Characteristics of earthquakes in damaged, heterogeneous, and temporally evolving fault zones

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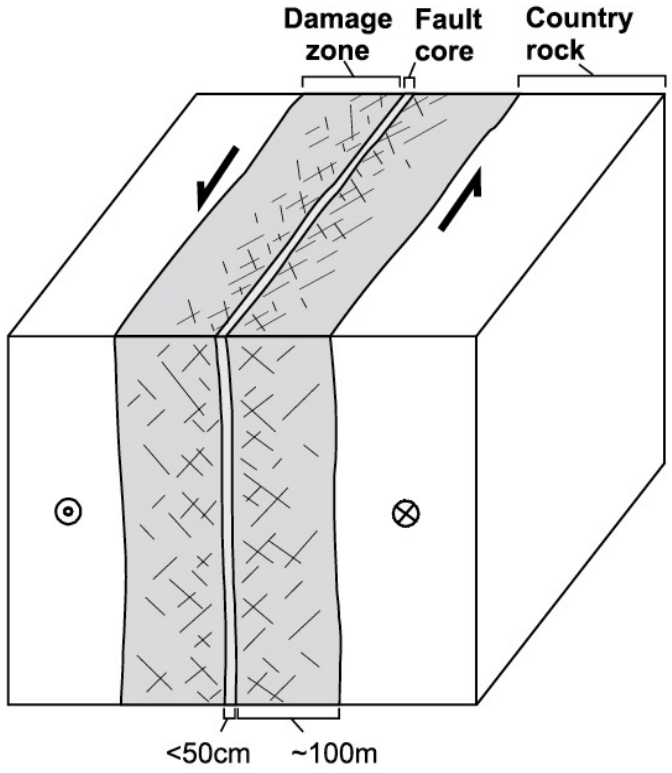
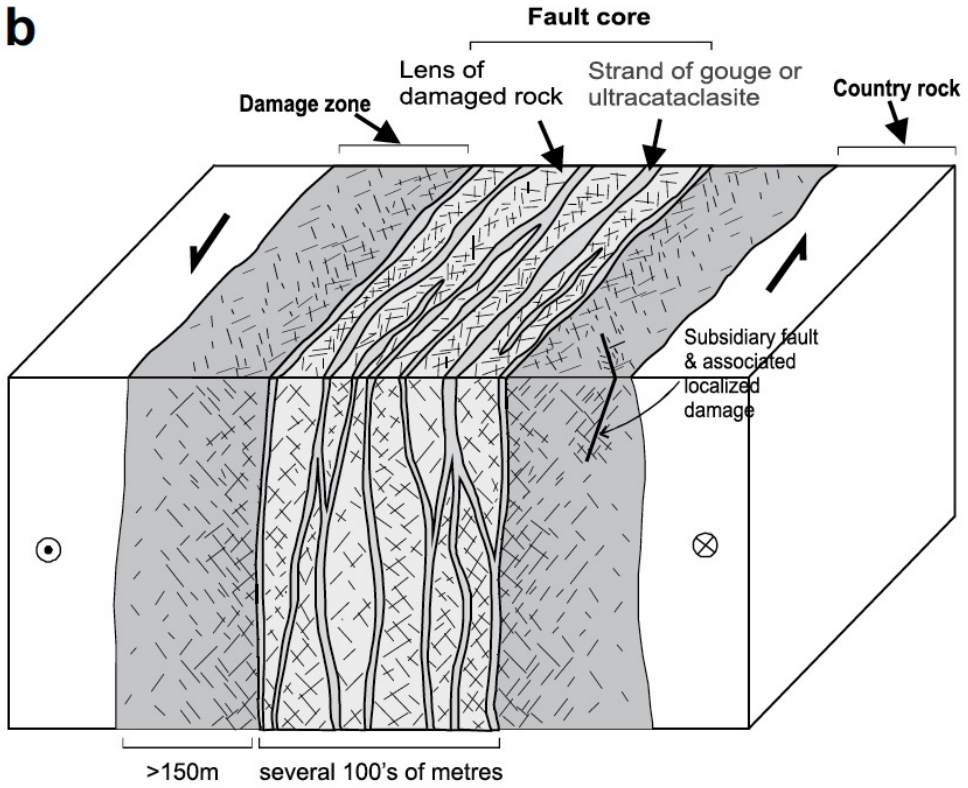
Faults are not planes. They are heterogeneous structures of rocks containing fault cores and damaged rocks.

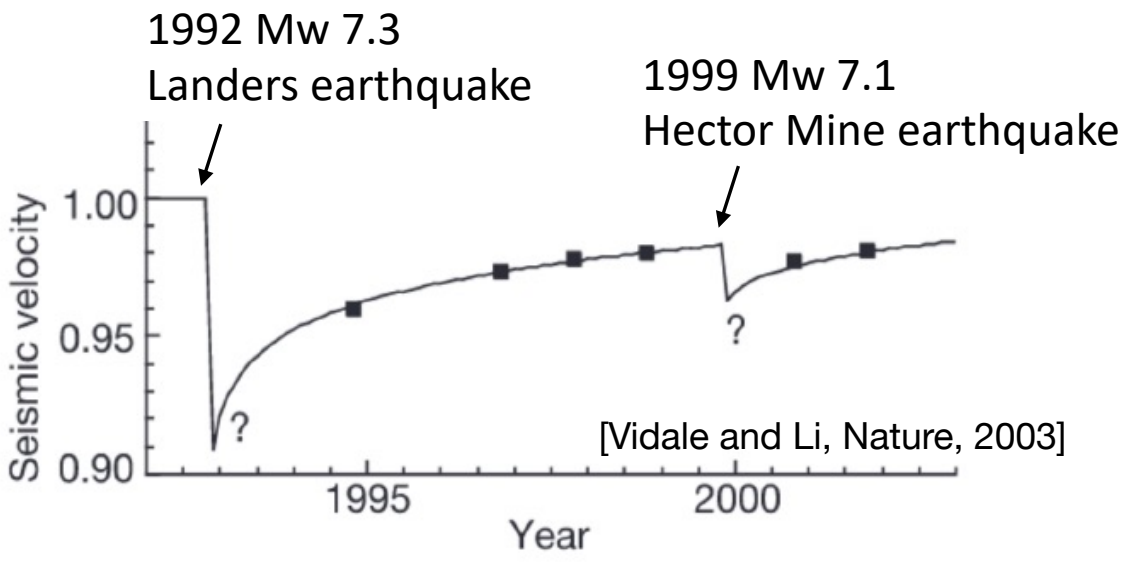
[Chester and Logan, Pageoph, 1986]

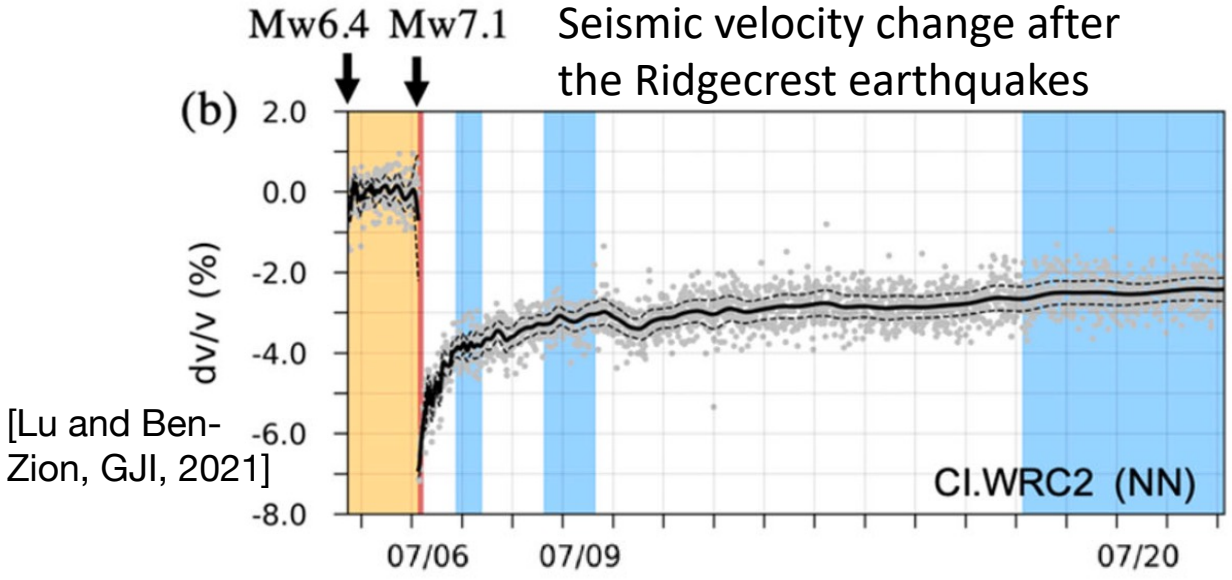




[Faulkner, Tectonophysics, 2003;
Mitchell and Faulkner, JSG, 2011]

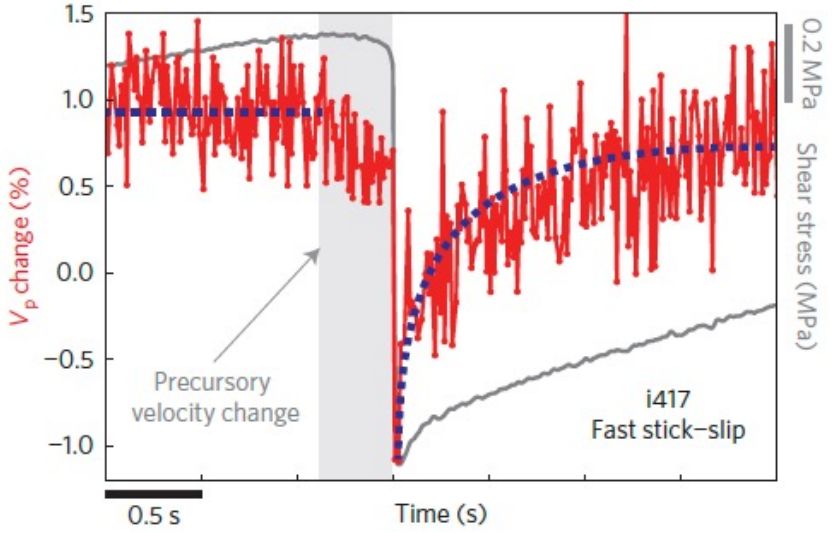
Fault damage zones evolve temporally due to coseismic damage and interseismic healing.

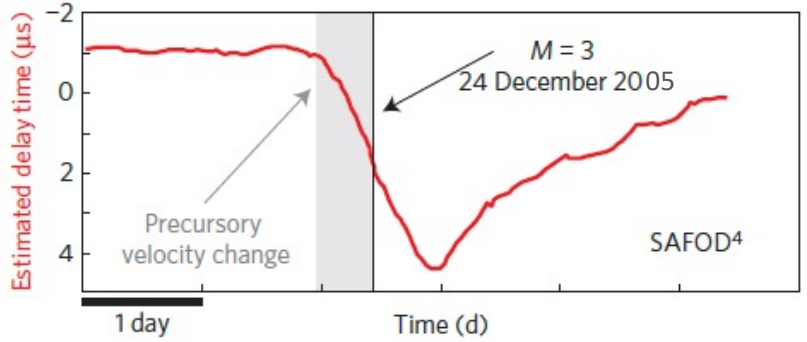




Seismic velocity change after the Ridgecrest earthquakes

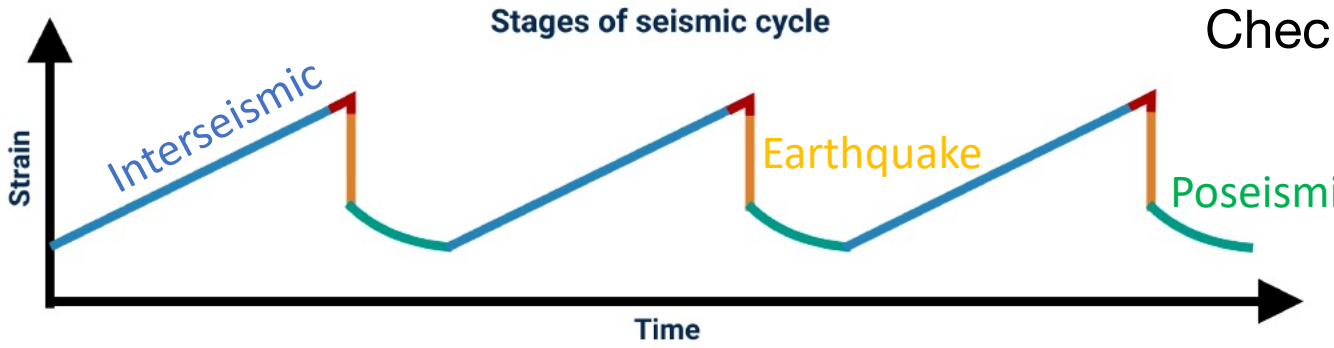
[Lu and Ben-Zion, GJI, 2021]





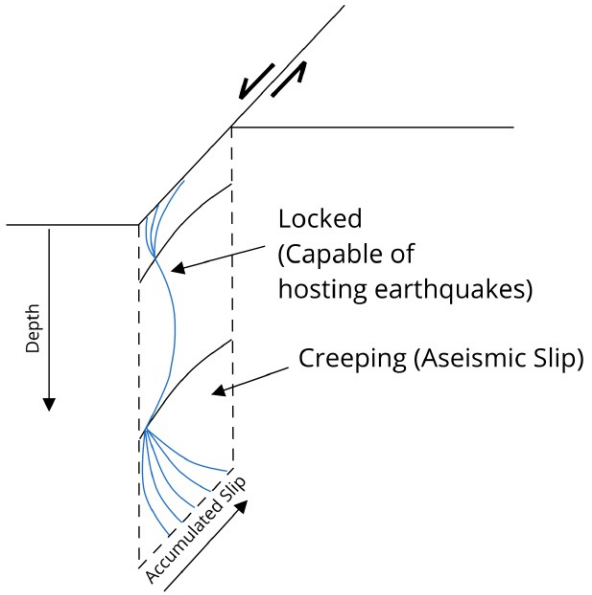
[Scuderi, et al., Nat. Geosci., 2016; Niu et al., Nature, 2008]

We use 2-D fully dynamic earthquake cycle models to understand the influence of fault zone structure on seismic and aseismic slip.

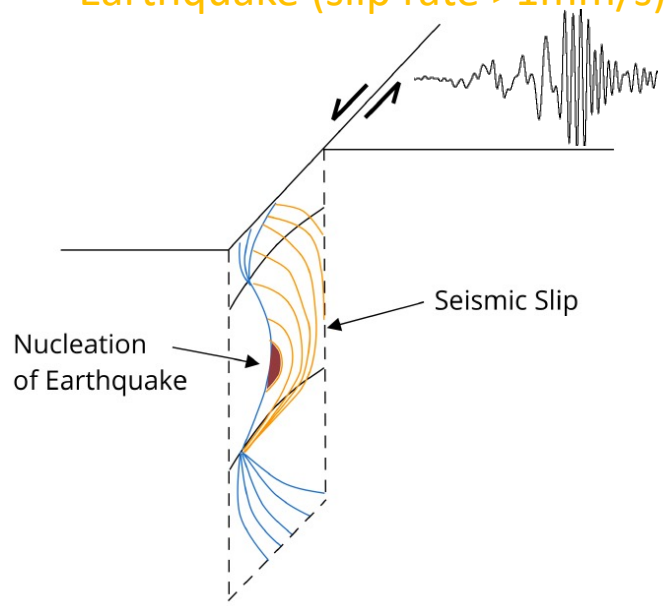


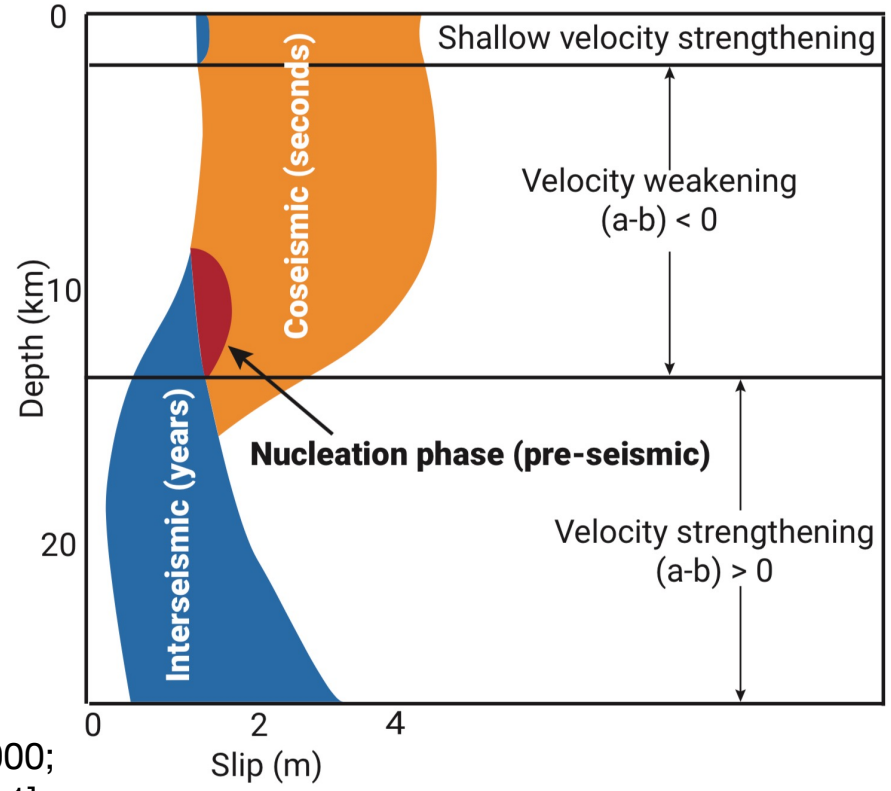
Check out SPEAR on GitHub!

Interseismic deformation



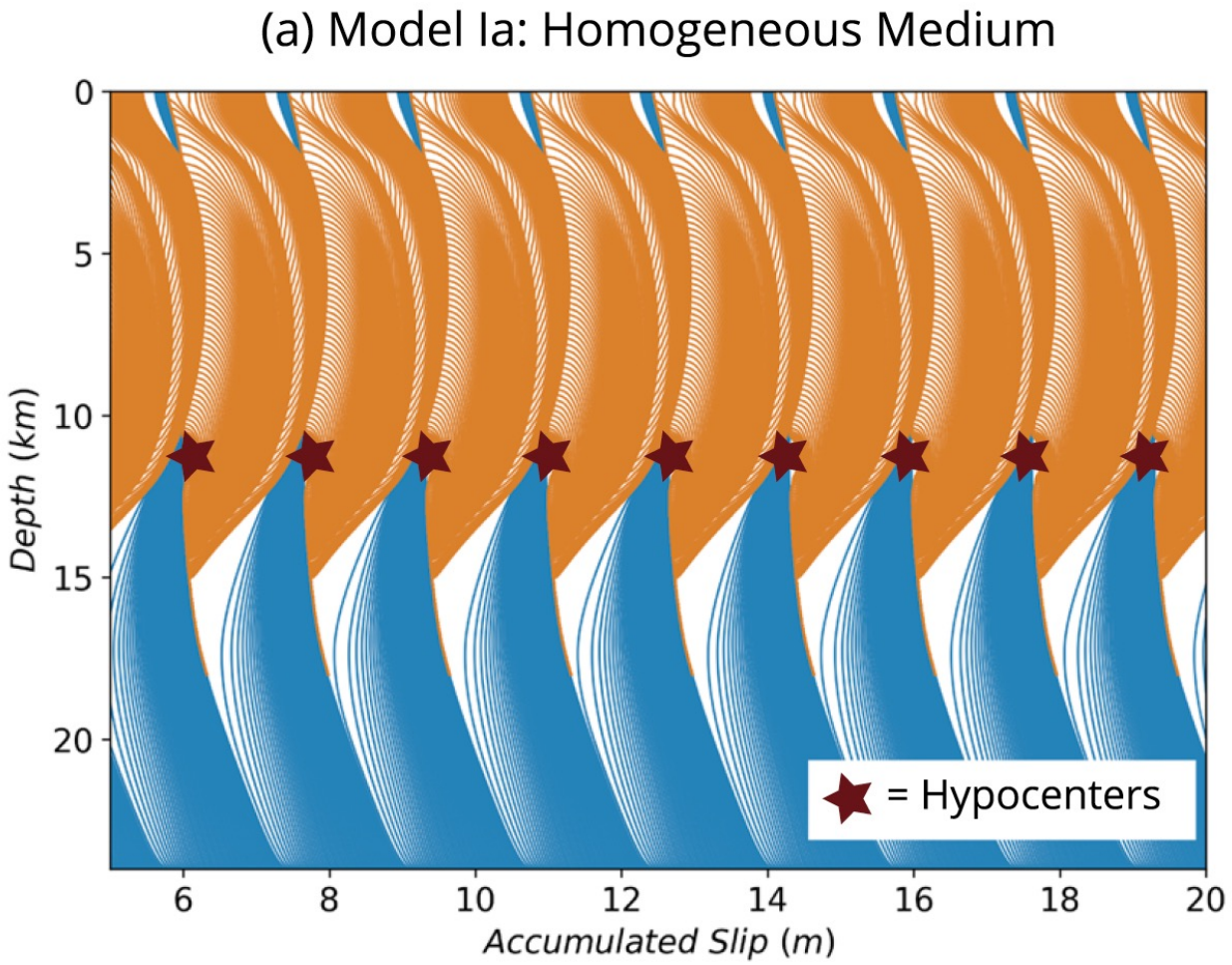
Earthquake (slip rate >1mm/s)

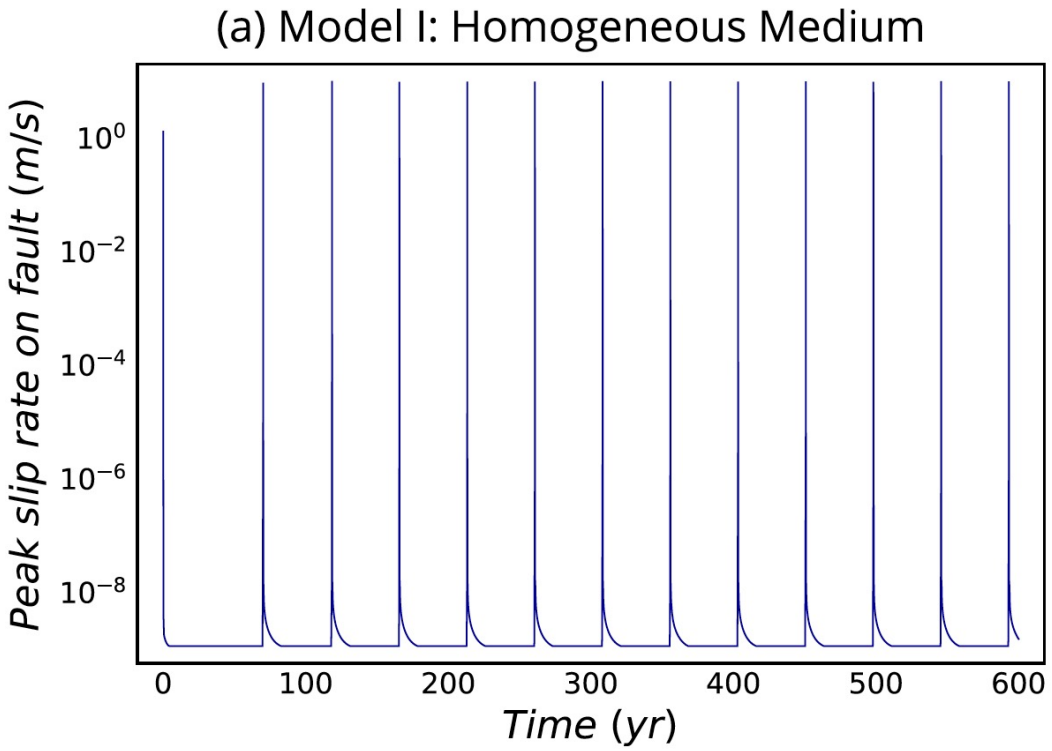




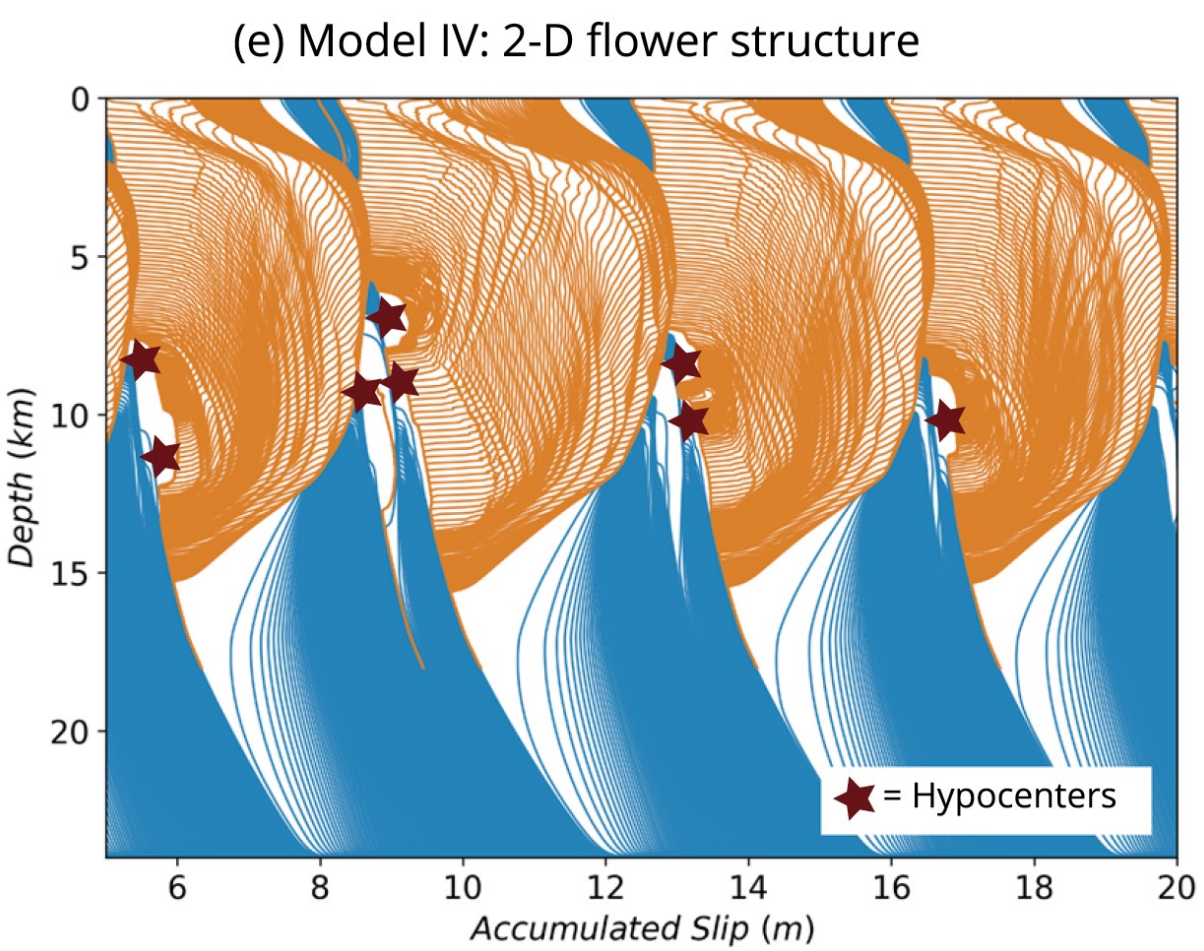
[Lapusta et al., JGR, 2000;
Kaneko et al., JGR, 2011]

