Characteristics of earthquake ruptures and dynamic off-fault deformation on propagating faults

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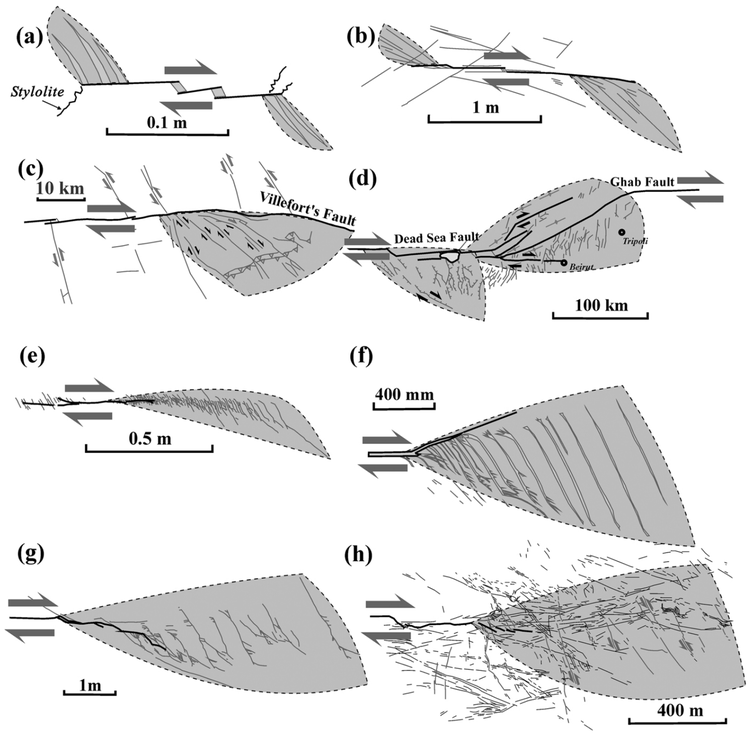
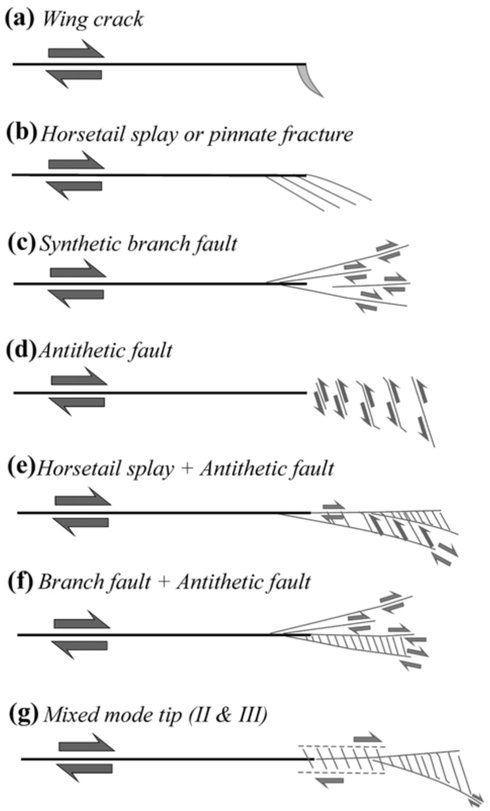
Motivation

