Long-term earthquake behavior on mature strike-slip faults: Effect of Fault Damage Zones

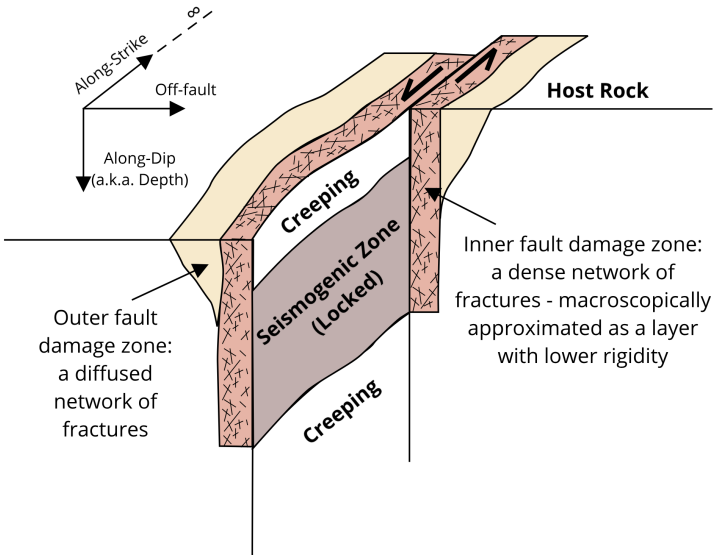
Prithvi Thakur

Advisor: Yihe Huang

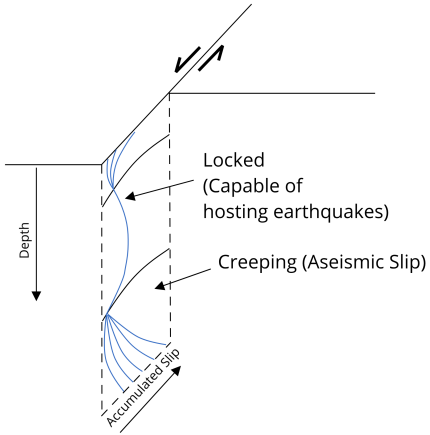
In Collaboration with Yoshi Kaneko

Feb 21, 2020

Background

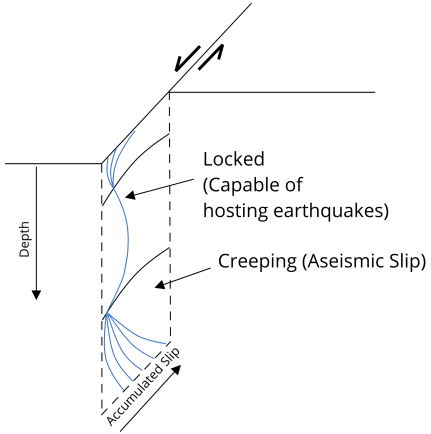

Along-Strike
∞
Off-fault
Along-Dip
(a.k.a. Depth)
Host Rock
Creeping
Seismogenic Zone
(Locked)
Creeping
Outer fault damage zone: a diffused network of fractures
Inner fault damage zone: a dense network of fractures - macroscopically approximated as a layer with lower rigidity

Seismic and Aseismic Slip



Slow Interseismic Deformation
(Years to Decades)

Seismic and Aseismic Slip



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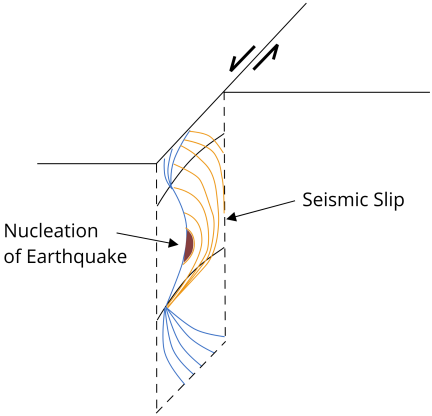
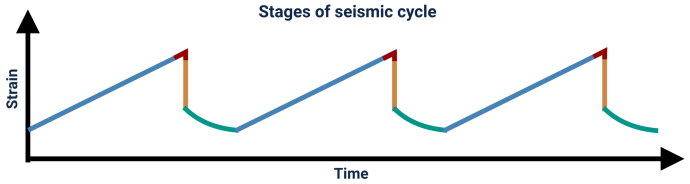


Earthquakes
(A Couple of Seconds)

Seismic and Aseismic Slip



Interseismic

Tectonic Plate motion.

Strain accumulation on the locked fault.

Timescale of years to decades.

Nucleation

Start of Acceleration.

Nucleation size has a critical effect on the spatiotemporal complexity.

Timescale of months to years.

Coseismic

Propagation of rupture generates seismic waves.

Damaged zones cause wave reflections that promotes stress heterogeneity.

Timescale of seconds.

Postseismic

Inelastic deformation after earthquakes due to stress relaxation.

It includes afterslip, viscoelastic and poroelastic deformation.

Timescale of months to years.

Part-I: Earthquake Sequences on Mature Fault Zones

Research Questions

What is the earthquake behavior of mature strike-slip faults in the presence of fault damage zones? What complexities can arise due to a low-velocity layer?

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- Variability in earthquake location
- Variability in earthquake size

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What is the earthquake behavior of mature strike-slip faults in the presence of fault damage zones? What complexities can arise due to a low-velocity layer?

- Variability in earthquake location
- Variability in earthquake size
- Spectrum of dynamic earthquakes and slow-slip events

Variability in Earthquake Location: Hypocenters

Where do earthquakes nucleate?

