Westward migration of oceanic ridges and asymmetric upper mantle differentiation

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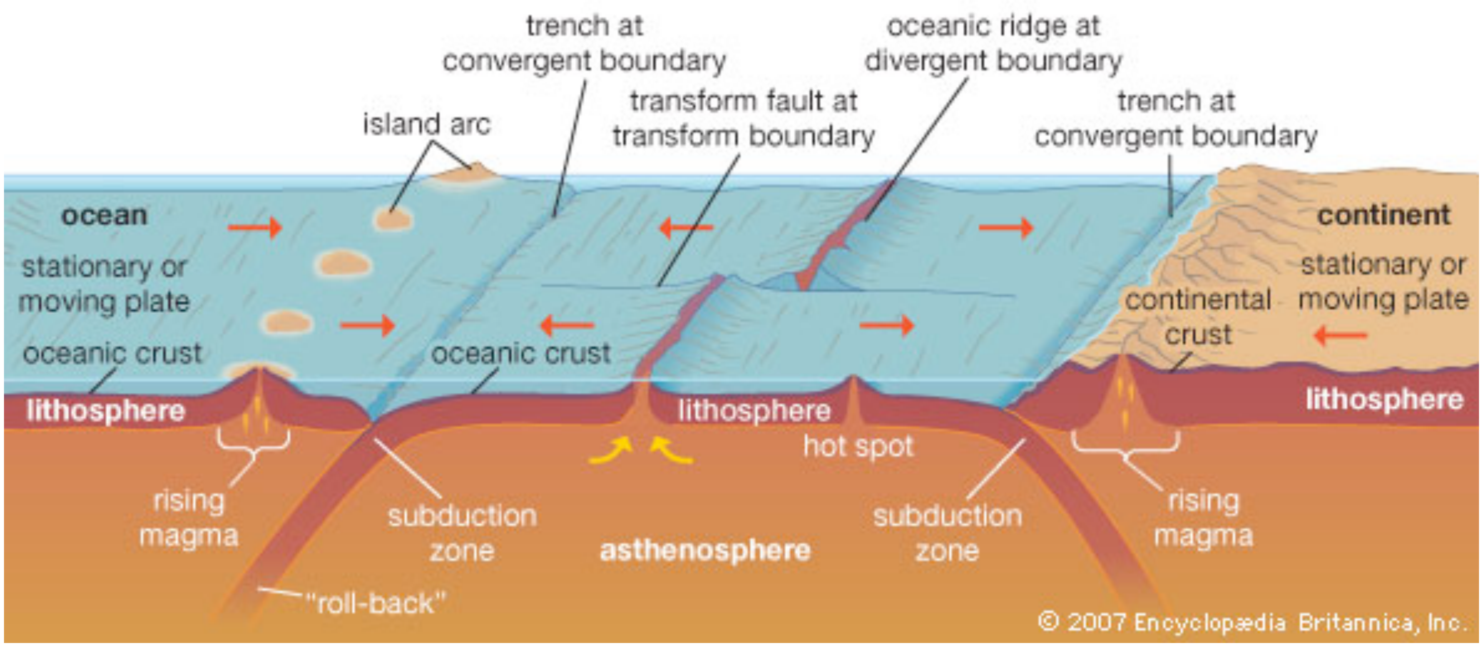
Why? What? How?

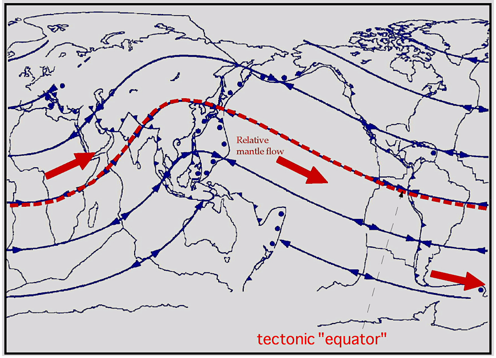
link between plate tectonics
and upper mantle compositional differentiation?



Why? What? How?

1. eastward mantle rotation implying westerly directed flow of lithosphere

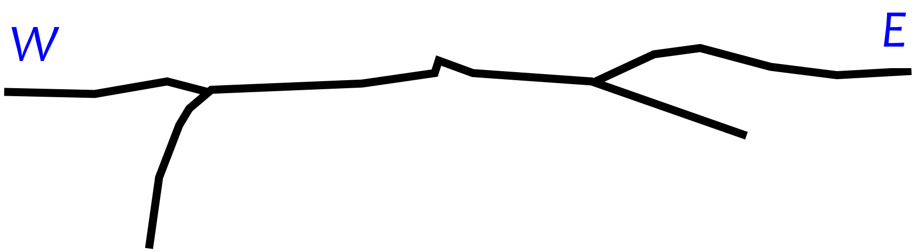
eastward mantle rotation



and tectonic equator

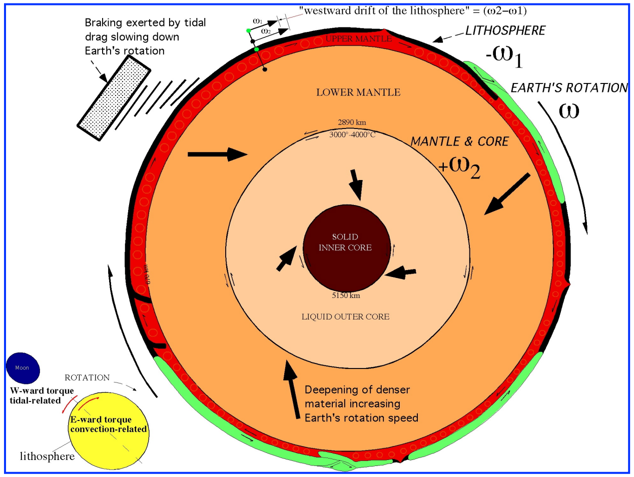
Bostrom, 1971; Doglioni 1990

2. orogens, subduction zones and rifts show an "E-W" global asymmetry



Doglioni et al 1999, 2003

3. plate tectonics is tuned by Earth's rotation



Scoppola et al 2006

Why? **What?** How?

interdependence between

- oceanic spreading process
- upper mantle differentiation
- plate kinematics driven by the westward drift of the lithosphere

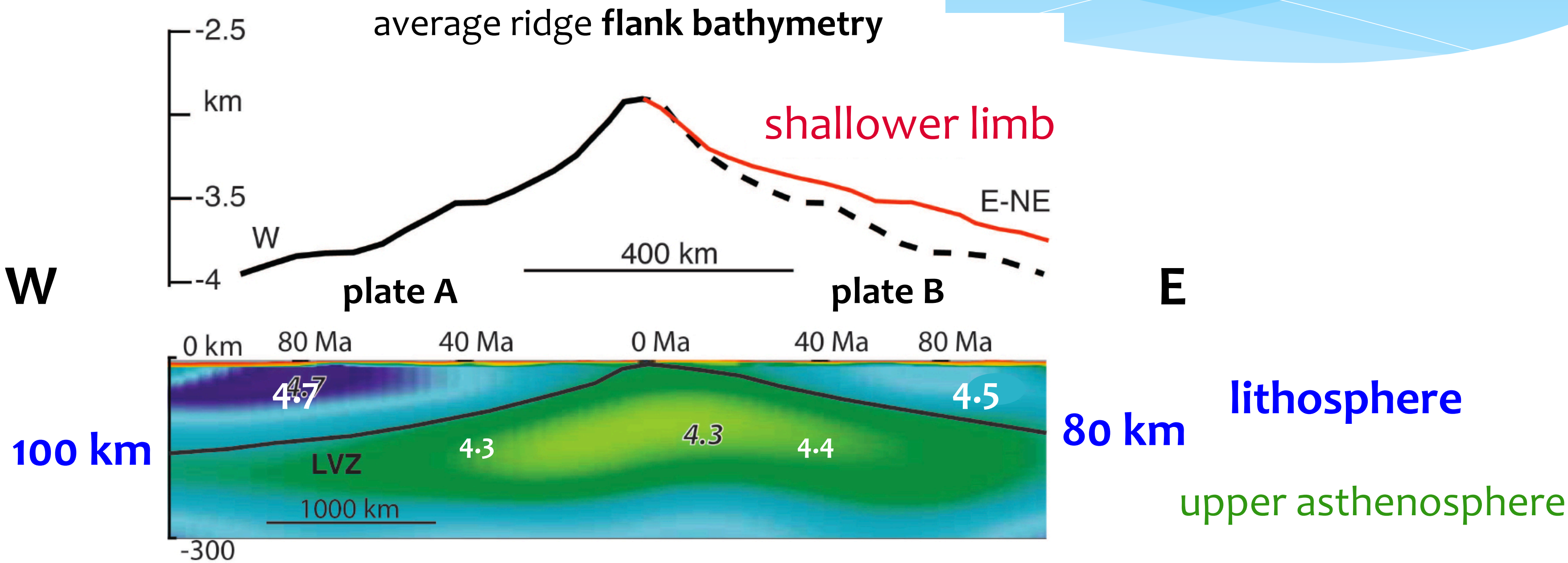
Why? What? **How?**

integration in space and time of

- **geophysical** data on oceanic plates and asthenosphere
- **petrological** data on mantle (↘300 km depth) and basalt
- **structural** data on oceanic detachment faults

Starting point of our brainstorming: ***geophysical data***

plate asymmetry on both sides of spreading ridge



- flank bathymetry: *shallower E*
- plate Vs (√μ/ρ): *slower E*
- plate thickness: *thinner E*