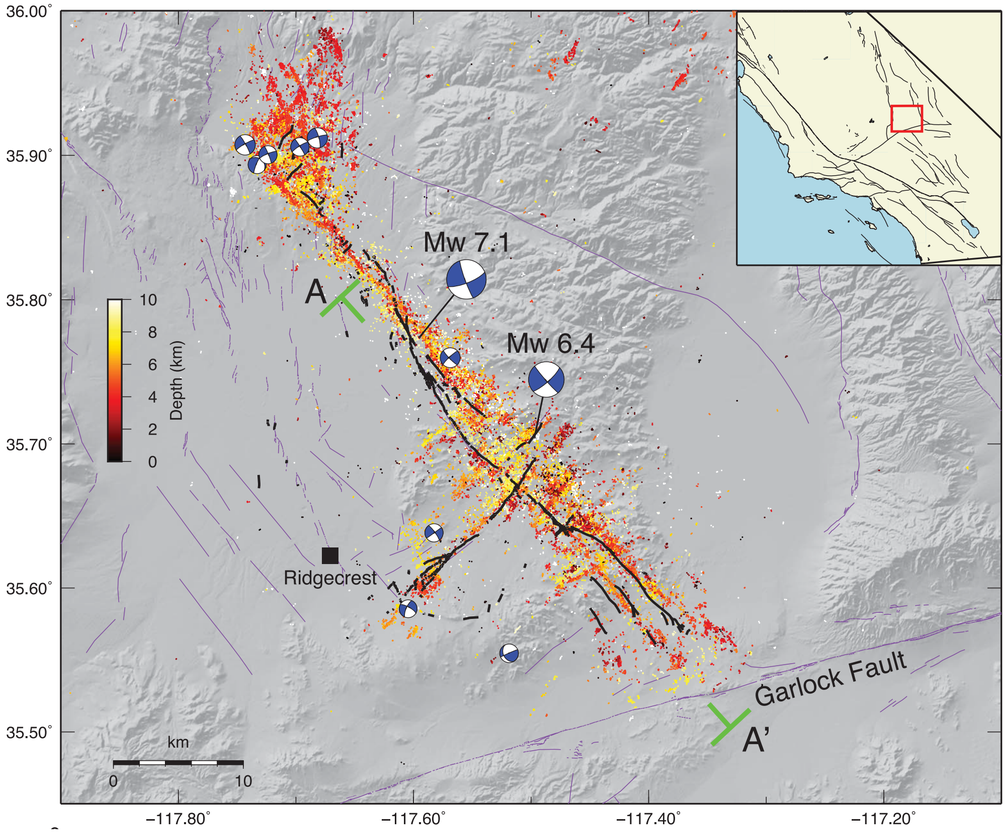
Pt. 1 — Complex fault evolution





[Kim et al., 2004]

Pt. 2 — Ridgecrest 2019 earthquakes



[Ross et al., 2019]

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Methods

I2ELVIS - *2-D continuum-based Finite-difference code* [Gerya and Yuen, PEPI, 2007]

STM 1 - *Seismo-Thermo-Mechanical Modeling* [van Dinther et al., JGR, 2013]

STM 2 - *Rate-and-state friction* [Herrendörfer et al., JGR 2018]

Conservation

of mass

of momentum

Rheology

Visco-elasto-plastic

Plastic yielding

$$\sigma_{\text{yield}} = \mu P + C$$

continuum-based invariant RSF

$$\sigma_{\text{yield}} = \tau_{II} = \mu P + C = \left[\mu_0 + a \ln\left(\frac{V}{V_0}\right) + b \ln\left(\frac{\theta V_0}{L}\right)\right] P + C$$

$$\frac{d\theta}{dt} = 1 - \frac{V \theta}{L}$$

[Dieterich, 1978, 1979; Ruina, 1983]

τ_{II} - second invariant of stress tensor
P - pressure
V - plastic slip rate
V_0 - reference slip rate
μ_0 - static friction coefficient
θ - state
L - characteristic slip distance

long-term fault evolution + spontaneous earthquakes ruptures

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Presentation objectives

1) Complex evolving fault geometries and earthquake ruptures on propagating faults

2) Complex earthquake rupturing in the Ridgecrest faulting case

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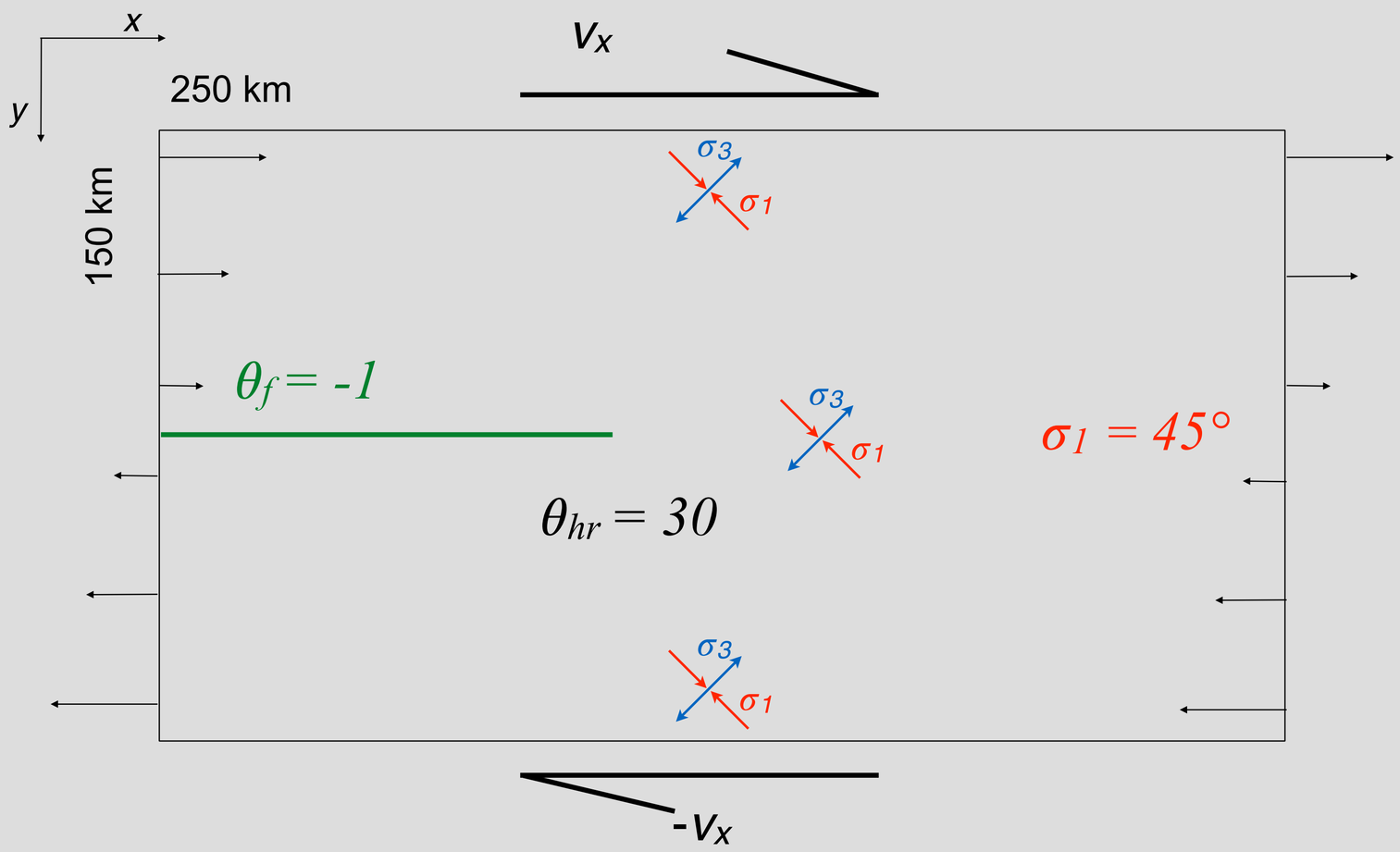
Model setup



