Mantle earthquakes: keys to mantle dynamics and the strength of the lithosphere

"50 Years of Plate Tectonics:

Then, Now, and Beyond"

Collège de France, Paris

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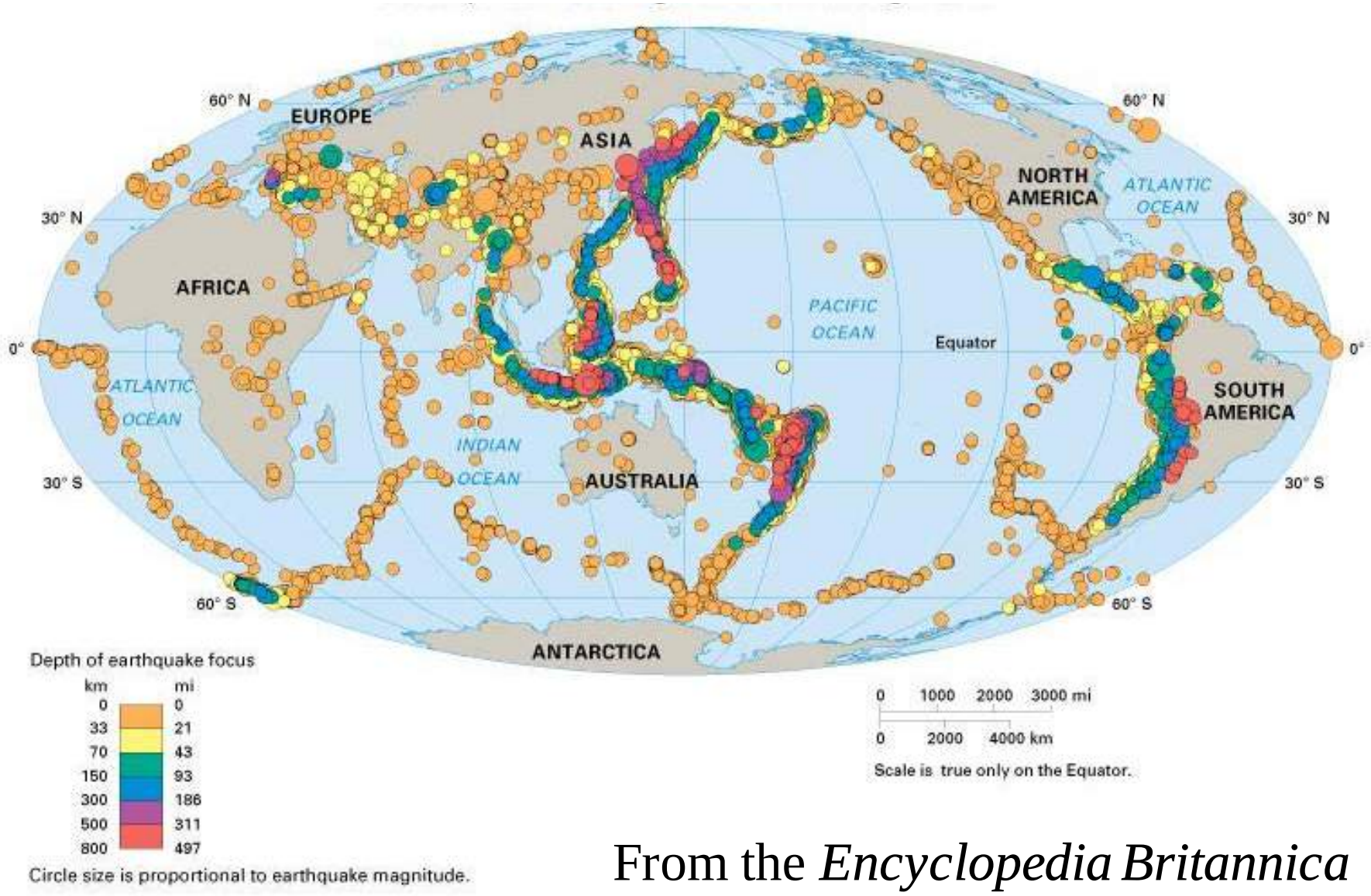
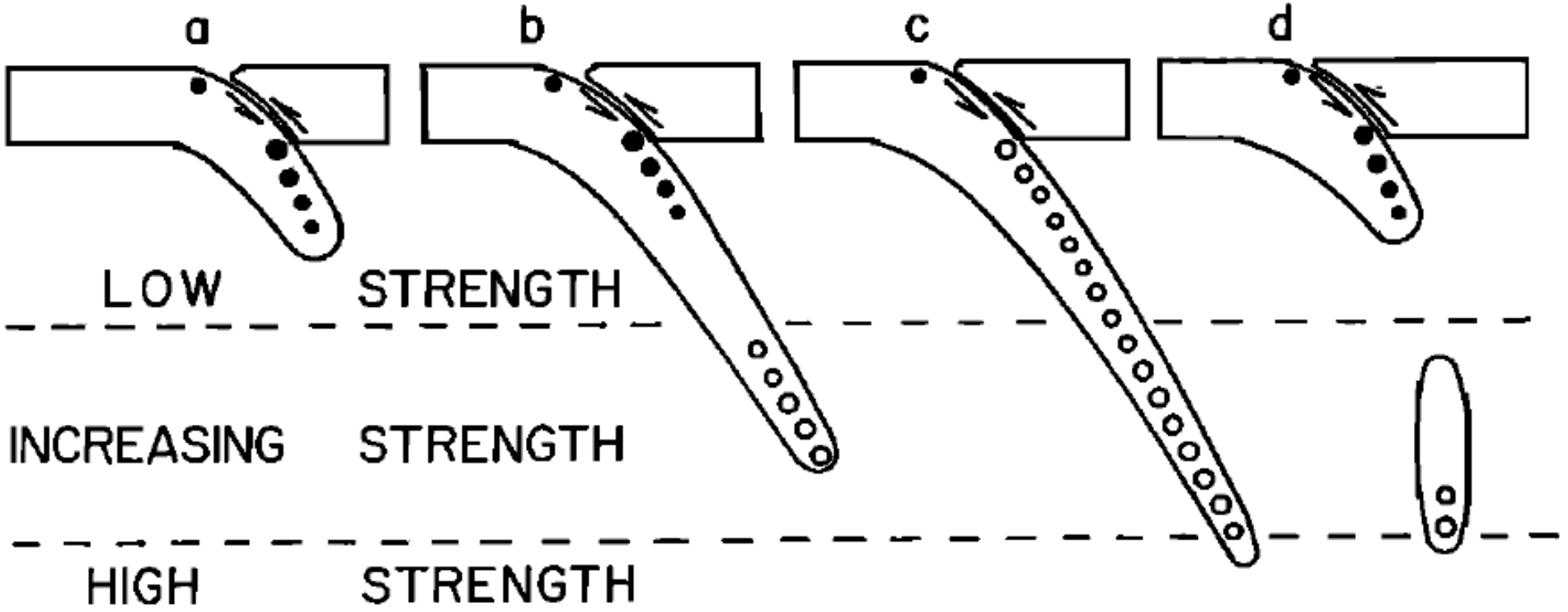
Global seismicity:
Note **Intermediate**- and **deep**-focus earthquakes



From the *Encyclopedia Britannica*

Interpretation of fault plane solutions of Intermediate and deep-focus earthquakes



- Downdip extension
- ° Downdip compression

[*Isacks and Molnar* 1969, 1971]

- Downdip extension
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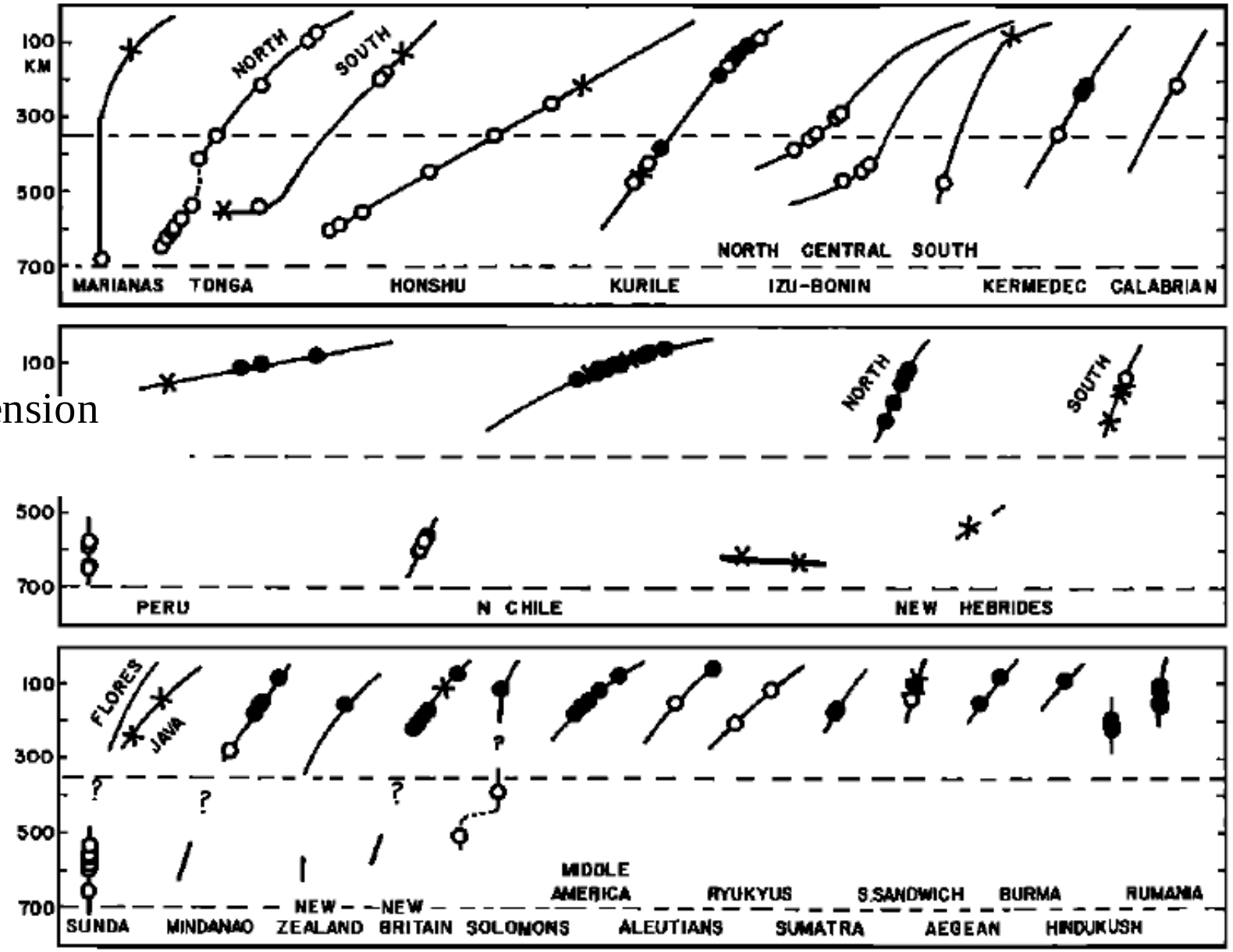


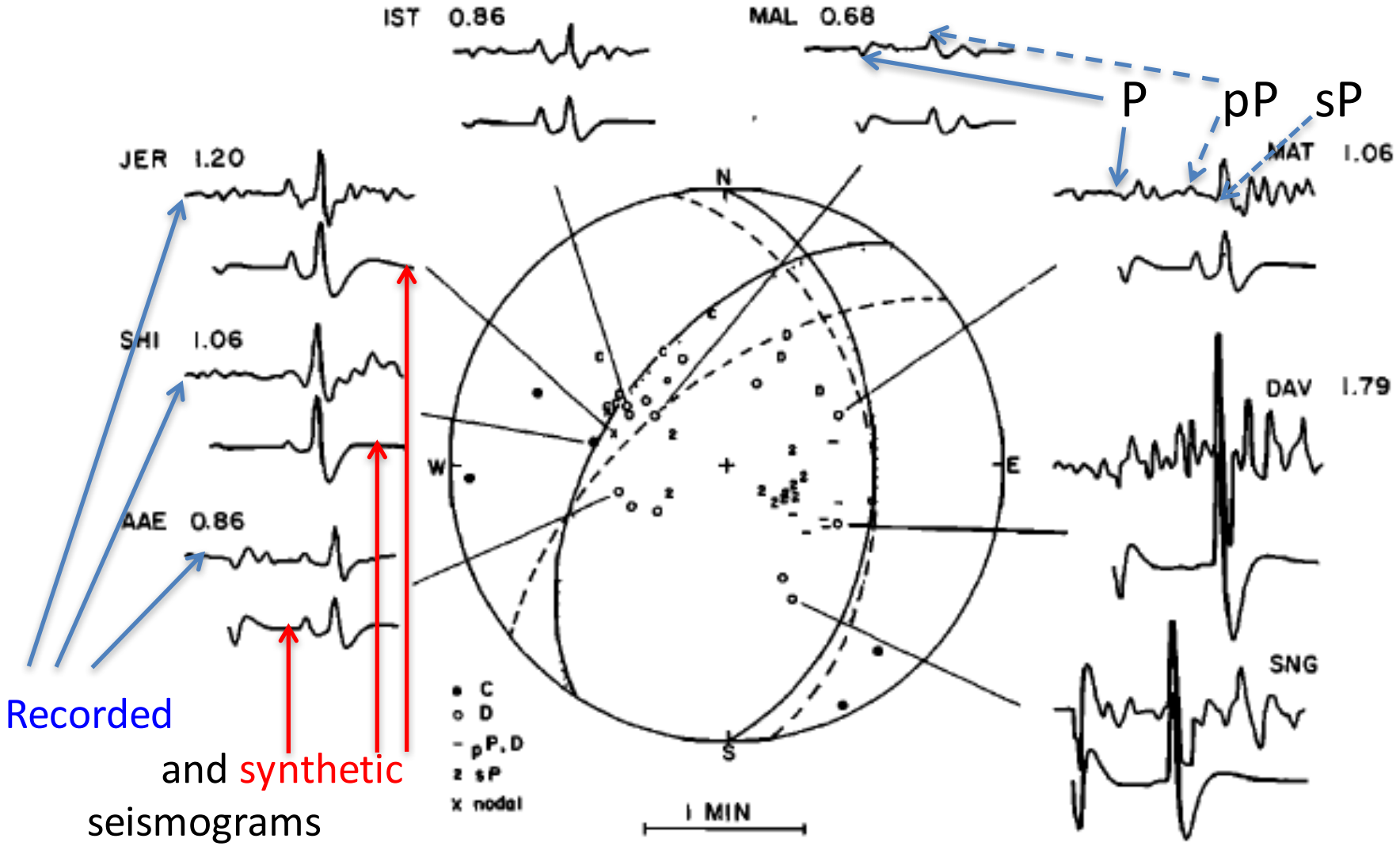
Fault plane solutions of intermediate and deep focus earthquakes

[Isacks and Molnar, 1971]

