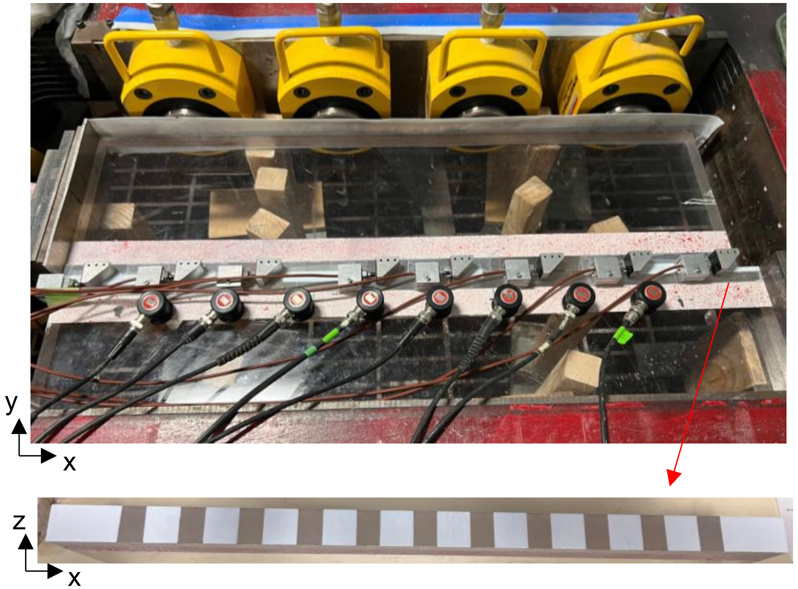

2025 SCEC Dynamic Rupture Workshop

Fault healing and asperity partitioning on a frictionally heterogeneous laboratory fault

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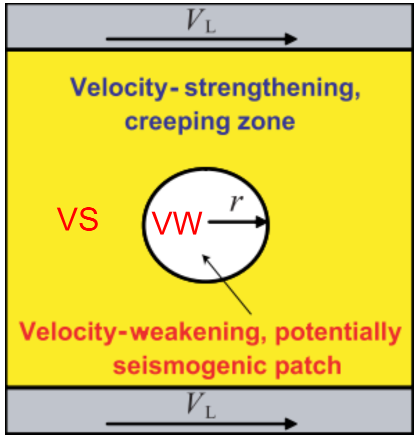
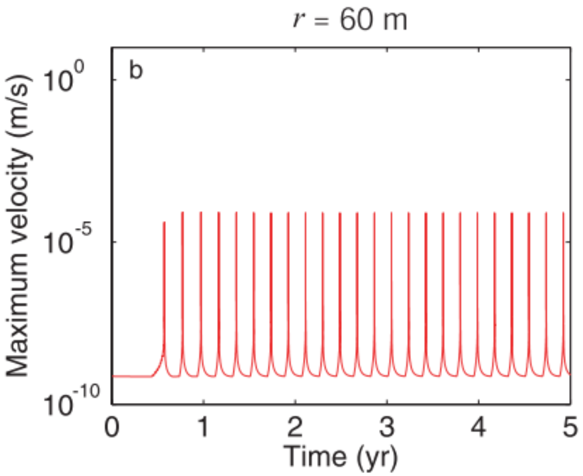
1. Introduction

Motivation

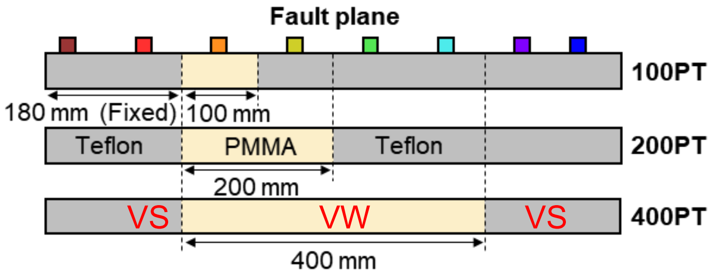


Simulation

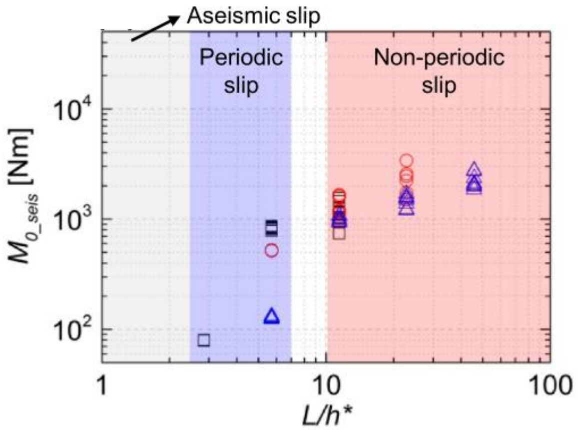


Chen and Lapusta (2009)

* Velocity-Strengthening (VS): Aseismic slip
Velocity-Weakening (VW): Seismic slip



Experiment



Song and McLaskey (2024)

