Geophysical Constraints on Incoming Plate Hydration

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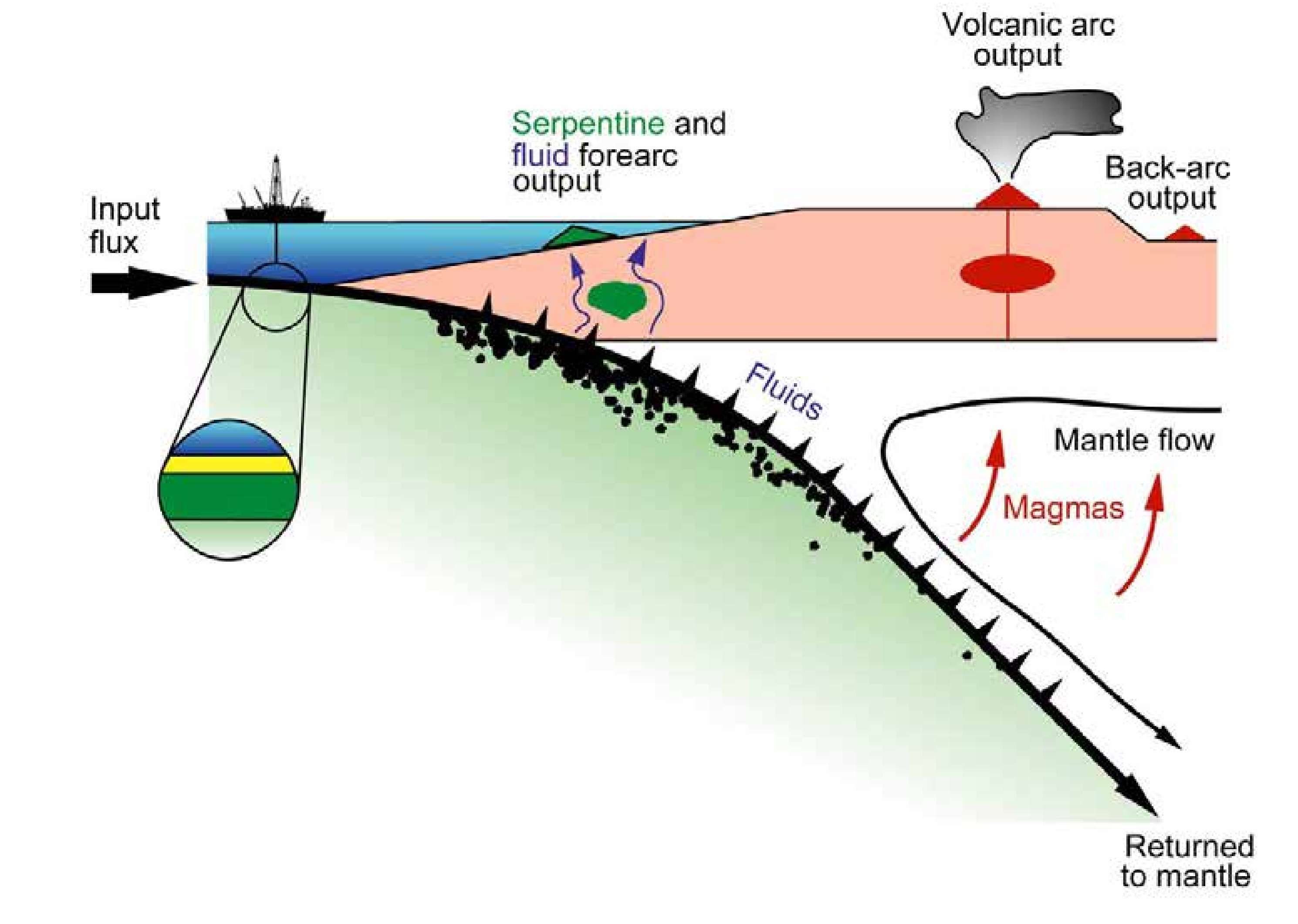
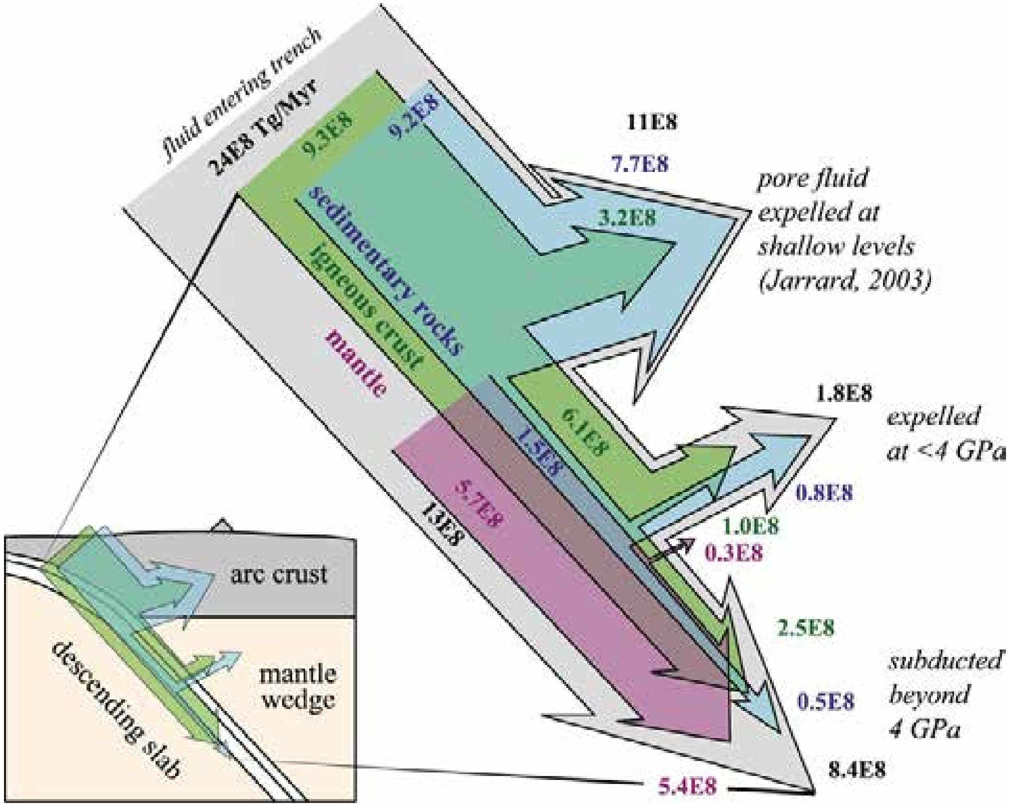
GeoPRISMS
Geodynamic Processes at Rifting and Subducting Margins

Subduction Cycles – the Incoming Plate



Subduction Input Water Budget



Bound water budget in 10^8 Tg/Myr
(*van Keken et al.*, 2011)

Input:

Sediment	0.7
Oceanic Crust	6.3
Upper mantle	3.0 ?

