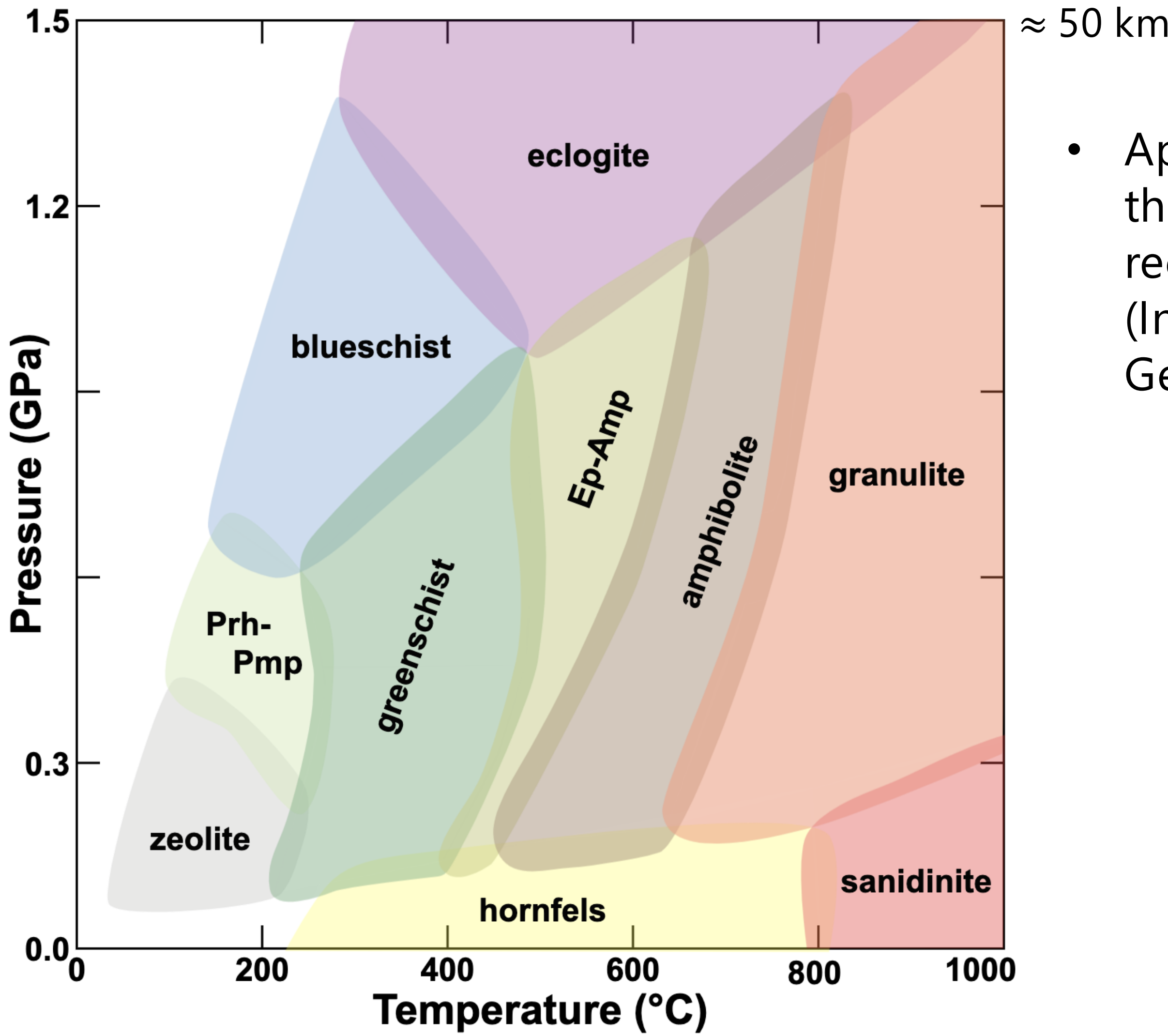
Rock exhumation

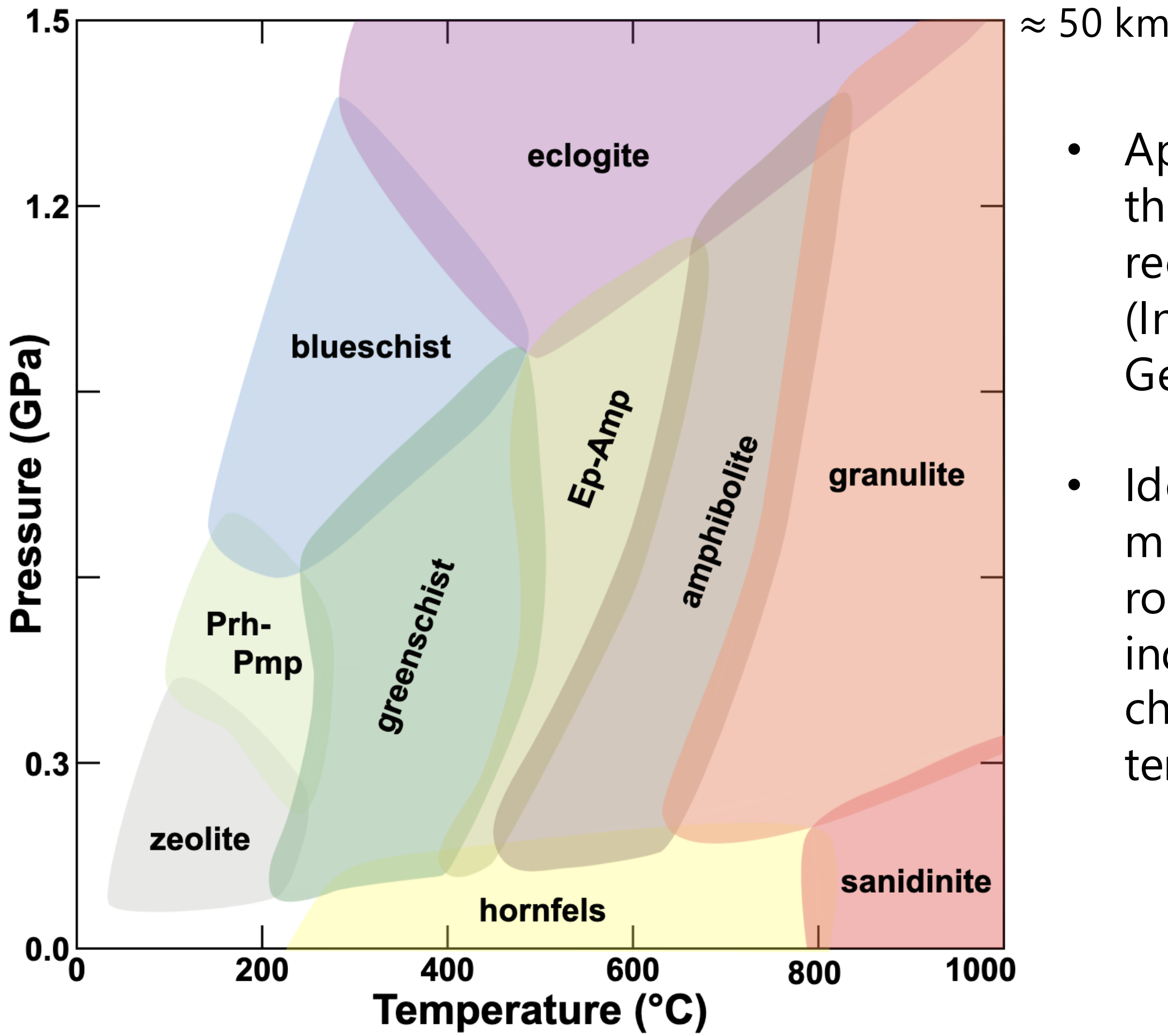
Metamorphic facies



- Approximate T-P regions of the ten metamorphic facies recommended by the IUGS (International Union of Geological Sciences)

https://science.smith.edu/~jbrady/petrology/

Metamorphic facies

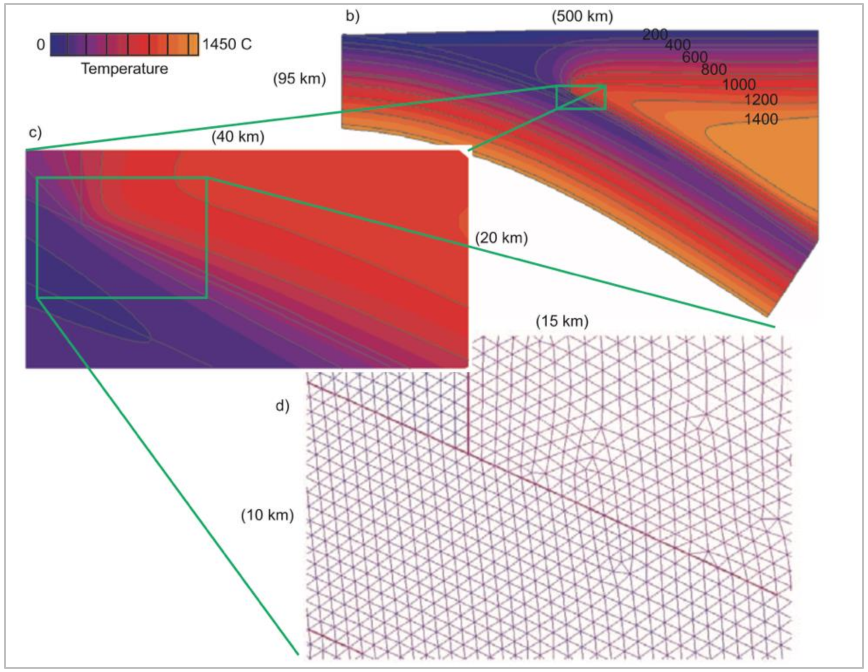


- Approximate T-P regions of the ten metamorphic facies recommended by the IUGS (International Union of Geological Sciences)
- Identifying the diagnostic minerals within exhumed rocks thus gives an indication of subduction channel/interface temperatures.

https://science.smith.edu/~jbrady/petrology/

Comparison of the rock temperatures with those from geodynamic models

van Keken et al., 2002



Kinematically-driven thermal models

Subduction properties (e.g., velocity, dip, ages)
<u>fixed</u> *to generate typically time-invariant solutions*

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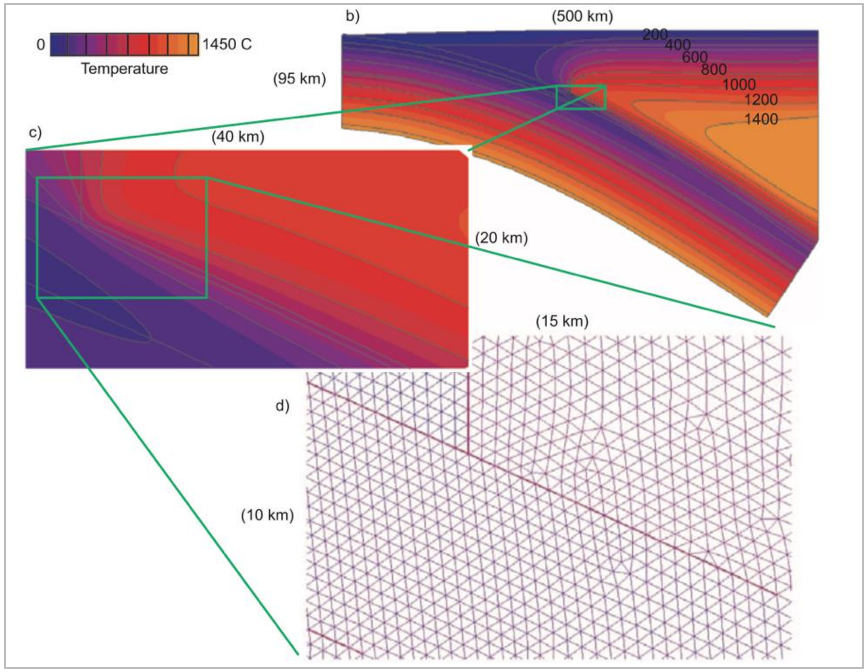
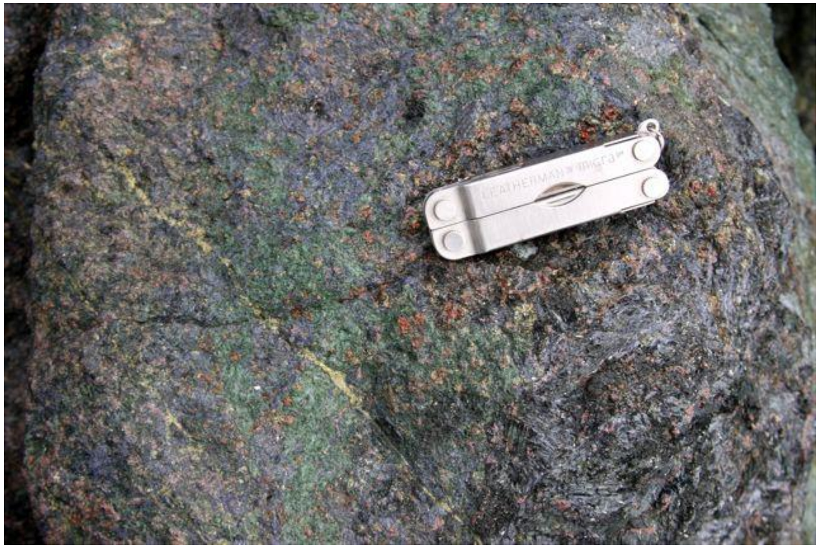


Kinematically-driven thermal models

Subduction properties (e.g., velocity, dip, ages)
<u>fixed</u> *to generate typically time-invariant solutions*

<u>Typical model constraints</u>:

- volcanic arc locations
- heat flow measurements
- exhumed rock *P-T* conditions



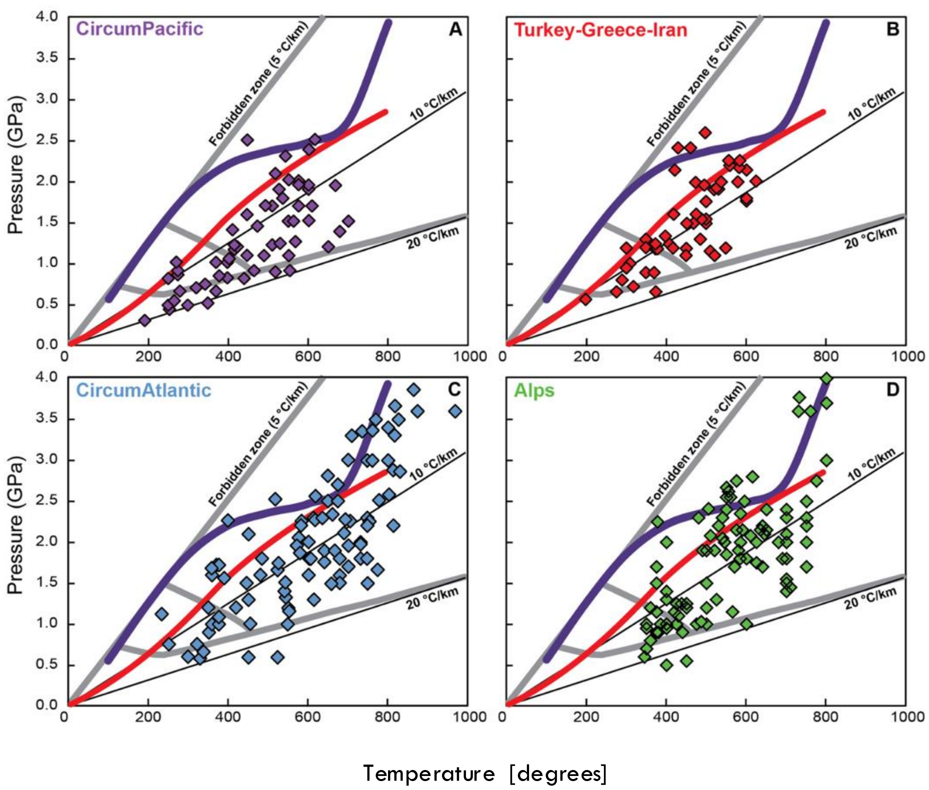
A blueschist from Syros, Greece (Zeb Page's webpage)

