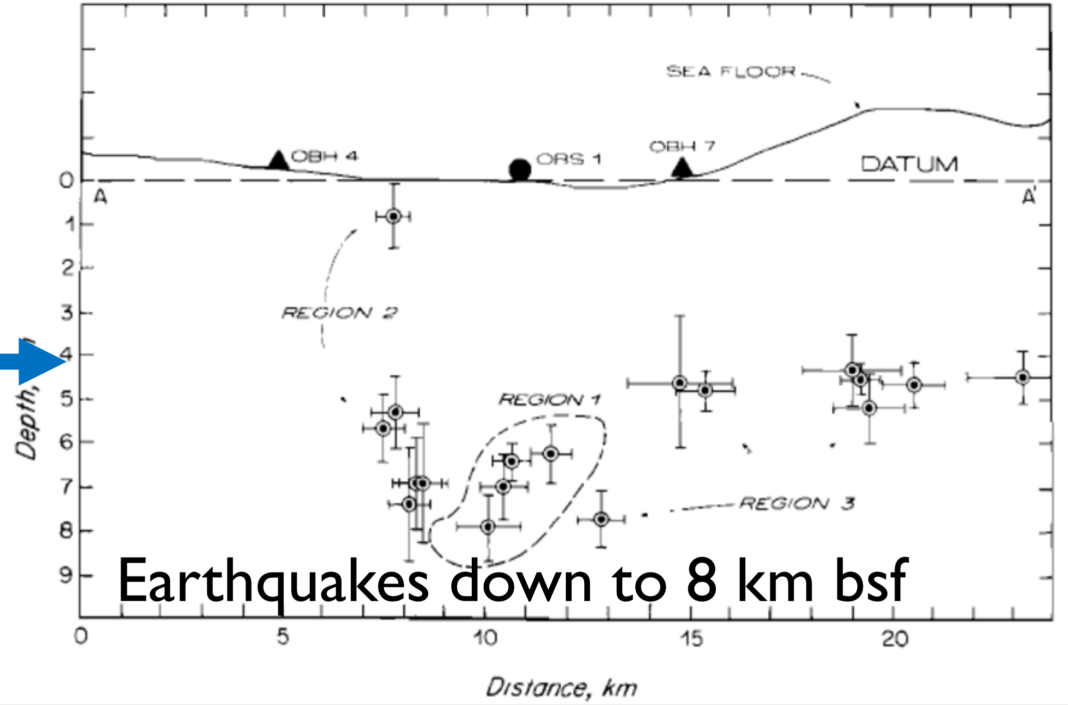
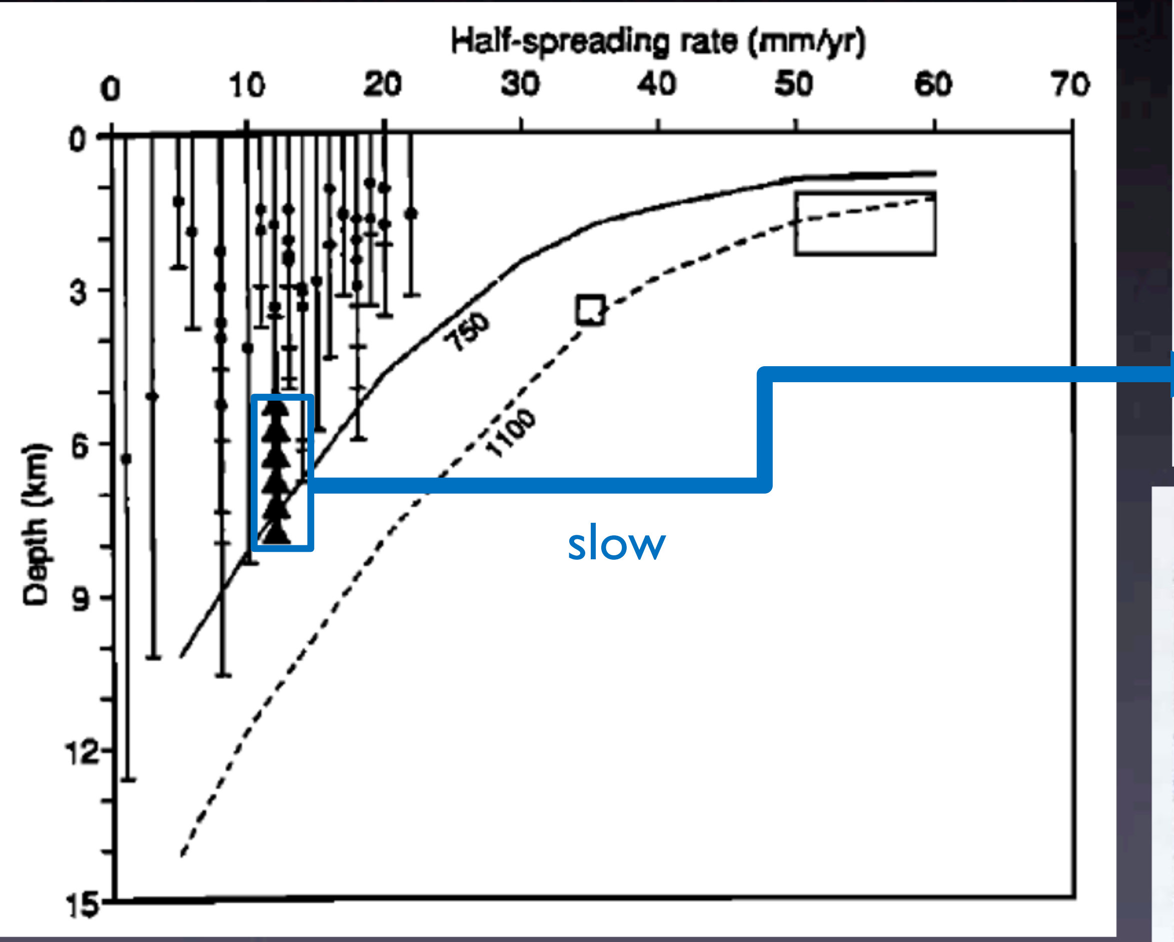


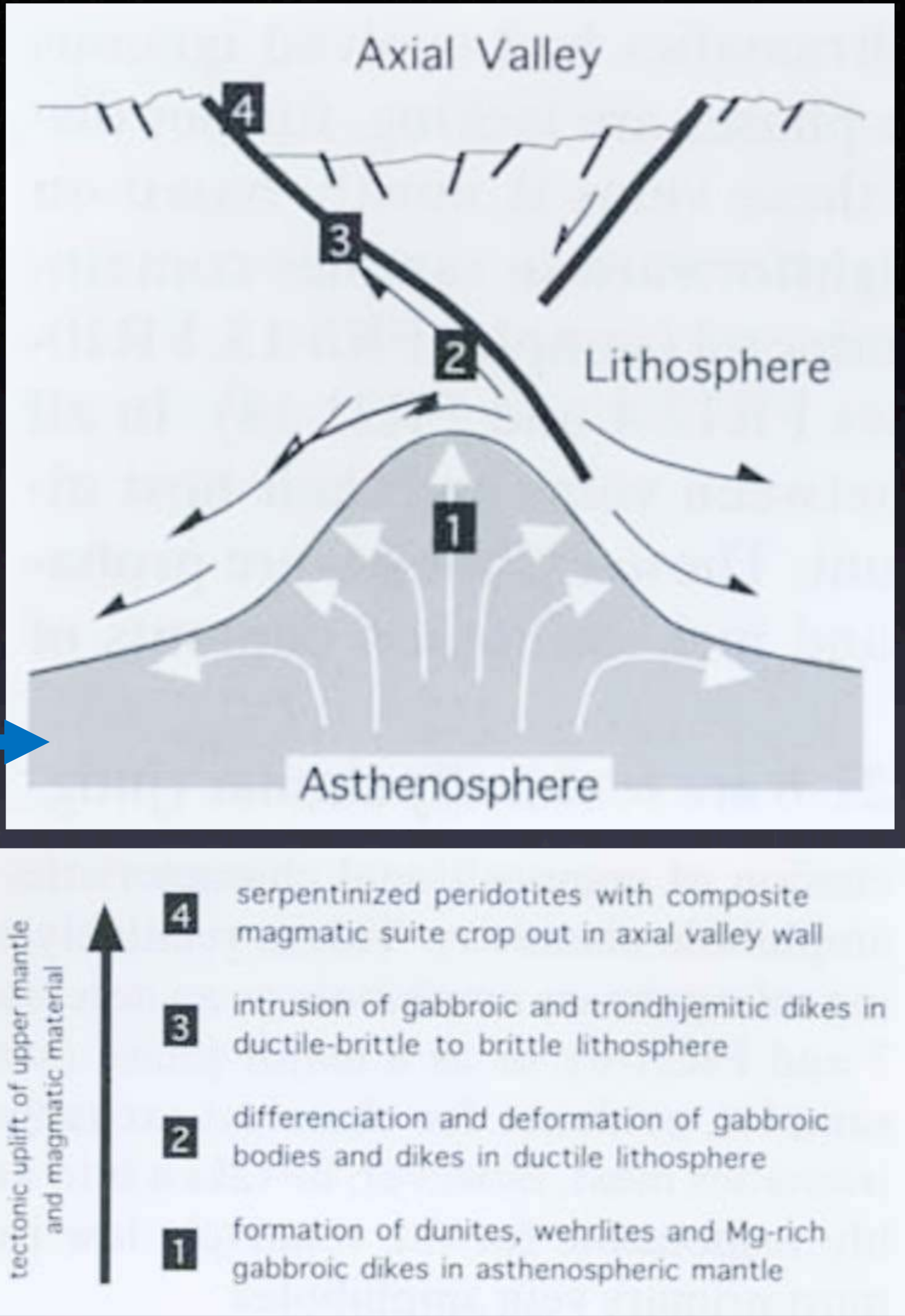
Earthquakes down to 8 km bsf

Toomey et al., 1985 / Mid-Atlantic Ridge 23°N

SLOW RIDGES: mantle-derived serpentinized peridotites and gabbros are exhumed in footwall of axial normal faults that cut through the thick axial lithosphere



