The Earth`s Deep Water Cycles

Lars Rüpke

with a lot of help from:

Jason Phipps Morgan (Cornell University)

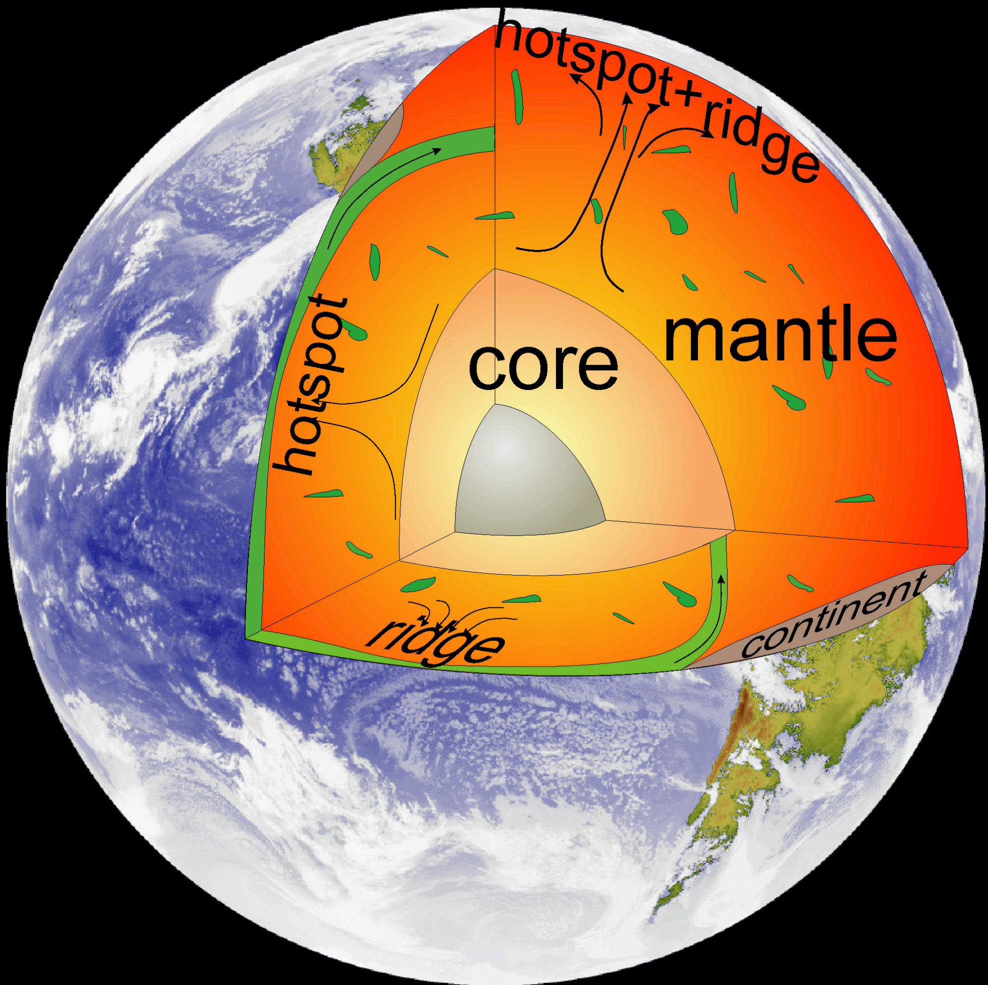
Matthias Hort (Universität Hamburg)

James Connolly (ETH-Zürich)

The World's Oceans

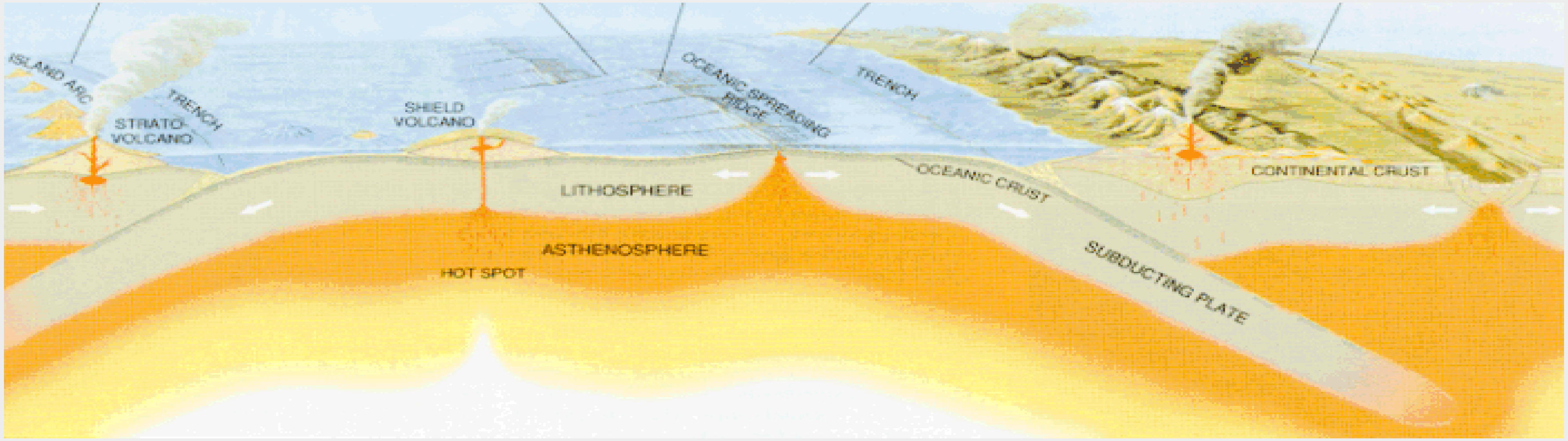
71% of the surface

The World's Oceans



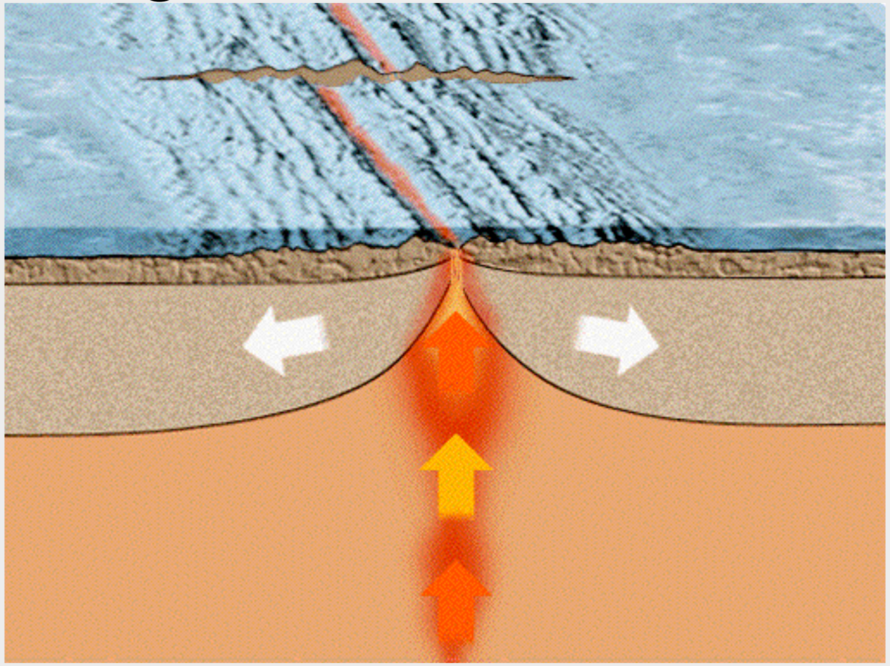
But only 0.025% of the mass

The Earth Deep Water Cycle



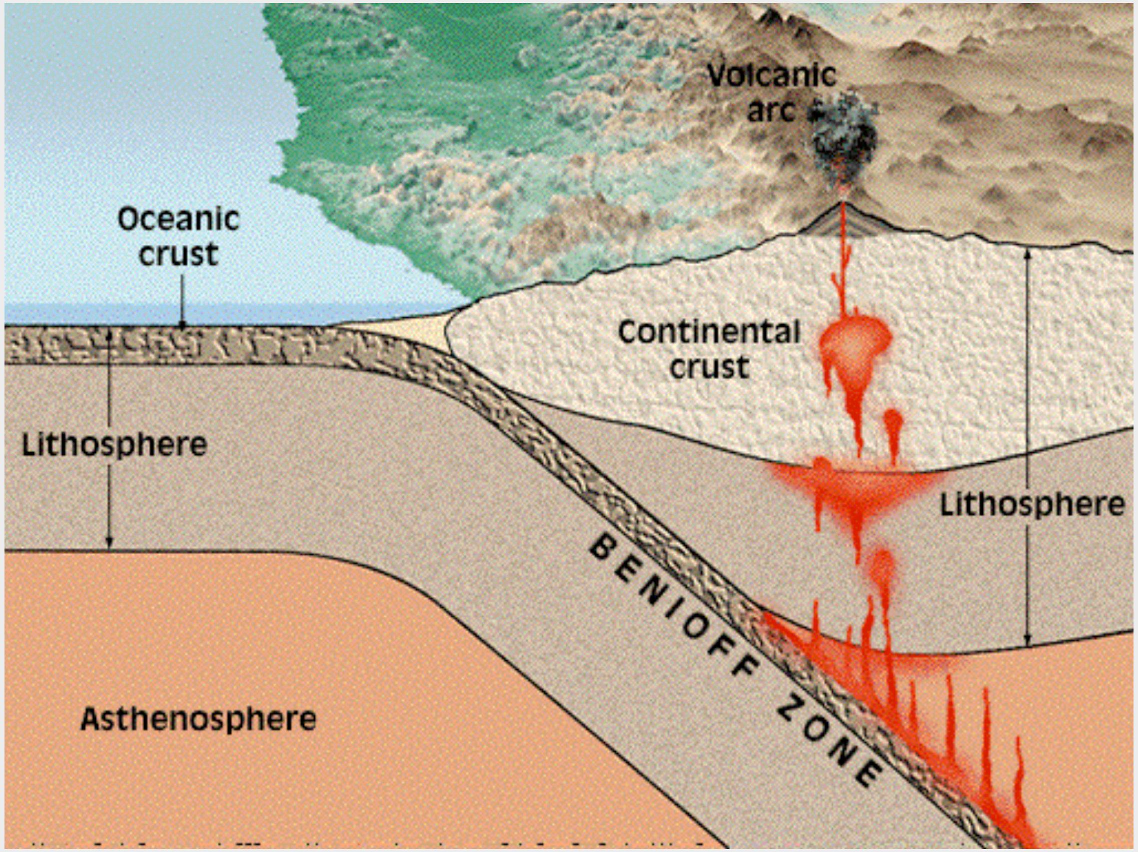
- There are evidences for oceans over the entire geologic record
- Water controls the geology as well as the biology (evolution of life)
- Oceans appear to be surface expressions for dynamic processes within the Earth

Mid-Ocean Ridges



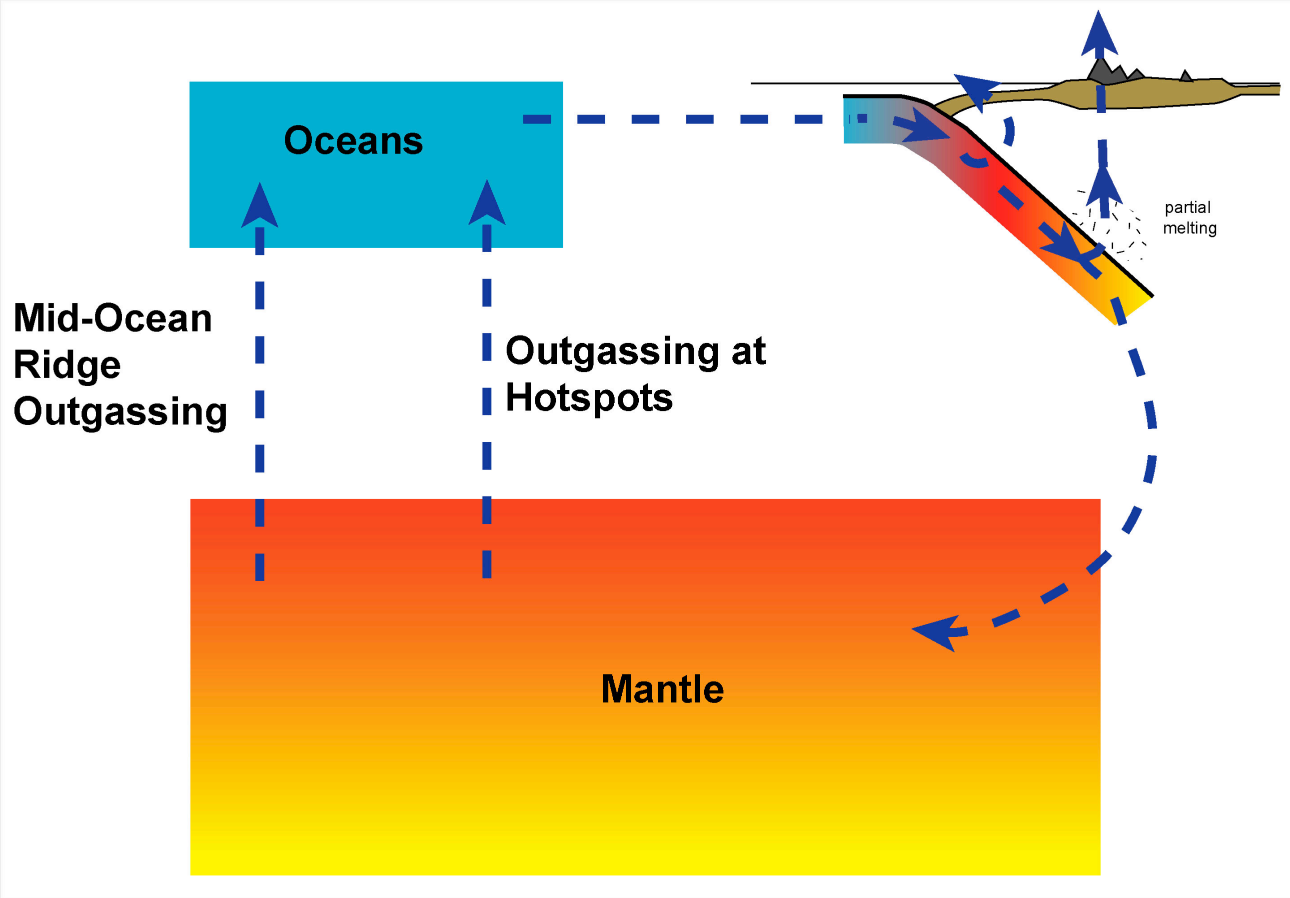
- Mid-ocean ridge melting and hotspot volcanism lead to water outgassing and ocean crust hydration
- Loss of mantle water into the oceans and atmosphere
- Plates hydrate during their lifetime on the ocean floor

Subduction Zones:



- Slab dehydration leads to arc volcanism
- But is dehydration complete?
- Plate subduction might efficiently recycle surface water back into the mantle

The Earth’s Deep Water Cycle’s

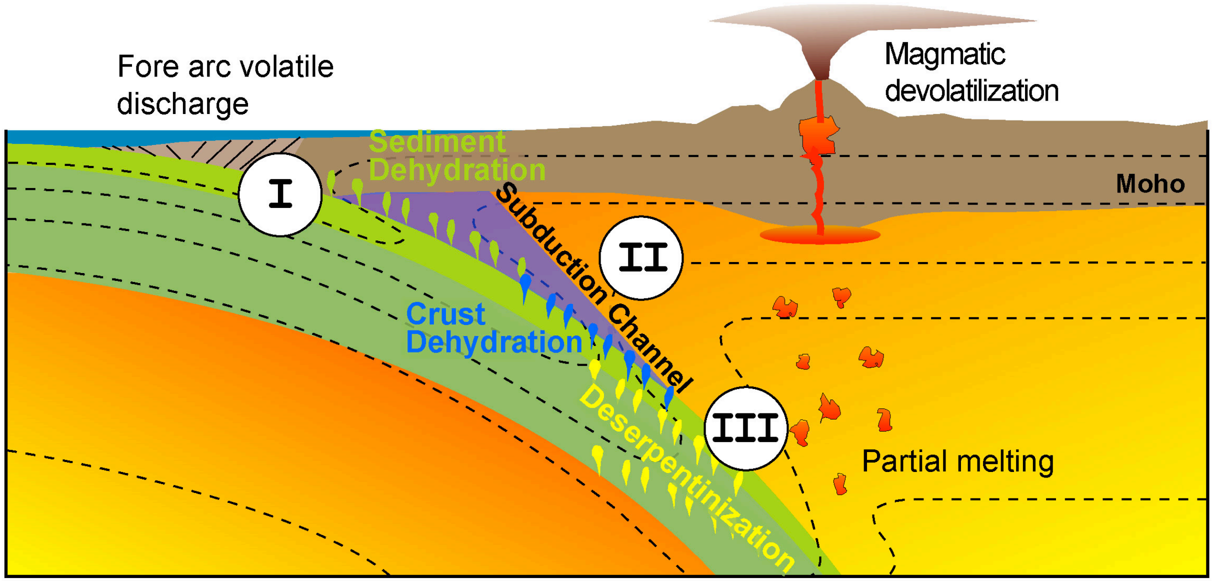


Outline

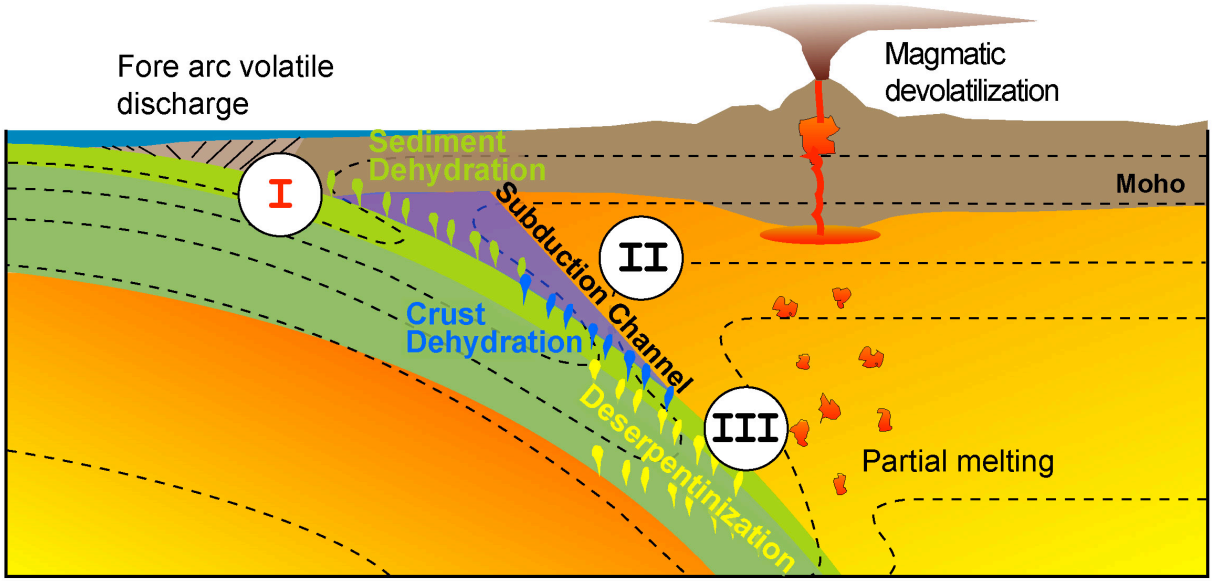
- Part 1: Overview - Fluids in Subduction Zones
- Part 2: Review - How much water is subducted?
- Part 3: Modeling the subduction zone water cycle
  - A chemo-thermo-mechanical subduction zone model
- Part 4: Global implications
  - The geologic water cycle
  - Geochemical implications

Part 1: Fluids in subduction zones

What do we know?



