Exhumation of deep seated rocks in collisional orogen

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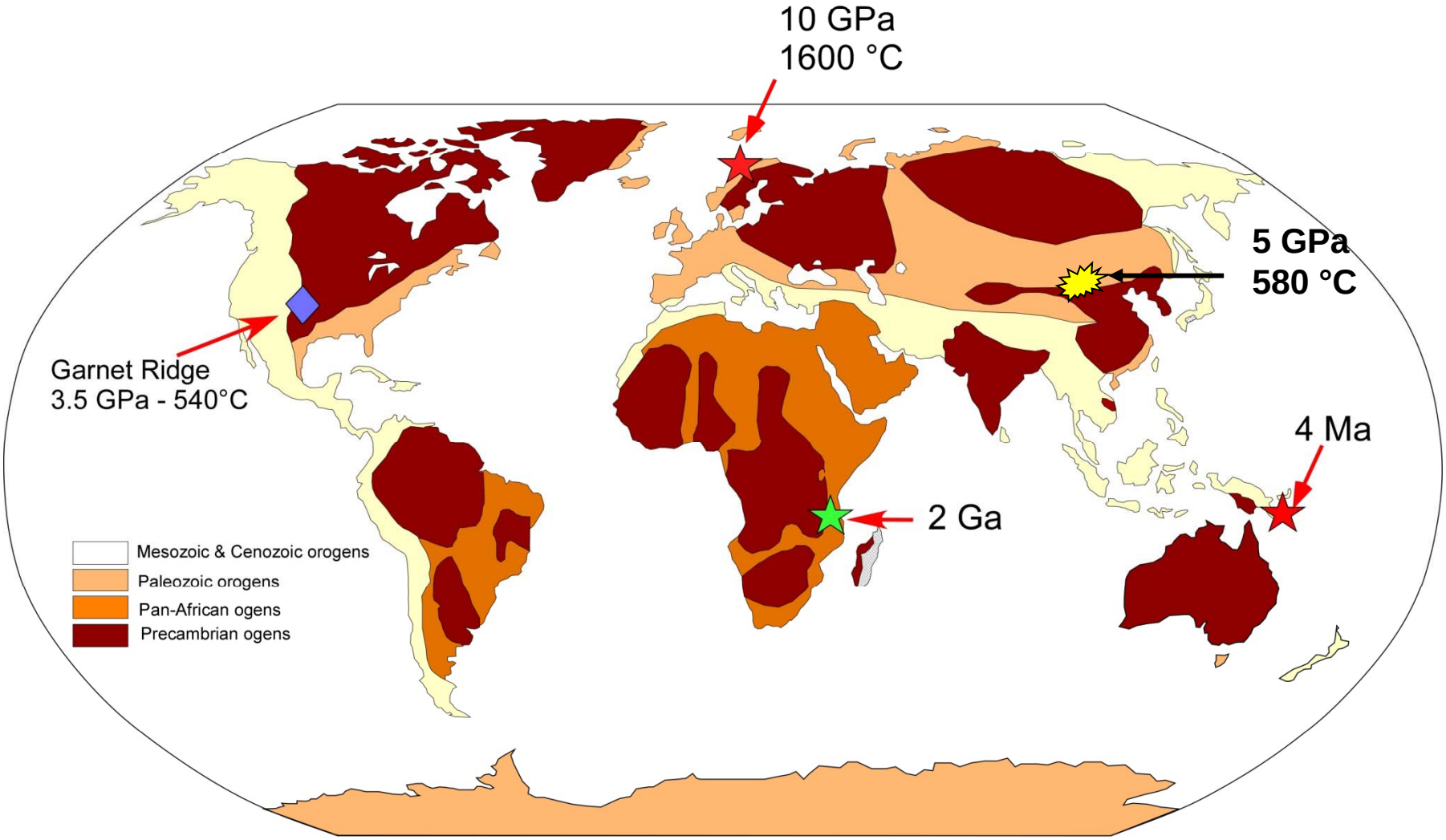
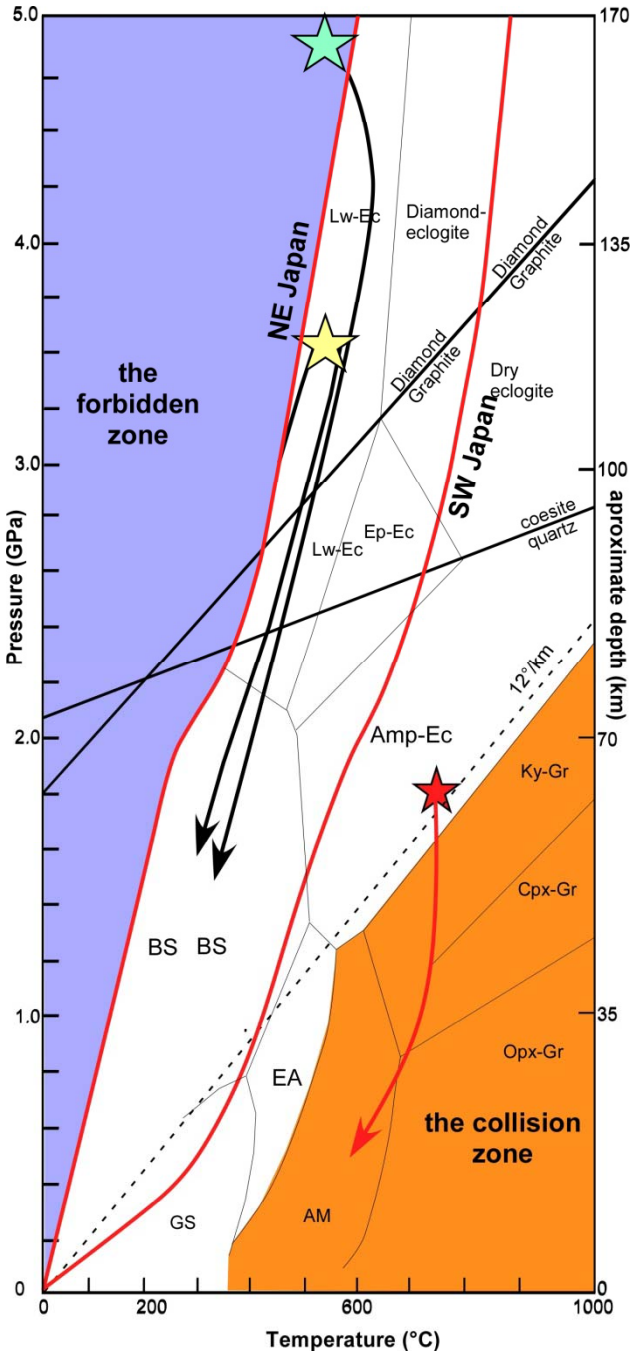
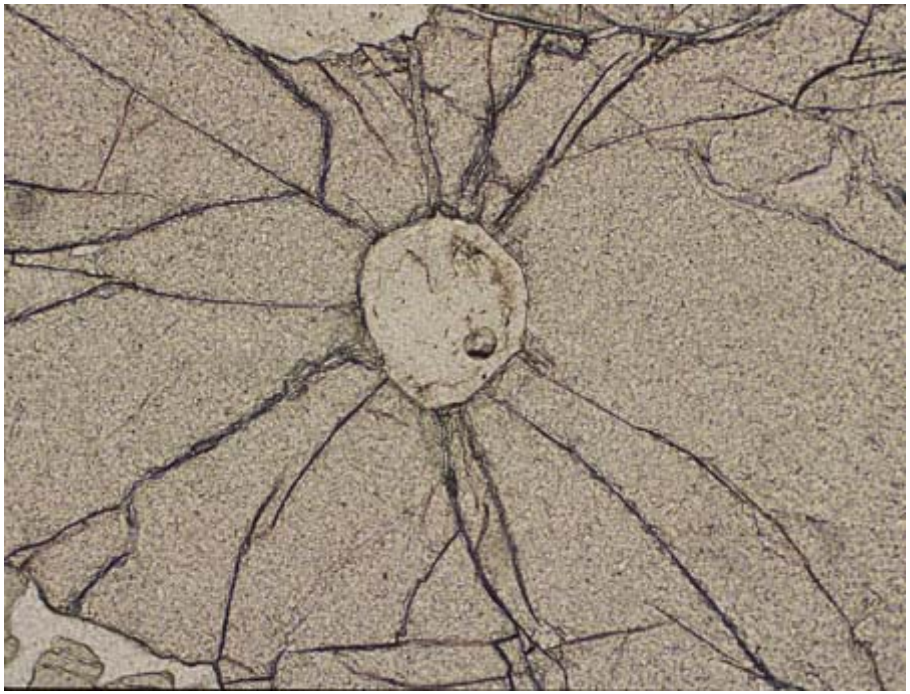


Extreme eclogites on Earth

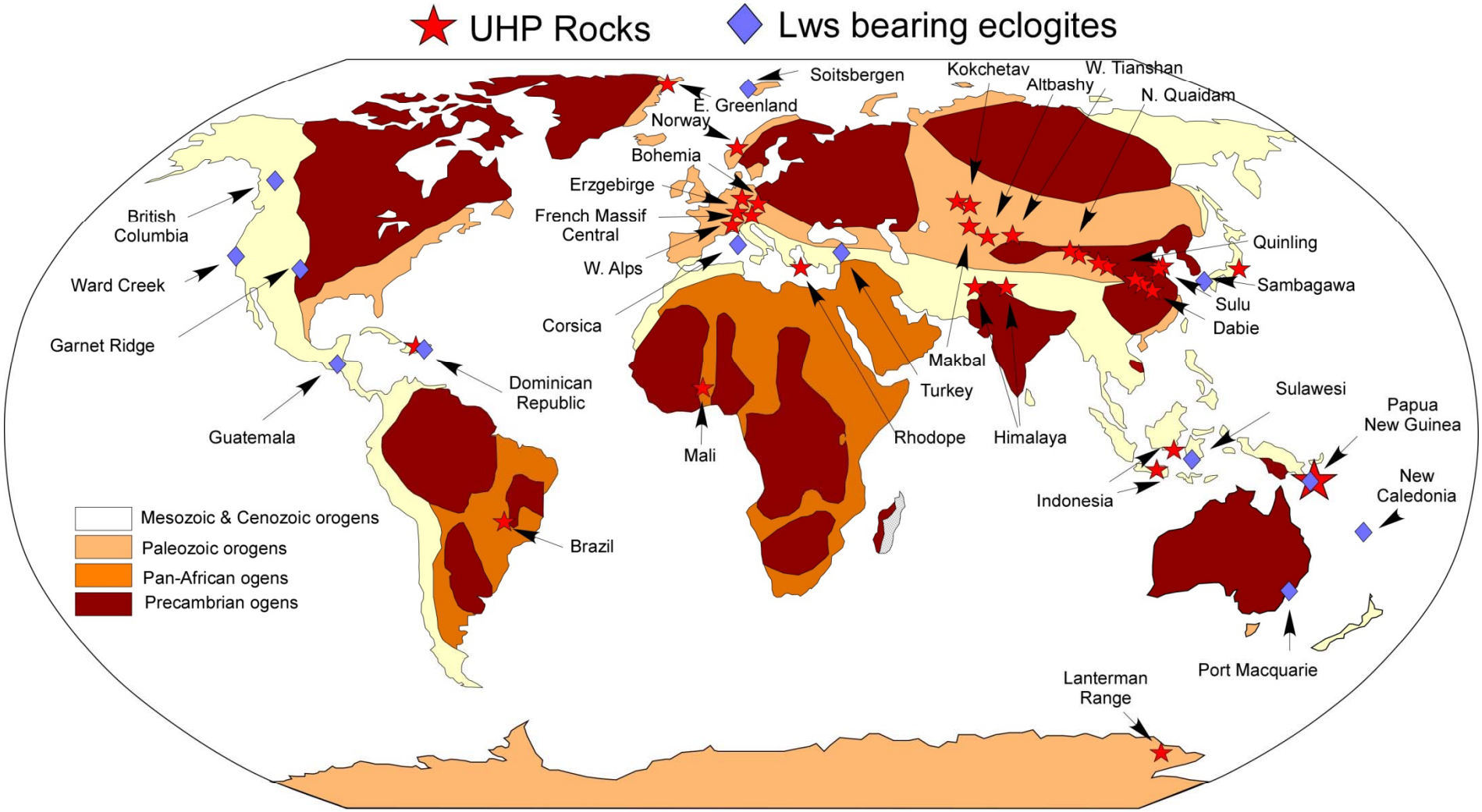
(after Van Roermund et al., 2004; Zhang et al., 2003; Collins et al., 2004, Baldwin et al., 2004)





At the first order
P-T data of eclogites from 2.0 Ga
to present day
match active subduction geotherm

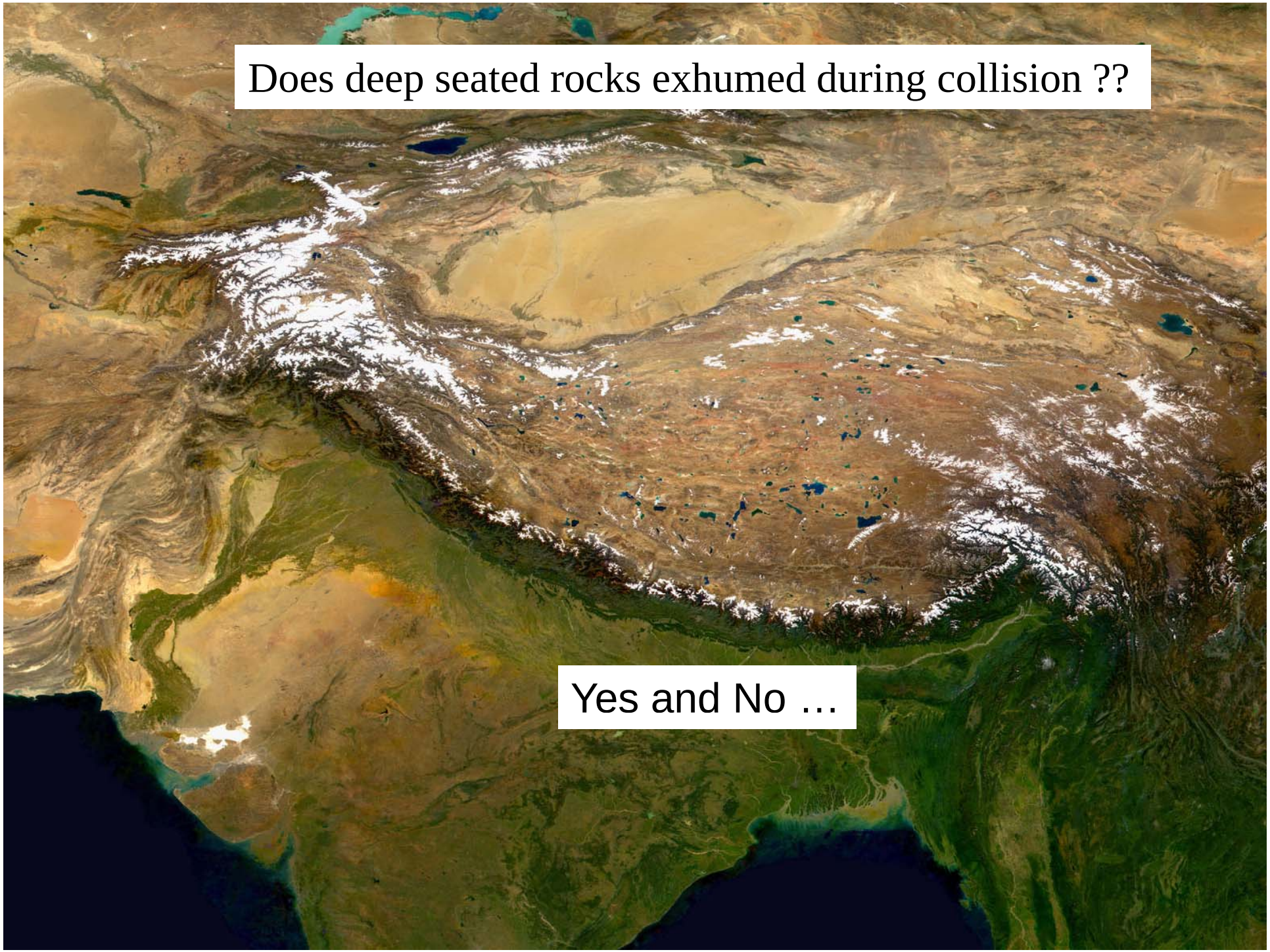
Petrological data can be used
to understanding subduction/collisional processes



Ultrahigh Pressure and Low temperature eclogites

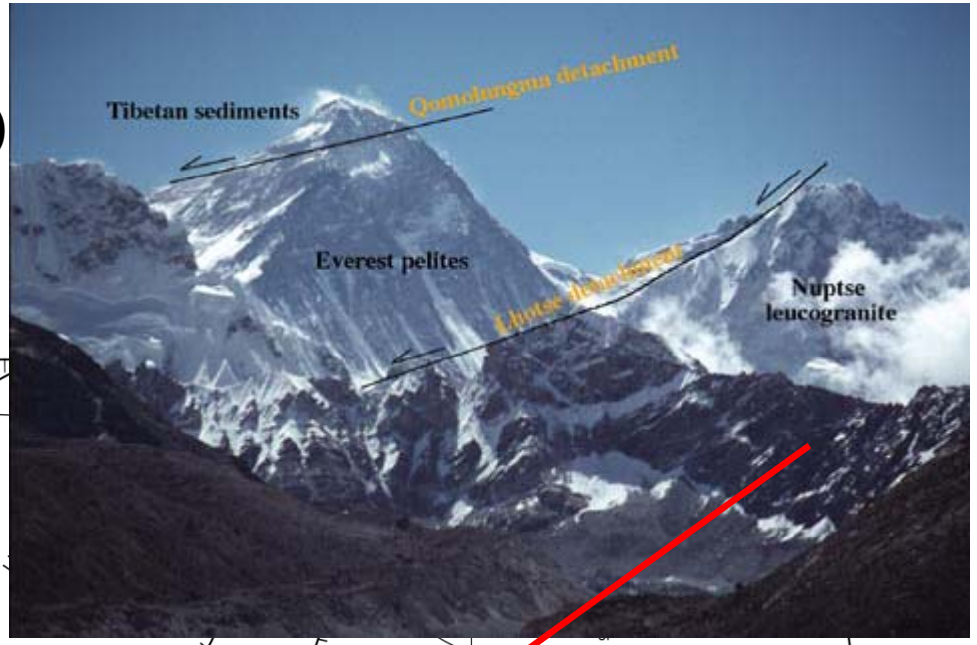
All this Rocks are observed in convergent settings

Guillot et al., 2009

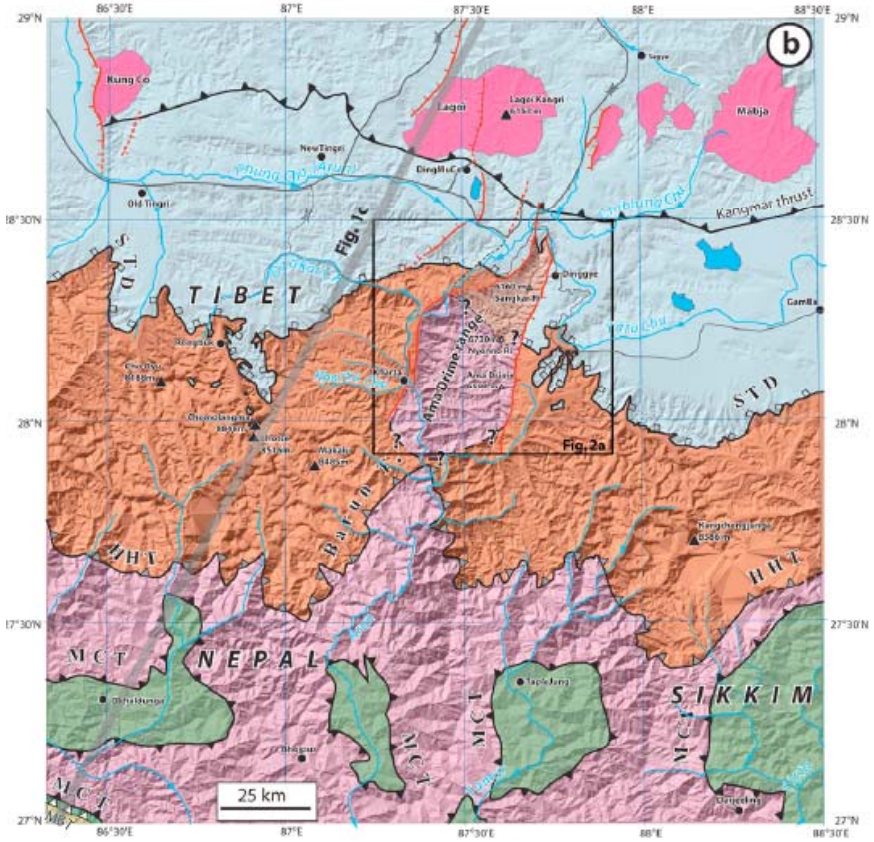

Does deep seated rocks exhumed during collision ??
Yes and No …

Metamorphic rocks are of course observed in the core of the orogen (HHC)

But not so deep (< 1.5-2.0 GPa)



Guillot et al., 2007

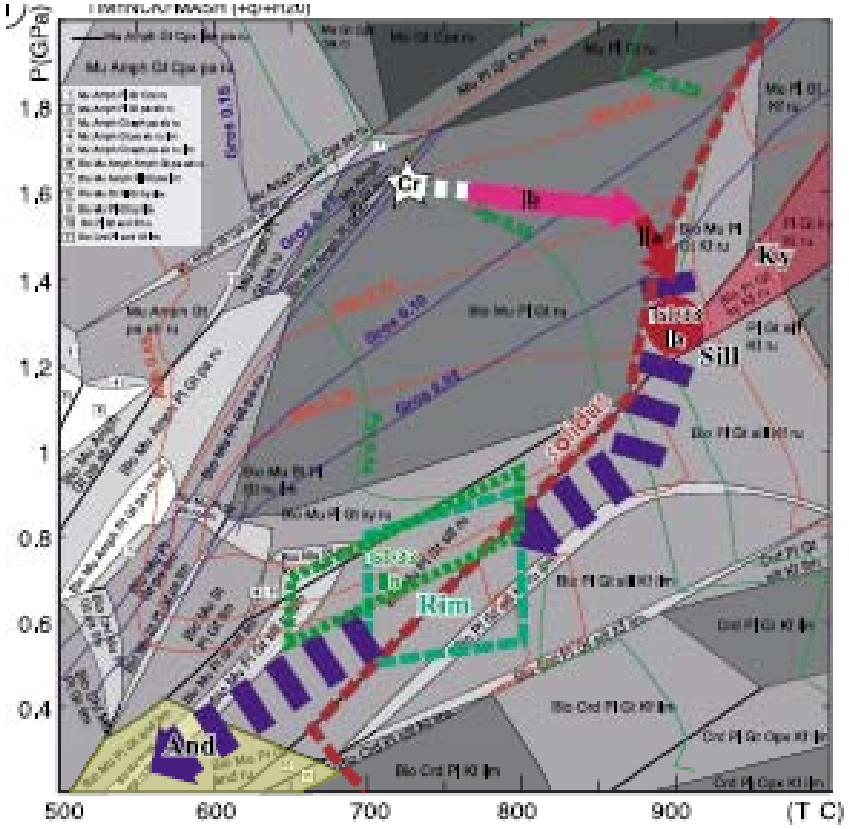


Lombardo and Rolfo, 2000
Groppo et al., 2007
Kali et al., 2010

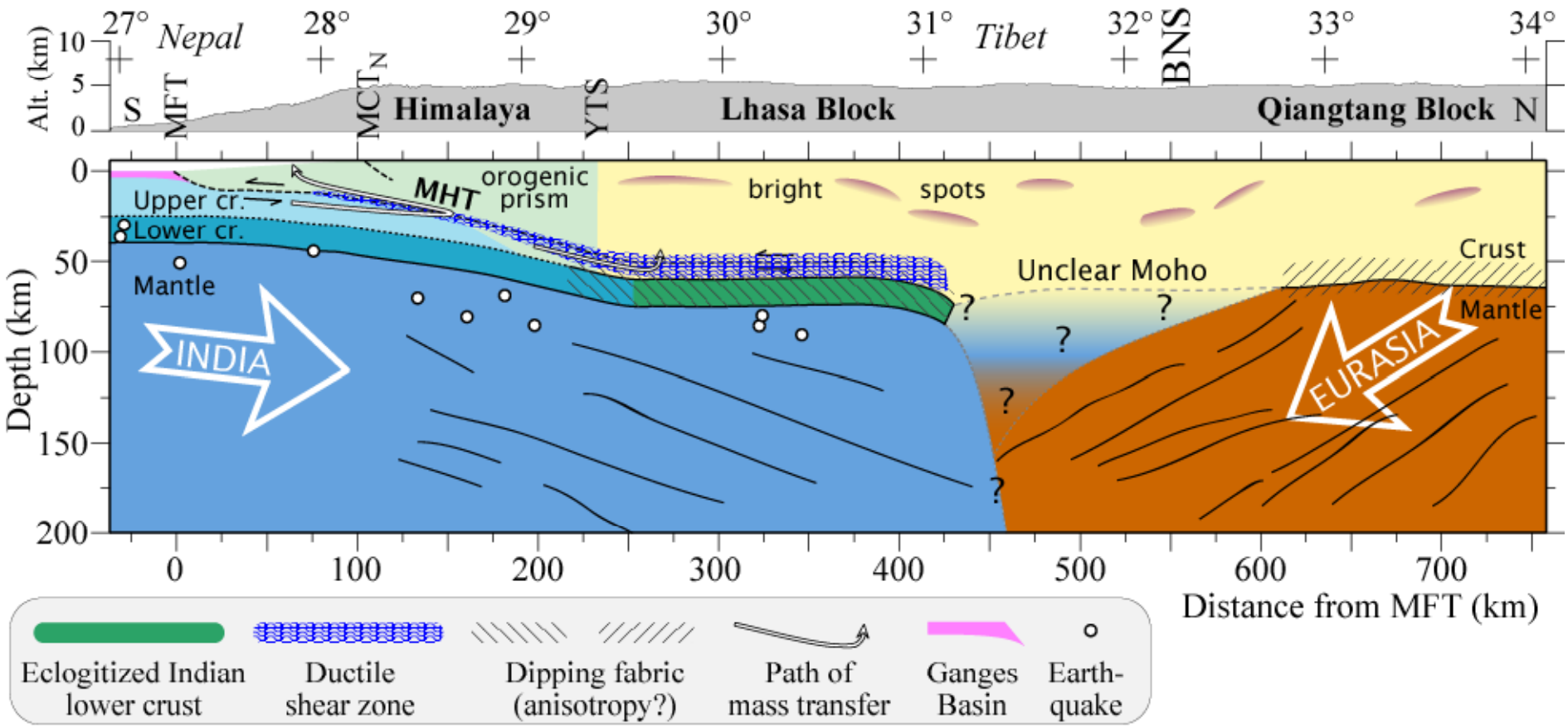
Core of the Himalaya

HP but HT deep seated rocks

Eclogite/Granulite

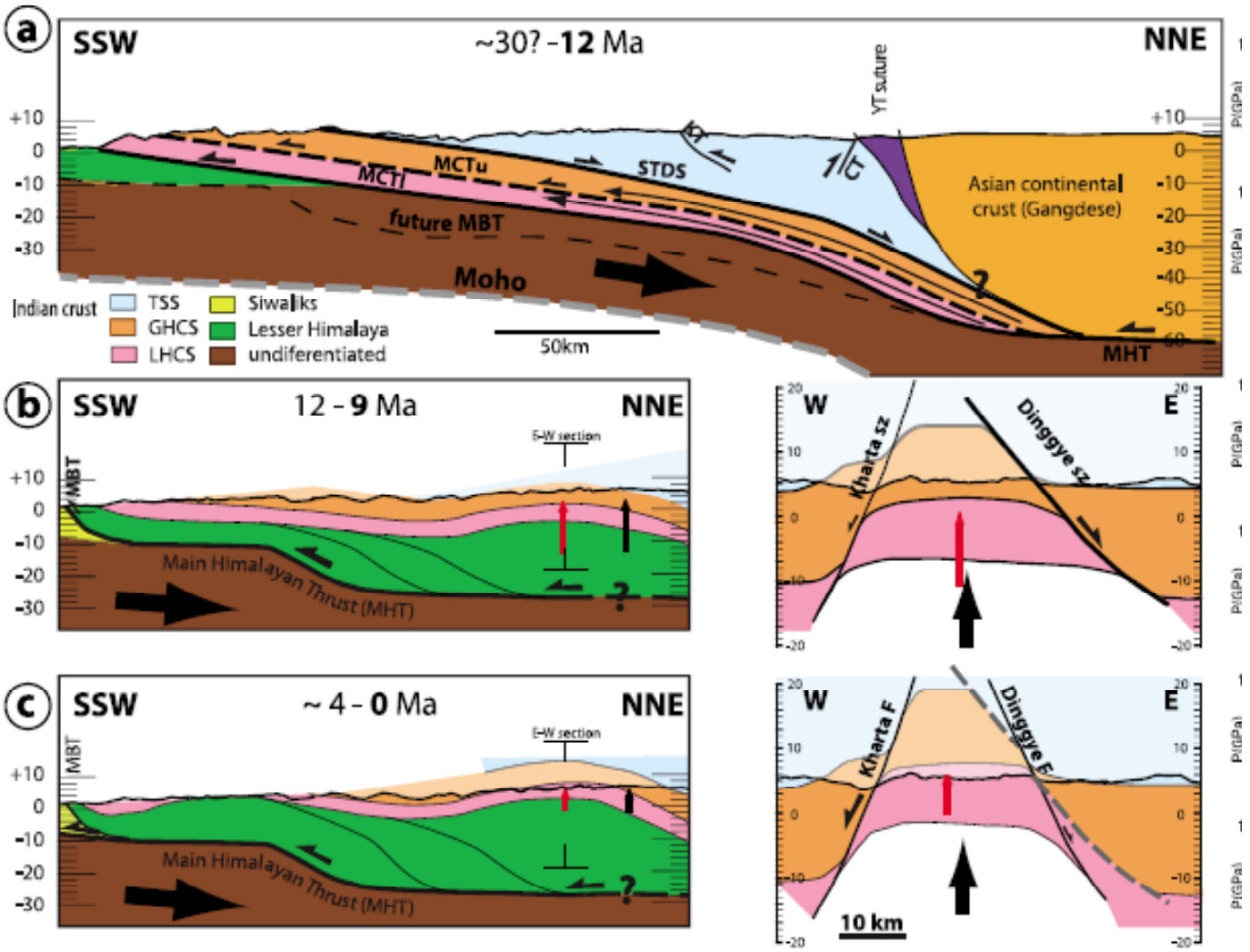


Continental Collision : offscraping of the upper crust
with underthrusting of the lower crust and upper mantle



Nabelek et al., Science 2009

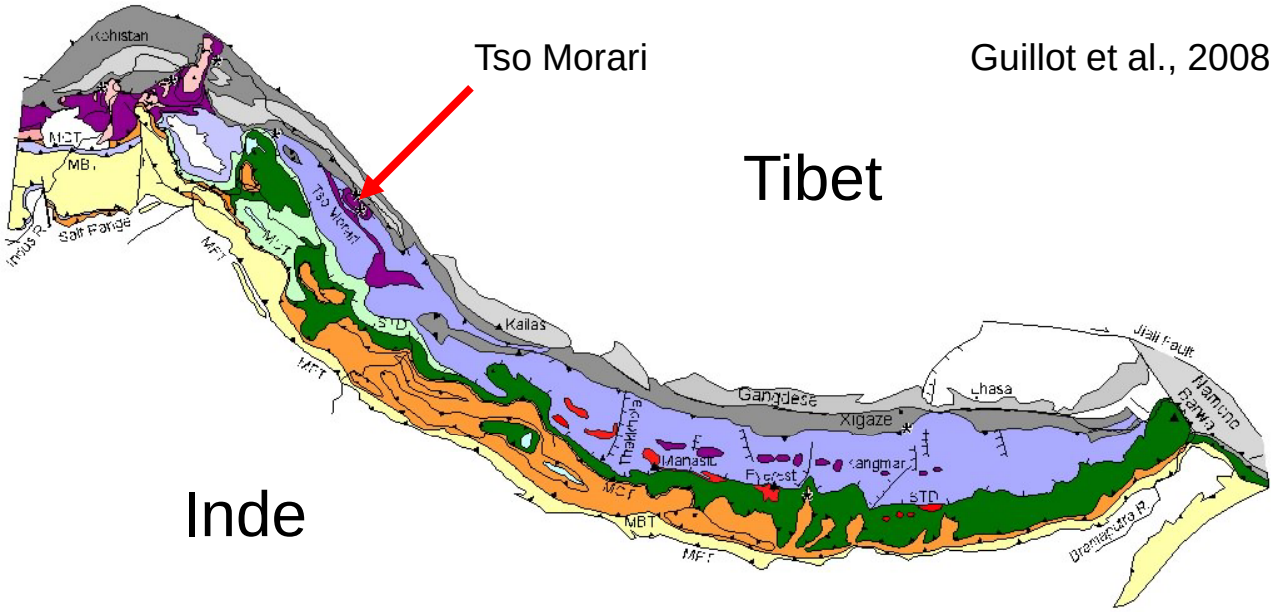
Collision: low-angle continental subduction
mostly exhumed amphibolitic and granulitic metamorphic rocks (A.B. Thompson, 1984)



Kali et al., 2010

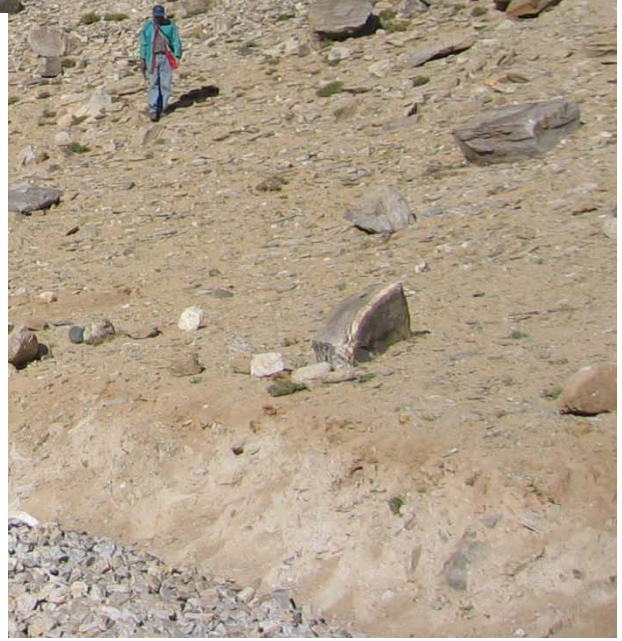
Tso Morari

Guillot et al., 2008



Tibet

Inde



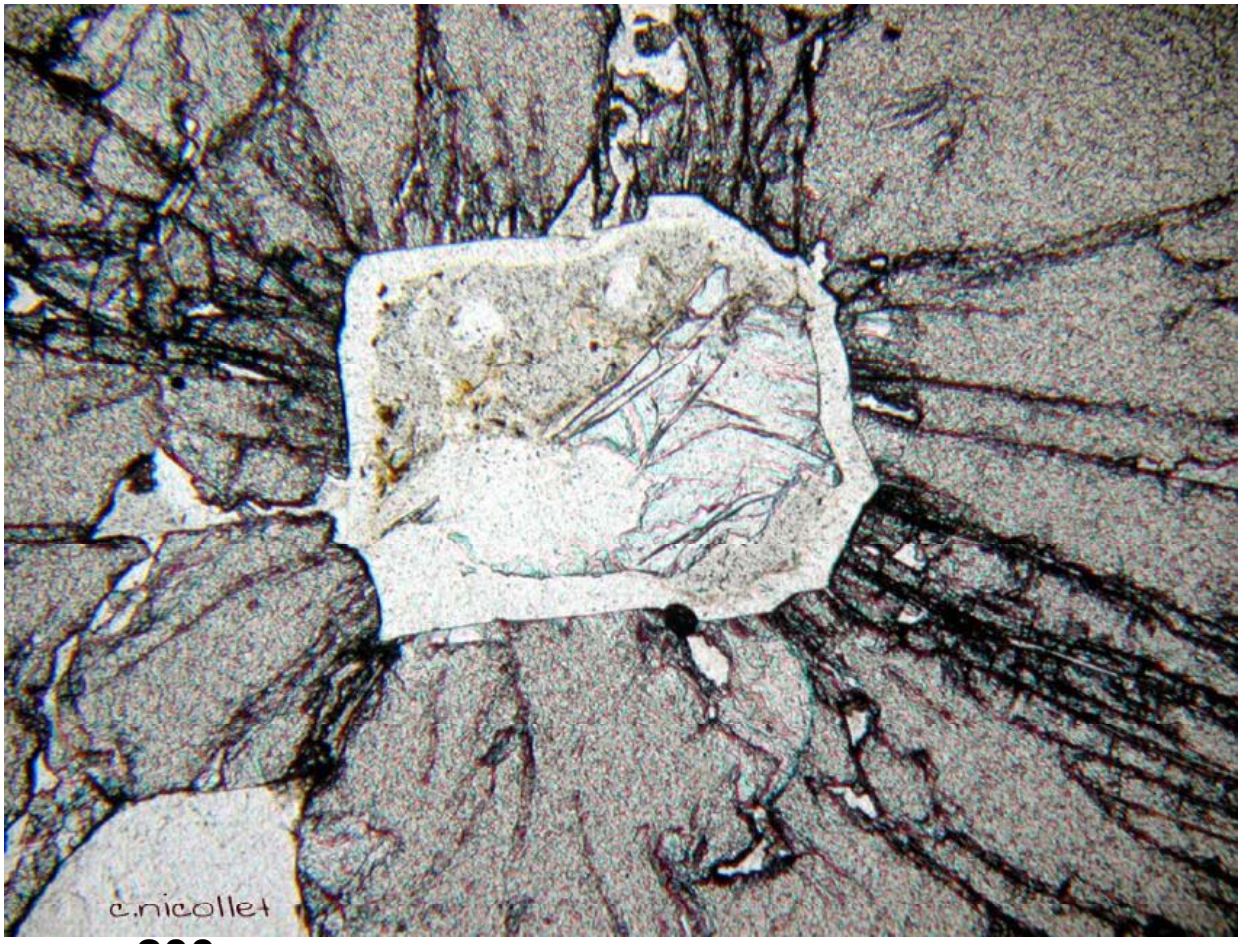
Coesite bearing eclogite

is

observed

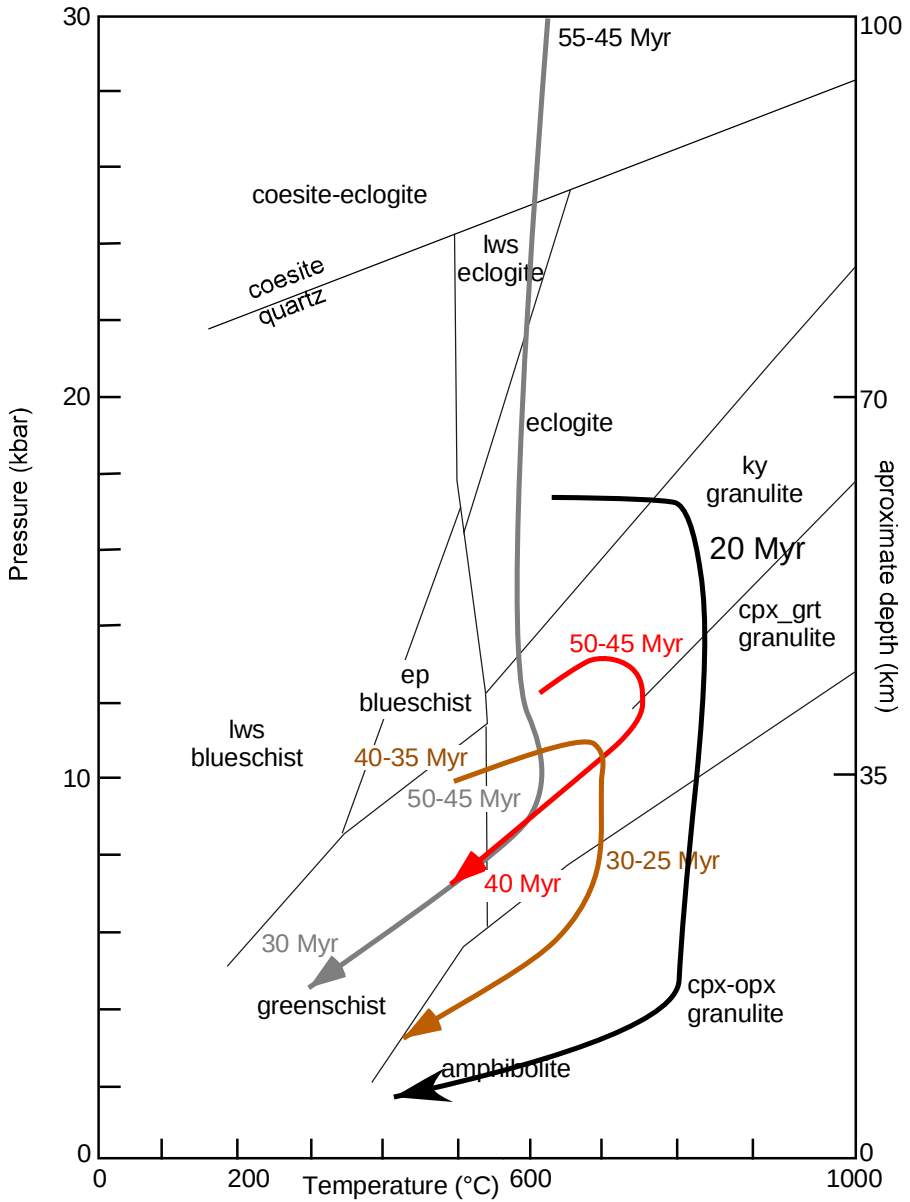
as in

Dora Maira



300 μm.