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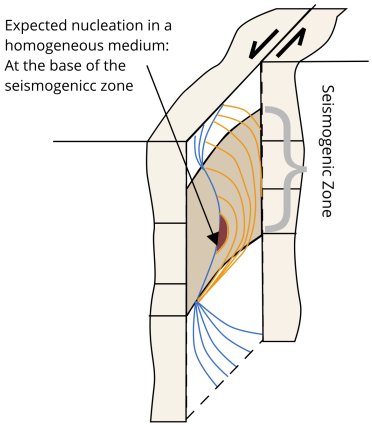

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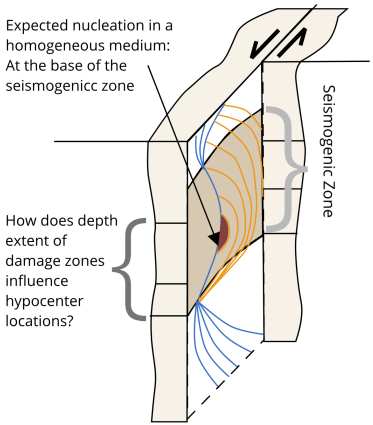

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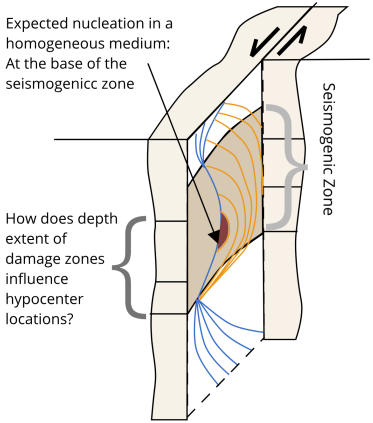

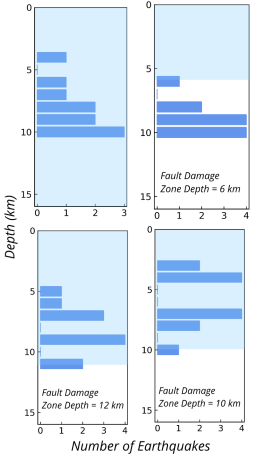

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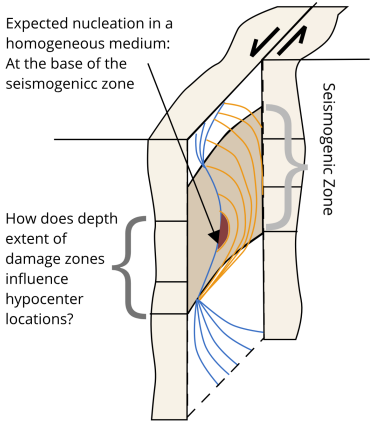

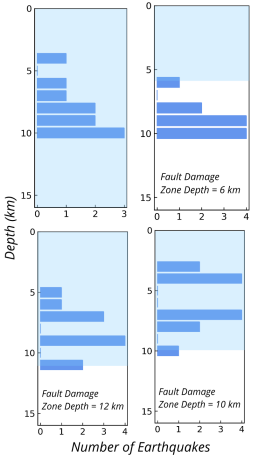

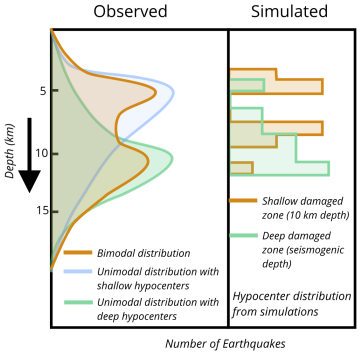

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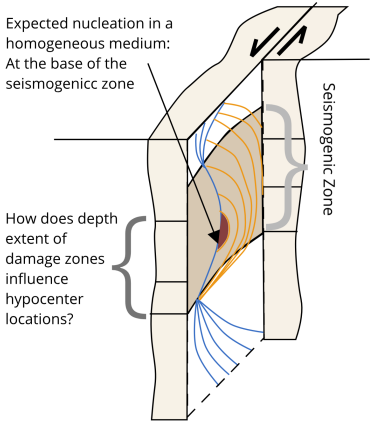

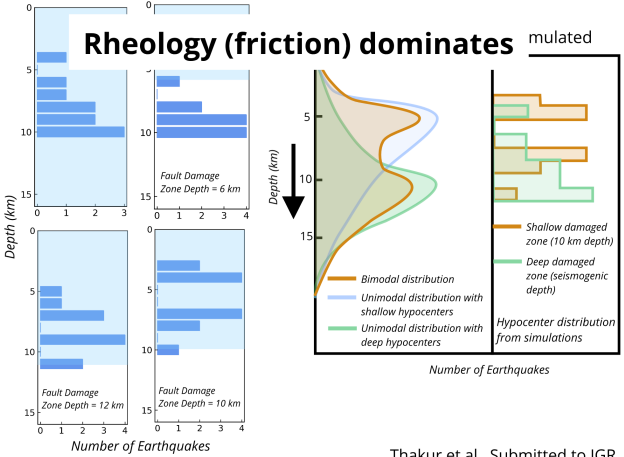

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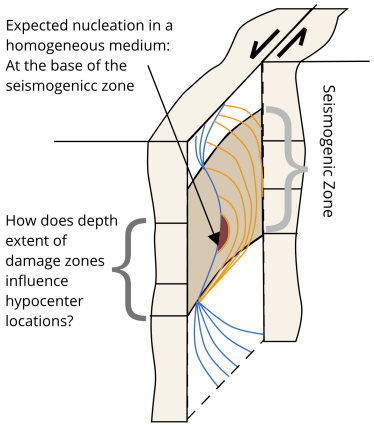