3 new ingredients

- **New dynamically adaptive measure of fault width**
- **Plastic strain weakening of bulk rate-and-state friction parameters *L* and *b***
- **2.5D approximation**

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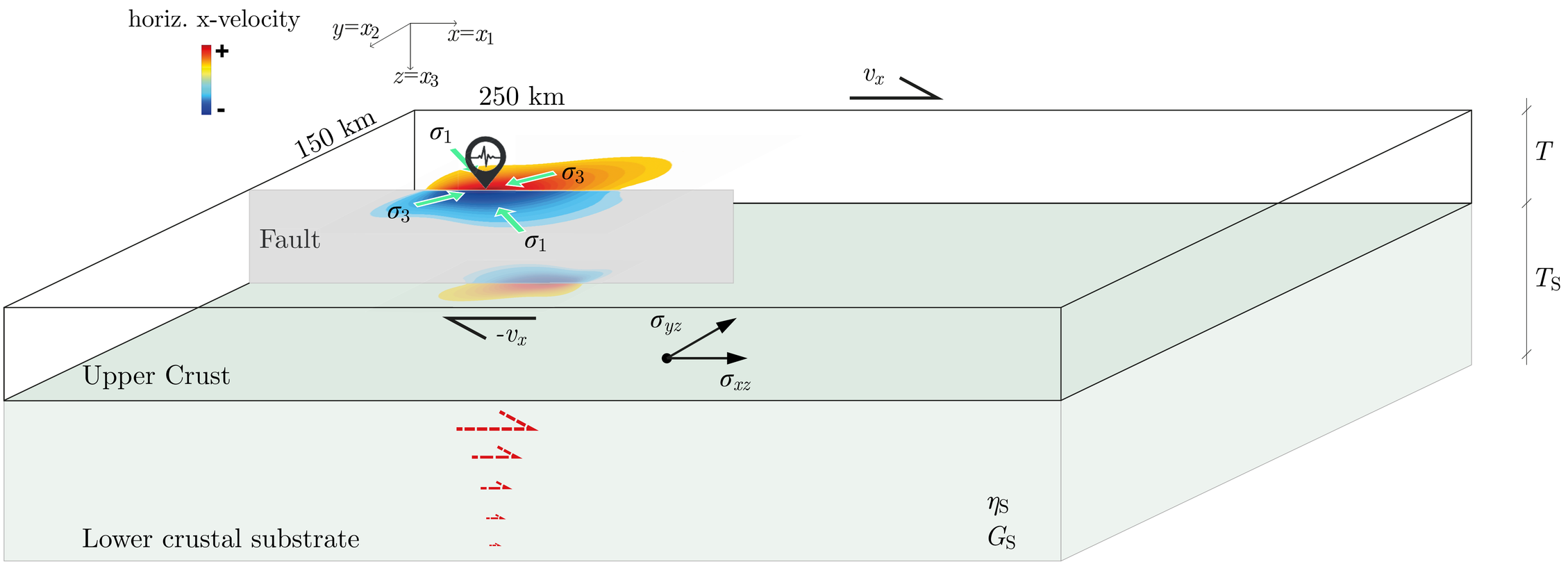
2.5D Model setup