The old idea:

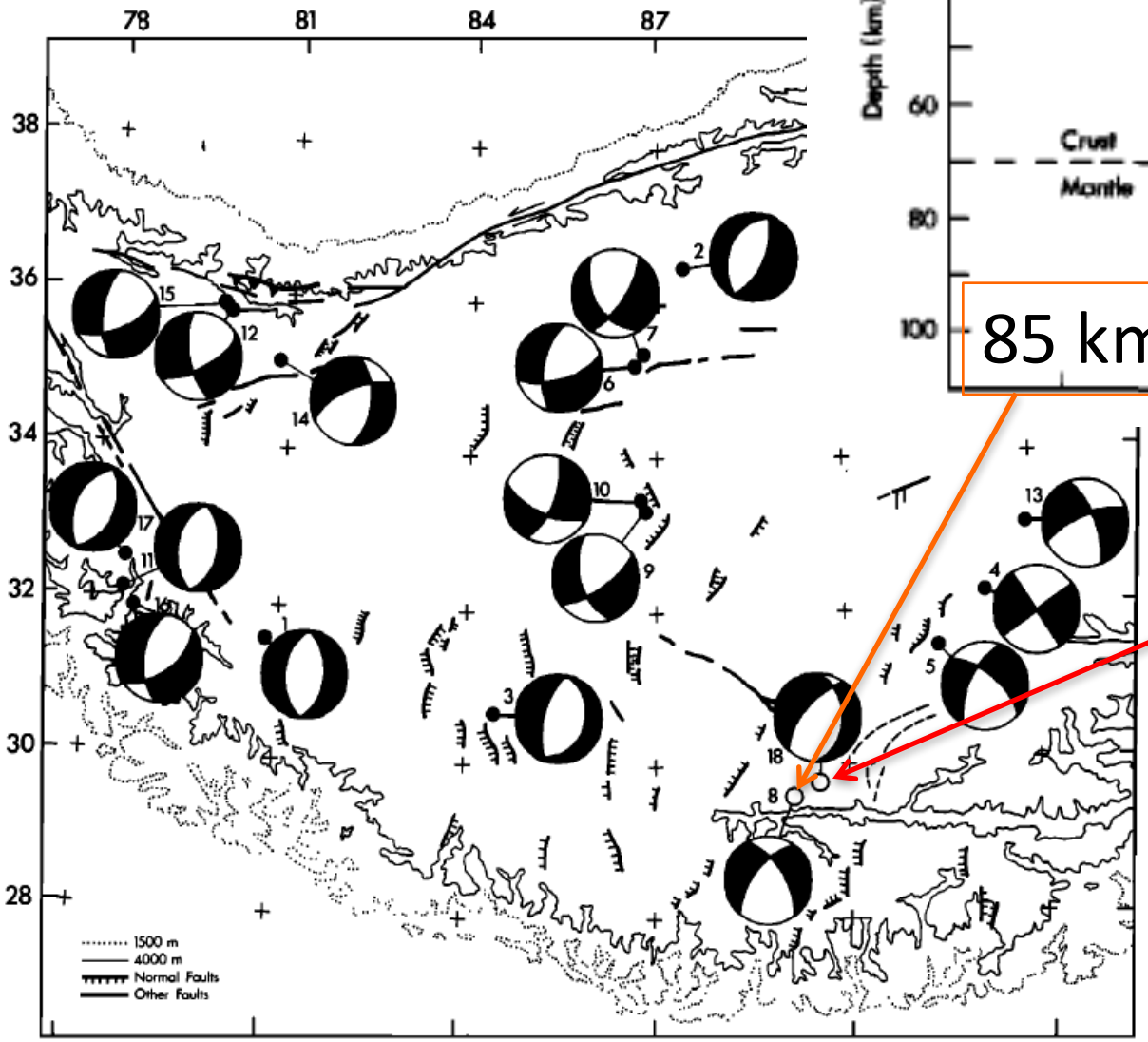
1. *Intermediate- and deep-focus earthquakes occur within downgoing slabs of lithosphere.*
2. *Of course, because temperatures are low there.*
3. *Conversely, the occurrence of intermediate- and deep-focus earthquakes implies the presence of downgoing slabs of lithosphere.*

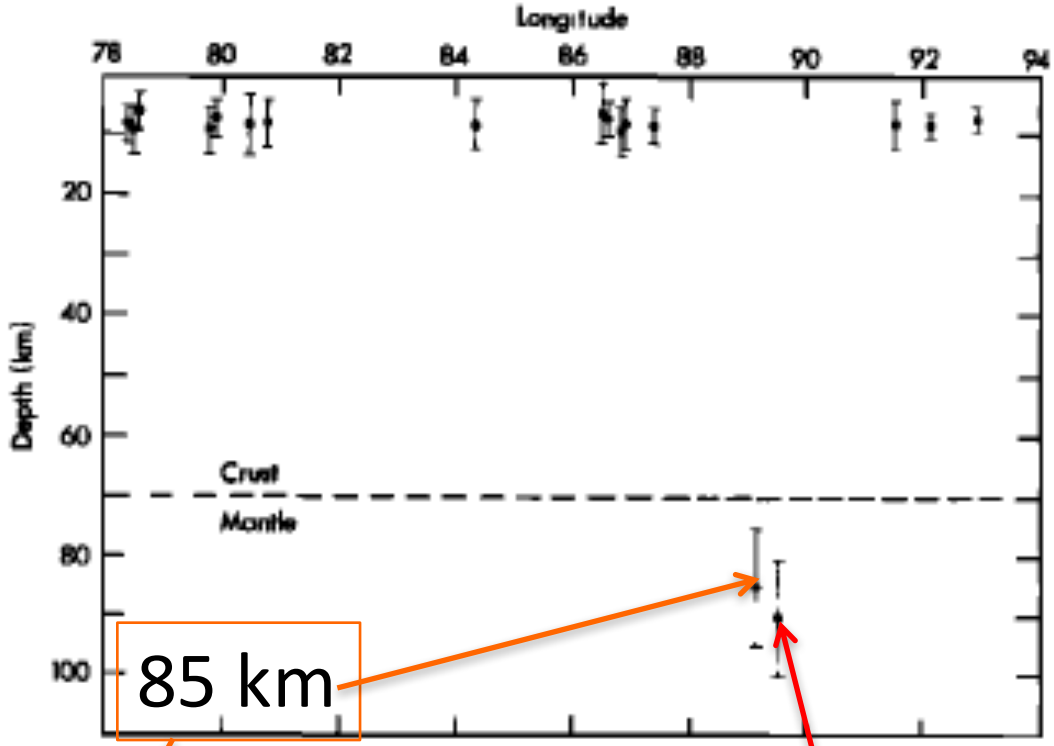
Intermediate-depth earthquake beneath Tibet



[*Chen et al., JGR*, 1981]

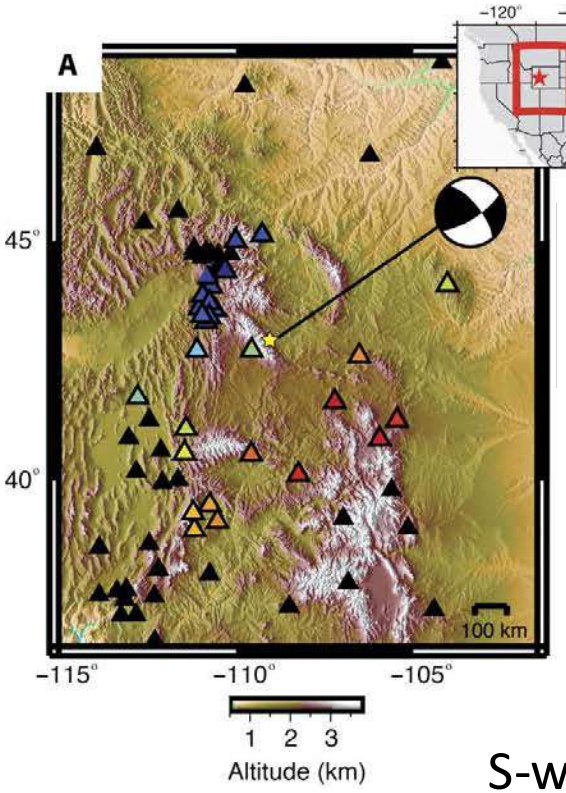
Depths of earthquakes beneath Tibet

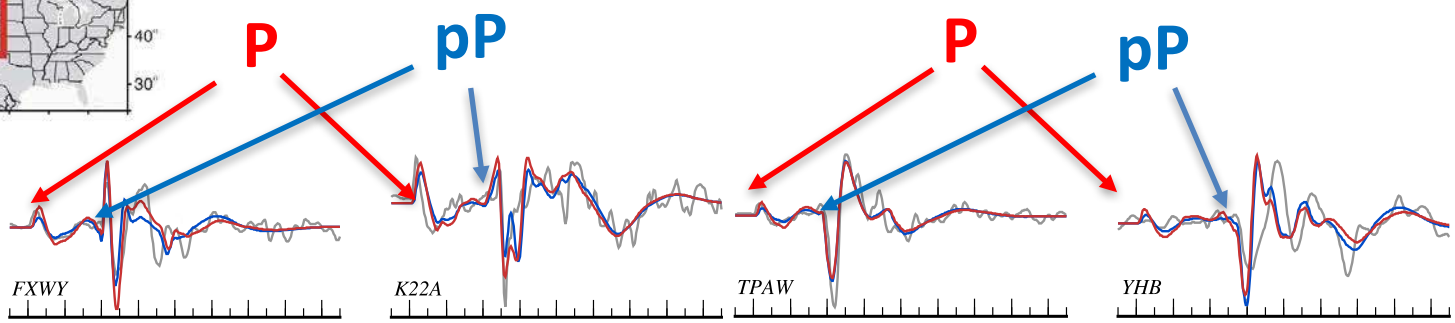




Fault plane solutions of shallow and subcrustal earthquake are similar.

[*Molnar and Chen, JGR*, 1983]



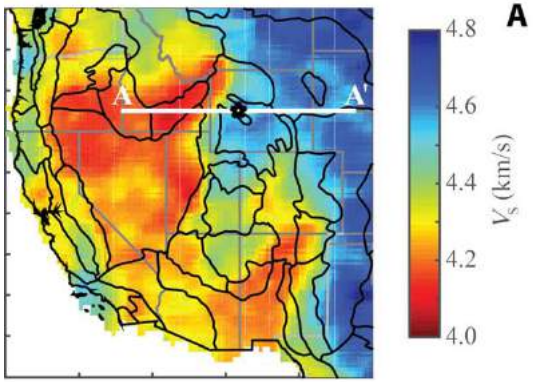


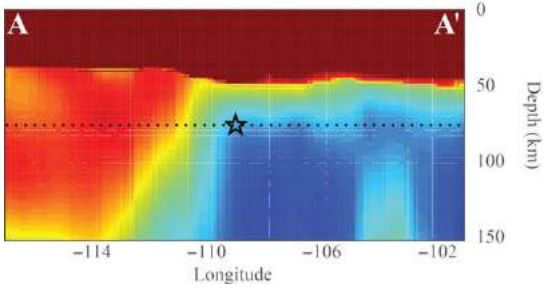
[Craig and Heyburn, *EPSL*, 2015]

[Prieto et al., *Science Advances*, 2017]