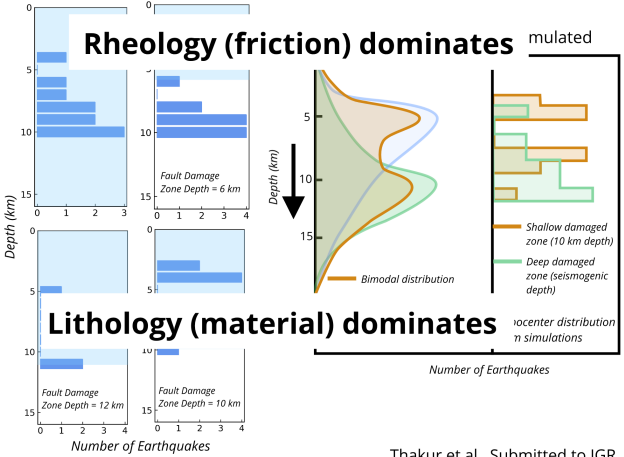

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Variability in Earthquake Size: Magnitude-Frequency Distribution

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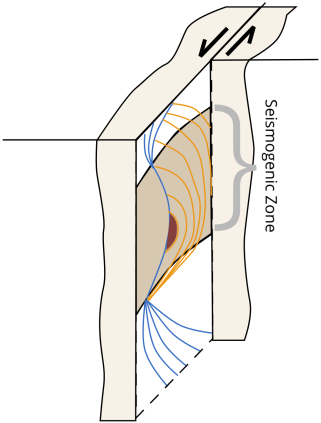

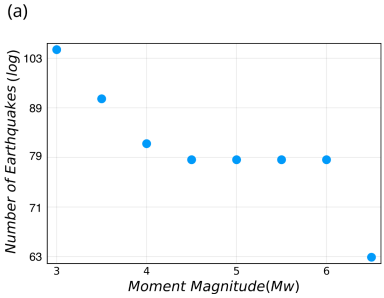

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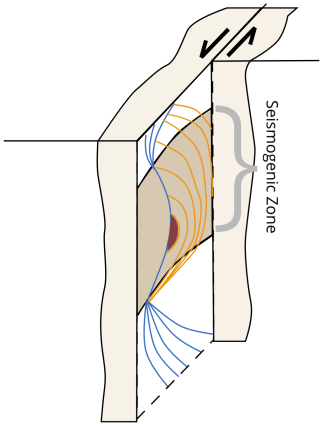

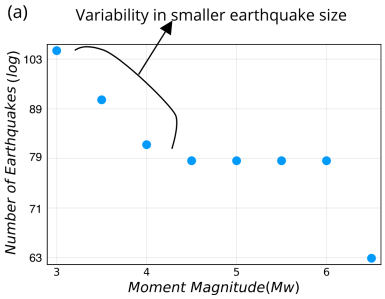

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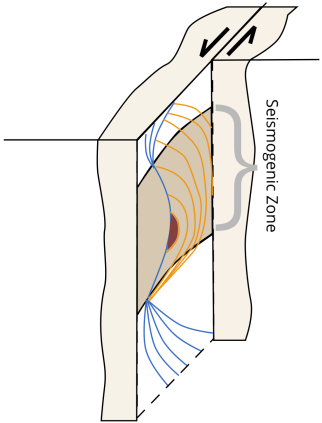

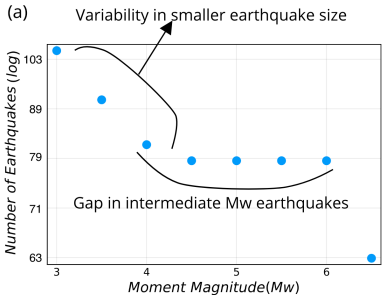

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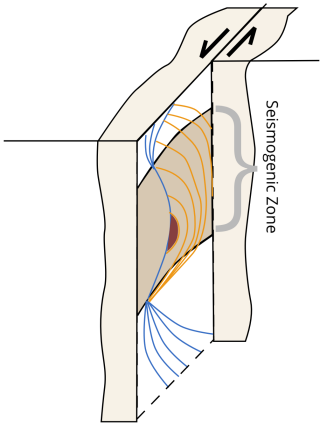

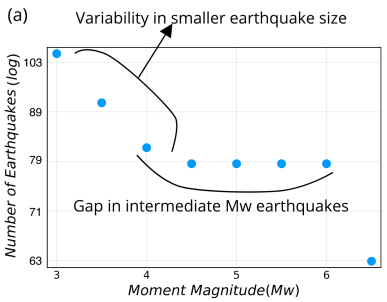

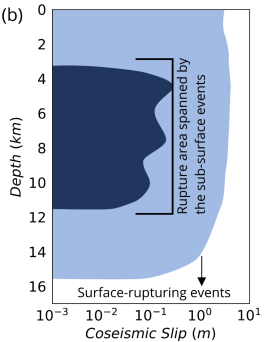

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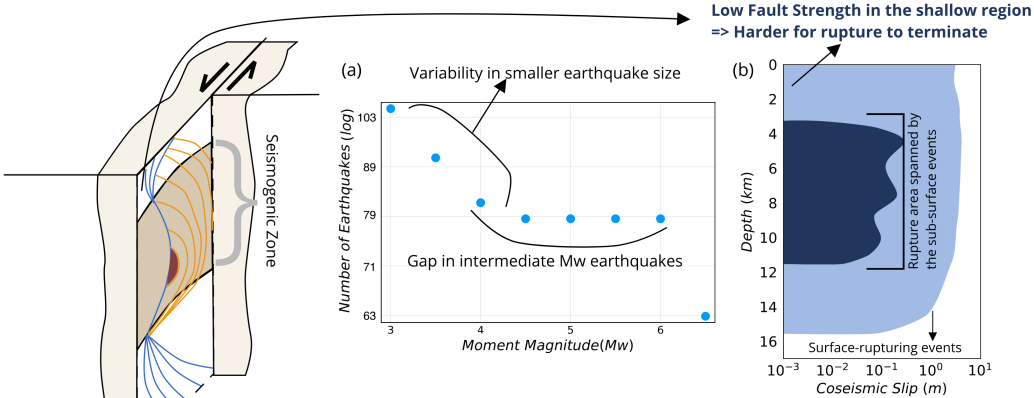

