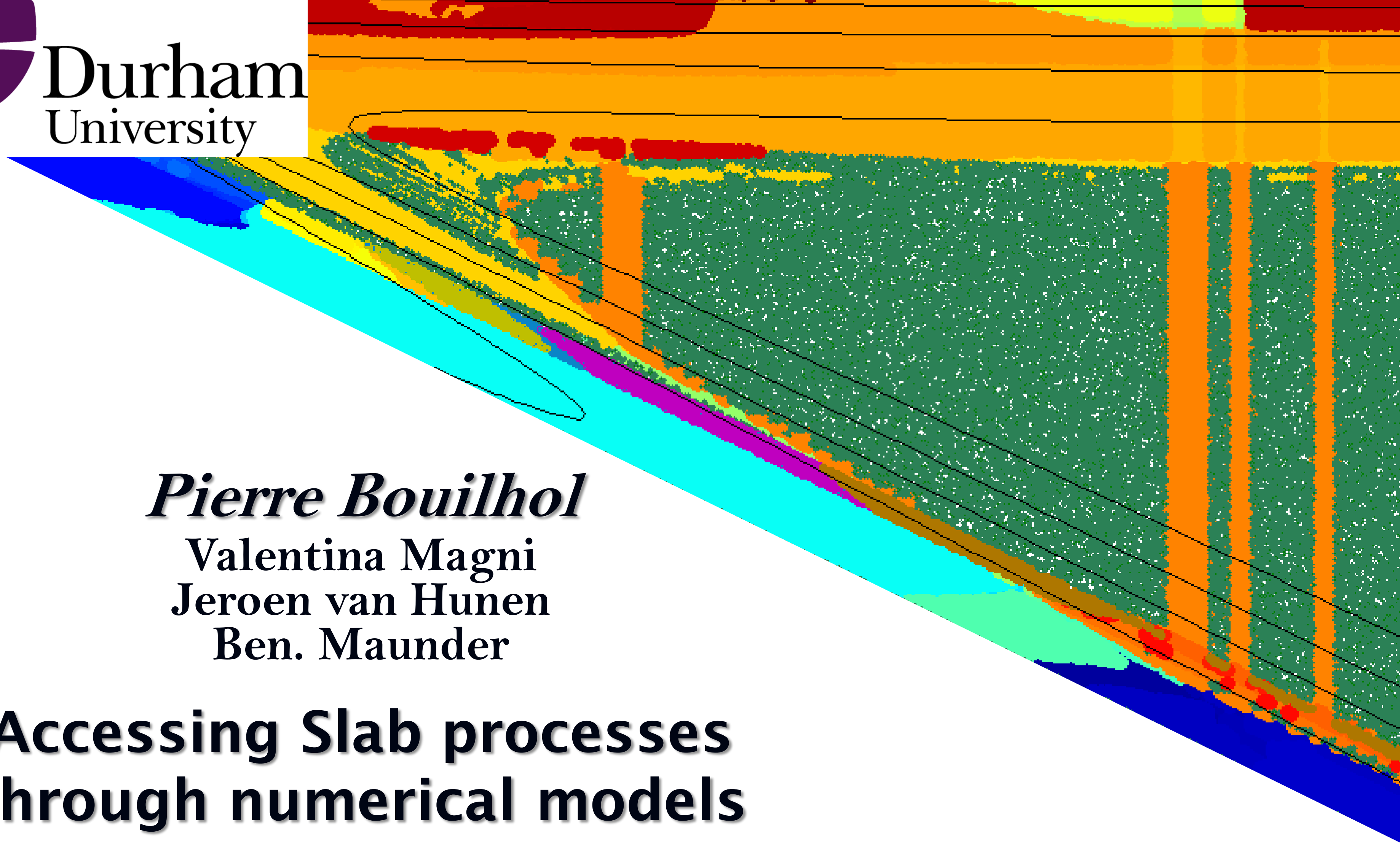
Durham University



Pierre Bouilhol

Valentina Magni

Jeroen van Hunen

Ben. Maunder

Accessing Slab processes through numerical models

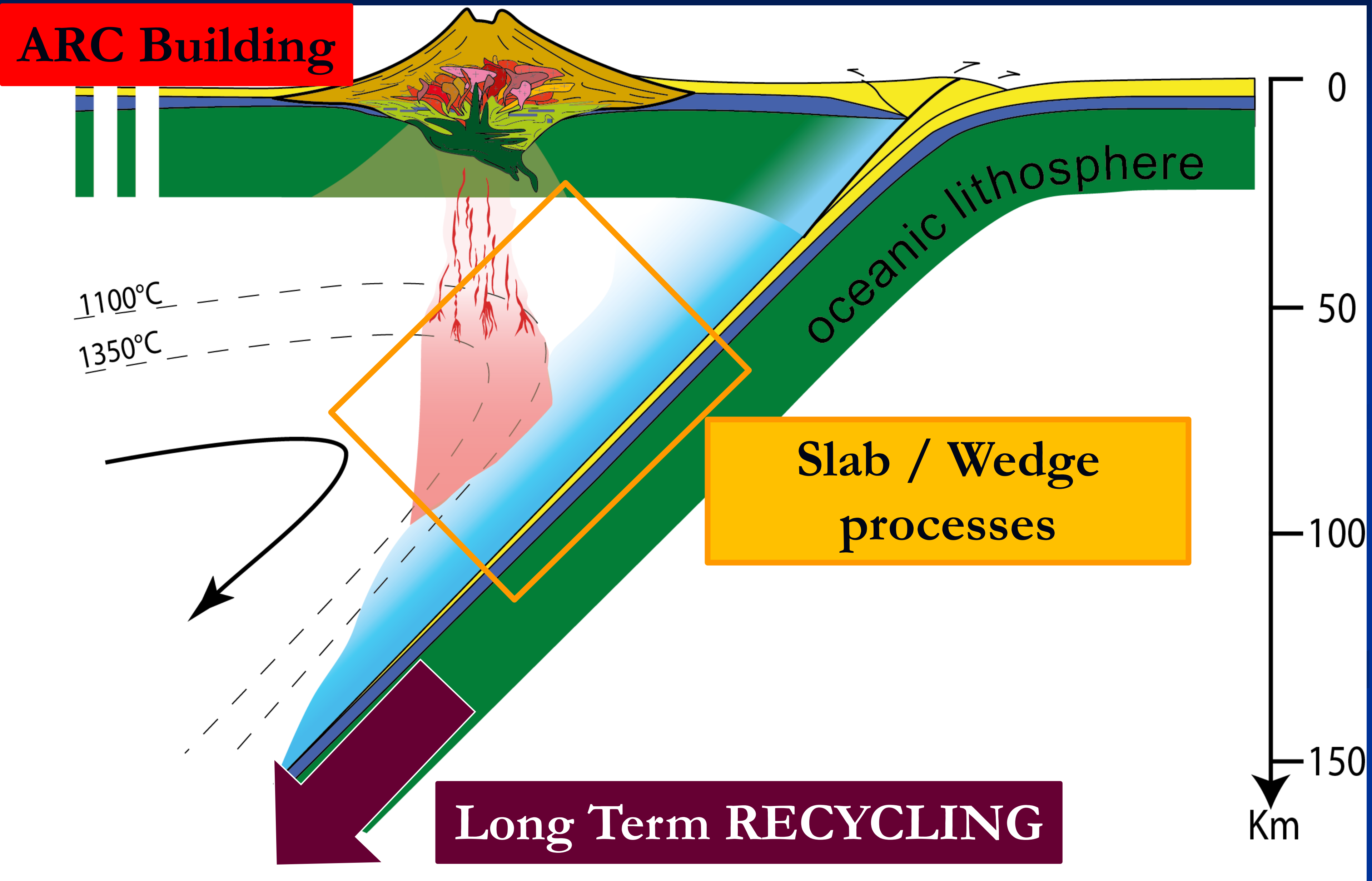
European Research Council

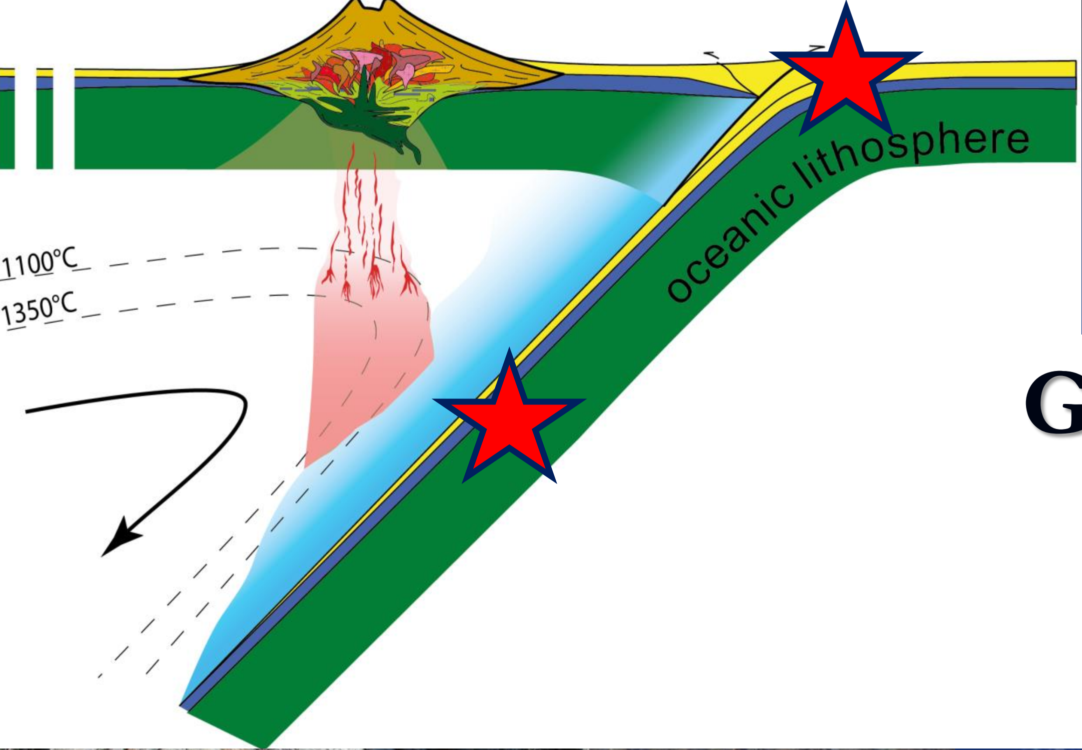
erc

MASE

Modelling the Archean Subduction Environment

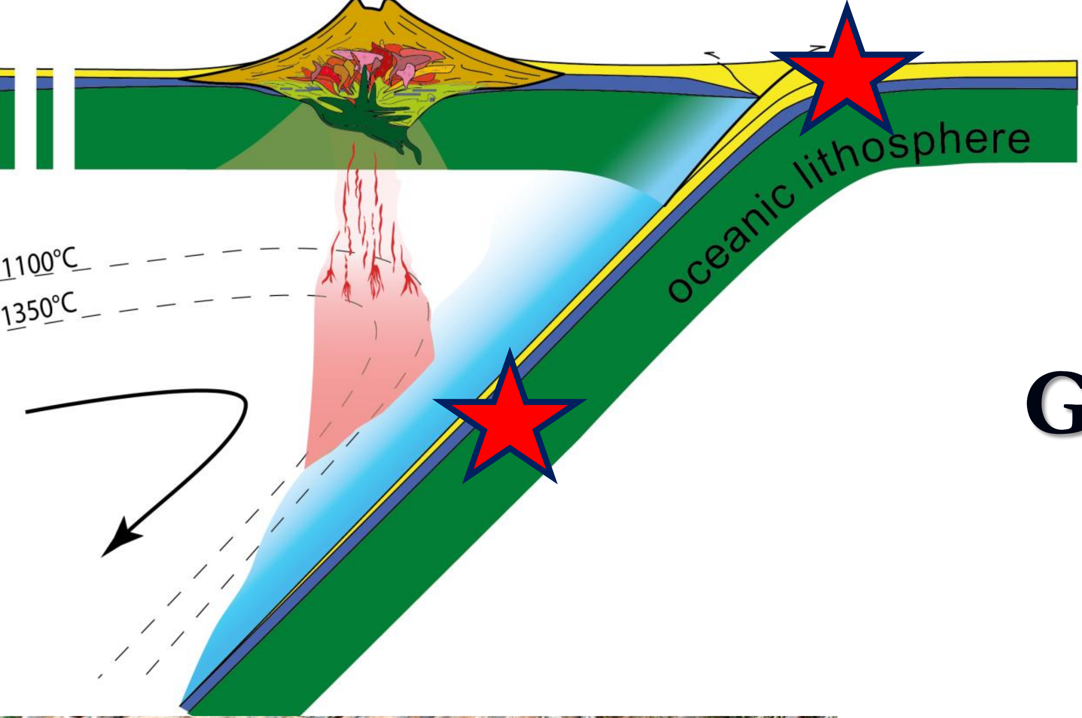
Continents ← Subduction / Arcs → Oceans





Slab / Wedge processes

Geological RECORD: Essential But Snapshots



Slab / Wedge processes

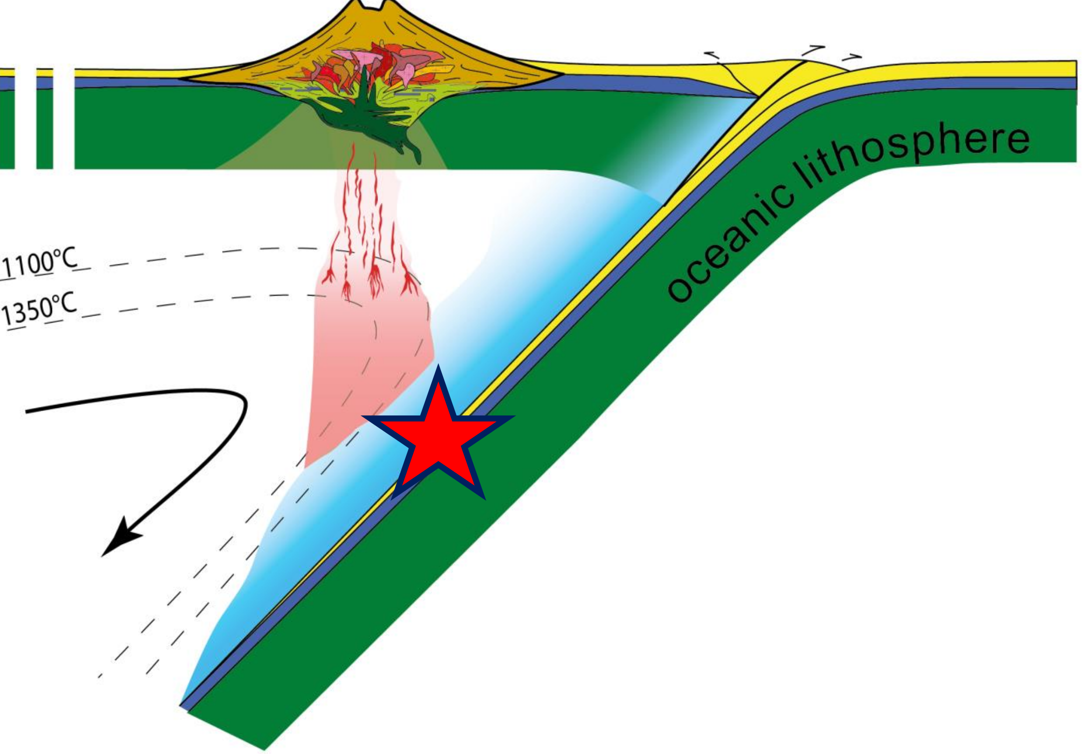
Geological RECORD: Essential But Snapshots

PTt paths

Mechanisms of Fluid extraction

Compositions

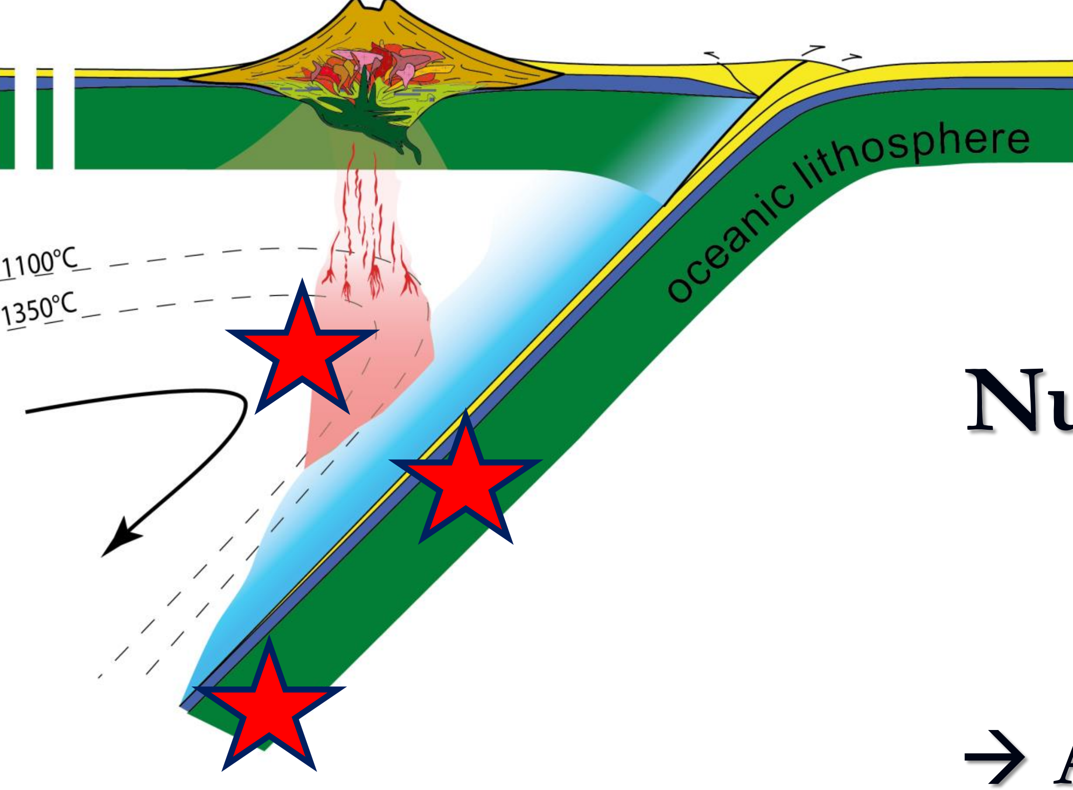
Complexity of interface



Slab / Wedge processes

Experiments: Essential But Snapshots (and tiny…)