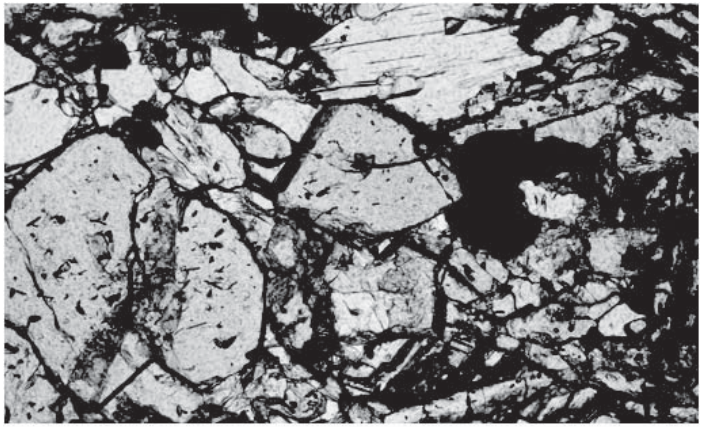
⇒ Burial and exhumation of continental crust at a minimum depth of 100 km

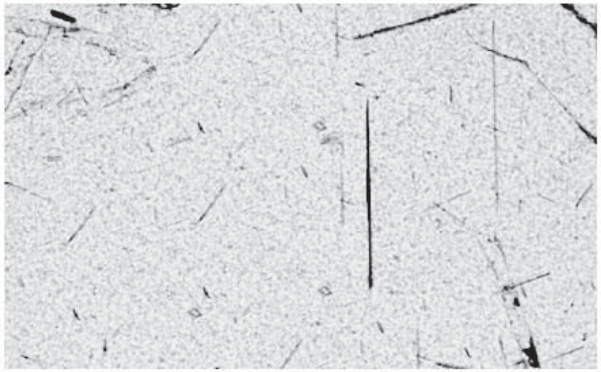


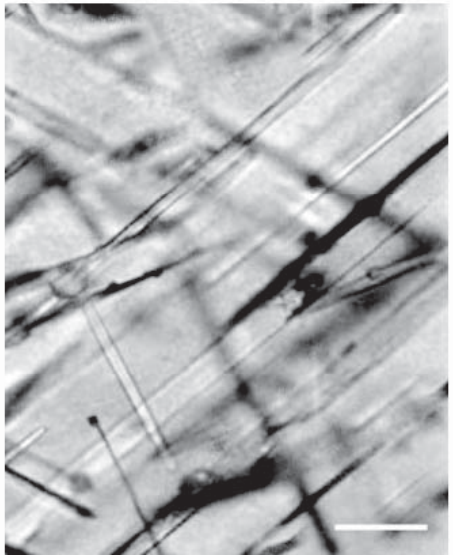
Subduction

Collision

Modified from Guillot et al., 2003







Pandey et al., 2010

described in the Tso Morari garnet

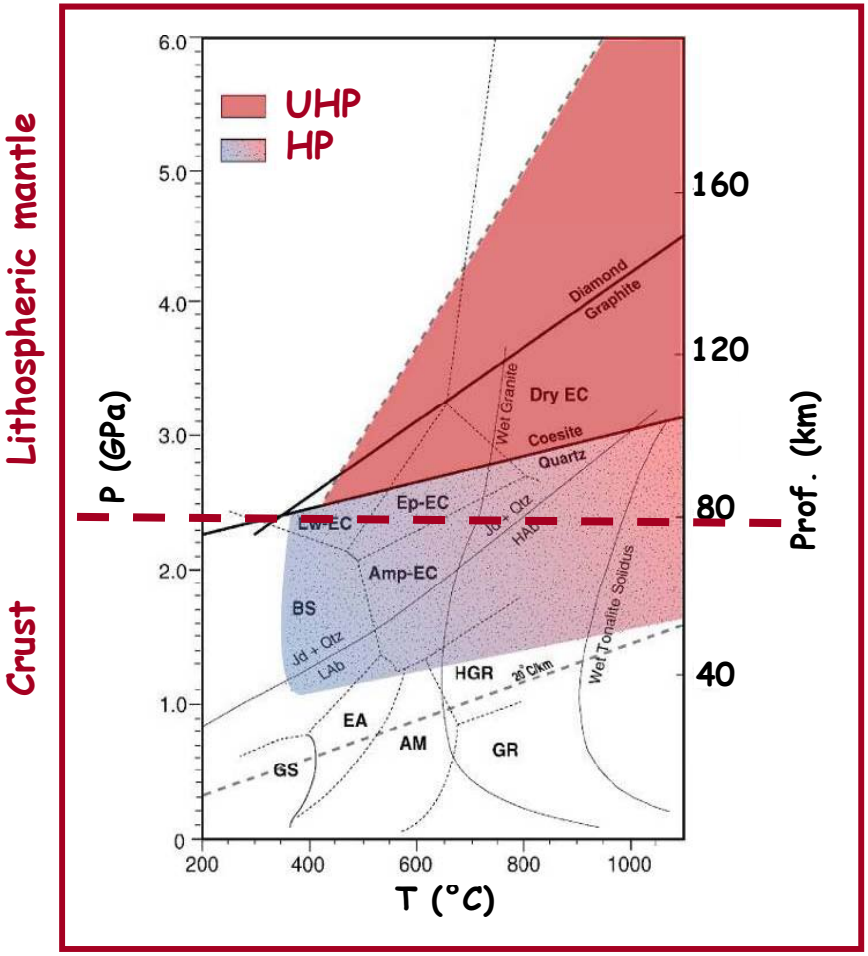
exsolved clinopyroxene needles

suggesting relict of majoritic garnet

=> exhumation from 200 km depth !!

Nothing to do with classical collisional processes

Exhumation from mantellic depth



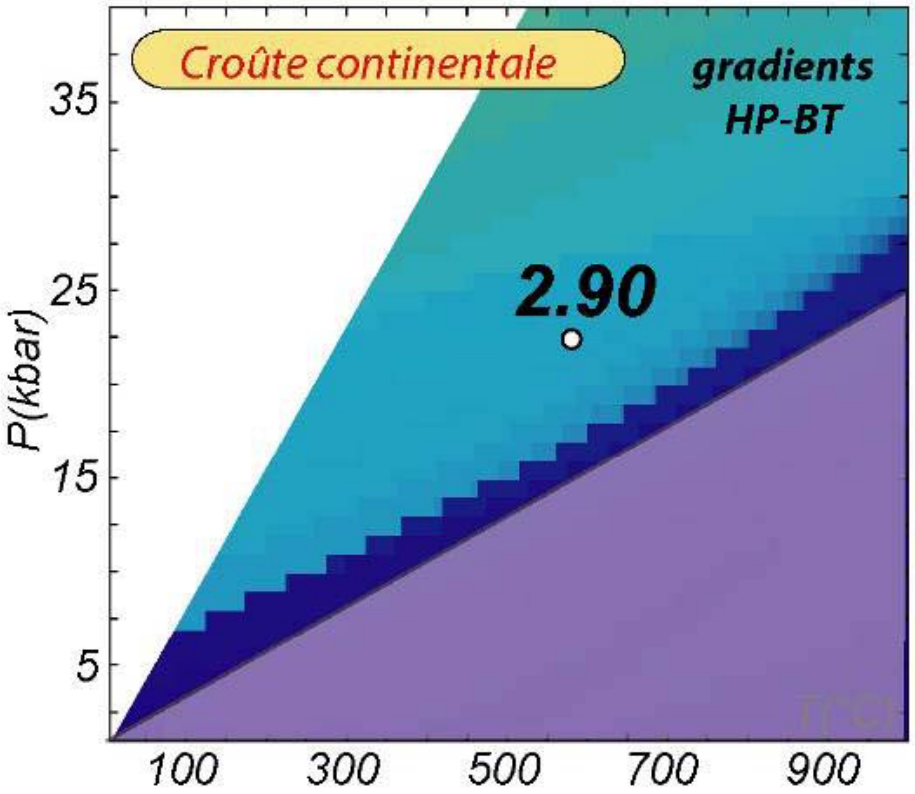
Exhumation within the mantle

Two difficulties...

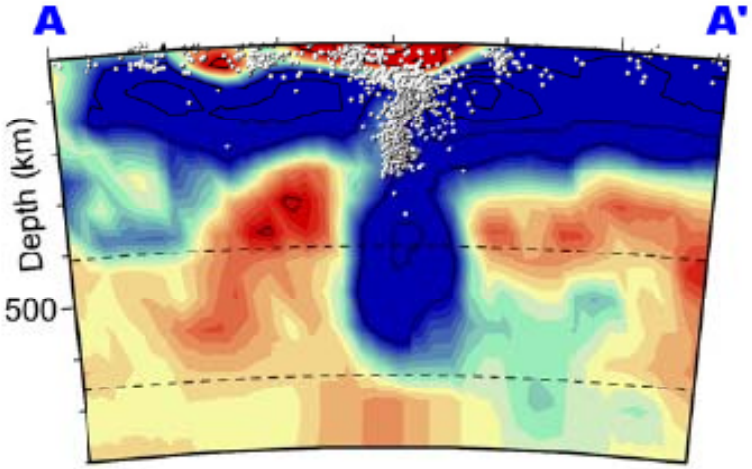
density

viscosity

The density continental case



Yamato et al. 2007



Negredo et al., 2007

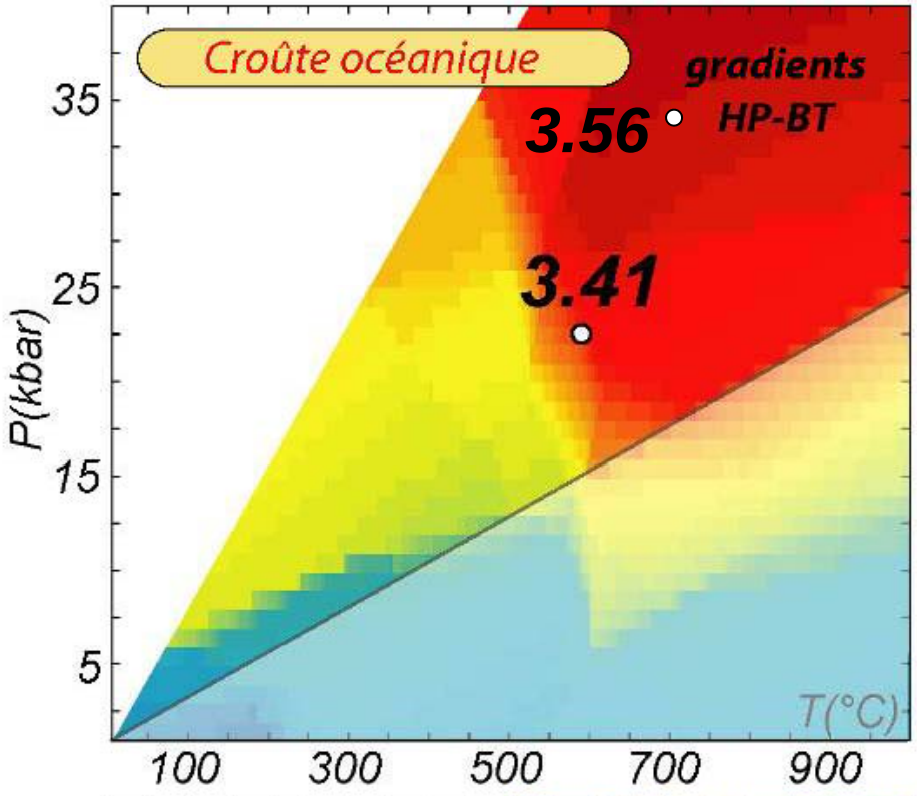
Upper mantle density

3.37 (Griffin et al., 1998)

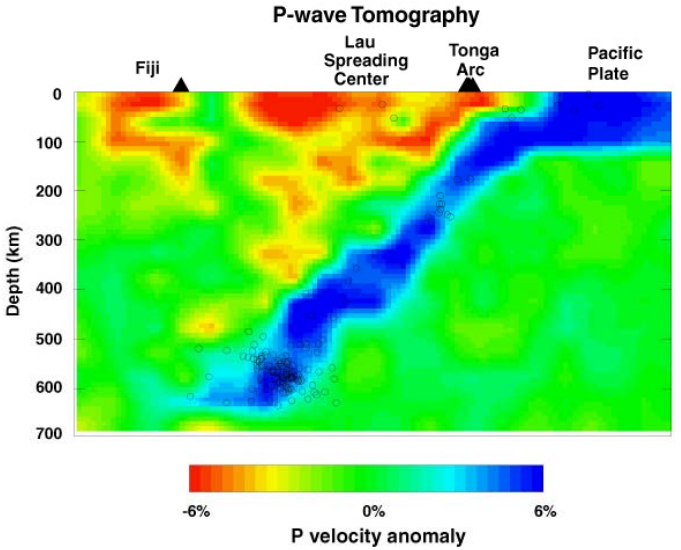
d continental crust < d mantle

=> Positive buoyancy

The density oceanic case



Yamato et al., 2007



Karato et al., 2000

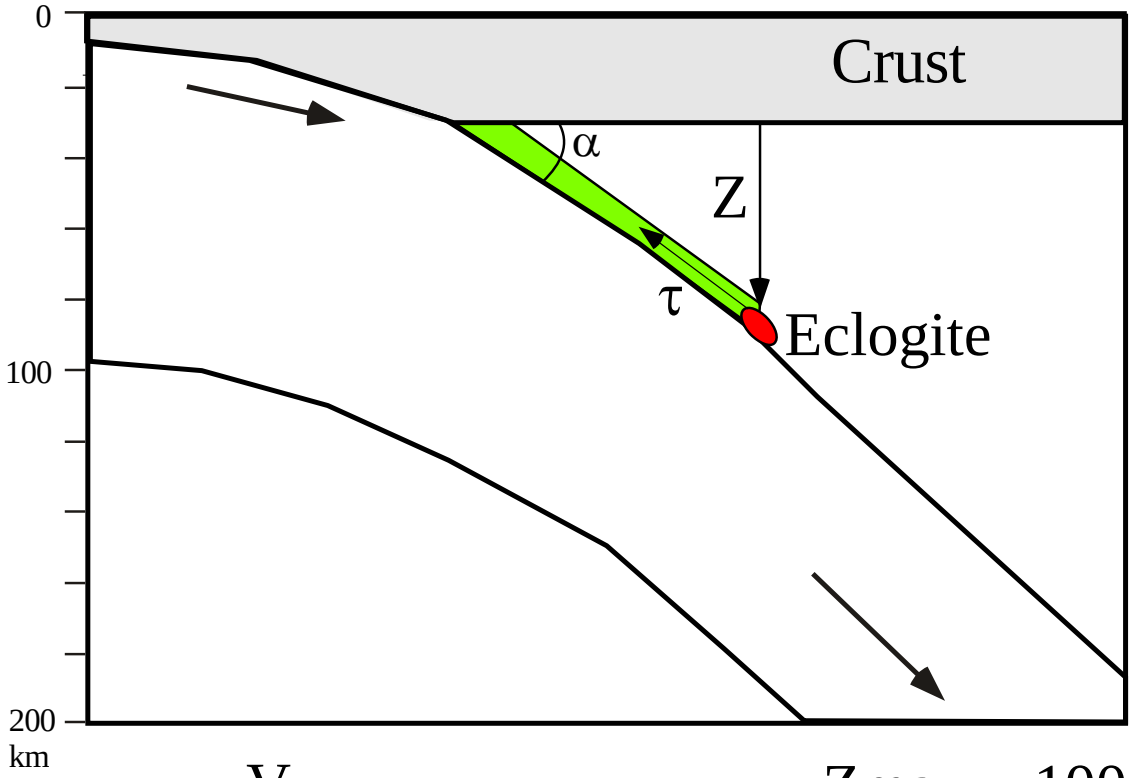
Upper mantle density

3.37 (Griffin et al., 1998)

d oceanic crust > d mantle

=> Negative buoyancy

The viscosity problem …



Guillot et al., 2001

$$\dot{\varepsilon} = \frac{V}{Z\sin\alpha} = 5.10^{-13} s^{-1}$$

Zmax = 100 km

Vmax = 1 cm/yr

τ : 10 MPa

$$\mu = \frac{\tau}{2\dot{\varepsilon}} = 10^{19} \text{ Pa.s}$$

Dry Mantle : $10^{22\text{-}24}$ Pa.s

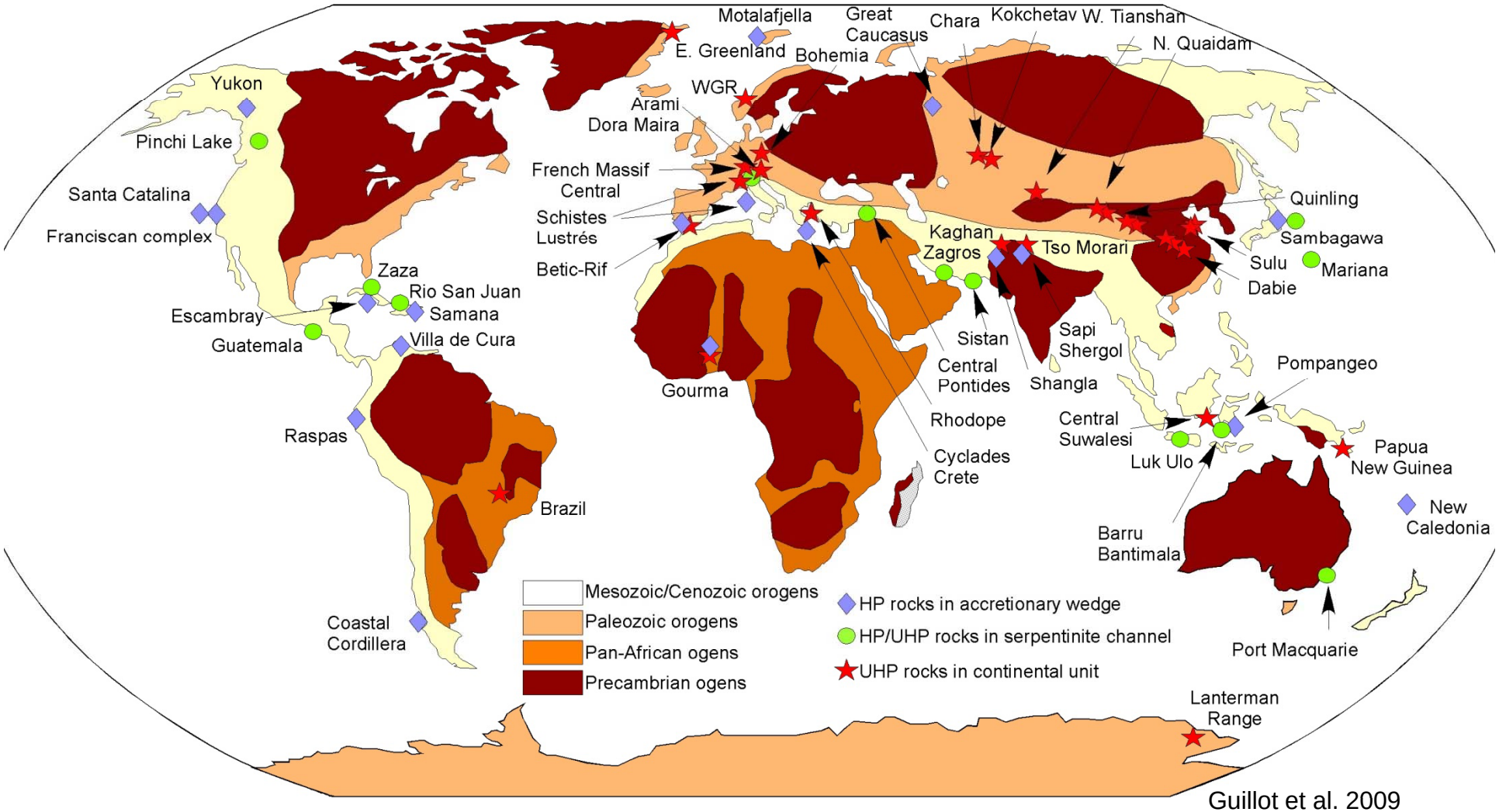
(Jelly Sandwich: Burov and Watts, 2006)

The viscosity of the subduction channel should be low !!

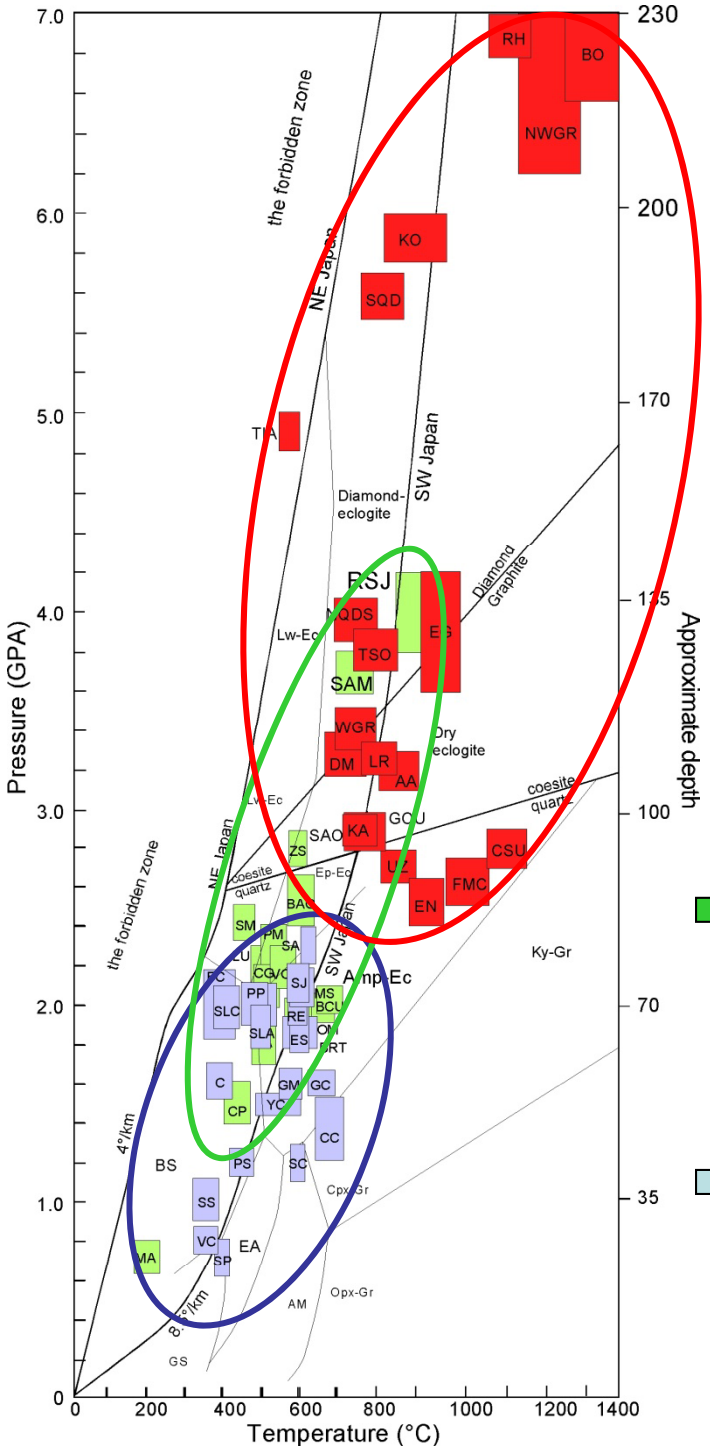
When and how the deep seated

rocks are exhumed ?

61 occurrences of Phanerozoic HP to UHP units



Guillot et al. 2009



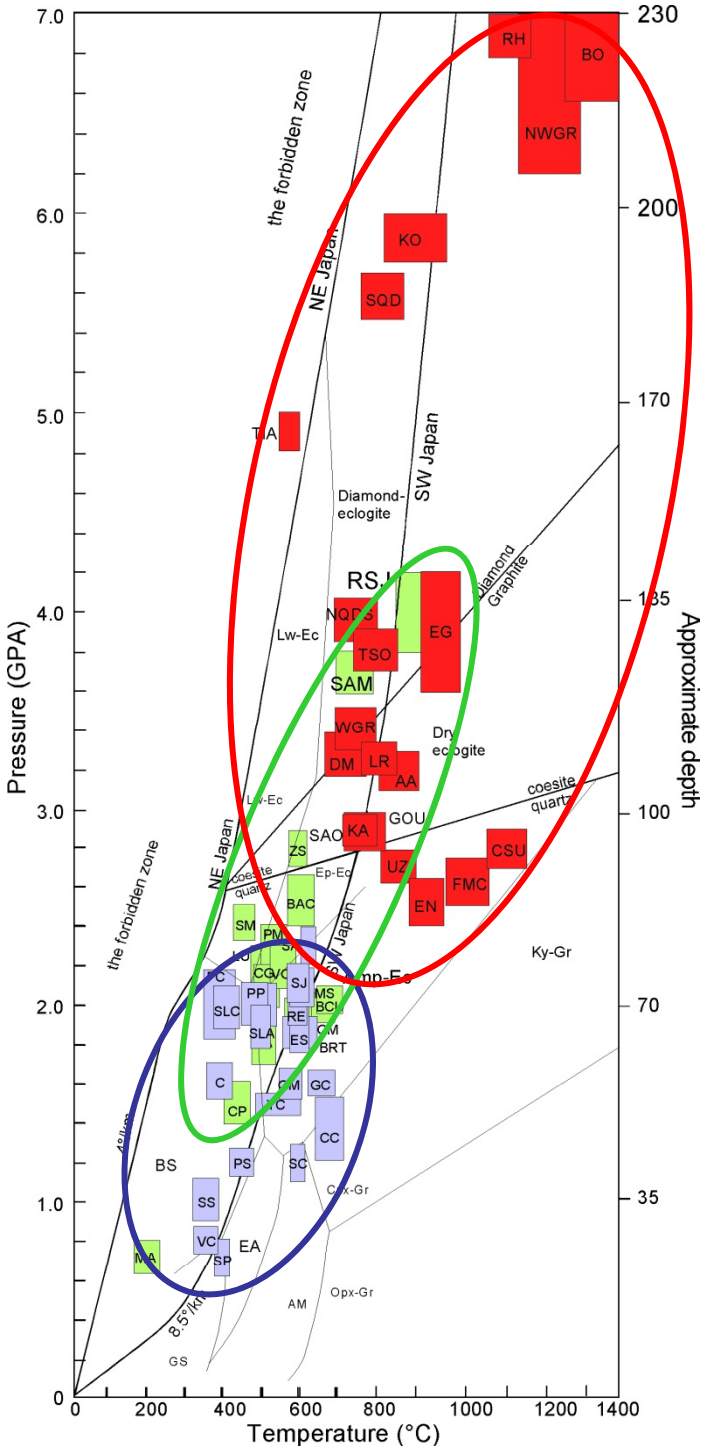
Pressure-Temperature conditions

Continental Subduction

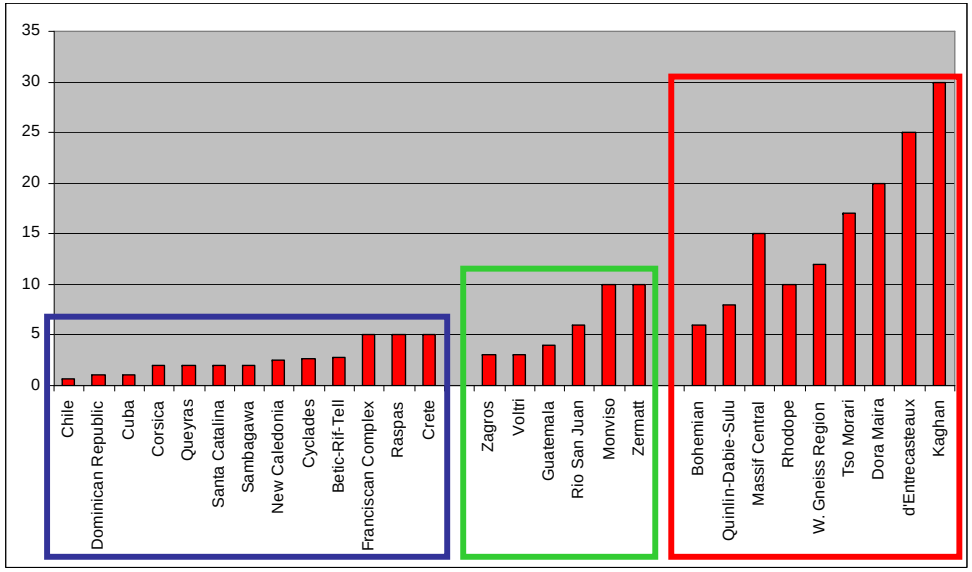
Serpentinite channel

Accretionary wedge

Guillot et al. 2009



Exhumation velocities cm/yr



Accretionary wedge

Serpentinite channel

Continental subduction

low V_{exhum} (1-5 mm/yr)

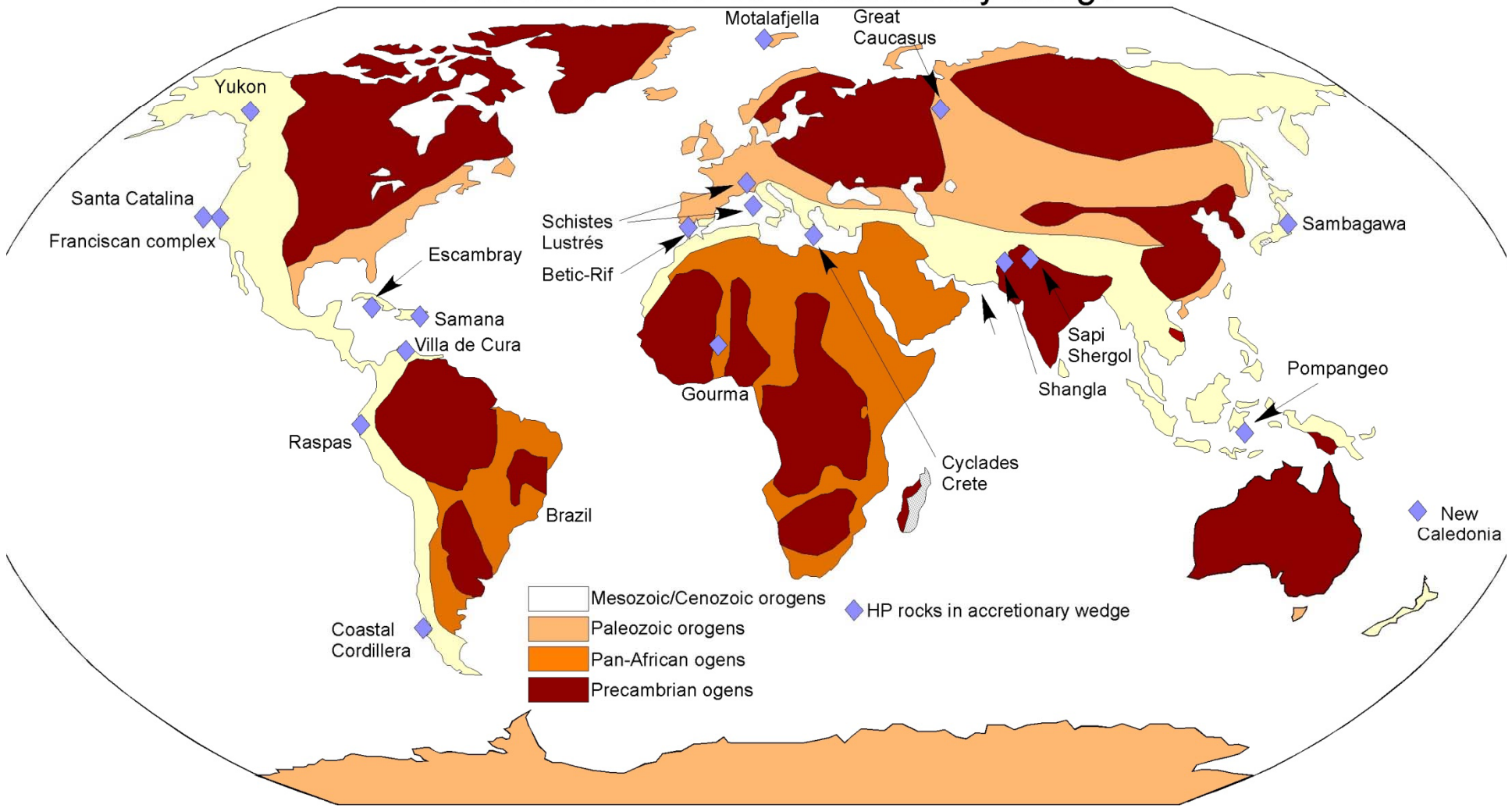
int V_{exhu} (0.5-1 cm/yr)

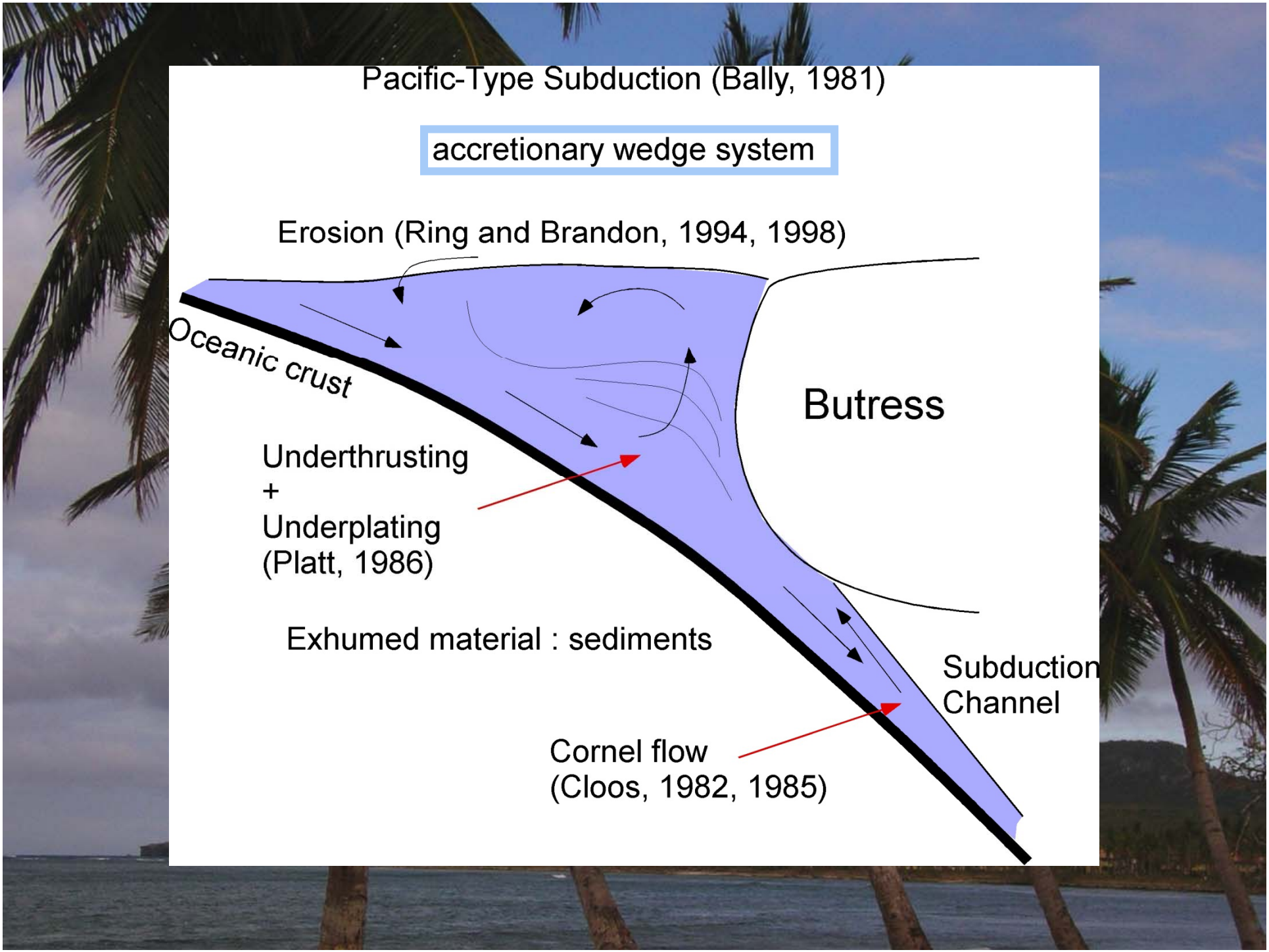
high V_{exhum} (0.7-3 cm/yr)