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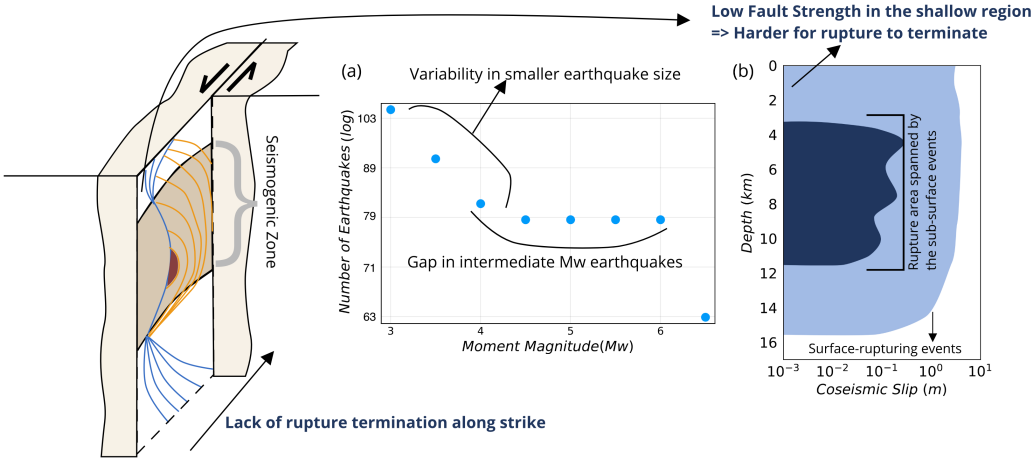

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Slow-Slip Events due to Fault Damage Zone

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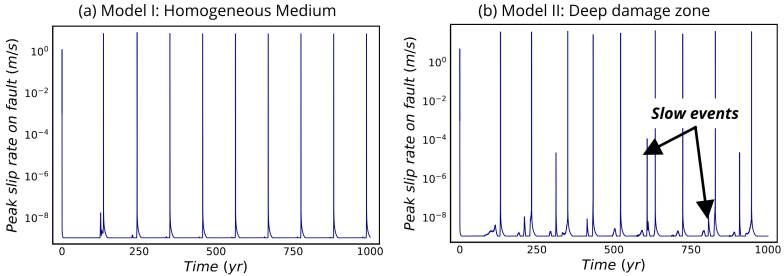

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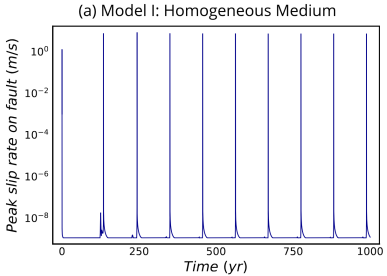

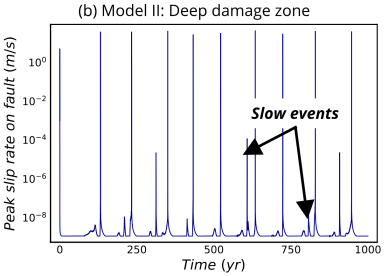

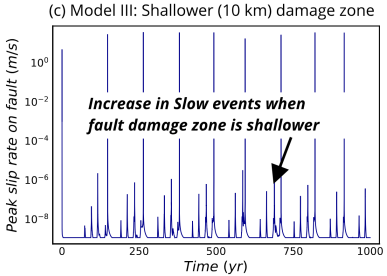

Mature faults with well defined damaged zones are more likely to exhibit slow slip as compared to immature faults

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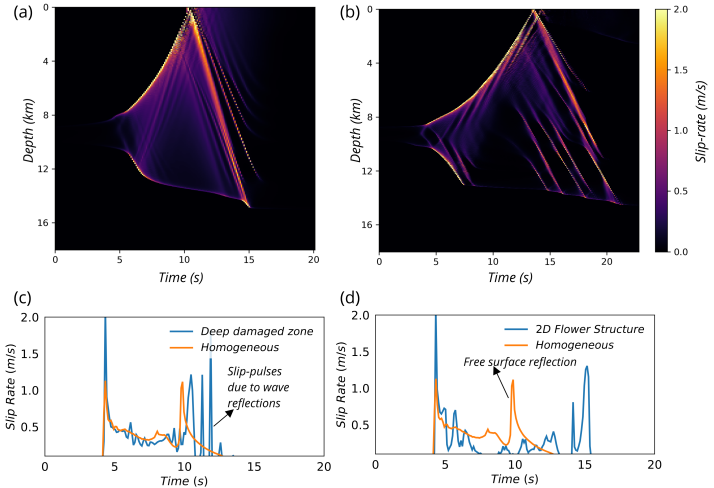
Origin of Such Complexities