Comparison of the rock temperatures with those from geodynamic models

But… "*Rocks are hotter than models*"

The global range of subduction zone thermal structures from exhumed blueschists and eclogites: Rocks are hotter than models

Sarah C. Penniston-Dorland[a,*], Matthew J. Kohn[b], Craig E. Manning[c] (2015, EPSL)



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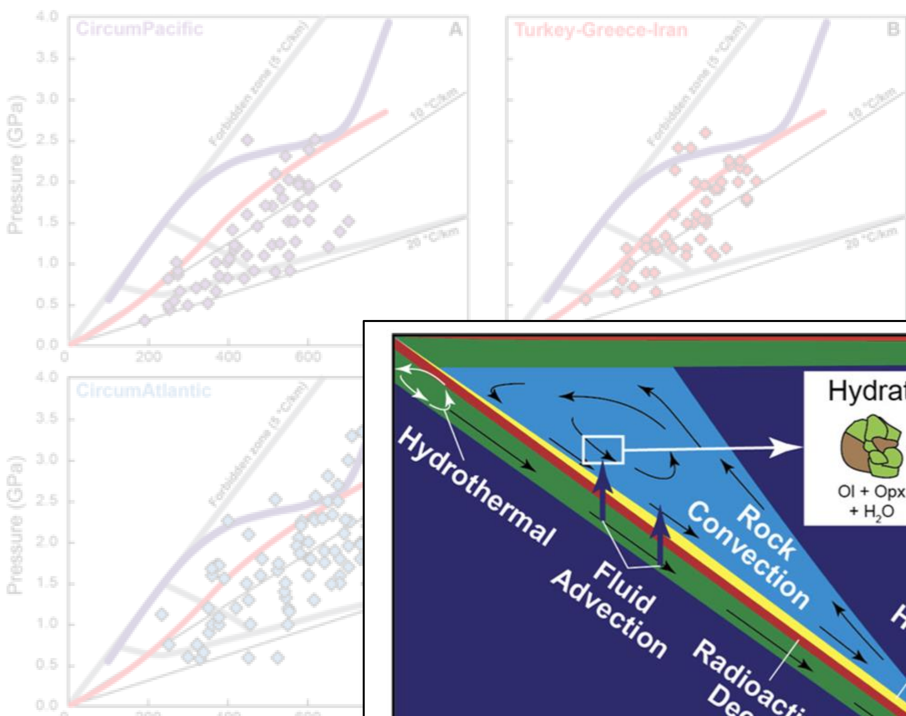
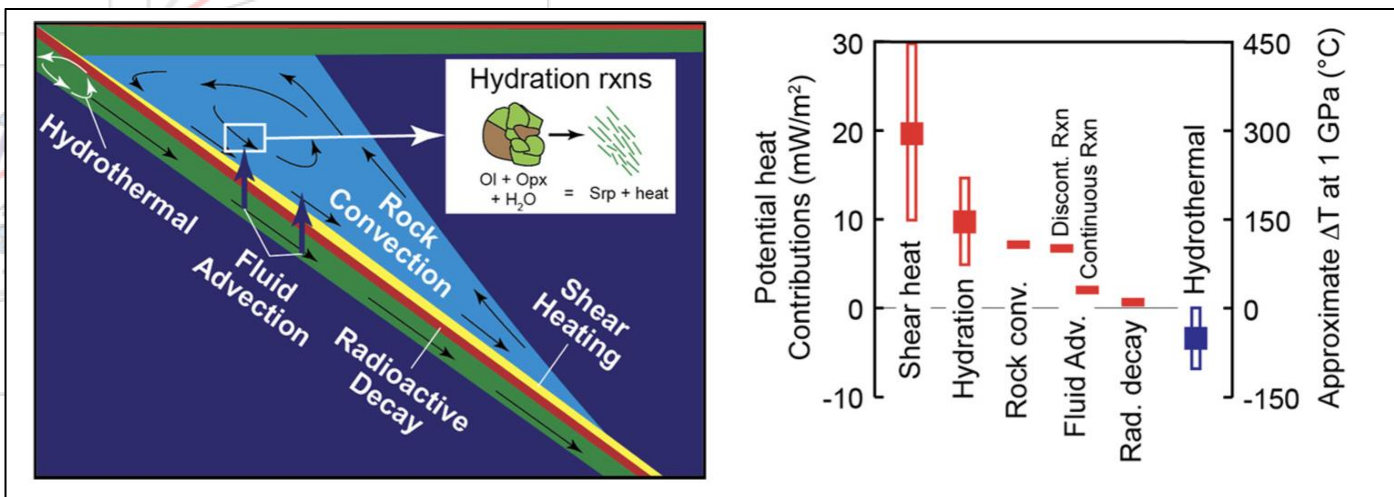


Possible explanations include:

- **<u>Missing heat sources</u>**

  Penniston-Dorland et al., 2015; Kohn et al., 2018,…



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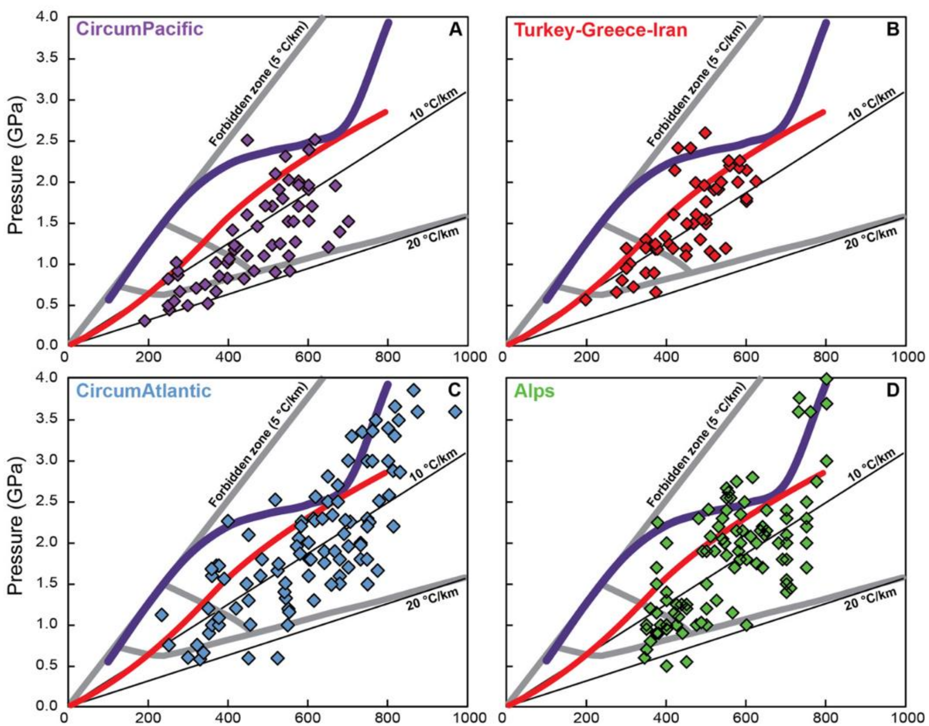


Temperature [degrees]

Possible explanations include:

- <u>**Missing heat sources**</u>

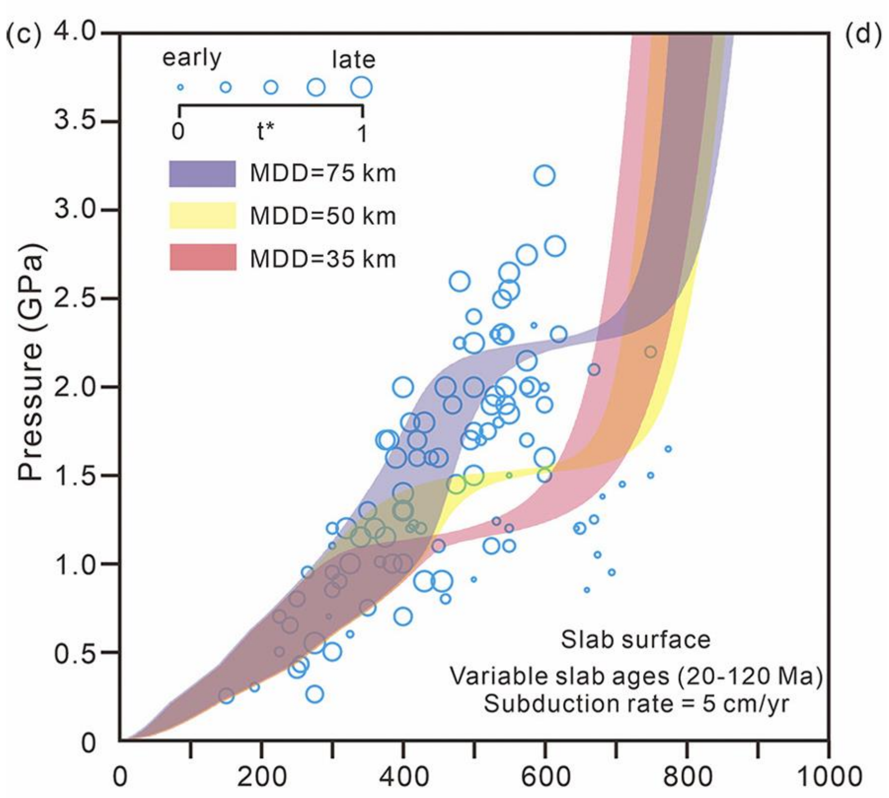
  Penniston-Dorland et al., 2015; Kohn et al., 2018,…

- <u>**Time variability in subduction zone temperatures and/or periods of anomalous subduction**</u>

  van Keken et al., 2018; Agard et al., 2009,…

Comparison of the rock temperatures with those from geodynamic models

But… “*Rocks are hotter than models*”



Wang et al., 2023
(cf. Holt and Condit, 2021)

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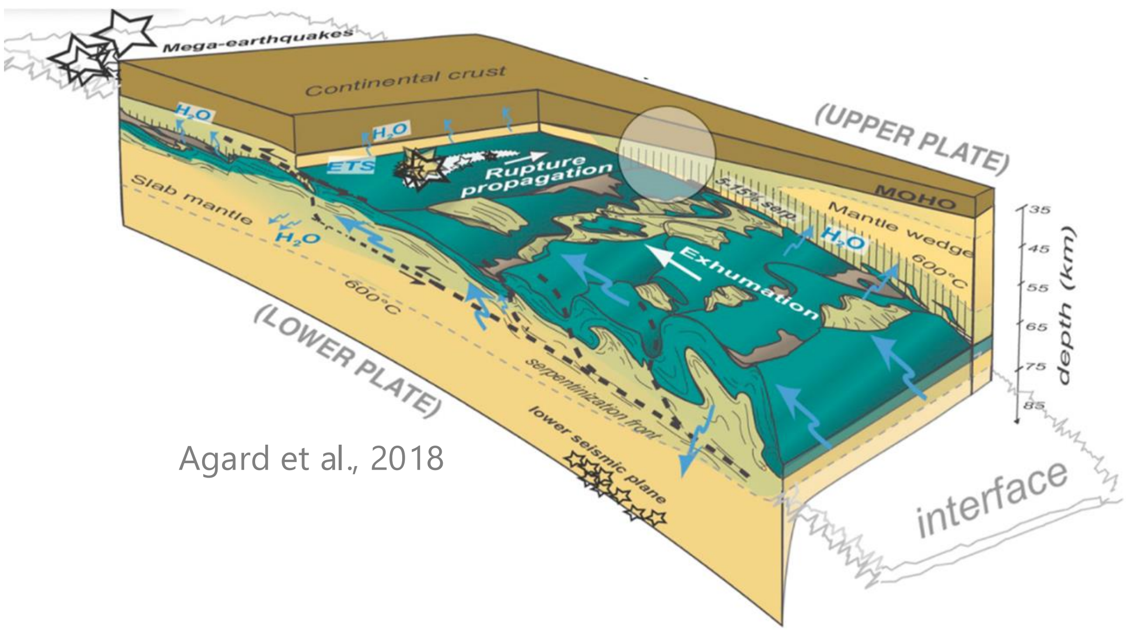
Maybe need to figure out:

What types of exhumed rocks at different types of subduction zones?

How do the exhumed rocks ascend to the surface at different subduction zones?



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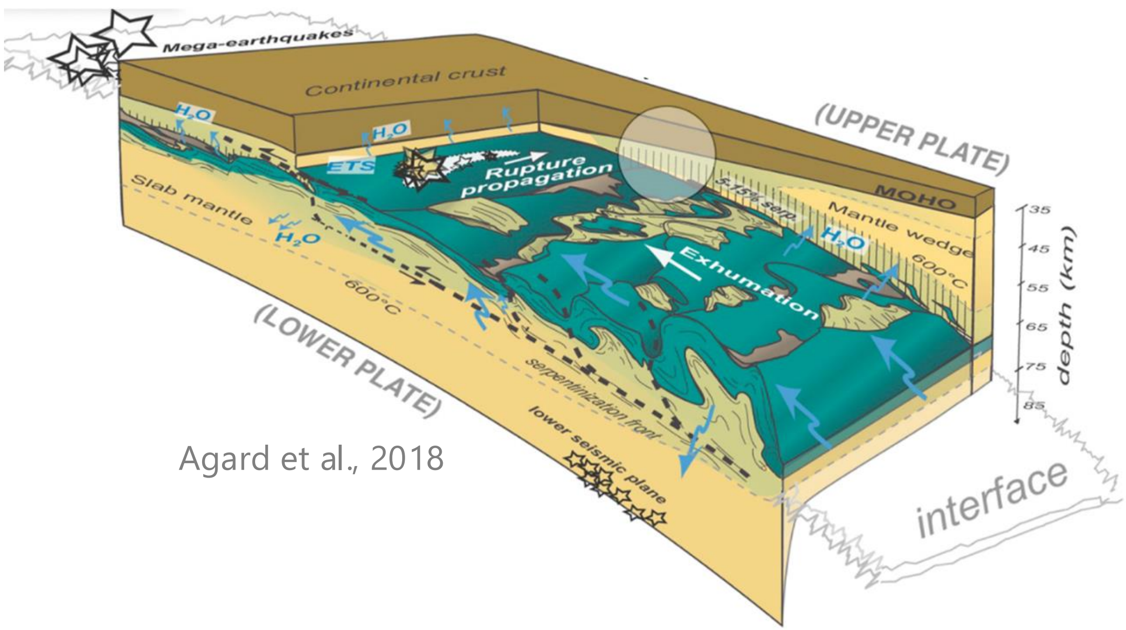

