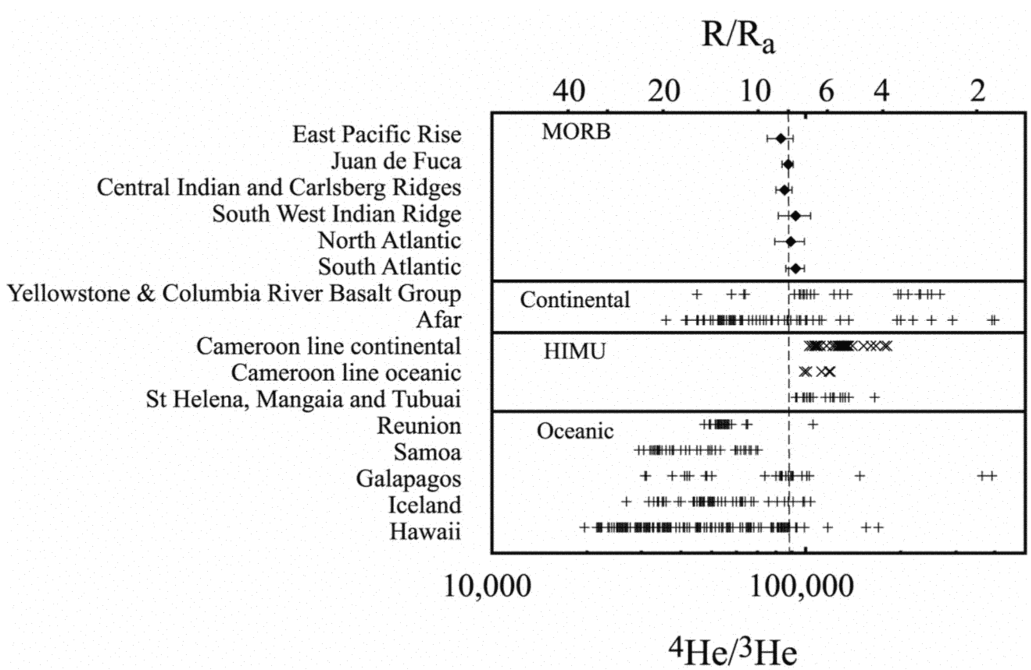
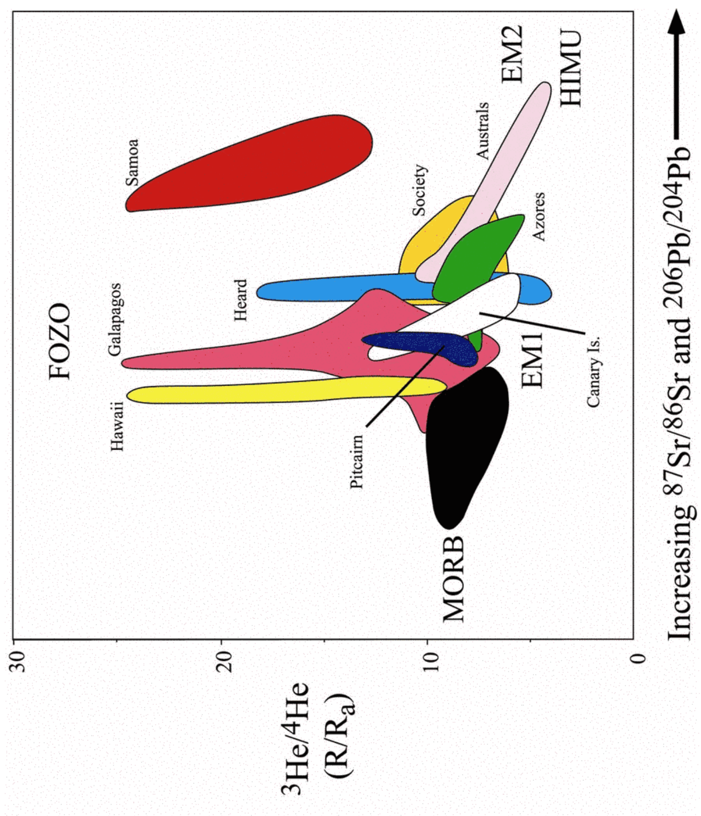
The C in Cider

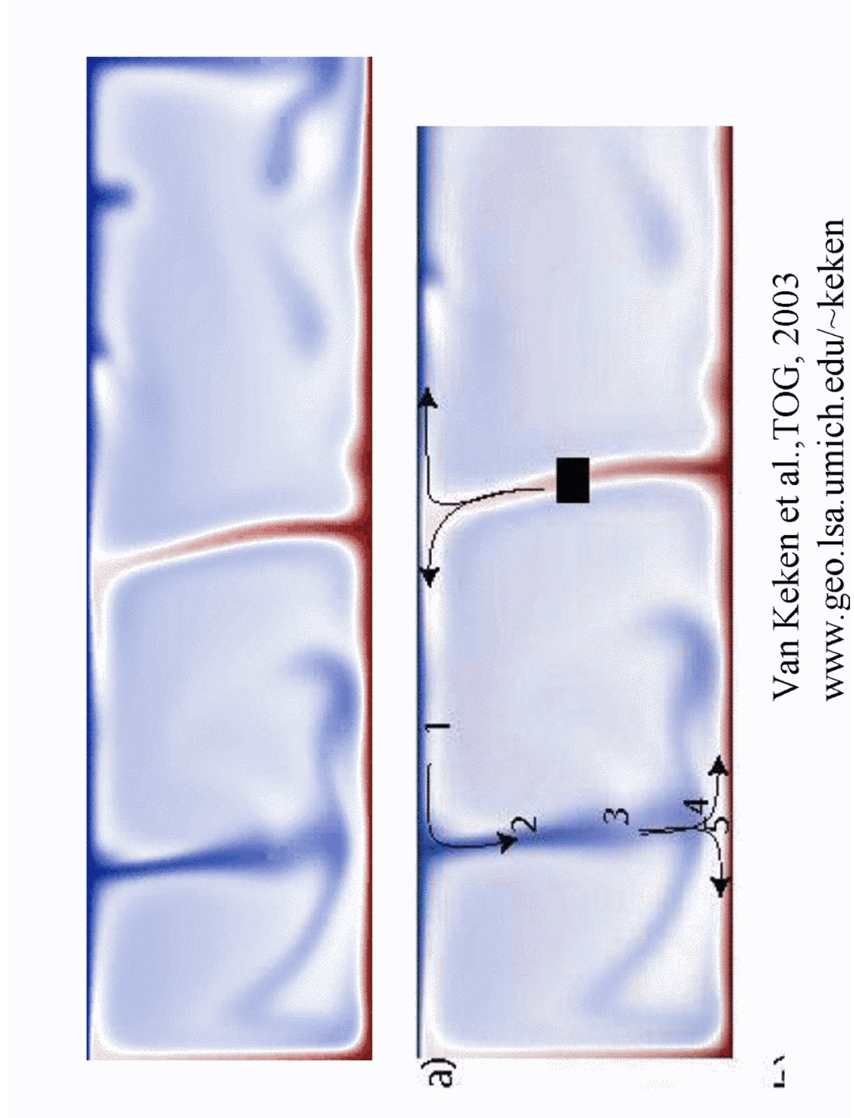
- Mantle mixing
  - Physics of ….
  - Tools for characterization
- Subduction zones
  - Thermal structure
  - EQ source mechanisms
  - Transport of H_2O
- Plate tectonics & early Earth
  - Limits of uniformitarianism?



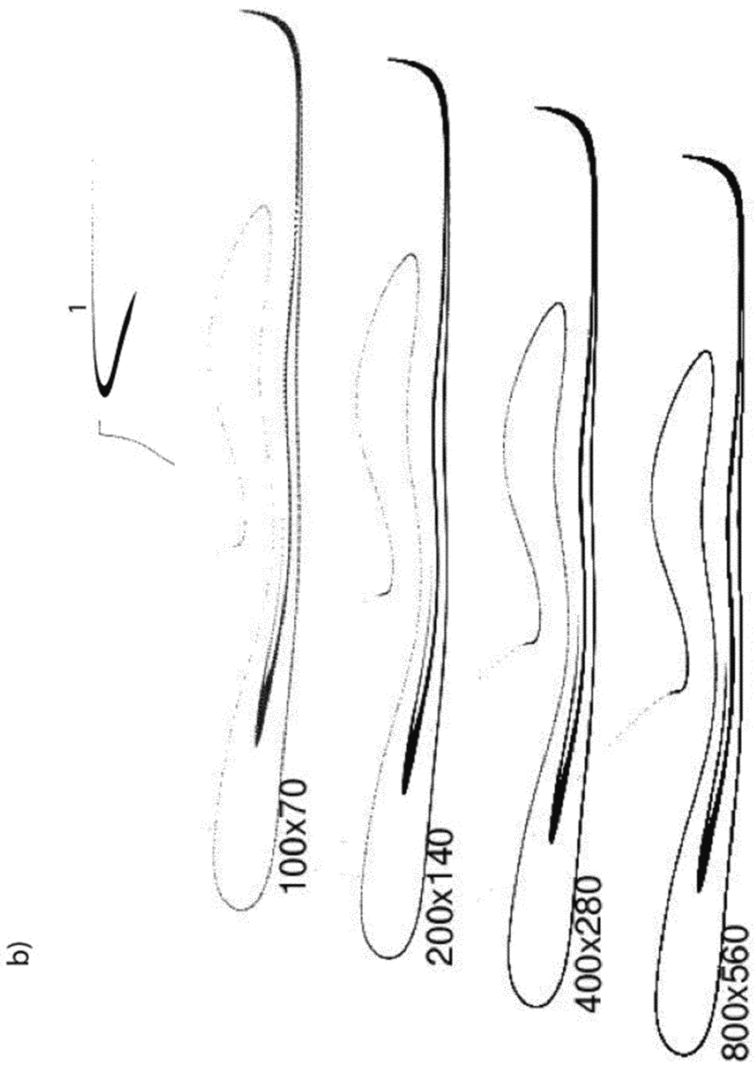
Compilation by Dan Barfod, PhD thesis, University of Michigan

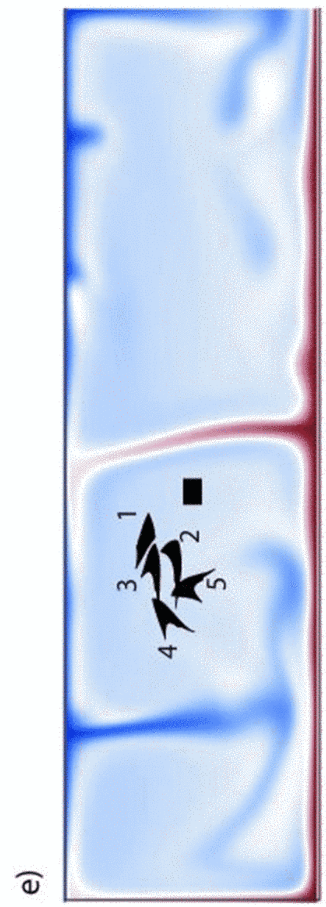


Van Keken, Ballentine and Hauri, Ann Rev., 2002



Van Keken et al., TOG, 2003
www.geo.lsa.umich.edu/~keken





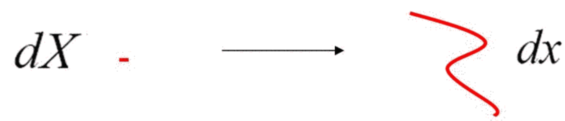
Van Keken et al., TOG, 2003

Mixing = stretching + folding

Physics of mixing

- Mixing processes
  - **Stretching**
  - **Folding**
  - Break up
  - Diffusion
- Efficient mixing
  - Strong deformation (velocity gradients)
  - Reorientation
  - Lagrangian turbulence

Physics of mixing



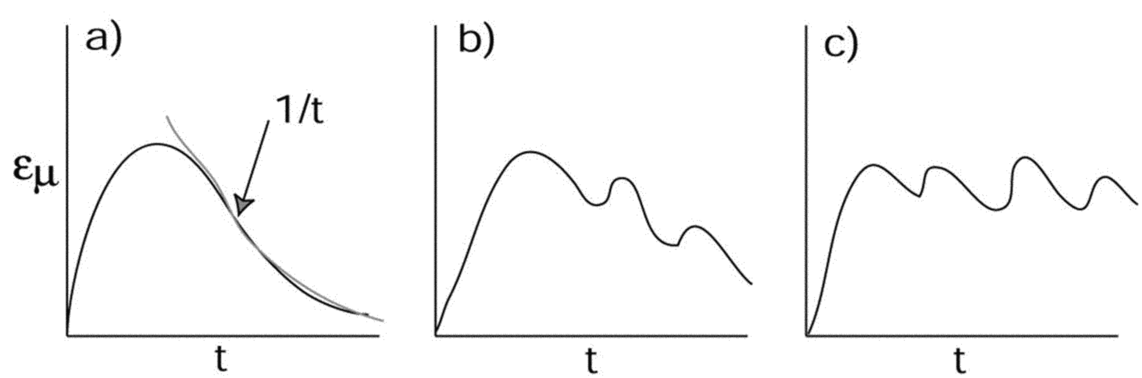
Stretching length $\mu = dx/dX \quad dX \rightarrow 0$

Efficient stretching $d(\ln \mu)/dt > 0.$

Stretching tensor $\mathbf{D} = \tfrac{1}{2}(\nabla \mathbf{v} + (\nabla \mathbf{v})^T)$

$$d(\ln \mu)/dt \leq (\mathbf{D}:\mathbf{D})^{1/2}$$

Stretching efficiency $\varepsilon_\mu = \dfrac{d(\ln \mu)/dt}{(\mathbf{D}:\mathbf{D})^{1/2}} \leq \{(n-1)/n\}^{1/2}$

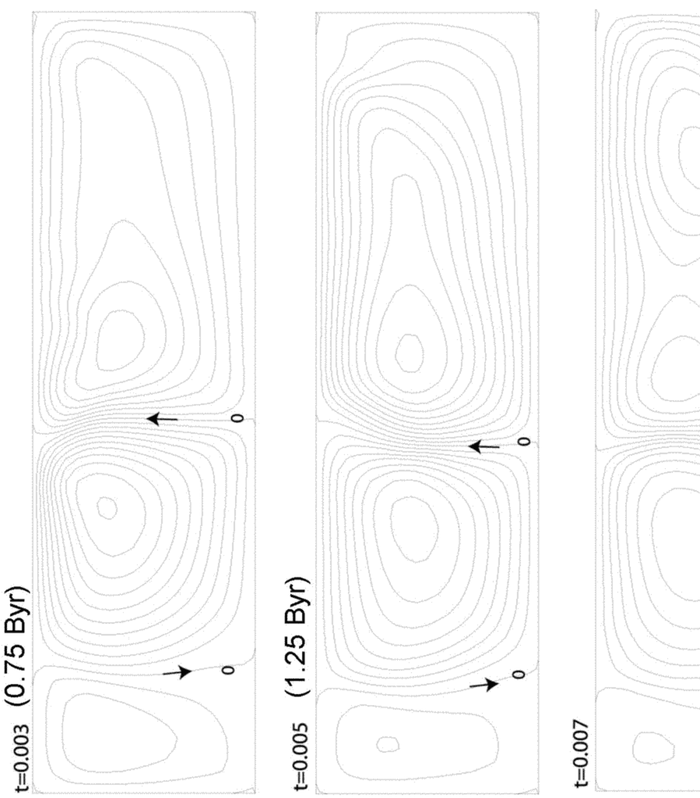


Simple stretching

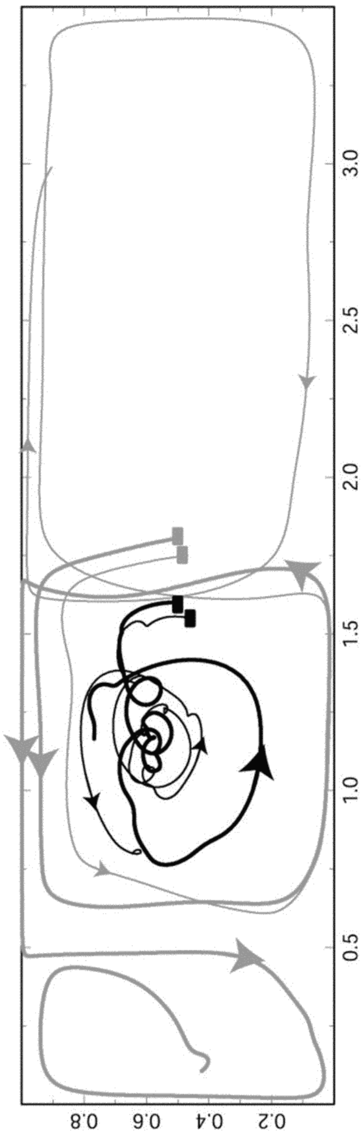
Stretching + occasional ('weak') reorientation