Output:

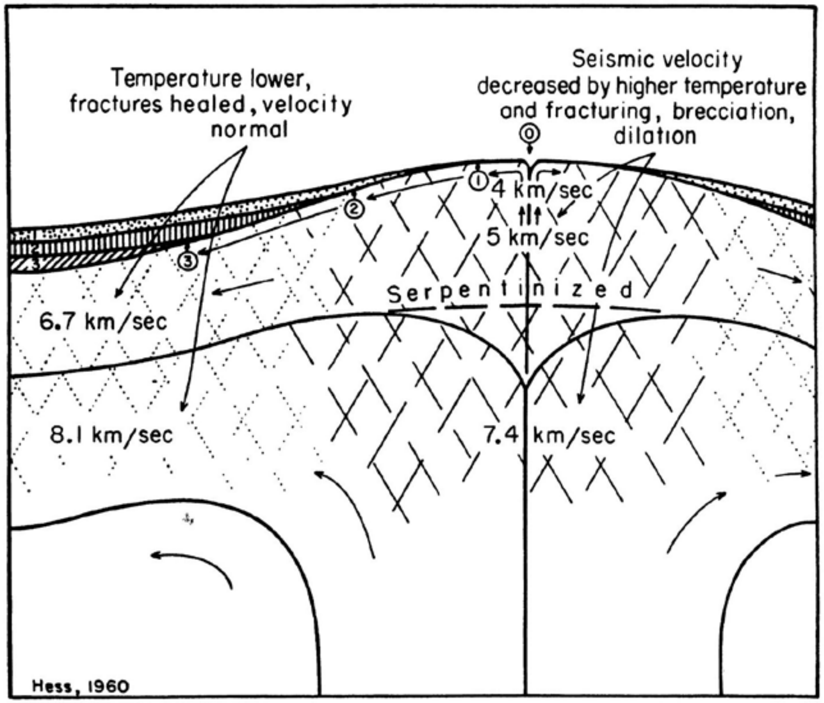
0-100 km depth	3.2
100-230 km	1.6 – 3.4
> 230 km	2.2 – 3.4

Hacker [2008]

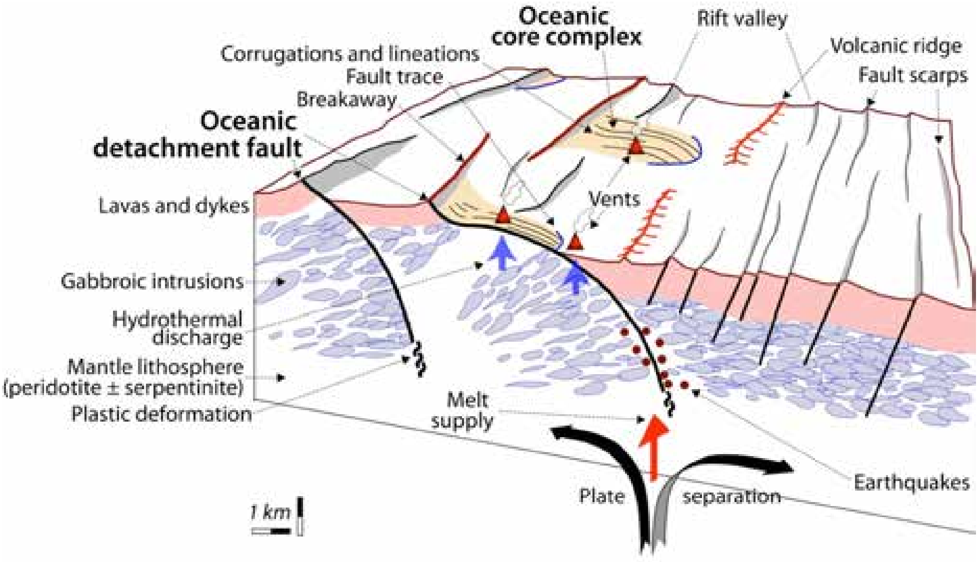
Water subducted beyond 100 km depth is highly dependent on unknown mantle hydration

How to hydrate the mantle: Mid ocean ridge processes?

“History of the Ocean Basins”
Hess (1962)

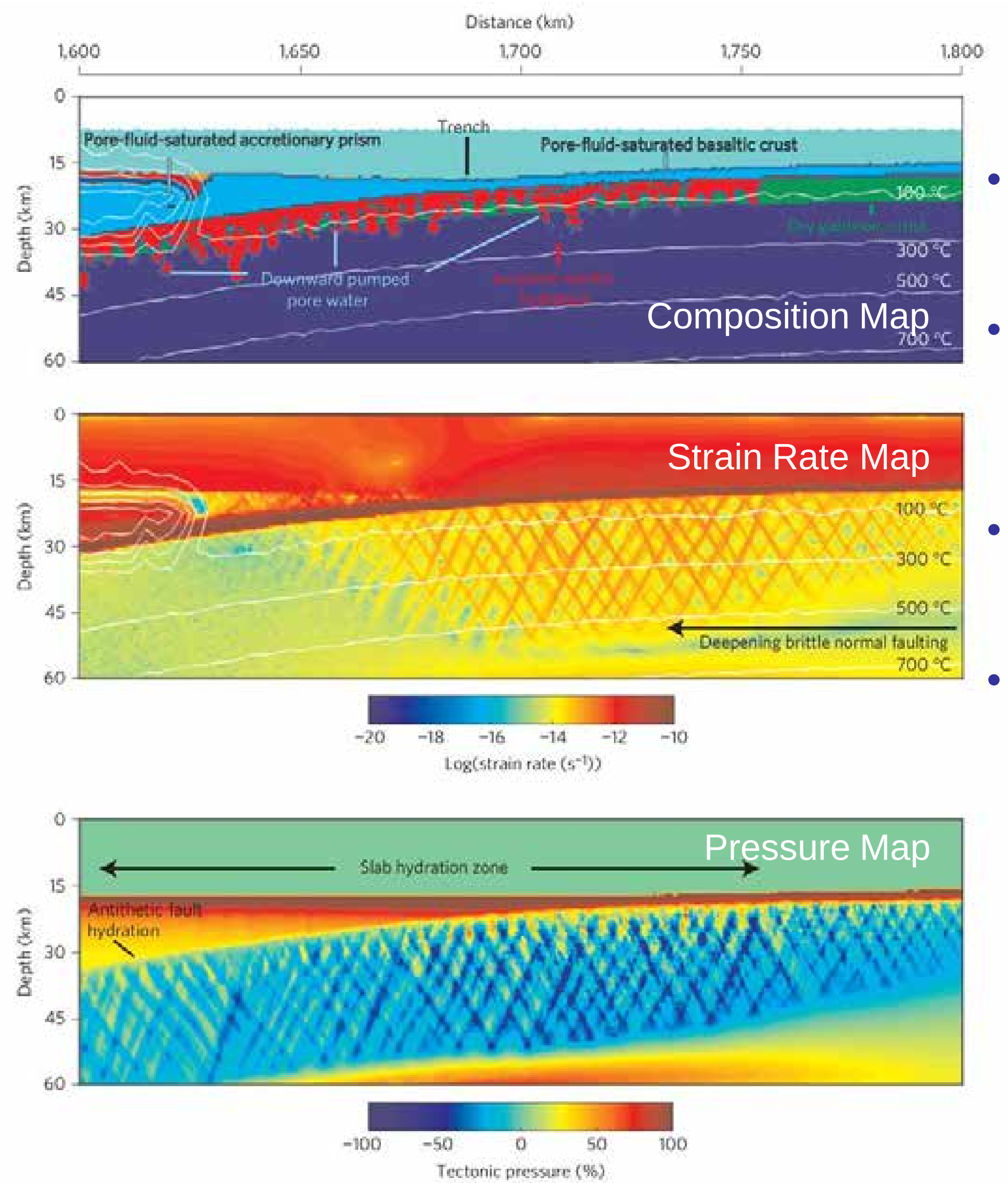


Serpentinization: Megamullion



- Serpentinization limited to tectonic features like “Megamullions” and transform faults
- Oceanic upper mantle is dry due to melt extraction at the MOR
- Seismic studies show high velocities (~ 8.1 km/s), so little serpenization