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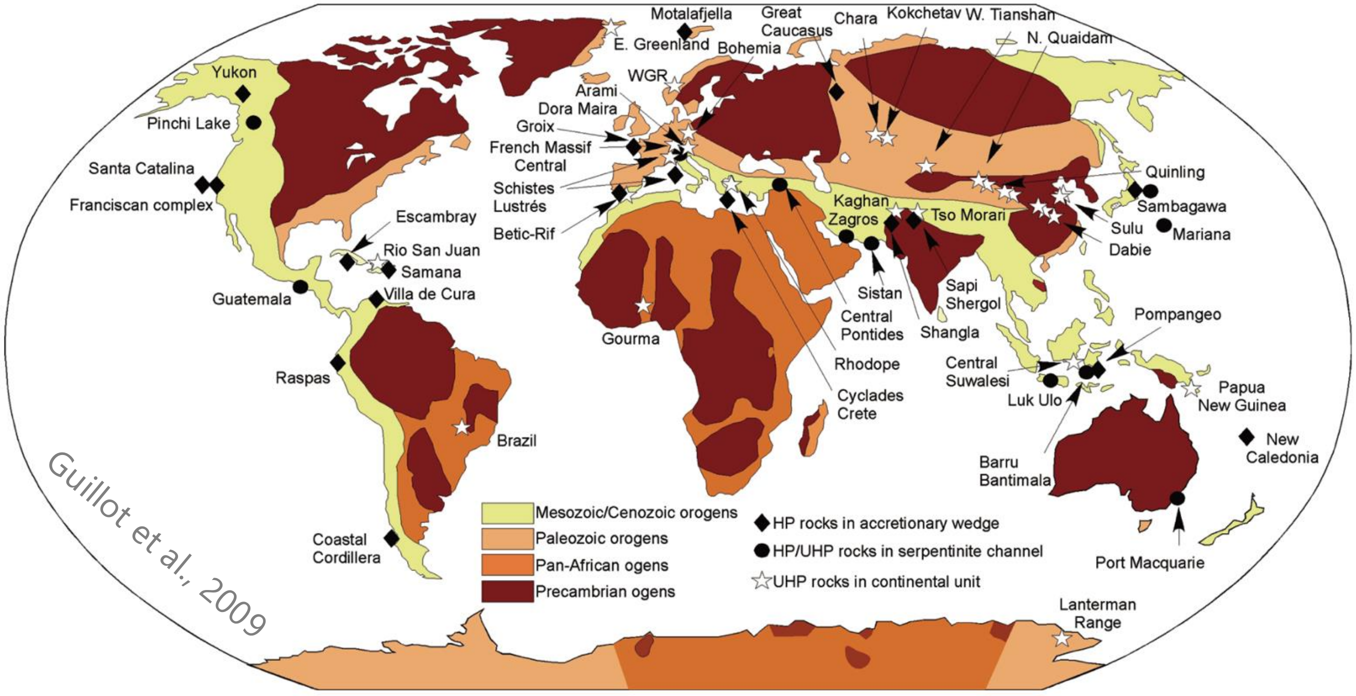
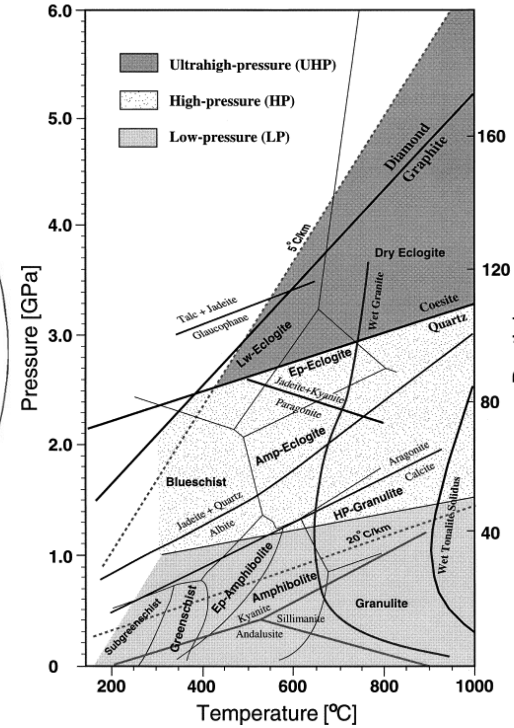
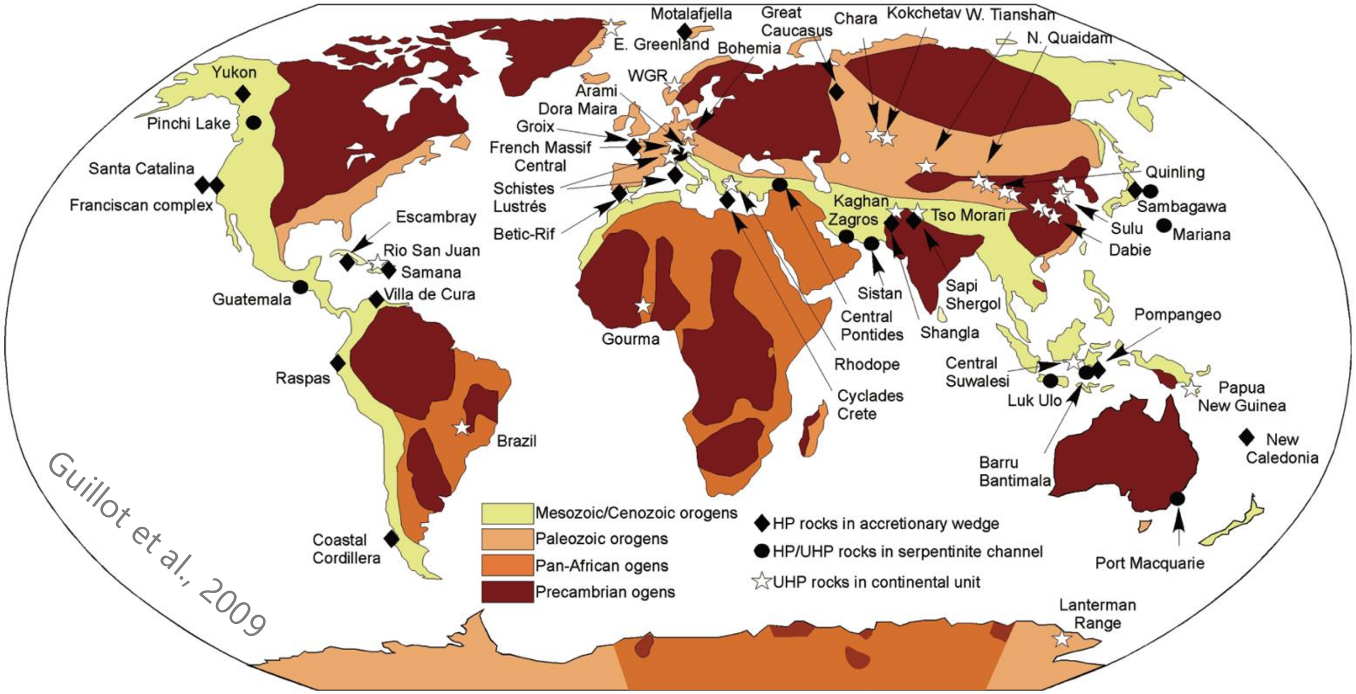
Types of exhumed rocks at different subduction zones

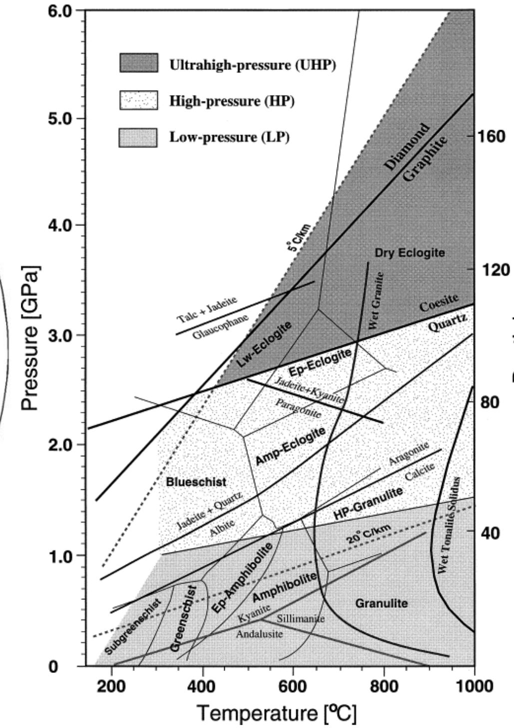




Guillot et al., 2009

Types of exhumed rocks at different subduction zones

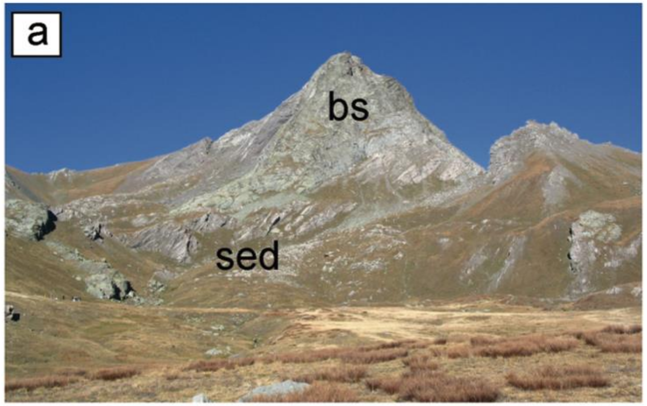




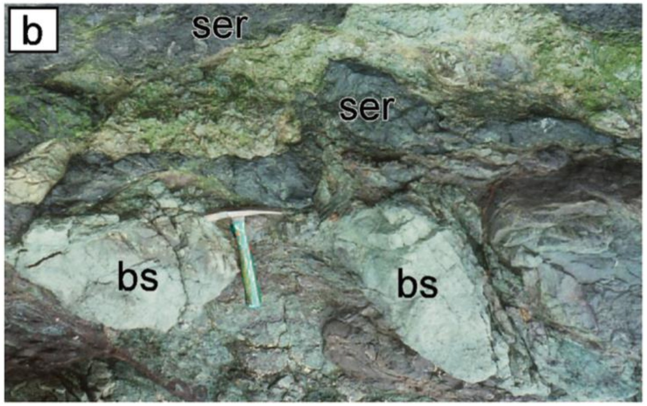
Guillot et al. (2009) propose three characterizations:

- ***Accretionary wedge exhumation***: relatively shallow exhumation (z < ~ 70 km); exhumation dependent on wedge shape (/buttress geometry); sediment protoliths. Slow exhumation velocities (1-5 mm/yr)
- ***Serpentinite type***: mainly highly sheared serpentinite matrices with blocks of metabasites. Melange-like. Mafic blocks mainly from downgoing plate. Intermediate exhumation velocities (3-10 mm/yr)
- ***Continental type***: UHP conditions greater than 100 km (contain coesite or diamond). Mainly upper continental crust protoliths (e.g., granite). Pre-existing structures may decouple slice of crust from rest of slab. Rapid exhumation velocities (~6-80 mm/yr)

Types of exhumed rocks at different subduction zones



Accretionary wedge type : oceanic blueschist in sedimentary matrix



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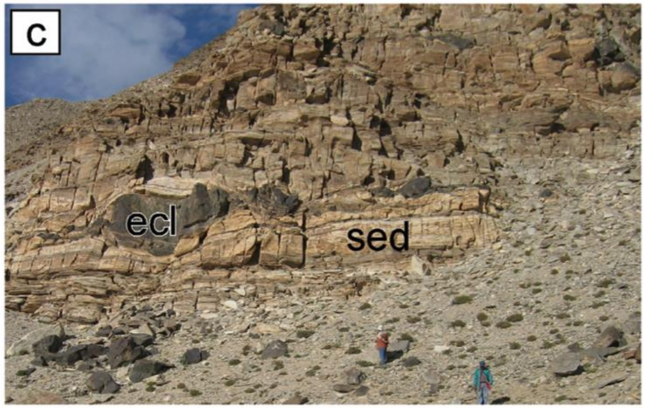
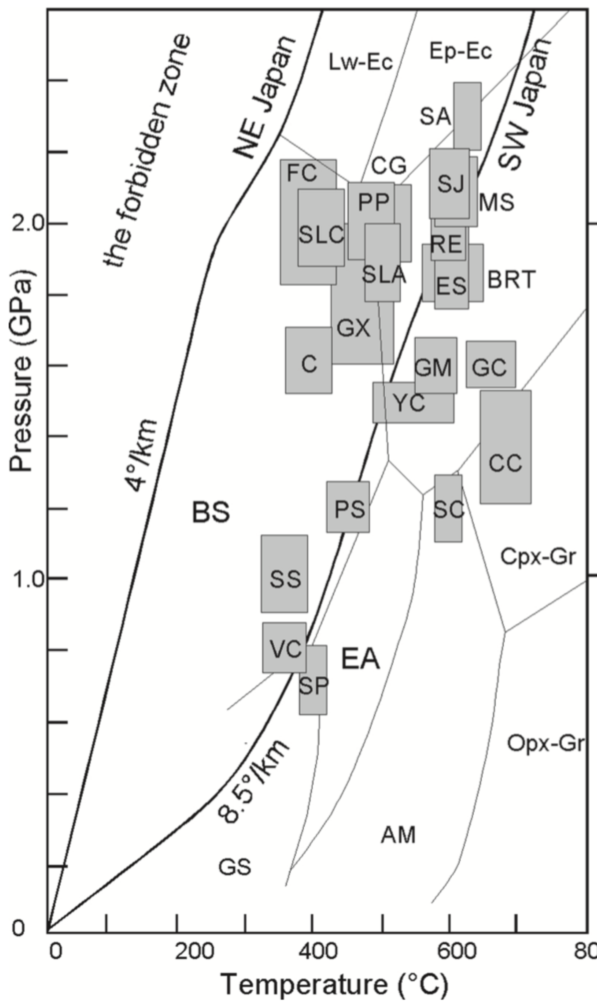


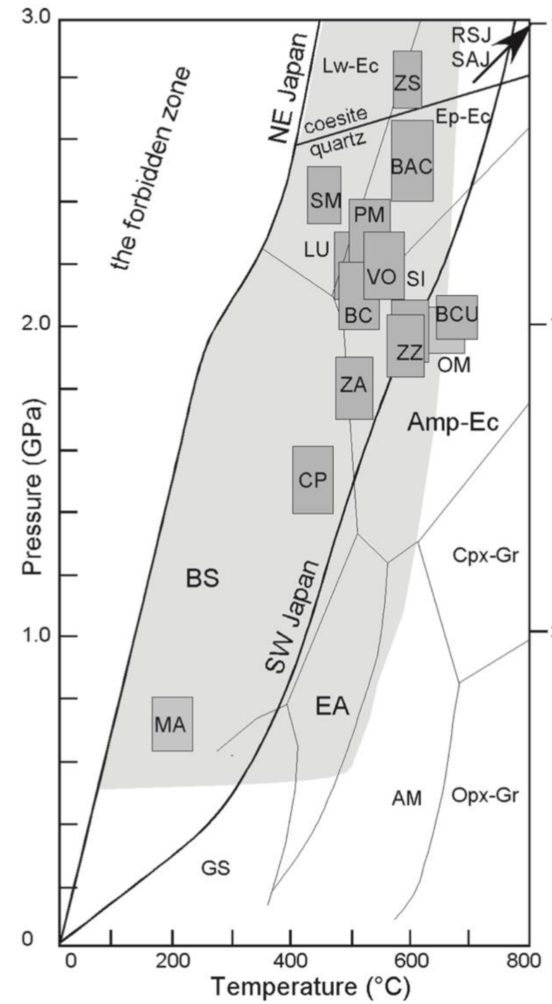
Continental subduction type : Coesite-bearing eclogite emplaced into sediment.