Chen and Morgan, 1990



4 serpentinized peridotites with composite magmatic suite crop out in axial valley wall

3 intrusion of gabbroic and trondhjemitic dikes in ductile-brittle to brittle lithosphere

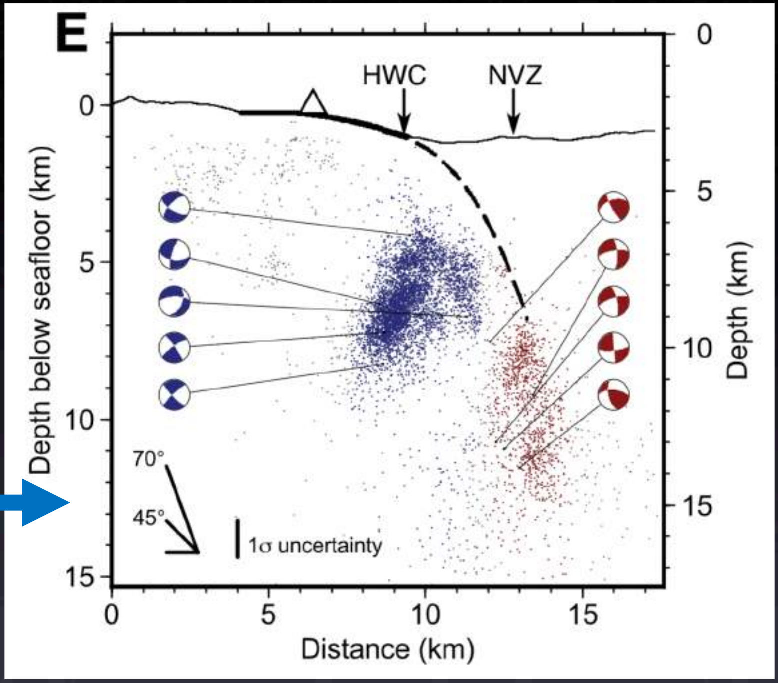
2 differenciation and deformation of gabbroic bodies and dikes in ductile lithosphere

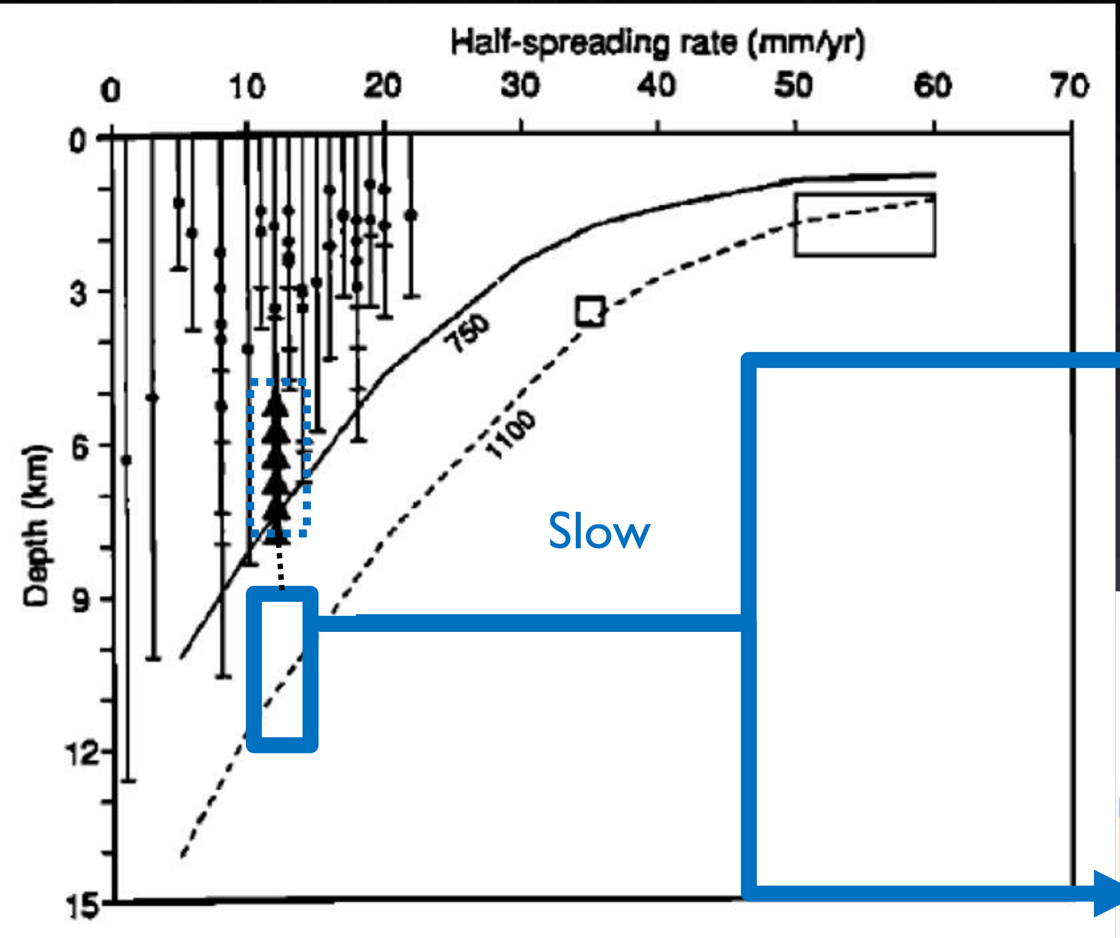
1 formation of dunites, wehrlites and Mg-rich gabbroic dikes in asthenospheric mantle

Cannat, 1993; figure from Cannat and Casey, 1995

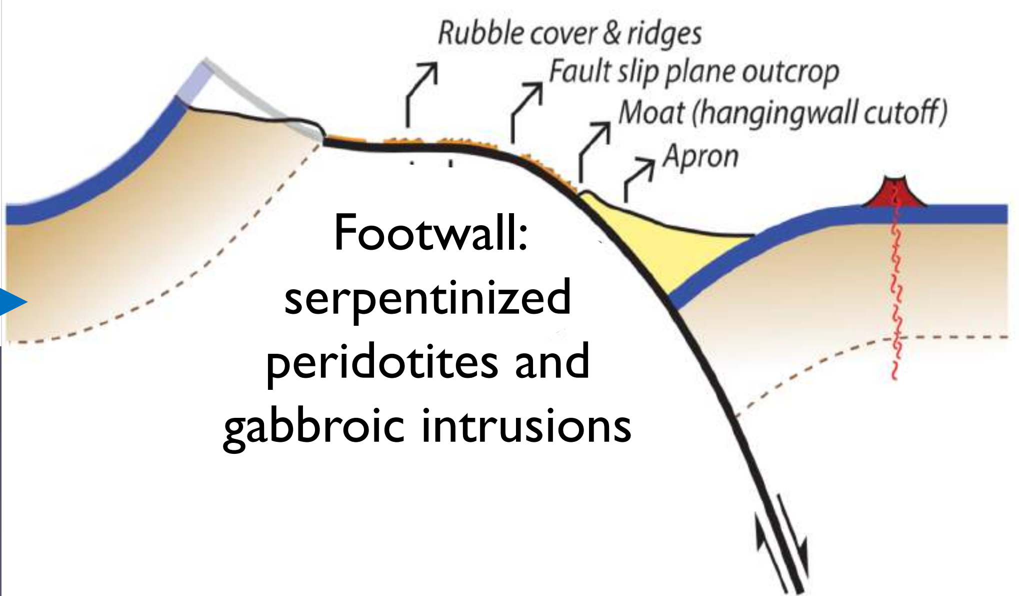
SLOW RIDGES: faults that exhume mantle-derived ultramafic rocks and gabbros are convex-downward detachments