P-T-t data suggest different exhumation processes

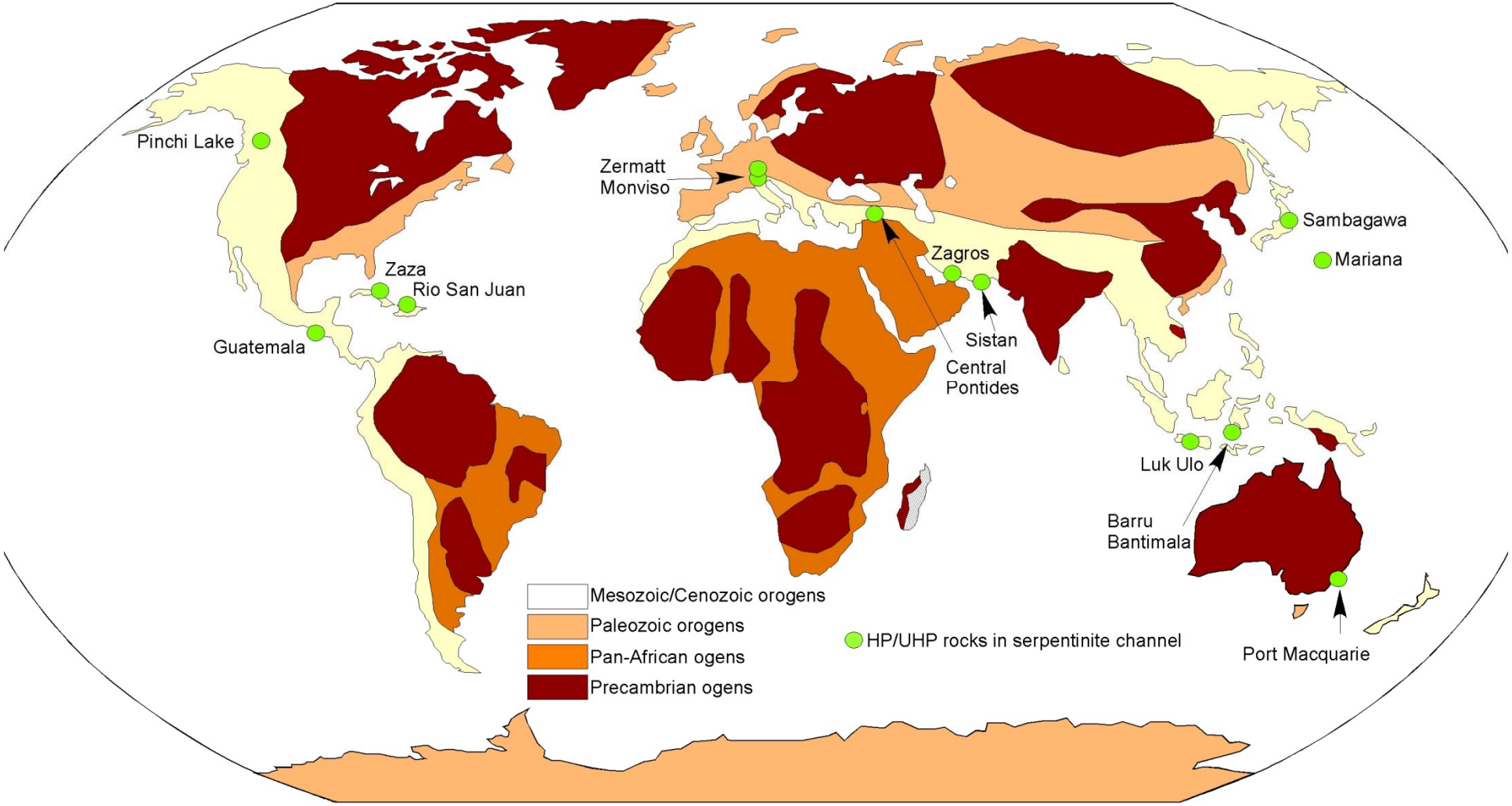
Guillot et al. 2009

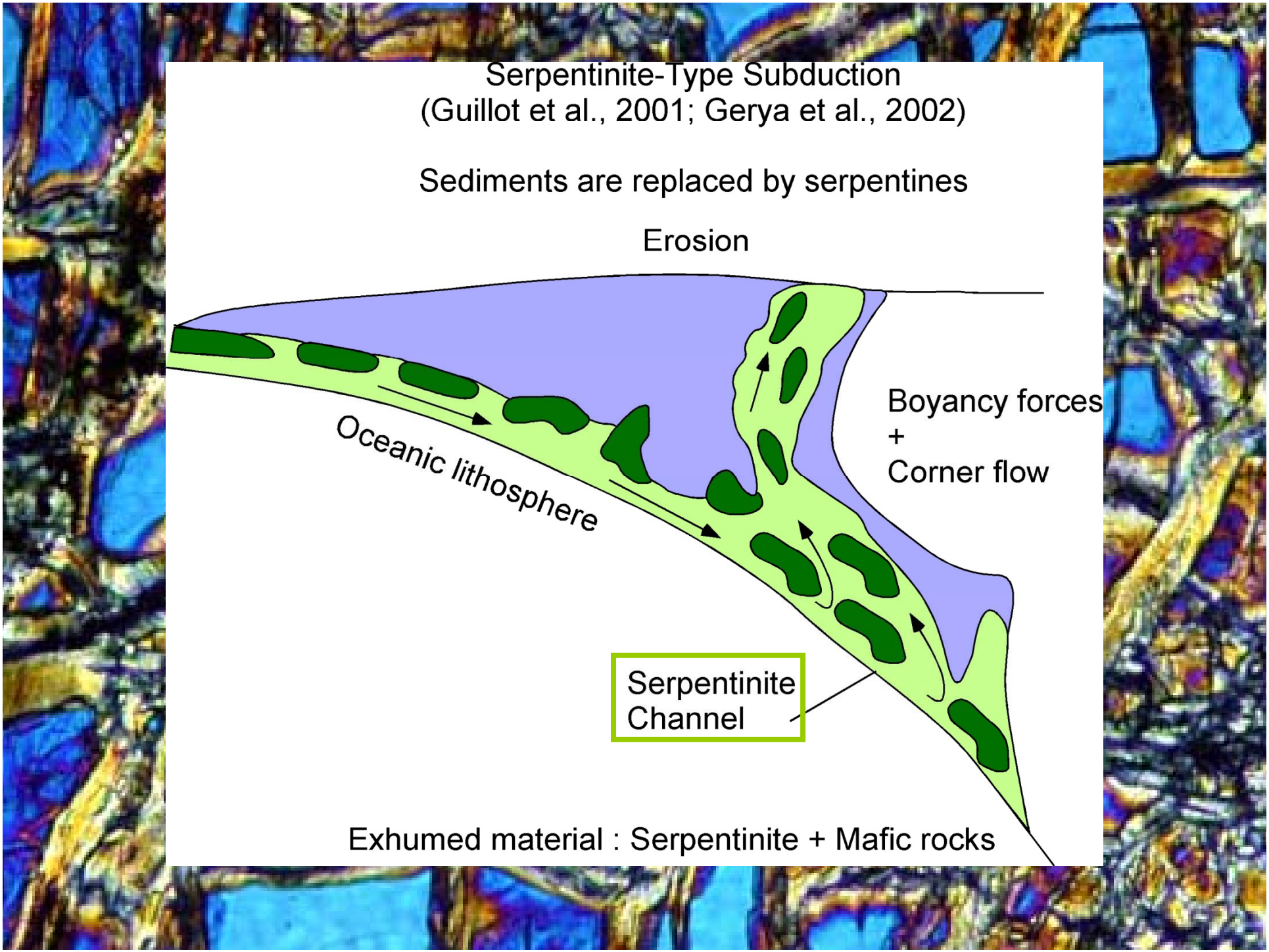
20 occurrences of HP accretionary wedge



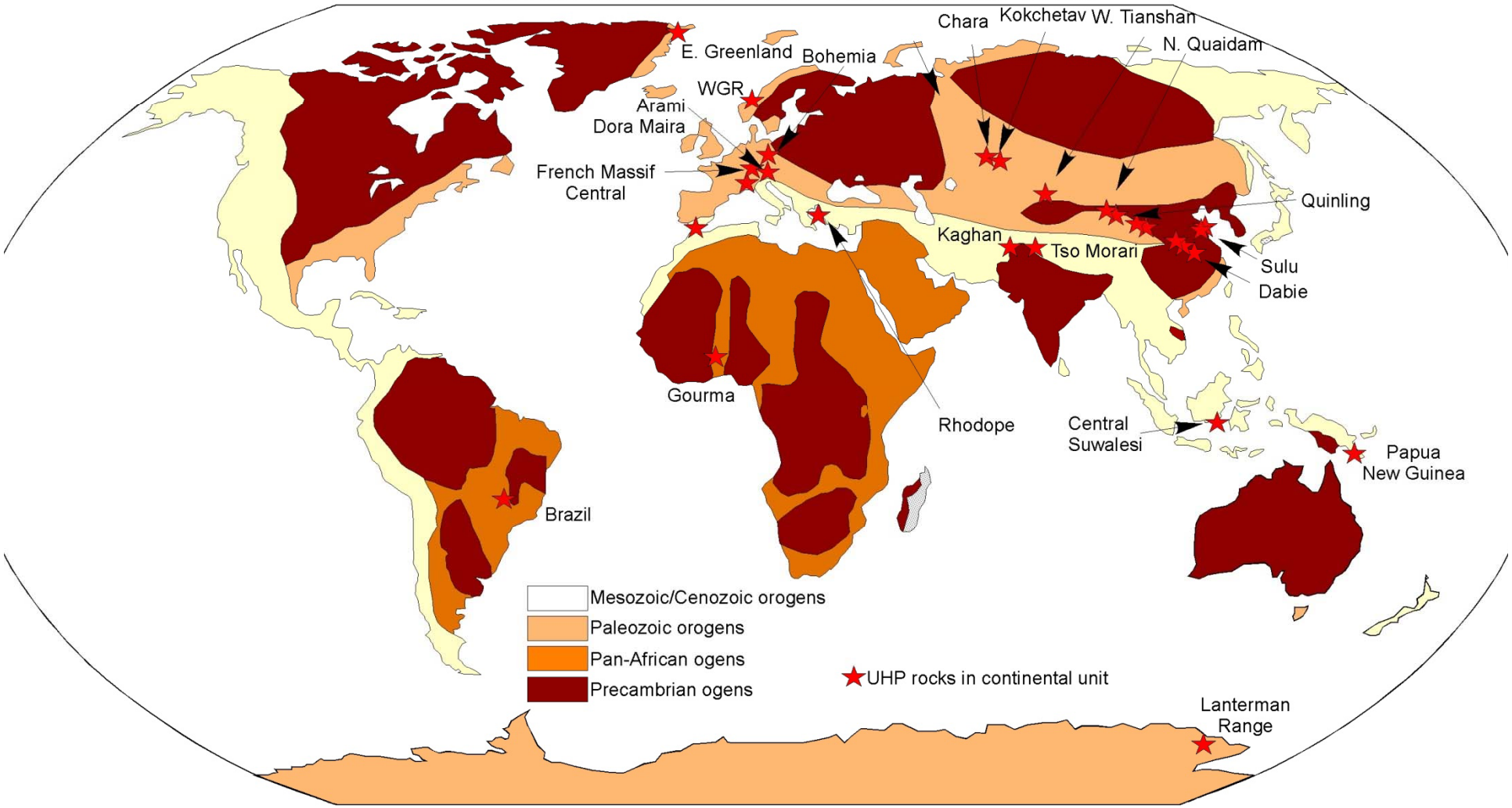

Pacific-Type Subduction (Bally, 1981)
accretionary wedge system
Erosion (Ring and Brandon, 1994, 1998)
Oceanic crust
Butress
Underthrusting
+
Underplating
(Platt, 1986)
Exhumed material : sediments
Subduction
Channel
Cornel flow
(Cloos, 1982, 1985)

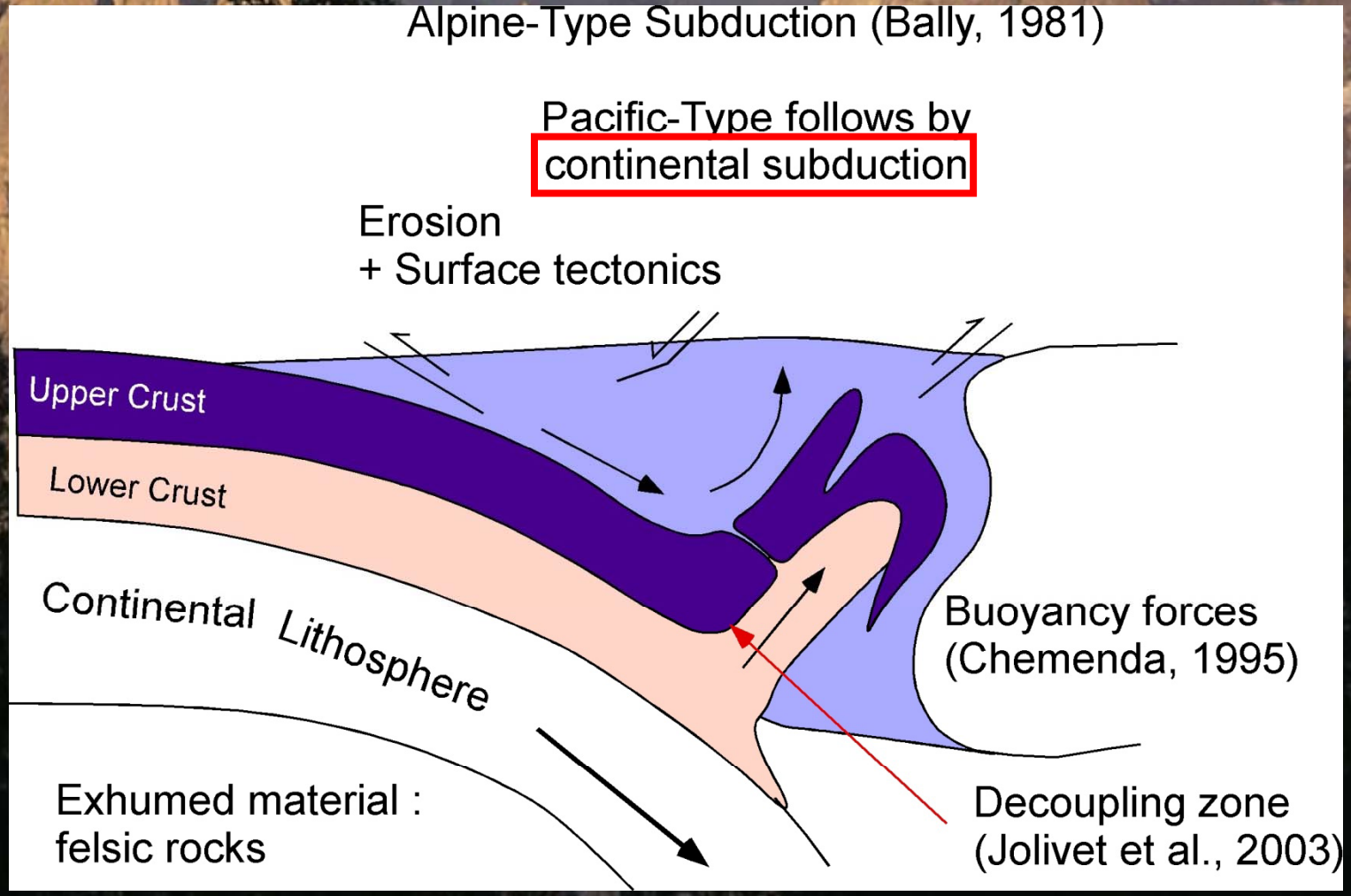
14 occurrences of HP-UHP rocks in serpentinite channel



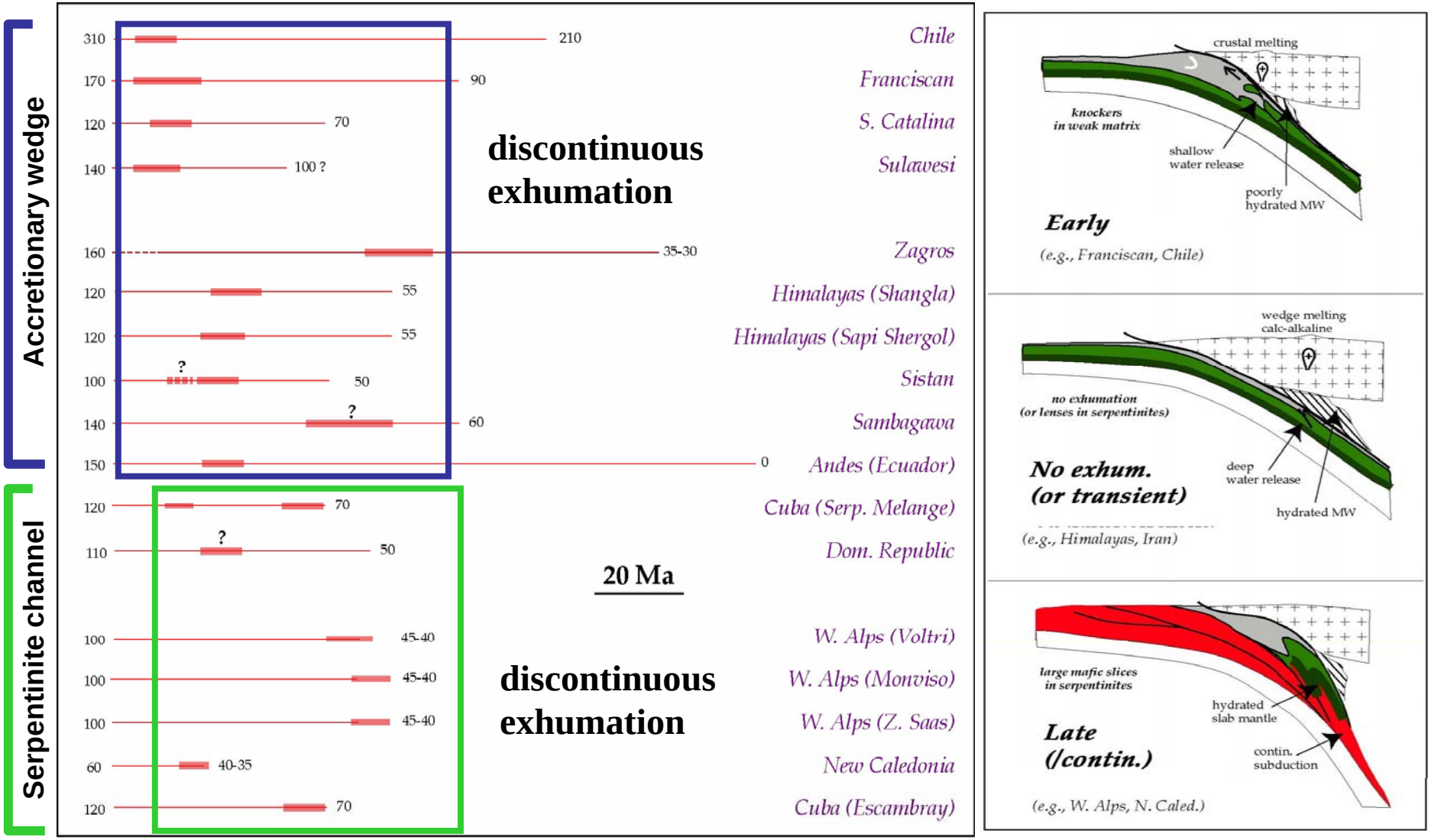

Serpentinite-Type Subduction
(Guillot et al., 2001; Gerya et al., 2002)
Sediments are replaced by serpentines
Erosion
Boyancy forces
+
Corner flow
Oceanic lithosphere
Serpentinite
Channel
Exhumed material : Serpentinite + Mafic rocks

27 occurrences of UHP continental units




Alpine-Type Subduction (Bally, 1981)
Pacific-Type follows by
continental subduction
Erosion
+ Surface tectonics
Upper Crust
Lower Crust
Continental Lithosphere
Buoyancy forces
(Chemenda, 1995)
Exhumed material :
felsic rocks
Decoupling zone
(Jolivet et al., 2003)

Timing of exhumation during oceanic subduction

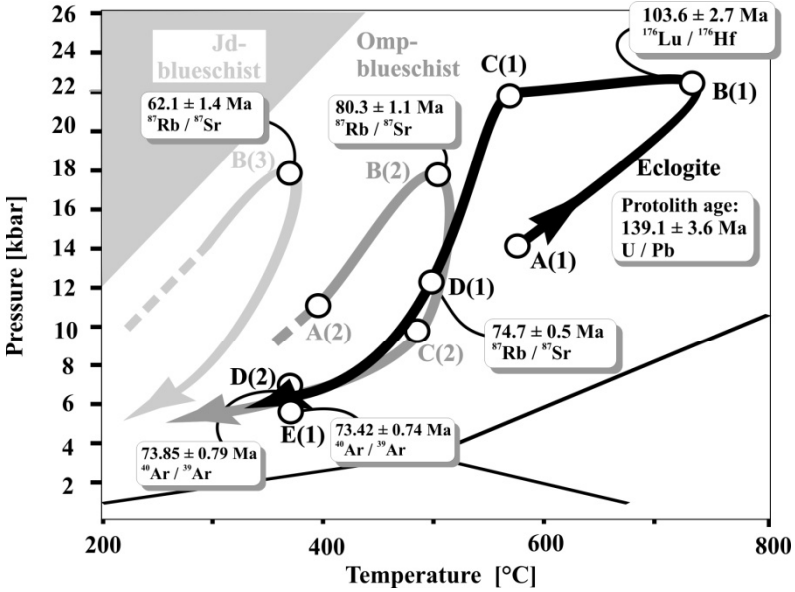


Agard et al., 2009

Discontinuous exhumation of oceanic materials is related to perturbation in the subduction dynamics:

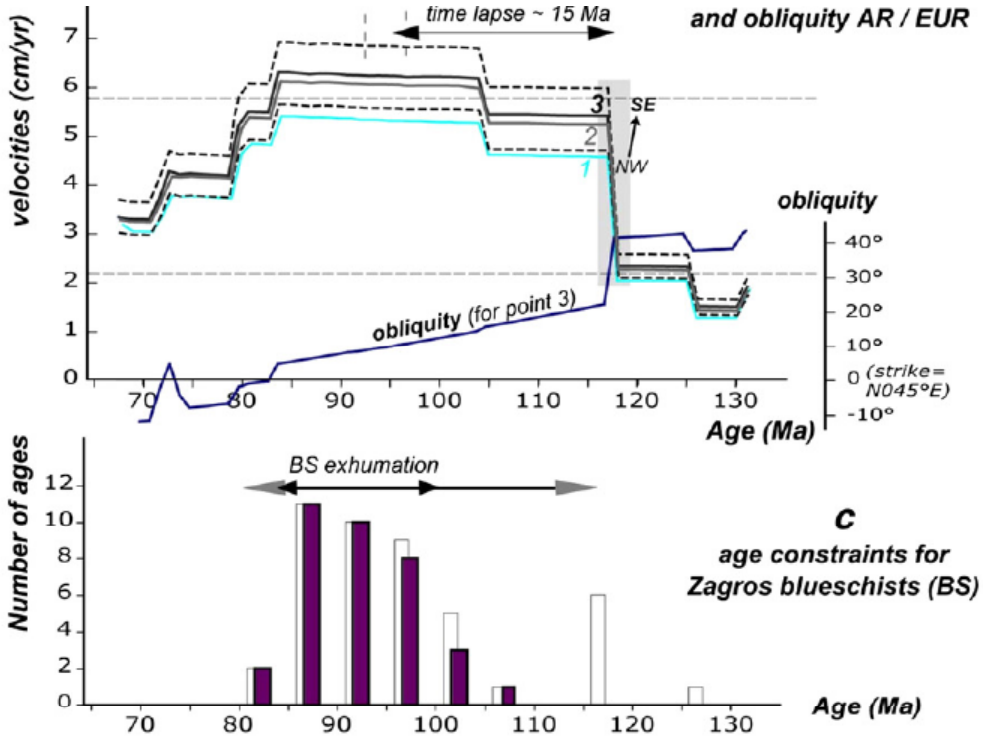
a) onset of oceanic subduction (North Carribean case) => Slab retreat

=> Counterclocwise P-T-t path



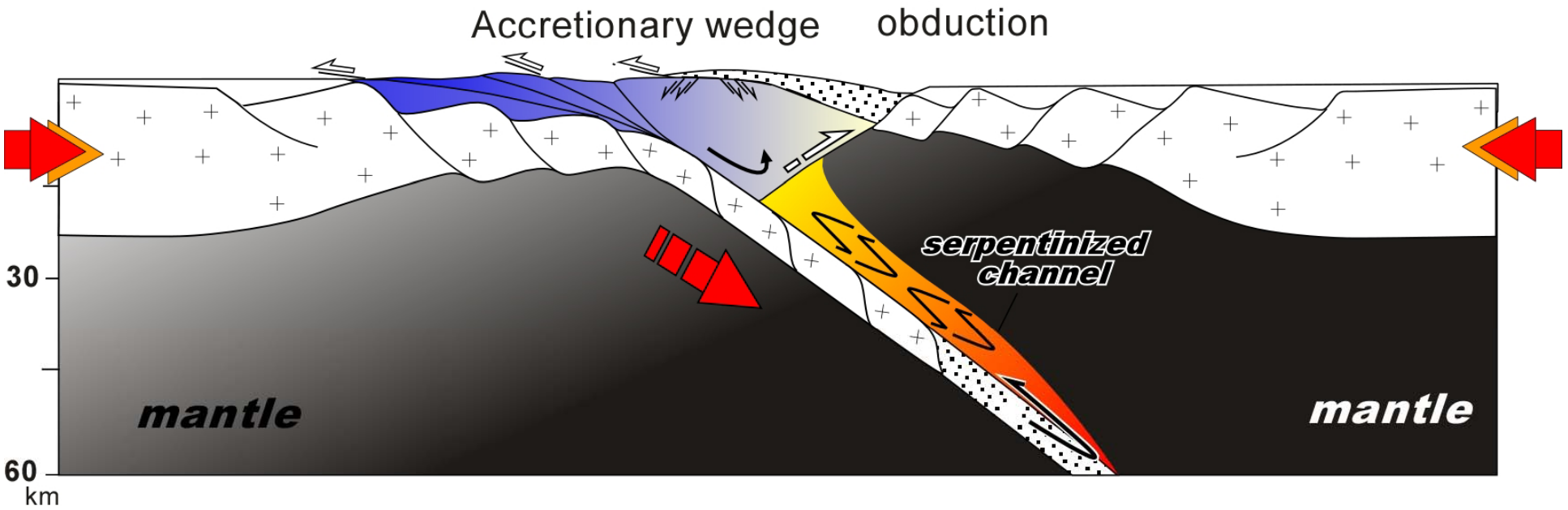
Krebs et al., in 2008.

b) increase in the subduction velocity (Zagros case)



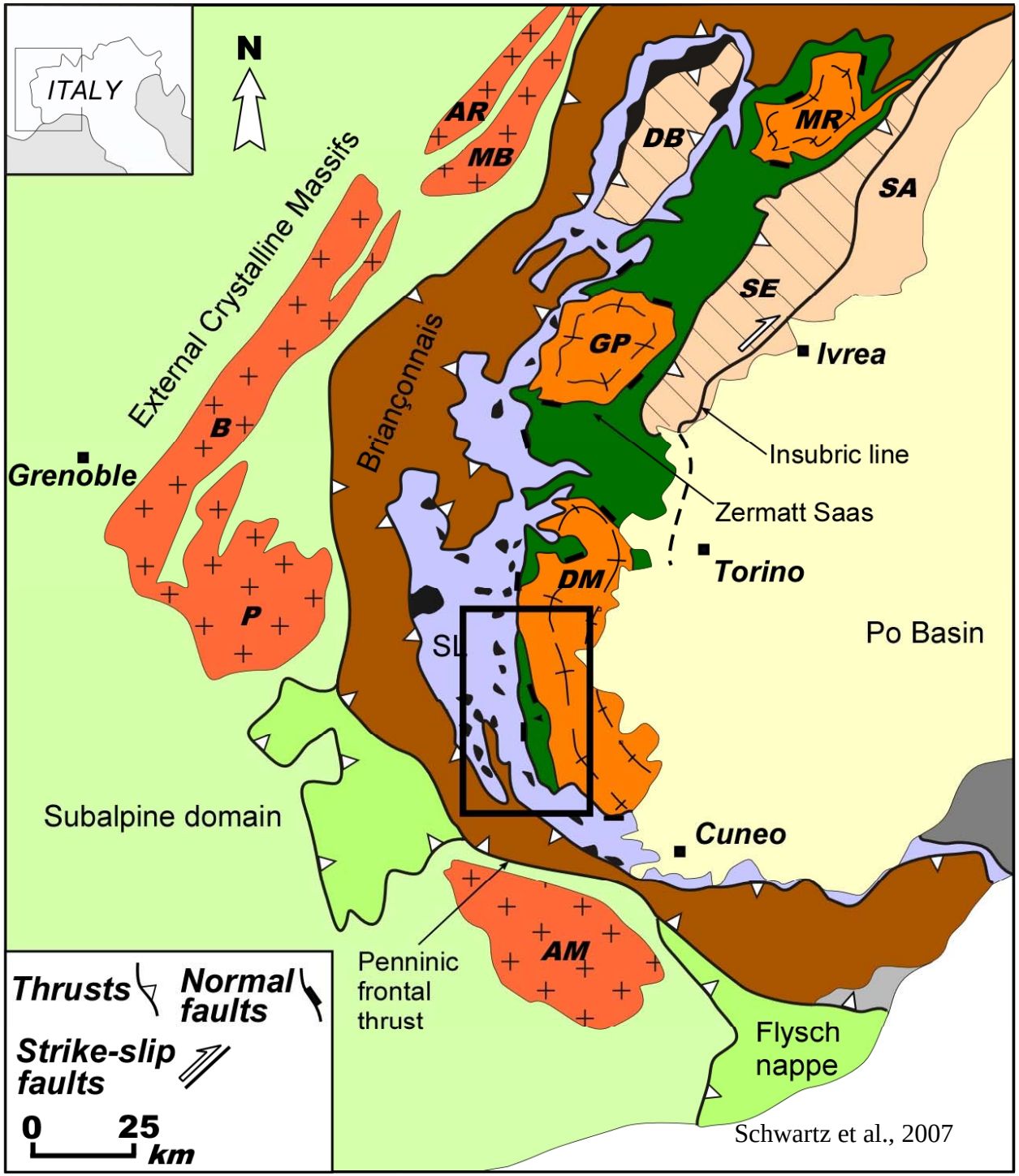
Agard et al., 2007

c) onset of continental subduction
(Alpine case)



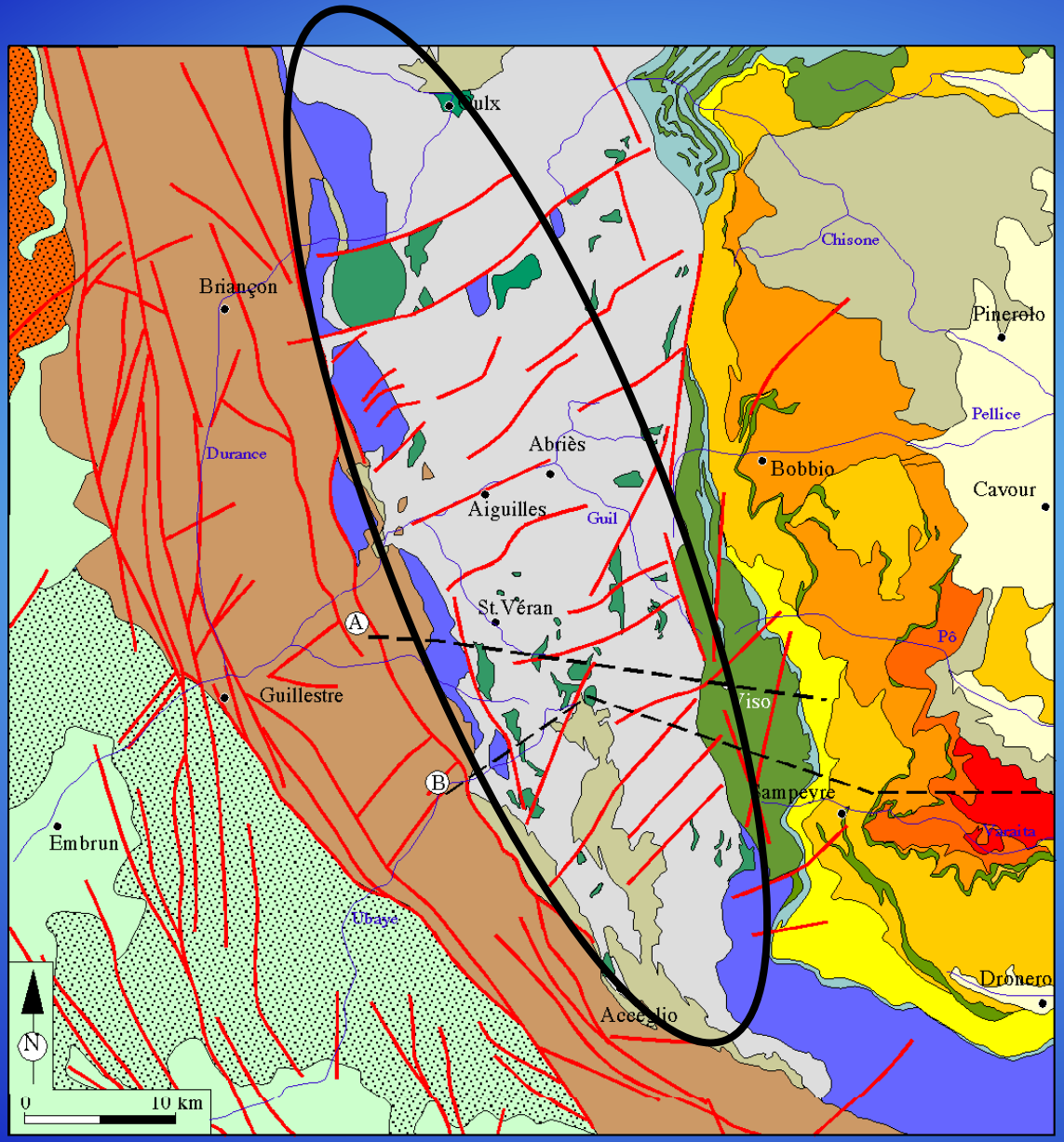
Guillot et al., 2005
Schwartz et al. 2007


Let’s go in the Alps
to see HP rocks



Schwartz et al., 2007

CARTE STRUCTURALE ET METAMORPHIQUE DES ALPES OCCIDENTALES



Zone Piémontaise Schistes Bleus

- Ophiolites
- Schistes Lustrés
- Piemontais de marge

- Massif du Pelvoux
- Nappes des Flyschs à Helmintoïdes
- Chaines Subalpines
- Zone Briançonnaise

Domaines éclogitiques Viso-Rocciavré

- Ophiolites
- Schistes Lustrés

- Ambin
- Zone d'Acceglio
- Unité de Pinerolo
- Sanfront

SB

- Failles tardives

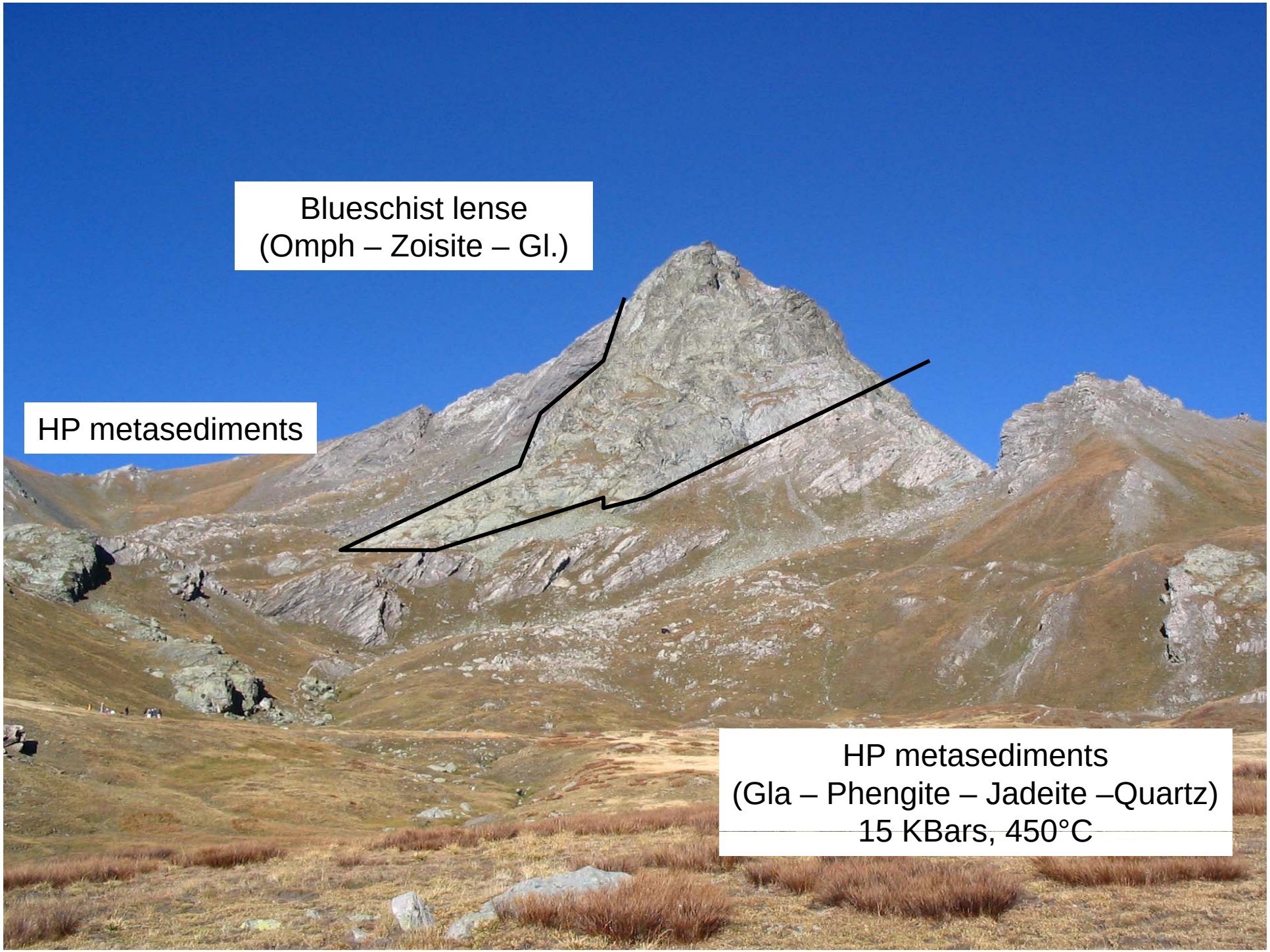
Massif de Dora-Maira

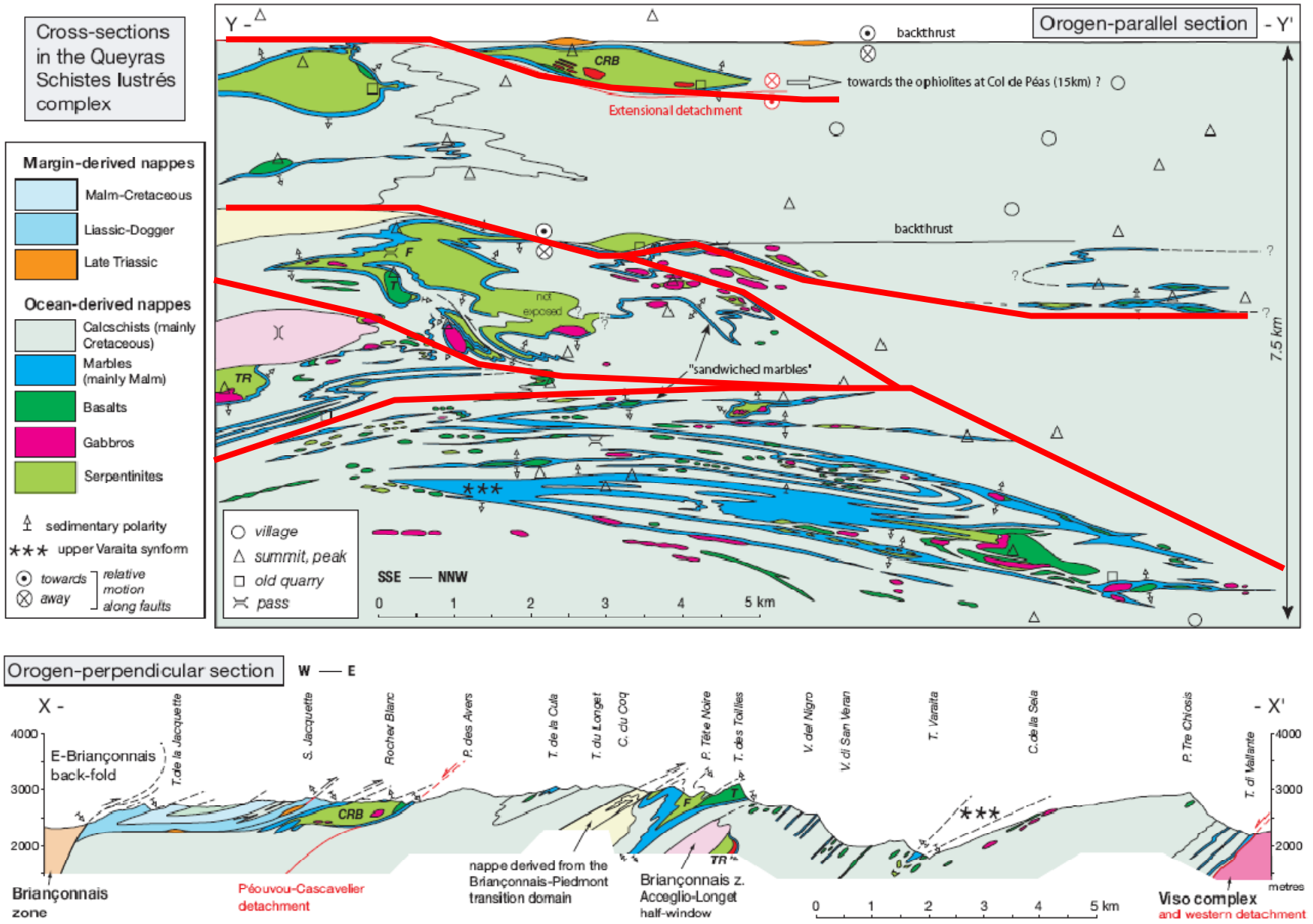
- Unité I UHP
- Unité II
- Unité III

Eclogitiques

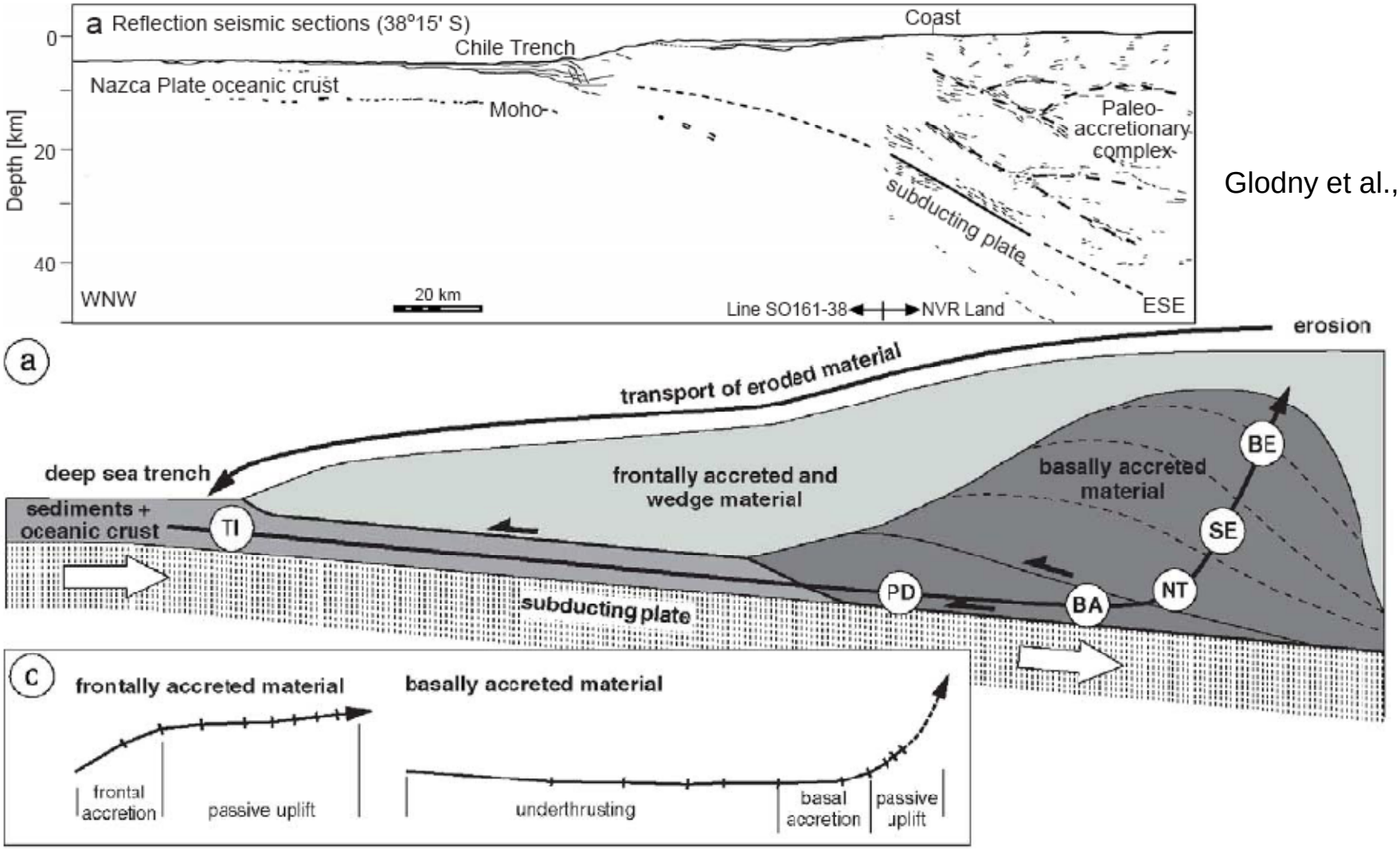
- Unité de Dronero Sampeyre Ecl/SB
- Couverture de Dronero Ecl/SB