Types of exhumed rocks at different subduction zones

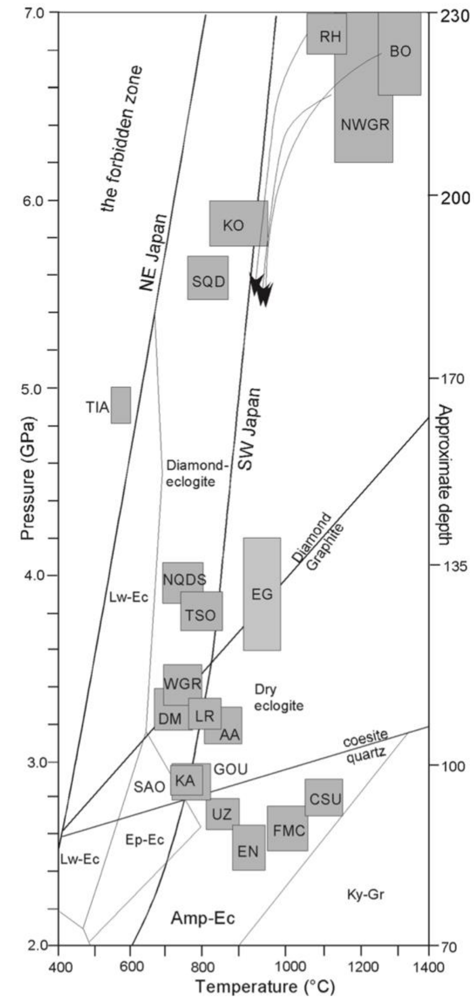
Accretionary type



Serpentinite type

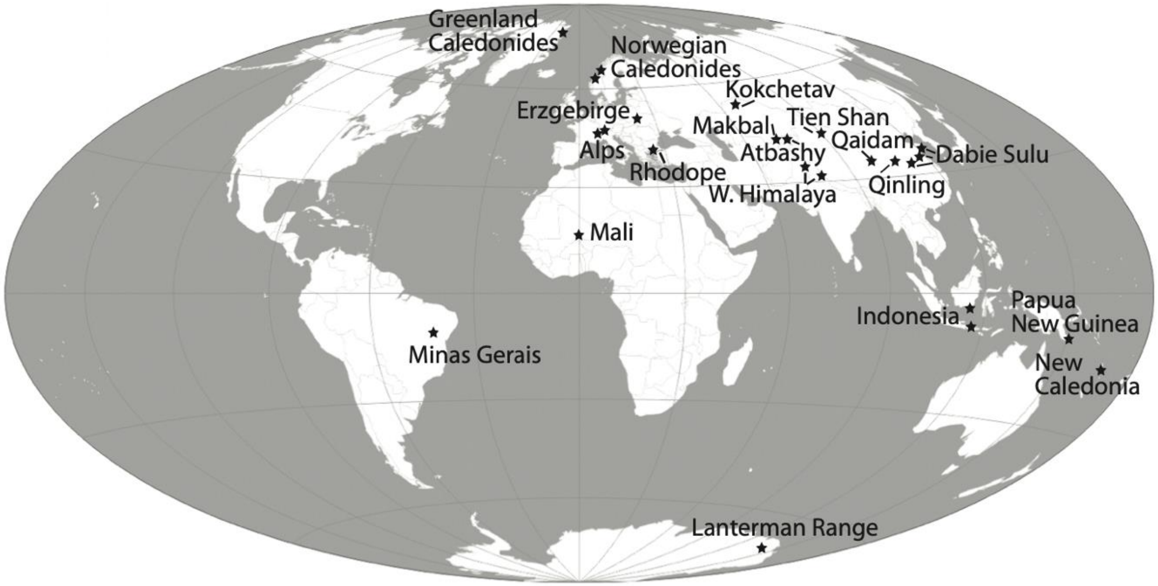


Continental type



<u>UHP</u> exhumation at continental collision zones

Warren (2013, Sol. Earth)



- UHP conditions documented within most Phanerozoic (i.e., since 541 Ma) continental collisional orogens.
- UHP minerals (coesite, diamond) usually preserved as microscopic inclusions, armored in strong hosts (garnet, zircon) from lower P conditions.

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- Could "overpressure" be responsible for the most extreme pressures (up to ~6 GPa)?

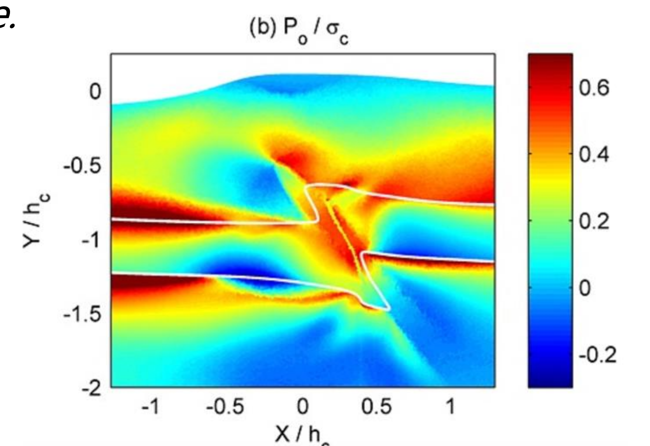
Numerical modelling results suggest that, in some cases, rocks can experience tectonic overpressures of up to 1.5 GPa more than lithostatic pressure.

Regular Article | Open Access

Tectonic overpressure in weak crustal-scale shear zones and implications for the exhumation of high-pressure rocks

Stefan M. Schmalholz, Yuri Y. Podladchikov

First published: 28 March 2013 | **https://doi.org/10.1002/grl.50417** | Citations: 106



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- UHP minerals (coesite, diamond) usually preserved as microscopic inclusions, armored in strong hosts (garnet, zircon) from lower P conditions.

- Could "overpressure" be responsible for the most extreme pressures (up to ~6 GPa)?
- High-strain zones are responsible for the detachment of subducted crust and its transport back up to mid-crustal levels of exhumation. The levels of weakening inferred from natural shear zones associated with UHP rocks may be up to a factor of 100 (Raimbourg et al., 2007). Potentially due to:
  - Strain weakening *(evidence from experiments)*
  - Melt weakening *(e.g., migmatites)*
  - Hydration weakening *(e.g., serpentinites)*
  - Grain size reduction

Maybe need to figure out:

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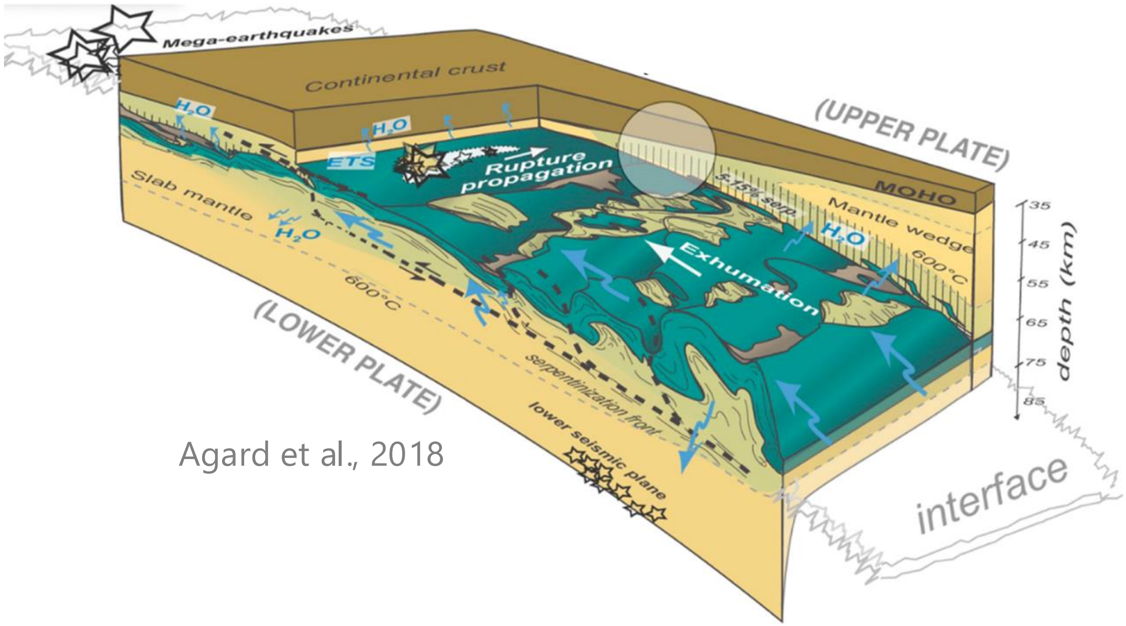
<u>How do the exhumed rocks ascend to the surface at different subduction zones?</u>

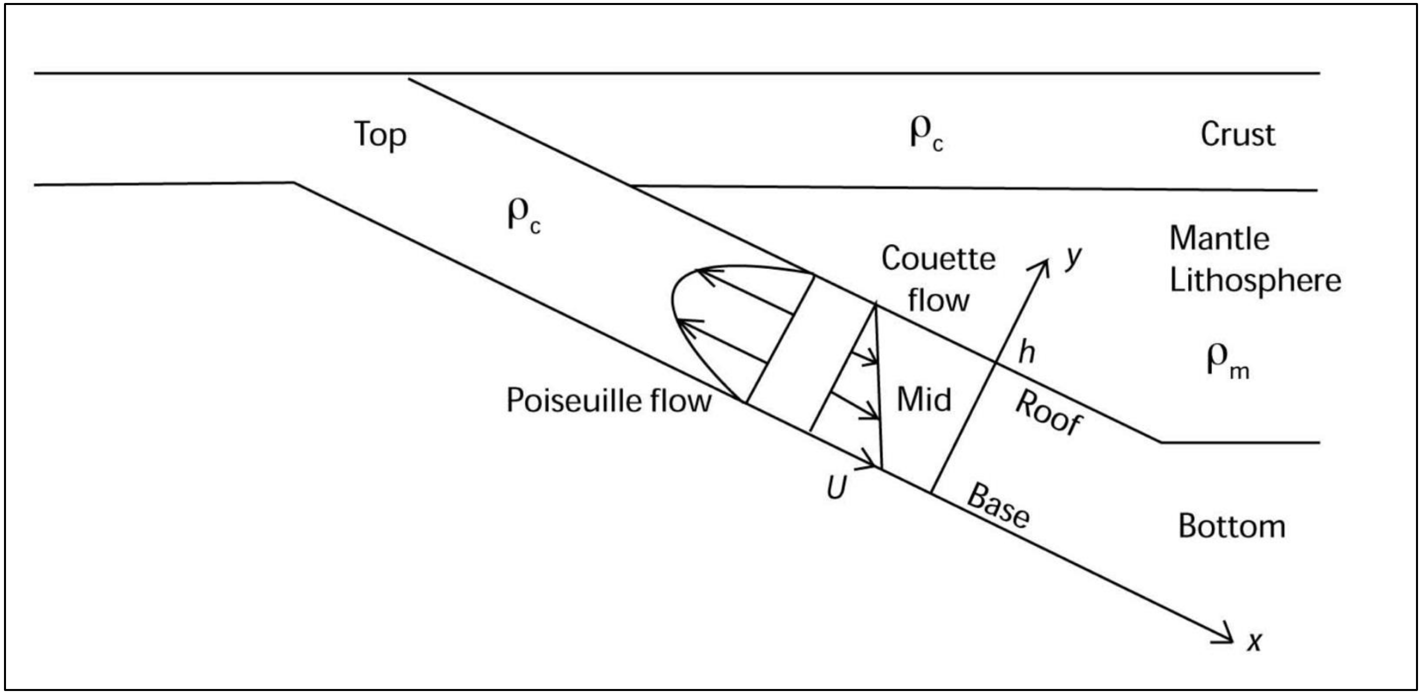


Agard et al., 2018

UHP exhumation mechanisms

Generally, focus around/within a subduction "channel"

Warren (2013, Sol. Earth)



UHP exhumation mechanisms

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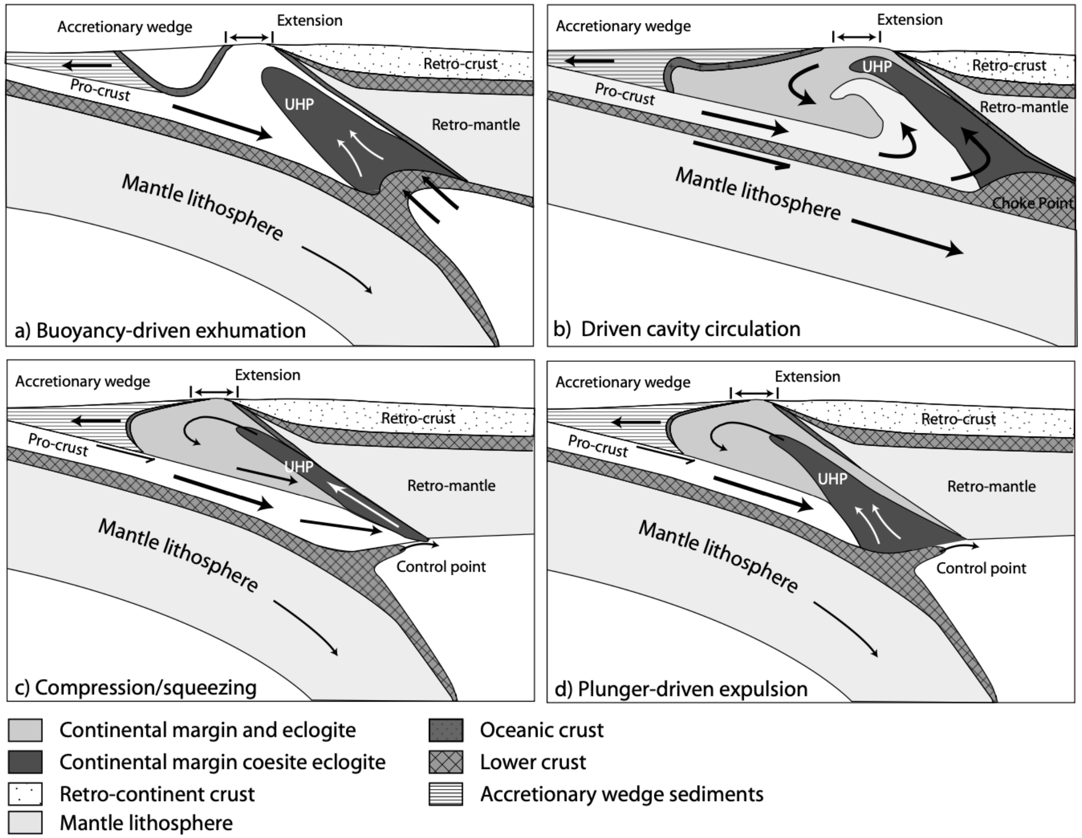