Parnell-Turner et al., 2017
Mid-Atlantic Ridge 13°N





Chen and Morgan, 1990

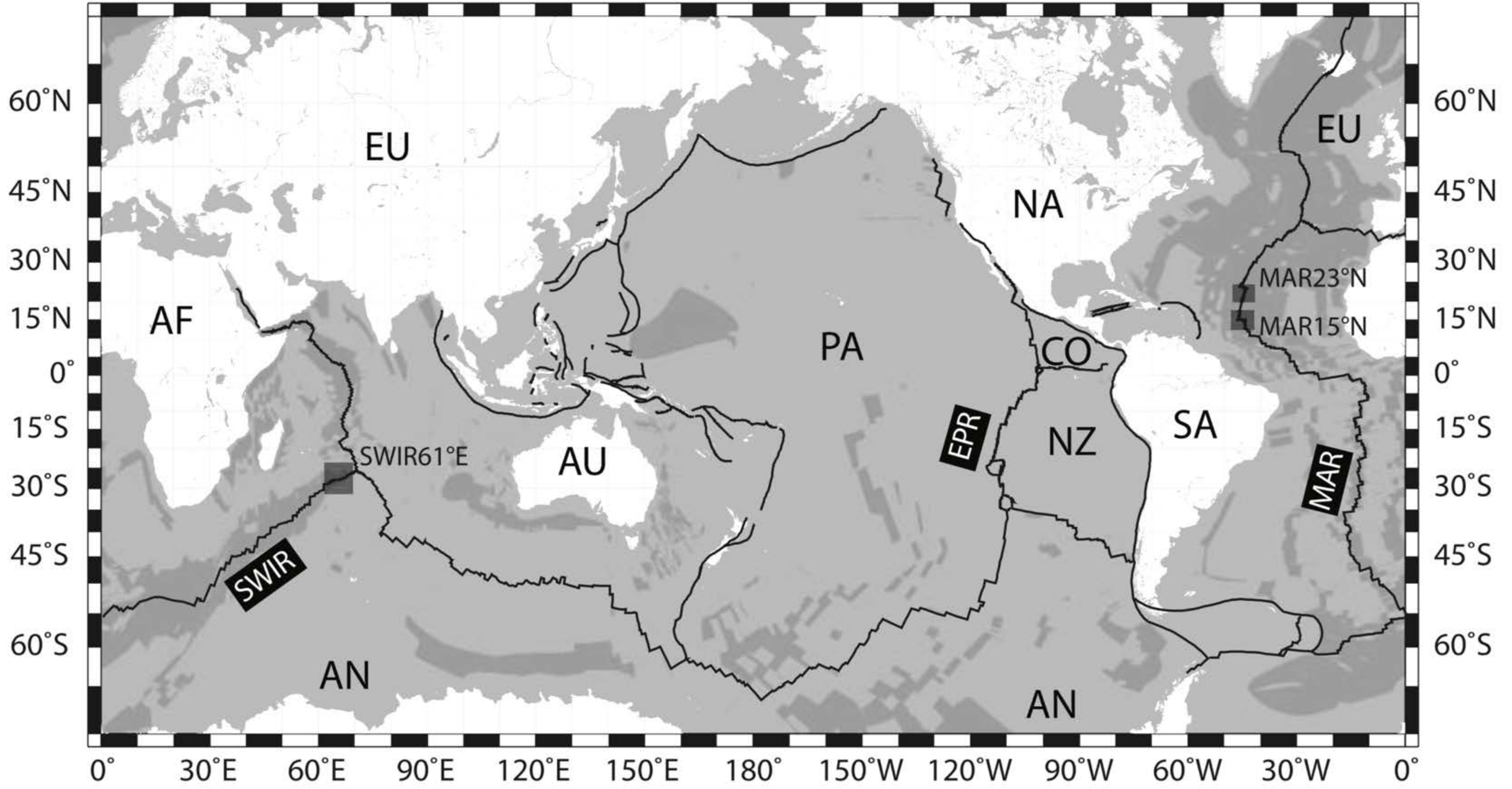


Footwall: serpentinized peridotites and gabbroic intrusions

Cann et al., 1997; Lavier et al., 1999; Smith et al., 2006; deMartin et al., 2007; MacLeod et al., 2009; figure in Escartin et al., 2017

SLOW RIDGES: Ultramafic seafloor (footwall of detachment faults) represents ~25% of seafloor accreted at rate < 40 mm/year

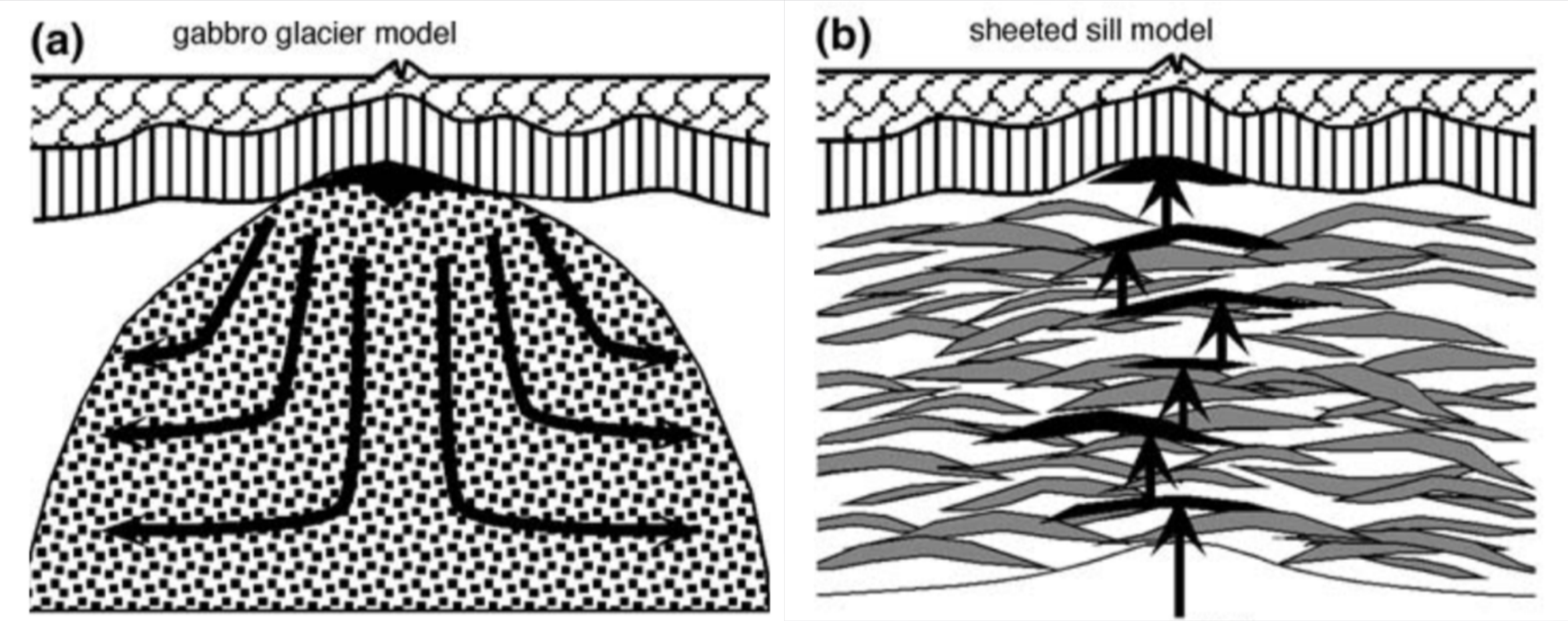
(darker grey areas in map)



Cannat et al., 1995; Escartin et al., 2008; figure in Cannat et al., 2010 after Bird 2003

FAST RIDGES: we still do not really understand how the lower magmatic crust crystallizes..

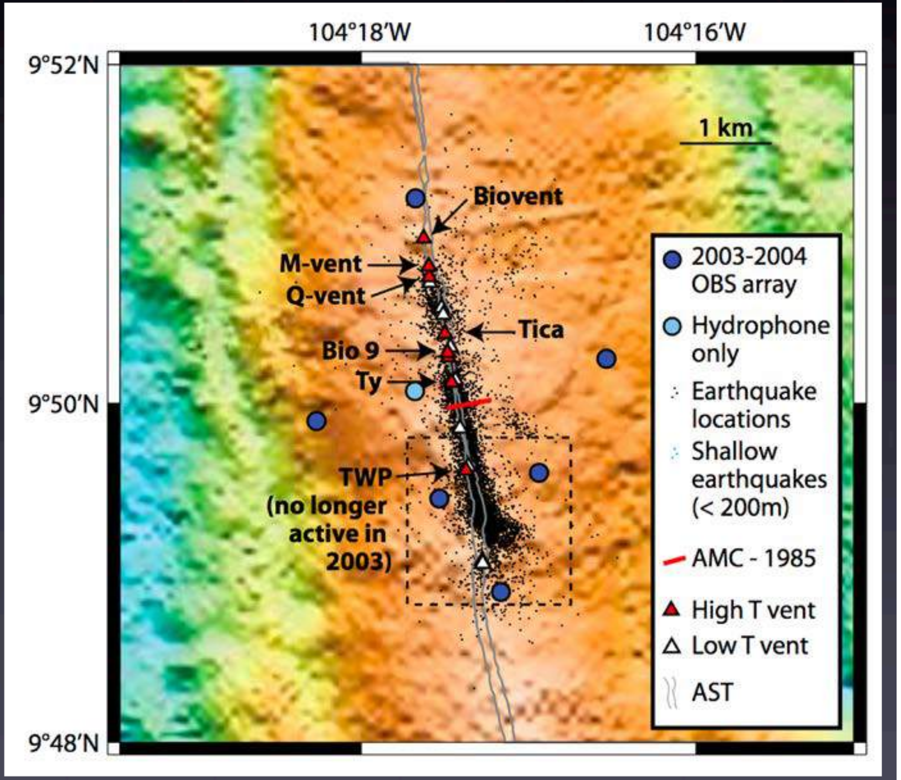
Two end-member across-axis models : b, or mix of a+b fit petrological data better… but the problem is how to extract the latent heat from deep into the axial melt-mush zone