Phase stability
Flaw laws
Kd's / Fluid Compositions

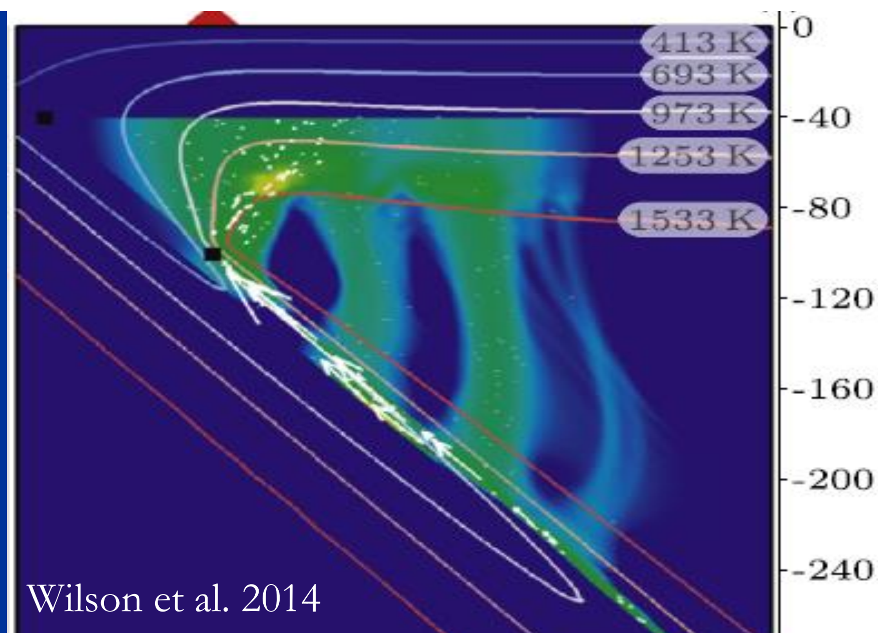


Slab / Wedge processes

Numerical MODELS: Essential Incomplete

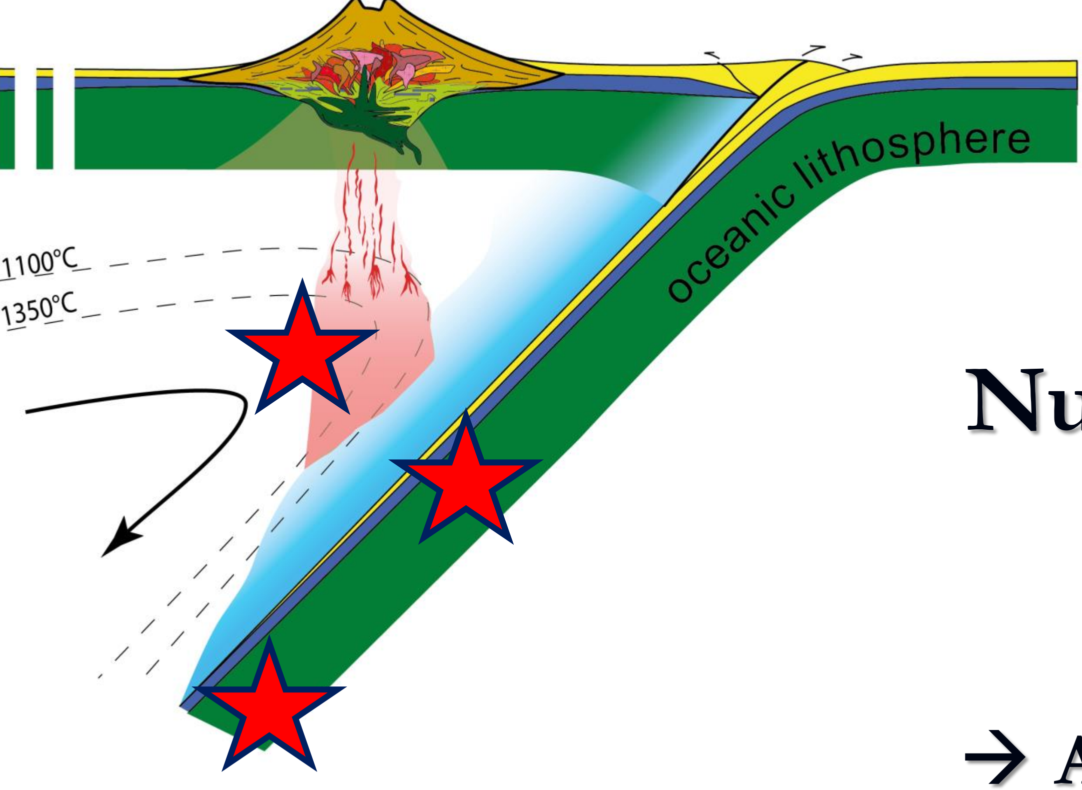
→ As too complex otherwise

→ Tackling problems 1 by 1



Fluid Flow

Re-hydration / melting patterns



Slab / Wedge processes

Numerical MODELS:
Essential
Incomplete

→ As too complex otherwise
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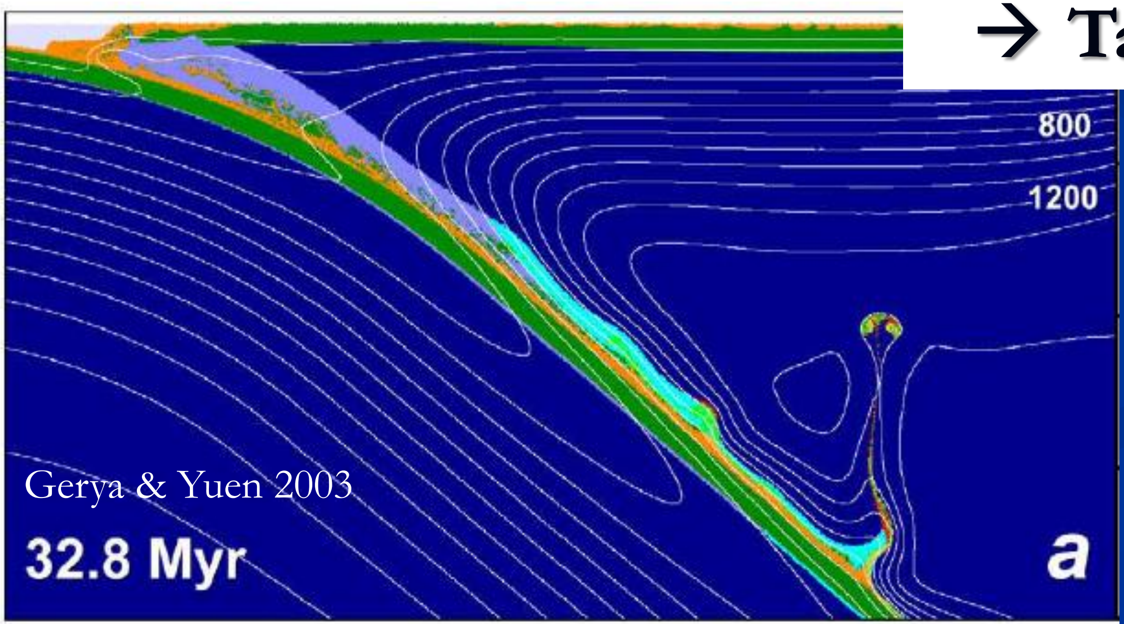
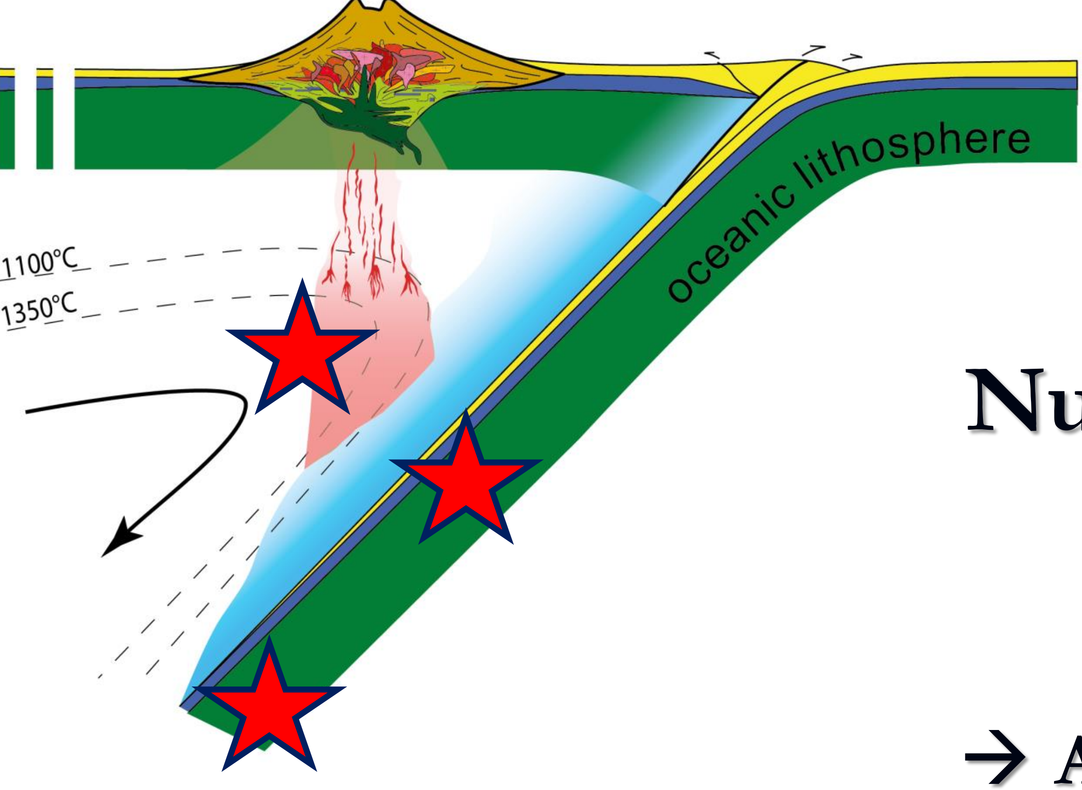


Rheology
Slab behaviour
Fate of solid fluxes

Slab / Wedge processes



Numerical MODELS:
Essential
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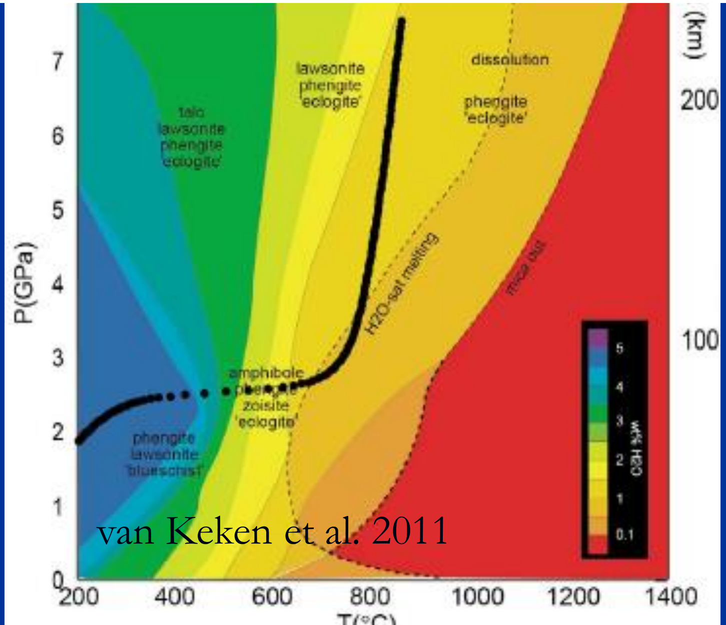
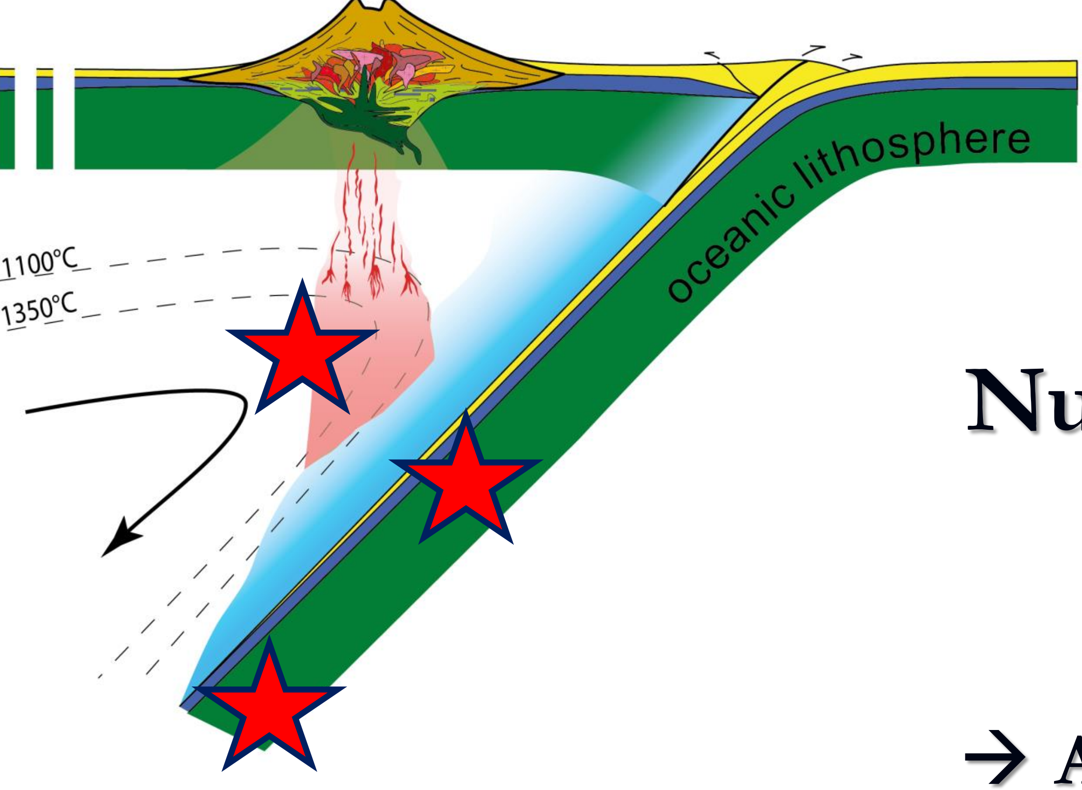


van Keken et al. 2011

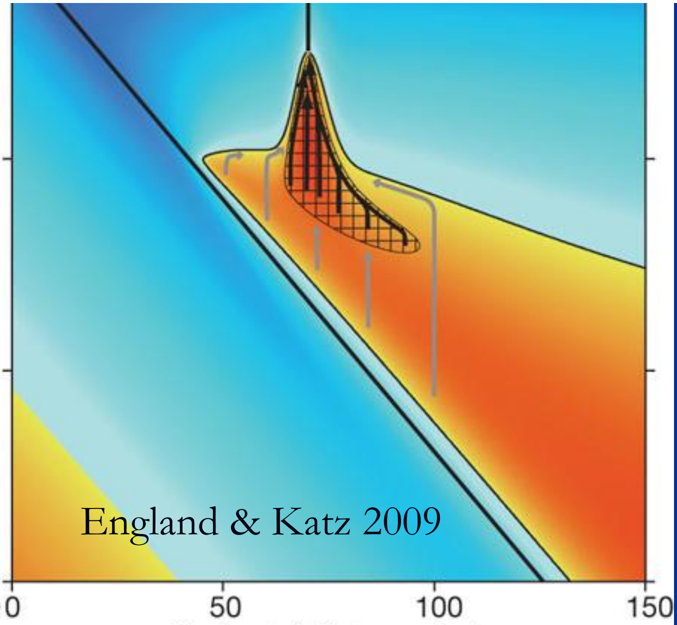
Thermodynamics
→ Petrology
H_2O flux
Melting potential

Slab / Wedge processes

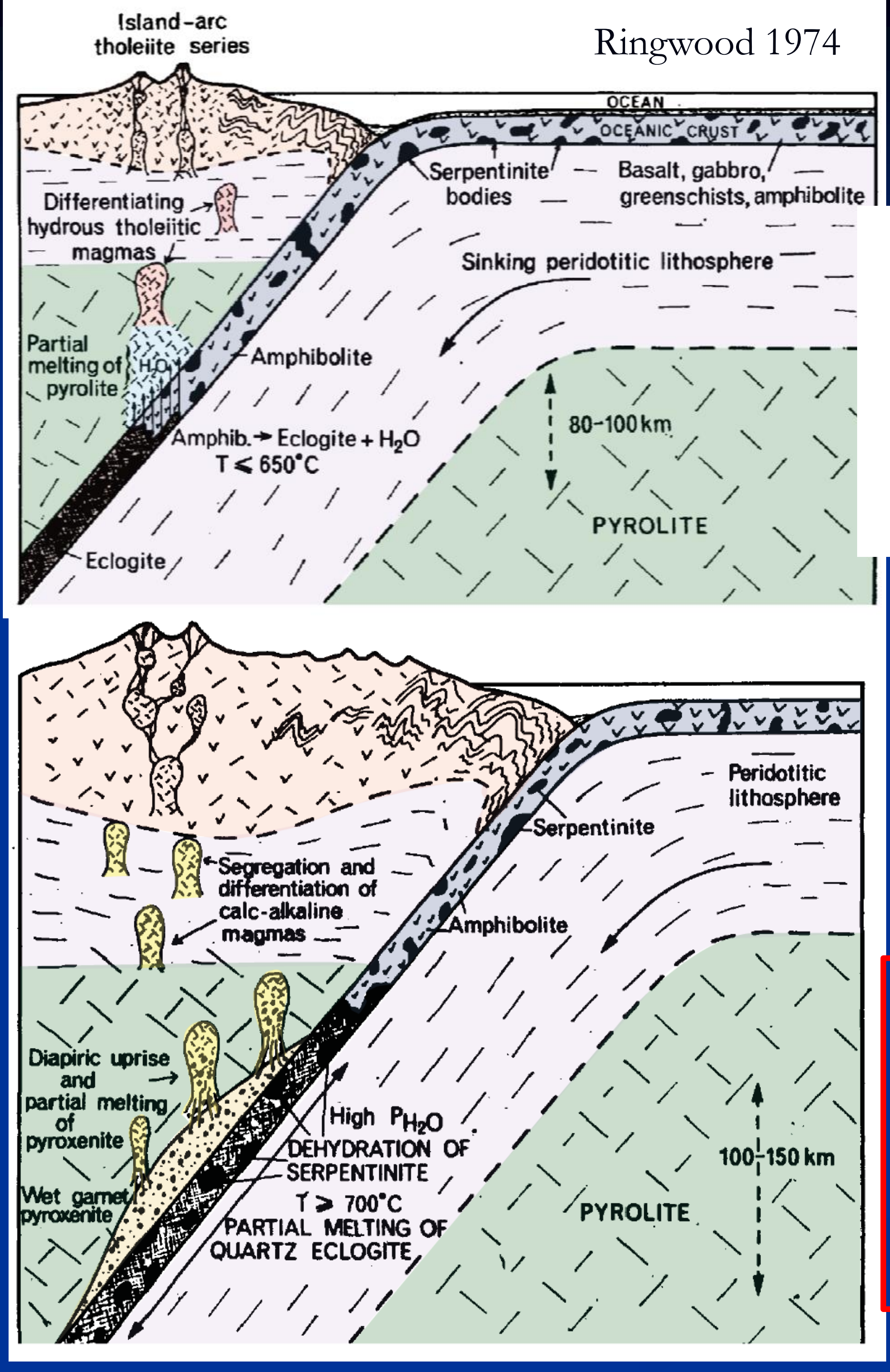


Numerical MODELS: Essential Incomplete

→ As too complex otherwise
→ Tackling problems 1 by 1



Melt extraction ?
Primitive compositions ?



Slab / Wedge processes

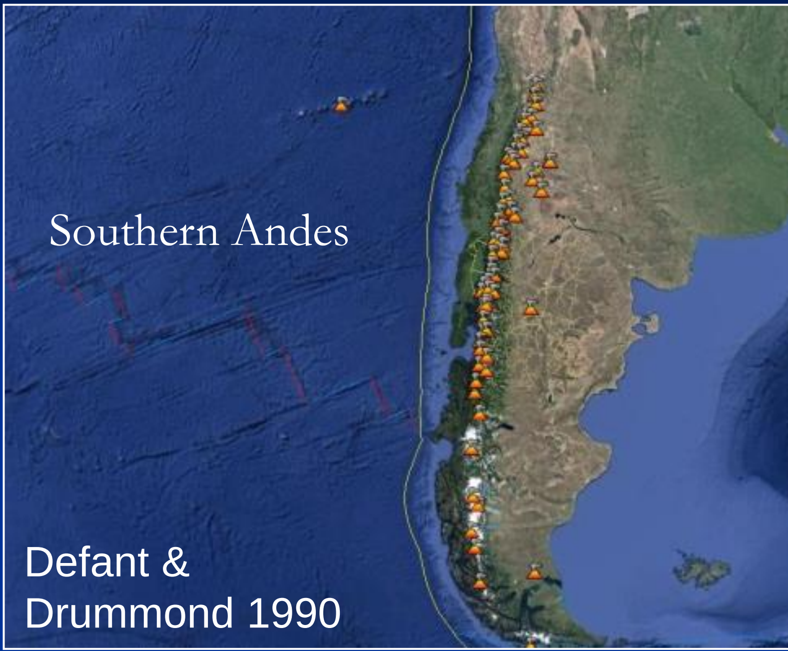
Numerical MODELS: Essential Complex & Complete ?