Stretching + frequent ('strong') reorientation

Visualizing mixing: streamlines

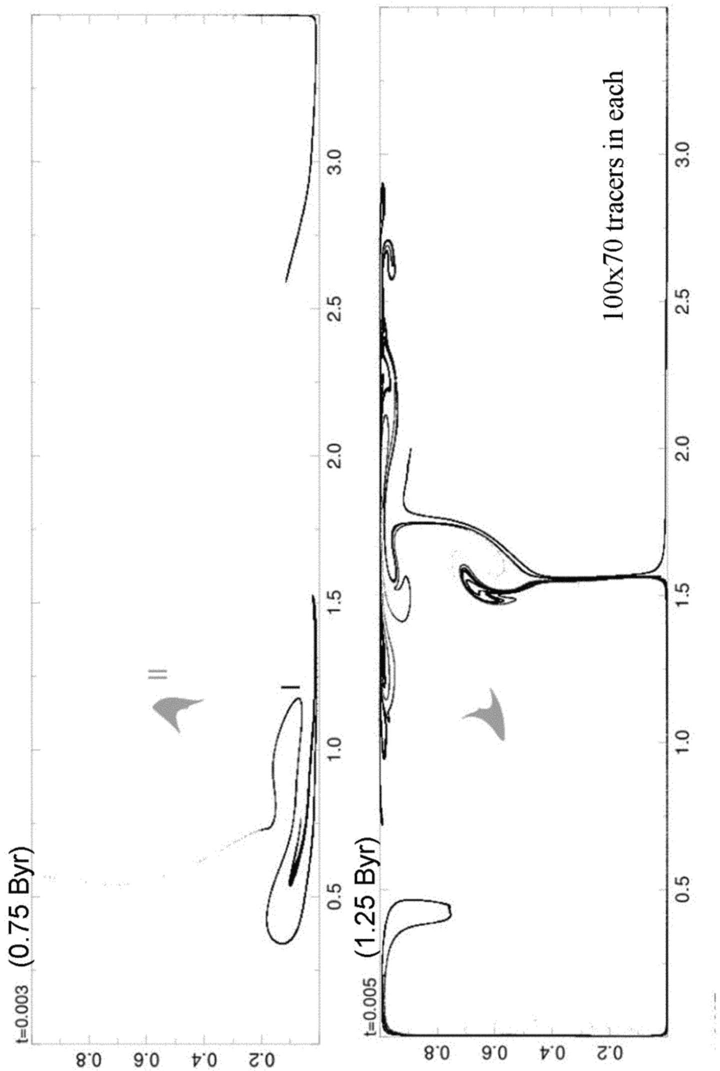


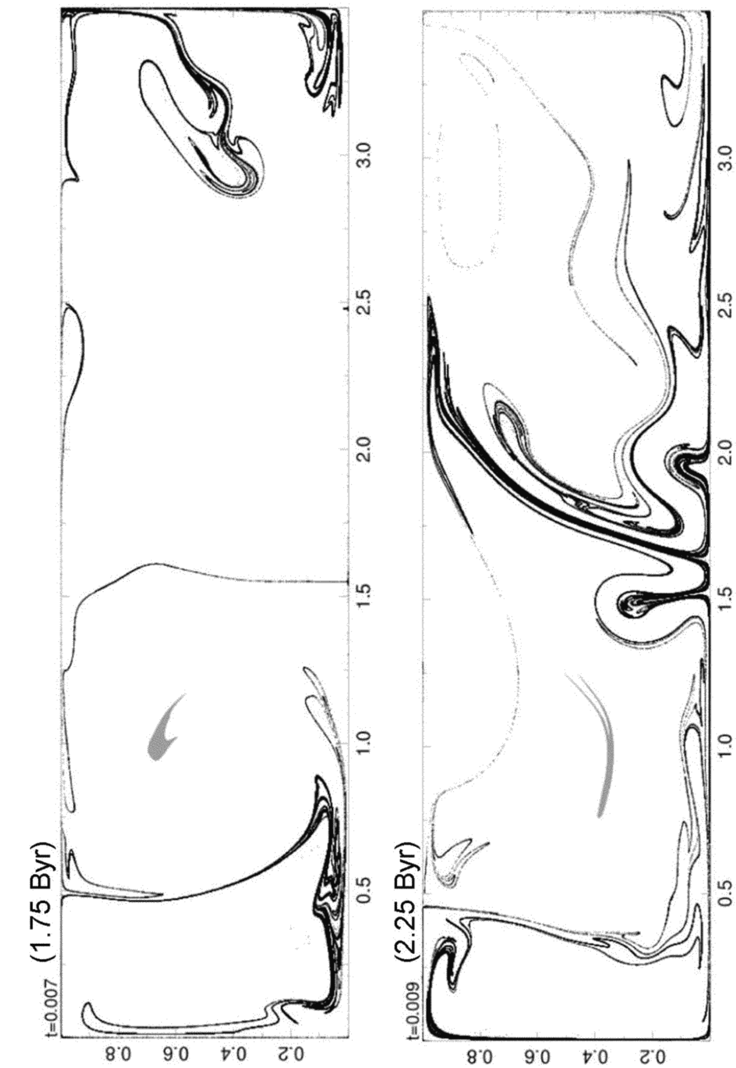
Visualizing mixing: particle paths



t=0-0.01 (2.5 Byr)

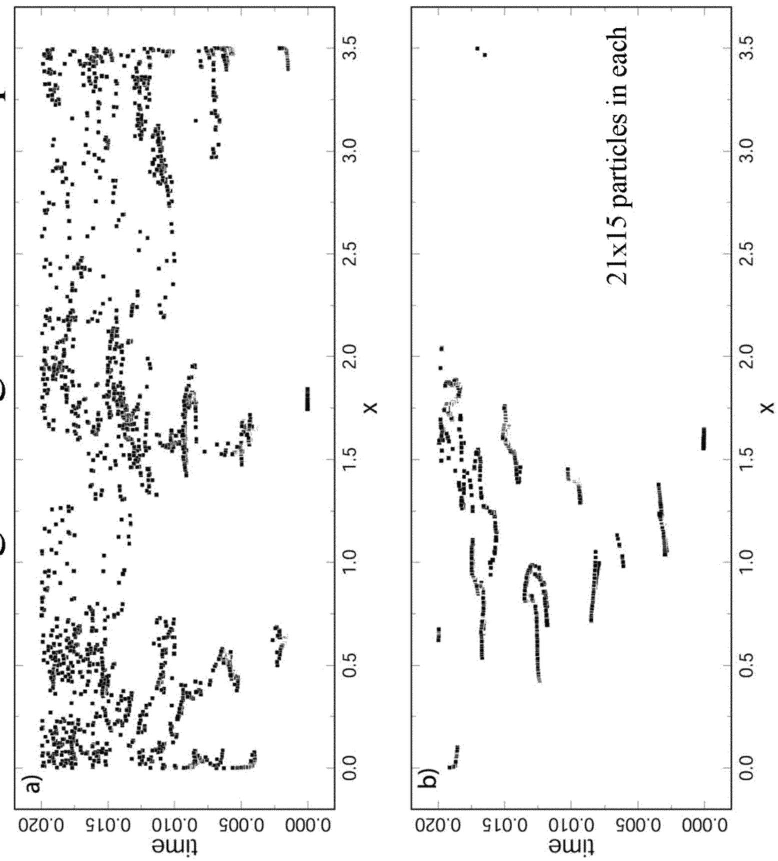
Visualizing mixing: dispersal of heterogeneity



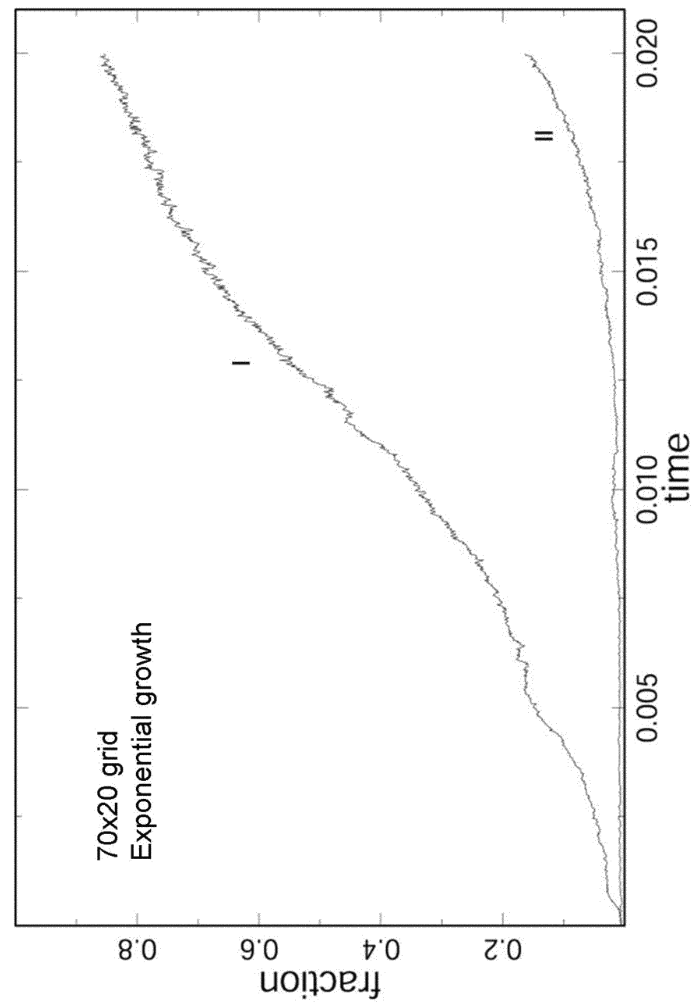


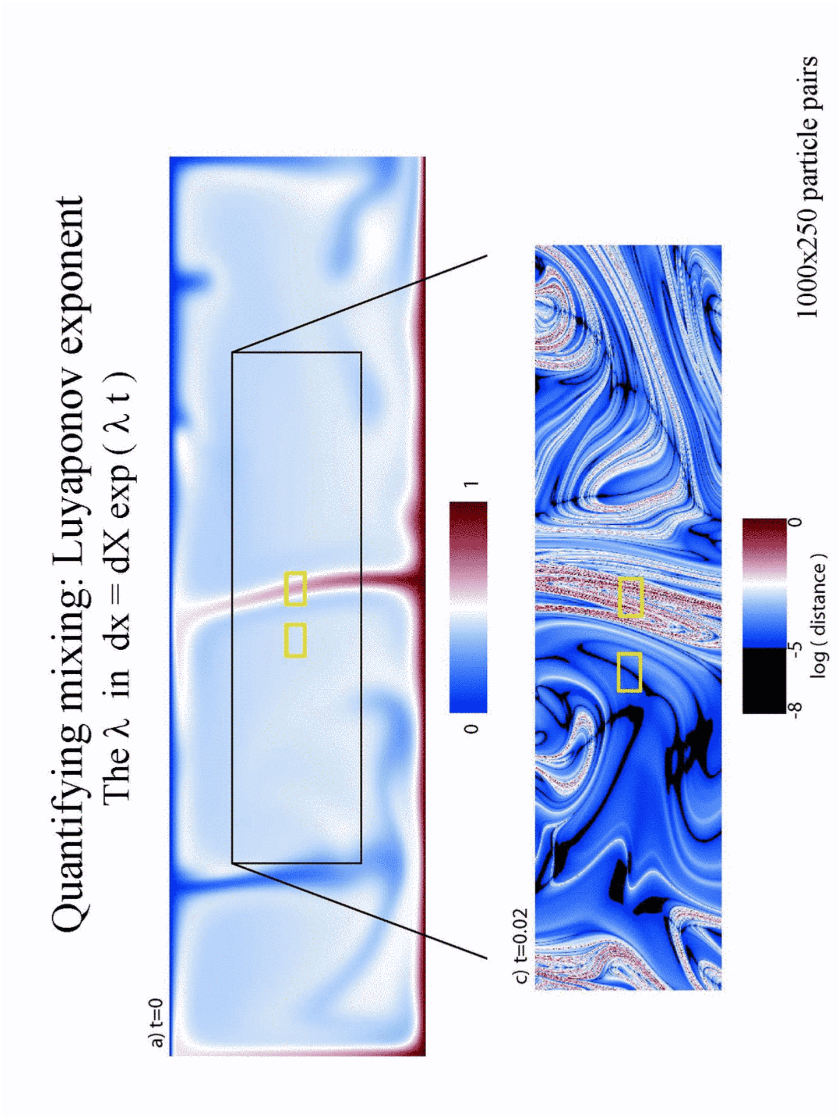
Van Keken et al., TOG, 2003

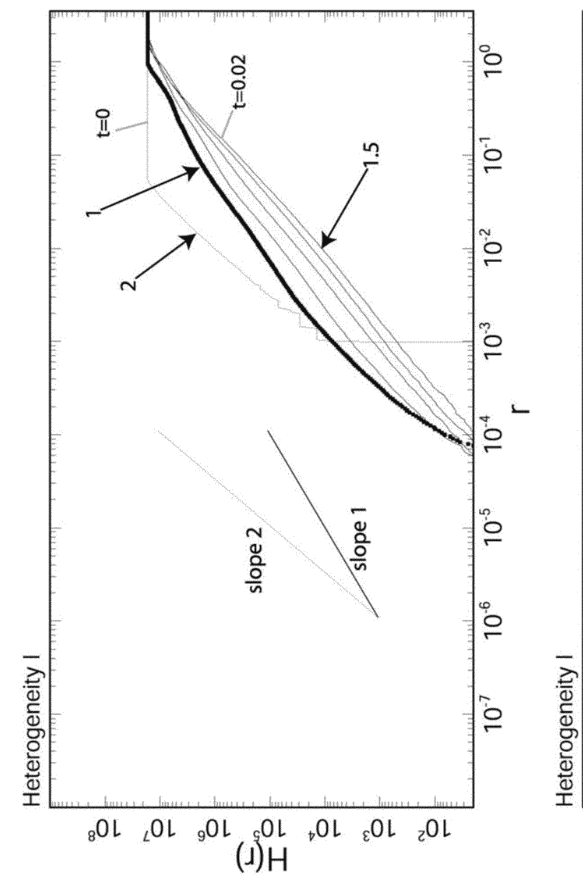
Visualizing mixing: Poincaré maps

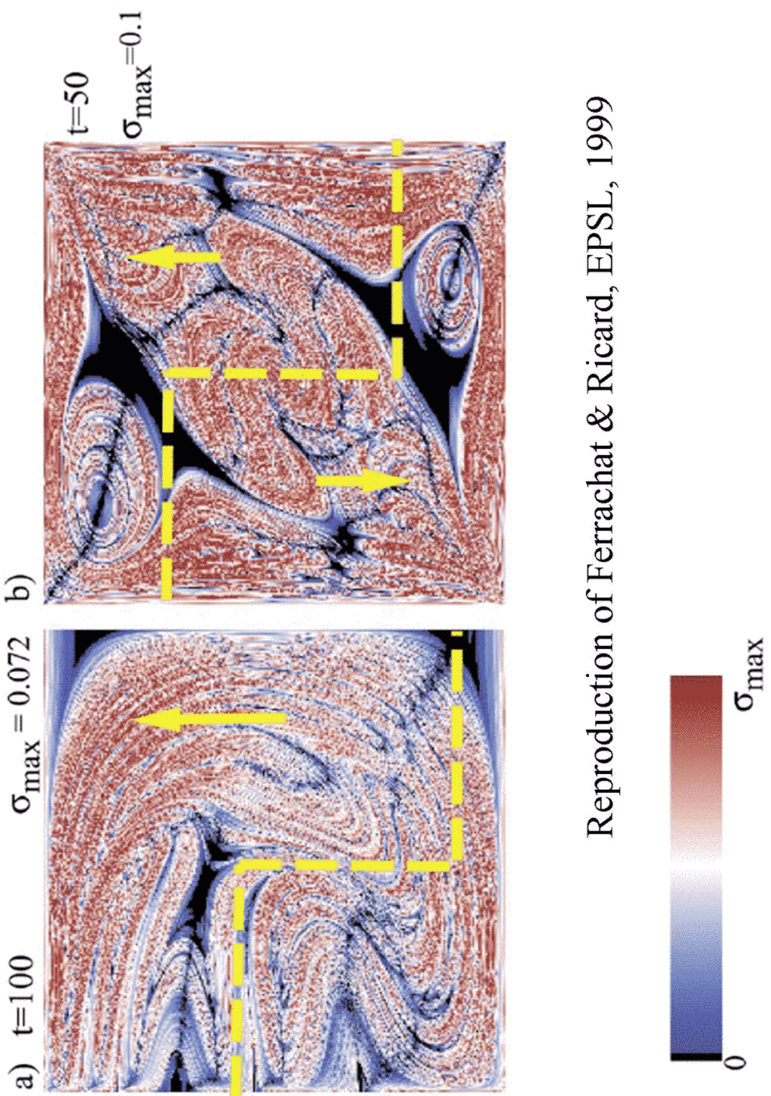


Quantifying mixing: box counting

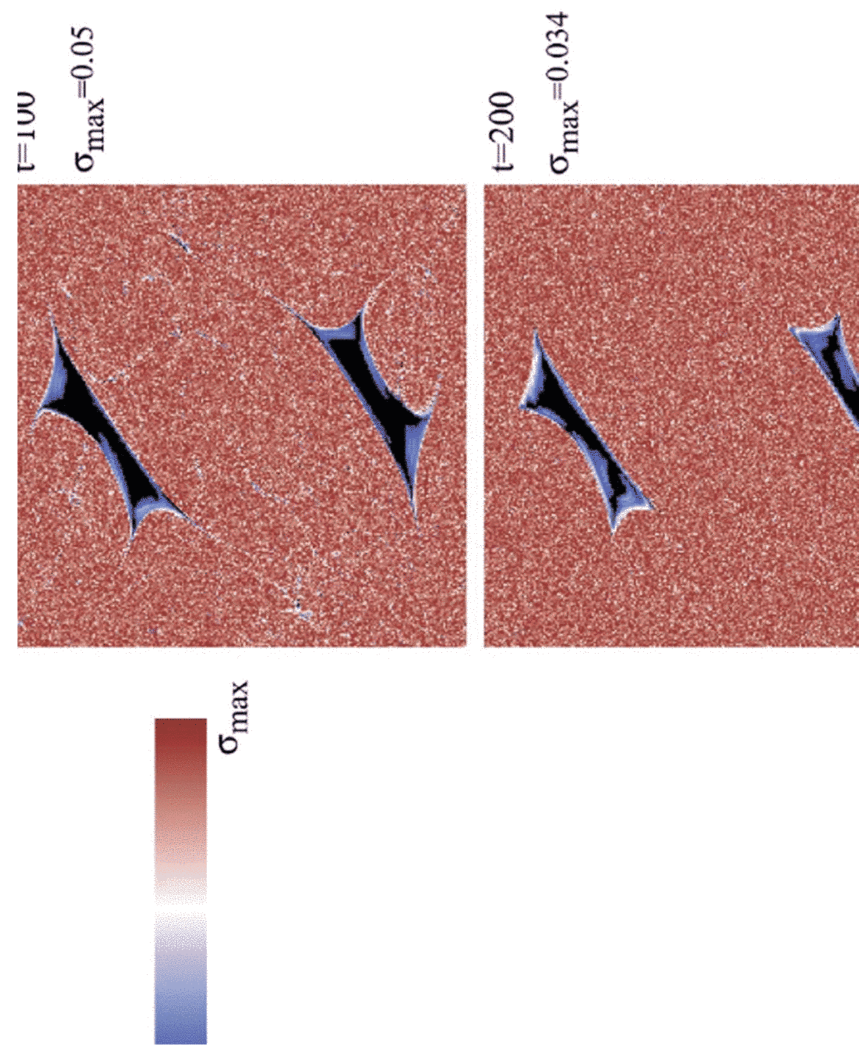


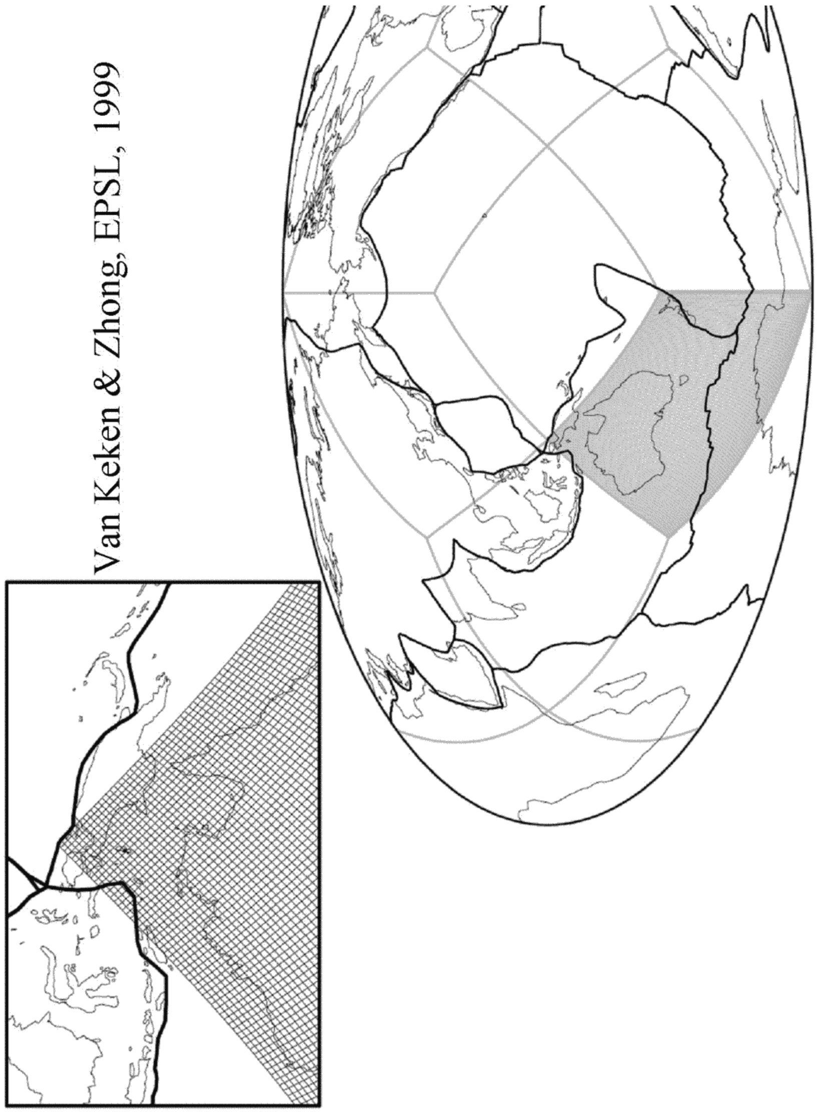

Quantifying mixing: Luyaponov exponent
The λ in dx = dX exp (λ t)
1000x250 particle pairs
a) t=0
c) t=0.02
0
1
-8
-5
0
log (distance)