- Rivières


Blueschist lense
(Omph – Zoisite – Gl.)
HP metasediments
HP metasediments
(Gla – Phengite – Jadeite –Quartz)
15 KBars, 450°C



Tricart and Schwartz, 2007



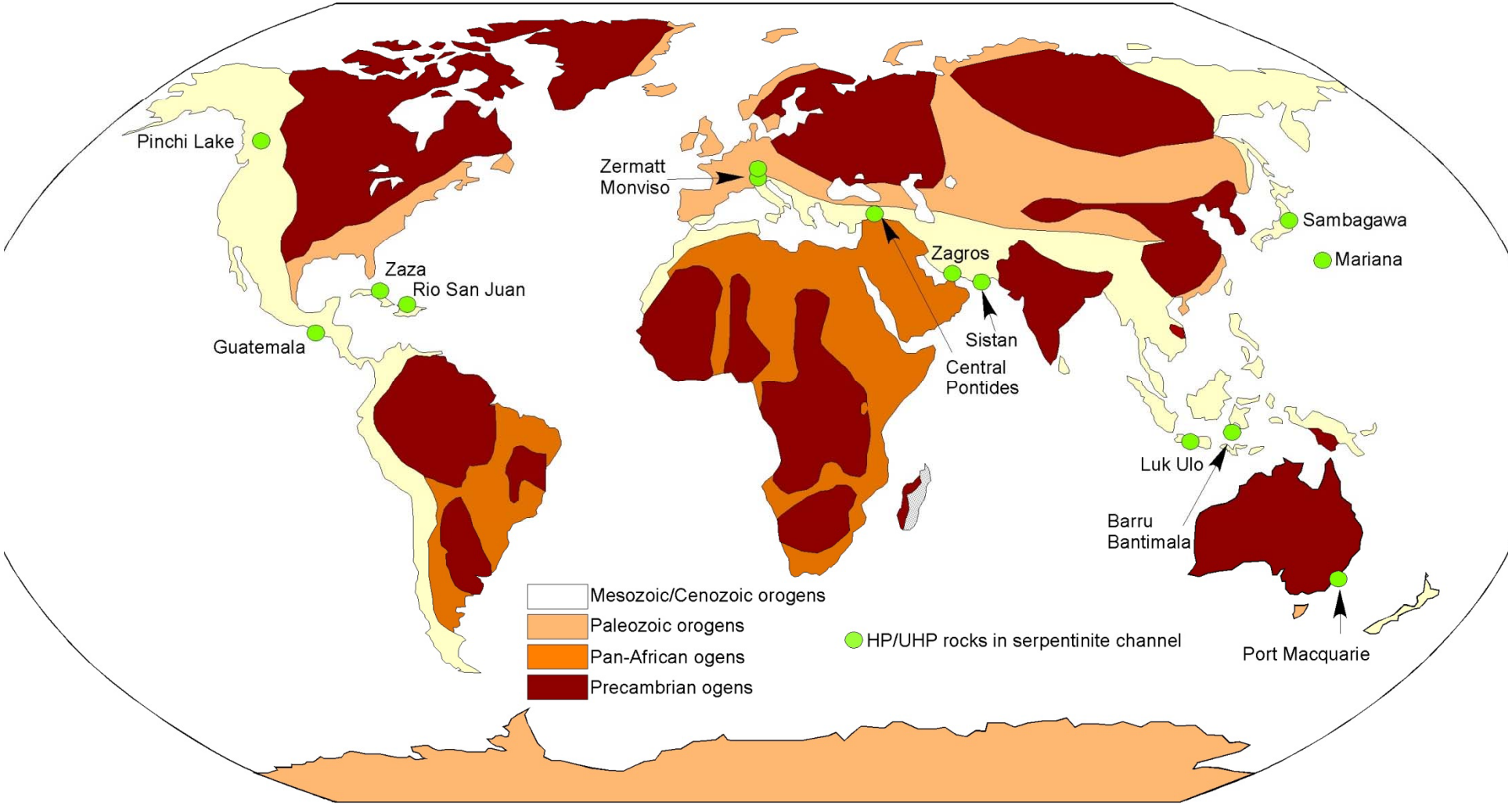
Glodny et al., 2005

Exhumation in a sedimentary accretionary wedge : e.g. Platt, 1986

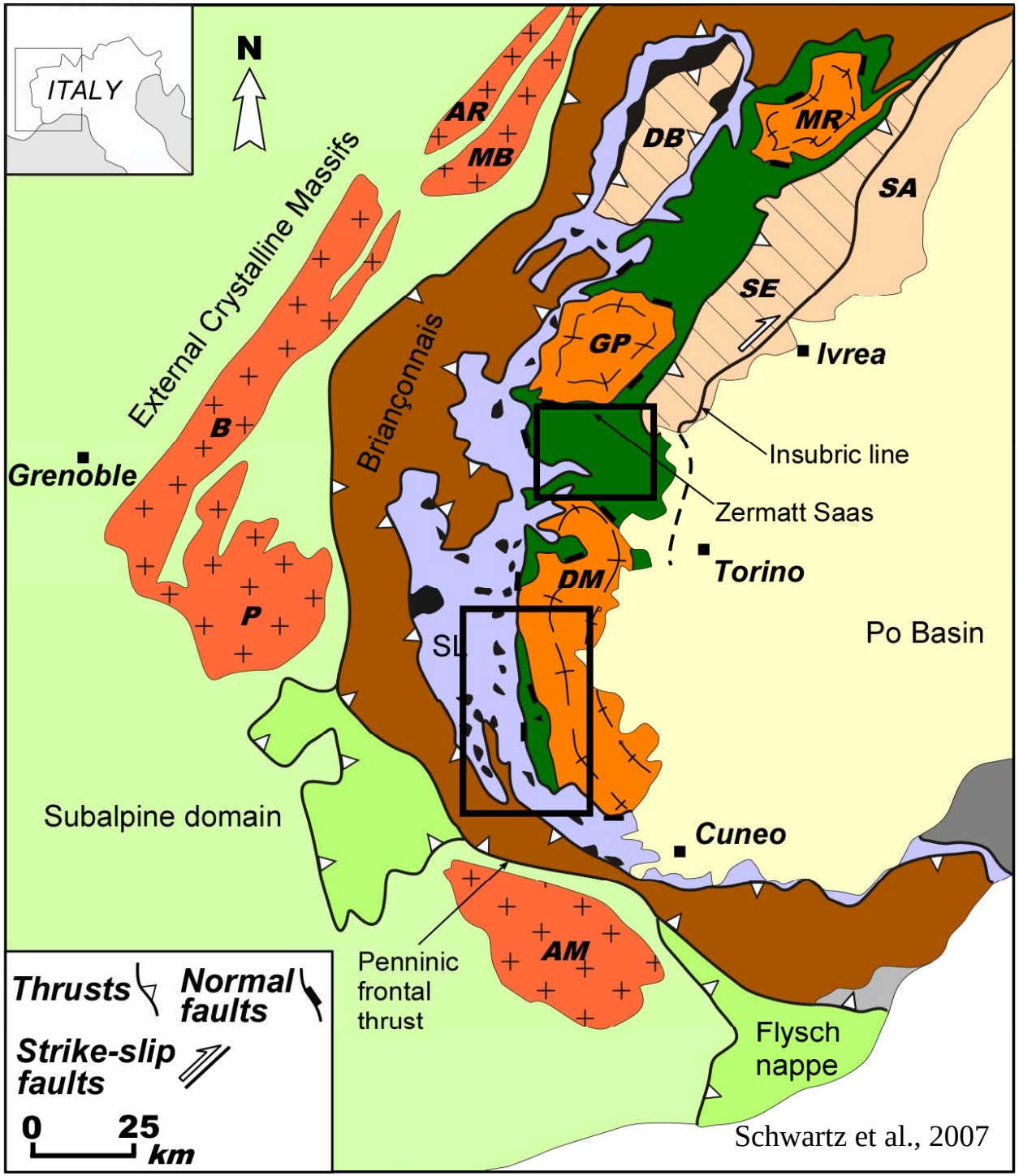
Low viscosity clastic sediments more abundant than rigid oceanic rocks

Basal accretion and extension + erosion at the surface

14 occurrences of HP-UHP rocks in serpentinite channel

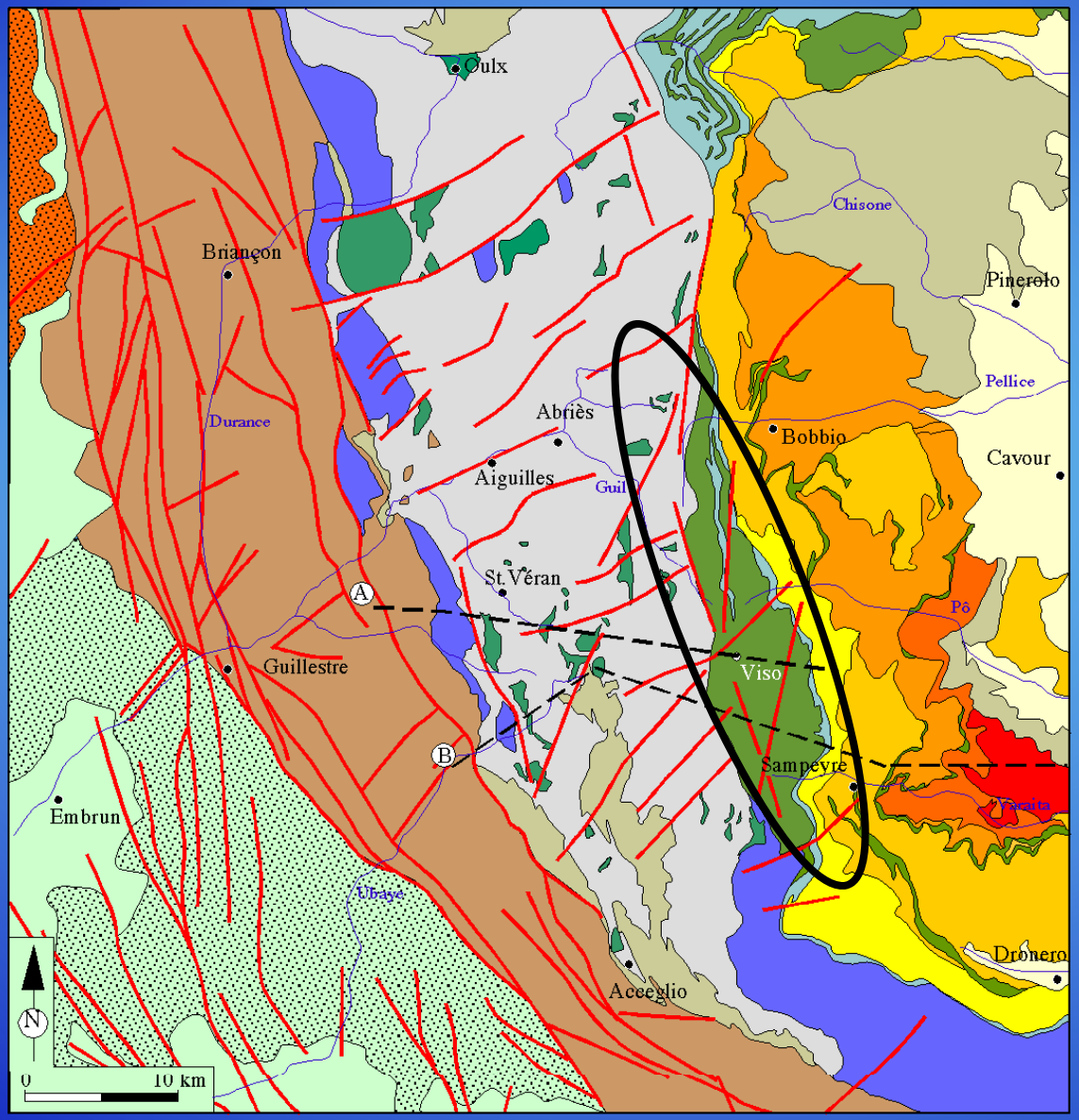


Guillot et al. 2009



Schwartz et al., 2007

CARTE STRUCTURALE ET METAMORPHIQUE DES ALPES OCCIDENTALES



Massif du Pelvoux

Nappes des Flyschs à Helmintoïdes

Chaines Subalpines

Zone Briançonnaise

Domaines éclogitiques Viso-Rocciavré

Ophiolites

Schistes Lustrés

Massif de Dora-Maira

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Unité III

Eclogitiques

Unité de Dronero Sampeyre Ecl/SB

Couverture de Dronero Ecl/SB

Rivières

Zone Piémontaise Schistes Bleus

Ophiolites

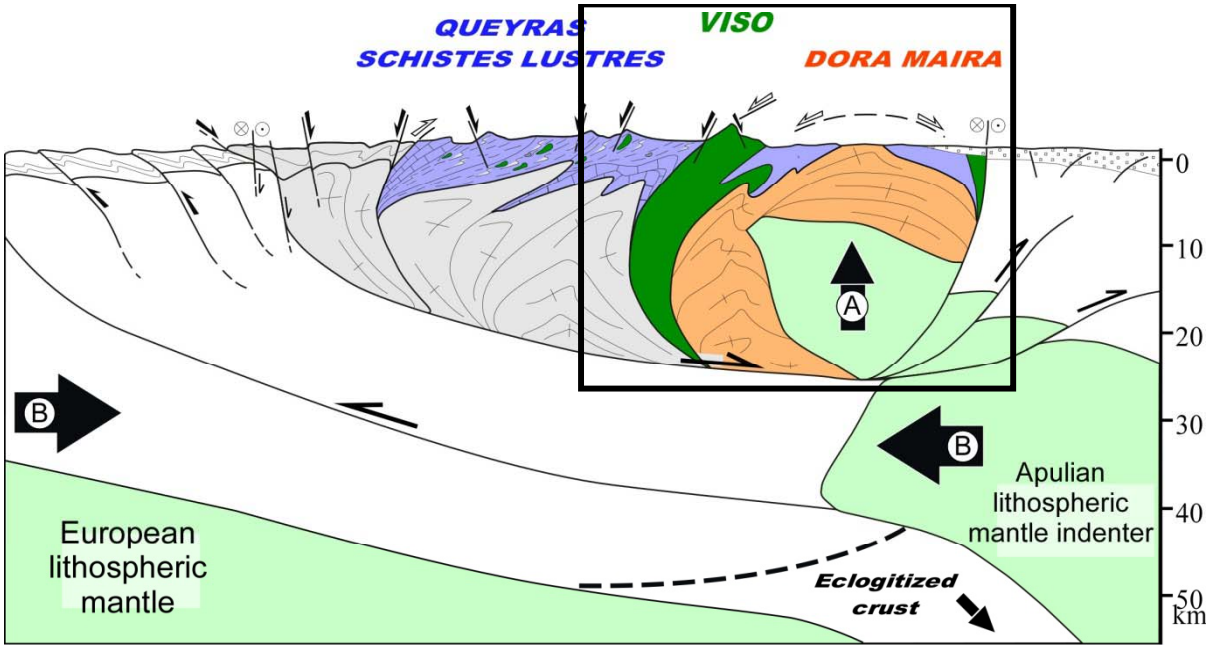
Schistes Lustrés

Piemontais de marge

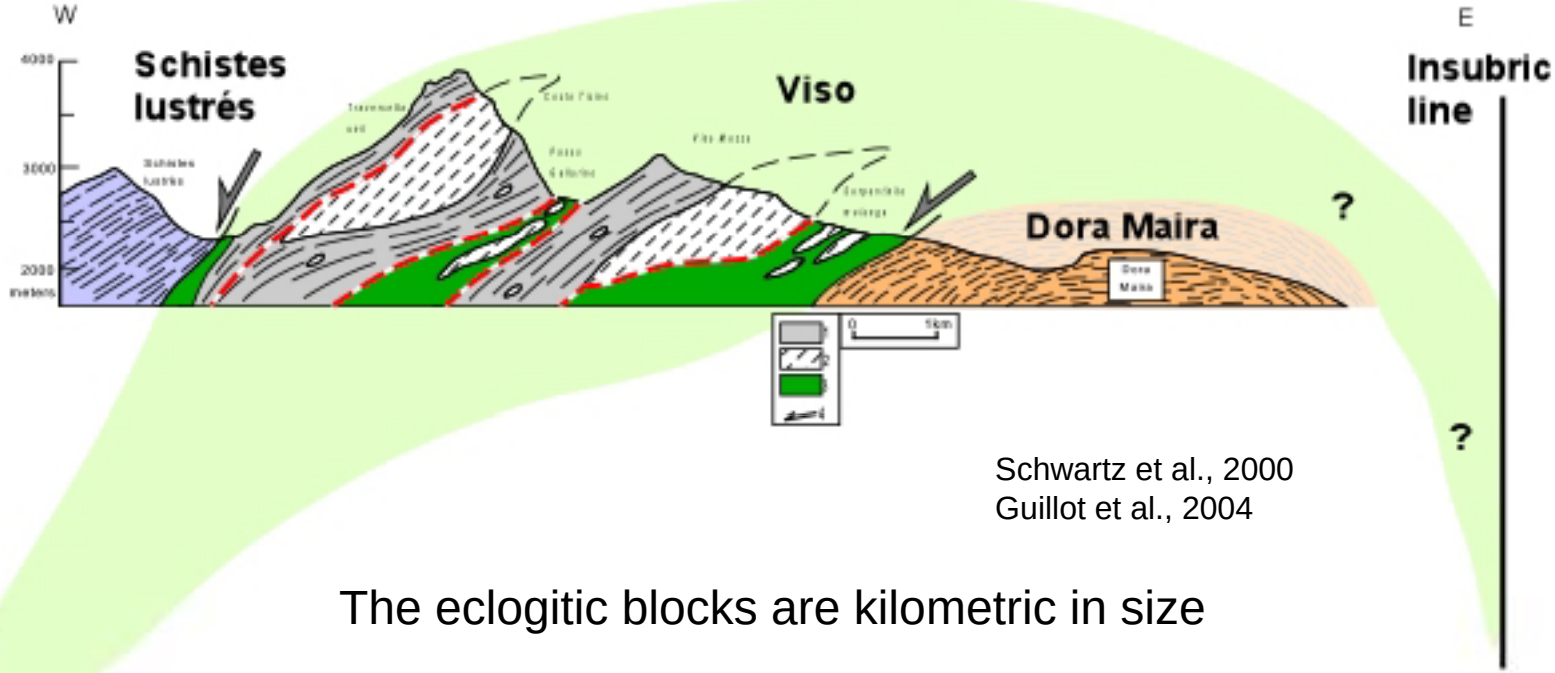
Ambin
Zone d'Acceglio
Unité de Pinerolo
Sanfront

SB

Failles tardives

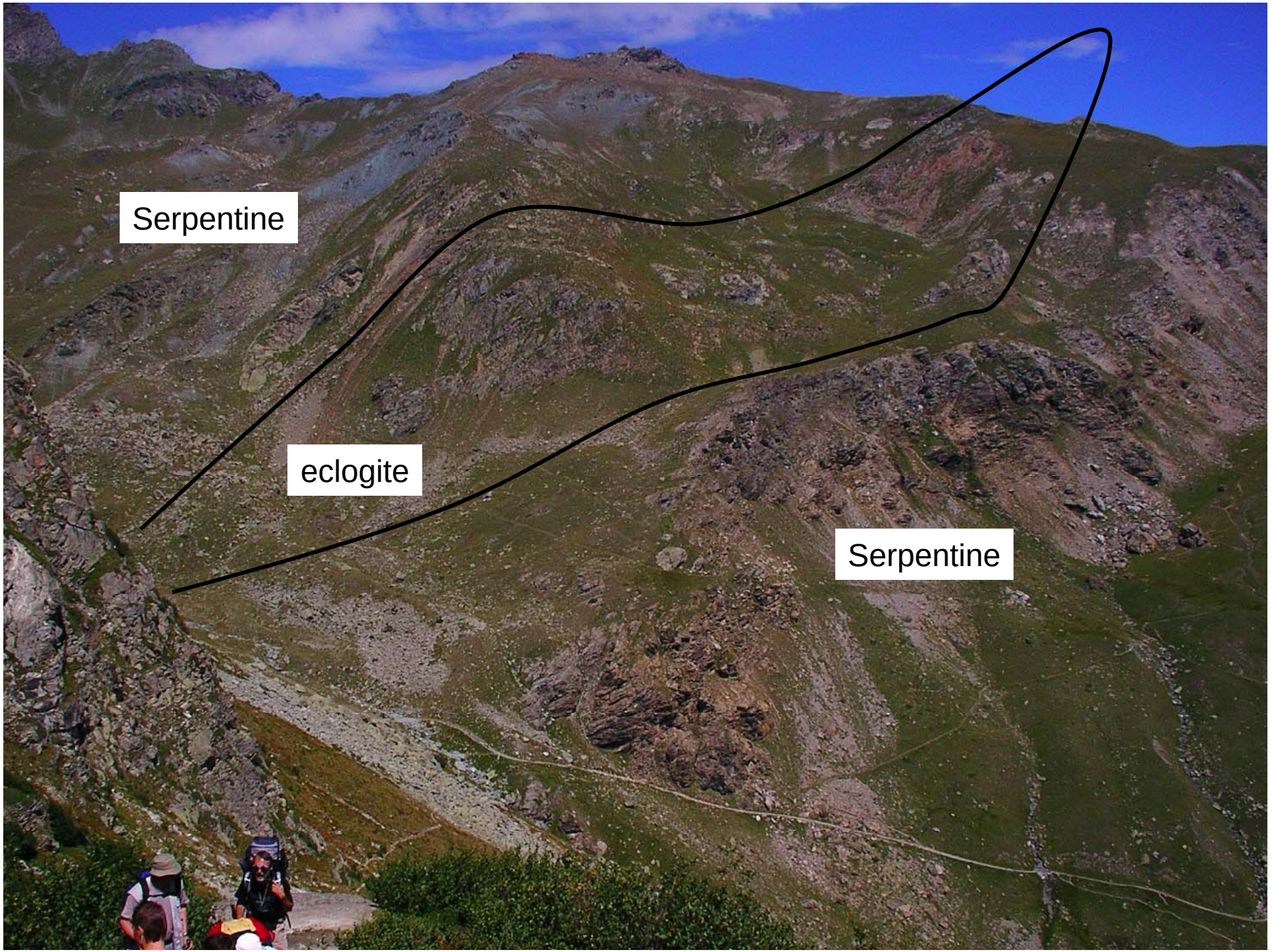


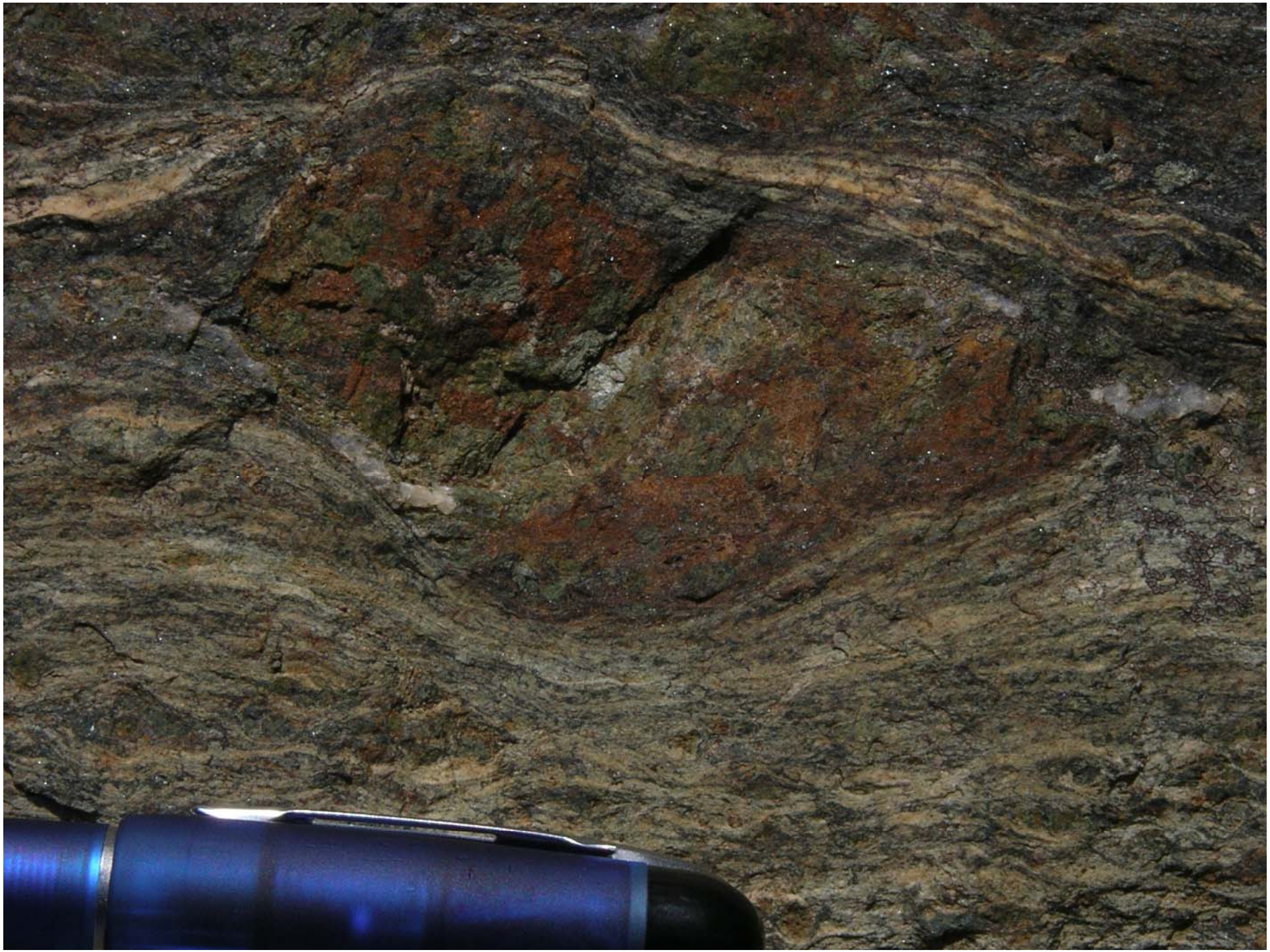
Lardeaux et al., 2007



Schwartz et al., 2000
Guillot et al., 2004

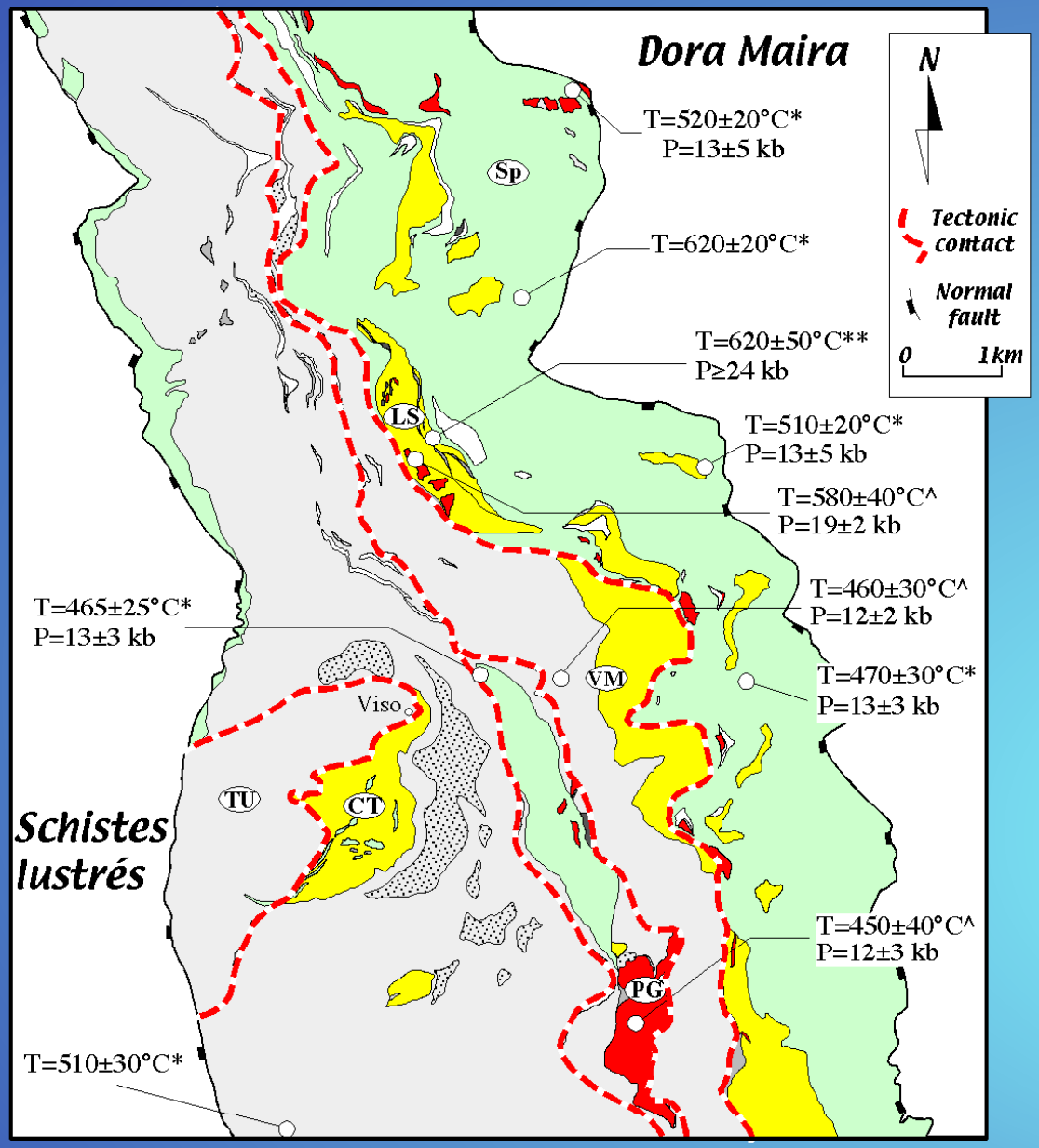
The eclogitic blocks are kilometric in size

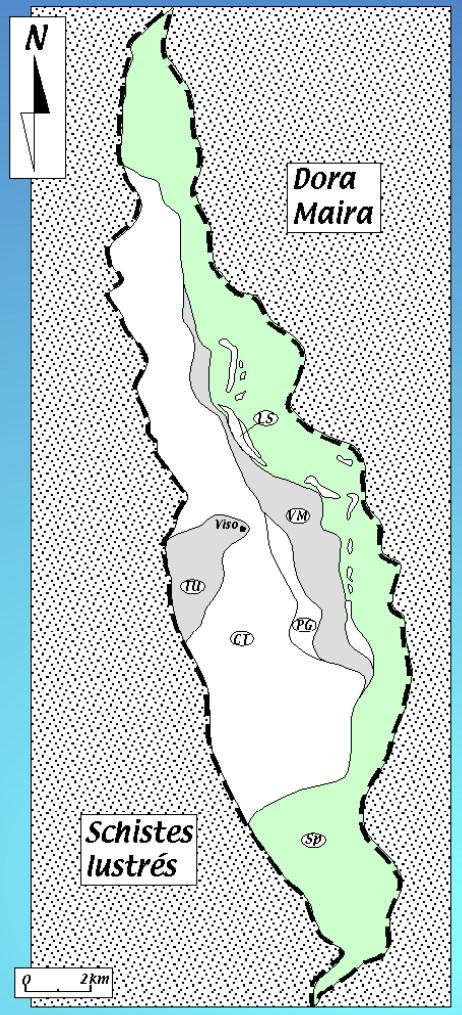

Serpentine
eclogite
Serpentine




iMPEGA
DRY WIPE MARKER

LA PARTIE CENTRALE DU MONVISO





PG Passo Gallarino **2.63km²**

VM Viso Mozzo **10.63km²**

CT Costa Ticino **46.35km²**

TU Traversetta unit **4.81km²**

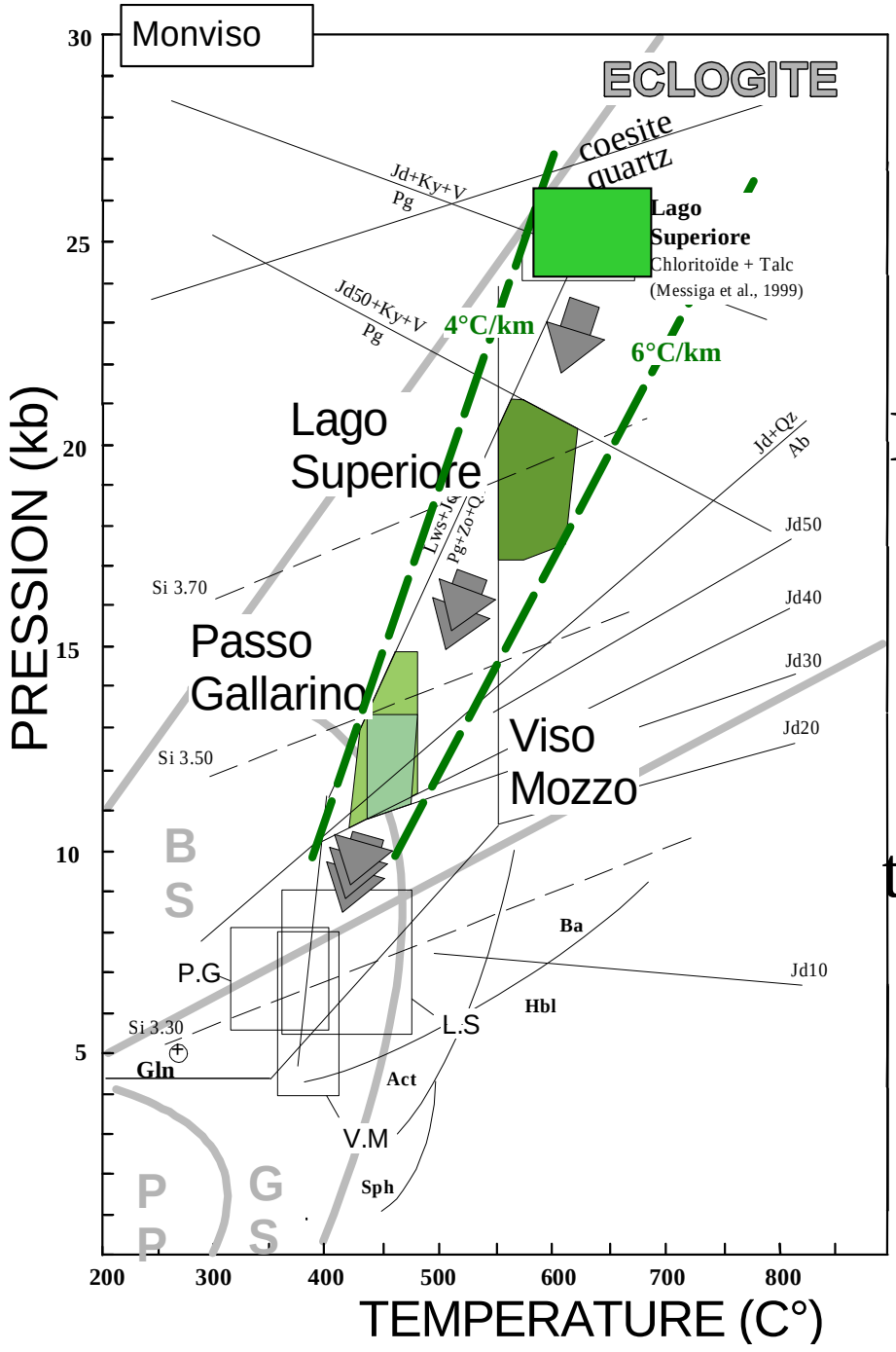
Sp Serpentinite melange **54.49km²** including