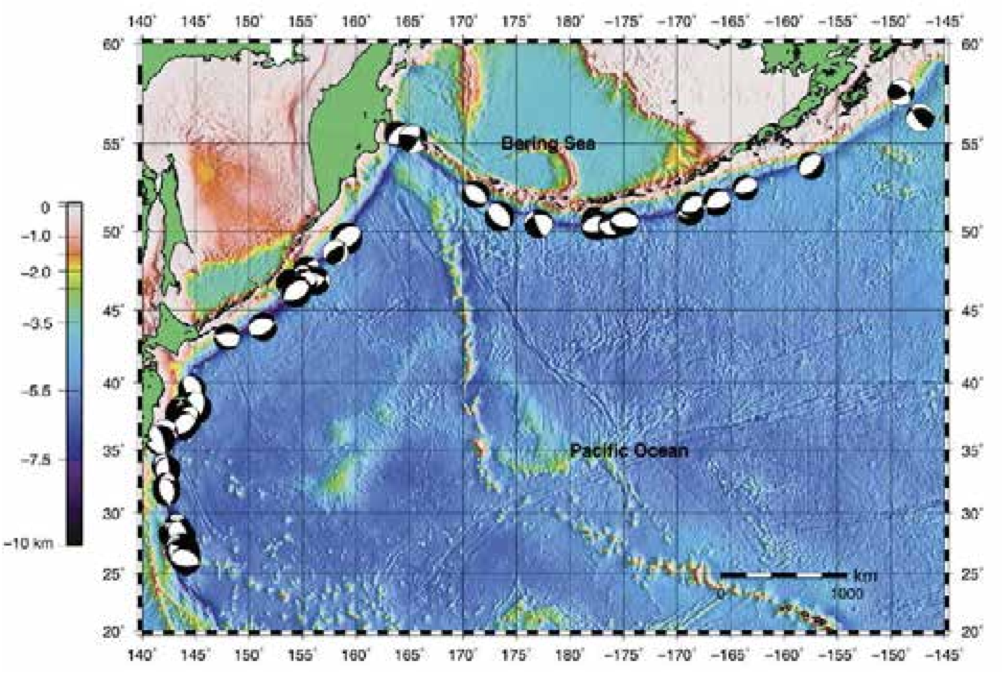
How to hydrate the mantle: bend faulting?

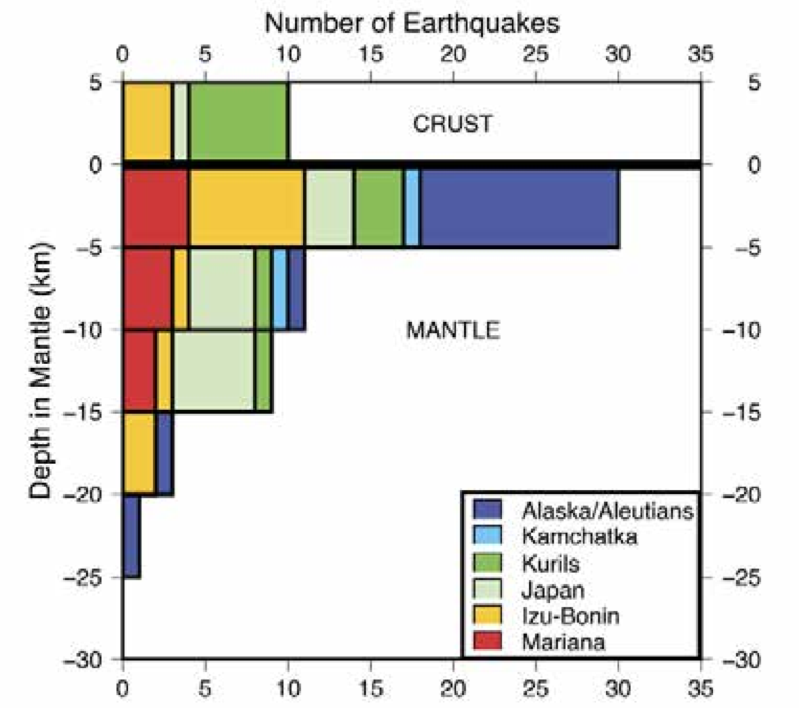


- Normal faults penetrate the mantle when the plate bends at trenches
- Modeling suggests that pressure gradients from the bending stresses will drive fluids downward
- Ocean water will react with fresh mantle peridotite to produce serpentine minerals
- Water will be transported away from faults into the surrounding rock by existing porosity and cracks

2-D thermomechanical map
by *Faccenda et al.* [2009]

Potential Importance of Incoming Plate Faulting



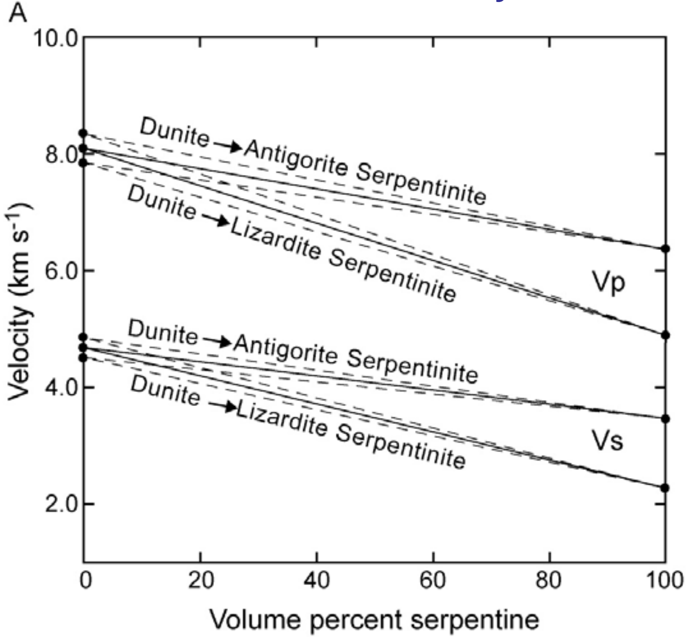


- Incoming plate normal faulting earthquakes are numerous in all subduction zones
- They are concentrated in the upper 10 km of the subducting mantle
- 2 wt % water in the upper 5 km and none below multiplies global input by factor of 2
- 3 % water in the upper 5 km & 1% water 5-15 km multiplies global input by factor of 4

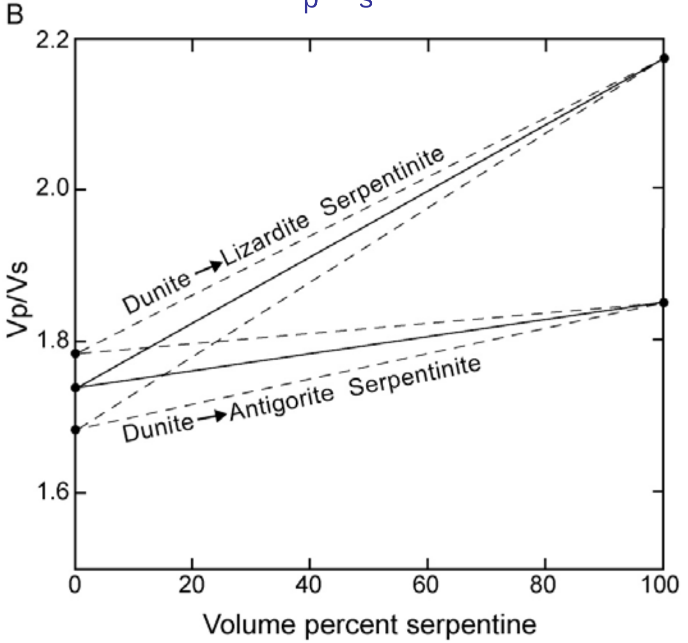
Emry & Wiens [2015]

Seismic Detection of Mantle Serpentinite

P and S velocity



V_p/V_s ratio



Christensen [2004]

- Serpentinization drastically reduces seismic velocity and raises V_p/V_s
- All three serpentine minerals contain 13 wt % water
- Lizardite/Chrysotile reduces velocity much more than Antigorite
- Water can be calculated from w(%) = -0.31 (ΔV_p %)