Heterogeneity I
H(r)
r
t=0
t=0.02
1
2
1.5
slope 1
slope 2



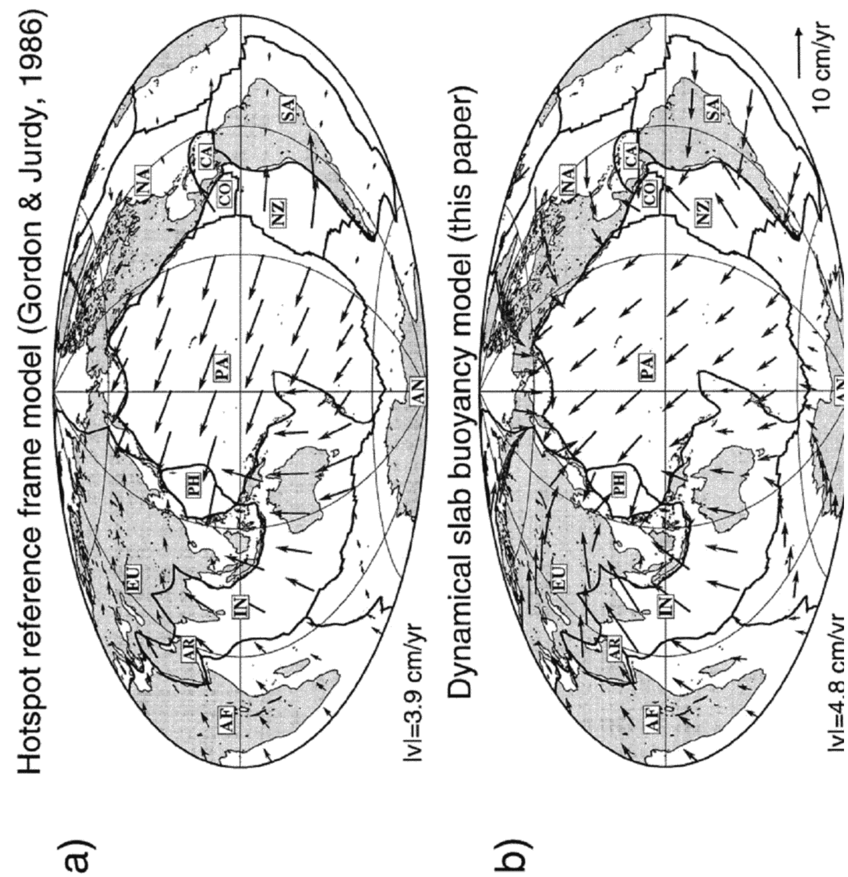
Reproduction of Ferrachat & Ricard, EPSL, 1999