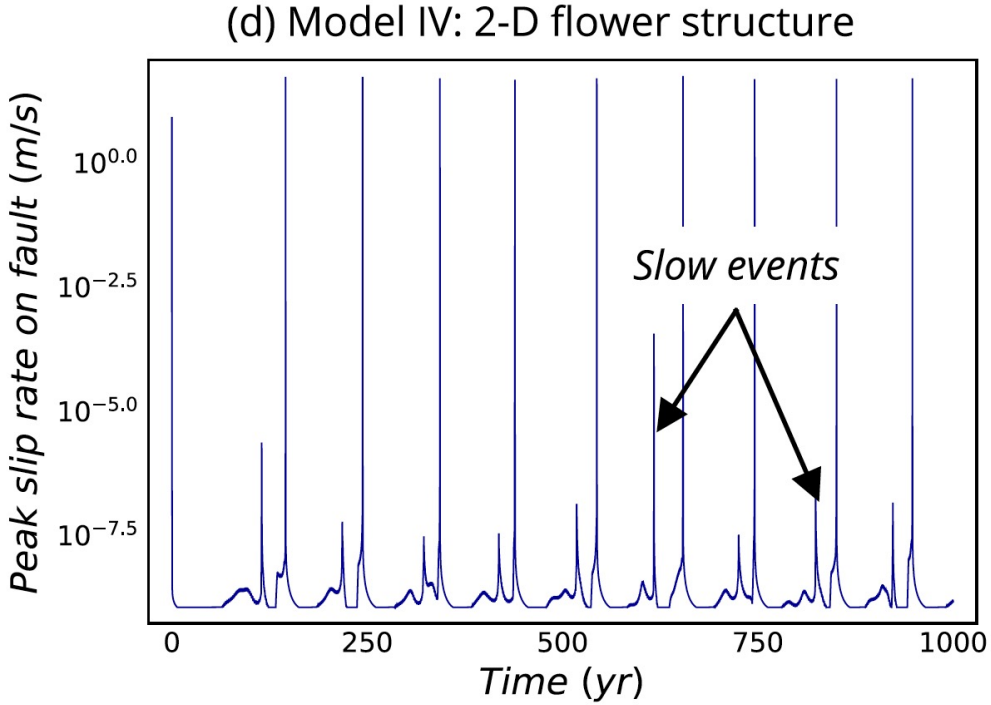
The frictional parameters we use give rise to periodic occurrence of M_w7 earthquakes in homogeneous media.

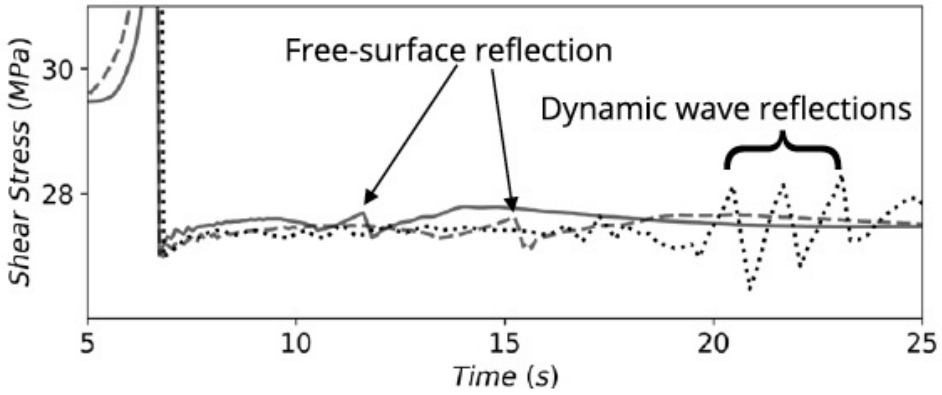




Fault damage zones generate small-scale stress heterogeneities and produce earthquakes of various sizes and hypocenter locations as well as slow events (unsuccessful nucleation of earthquakes).