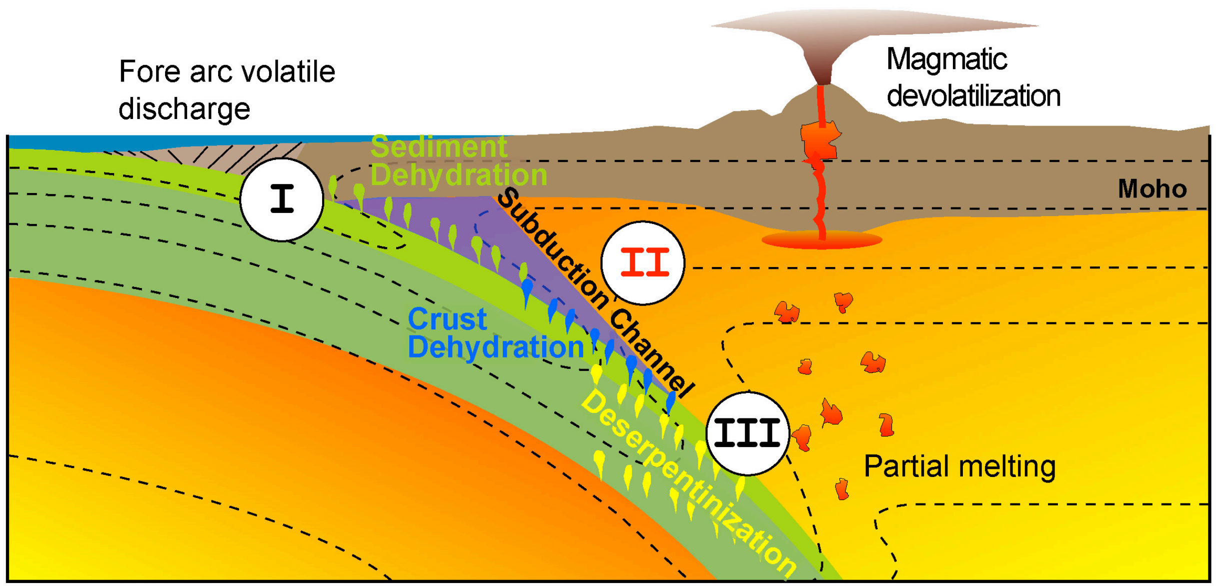
Shallow water release (0-20km)

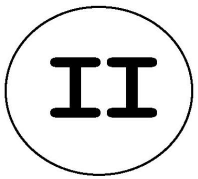


I

Shallow water release (<20km) from subducting sediments is related to fluid expulsion at cold vent sites in the fore arc region, hydrofracturing of the upper plate, and potentially to the upper limit of the seismogenic zone.

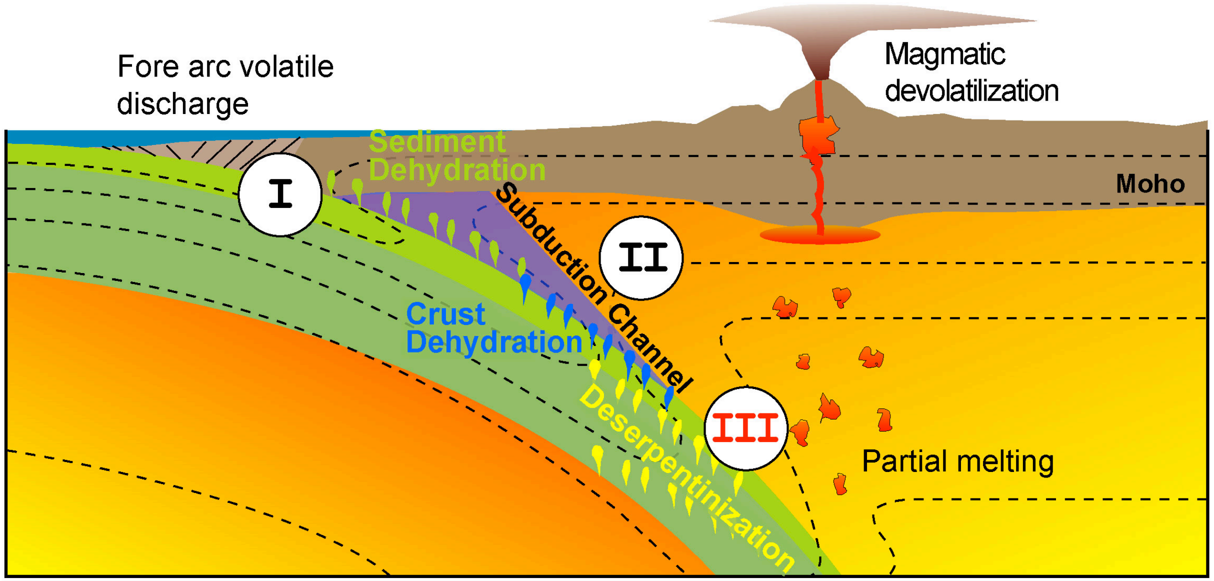
Intermediate depth water release (20-100km)





Intermediate depth (20-100km) water release from sediments and oceanic crust is related to thermal erosion of the mantle wedge, cold upwelling, and the resurfacing of higher pressure metamorphic rocks along the 'subduction channel'.

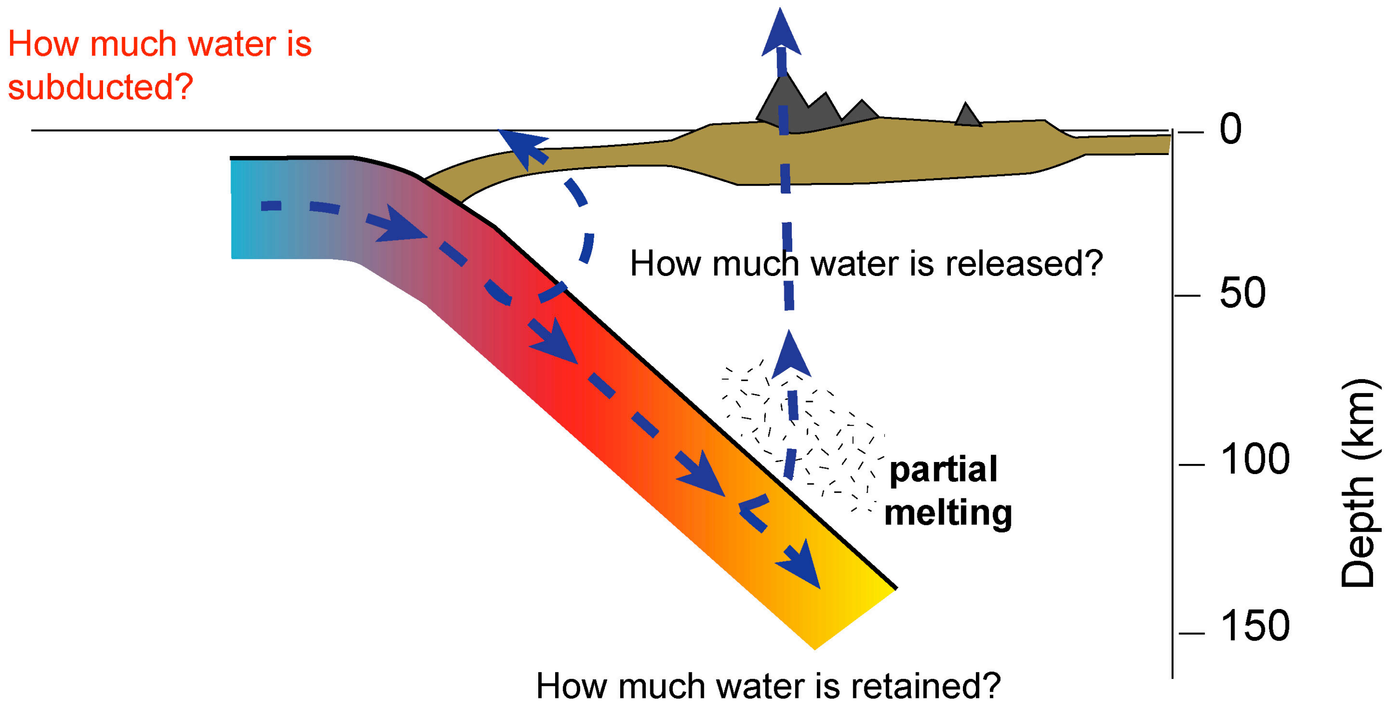
Deep water release (>100km)



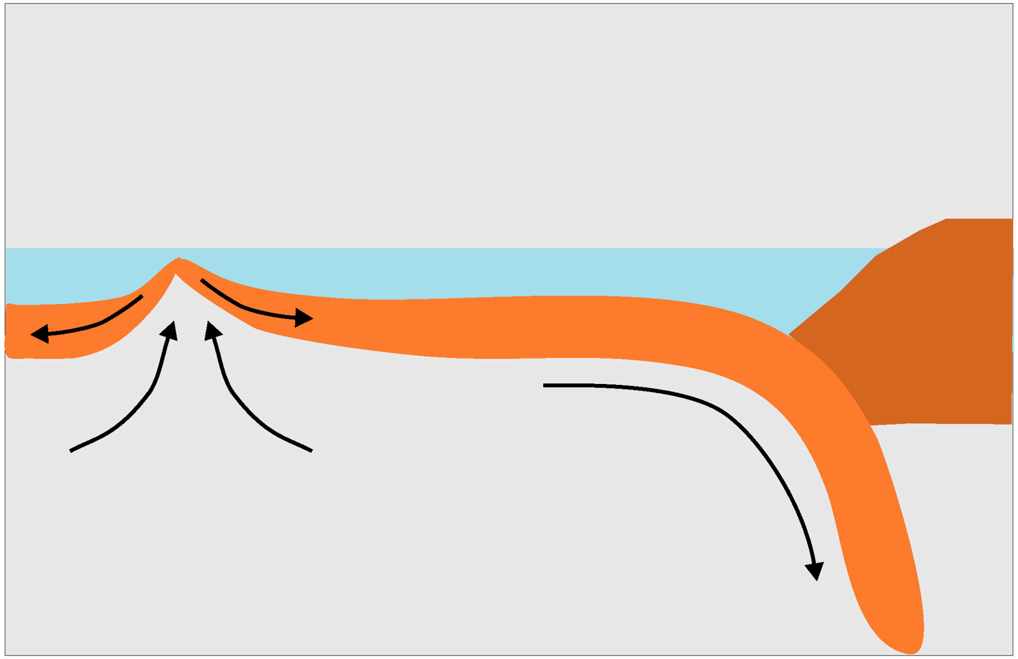
III

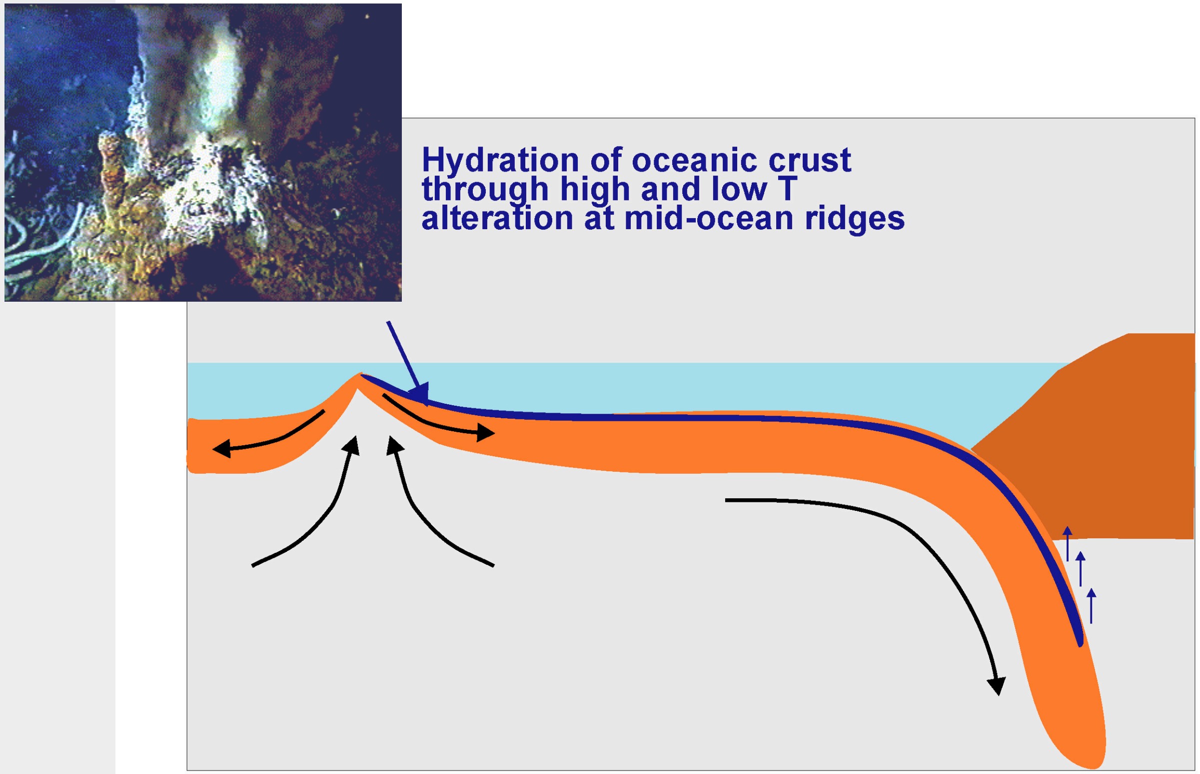
Deep fluid release (>100km) from sediments, oceanic crust, and serpentinized mantle is thought to trigger arc melting. Slab fluid fluxing is also thought to transfer trace elements from the slab into the melting region which results in the often observed chemical slab signature of arc lavas.

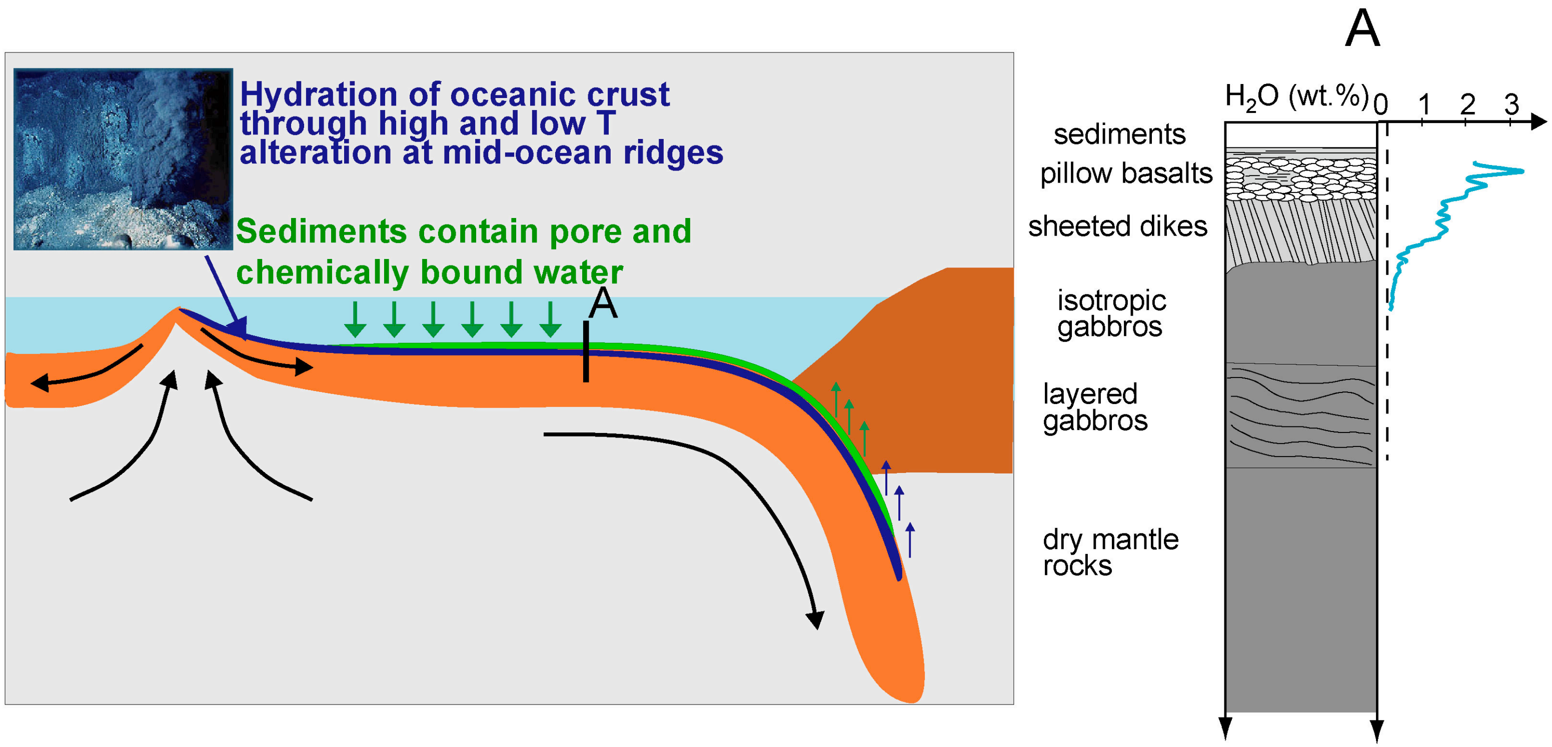
Quantify the Subduction Zone Water Cycle

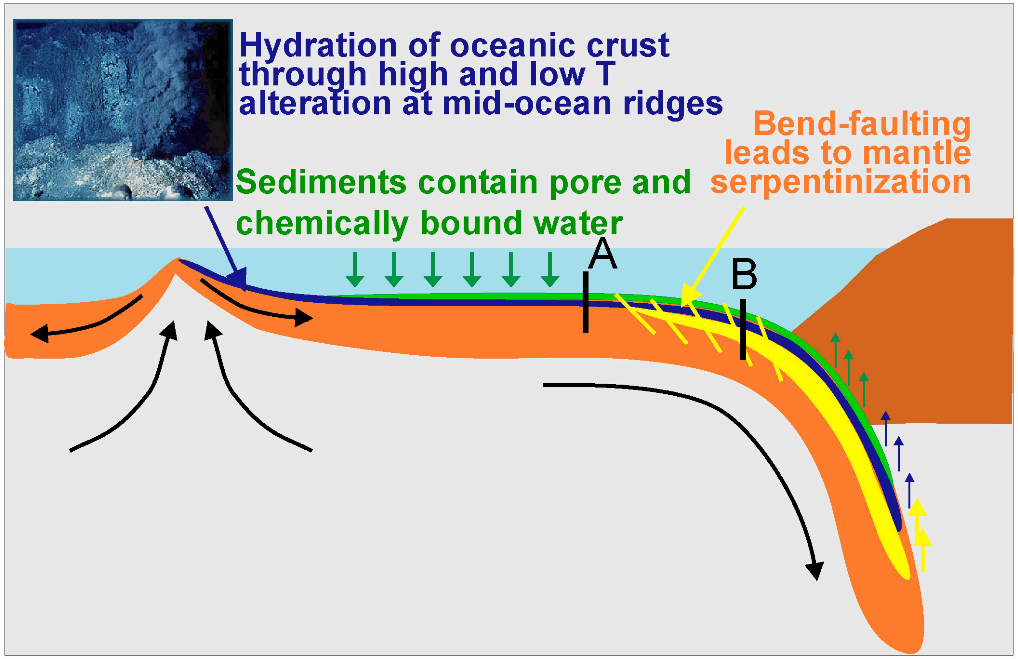


Part 2: How much water is subducted?