Upper Mantle Serpentinization: Central America

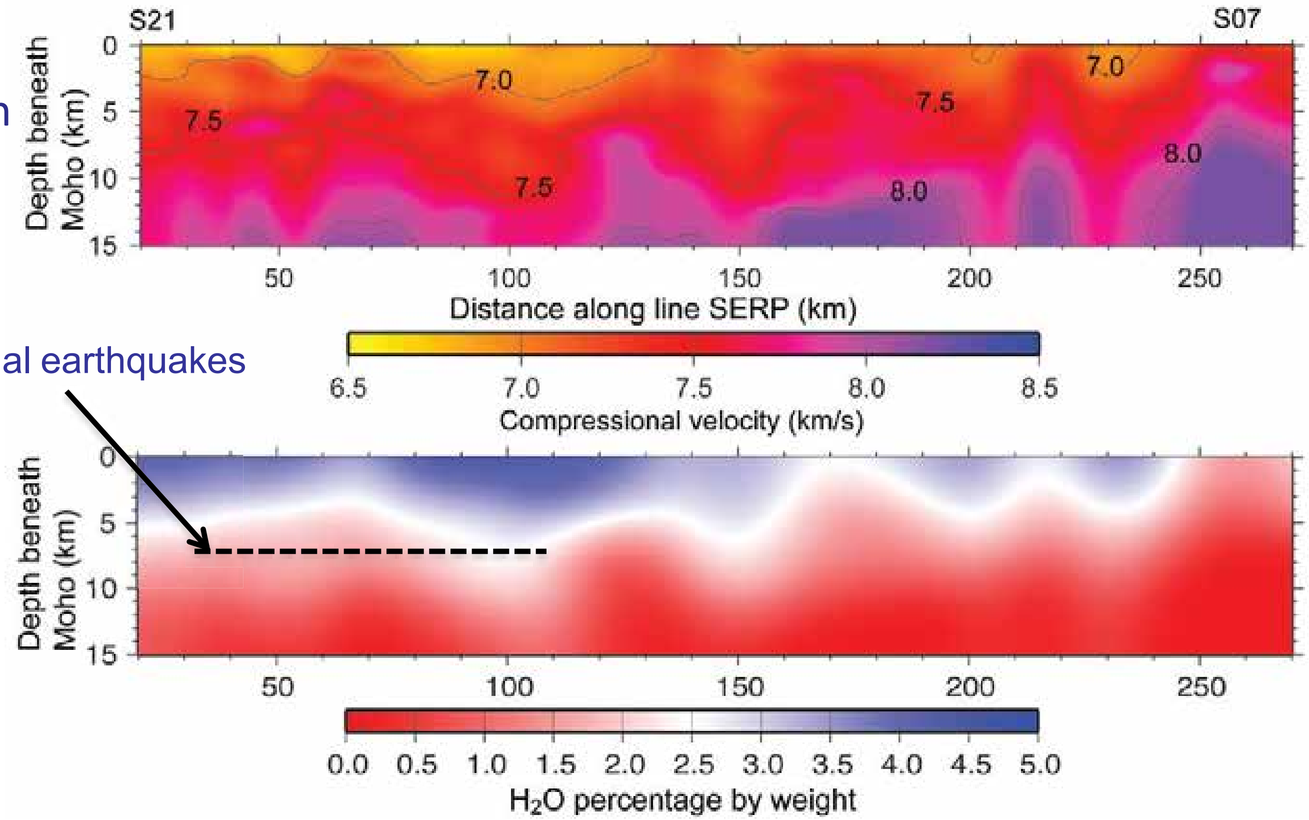
Seismic section of the subducting mantle parallel to the trench

Nicaragua Costa Rica

Sub-Moho seismic velocity in subducting Cocos plate

Maximum depth of extensional earthquakes
Lefeldt et al. [2009]

H2O distributed in mantle

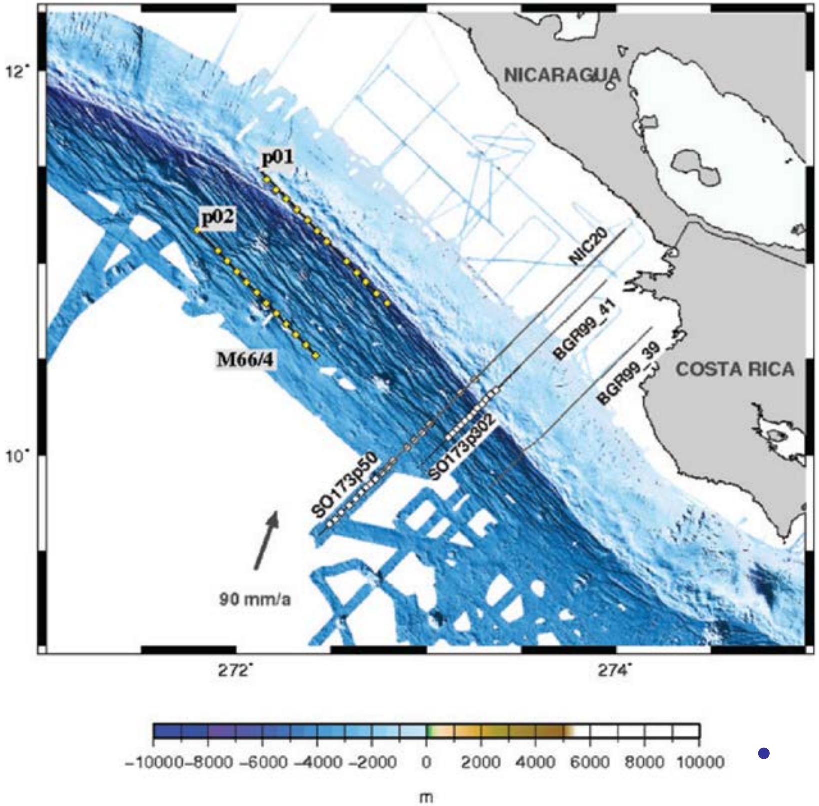


- Low velocities show strong serpentinization of the Nicaragua mantle
- Serpentinization is bounded by the maximum depth of extensional earthquakes
- Estimate 3-4 wt % water in the upper 5 km of the subducting mantle
- Serpeninization is stronger in Nicaragua, where there is extensive faulting

van Avendonk et al. [2011]