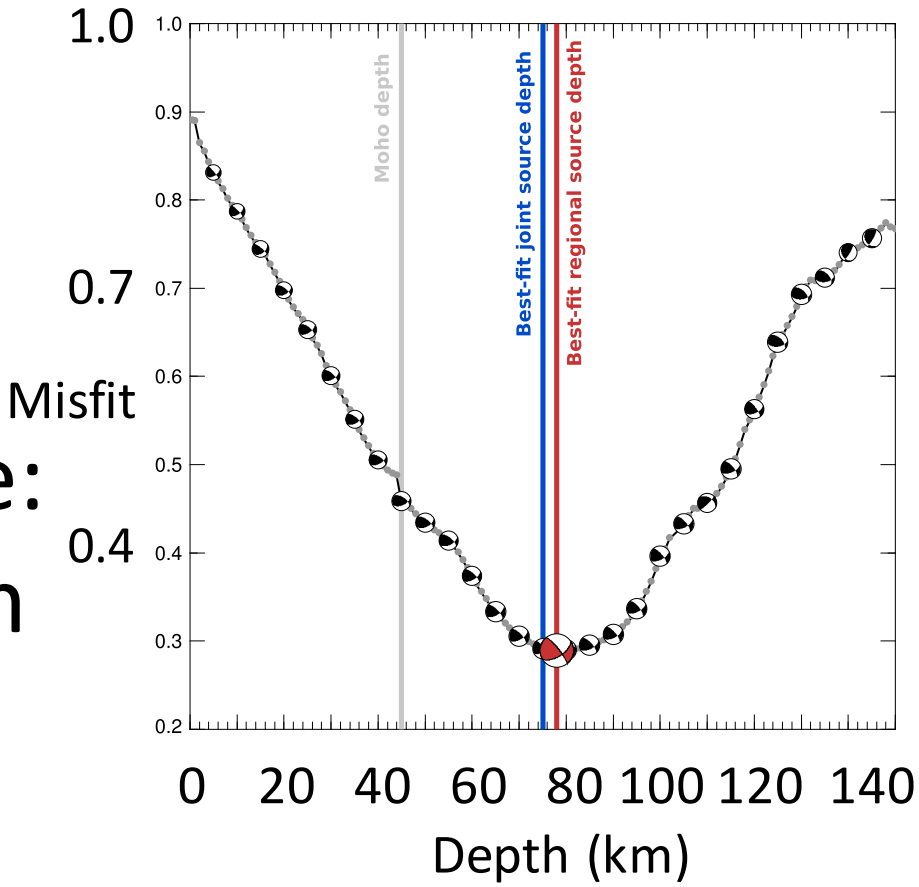
S-wave speeds

70 km

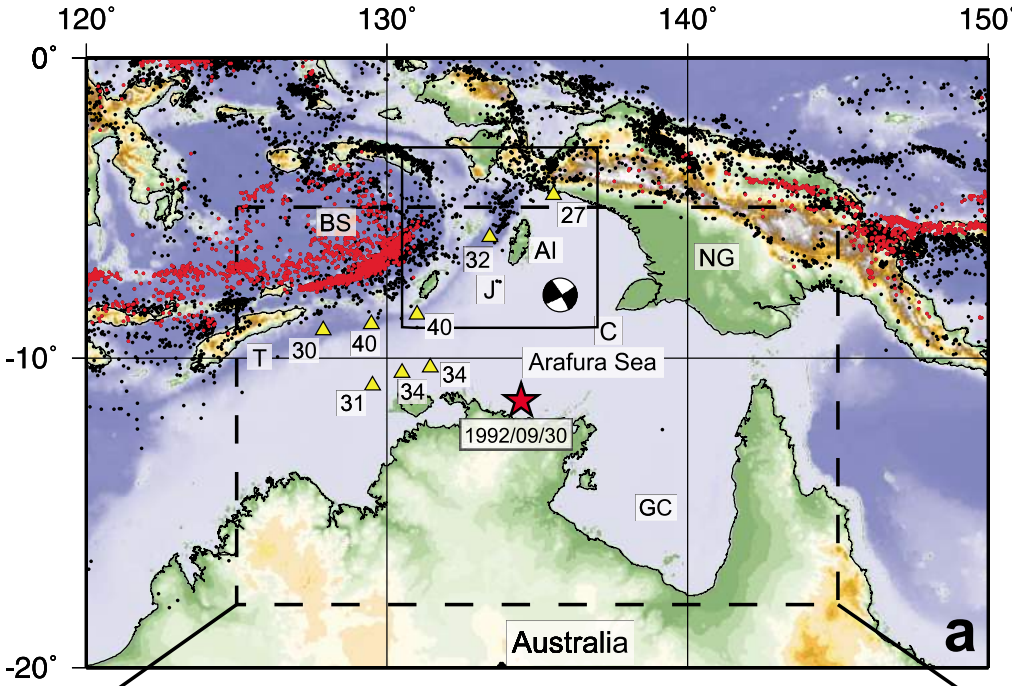


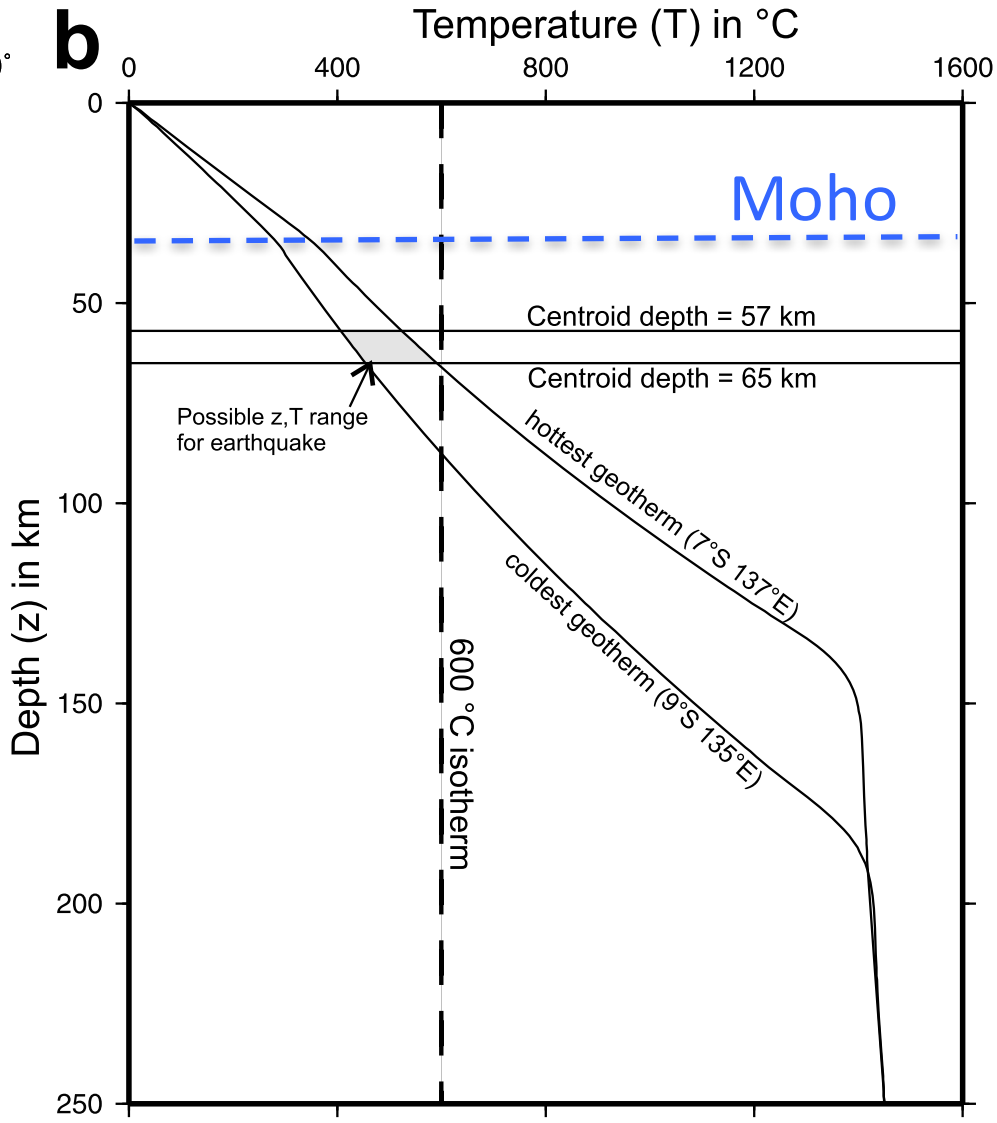


Earthquake: 75 ± 10 km beneath Wyoming



Earthquake at 61 ± 4 km beneath northern Australia





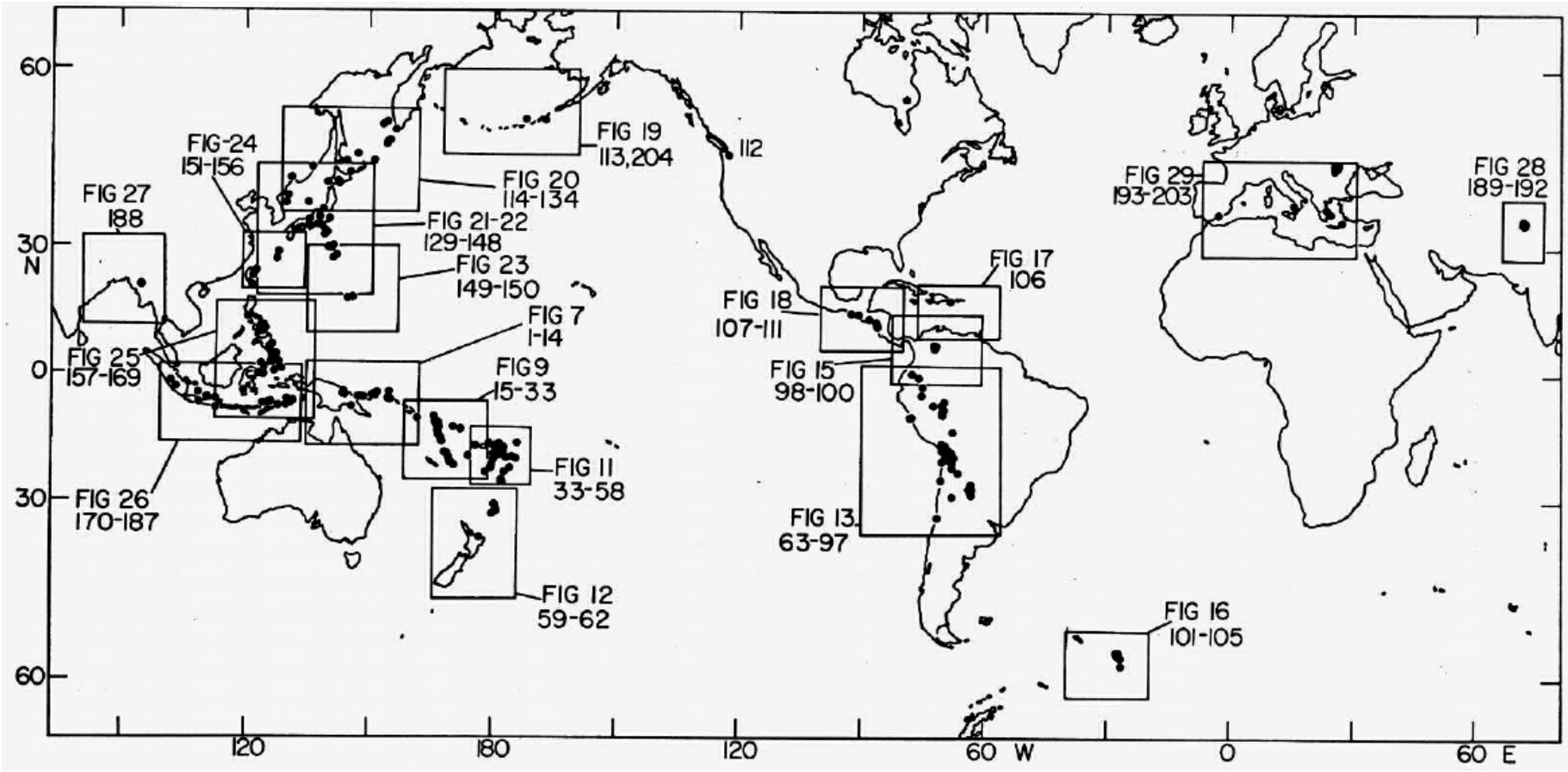
[Sloan and Jackson, *JGR*, 2012]

Mantle earthquakes

Earthquakes occur in the mantle, including many at intermediate depths (70-300 km), in several regions: southern Tibet, Wyoming, north of Australia, New Zealand, east Africa, the Amazon region of South America, and more.

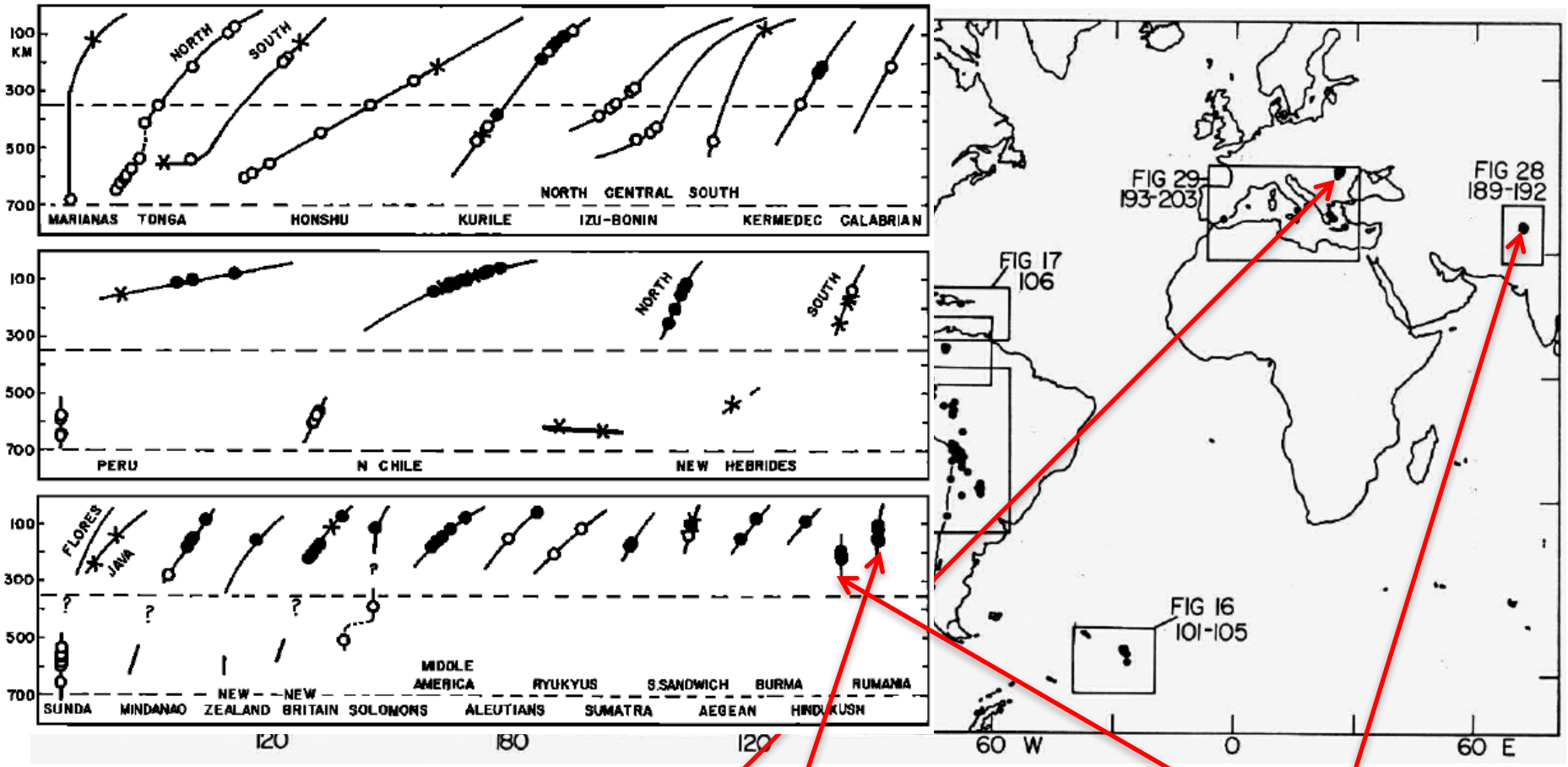
These earthquakes, however, do not occur in dipping zones (sinking slabs of lithosphere).

Intermediate and deep-focus earthquakes.