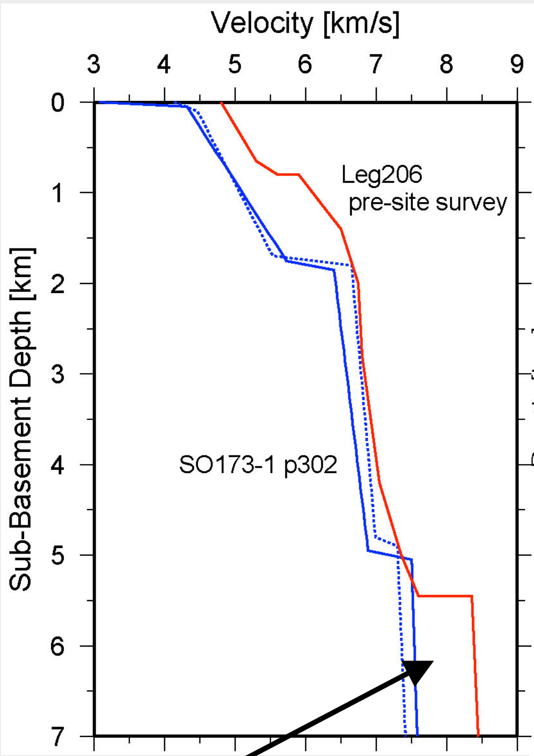



Hydration of oceanic crust
through high and low T
alteration at mid-ocean ridges

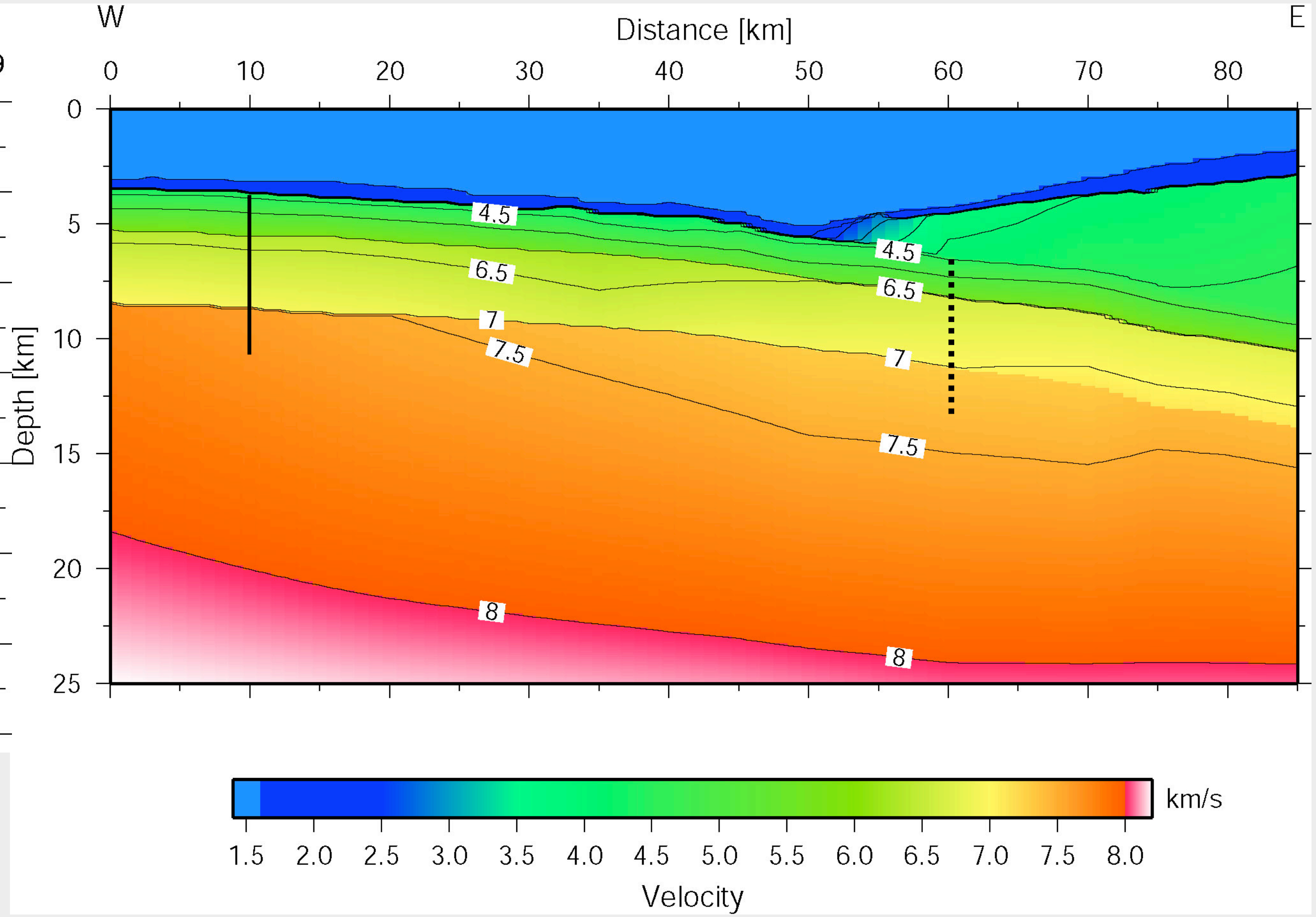

Hydration of oceanic crust through high and low T alteration at mid-ocean ridges
Sediments contain pore and chemically bound water
A
A
H2O (wt.%)
0
1
2
3
sediments
pillow basalts
sheeted dikes
isotropic gabbros
layered gabbros
dry mantle rocks


Hydration of oceanic crust
through high and low T
alteration at mid-ocean ridges
Bend-faulting
leads to mantle
serpentinization
Sediments contain pore and
chemically bound water
A
B

P-wave velocity reduction due to serpentinization?

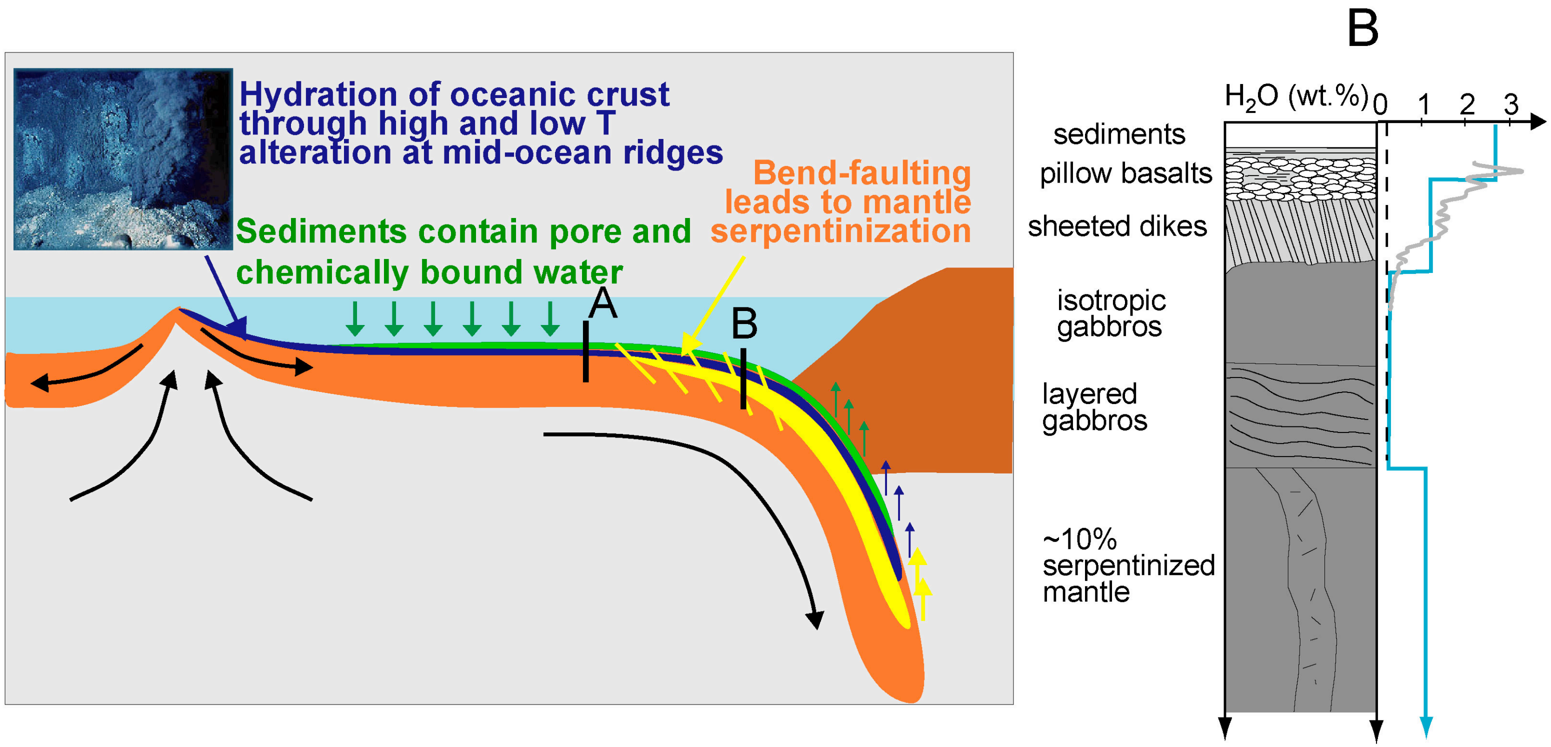


10-20% serpentinization?



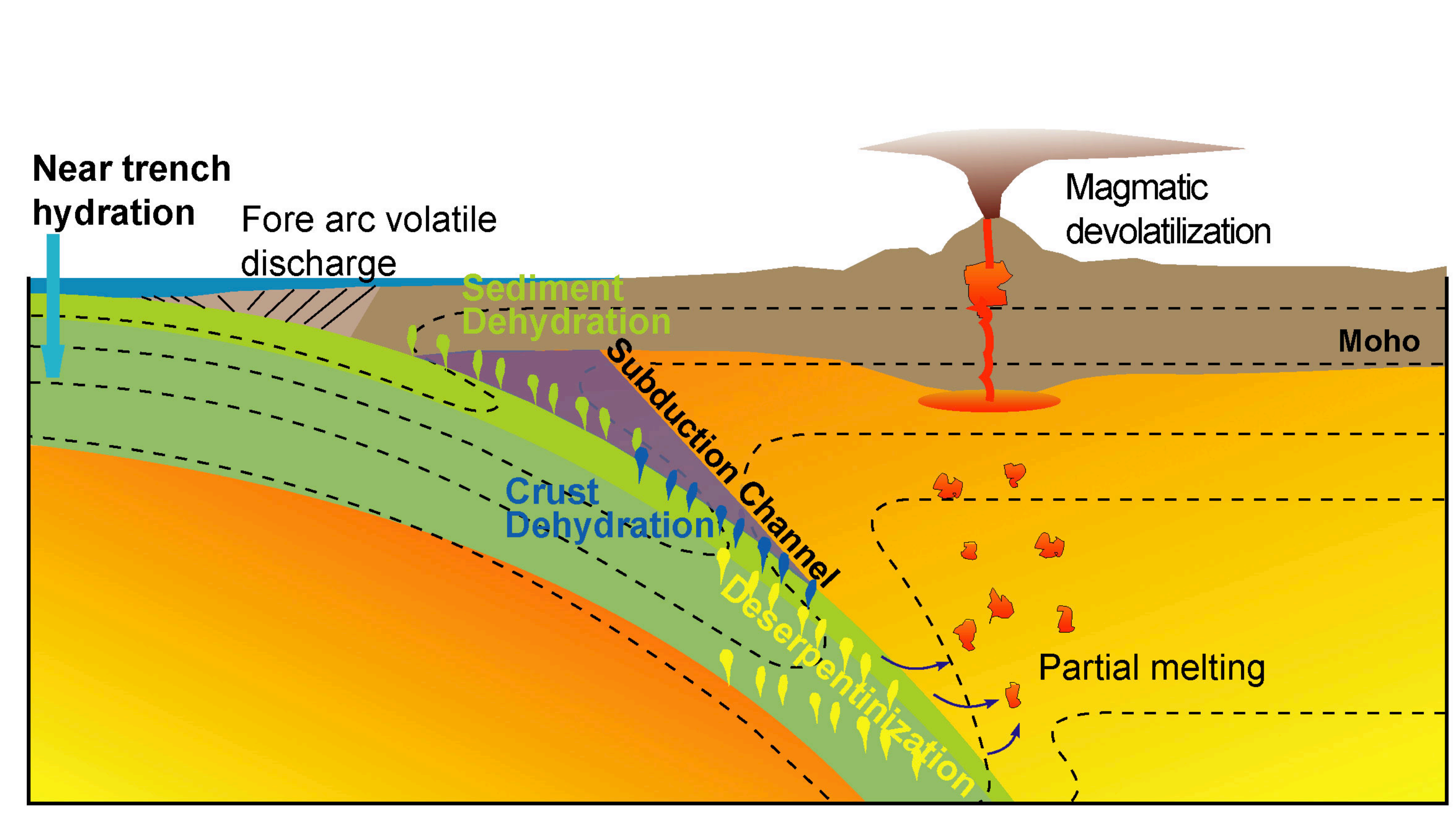
Seismic profile across Nicaraguan trench

Pilot study by Grevemeyer et al

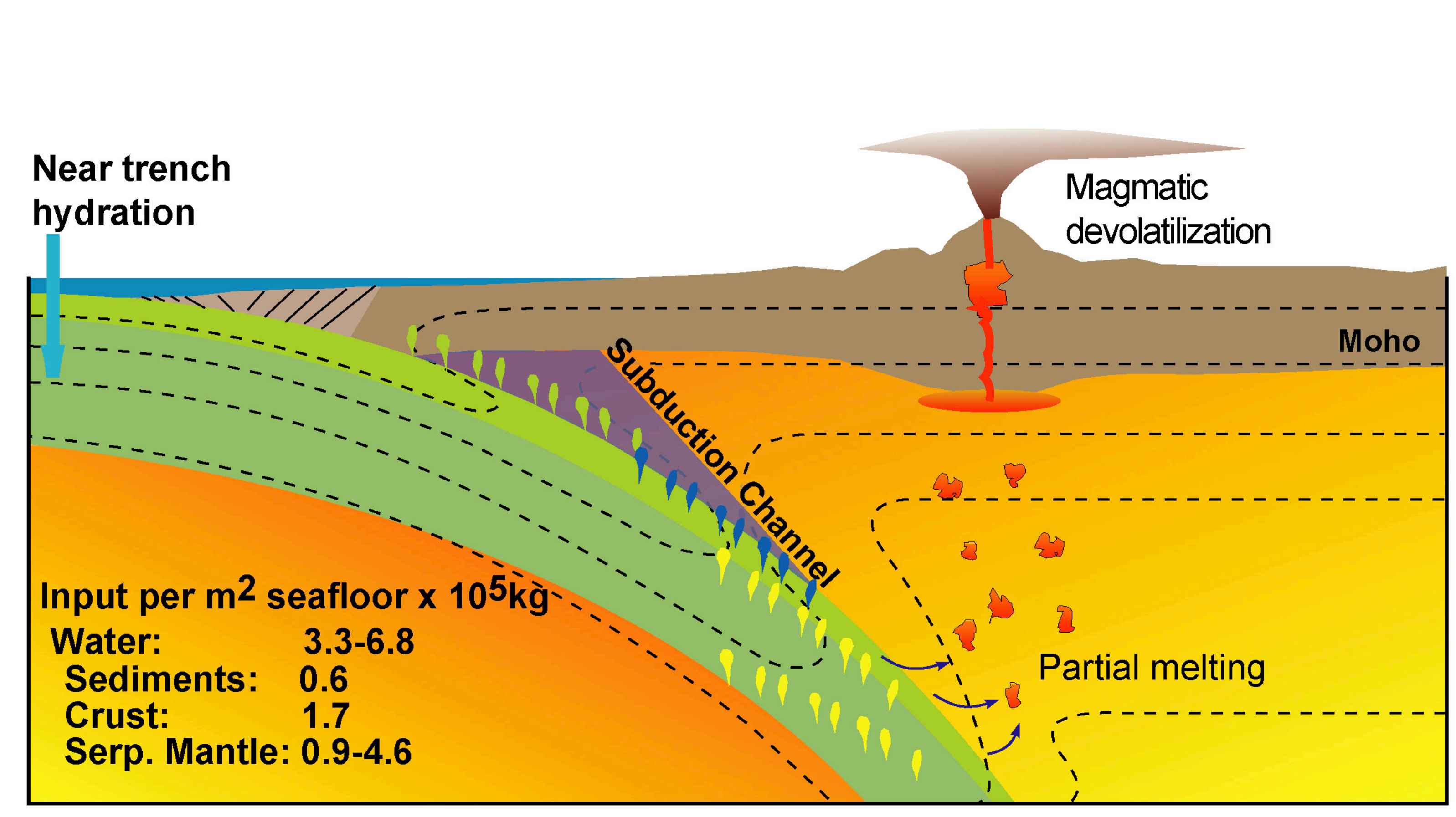


A subducting slab contains three potential fluid sources: sediments, crust, and serpentinized mantle