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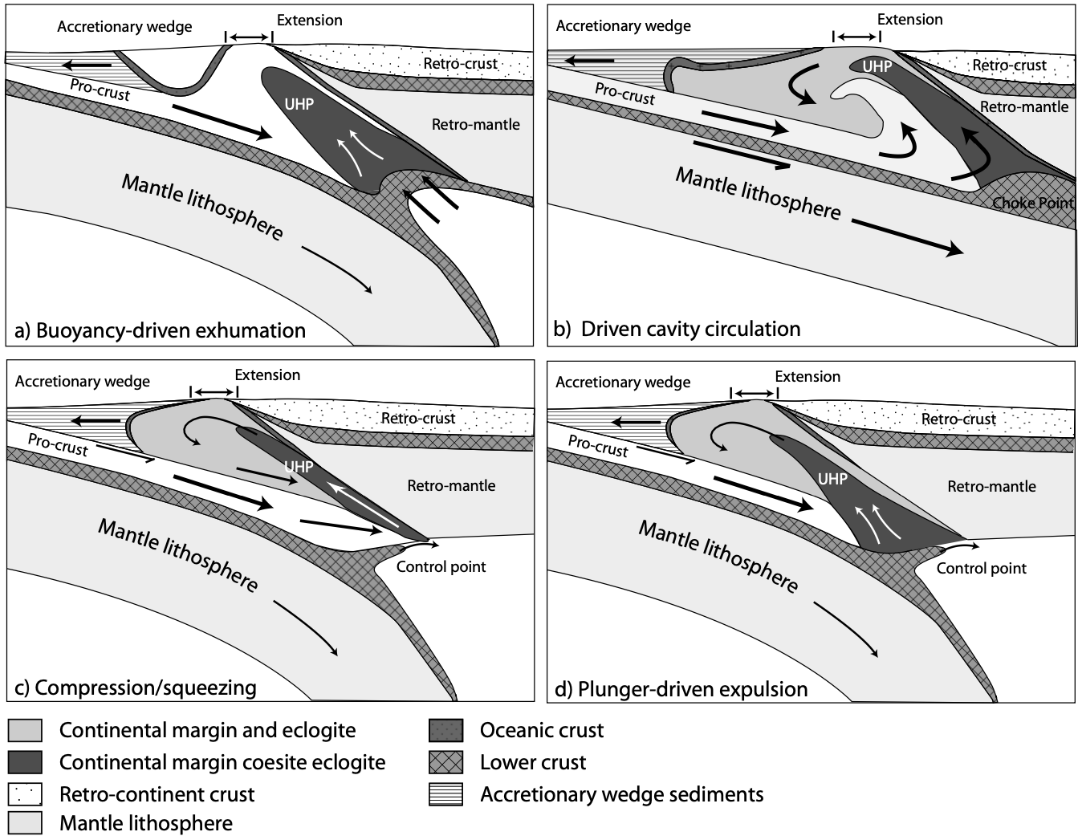
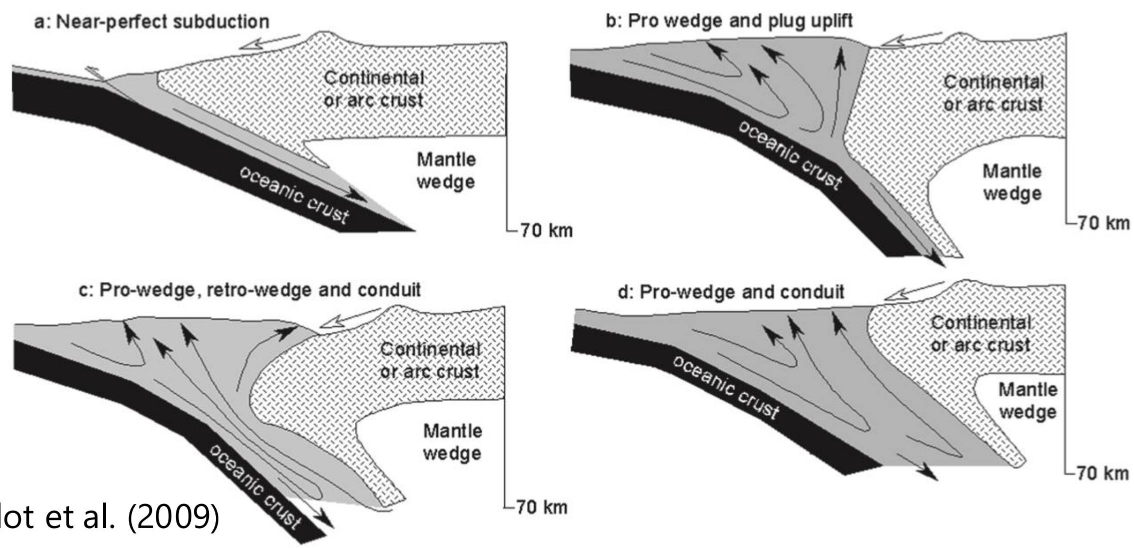


- Buoyancy driven (internal driver): Continental crust generally less dense than surrounding material.
- Plunger expulsion (external/tectonic driver): Expulsion of weak crust due to insertion of stronger crust into the channel.
- Driven cavity / forced return flow (external/tectonic driver): Return flow driven by the tractions from the subducting plate.

~~UHP~~ HP exhumation mechanisms in oceanic subd.



Guillot et al. (2009)

Accretionary prism exhumation. Geometry dictates depth and likelihood of exhumation.

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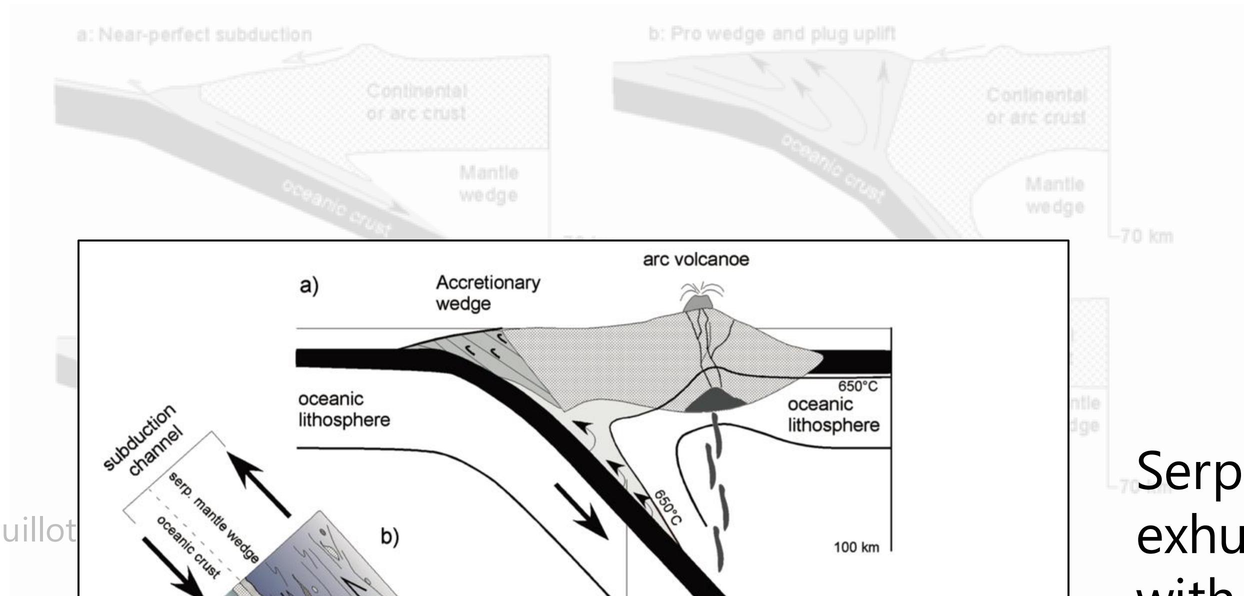

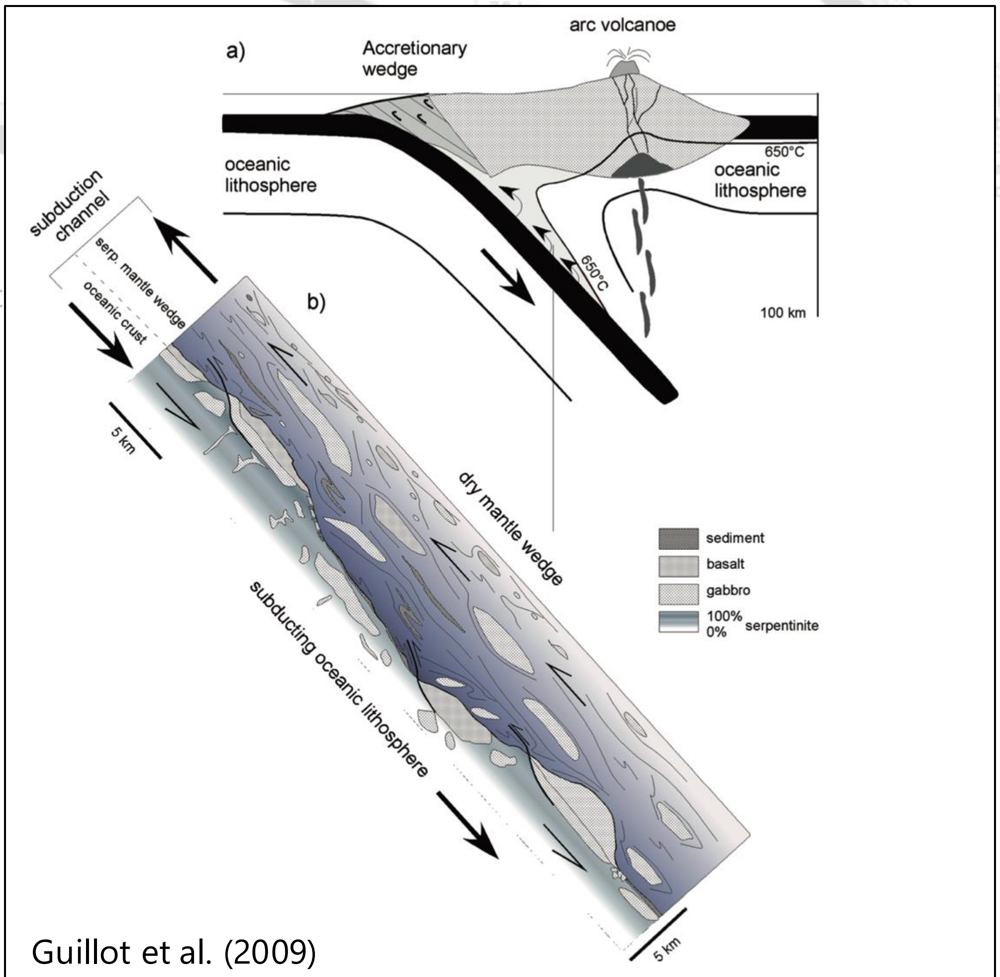

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Accretionary prism exhumation. Geometry dictates depth and likelihood of exhumation.

Serpentinite-type exhumation. Can co-exist with accretionary exhumation (e.g., Franciscan), both with slow exhumation velocities. Accretionary – kilometric slices. Serp. channel – melanges.

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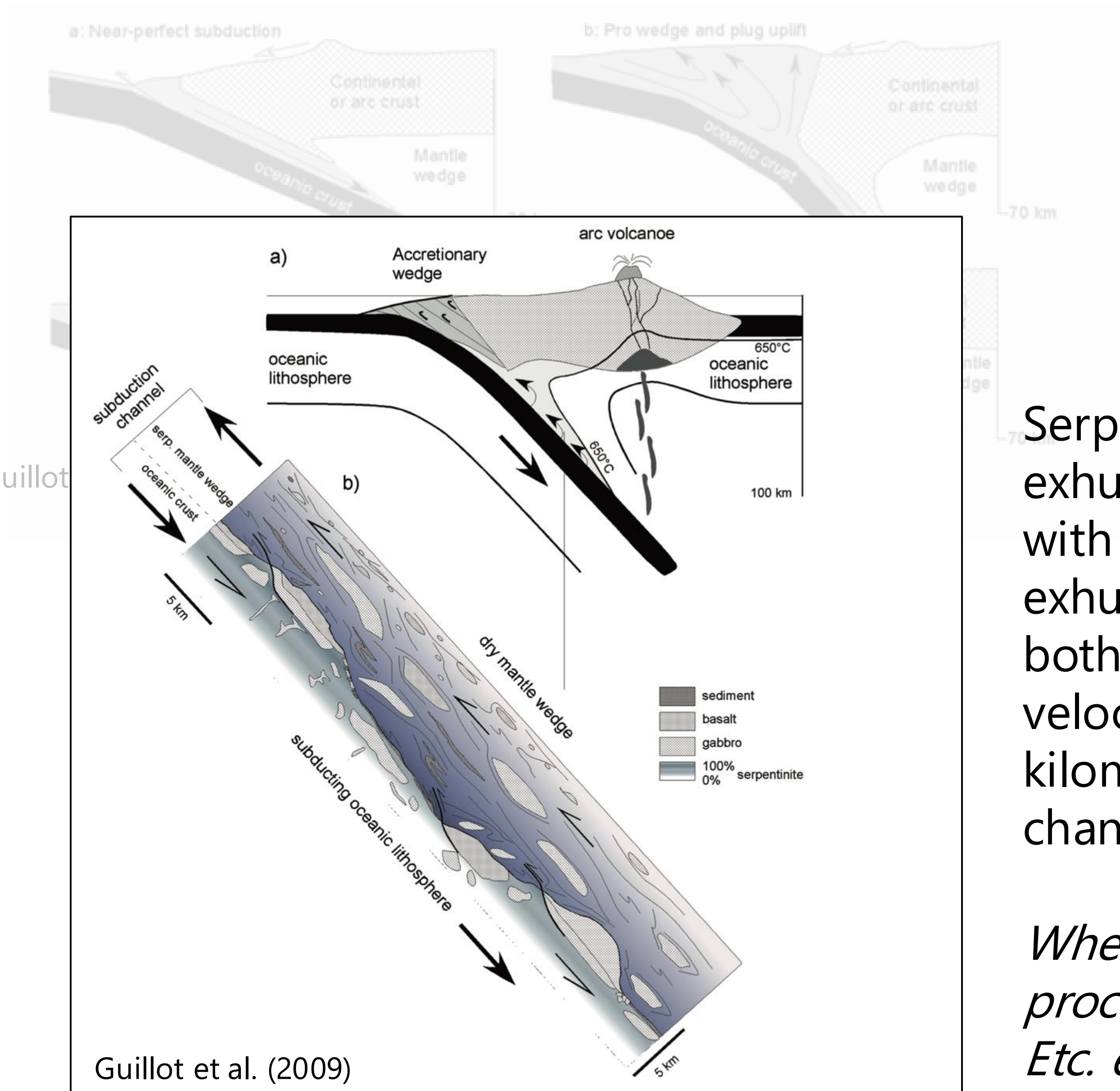

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When during the subd. process? As what depths? Etc. etc.