[Isacks and Molnar, 1971]

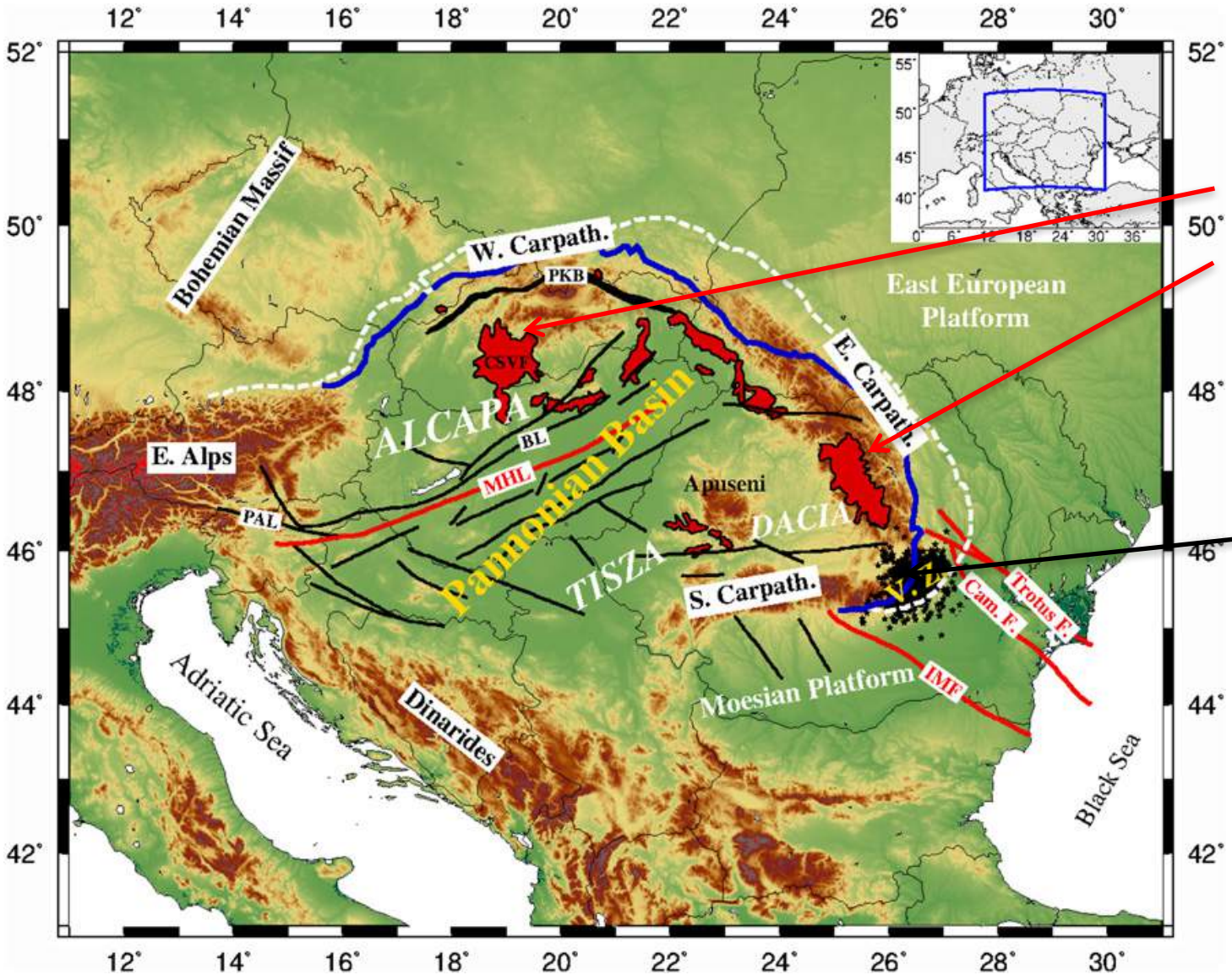
Intermediate and deep-focus earthquakes. All are in island arcs



Except Two: Carpathians and Pamir-Hindu Kush

[Isacks and Molnar, 1971]

Carpathians

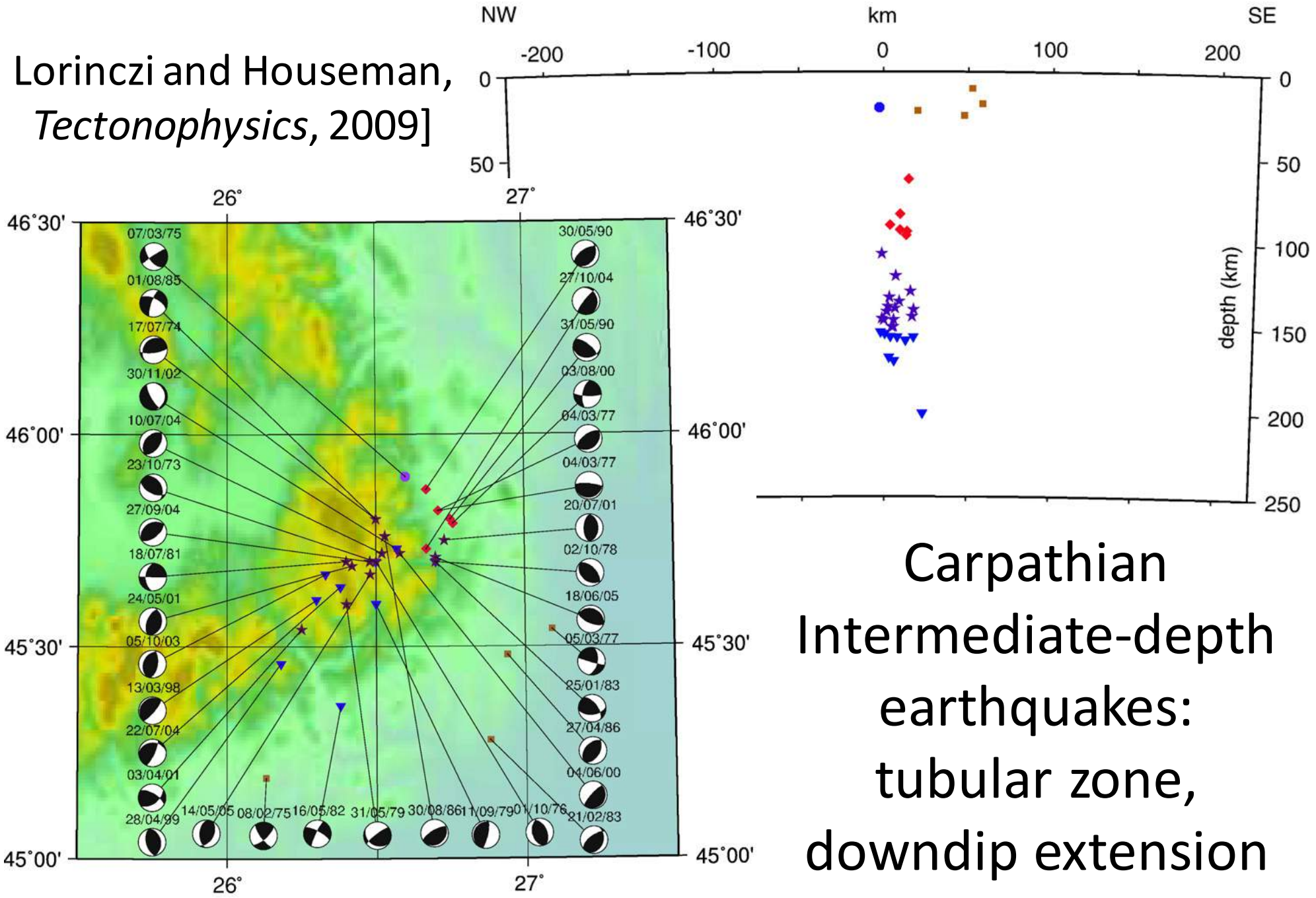


Calc-alkaline volcanic rock

Intermediate depth earthquakes

[Ren et al., *EPSL*, 2012]

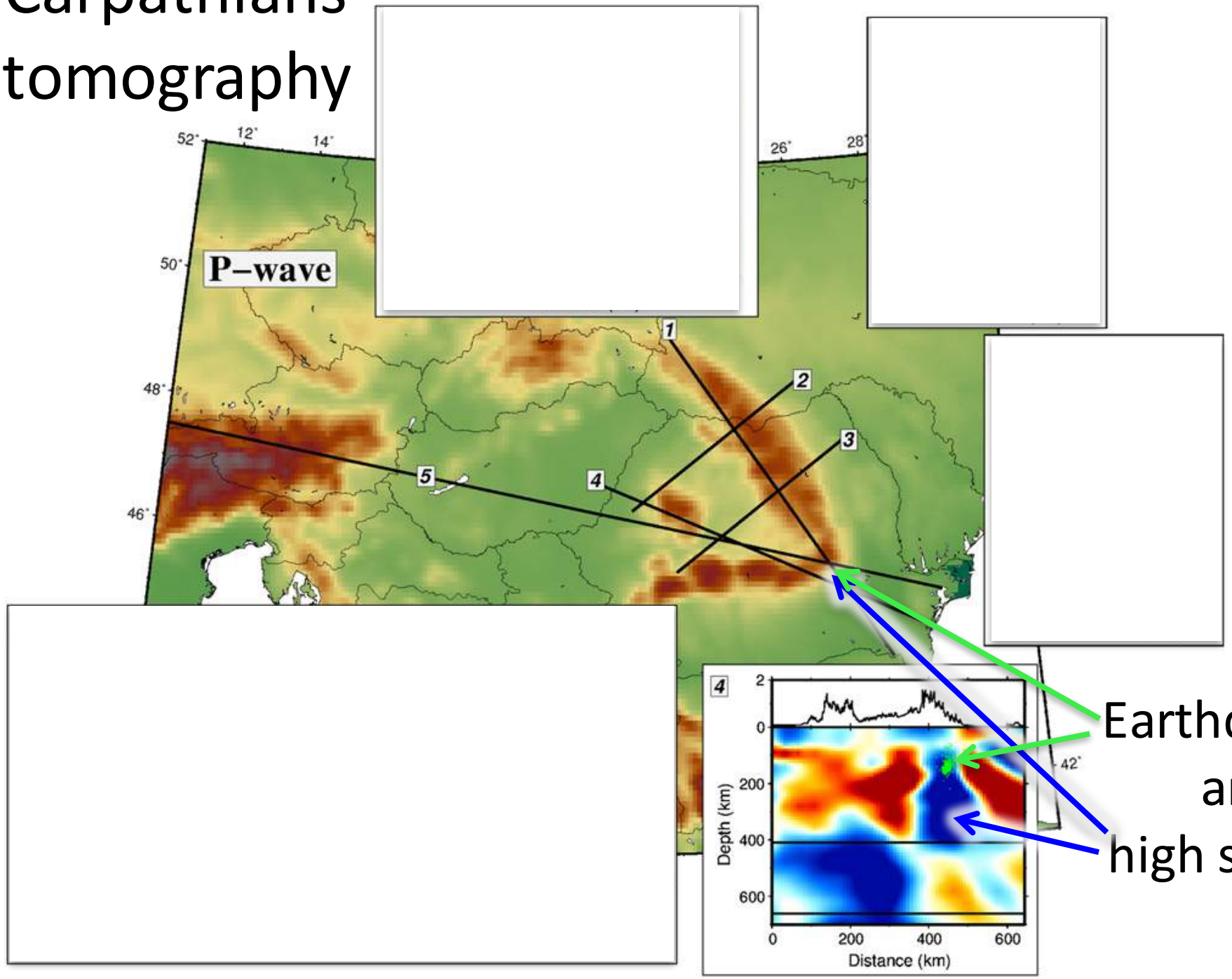
Lorinczi and Houseman, *Tectonophysics*, 2009]



Carpathian Intermediate-depth earthquakes: tubular zone, downdip extension

Carpathians tomography

Red = low speed ≈ **hot**; Blue = high speed ≈ **cold**



[Ren et al. EPSL, 2012]

Earthquakes and high speeds

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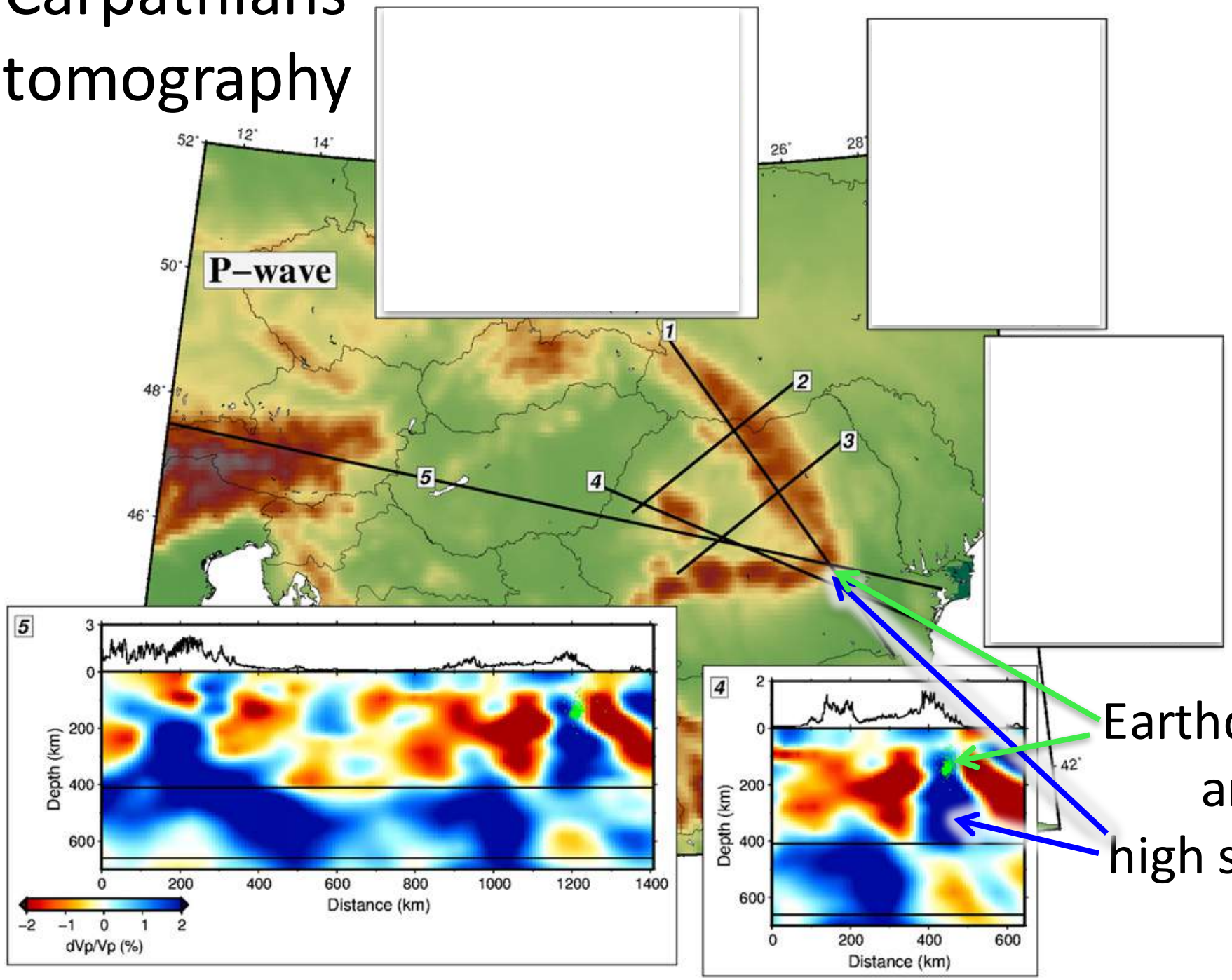