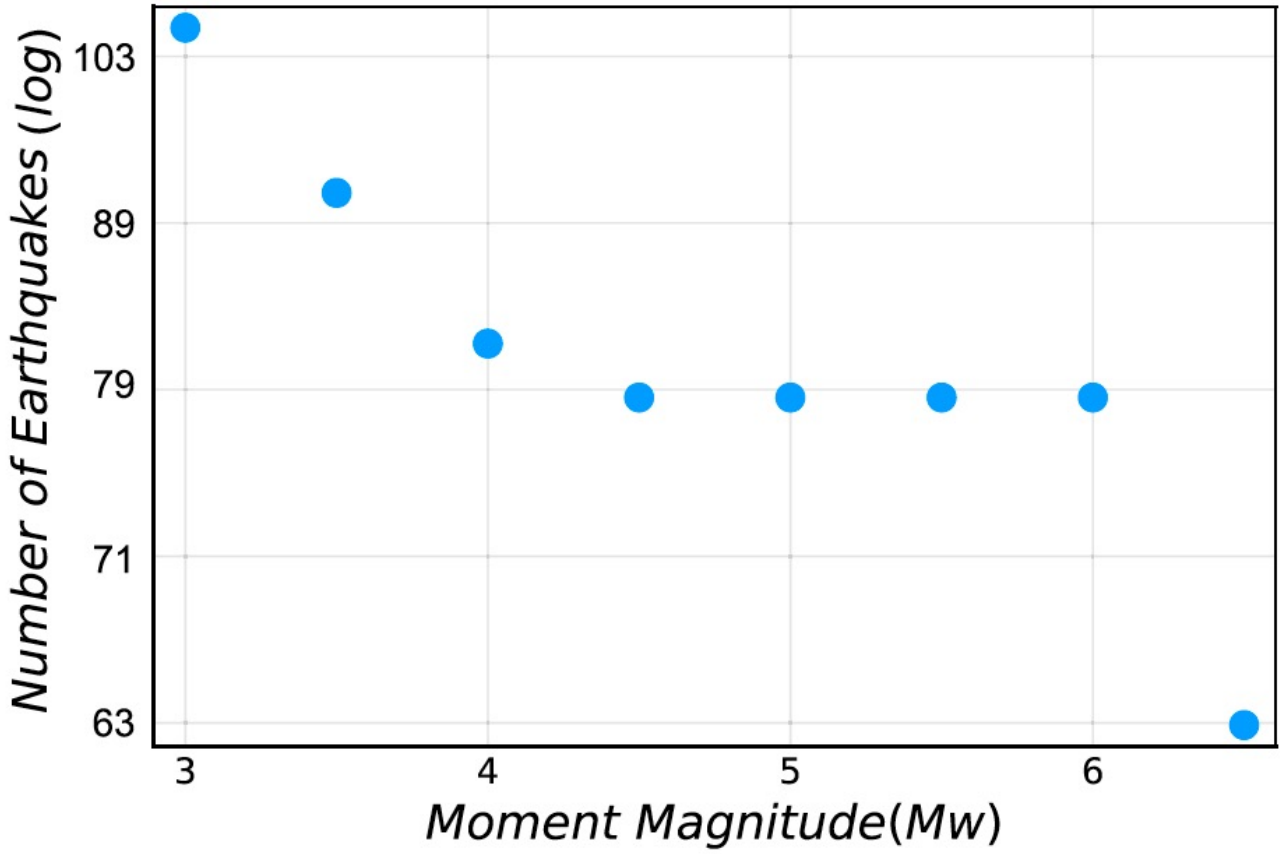






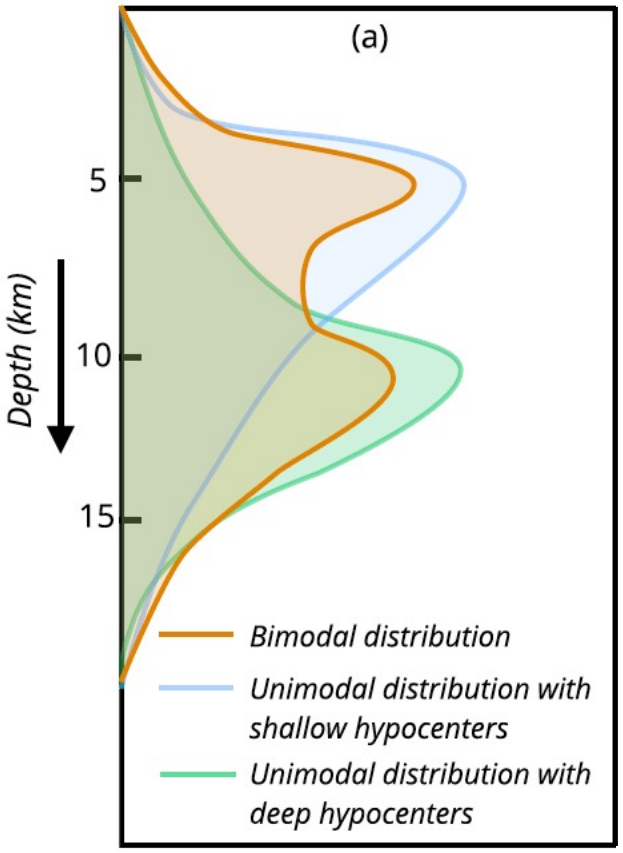
[Thakur et al., JGR, 2020]

There is an increasing number of earthquakes as they become smaller, though the magnitude-frequency distribution (MFD) is different from the Gutenberg-Richter law. Our results show that the MFD observed in nature also manifests the material heterogeneities around faults (Mogi, 1962).

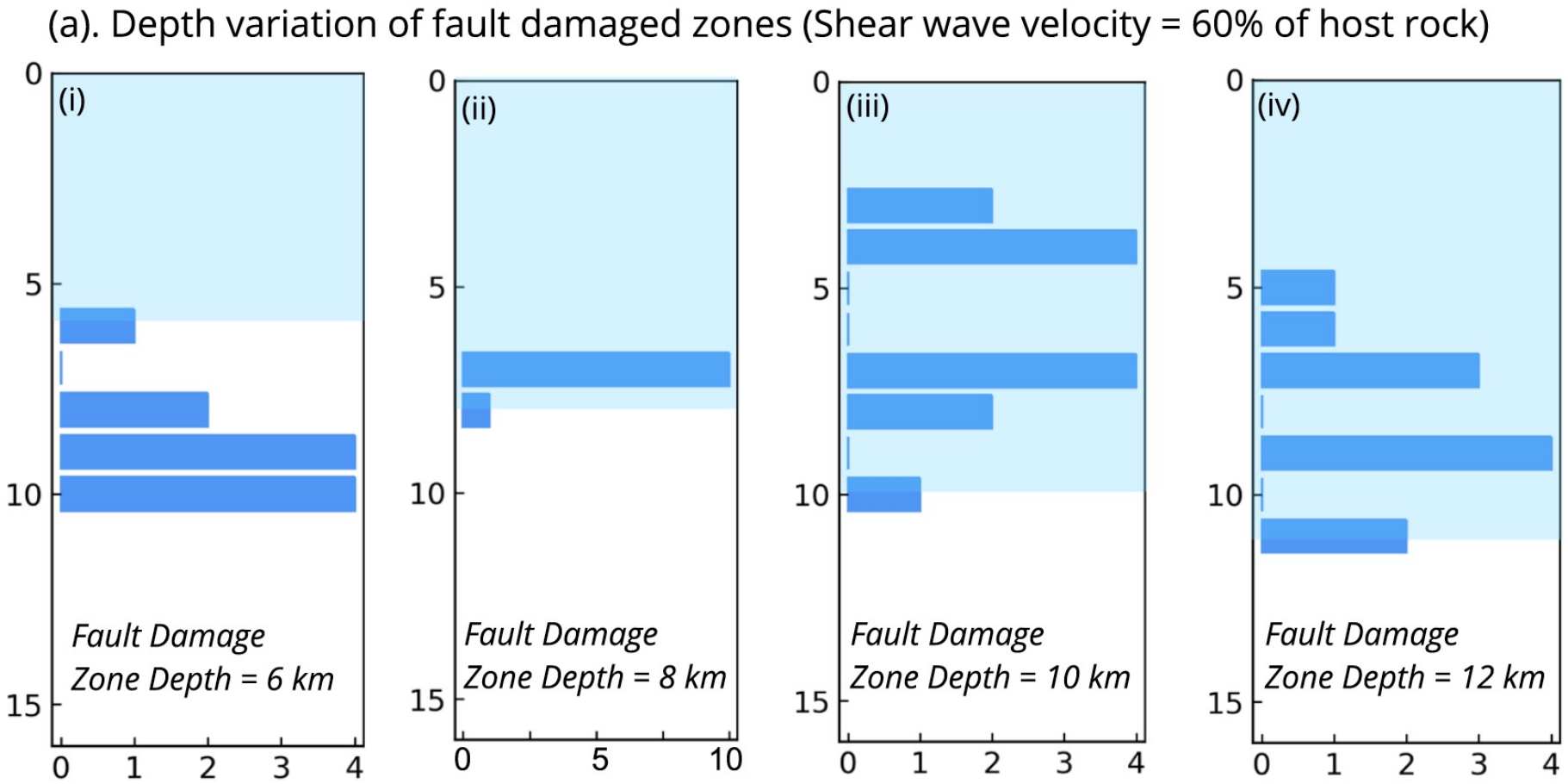


[Thakur et al., JGR, 2020]