Let’s take the world view of the Agard group:

Lithos 320–321 (2018) 537–566

Contents lists available at ScienceDirect

Lithos

journal homepage: www.elsevier.com/locate/lithos

Invited Review Article

The subduction plate interface: rock record and mechanical coupling (from long to short timescales)

P. Agard [a,*], A. Plunder [a], S. Angiboust [b], G. Bonnet [a], J. Ruh [a,c]

[a] Sorbonne Université, CNRS-INSU, Institut des Sciences de la Terre Paris, ISTeP UMR 7193, F-75005 Paris, France
[b] Institut de Physique du Globe de Paris, Sorbonne Paris Cité, Univ. Paris Diderot, CNRS,F-75005 Paris, France
[c] Institute of Earth Science Jaume Almera, ICTJA-CSIC, Barcelona, Spain

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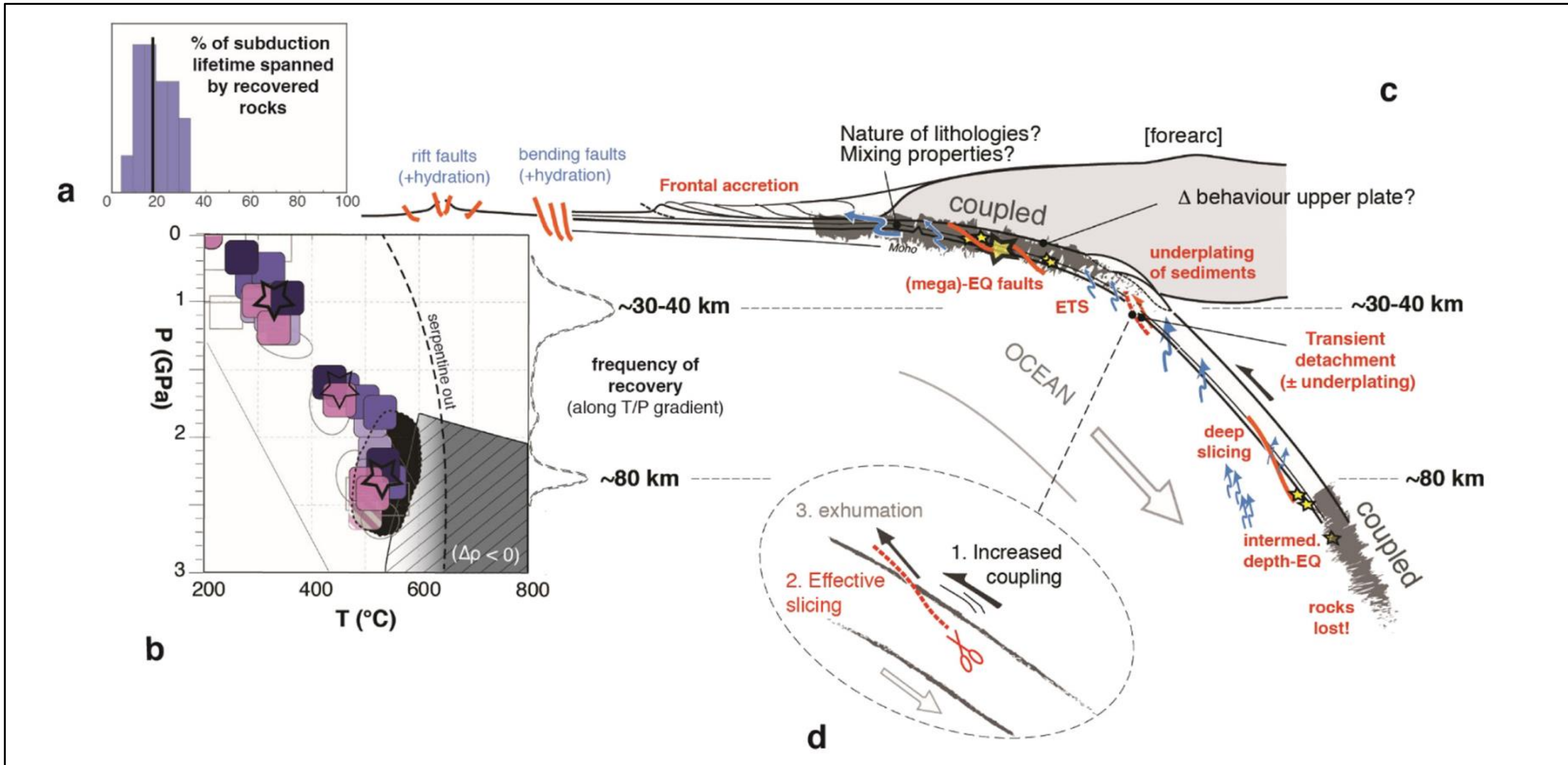

- Rock recovery is **episodic**: subducted rocks are returned over relatively short-lived episodes representing only a fraction of subduction lifetime (doesn't support a steady return flow process).

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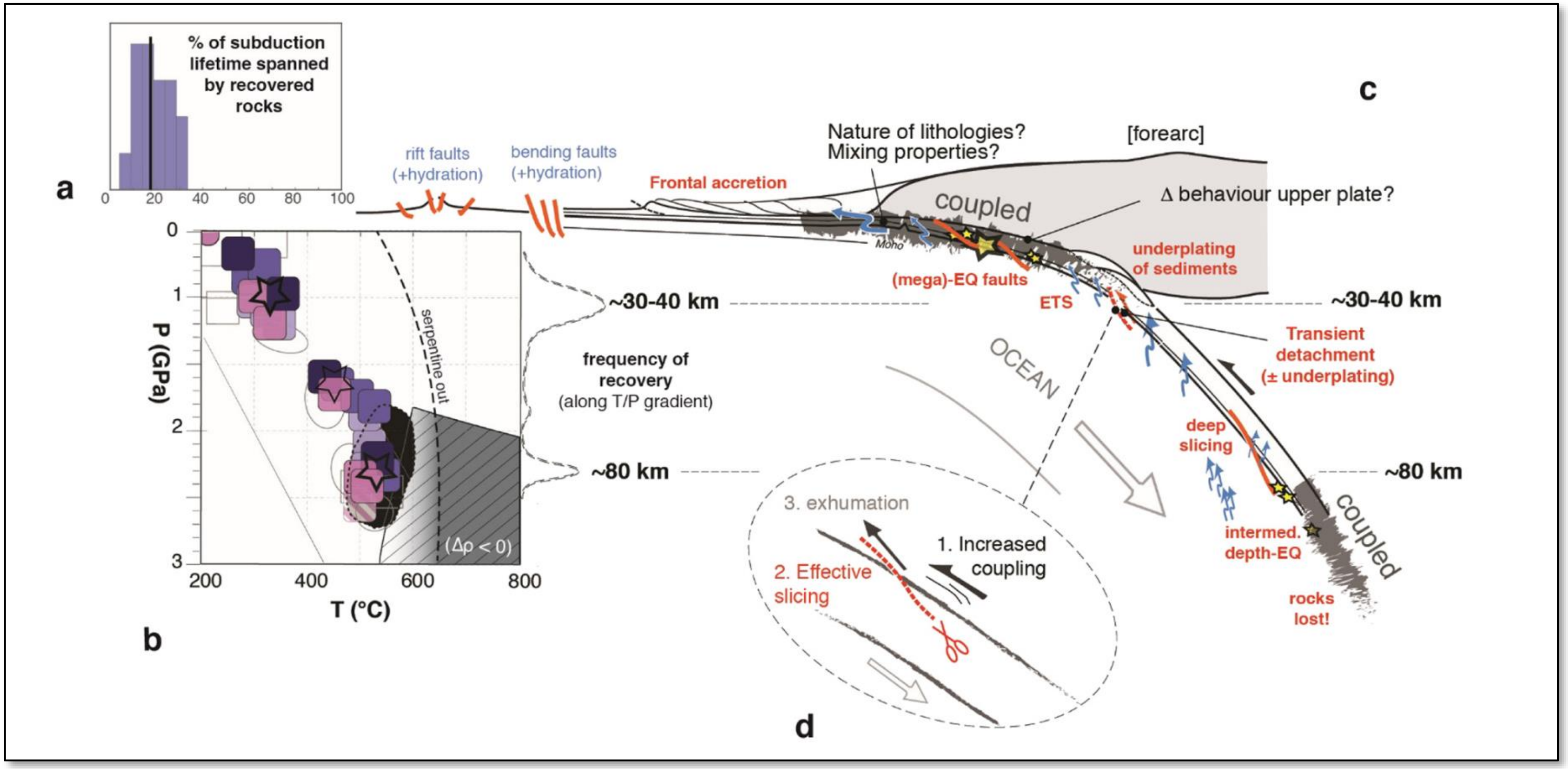
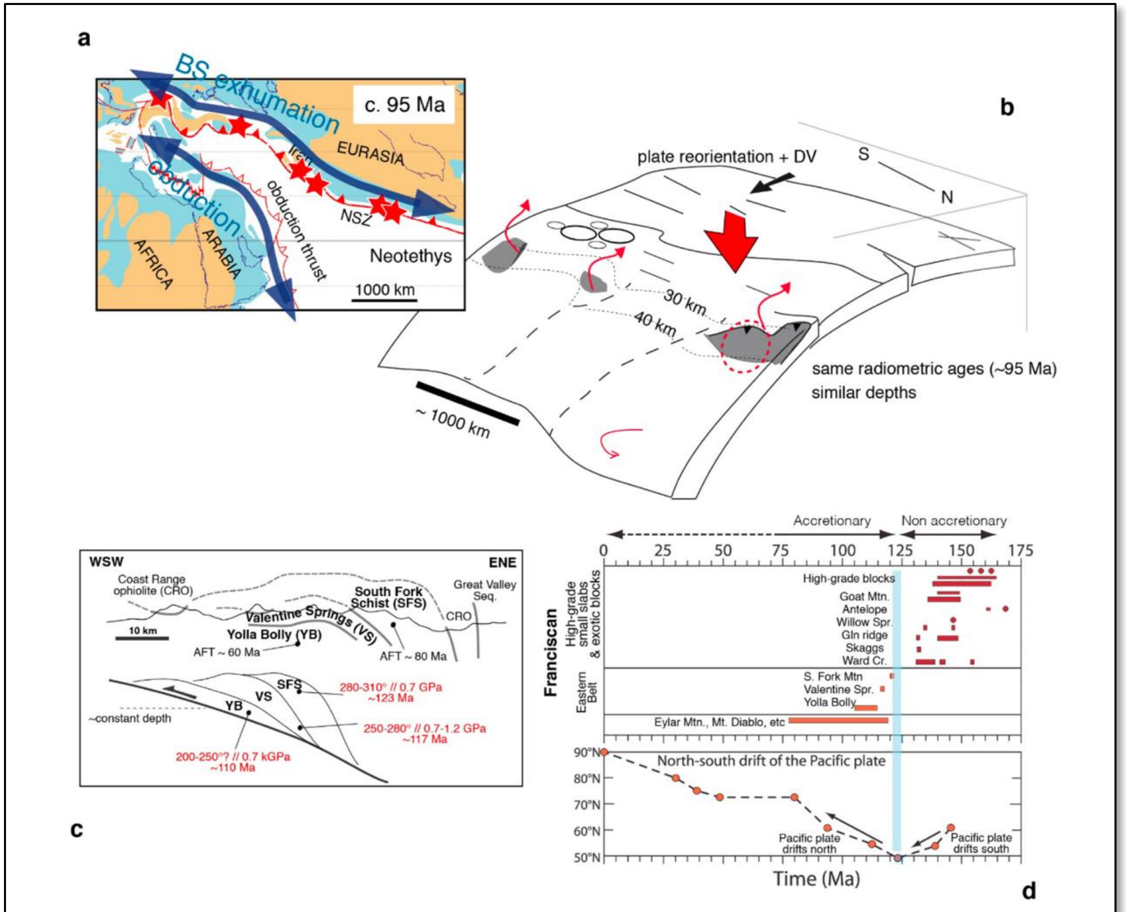


- Rock recovery is **<u>episodic</u>**: subducted rocks are returned over relatively short-lived episodes representing only a fraction of subduction lifetime (doesn't support a steady return flow process).
- **<u>Clusters</u>** in maximum depths (peak burial) at 30-40 km (downdip of seismogenic zone) and ~80 km (decoupling transition). Possible another at 50-55 km (less clear).

Let's take the world view of the Agard group:



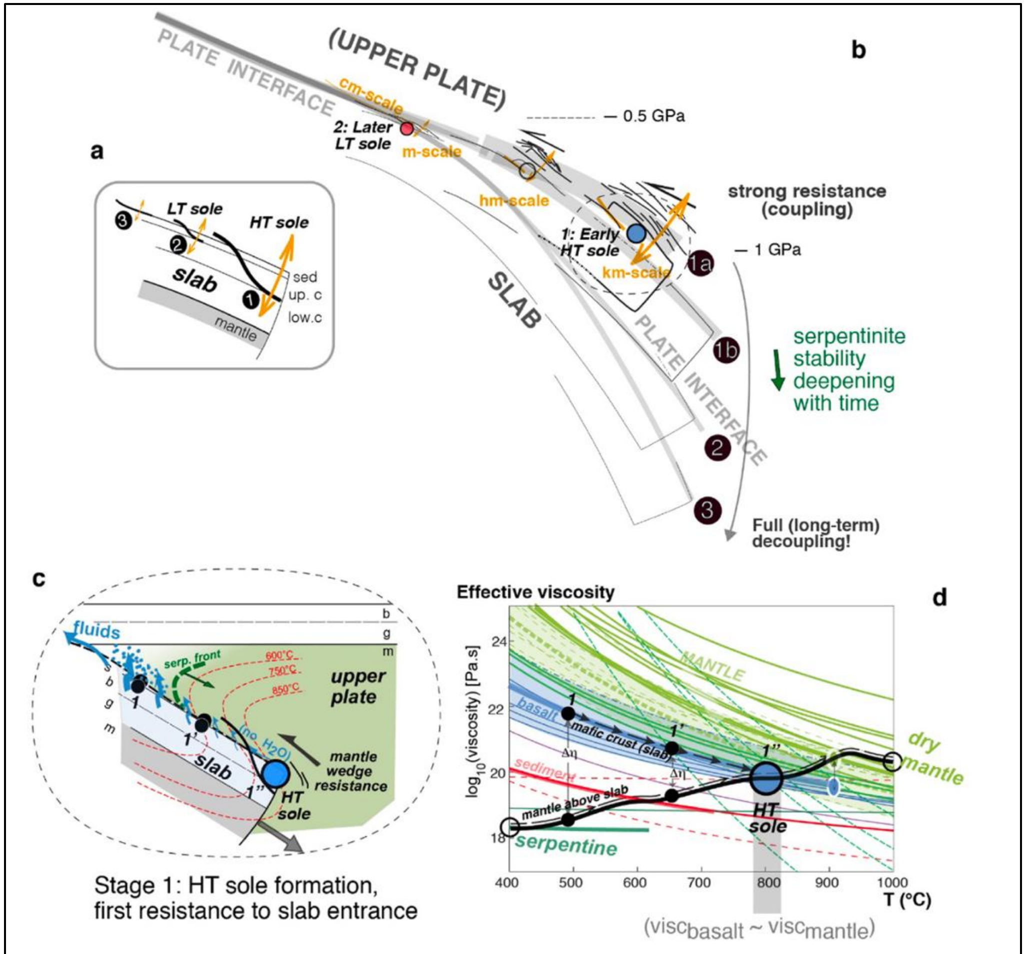
A-B:

In the Neoteythys, blueschists returned from 30-40 km and over a relatively narrow time range (~20 Ma). Possible linked to change in plate velocity.

C-D:

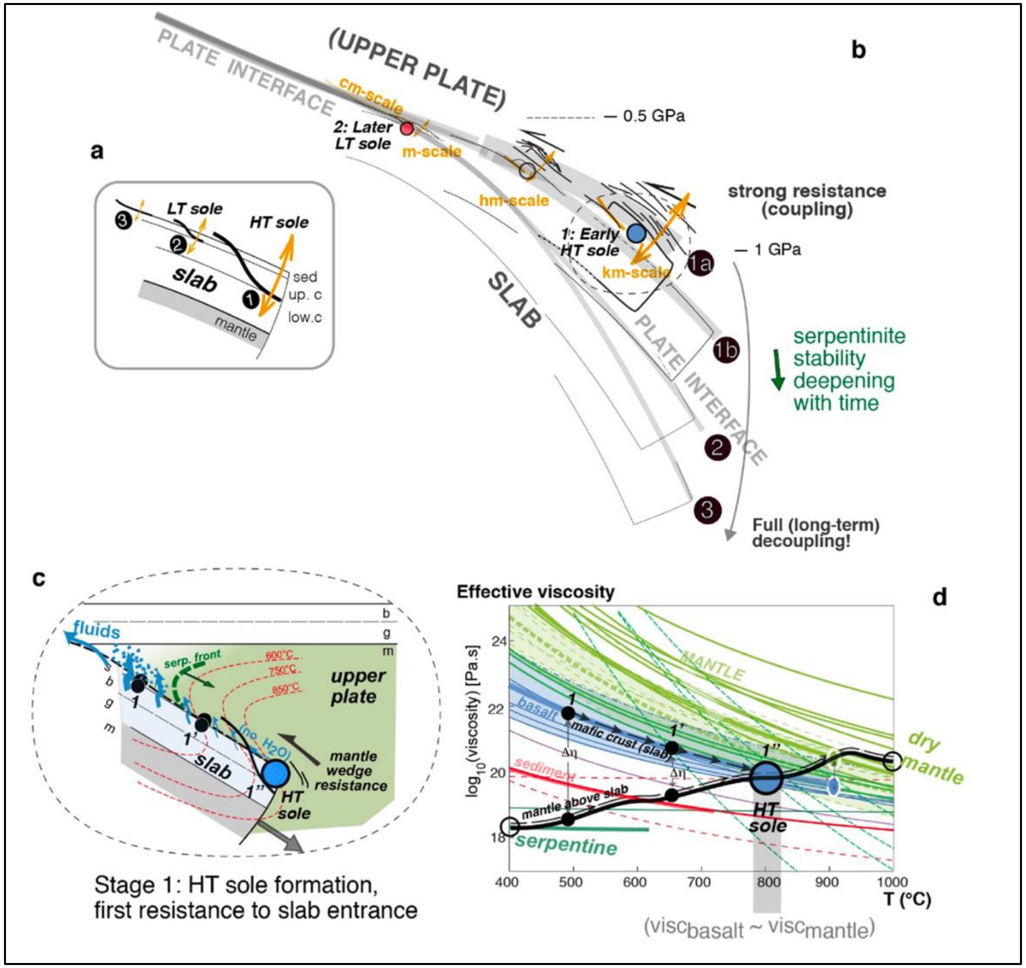
In the Franciscan (CA), most rock recovery and rock recovery within the Cretaceous (145-66 Ma). Coincided with large-scale geodynamic re-organization.