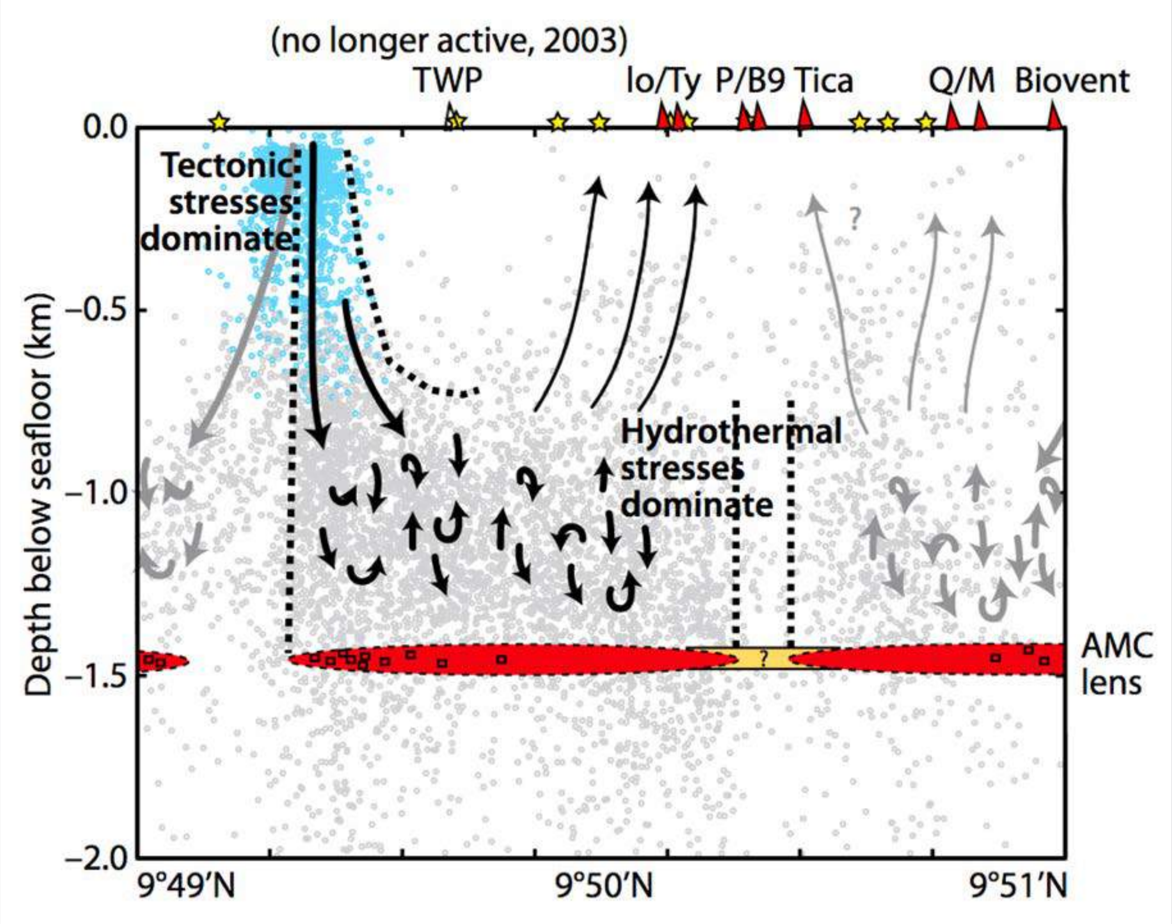


Sketches from Perk et al., 2007 after Phipps Morgan and Chen, 1993, Quick and Dellinger, 1993, Kelemen et al. , 1997 and others....

FAST RIDGES: hydrothermal systems operate ALONG AXIS in the narrow domain where most eruptions occur. They appear coupled with magma dynamics in AMC lens

East Pacific Rise 9°N

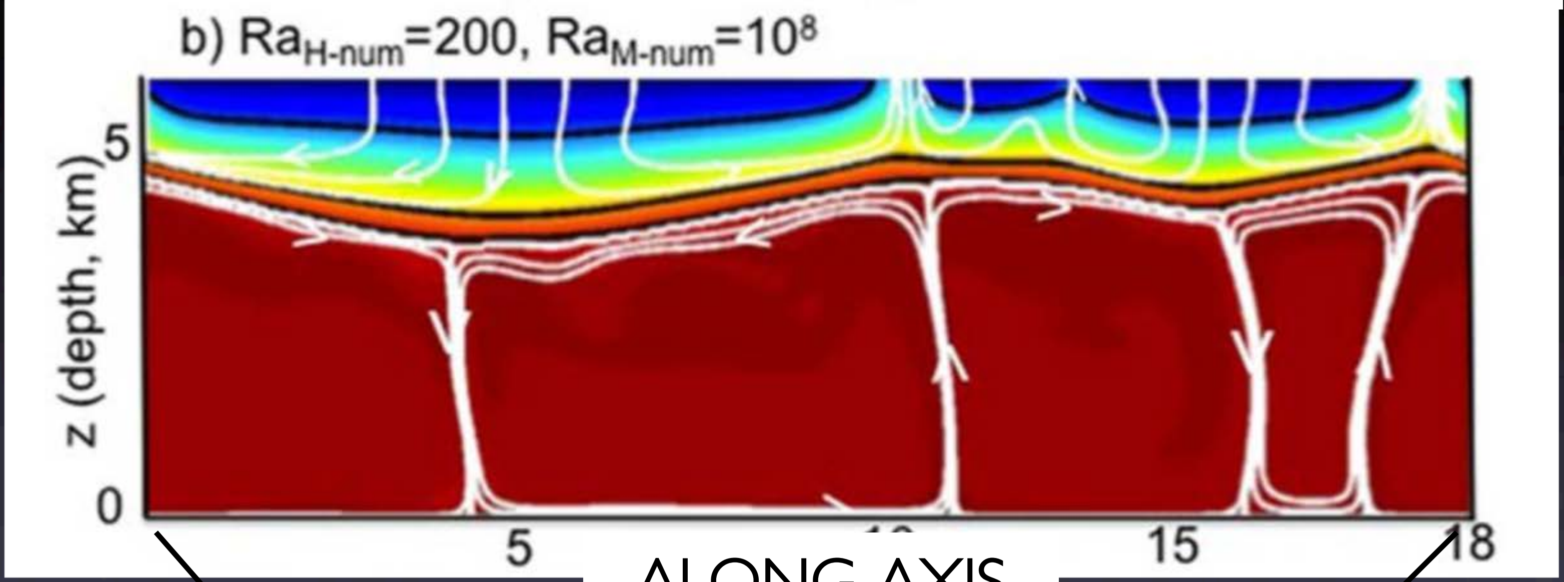




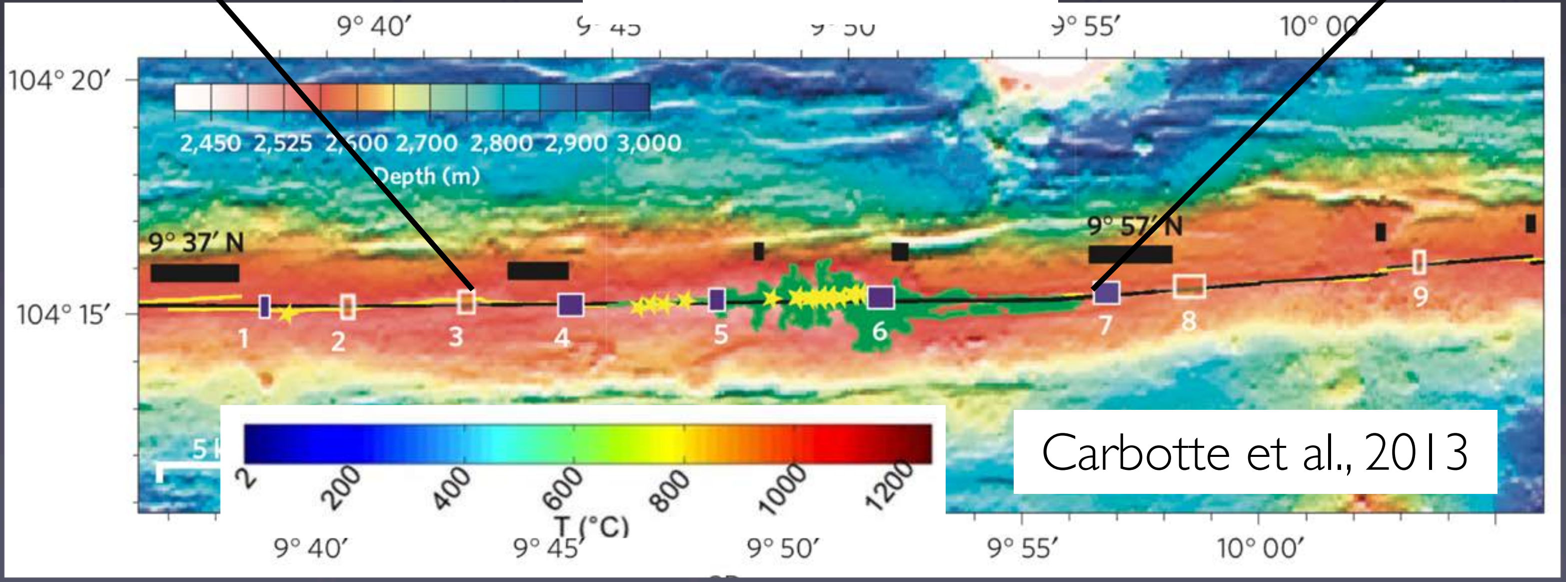
Figures in Tolstoy et al., 2008; Lowell et al., 2012; Wilcock et al., 2009; Carbotte et al., 2013; Marjanovic et al., 2017

FAST RIDGES: could heat extraction from crystallizing lower crust result from ALONG-AXIS coupling of magmatic and hydrothermal convections in narrow melt rich axial domain ?

Fontaine et al., 2017



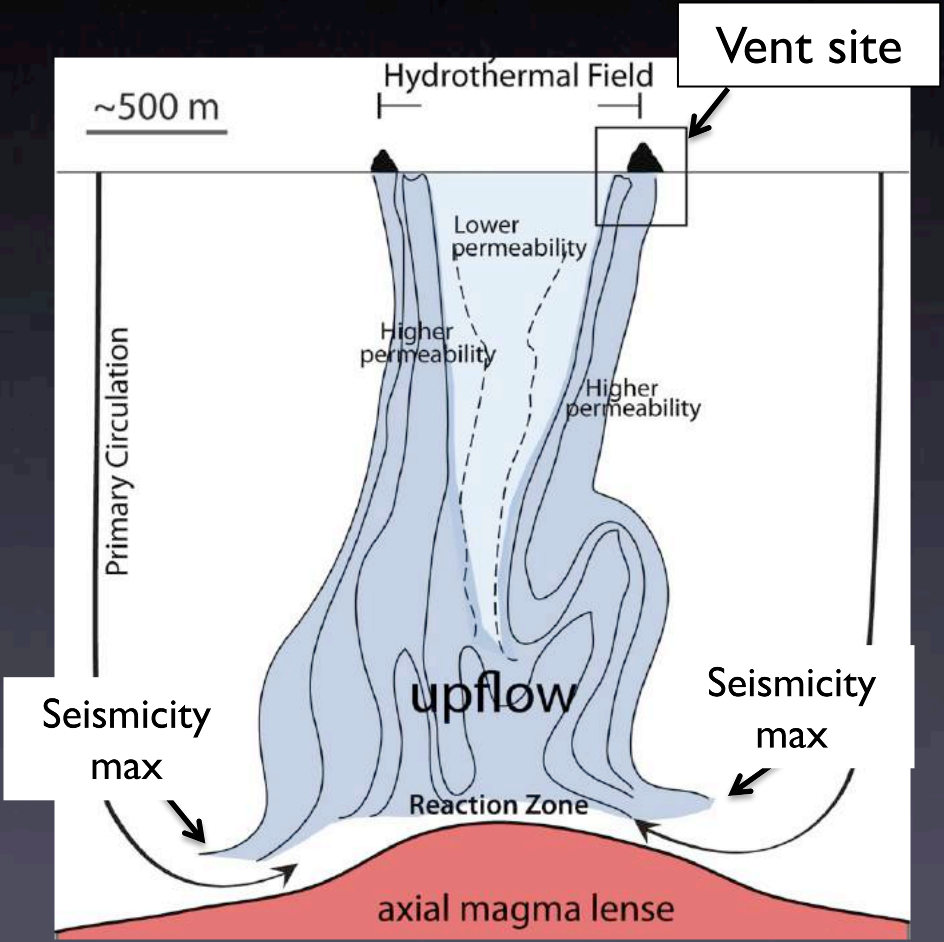
ALONG-AXIS



Carbotte et al., 2013

FAST & SLOW RIDGES: hydrothermal fluxes are poorly constrained and partitionned into focused (<<) and diffuse (>>) vents.