Origin of Such Complexities: Slip Pulses



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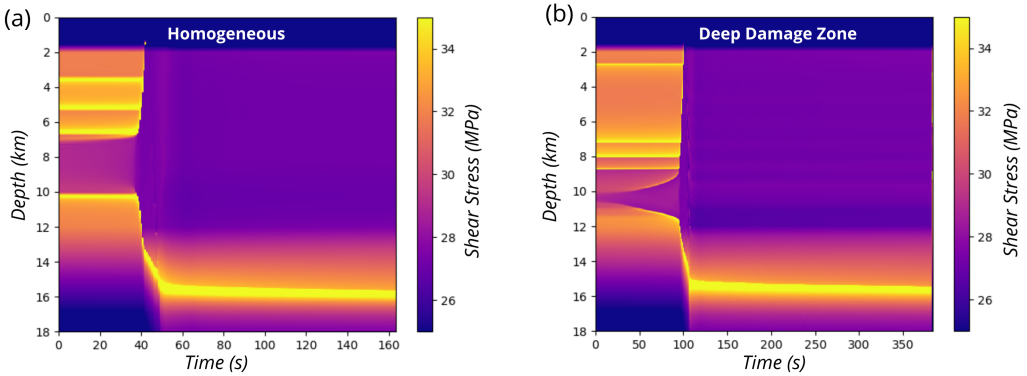
Origin of Such Complexities: Slip Pulses=> Stress Heterogeneities



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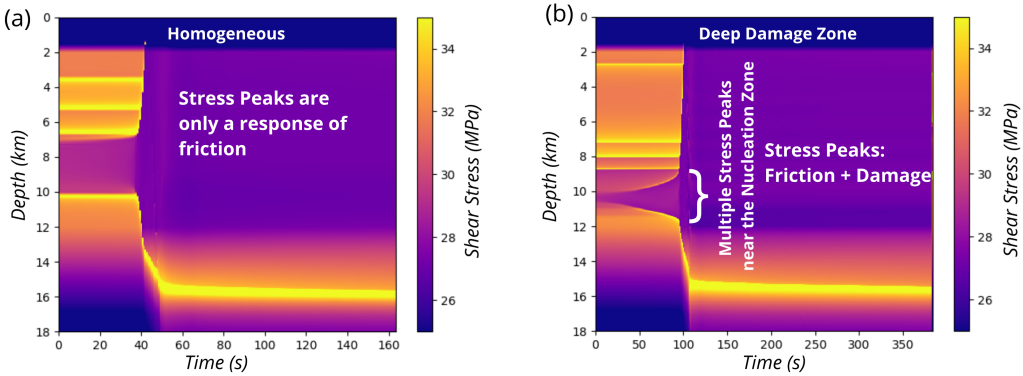

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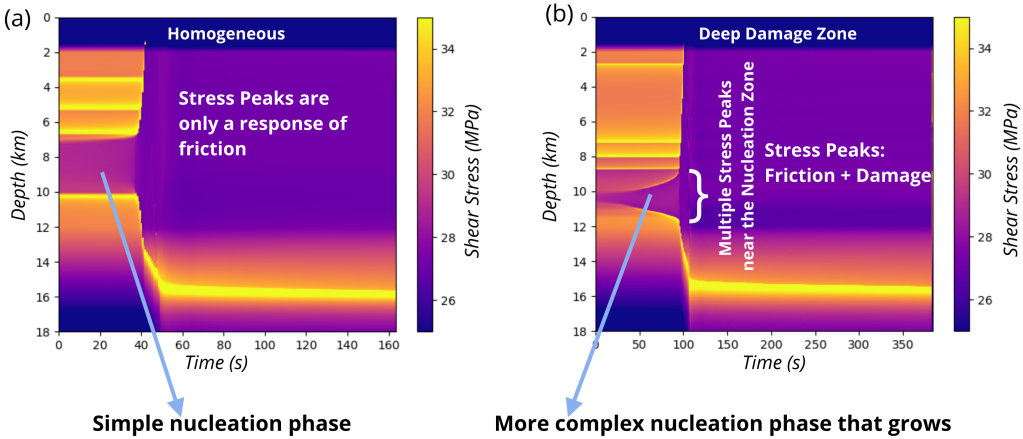

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Key Conclusions

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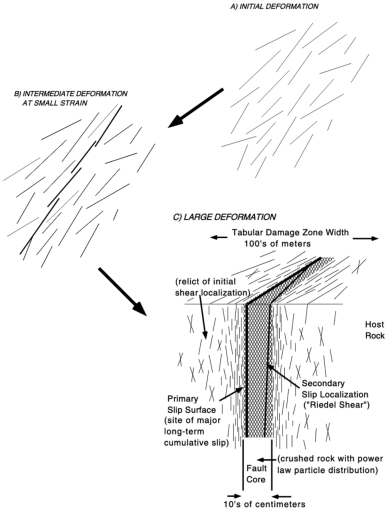
- Fault Damage Zone promotes complexities in earthquakes such as variability in size and hypocenter location, and introduces slow-slip events in addition to dynamic ruptures
- The depth distribution of seismicity is influenced by both rheology (frictional) and lithology (material)

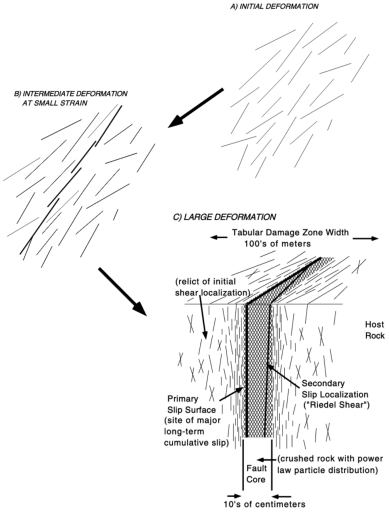
Part-II: Evolution of Fault Damage Zones