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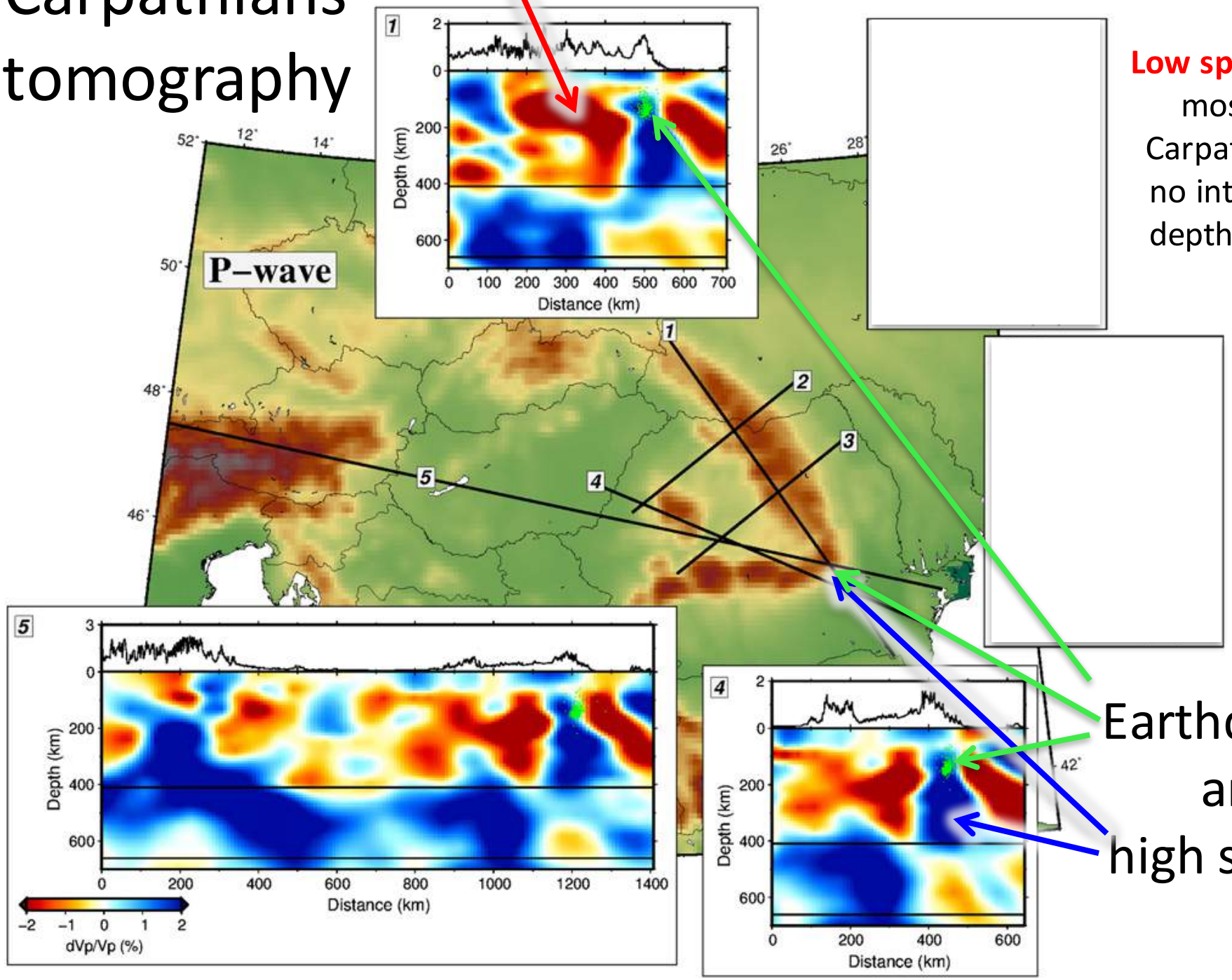

Low speeds under most of the Carpathians and no intermediate depth seismicity

[Ren et al. EPSL, 2012]

Earthquakes and high speeds

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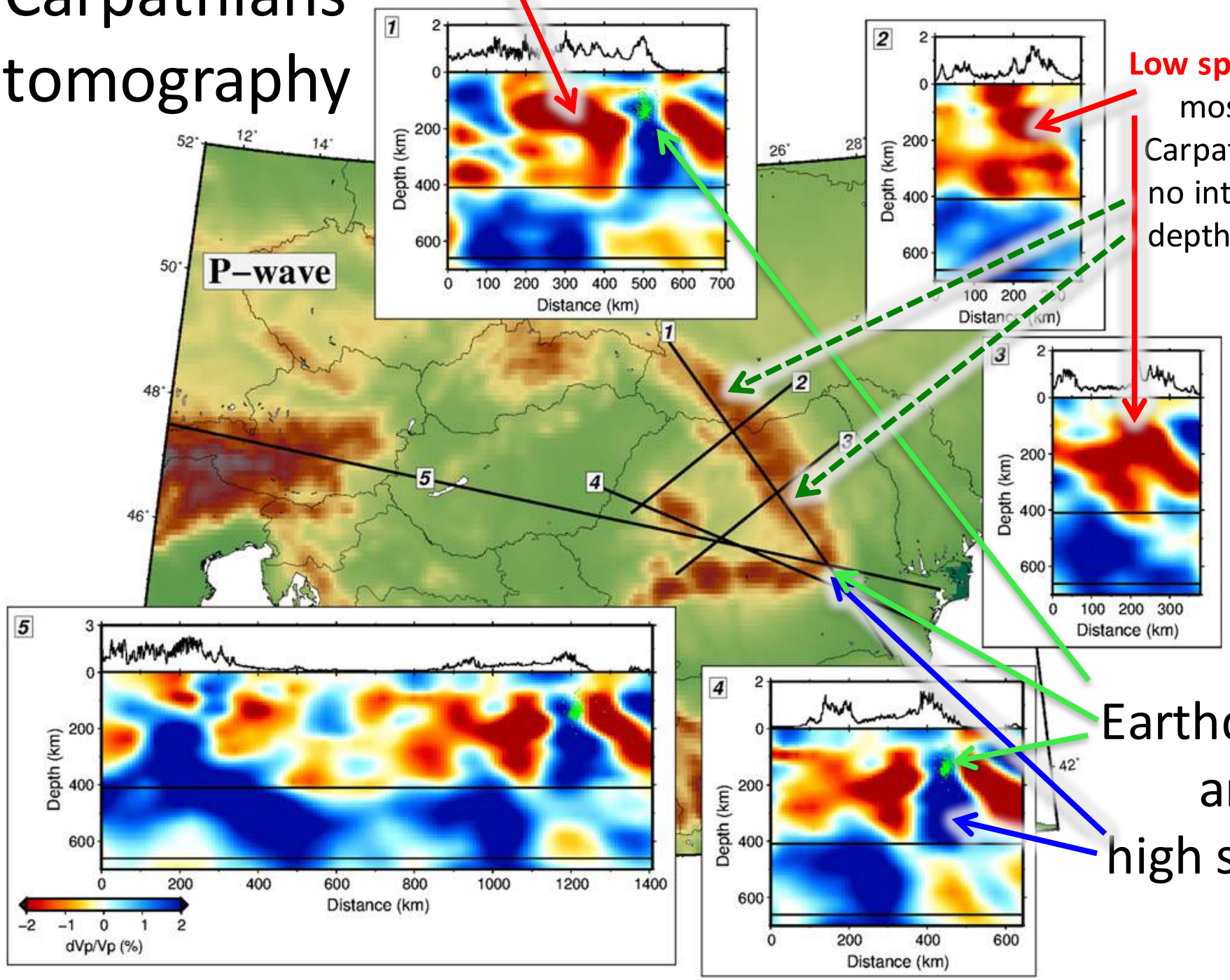


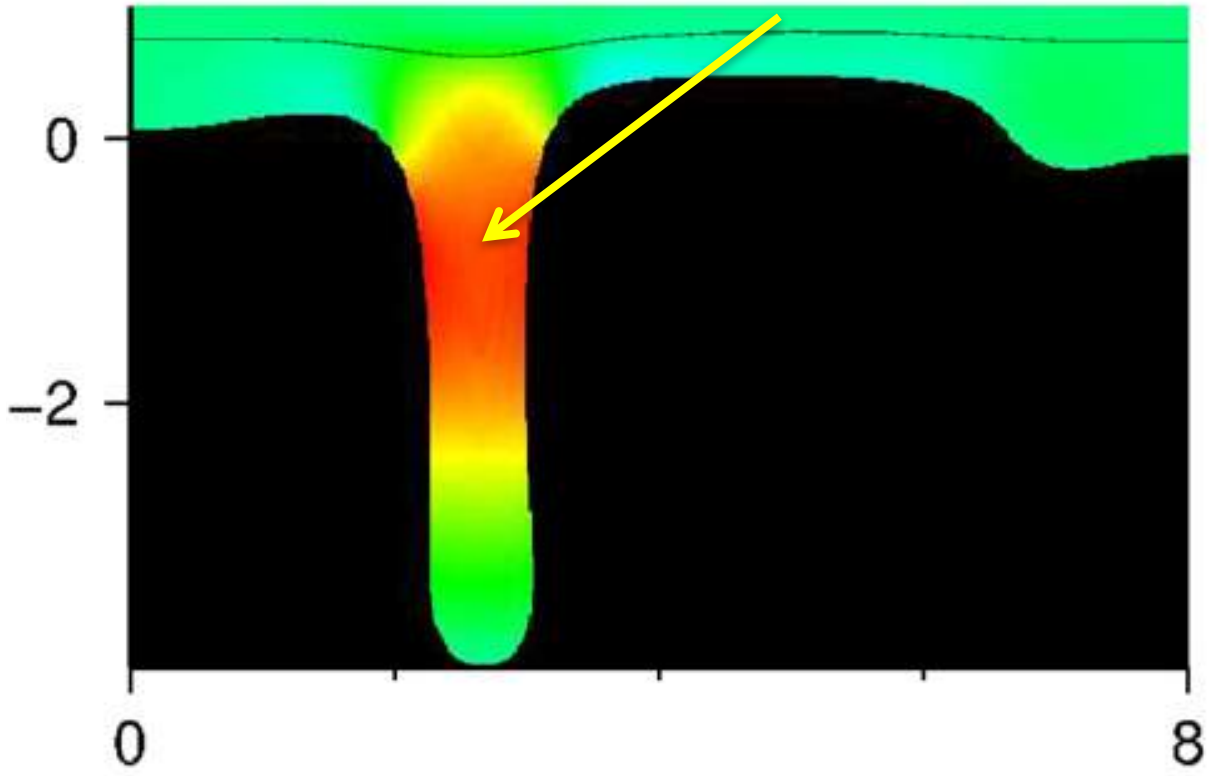
Low speeds under most of the Carpathians and no intermediate depth seismicity

[Ren et al. EPSL, 2012]

Earthquakes and high speeds

Strain rates from seismic moments of earthquakes and strain rates in a sinking blob

Sinking blob: **High extensional strain rate**



[Lorinczi and Houseman, *Tectonophysics* 2009]

Strain rates from seismic moments of earthquakes and strain rates in a sinking blob

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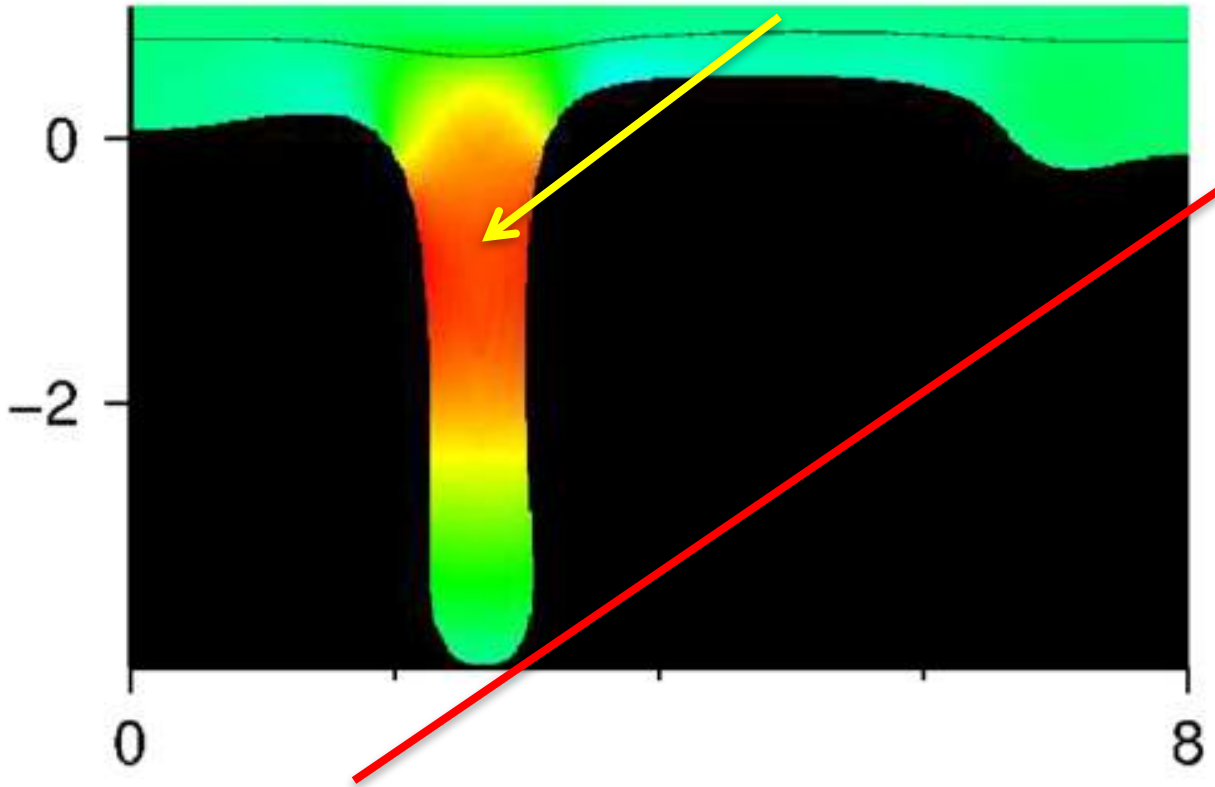
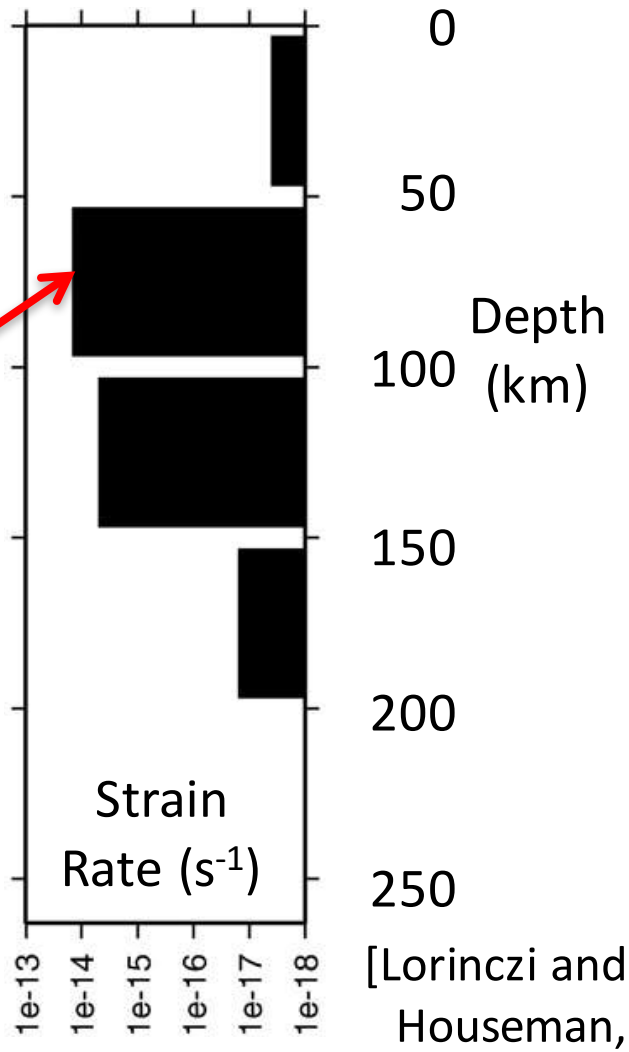




