# A closer look at the relationship between slab (un)bending and double seismic zone seismicity

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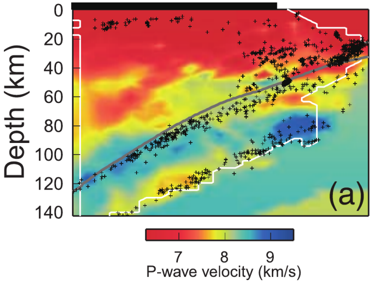
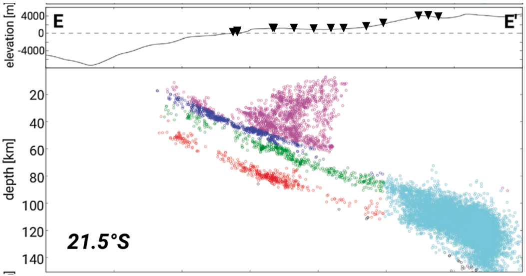
## What are Double Seismic Zones?




Tsuji et al., 2008:
Honshu, Japan

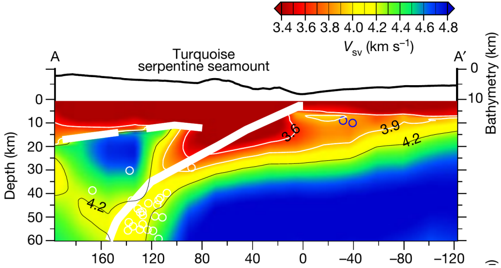



Sippl et al., 2018:
Northern Chile

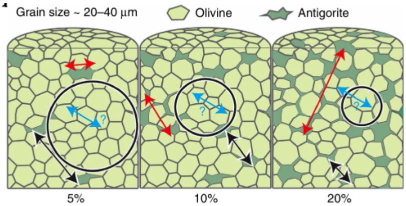
### Double Seismic Zones

- Arrangements of two parallel planes of earthquake hypocenters along slab dip
- Observed at intermediate depths (50-300 km) in many subduction zones
- Spacing between two planes is variable (usually 15-35 km) and apparently temperature-dependent (colder slab → larger spacing)

## How are they created?



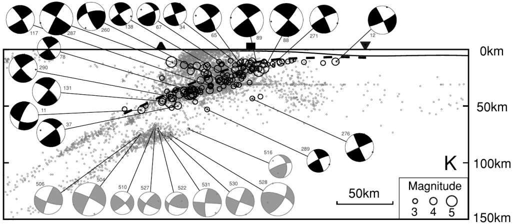

Cai et al., 2018 (Marianas)



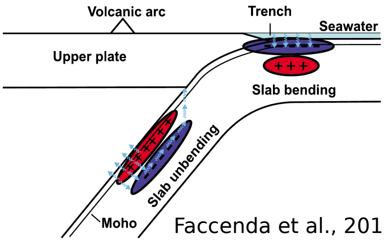

Ferrand et al., 2017

- Oceanic plates get hydrated at MORs, fracture zones, hotspot tracks and (most importantly) at the outer rise; Figure: reduced S-wavespeeds show plate hydration down to ca. 25 km at Marianas outer rise
- Dehydration of hydrous mineral phases at elevated p-T conditions is responsible for intermediate-depth earthquakes
- Physical mechanism is unclear; candidates include dehydration embrittlement, thermal runaway, dehydration-driven stress transfer (Figure)
- Lower plane seismicity likely due to antigorite dehydration (in mantle lithosphere); upper plane may be lawsonite or brucite dehydration (oceanic crust or uppermost mantle)

## Stress field observations




Gamage et al., 2009

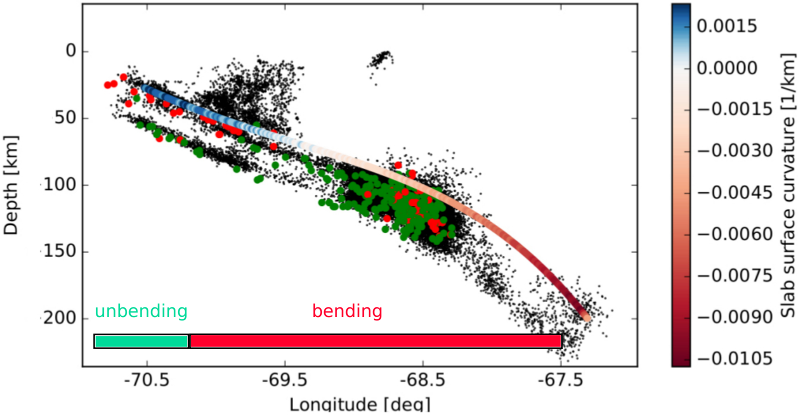



Faccenda et al., 2012

### DSZ and plate unbending

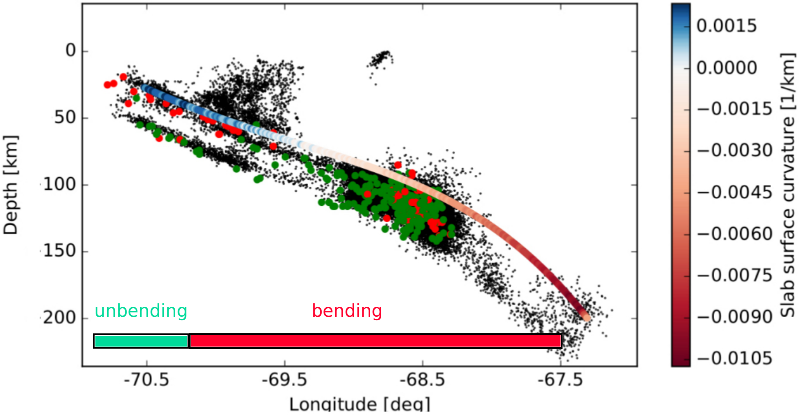
- Observations: most DSZs (e.g. left image) show downdip compressive earthquakes in upper and downdip extensive earthquakes in lower plane
- This is opposite to the bending signature in the outer rise region and hints at plate unbending
- Some models link DSZ occurrence to plate unbending; e.g. Faccenda et al. (2012) propose that plate unbending could be responsible for deep hydration of the slab

## Comparing slab geometry to focal mechanisms



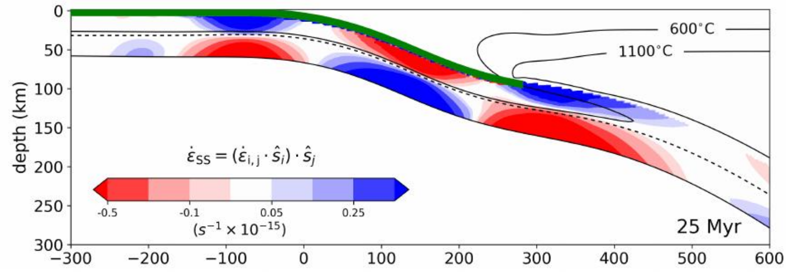

- Earthquake mechanisms (from Sippl et al., 2019): green = downdip extensive; red = downdip compressive
- Observation: dominance of downdip extension everywhere except in upper plane under plate interface

## Comparing slab geometry to focal mechanisms




- Colored line: slab curvature determined from slab surface model of Sippl et al. (2018)
- Bending and unbending are derived from downdip gradient of plate surface curvature; assumption: geometrical steady state (= slab geometry does not change with time)

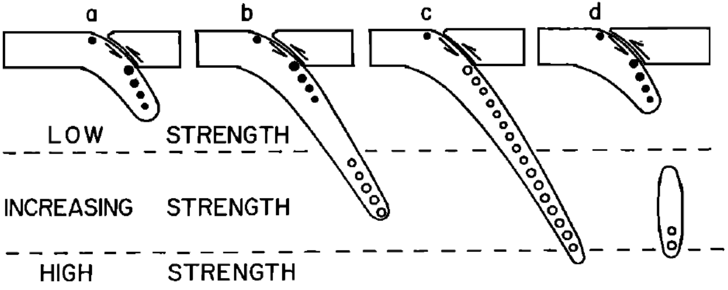
## Meaning?




*Sandiford et al., 2019*

- N Chile DSZ mechanisms do not show unbending signature (other examples for this in literature: New Zealand, Ryukyu, Central Chile)
- Theoretical stress field: sign change should occur when slab geometry changes from bending to unbending or vice versa (Figure)
- Observations in N Chile do not show this (e.g. lower plane is downdip extensive everywhere)
- Possible reasons: Ongoing slab geometry change; influence of volume reduction in dehydration reactions,???

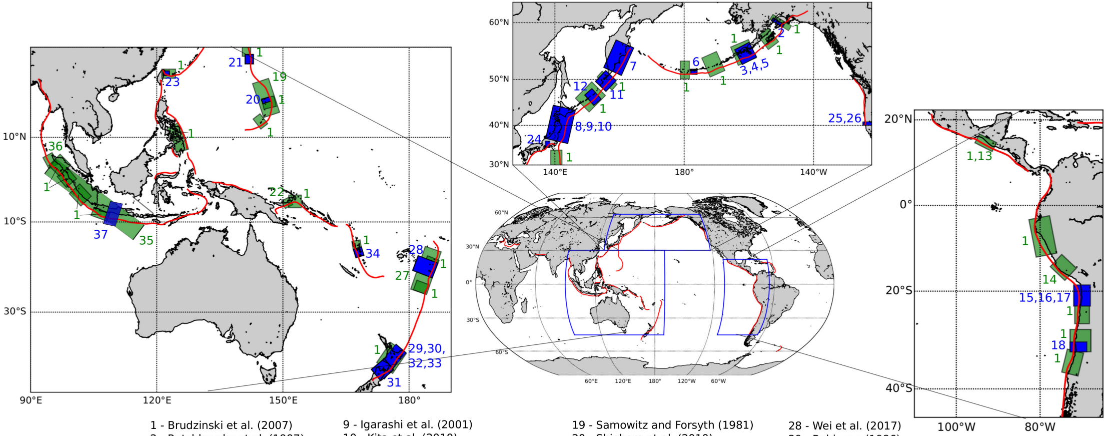
## Additional player: Transition zone processes




*Isacks and Molnar, 1971*

- Stress transfer from mantle transition zone to shallower slab is another possible influence
- Slabs that are deflected at or impinging onto 660 tend to be compressive, if they have penetrated it or not reached it yet more extensive
- Nazca slab in N Chile apparently penetrates through 660 and flattens in the lower mantle
- Single case (N Chile) is maybe insufficient to disentangle the relationships between DSZ occurrence, intraslab stress field, slab geometry and transition zone processes; global study is needed (Work in progress!!)

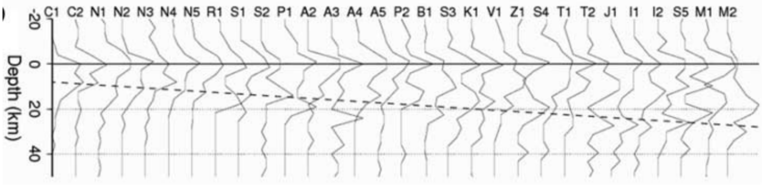
## DSZ locations (blue - from local seismic data; green - from teleseismic data)




1 - Brudzinski et al. (2007)
2 - Ratchkovsky et al. (1997)
3 - Reyners and Coles (1982)
4 - Hudnut and Taber (1987)
5 - Abers (1992)
6 - Engdahl and Scholz (1977)
7 - Gorbatov et al. (1994)
8 - Hasegawa et al. (1978)
9 - Igarashi et al. (2001)
10 - Kita et al. (2010)
11, 12 - Kuo and Chen (1995)
13 - Zhang et al. (2019)
14 - Isacks and Barazangi (1977)
15 - Comte et al. (1999)
16 - Sippl et al. (2018)
17 - Rietbrock and Waldhauser (2004)
18 - Marot et al. (2013)
19 - Samowitz and Forsyth (1981)
20 - Shiobara et al. (2010)
21 - Nakata et al. (2019)
22 - McGuire and Wiens (1995)
23 - Kao and Rau (1999)
24 - Seno et al. (2001)
25 - Smith et al. (1993)
26 - Wang and Rogers (1994)
27 - Kawakatsu (1985)
28 - Wei et al. (2017)
29 - Robinson (1986)
30, 31 - McGinty et sl. (2000)
32 - Reyners et al. (2011)
33 - Evanzia et al. (2019)
34 - Prevot et al. (1994)
35 - Slancova et al. (2000)
36 - Qin and Singh (2015)
37 - Koulakov et al. (2007)

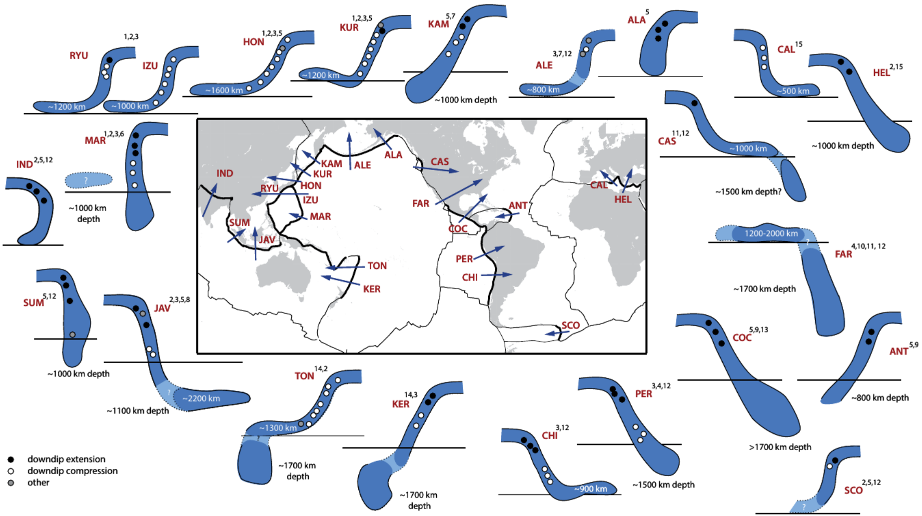
## Literature-derived datasets

- DSZ locations (previous page), with parameters like depth extent, plane separation, etc., are harvested from literature
- Information on focal mechanisms for upper/lower plane and slab structure in the transition zone (next page), is likewise compiled
- Goal: global correlation of DSZ occurrence and stress fields with slab shape-derived bending or unbending areas



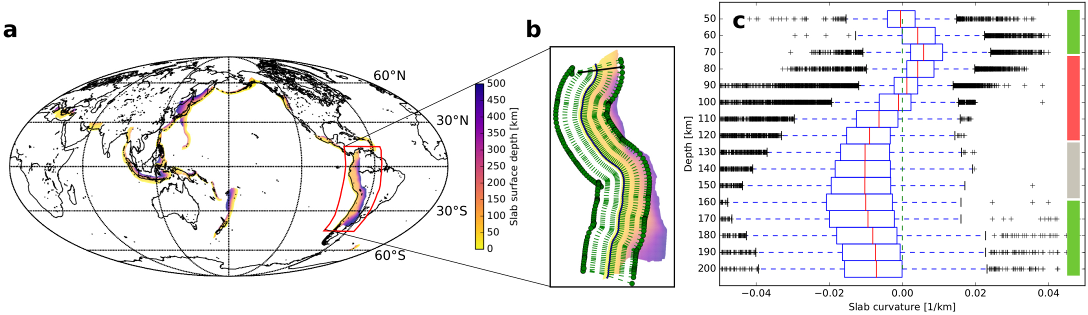

*DSZ interplane separations according to Brudzinski et al. (2007)*

## Slabs in the transition zone




*Goes et al., 2017*

## Slab geometries from slab2

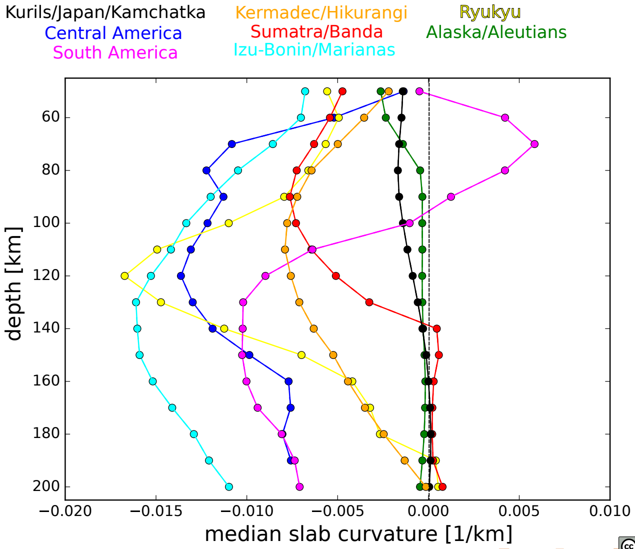



### Slab surface curvature from slab2

- a slab2 (Hayes et al., 2018): Slab surface grids with 0.05° lateral resolution
- b Approach: profiles every 50 km taken perpendicular to the 20 km isodepth contour; compute curvature as (smoothed) downdip gradient of slab dip (similar to Buffet and Heuret, 2011)
- c Analyze resulting profiles in depth bins; positive corresponds to upward curvature; depth ranges of unbending (green) and bending (red) are marked

## First (very) preliminary global results

- Shown: median slab curvature vs. depth for 8 major slabs
- Big variety of curvature evolution between different slabs



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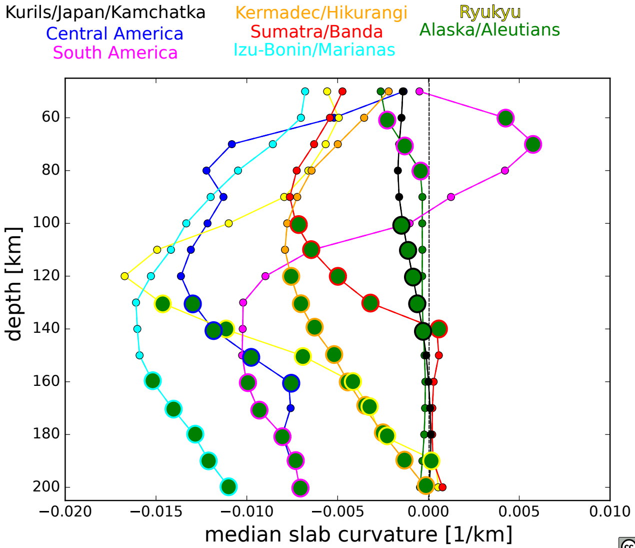
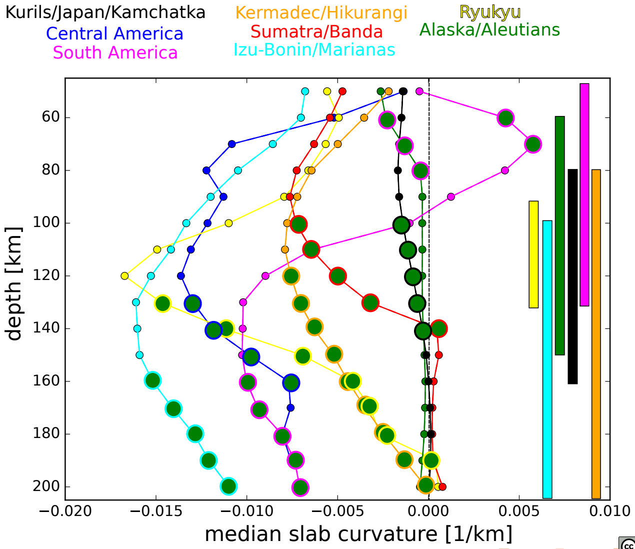
- Green disks: regions of slab unbending (downward curvature decrease)



## First (very) preliminary global results

- Shown: median slab curvature vs. depth for 8 major slabs
- Big variety of curvature evolution between different slabs
- Green disks: regions of slab unbending (downward curvature decrease)
- Bars: approximate depth extent of DSZ seismicity in these subduction zones



Conclusions:

- Variety of slab shapes is larger than expected; often no simple progression from bending at the trench to unbending deeper down, but more complex
- Depth extent of DSZ seismicity fits to unbending depths only at some subduction zones; this has to be investigated in more detail though

Next steps:

1. Focused analysis of areas with/without DSZ (not just medians for entire slabs)
2. Bring DSZ earthquake focal mechanisms into the game (do they correspond to bending/unbending stress fields expected from slab geometry?
3. Formal correlation between (un)bending stresses and DSZ occurrence
4. Investigate importance of transition zone processes (modeling?)

## Too many, I know...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