Ex: 9°50’N EPR smokers 40±15 MW / diffuse 300±200 MW *

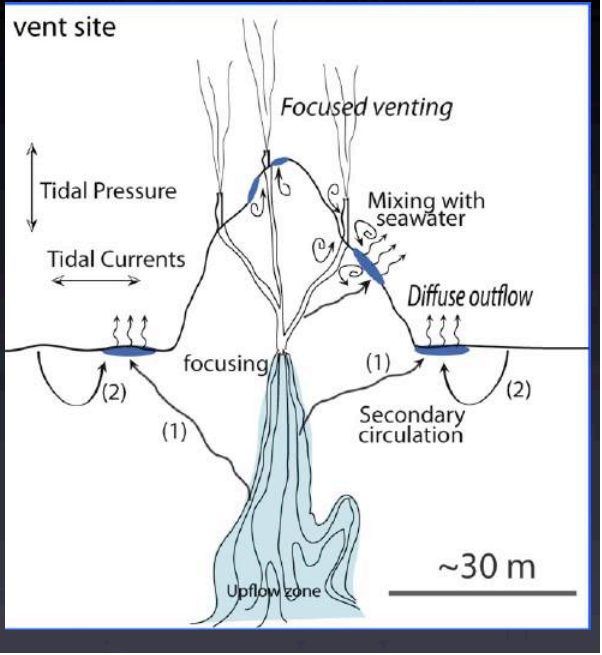


Vent site

Seismicity max

Seismicity max

Tivey, 2007; Humphris and Cann, 2000; * Ramondenc et al., 2006; Barreyre et al., 2012

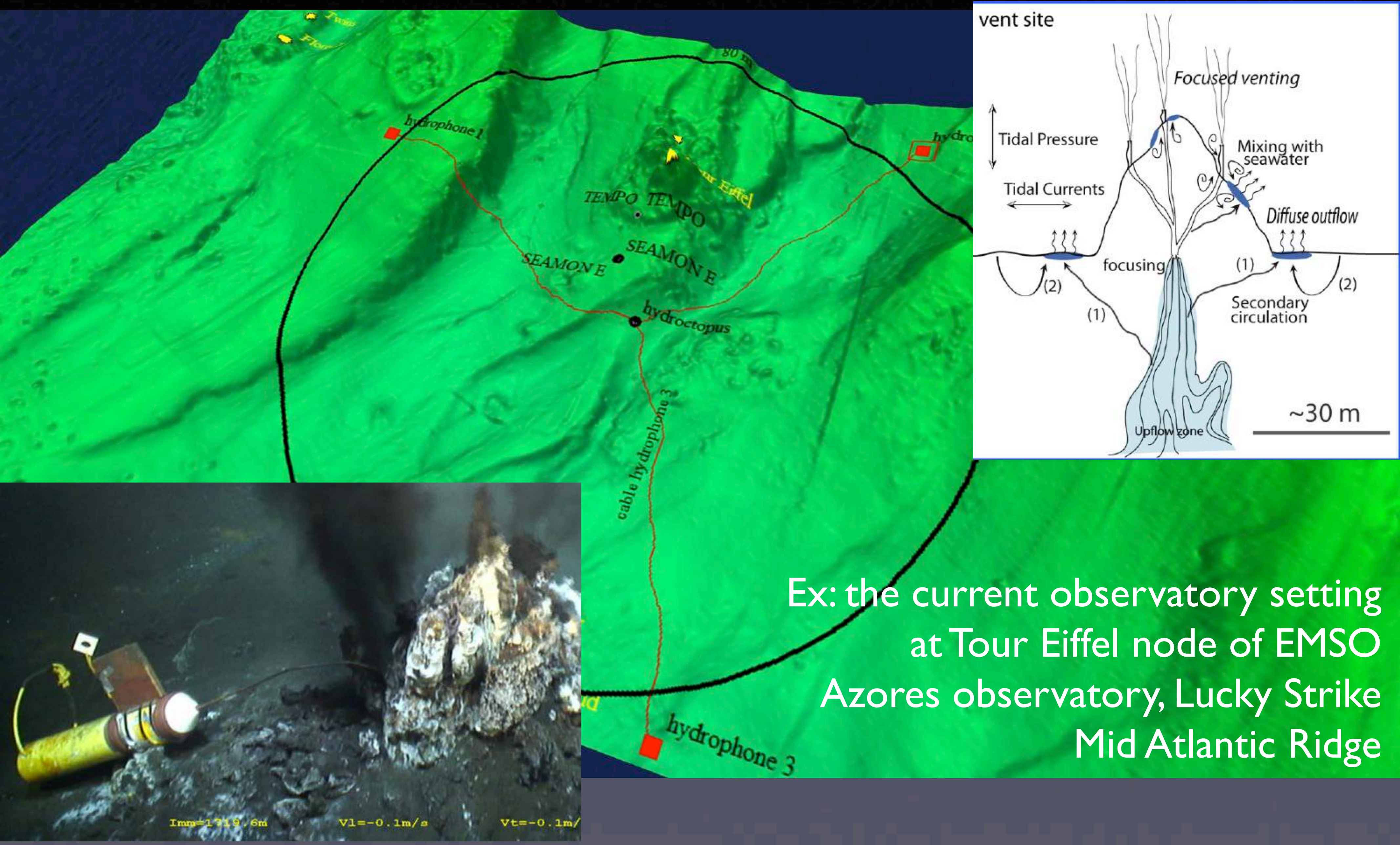


Focused vent (black smoker)

Diffuse vents (where life is)

@ CNRS-Ifremer. Lucky Strike vent field Mid Atlantic Ridge

FAST & SLOW RIDGES: observatories to monitor primary and secondary hydrothermal circulations and their impact on life and heat+chemical transfers to ocean



Ex: the current observatory setting
at Tour Eiffel node of EMSO
Azores observatory, Lucky Strike
Mid Atlantic Ridge

FAST & SLOW RIDGES: a diversity of endmember hydrothermal fluids

	T °C	pH	H2 mmol/kg	CH4 mmol/kg	CO2 mmol/kg	Fe µmol/kg
Lucky Strike	330	3	0.02-0.7	0.5-0.9	13-28	30-862
Rainbow	365	2.8	16	2.5	16	24000
Lost City	90	11	0.5-15	1-2	$<10^{-3}$	-

Charlou et al., 2002; Kelley et al., 2005

SLOW RIDGES: non magma-fueled ultramafic-hosted vents have low fluxes (heat, volume) of high pH serpentinization-derived fluids, yet they appear to cause the precipitation of large volumes of carbonates …

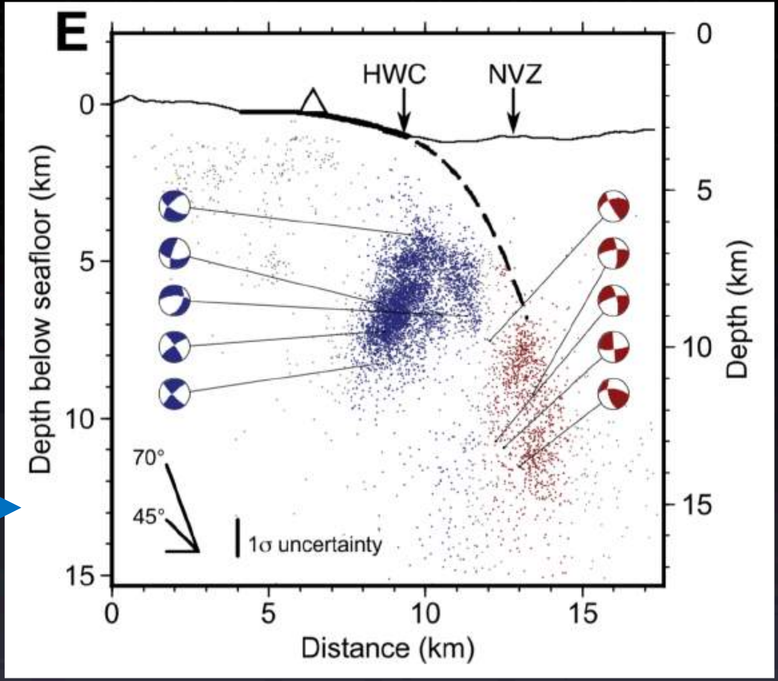
$$\begin{gathered} HCO_3^- + Ca^{2+} + OH^- \\ Mg^{2+} + 2\,OH^- \\ \Downarrow \\ CaCO_3 + H_2O \\ Mg(OH)_2 \end{gathered}$$