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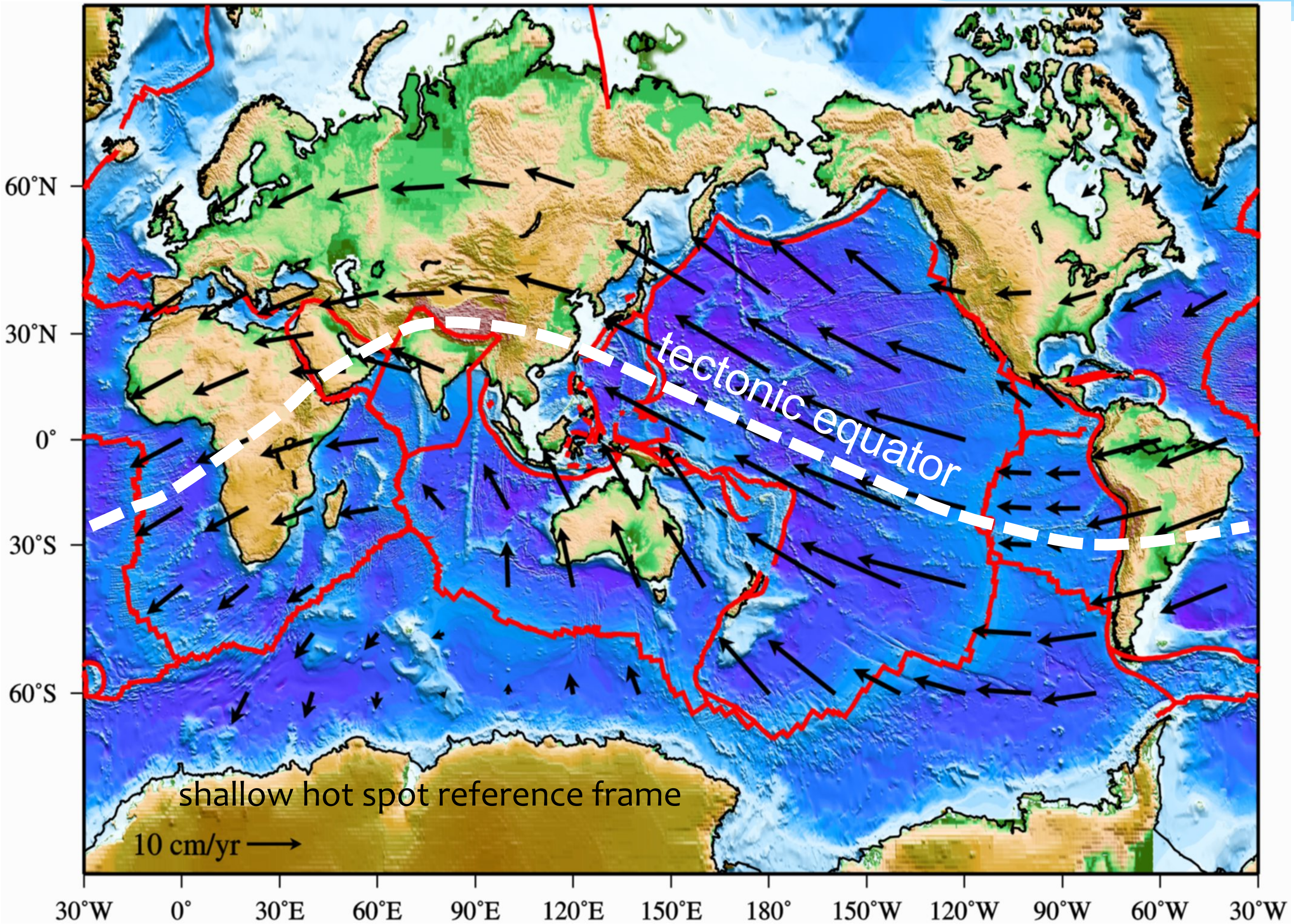
Doglioni et al. 2014

Starting point of our brainstorming: ***kinematic data***

westward rotation of the lithosphere



with velocity variations along sinusoidal flow of plates

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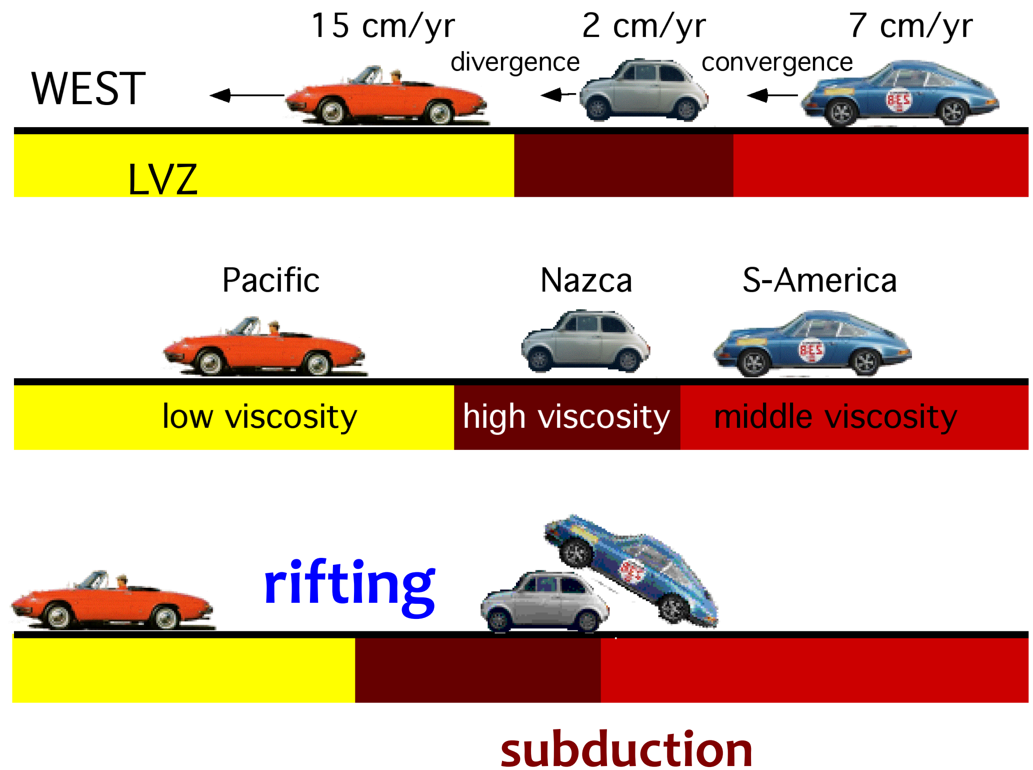
Cuffaro & Doglioni, 2007

plate velocity asymmetry

- velocity variations from one plate to another



➢ induced by viscosity variations of underlying low-velocity zone

➢ inducing rifting and subduction

rifting process

… *when* eastern plate velocity slower than western plate velocity

westward ridge migration and oceanic spreading ?

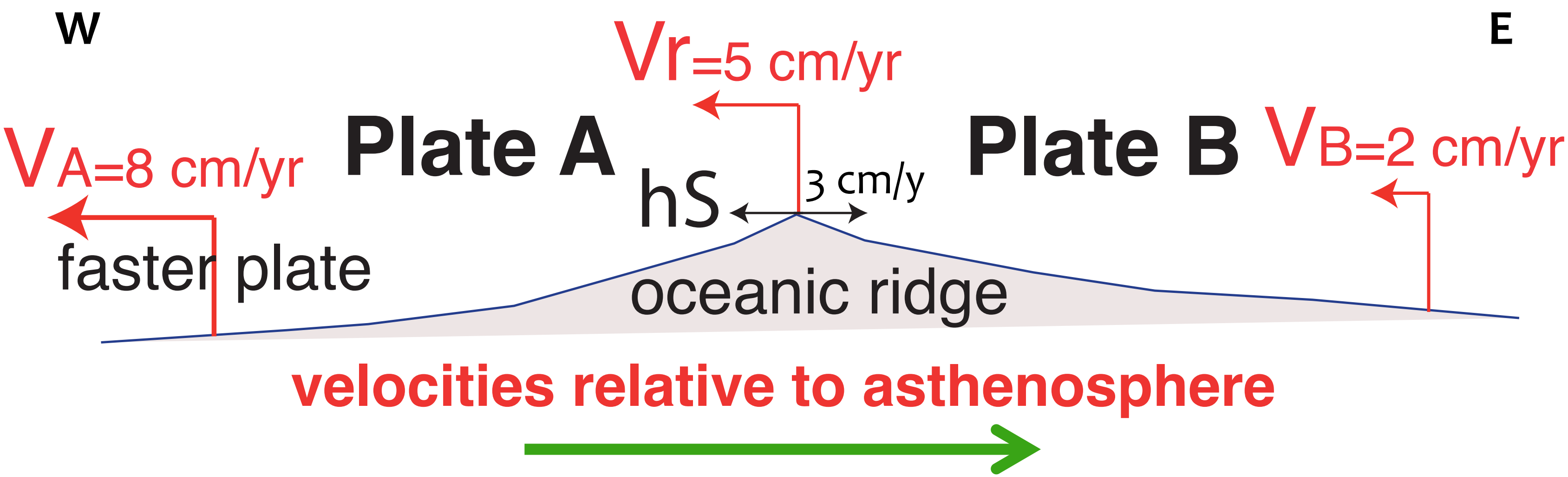
VA, VB=plate velocity

Vr=ridge migration
Vr=(VA+VB)/2

hS=half spreading
hS=(VA-VB)/2

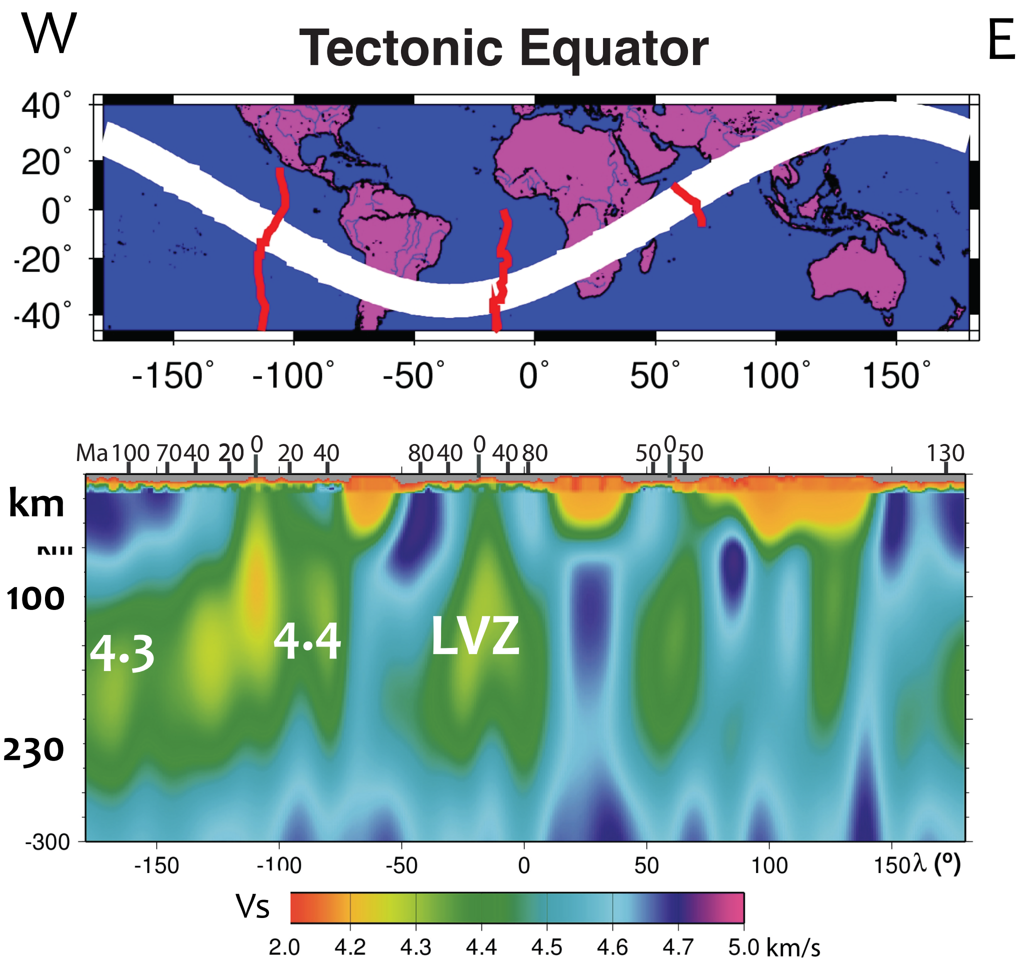
Vr > hS

westward drift (Vr) of ridge
synchronous but faster than
oceanic half-spreading (hS)



