Deep Earthquakes and their surrounding structure as inferred from regional seismic waves

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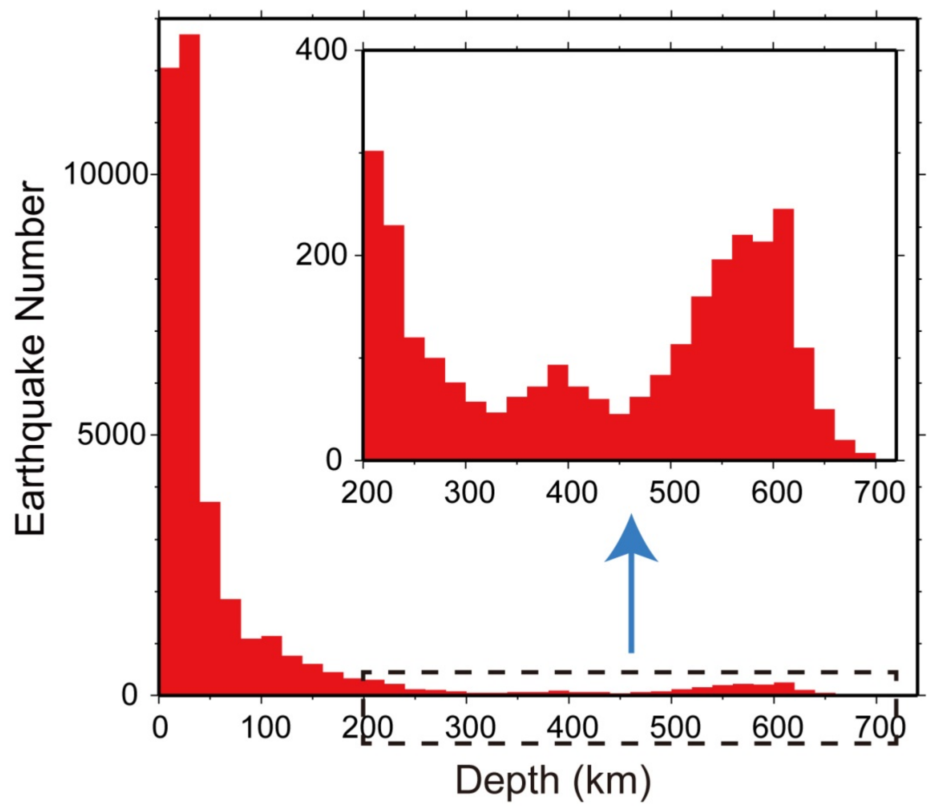
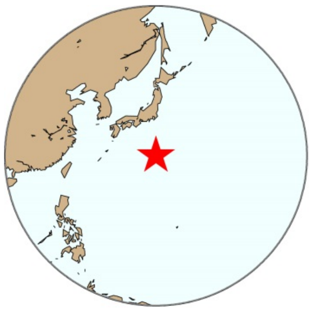
Deep earthquakes

- ✓ The physical mechanism remains controversial.
- ✓ One of the properties to be explained by candidate mechanisms is the termination of deep earthquakes at depth around 700 km.
- ✓ Near the depth, there exists the 660 km discontinuity.



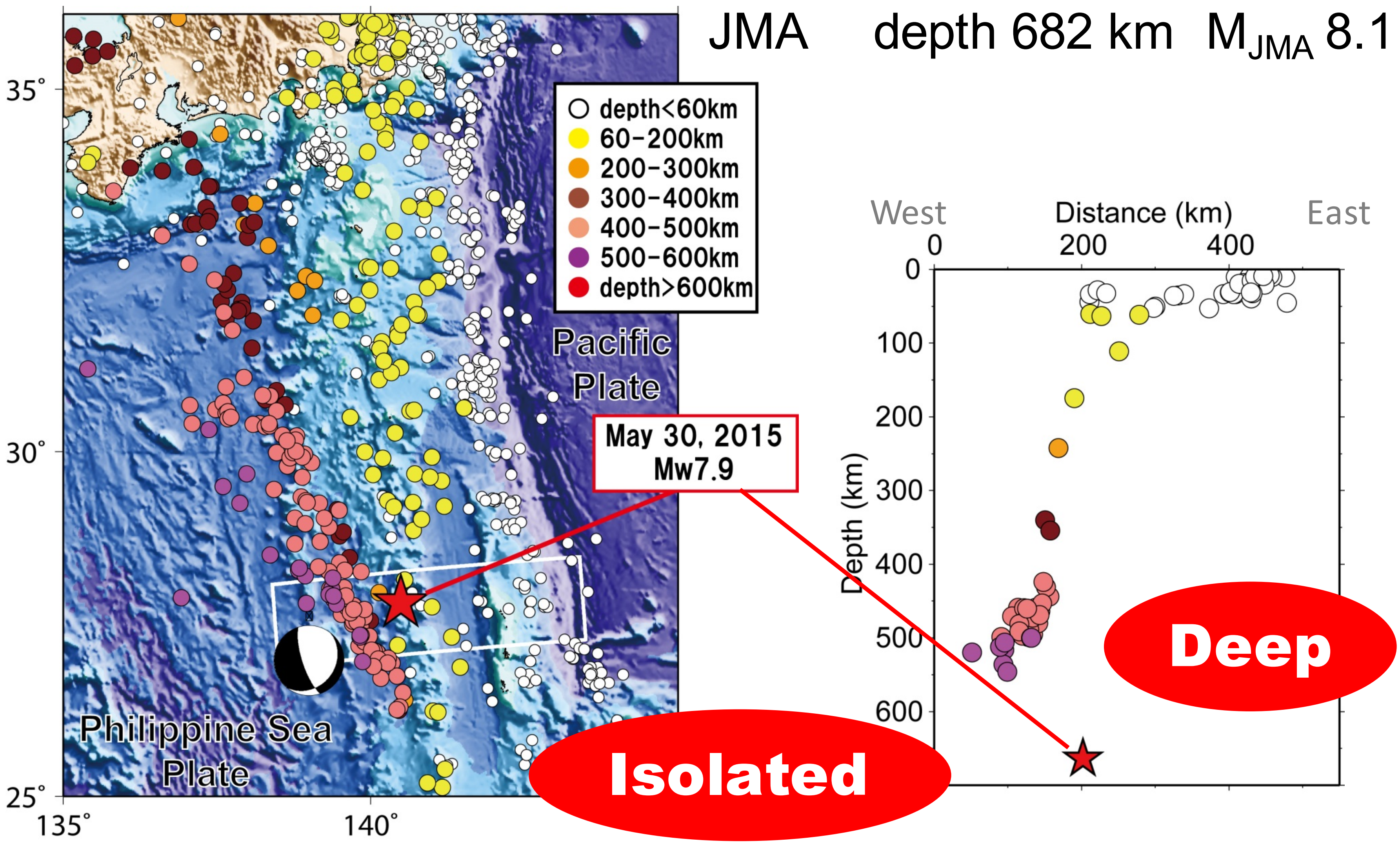
What is the relation between the seismicity and 660 km discontinuity?