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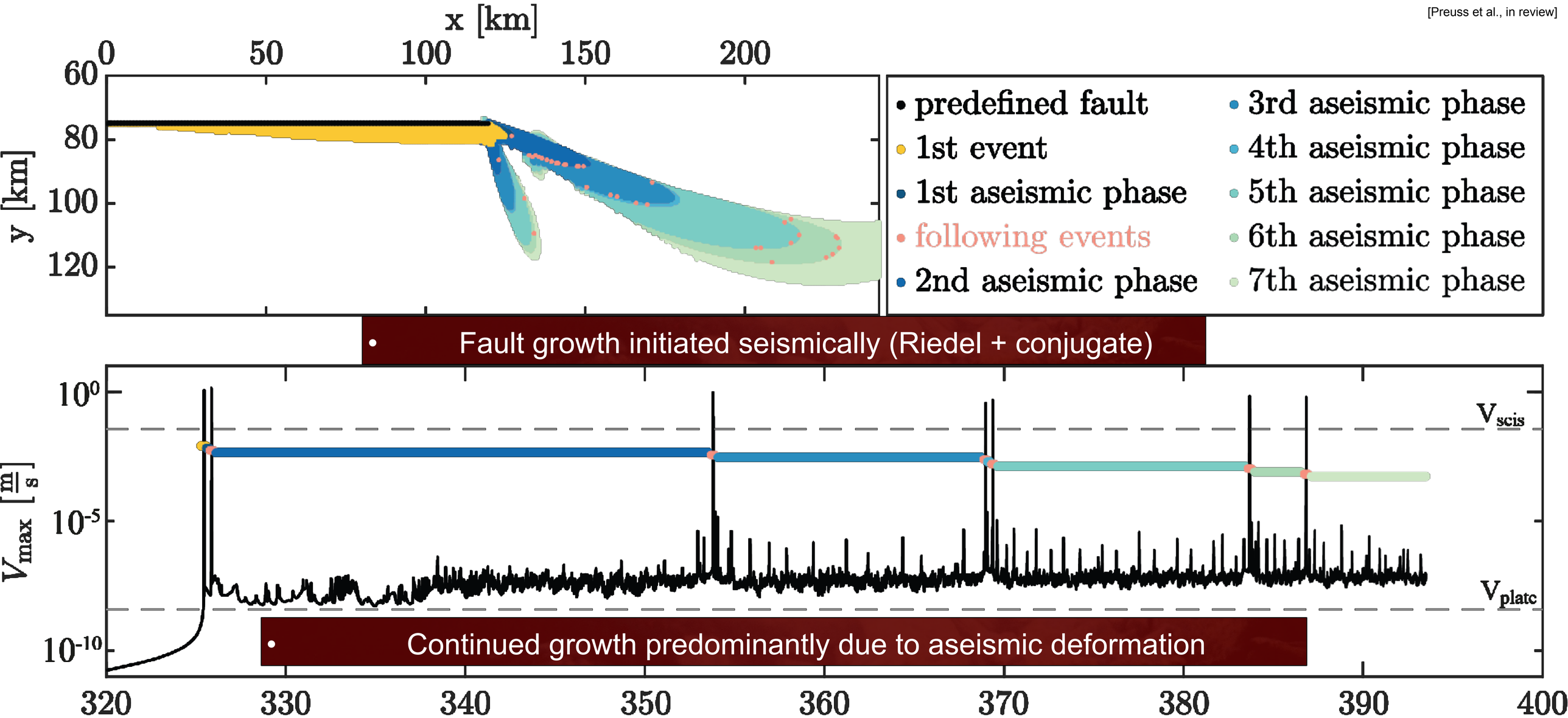
[Preuss et al., in review]

Aseismic vs. seismic growth

[Preuss et al., in review]



- Fault growth initiated seismically (Riedel + conjugate)
- Continued growth predominantly due to aseismic deformation
- Seismic contribution to localize and steepen/flatten the fault angle + causing off-fault deformation