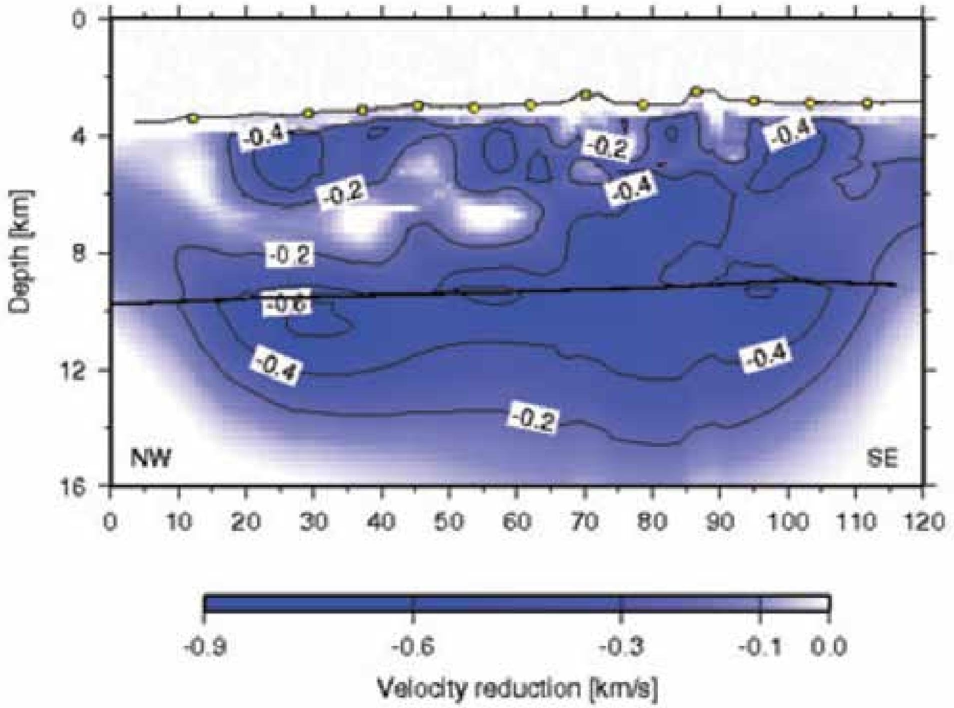
Velocity changes with bending

Location of Lines



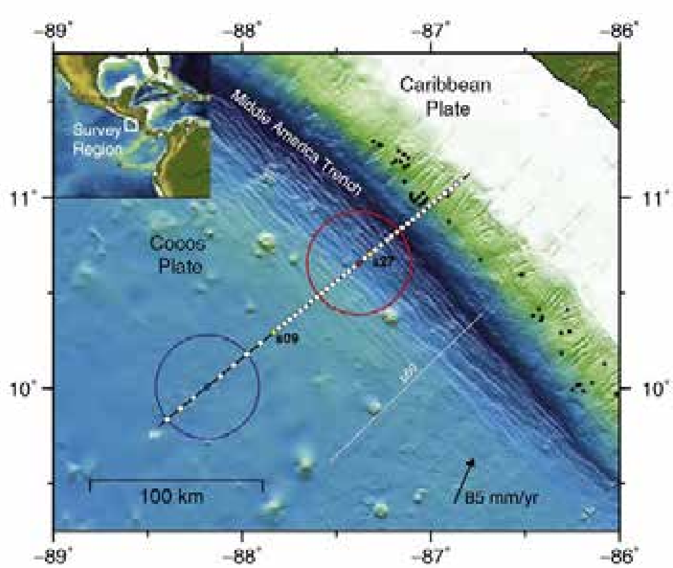
Ivandic et al. [2010]

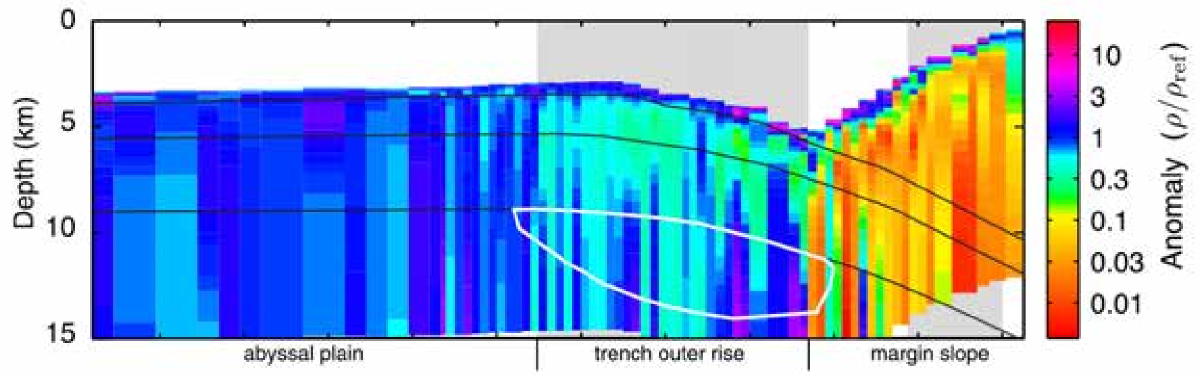
Velocity difference between lines



- Low velocities can result from anisotropy or mis-identification of the moho
- This study shows that mantle velocities are reduced by up to 600 m/s between outer rise and trench
- The remaining question is whether all the velocity reduction results from serpentinization or is some due to water-filled cracks?
- Depth extent not well constrained

Electromagentic imaging of high porosity channels

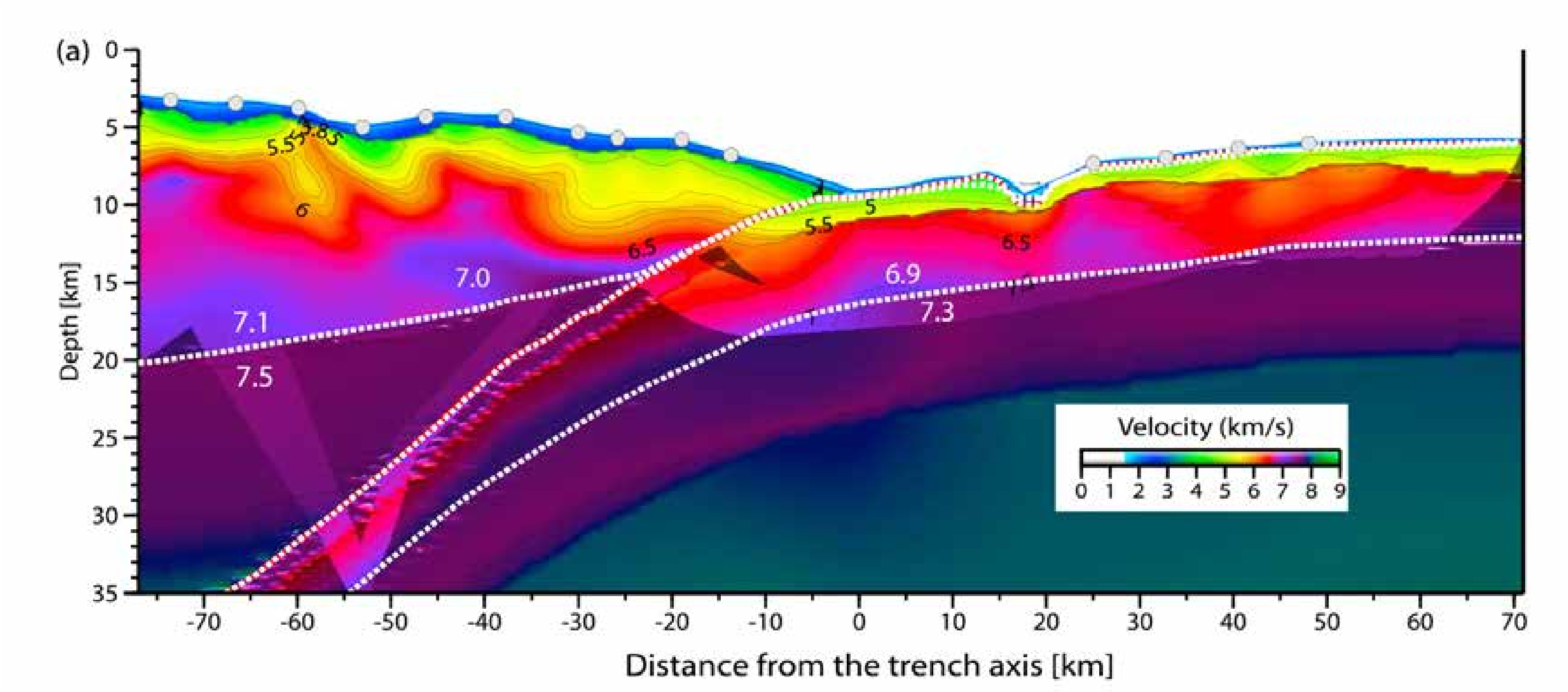




Key et al. [2012]

- Controlled Source EM images low resistivity regions in crust and upper 5 km of mantle associated with plate bending
- Low resistivity indicates high water porosity along faults extending into the mantle

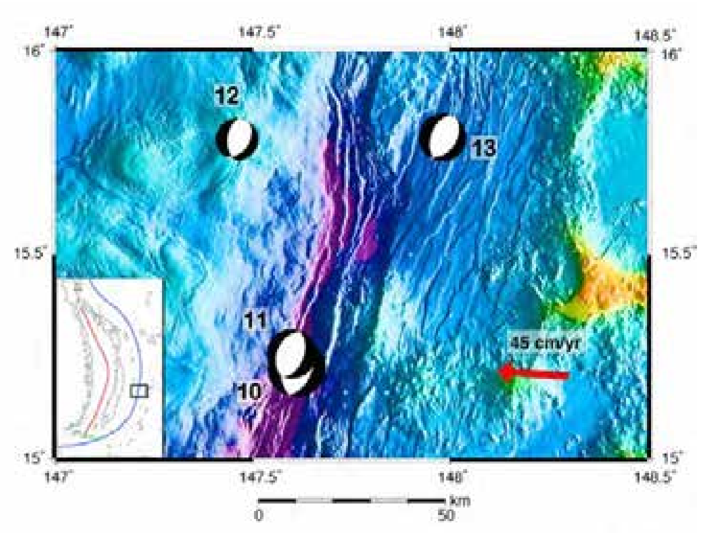
Another example: Tonga

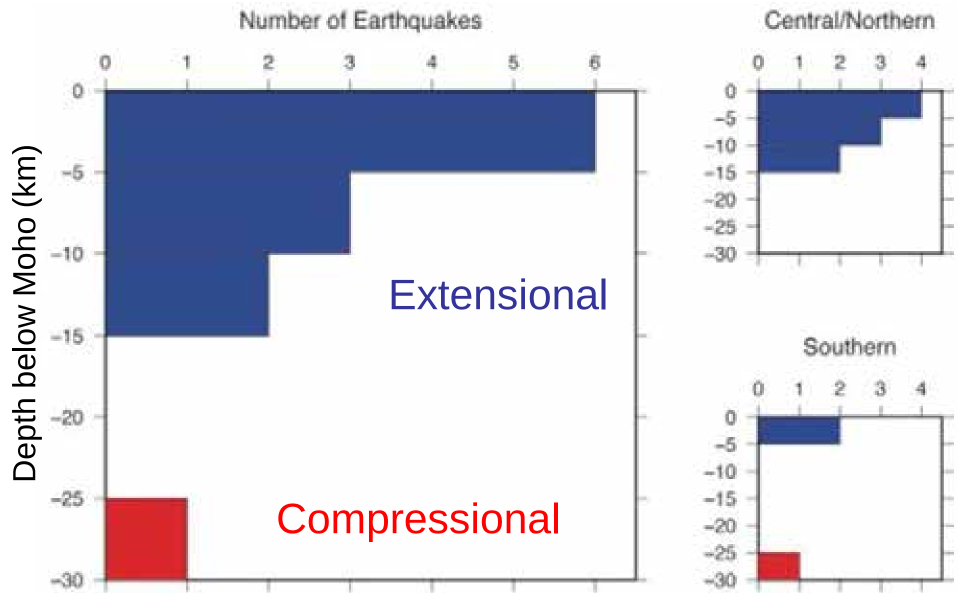


Contreras-Reyes et al. [2011]

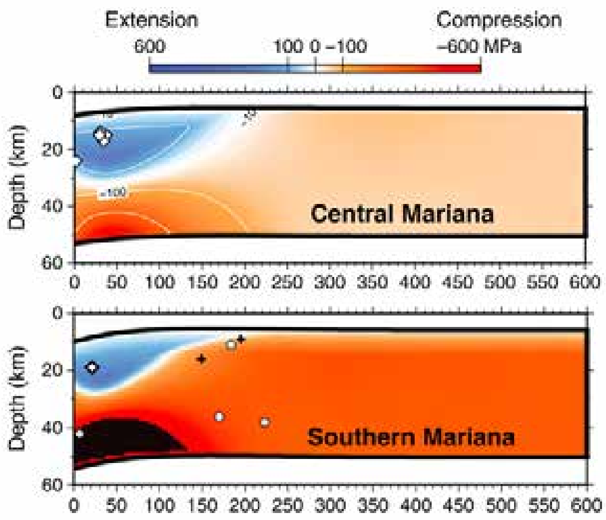
- Active source seismic transect of Tonga trench
- Shows low uppermost mantle Vp of 7.3 km/s
- Consistent with 30% mantle serpentinization, or 3-4% water
- Low mantle velocities near the trench also found in Alaska, Chile, Kuriles

Plate-bending faults and serpentinization of the Mariana incoming plate





Finite Difference Flexure Models

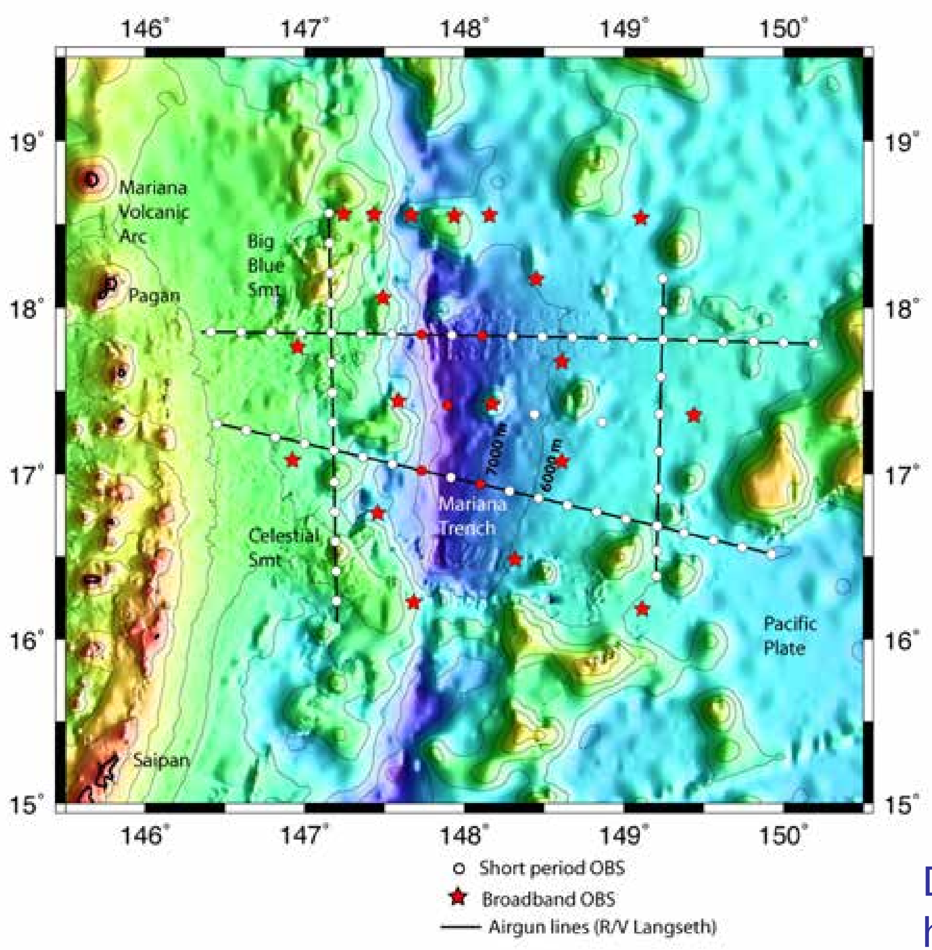


- Tensional earthquakes occur down to the upper 15 km of the mantle
- Do tensional earthquake depths control the depth of mantle serpentinization?
- Does depth of faulting cause along strike changes in subducted water?

Emry et al., [2014]
Depths and mechanisms from waveform inversion

2012-2013 Mariana Trench Experiment

Investigate slab and forearc serpentinization



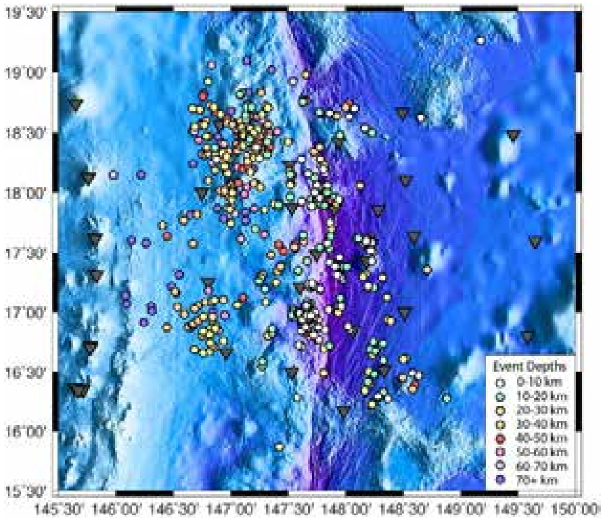
20 broadband, 60 short period, and 5 tethered hydrophones

