# Imaging Circum-Pacific Subduction Zones with Earthquakes: Fluid Pathways and the Origins of Volcanic Arcs

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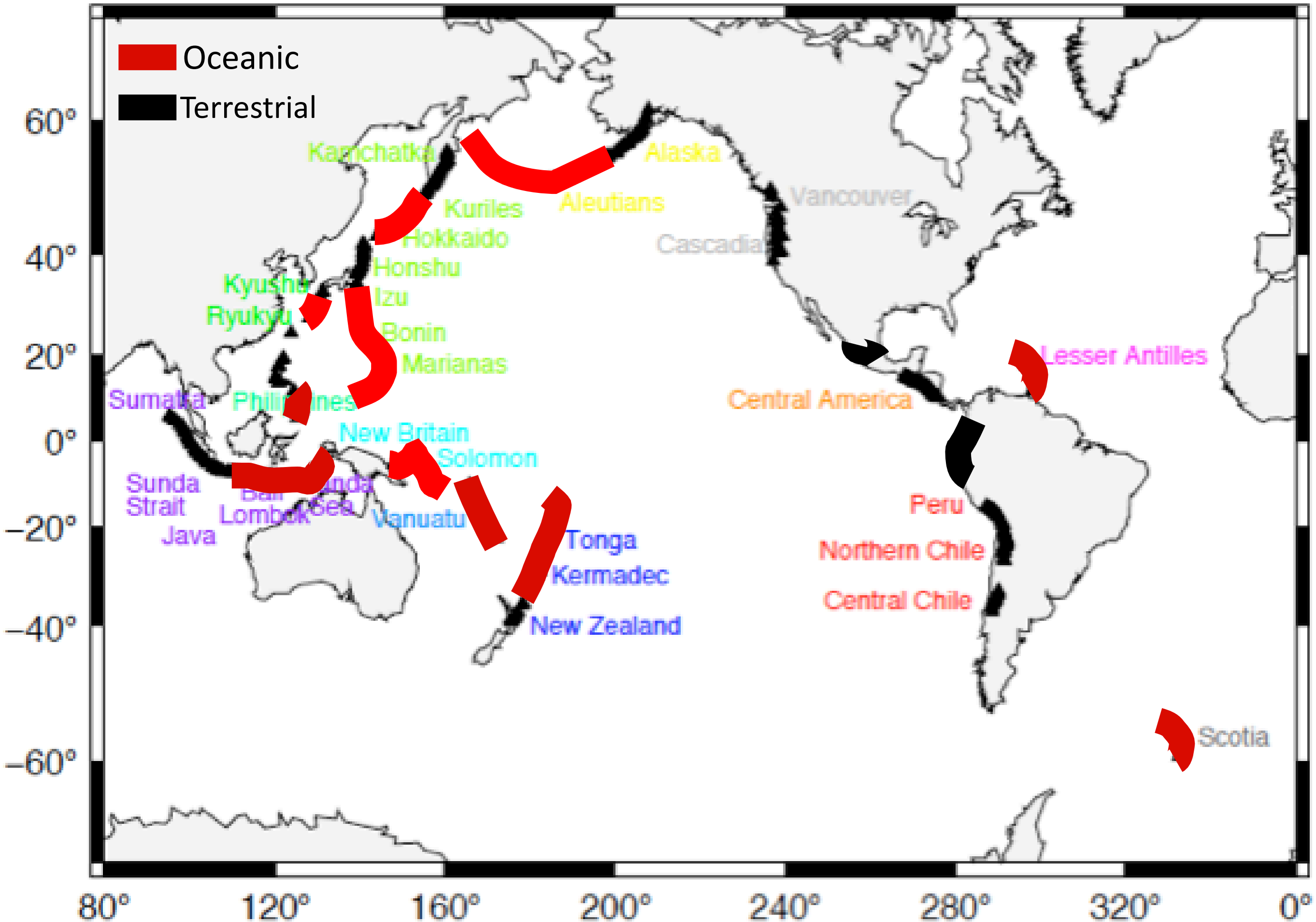
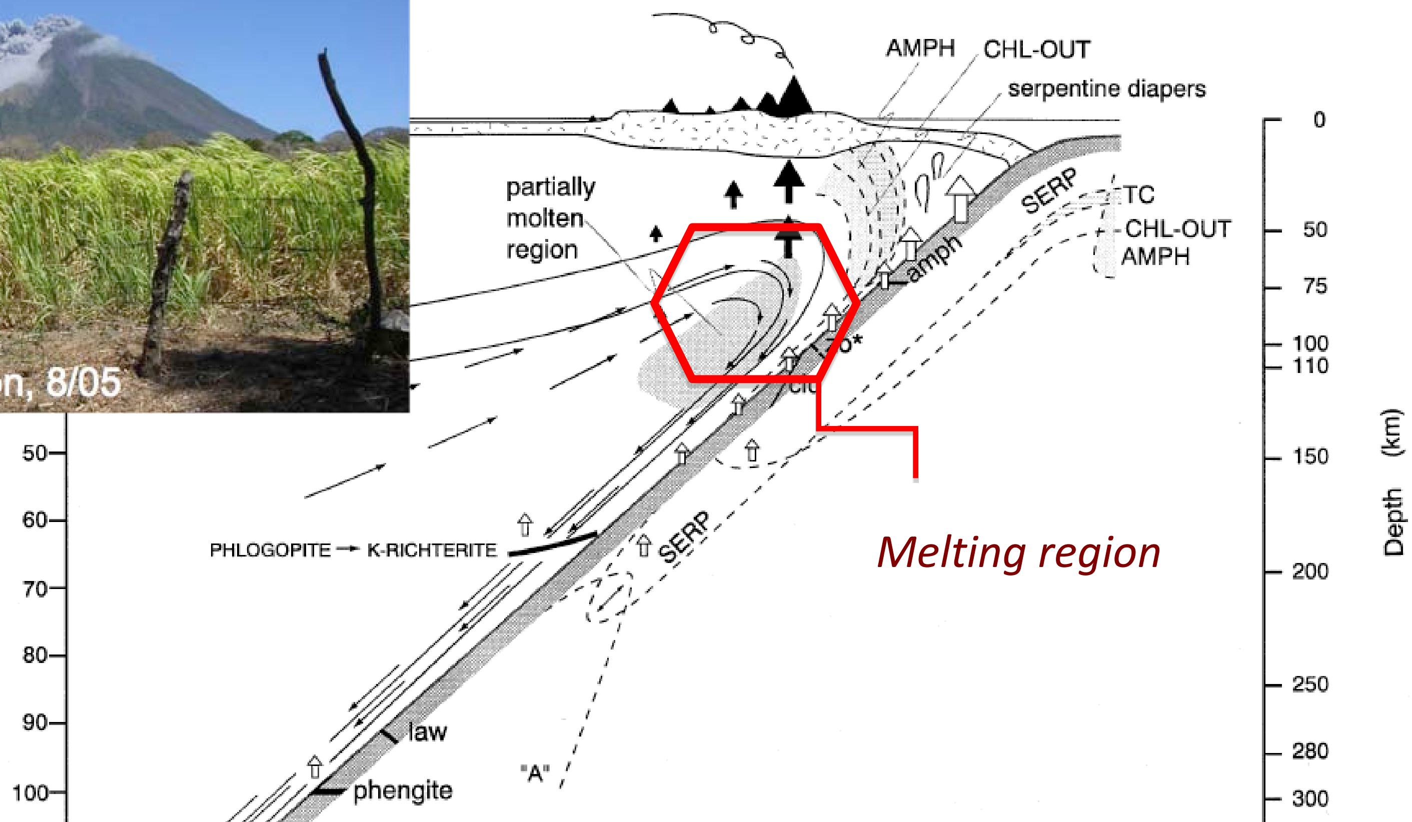



- Water and volcanism
- Imaging
- Lessons from Central America

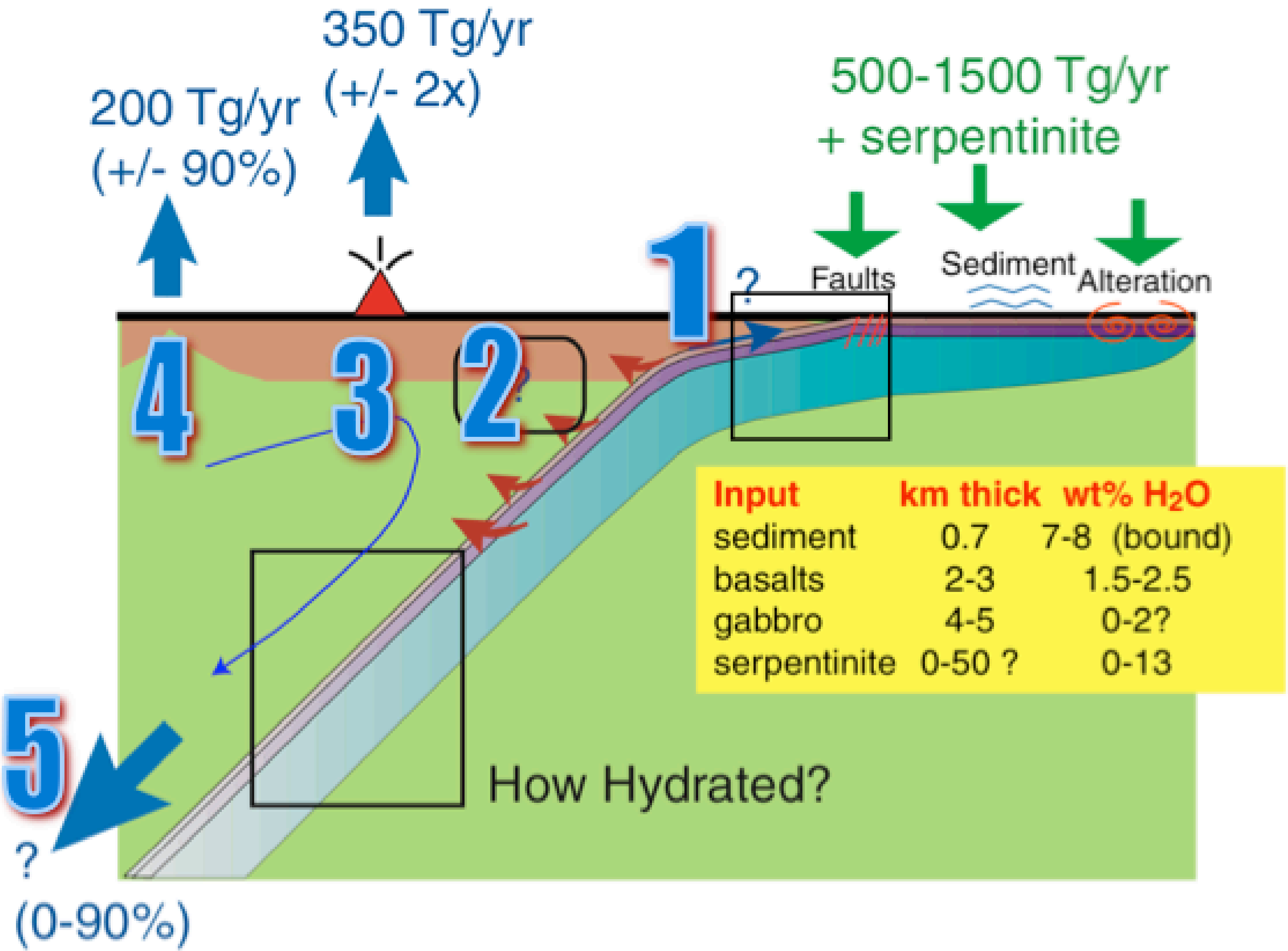
# Wet + hot mantle make volcanoes; water controls explosivity

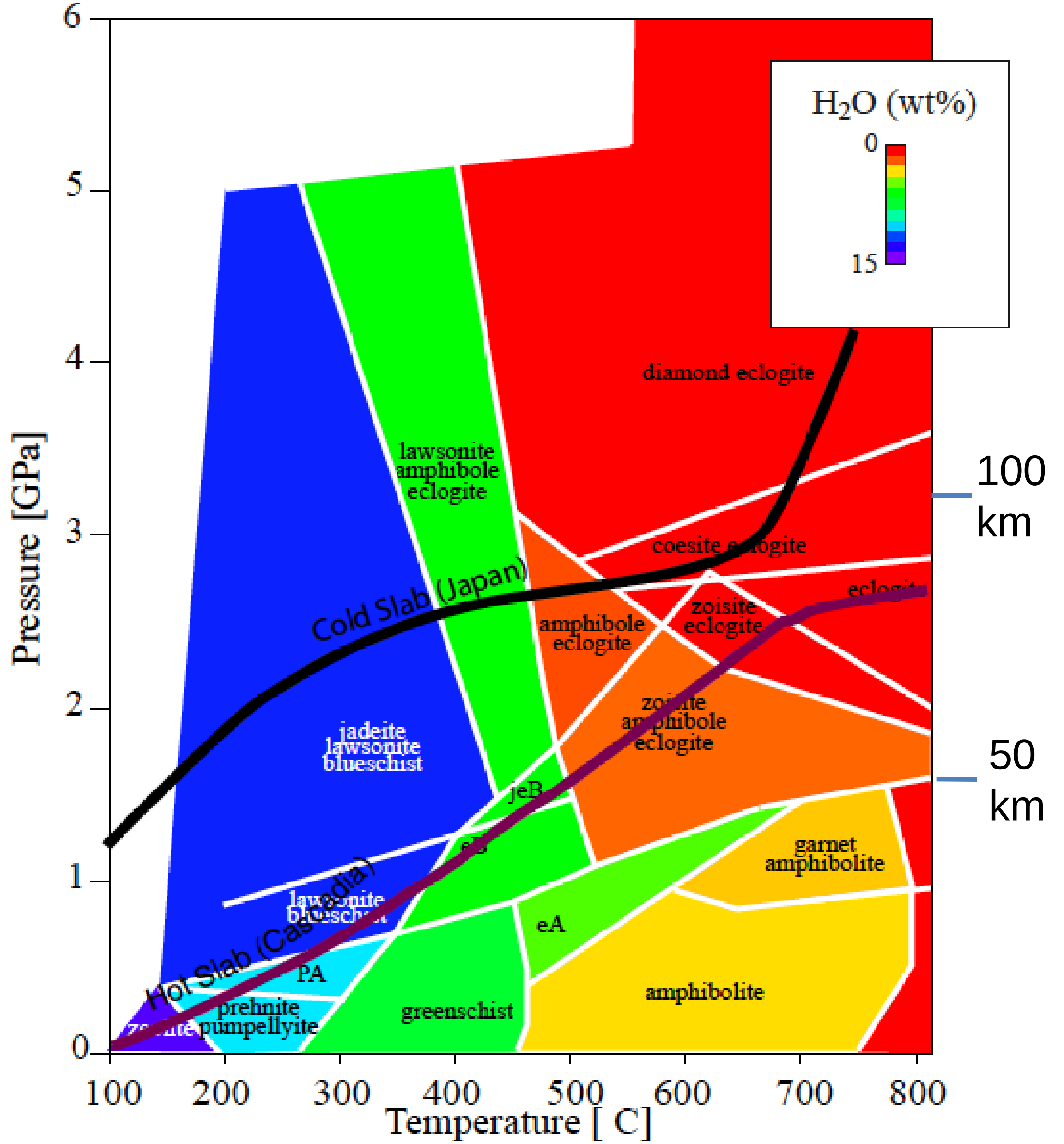

(Schmidt and Poli, 1998)

- Where does $H_2O$ originate?
- What pathways?

# Water in Subduction Zones



# Water release is by metamorphic dehydration of crust



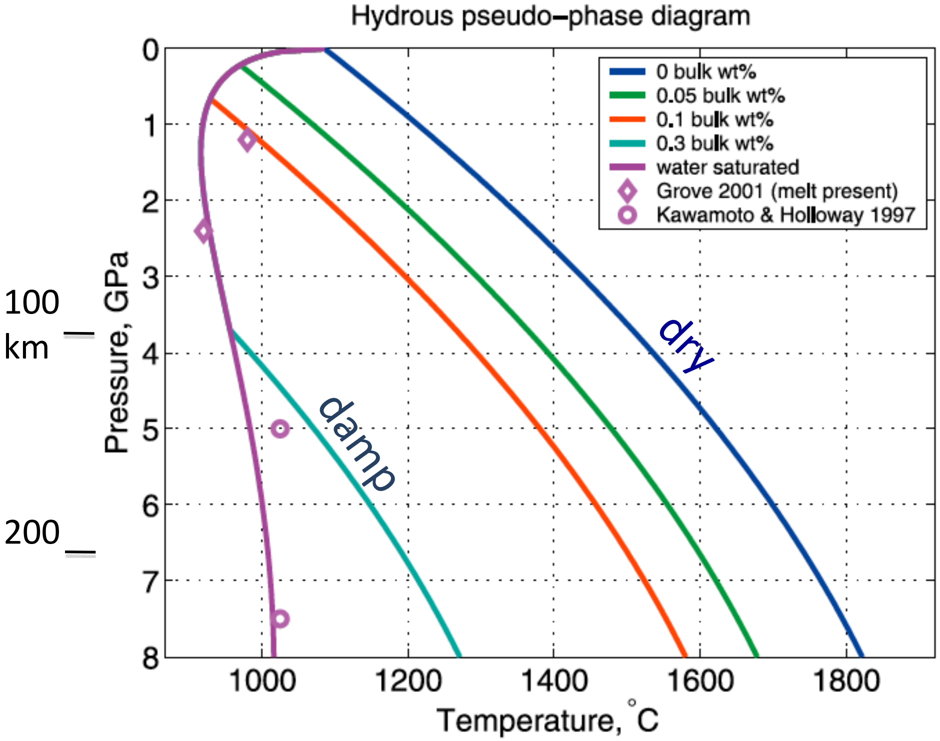

Lines: descent path followed by slab surface

1 GPa ~ 30 km

(Hacker et al., 2003)

# Wedge melting facilitated by $H_2O$

*Melting Temperature (solidus)*



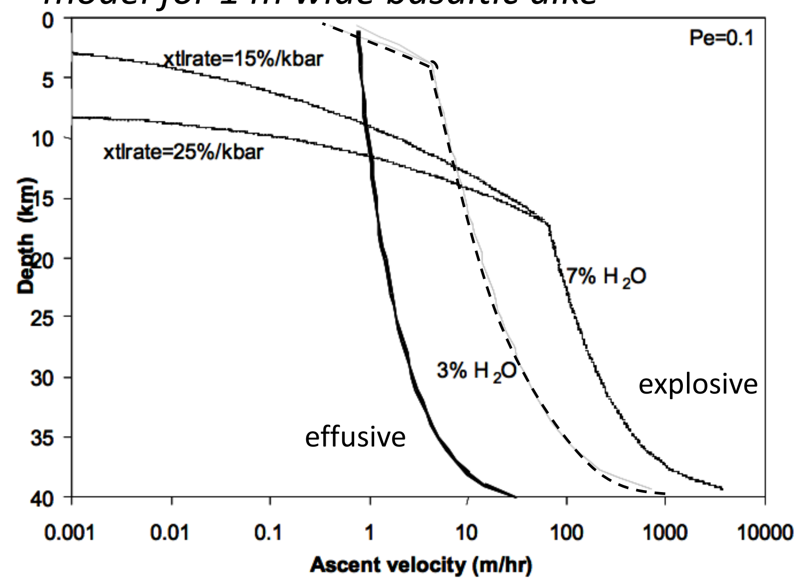

*Wt% $H_2O$ in solid*

(Katz et al., 2003)

*Eruption Style:*

*Magma velocity vs. %$H_2O$*

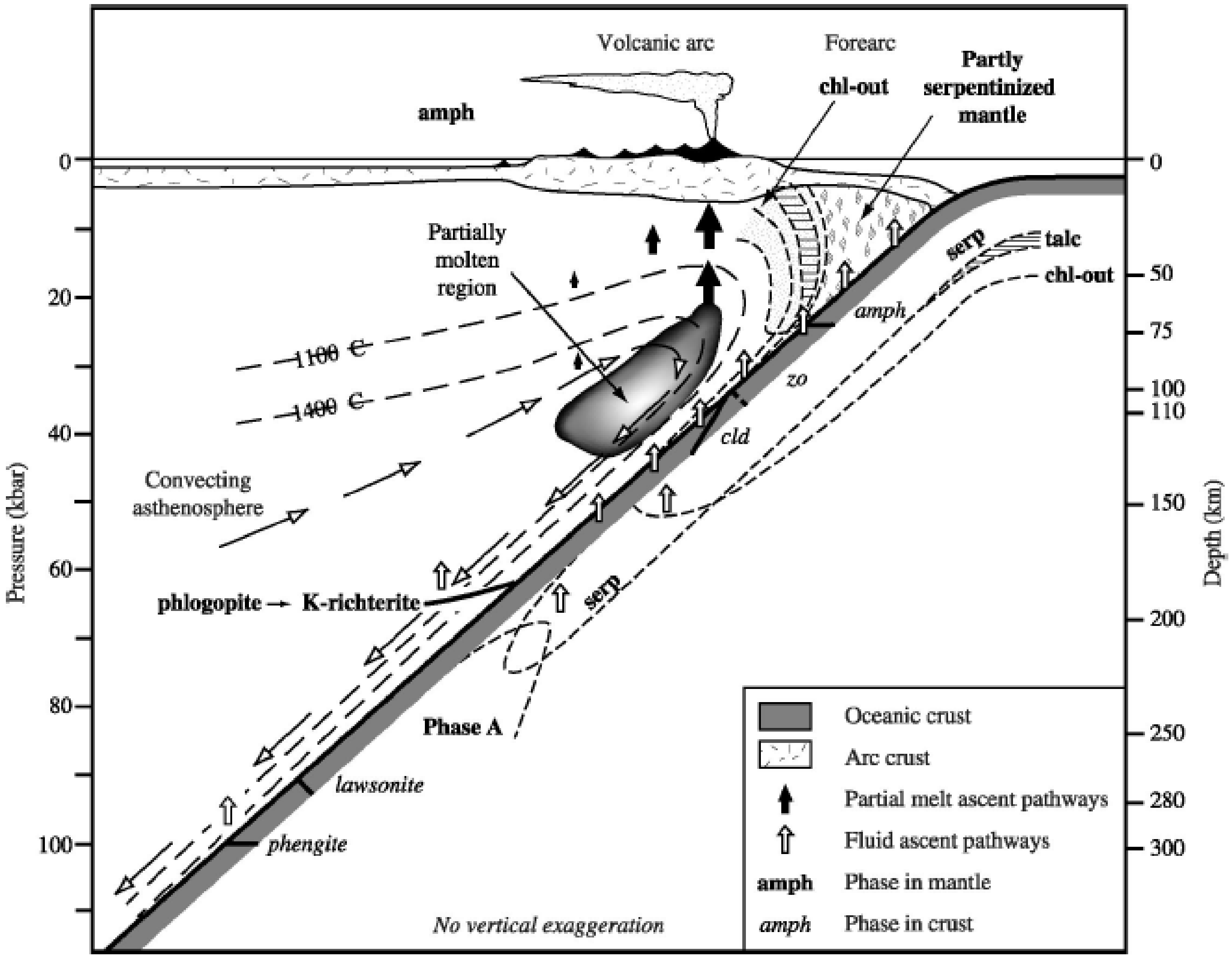
*model for 1 m wide basaltic dike*




*Wt% $H_2O$ in magma*

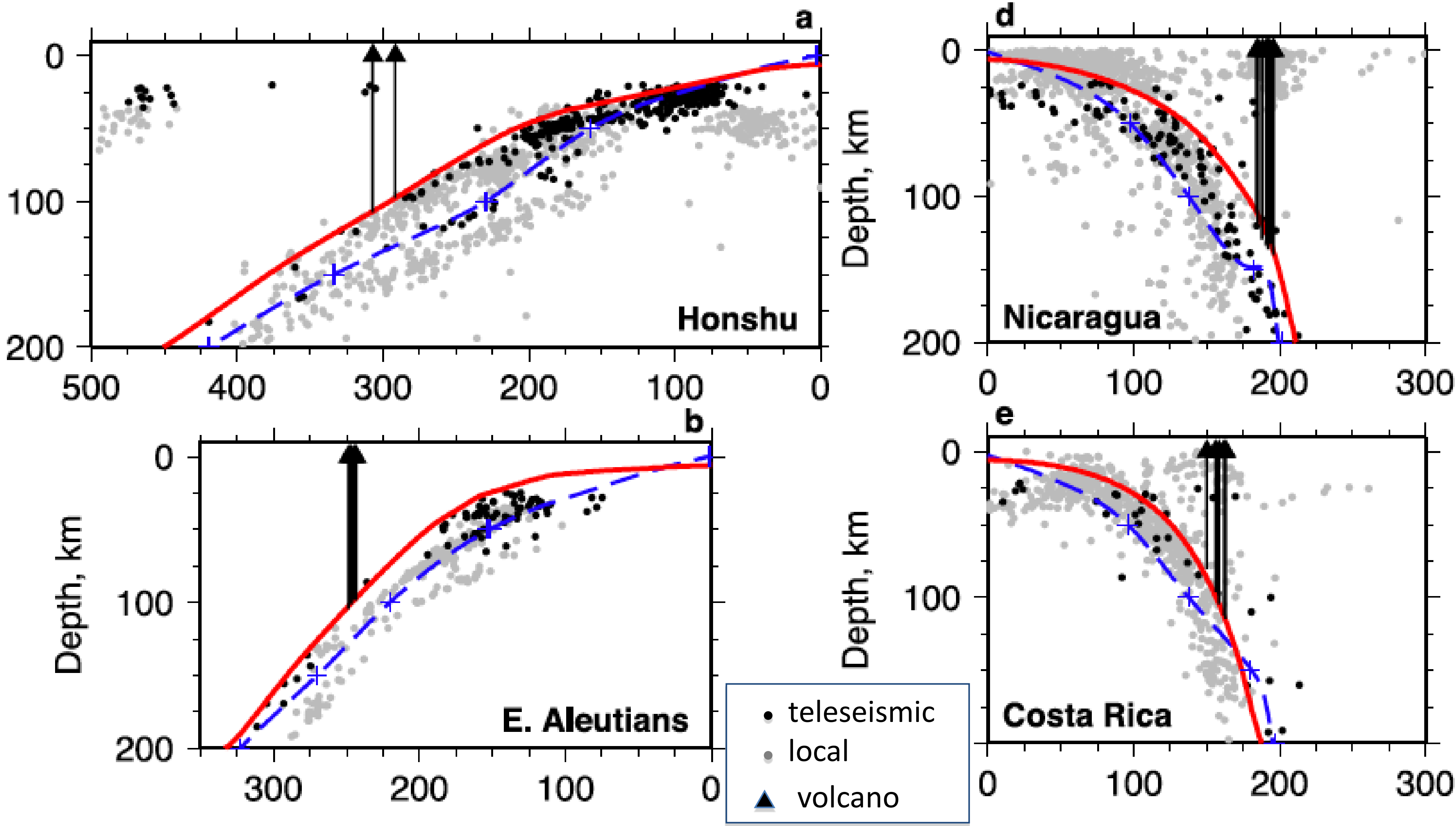
(Zimmer, in prep.)

# Melting: control by *geometry*, *$H_2O$ inputs*, *thermal structure*




(Stern, 2002; Schmidt & Poli, 1998)

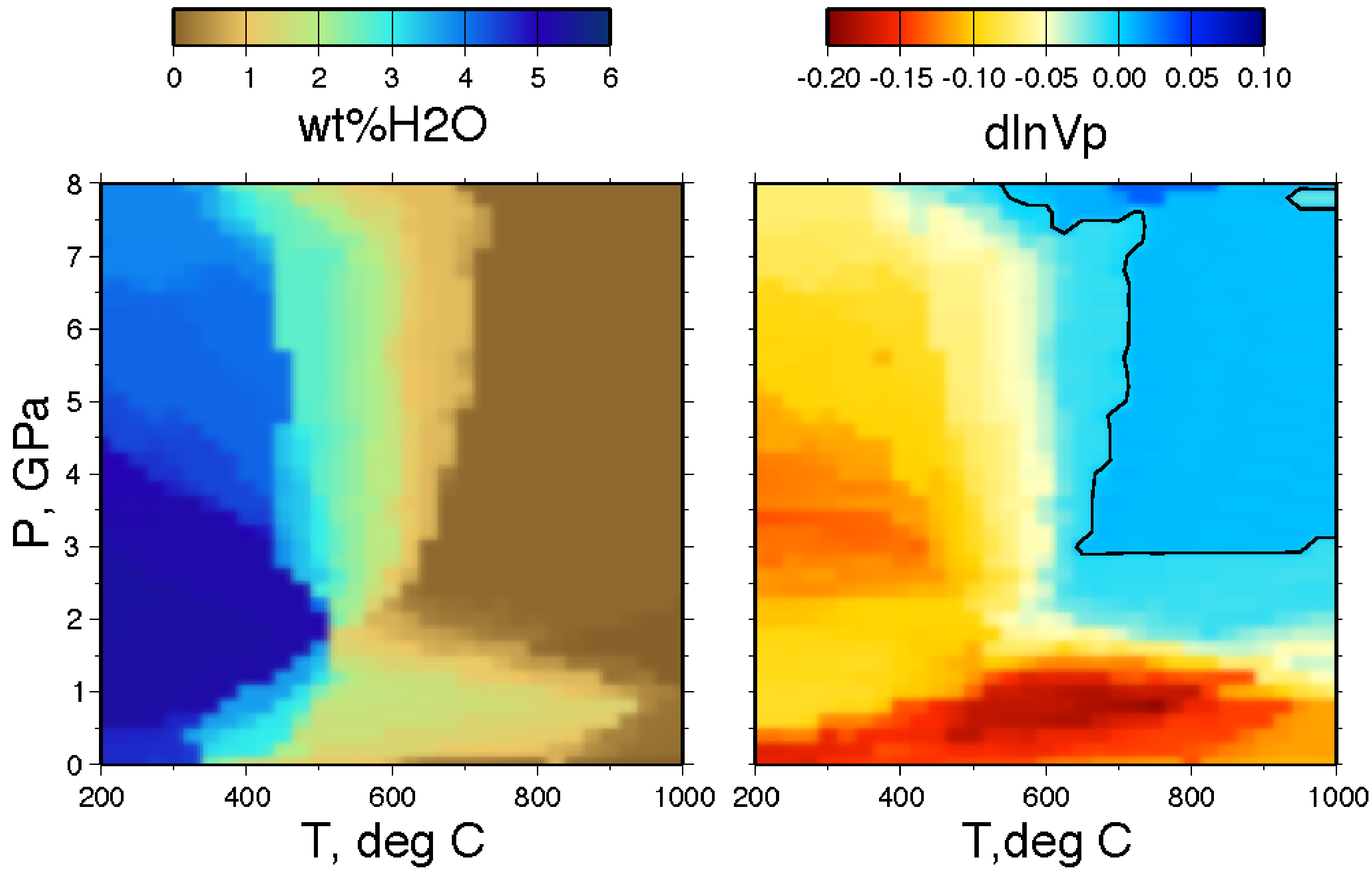
# What is subduction geometry?
# Traditional: Seismicity




(Syracuse and Abers, 2006)

# Subduction geometry and crustal dehydration

Seismic velocities track hydration: Vp versus dry mantle

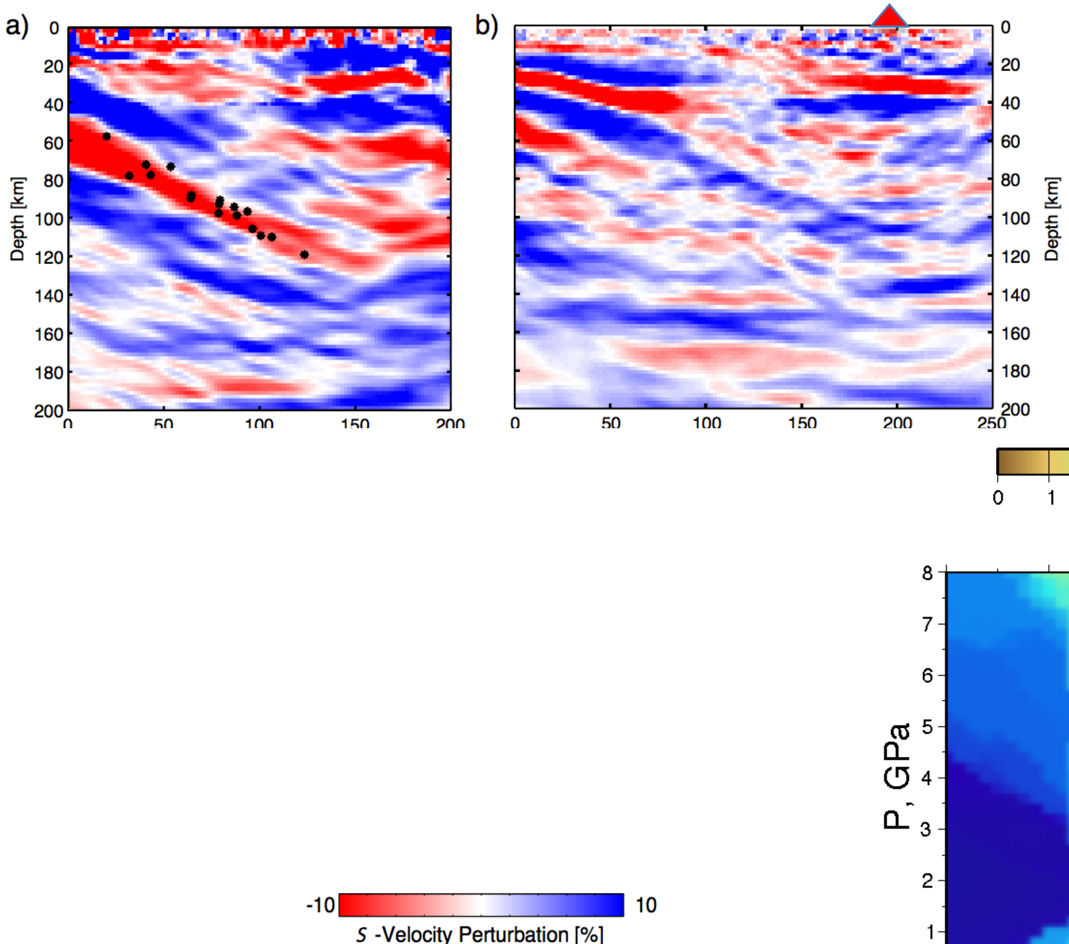



(after Hacker, 2008; Hacker and Abers, 2004)

# Subduction geometry and crustal dehydration: *P*-coda scattered wave imaging

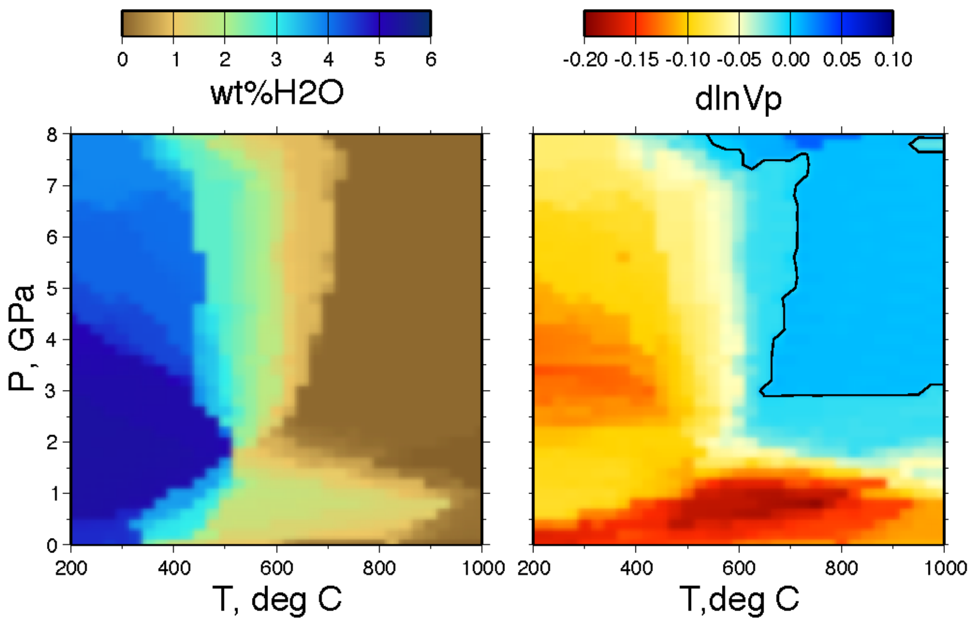
(Rondenay, Abers & van Keken, Geology, 2008)