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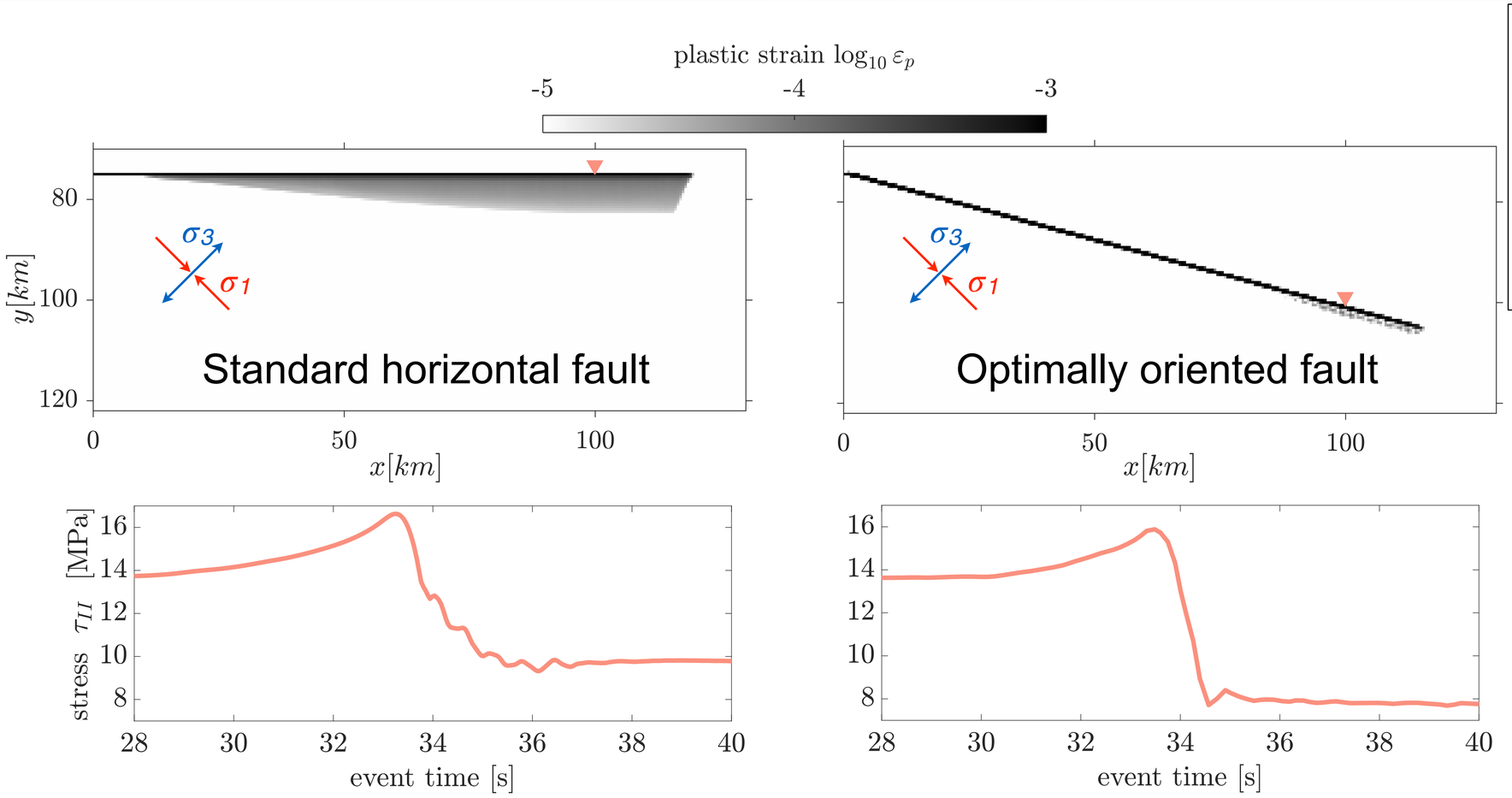
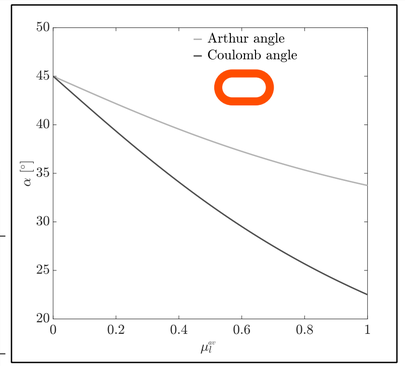
Role of the fault angle





[Preuss et al., in review]

1) Findings

1) Complex evolving fault geometries and earthquake ruptures on propagating faults

- Fault growth predominantly aseismically
- Seismic contribution to localize and steepen the fault angle + causing off-fault deformation
- Plastic off-fault dissipation strongly dependent on initial fault orientation
  - Hypothesis: Non-optimality causes structural complexity

2) Outlook: Complex earthquake rupturing in the Ridgecrest faulting case

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Presentation objectives

1) Complex evolving fault geometries and earthquake ruptures on propagating faults
   - Fault growth predominantly aseismically
   - Seismic contribution to localize and steepen the fault angle + causing off-fault deformation
   - Plastic off-fault dissipation strongly dependent on initial fault orientation
     - Hypothesis: Non-optimality causes structural complexity