May 30, 2015 Ogasawara (Bonin) earthquake

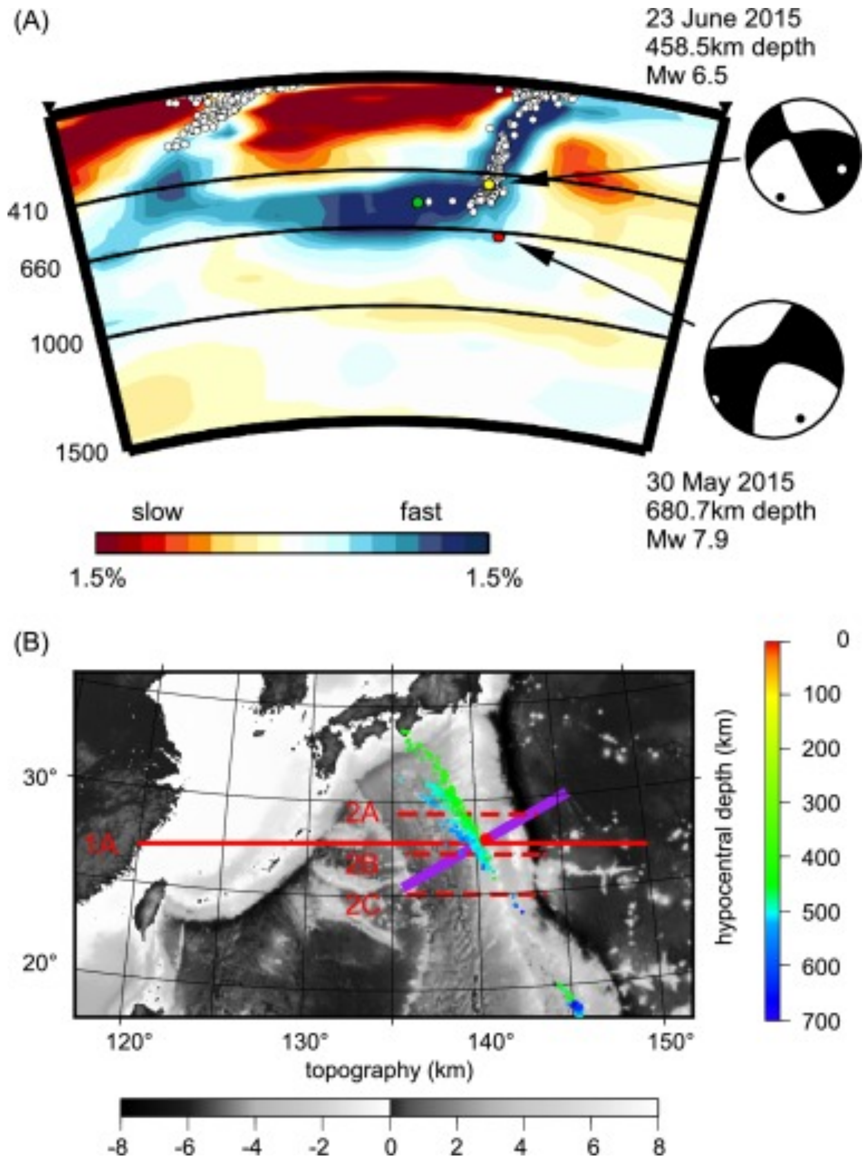
USGS depth 664 km M_w 7.9

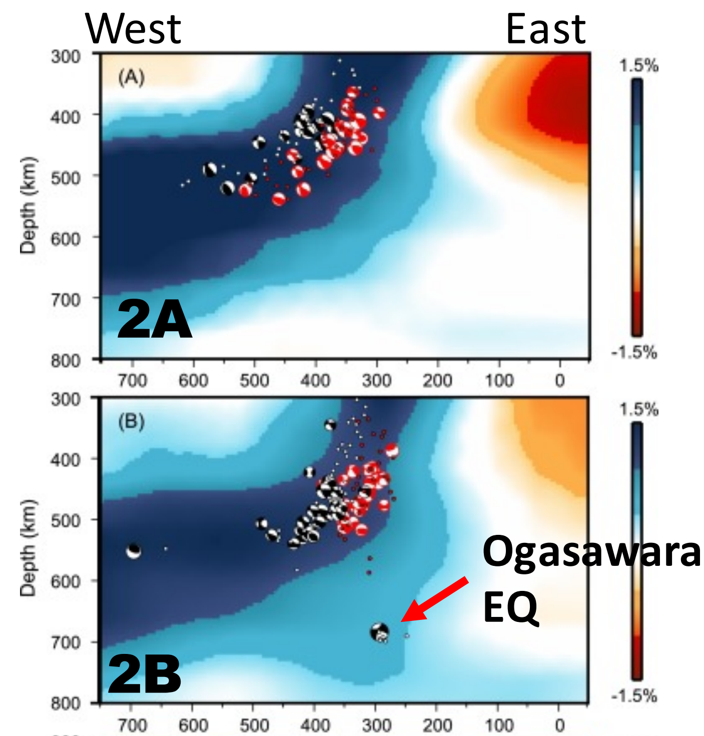
JMA depth 682 km M_{JMA} 8.1



P-wave tomography

Obayashi et al. (EPSL 2017)