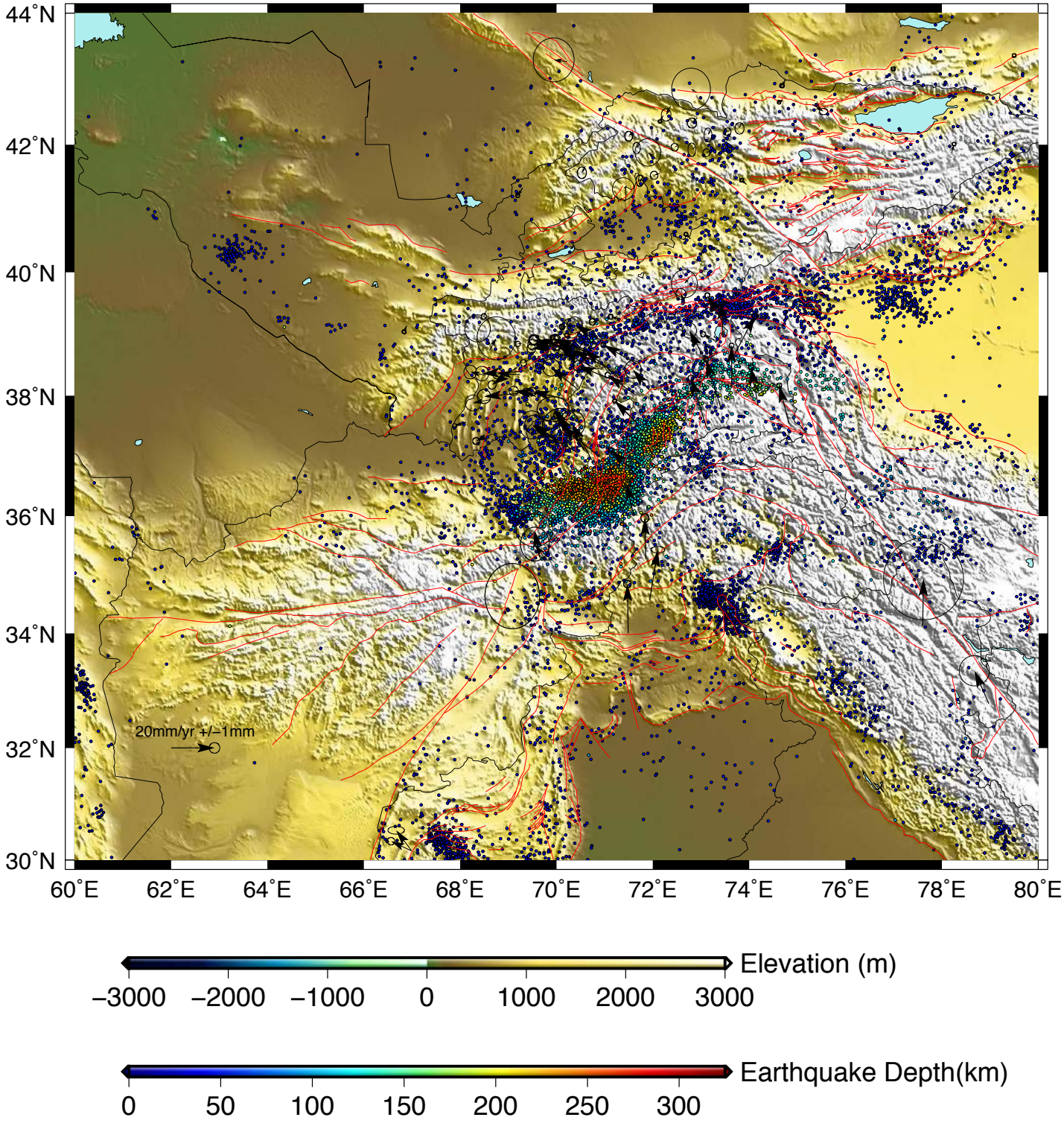
[Lorinczi and Houseman, *Tectonophysics* 2009]

$1.1 \times 10^{-14}\ s^{-1}$ = 35% Myr^{-1} or 18 mm/yr

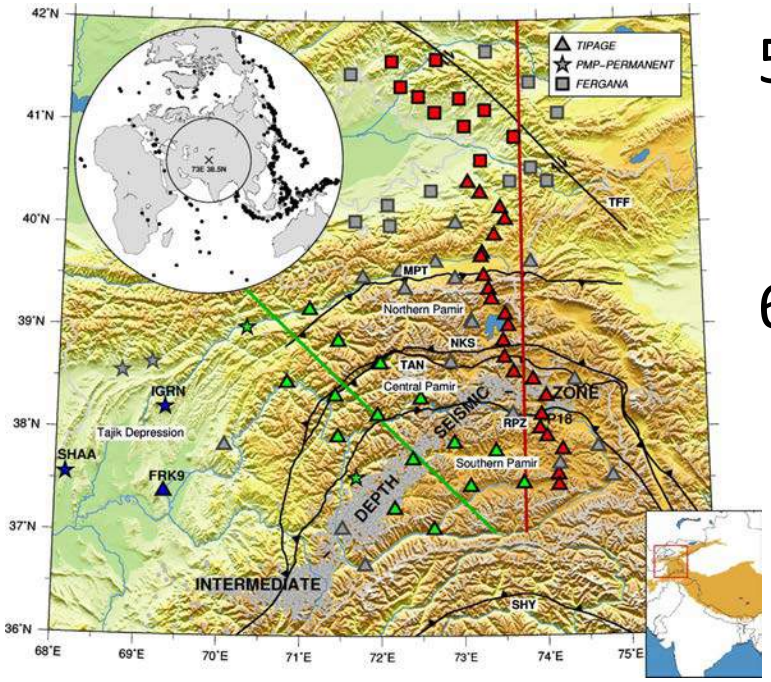
Thus, stretching by 2 times, in 3 Myr

The bottom sinks at 25 mm/yr with respect to the top.

Hindu Kush and Pamir: shallow and intermediate depth earthquakes



Pamir: Migrated receiver functions

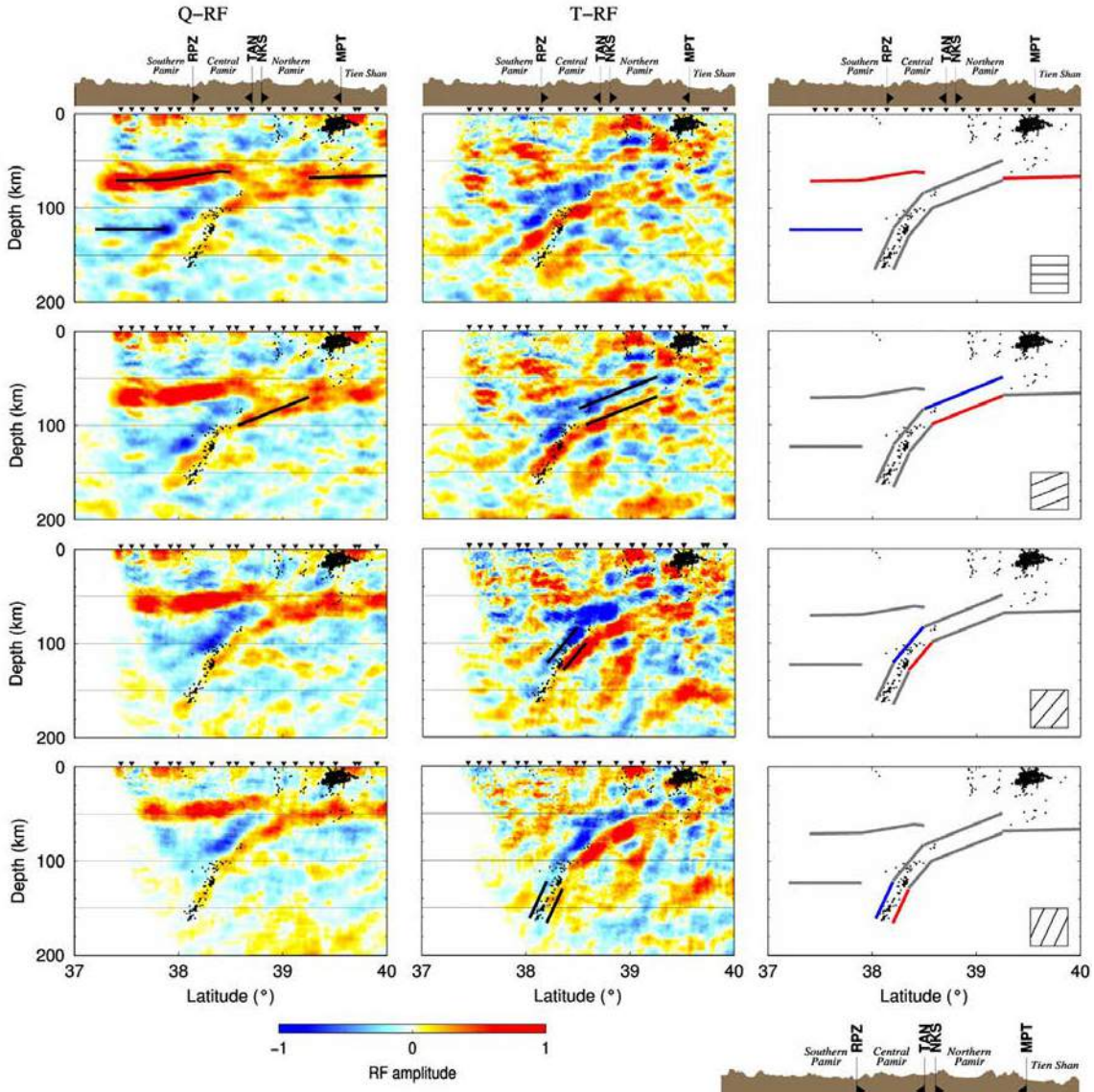


No Dip

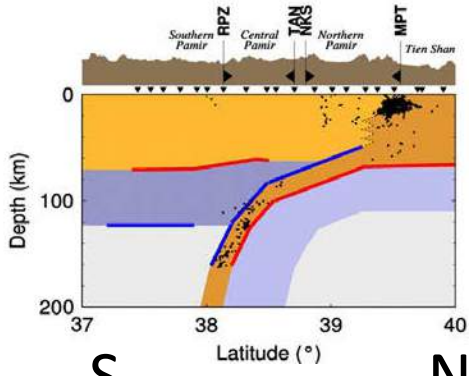
22°

50°

65°



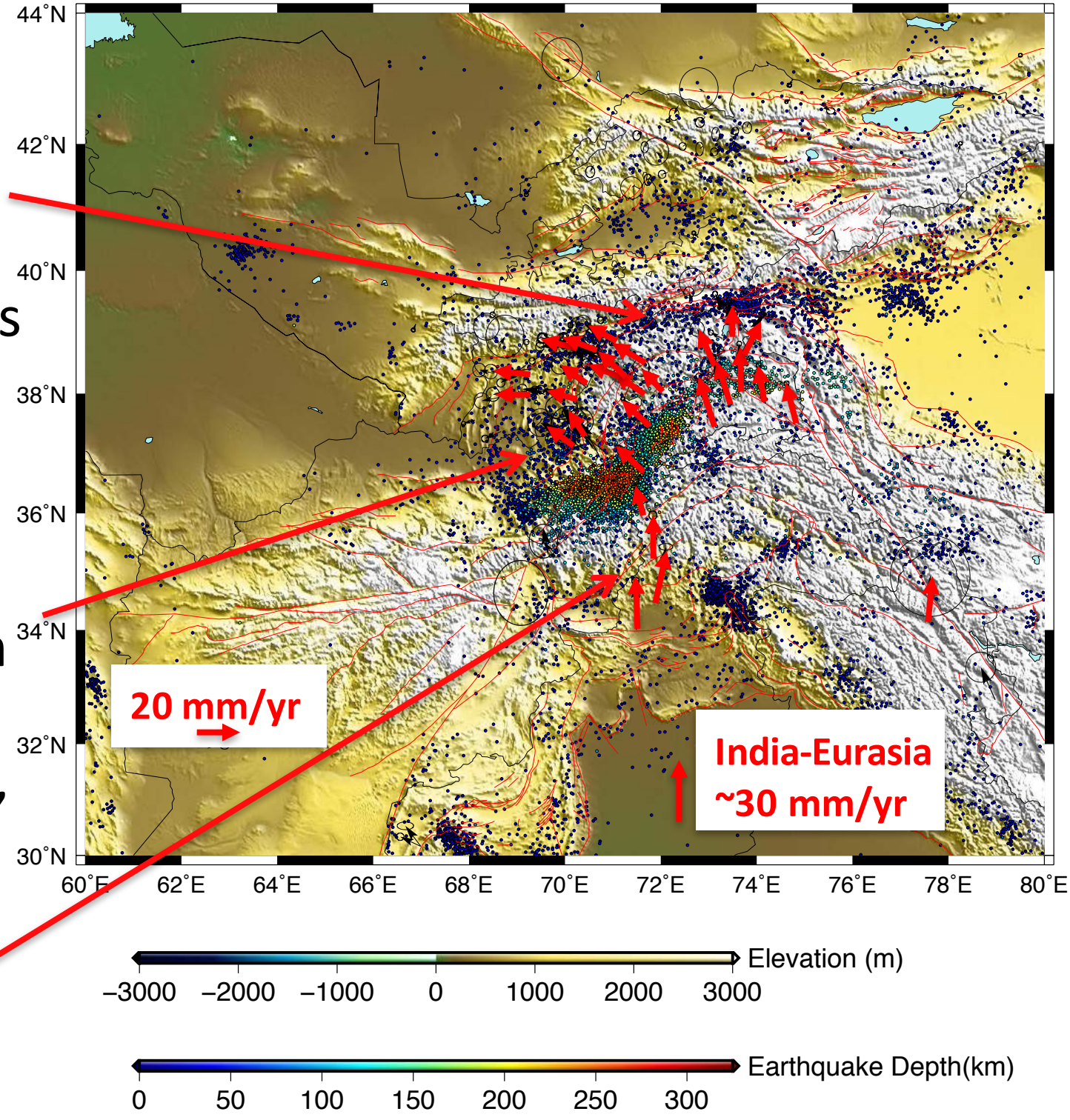
[Schneider et al., *EPSL*, 2013]