Starting point of our brainstorming: ***geophysical data***

upper asthenosphere asymmetry



- LVZ mainly below oceans
  - ➢ "solid+incipient melt" area
- length: larger W
- thickness: higher W
- Vs (√μ/ρ): slower W
  - ➢ lower μ W-ward

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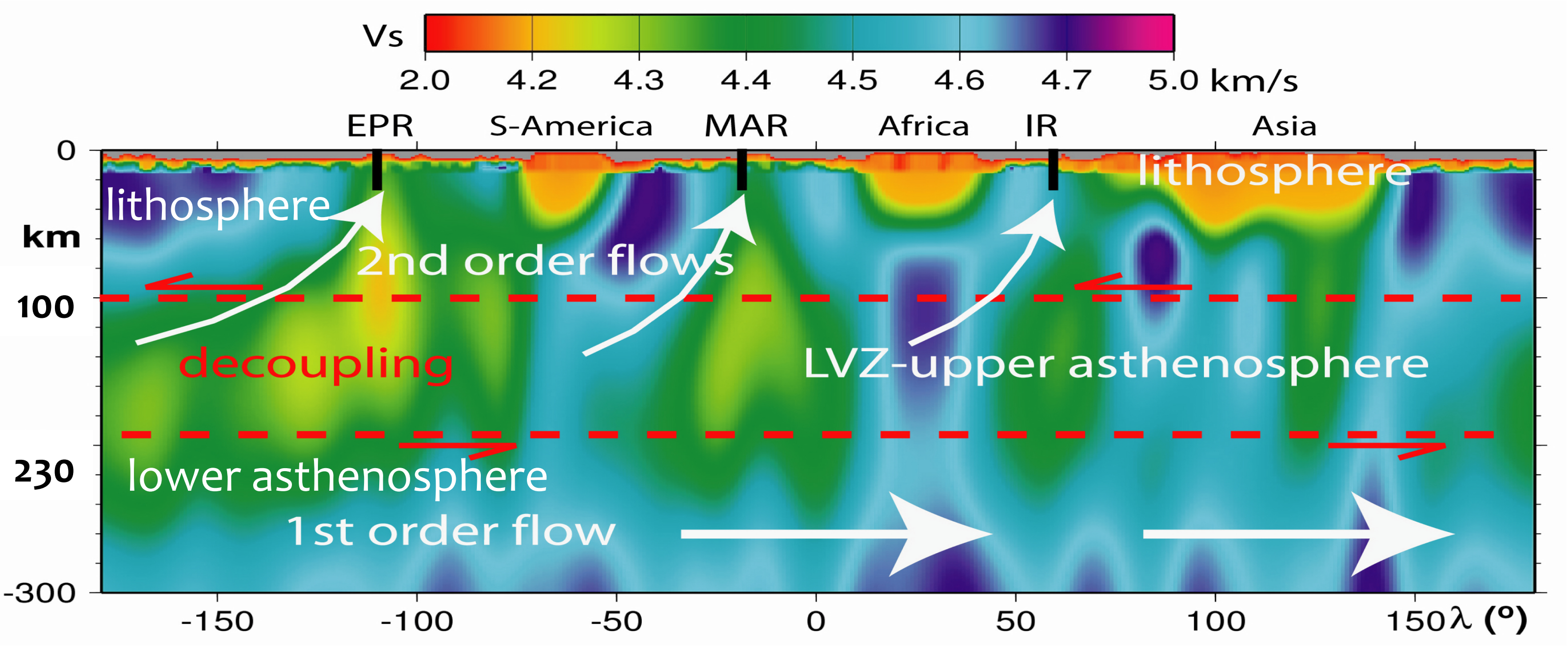
Panza et al 2010

upper asthenosphere (LVZ) ≈ **decoupling level**

between lithosphere and lower asthenosphere

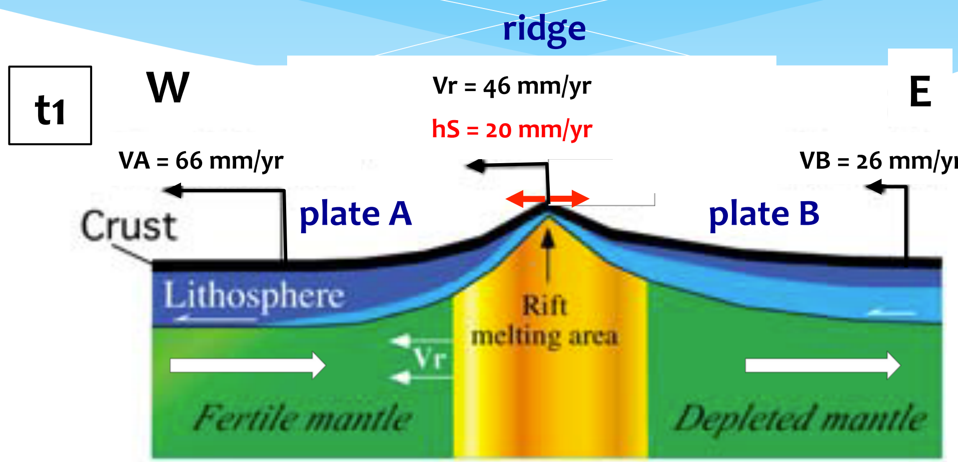


Preliminary global model from Panza et al, 2010

ridge migration has a key-role in producing plate and asthenosphere **asymmetry**

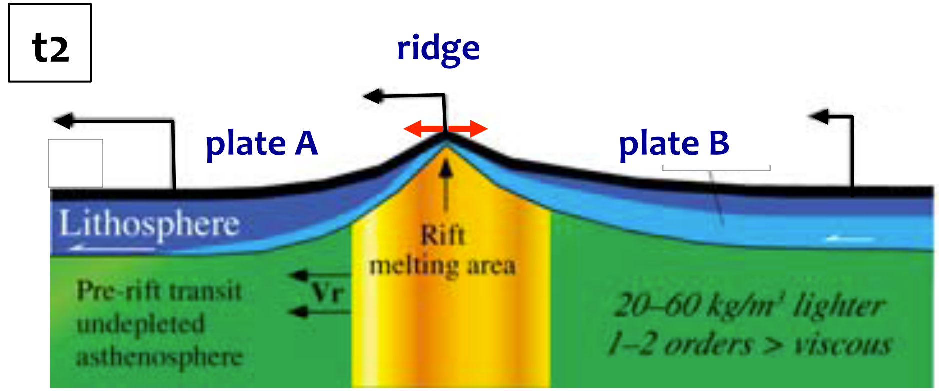
t1. plate spreading →

- ★ plate uplift + rift melting area
- ★ ± residual E-asthenosphere



t2. westward ridge drifting →

- ★ migration of melting area with Vr > hS
- ★ lower "refertilisation + thickening + subsidence" of E-plate (B)



“En route” for an alternative
plate spreading model

integrating our updated knowledge
on mantle petrology

lithosphere in our model

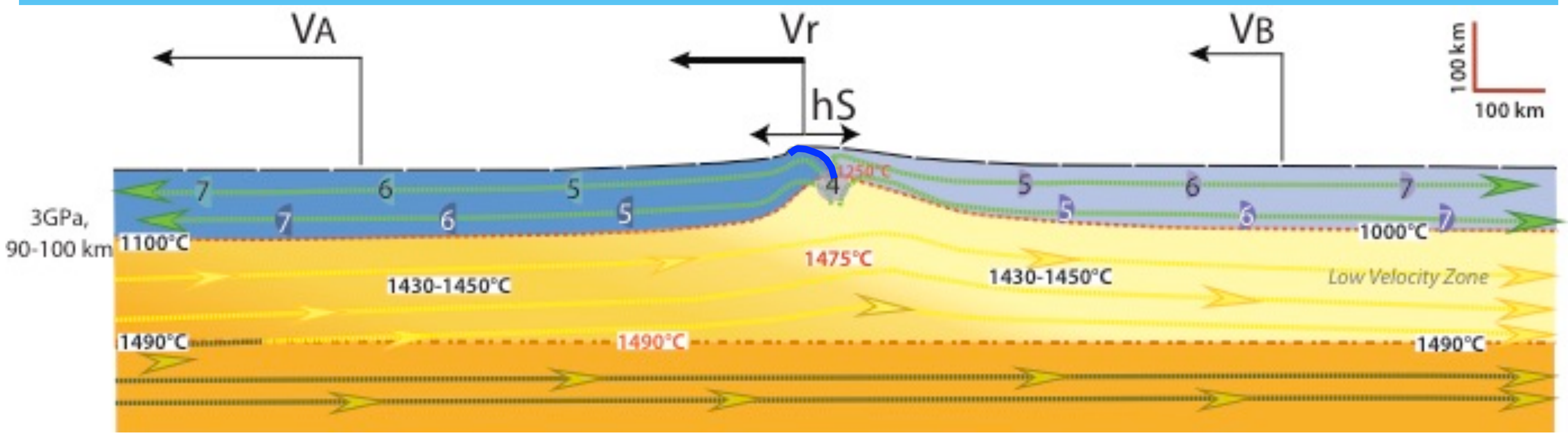


plate A : strongly re-enriched harzburgitic mantle

plate B : barely re-enriched harzburgitic mantle

mantle vapour-saturated solidus ≈100 km

detachment faults

path & direction of mantle transfer by spreading

half-spreading residues

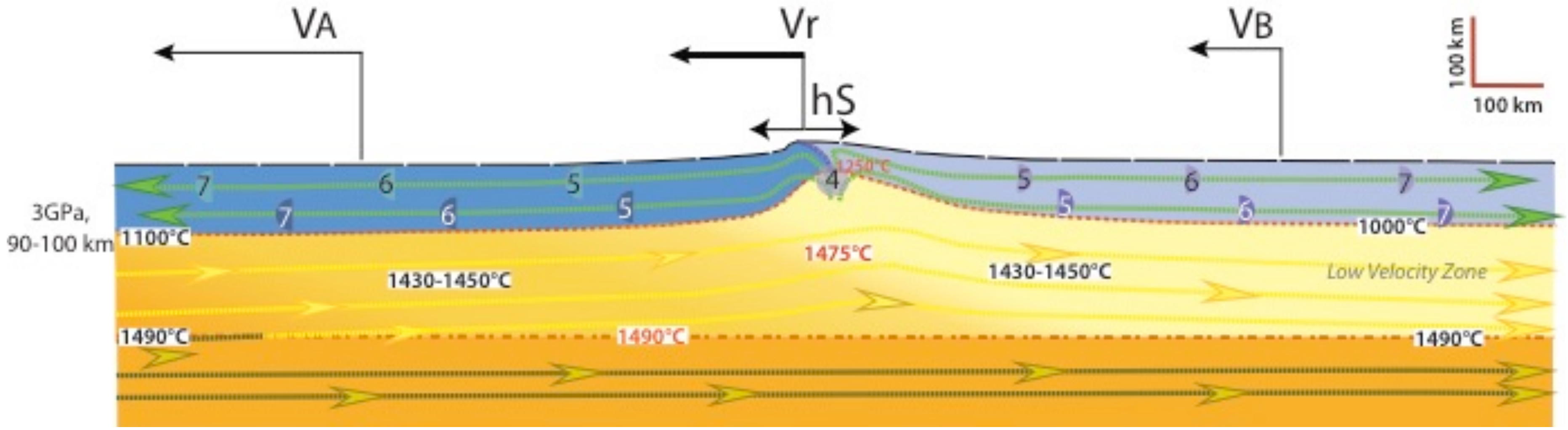
strongly re-enriched in plate A

barely re-enriched in plate B

asymmetry of mantle lithosphere

density + rigidity

how eastern plate B becomes less dense and rigid than western plate A ? Loosing Fe and cooling becomes more viscous viscous