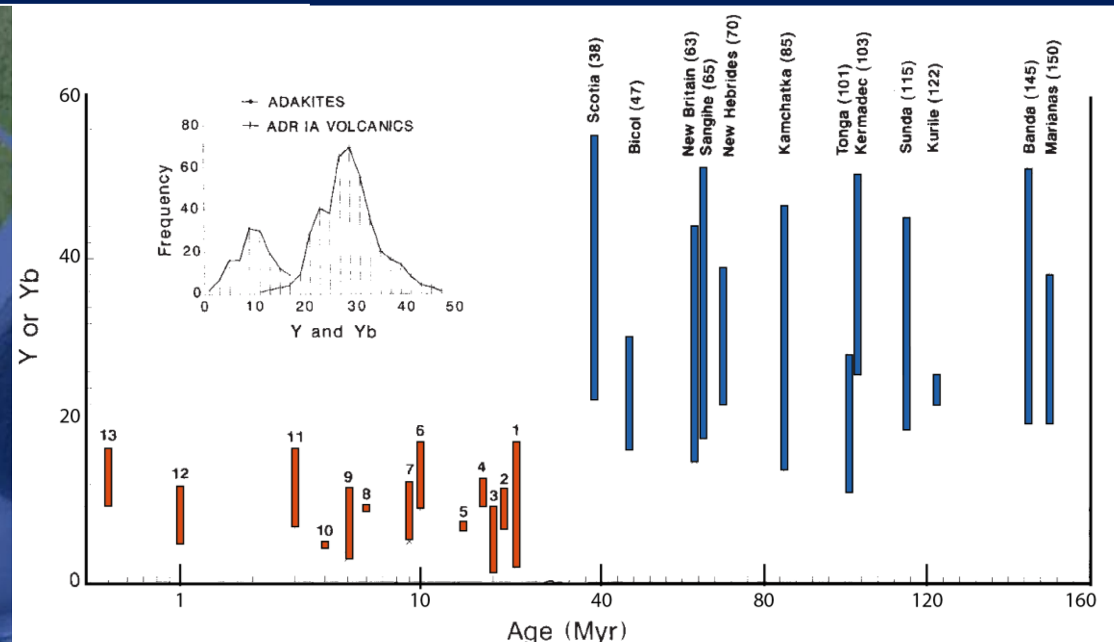
We have the tools: Thermomech. codes Thermodynamics

Numerical Community is building the bridge
→ Still need to represent reality

So for now stuck to a
1 to 1 problem to fit geological record.

Application to Hot Subduction





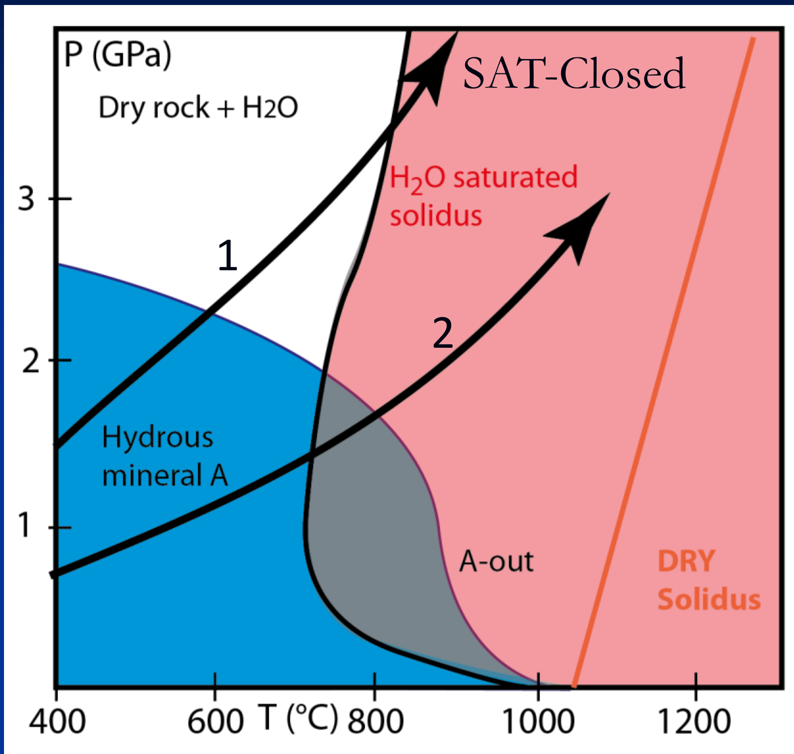
Hot subduction:

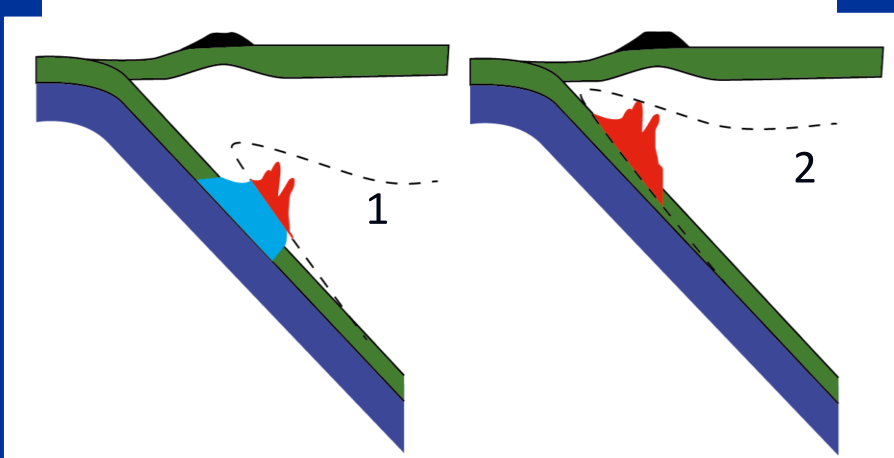
→ Atypical signature of arc melts (so called "Adakitic")

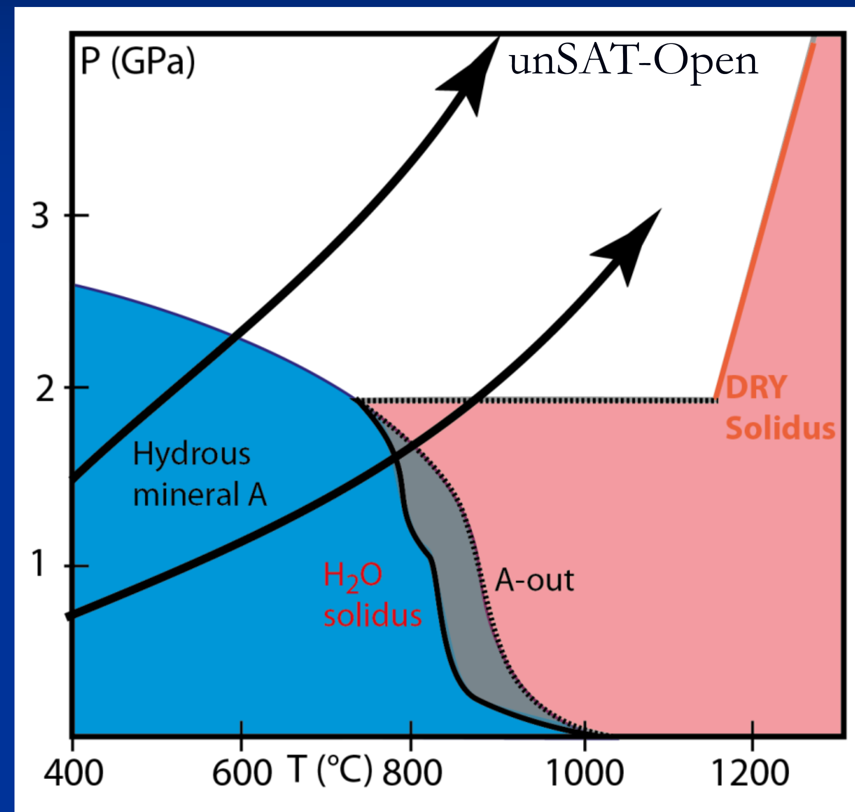
→ Attributed to Slab melting (mafic crust) as a popular interpretation but really means Grt involved…

Hot Subduction = slab melting ?

Dehydration melting ?
Saturated melting ?

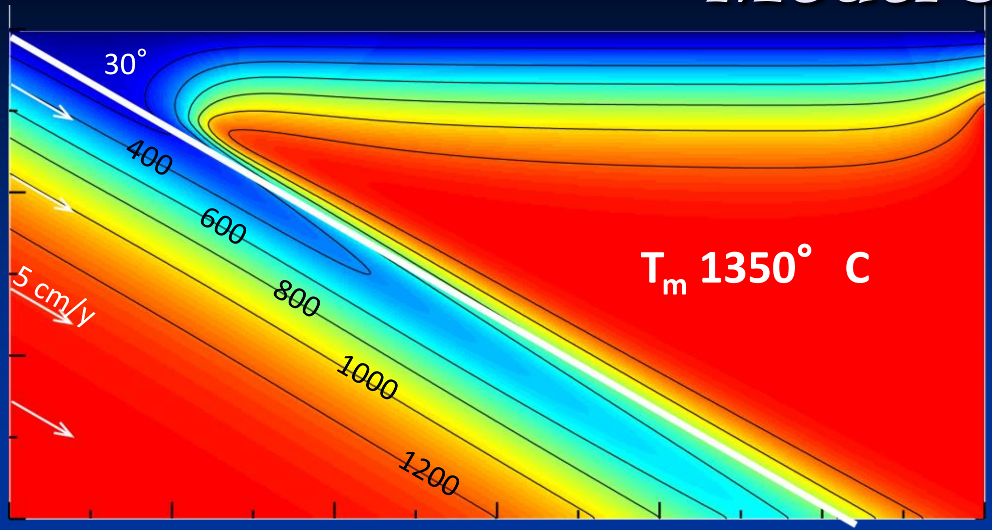






Need to be able to track dehydration vs melting In a consistent way

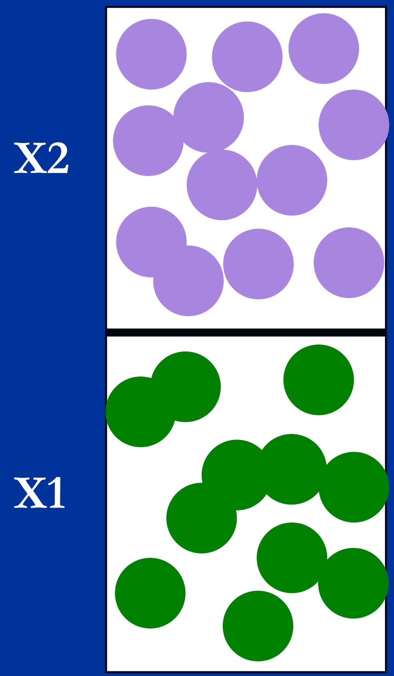
Model Set-up



Thermal convection finite element model (Citcom)

integrated with

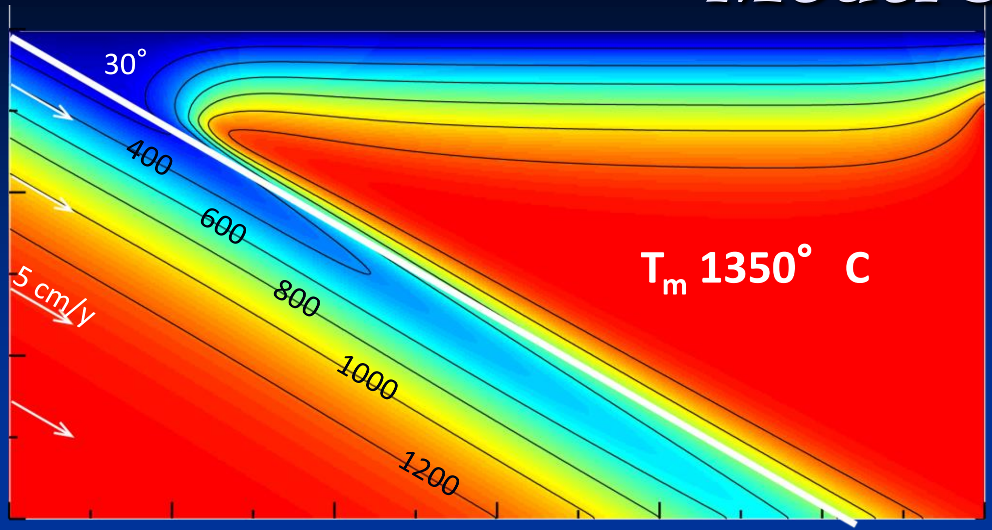
Thermodynamic database (Perple_X package)



Passive tracers that move with the velocity field.
At each timestep:
Assemblage is recalculated f(P-T-X)
X being single or multi-component !

Bouilhol, Magni et al. *EPSL 2015*
Magni, Bouilhol et al. *G3 2014*

Model Set-up



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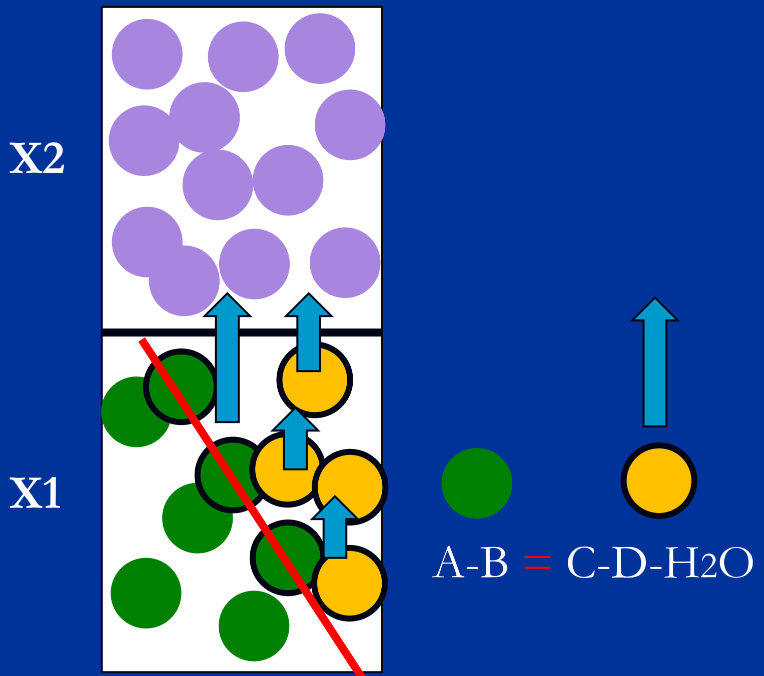
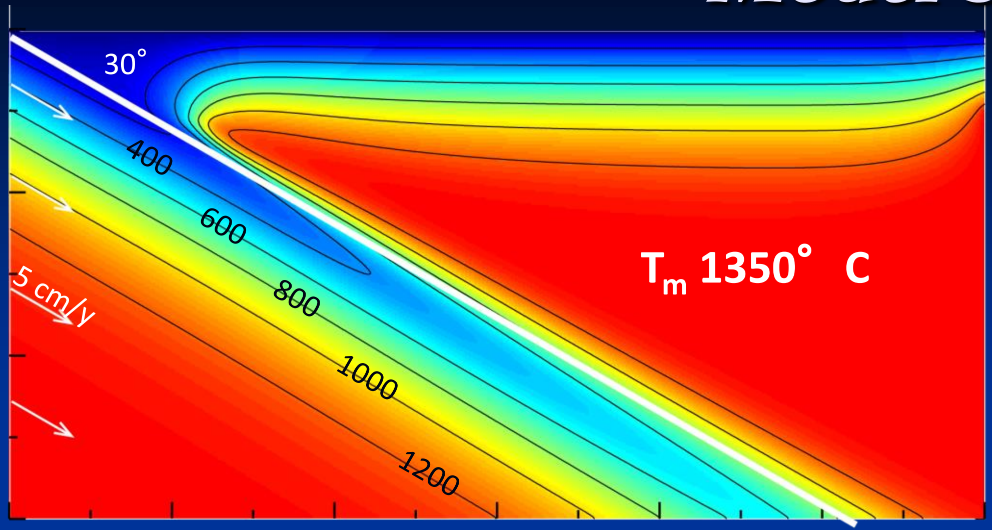


Passive tracers that move with the velocity field.
At each timestep:
Assemblage is recalculated f(P-T-X)
X for now is H2O

Model Set-up



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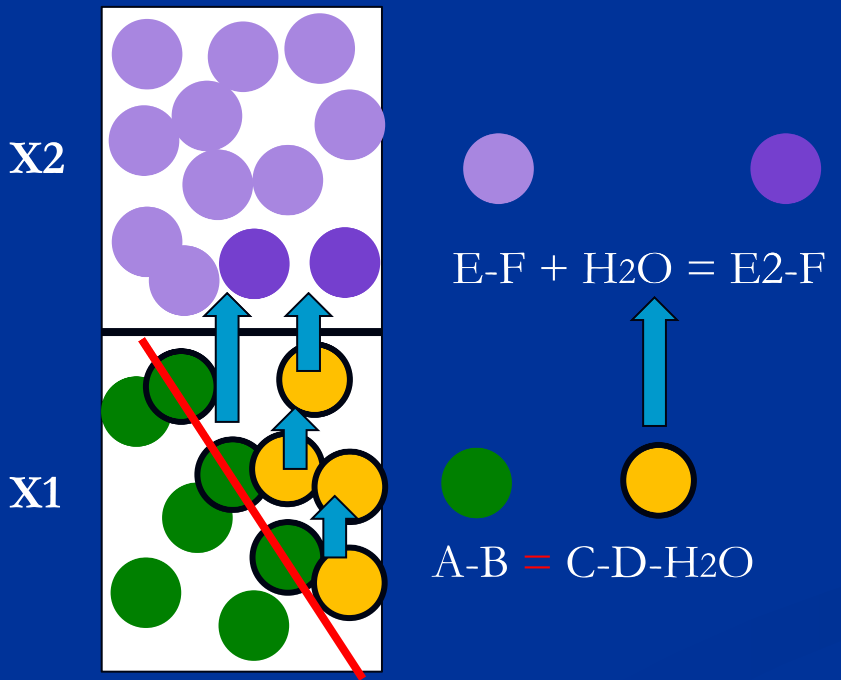

Passive tracers that move with the velocity field.
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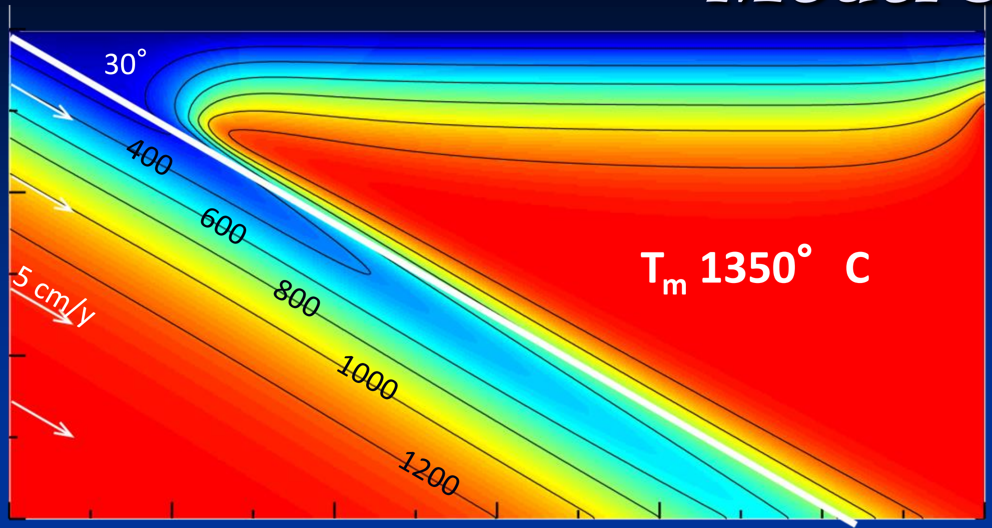
Model Set-up