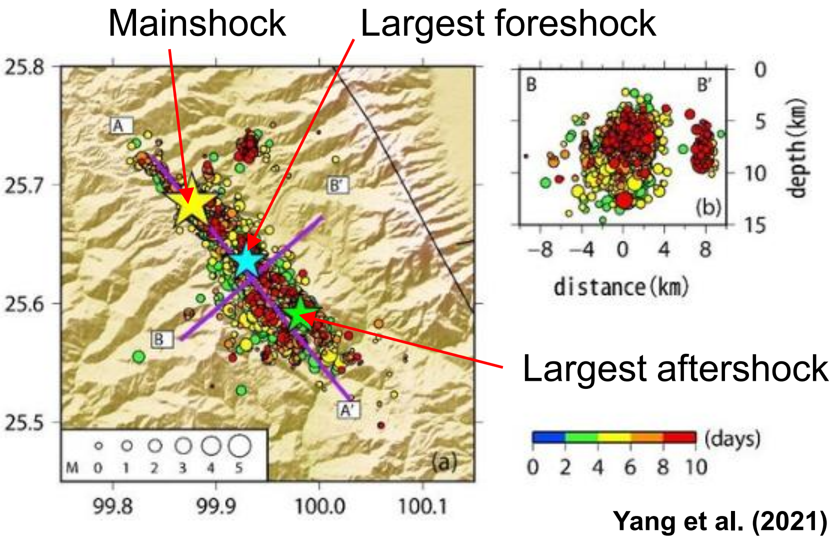
Repeating earthquake at Parkfield

Slip behavior with L/h^*

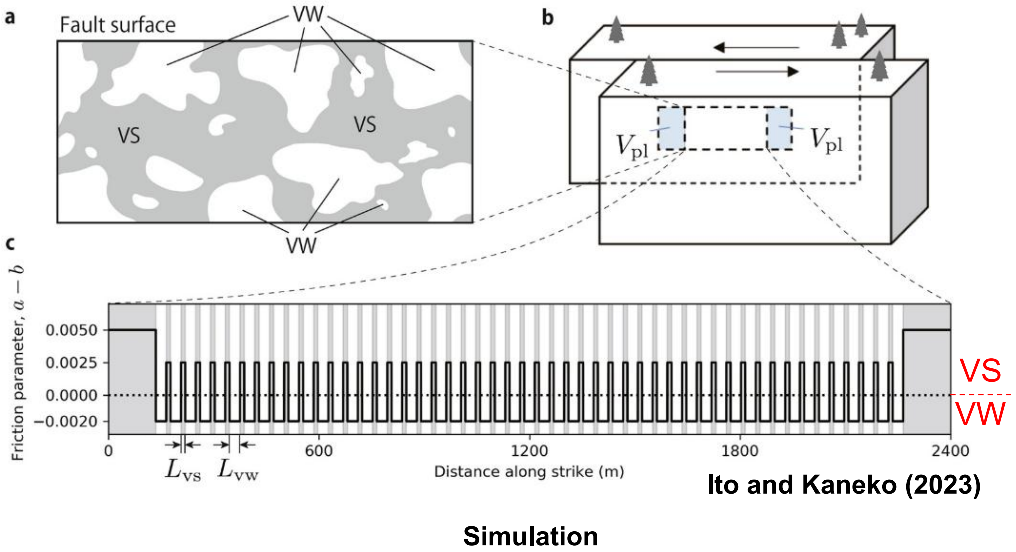
- Single asperity model (a single VW patch surrounded by VS area) is used to describe simplified earthquake behavior
- This framework is effective for explaining repeated earthquake sequences
- Slip behavior is often characterized by the ratio L/h^*, (L = asperity length and h^* = critical nucleation length)