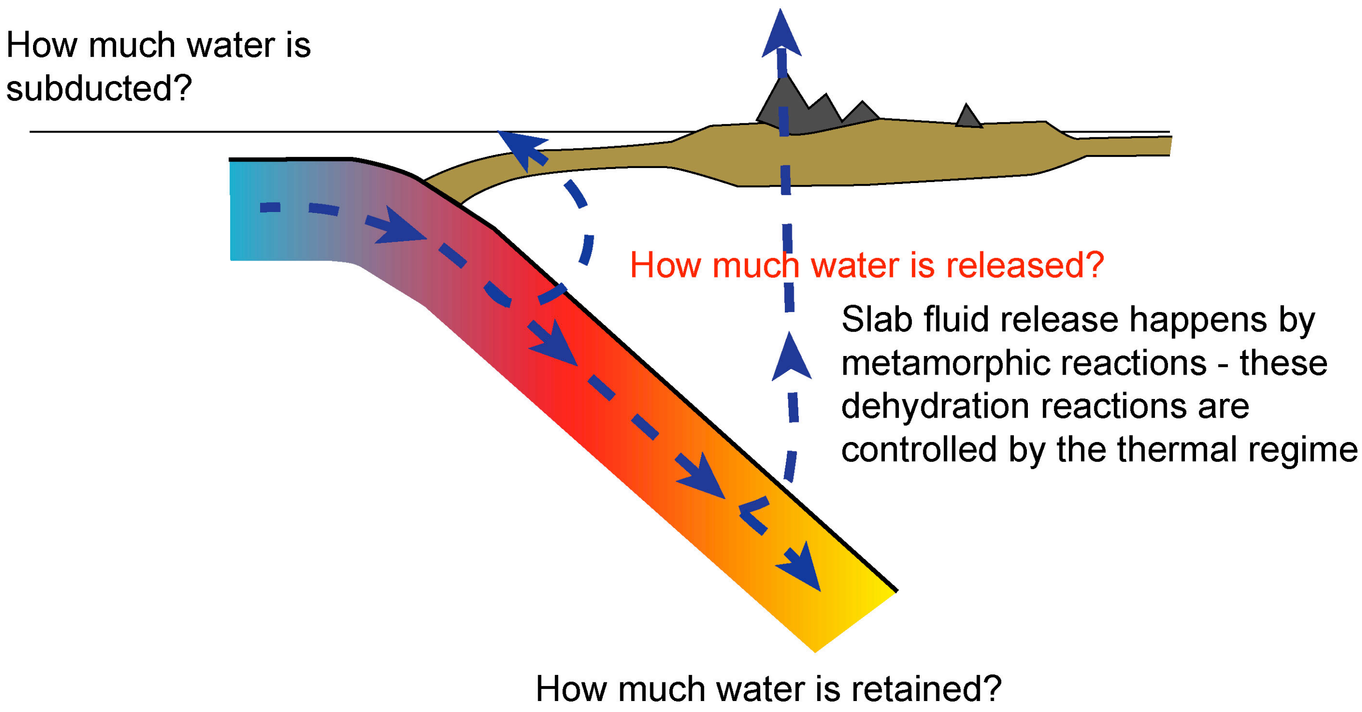
A possible water budget for subduction zones



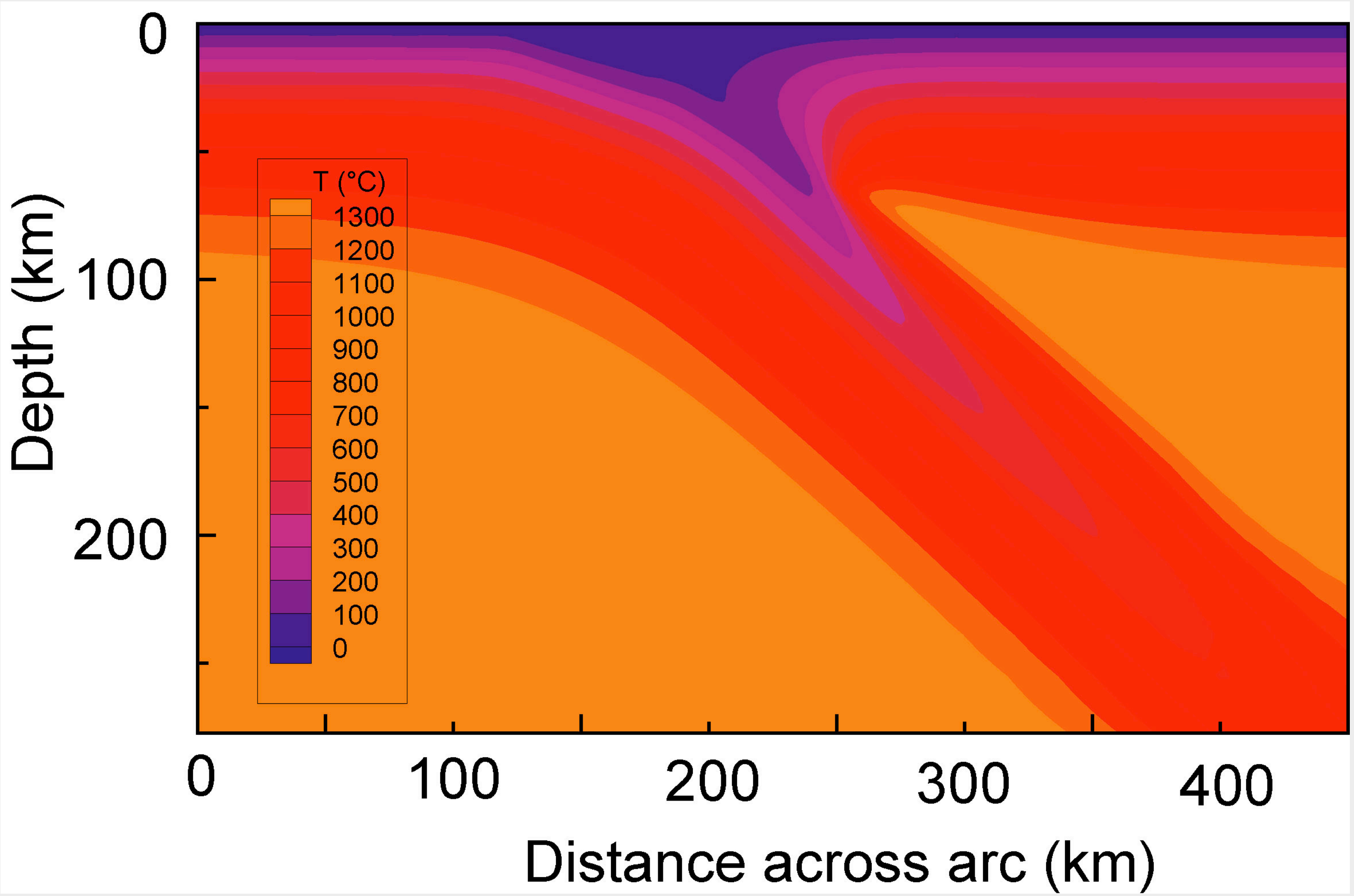
A possible water budget for subduction zones



Part 3: Study of slab fluid release

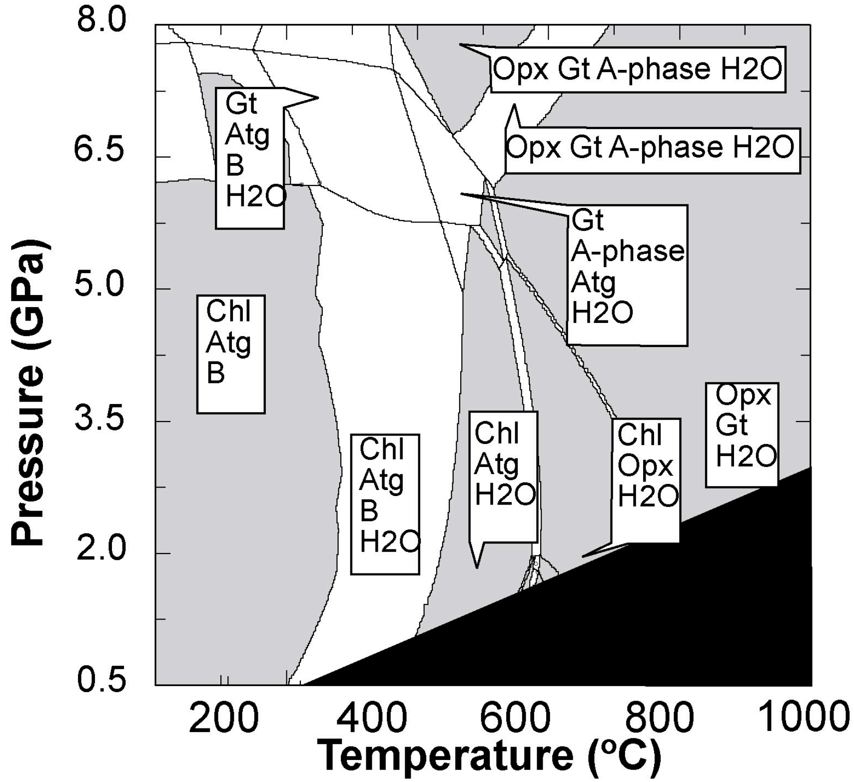


2-D fluid dynamic model solves for temperature and mantle flow



To implement slab metamorphism phase diagrams for the 3 fluid sources (sediments, crust, serp. Mantle) are needed.

Synthetic phase relations and p-T water content of hydrous peridotite as calculated with PERPLEX