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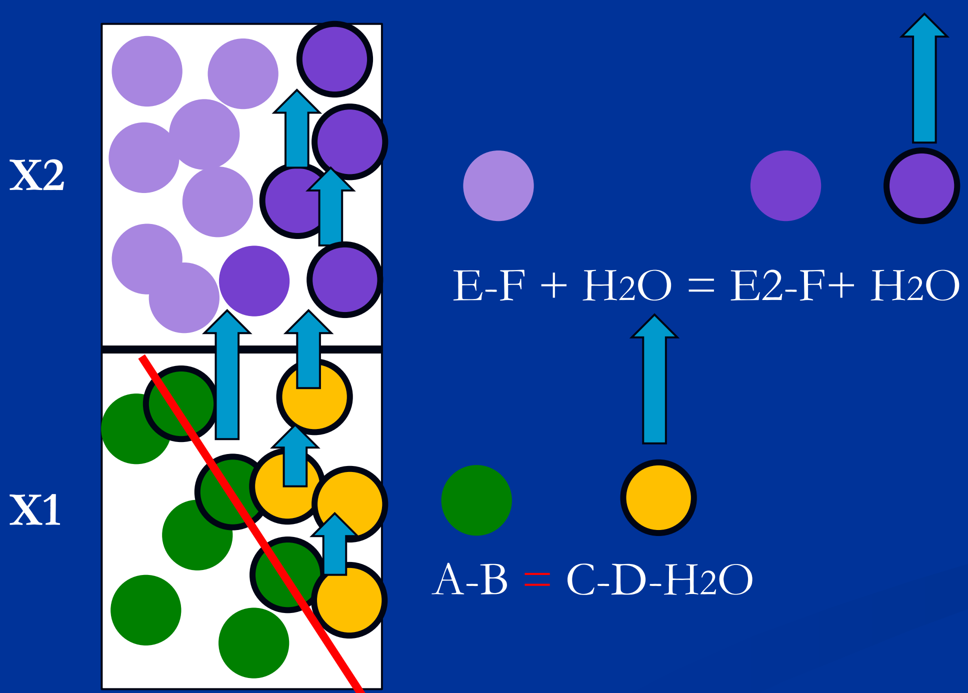
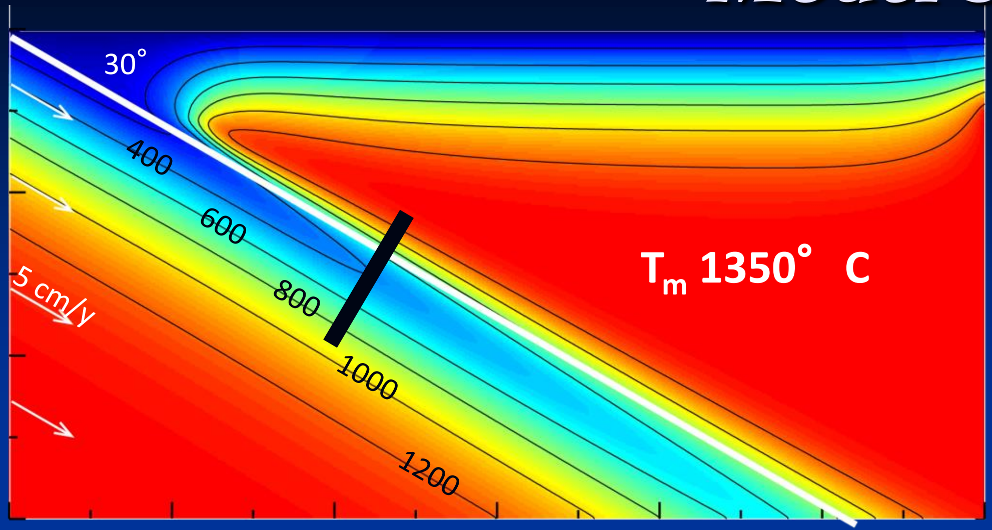


Passive tracers that move with the velocity field.
At each timestep:
Assemblage is recalculated f(P-T-X)
X for now is H_2O

Allows to model Dehydration & Re-hydration reactions
→ Melting conditions
Reactions / Compositions

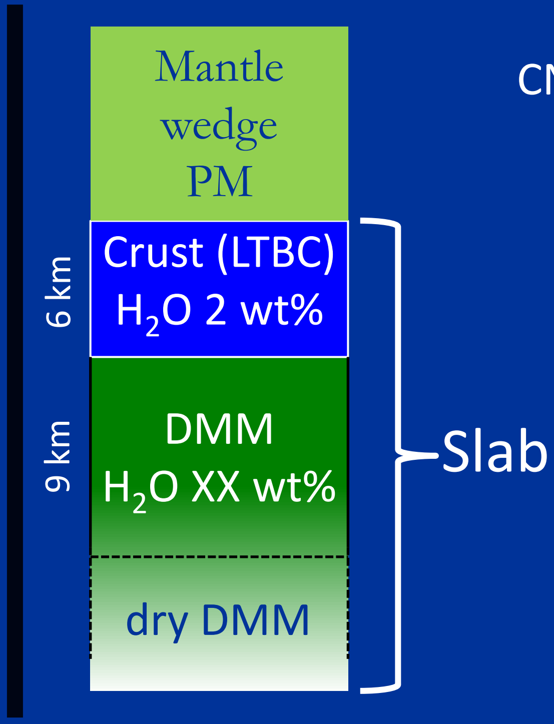
Model Set-up



Thermal convection finite element model (Citcom)

integrated with

Thermodynamic database (Perple_X package)

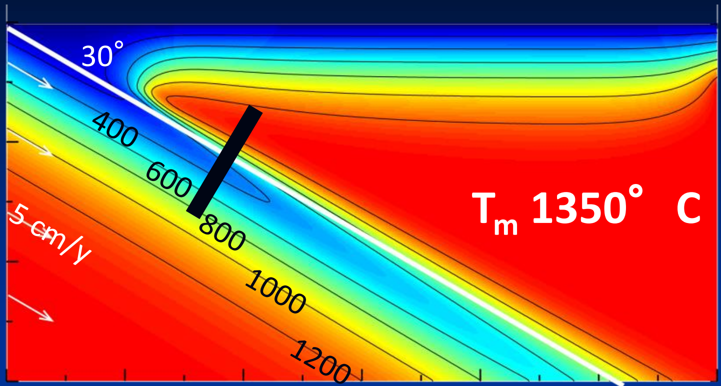


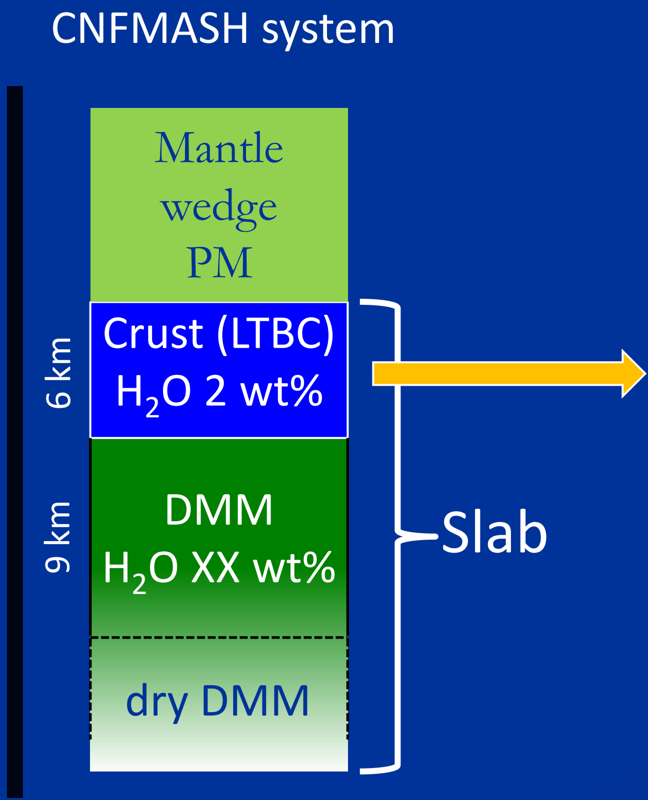
CNFMASH system

Passive tracers that move with the velocity field.
At each timestep:
Assemblage is recalculated f(P-T-X).

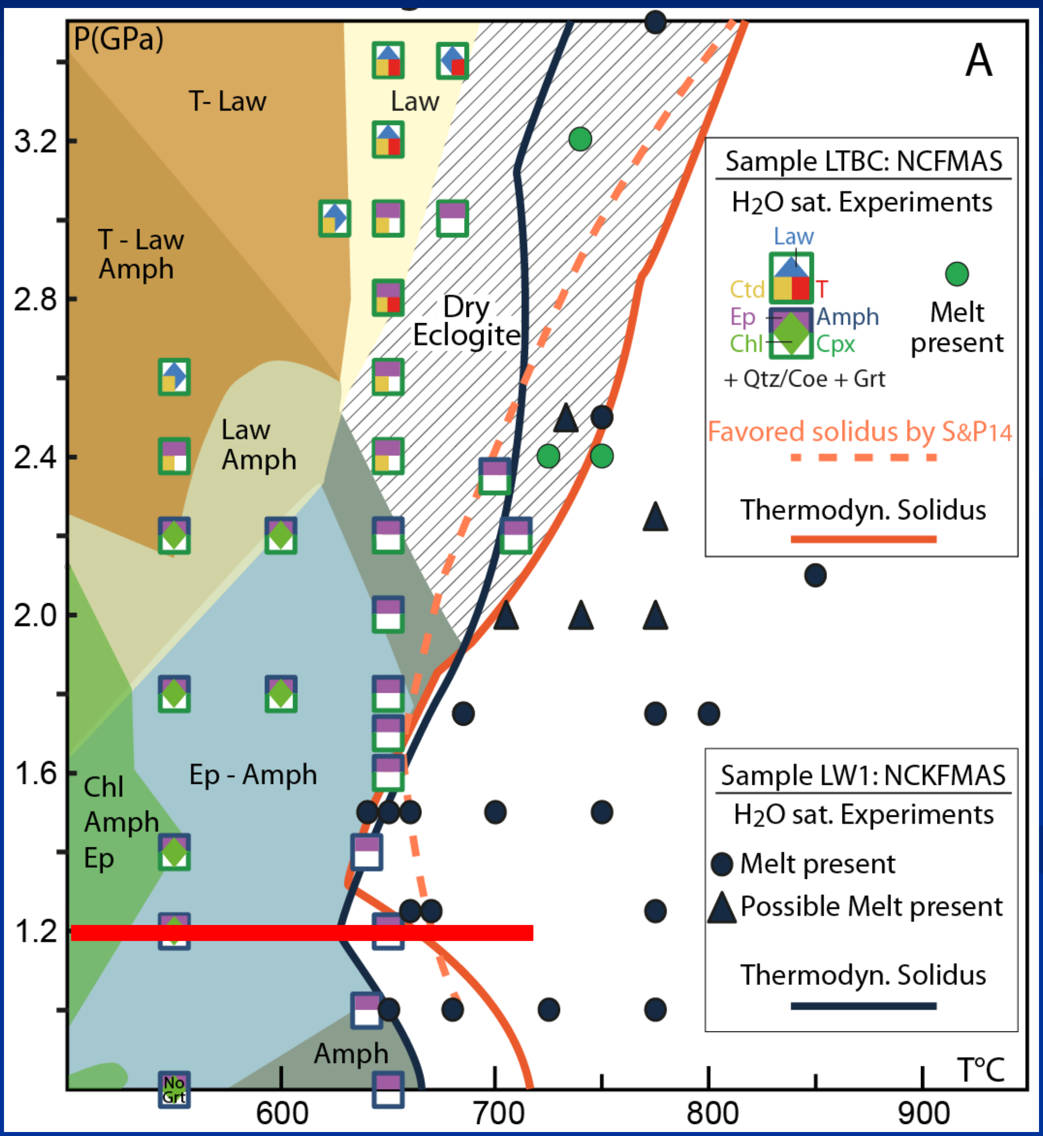
Allows to model Dehydration & Re-hydration reactions → Melting conditions Reactions / Compositions