1. Introduction

Motivation



Multiple shocks in a slip cycle

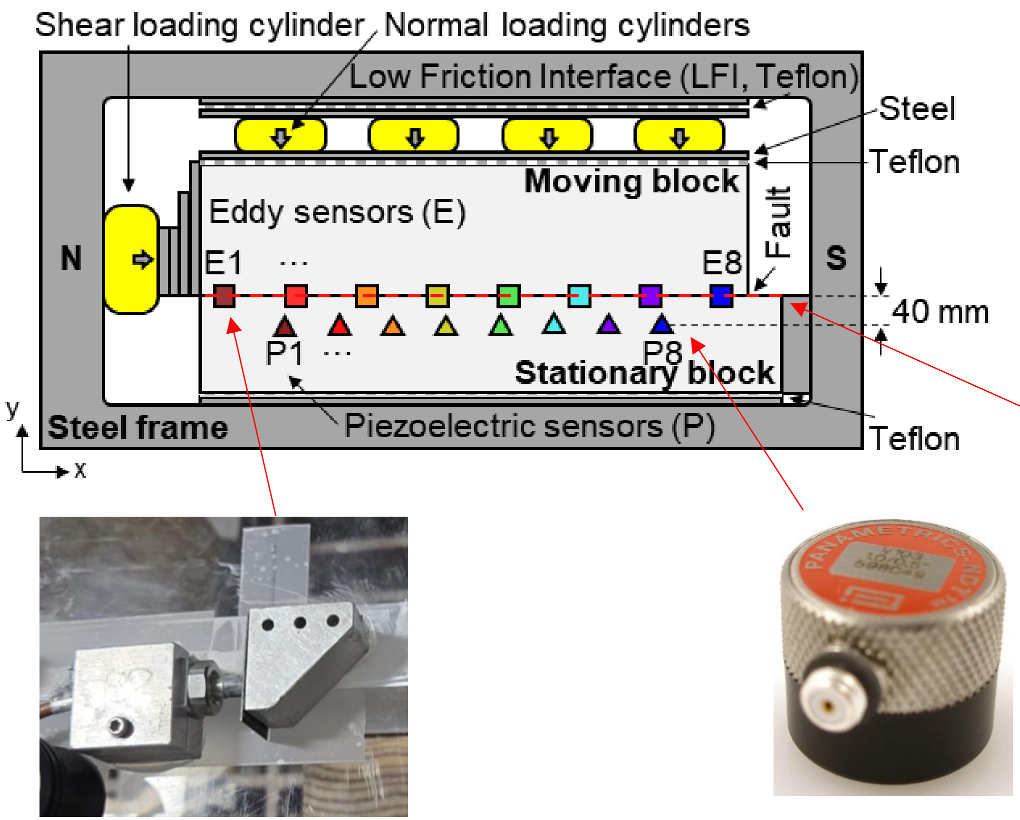


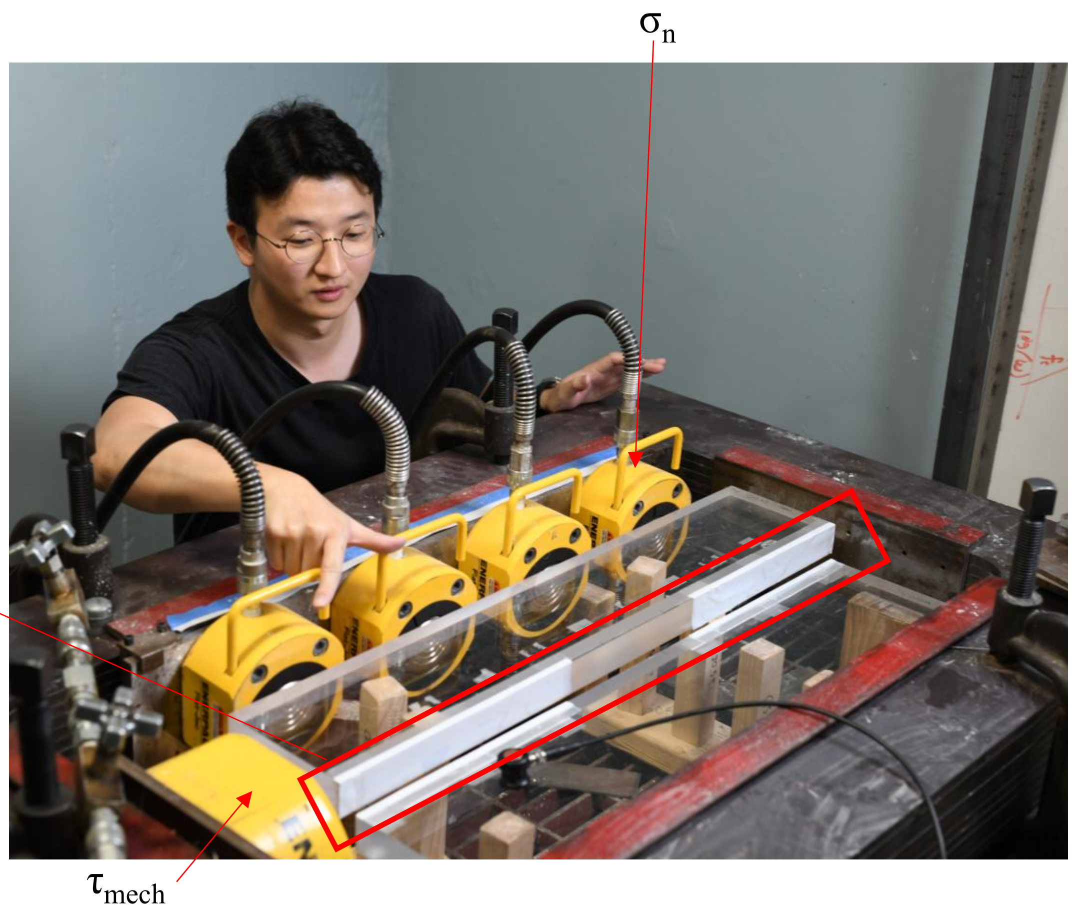
Multiple asperities model using VW and VS patches

- Intricate natural earthquakes such as multiple shocks in a slip cycle, cannot be explained by the single asperity model
- Frictional heterogeneity is one of the factors that can explain this phenomenon
  - Simulations often incorporate alternating VW and VS patches
  - Experimental studies on such frictionally heterogeneous faults remain limited