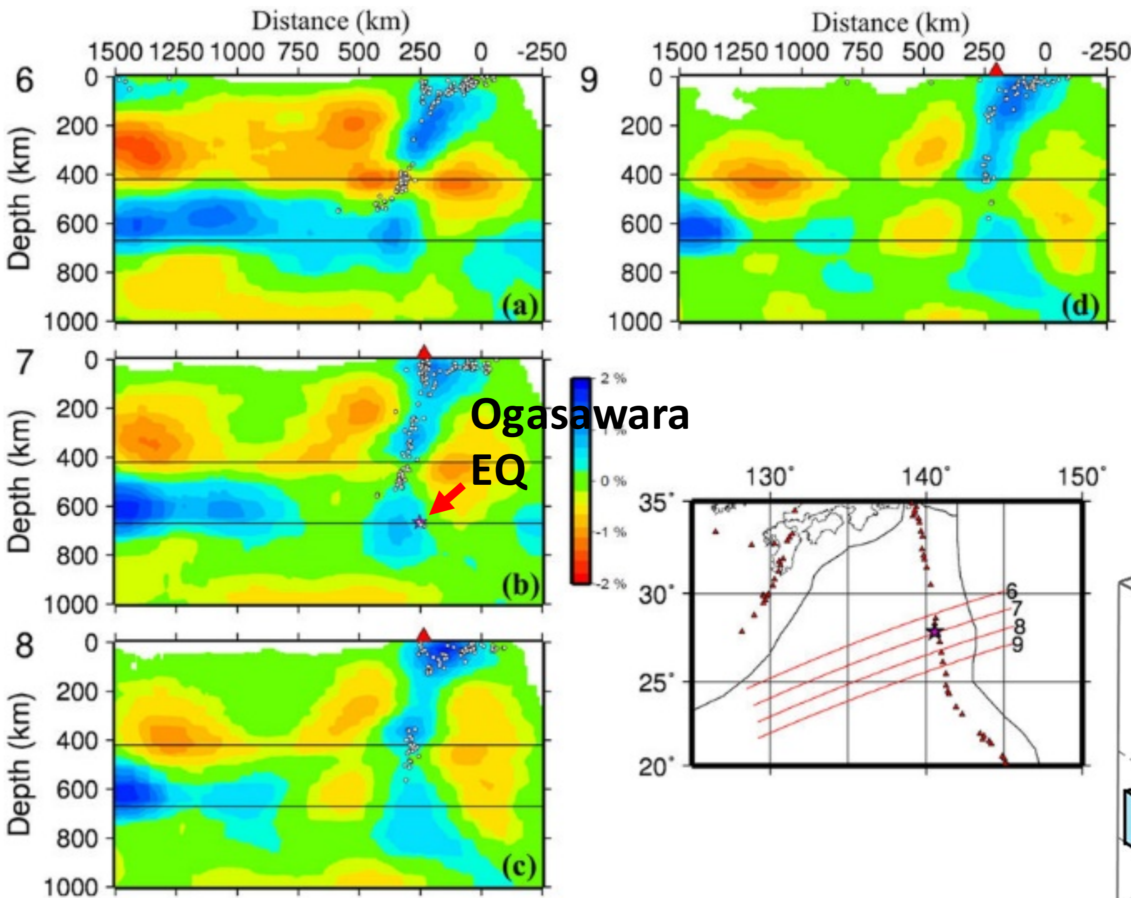


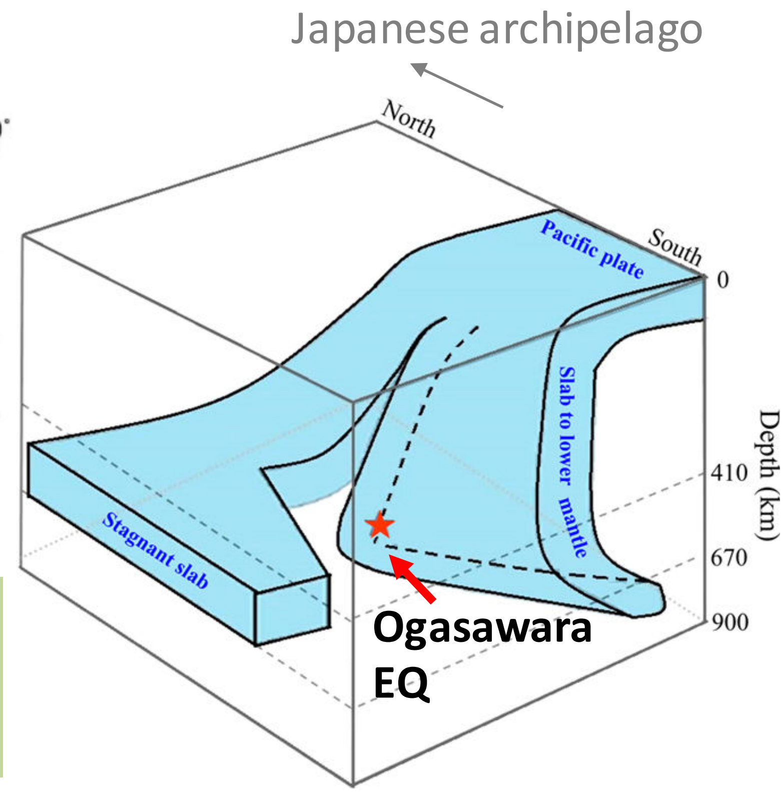


Descent of the heel part of slab to initiate penetration into the lower mantle

P-wave tomography

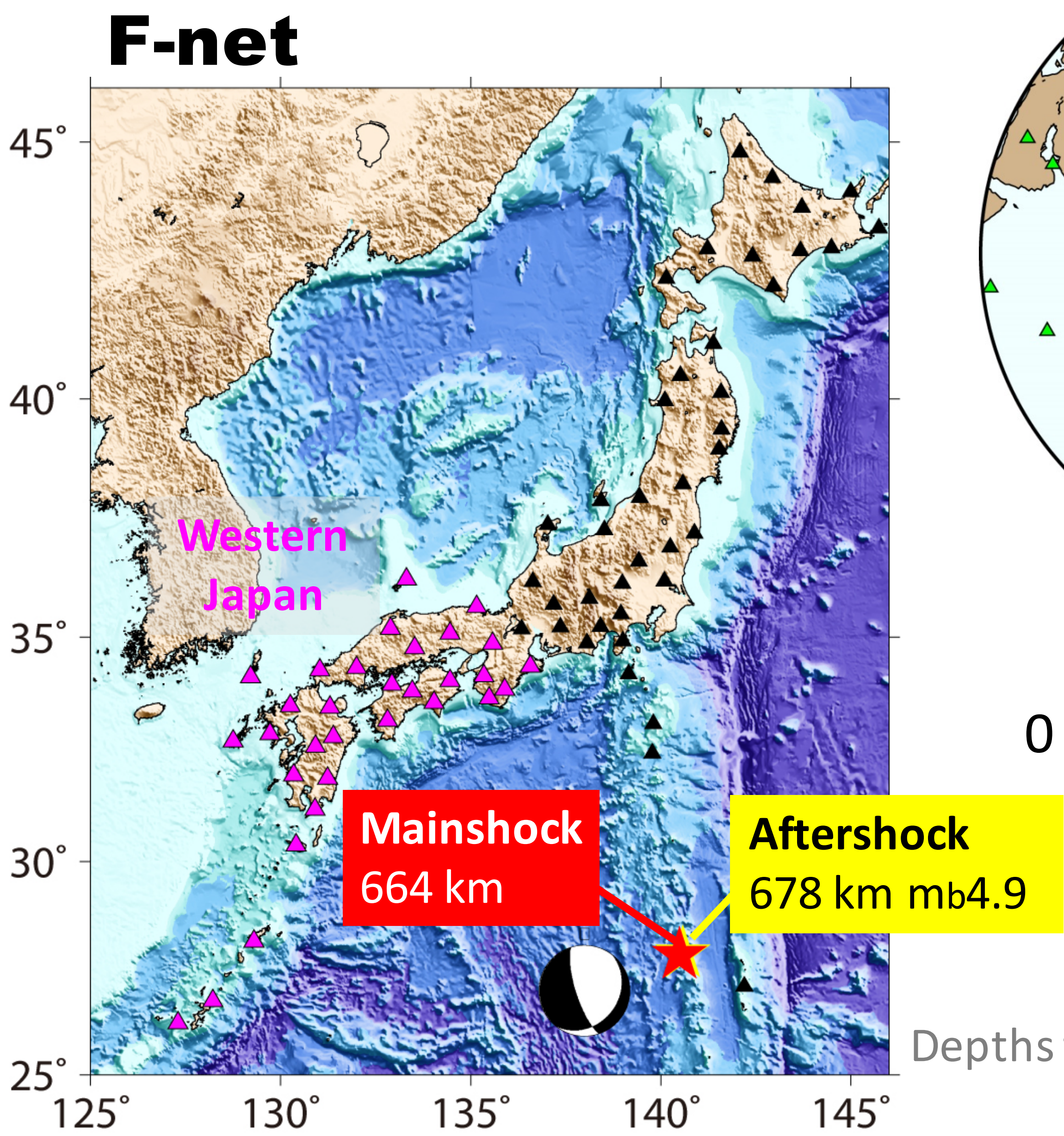
Zhao et al. (Sci. Rep. 2017)

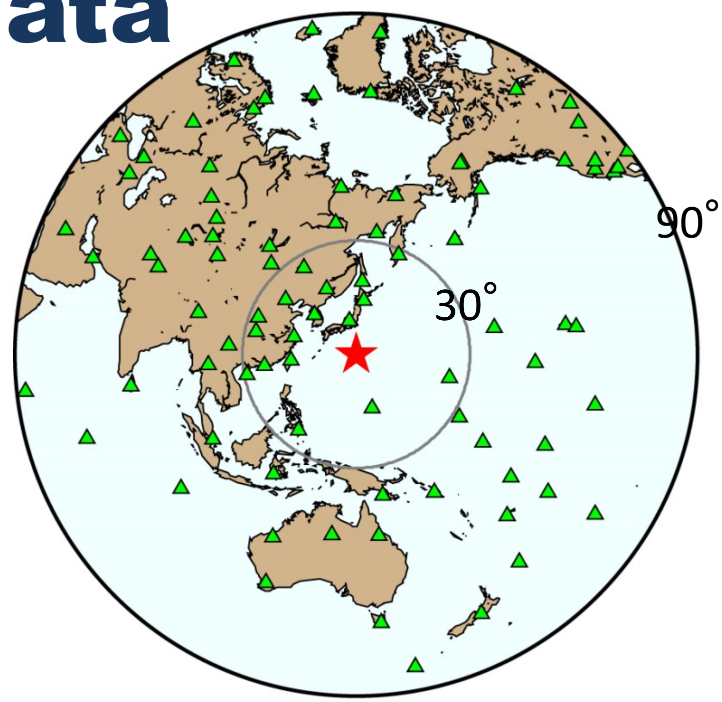




Pacific slab is split near the Ogasawara earthquake.

Broadband seismic data





IRIS GSN

0 < distance < 90 degrees