Underplating / metamorphic soles during infancy



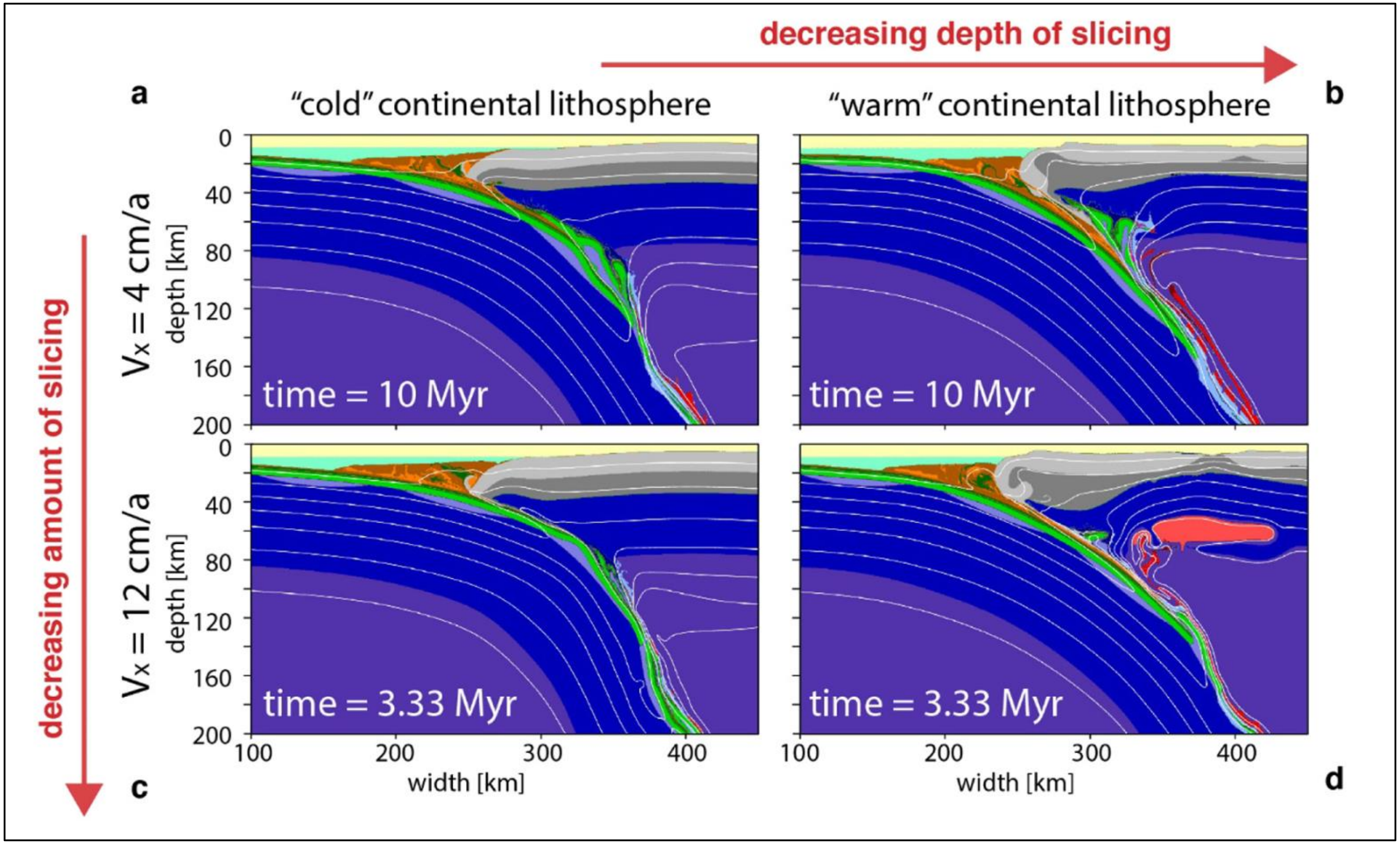
- Metamorphic soles show transient mechanical coupling along the plate interface.
- Highlight the importance of fluid release and contrasting mechanical behavior of incoming materials.

Underplating / metamorphic soles during infancy



- Metamorphic soles show transient mechanical coupling along the plate interface.
- Highlight the importance of fluid release and contrasting mechanical behavior of incoming materials.
- Agard suggests that similar mechanisms may also control the transient detachment and subsequent underplating/exhumation of HP–LT rocks in mature subduction systems.

Slab slicing in numerical models

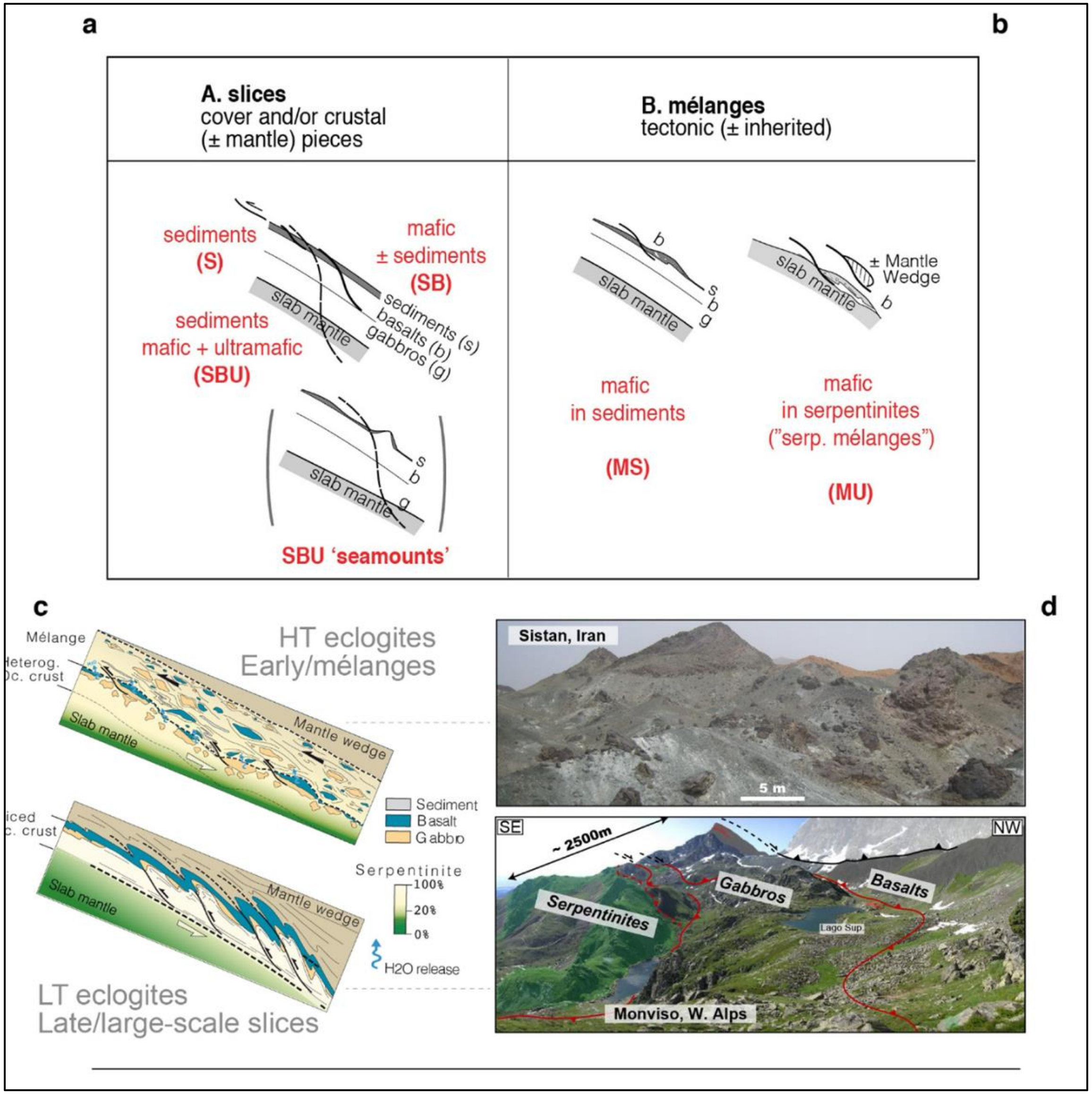


Ruh et al (2015): Requires the slab to be pre-weakened. In this cases, lenses of weak serpentinite imposed within the slab lithosphere.

i.e., such slicing is difficult without changes in mechanical coupling above the slab

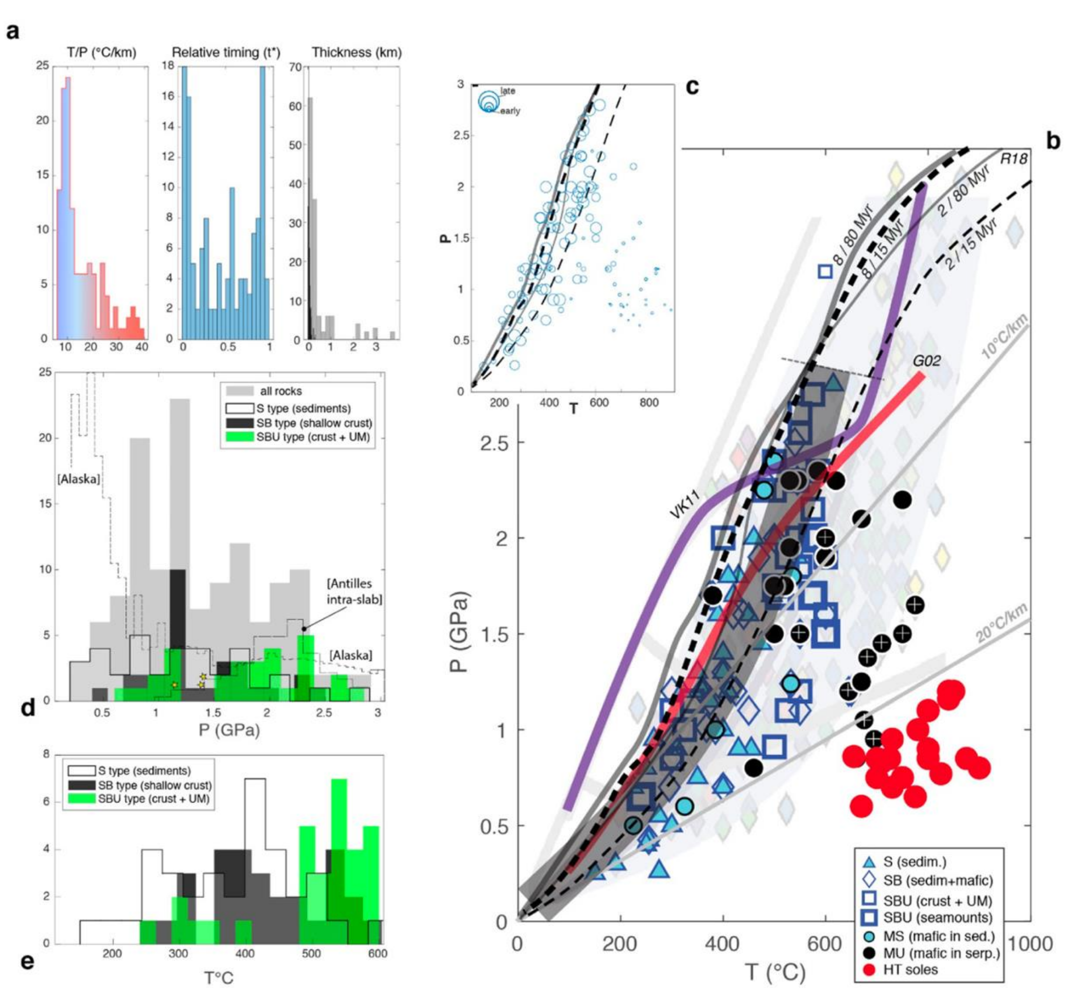
Fossil subduction zone compilation

Endmember types:



Fossil subduction zone compilation

Compilation:



- Depth cut off at ~2.8 GPa (84 km). Slab too dense?
- Less clustered with depth than previous compilations.
- Punctuated recovery: Most towards the start and the end.
- Long-term cooling trend.