➢ **at spreading axis** → mantle residue accretion at base of lithosphere (≥ 30km) + basalt upwards percolation
→ **mantle thickening and mantle residue refertilisation**

➢ **as Vr > hS** → refertilisation and thickening are **much less significant in the eastern limb** (plate B)

✧ plate A mantle: secondary lherzolite

✧ plate B mantle: barely refertilized harzburgite

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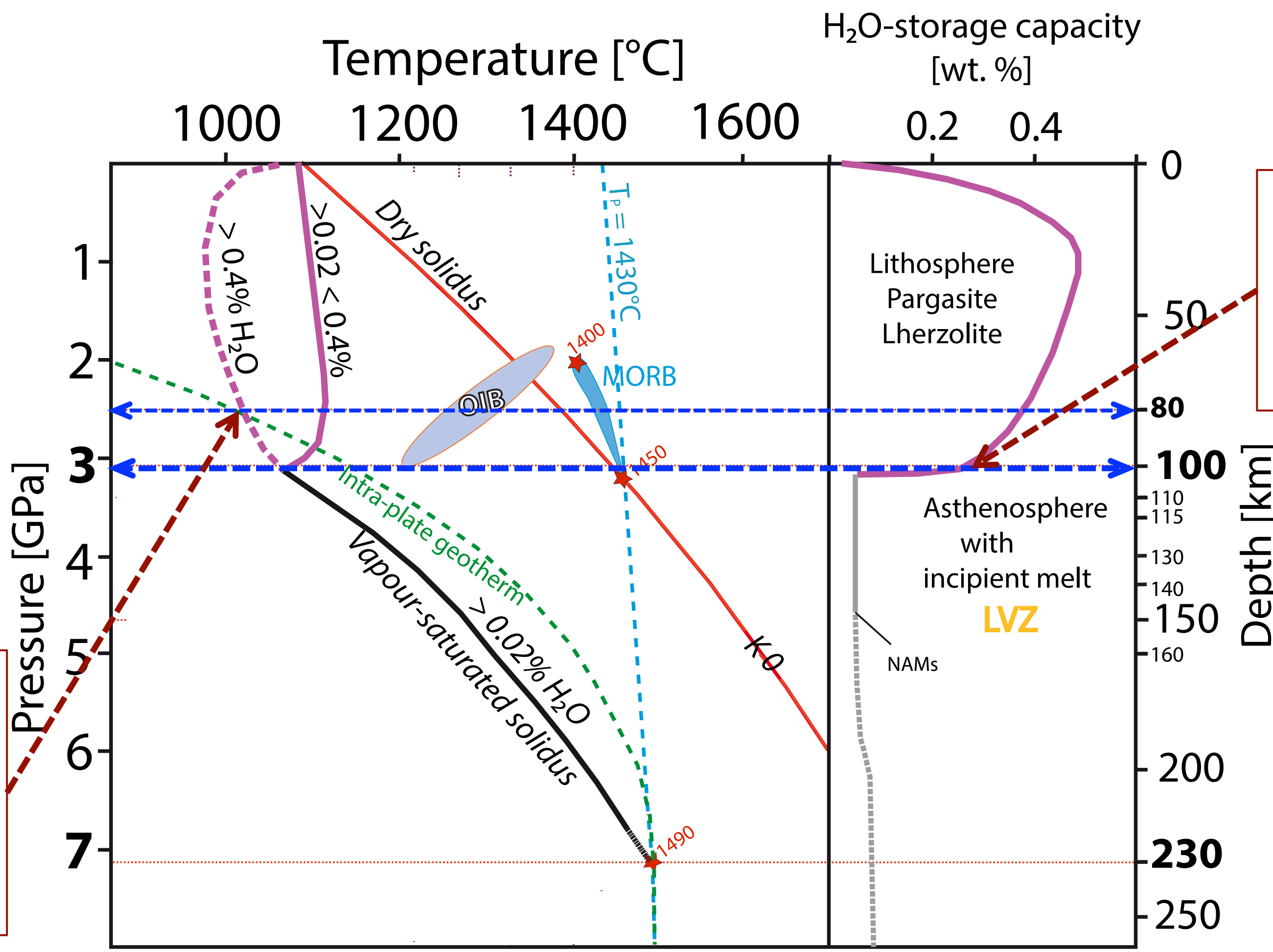
thickness

why a plate thickness between 80 and 100 km ?

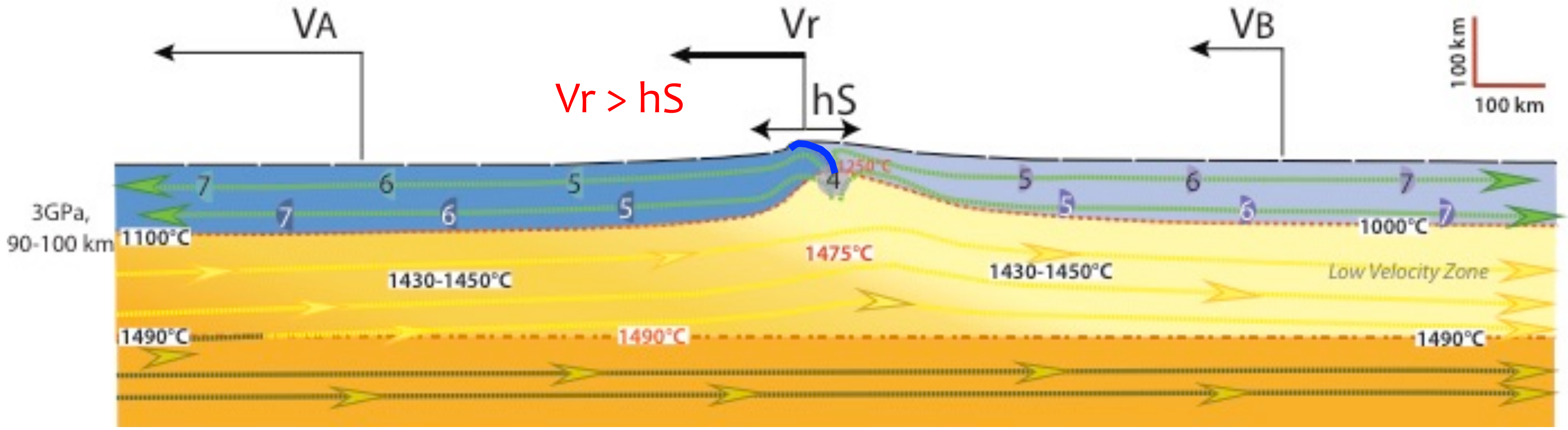


amphibole destabilization **by lithosphere thickening (100 km maxi)**

intersection geotherm and solidus **(80 km mini) by asthenosphere cooling**

asymmetry of mantle lithosphere

how is mantle transfer organized for fitting both with oceanic spreading and W-ward drift of the lithosphere ?



path & direction of mantle transfer by spreading

detachment faults

half-spreading residues

strongly re-enriched in plate A

barely re-enriched in plate B

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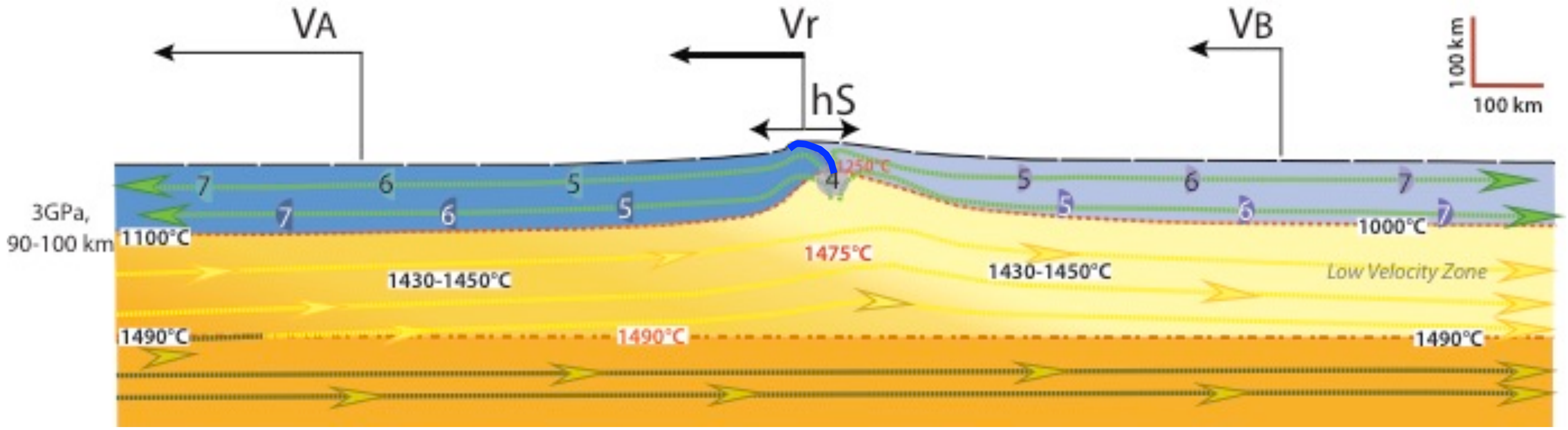

- Residues successively transferred upwards and laterally **at hS rate** within the mantle lithosphere
- **As Vr > hS →** bending of the path followed by the mantle transfer towards the surface
- As asthenosphere moves “eastward” relative to the lithosphere, the westward drift of the lithosphere is necessarily slowed down at its base, inducing a **TOP to DOWN DECOUPLING within the mantle lithosphere**
- **DETACHMENT FAULTS,** large offset low-angle faults capping the eastern (rarely western) side of oceanic mantle core complexes (OCC), **are effects of top to bottom asymmetric lithospheric mantle shear**