Alaska Oregon Cascades

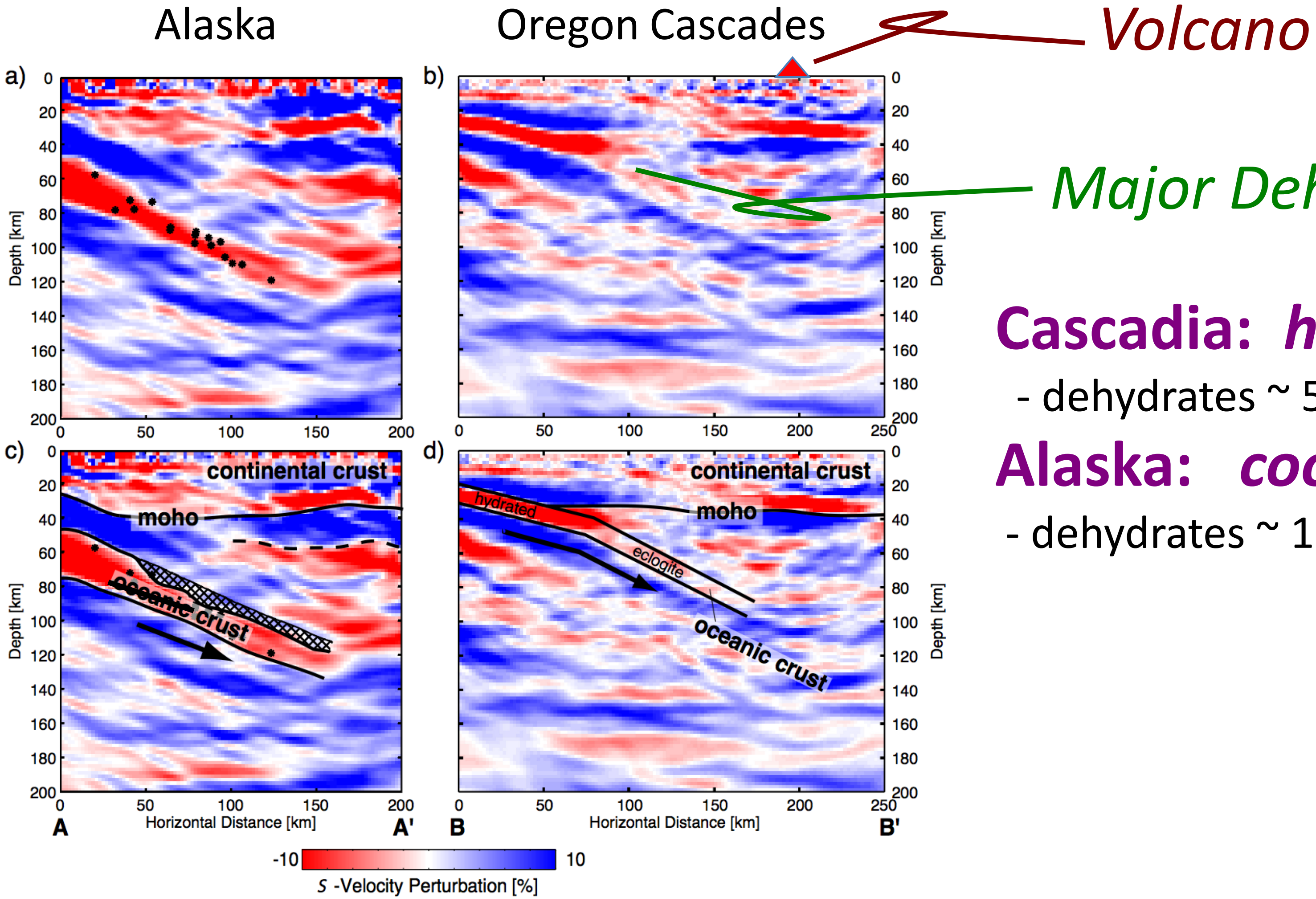



receiver functions migrated to dVs/V

Seismic velocities track hydration



# Observe: dehydration feeds arcs, but does *not* produce the volcanic front




**Cascadia: *hot, young***

- dehydrates ~ 50 km depth

**Alaska: *cool***

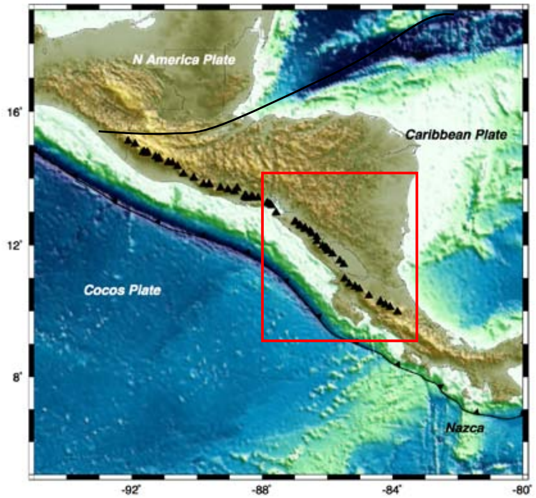
- dehydrates ~ 130 km depth

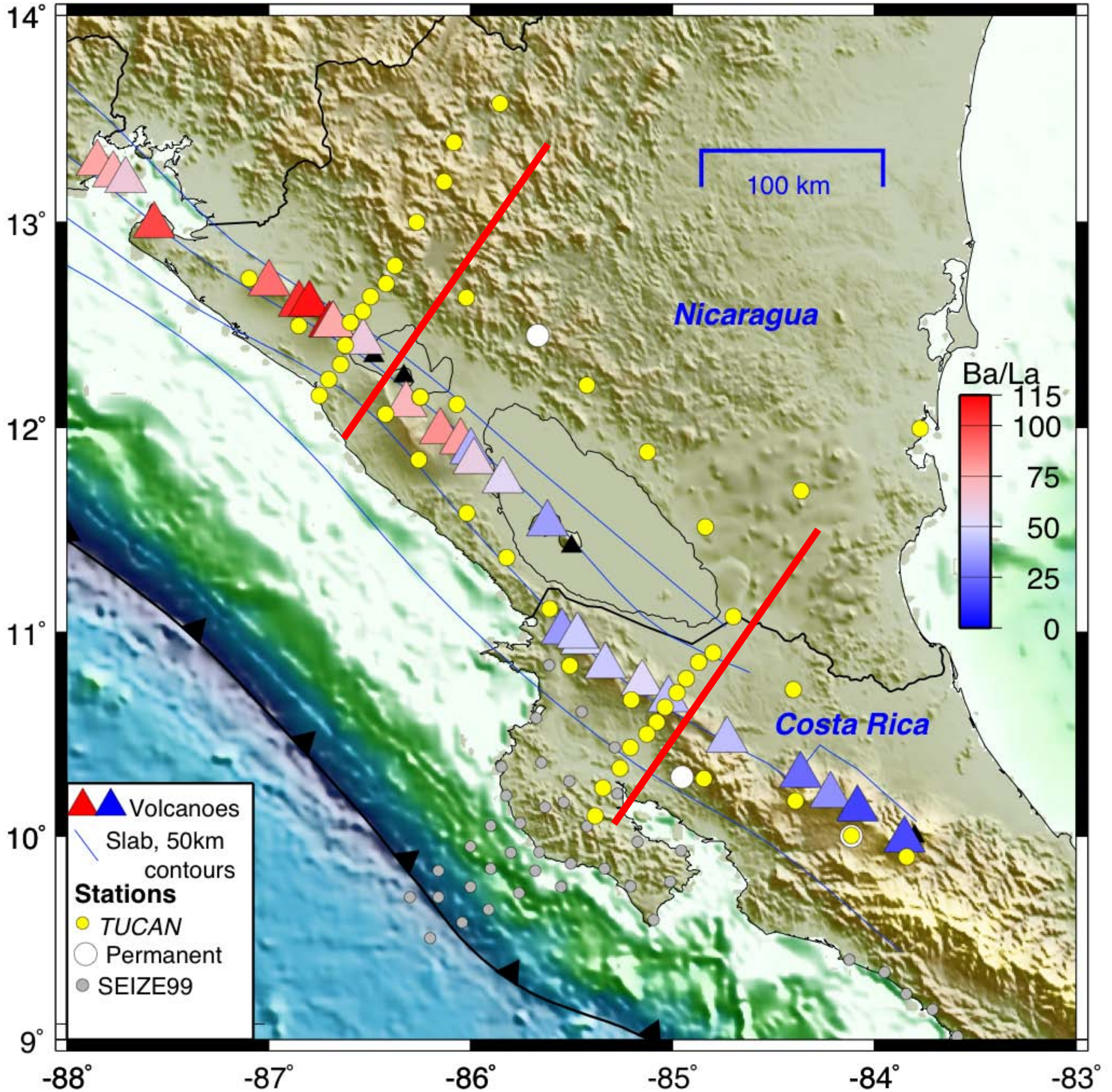
receiver functions migrated to dVs/Vs

# TUCAN

Tomography (and other things)
Under Costa Rica and Nicaragua

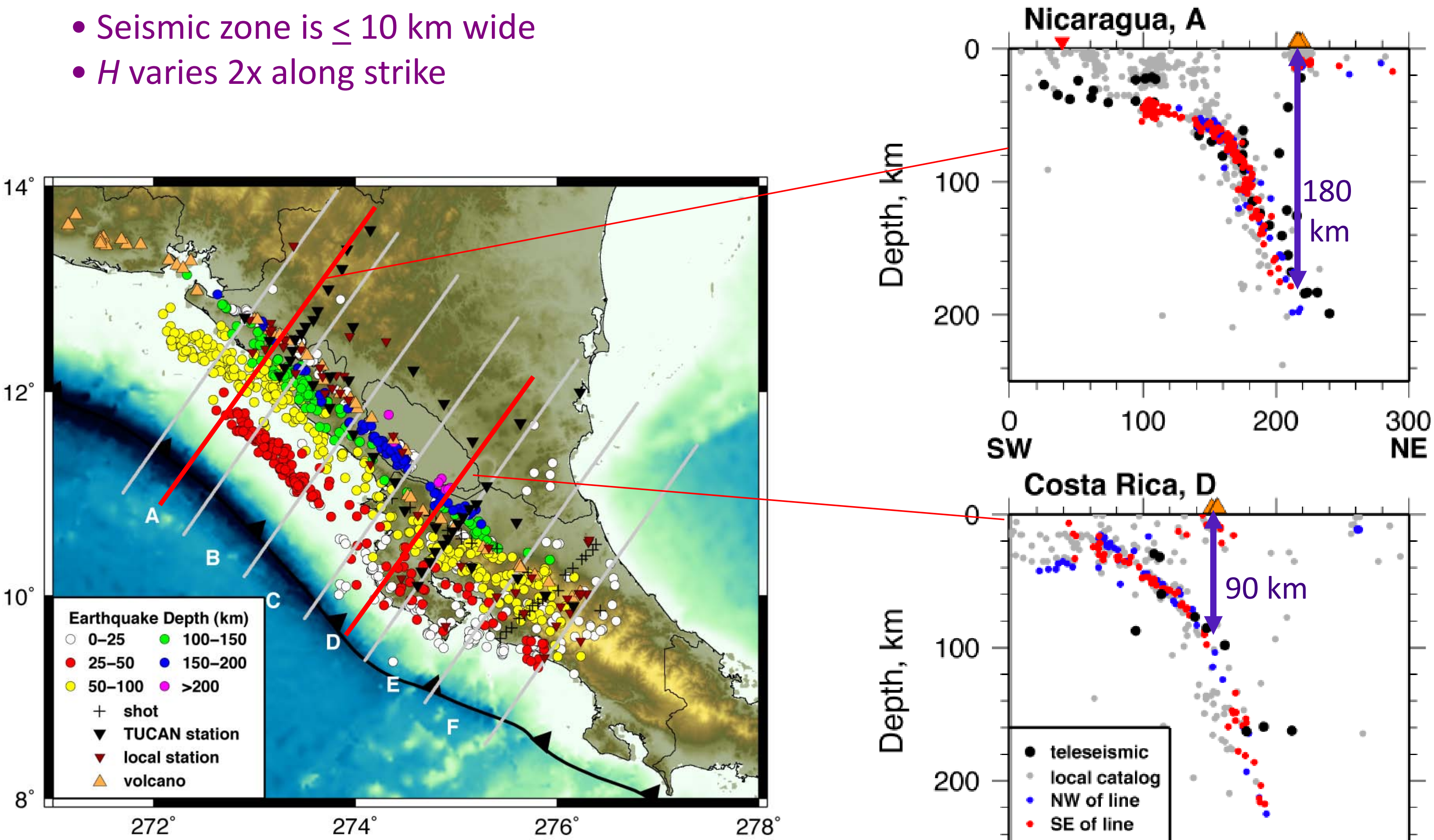
- ***Cooperative*** US, Nicaragua, Costa Rica Seismic Array (BU/LDEO, Brown, INETER, OVSICORI)
- 48 broadband seismographs, 2004-2006
- main lines sample change in volcano geochemistry



# Hypocenters and slab shape: Joint inversion with 3D structure

- Seismic zone is $\leq$ 10 km wide
- *H* varies 2x along strike



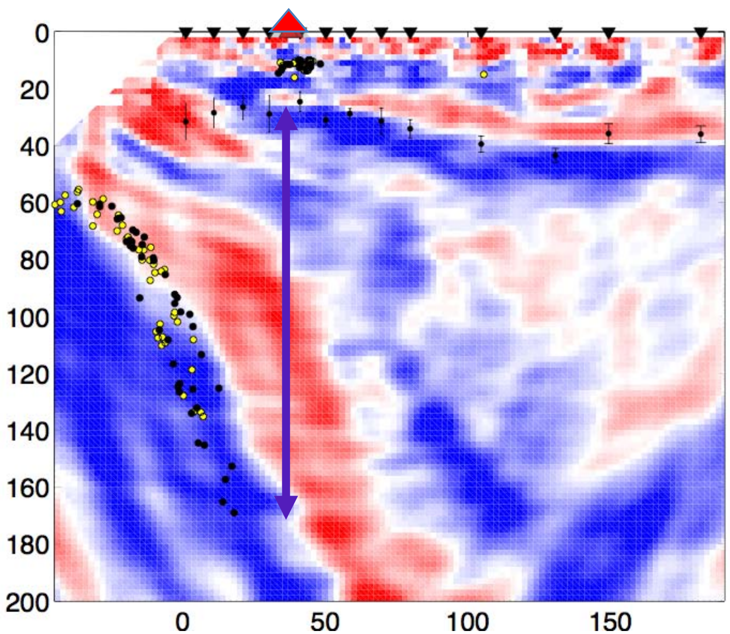

*Joint inversion for hypocenters + Vp + Vs*

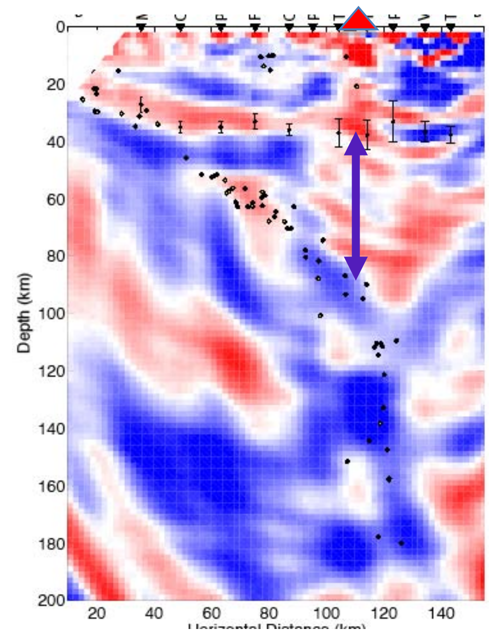
*1025 earthquakes: 37,000 arrivals*

# Nicaragua vs. Costa Rica

## Scattered wave images

- Crust: 25-30 km vs. 36-42 km
- Slab depth: 180 km vs 90 km (imaged as base of slow, hot wedge)
- *Melting region is 150 vs 50 km taller*

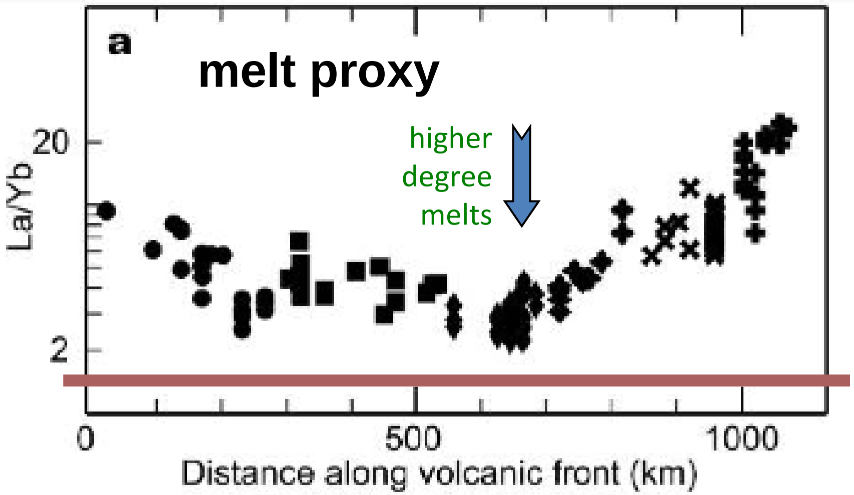


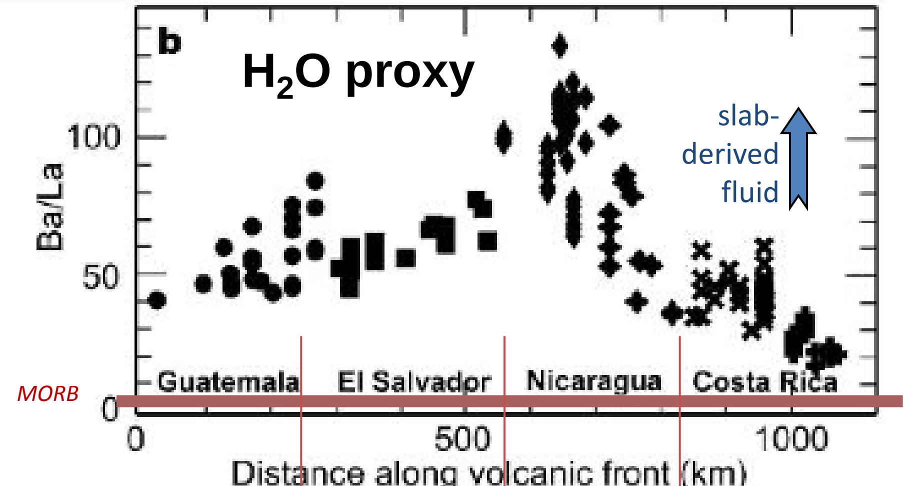



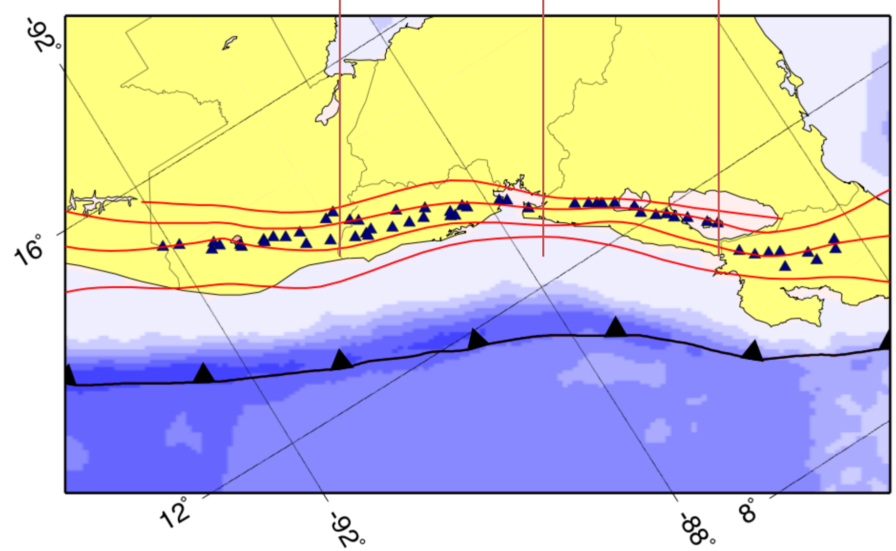

(MacKenzie et al., 2010 EPSL)

# Melting below Central America volcanoes:
## Geochemistry variations along strike

(Carr et al., 2006; 2007; etc.)