Fossil subduction zone compilation

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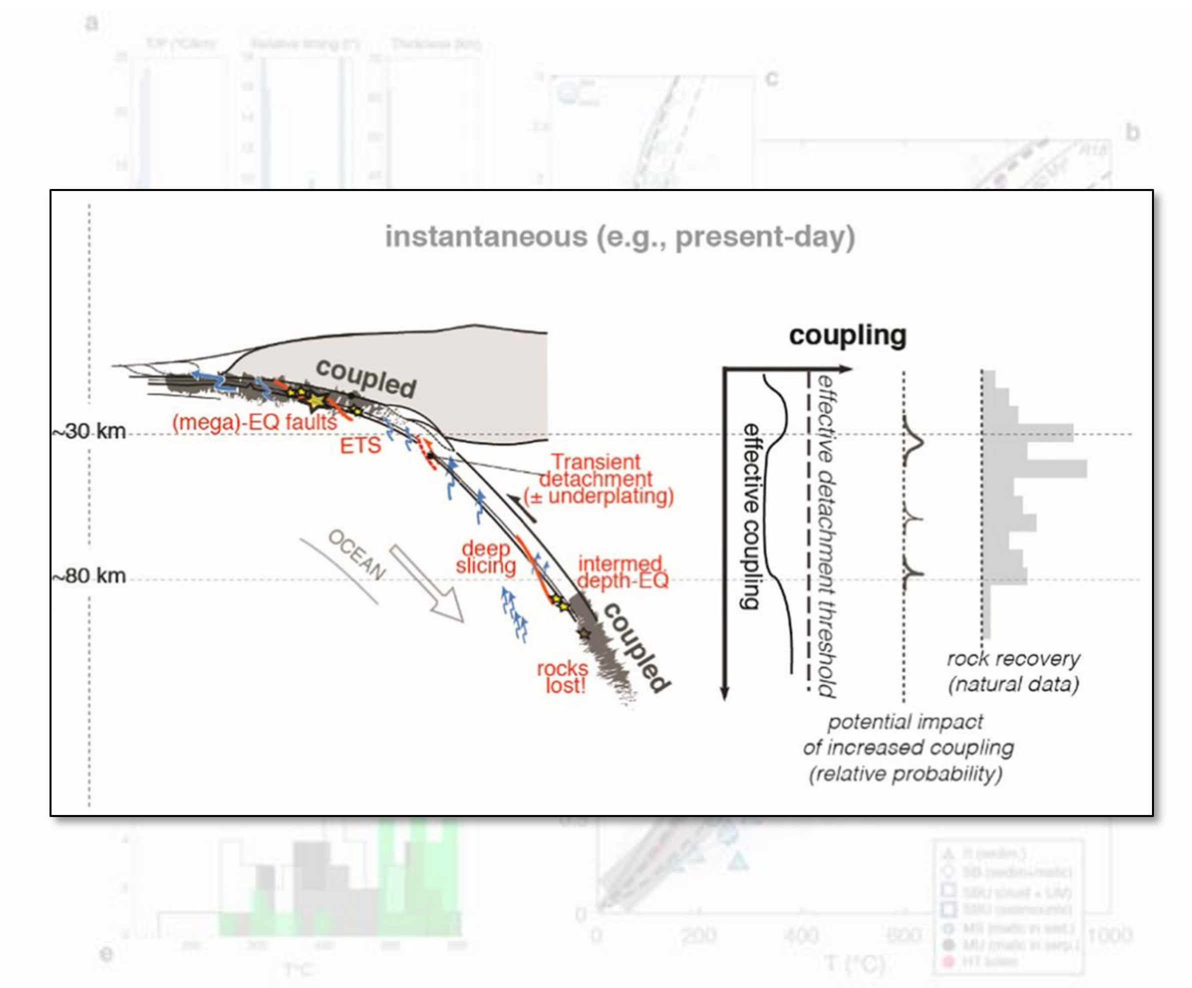
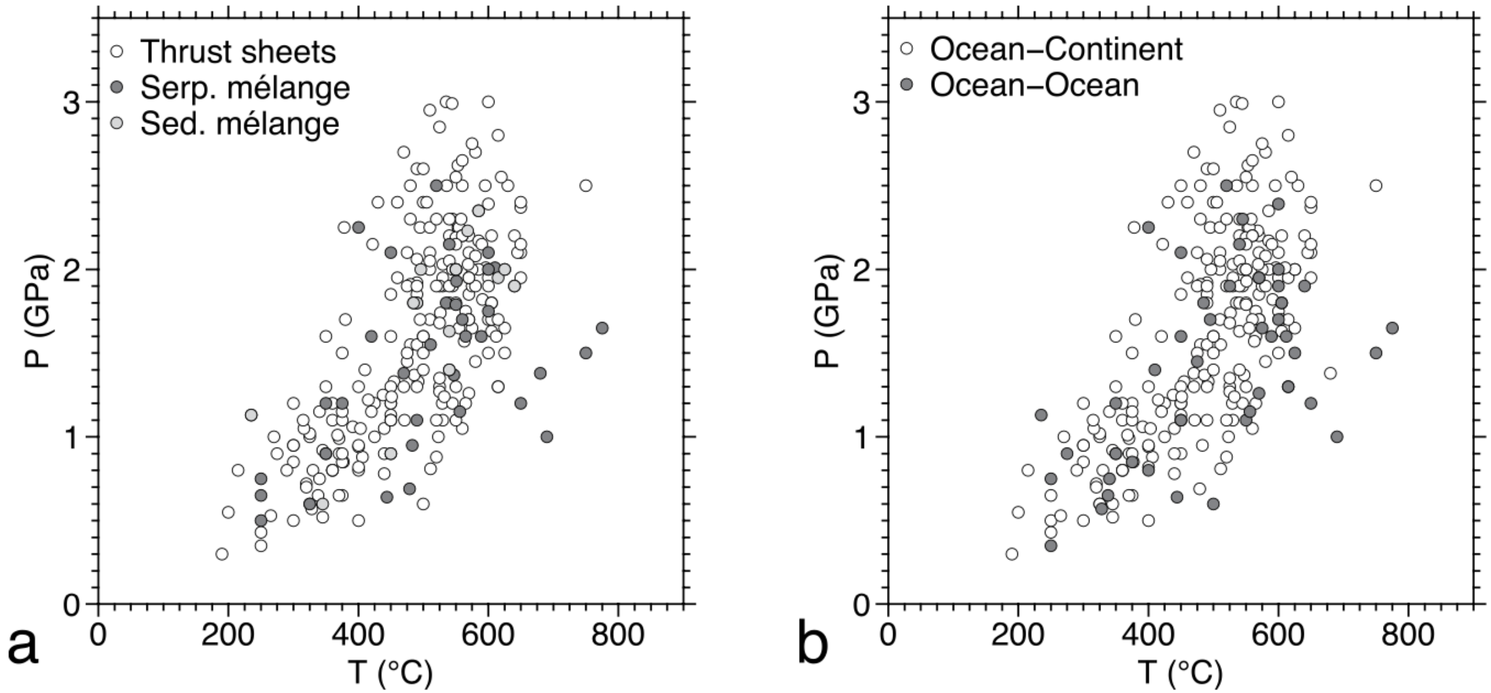


- Depth cut off at ~2.8 GPa (84 km). Slab too dense?
- Less clustered with depth than previous compilations.
- Punctuated recovery: Most towards the start and the end.
- Long-term cooling trend.
- Only "accidents" exhume cold rocks during subduction maturity (coupling too low).

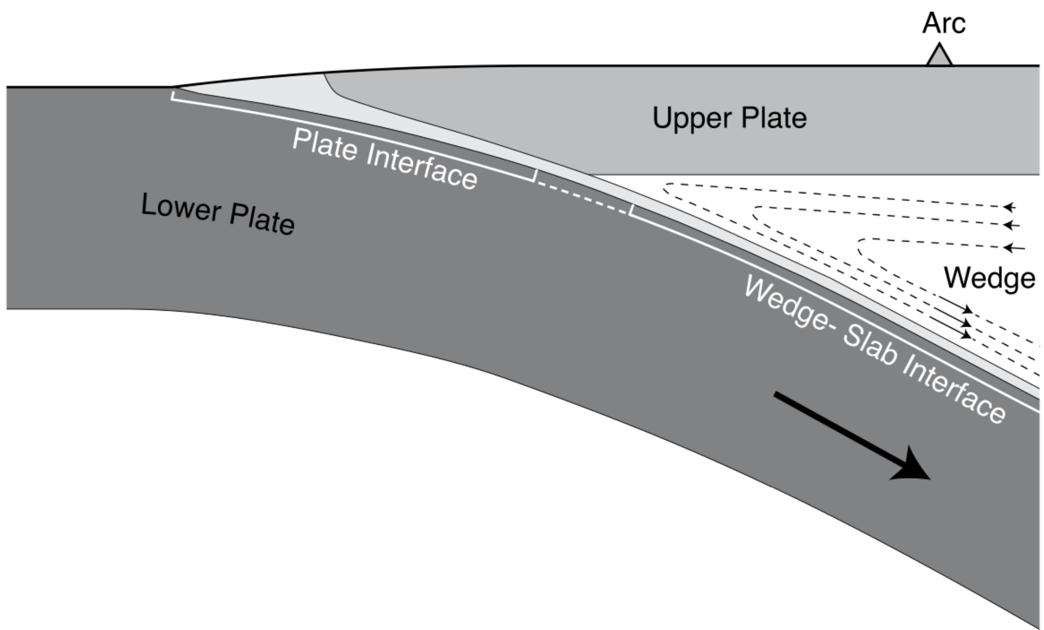
Another similar compilation: England & Smye (2023)



- No support for two depth peaks.
- No clear difference between SZ with oceanic and continental OPs
- No clear difference between sheets and melanges.

Another similar compilation: England & Smye (2023)

Simple model setup:



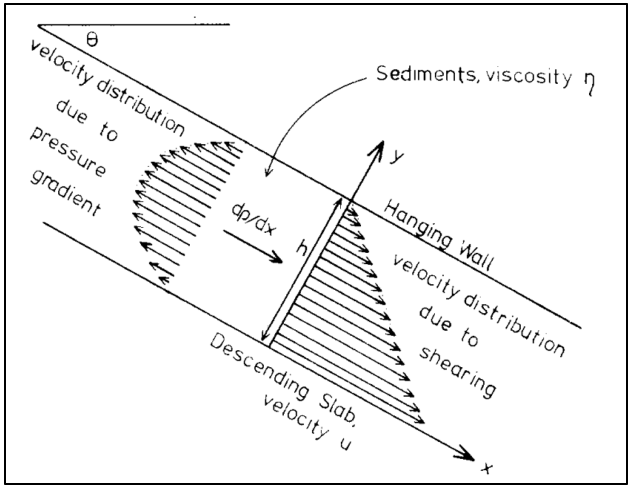
- They firstly use an analytical model to predict slab-top temperatures. Main conclusion: Shear heating needed to reconcile models and rocks.

- They then set up simple analytical models of flow in the viscous channel. Exhumation when (postivie) buoyancy exceeds down-slab shear. Apparently only feasible for slow/zero subduction velocities.

$$\frac{\mathrm{d}\tau}{\mathrm{d}y} = C\frac{\mathrm{d}}{\mathrm{d}y}\left[\frac{\mathrm{d}v}{\mathrm{d}y}\left|\frac{\mathrm{d}v}{\mathrm{d}y}\right|^{(1/n-1)}\right] = g\sin(\delta)\Delta\rho$$

Exhumation modeling

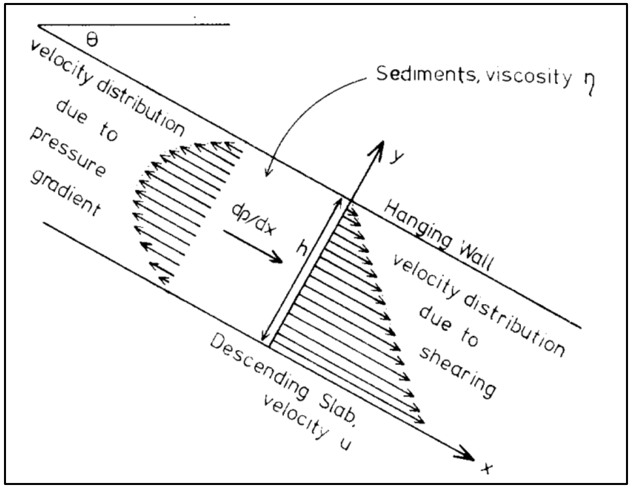
From super simple models:



e.g., England and Holland, 1979

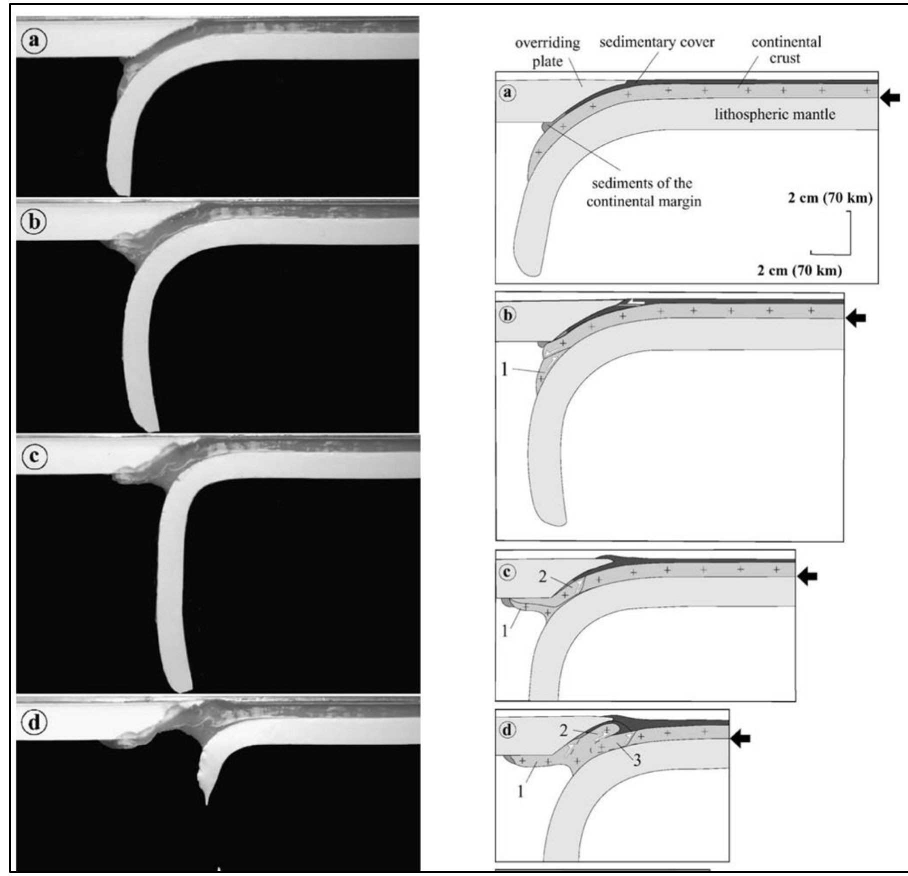
Exhumation modeling

From super simple models:



e.g., England and Holland, 1979

To moderately complex ones:



e.g., Boutelier et al., 2004

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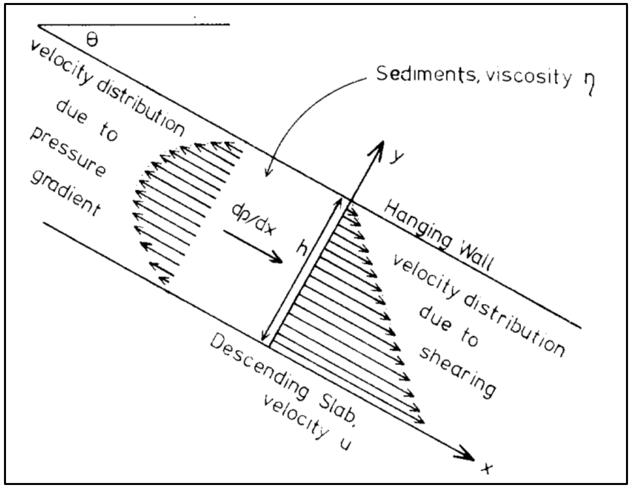
From super simple models:



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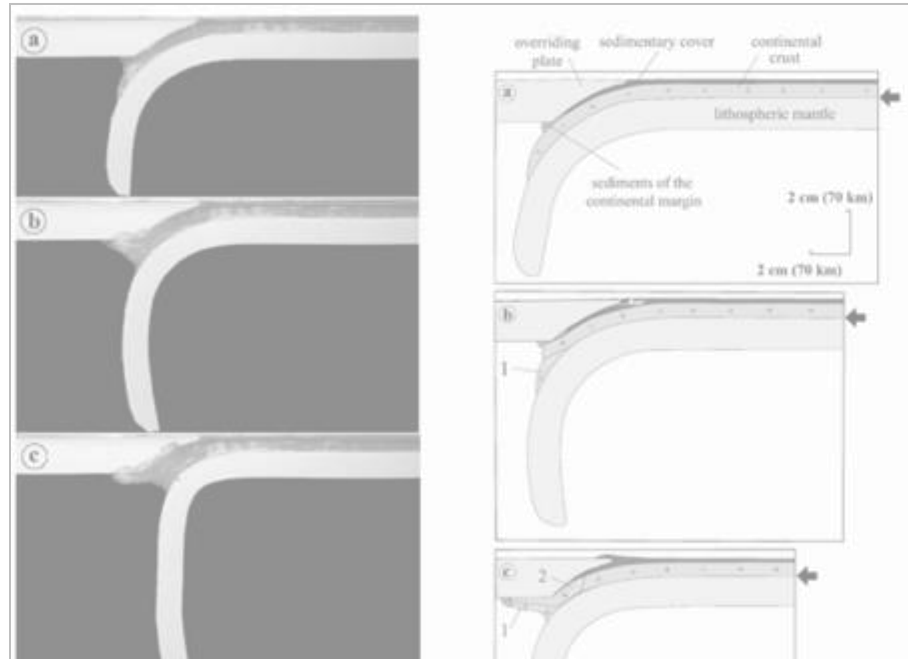
To moderately complex ones:



To very complex ones: