Volatile Fluxes & Arc Magmatism: The Observational Record & Unresolved Questions

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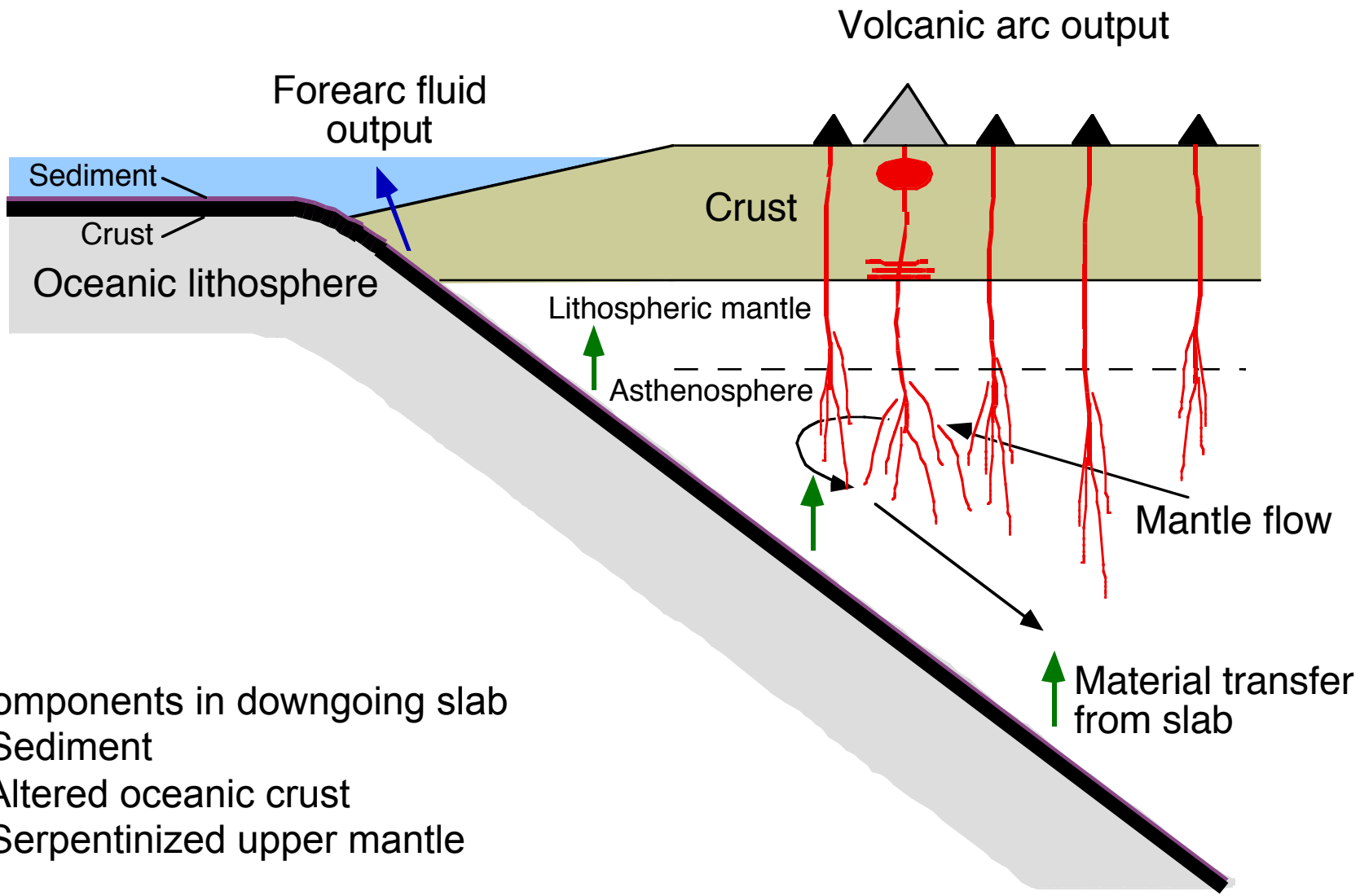
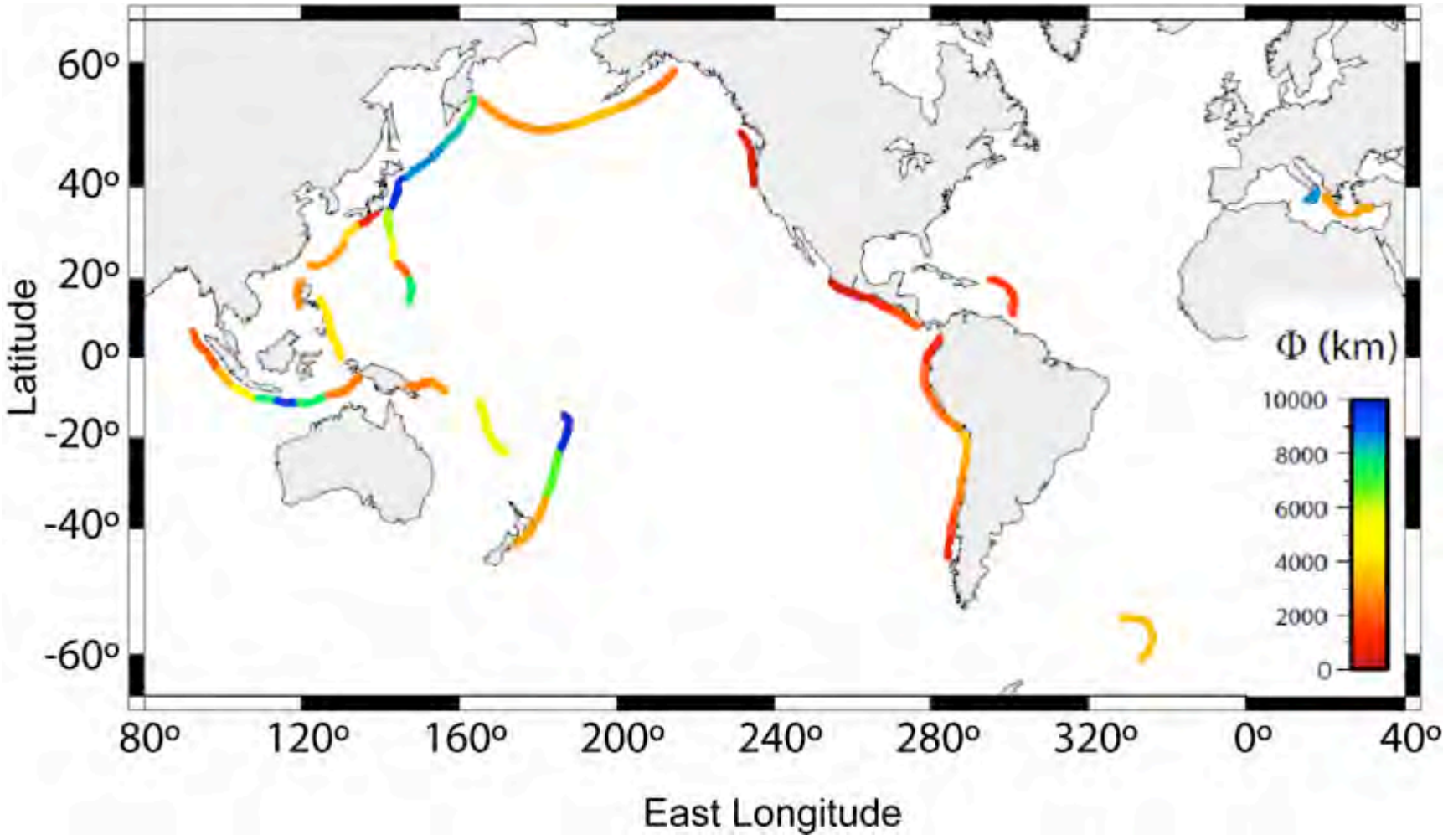
Volatile Recycling & Subduction Zone Magmatism



Components in downgoing slab
- Sediment
- Altered oceanic crust
- Serpentinized upper mantle

Variations in Thermal State of Subducted Lithosphere



Slab Thermal Parameter: $\Phi = V_c * \text{Age} * \sin \delta$

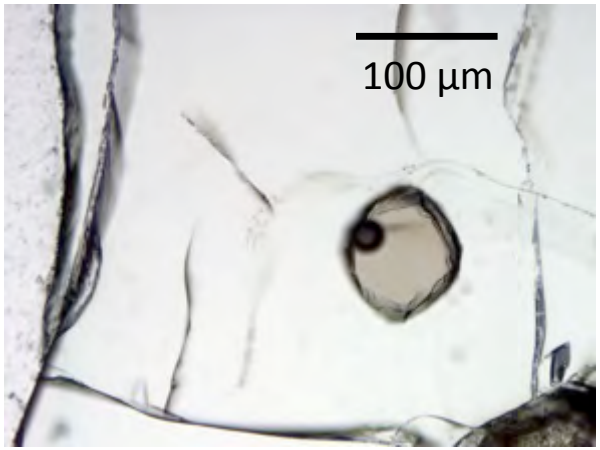
van Keken et al. (2011)

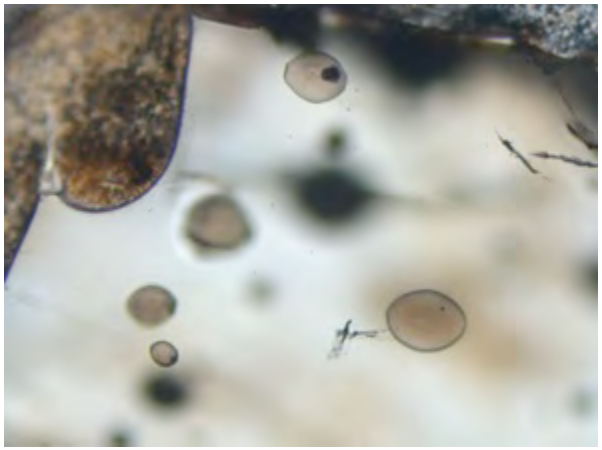
Key Questions

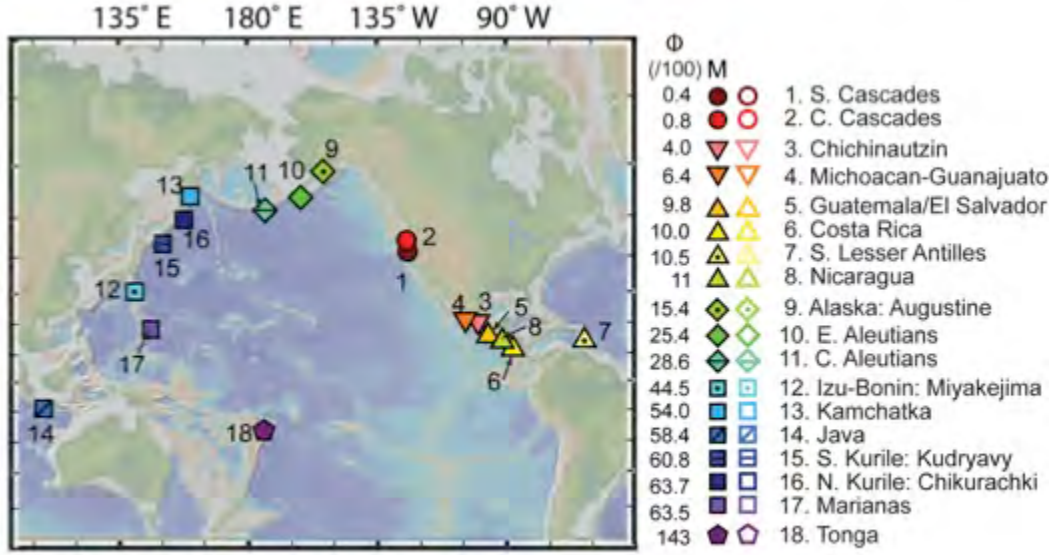
- What is the range of H_2O content & other volatiles in arc magmas & how do they vary with slab temperature?
- Do sediment and basaltic crust dehydrate or melt beneath volcanic arcs?
- What happens to hydrated forearc mantle? What pathway does hydrous material take from the slab into the magma generation zone in the mantle wedge?
- Do other aspects of arc magma geochemistry vary with slab temperature?
- Do volatile outputs from arcs vary with slab temperature?
- Are hot-slab subduction zones like the Cascades more magmatically feeble than other arcs?

Data & Methods

- Melt inclusions trapped in olivine phenocrysts provide a record of volatiles & can also be analyzed for trace elements.
- Published data for 100 volcanoes from 18 subduction zone segments.

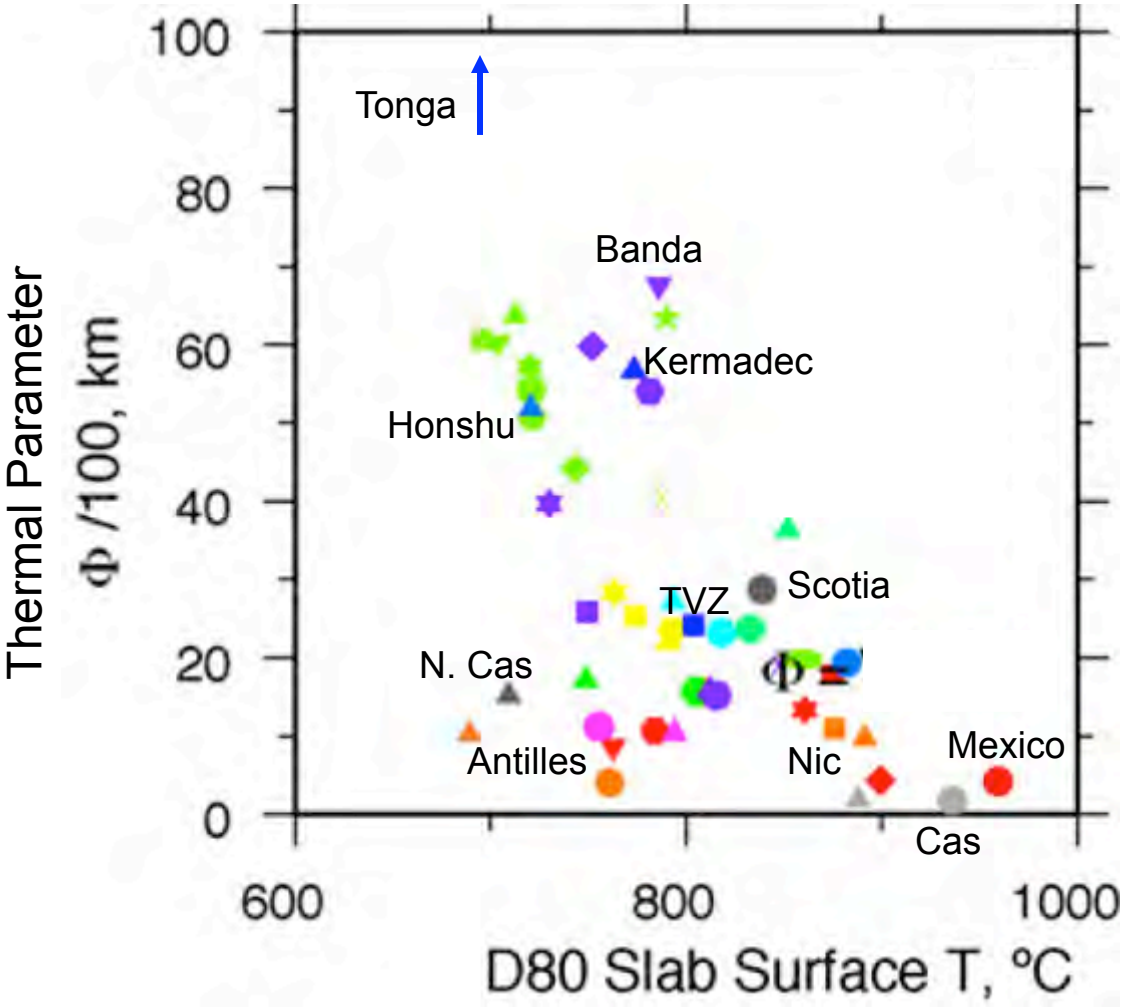






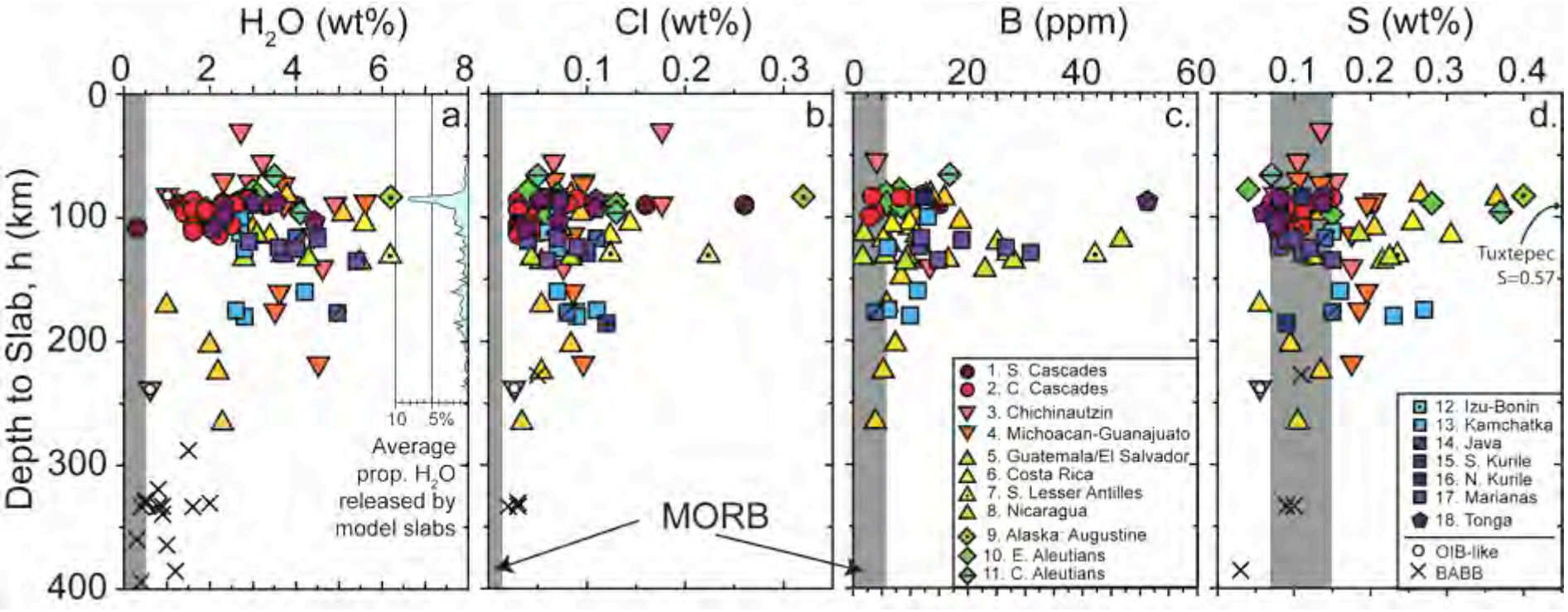
Cooper et al. (2012) G-Cubed
Ruscitto et al. (2012) G-Cubed
Plank et al. (2013) EPSL

Estimated Slab Top Temperatures at Sub-Arc Depths



Syracuse et al. (2010)

Volatile Contents of Primitive Arc Magmas

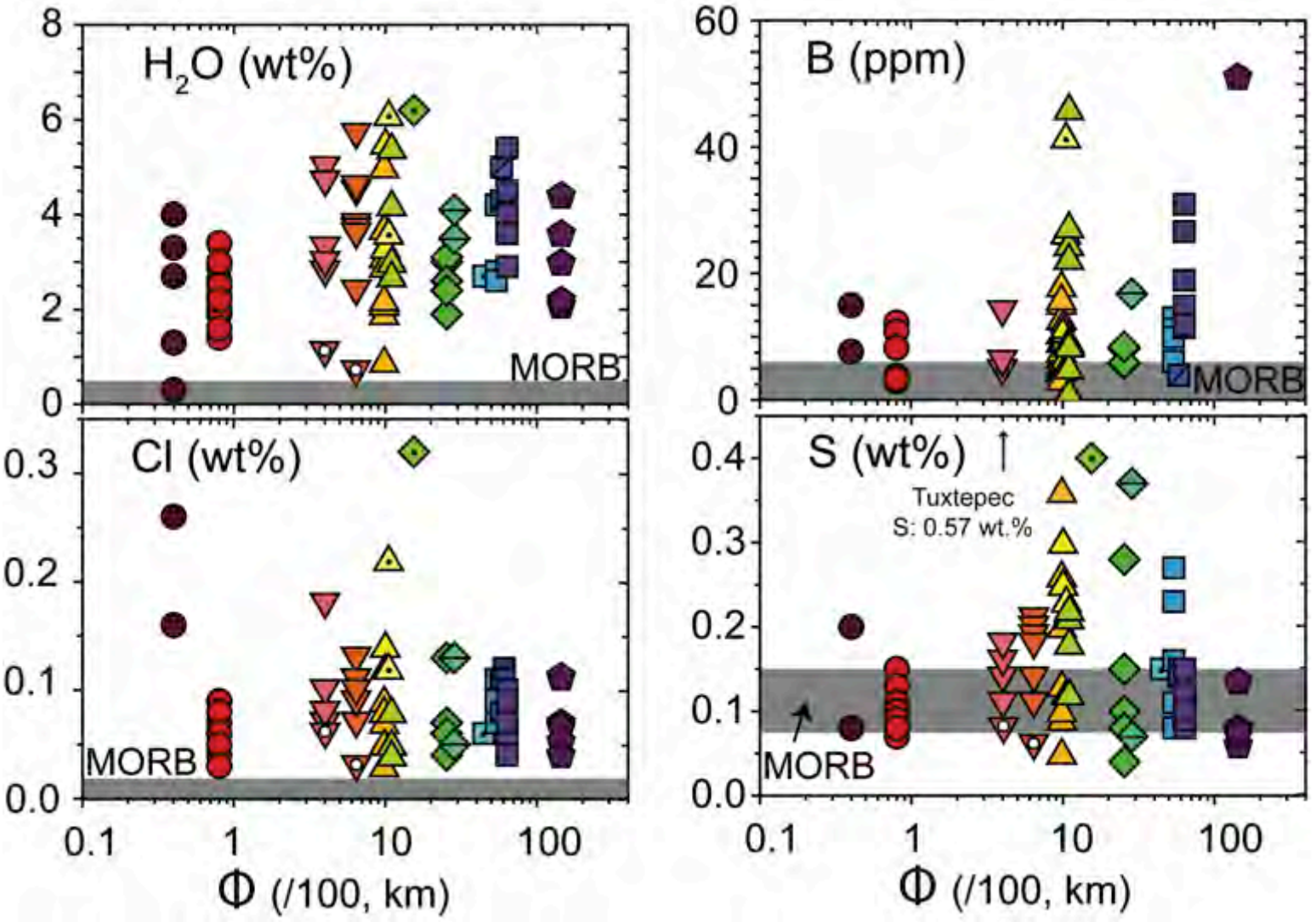


Ruscitto et al. (2012)

- Each data point represents a single volcano based on melt inclusion data
- All compositions have been corrected to equilibrium with Fo_{90} olivine

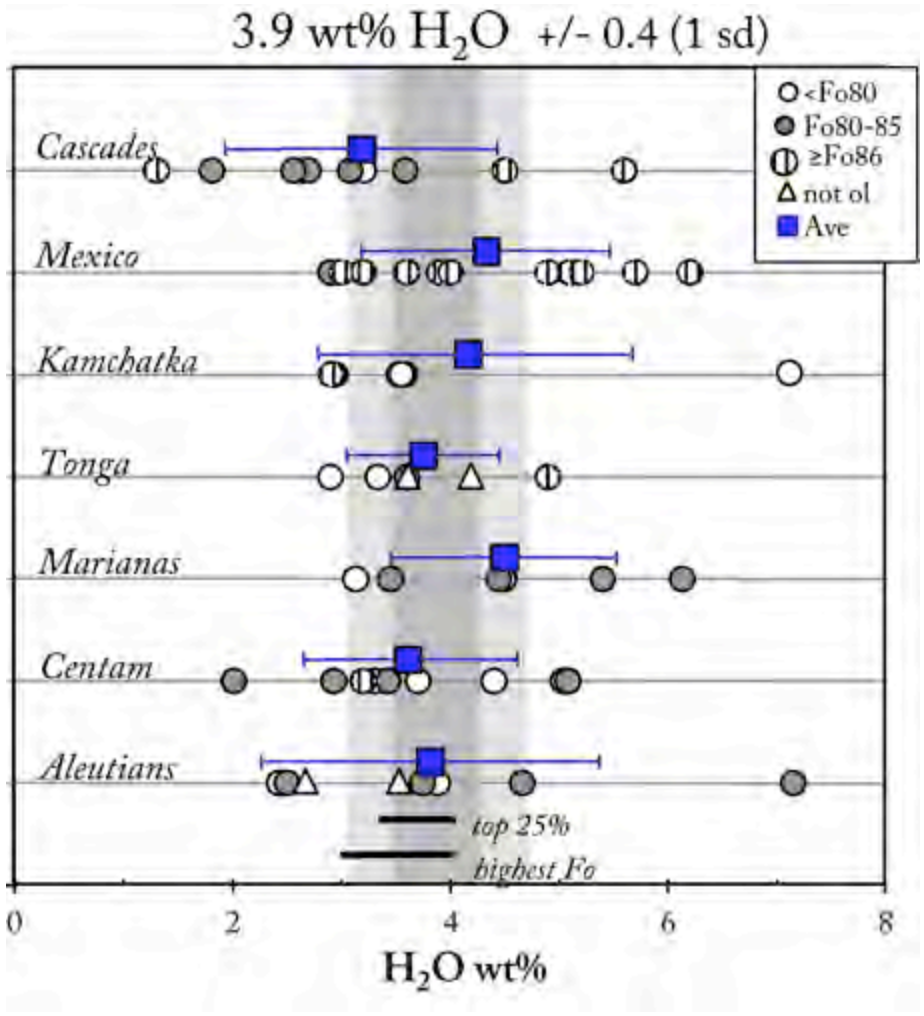
H_2O release in A from van Keken et al. (2011)

Comparison of Volatile Content & Slab Thermal Parameter



Ruscitto et al. (2012)

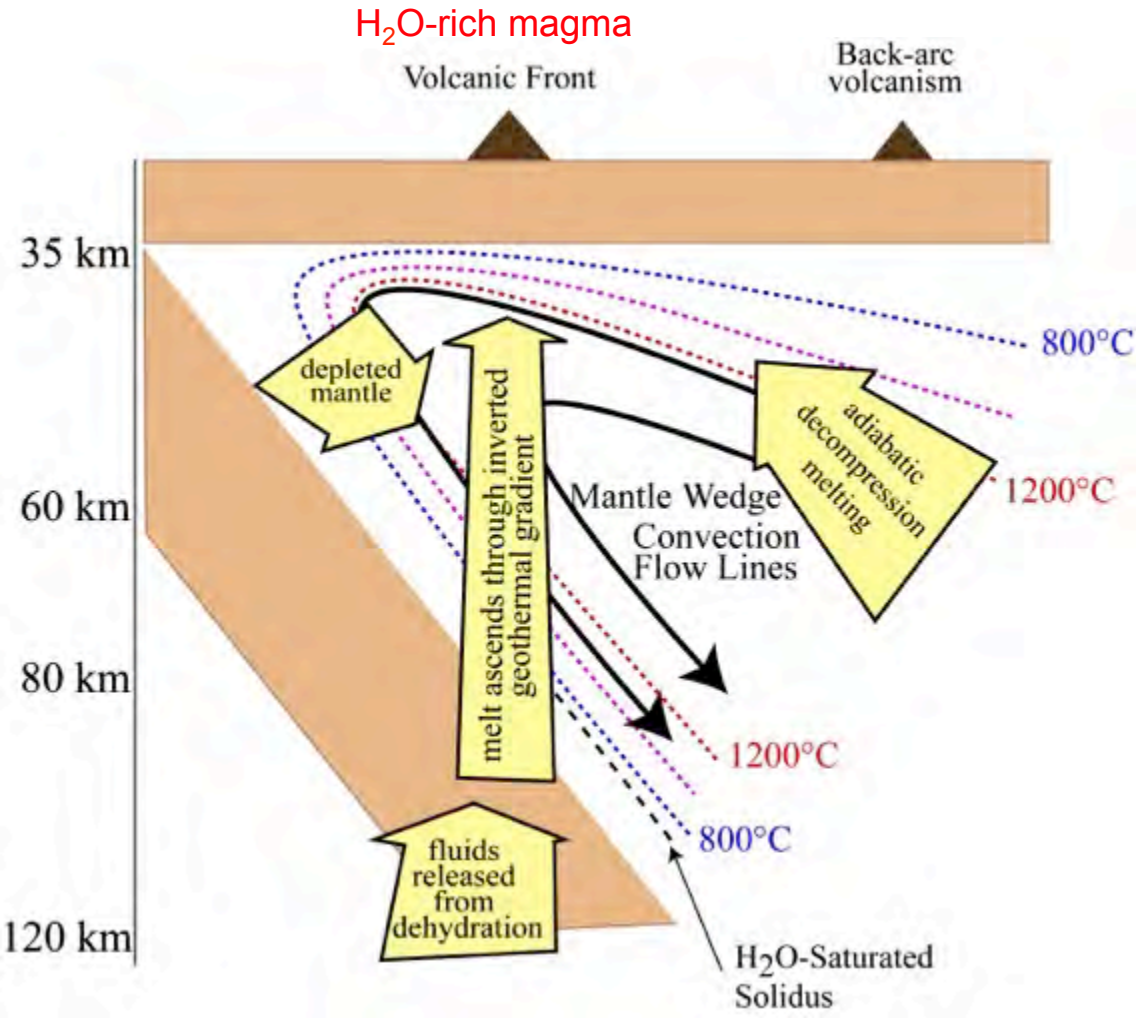
Average & Range of H_2O Data for Arc Front Volcanoes



- Why the narrow range of H_2O when other elements like Ba and Nb vary by 1 to 2 orders of magnitude?

Plank et al. (2013)

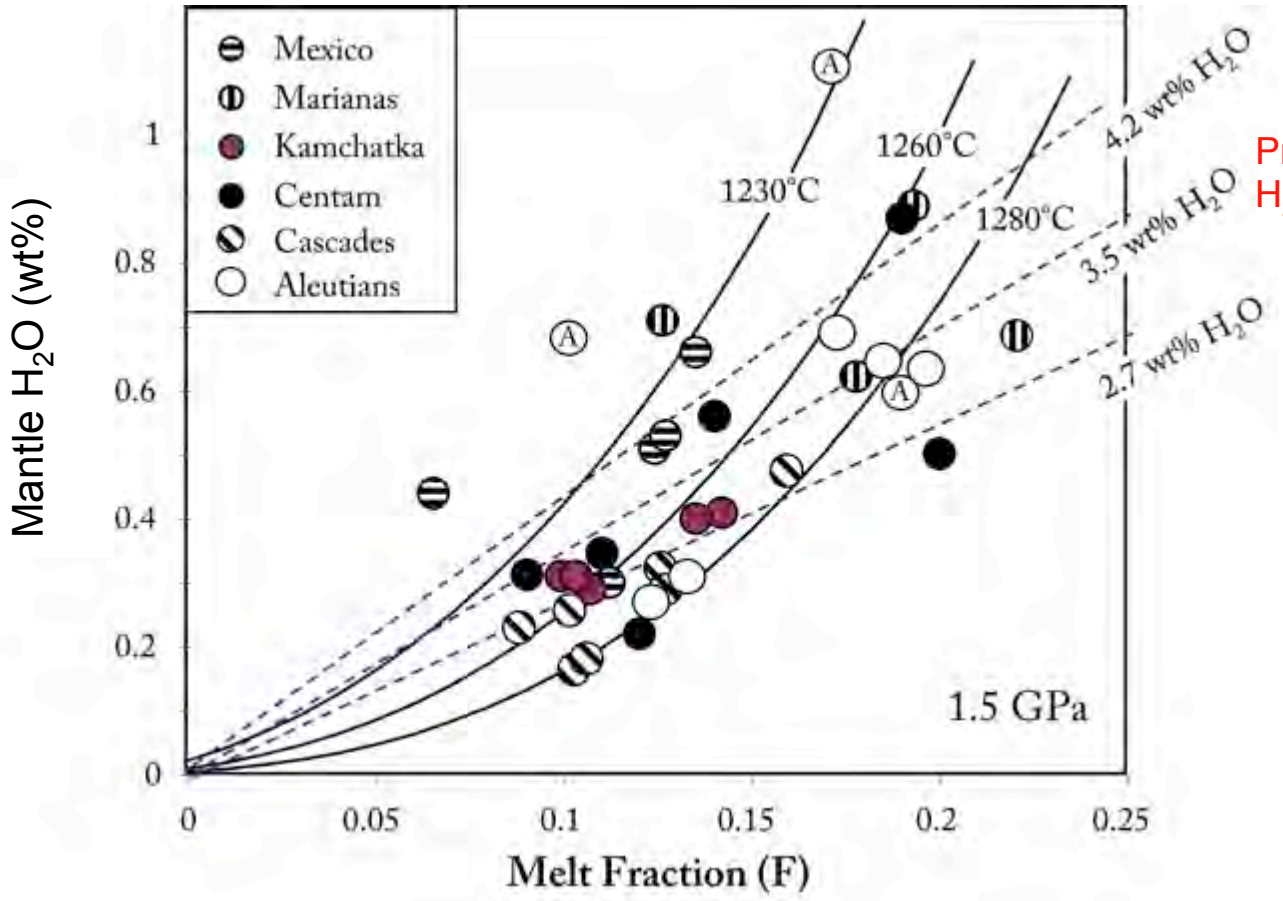
Flux Melting in Subduction Zones



- H_2O-rich magmas form as fluids or hydrous melts percolate upward through the inverted thermal gradient in the mantle wedge

Grove et al. (2006)

Mantle Melt Fraction vs. Mantle H_2O Concentration

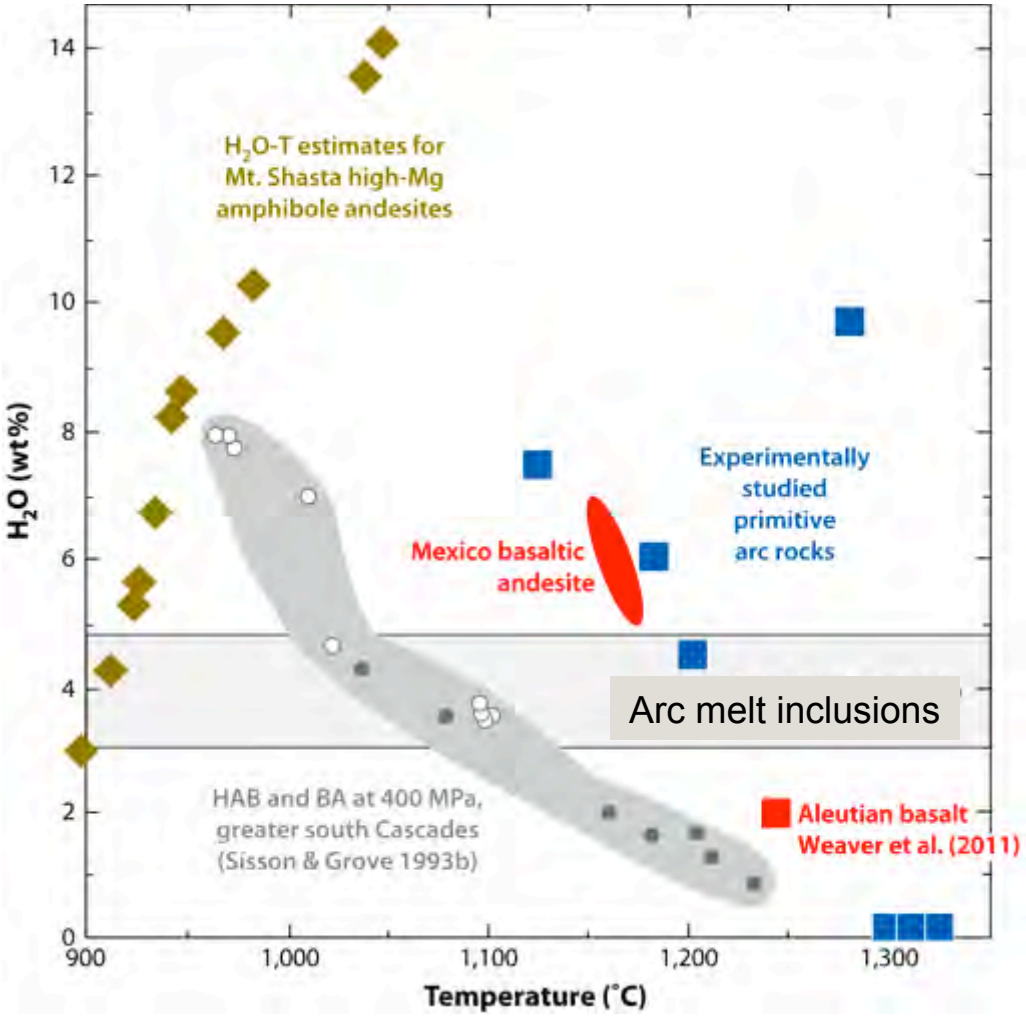


Primitive melt H_2O content

Interpretation 1: Feedback between mantle H_2O & degree of melting limits melt H_2O

Plank et al. (2013); Kelley et al. (2010)

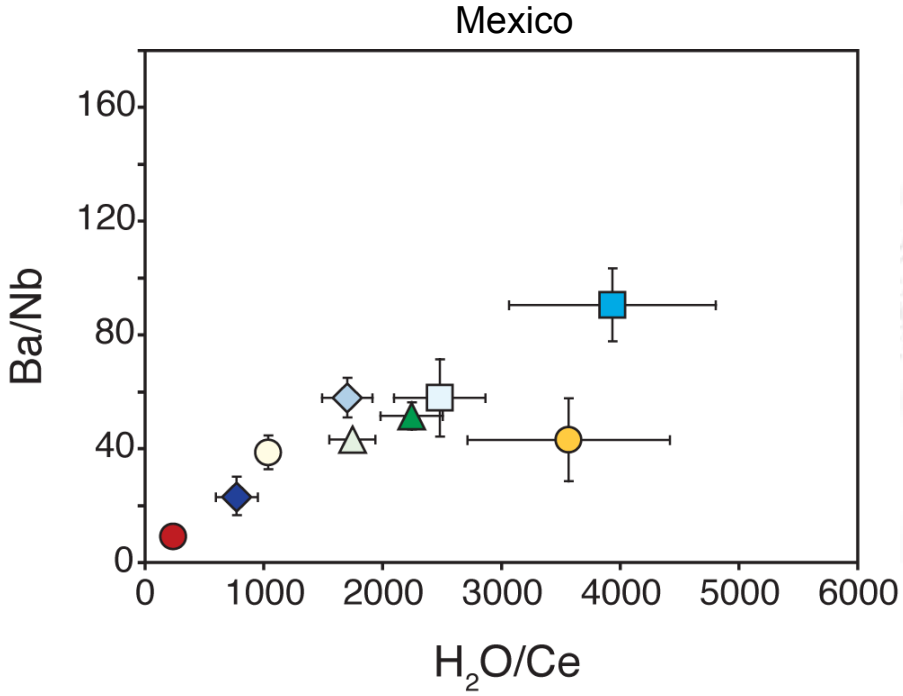
Comparison of Melt Inclusions & Experimental H_2O Estimates

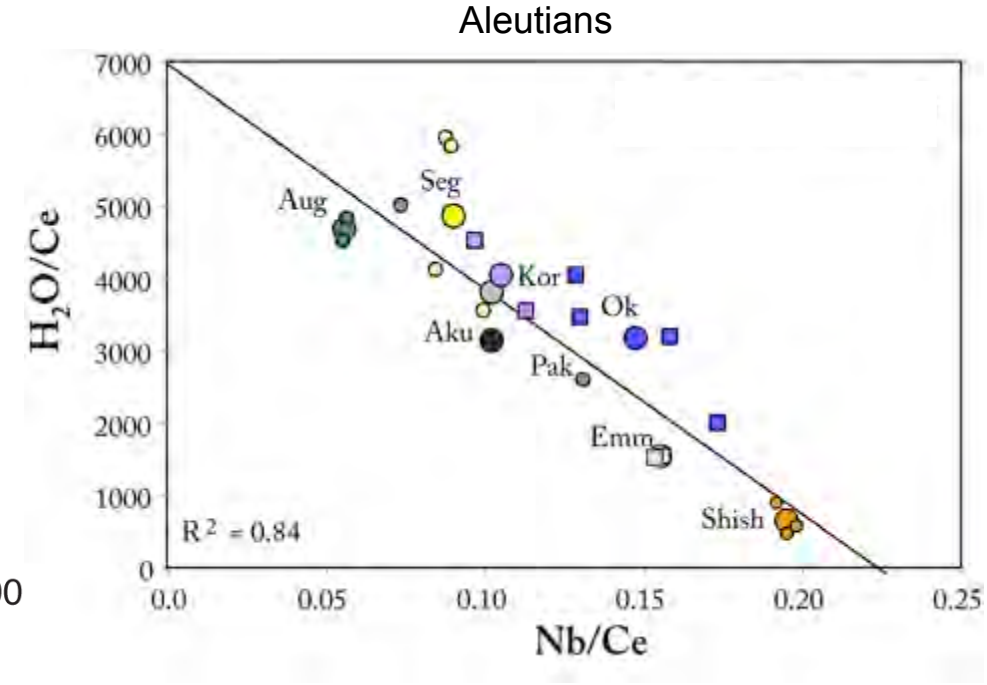


Interpretation 2: Arc magmas start with higher H_2O than is recorded in melt inclusions

Modified from Grove et al. (2012)

Correlations Between Melt Inclusion H_2O & Trace Elements

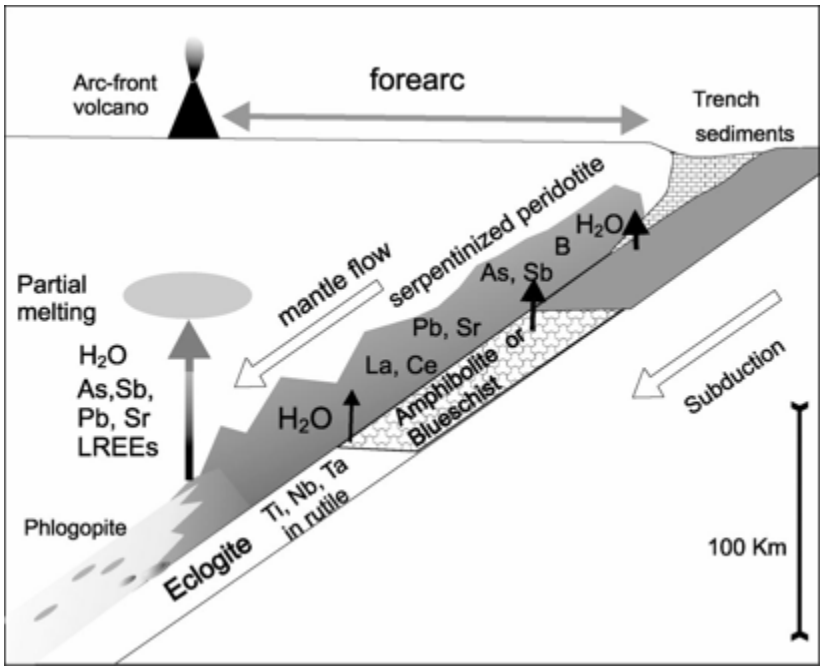


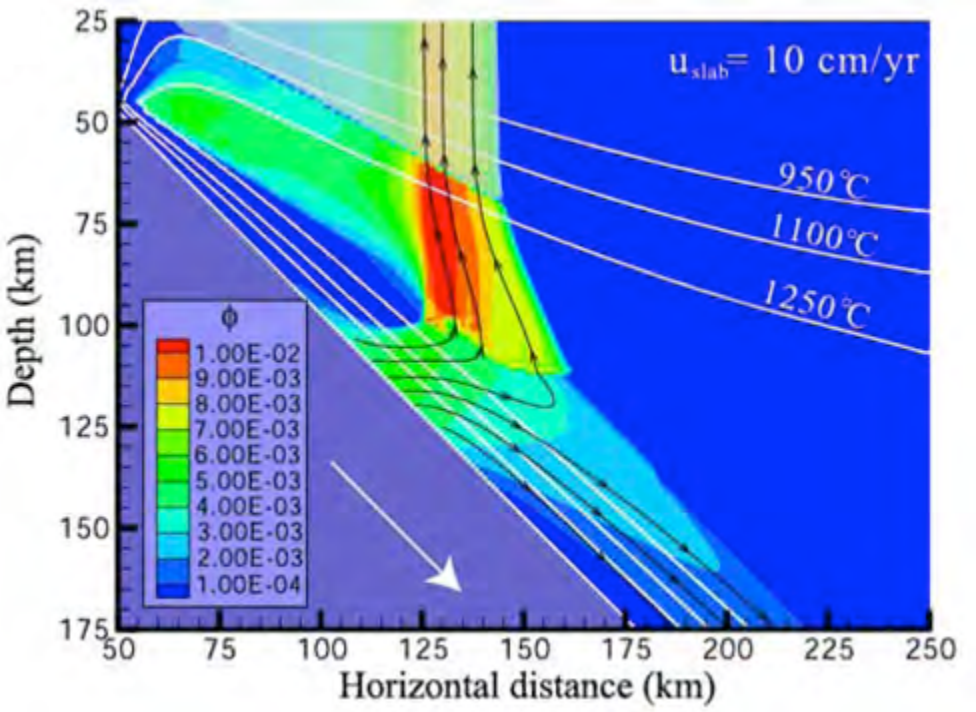


- Relations are <u>not</u> consistent with the interpretation that all melt inclusions are substantially degassed relative to primary melts

Johnson et al. (2010); Zimmer (2009); Zimmer et al. (2010)

How Do Fluids & Melts Move Through the Mantle Wedge?





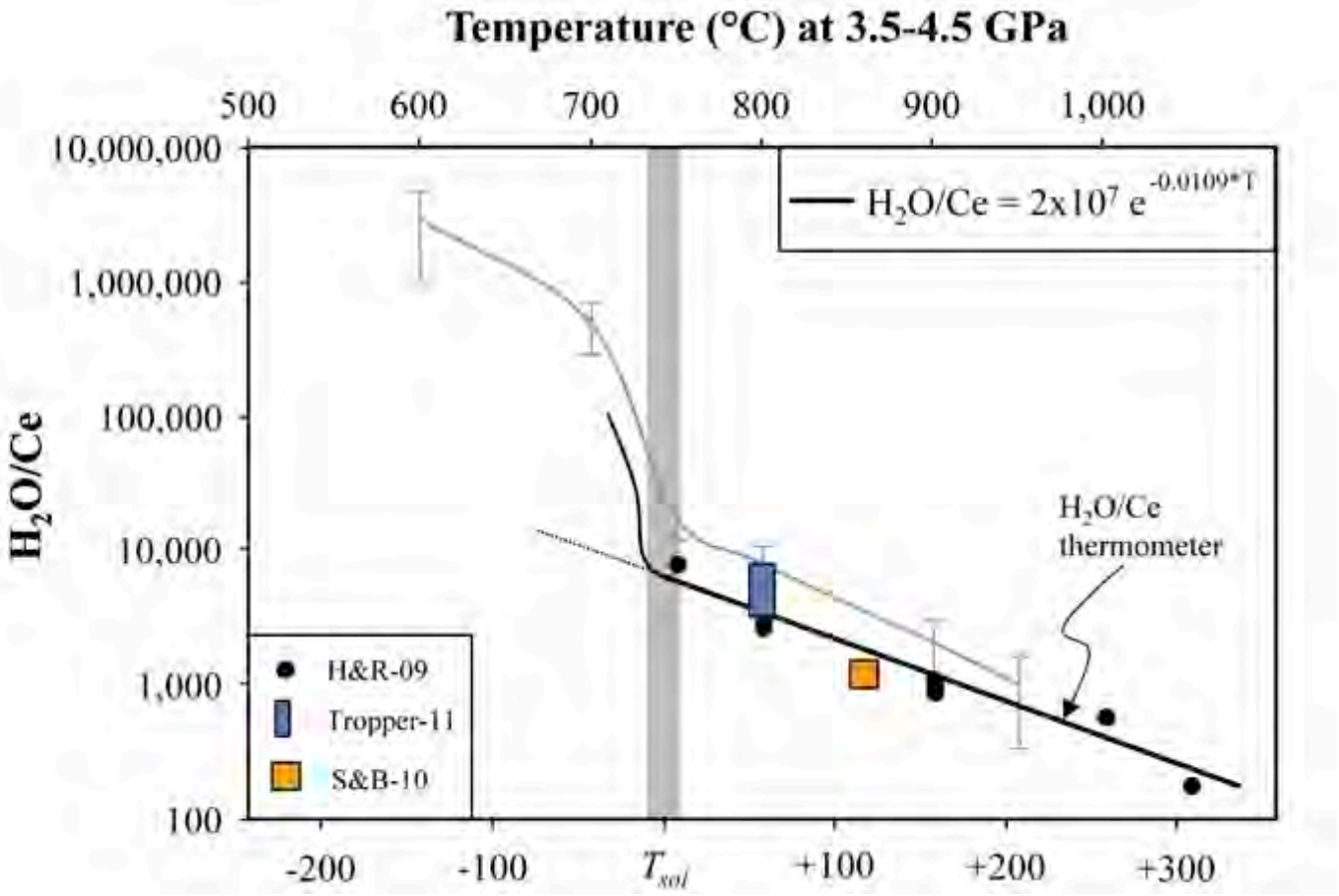
Downdragging of forearc mantle supplies fluid through multistage process

Effects of solid mantle flow on fluid & melt in the mantle wedge

Hattori & Guillot (2004)

Cagnioncle et al. (2007)

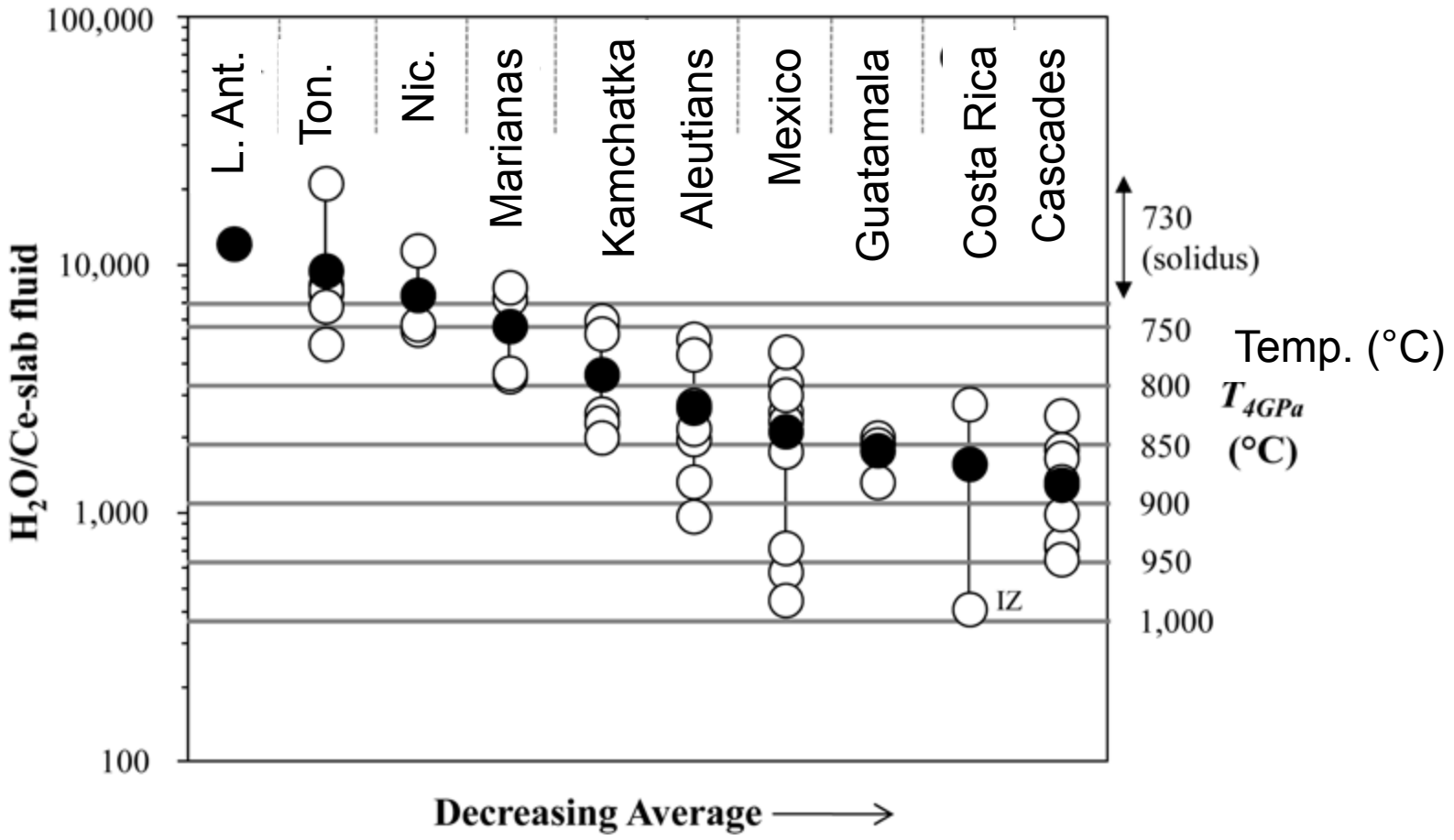
H_2O/Ce Slab Geothermometer: Experimental Calibration



- Geochemical data for arc magmas can be used to infer slab top temperatures
- Requires allanite and/or monazite to be present in metasediment & metabasalt

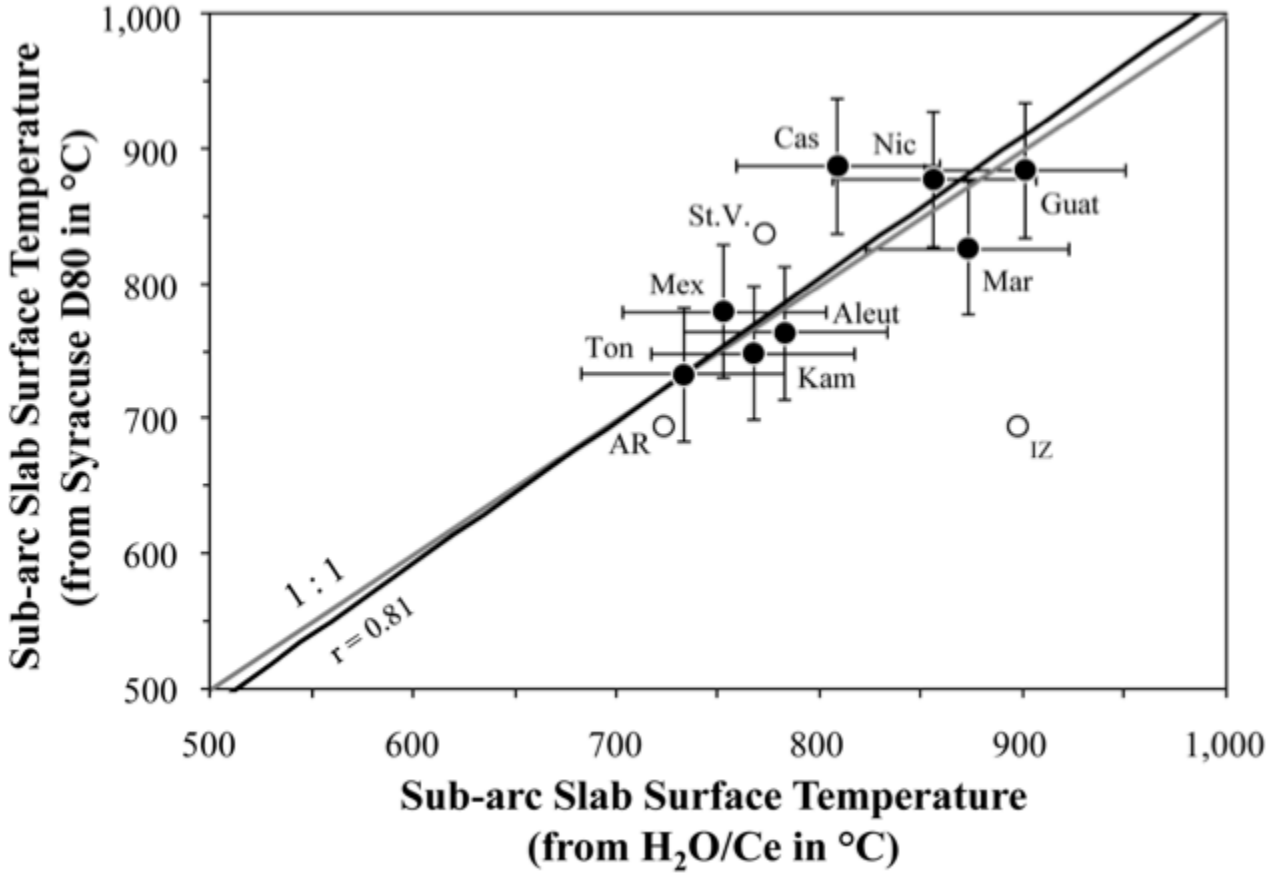
Plank et al. (2009); Cooper et al. (2012)

Slab Temperatures Predicted from H_2O/Ce



Cooper et al. (2012)

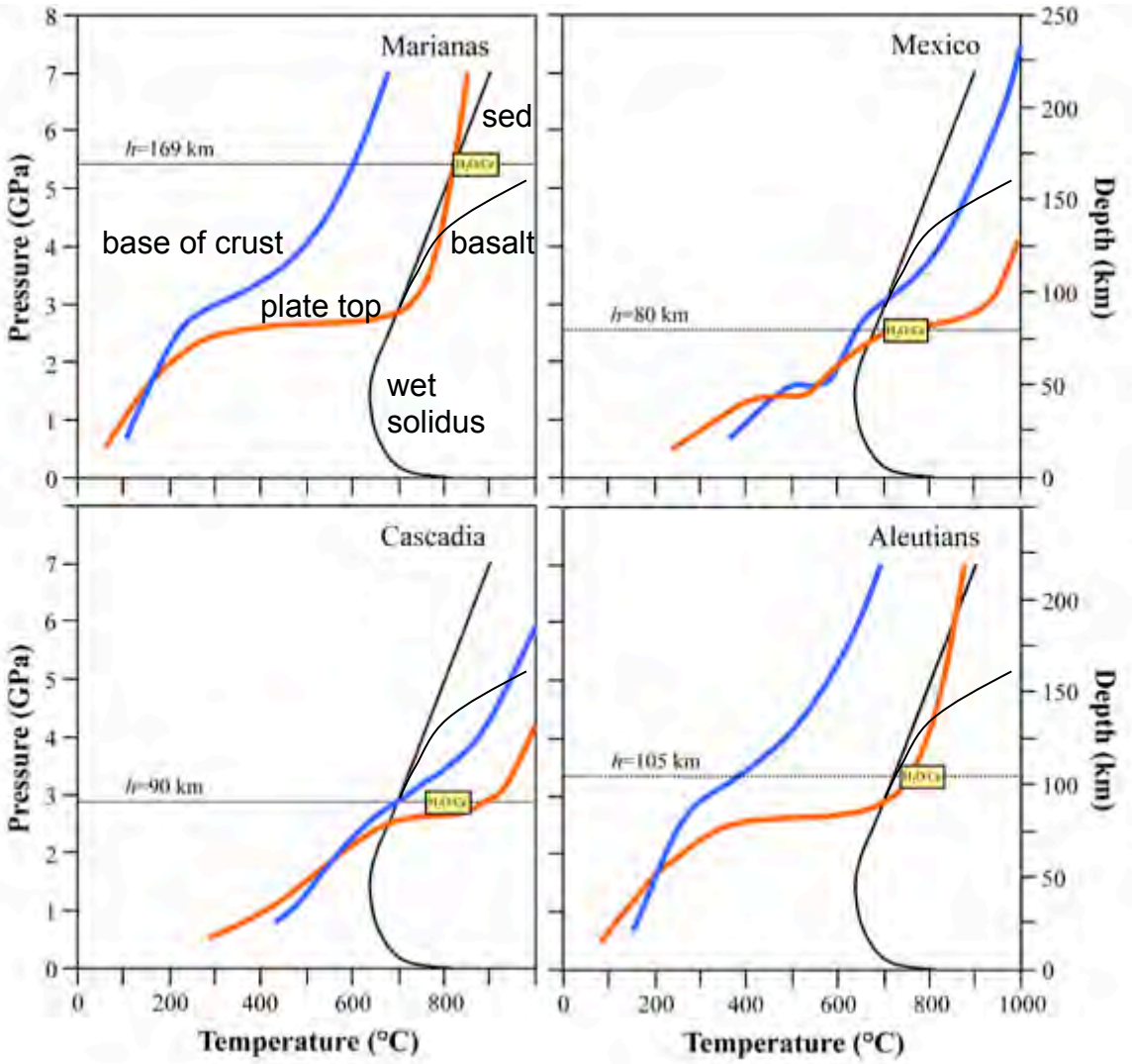
Comparison of Temperatures from H_2O/Ce & Geodynamic Models