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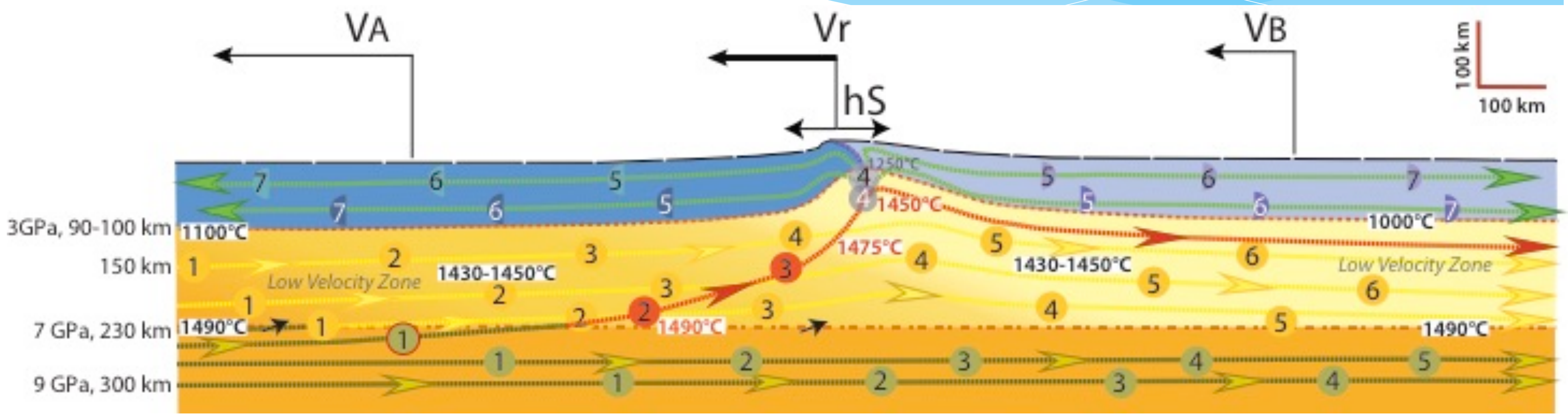
asthenosphere in our model



Upper — syn-melting lherzolite, Fe-depleted eastwards

mantle vapour-saturated solidus (230km)

Lower (upper part) — subsolidus lherzolite

path & direction of mantle transfer along the main flow

path & direction of transfer of MORB mantle source

solid mantle + incipient melt

sub-solidus mantle

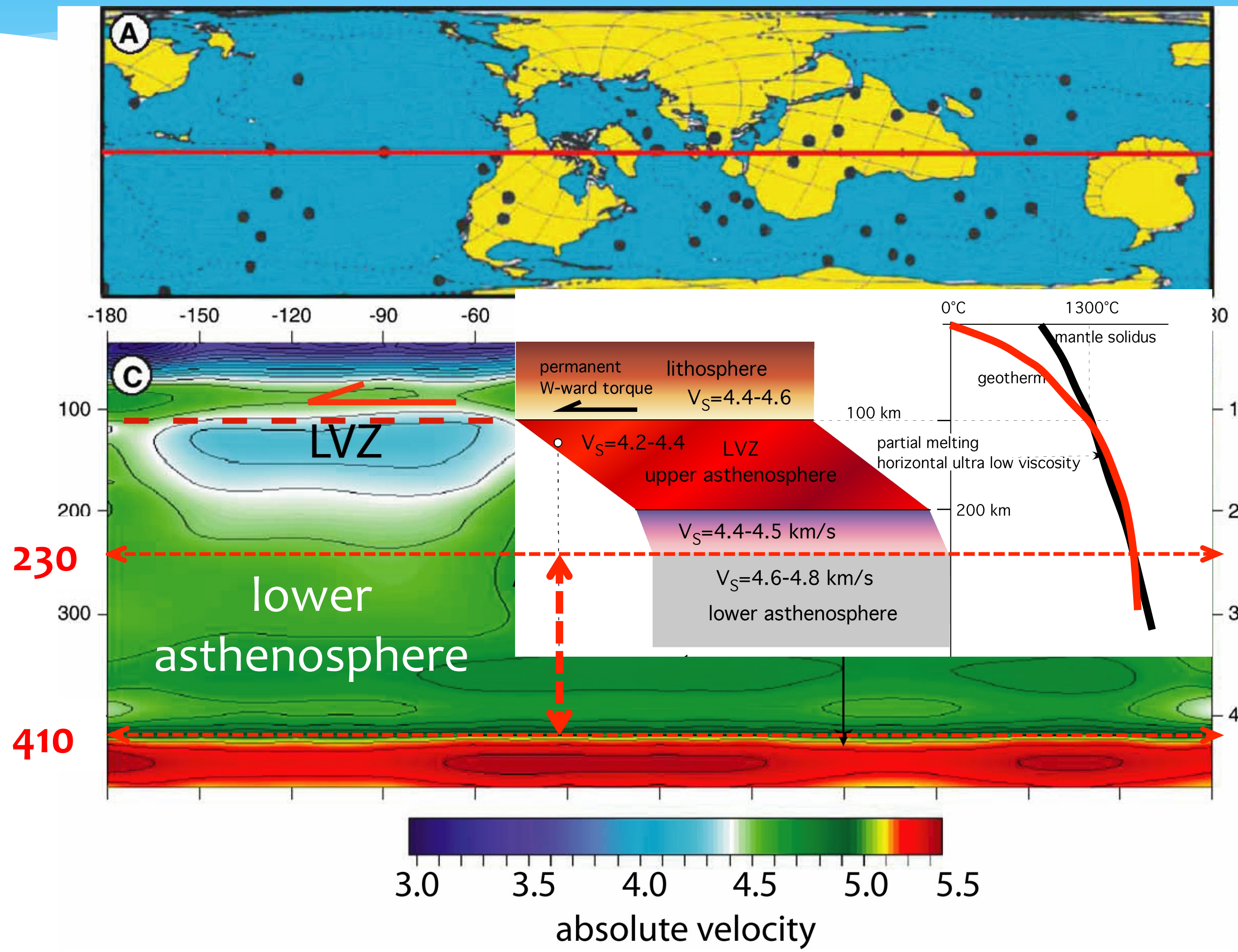
melt+++ (20%) residue

melt++ (10%) residue

MORB source mantle

geophysical data

NO relevant asymmetry of lower asthenosphere wrt LVZ

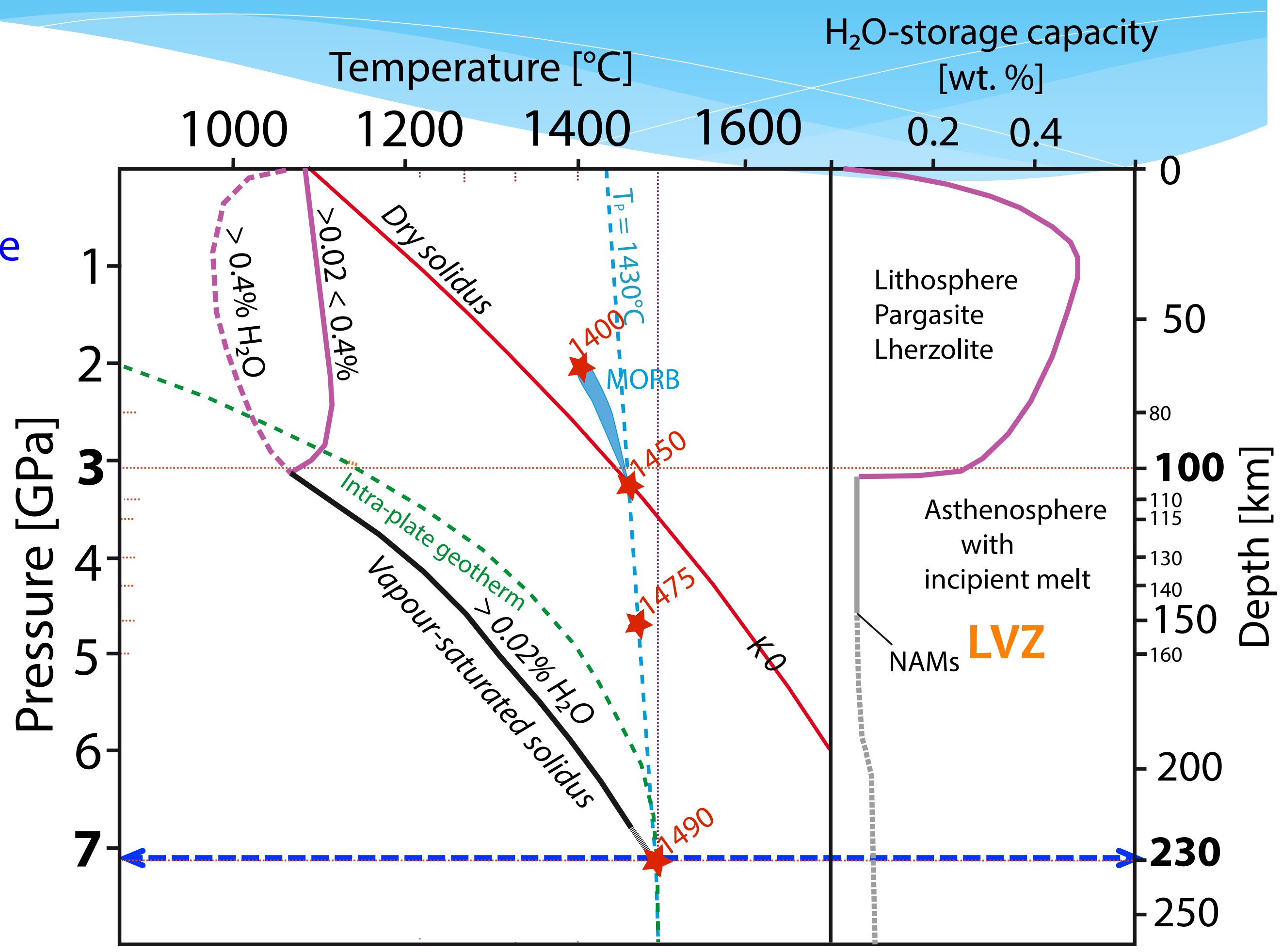


- Vs rather homogeneous
- ≈ 180 km thick

petrological data from N-MORB and mantle experimental data

lower asthenosphere is the N-MORB mantle source

- below 7 GPa / 230 km
- at 1490 °C
- fertile garnet lherzolite
- depleted in the most incompatible TE
- with ≥ 200 ppm H_2O