2) Complex earthquake rupturing in the Ridgecrest faulting case

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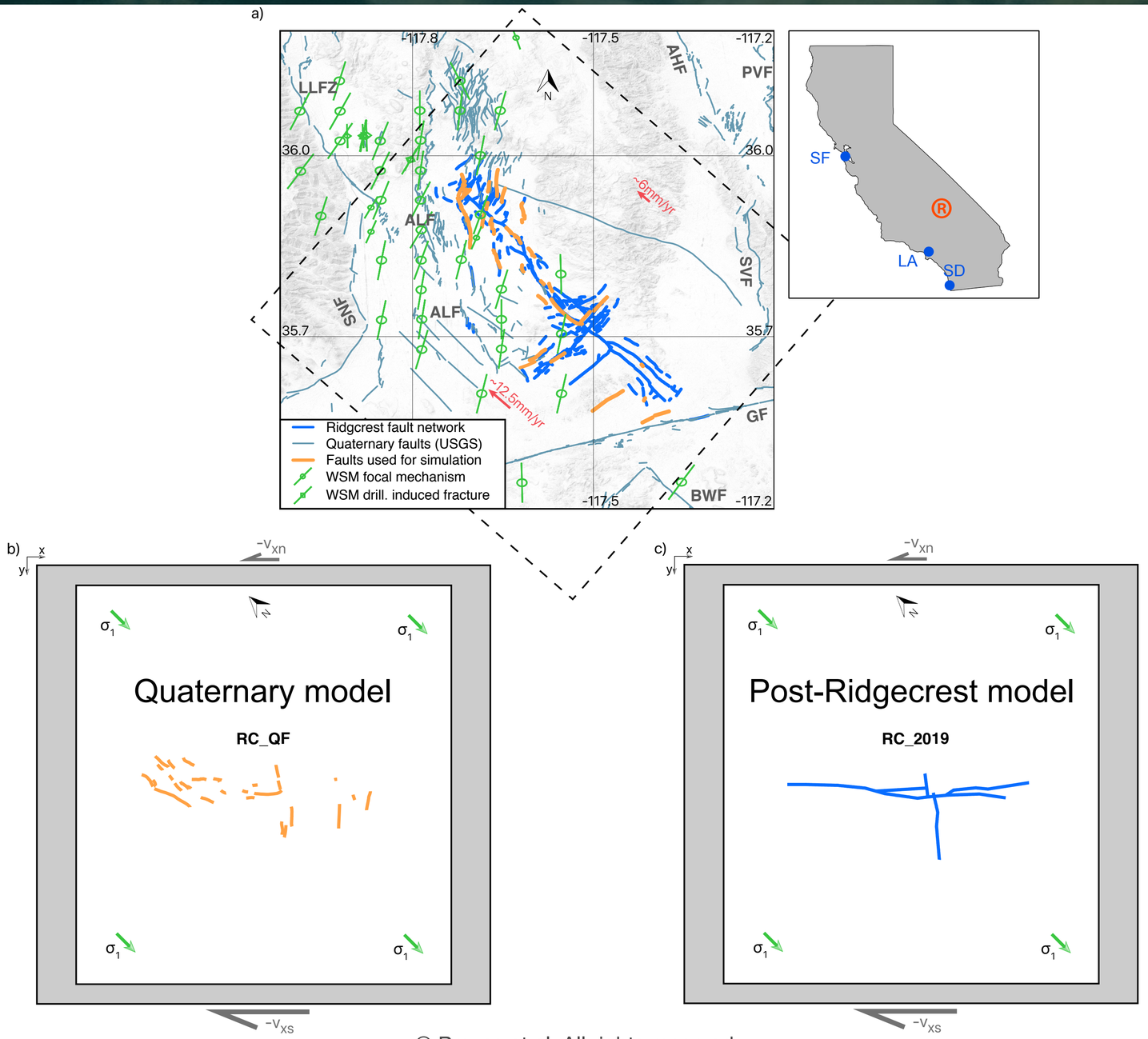
Ridgecrest 2019 earthquake sequence