Atg = Antigorite

B = Brucite

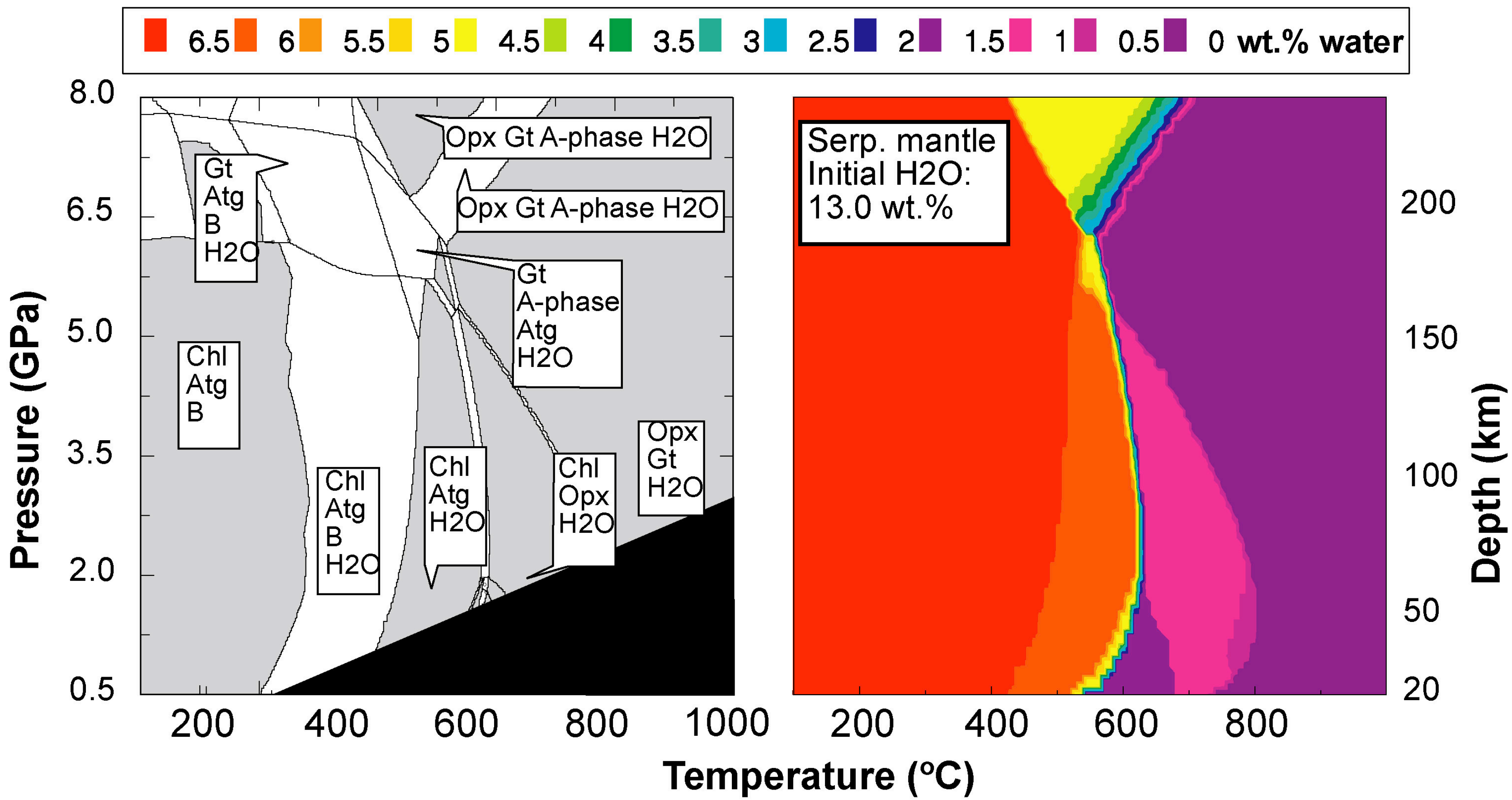
Chl = Chlorite

Gt = Garnet

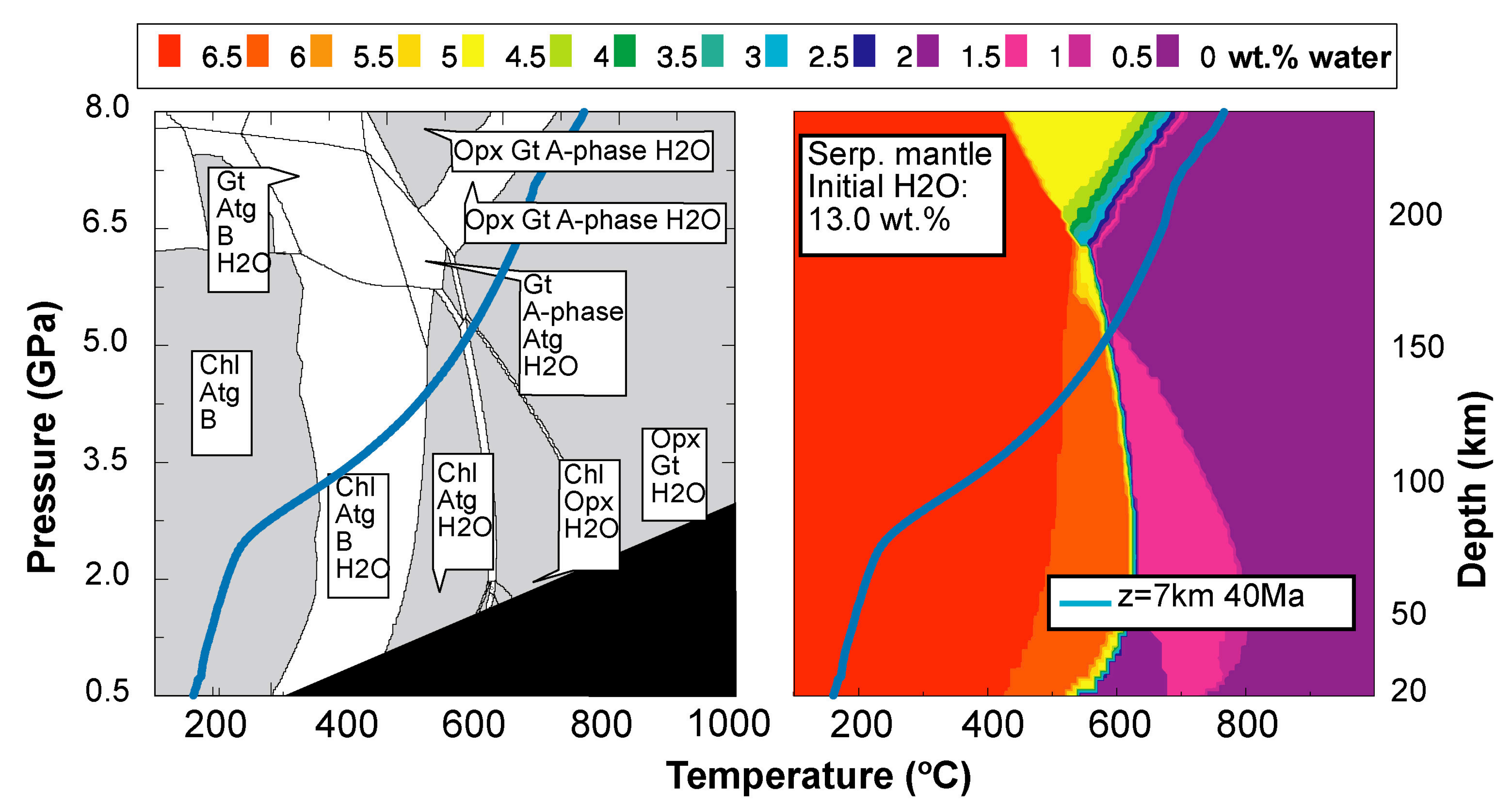
Opx = Orthopyroxene

Clinopyroxene and olivine is stable in all fields

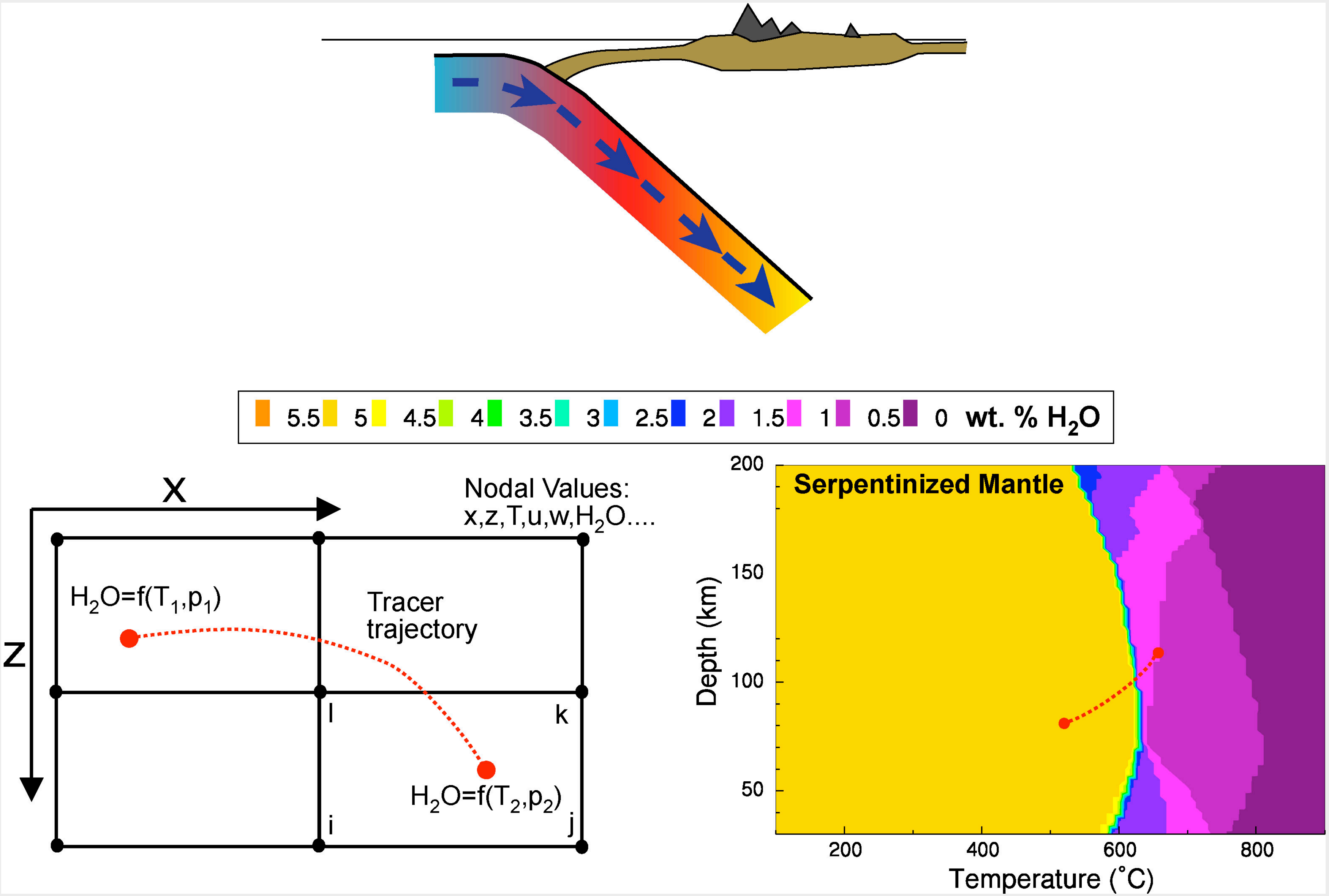
Synthetic phase relations and p-T water content of hydrous peridotite as calculated with PERPLEX

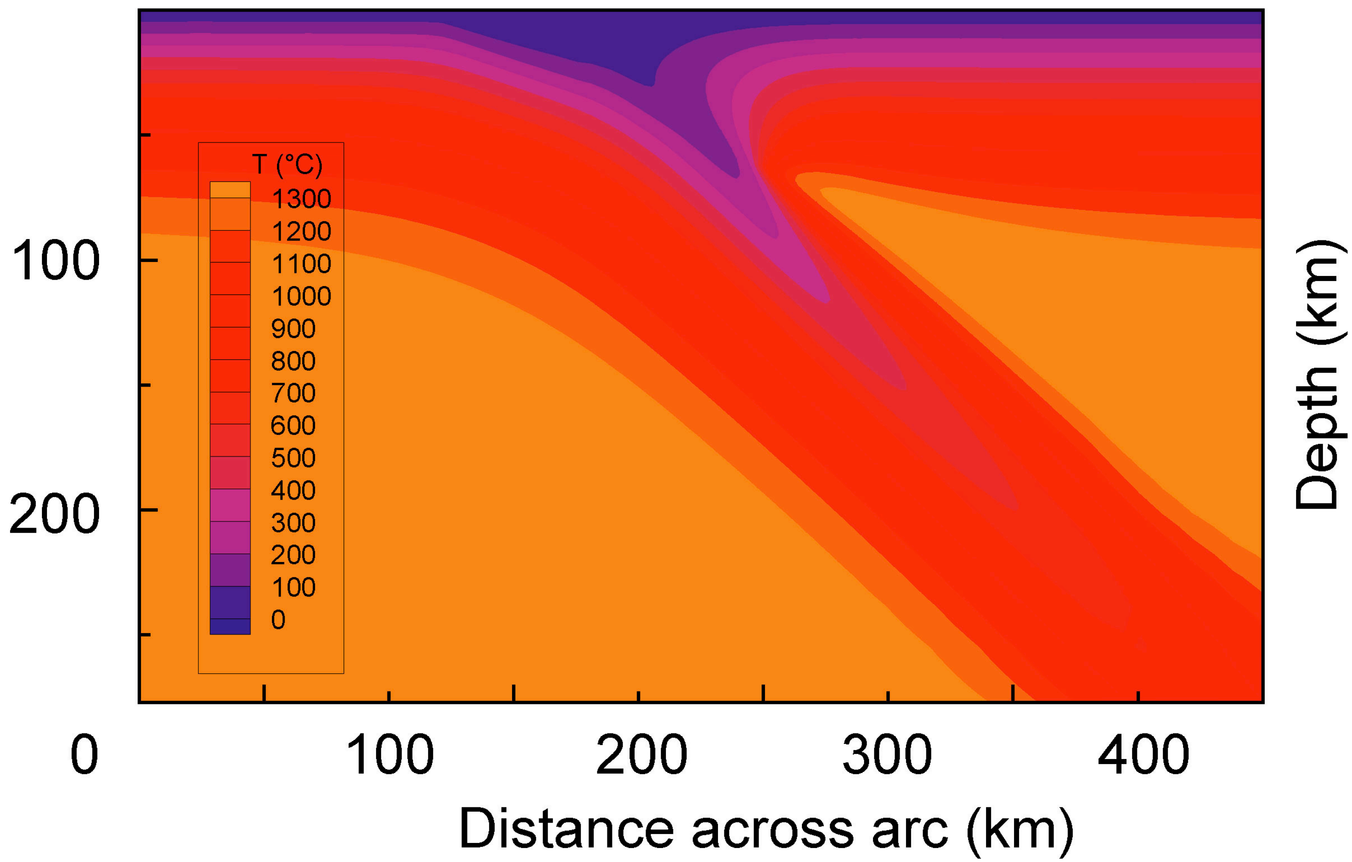


Synthetic phase relations and p-T water content of hydrous peridotite as calculated with PERPLEX

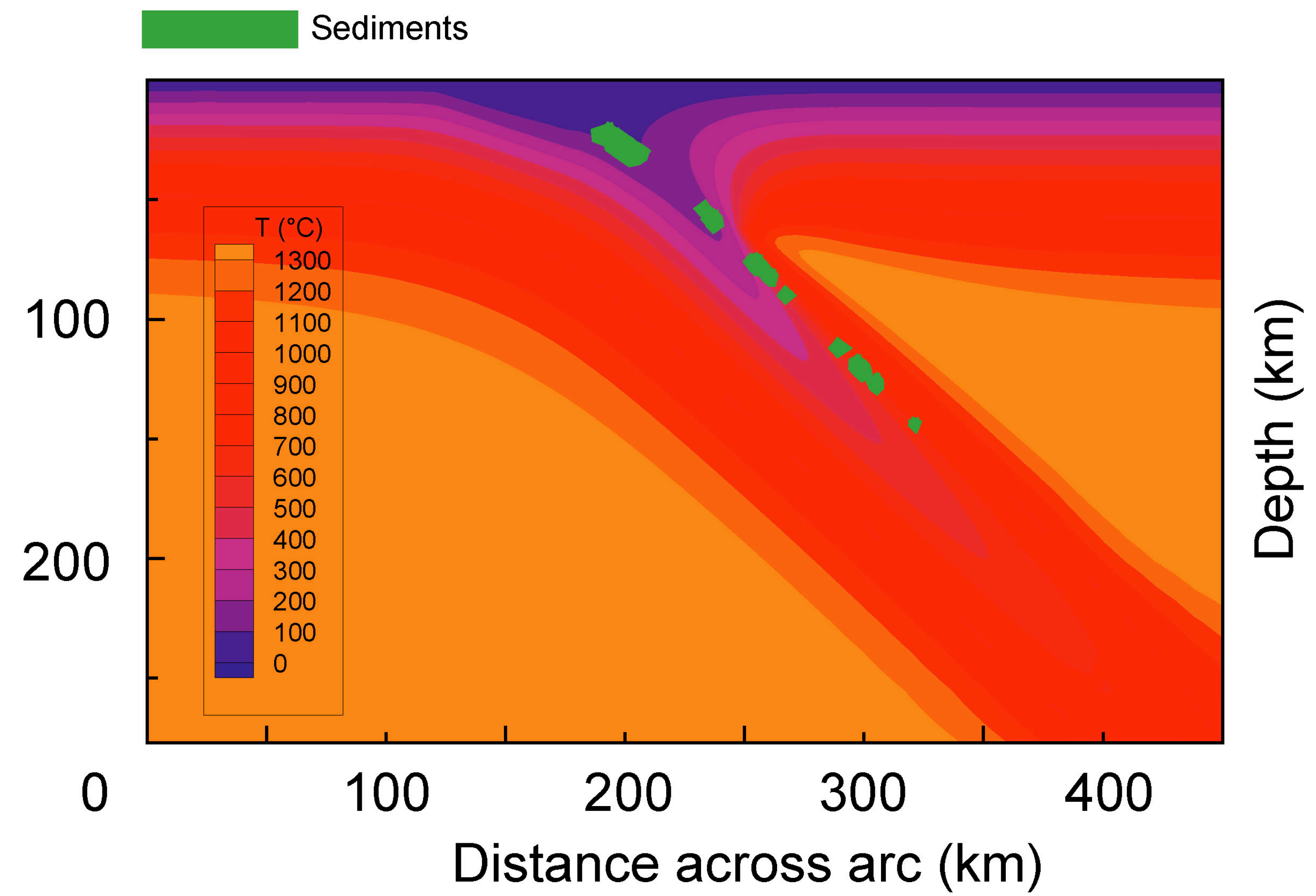


Tracer particle based implementation of water release

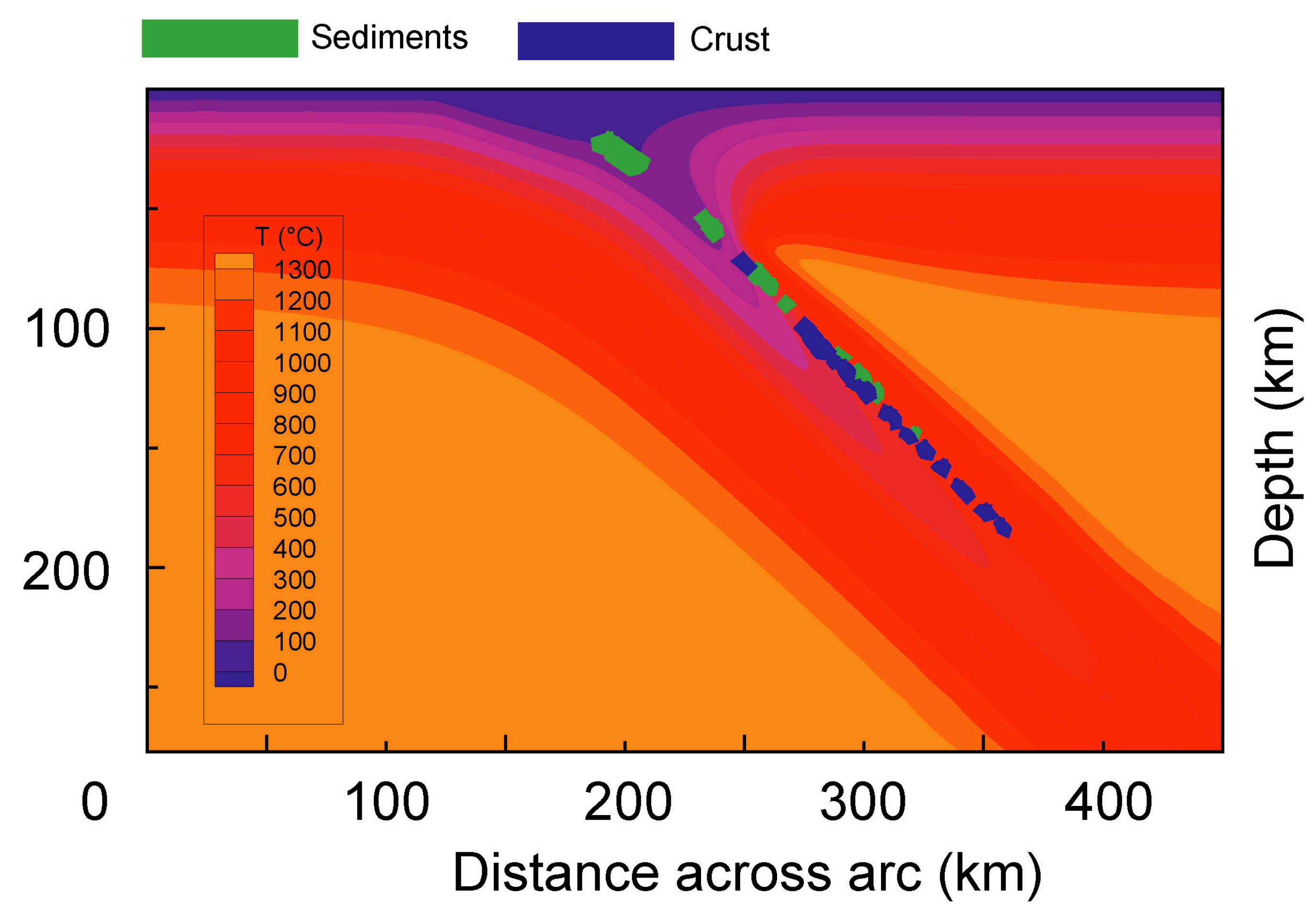



T (°C)
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
100
200
0
100
200
300
400
Distance across arc (km)
Depth (km)