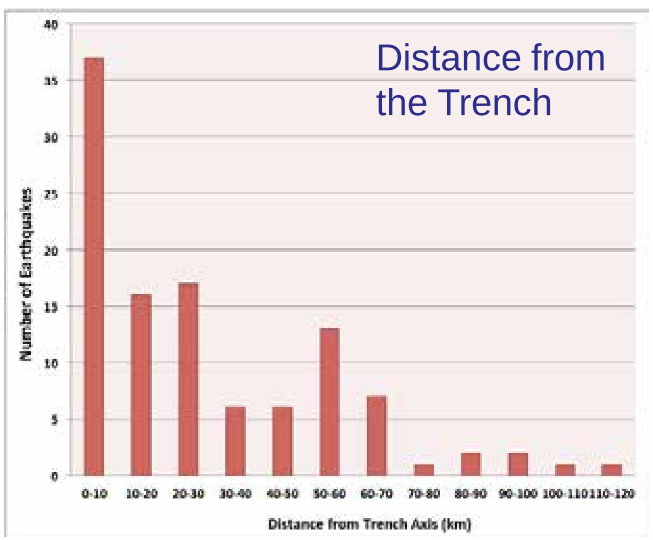
R/V *Langseth*

Deploying moored hydrophones near the Mariana Trench axis

Preliminary Results from the Mariana Trench

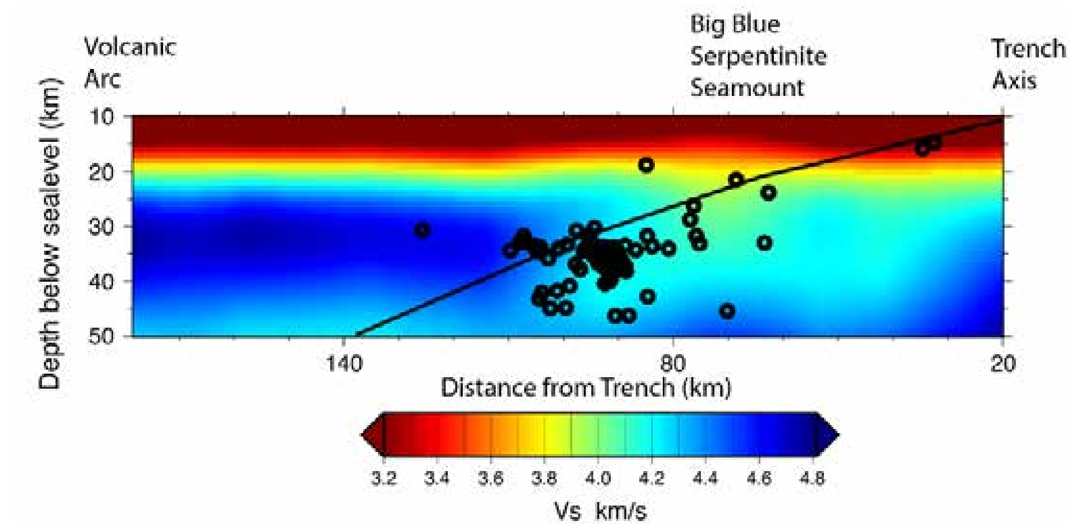
Earthquake Locations





From work by Melody Eimer and Hope Jasperson

V_S Structure from Ambient Noise

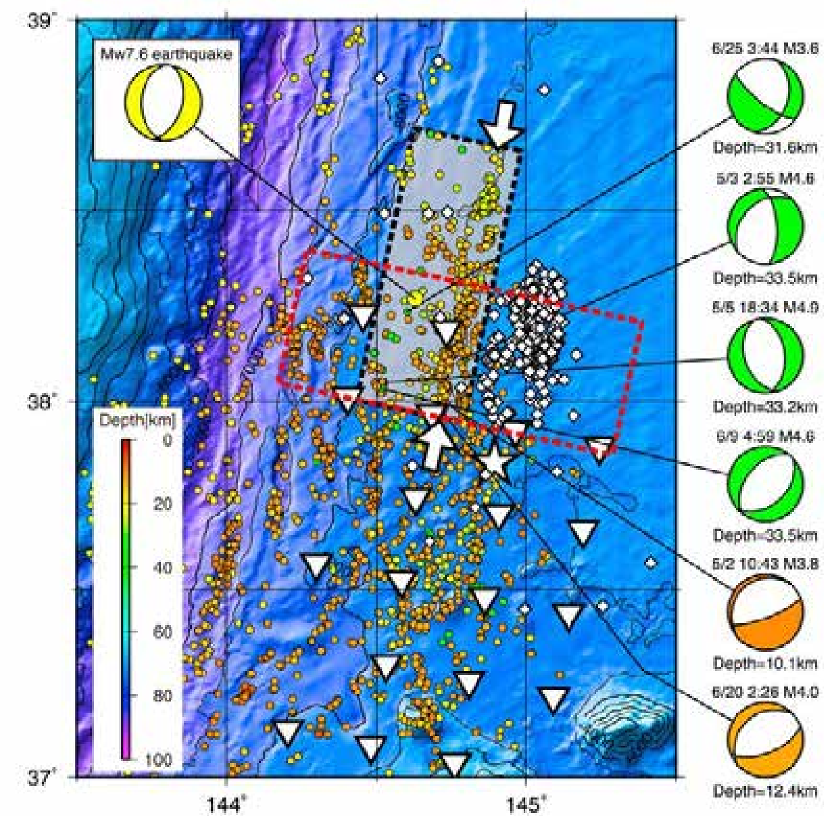


Cai et al., AGU poster, 2015

- Incoming plate earthquakes in upper 25 km
- Concentrated within 30 km of the trench
- Ambient noise correlation should allow deeper resolution and provide V_s for V_p/V_s ratio
- V_S structure shows slow velocities (4.0-4.1 km/s) up to 15 km below subducting moho

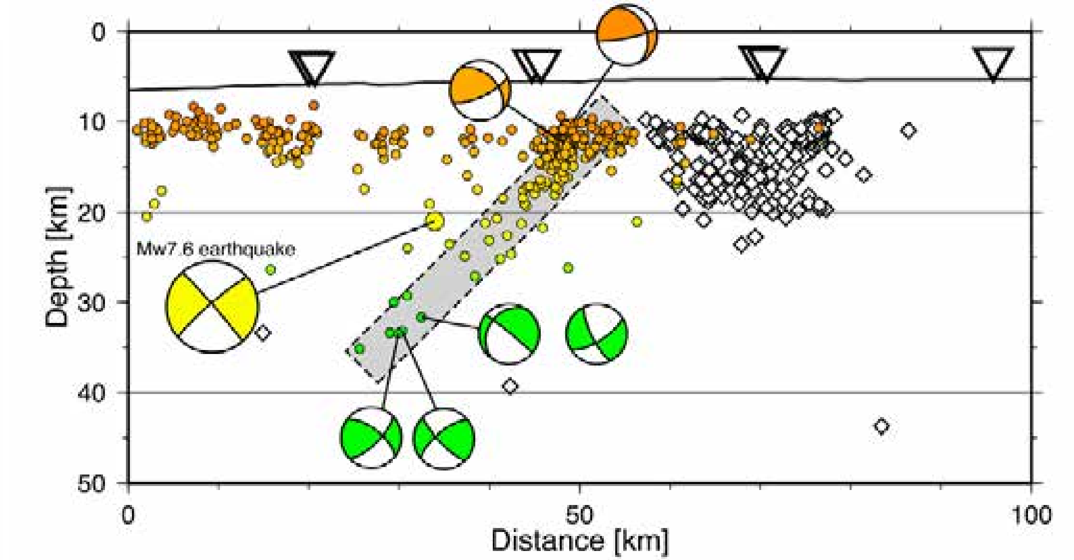
Temporal variation in faulting depth?