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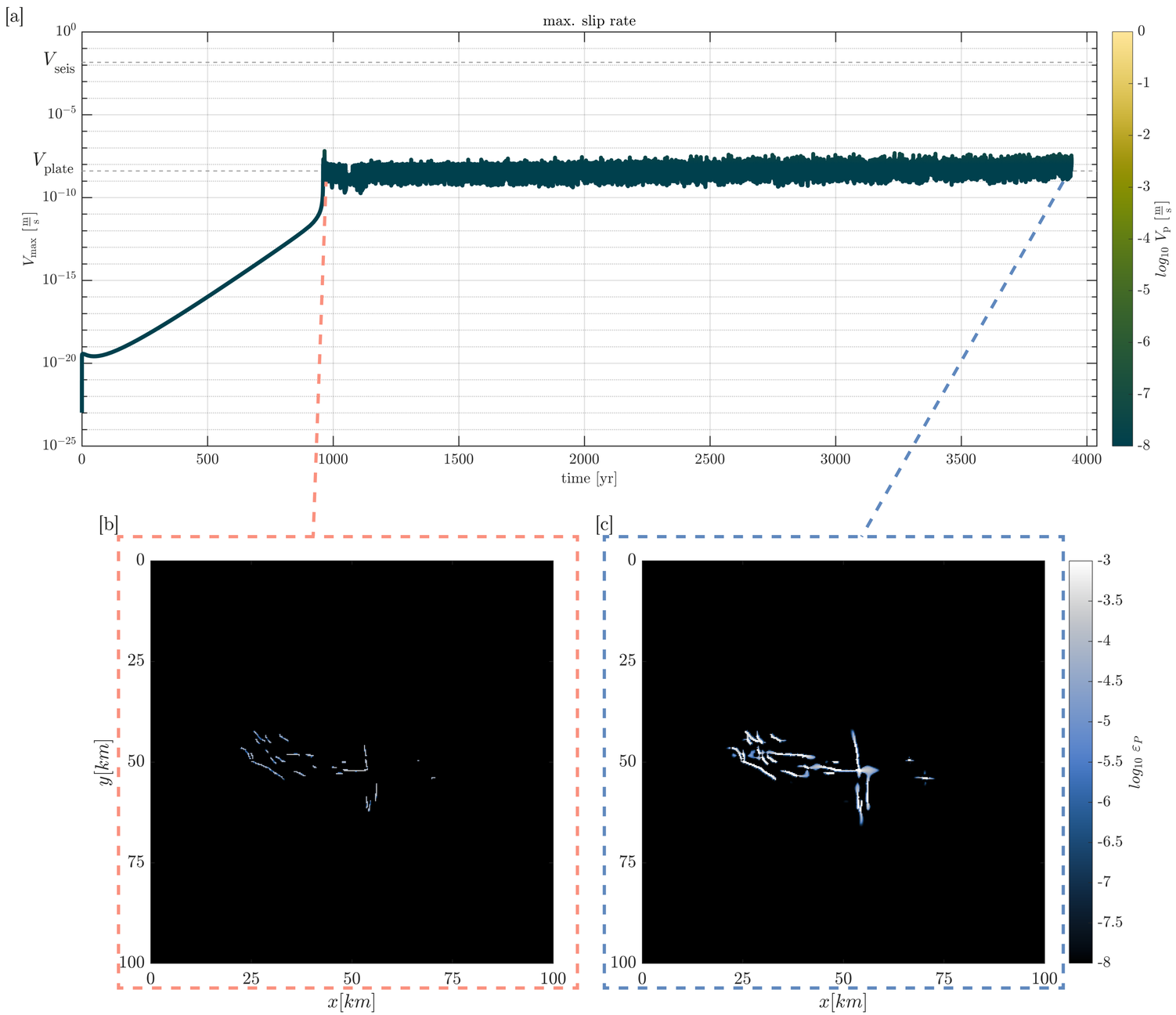
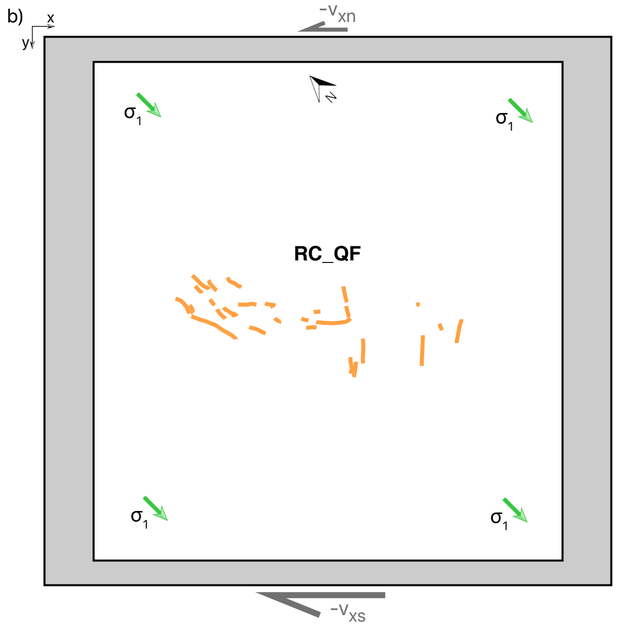
Preuss, 2020. PhD Thesis @ ETH Zurich