Structural Evolution of Fault Zones



Sammis and Ben-Zion, 2003

Structural Evolution of Fault Zones



Distributed Fracture

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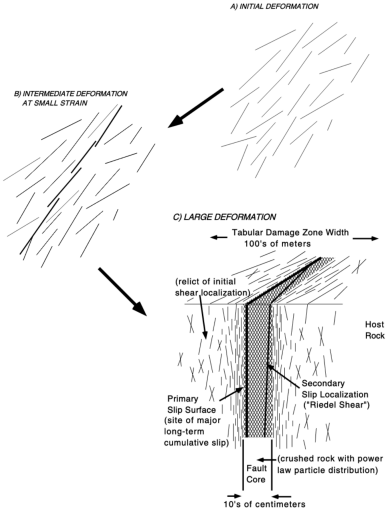

Distributed Fracture

More Localized with well defined Damage Zones

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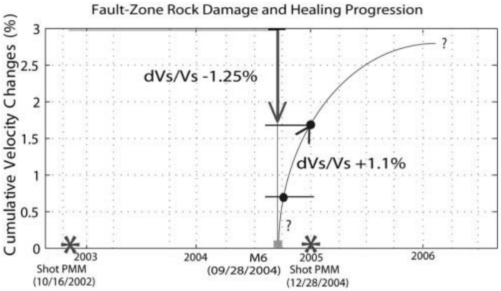
Evidence for Restrengthening of Fault Zones



Observed shear wave velocity change after Parkfield earthquake.

Li et al., 2006

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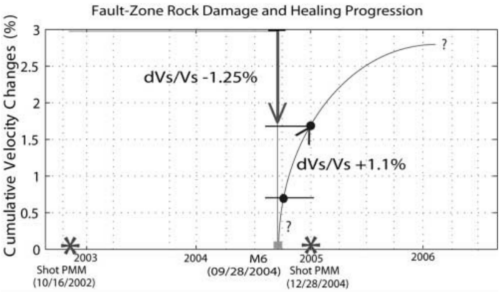

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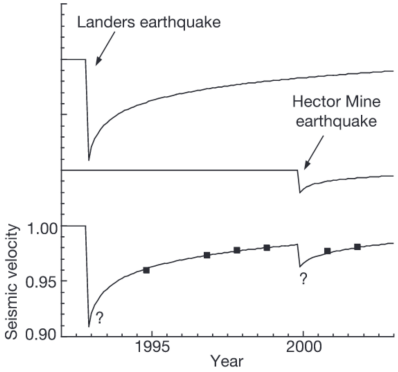
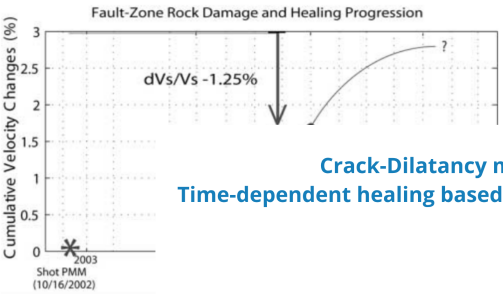


Inferred healing model based on closure of cracks

Li et al., 2006

Vidale and Li, 2003

Evidence for Restrengthening of Fault Zones



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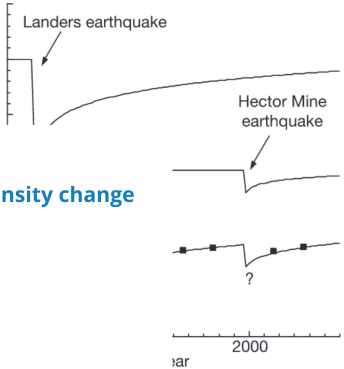

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Crack-Dilatancy mechanism:
Time-dependent healing based on crack density change

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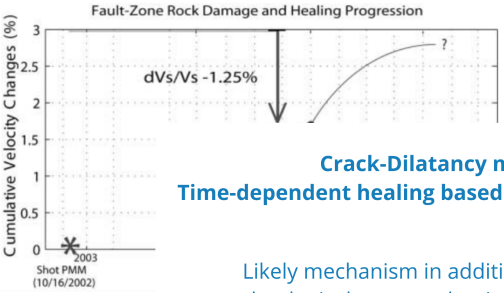

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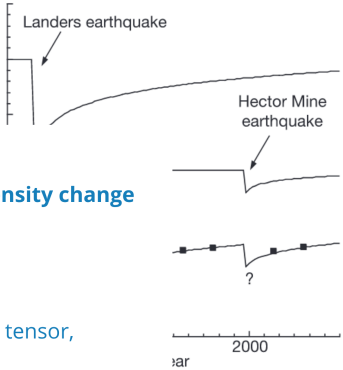

g model based
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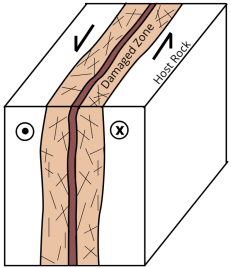
Crack-Dilatancy mechanism:
Time-dependent healing based on crack density change

Likely mechanism in addition to:
rheological restrengthening,
strain-rate dependence of deformation tensor,
fluid variations, etc.