A dynamic solidus

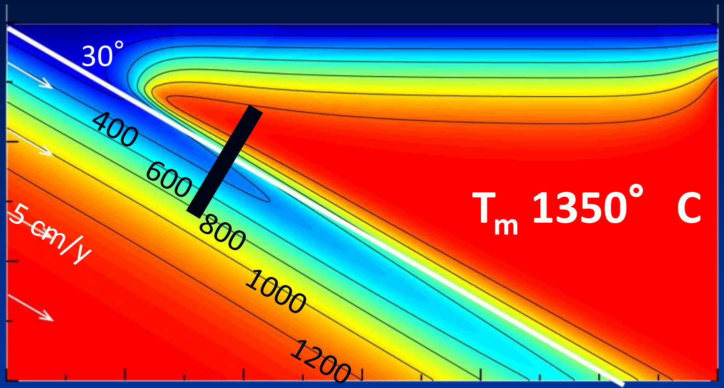




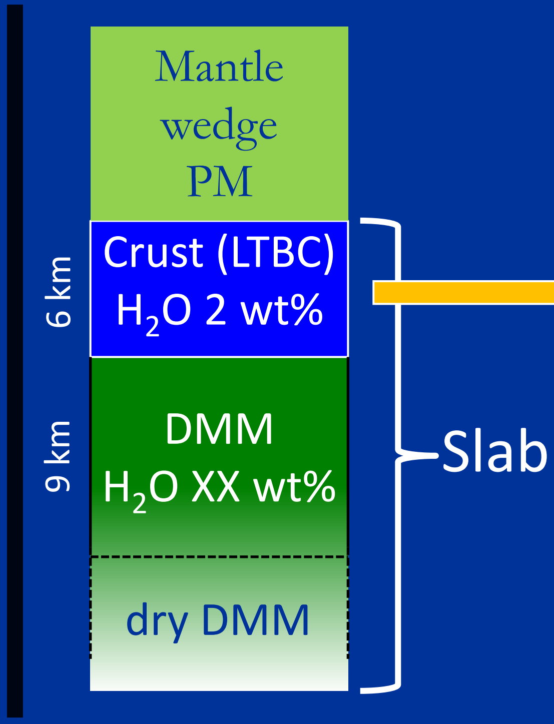
CRUST: Water *vs* melting



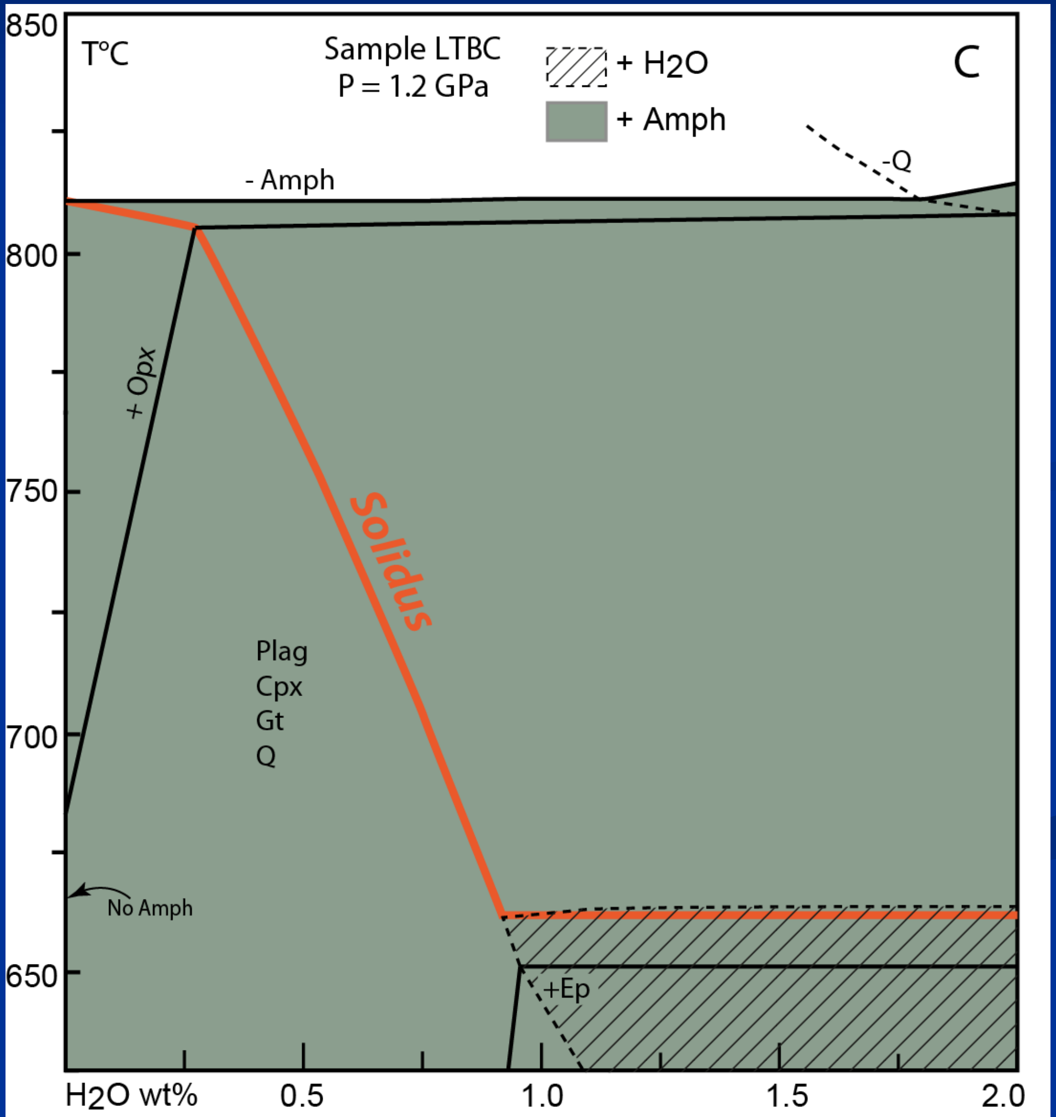
A dynamic solidus



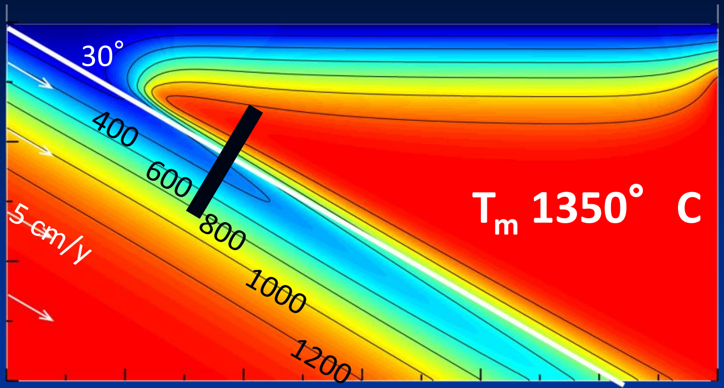
CNFMASH system



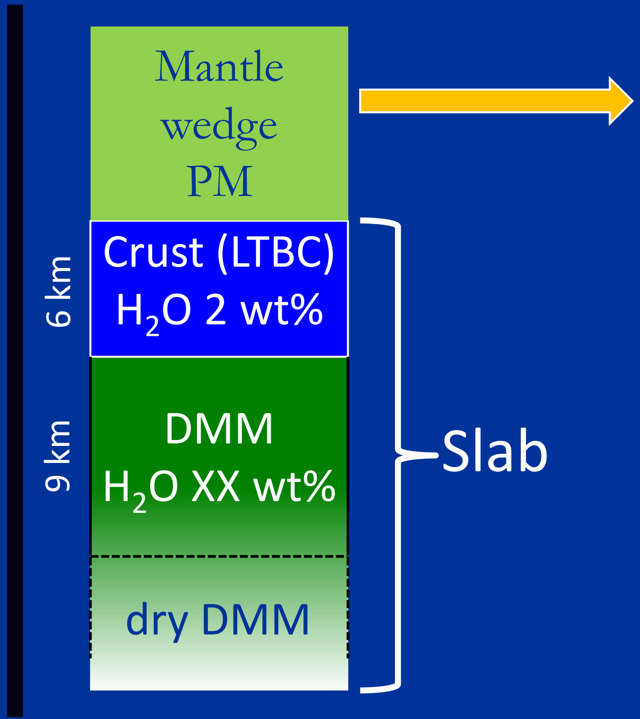
CRUST: Water *vs* melting



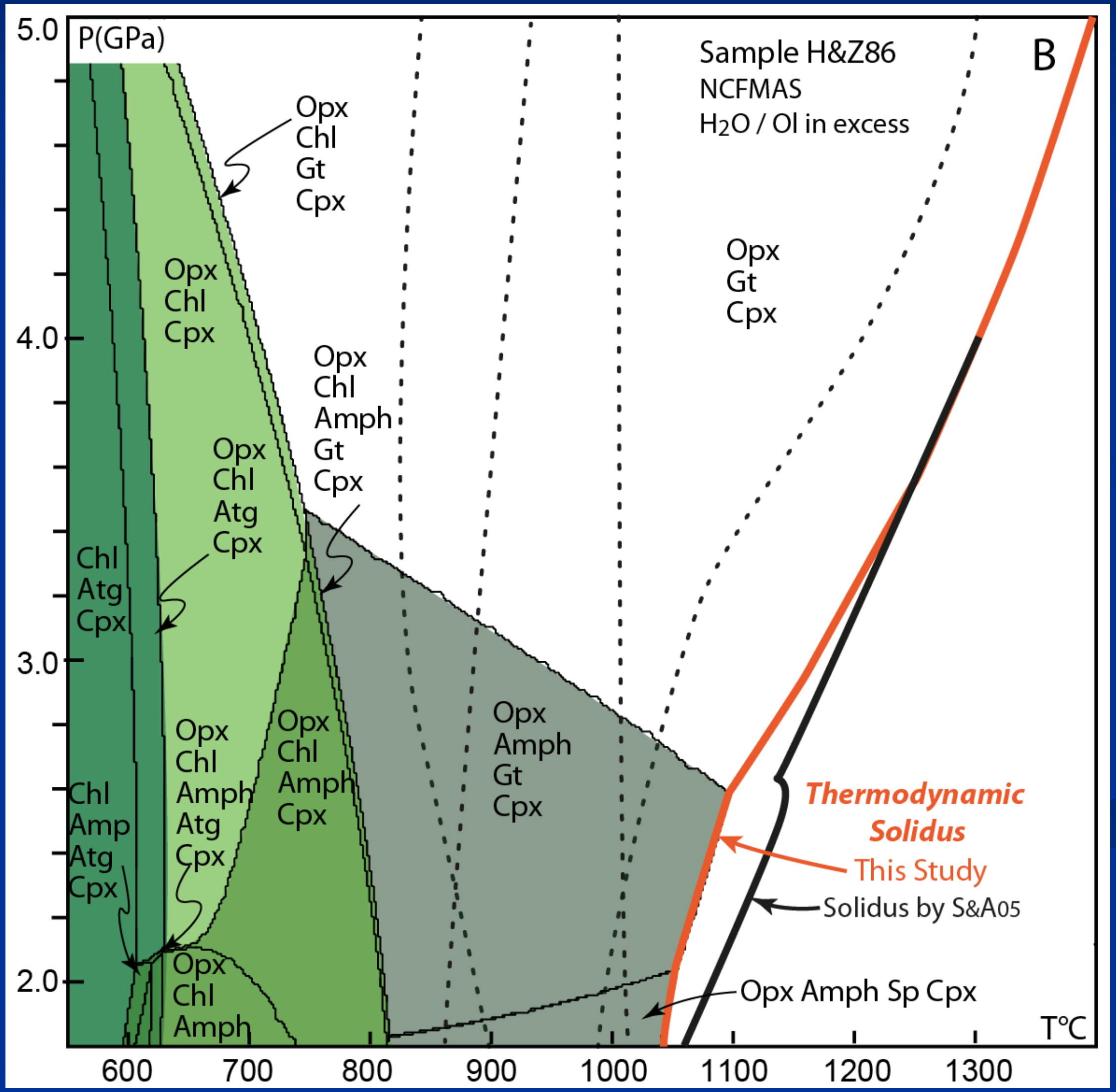
A dynamic solidus



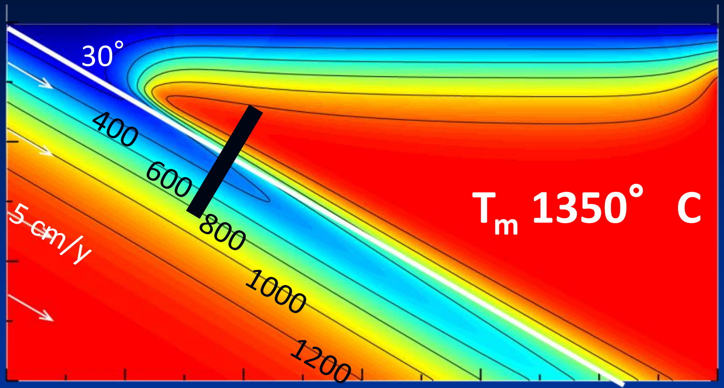
CNFMASH system



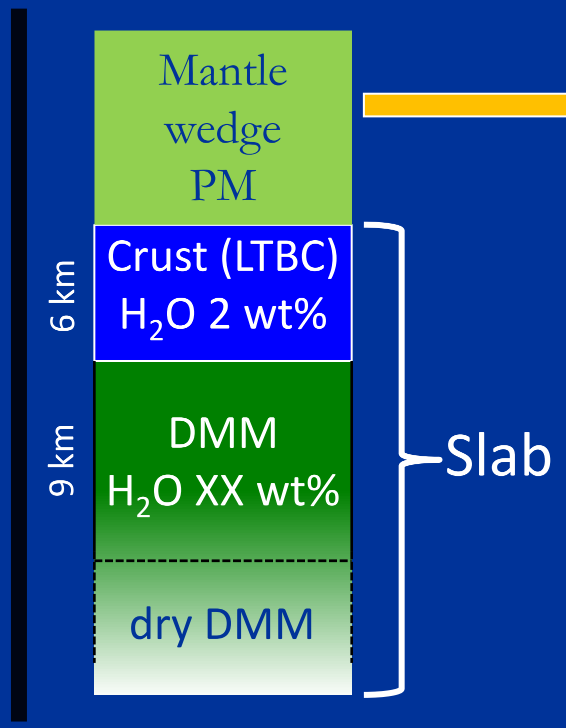
MANTLE: Water *vs* melting



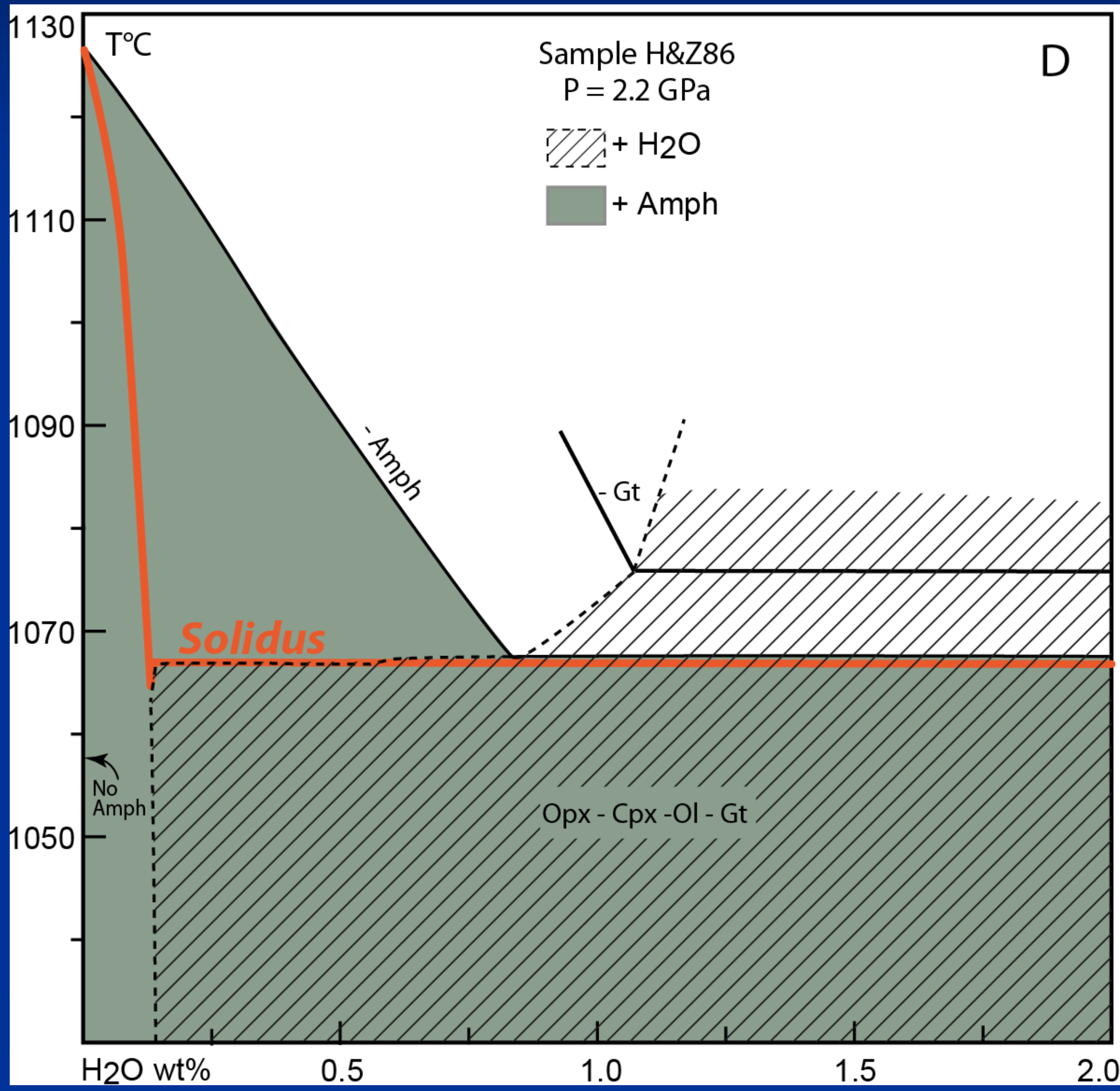
A dynamic solidus



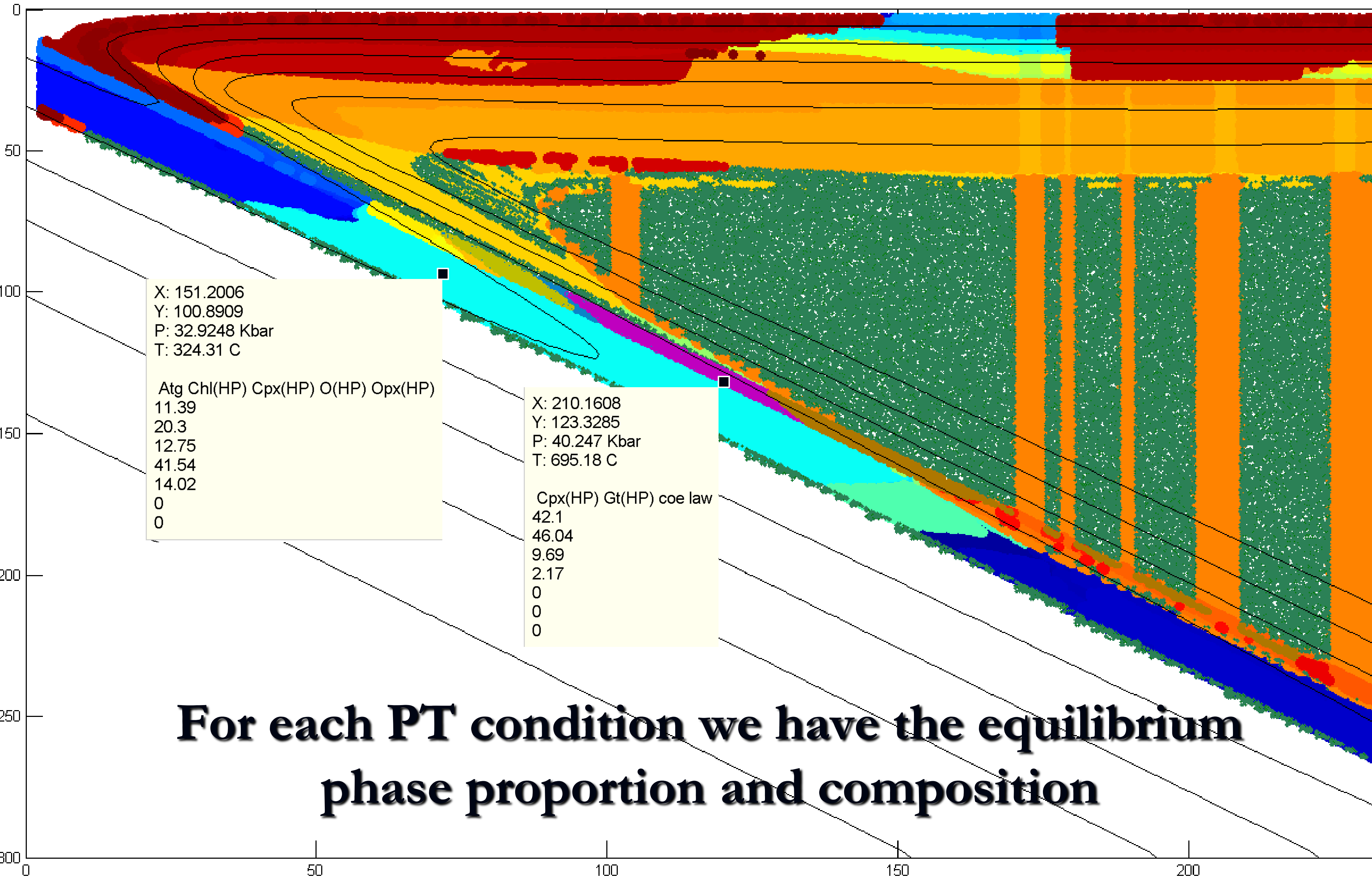
CNFMASH system



MANTLE: Water *vs* melting

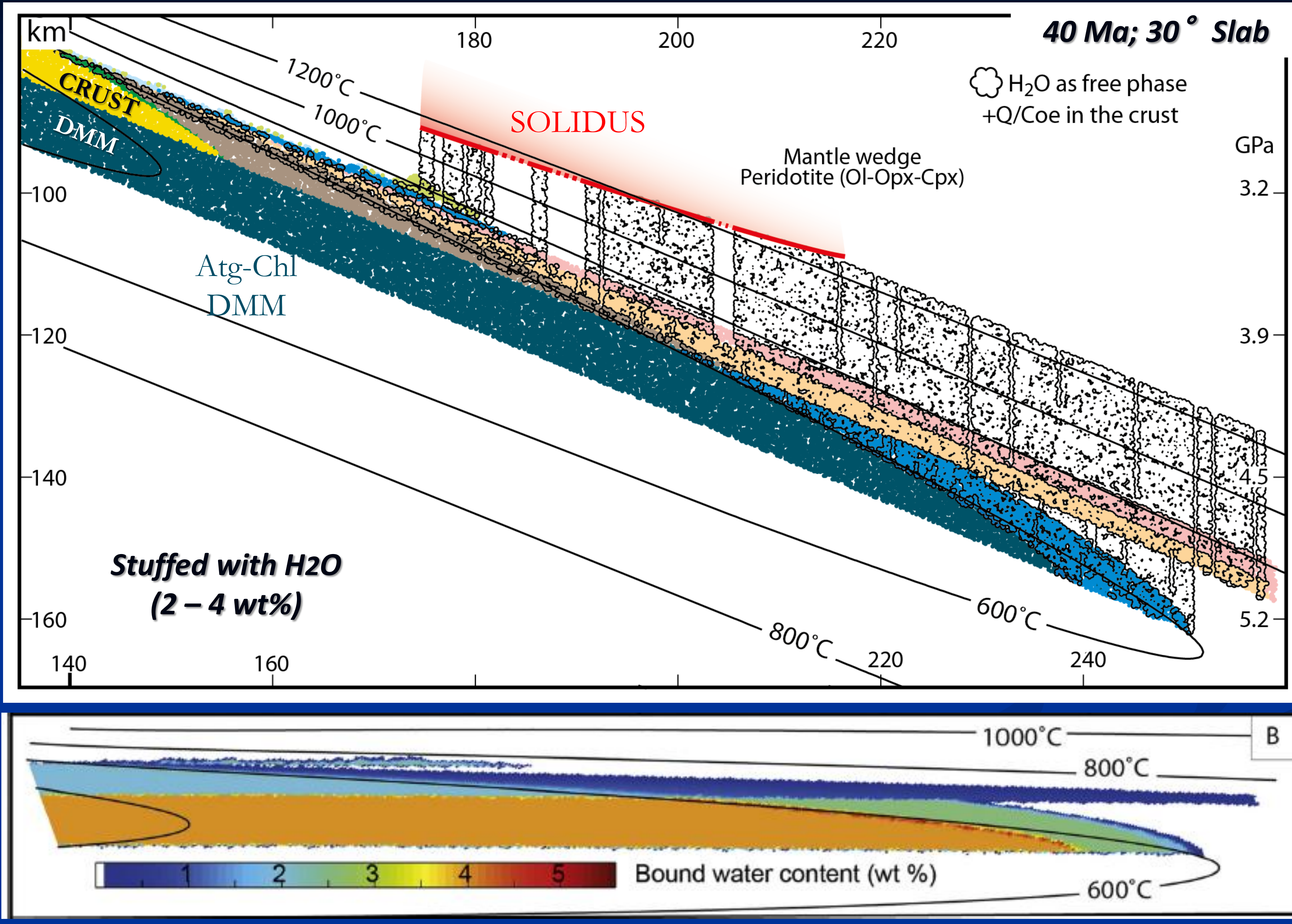


A petrological subduction zone model



For each PT condition we have the equilibrium phase proportion and composition

Bouilhol et al. EPSL 2015

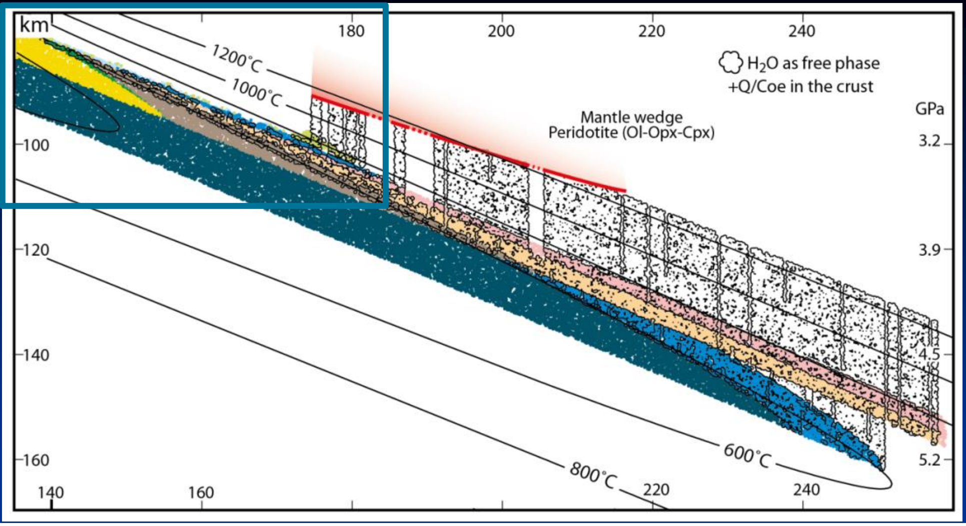


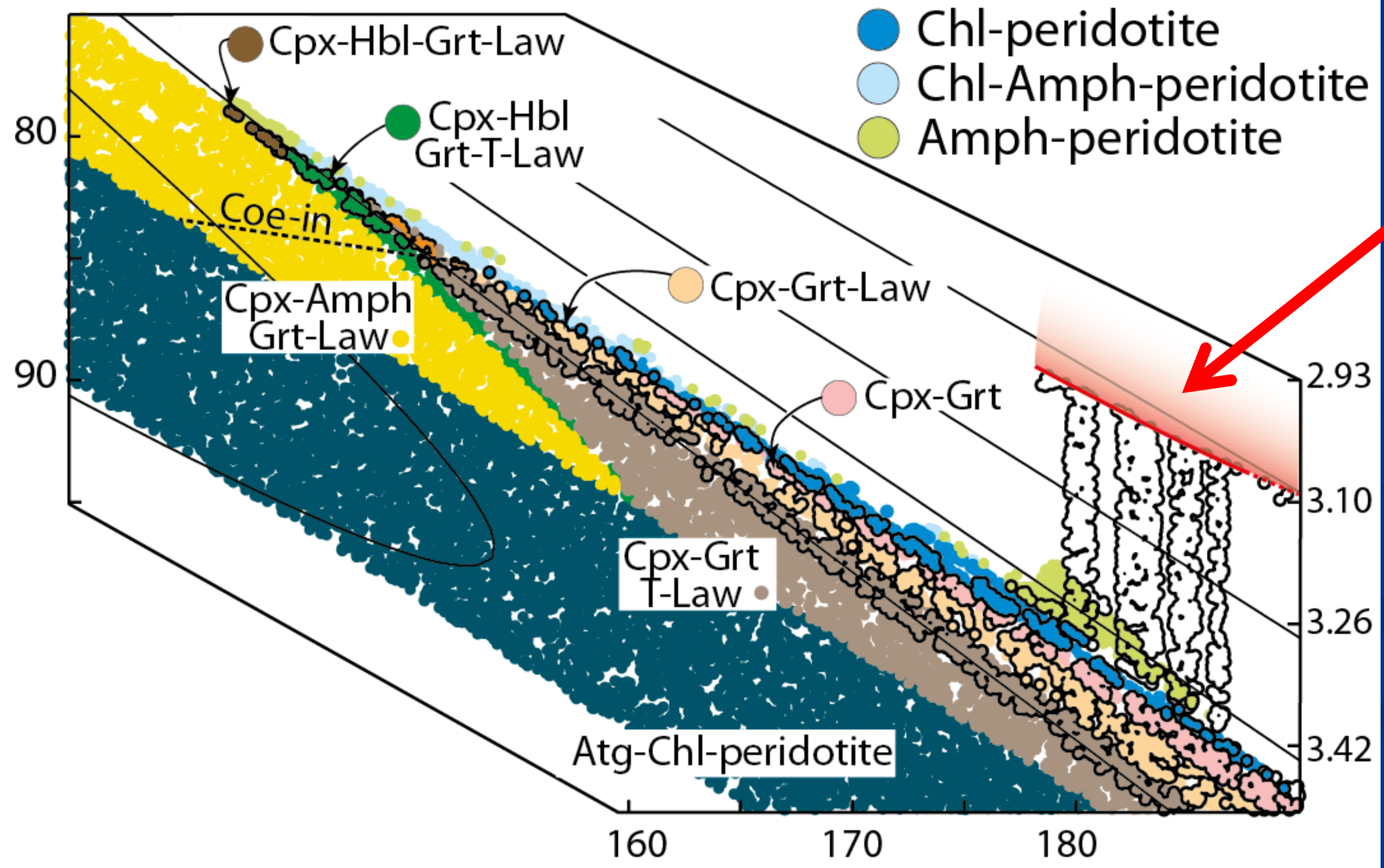
Shallow Depth:

Crust dehydration

Mantle wedge hydration

Mantle wedge dehydration & Melting



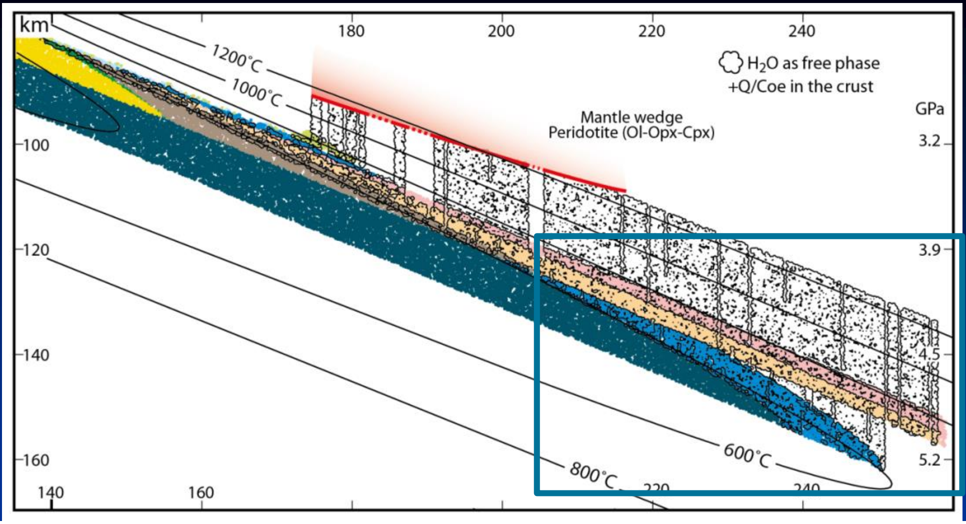


Peridotite + H2O

Amph-out

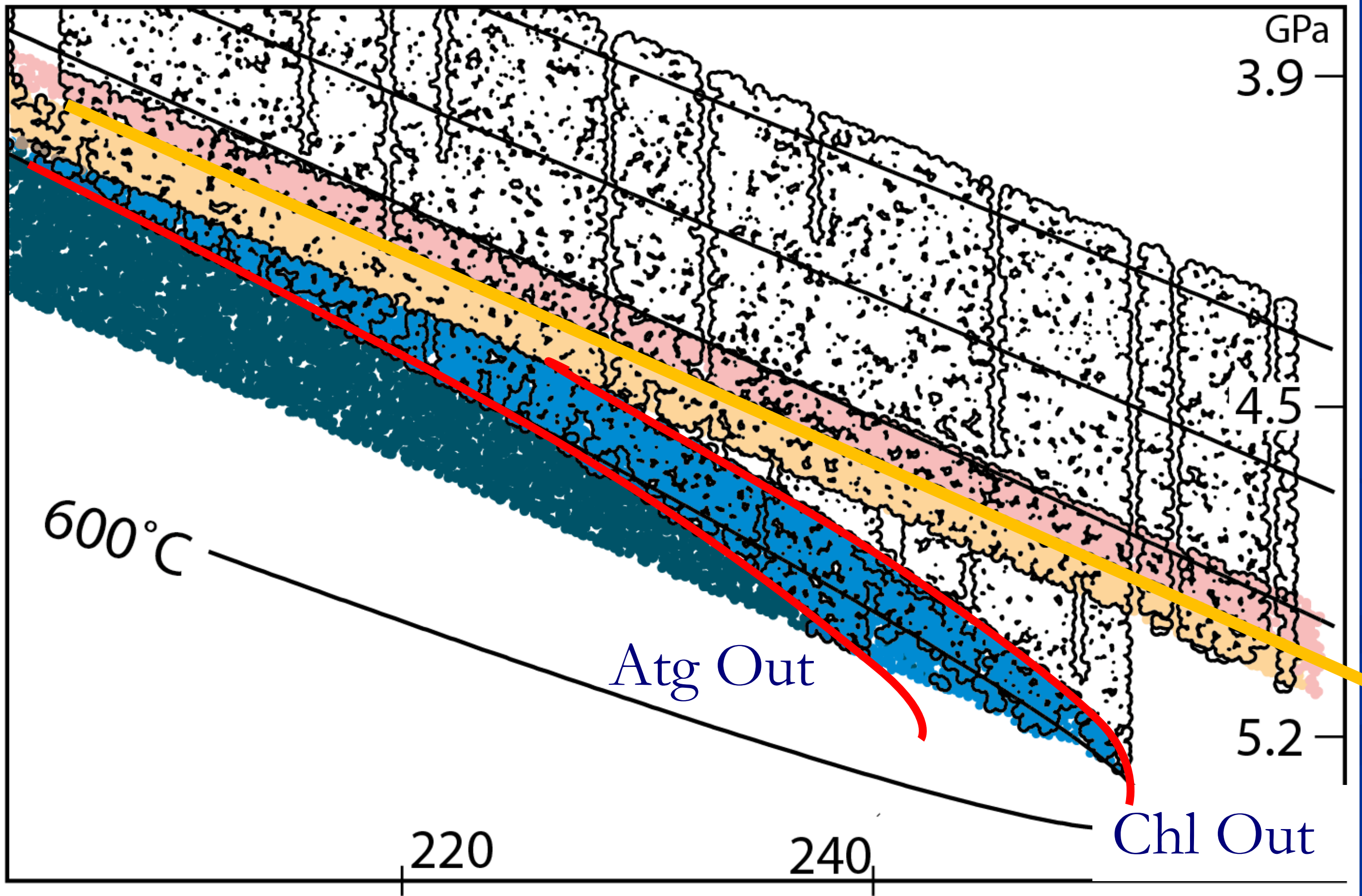
Talc-out

At Depth:



Crust dehydration

Slab mantle dehydration



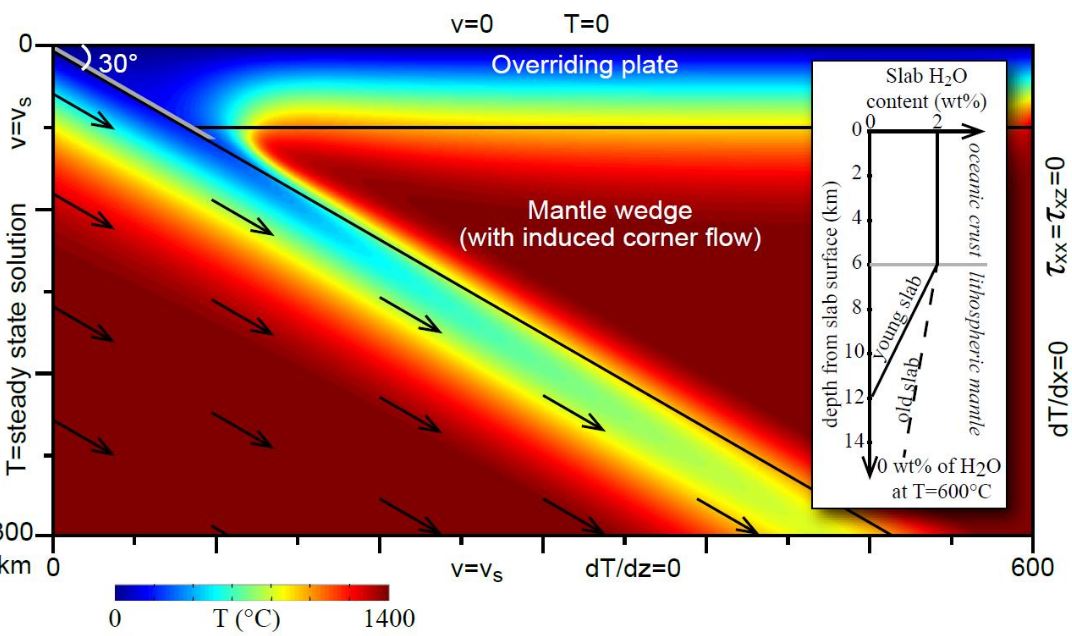
Supercrit. Liq.
Fate (?)

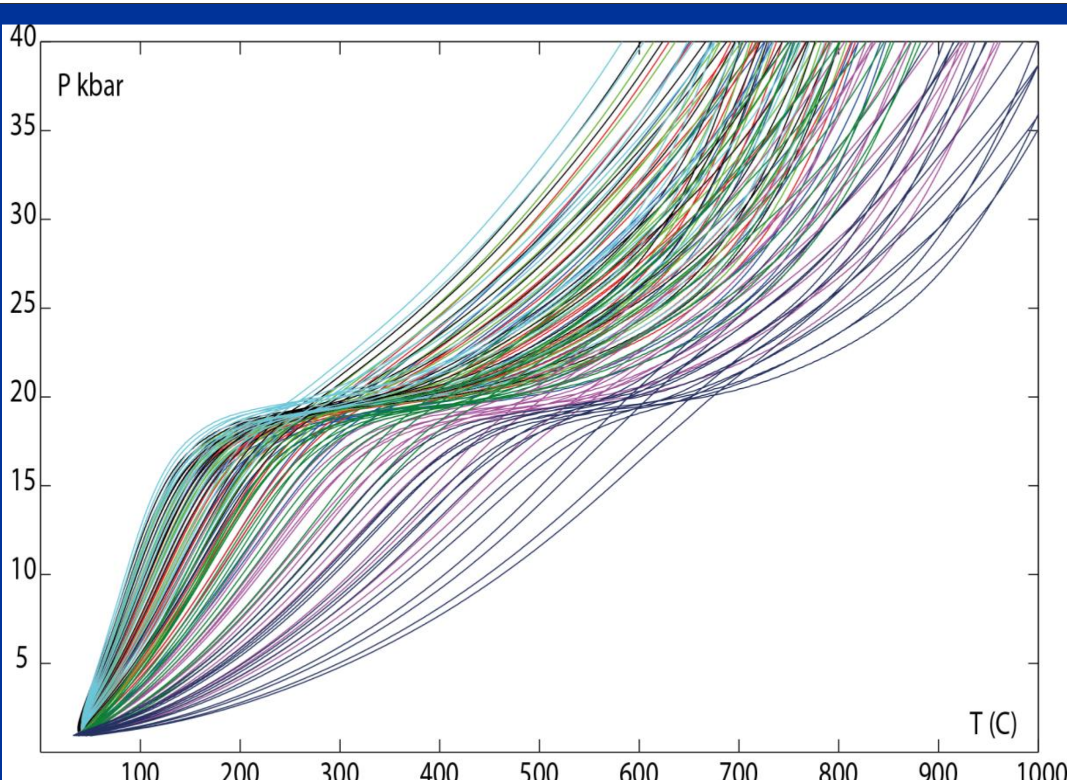
Dry Eclogite
(Cpx+Grt)
+ H2O

Law-out

Ph-A → DHMS

Parametric study: What controls dehydration patterns ?