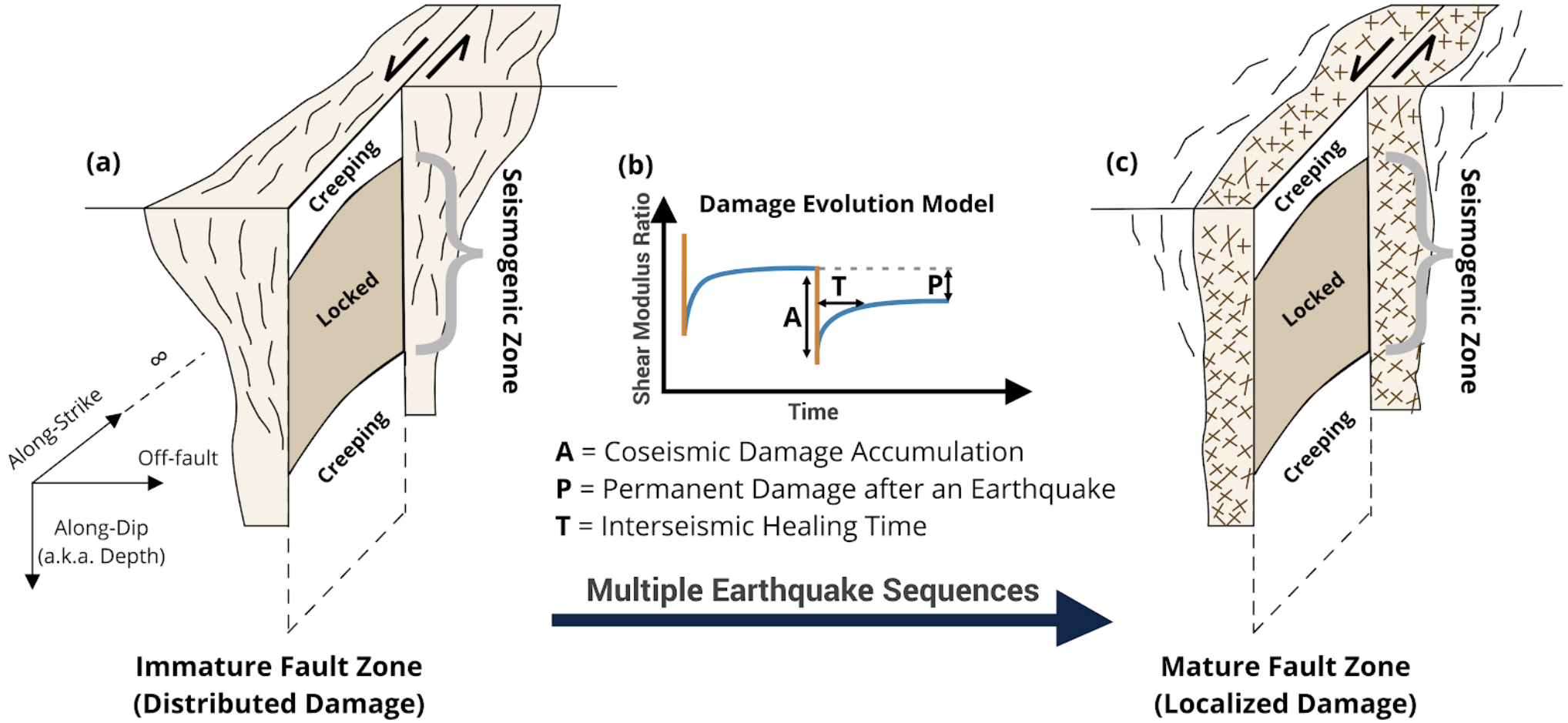
Fault damage zones that penetrate into seismogenic depths tend to cause a bimodal depth distribution of seismicity, i.e., strong clustering of earthquakes at both shallower and deeper depths.



[Thakur et al., JGR, 2020]