Depths from USGS

This talk

Based on observed regional P and S waves,
I consider the structure surrounding the 2015 Ogasawara earthquake, by addressing

- 660 km discontinuity
- Slab configuration
- Anisotropy

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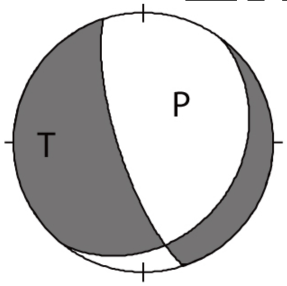
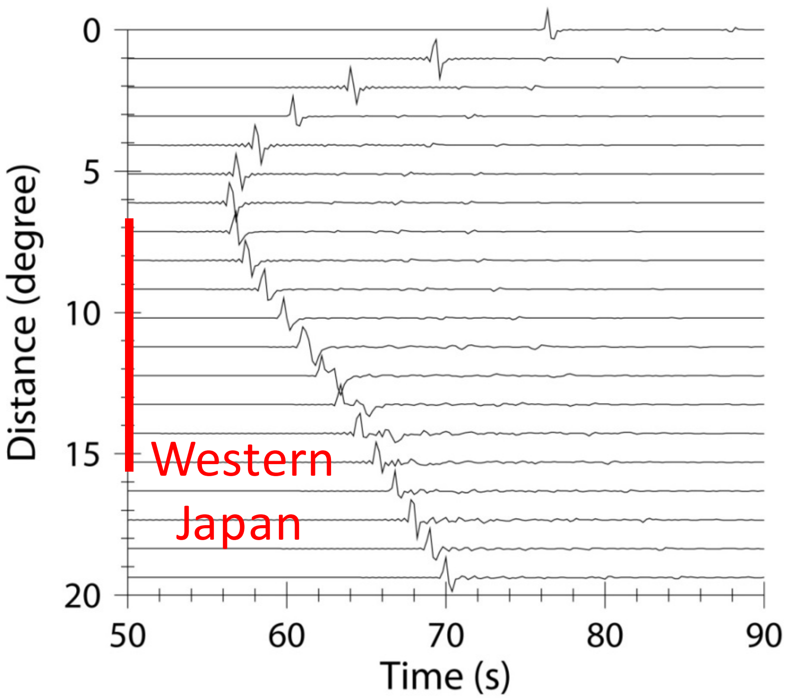
- **660 km discontinuity**
- Slab configuration
- Anisotropy