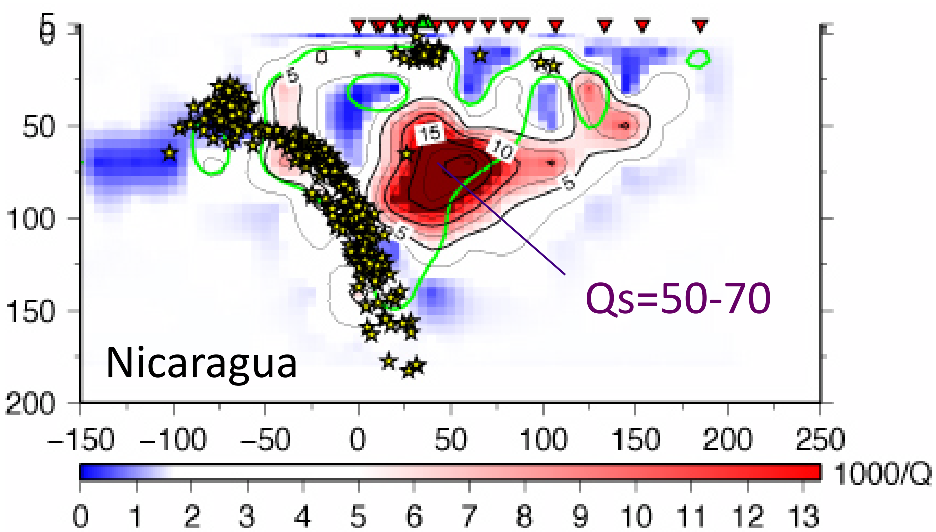



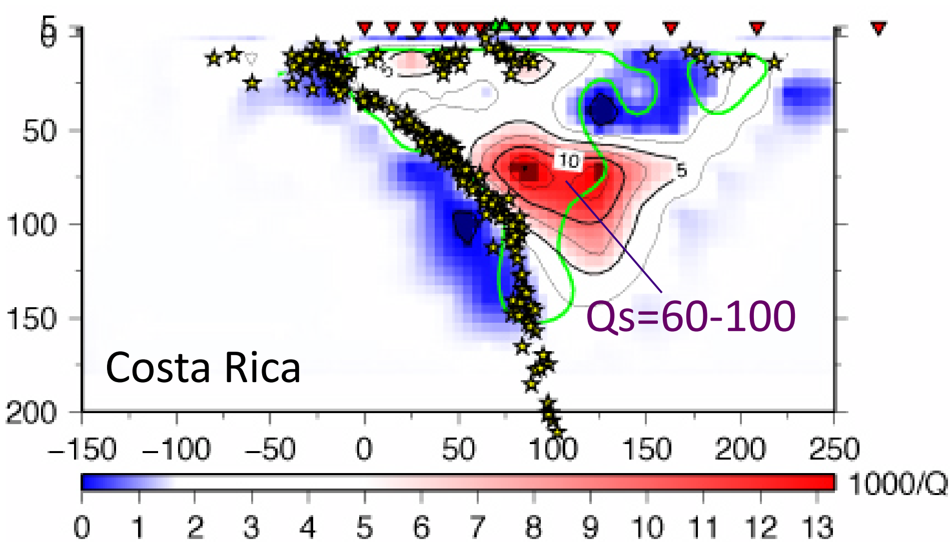




- Nicaragua has:
  - deeper/more melting
  - more 'slab-derived fluid'

than Costa Rica

# Shear wave Attenuation (1/*Qs*): Temperature + hydration?




Rychert et al. (2008)

Temperature
Hydration
Qs

- 1/Qs High beneath arc and back-arc

Nicaragua has higher *T* and/or $H_2O$

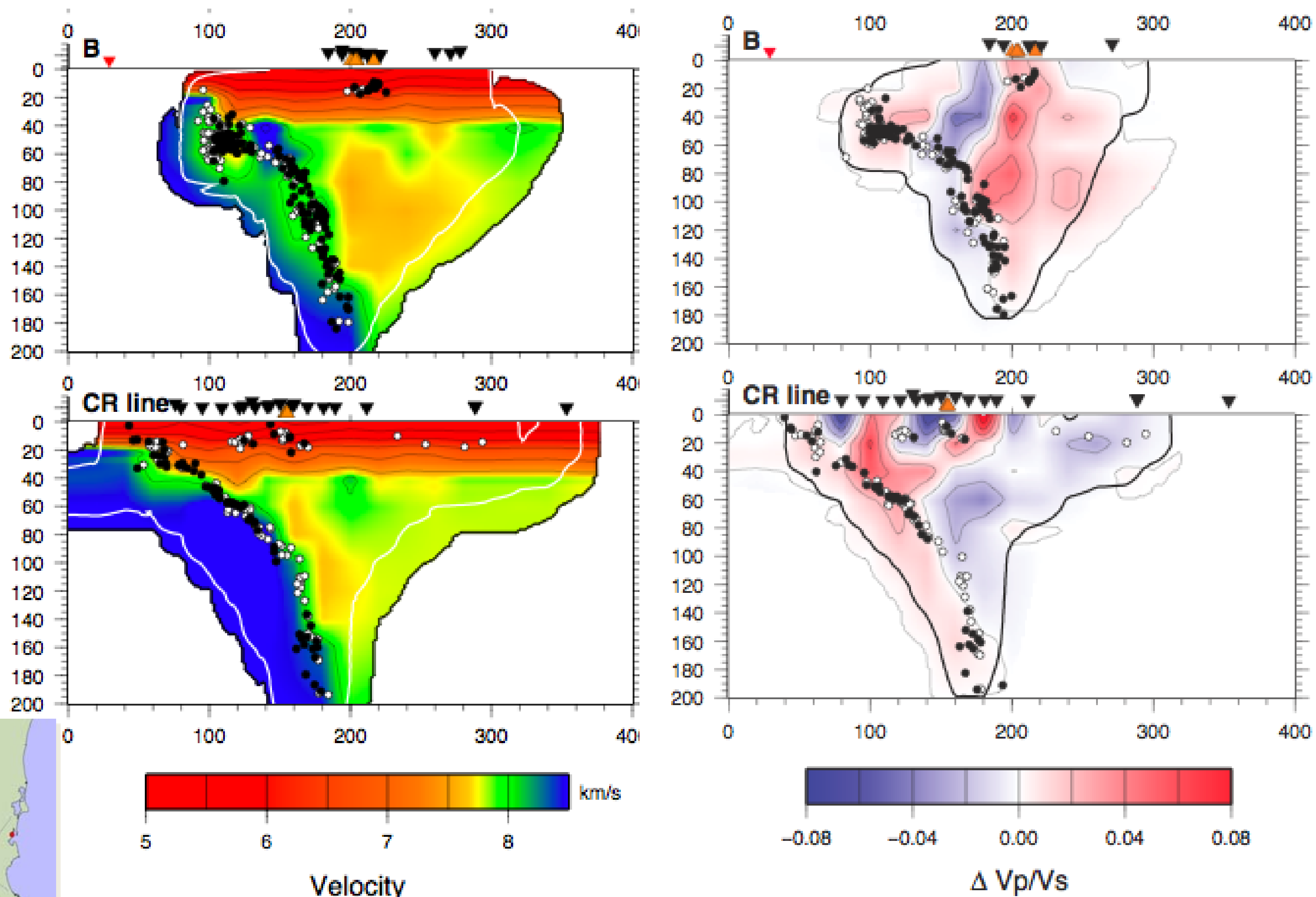
# High *Vp/Vs* column under arc: *melt pathway?*

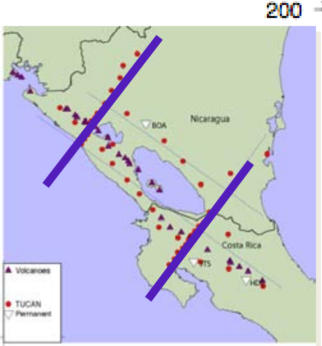
Vp

Vp / Vs

Nicaragua

Costa Rica



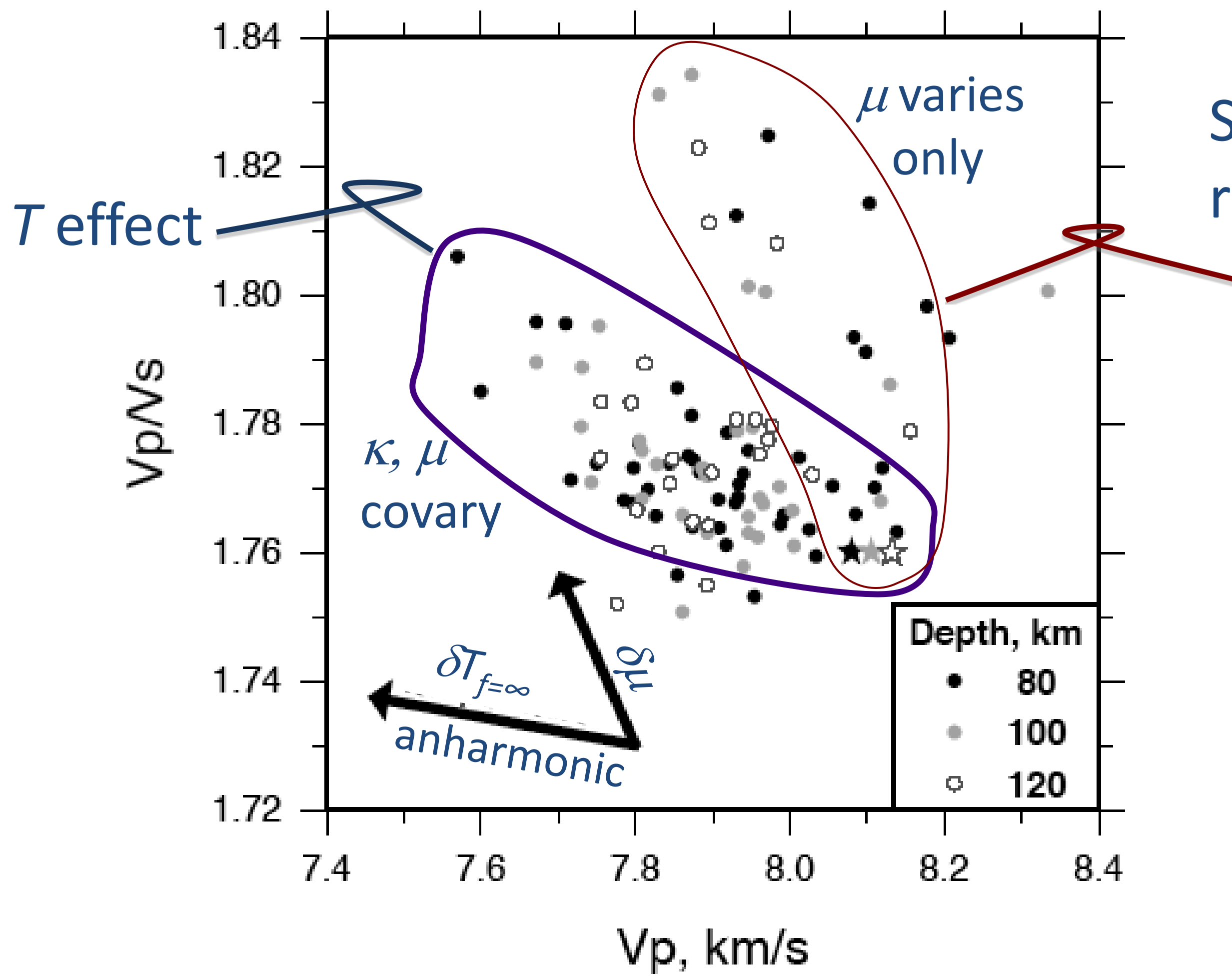




Syracuse et al. (Gcubed, 2008)