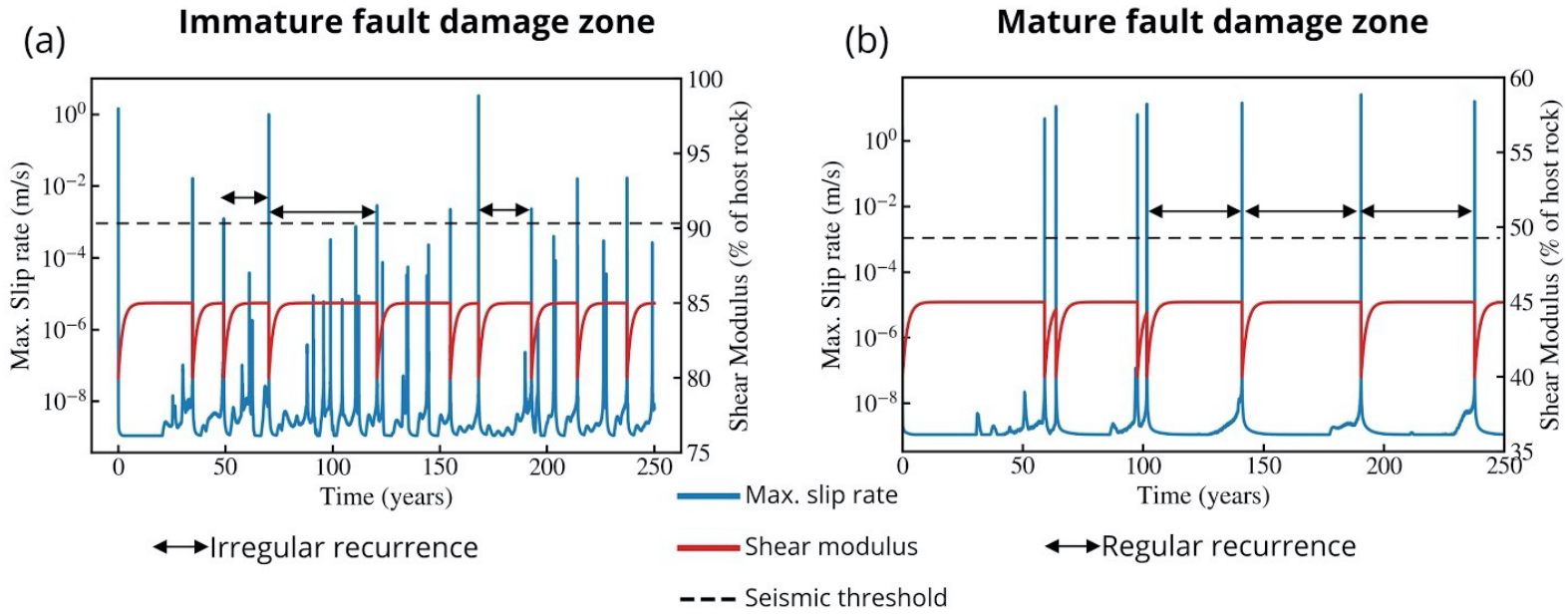


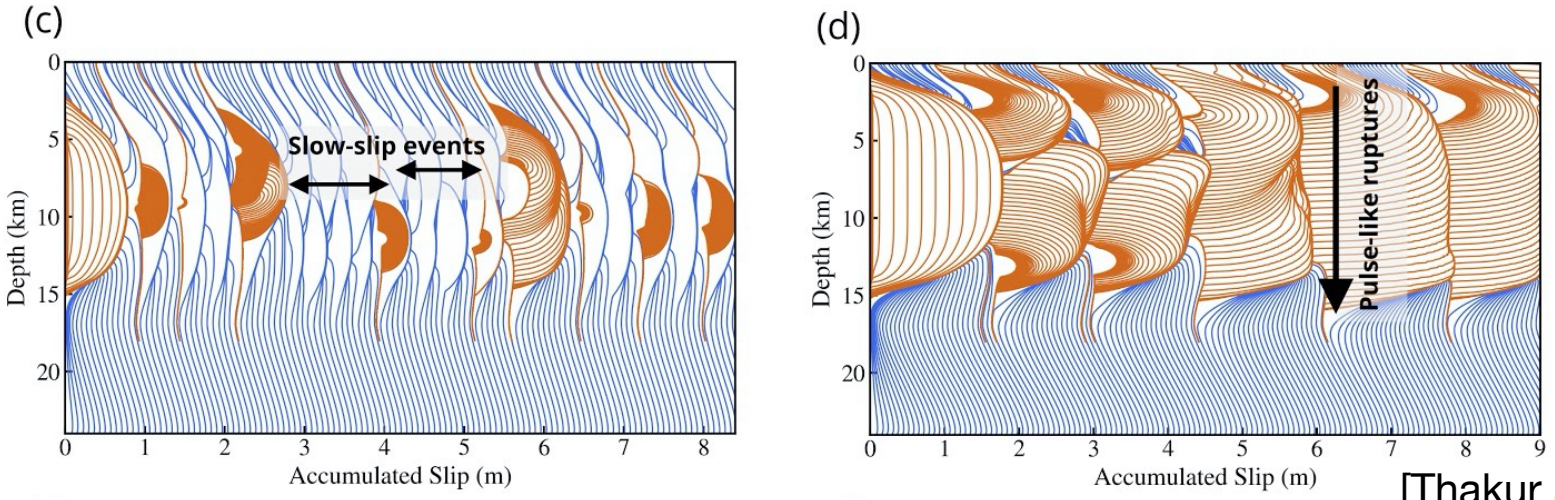
We simulate earthquake cycles in fault damage zones that undergo coseismic damage and interseismic healing for both immature and mature fault zones (a threshold of 30% fault zone velocity reduction).



[Thakur and Huang, GRL, 2021]

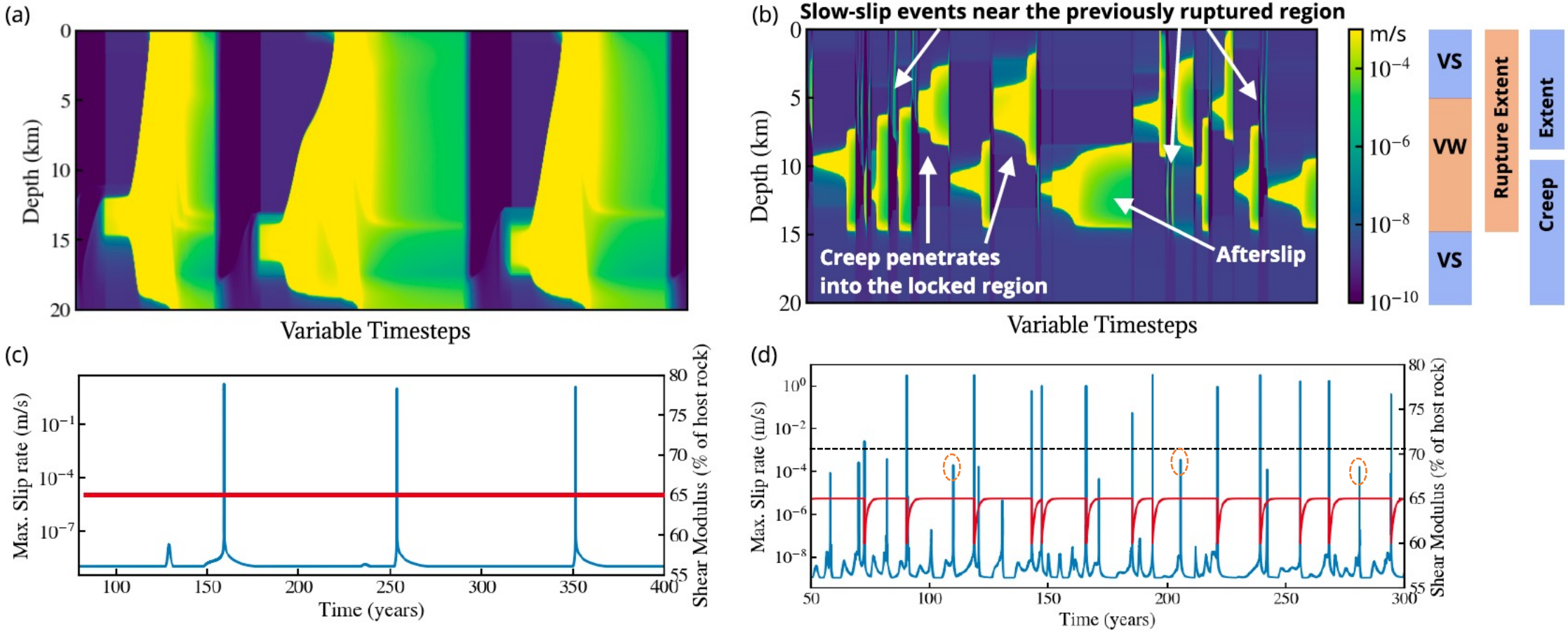
Immature fault zones generate more heterogeneity in long-term slip rate, more irregular earthquake intervals and more slow-slip events.





[Thakur and Huang, GRL, 2021]

Interseismic healing promotes slow-slip events and creep accumulation within the velocity-weakening segment of the fault and leads to partial earthquake ruptures. The slow-slip events also delay the onset of subsequent earthquakes.



[Thakur and Huang, GRL, 2021]

Conclusions:

- We simultaneously consider dynamic fault zone waves that occur within seconds and earthquake cycles that span hundreds of years in fully dynamic earthquake cycle simulations.
- Fault damage zones promote small-scale fault stress heterogeneities that give rise to variable earthquake sizes and hypocenter depths.
- We find immature fault zones tend to promote aseismic slip that limits earthquake sizes, whereas earthquakes in mature fault zones occur more regularly and are larger since they can break through to the surface.