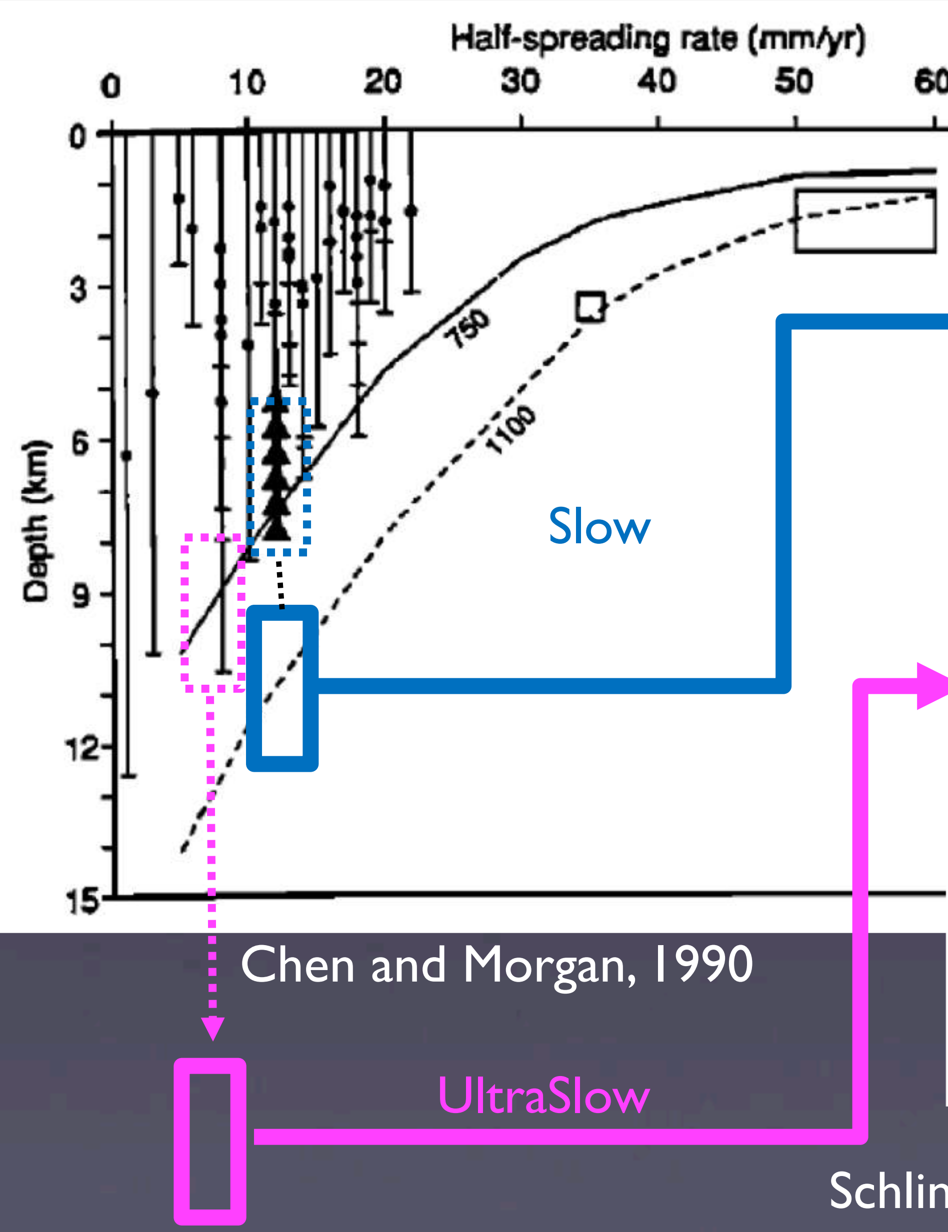
@ CNRS-Ifremer.
Old City vent field
Southwest Indian
Ridge

Ludwig et al., 2006; Kelley et al., 2005; Cannat et al., in prep.

ULTRASLOW RIDGES: a very thick axial seismogenic lithosphere

Parnell-Turner et al., 2017
Mid-Atlantic Ridge 13°N

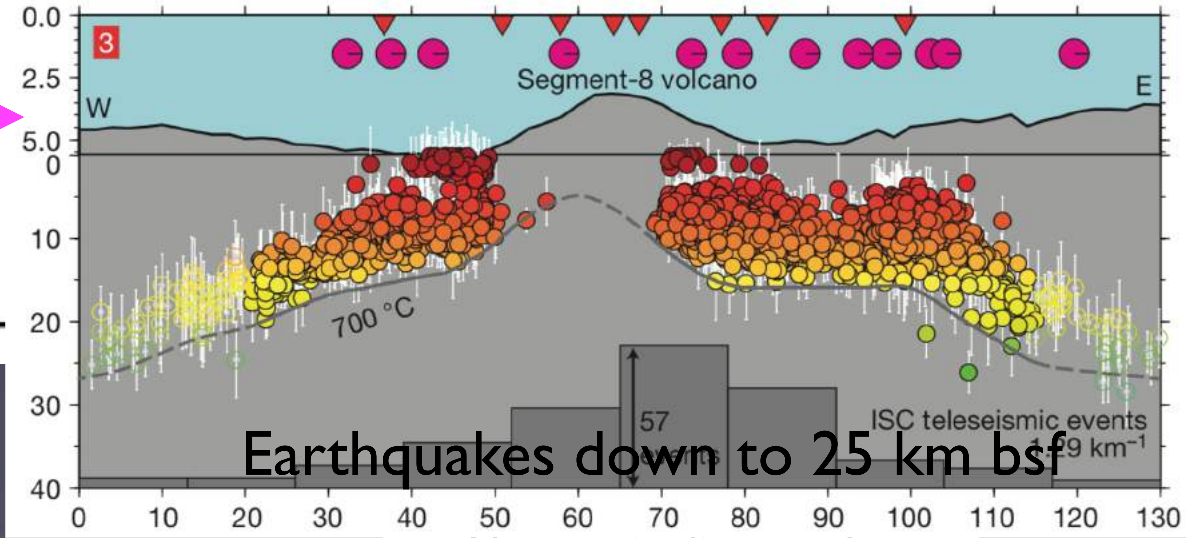




Slow

Chen and Morgan, 1990

UltraSlow



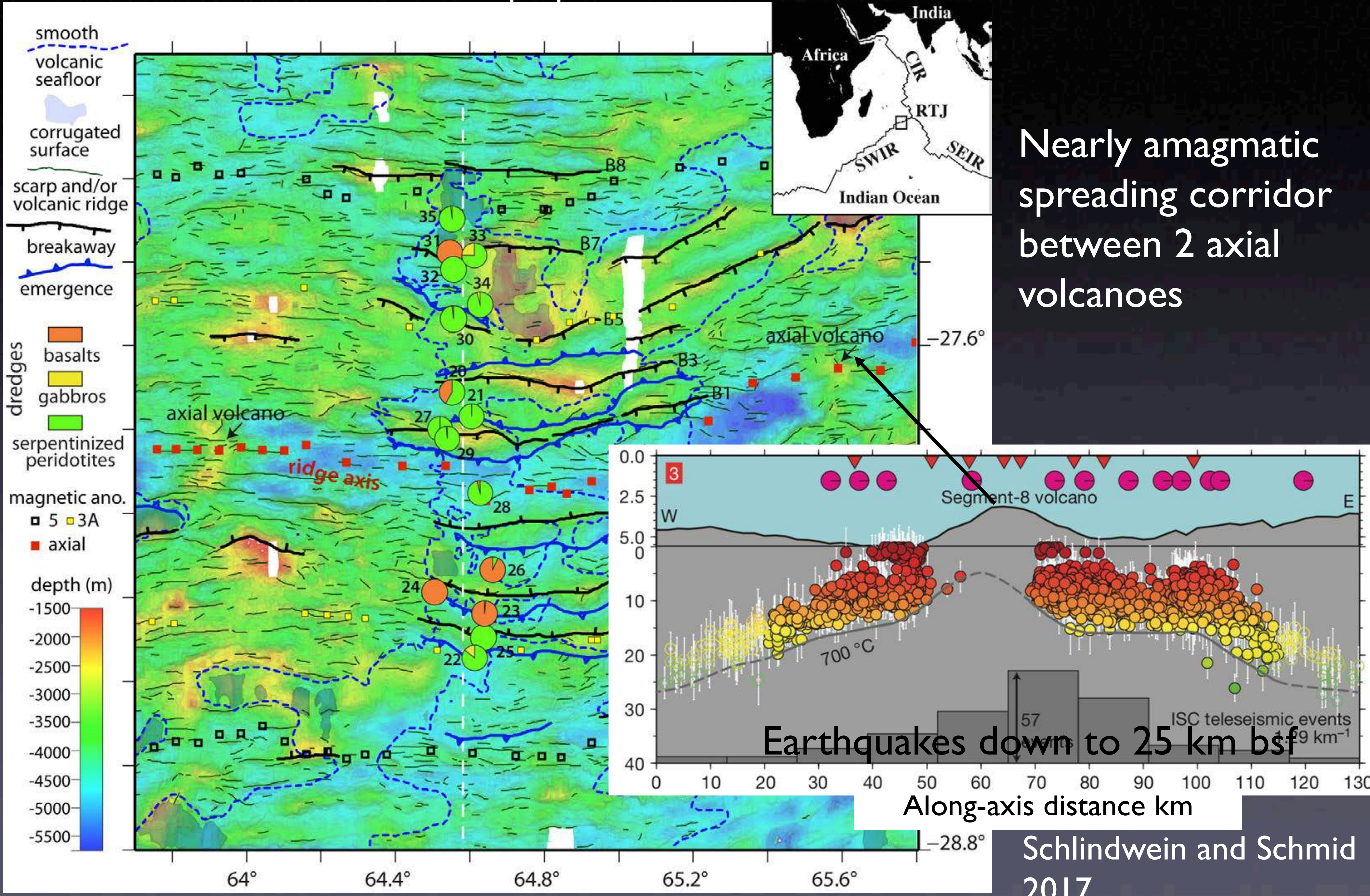
Earthquakes down to 25 km bsf

Along-axis distance km

Schlindwein and Schmid 2017/ Southwest Indian Ridge 66°E

ULTRASLOW RIDGES: the melt-poor eastern SWIR laboratory

Sauter et al., 2013; Cannat et al., in prep.