Effect of 660 km discontinuity on theoretical P waveforms

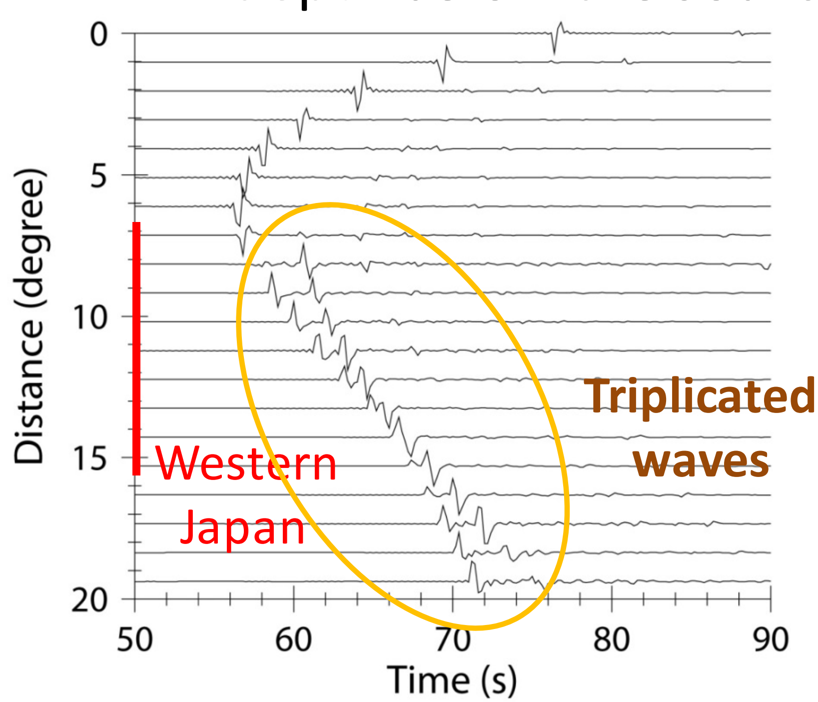


Point-source depth 664 km

iasp91: 660 km discontinuity **above the source**



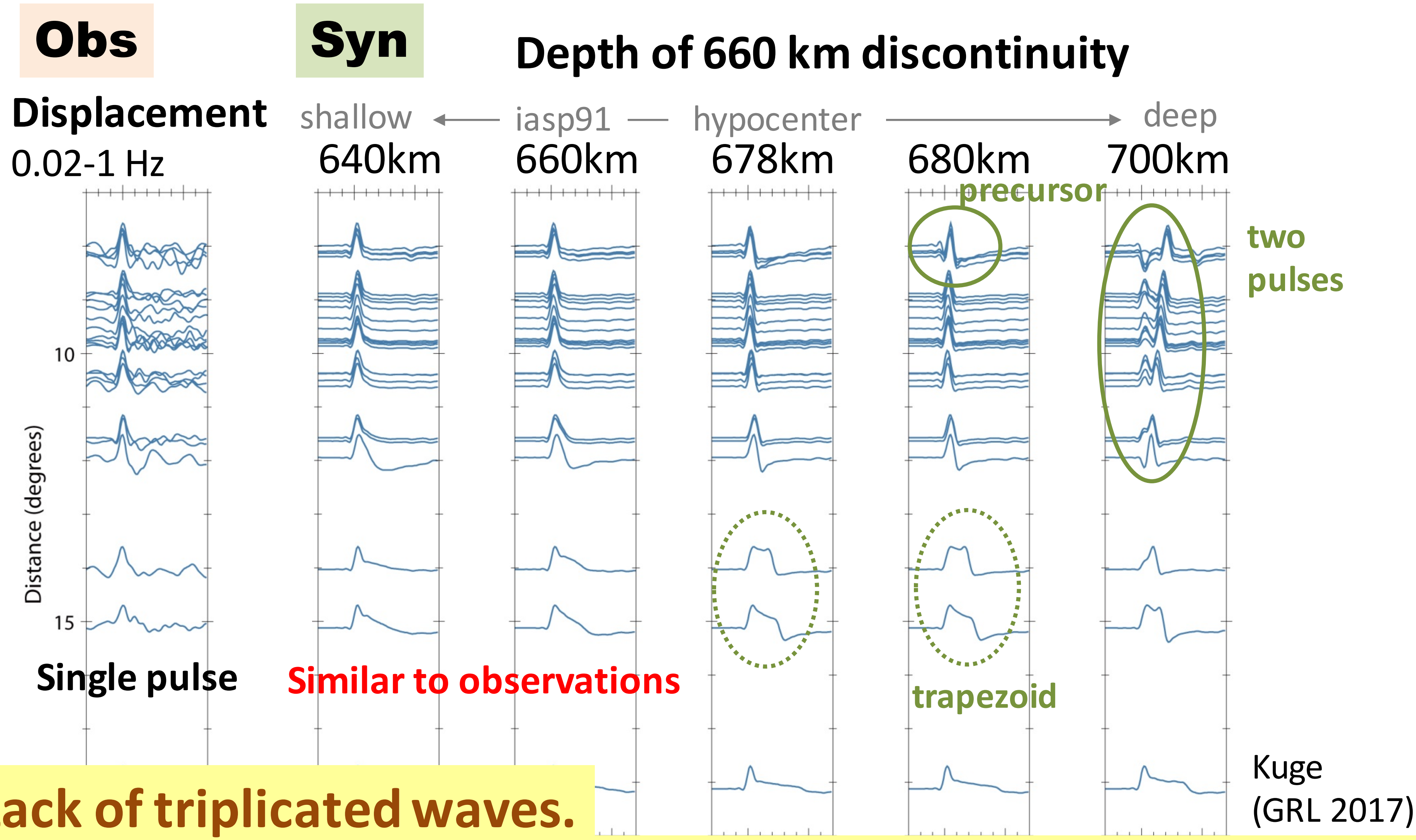
660 km discontinuity at 700 km depth **below the source**