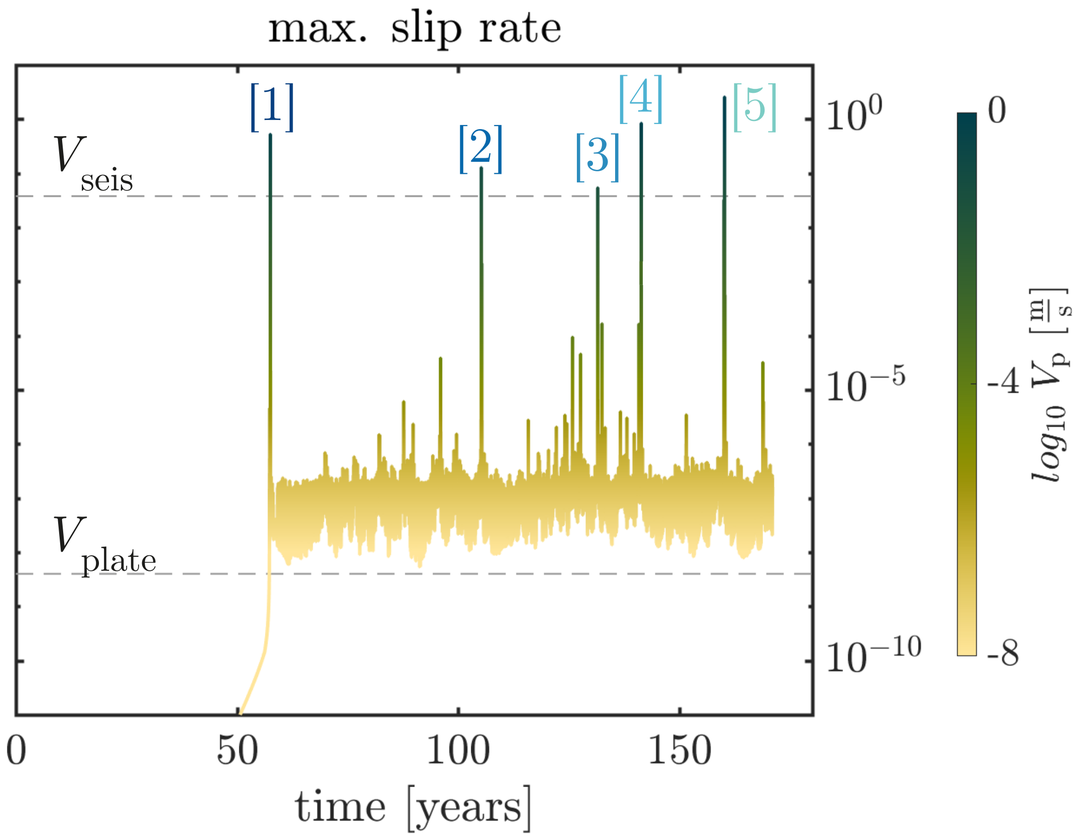
Quaternary model

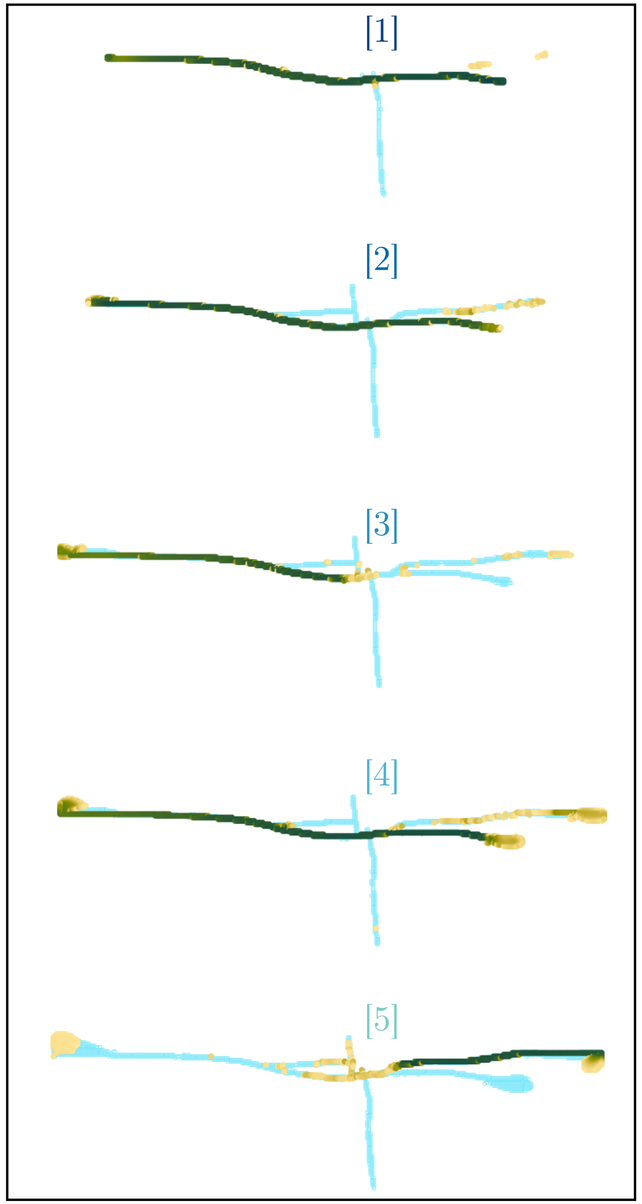


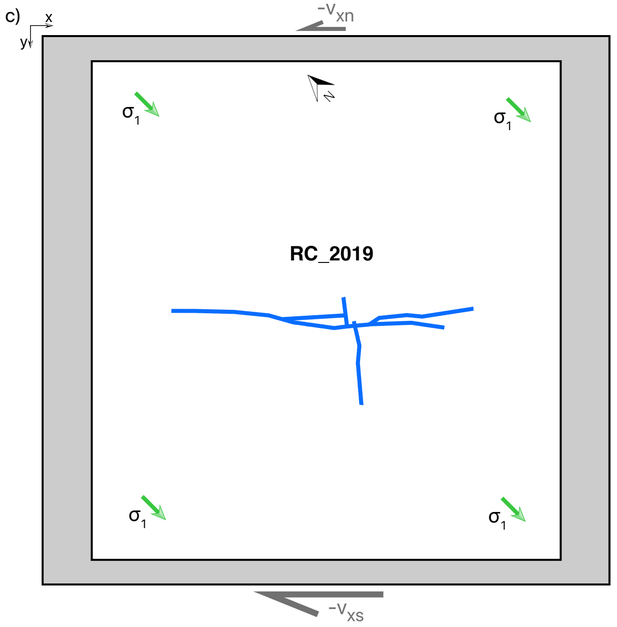


Preuss, 2020. PhD Thesis @ ETH Zurich

Post-Ridgecrest model







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Conclusions

1) Complex evolving fault geometries and earthquake ruptures on propagating faults

- Fault growth predominantly aseismically
- Seismic contribution to localize and steepen the fault angle + causing off-fault deformation
- Plastic off-fault dissipation strongly dependent on initial fault orientation

2) Complex earthquake rupturing in the Ridgecrest faulting case

- Orthogonal faulting but not yet orthogonal rupturing
- Ongoing research

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References

- The majority of this work in under review at EGU's Solid Earth:
  - Preuss, S., Ampuero, J. P., Gerya, T., and van Dinther, Y.: Characteristics of earthquake ruptures and dynamic off-fault deformation on propagating faults, Solid Earth Discuss., https://doi.org/10.5194/se-2020-16, in review, 2020.

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