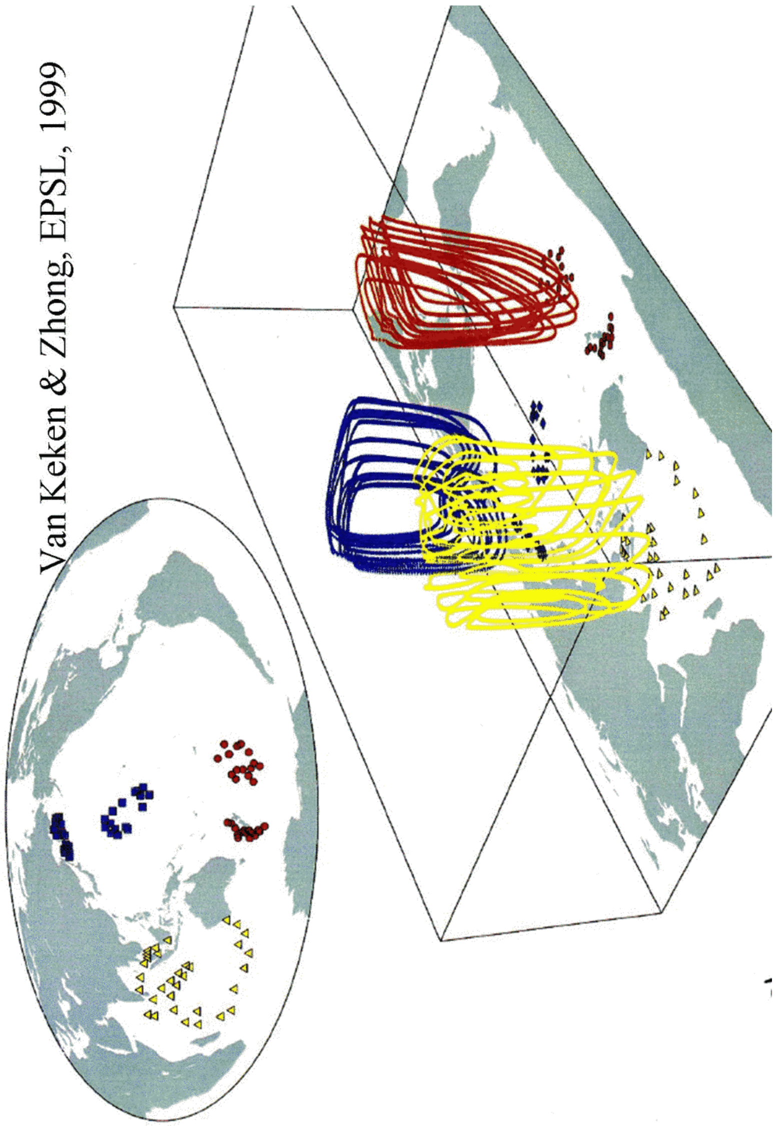


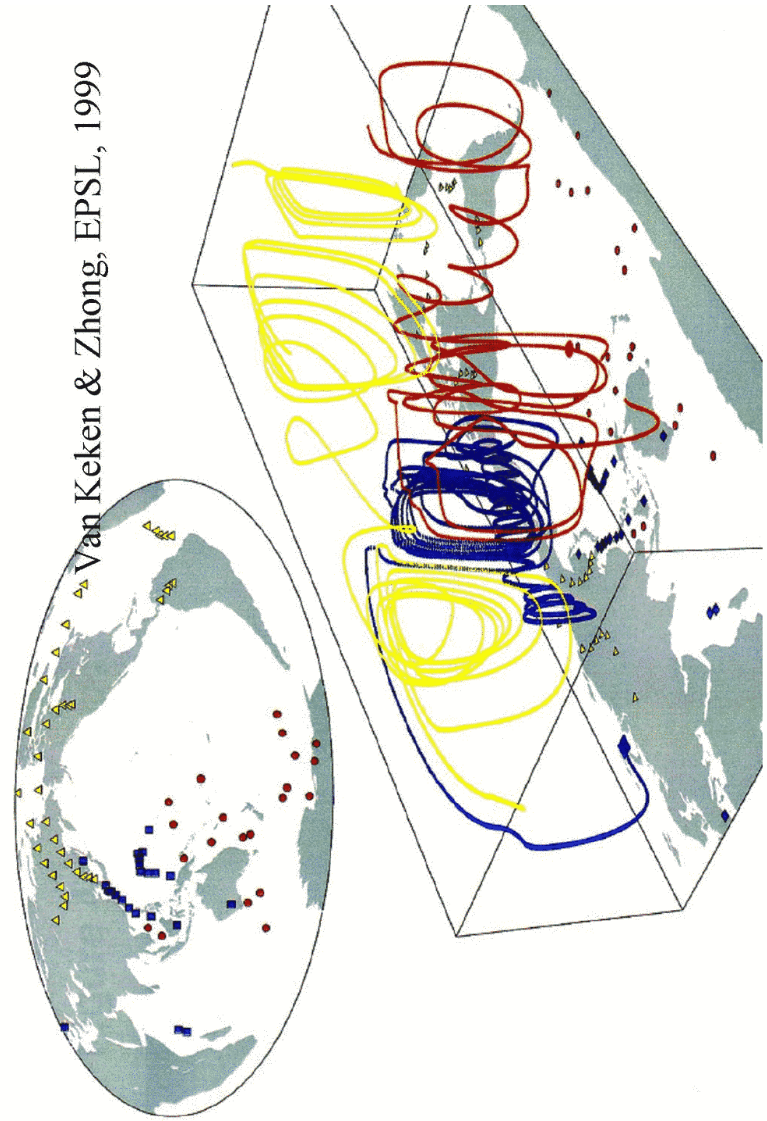


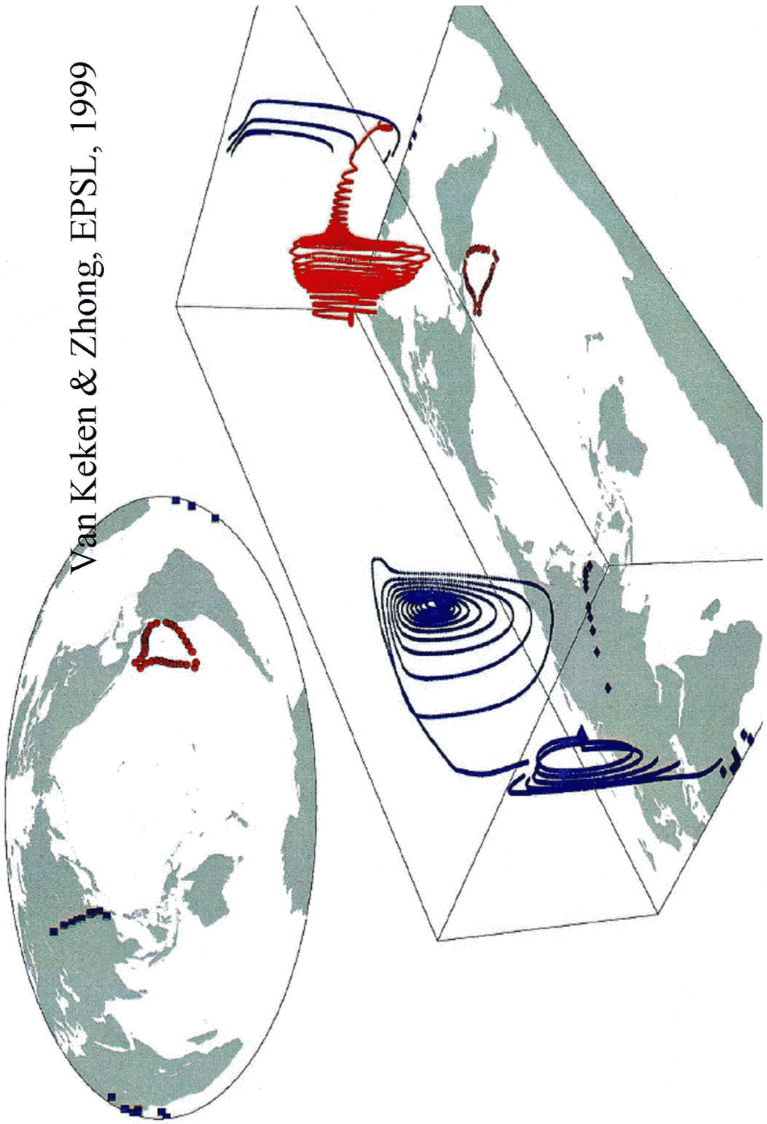
Van Keken & Zhong, EPSL, 1999

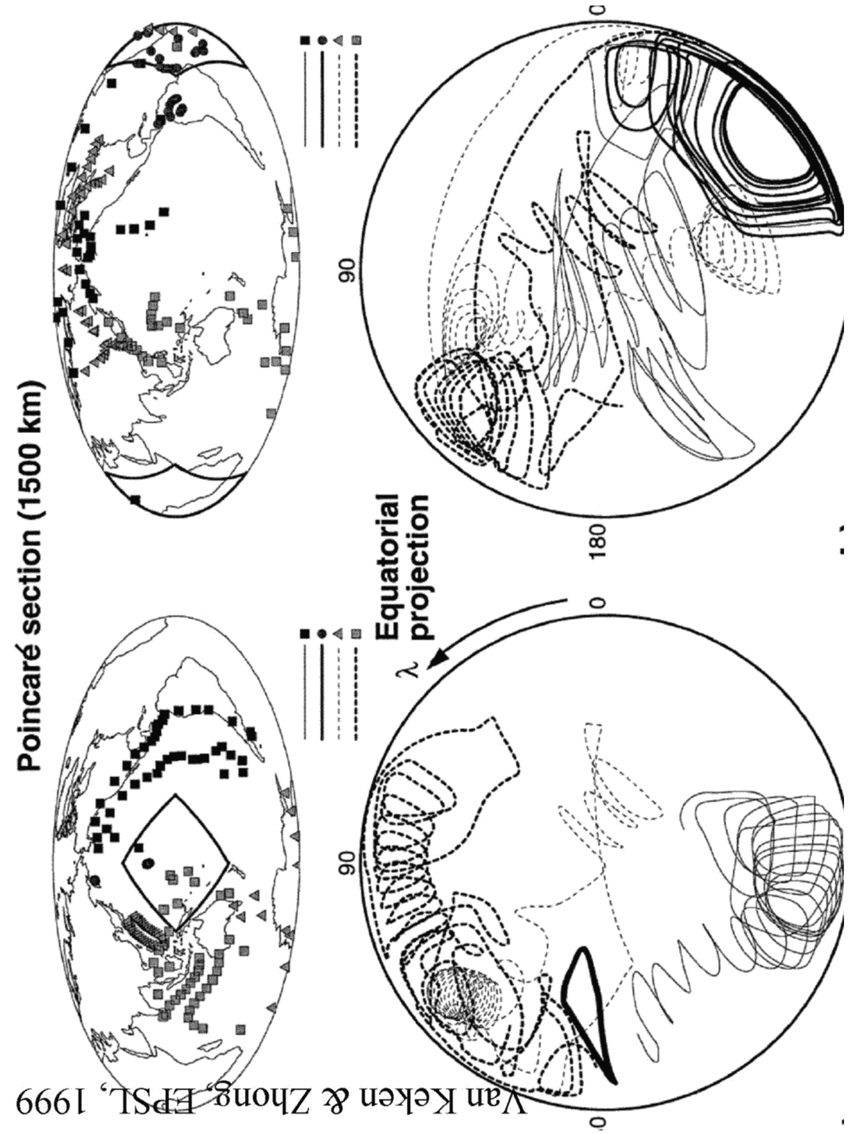
Van Keken & Zhong, EPSL, 1999

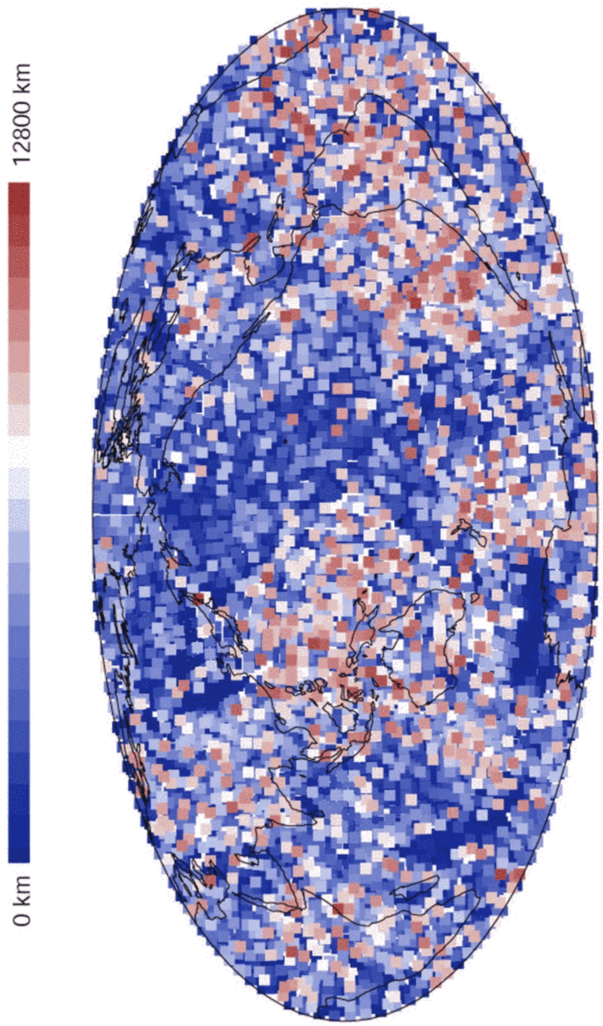



Van Keken & Zhong, EPSL, 1999

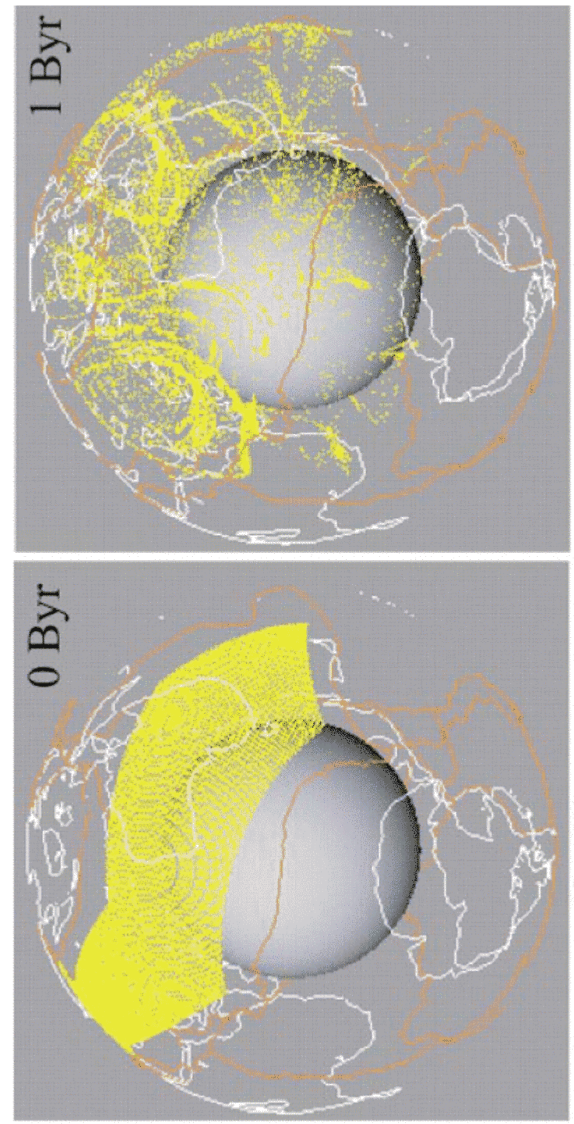

Van Keken & Zhong, EPSL, 1999


Van Keken & Zhong, EPSL, 1999

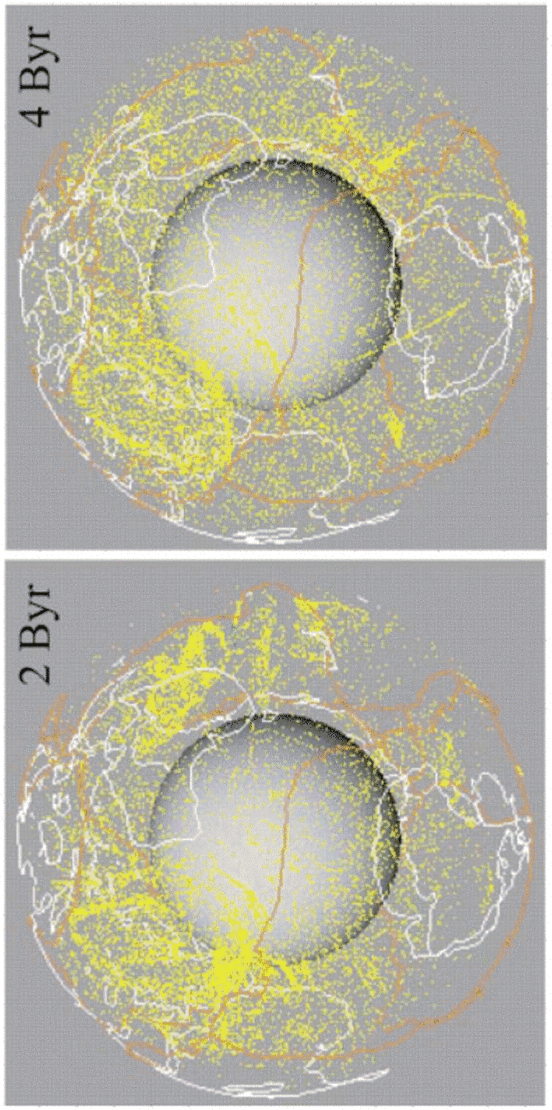

Poincaré section (1500 km)
Equatorial projection
λ
0
90
180
Van Keken & Zhong, EPSL, 1999



Van Keken & Zhong, EPSL, 1999

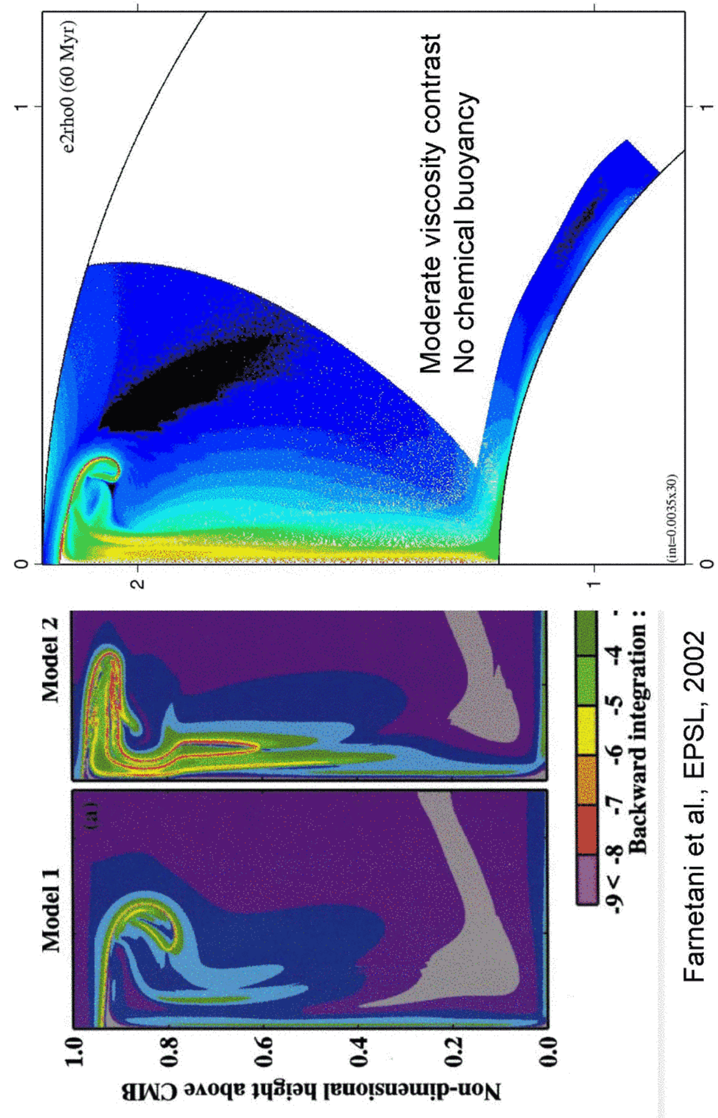


Van Keken & Zhong, EPSL, 1999

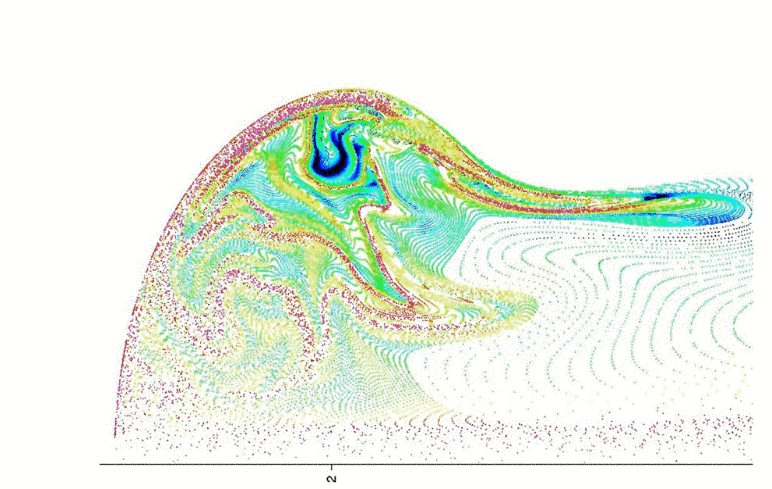


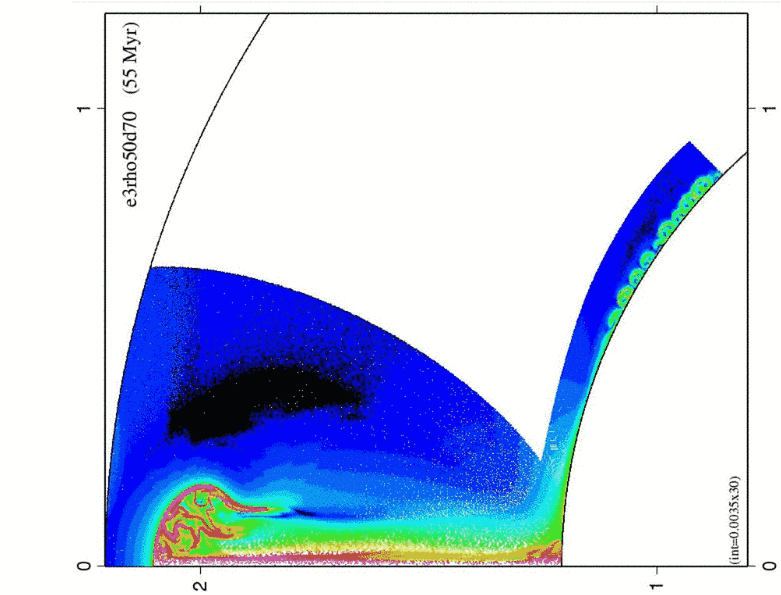
Van Keken & Zhong, EPSL, 1999

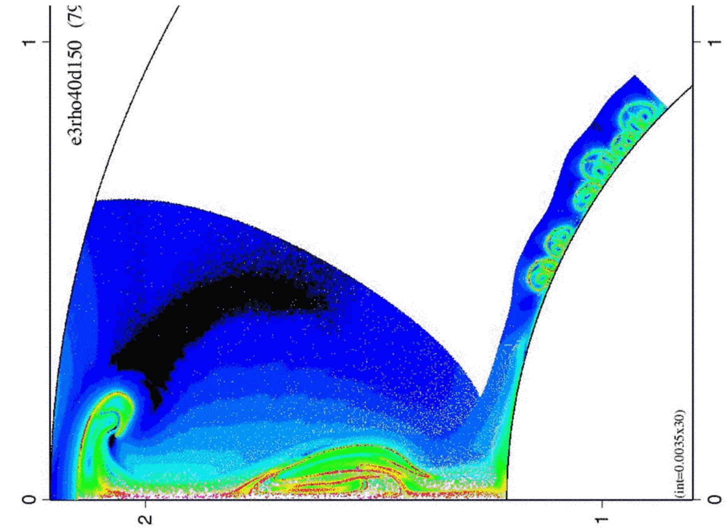
Mixing in plume heads and tails

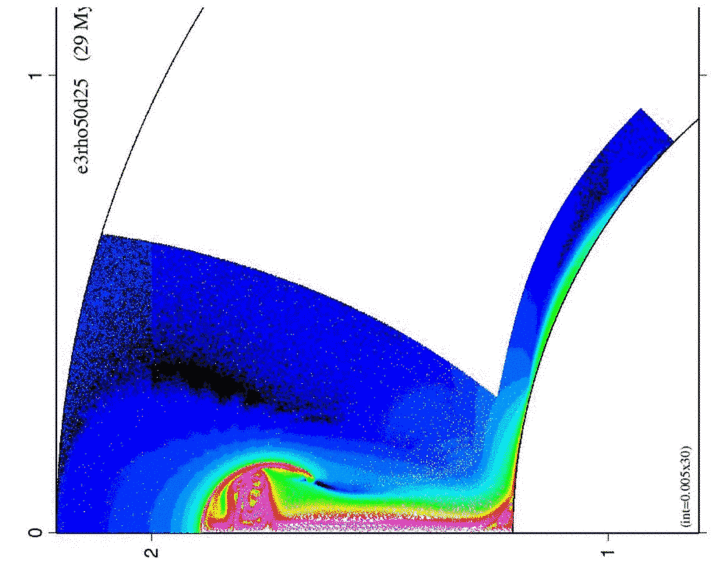


Farnetani et al., EPSL, 2002



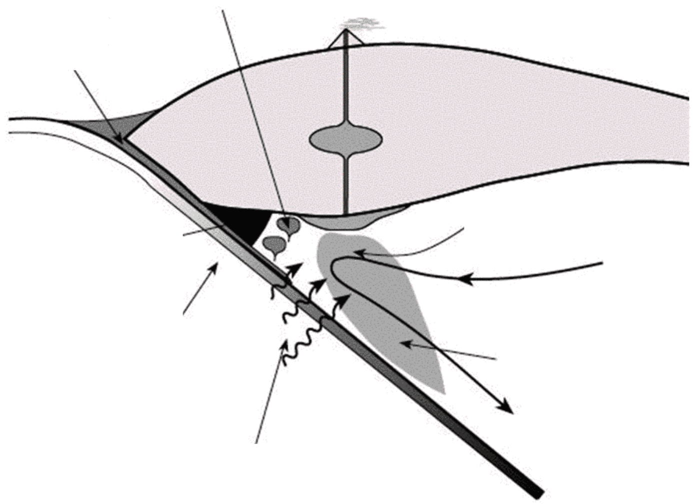

e3rho50d70 (55 Myr)
(int=0.0035x30)


e3rho40d150 (79
(int=0.0035x30)


e3rho50d25 (29 My
(int=0.005x30)

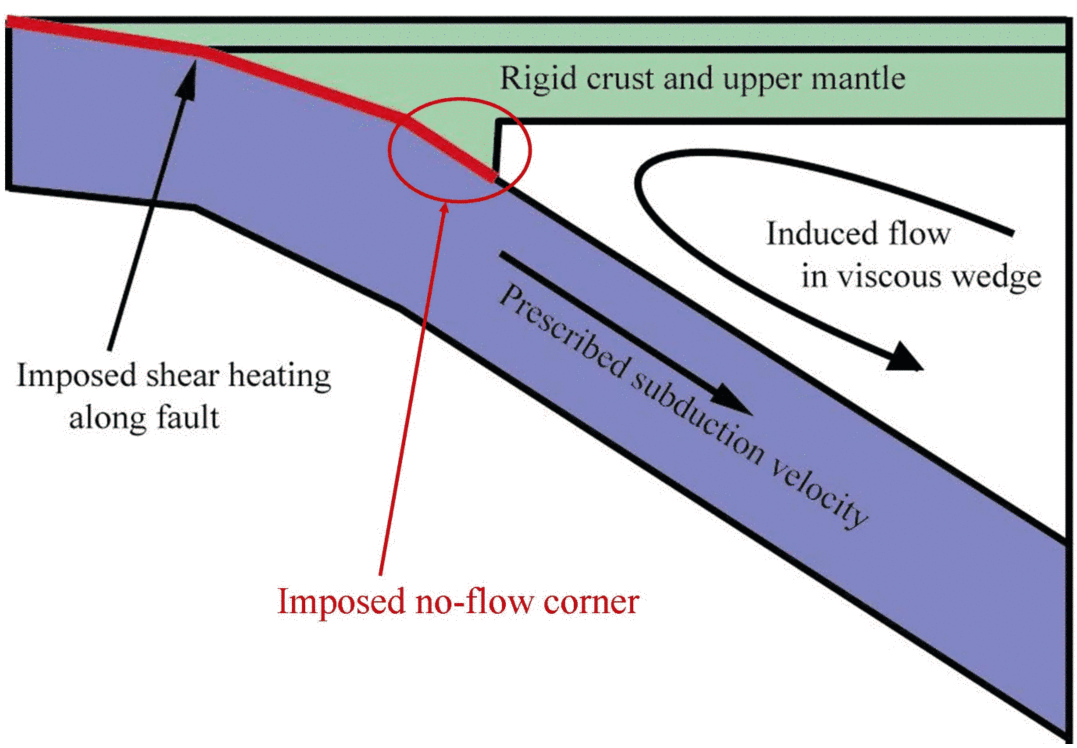
C en cidre, part deux

Controls on slab thermal structure:
- age & speed of incoming slab
- geometry
- structure and dynamics of the wedge
- shear heating along the seismogenic zone
- phase changes