Azimuth N310E

Reduce speed 8 s/degree

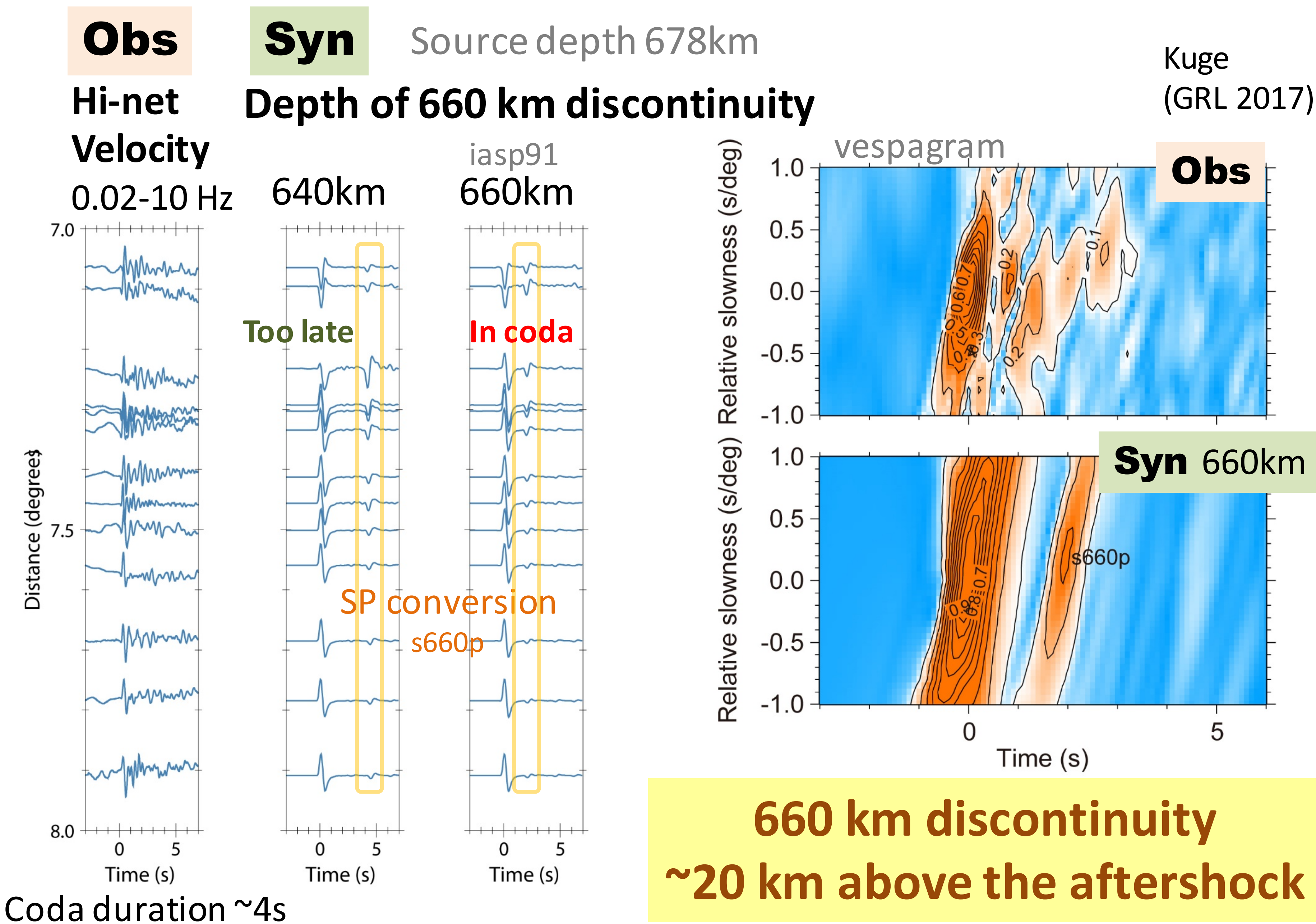
P waves in western Japan from the aftershock depth 678 km mb 4.9 (USGS)



Lack of triplicated waves.

660 km discontinuity above the aftershock fits observations.

Short-period P waves closer to the aftershock



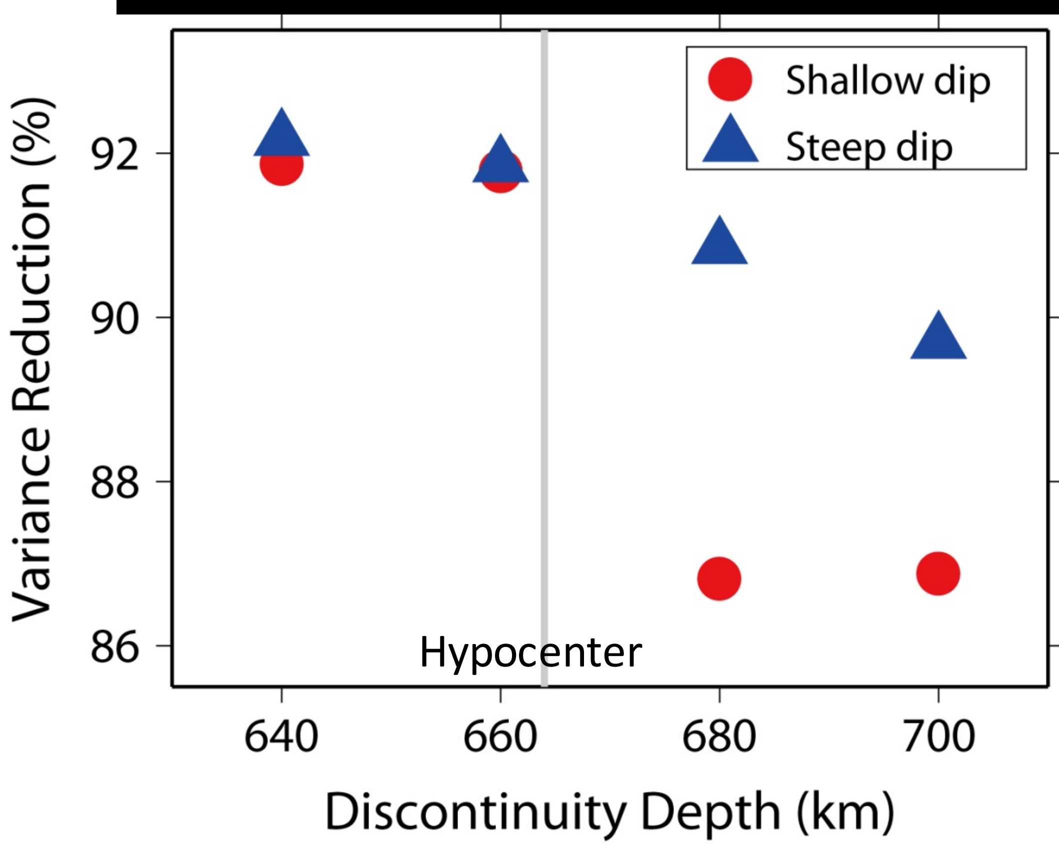
660 km discontinuity ~20 km above the aftershock

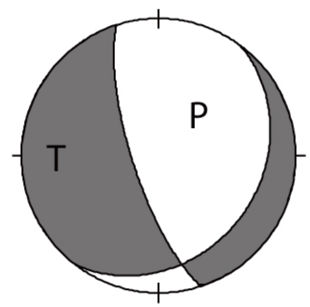
Mainshock

Variation of finite-fault model waveform fit with 660 km discontinuity depth

P waves (distance<30 degrees)

Waveform fit better





Kuge (GRL 2017)

When the 660 km discontinuity is assumed above the hypocenter, the mainshock waveform fit is better.