# Quantitative comparison: wedge velocities

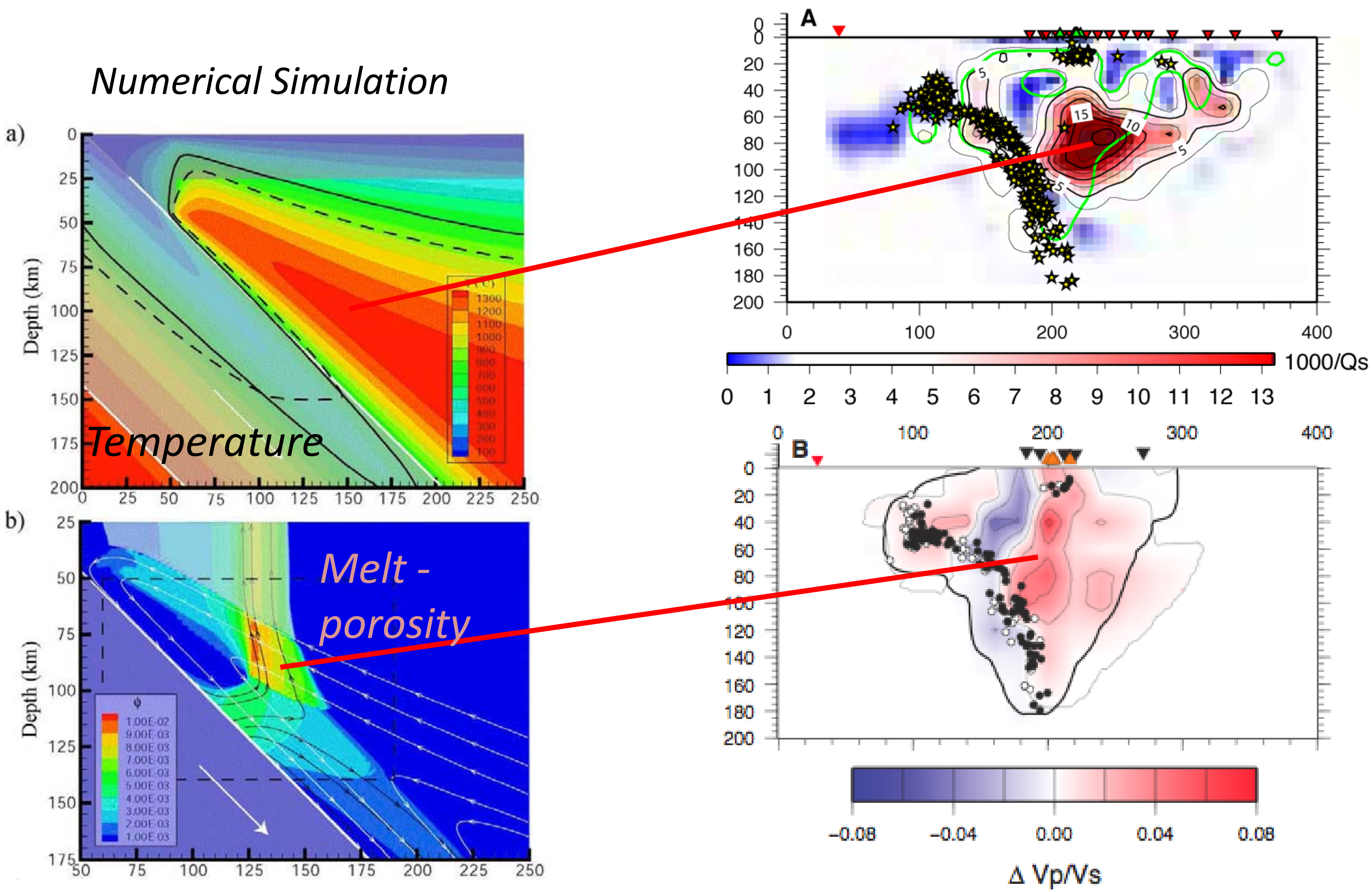
$$Vp = \sqrt{\frac{\kappa + (4/3)\mu}{\rho}}$$

$$Vs = \sqrt{\frac{\mu}{\rho}}$$



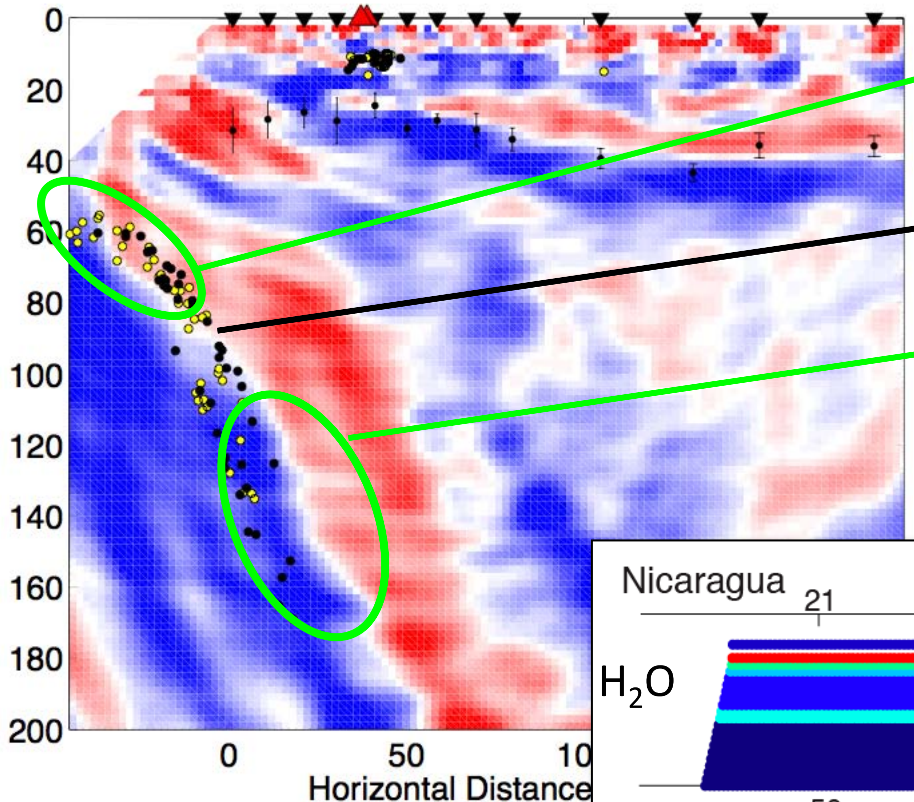

Shear modulus ($\mu$) reduction:
melt signature?

# *Hot Wedge & Melting Column*




*Cagnioncle et al.,JGR, 2007*

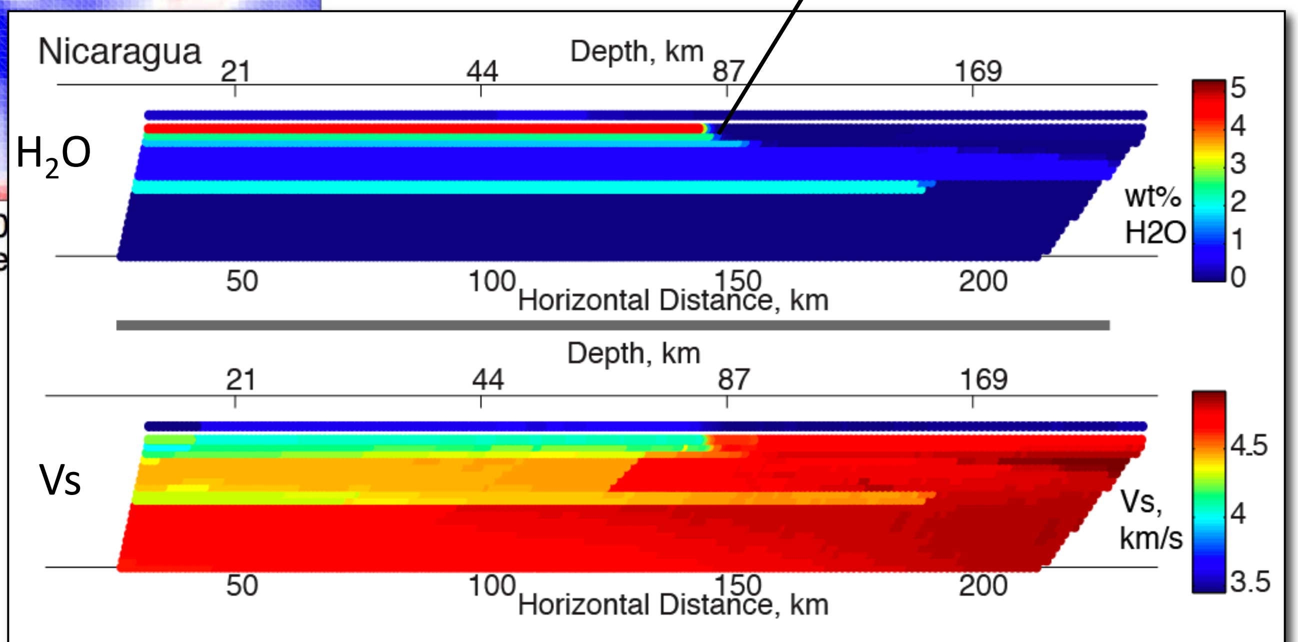
# Ongoing work: Nicaragua image vs. petrologic prediction



