Christine Houser

Water, water everywhere, except the lower mantle
Water in the early solar system

Sean Raymond
Accretion leads to volatile depletion

S. Day, Geology Today, 2015
Accretion leads to volatile depletion

Y. Wang+, Icarus, 2018
Yet, the solar system is full of water
And others likely are too..

Unterborn+, Nat. Astronomy, 2018

TRAPPIST-1/Solar System Comparison
• Have natural samples.
• Have more experiments.
Need TZ topography and velocity to distinguish between temperature and water.
Combine TZ topography with shear velocity

TZ constrained by surface and lower-mantle body waves
Mapping Water Content

Topography & Velocity Pattern

Locations Consistent with Water

Only 105 out of 1300 bins (8%) are consistent with water.
Very few locations where grouping is greater than random

Case 8: - Vs, - 410, + 660

Houser, EPSL, 2016
What is ambient mantle?

red=slow, blue=fast

clear=average=???
Shear Velocity

Comparing Fit to PREM:
Perovskitite versus Harzburgite

Error

Discriminatory Power

Optimistic
At least 400 K temperature uncertainty in lower mantle
Today’s BEAMS:
The ambient lower mantle
Geochemistry argues for ancient-primordial reservoirs

LETTER

doi:10.1038/nature21023

Primordial helium entrained by the hottest mantle plumes

M. G. Jackson, J. G. Konter & T. W. Becker

Max $^{3}\text{He}/^{4}\text{He}$ (Ra)

- 25
- 15
- 5

δν (%) SNEAN2 at 200 km

Boschi-1 plume catalogue
Bridgmanite Enriched Ancient Mantle Structure
Bridgmanite Enriched
Ancient Mantle Structure

FOZO?

FOZO?
Let’s look at fluxes.
Need Low Temperature

Fig. 7. Phase relations for subducting serpentinite with an average mantle (Ito and Katsura, 1989) and hypothetical subducting P-T paths. Colored area shows hydrous minerals are stable. Numbers denote water contents in solid phase assemblages in the subducting slabs. Red lines are dehydration reactions, and thin black lines are fluid-absent solid–solid reactions. Thin broken line denotes the water-bearing reaction which does not occur in the subduction process. Note that free fluids generated by the dehydration reactions are assumed to escape from the system, such that no hydration reaction occurs in the slabs.
Aluminum increases water storage potential.

[Diagram showing phase relationships in the mantle under high pressure, with the stability field of aluminous phase H indicated.]
Slab temperature models

Top of Slab: basalt

Slab Moho: harzburgite

Pressure–temperature paths of the slab surface for all arc segments in each case, with
parameters. A comparison to slab surface
anomalously cool slab interiors in comparison to their thermal
distribution of maximum mantle wedge temperature is also sim-
the maximum mantle wedge temperature beneath the arc has
wedge temperature is a free parameter (D80, X25, and T550),
the smallest standard deviation for the X25 case, though the
maximum mantle wedge temperature beneath the arc has
range of maximum subarc wedge temperatures, as other geo-
physical and geochemical studies have suggested (Hacker, 2008
−
183 (2010) 73–90

Pressure–temperature paths to models of slab petrology. Slab surface tem-
perature of coldest part of the slab interior (E.M. Syracuse et al. / Physics of the Earth and Planetary Interiors
value, shows good corre-
Fig. 13.

While the temperature of the slab beneath the arc and

The amount of shear heating cannot be large given the constraints
considered in this work, so it is possible that slab temperatures
in the T550 case is consistent with other tests; the temperature is
well within the range of slab surface temperatures at the end of

4. Discussion

Peacock and Wang, 1999

56 and 240 km depth shows that this can also be used
temperature alone, and therefore does not follow a simple flow law. The

The temperature far below the coupling transition is also largely
independent of the coupling transition depth. At 240 km depth, all

temperature of the slab surface at shallower depths is con-

The equation:

where

is the depth of the slab at which temperature is calcu-

∼

R

However, subarc temperatures exceed 1200
◦C and a standard deviation of 157

The equation:

Pressure–temperature paths and symbols are shown in

While an element of temperature

measurements image a cold nose. While an element of temperature

occurs to 500

ies thus far have shown the cold nose being localized trenchward

However for Tonga, the coupling transition occurs beneath the back

in the Cascades to 129 km (4.2 GPa) in Tonga, with a mean of 72 km.

The equation:

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The equation:
Mantle rock, not crust, most likely to transport water past arc.

Data sources for oceanic subduction zone parameters were: age of subducting plate \cite{Lallemand2005}, length \cite{Jarrard2003}, plate dip \cite{Jarrard2003, Lallemand2005, Syracuse2006}, subduction erosion rate \cite{Clift2004}, and subduction velocity (intermediate value of \cite{Jarrard2003, Lallemand2005, Syracuse2006}), neglecting the eastern Sunda, Aegean, New Zealand, and smaller arcs because of incomplete data sets. This data set encompasses a global ocean floor subduction rate of $2.7 \text{ km}^2/\text{a}$.

Note that the division of the semicontinuous arc systems into arc segments (e.g., splitting South America into Colombia, Peru, N Chile, and S Chile subduction zones), although motivated by real along-strike differences, creates artificial subdivisions in the data set and calculation outcomes.

To calculate the postarc slab $H_2O$ content for individual subduction zones, the temperature at 4 GPa for each subduction zone of interest must be determined. To do so, thermal models calculated by P. van Keken (personal communication, 2007) for specific subduction zones were generalized to all subduction zones by using the slab thermal parameter of Kirby et al. \cite{Kirby1991}:

$$\text{slab thermal parameter} = \frac{\text{plate age}}{\text{slab descent rate}}$$

**Figure 7.** Variability in maximum $H_2O$ content for arc types in cold and hot slabs. Troctolite and peridotite are best suited to carry $H_2O$ in hot slabs. Clay-rich pelagic sediments carry the most $H_2O$ in cold slabs.

**Figure 8.** Amount of $H_2O$ subducted to depth scales with bulk rock $K_2O$.
Earth’s surface water loss to the interior

• Low end: Parai and Mukhopadhyay, EPSL, 2012: $\sim2\times10^{13}$ mol/yr $\rightarrow$ lose 25% of Earth surface water in 1 Gyr

• High end: Rupke+, EPSL, 2004: $\sim9\times10^{13}$ mol/yr $\rightarrow$ lose 100% in 1 Gyr
Other constraints: D/H ratio

• Find 3 scenarios to fit the current observations.

• Suggest observations to test the scenarios.

• On scenario requires regassing one ocean: sure, that’s easy.

A true ELSI collaboration
The Earth is not a sponge, but hydrogen can leak into the interior

- Cases where subduction does manage to shove water into its interior, the hydrogen is not stable at interior pressures and will likely return to the surface.

- If water (i.e. H) could be stored in the lower mantle rocks and if it was transported to the lower mantle efficiently, then we would have no ocean.
What if liquid water has little to do with water and everything to do with rock?

Rockability?
The conditions for which rock can develop and sustain feedbacks between the surface and the interior controls the state of water at the surface.
Using the Schulze+ 2018 results

Houser, EPSL, 2016