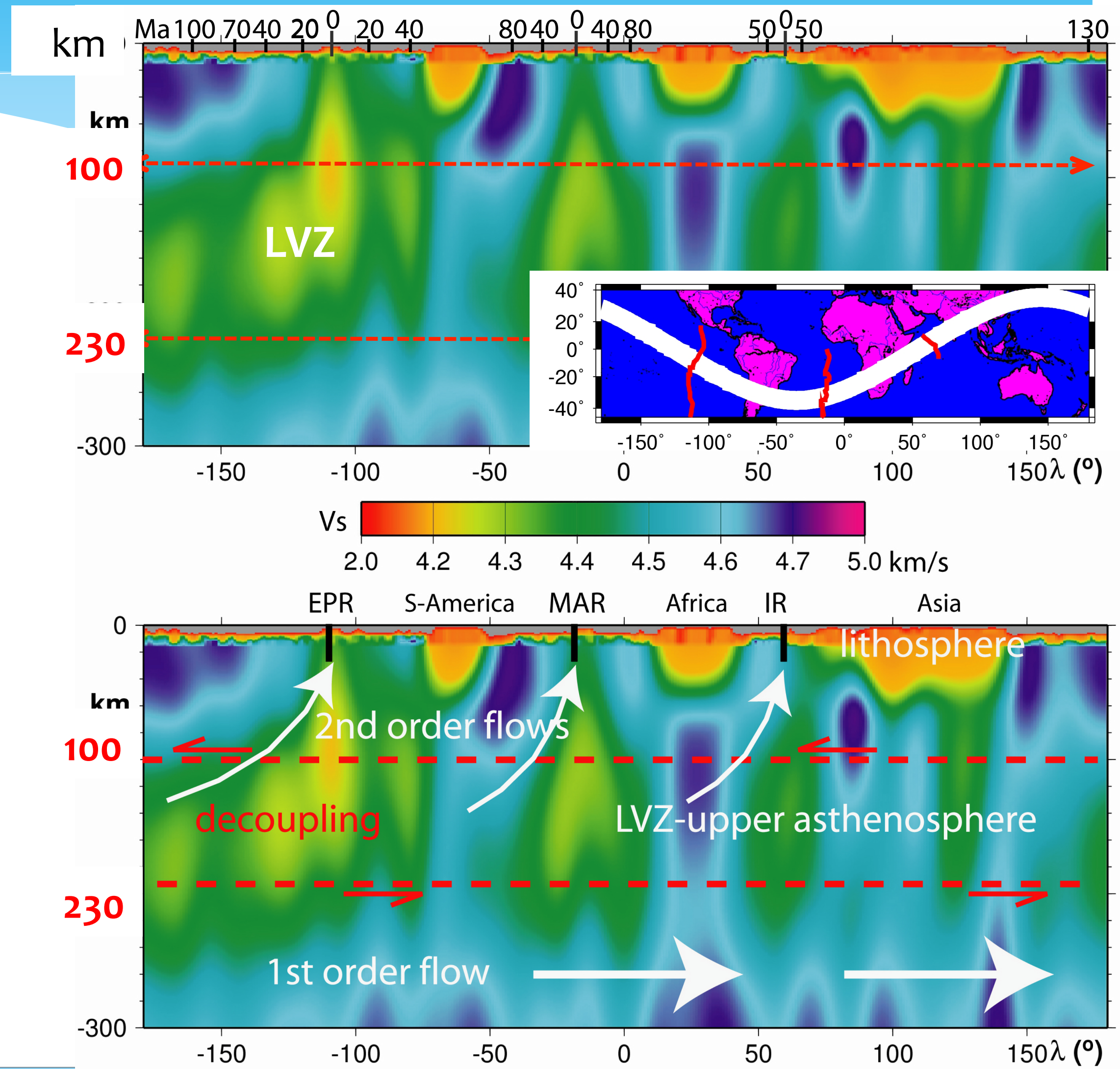
asymmetry of upper asthenosphere (LVZ)

W-ward

- thicker (130 vs 100km)
- more developed (2/3 in volume)
- Vs (√μ/ρ) slower

➢ lower rigidity μ
because of incipient melting

decoupling and shear heating
→ T°C ↗ 30-120°C
→ ↗ incipient melting

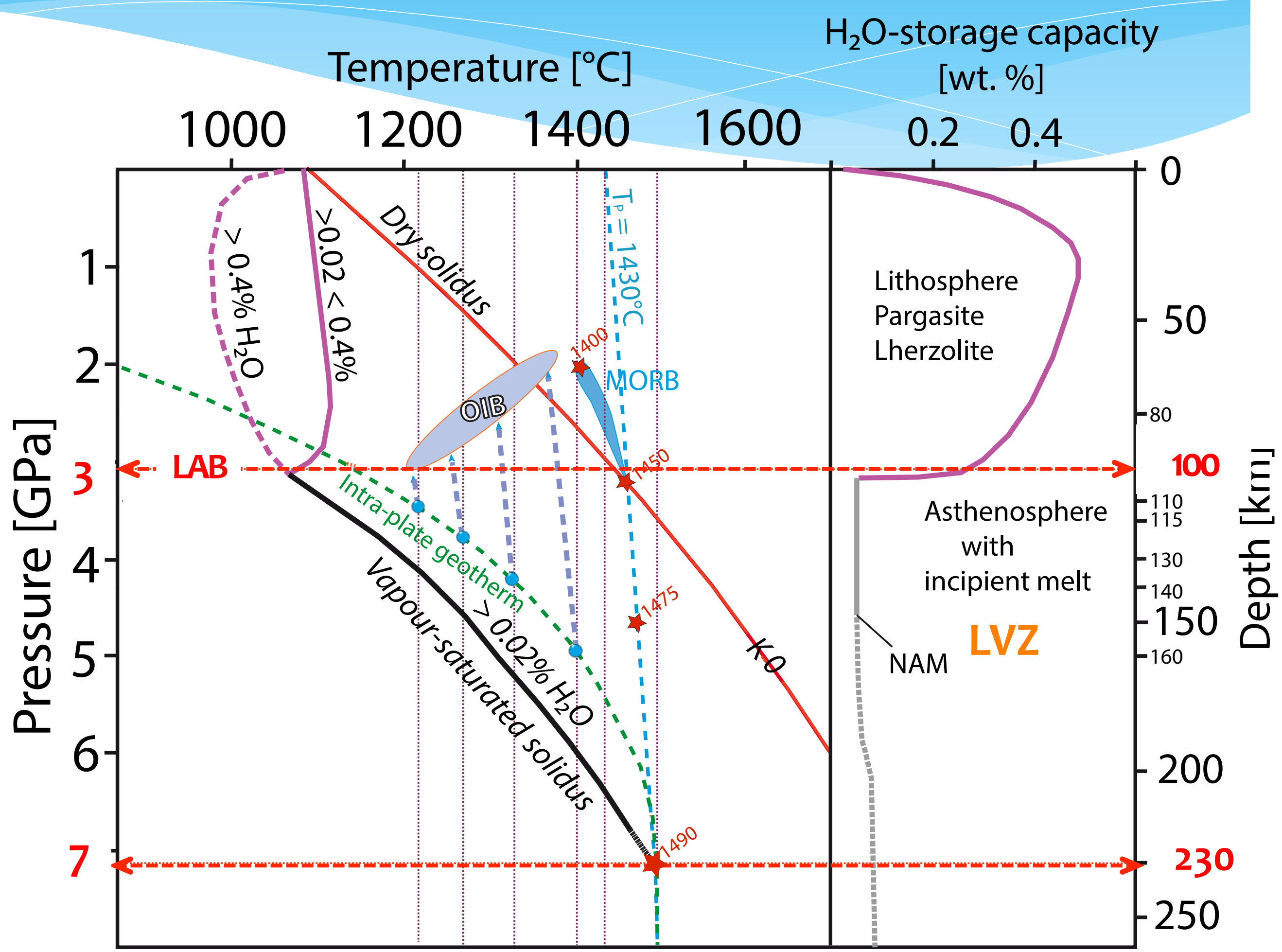


Panza et al. 2010

petrological data from OIB and mantle experimental data

upper asthenosphere is the OIB mantle source

- along intraplate geotherm
- "solid + incipient melt (0.05-0.1%)"
- garnet to spinel lherzolite
- TE enriched



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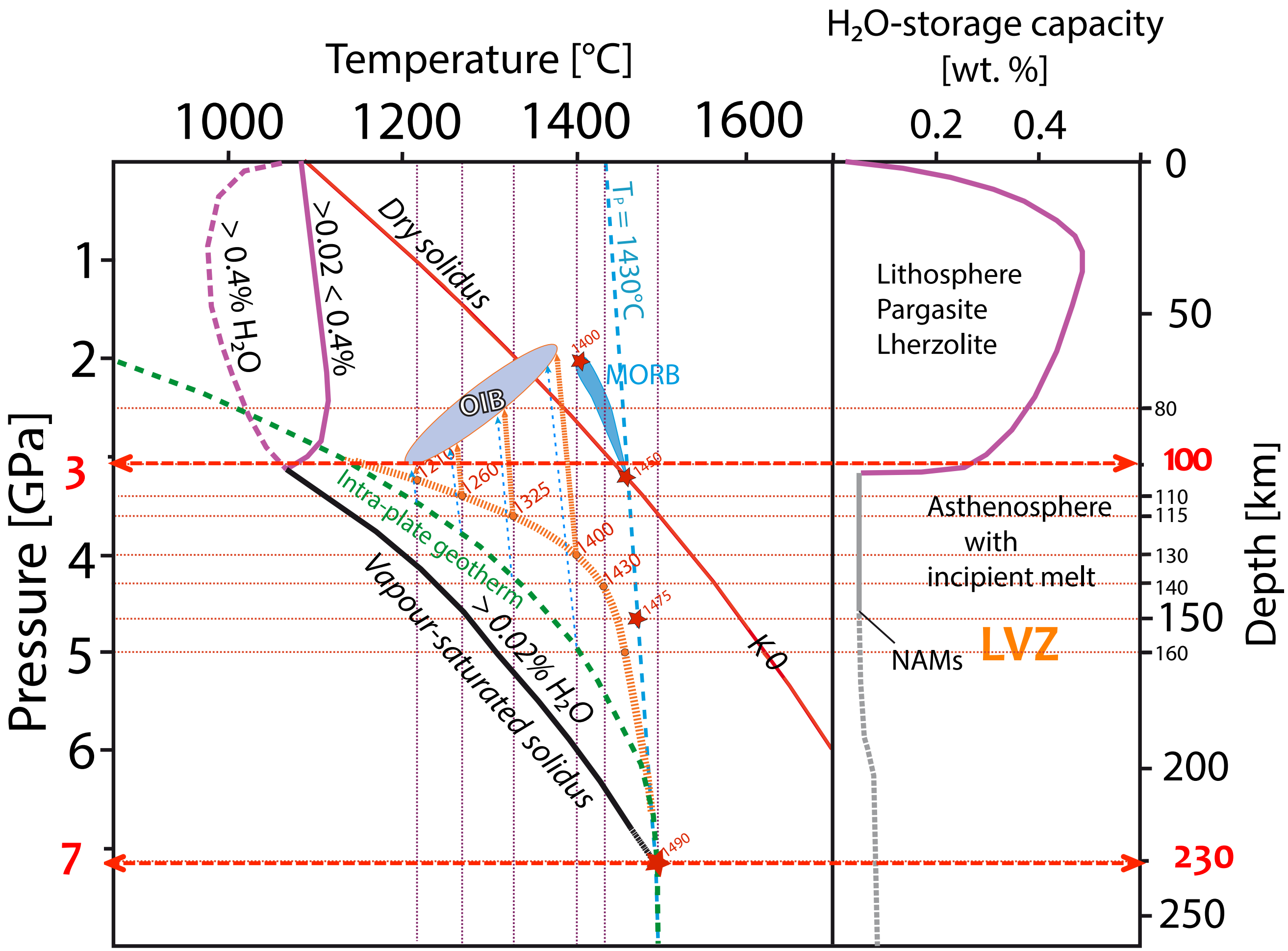
from Green et al 2014, modified

petrological data from OIB and mantle experimental data

with shear heating effect, shallower OIB mantle sources

- along intraplate geotherm
- "solid + incipient melt (0.05-0.1%)"

- with shear heating (up to 120°C)
- melting increases up to 1.5% at shallower depth



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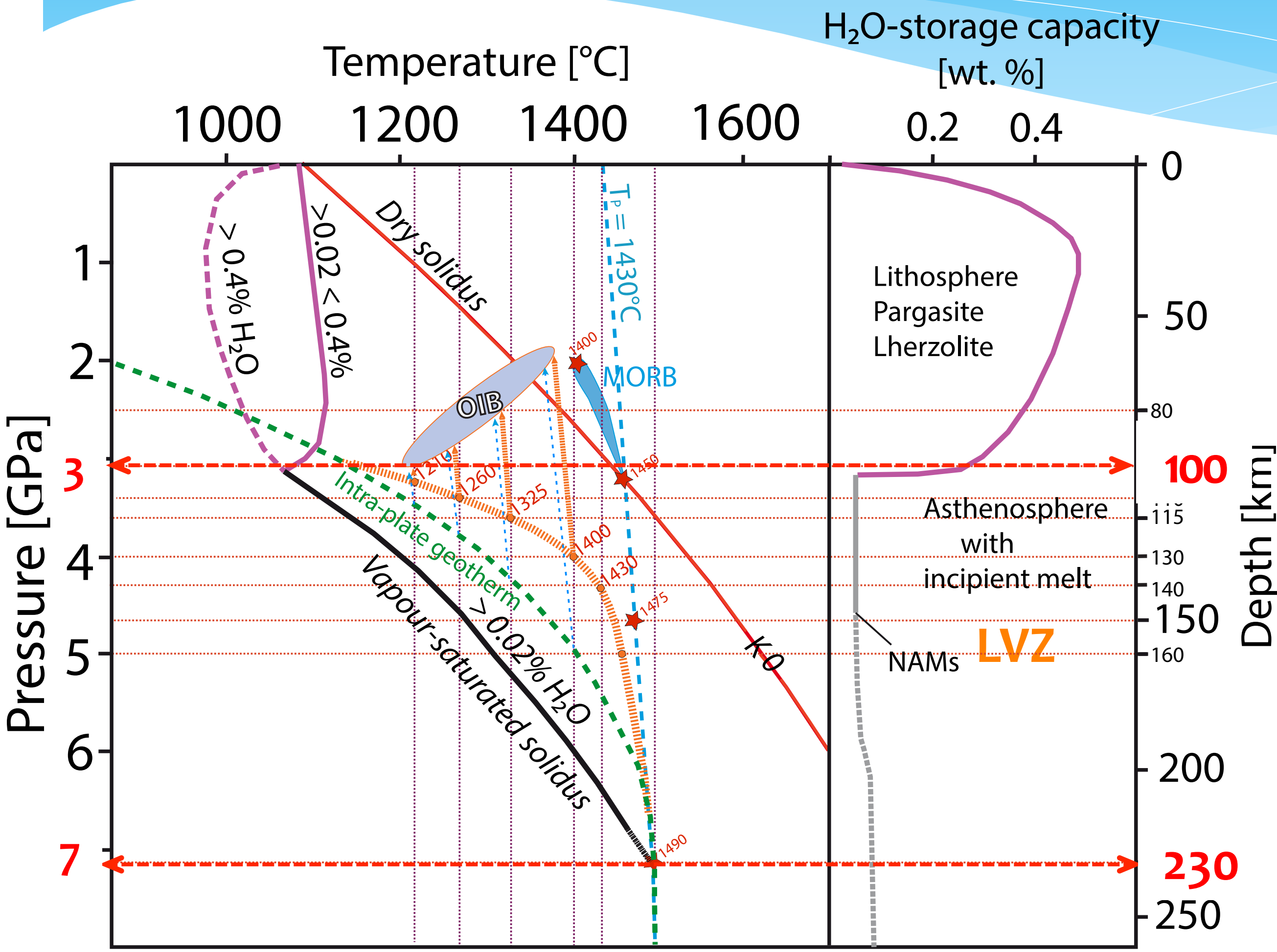
from Doglioni et al 2005 & Green et al 2014, modified

petrological data from N-MORB and mantle experimental data

double origin for uppermost asthenosphere



lithosphere

- amphibole destabilization

lower asthenosphere

- "rather dry" towards the **MORB** genesis area
- "rather wet" towards the **OIB** genesis area

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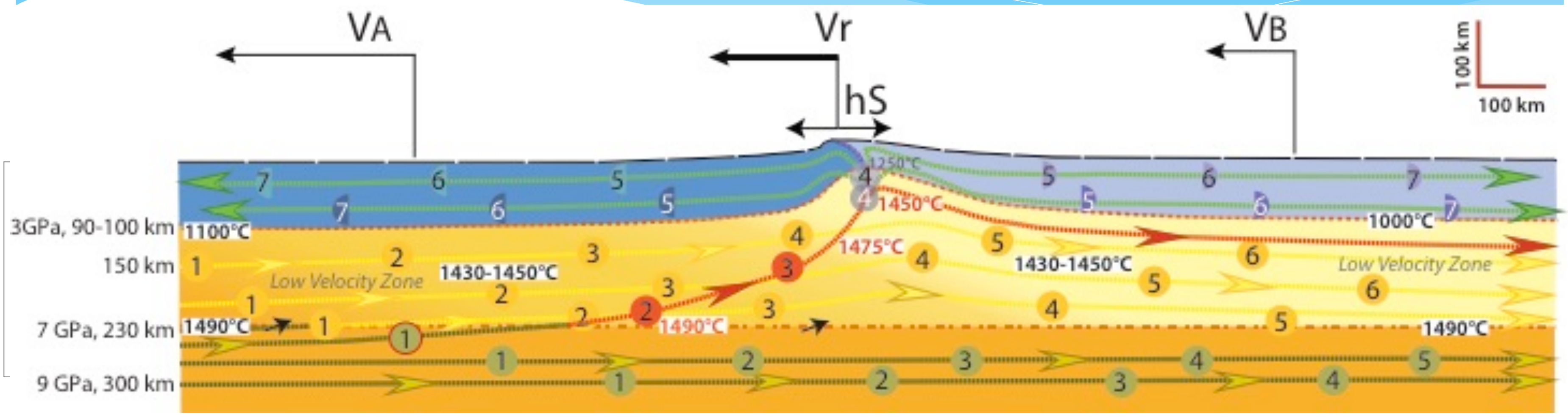
from Doglioni et al 2005 & Green et al 2014, modified

asymmetry of upper asthenosphere

why a larger "solid + incipient melting" area on the western side ?



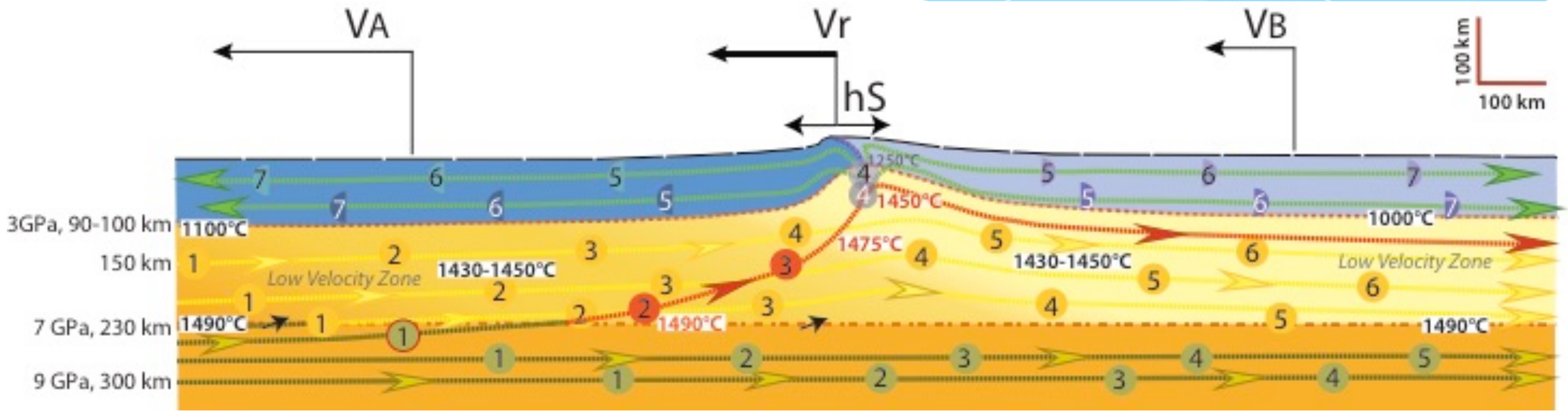
→ oblique, *and not vertical*, mantle ascent from lower to upper asthenosphere

→ 2 ≠ paths of transfer according to the entrance angle

- main path → very low entrance angle
- single path → more opened entrance angle

asymmetry of upper asthenosphere

why a larger "solid + incipient melting" area on the western side ?