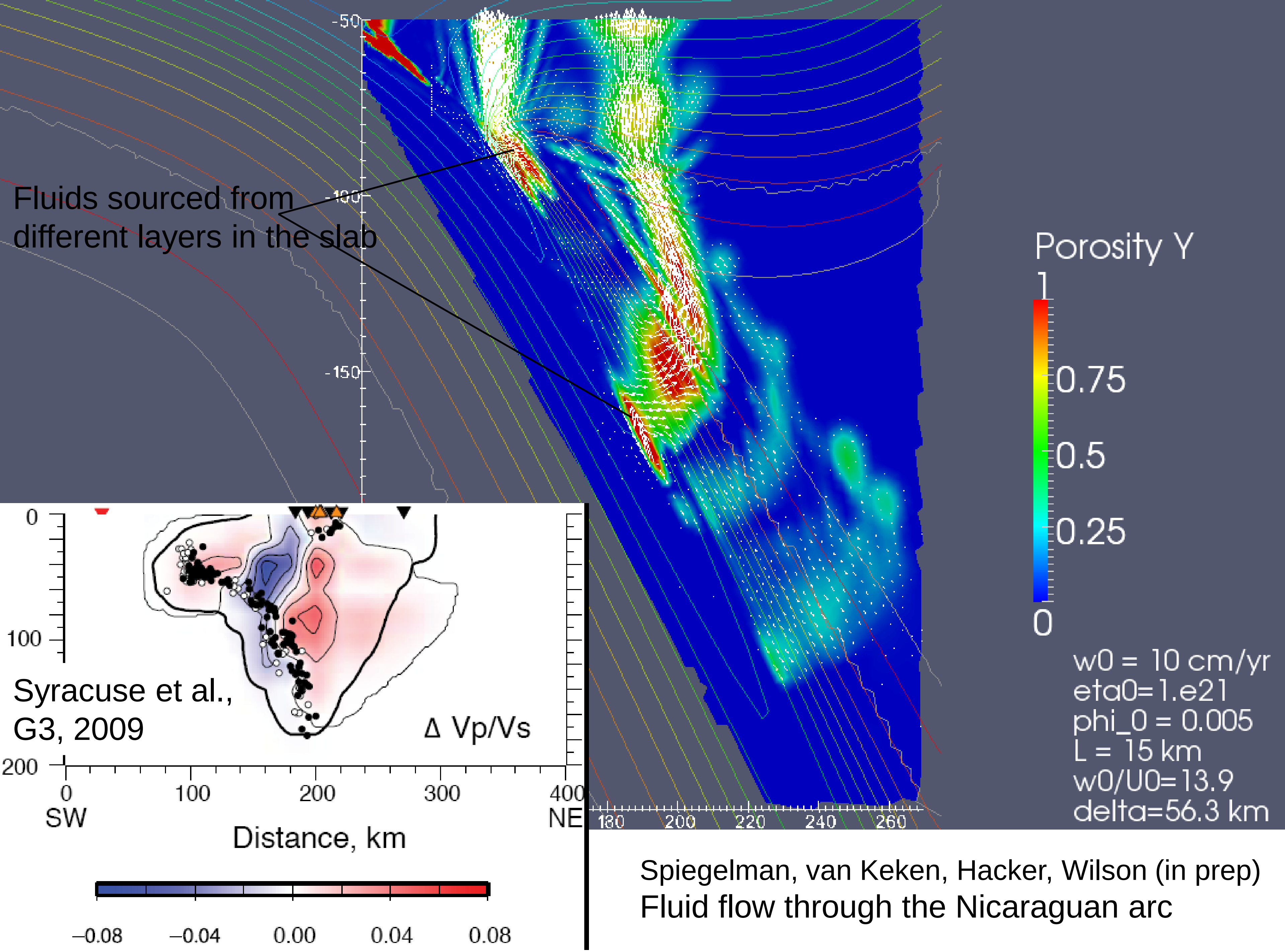

*Sharp: Compositional boundary (Cocos Plate Moho)*

*Eclogitization/dehydration*

*Gradient: Thermal boundary above slab*



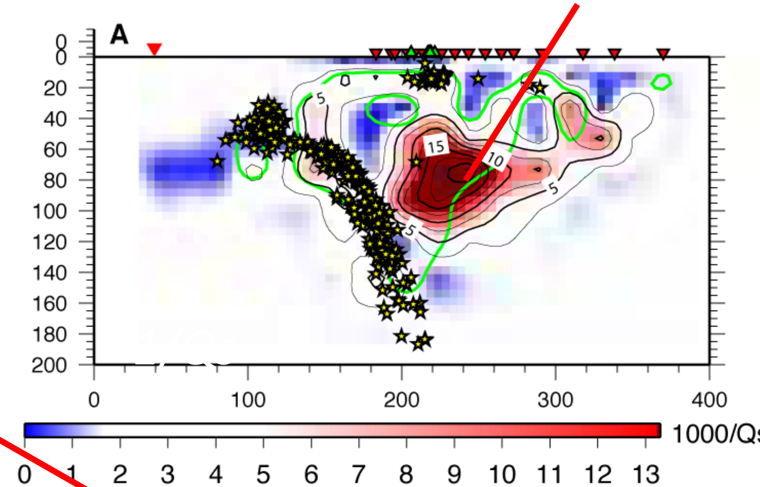

Syracuse et al., 2010;
van Keken et al., 2010




Spiegelman, van Keken, Hacker, Wilson (in prep)
Fluid flow through the Nicaraguan arc

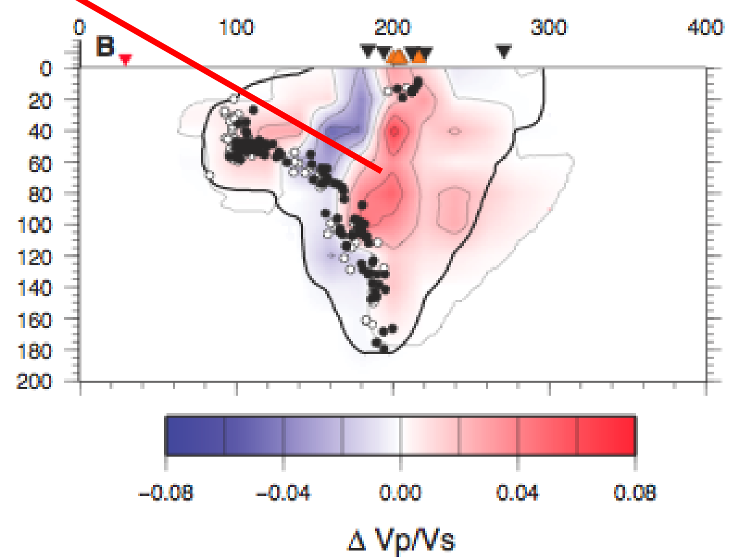
# *Summary: the fluid cycle*

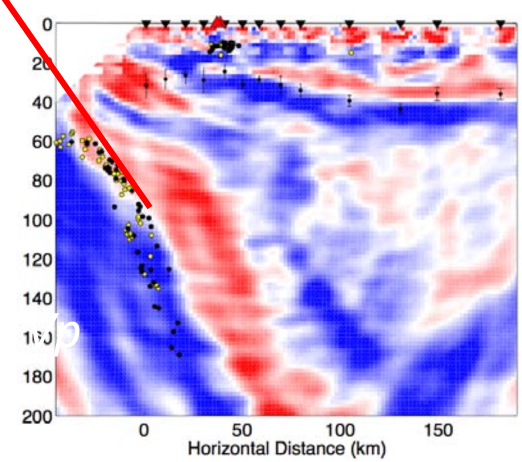
Wedge is usually hot..

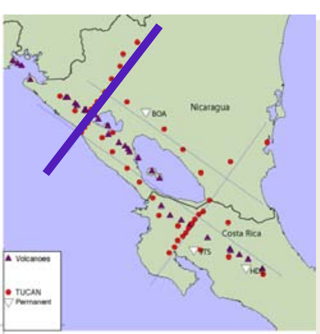



… and dehydration of subducting crust fluxes hot wedge…

… producing high melt-fraction conduits when dehydrates.



# Translating this mapping to the surface

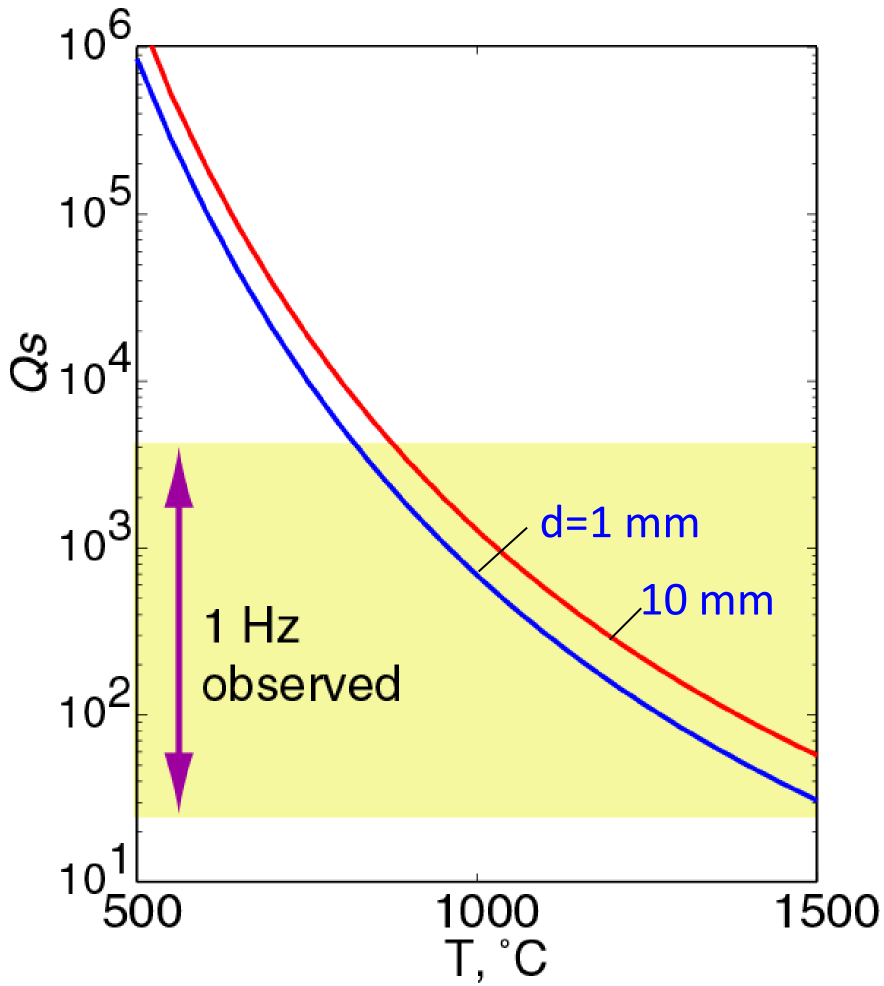
- How can understanding deep volcanic plumbing translate into hazard understanding?
  - Can we assess eruption size absent historic record?
  - Are there eruption precursors in the mantle?

- What is the link between slab devolatilization and explosivity:
  - Quantitative volatile estimates?
  - Link between mantle temperatures and viscosity?
  - Can differentiation ($SiO_2$ content) be predicted?

San Jacinto, Nicaragua

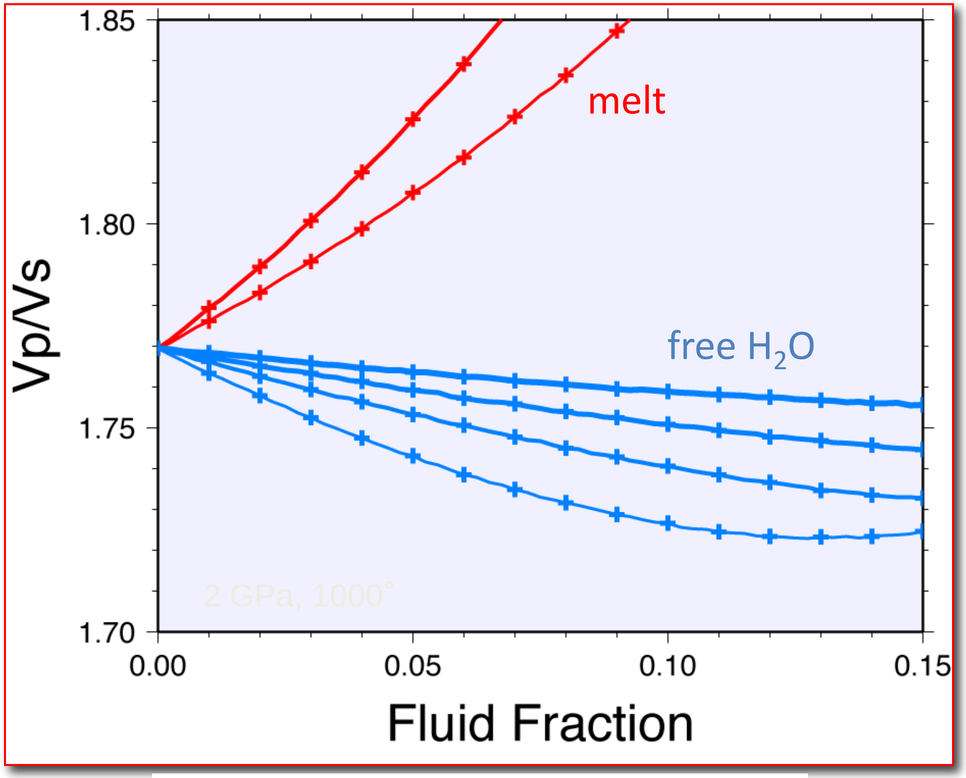
# Seismic proxies for *T*, melt

Shear Attenuation (1/Qs)




Faul & Jackson (2005), adjusted to 2.5 GPa

Poisson's Ratio ~ Vp/Vs




Takei (2002) poroelastic theory

(other theories scale differently)

# Thanks to many collaborators & students

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