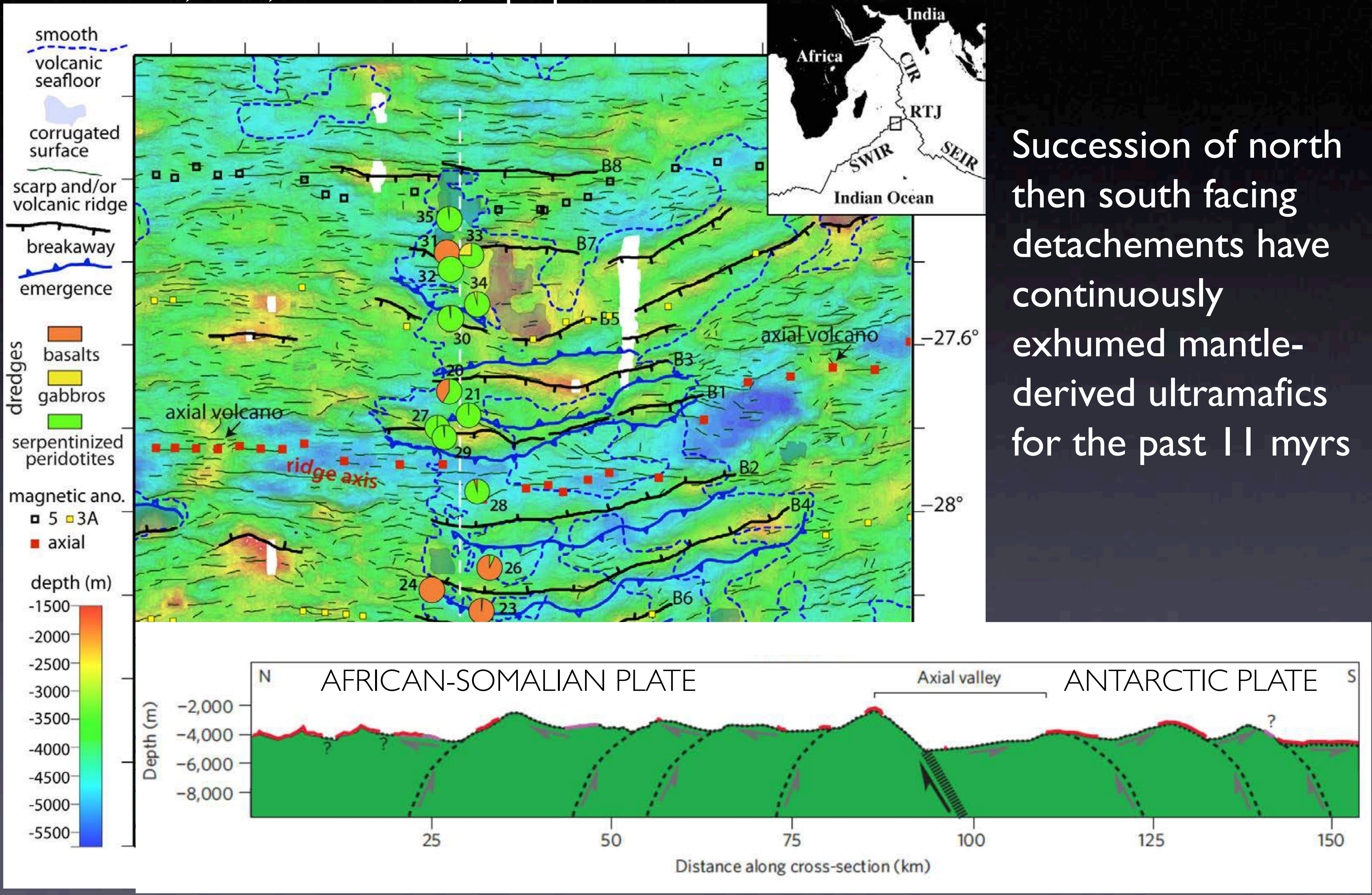
Nearly amagmatic spreading corridor between 2 axial volcanoes

Earthquakes down to 25 km bsf

Schlindwein and Schmid 2017

ULTRASLOW RIDGES: the melt-poor eastern SWIR laboratory

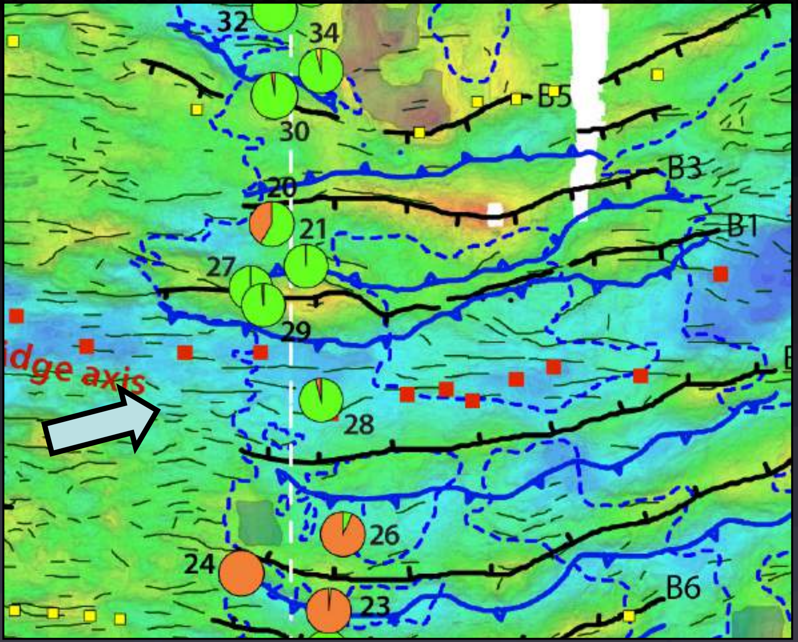
Sauter et al., 2013; Cannat et al., in prep.

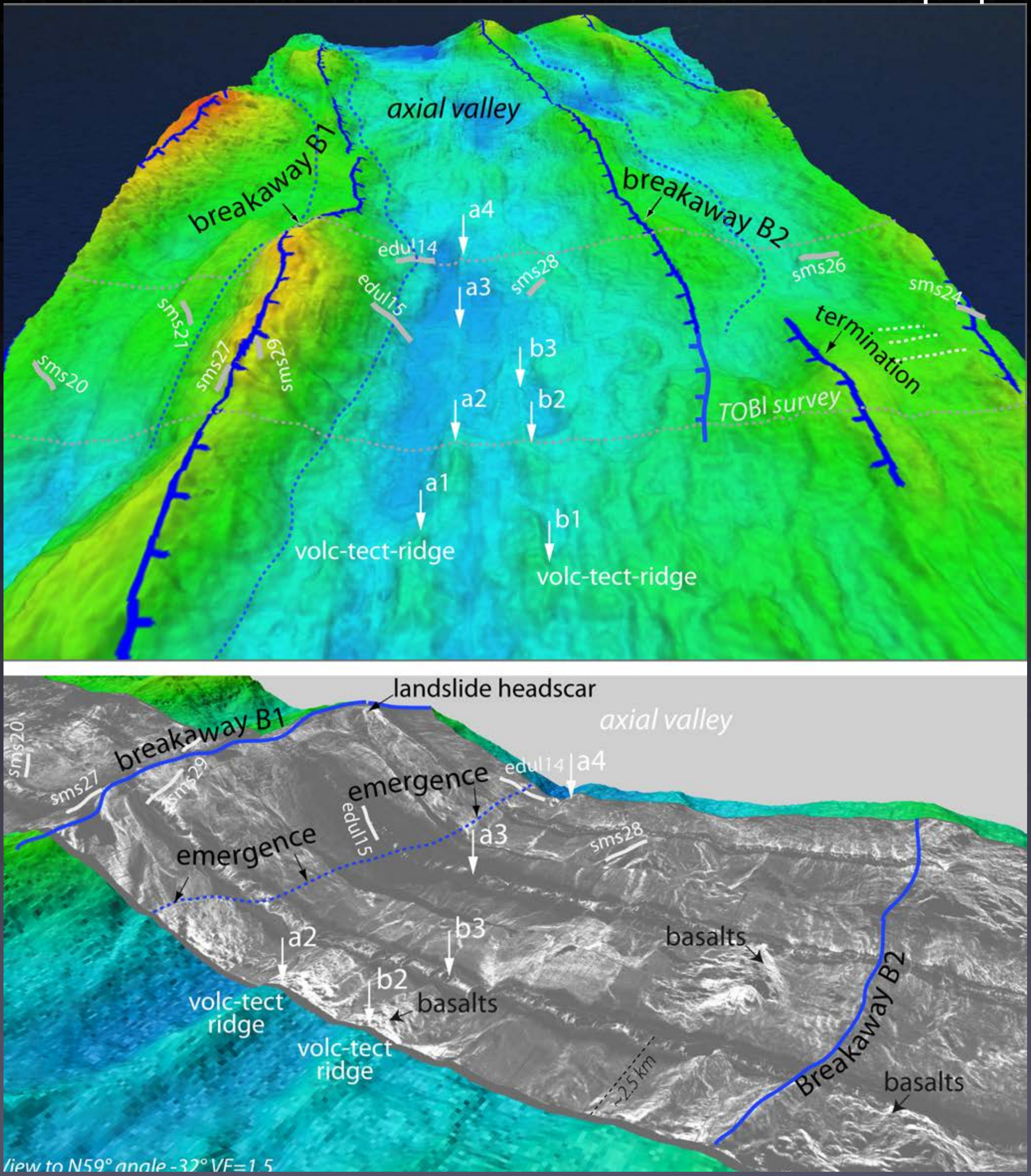


Succession of north then south facing detachements have continuously exhumed mantle-derived ultramafics for the past 11 myrs

ULTRASLOW RIDGES: the melt-poor eastern SWIR field laboratory

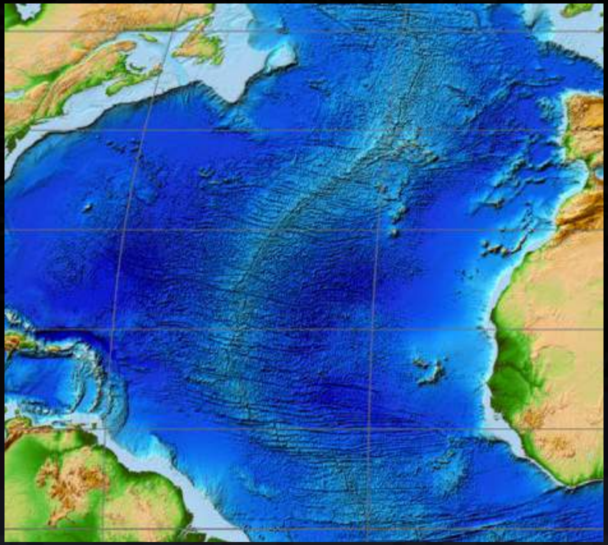
Sauter et al., 2013; Cannat et al., in prep.