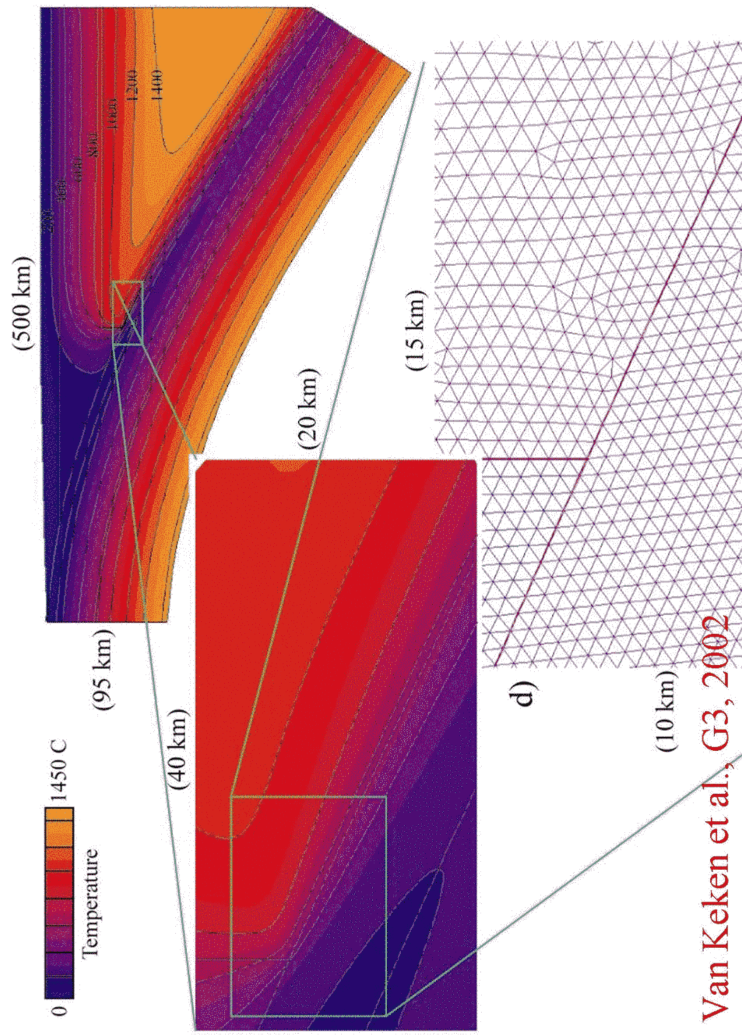


Van Keken, EPSL, 2003

II Kinematic/dynamic models

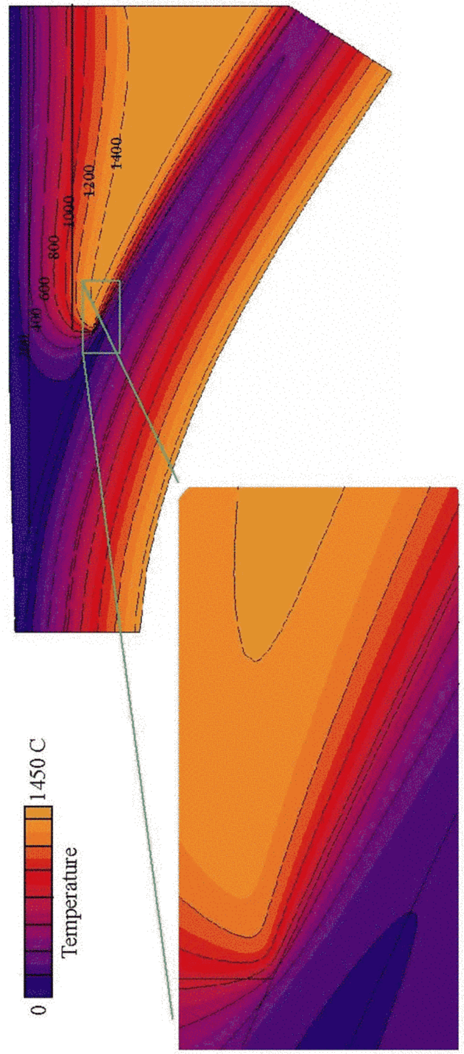


Honshu; isoviscous

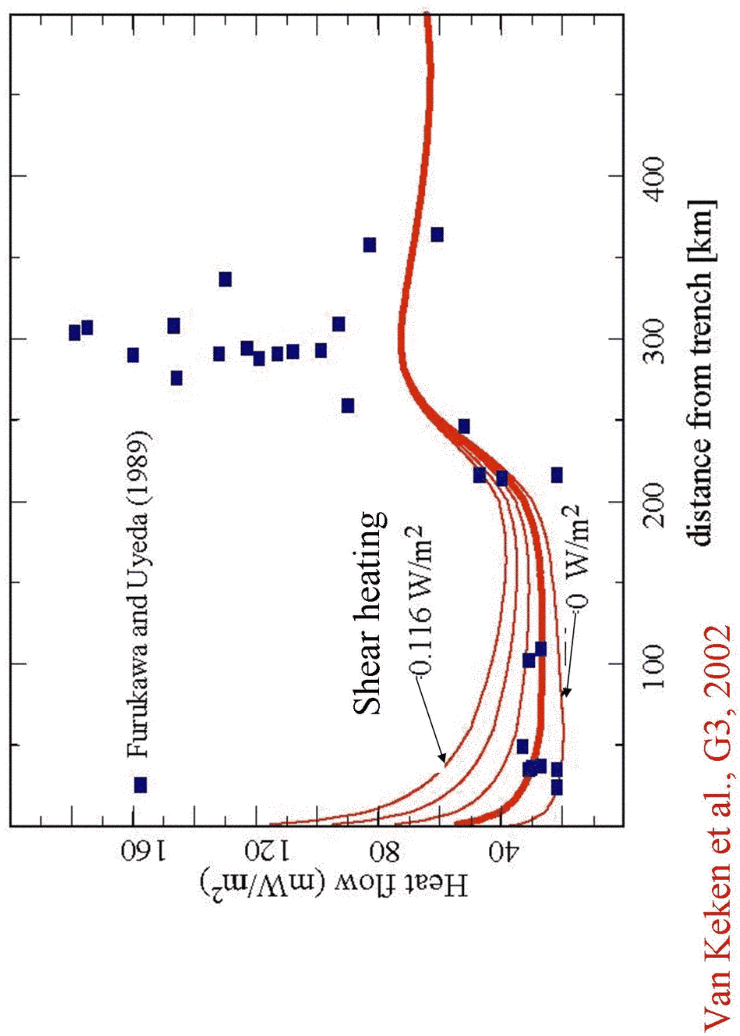


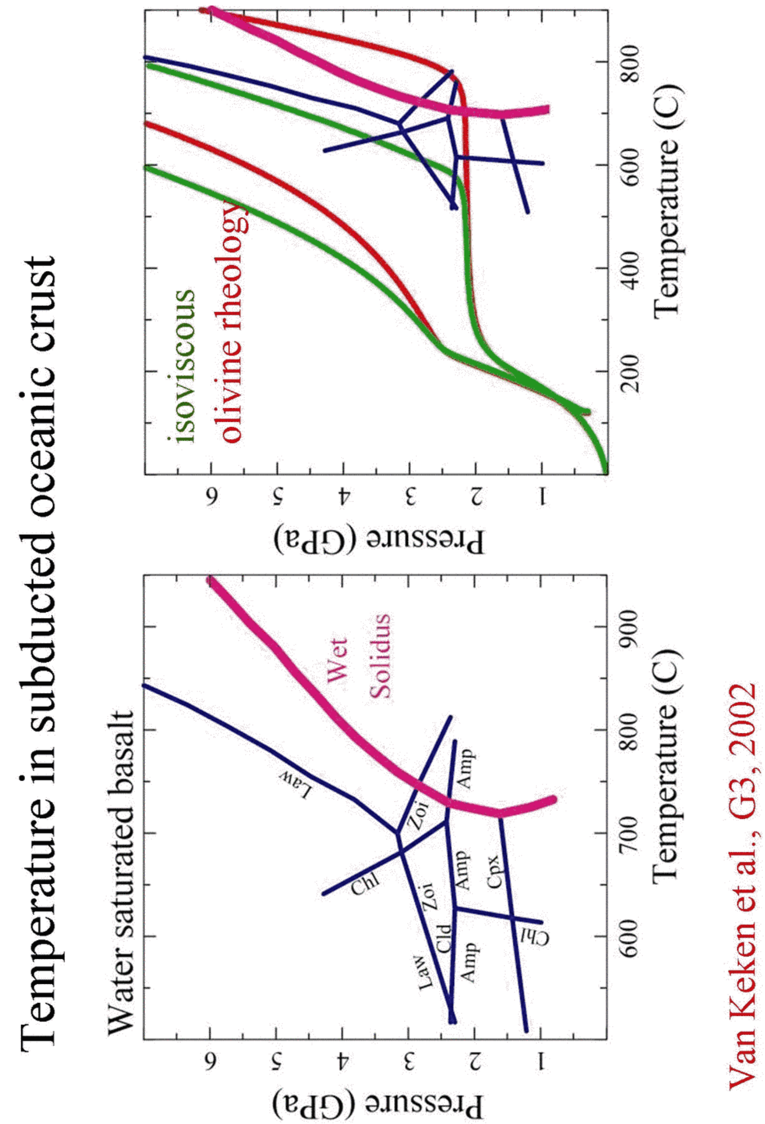
Van Keken et al., G3, 2002

Honshu; Olivine rheology

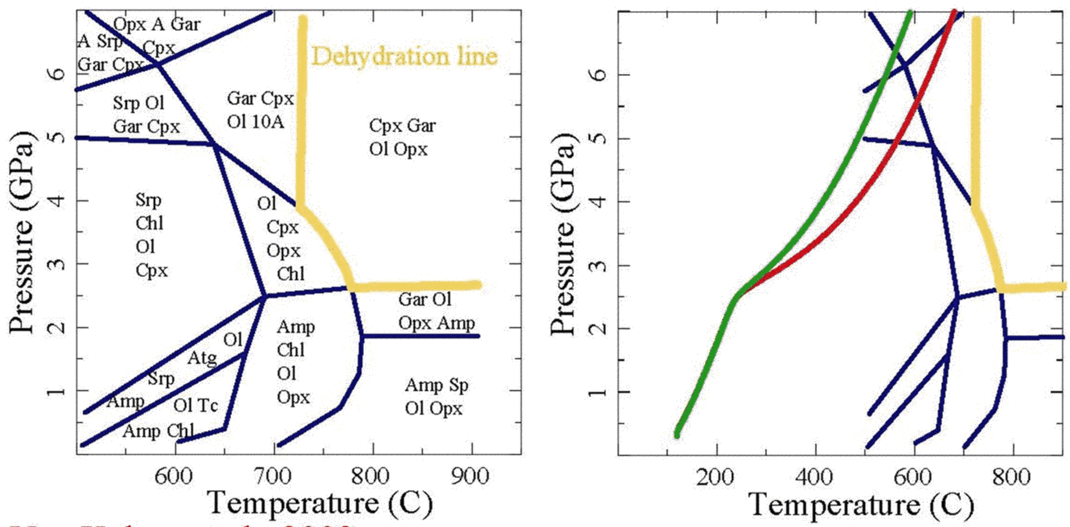


Van Keken et al., G3, 2002


Furukawa and Uyeda (1989)
Shear heating
0.116 W/m²
0 W/m²
Heat flow (mW/m²)
distance from trench [km]
Van Keken et al., G3, 2002

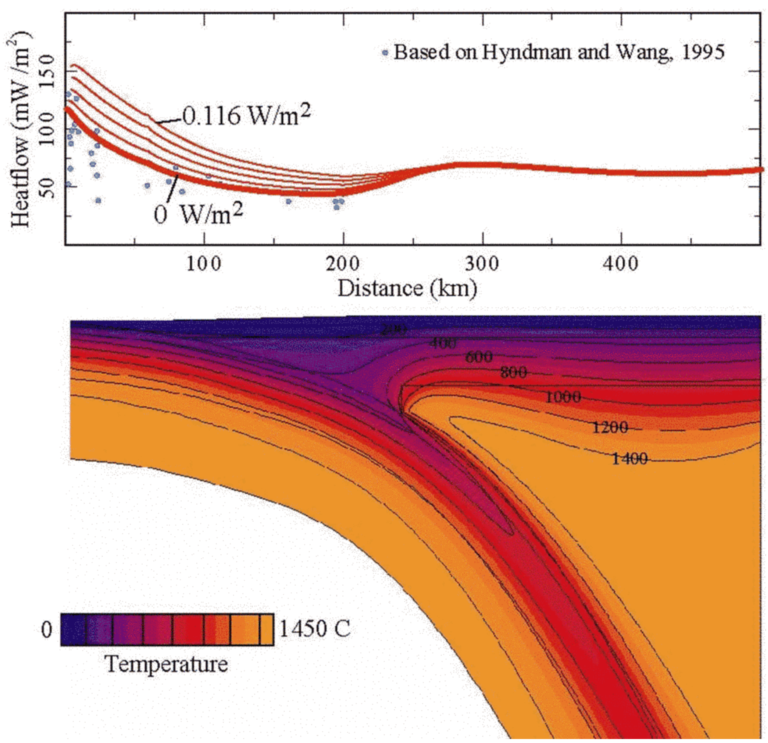

Temperature in subducted oceanic crust
Water saturated basalt
Wet Solidus
Law
Zoi
Amp
Chl
Cld
Cpx
Pressure (GPa)
Temperature (C)
isoviscous
olivine rheology
Van Keken et al., G3, 2002

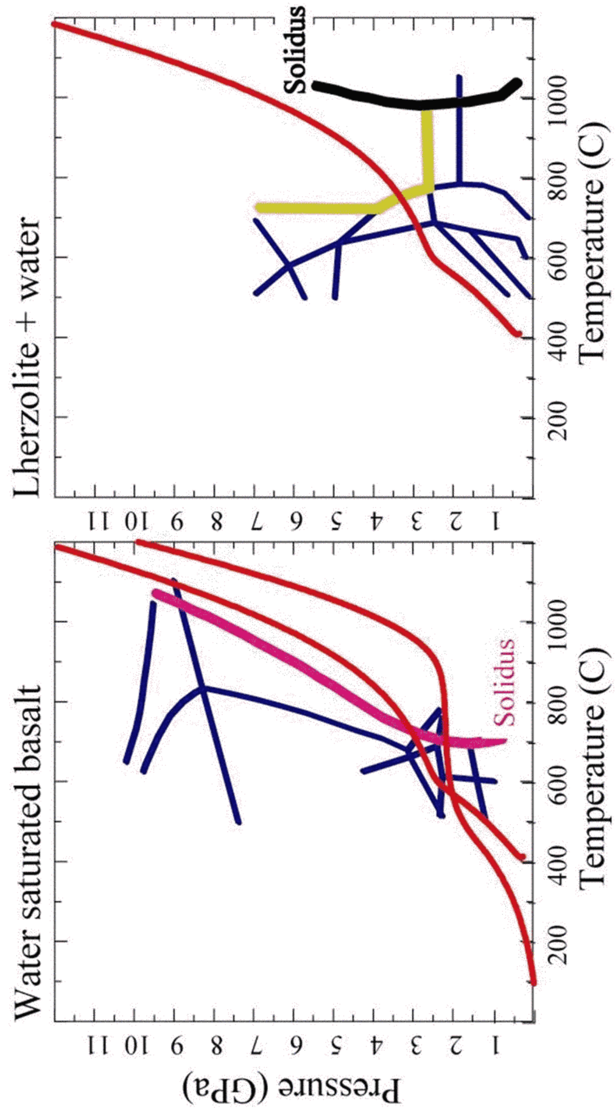
Temperature in subducted oceanic upper mantle

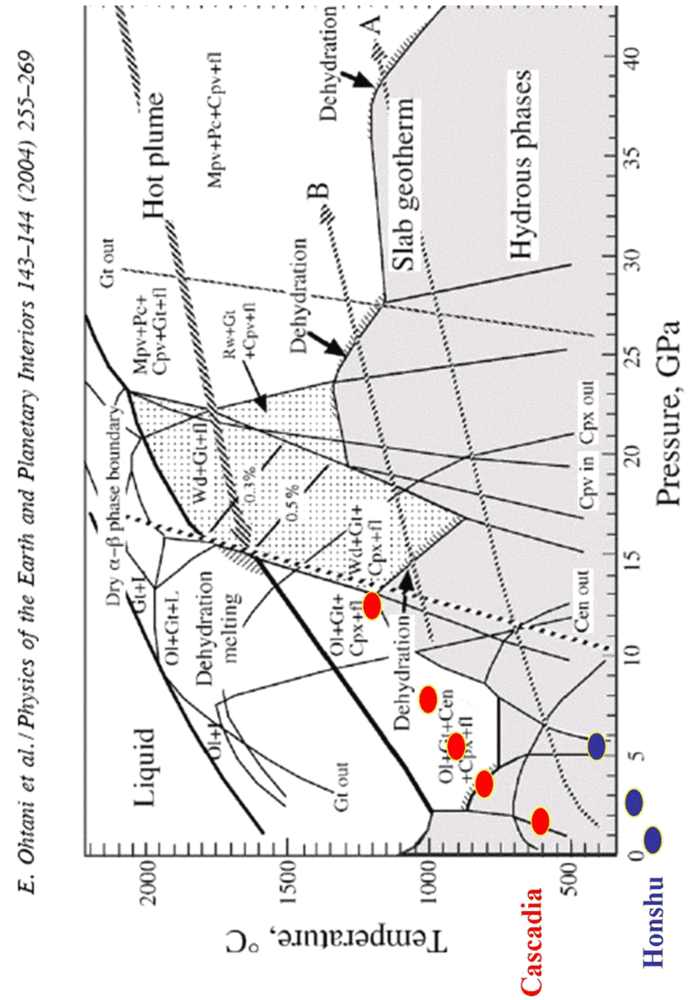


Van Keken et al., 2002

Cascadia; Olivine rheology



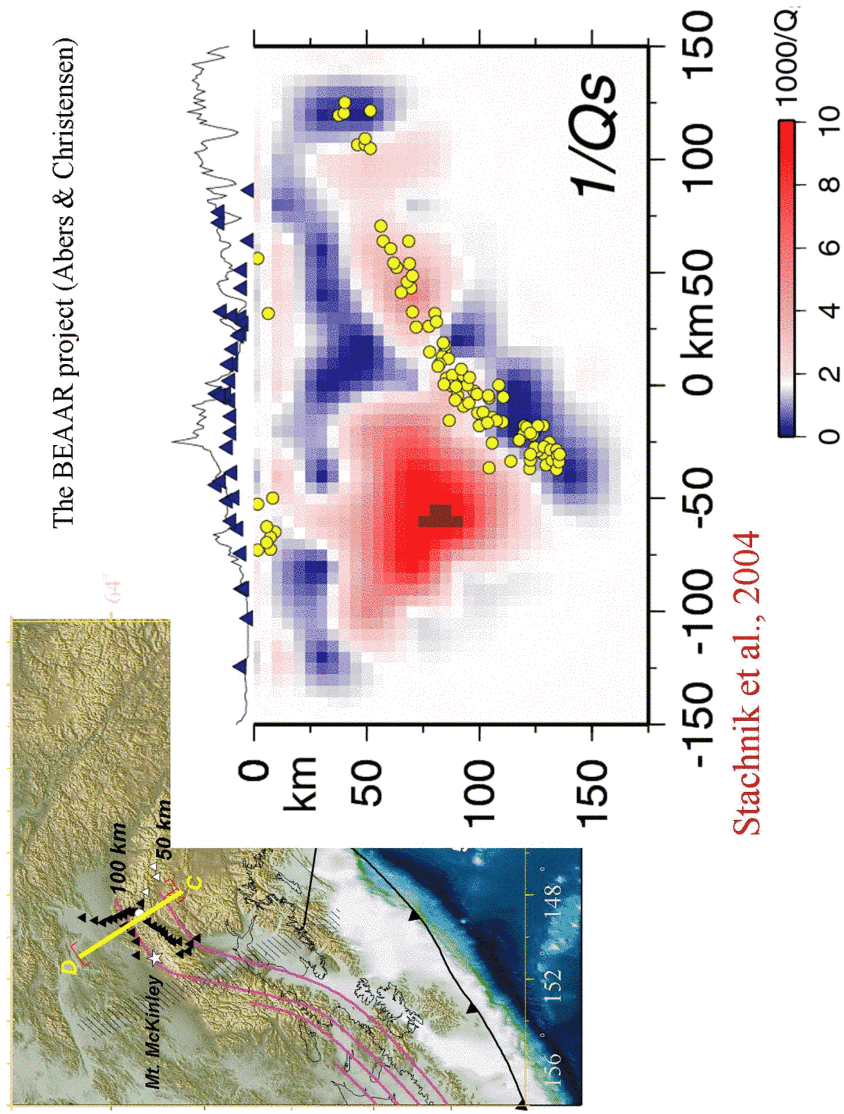




T along particle paths at 10 km below top of slab

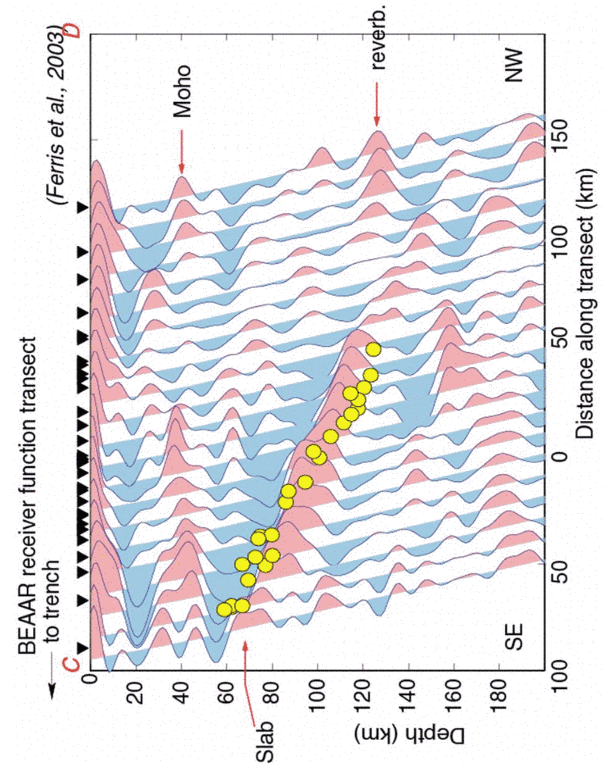
Hirschmann and van Keken, in prep.