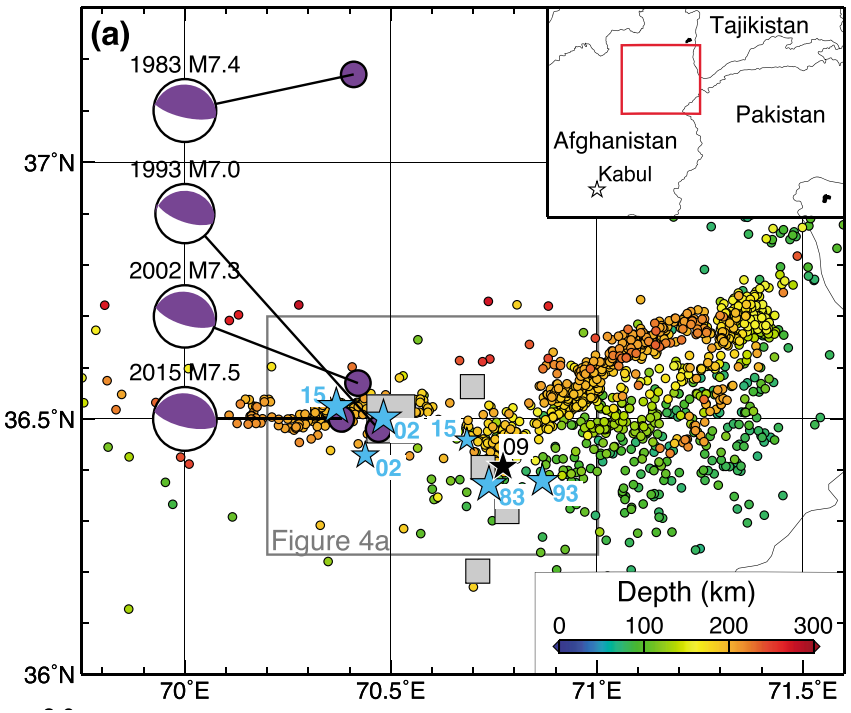
S N

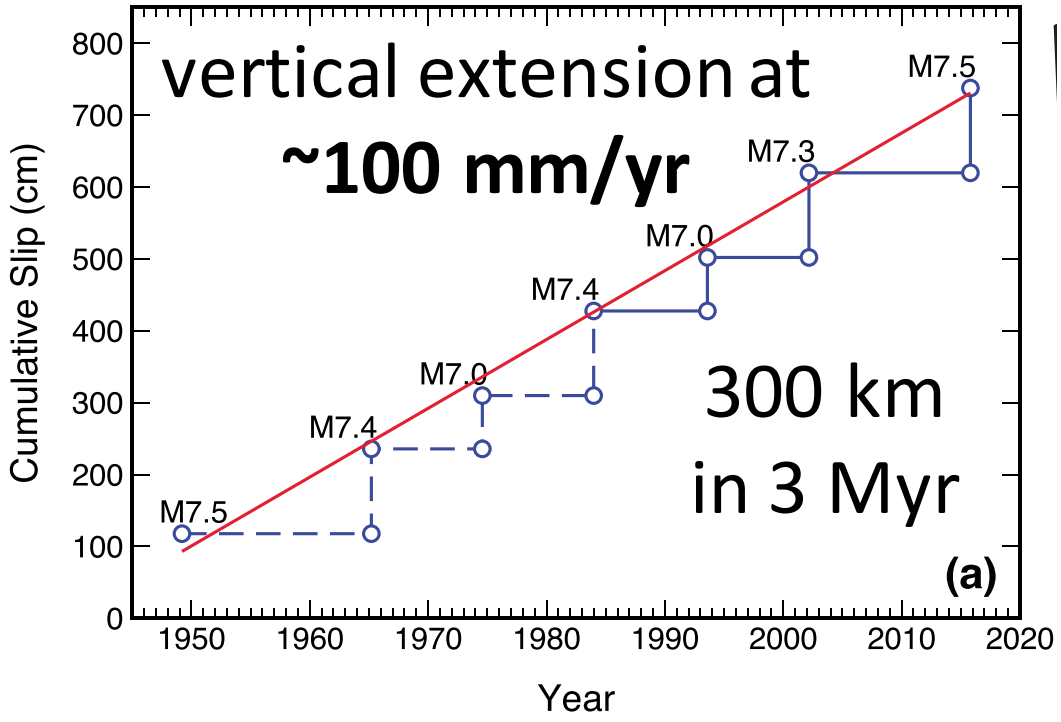
Southward subduction beneath the Pamir. GPS gives ~15 mm/yr of N-S shortening.

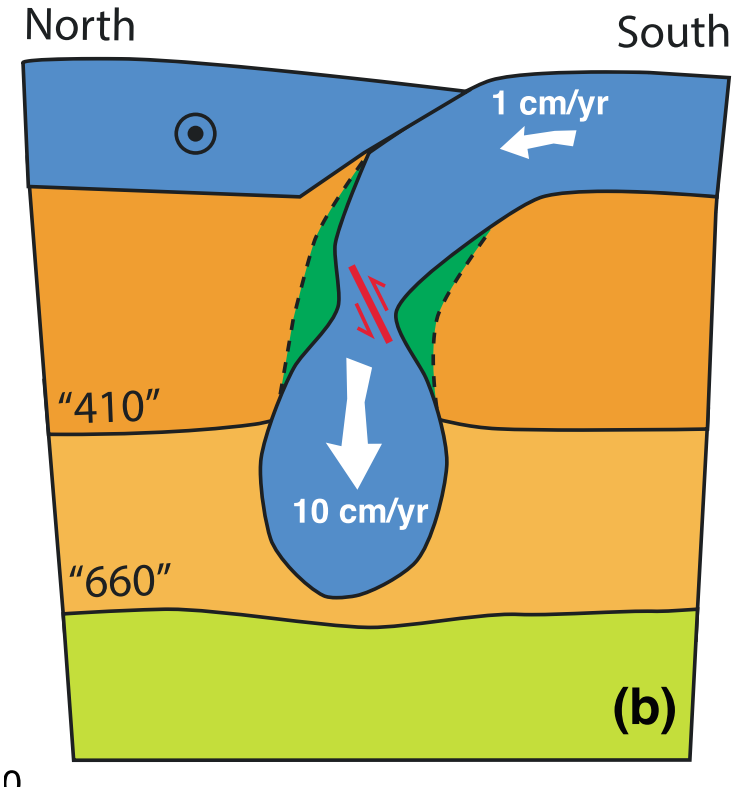
Rapid NW-SE convergence on the NW side of the Hindu Kush, comparable to the rate on the south side.



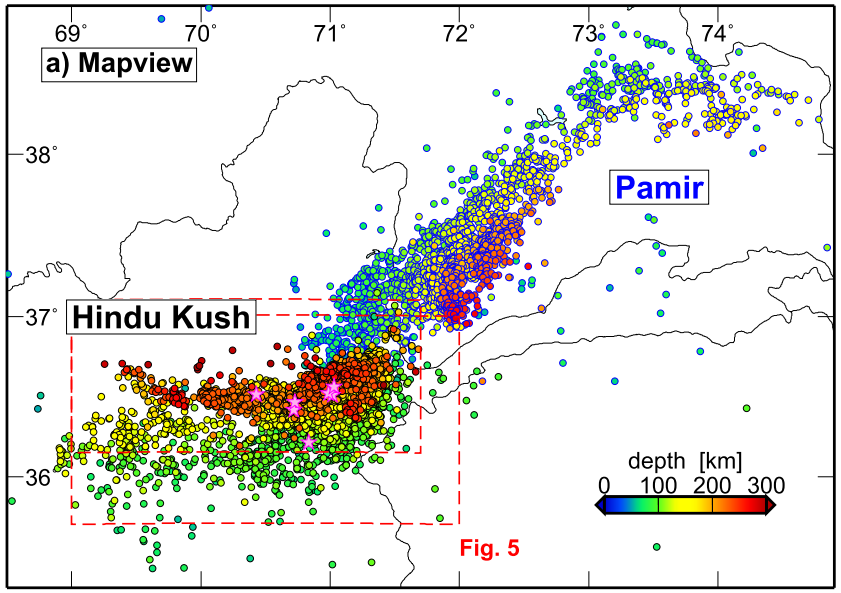
Seismic Moments of Hindu Kush Intermediate-depth earthquakes



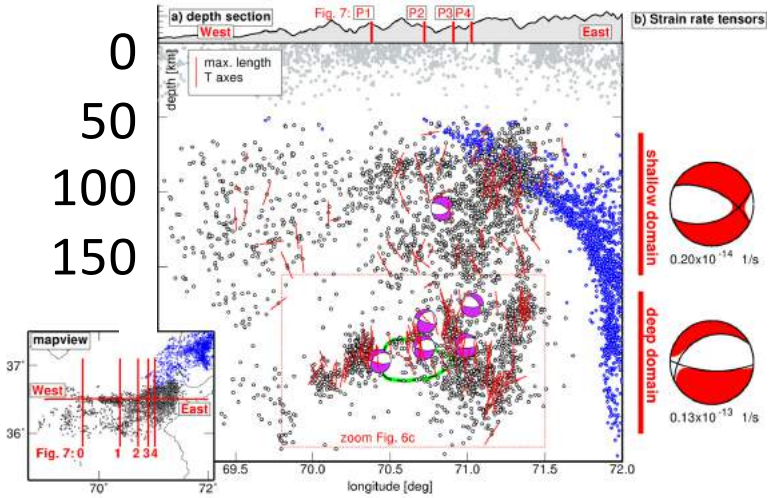




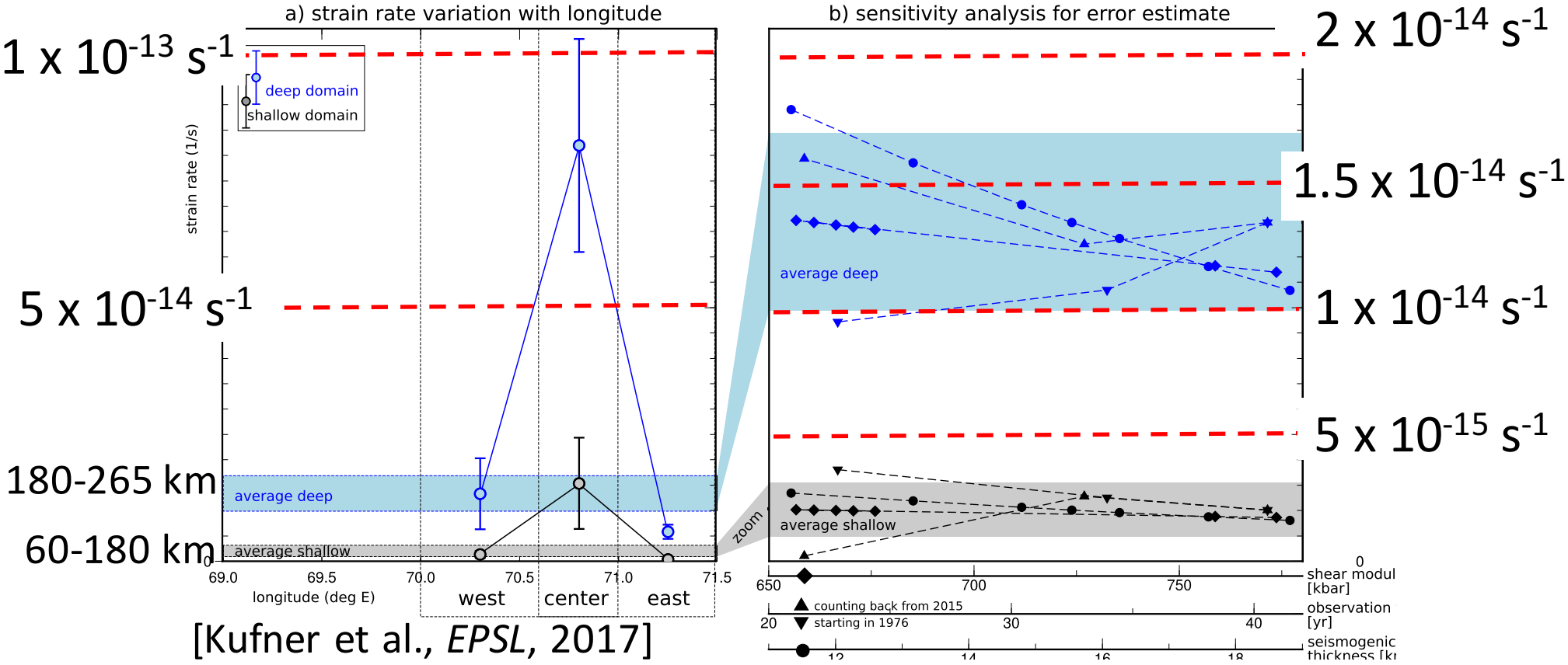
[Zhan and Kanamori, *GRL*, 2016]



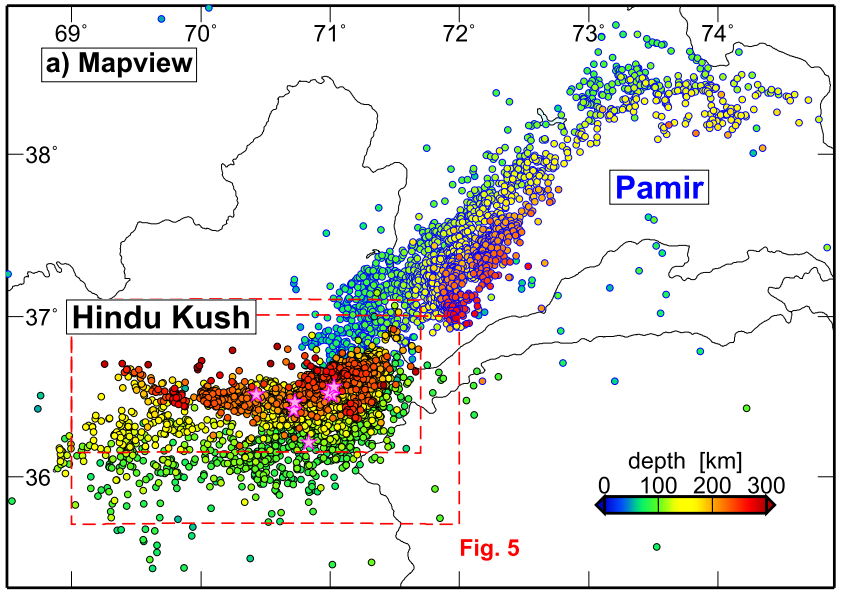
Strain rates from Seismic moments



East-west profile



[Kufner et al., *EPSL*, 2017]



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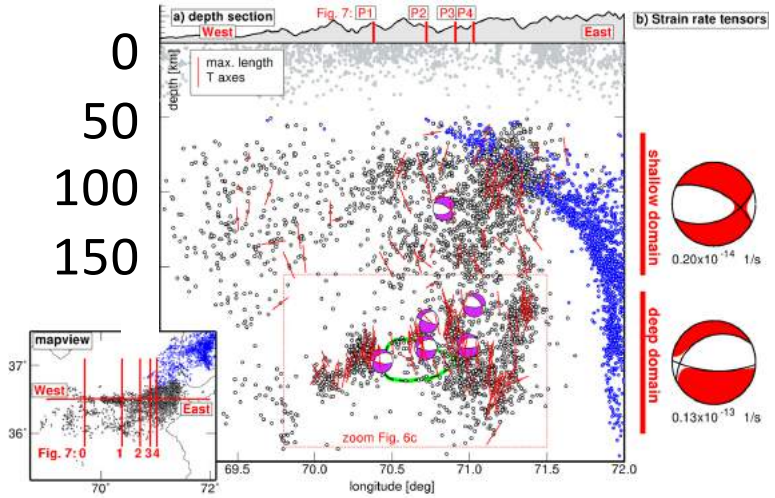