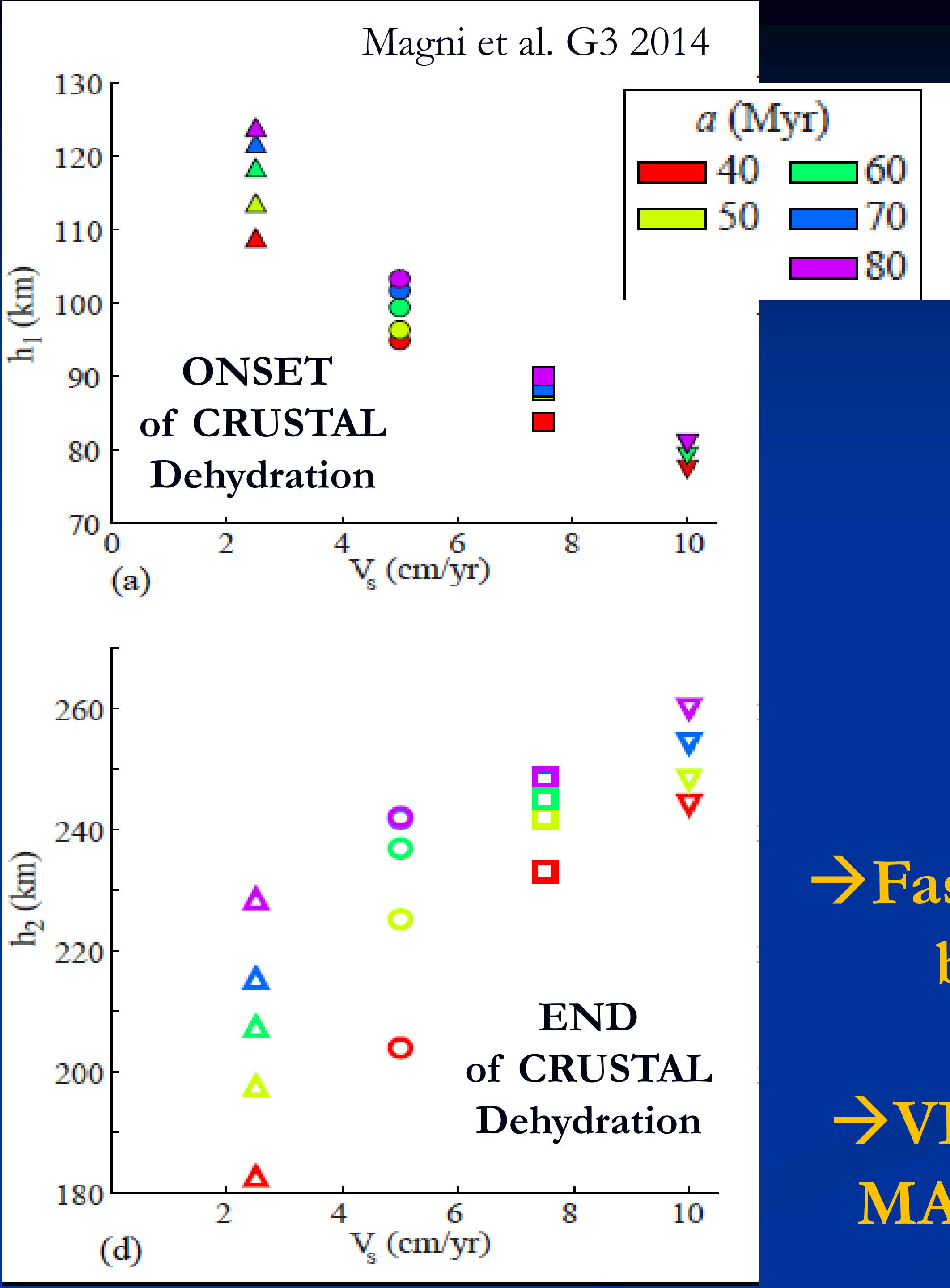
Overriding plate : Oceanic

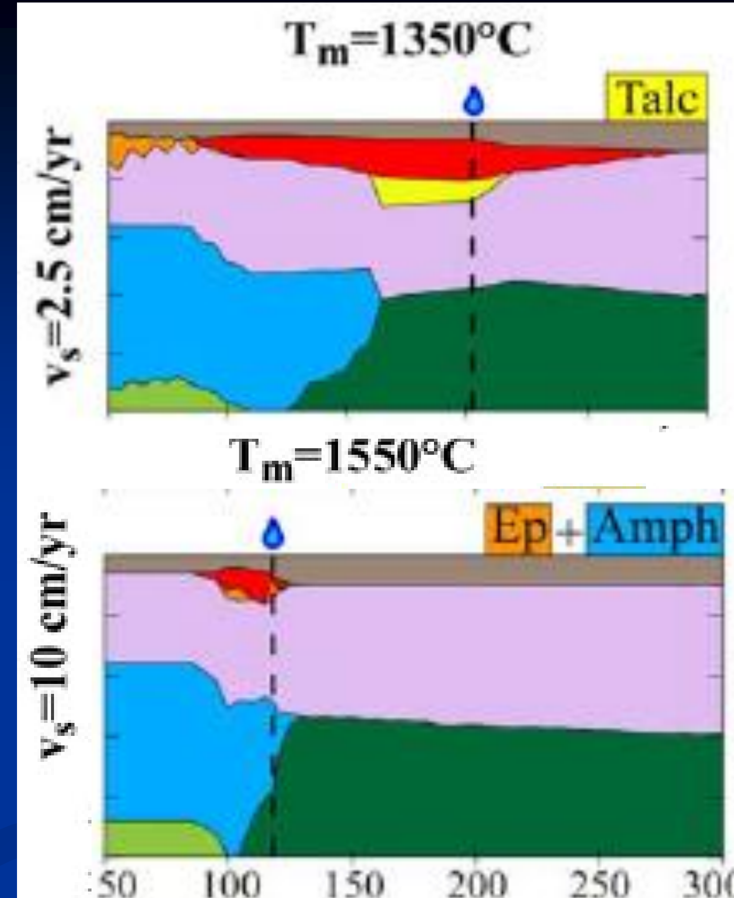
Age : 80-5Ma

Velocity: 10 – 2.5 cm/yr

Mantle temperature: 1550 - 1350

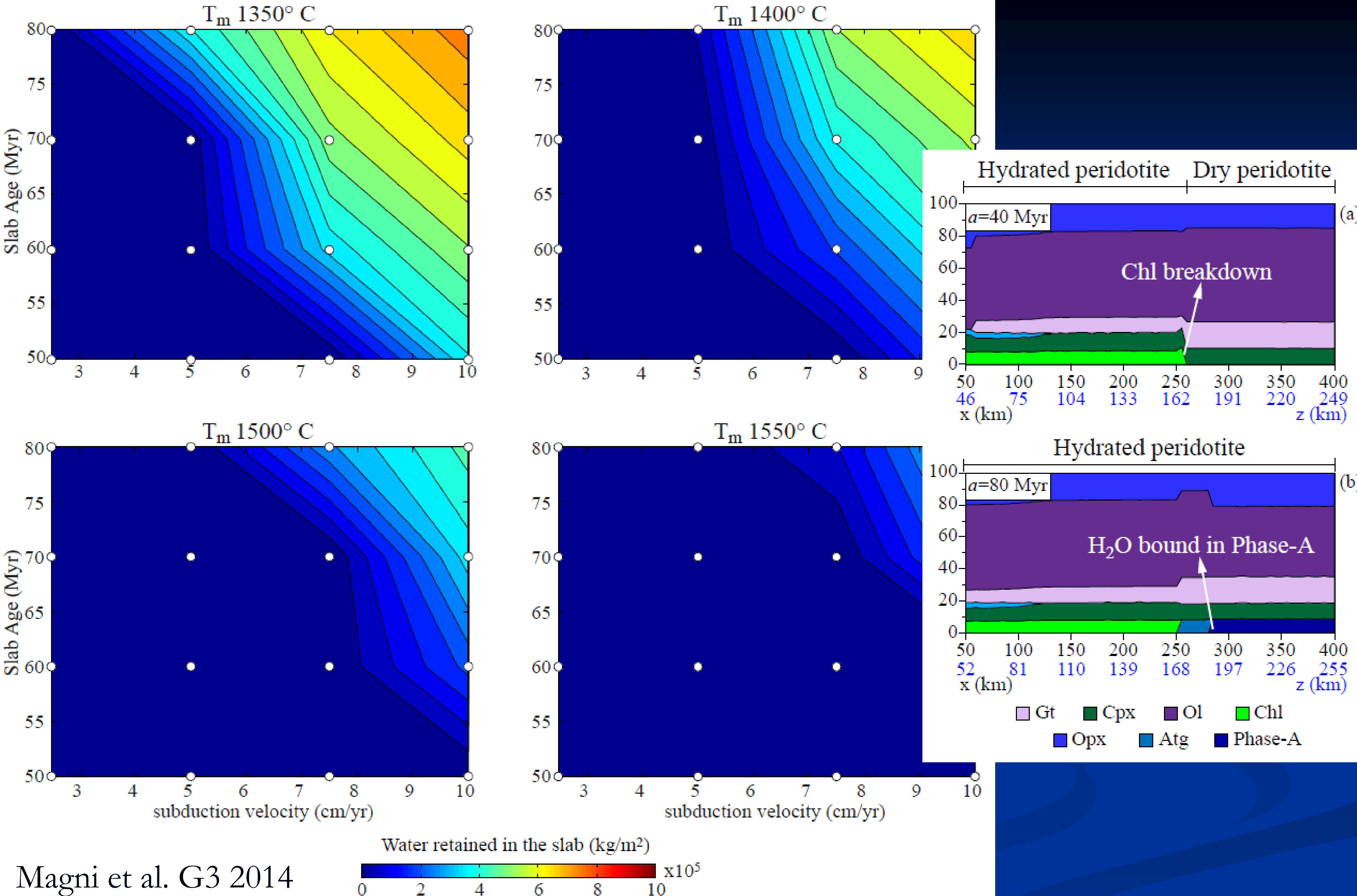
DMM H2O% f(age)





→Fast = shallow dehydration but also deeper release

→VELOCITY IS KEY FOR MANTLE melting potential



Magni et al. G3 2014

H2O recycling

$$W = 1.06 v_s + 0.14 a - 0.023 T_m + 17$$

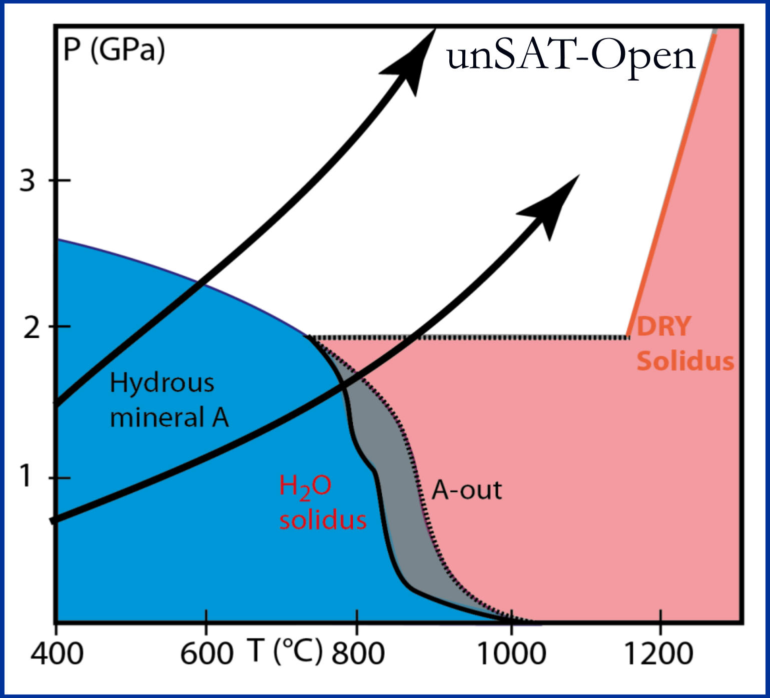
Some conclusions from these models:

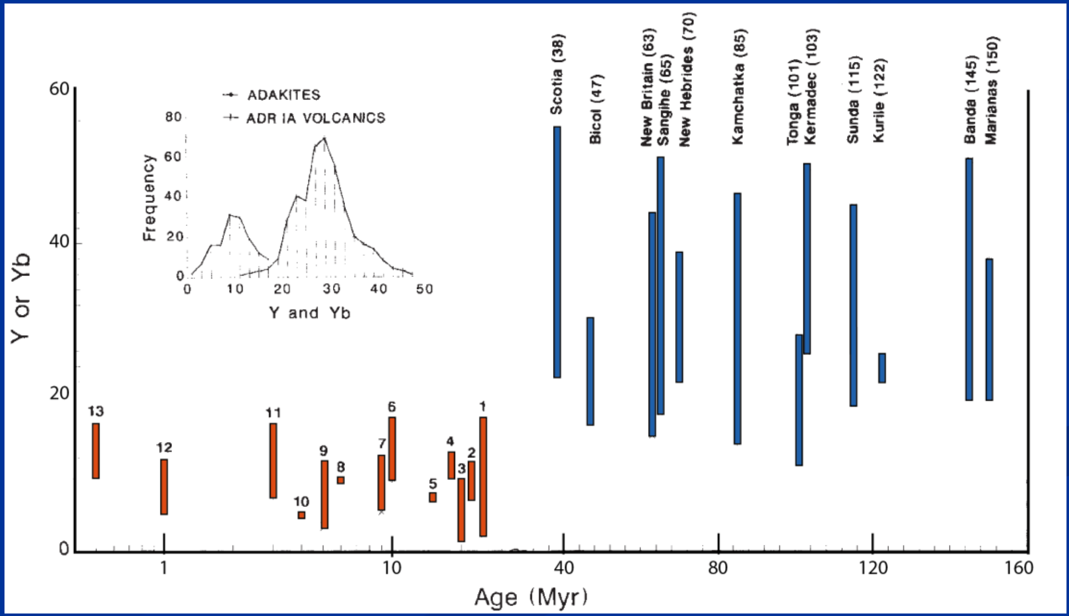
- Plate velocity controls slab top temperature

→ Controls devolatilization and the location of melting

→ Important parameter for recycling.

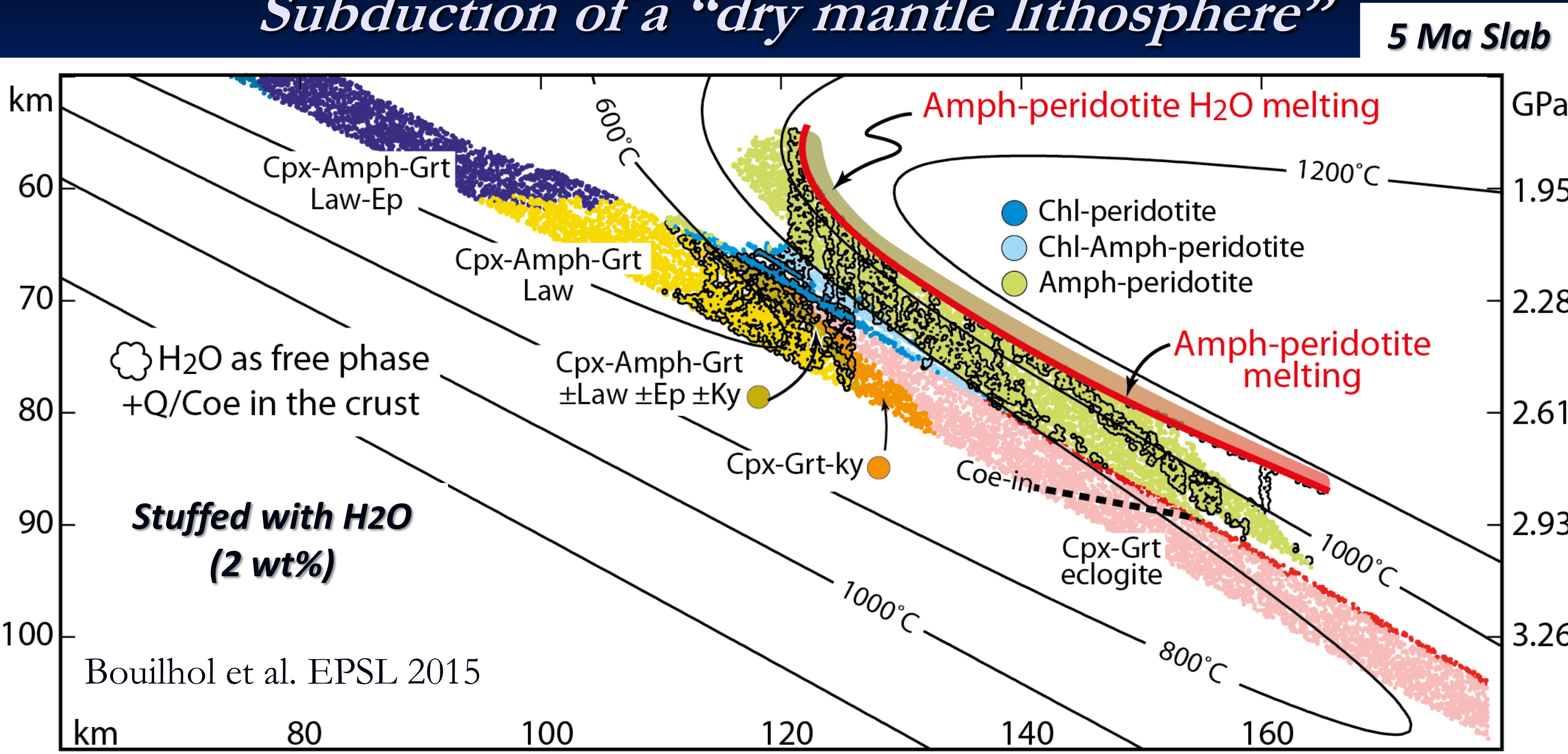
$$W = 1.06 v_s + 0.14 a - 0.023 T_m + 17$$





Dehydration melting ?

Subduction of a "dry mantle lithosphere"

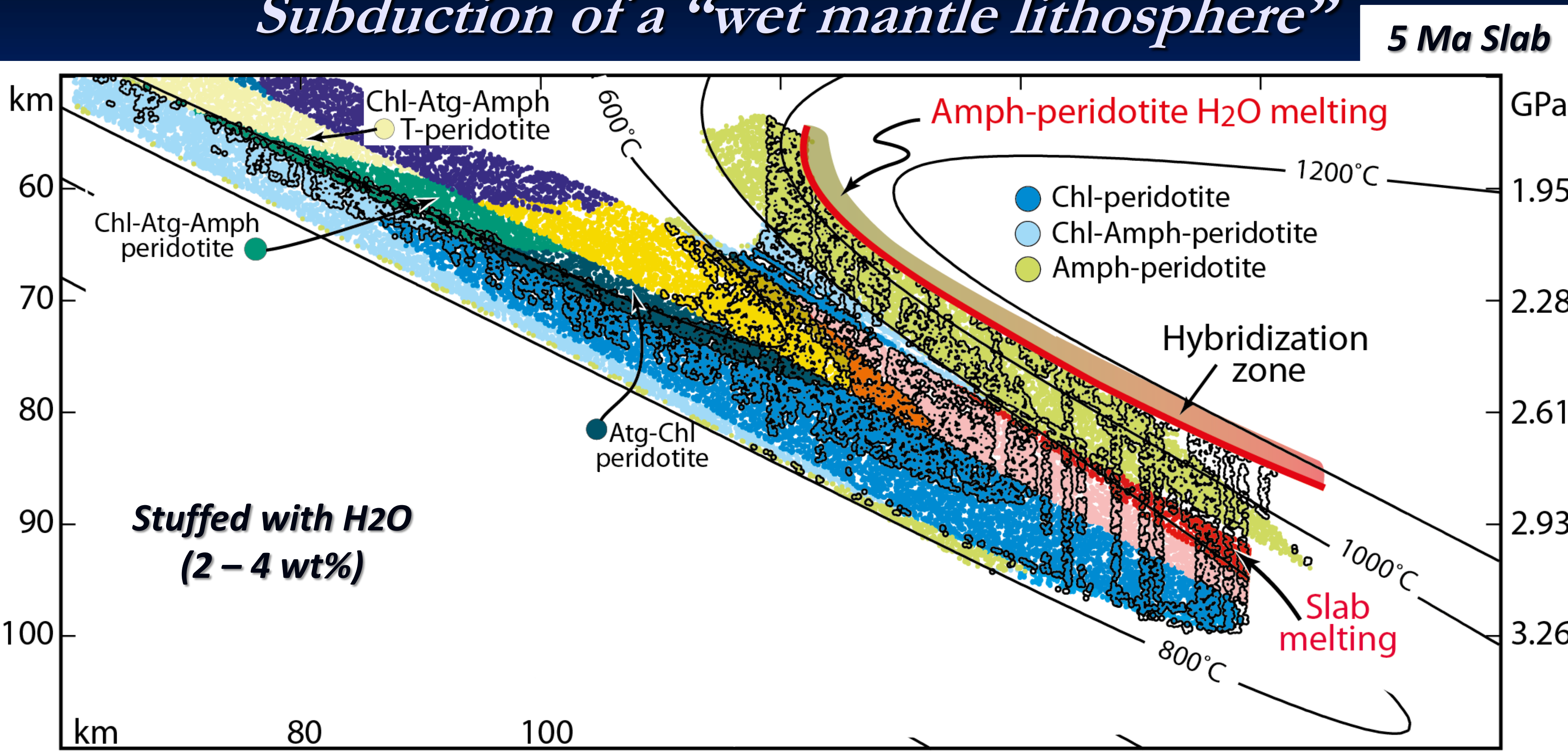


Dehydration achieved before the solidus is reached

Important mantle wedge melting at shallow depth

Water assisted melting

Subduction of a "wet mantle lithosphere"

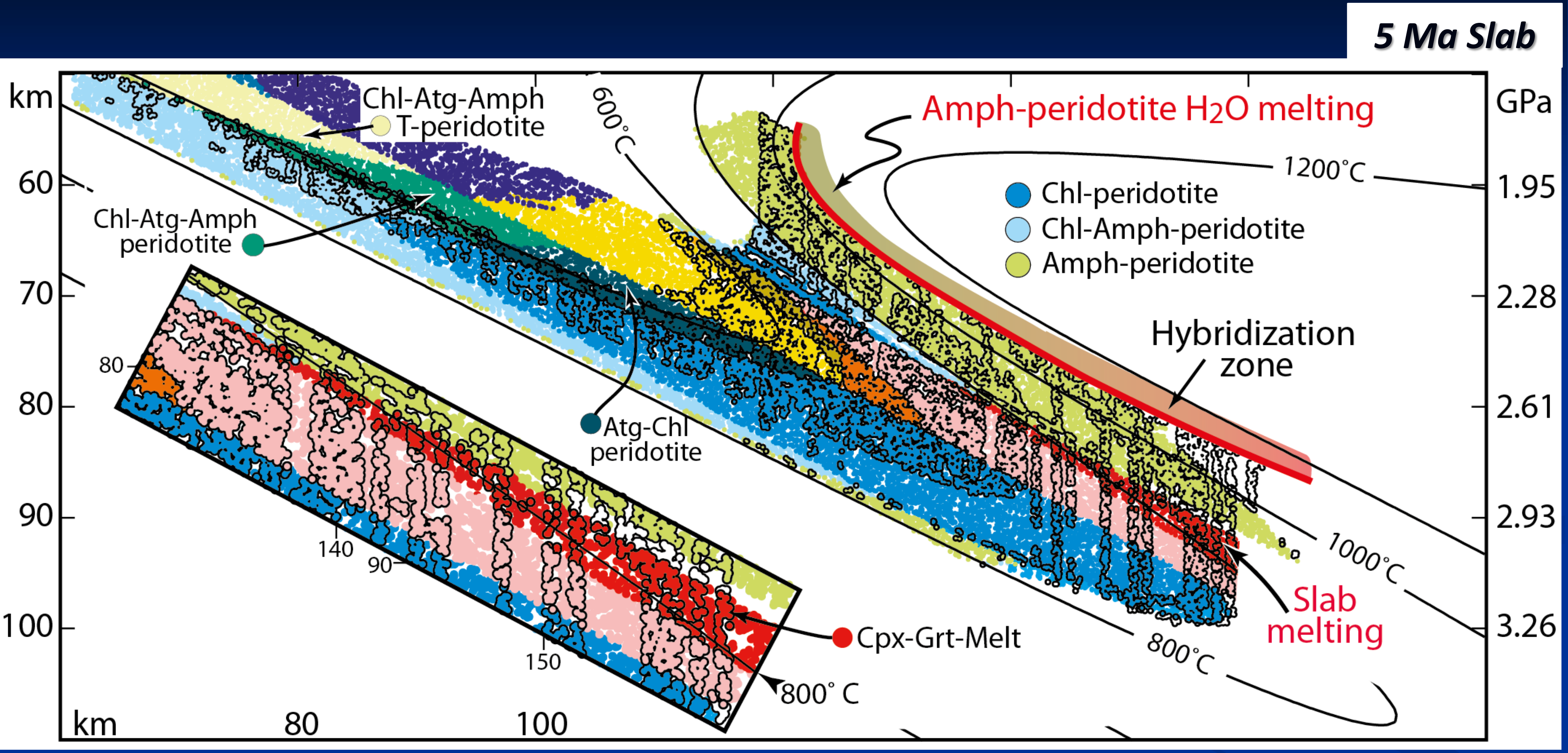


Important mantle wedge melting at shallow depth

Crust melting through water advection only

Cpx + Grt +H_2O ± q/coe → Melt

Hot subduction



Young Slab = Hot subduction = Early dehydration

Early dehydration = Different mantle melts

Fate of Crustal melts ? Pyroxenites ???

Overriding lithosphere control (HP fractionation / re-melting)

Some conclusions from these models:

- Plate velocity controls slab temperature

→ Controls devolatilization and the location of melting

→ Important parameter for recycling. $W = 1.06 v_s + 0.14 a - 0.023 T_m + 17$

- The amount of H_2O subducted is equally important as the temperature architecture of the system

- Slab melting is feasible for young slabs

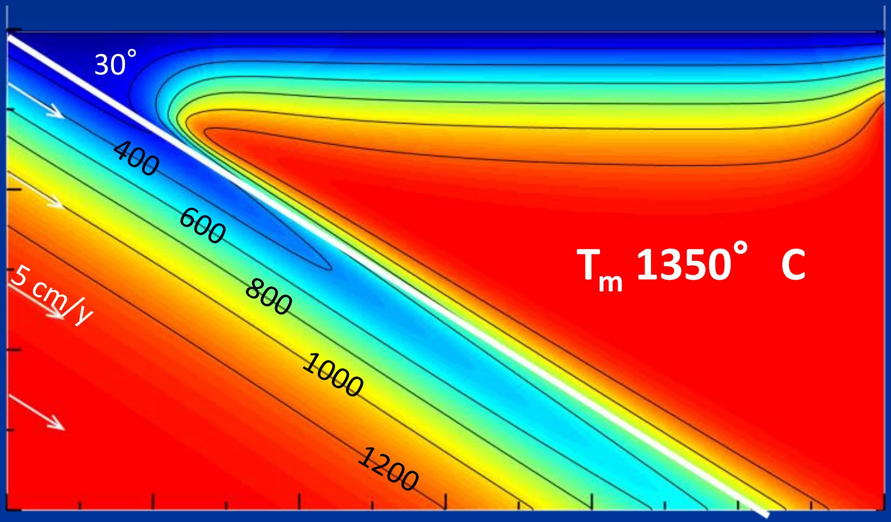
Only if enough water (is there enough ?)