LS Lago Superiore **1.10km²**

Le volume des différentes unités est inférieur à 50km³

(*) Blake *et al.*, 1995
(**) Messiga *et al.*, 1999
(^) Schwartz *et al.*, 2000

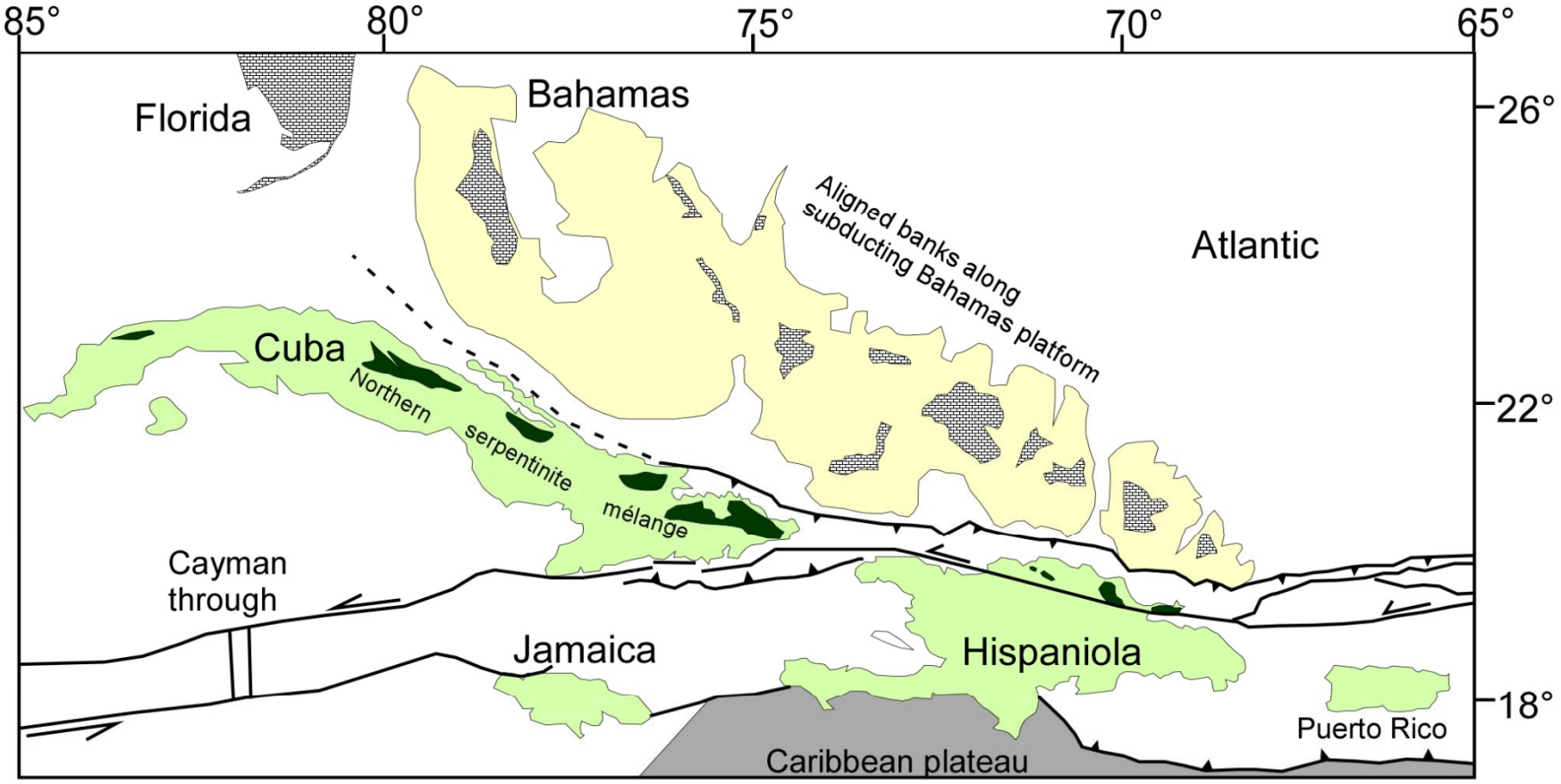
Schwartz et al., 2001



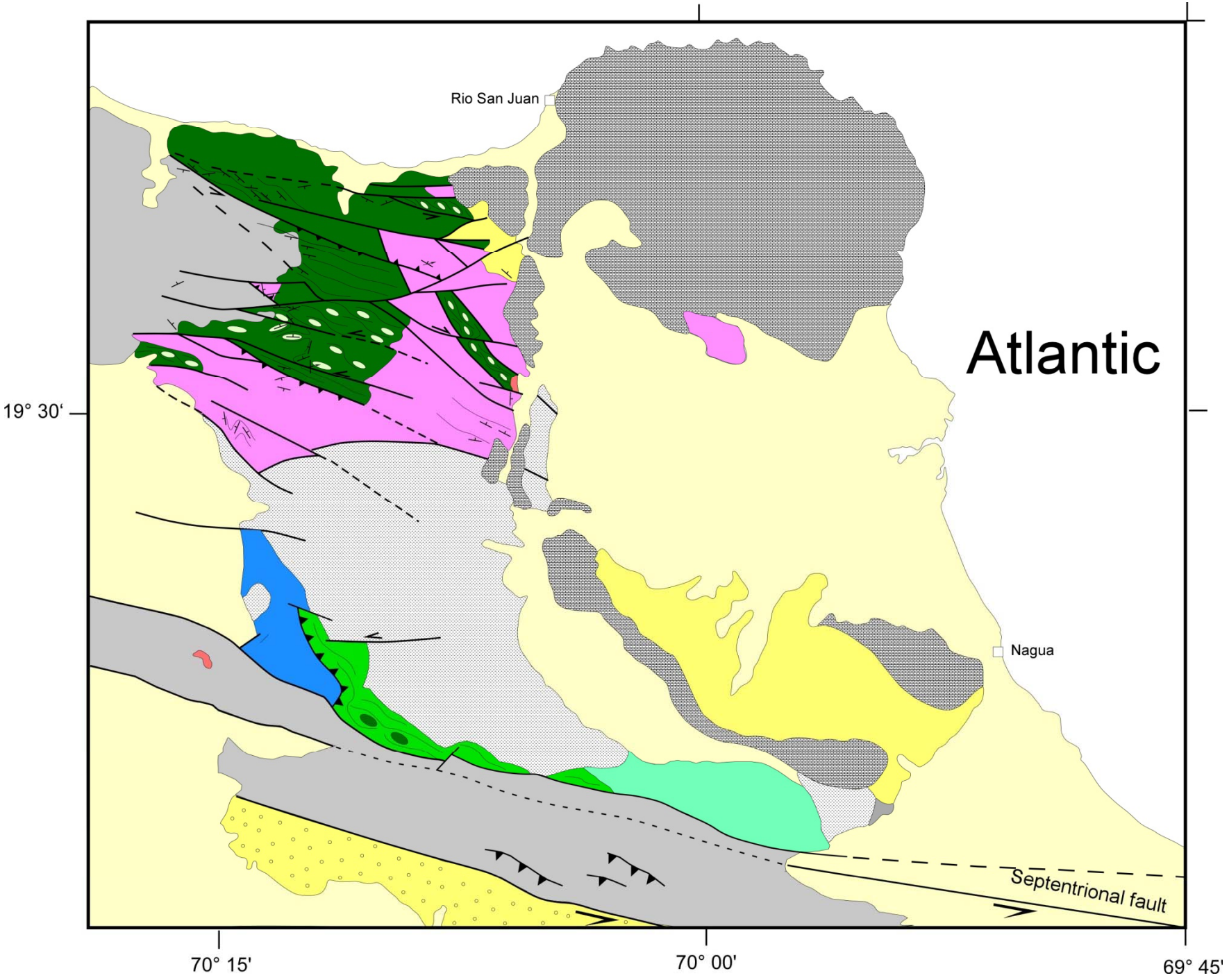
Each eclogitic block records different P-T conditions but aligned along the same geotherm =>

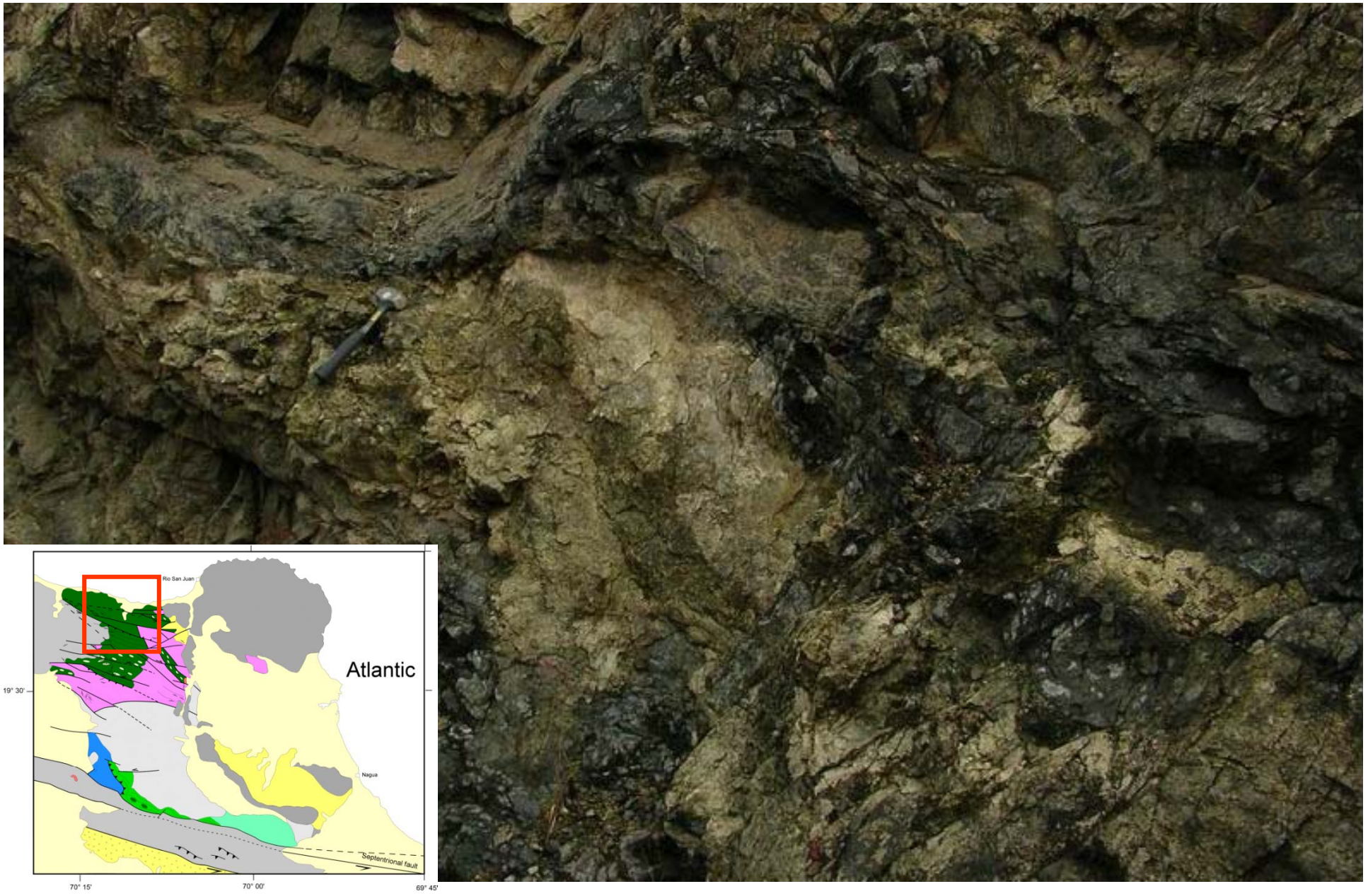
typical of a tectonic mélange in the subduction channel

Schwartz et al., 2000, 2001

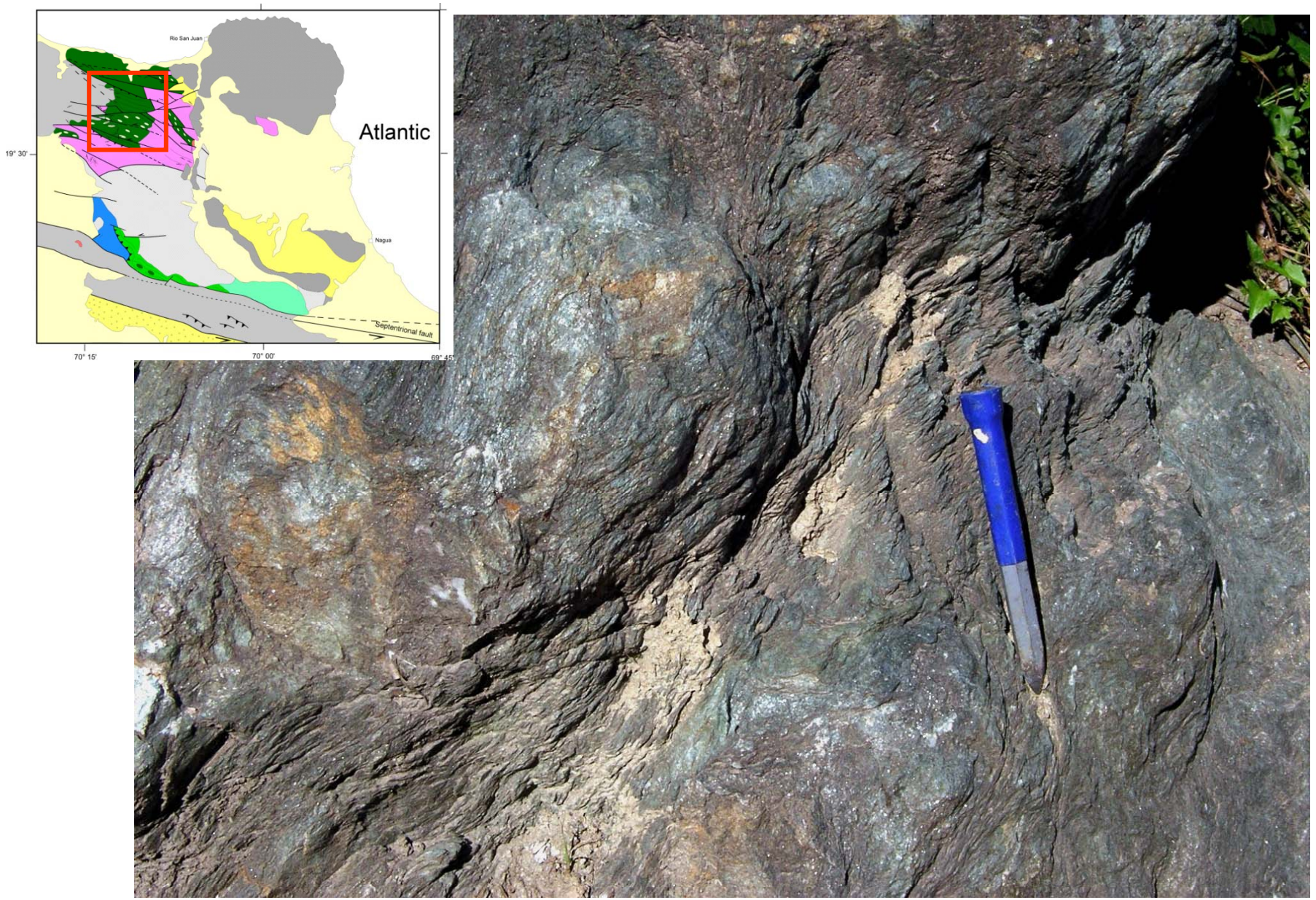


Gorczyk et al, 2007
Saumur et al., 2010

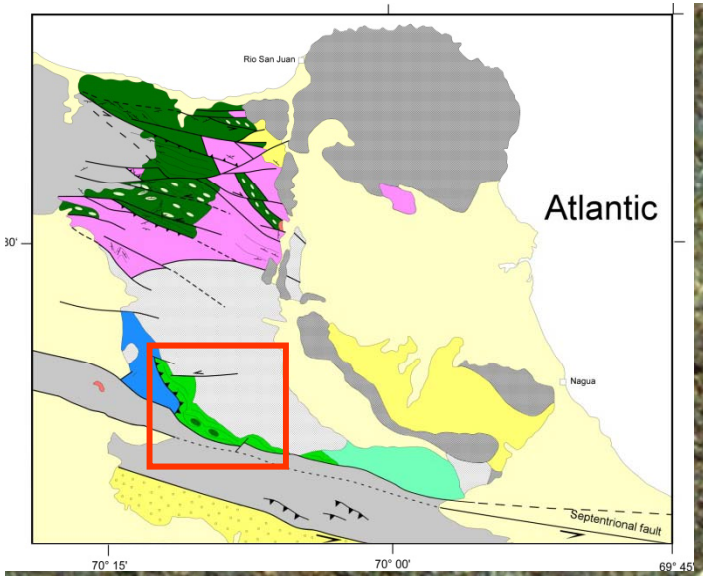

Rio San Juan
Atlantic
Nagua
Septentrional fault
19° 30'
70° 15'
70° 00'
69° 45'

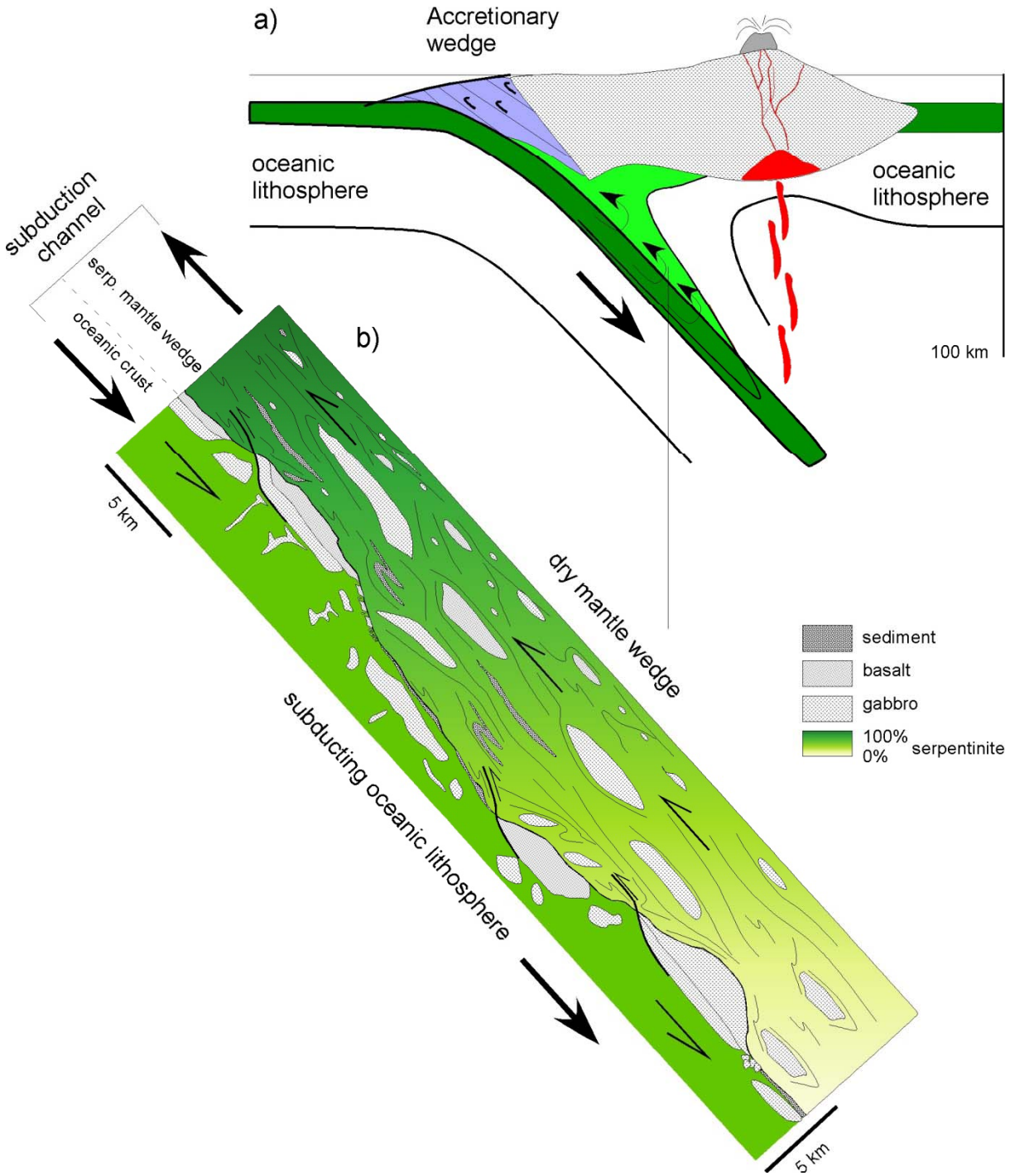


External forearc : dolertic sills in a serpentine matrix

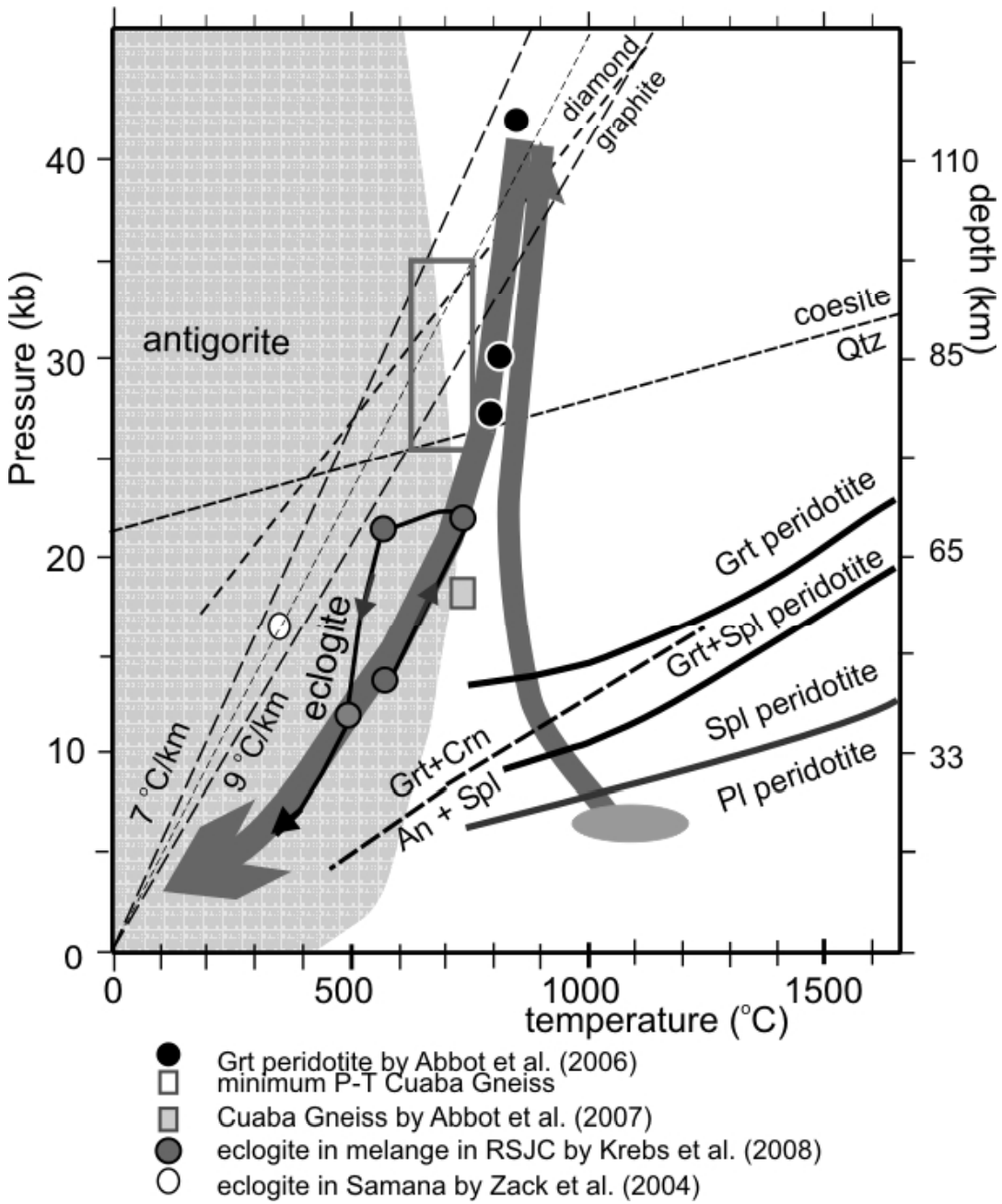


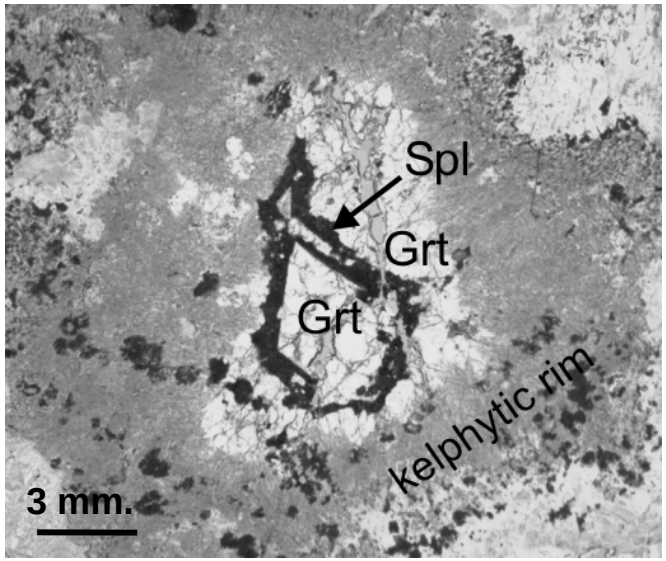
Forearc: blueschists and eclogites are exhumed in a serpentine matrix

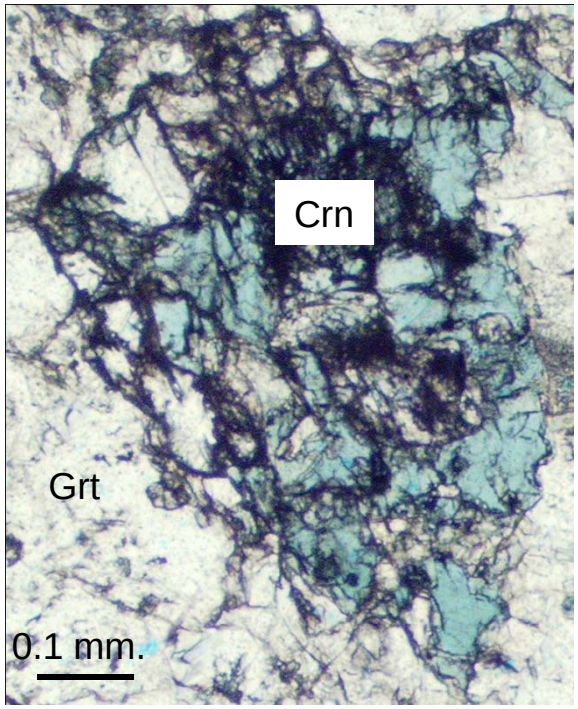

Rio San Juan
Atlantic
Nagua
Septentrional fault
70° 15'
70° 00'
69° 45'



Guillot et al., 2009

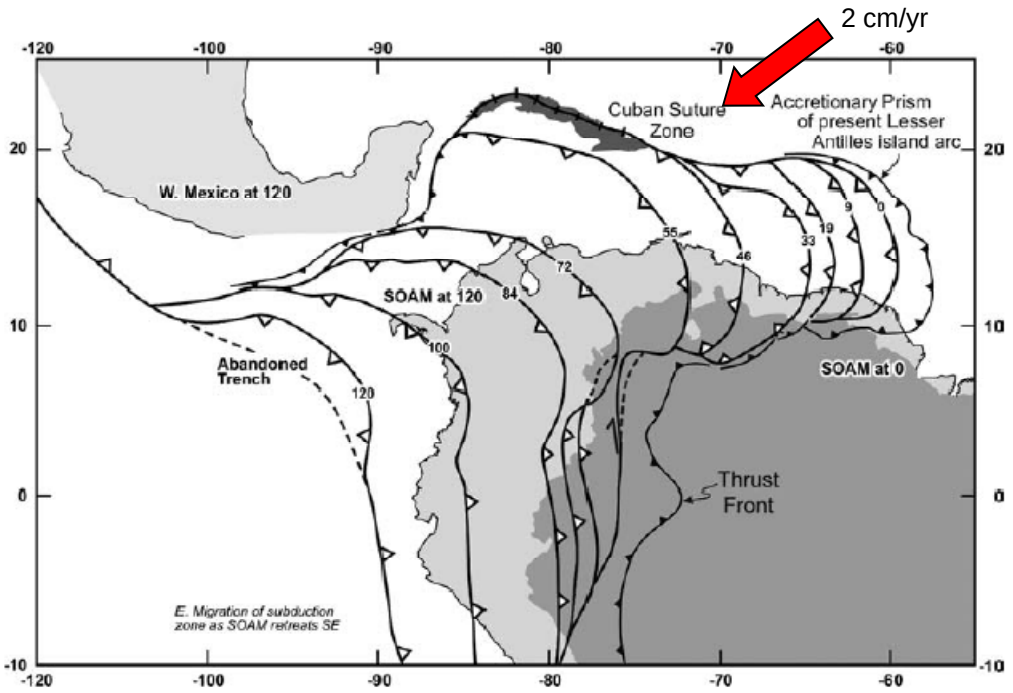




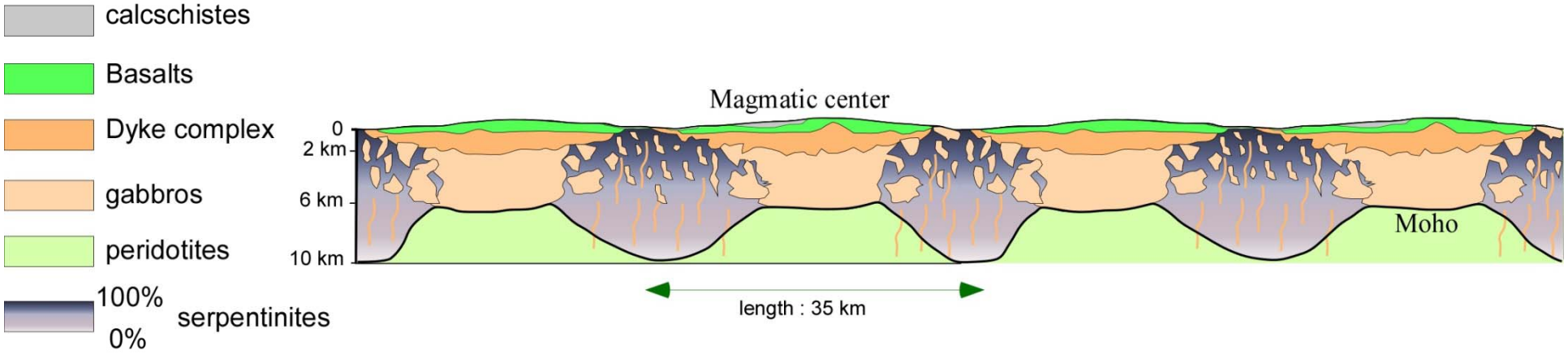


Hattori et al., Lithos, 2010

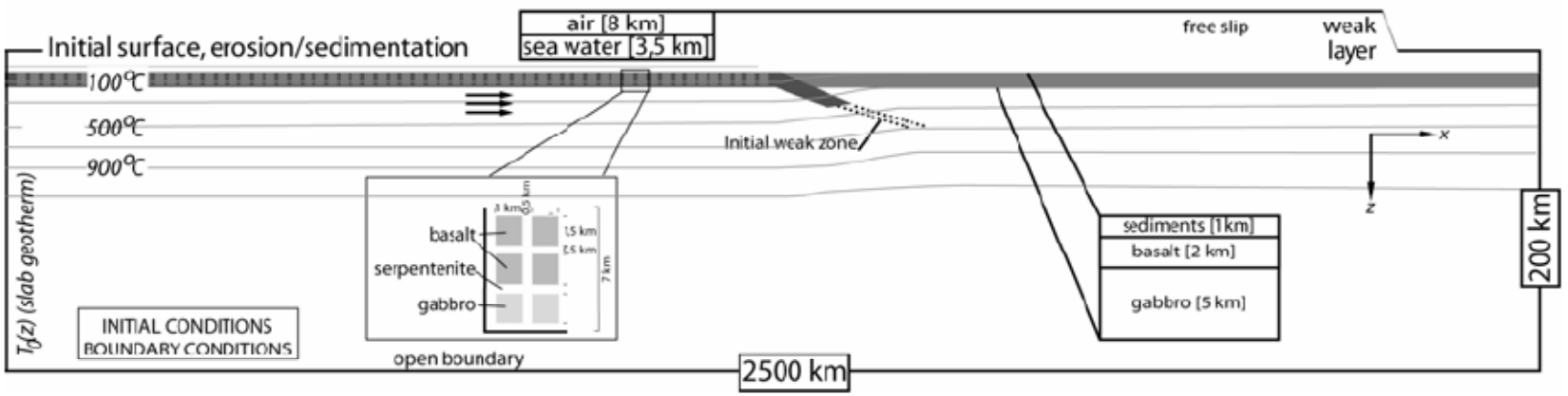
Modelling the serpentinite channel

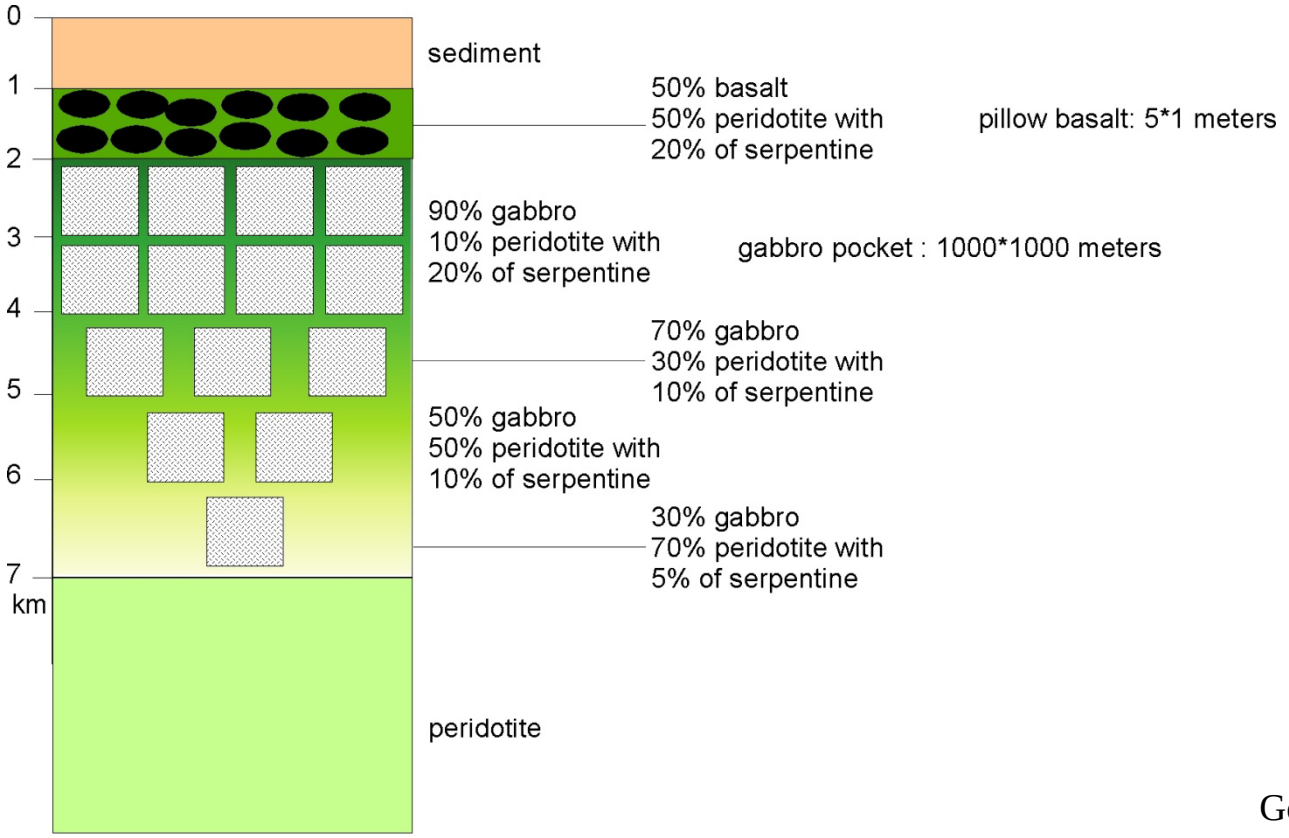


Atlantic-type oceanic floor

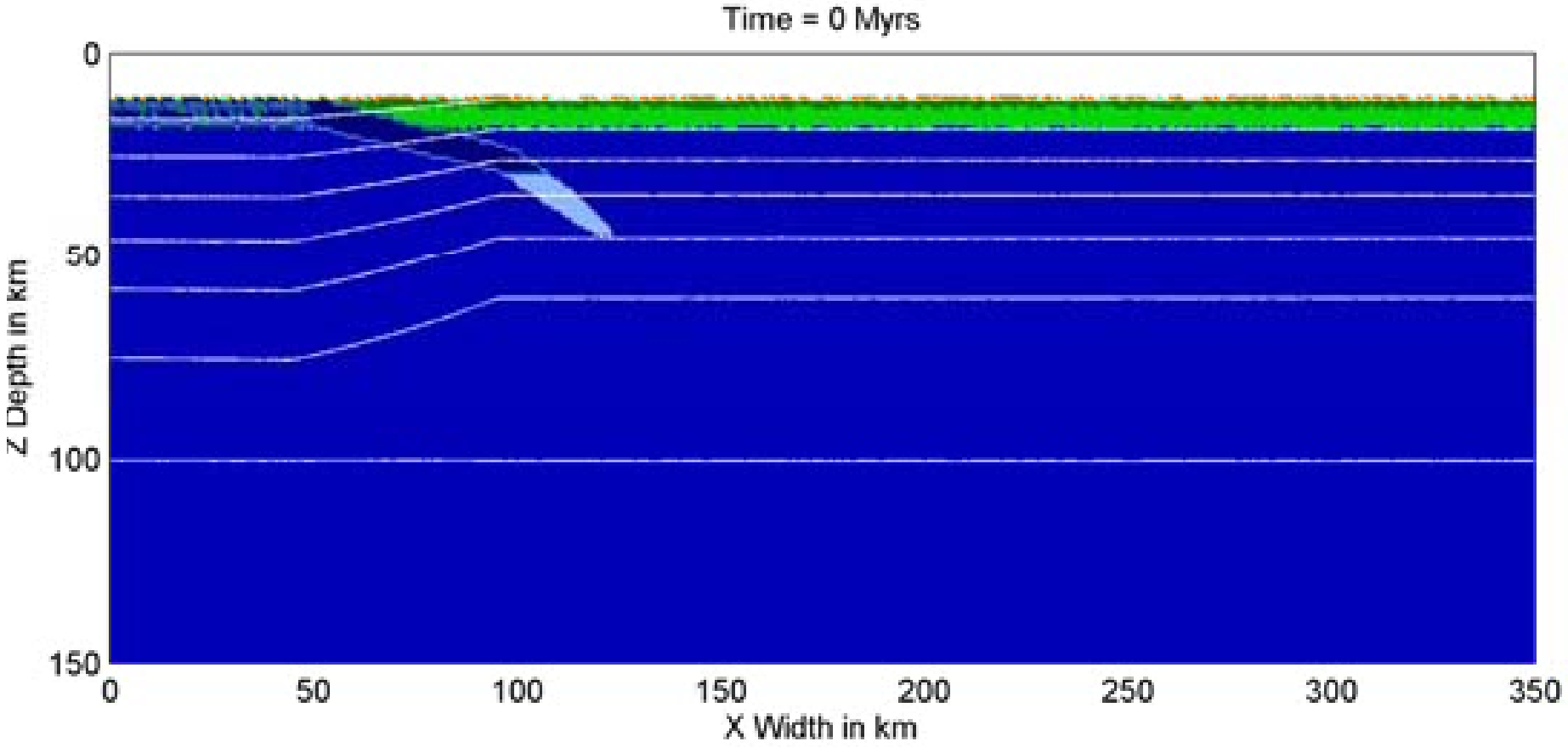


Cannat et al., 1995

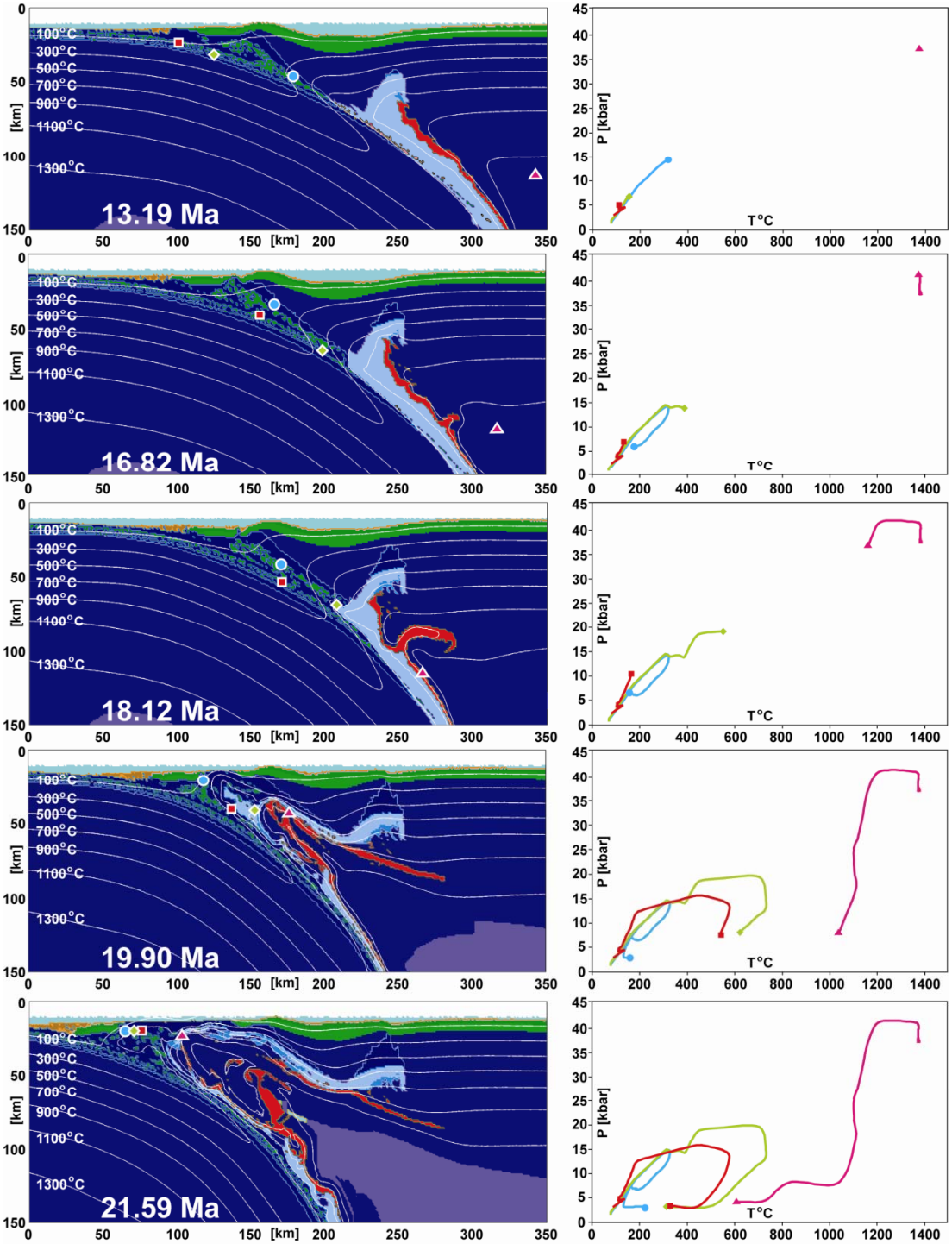


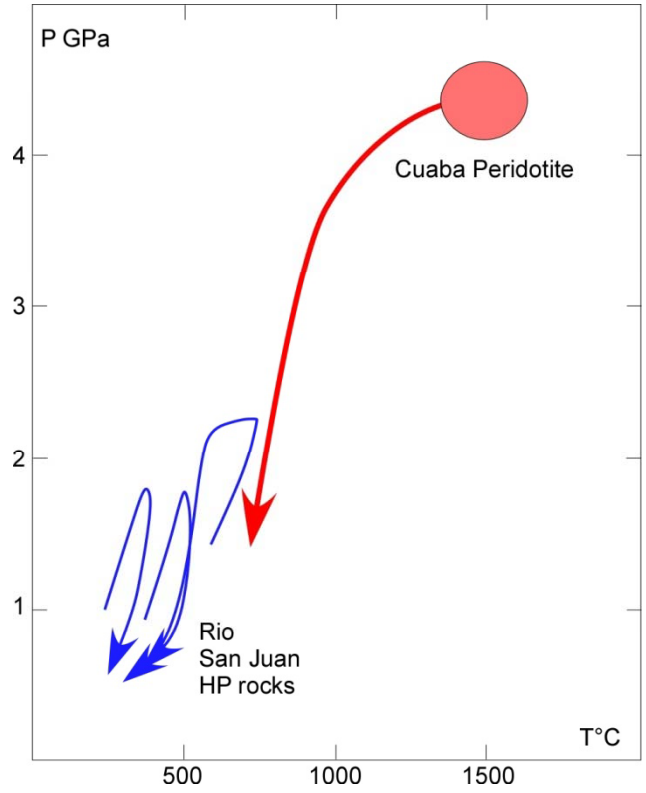


Gorczyk et al, 2007

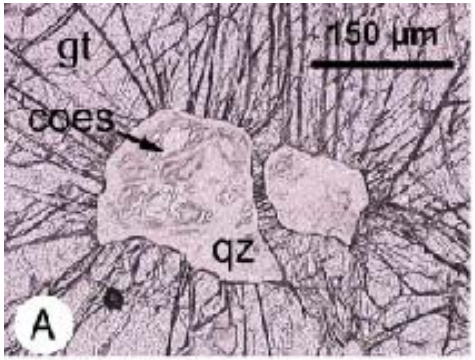


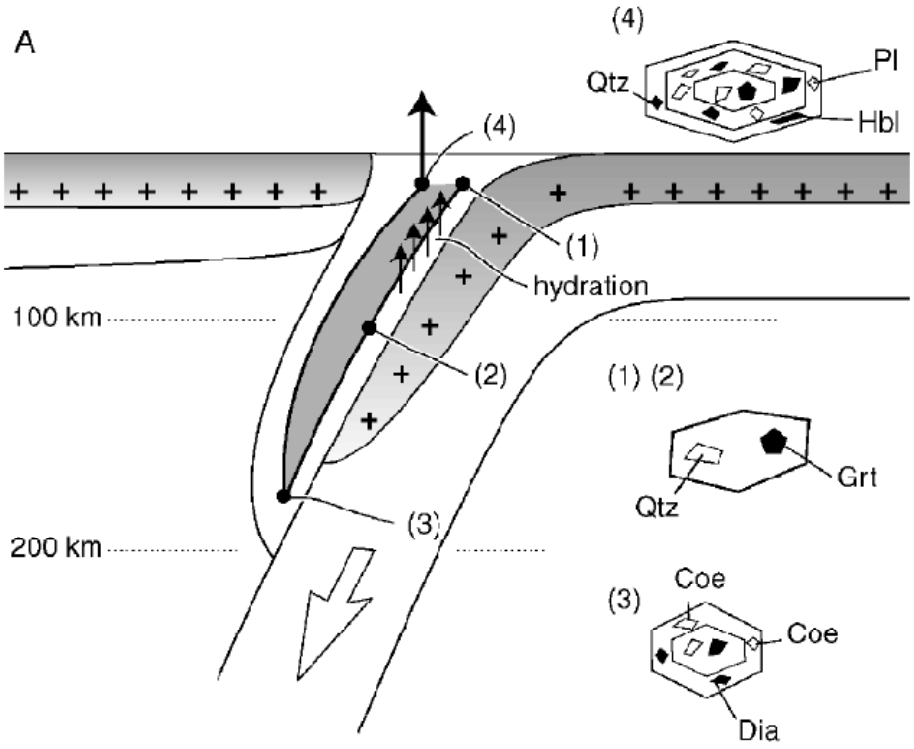
Gorczyk et al, 2007.