Li et al., 2006

Vidale and Li, 2003

Simple Elastic Model for Damage Evolution and Healing



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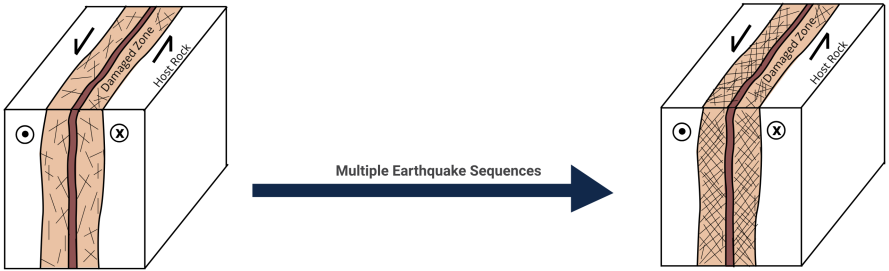

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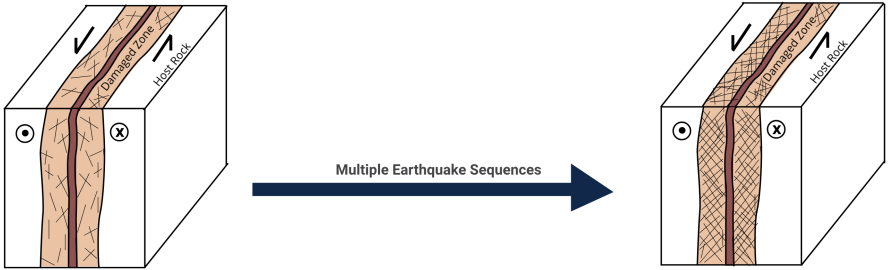

Immature (young) fault damaged zone

Diffused damage boundary.

Lower fracture density, which implies lower rigidity contrast with the host rock and therefore lower shear wave velocity contrast.

Examples: Ridgecrest-California, Pelopponese-Greece.

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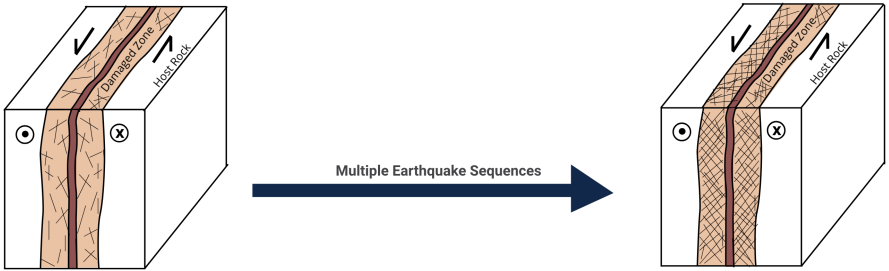

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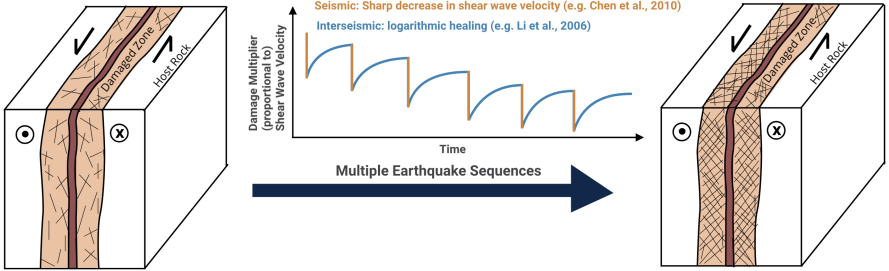
Mature (old) fault damaged zone

Sharp Damaged Boundary.

Higher fracture density, which implies higher rigidity contrast with the host rock and therefore higher shear wave velocity contrast.

Examples: San Andreas Fault, North Anatolian Fault.

Simple Elastic Model for Damage Evolution and Healing



Immature (young) fault damaged zone

Diffused damage boundary.

Lower fracture density, which implies lower rigidity contrast with the host rock and therefore lower shear wave velocity contrast.

Examples: Ridgecrest-California, Pelopponese-Greece.

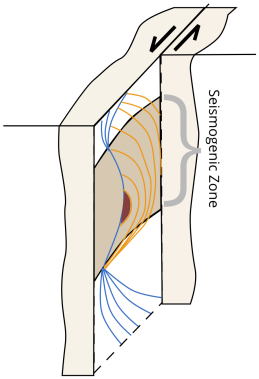
Mature (old) fault damaged zone

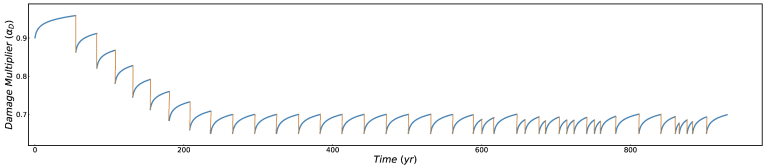
Sharp Damaged Boundary.

Higher fracture density, which implies higher rigidity contrast with the host rock and therefore higher shear wave velocity contrast.

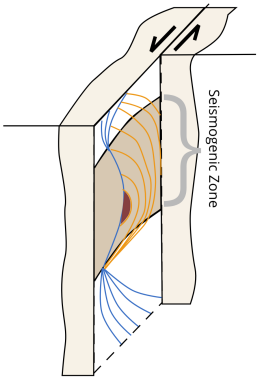
Examples: San Andreas Fault, North Anatolian Fault.