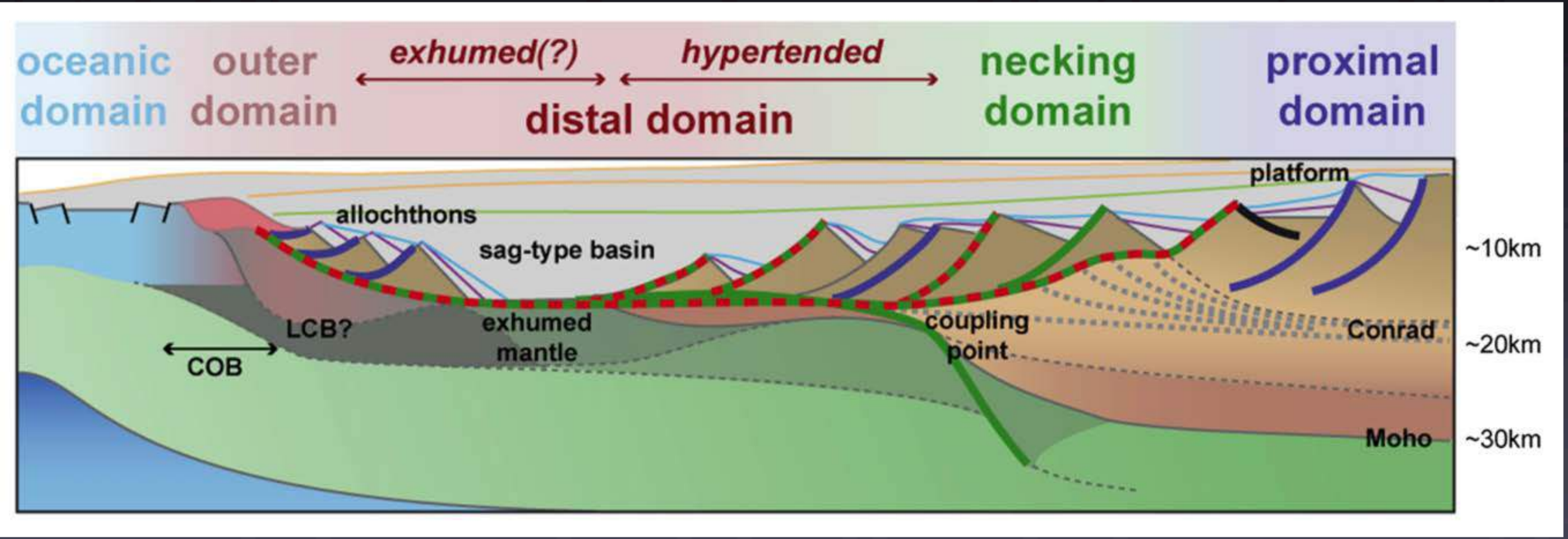


Active tectonic, hydrothermal (and sparse volcanic) processes at a melt-starved divergent plate boundary

mid-ocean ridge research perspectives (3)



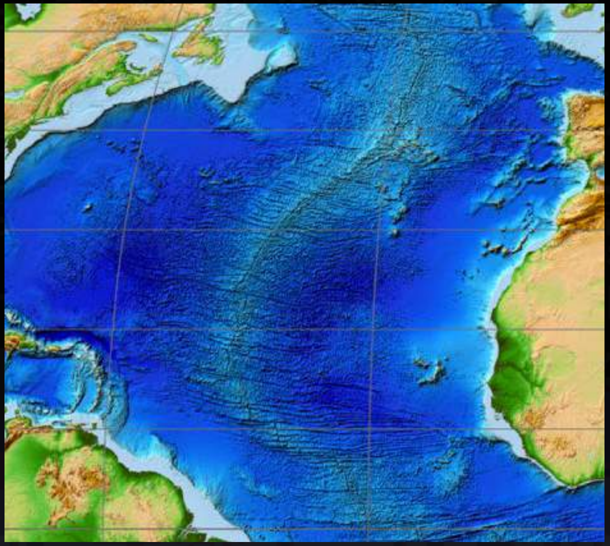
Develop comparative approaches (to mutual benefit) with distal divergent continental margins and initial oceanic crust



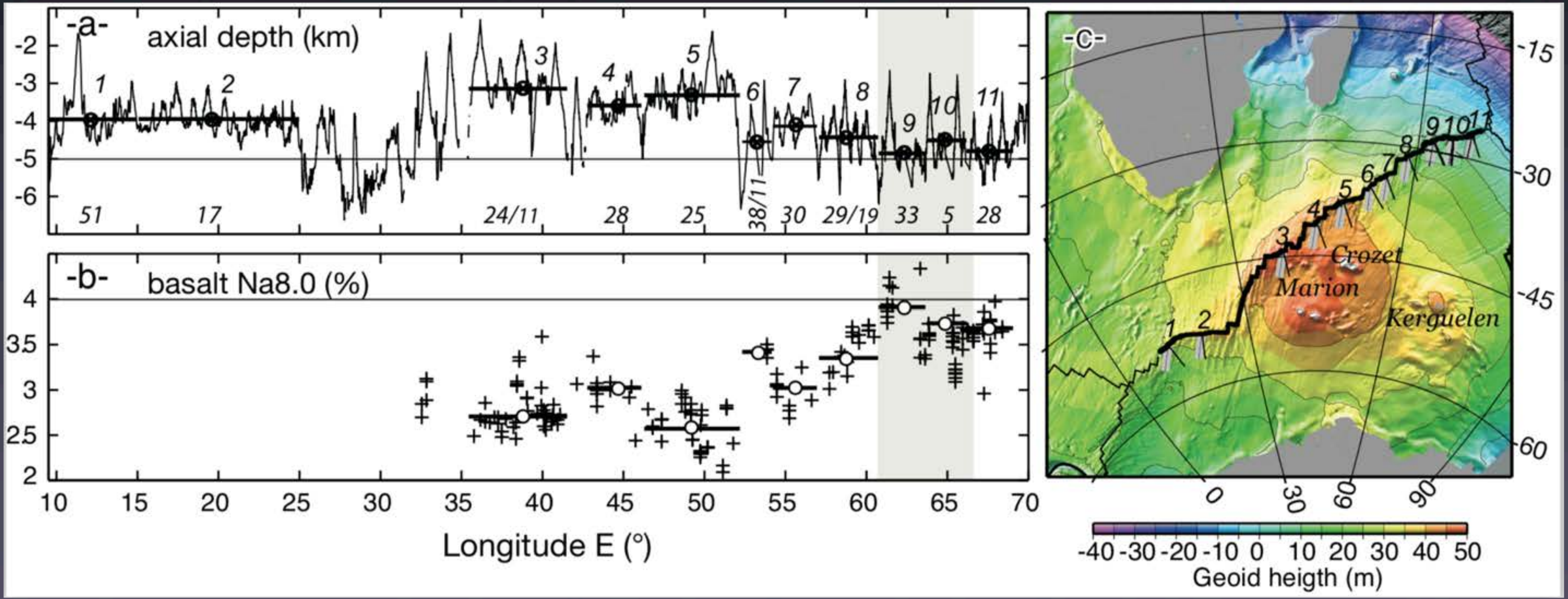
Péron-Pinvidic et al., 2013

Study the effect of variable melt supply, sediment thickness, mantle inheritance on tectonic-magmatic-hydrothermal interplays, crustal structure, depth, thermal regime

mid-ocean ridge research perspectives (2)

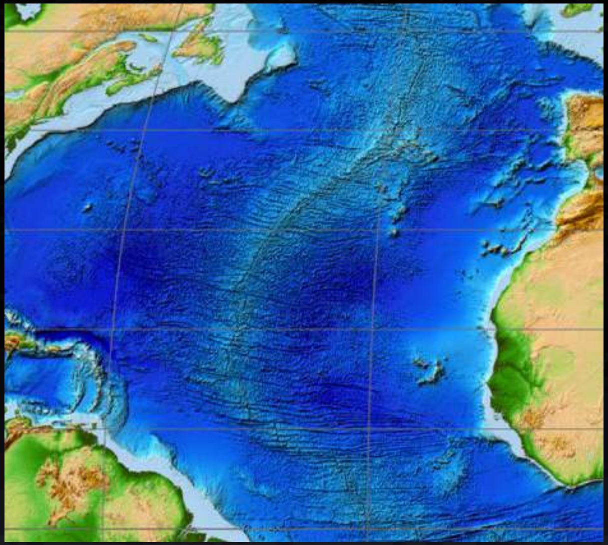


Look at the old mantle under the young seafloor, understand the impact of plumes and the inheritance of past plate tectonic cycles



Cannat et al., 2008

mid-ocean ridge research perspectives (1)



Study mid-ocean ridges as part of a more global system that includes life and the ocean.

Use mid-ocean ridges as natural laboratories to monitor active processes such as faulting and seismicity, volcanism, and fluid-rock-life interactions

@ CNRS-Ifremer. Old City vent field Southwest Indian Ridge