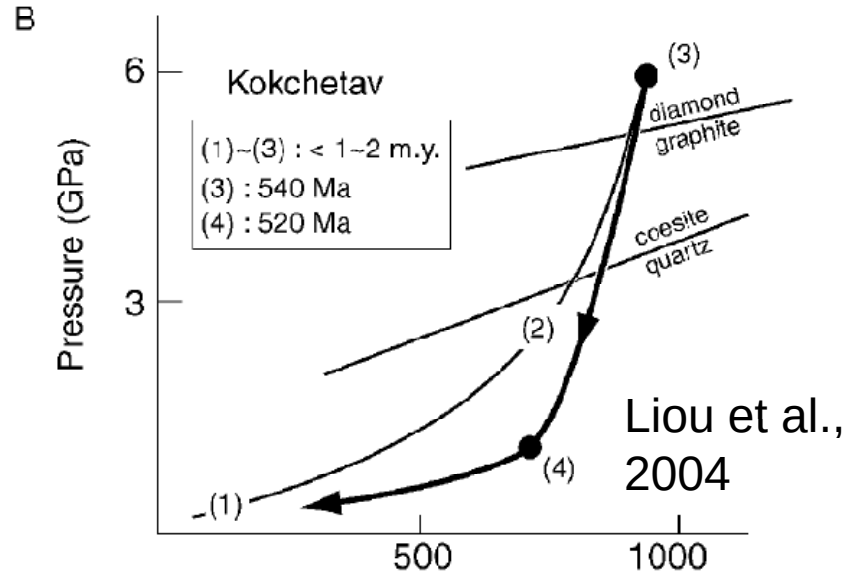
after Abbott et al., 2006,
Krebs et al. 2007
Hattori et al., 2010



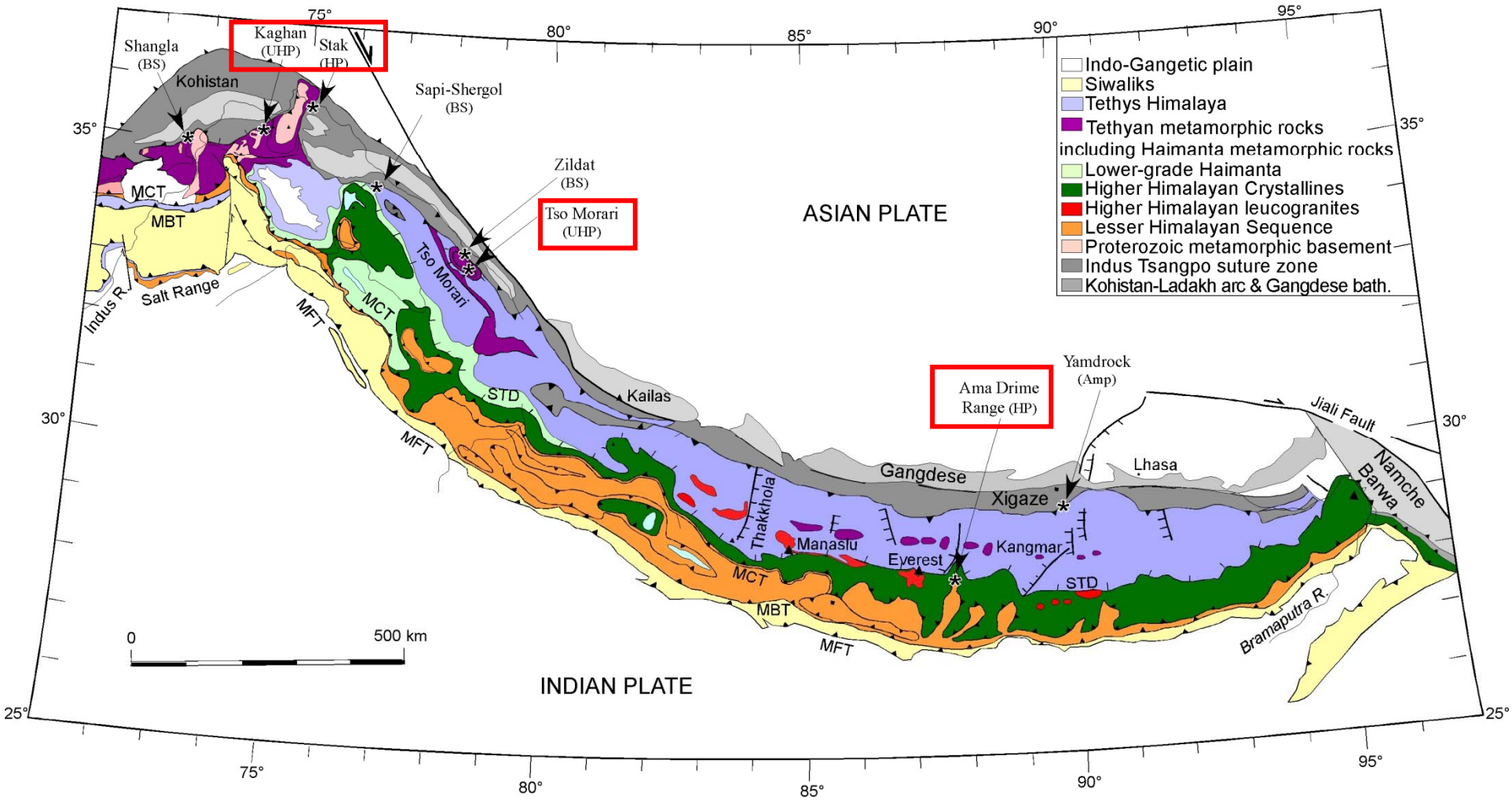


Continental Subduction

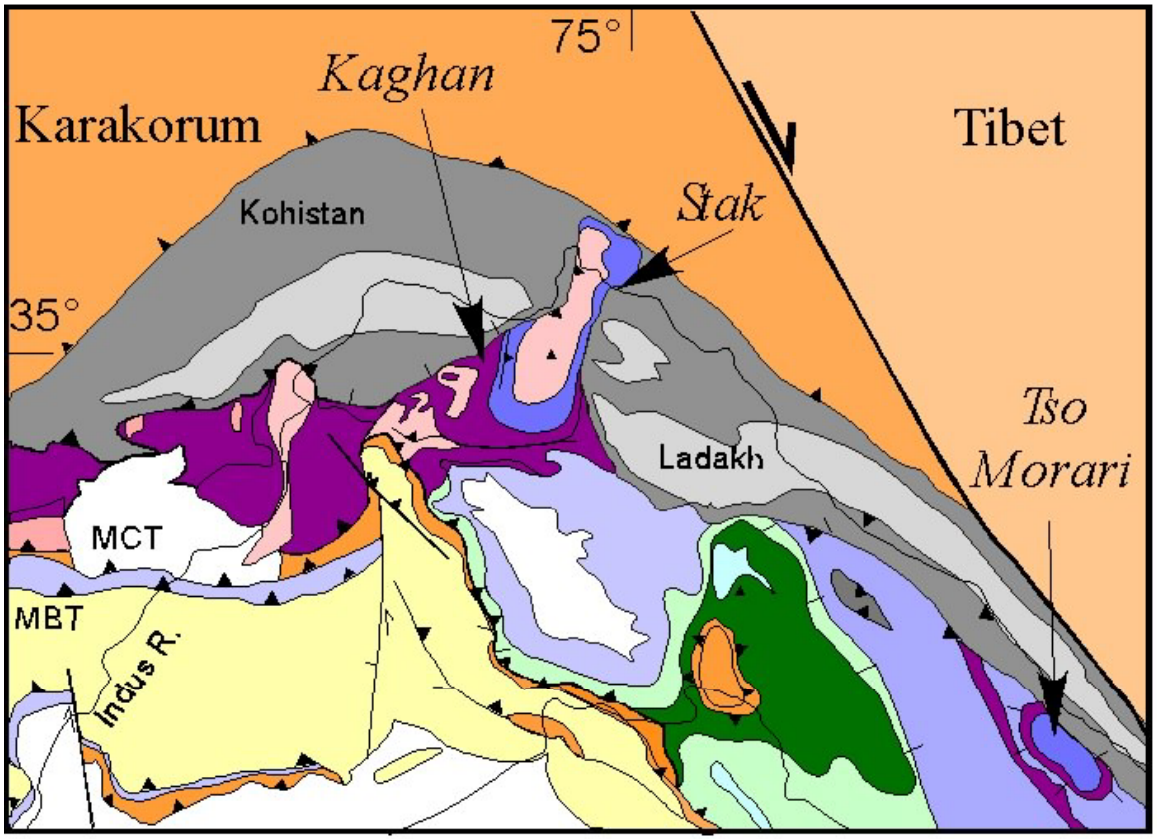
Transient and rapid exhumation of continental slices from depth between 100 and 200 km (Ernst, 1999)

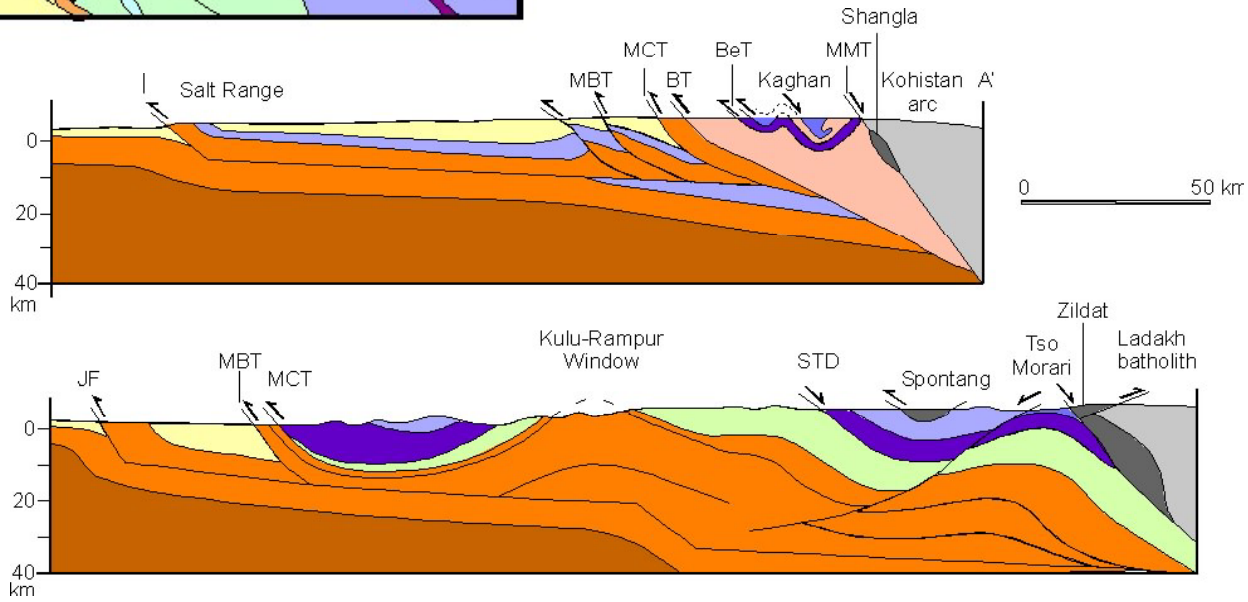


Liou et al., 2004

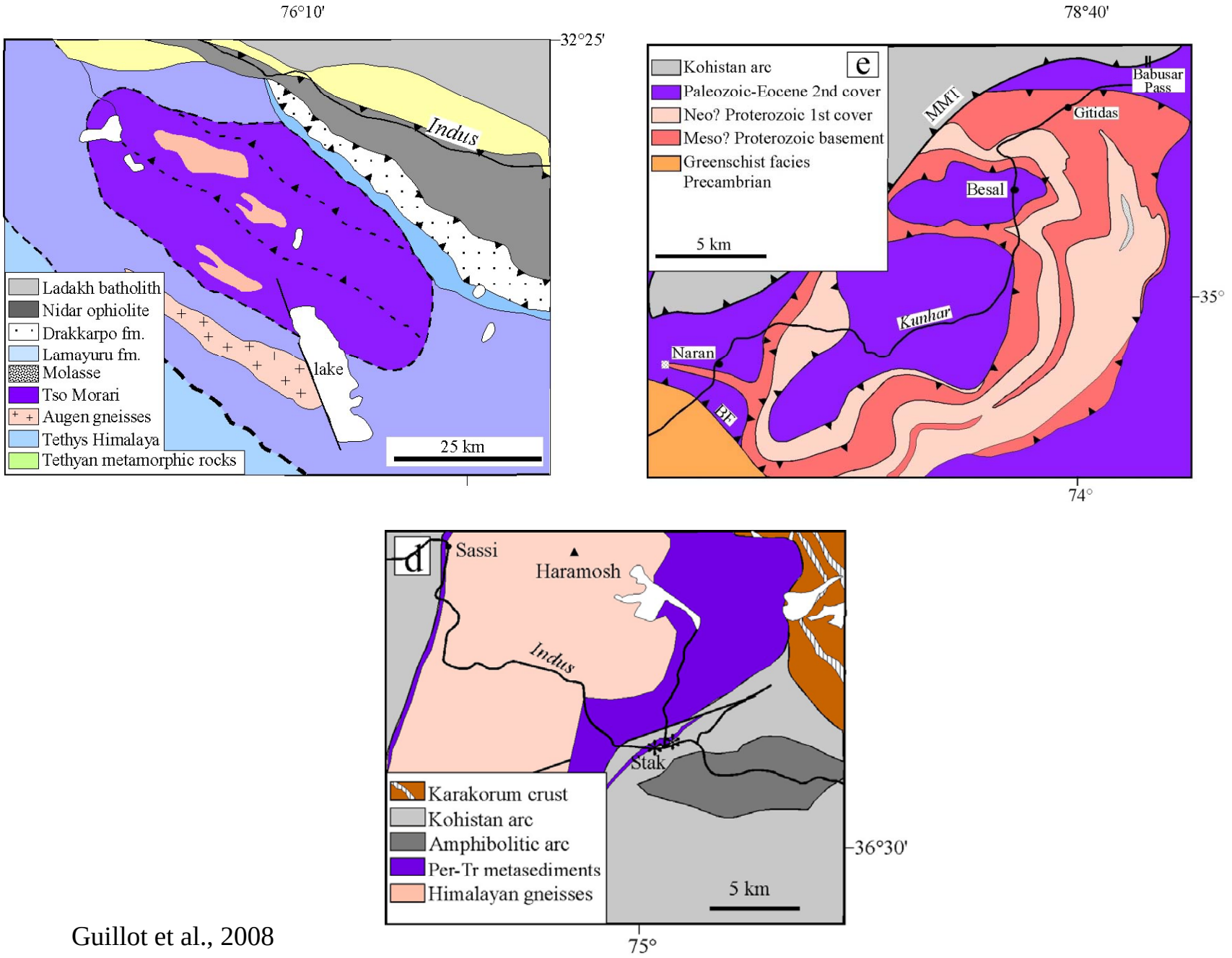


Guillot et al., 2008

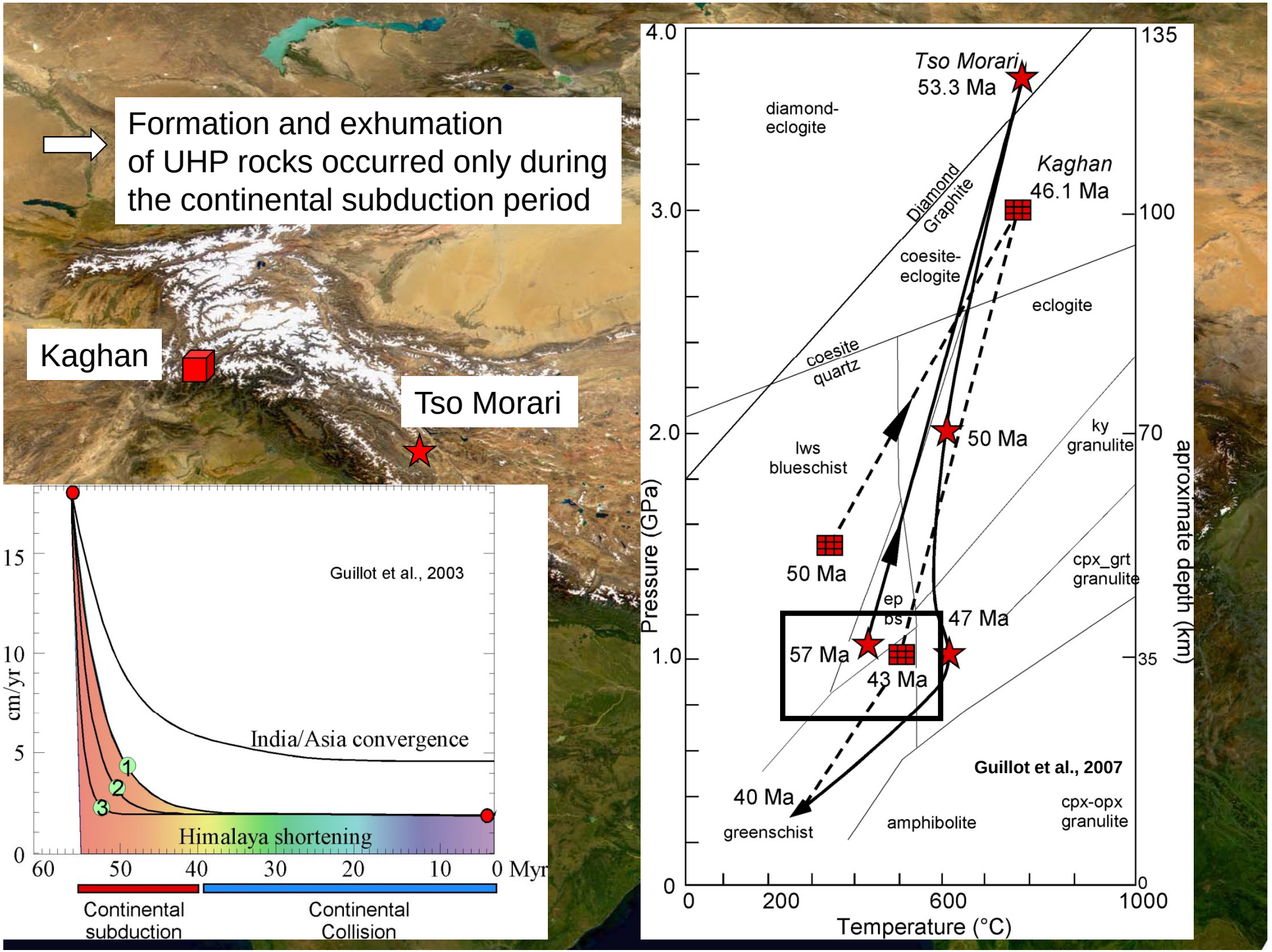




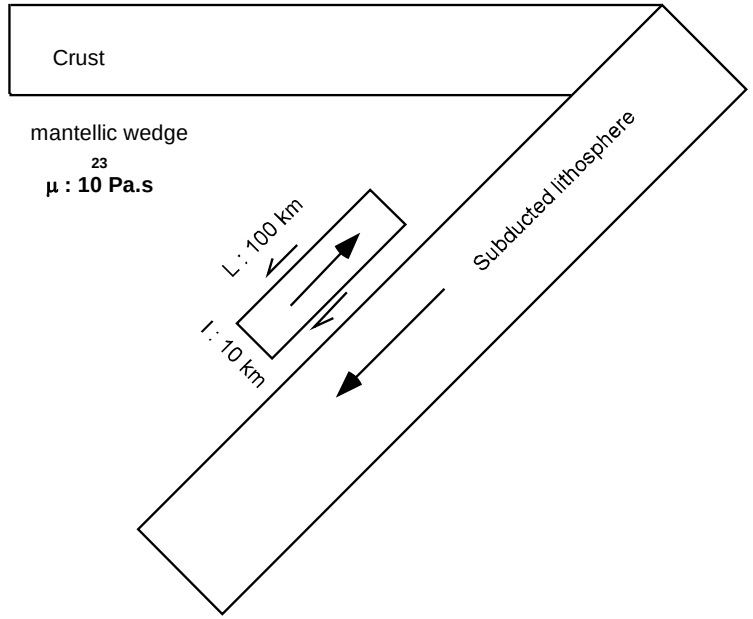
Guillot et al., 2008



Guillot et al., 2008


Formation and exhumation
of UHP rocks occurred only during
the continental subduction period
Kaghan
Tso Morari
Guillot et al., 2003
India/Asia convergence
Himalaya shortening
cm/yr
Myr
Continental
subduction
Continental
Collision
Tso Morari
53.3 Ma
Kaghan
46.1 Ma
50 Ma
50 Ma
47 Ma
57 Ma
43 Ma
40 Ma
diamond-
eclogite
Diamond
Graphite
coesite-
eclogite
eclogite
coesite
quartz
lws
blueschist
ky
granulite
cpx_grt
granulite
ep
bs
greenschist
amphibolite
cpx-opx
granulite
Guillot et al., 2007
Pressure (GPa)
Temperature (°C)
aproximate depth (km)

Exhumation of UHP rocks by buoyancy forces in a dry mantle wedge ? ?



The **buoyancy Forces** induced by the eclogitic unit (d1) exhumed within the mantle (d2) is :

$$Fa = \Delta(d2-d1).g.v = 3.10^{18}\ N$$

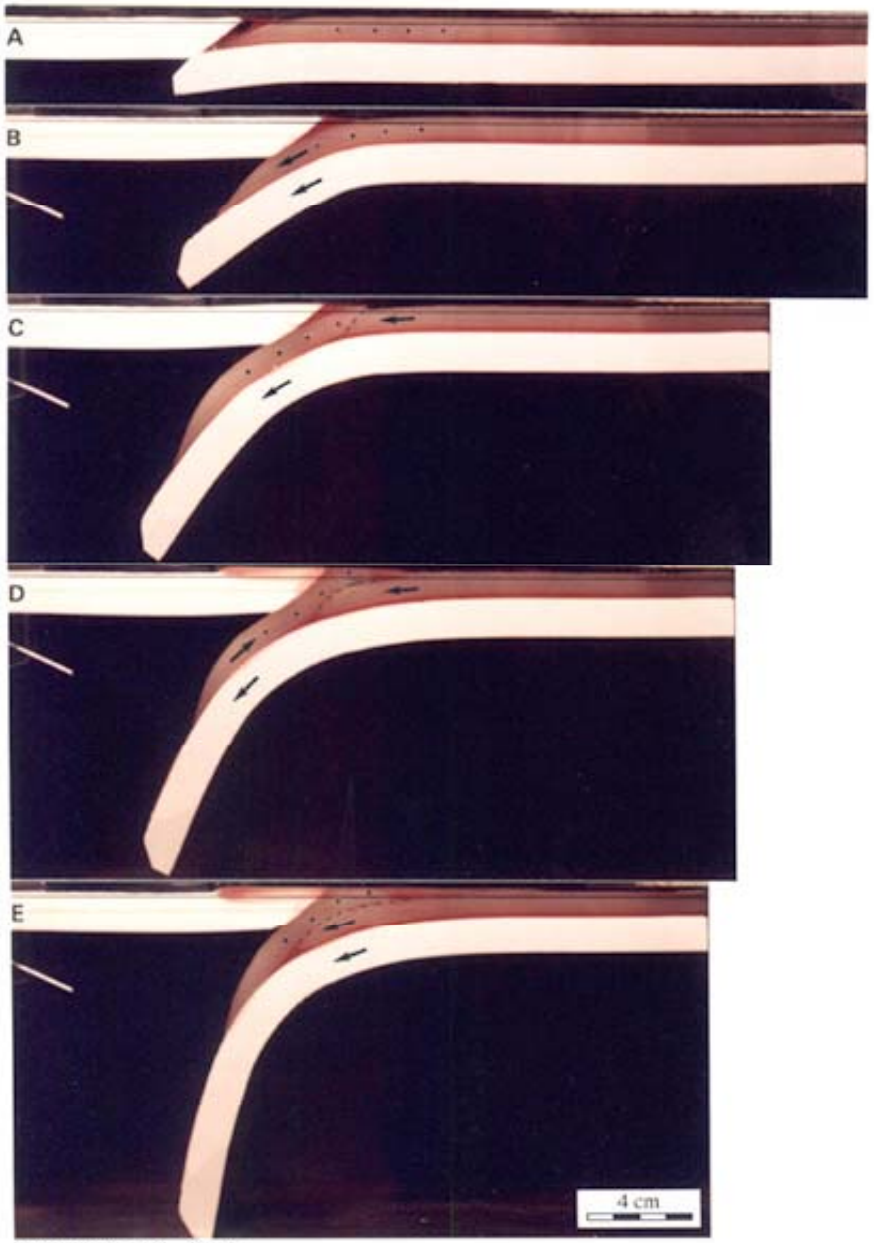
The resistance forces induced by the dry mantle for an eclogitic unit exhumed at 1 cm/yr is :

$$Fr = 2.L.\mu.\delta u/\delta z = 5.10^{13}\ N$$

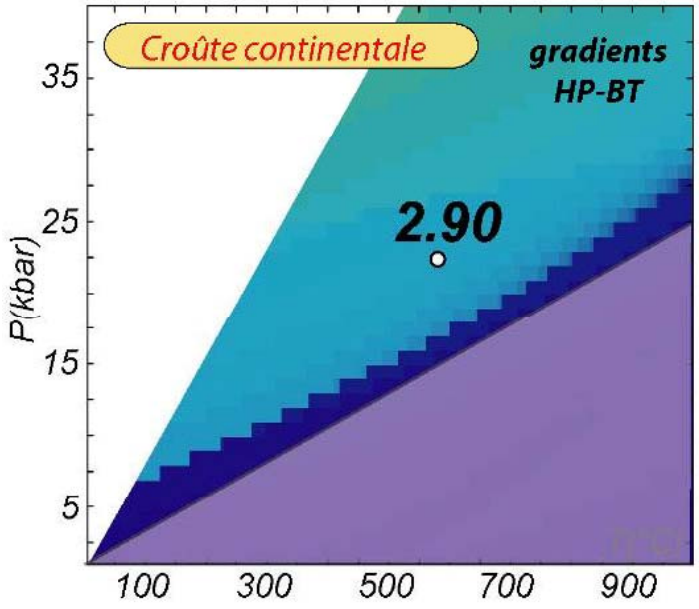
=> buoyancy forces >> resistance forces

Guillot, 2001

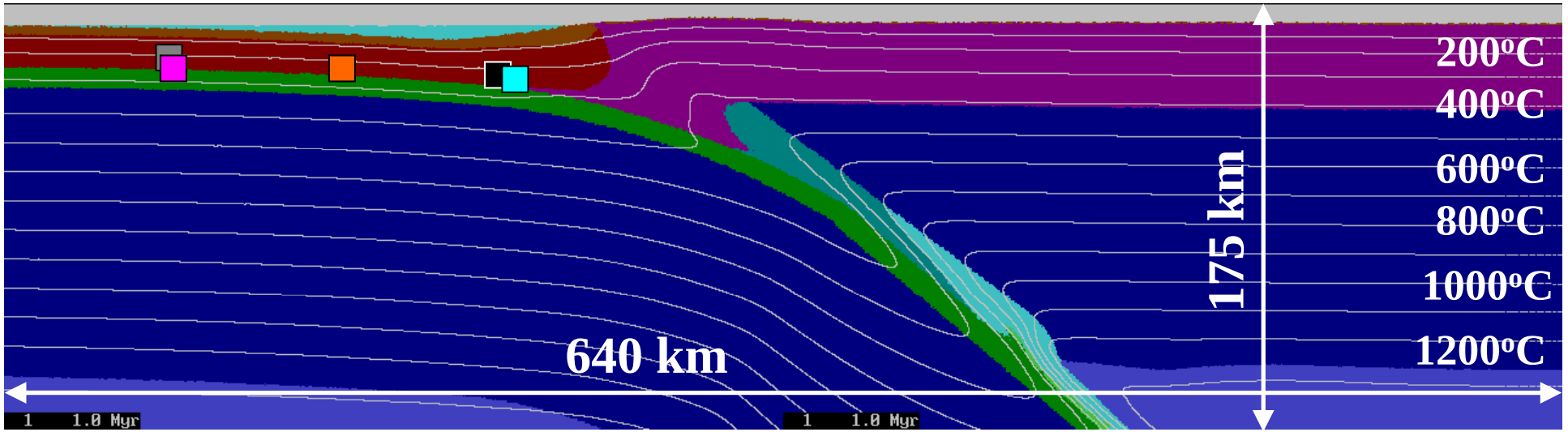
Exhumation of upper crust unit : buoyancy driven exhumation :

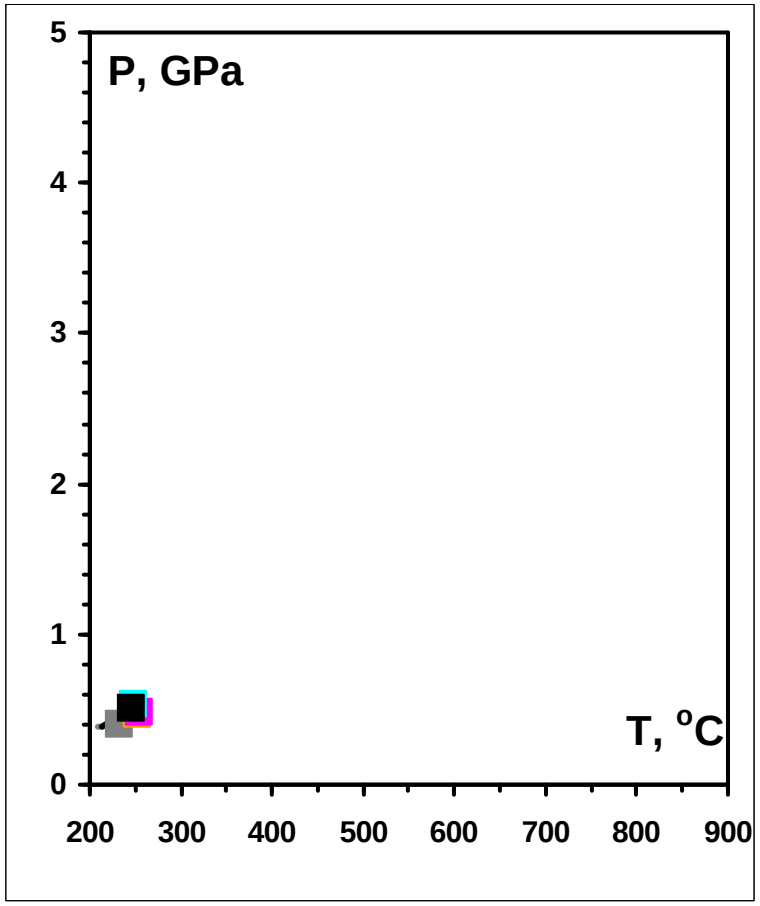


(Chemenda et al., 1995)



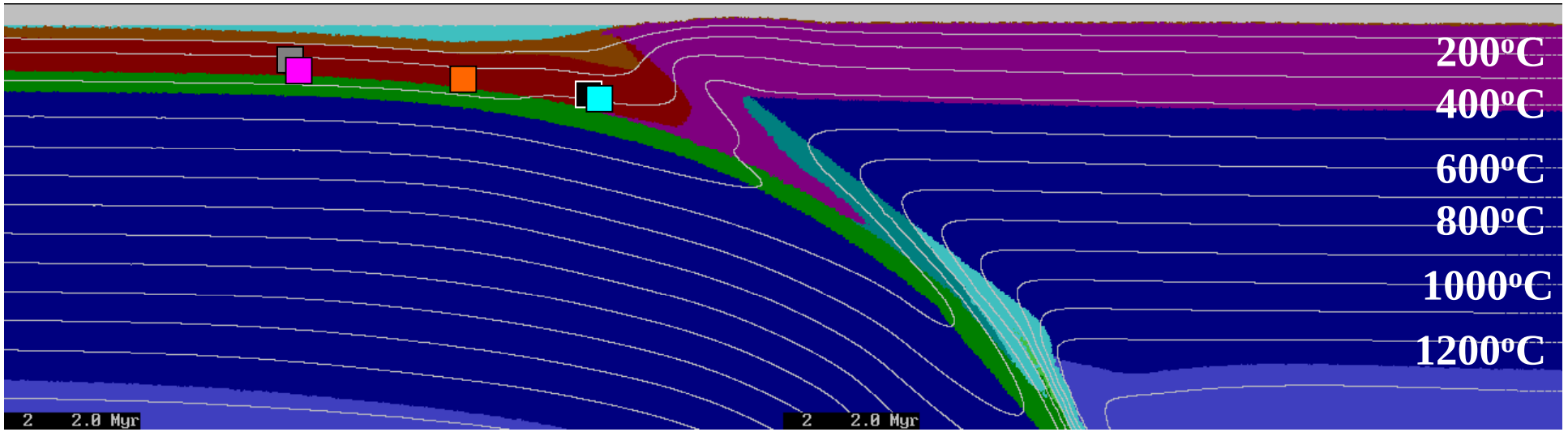
Yamato et al., 2007

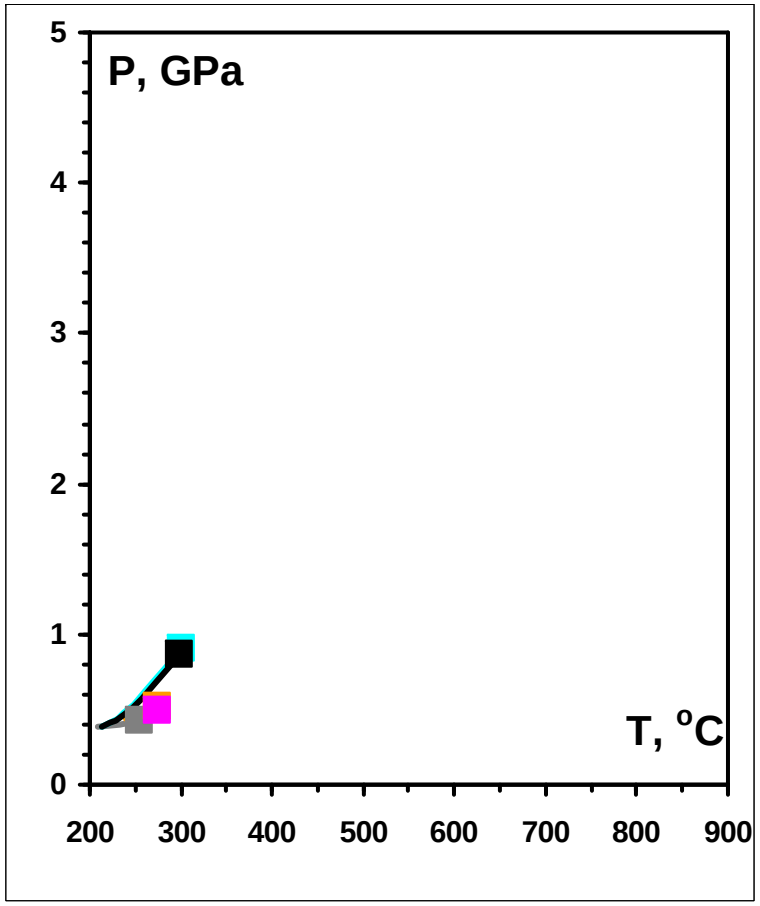




ftp://nazca.ethz.ch/tgerya/animations/Hot_Channe.ppt

(Gerya et al., 2007)