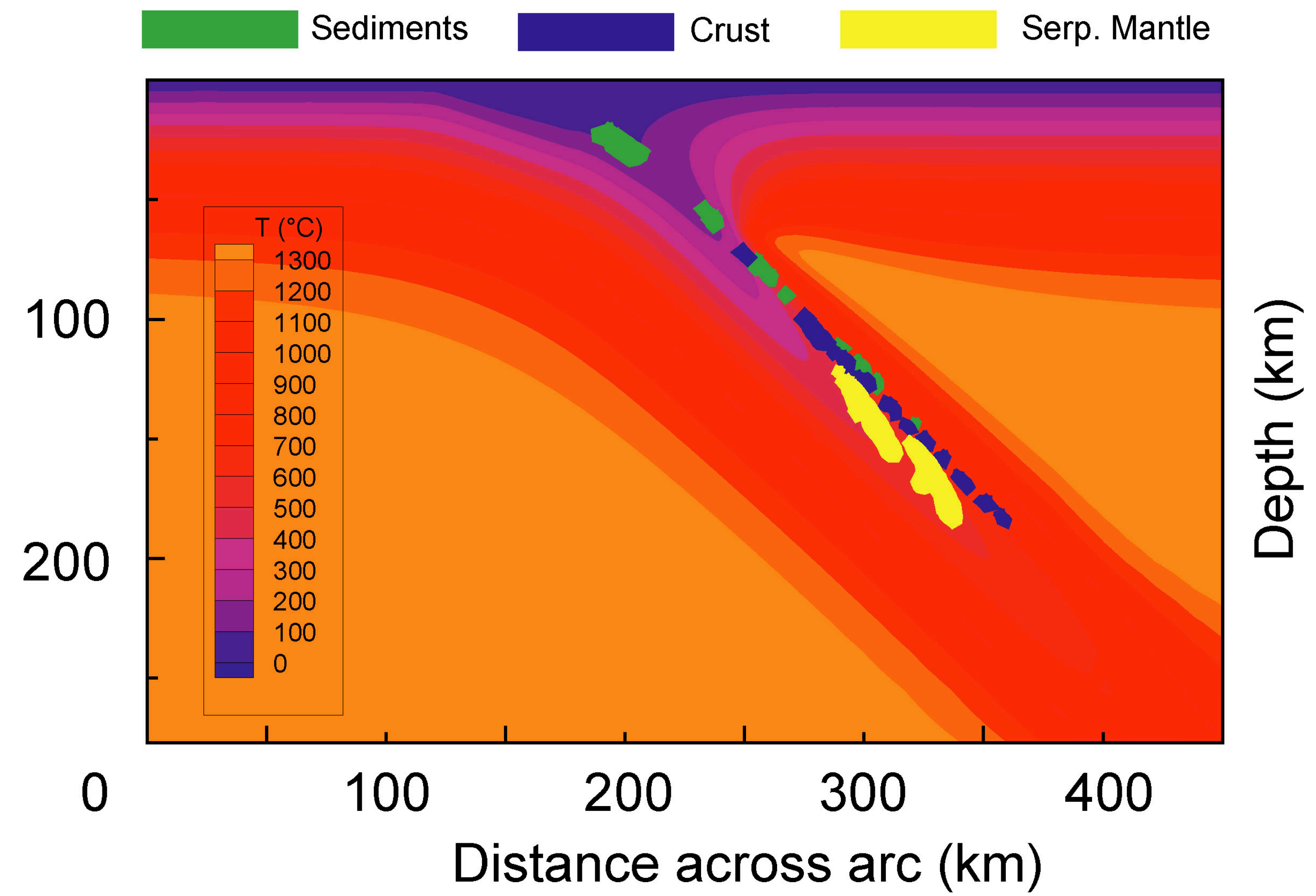
Modeled pattern of slab fluid release



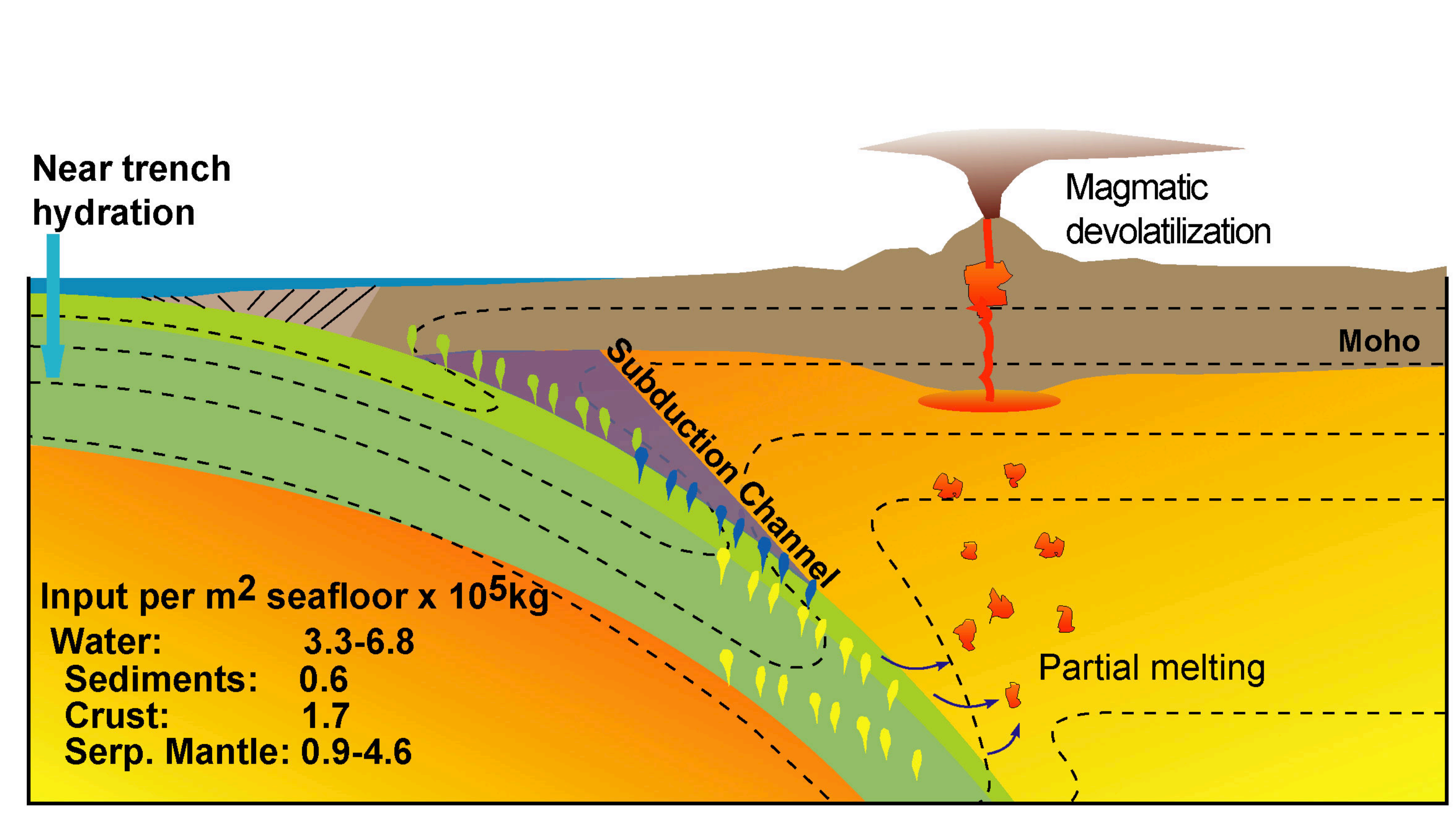
Modeled pattern of slab fluid release



Modeled pattern of slab fluid release



A possible water budget for subduction zones



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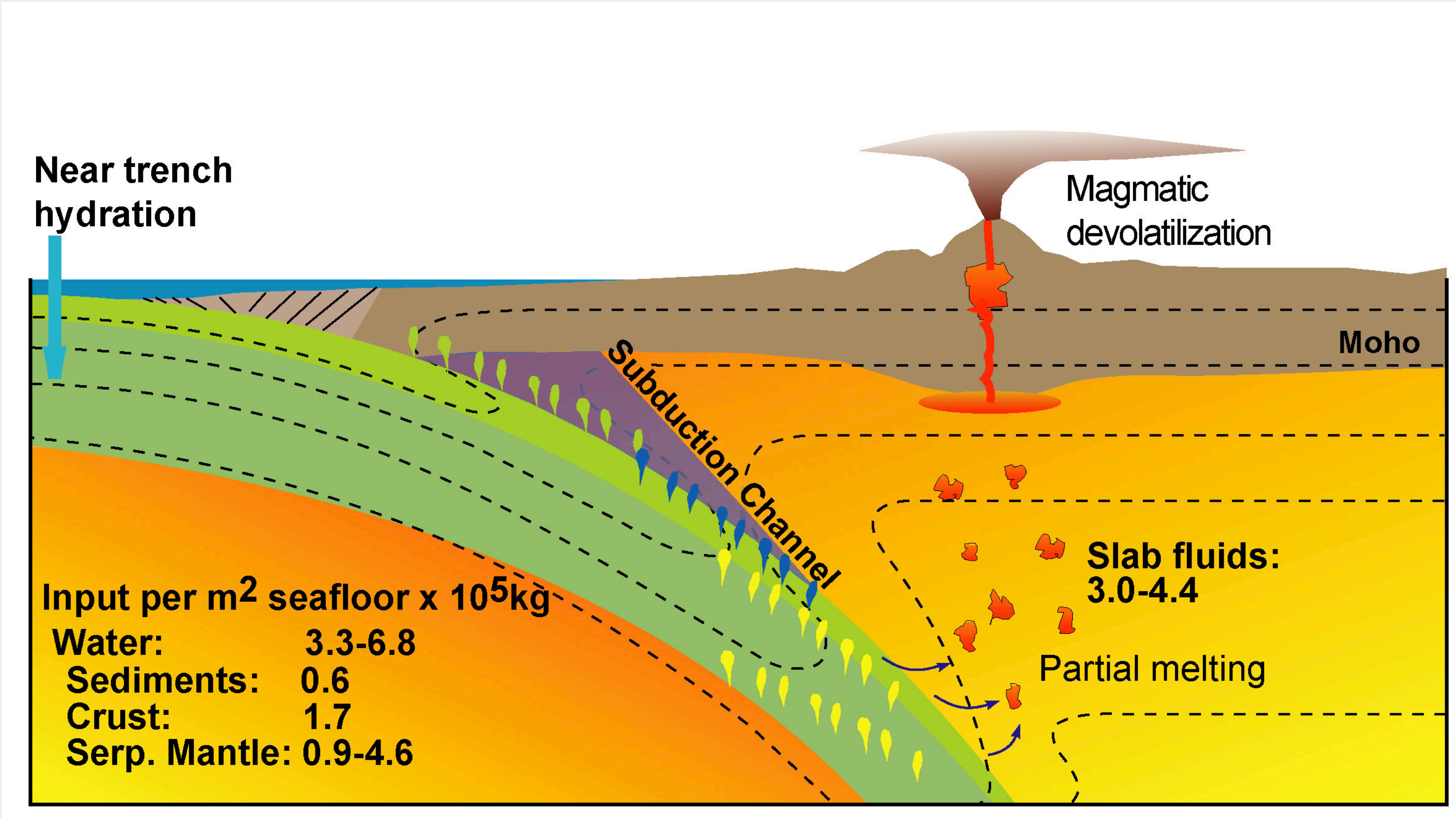
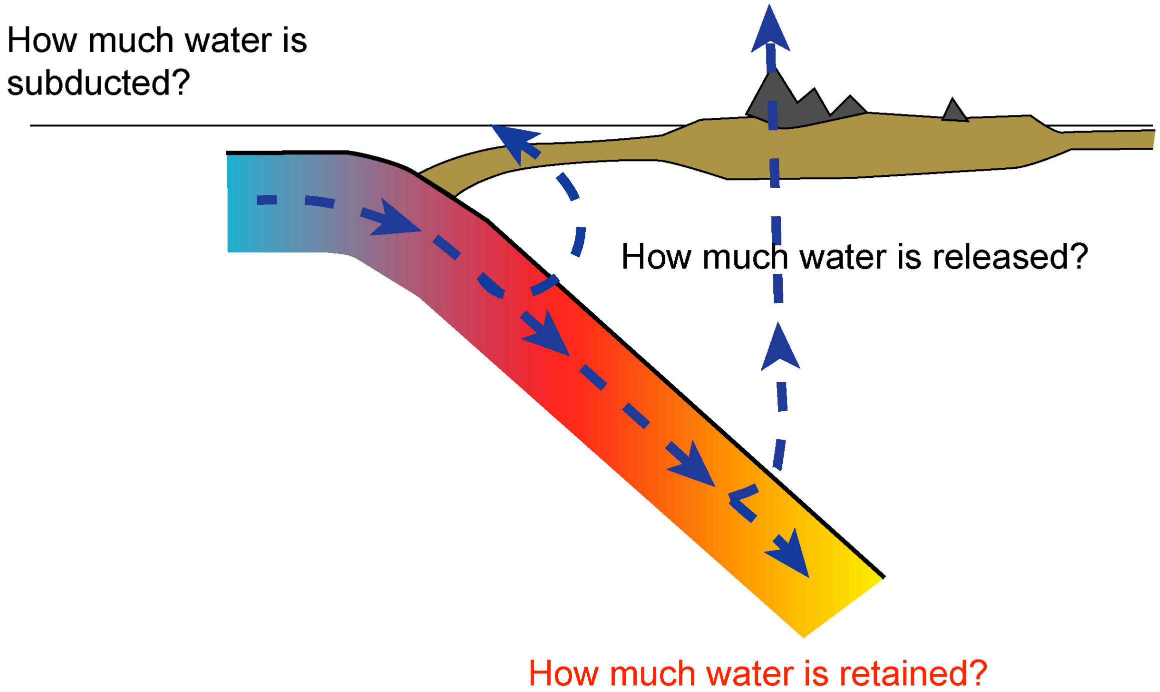
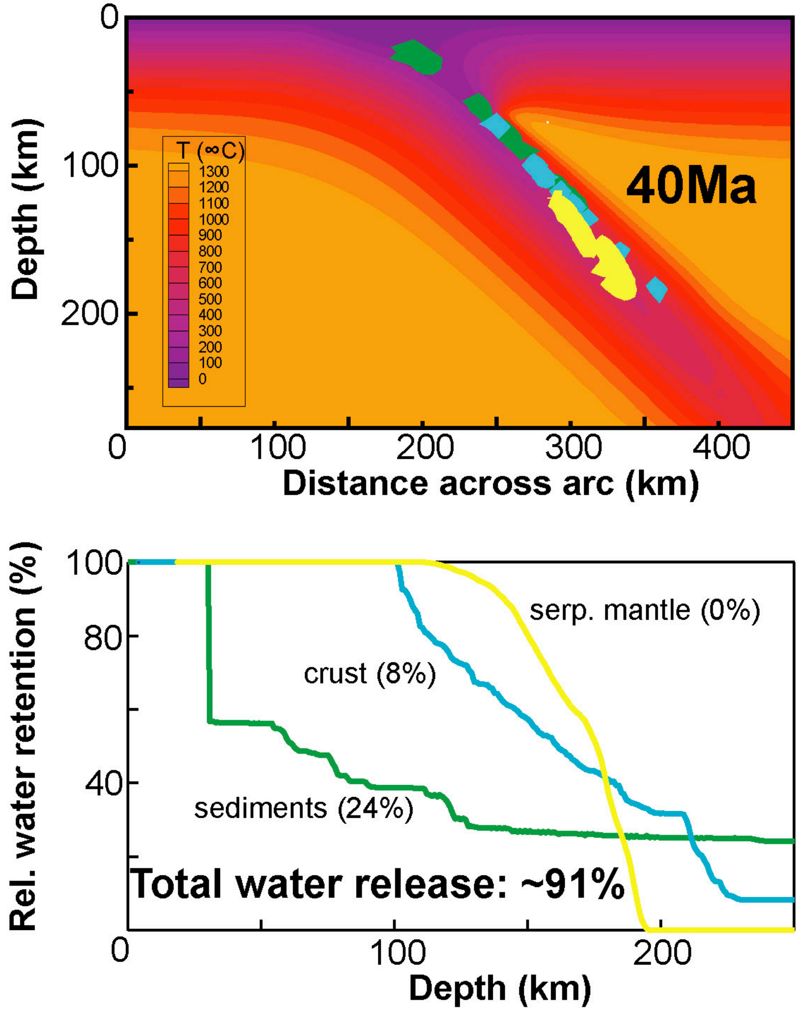


Part 3: Global implications of deep water recycling at subduction zones

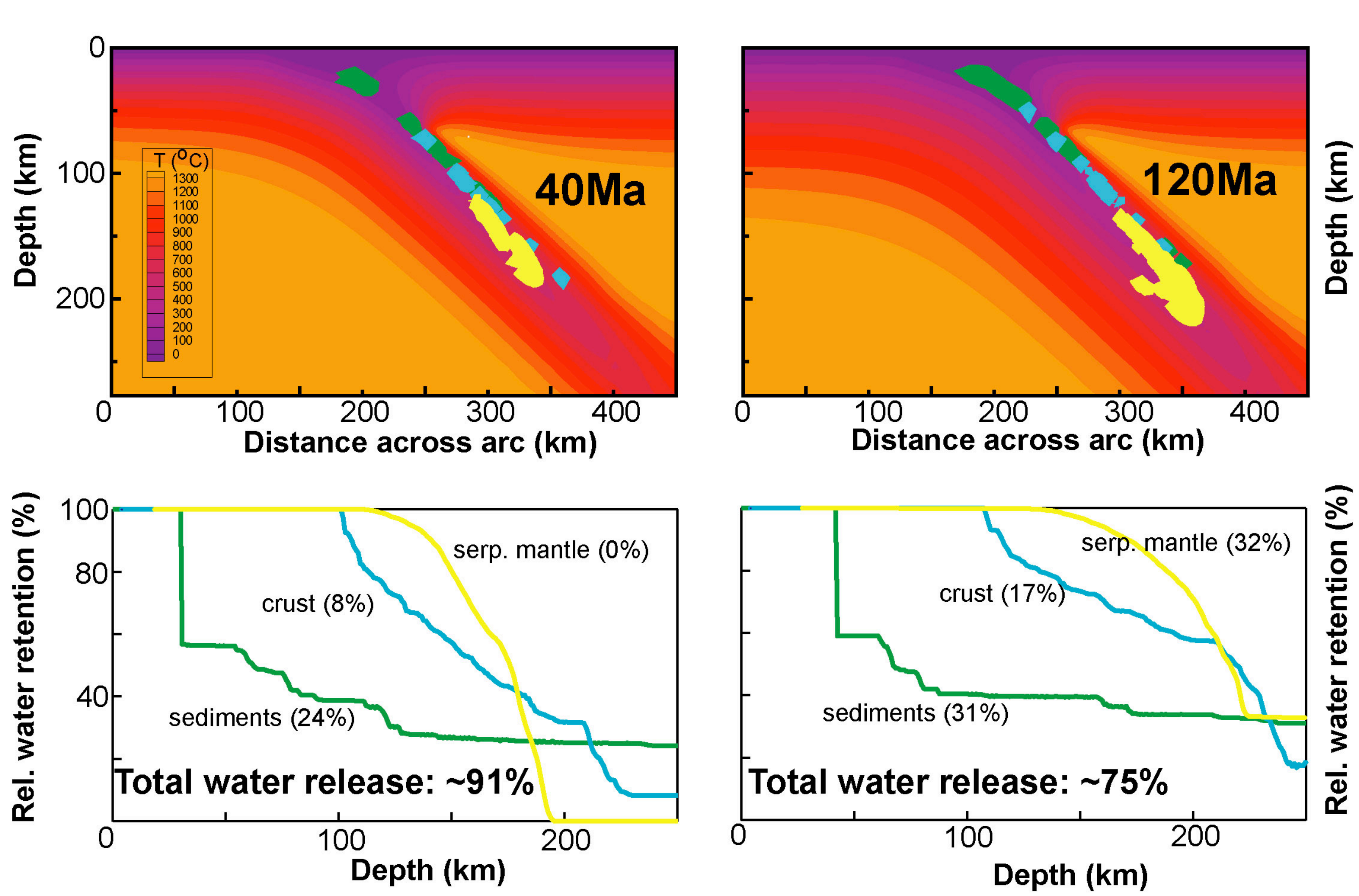


Deep water recycling at subduction zones



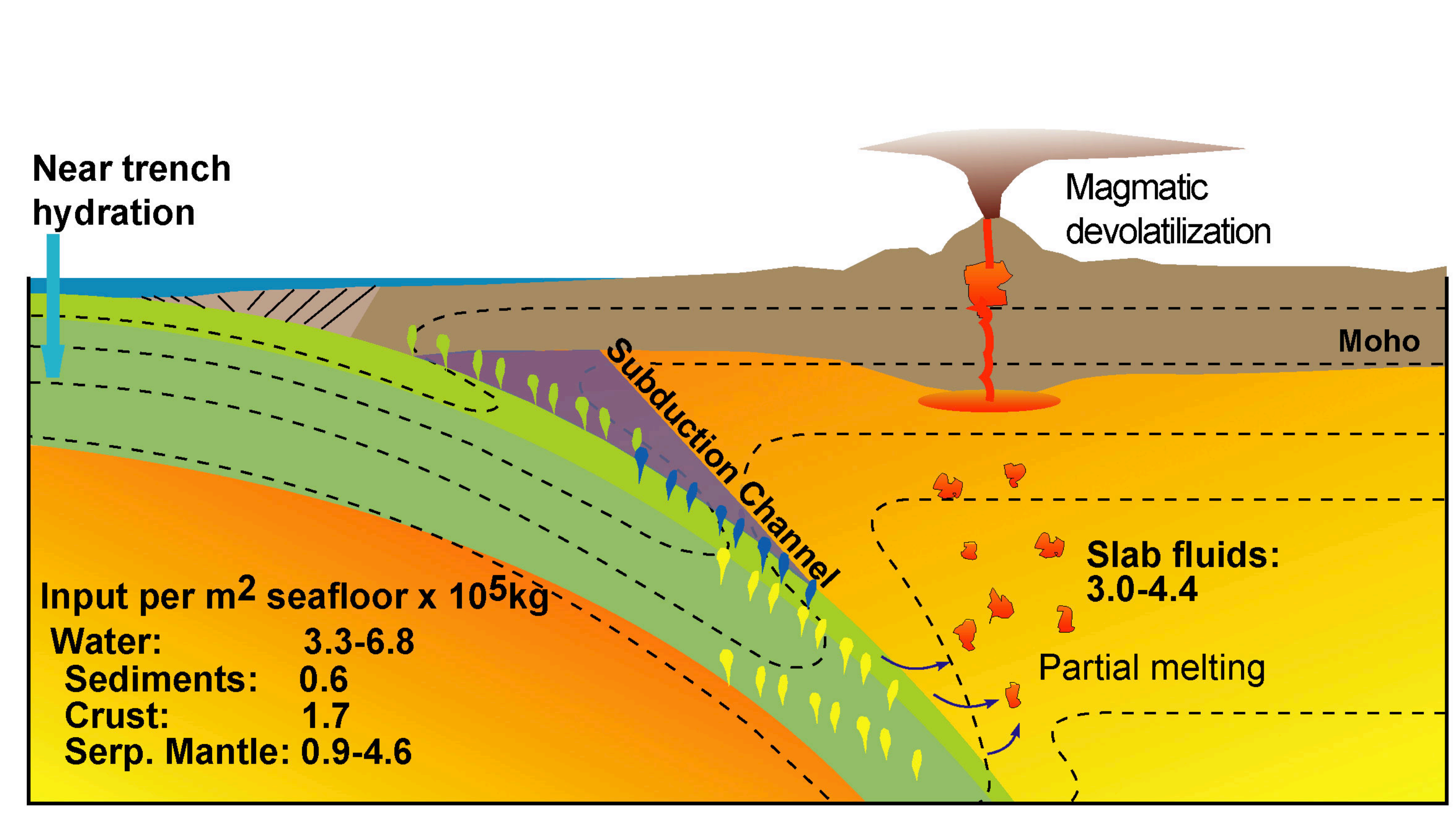
Young and hot slabs dewater very efficiently…