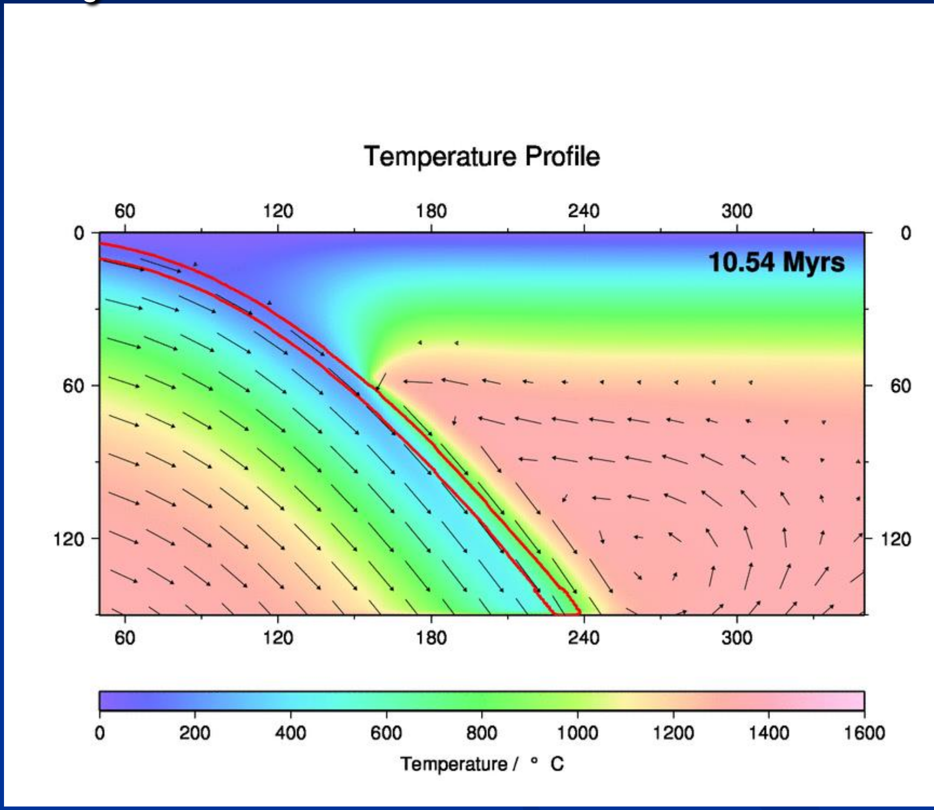
→But Amph-peridotite ± H_2O melting would dominate

→Implication for making the C-Crust / Early earth SZ

Next steps:

- Need Slab dynamics

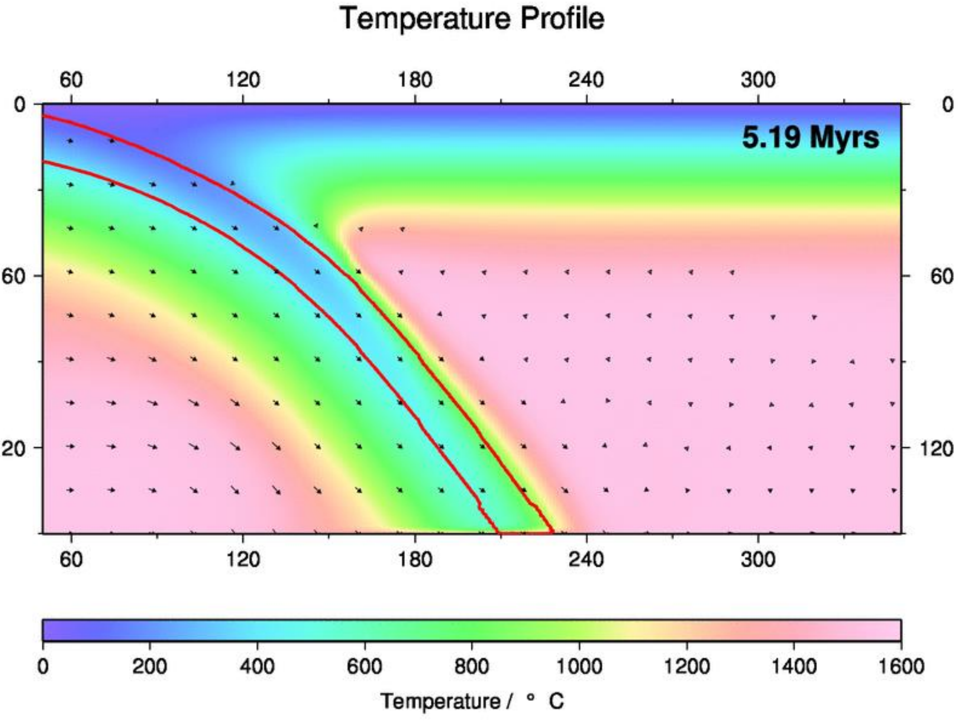


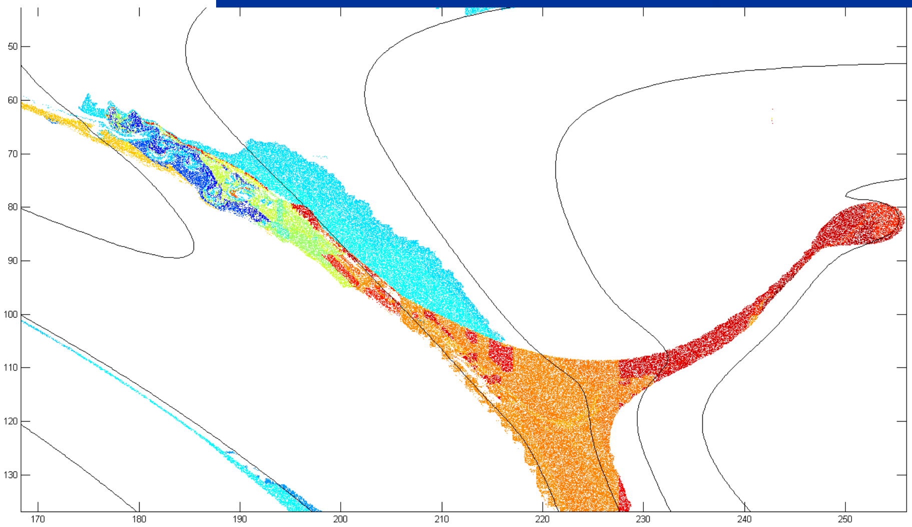


Next steps:

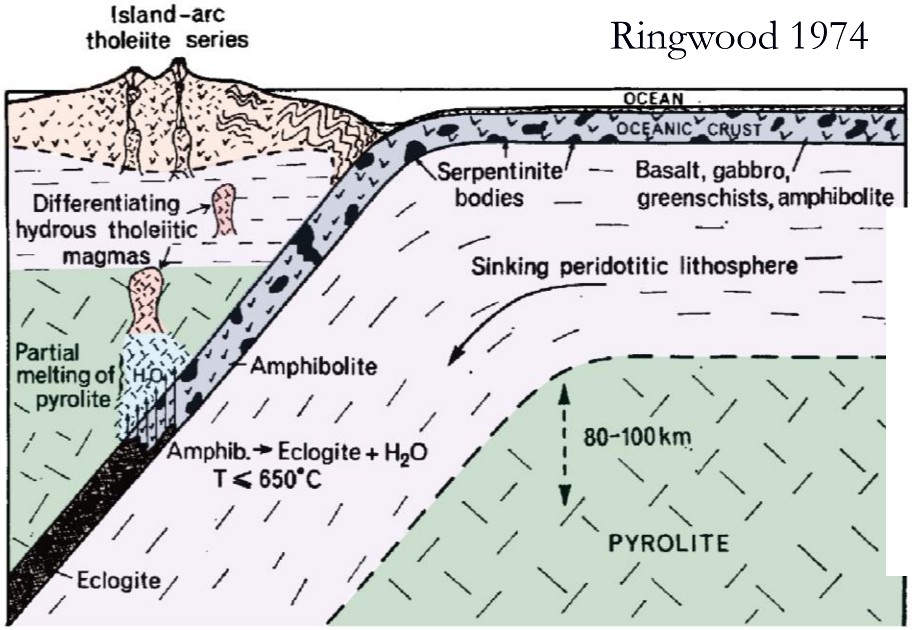
- Need Slab dynamics

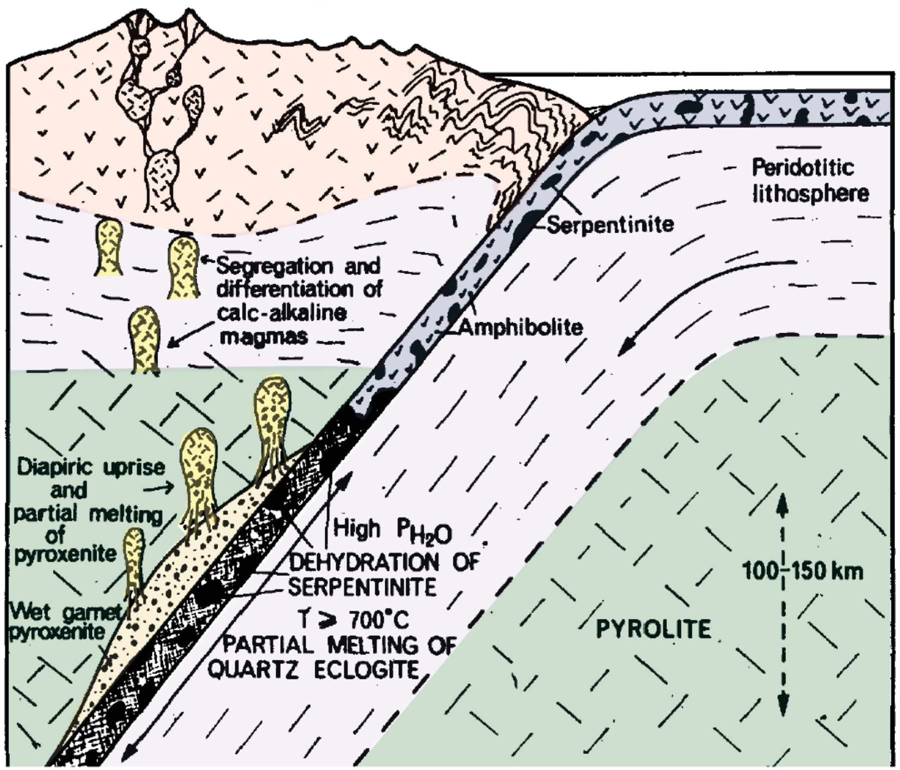
B. Maunder PhD: Testing mafic crust delamination.
For now: f(σ / T) soon f([H2O/Melt])





Ringwood 1974





Slab / Wedge processes

Numerical MODELS: Essential Complex & Complete ?

YES

Getting there

By bringing in all the necessary ingredients (Rheology, petrology, fluid low …)

Next steps :

- **Need Fluid / Melt dependent rheology**

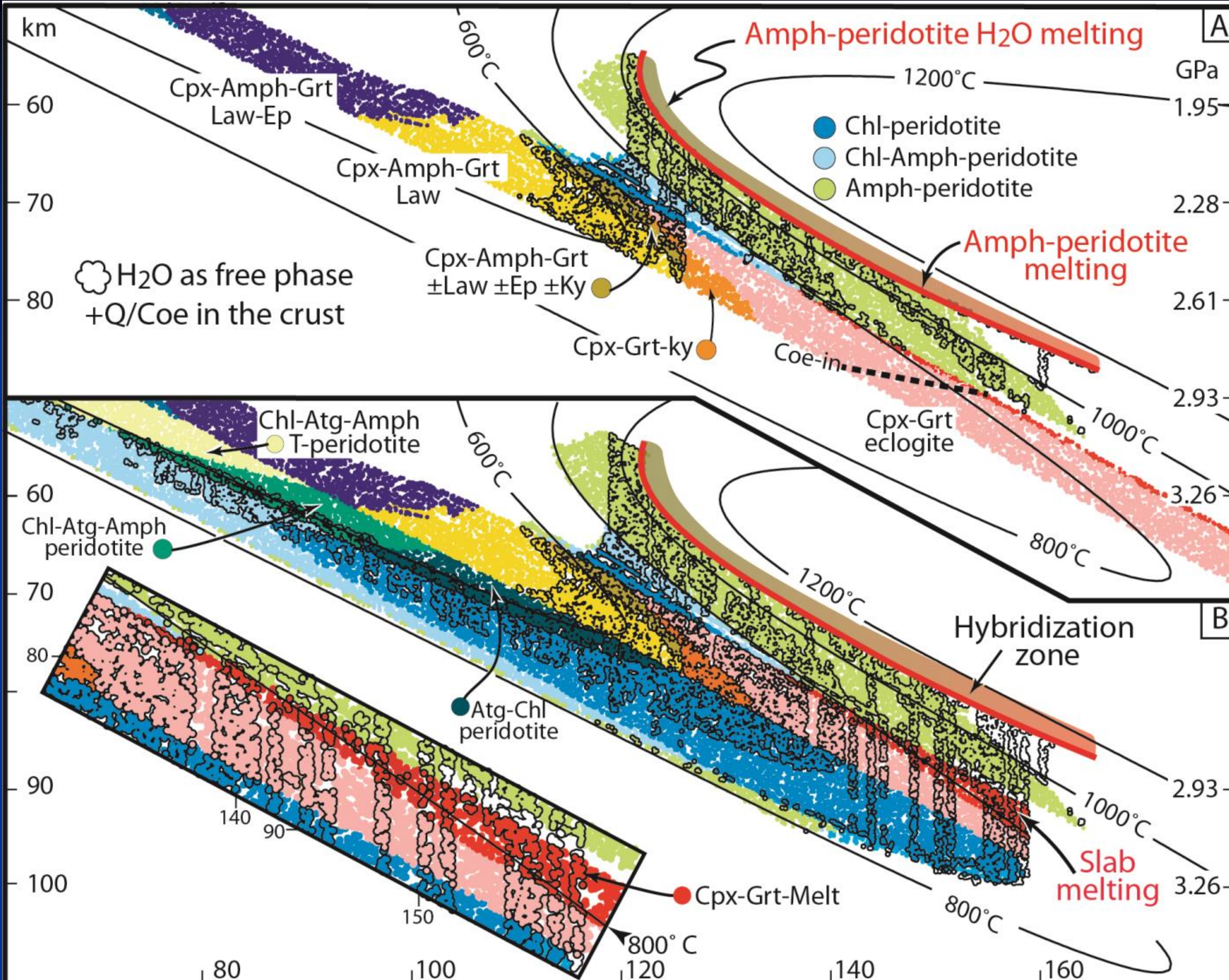
WITH Melt extraction

- **Need a proper H2O Mantle melt model**

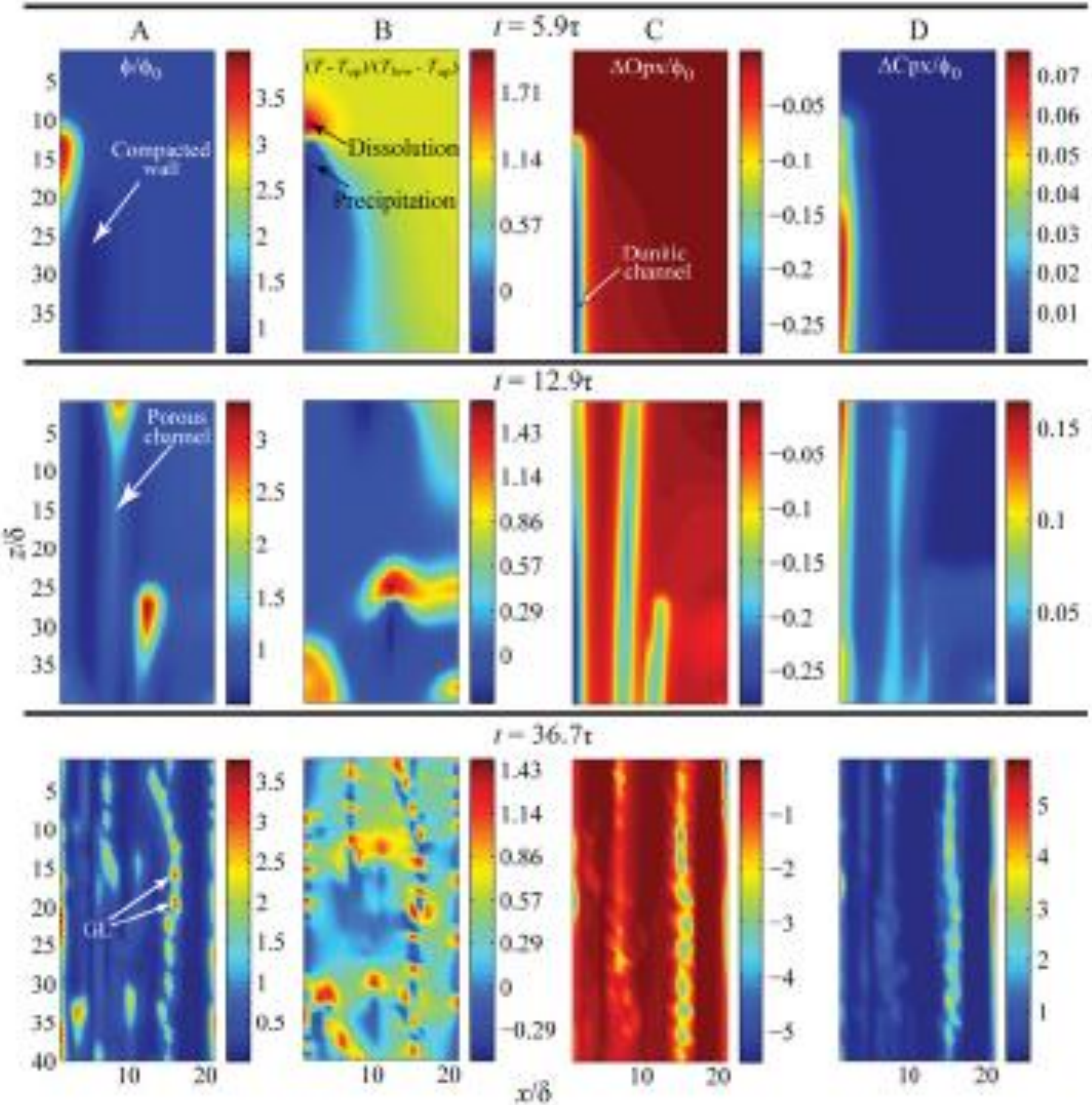
(now OK for crust/ NOT great for H2O mantle)

Melt model + Melt/Fluid dynamics

→ accessing primary melt composition / reaction throughout the wedge, until it reach the crust, and feed back mechanism on the dynamic of the system…



km
A
Amph-peridotite H2O melting
600°C
1200°C
GPa
1.95
60
Cpx-Amph-Grt
Law-Ep
Chl-peridotite
Chl-Amph-peridotite
Amph-peridotite
Cpx-Amph-Grt
Law
70
2.28
Amph-peridotite
melting
H2O as free phase
+Q/Coe in the crust
Cpx-Amph-Grt
±Law ±Ep ±Ky
80
2.61
Cpx-Grt-ky
Coe-in
2.93
1000°C
Cpx-Grt
eclogite
Chl-Atg-Amph
T-peridotite
600°C
60
3.26
Chl-Atg-Amph
peridotite
800°C
70
1200°C
B
Hybridization
zone
80
Atg-Chl
peridotite
90
2.93
1000°C
140
90
Slab
melting
100
3.26
Cpx-Grt-Melt
150
800°C
800° C
80
100
120
140
160



Bouilhol et al. 2011