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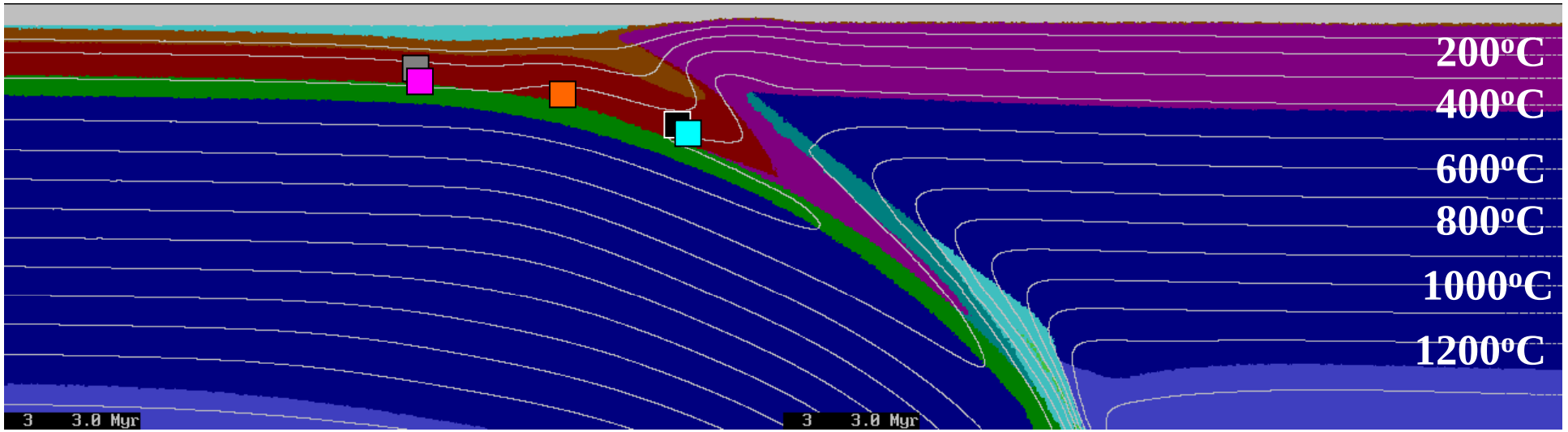
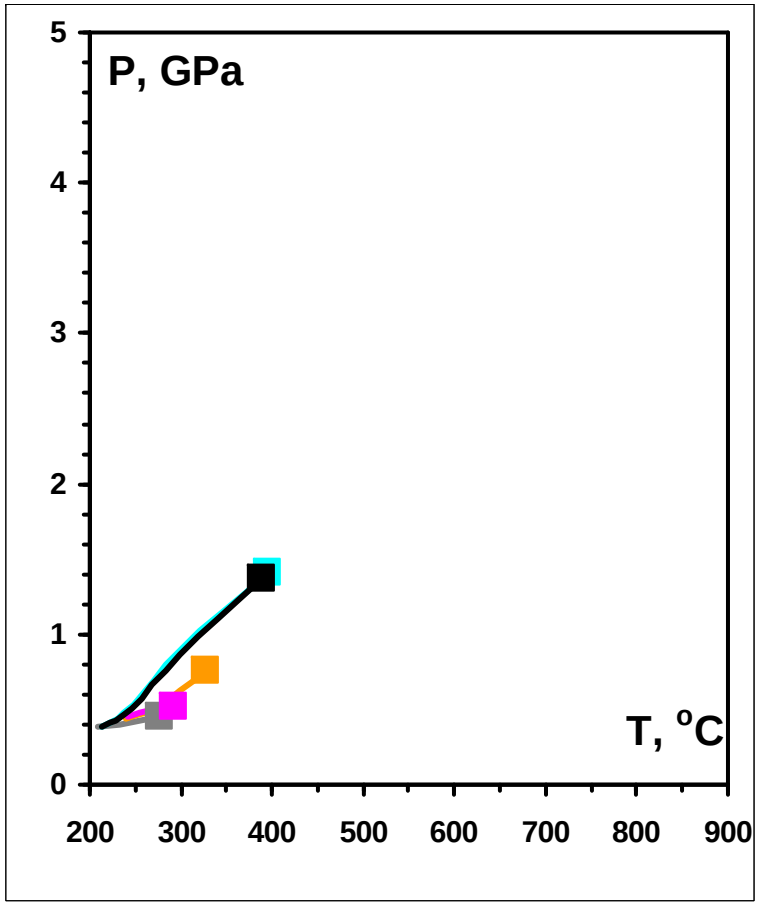
(Gerya et al., 2007)





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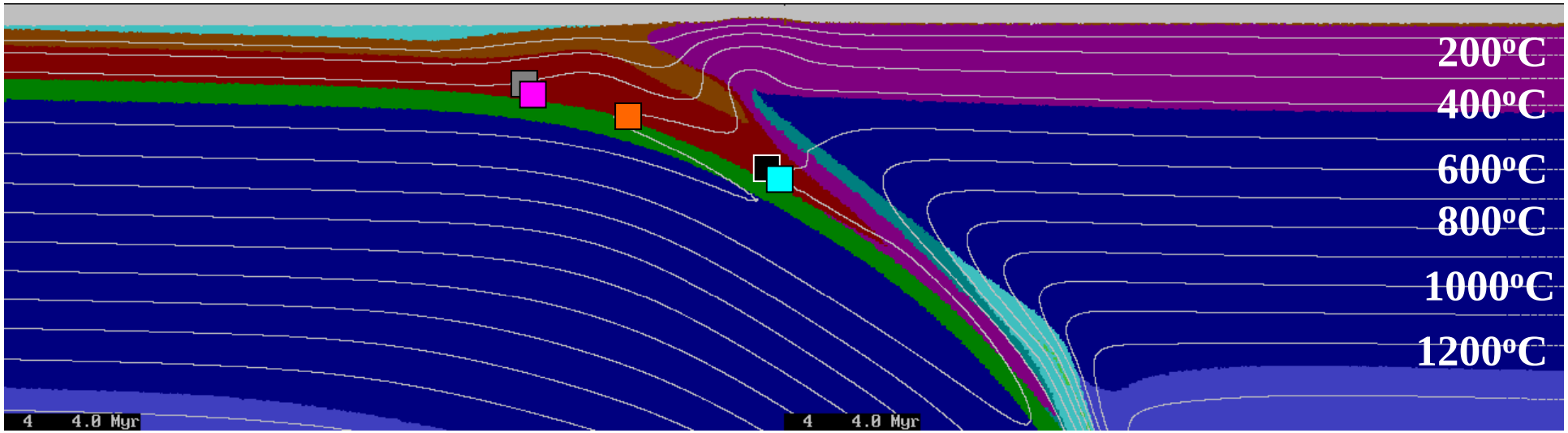
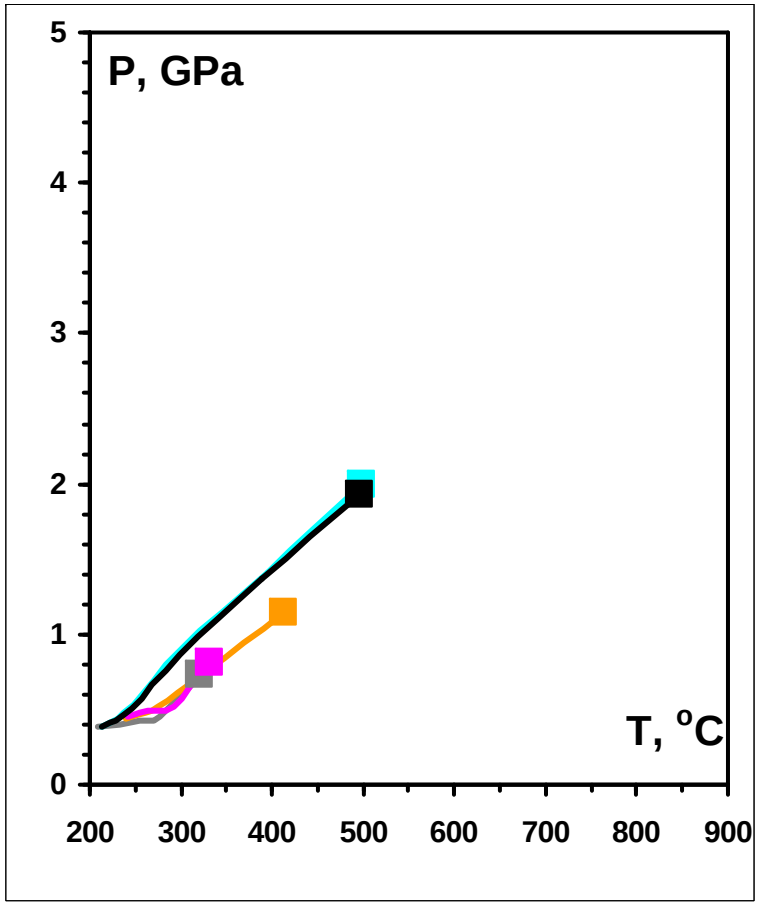
(Gerya et al., 2007)





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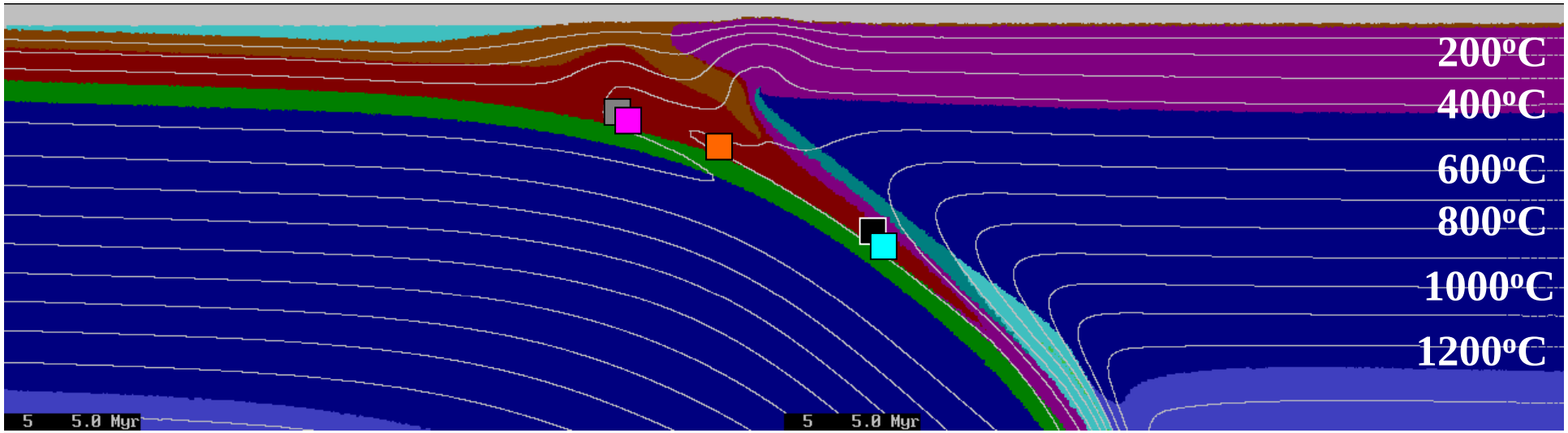
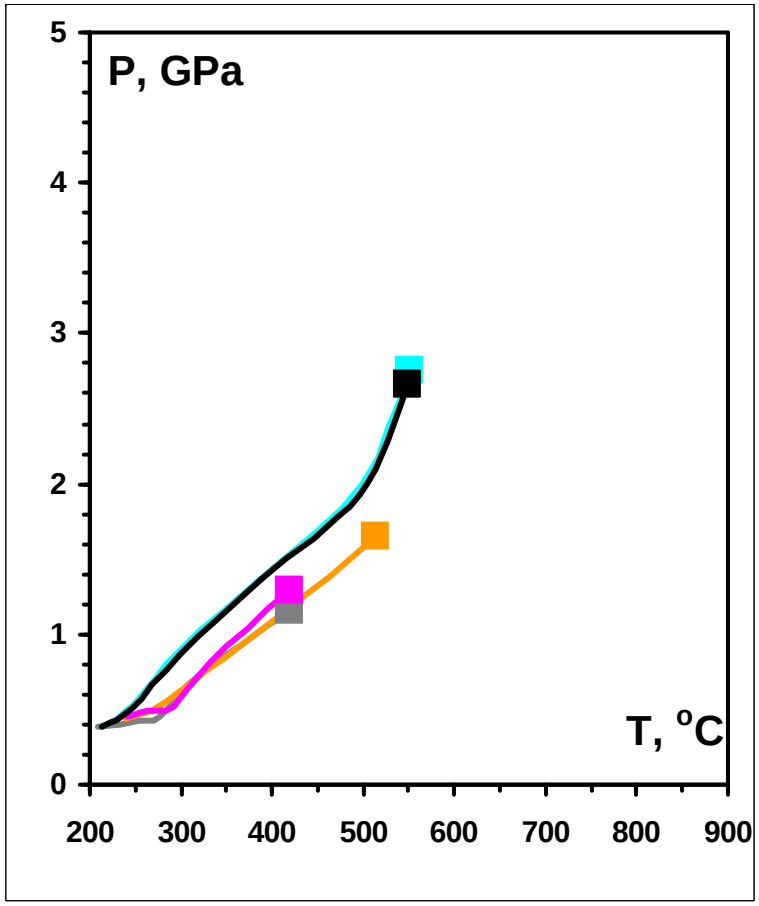
(Gerya et al., 2007)





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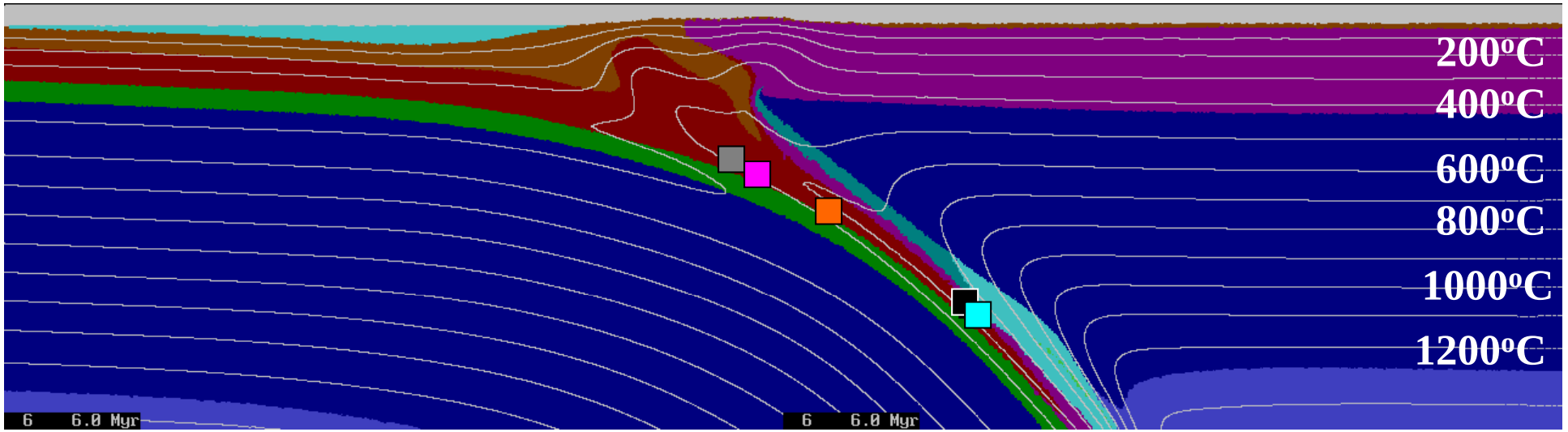
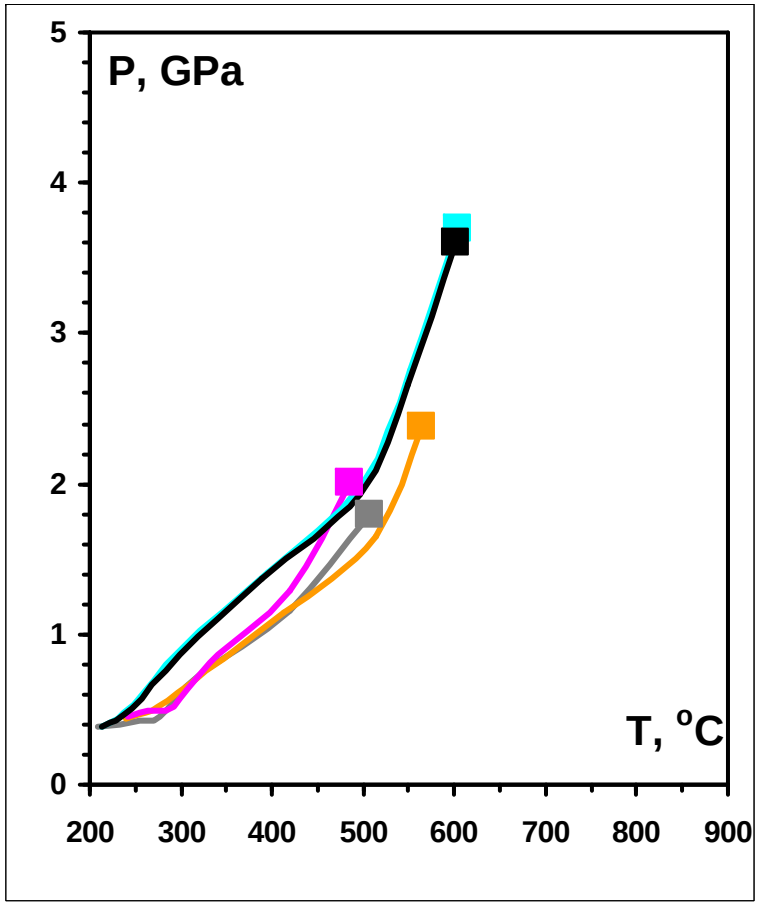
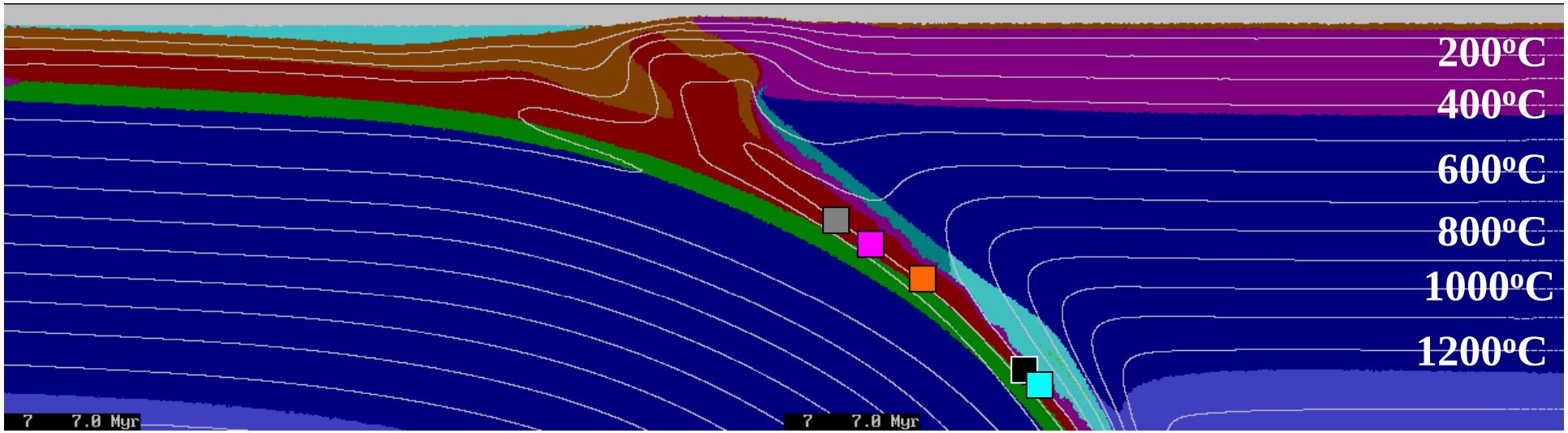
(Gerya et al., 2007)

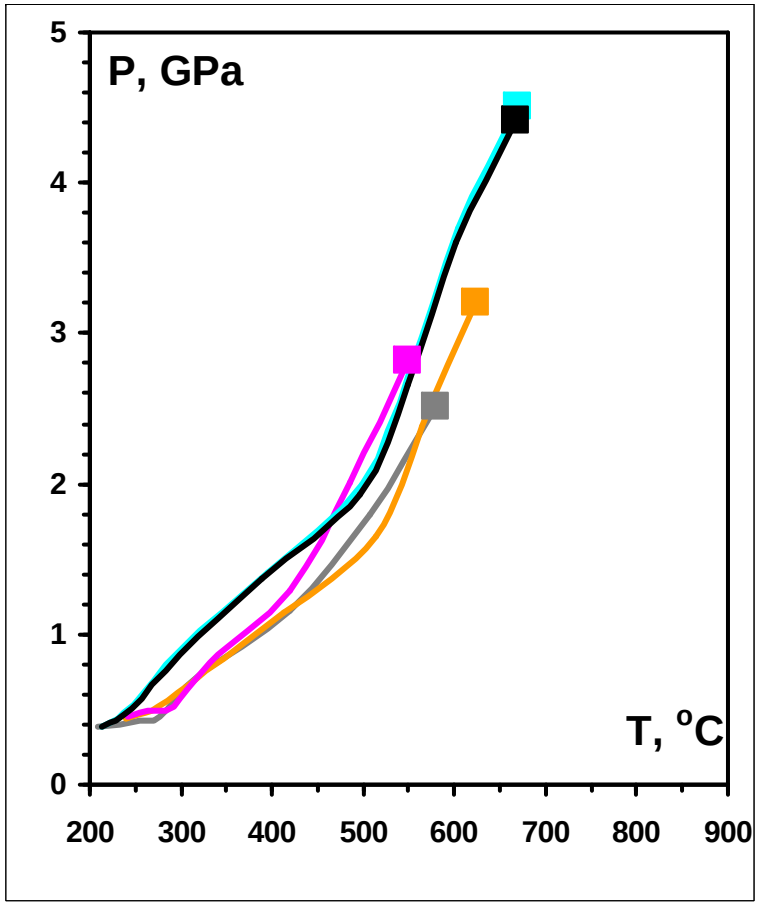




ftp://nazca.ethz.ch/tgerya/animations/Hot_Channe.ppt

(Gerya et al., 2007)





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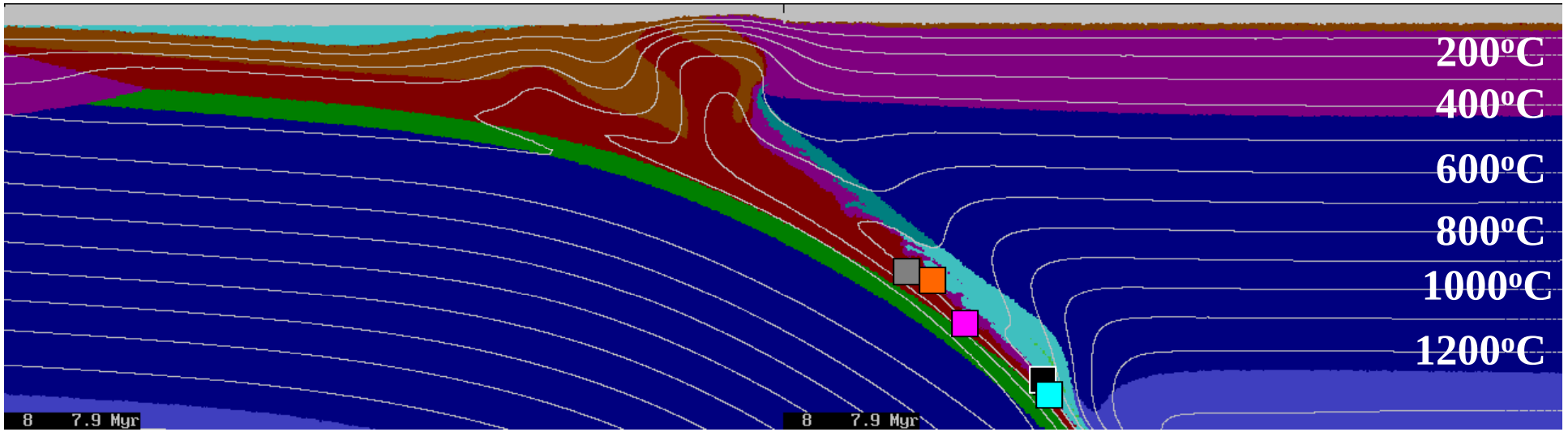
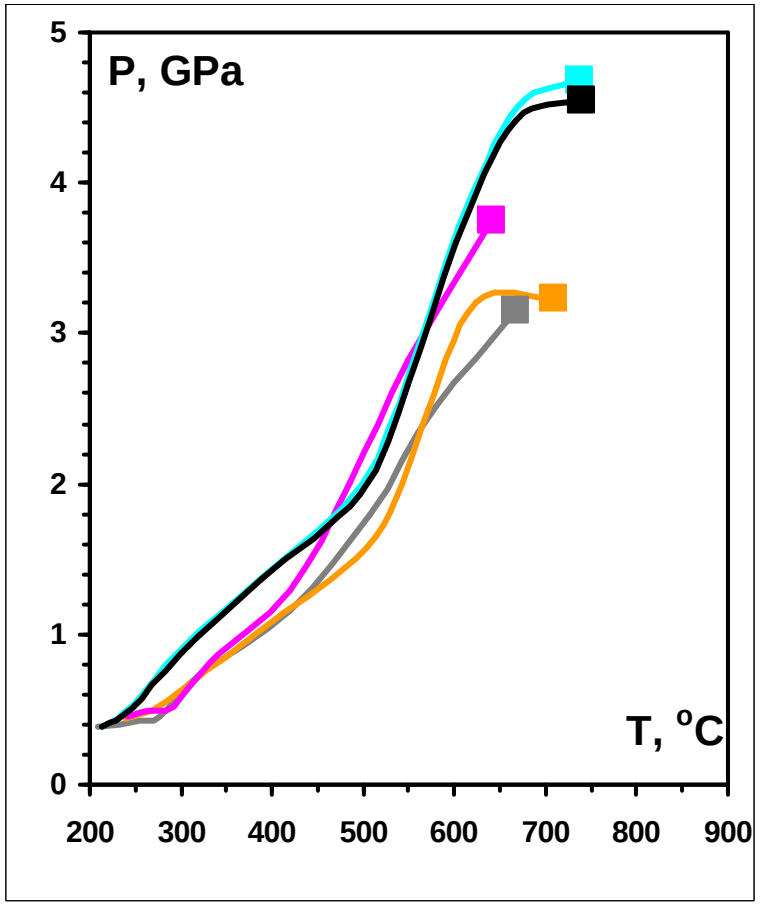
(Gerya et al., 2007)





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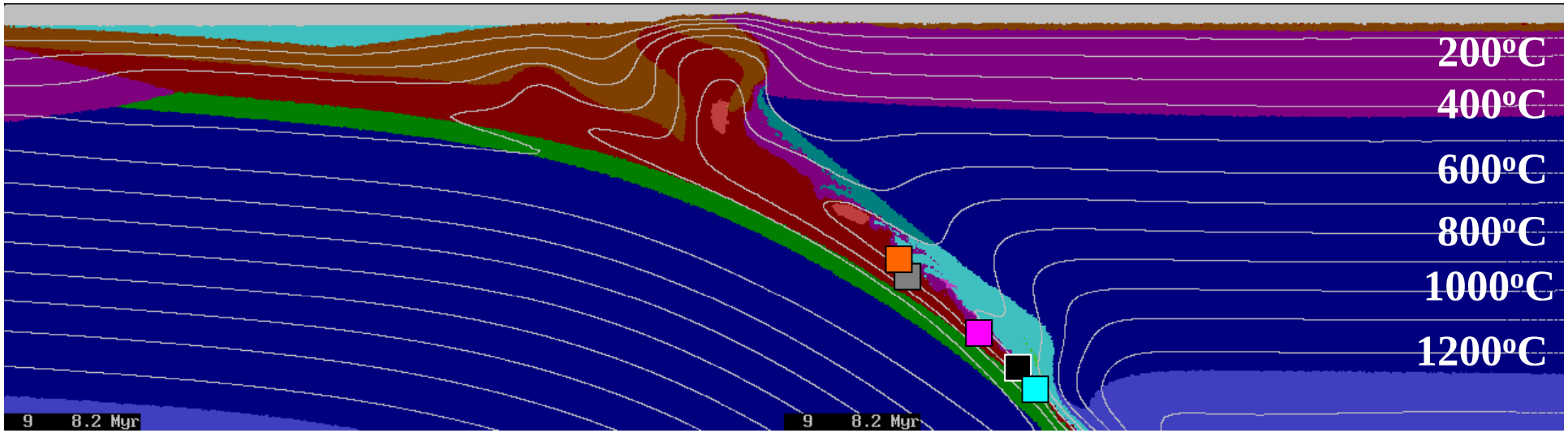
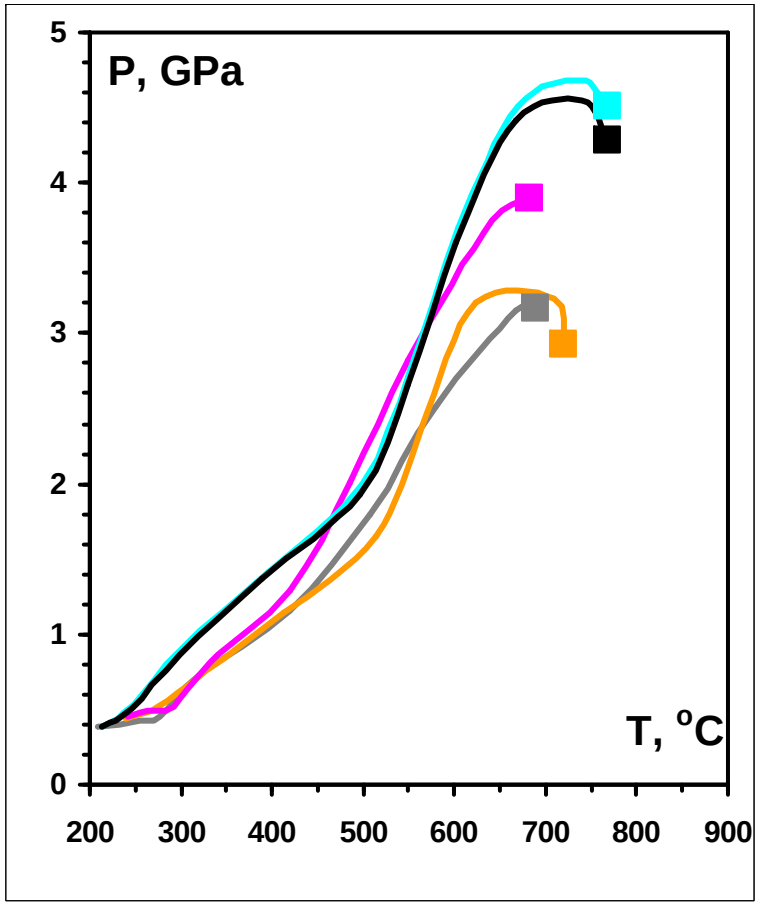
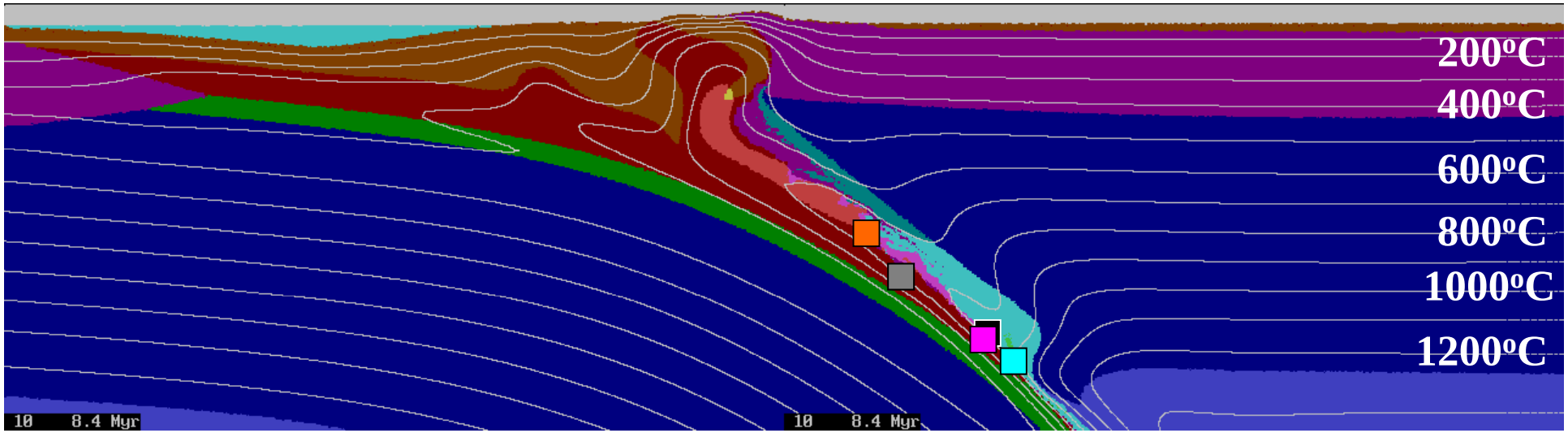
(Gerya et al., 2007)

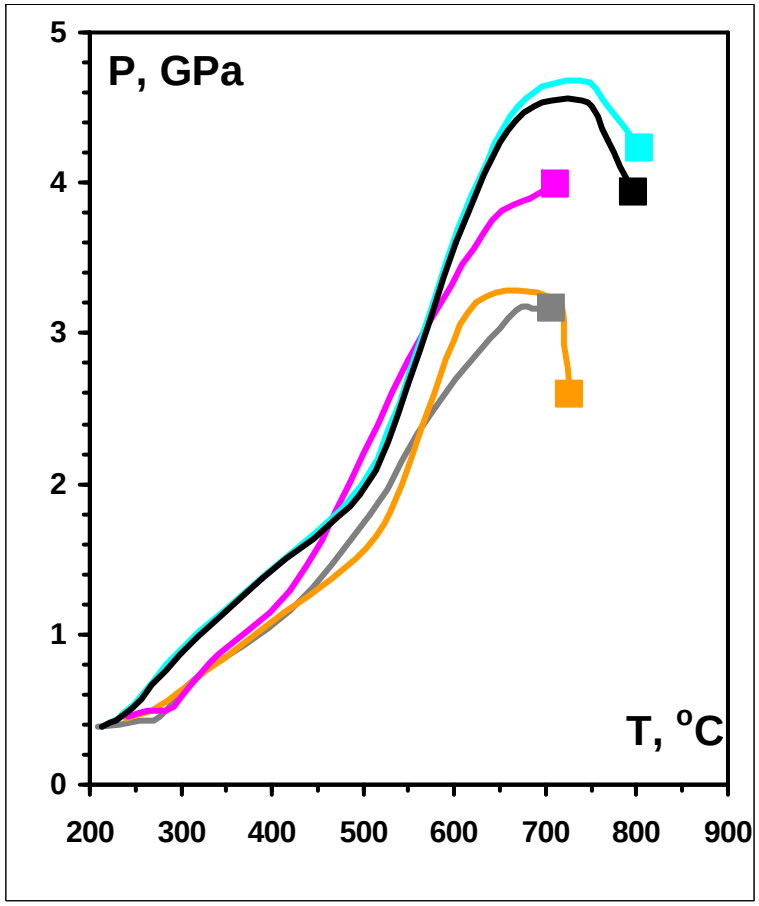




ftp://nazca.ethz.ch/tgerya/animations/Hot_Channe.ppt

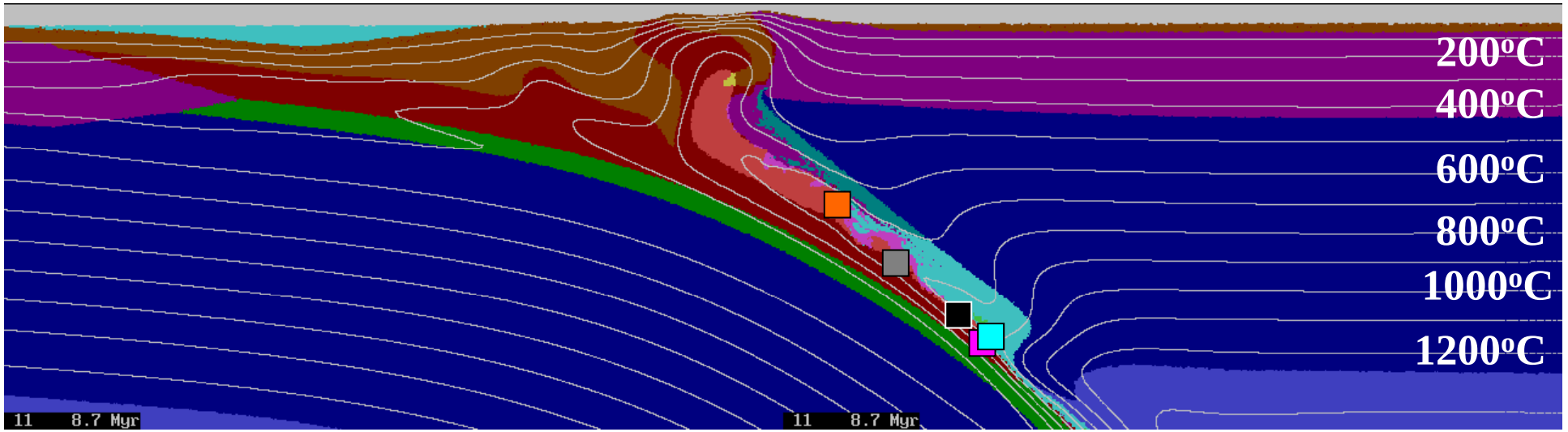
(Gerya et al., 2007)

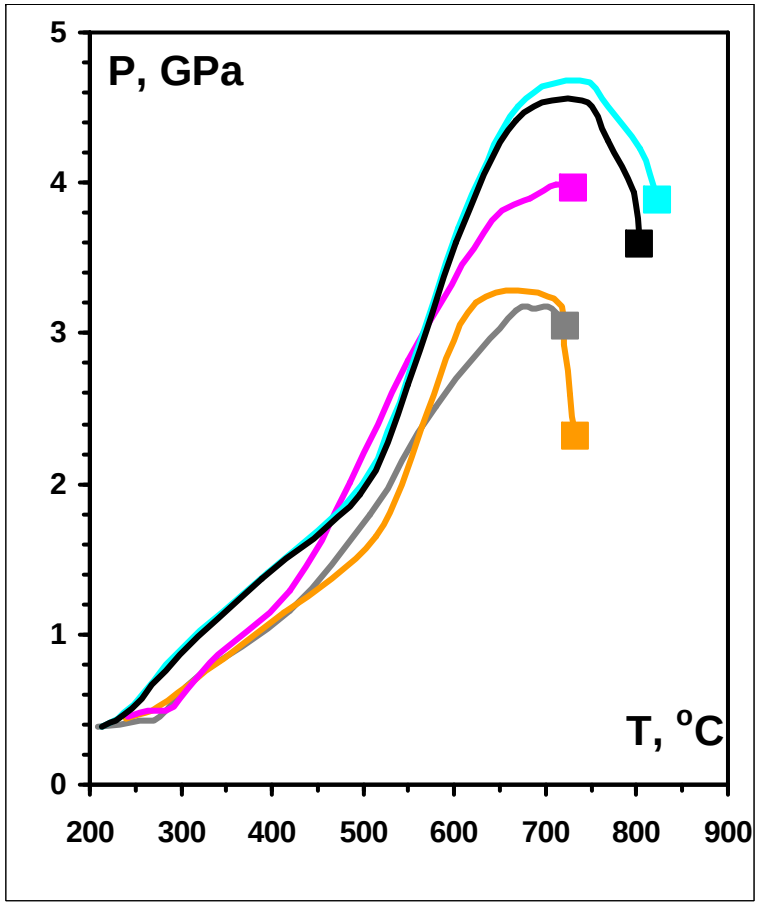




ftp://nazca.ethz.ch/tgerya/animations/Hot_Channe.ppt

(Gerya et al., 2007)