Deep water recycling at subduction zones



…old slabs may remain cold enough to retain some water

A possible water budget for subduction zones



A possible water budget for subduction zones

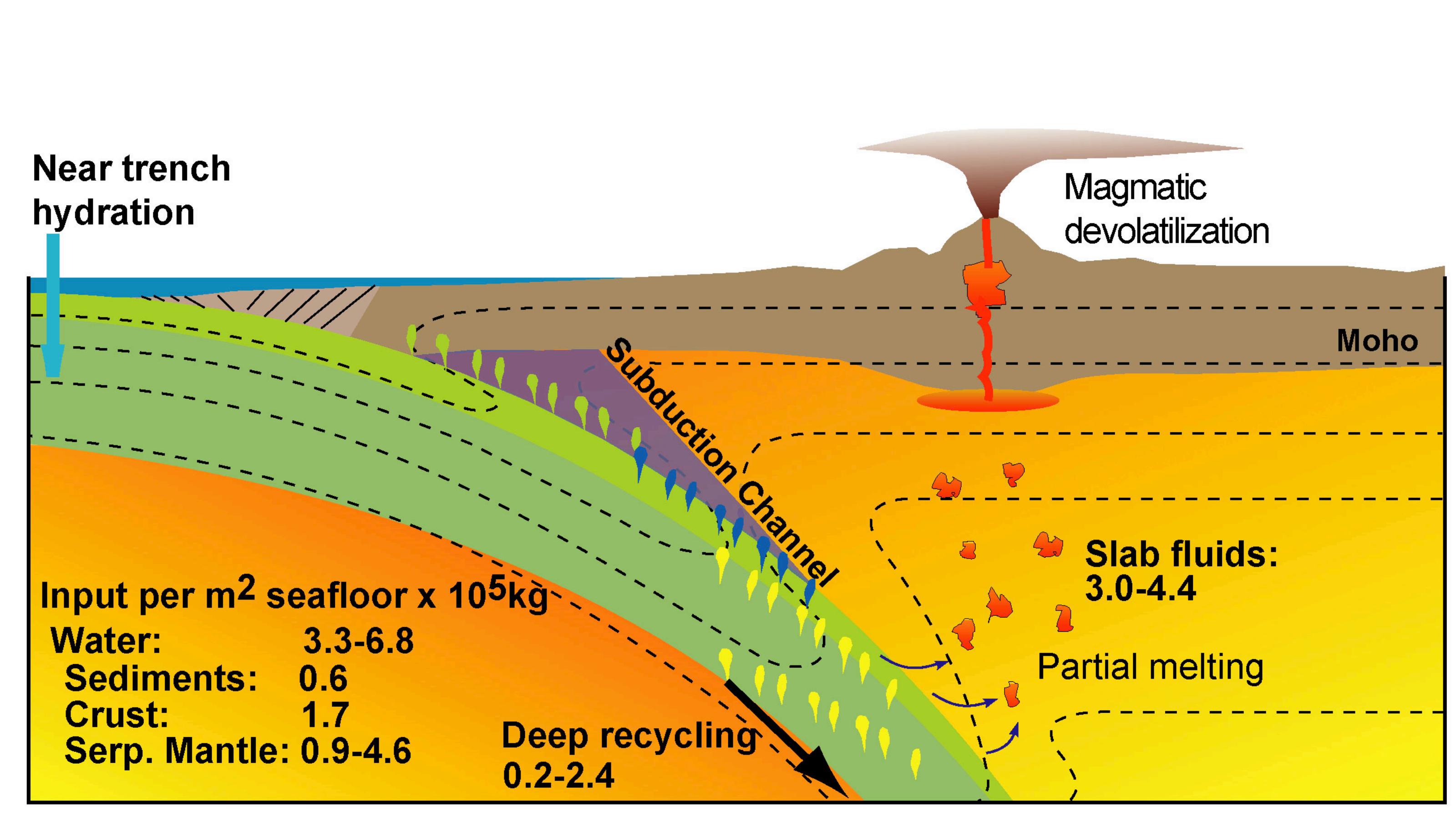
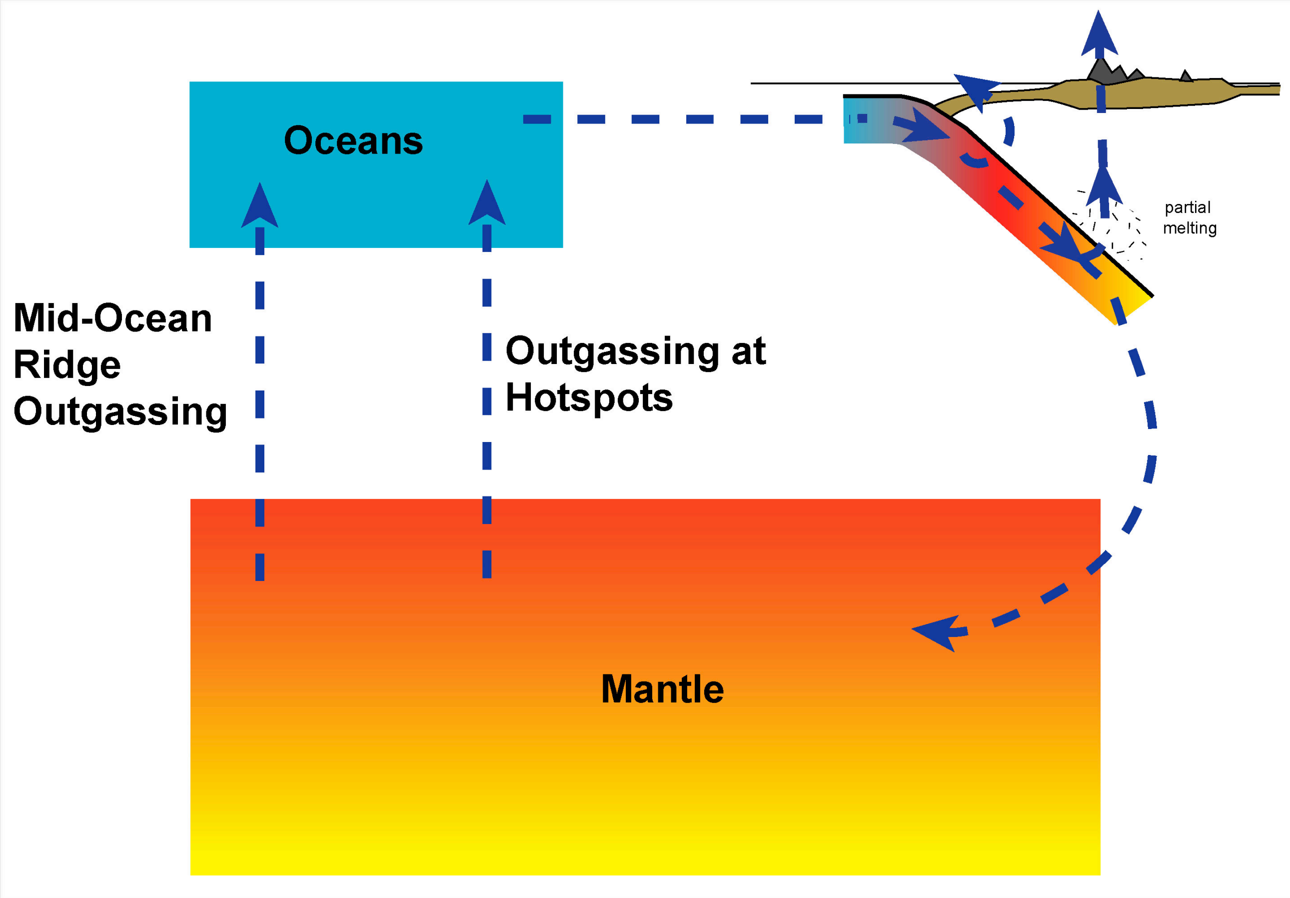
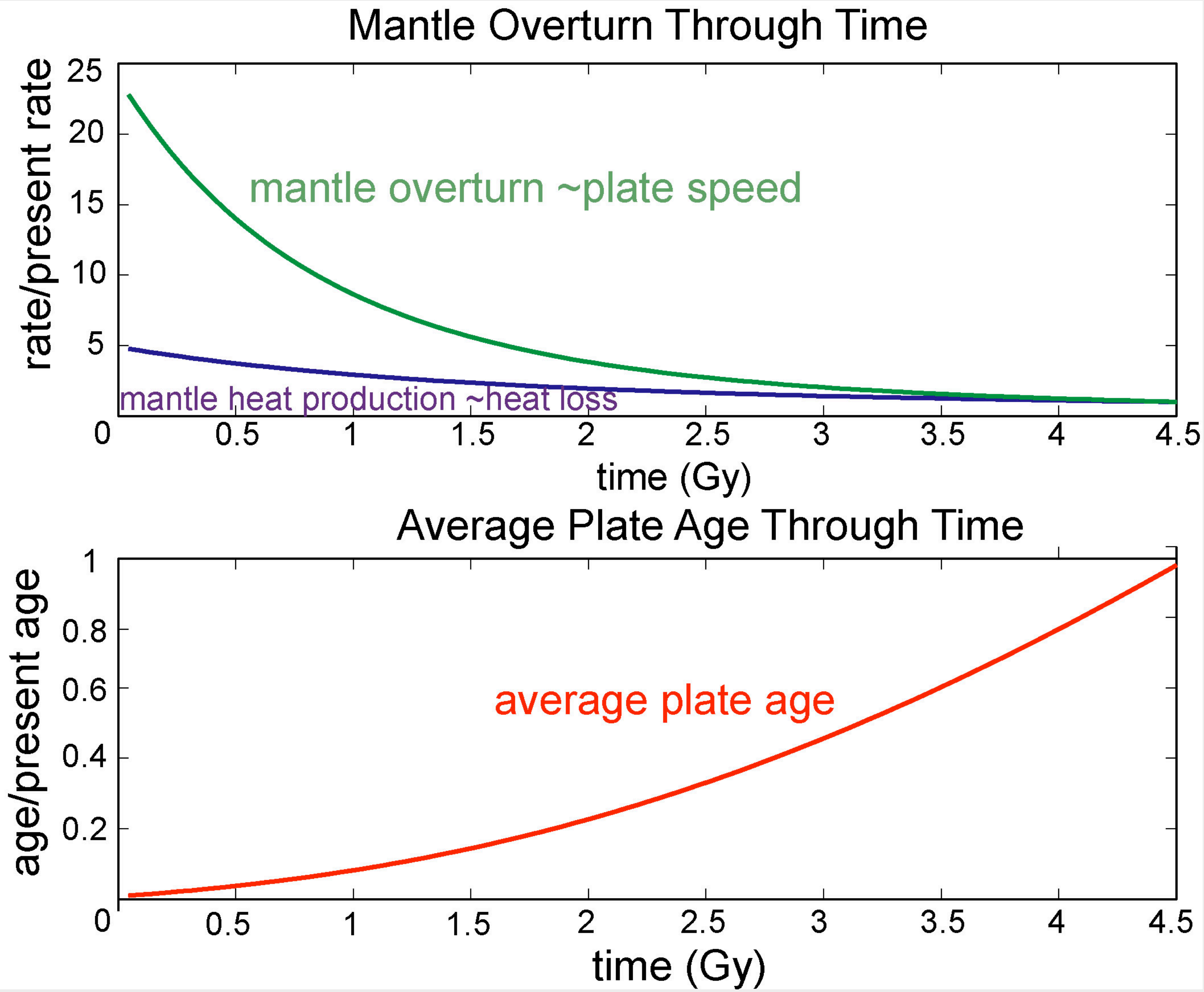


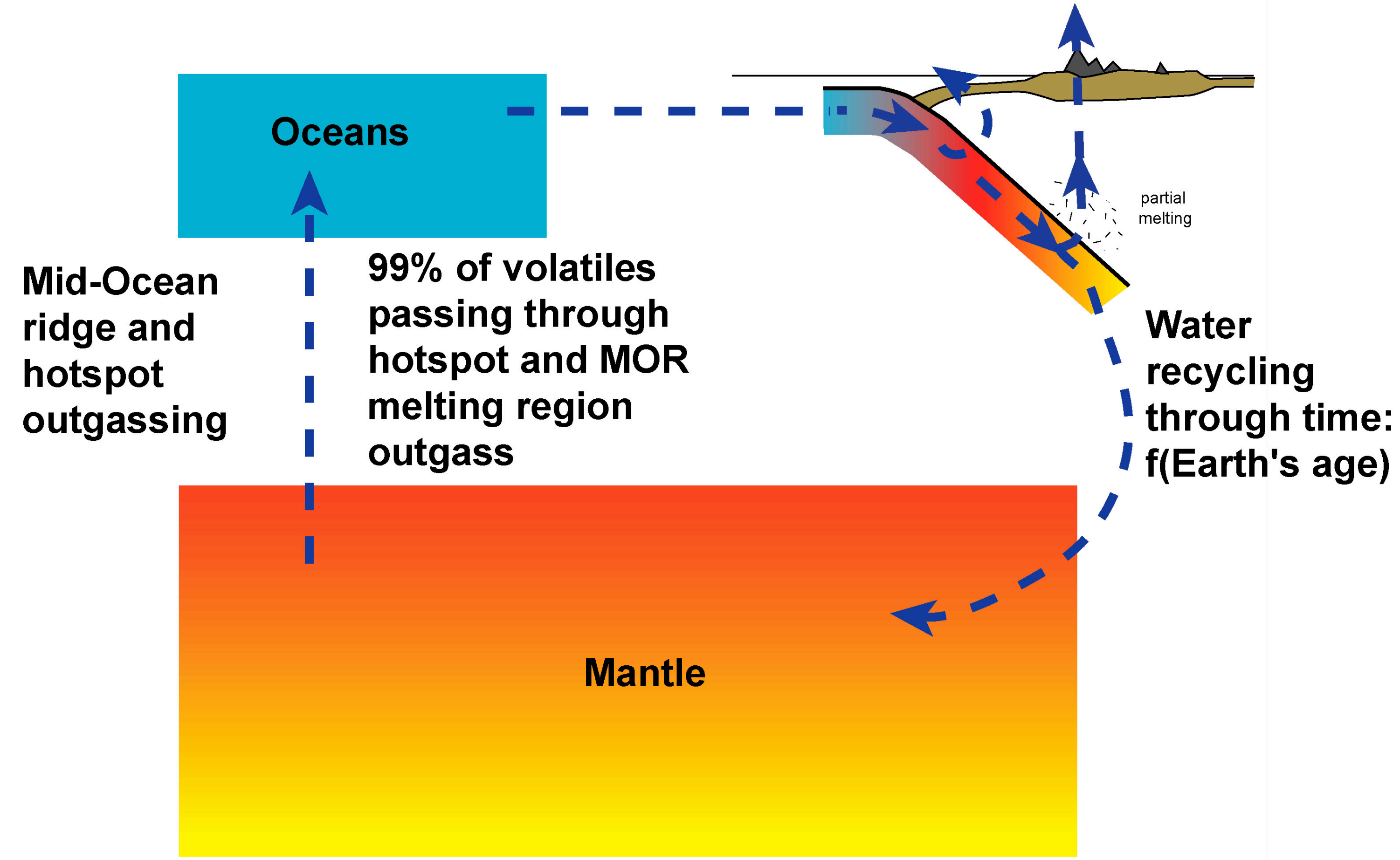
Plate subduction as part of the global geochemical water cycle