- Relatively good agreement between geodynamic models & H_2O/Ce temperatures
- Suggests mainly vertical rise of slab components

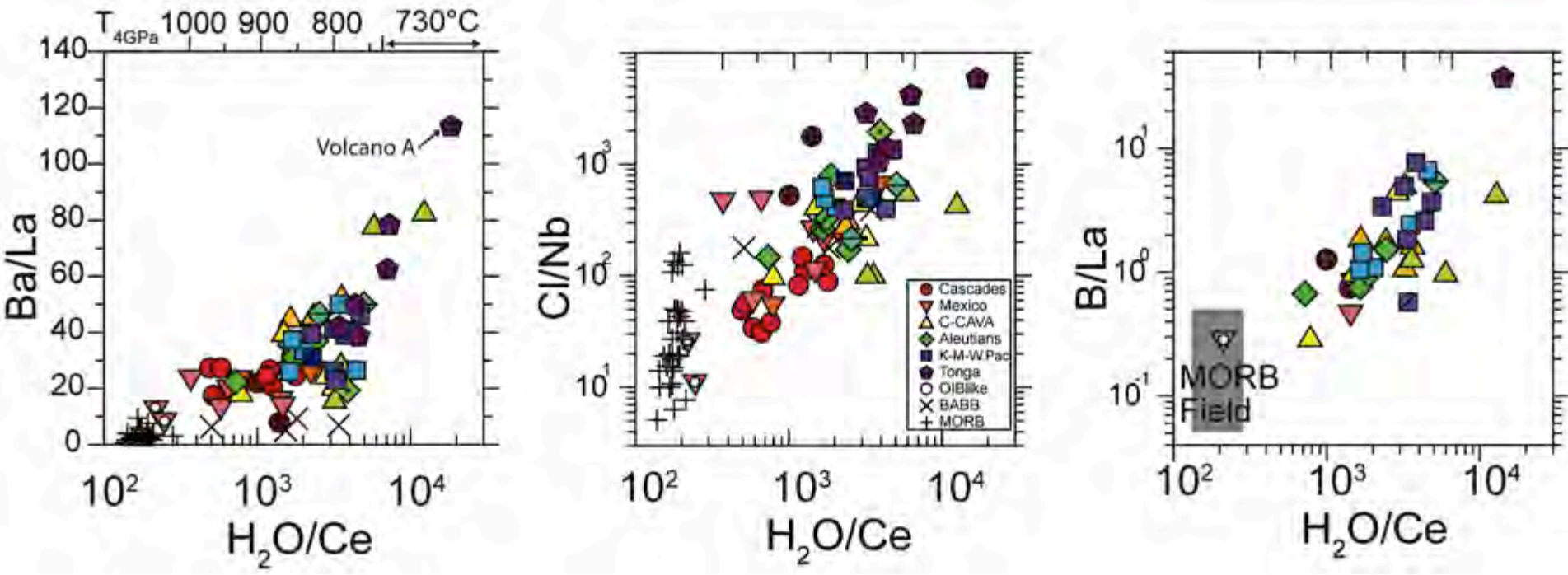
Cooper et al. (2012)

Hot Temperatures Cause Melting of the Slab Top Beneath Arcs



Modified from Cooper et al. (2012); wet basalt solidus from Poli & Schmidt (1998), Kessel et al. (2005)

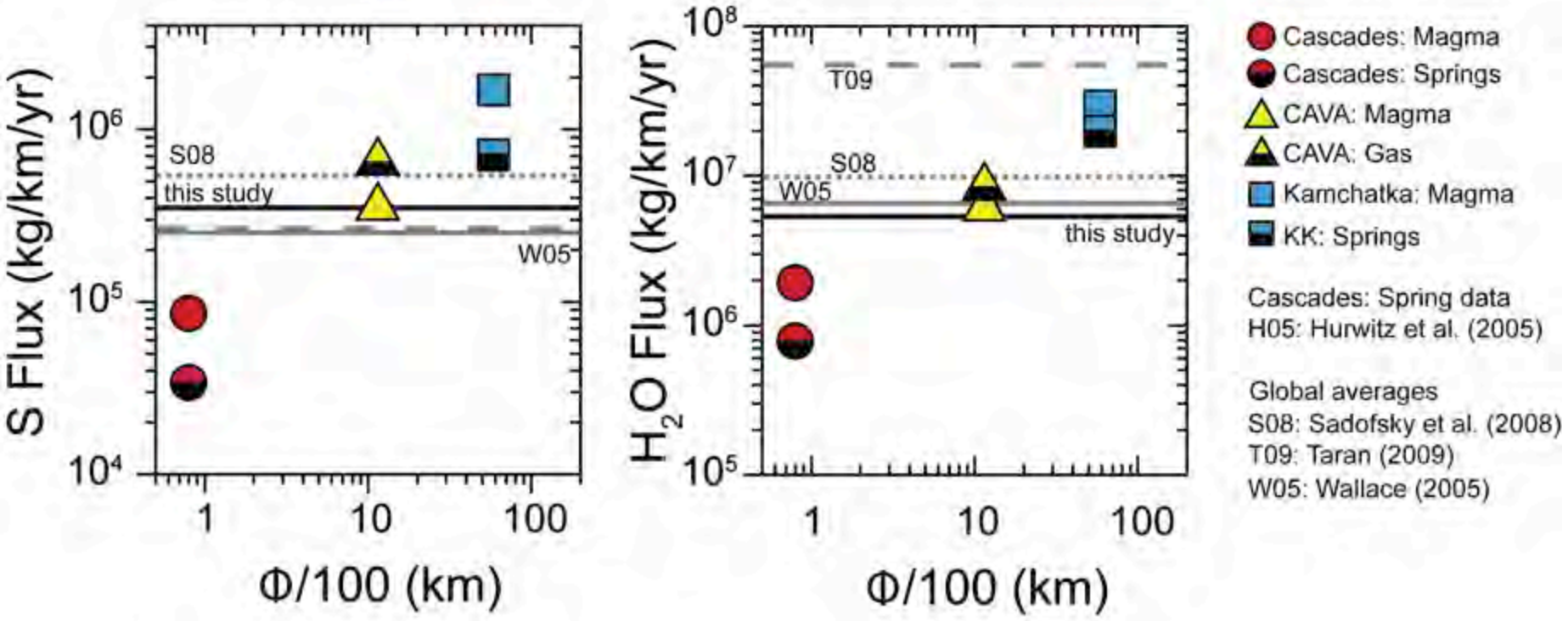
Relationship of H_2O/Ce to Other Slab Tracers



- Geochemical variations that have been attributed to sediment vs. basalt sources or to different sediment compositions might also, in part, be related to slab temperature variations

Ruscitto et al. (2012)

Arcs With Hotter Slabs Have Lower Volatile Outfluxes



- Consistent with prediction that hot slabs strongly dehydrate beneath the forearc

Ruscitto et al. (2012)

Are Hot-Slab Arcs More Magmatically Feeble?

The myth of low magma productivity in the Cascades

- "It has commonly been asserted that volcanic output along the Cascade arc is low relative to that of many arcs, but the basis of the assertion has never been clear."

- Output is difficult to estimate because of large losses by glacial erosion.

Estimates of Quaternary eruptive products in different arcs (±25%):

Cascades	1250 km margin	6400 km^3
Central America	1100	3800
NE Japan	1000	6000
Alaska Peninsula	1150	2000-3000
Andes SVZ	1400	5300

Hildreth (2007)

Outstanding Questions

- What happens to hydrated forearc mantle?
- What is the geochemical fingerprint of material derived from serpentinite in the mantle of the downgoing plate?
- What are fluid/melt pathways like in the slab & wedge? Porous vs. channelized flow? Diapirs?
- How do input & output fluxes of volatiles compare? Problem of intrusive magma flux.
- Why are the H_2O contents of mafic and silicic arc magmas similar?
- Are the relatively rare primitive basalts in arcs really parental to more voluminous intermediate to silicic magmas, or is H_2O-rich primitive andesitic magma common at depth but relatively uneruptible?