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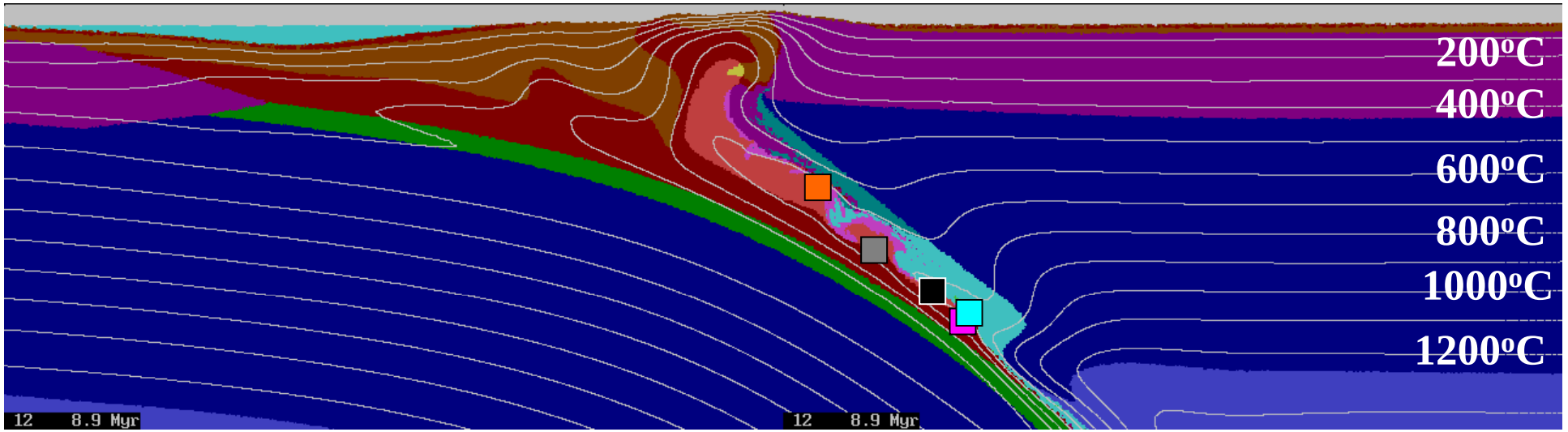
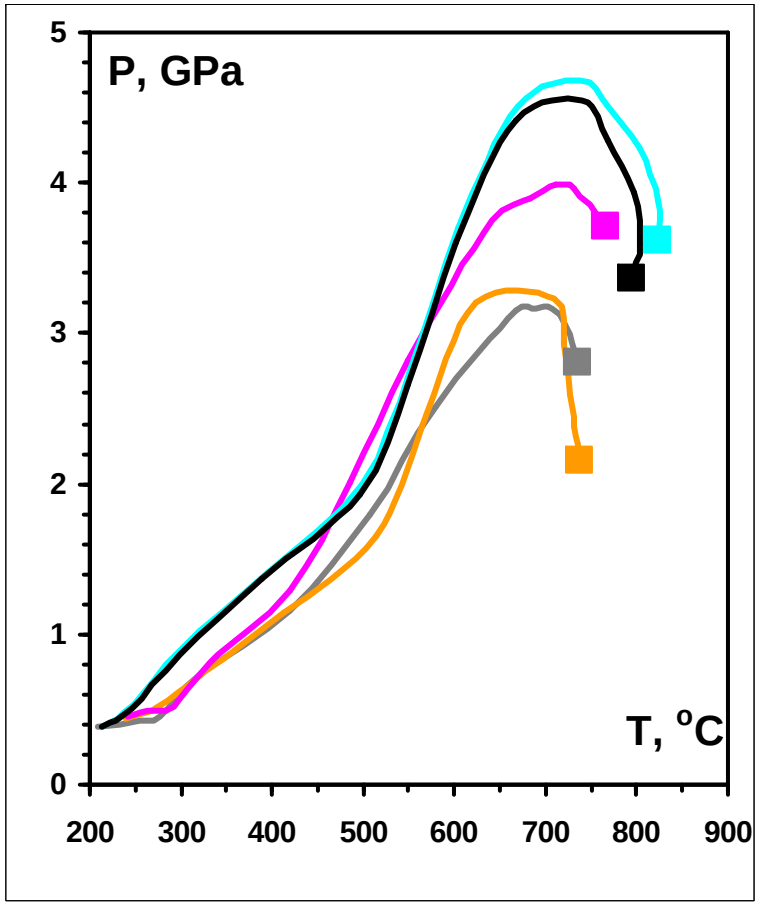
(Gerya et al., 2007)





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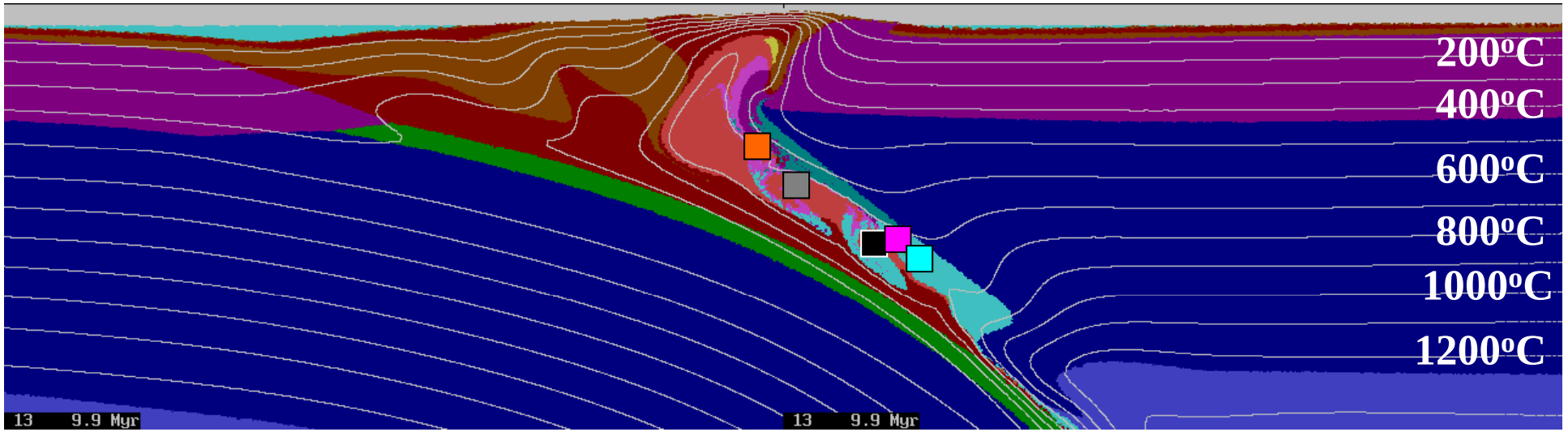
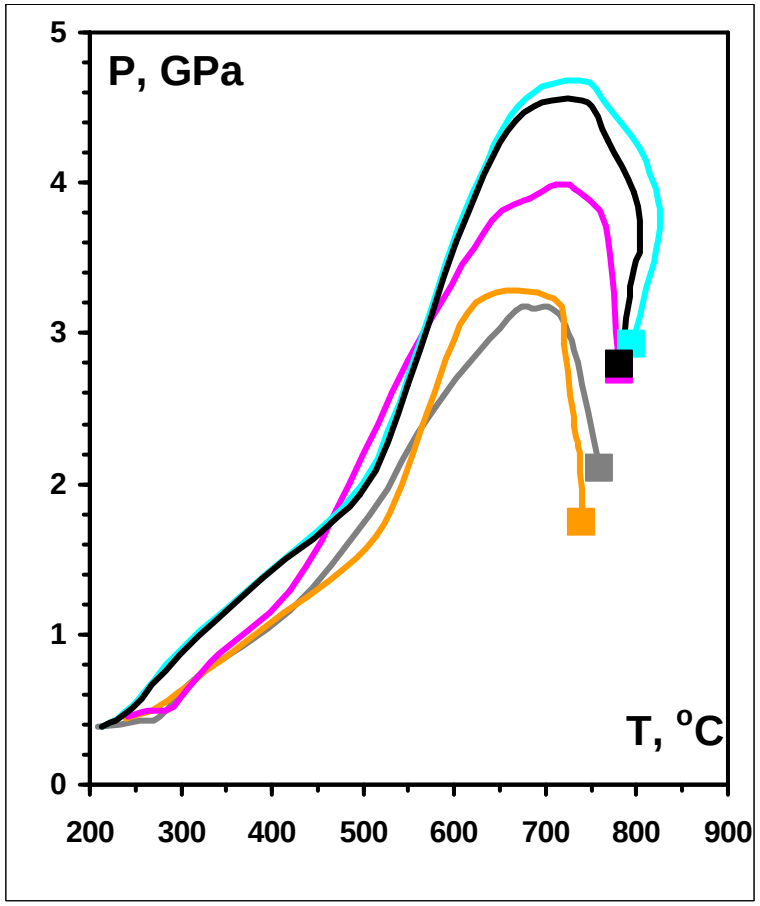
(Gerya et al., 2007)





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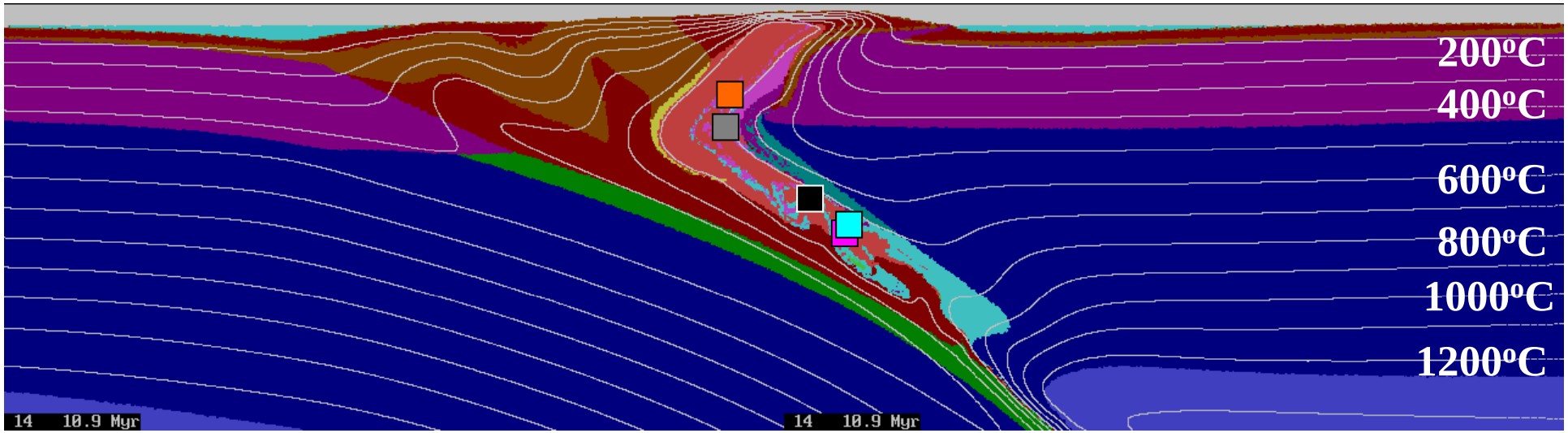
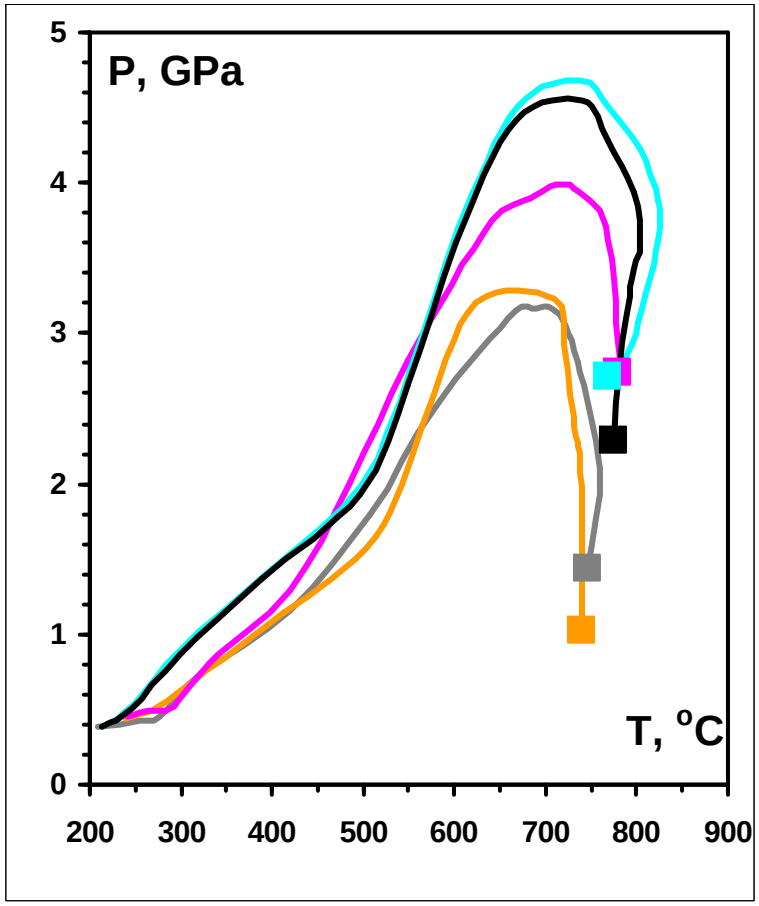
(Gerya et al., 2007)





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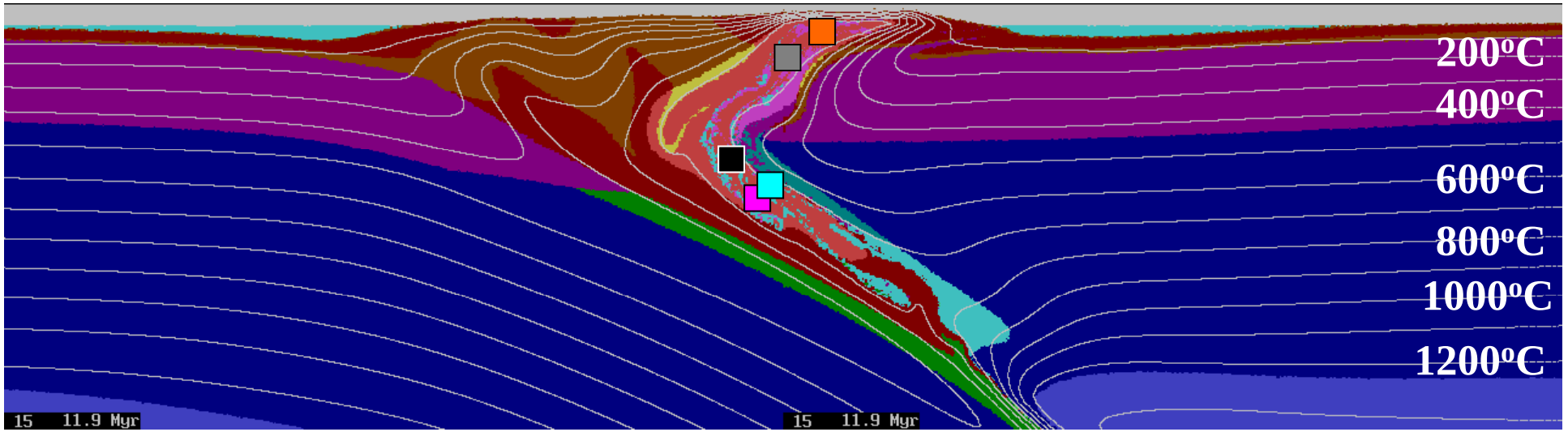
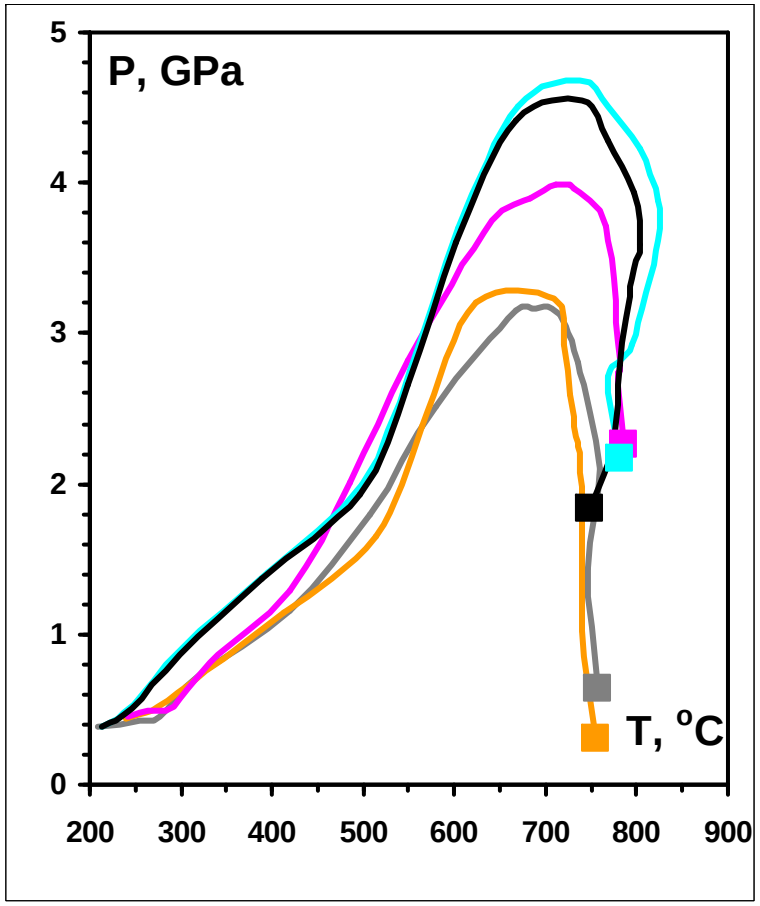
(Gerya et al., 2007)





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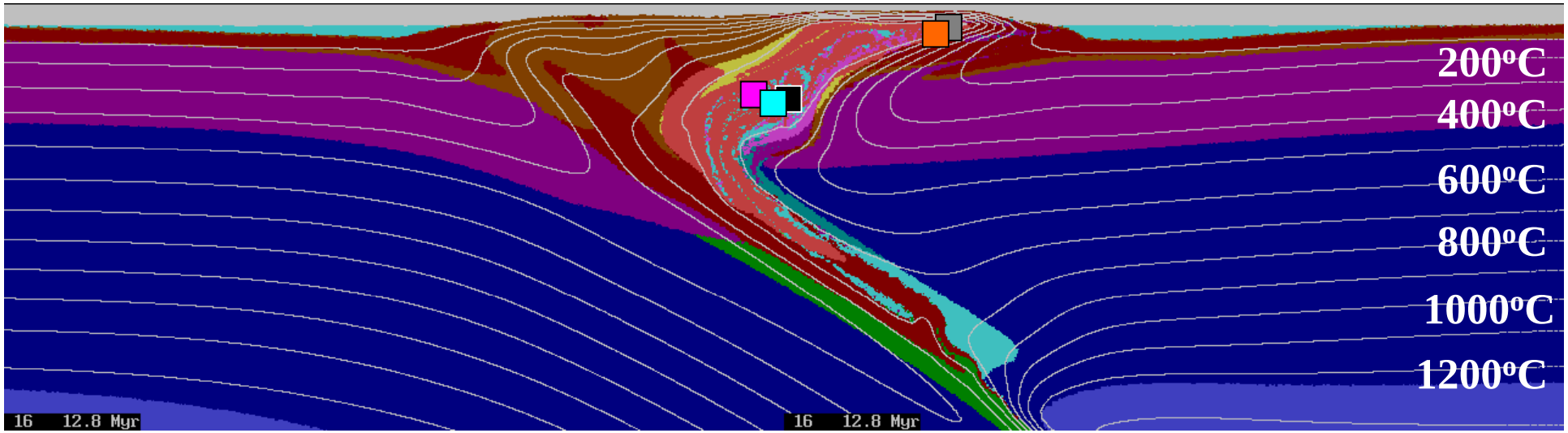
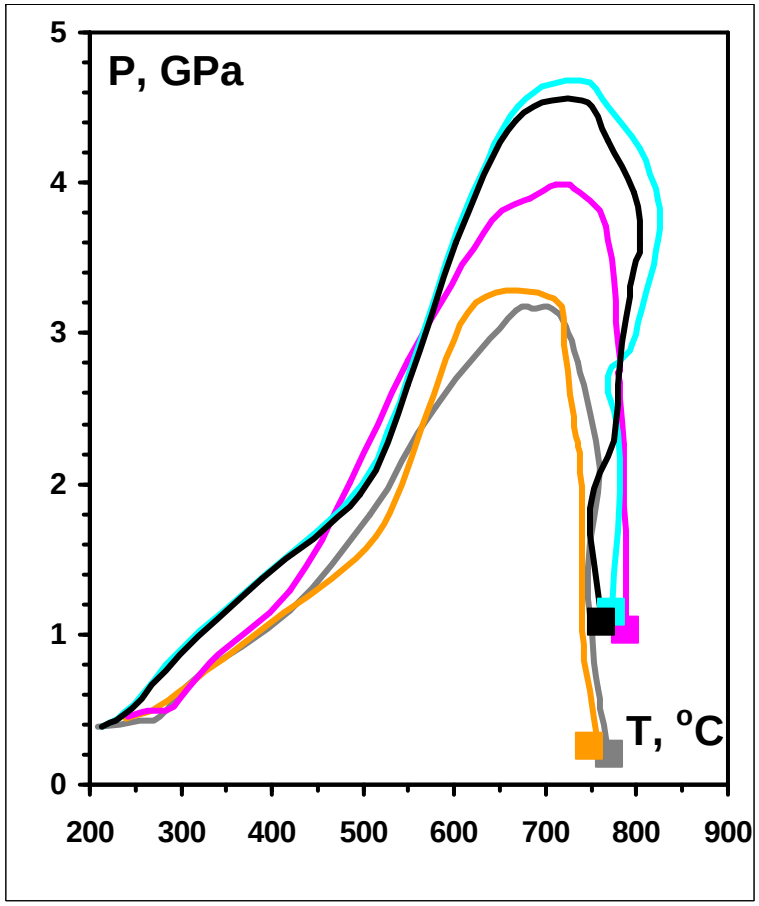
(Gerya et al., 2007)





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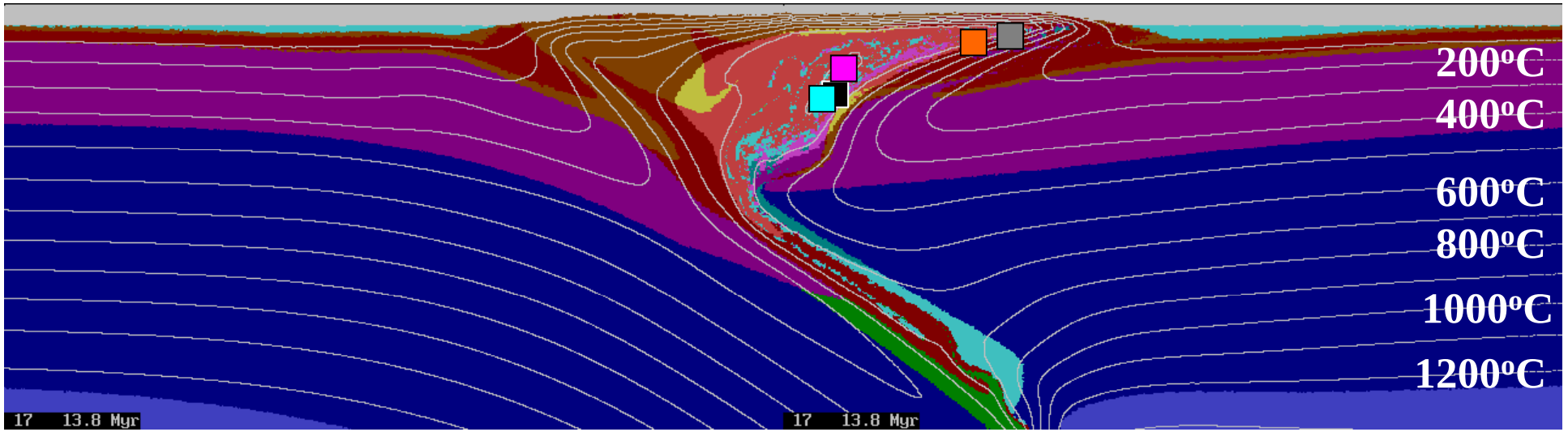
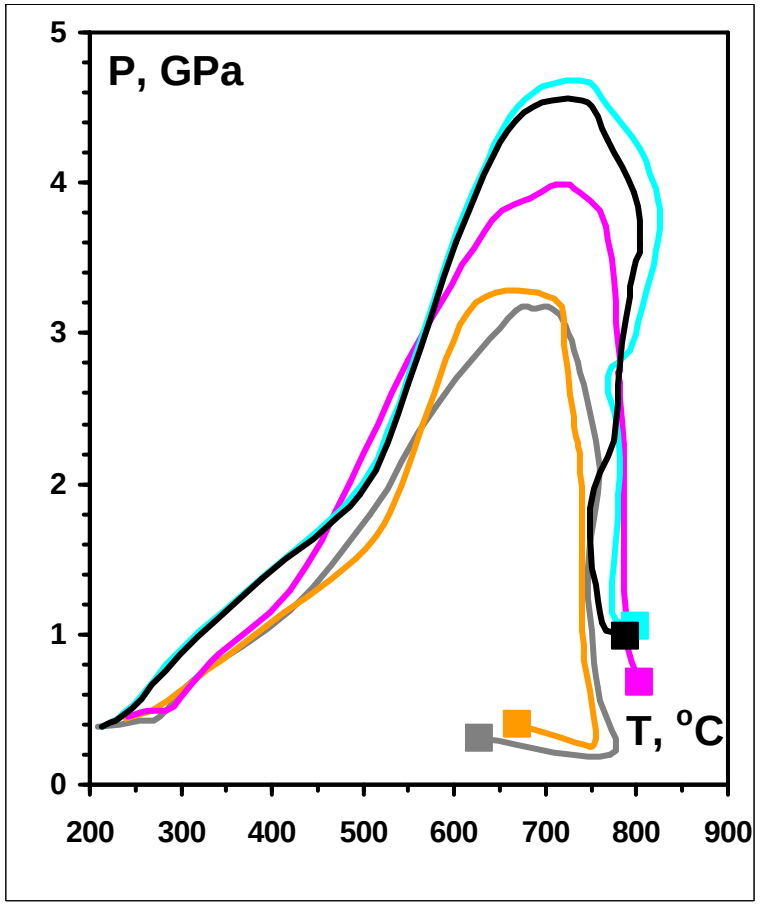
(Gerya et al., 2007)





ftp://nazca.ethz.ch/tgerya/animations/Hot_Channe.ppt

(Gerya et al., 2007)

Conclusions

- Whatever their origin (continental or oceanic), the major part of the exhumation (from mantle depth to crustal depth) of HP to UHP rocks is related to subduction processes, the final exhumation is related to collisional processes.

- Exhumation of solid rocks requires the weakening of the subduction channel by the occurrence of hydrated sediments, hydrated peridotites.

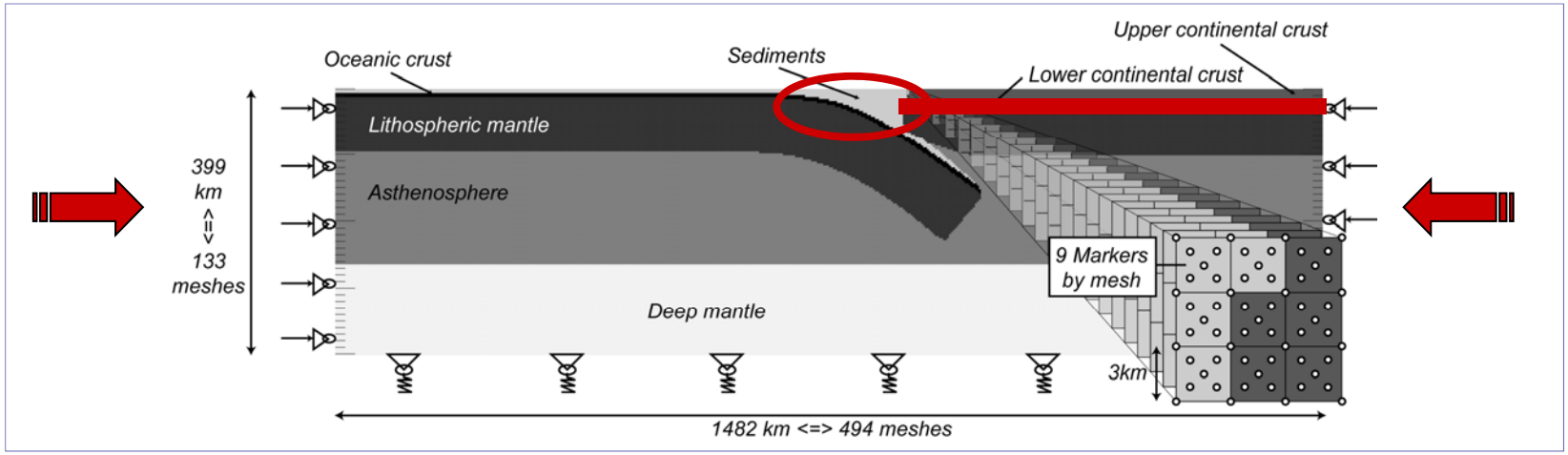
- The driving forces responsible for exhumation are a combination of buoyancy (dominant for exhumation of continental rocks) and channel flow coupled with underplating (dominant for exhumation of oceanic rocks)

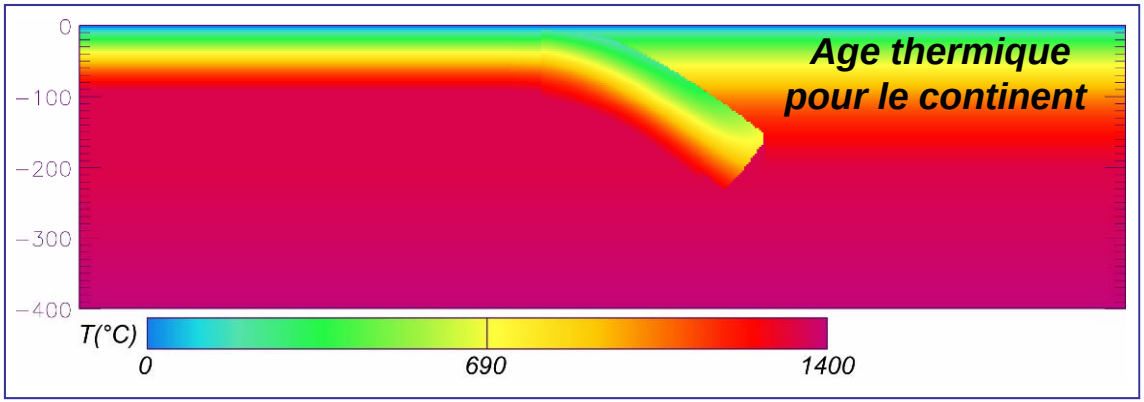
- Exhumation velocities are independent of plate velocities: in Himalaya : 10 cm/yr, in the Alps : 1 cm/yr while exhumation rate : 1 to 3 cm/yr

- Low velocity (< 5 mm/yr) exhumation of HP-LT metasediments is a long-lasting process, which occurs in an accretionary wedge environment;

- low to intermediate velocity (1 < v < 20 mm/yr) exhumation of HP to UHP oceanic rocks is a discontinuous process which occurs within a serpentinized subduction channel

- high velocity exhumation (up to 80 mm/yr) of UHP units is extremely short-lived (<10Myr) and occurs in the mantle wedge, combining both astenospheric return flow and buoyancy forces.



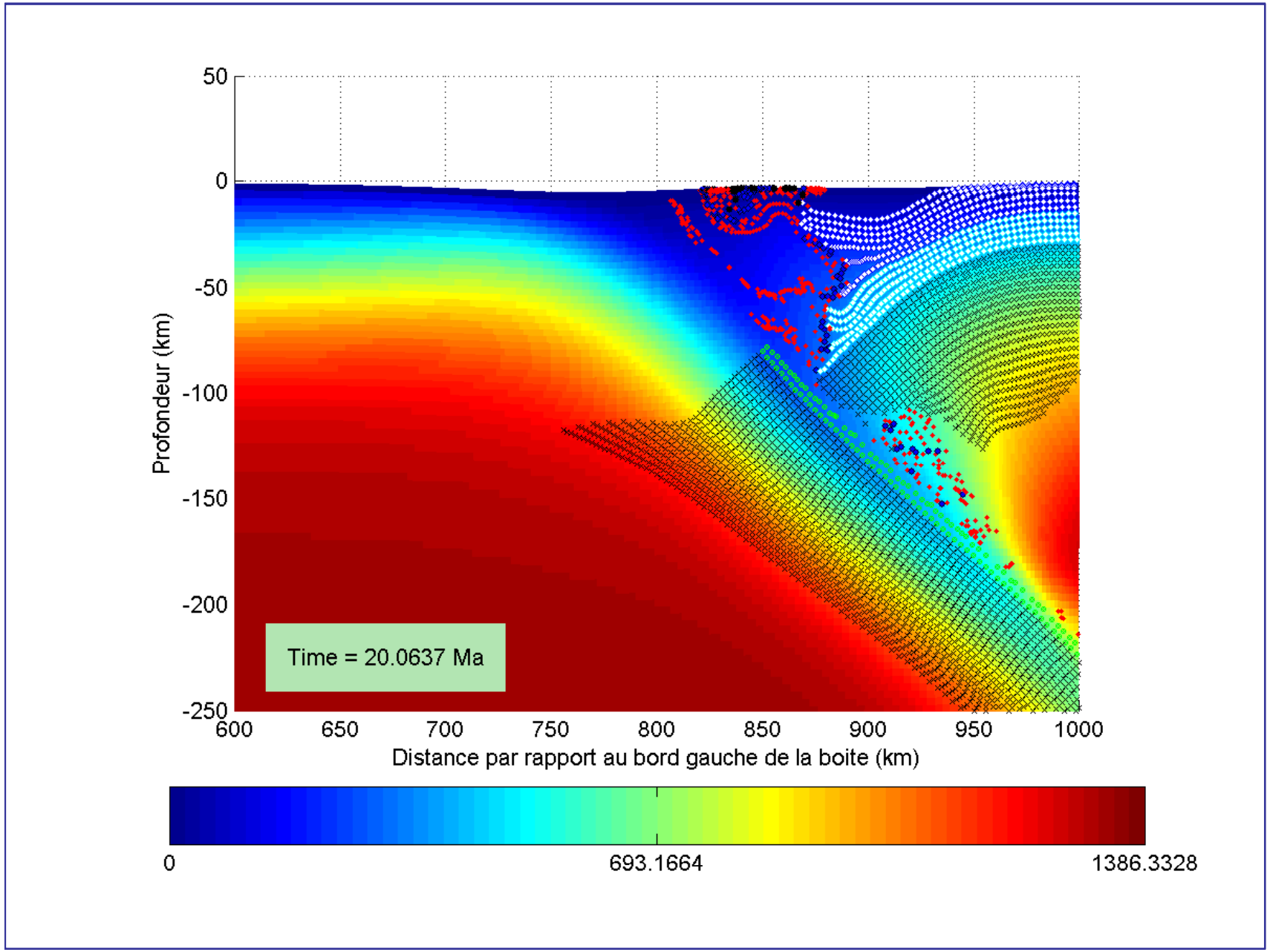


Les paramètres testés

Yamato et al., 2007

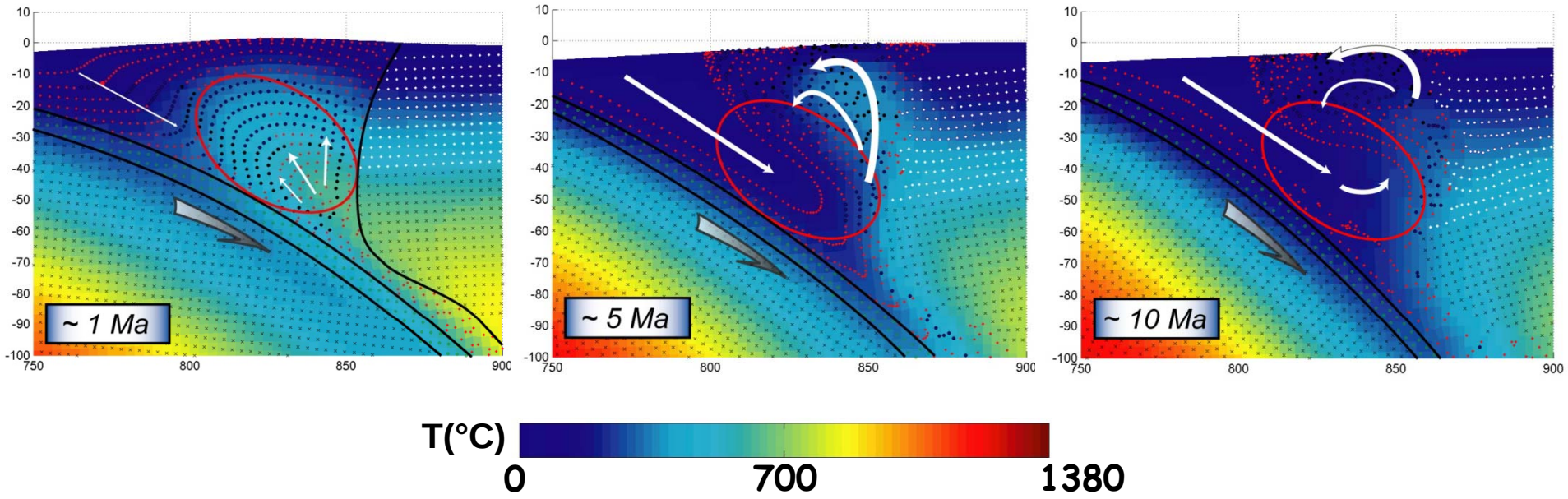
Expérience Standard

La vitesse de convergence	*3 cm.an^{-1}*	*1,5 cm.an^{-1}*	*6 cm.an^{-1}*
Age thermique pour le continent	*160 Ma*	*250 Ma*	
Croûte continentale inférieure	*Diabase*	*Quartz*	
Prisme d'accrétion	*Quartz*	*Quartz faible*	*Schistes*


50
0
-50
-100
-150
-200
-250
Profondeur (km)
600
650
700
750
800
850
900
950
1000
Distance par rapport au bord gauche de la boite (km)
Time = 20.0637 Ma
0
693.1664
1386.3328

Les résultats

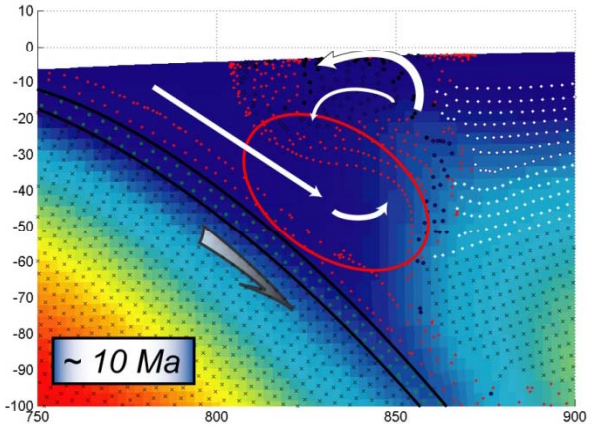
Evolution au sein du prisme d'accrétion

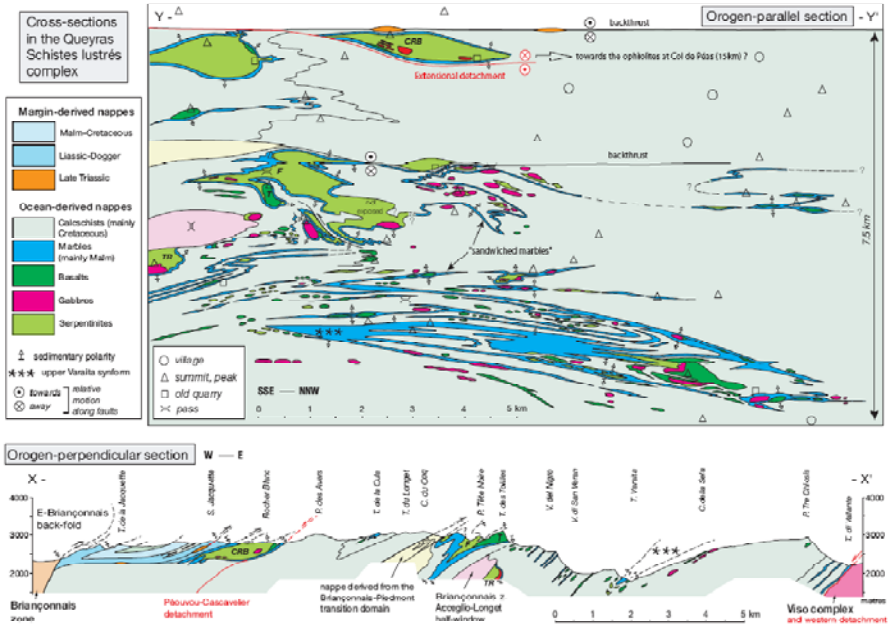


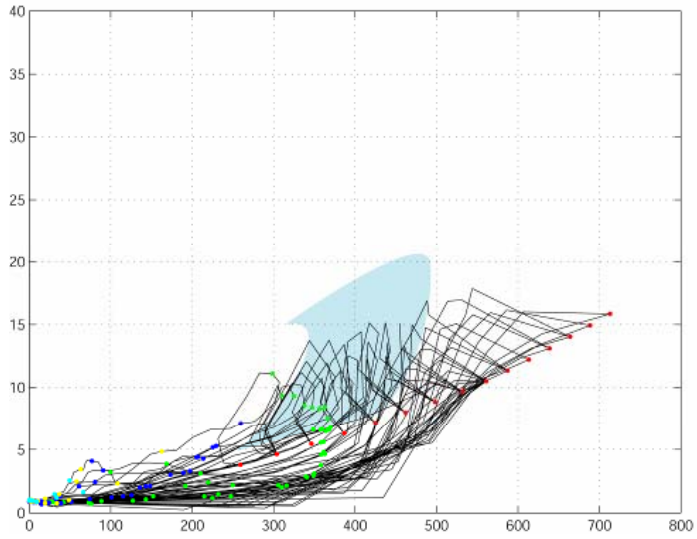
Yamato et al., 2007

Les résultats

Bon accord avec les données naturelles







Mais pas d'exhumation de la croûte océanique …