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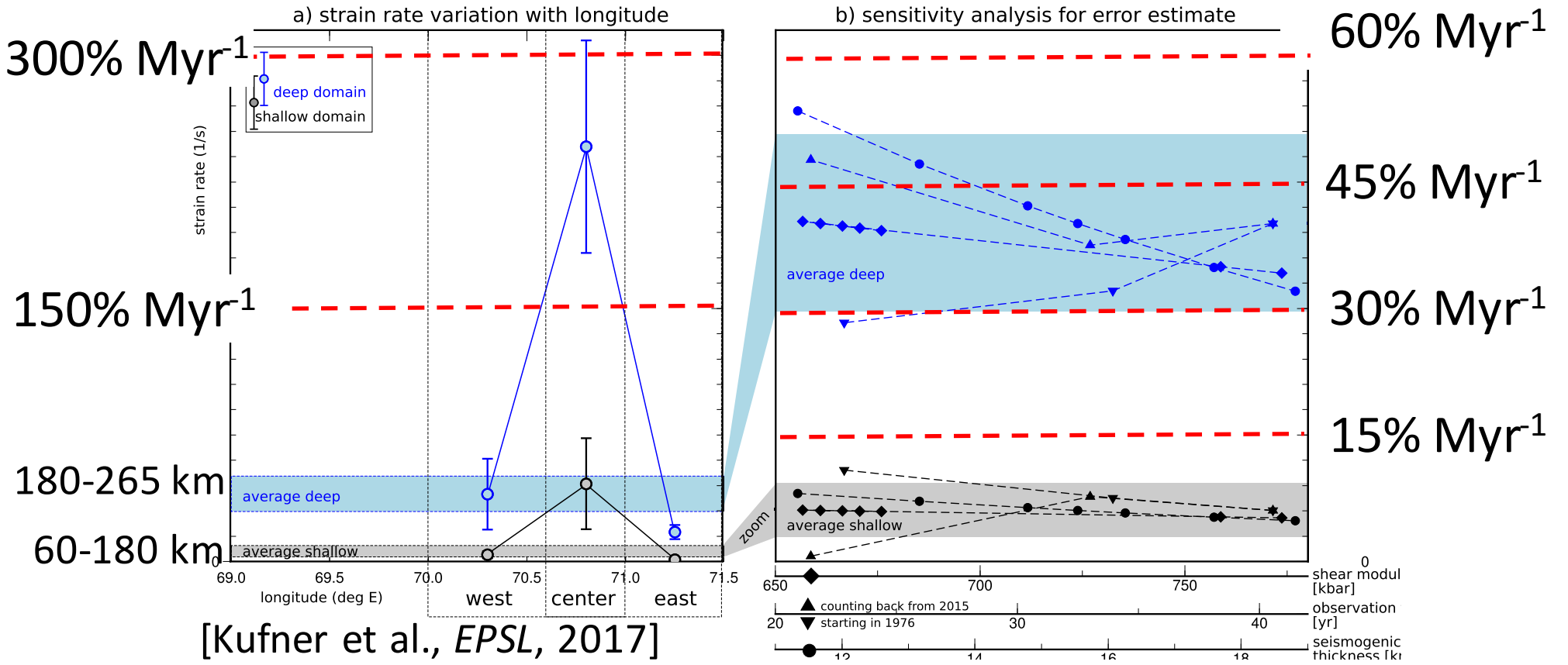
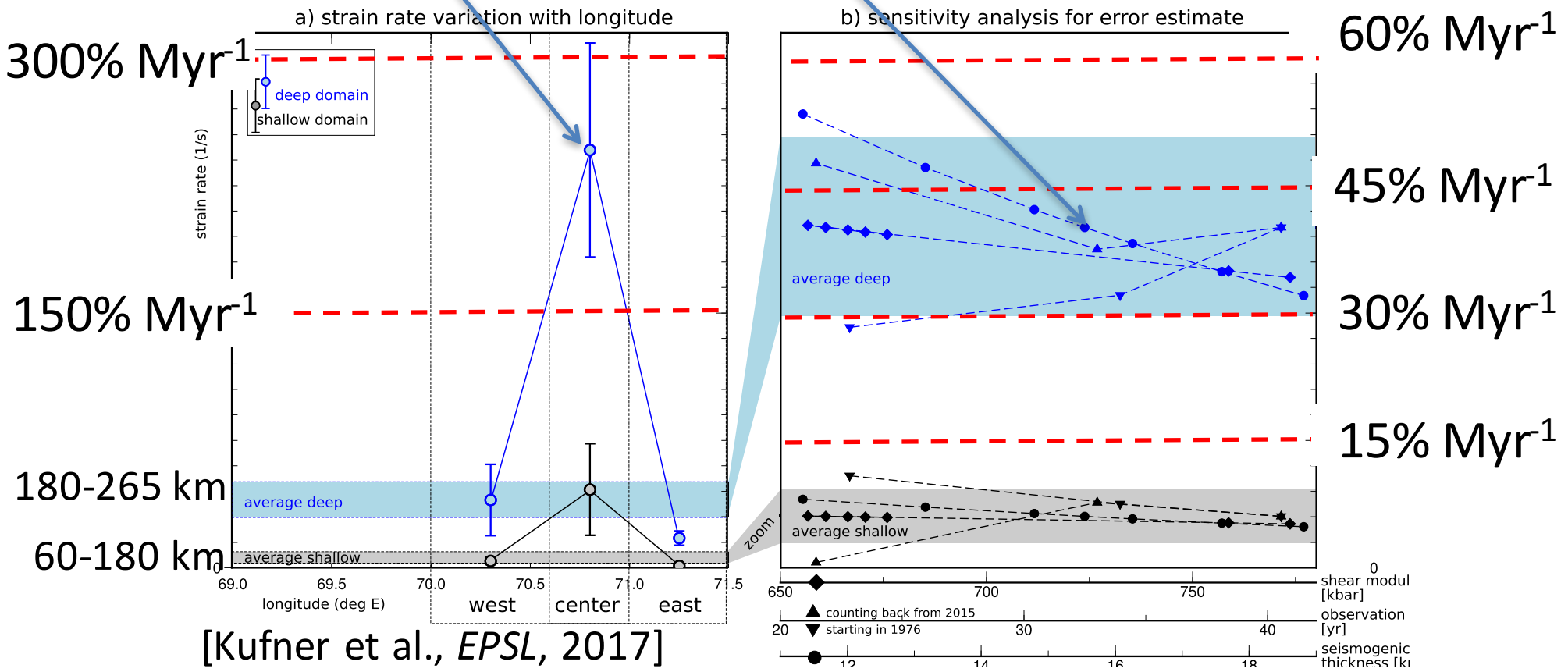


[Kufner et al., *EPSL*, 2017]

Strain at **42% Myr^{-1}** over a depth range of 85 km (180-265 km) implies 36 km/Myr, or 36 mm/yr of divergence between the top and bottom.

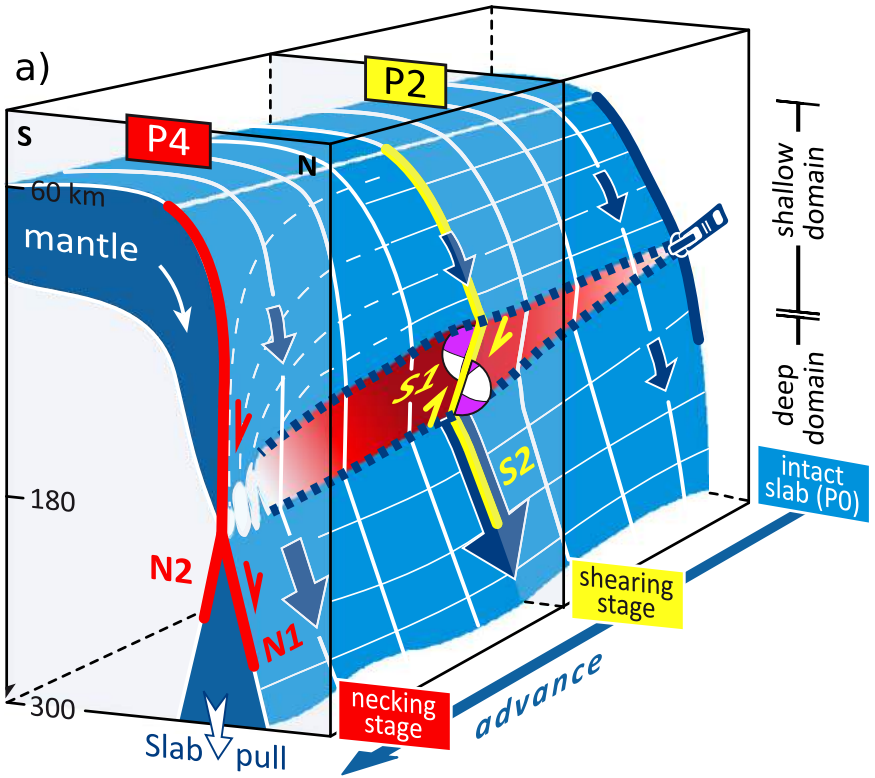
At **200% Myr^{-1}** over the same depth range of 85 km implies 170 km/Myr, or 170 mm/yr, of divergence between the top and bottom.



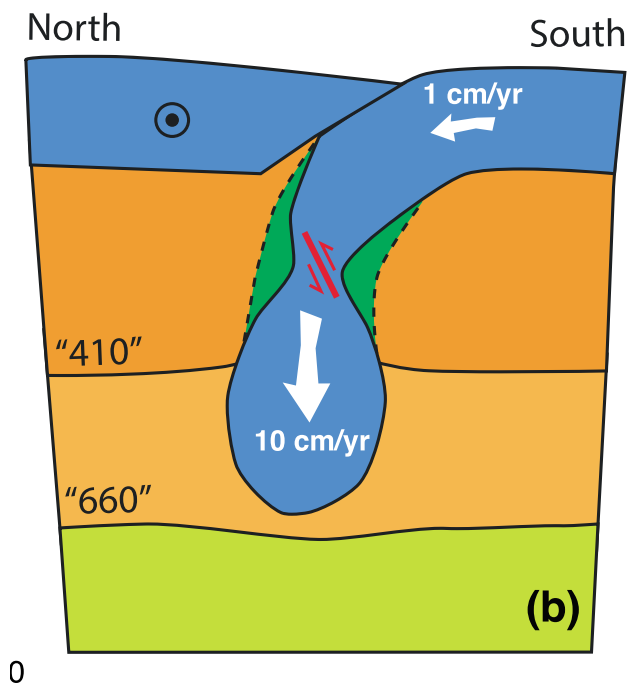
[Kufner et al., *EPSL*, 2017]

Seismic Moments of Hindu Kush Intermediate-depth earthquakes

The deep part sinks at ~36 mm/yr = 36 km/Myr [Kufner et al., 2017] (if not 100 mm/yr = 100 km/ Myr [Zhan and Kanamori [2016]) with respect to the shallow part.



[Kufner et al., EPSL, 2017]



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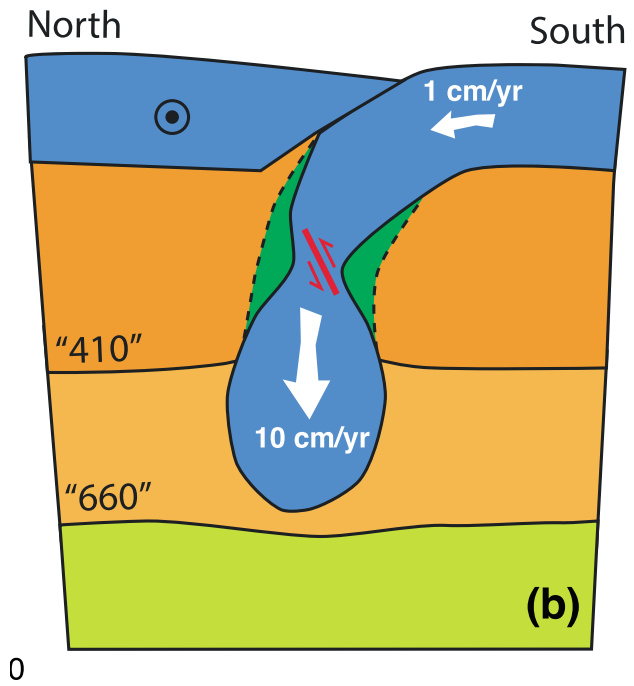

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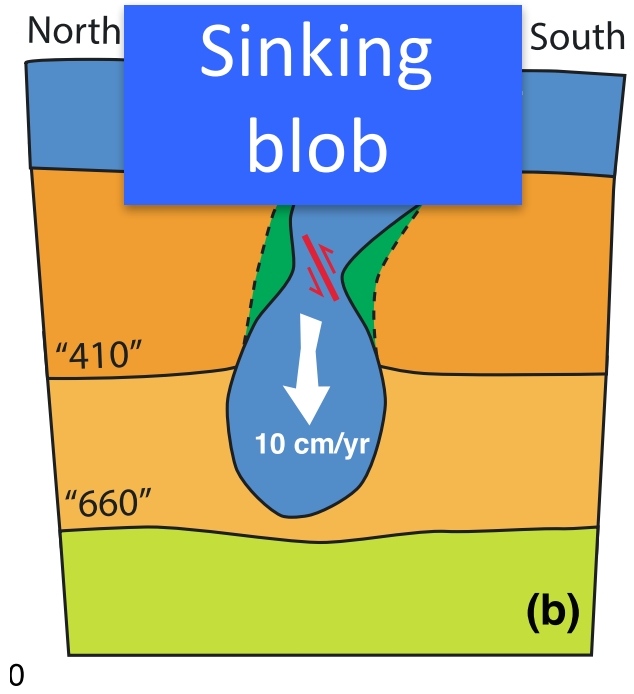
As shown by GPS, however, convergence across the Hindu Kush is absorbed equally on the NW and SE sides. Evidence of subduction of the Indian plate does not exist. A simpler interpretation is that a blob of lithosphere sinks and stretches.



[Zhan and Kanamori, *GRL*, 2016]

The old idea, revised:

1. *Intermediate- and deep-focus earthquakes occur within ~~downgoing slabs of~~ **mantle** lithosphere.*
2. *Of course, because temperatures are low there.*
3. *Conversely, the occurrence of intermediate- and deep-focus earthquakes implies the presence of ~~downgoing slabs of~~ **cold mantle** lithosphere.*

Conclusion

Seismic evidence from the Carpathians [Lorinczi and Houseman, 2009] and the Hindu Kush [Kufner et al., 2017; Zhan and Kanamori, 2016] shows the **sinking** and **stretching** of **blobs of mantle lithosphere** ("deblobbing"), and hence the **removal** of **mantle lithosphere** (but not as "delamination" as Bird [1978] defined it).