The BEAAR project (Abers & Christensen)

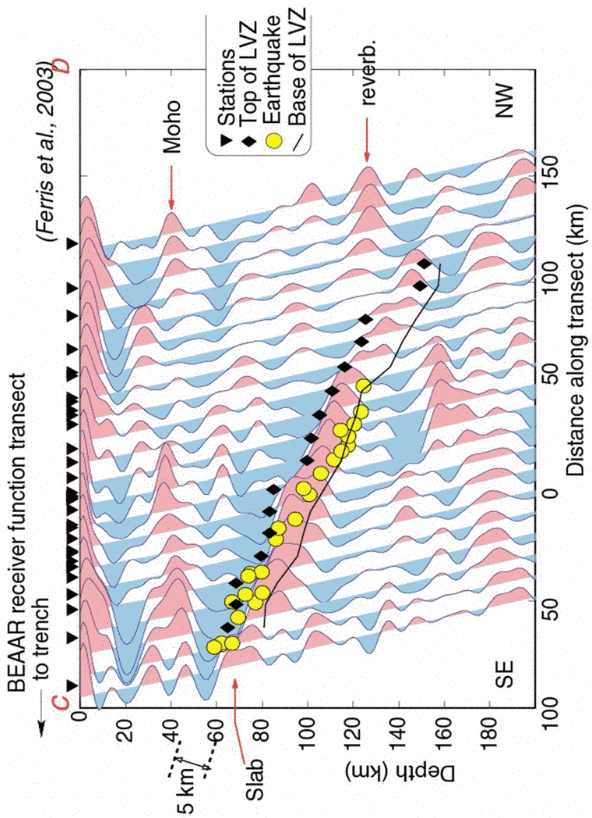


Stachnik et al., 2004

NW Back-azimuth: Processed Image

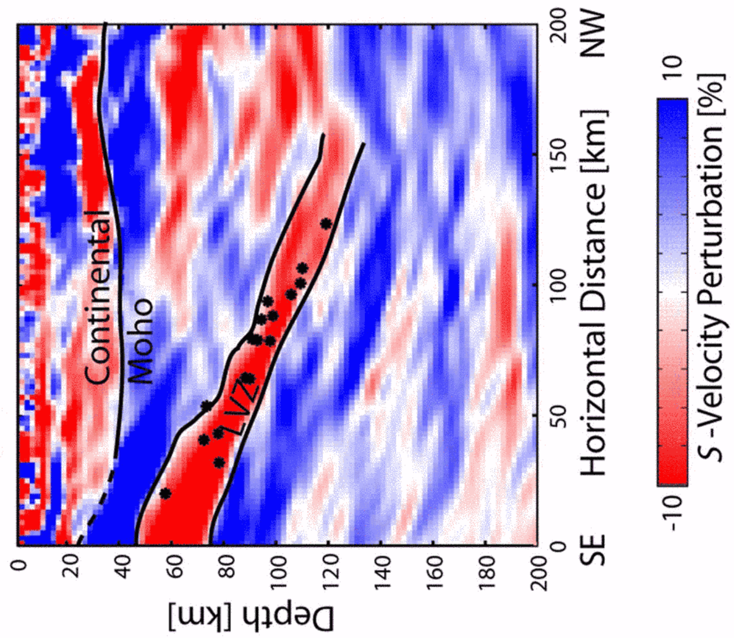


Subducting Low-Velocity Zone



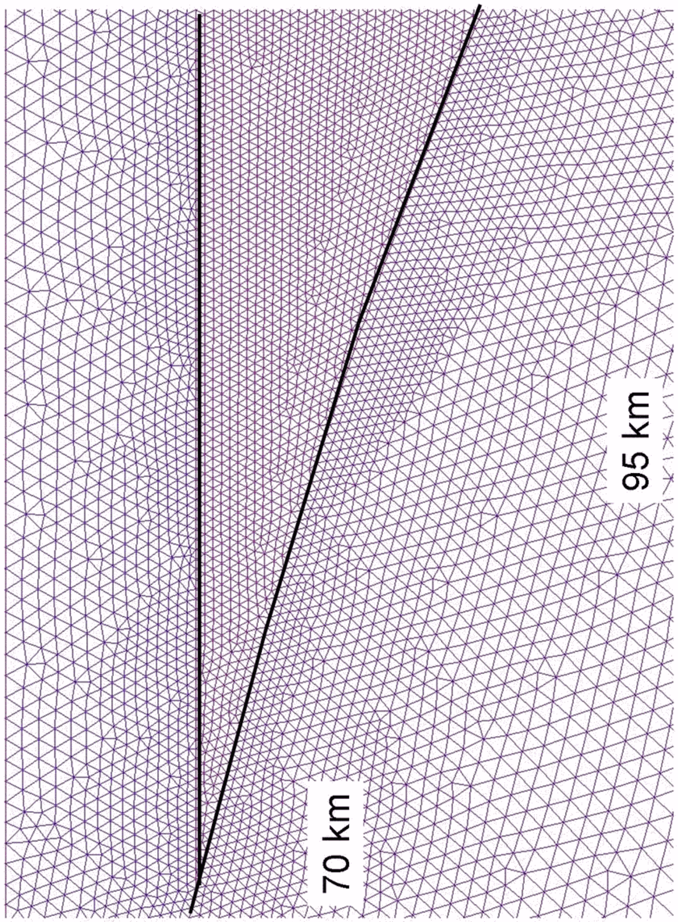
Migration

δβ/β perturbations

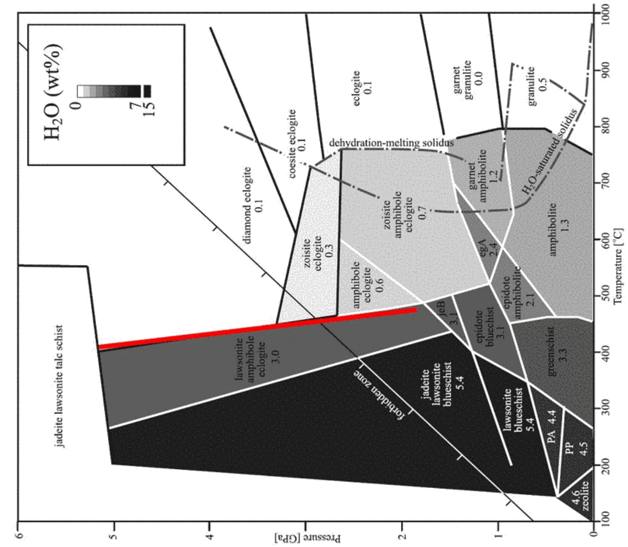


(S. Rondenay)

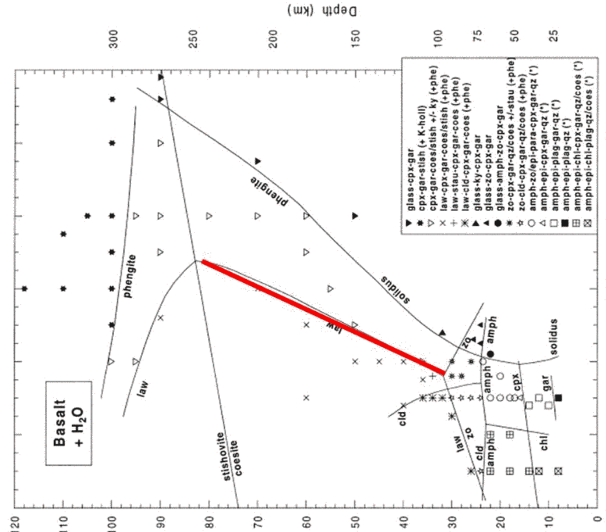
Thermal modeling of the Alaska subduction zone



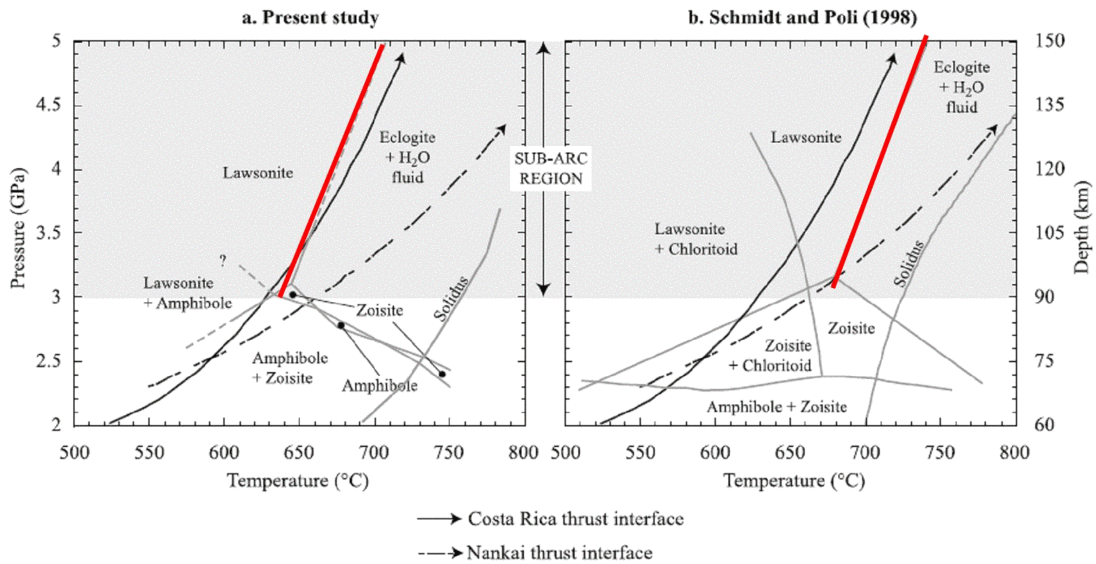
Abers et al., EPSL, 2006



Hacker et al., JGR, 2003

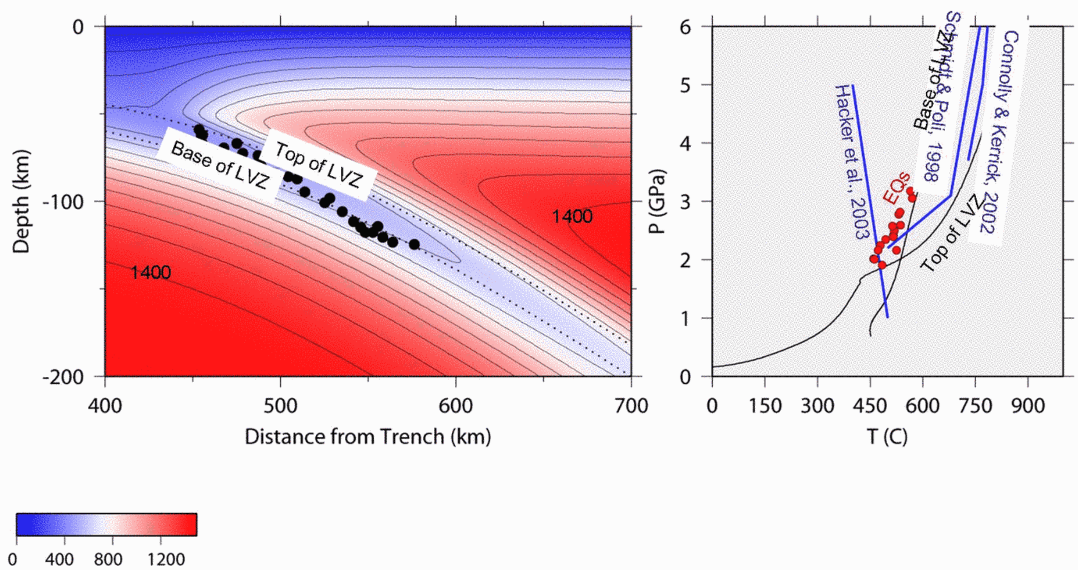


Schmidt and Poli (1998)

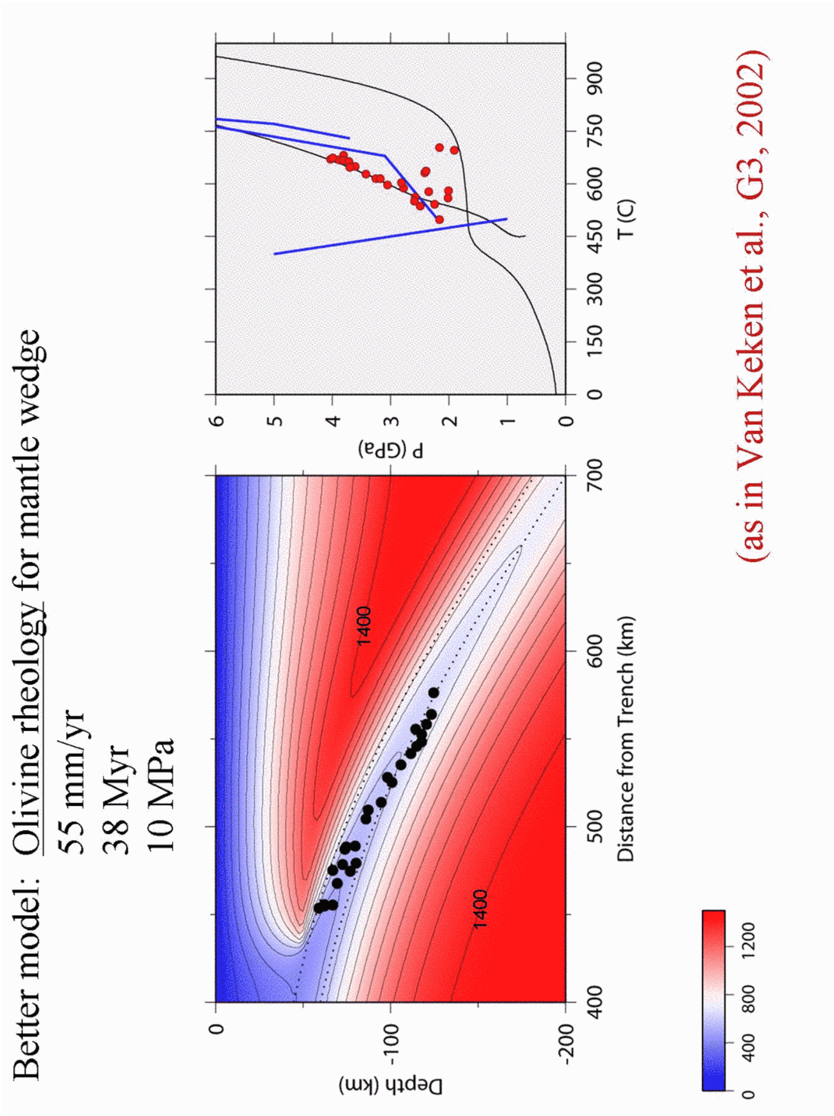


Forneris & Holloway, EPSL, 2003

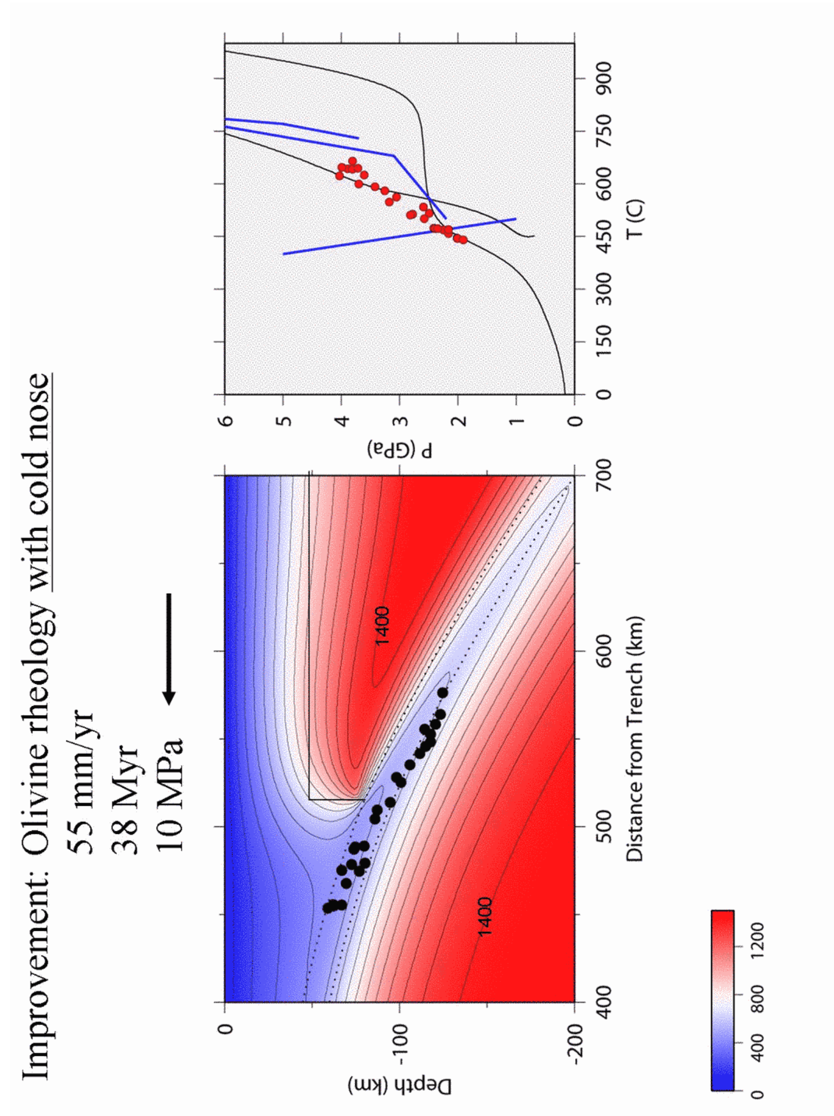
Base model: Isoviscous wedge
55 mm/yr
38 Myr half space cooling model (T_m=1450 C)
16 mW/m^2 shear heating (10 MPa)



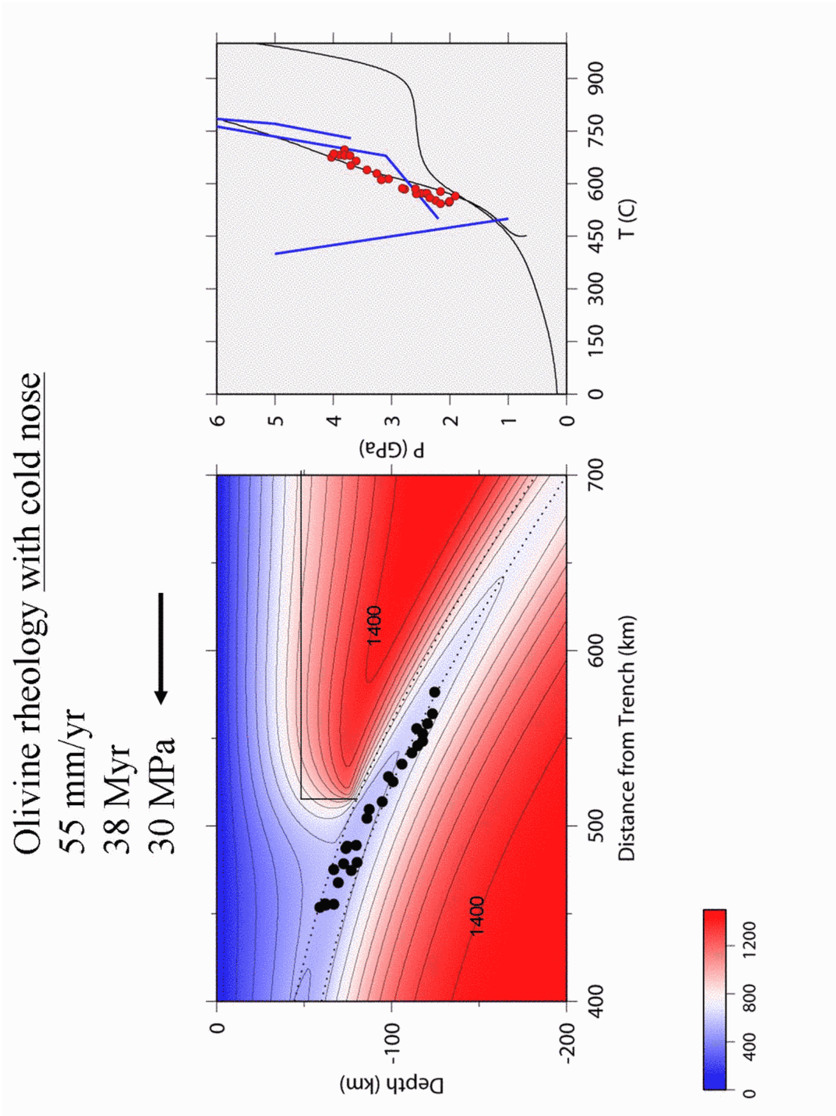
(Similar to Peacock & Gutscher 2003)

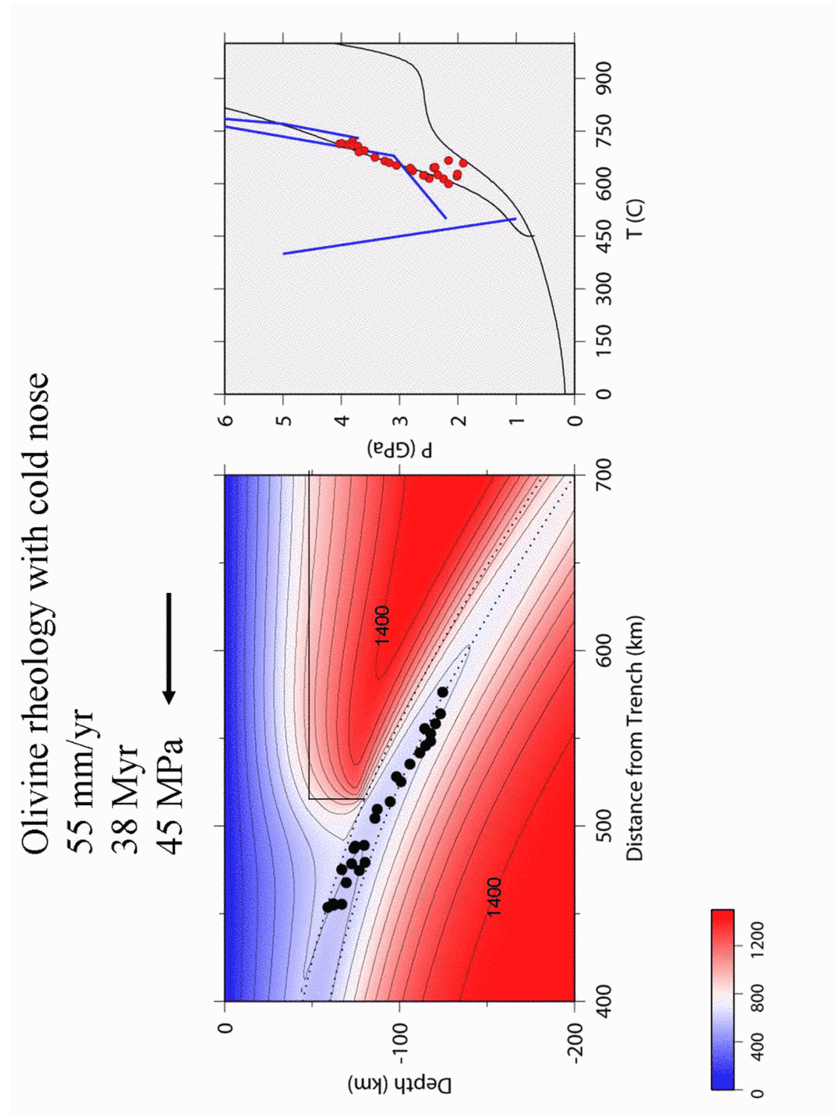


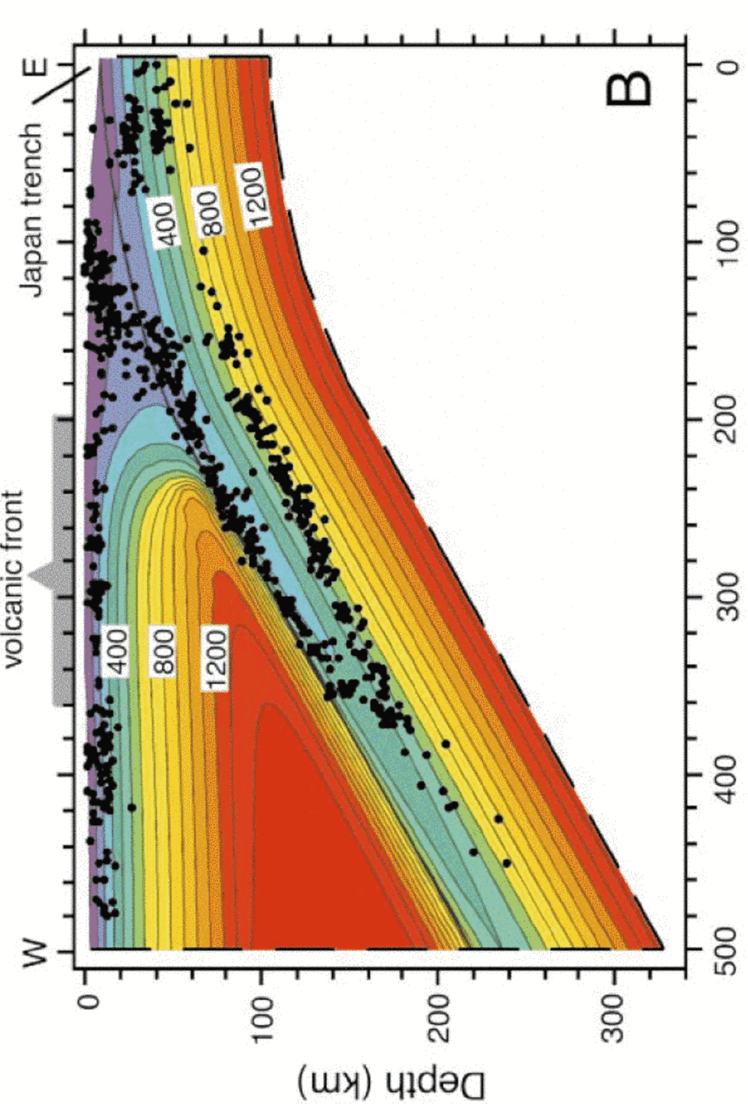
Better model: Olivine rheology for mantle wedge
55 mm/yr
38 Myr
10 MPa
(as in Van Keken et al., G3, 2002)
Depth (km)
Distance from Trench (km)
1400
1400
P (GPa)
T (C)
0 400 800 1200



Improvement: Olivine rheology with cold nose
55 mm/yr
38 Myr
10 MPa
Depth (km)
Distance from Trench (km)
1400
1400
P (GPa)
T (C)
0 400 800 1200


Olivine rheology with cold nose
55 mm/yr
38 Myr
30 MPa
1400
1400
Depth (km)
Distance from Trench (km)
P (GPa)
T (C)

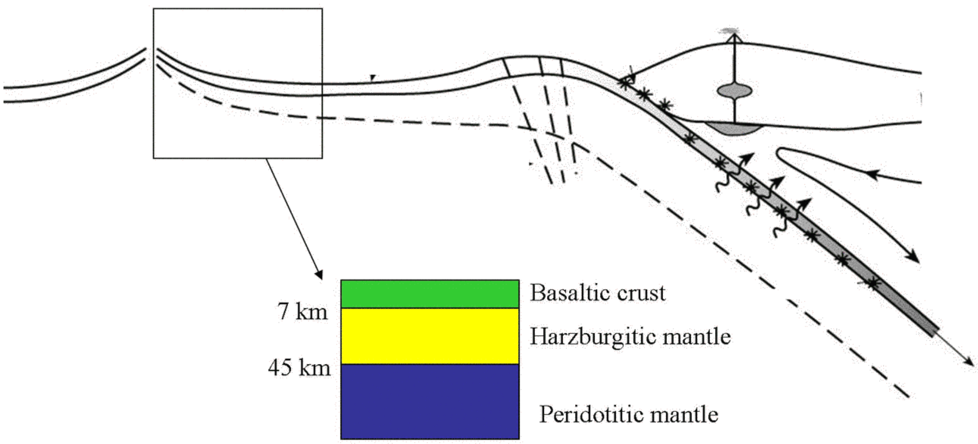

Olivine rheology with cold nose
55 mm/yr
38 Myr
45 MPa
1400
1400
Depth (km)
Distance from Trench (km)
P (GPa)
T (C)



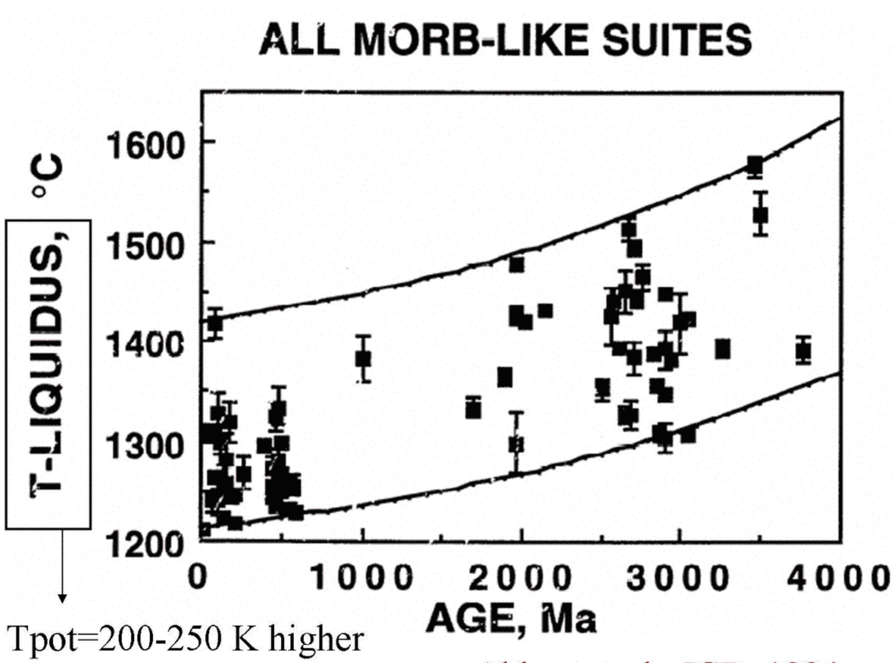
Peacock, Geology, 2001

Penrose conference on start of plate tectonics, Lander, WY

Compositional stratification



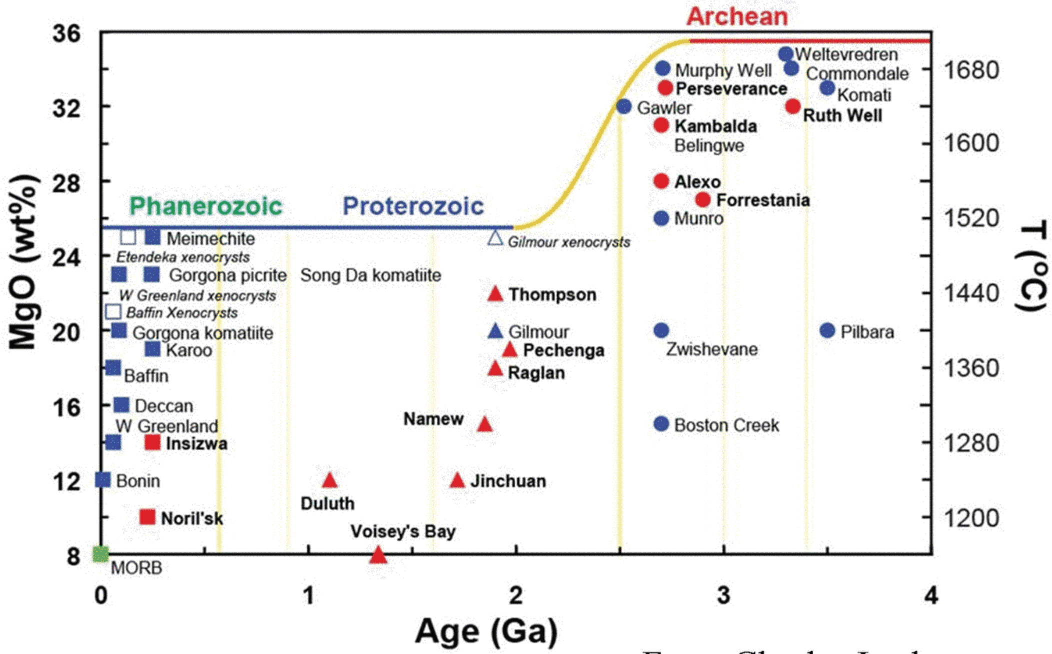
Van Keken, EPSL, 2003



Tpot=200-250 K higher

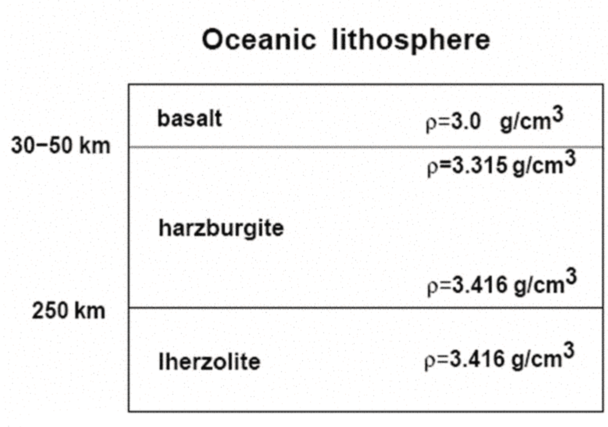
Abbott et al., JGR, 1994

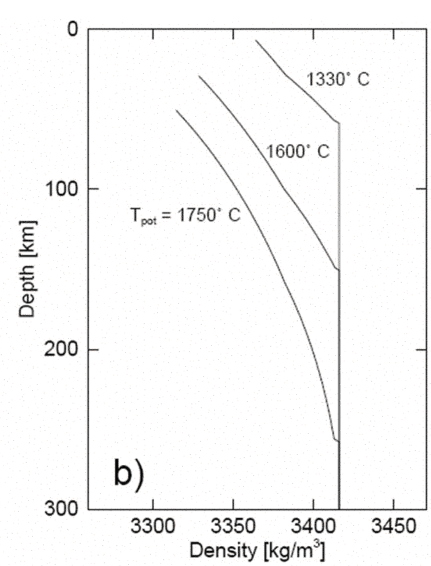
High-MgO Magmas vs. Time



From Charles Lesher

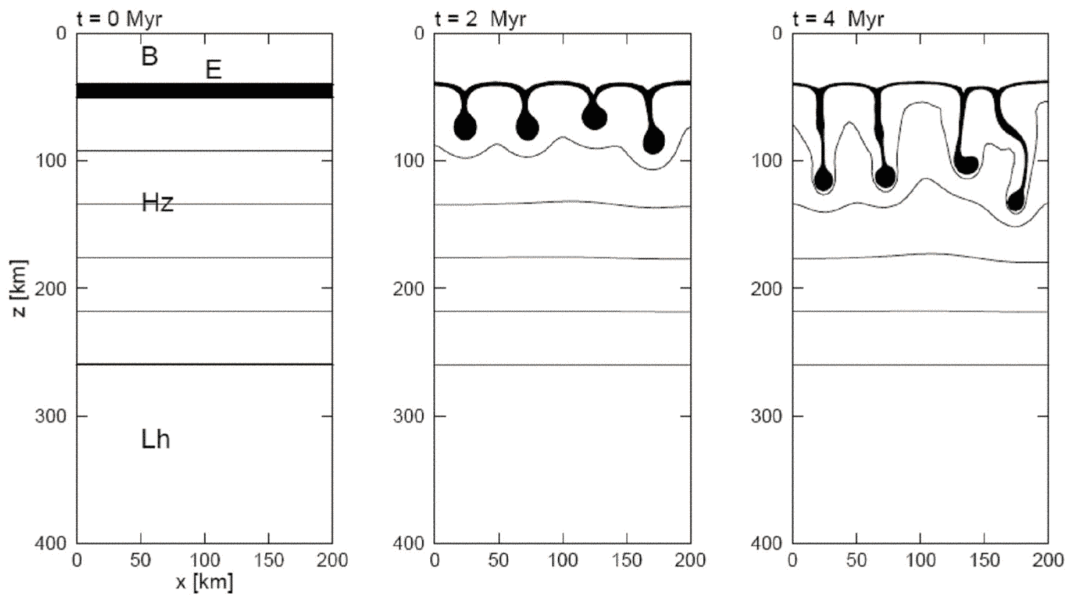
Compositional stabilization of oceanic lithosphere





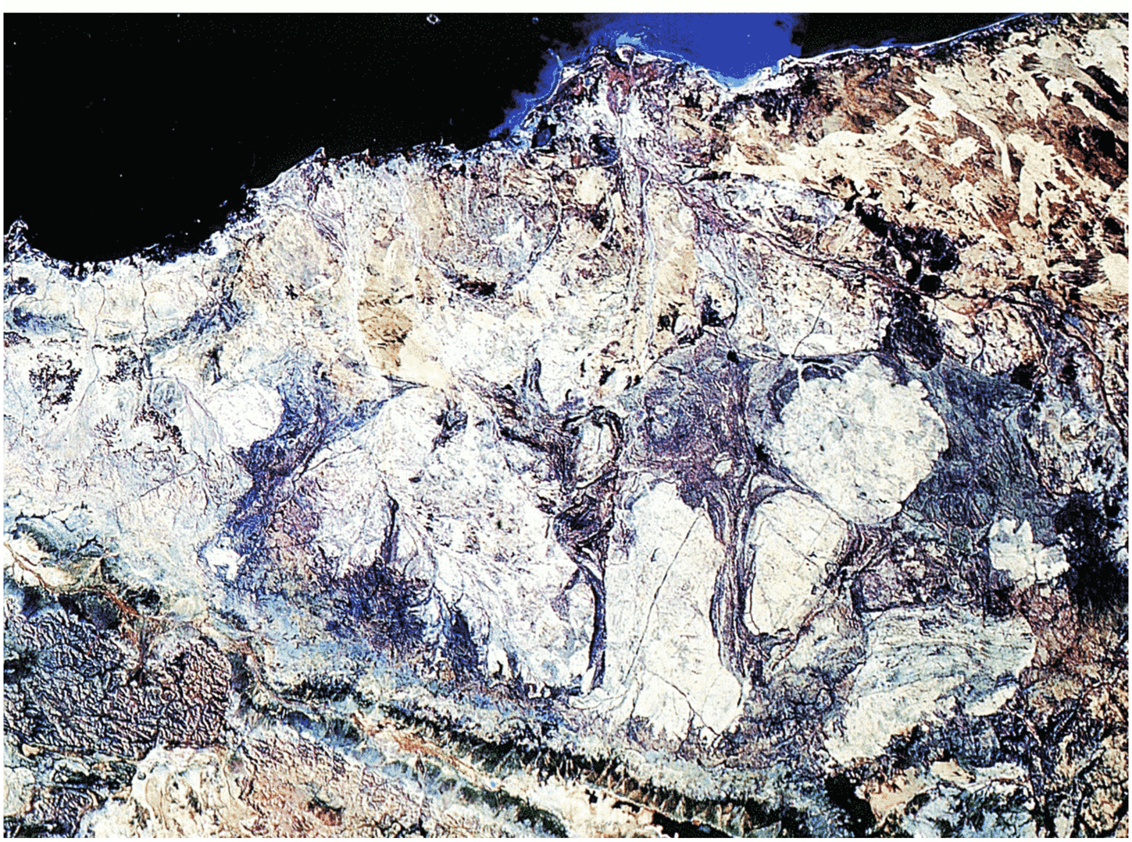
Vlaar et al., EPSL, 1994

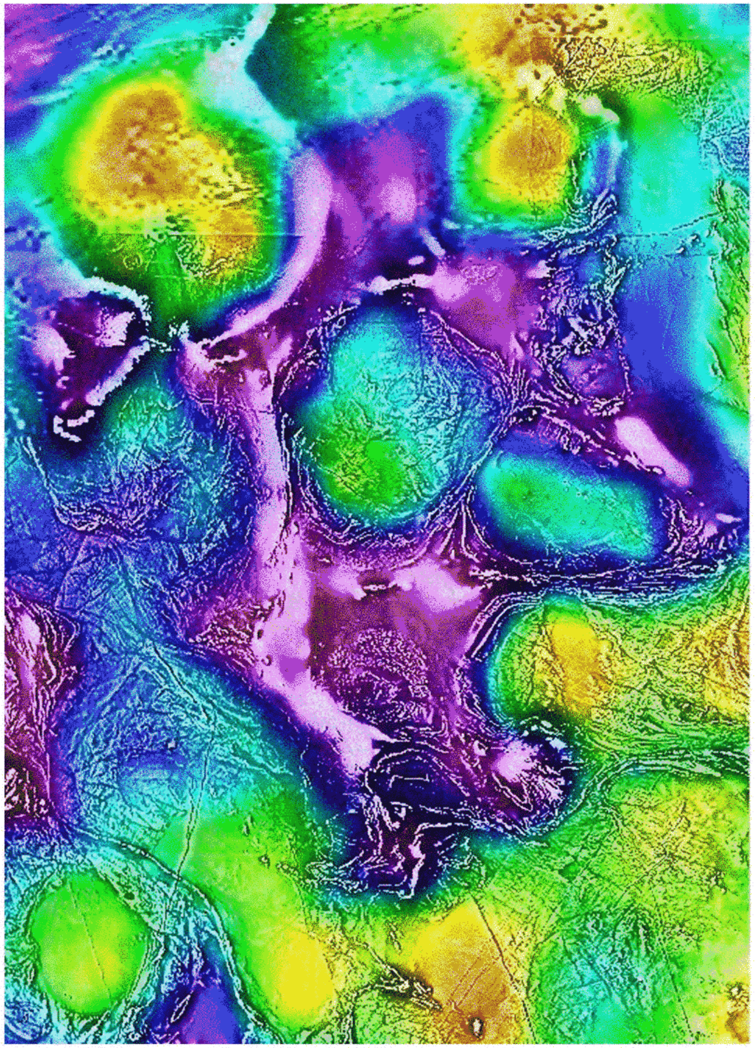
Pre-plate tectonic cooling mechanism (?)



Sufficient to cool to near-present day
Tpot within 1 Byr

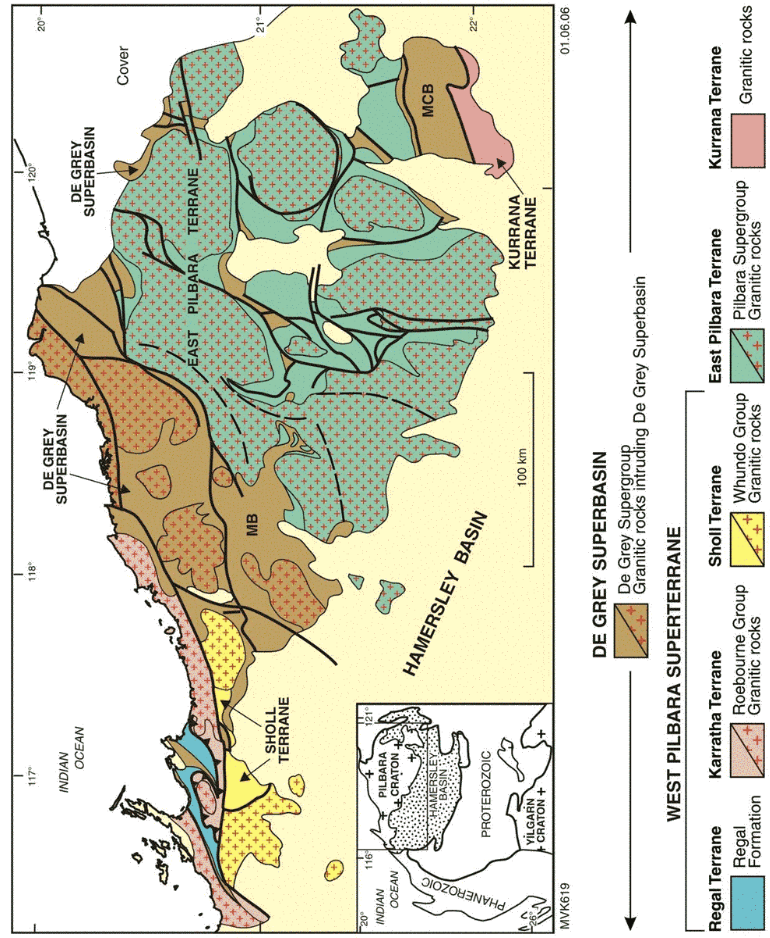
Vlaar et al., EPSL, 1994

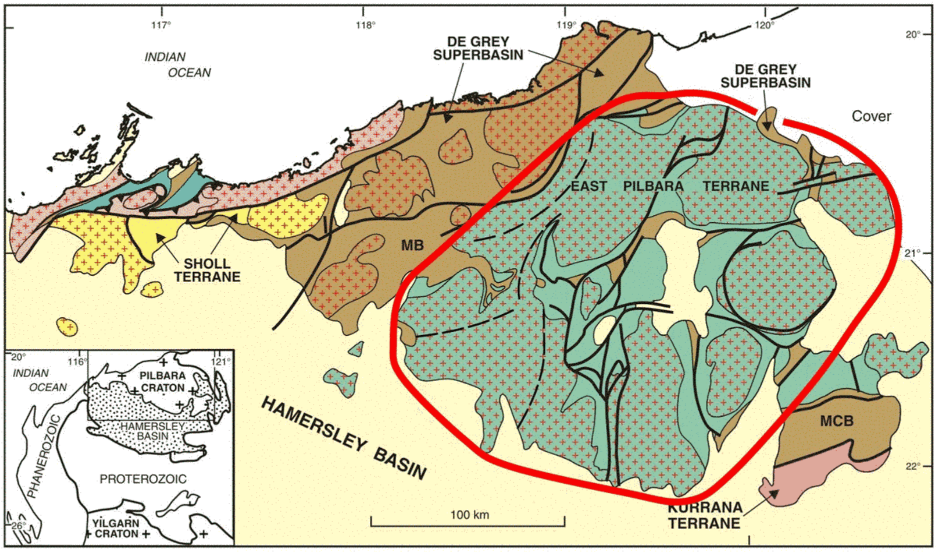




Courtesy of R. Blewett

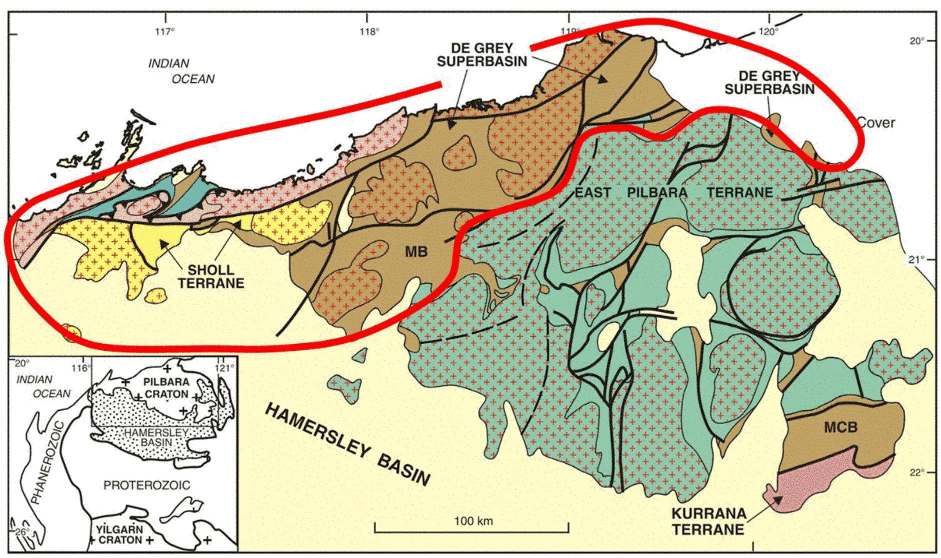
From Hugh Smithies





From Hugh Smithies

Old (3.53-3.2 Ga) east Pilbara nucleus – contains no clear evidence for modern-style plate tectonics. This thick crustal block most likely began as some form of oceanic plateau type crust.

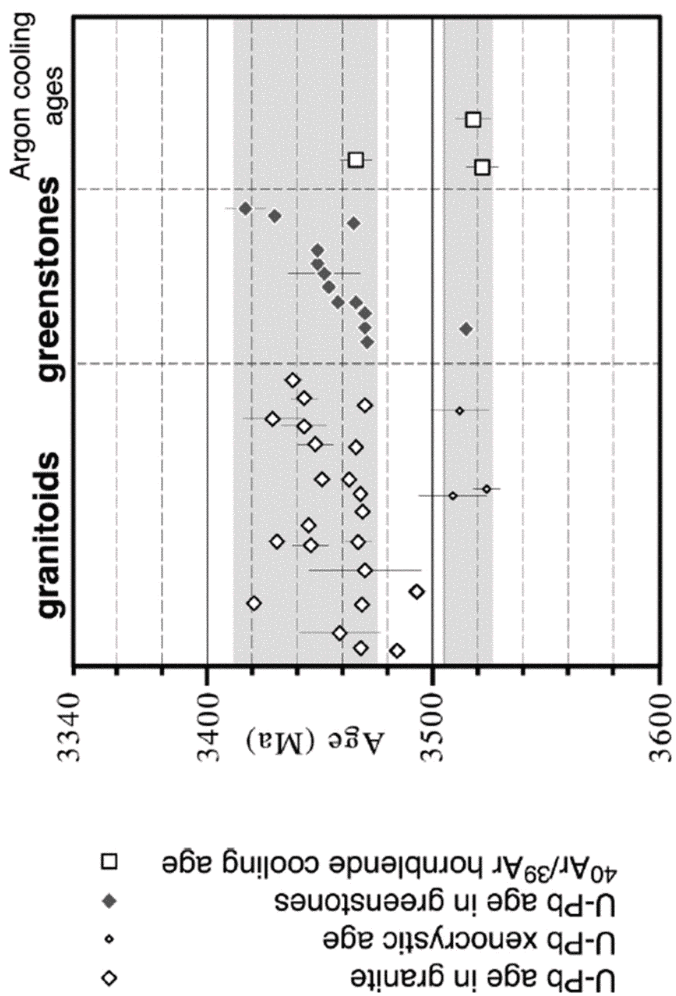


From Hugh Smithies

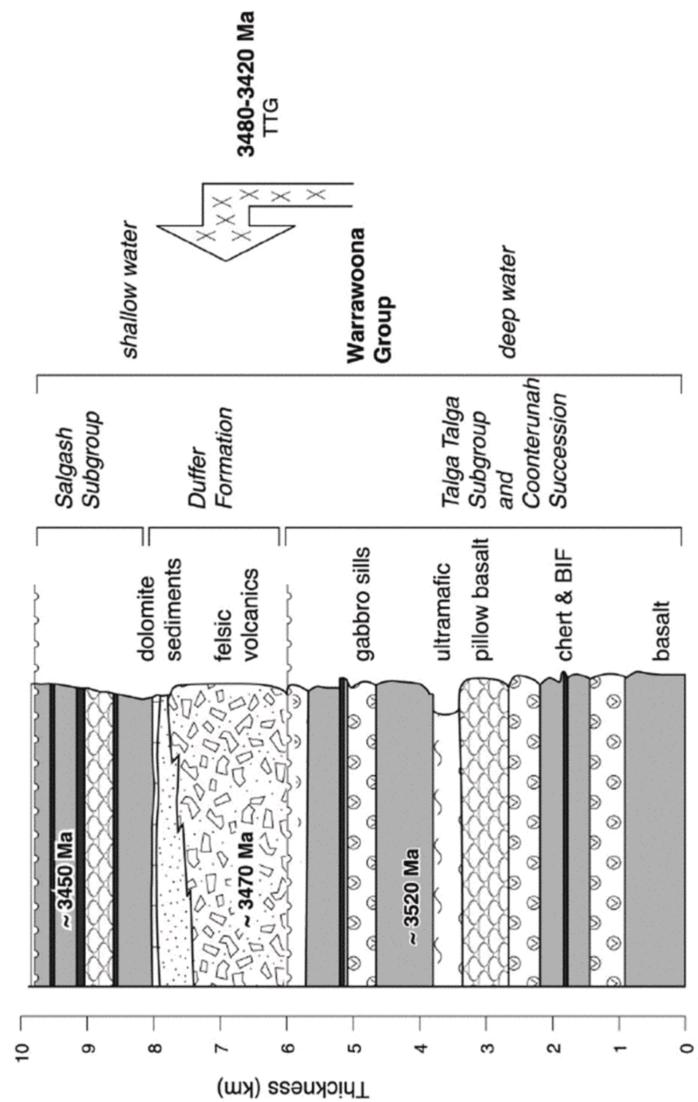
The West Pilbara Superterrane

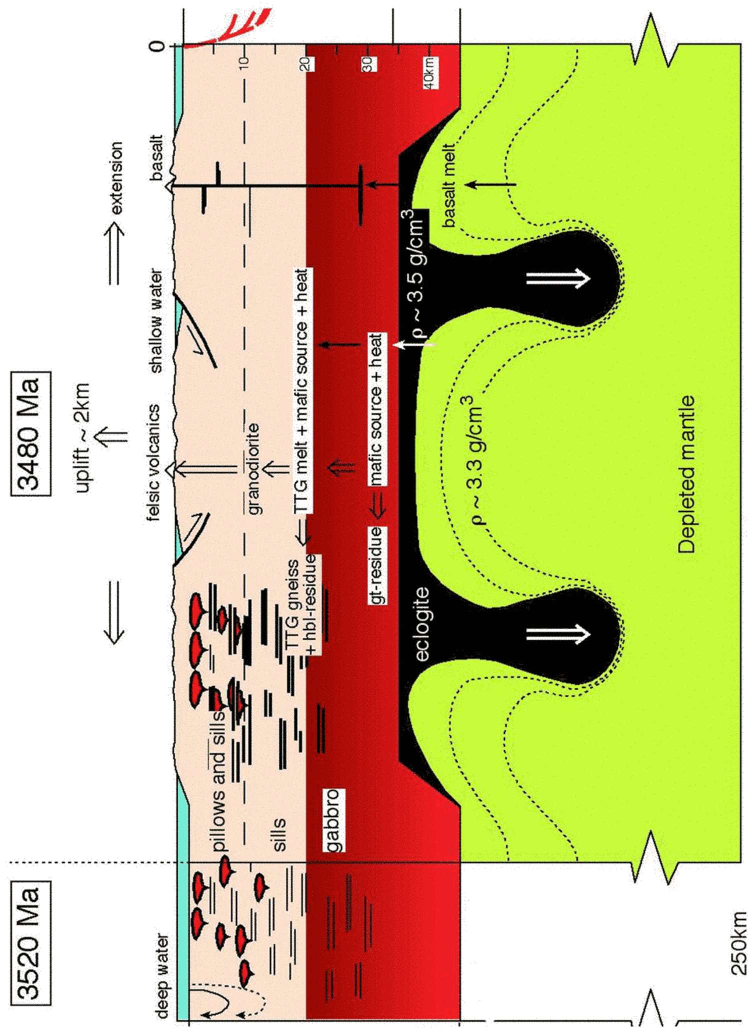
A younger (3.3 – 3.05 Ga) amalgamation of terranes – contains extensive set of features that collectively present a compelling case for modern steep-style subduction at ~3.2 Ga. This represents accretion peripheral to the East Pilbara nucleus.

Zegers and Van Keken, Geology, 2001



Zegers and Van Keken, Geology, 2001





Zegers and Van Keken, Geology, 2001