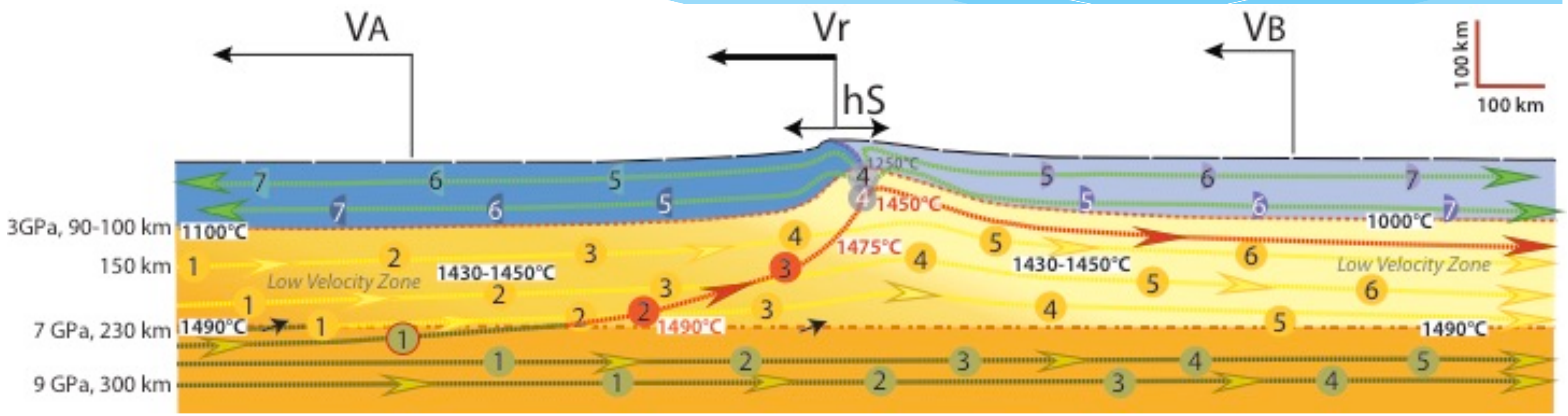


- **main path →** very low entrance angle trajectory
  - emerging rather far laterally (> 500 km) from the ridge
  - barely deviated in passing below the ridge

✧ **OIB** mantle sources

asymmetry of upper asthenosphere

why a larger "solid + incipient melting" area on the western side ?

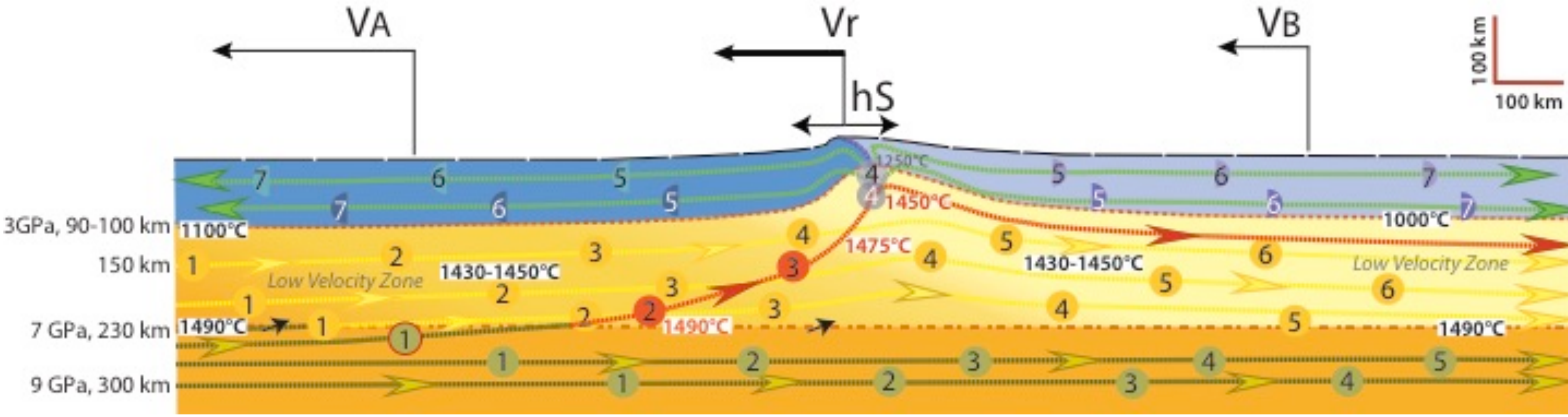


- **single path** → more opened entrance angle trajectory
- emerging at a shorter distance from the ridge (≤ 500 km)
- induced by isostatic suction of the migrating spreading ridge

✧ the one producing **MORB**, permanently renewed because of the westward drift of lithosphere

asymmetry of upper asthenosphere

why eastern upper asthenosphere has a faster Vs ?

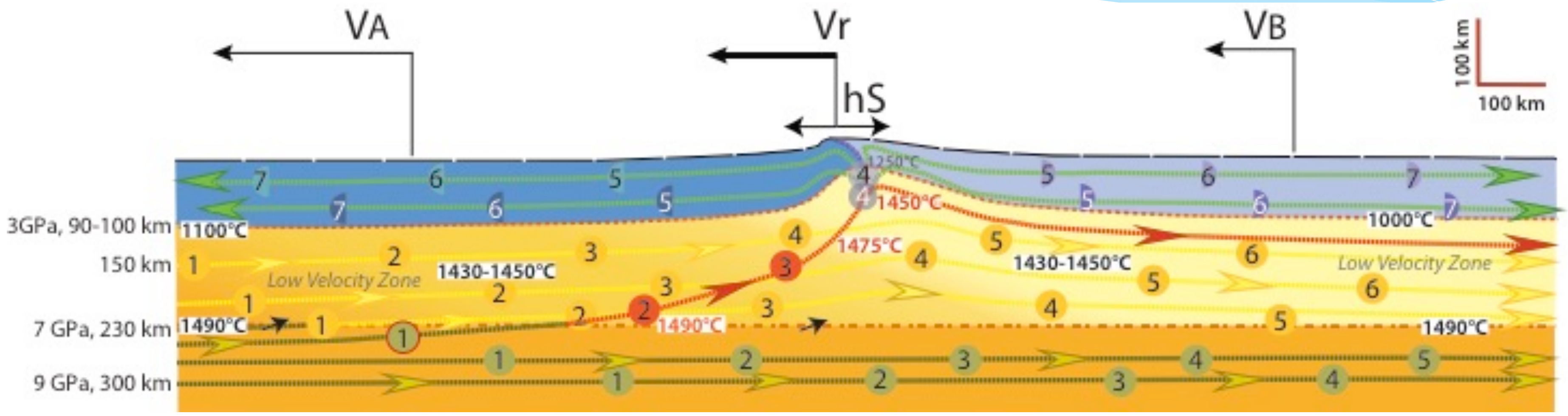


- ○ somewhat Fe-depleted, but above all fluid-depleted
- ➢ rigidity μ increase and density ρ decrease

higher rigidity of the eastern LVZ → higher coupling with overlying plate B → slower velocity plate B

Why? How? **What?**

plate tectonics induces upper mantle differentiation



strong mechanical effects of "westward ridge migration + plate spreading" on lateral and upwards mantle transfers, → on mantle partial melting and percolation/reaction processes → on mantle differentiation … and in turn on plate spreading !

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Why? How? **What?**

mantle lithosphere

✓ higher mantle refertilisation of the western plate

✓ intra-mantle decoupling inducing detachment faults and exhumation of core complexes

asthenosphere

✧ eastward *strongly* oblique mantle upwelling from lower asthenosphere & MORB genesis

✧ eastward *slightly* oblique mantle upwelling of upper asthenosphere & OIB genesis

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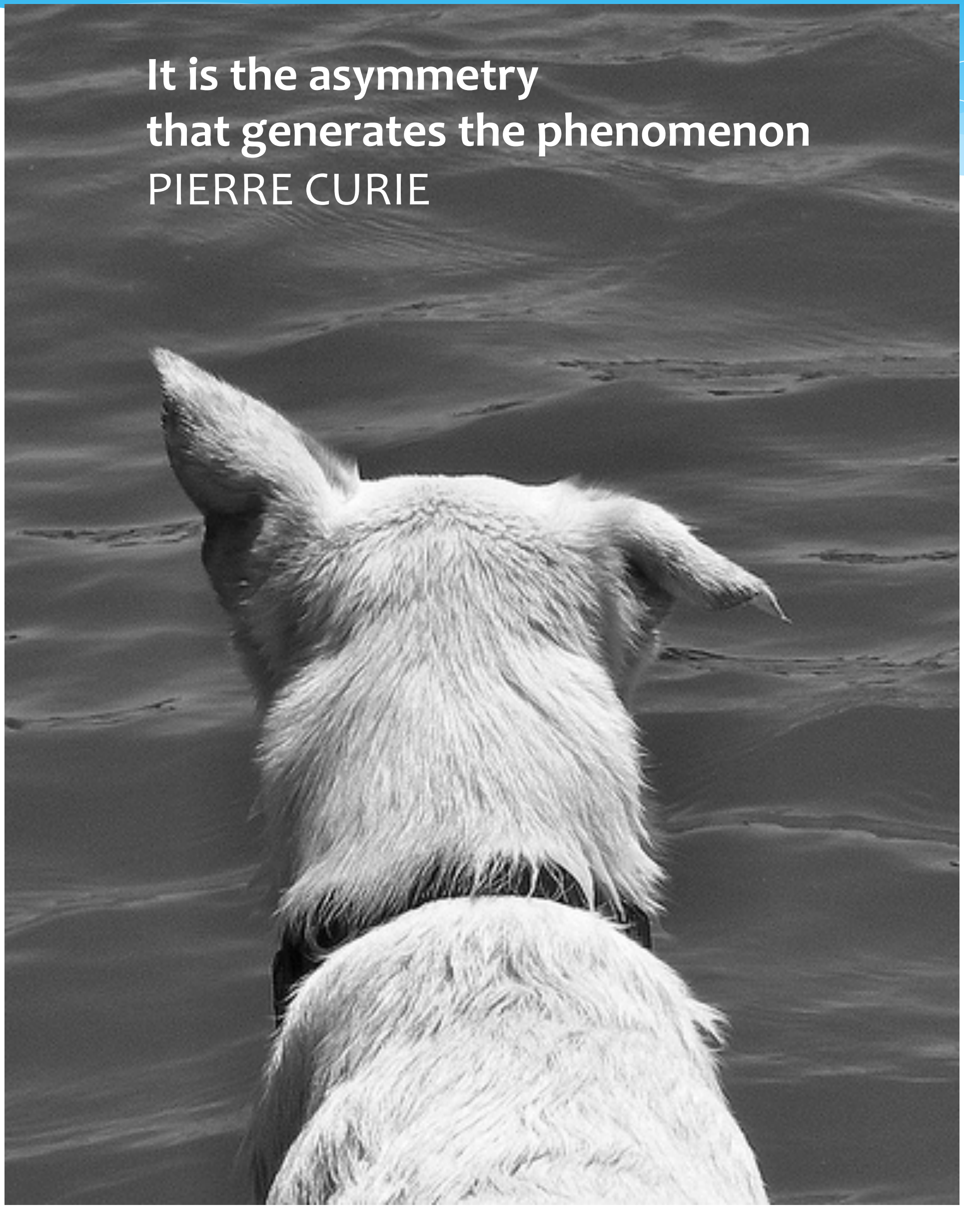
It is the asymmetry
that generates the phenomenon
PIERRE CURIE