Incoming plate faulting triggered by 2011 Tohoku M_w 9.0 event



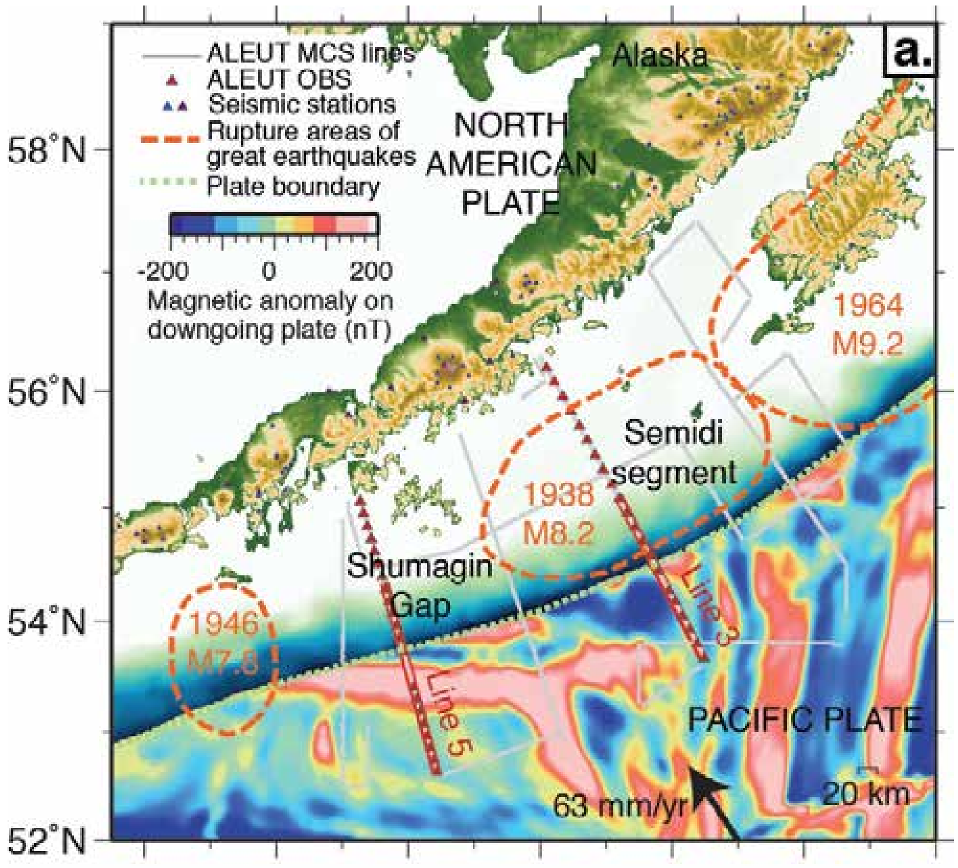
Obana et al [2012]

Depths of Extensional events from OBSs



- Maximum depth of extensional earthquakes prior to the 2011 event was ~ 20 km
- Extensional events are now found to ~ 40 km depth
- The 2011 event increased tensional stresses and deepened the neutral plane
- Which depth limits possible serpentinization?
- Is there more hydration at “coupled” trenches?
- *Lefeldt et al*]2012] suggested serpentinization is limited by depth of extensional microearthquakes and not larger events

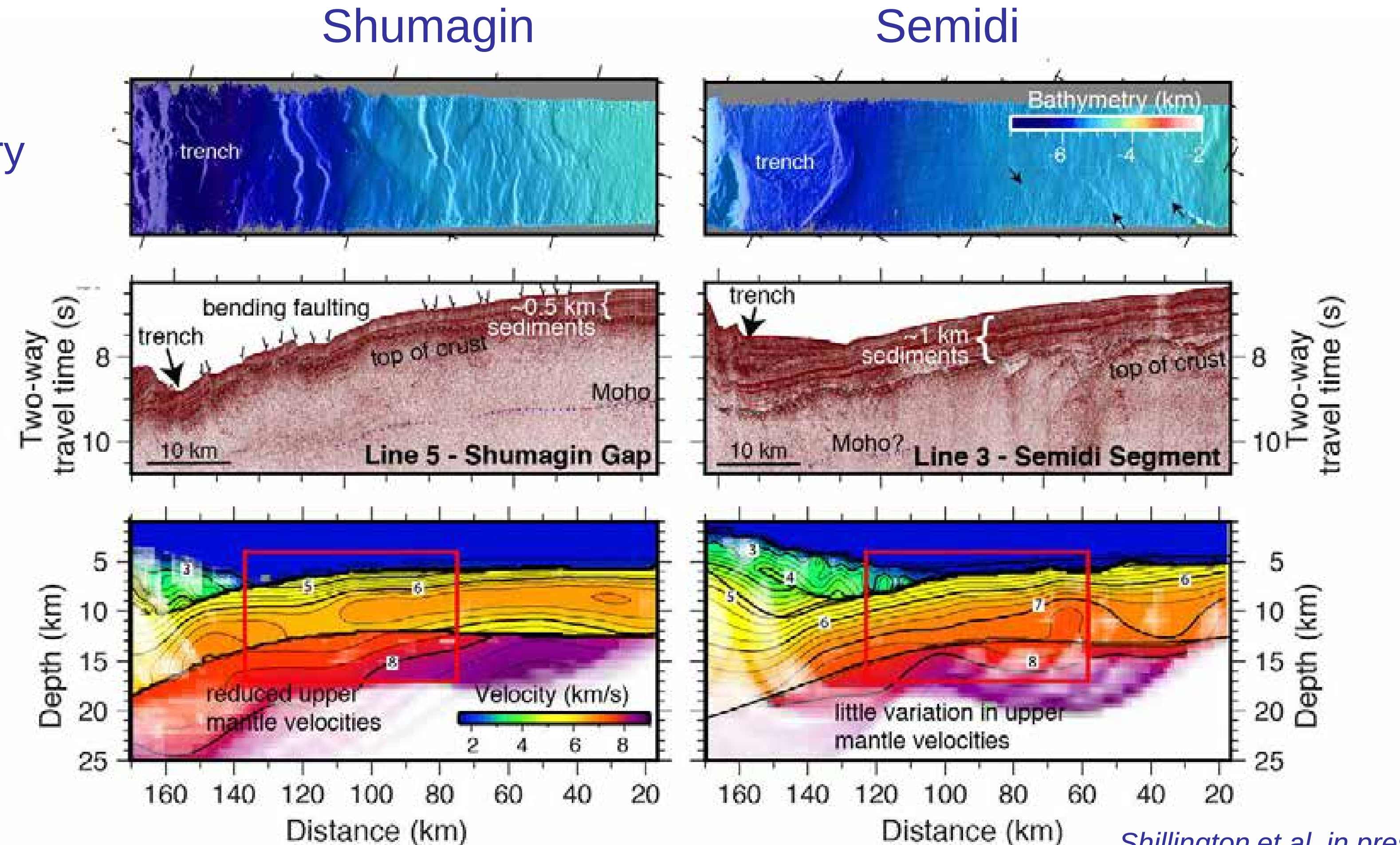
Along-strike variation in water input?



Shillington et al, in press

- Contrasting segments of the Alaska trench
- Semidi segment is locked, Shumagin segment is slipping
- Semidi segment has megathrust earthquakes; Shumagin may have no large events
- Seafloor fabric is nearly parallel to the trench in Shumagin, but highly oblique in Semidi
- Much more incoming plate, thrust zone, and intermediate depth seismicity in Shumagin

Contrast between adjacent segments



Shillington et al, in press

- Much larger velocity reduction (and thus Serpentinization) observed in Shumagin, consistent with more faulting
- Water content of the slab is highly variable along strike
- No apparent connection with megathrust activity; faulting and fabric are key?
- May have great effects on deeper arc and slab processes

Conclusions

- **The amount of water subducted into the mantle is poorly known due to the lack of constraints on water in the incoming plate mantle.**
- **The oceanic mantle is likely serpentinized at the plate bending region and trench (not "outer rise"). Different estimates can vary the amount of subducted water by factors of 3.**
- **Seismic studies show low mantle seismic velocities at several trenches, with corresponding estimates of 20-30% serpentinization and 3-4 wt % bound water.**
- **Key questions include how much velocity reduction comes from water filled cracks, as well as the depth extent of the serpentinization**
- **Serpentinization seems highly variable along strike and may be partially controlled by the incoming plate fabric**