The 660 km discontinuity around the 2015 Bonin earthquake

- A significant, subhorizontal 660 km discontinuity could not be located below the aftershock.

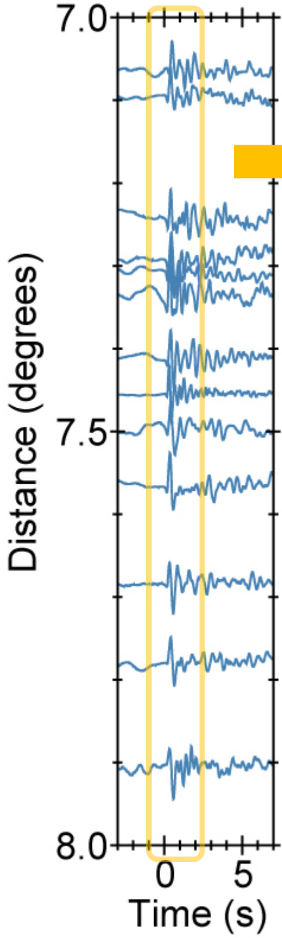
- The observed waveforms are sensitive to the relative location between the aftershock and discontinuity, not the exact depth of the discontinuity.

- The discontinuity may be around 20 km above the aftershock. The master-event analysis relocated the aftershock to be 6 km deeper, relative to the mainshock. The depth of the 660 km discontinuity corresponds to
  - 650 km for the USGS mainshock (depth 664 km)
  - 670 km for the JMA mainshock (depth 682 km)

Short-period P waves closer to the aftershock

Obs

Hi-net
Velocity
0.02-10 Hz

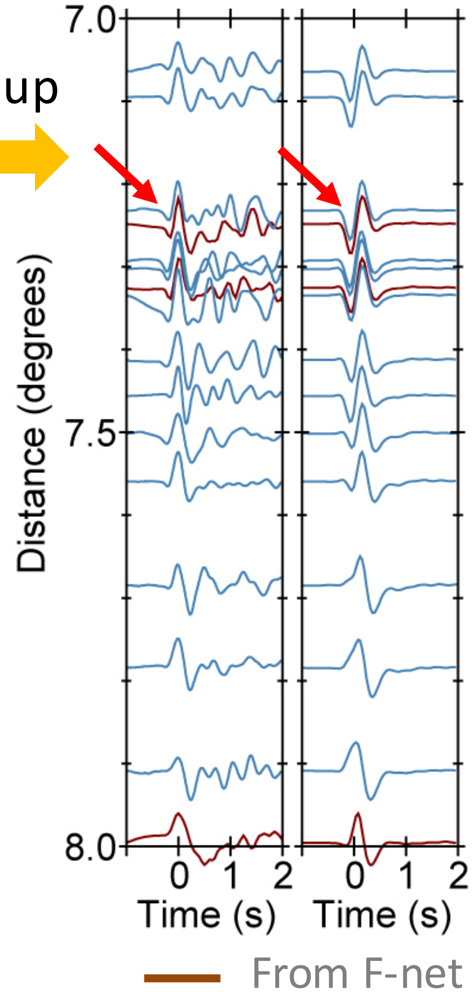


Zoom up

Obs **Syn** Source depth 678km

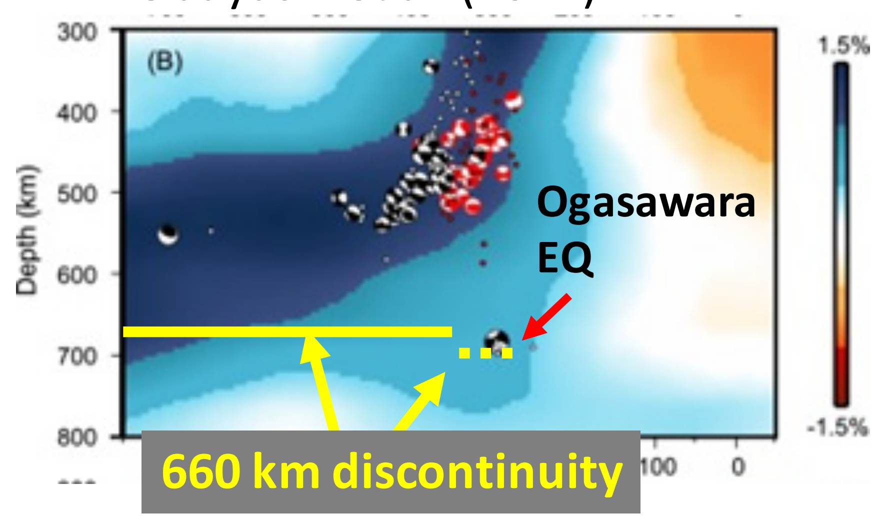
Kuge
(GRL 2017)

660 km discontinuity
at 680km with jump -40%



Local, small jump just below the aftershock?

Obayashi et al. (2017)



What could cause earthquake rupture below the 660 km discontinuity?