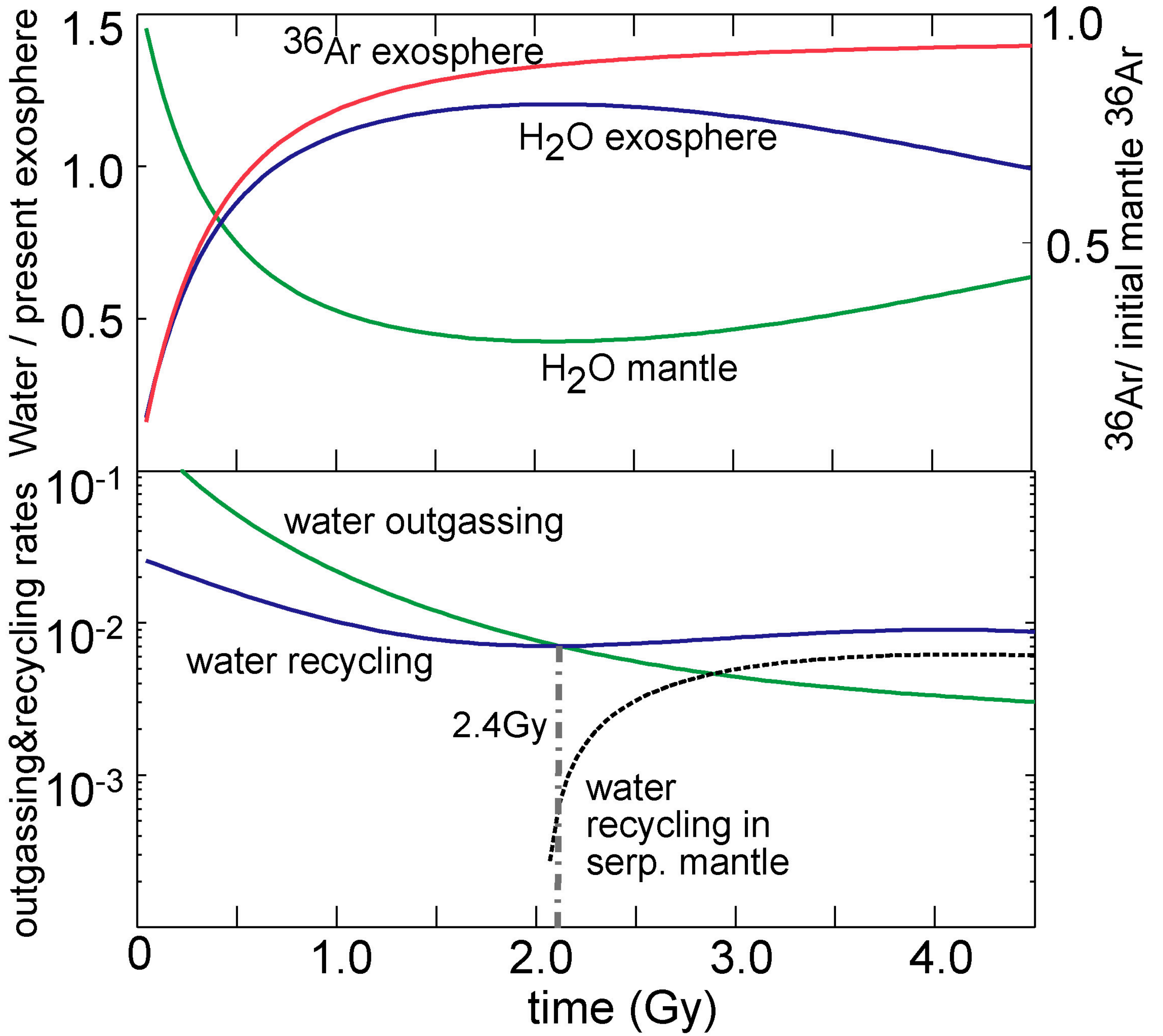
How may this system have evolved through time?

Parameterized convection
Average plate age and speed throughout Earth history

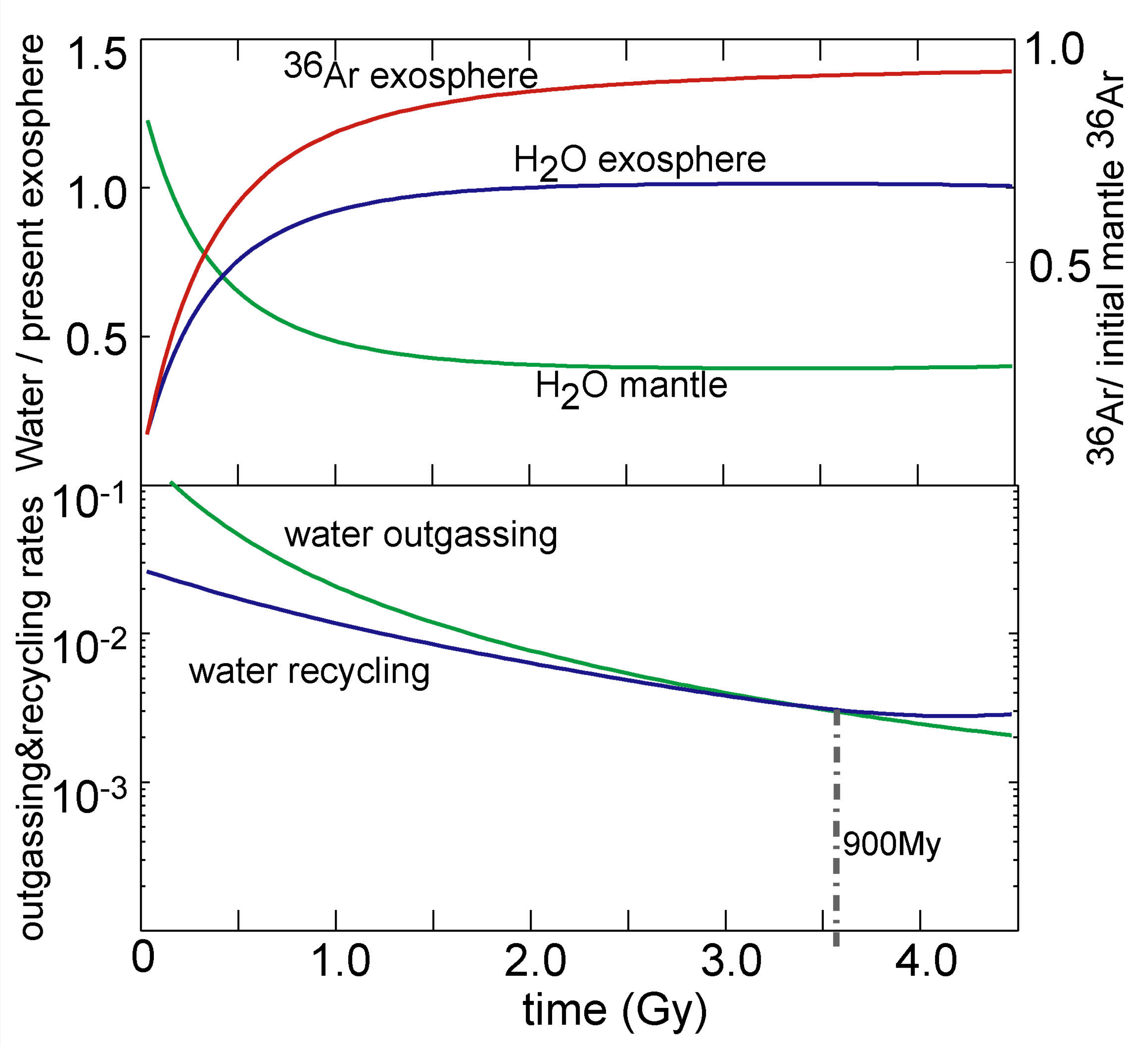



Oceans
Mid-Ocean ridge and hotspot outgassing
99% of volatiles passing through hotspot and MOR melting region outgass
partial melting
Water recycling through time: f(Earth's age)
Mantle

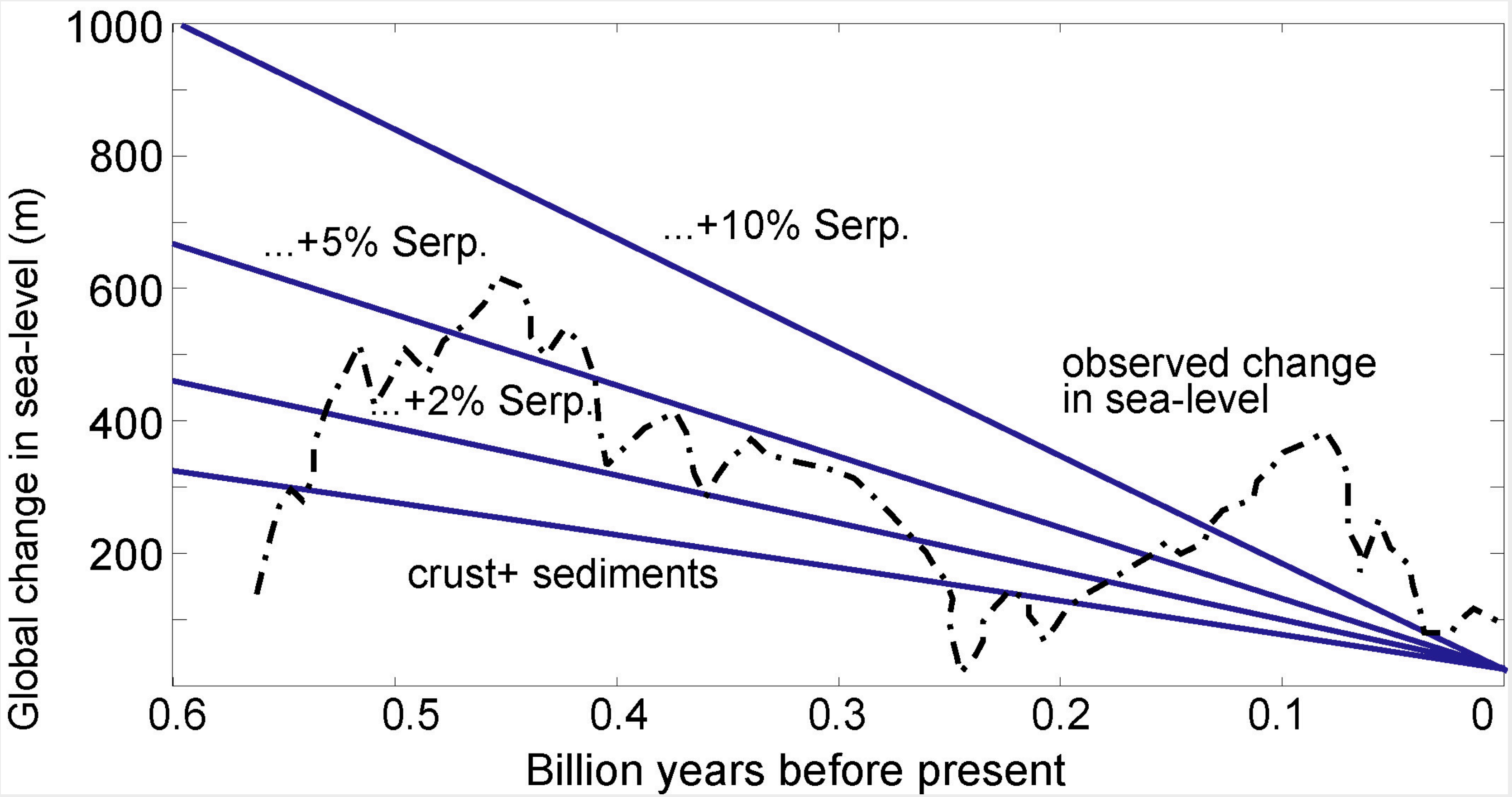
Modeled geologic water cycle
Initial plate hydration includes 5% near Moho serpentinization



Modeled geologic water cycle
Initial plate hydration includes no mantle serpentinization



Sea level changes over past 600Ma

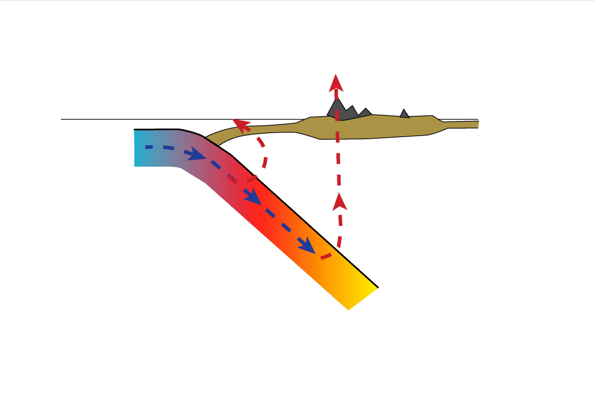


Implications

- Earth's surface and deep water cycle appear to be still in close contact
- Present day mantle is highly outgassed (~93%) and contains only ~1/3 of its initial water
- Residual serpentinites may dominate present day water recycling
- Plate subduction induces long drop in sea level

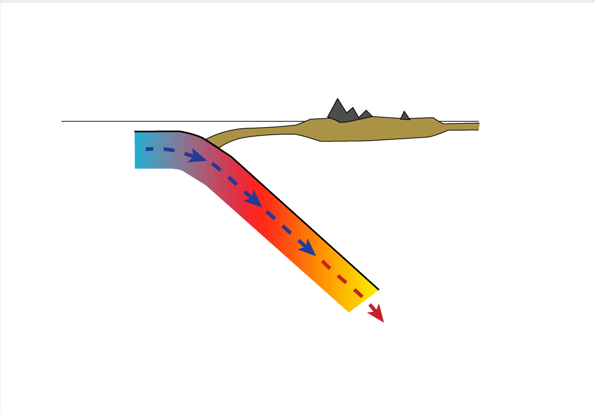
General Conclusions

Sub-arc water release:



- Fluids are continuously released from a subducting slab
- Host lithology changes with depth
- Serpentine may be dominant fluid source at depths >100km

Deep water recycling:



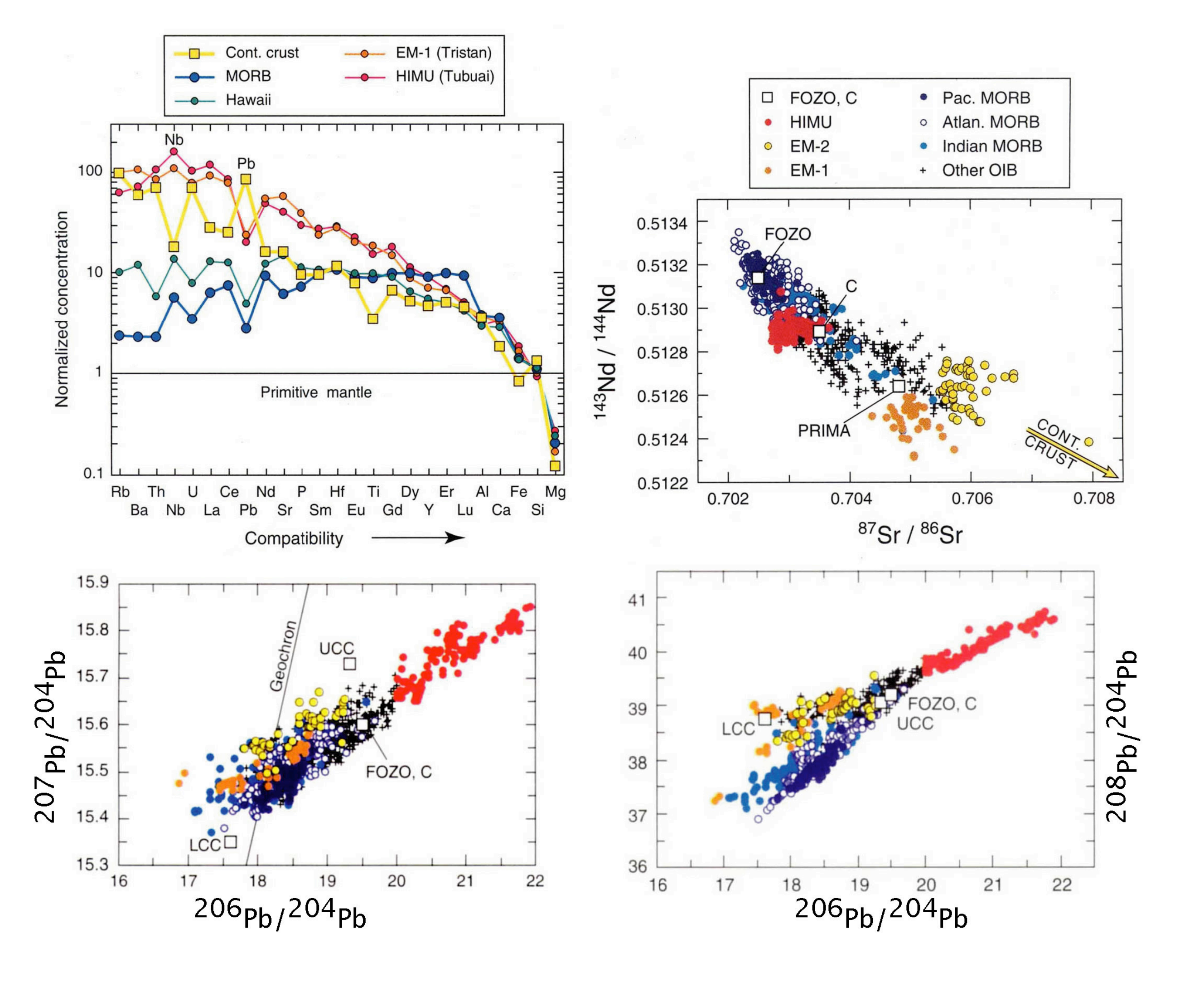
- Old slabs may remain cold enough to recycle water into the deeper mantle
- Best ‘transport-lithology’ is hydrated mantle
- Earth’s surface and deep water cycle may therefore still be in close contact

How can we test these results?

How can we test these results?

With Geochemistry

Mantle Chemistry



The mantle contains chemically distinct components…

…with distinct water concentrations!

Water concentrations after Dixon et al 2002 (Nature):

Primitive mantle: ~750ppm

…with distinct water concentrations!

Water concentrations after Dixon et al 2002 (Nature):

Primitive mantle: ~750ppm

…our model predicts ~815ppm

…with distinct water concentrations!

Water concentrations after Dixon et al 2002 (Nature):

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Slab influenced mantle components (e.g. HIMU): <400ppm

…with distinct water concentrations!

Water concentrations after Dixon et al 2002 (Nature):

Primitive mantle: ~750ppm

…our model predicts ~815ppm

Slab influenced mantle components (e.g. HIMU): <400ppm

…our model predicts more than ~269ppm

…with distinct water concentrations!

Water concentrations after Dixon et al 2002 (Nature):

Primitive mantle: ~750ppm

…our model predicts ~815ppm

Slab influenced mantle components (e.g. HIMU): <400ppm

…our model predicts more than ~269ppm

Depleted mantel source of MORB: ~100ppm

…with distinct water concentrations!

Water concentrations after Dixon et al 2002 (Nature):

Primitive mantle: ~750ppm

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Slab influenced mantle components (e.g. HIMU): <400ppm

…our model predicts more than ~269ppm

Depleted mantel source of MORB: ~100ppm

…our model predicts less than ~269ppm

Geochemical implications of subduction rehydration in a plum-pudding mantle