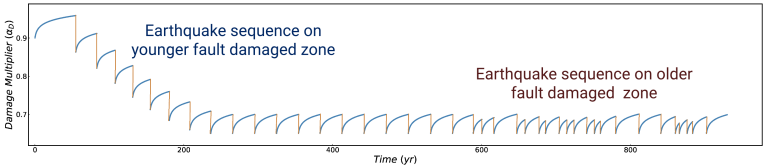
Preliminary Results



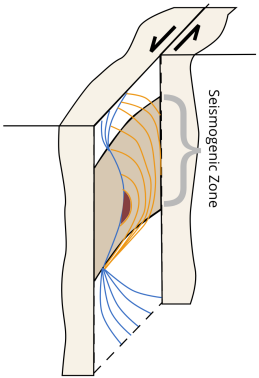


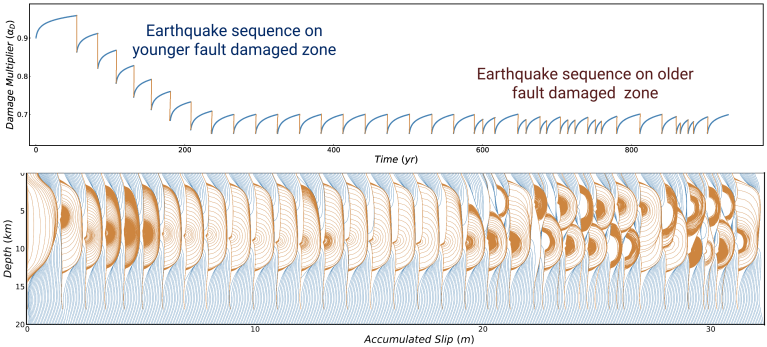
Preliminary Results



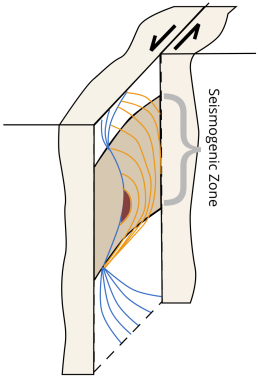


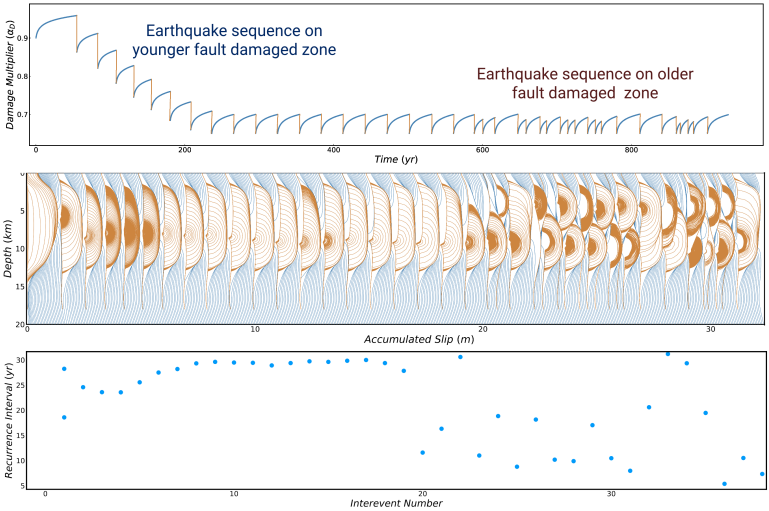
Preliminary Results



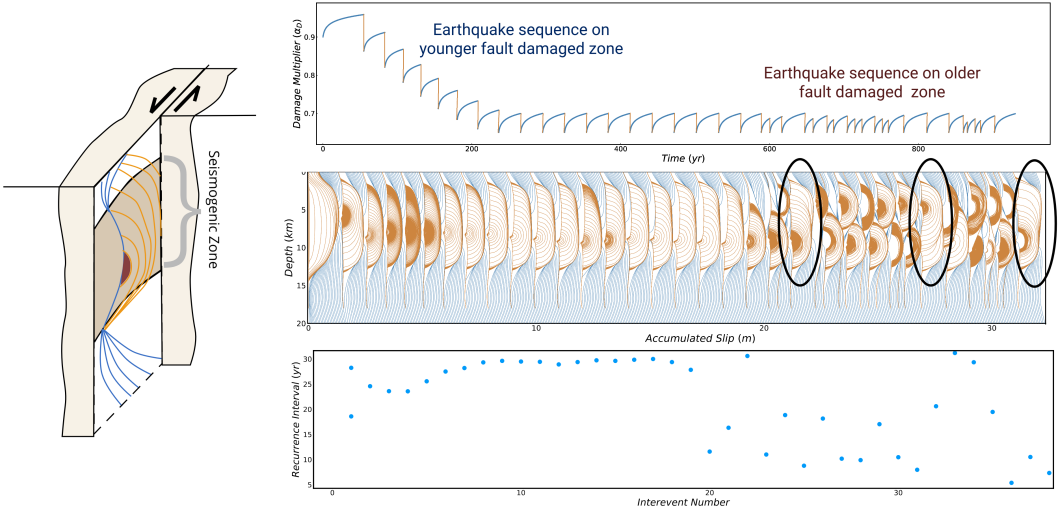


Preliminary Results





Preliminary Results



Concluding Remarks

- Interseismic healing, under an elastic approximation, can potentially explain why certain fault zones have longer duration between large earthquakes.

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- Interseismic healing, under an elastic approximation, can potentially explain why certain fault zones have longer duration between large earthquakes.
- A time-dependent stiffness of the near-fault material indicates that the earthquake nucleation phase should also be time-dependent. Ideally, nucleation would reduce immediately after large earthquake thereby facilitating re-rupturing of the fault. Thus, the rate of interseismic healing could have important implications for the aftershock activity and earthquake triggering of a given fault zone.


That's all Folks!