Melt and shear instability

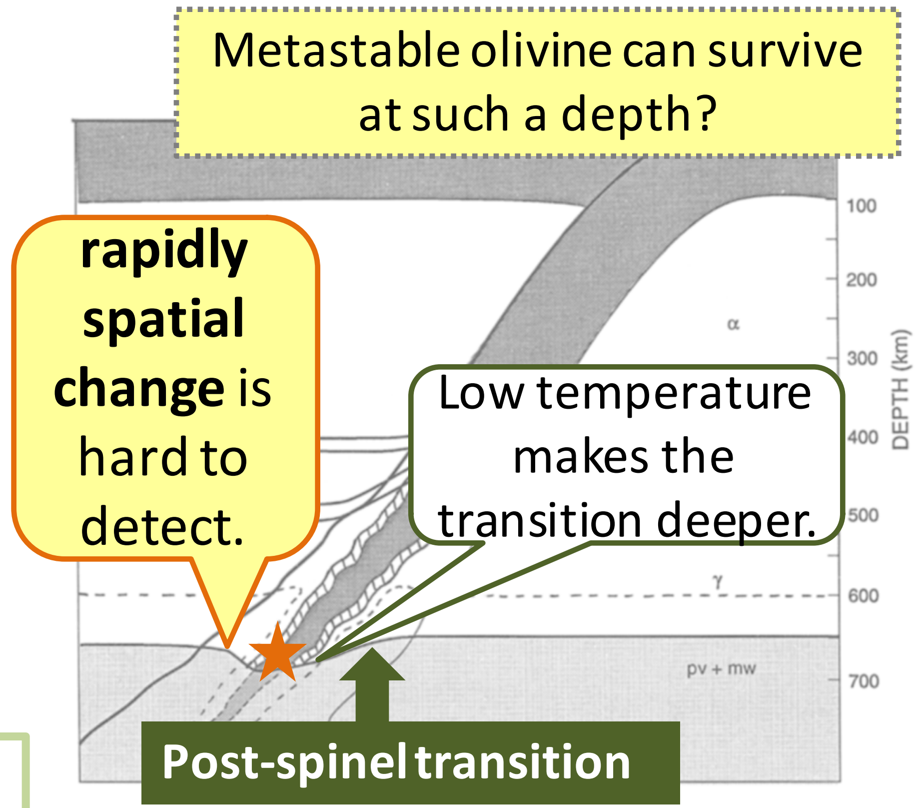
Possible once triggered

Transformational faulting in metastable olivine

- Endothermic reaction of spinel to perovskite
- Very slow diffusion needed by disproportionation reaction of metastable-olivine to perovskite

➡ Termination of earthquakes at the 660 km discontinuity

(Green and Zhou, 1996)



Green and Zhou (1996)

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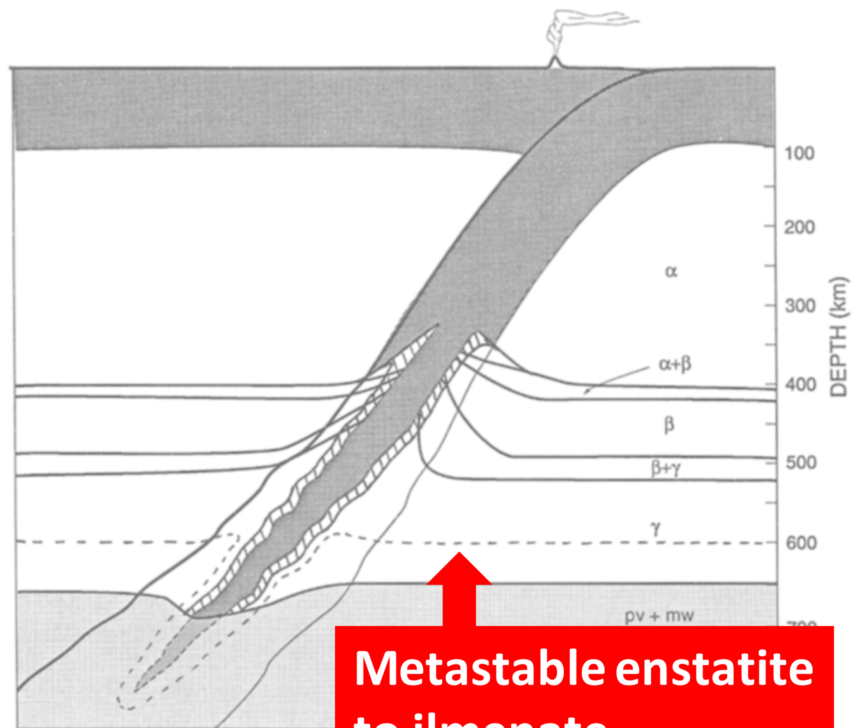


Metastable enstatite to ilmenate

Green and Zhou (1996)

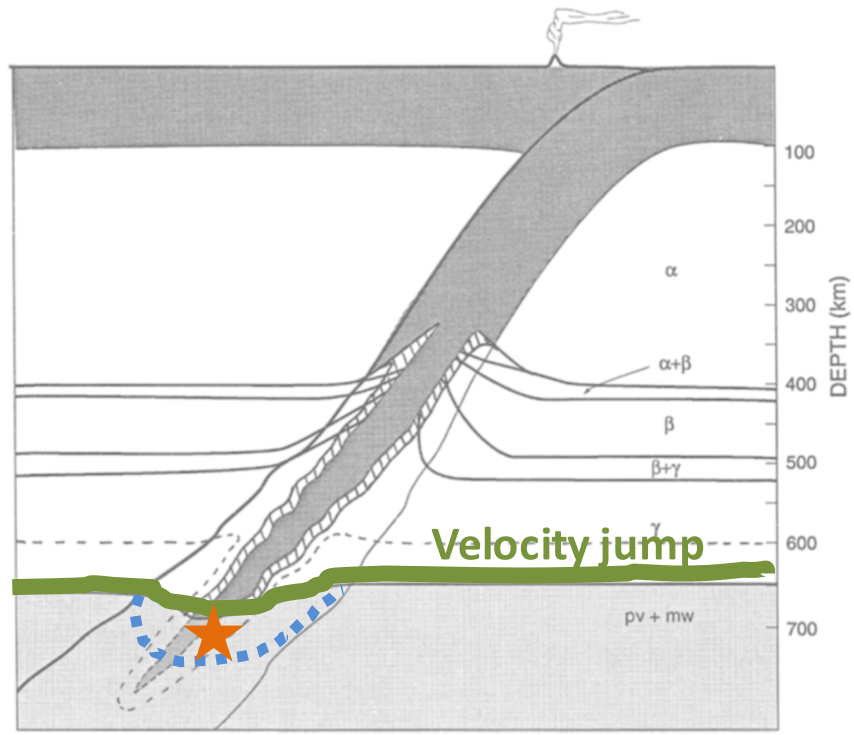
Metastable enstatite

Enstatite can appear as a metastable phase in deeper portions than olivine.

➡ Deep earthquakes

(Hogrefe et al. 1994)

The transition to perovskite could occur deeper, compared with the olivine system. (e.g. Poli and Schmidt 2002)



Green and Zhou (1996)

If metastable enstatite can trigger deep earthquakes and the 660 km velocity discontinuity is characterized by olivine,

➡ **earthquake rupture may occur below the 660 km velocity discontinuity.**

Summary

The structure surrounding the 2015 Ogasawara (Bonin) deep earthquake was explored by observed regional P and S waves.

- The 660 km discontinuity can be located above the earthquake. A local, small velocity jump might also exist just below the earthquake. Different discontinuities are not required for P and S waves.
- If a slab extends to the earthquake, it can bend to the east just above the earthquake. In the northwestern side of the earthquake, the presence of slab is not required, and anisotropy with fast direction in ENE-WSW can exist.

The results appear to agree with the slab image by Zhao et al. (2017).