2. Materials and methods

▣ Experimental setup

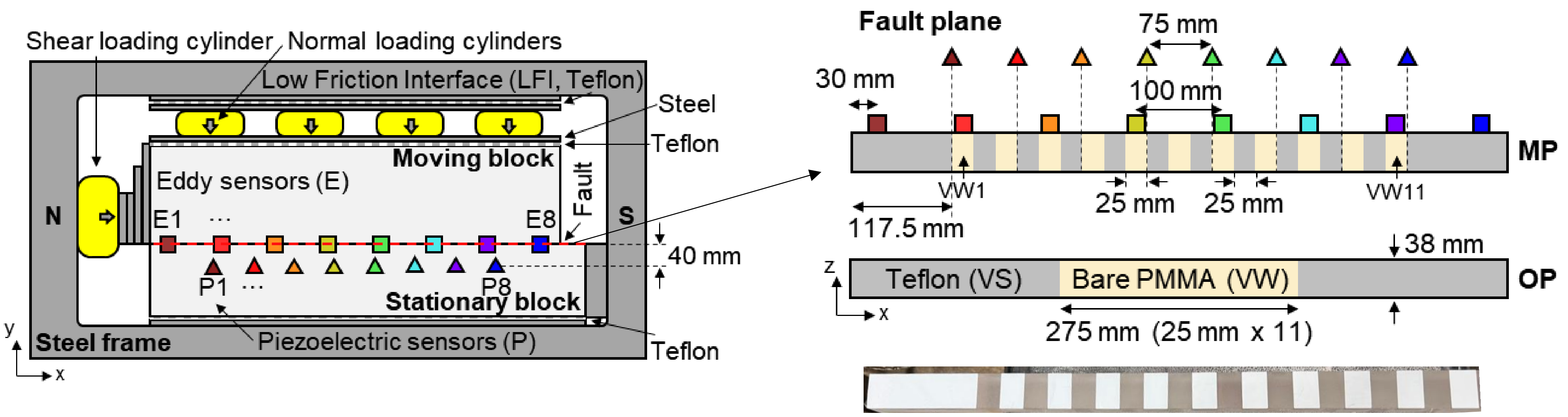




- Measure slip with fault (E1 to E8) and seismic motion (P1 to P8)

2. Materials and methods

▣ Experimental setup

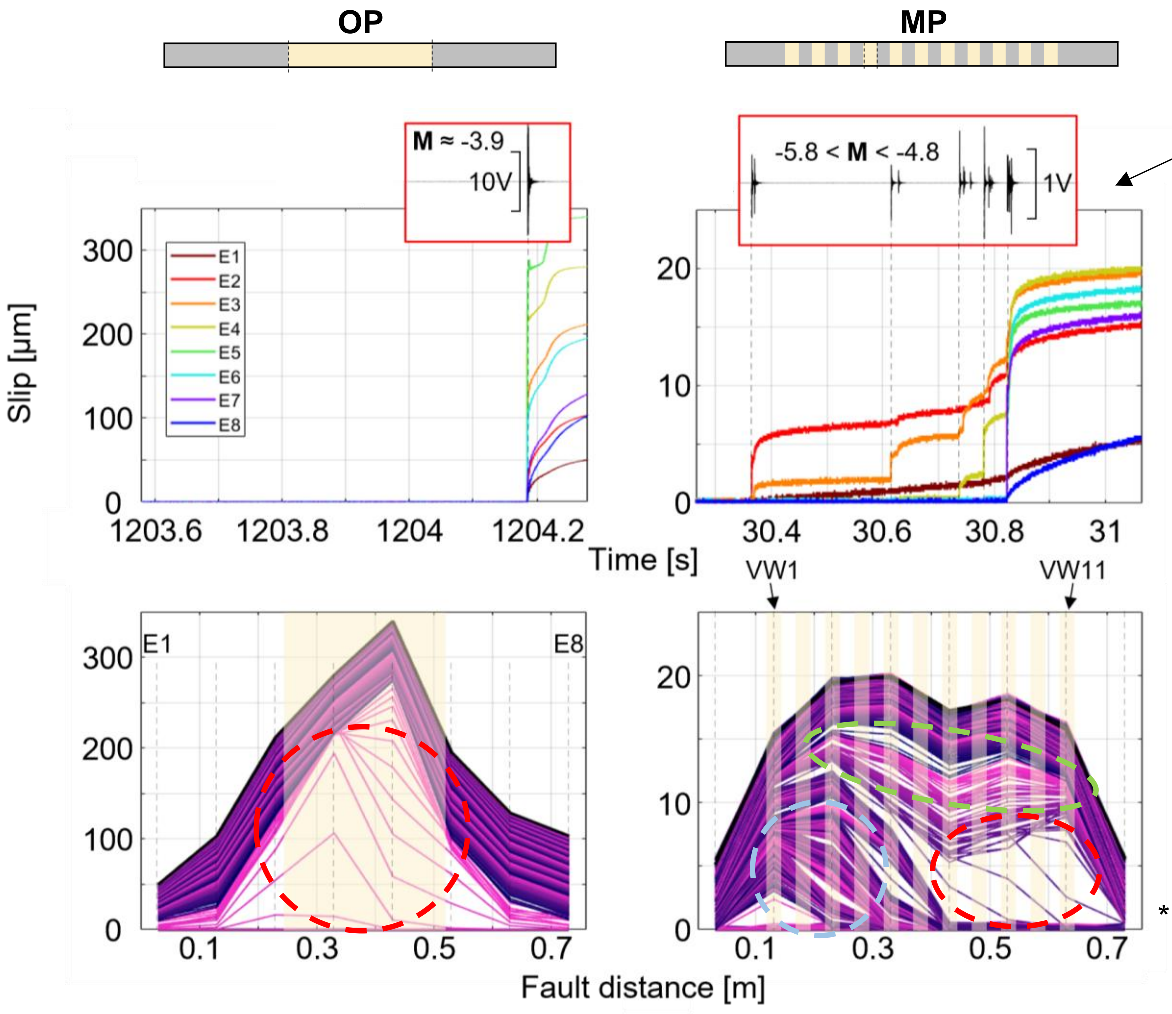


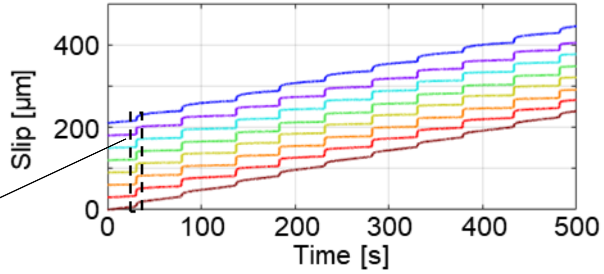
Experimental setup and fault conditions

- Teflon for VS patch and bare PMMA for VW patch (Song and McLaskey, 2024)
- Partitioned VW patches (MP test) and a single VW patch (OP test) with the same VW patch area
- Normal stress : 16 MPa
- Loading rate : 0.45 μm/s (slow), 1.4 μm/s, and 4.5 μm/s (fast)

3. Results and Discussion

▣ Overview of slip behavior





- OP test: larger slip with a single large event
- MP test: small slip with multiple small magnitude events

- MP test
  - Mainshock: slip event with largest magnitude
  - Foreshocks: Slip events before mainshock
  - Aftershocks: Slip events after mainshock
- OP test - only a mainshock

* Each line: 100 µs

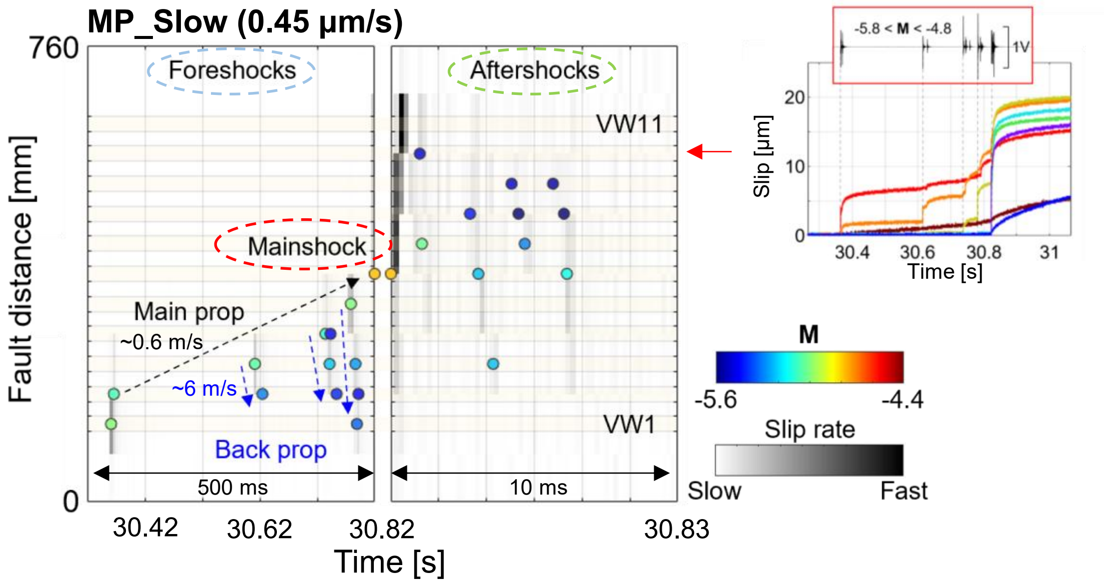
Large gap – Fast slip

Small gap – Slow slip

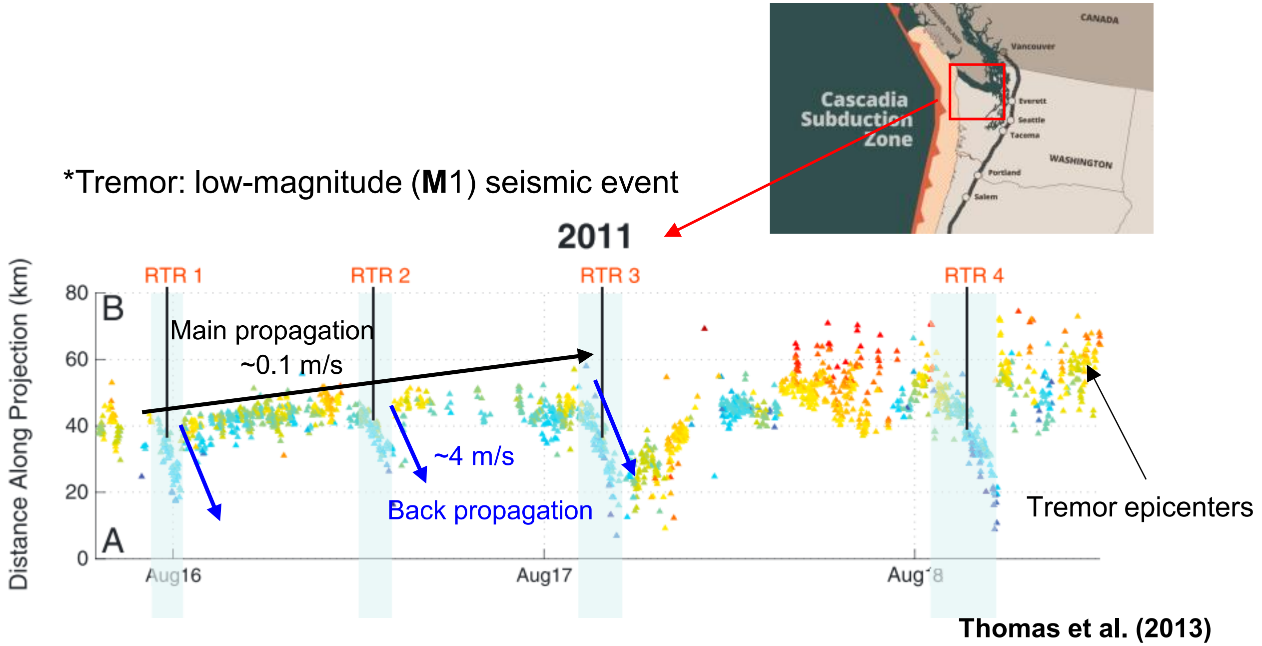
Overview of slip with time (0.45 µm/s)

3. Results and Discussion

▣ Backward propagation



Rupture location with time in the MP test at 0.45 μm/s

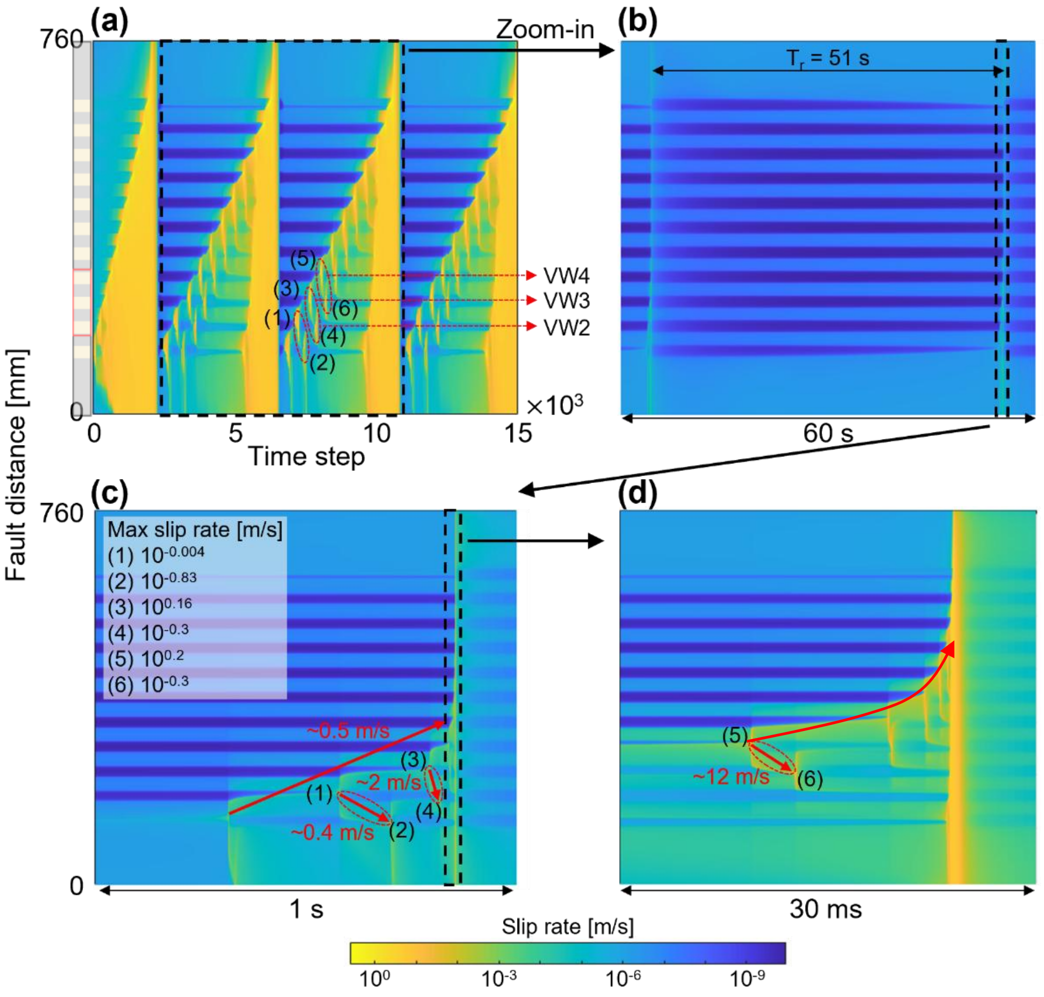


Rapid Tremor Reversal (RTR) in Cascadia subduction zone

- Back propagation of rupture with 10 times faster than main propagation
- Rapid Tremor Reversal (RTR): Back propagation at 20 to 40 times faster than its main propagation
- Frictional heterogeneity exists in Subduction zone
- Tremor foreshocks may be the precursors to a mainshock in the future

3. Results and Discussion

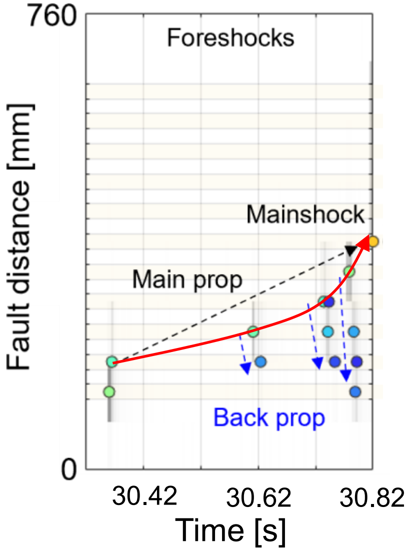
▣ 2D numerical simulation



Simulation results of the MP test at 0.45 μm/s

Prof. Cattania at MIT

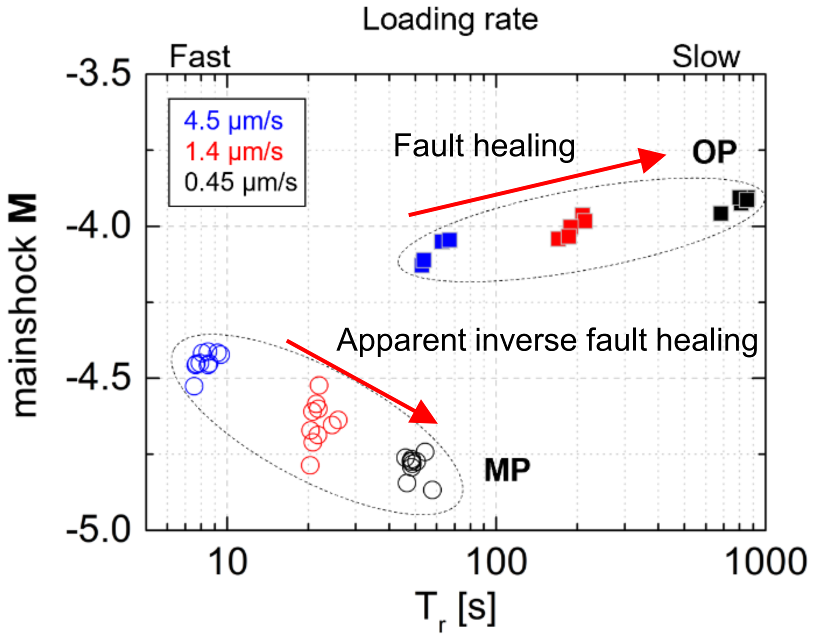
- 2D Quasi-dynamic simulations
  - Approximation of full dynamic effects
  - Instant stress transfer without full wave effects



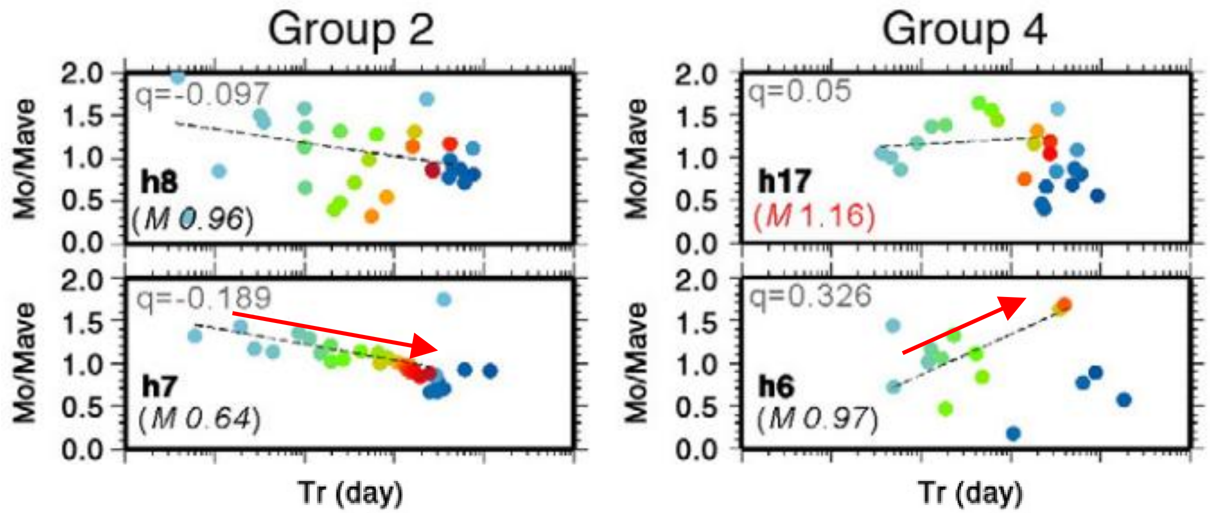
- Similar recurrence time (50 s)
- Event magnitude (peak slip rate) decreases during back-propagation
- Both the main front and back-propagation accelerate with time

3. Results and Discussion

▣ Loading rate effect (Comparing OP and MP)



Magnitude of mainshocks with recurrence time



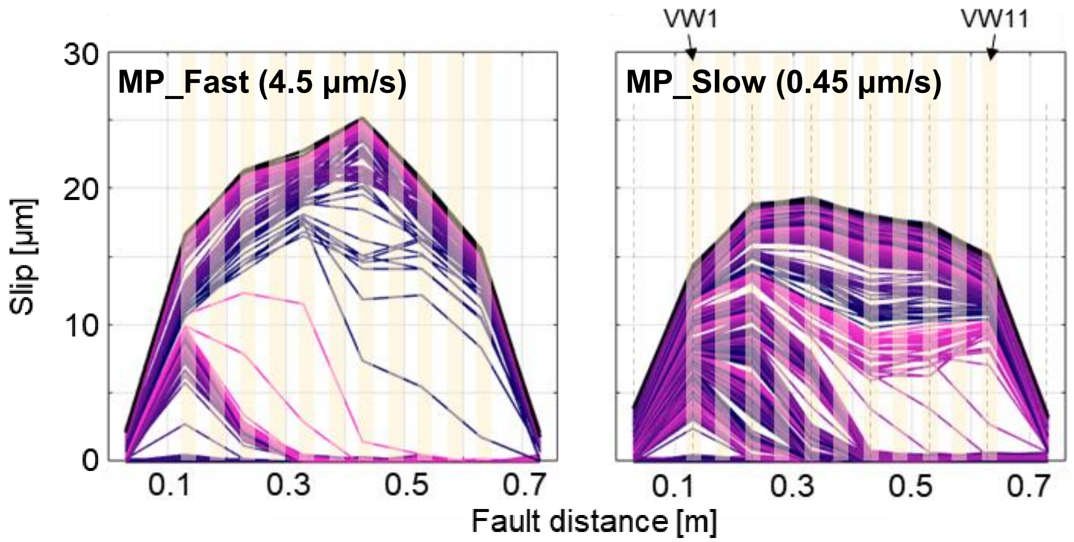
Chen et al. (2010)

Various trends of repeating earthquakes at Parkfield, California

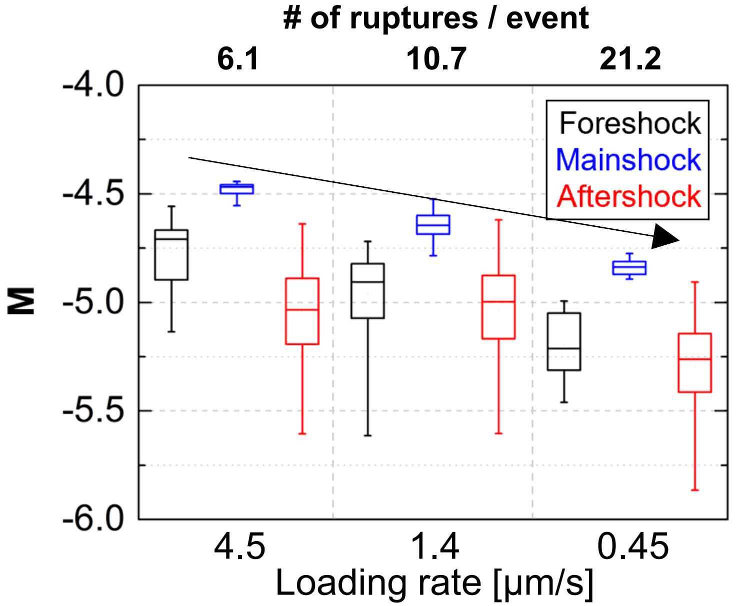
- OP test: Loading rate ↓, Magnitude (mainshock) ↑ due to fault healing
- MP test: Loading rate ↓, Magnitude (mainshock) ↓, Apparent inverse fault healing
- Similar trend in the repeating earthquakes in Parkfield, California

3. Results and Discussion

▣ Loading rate effect (MP tests)



Slip with fault distance in the MP tests



Magnitude in the MP tests

- Fast loading rate: fewer large-slip events and slow loading rate: multiple small-slip events

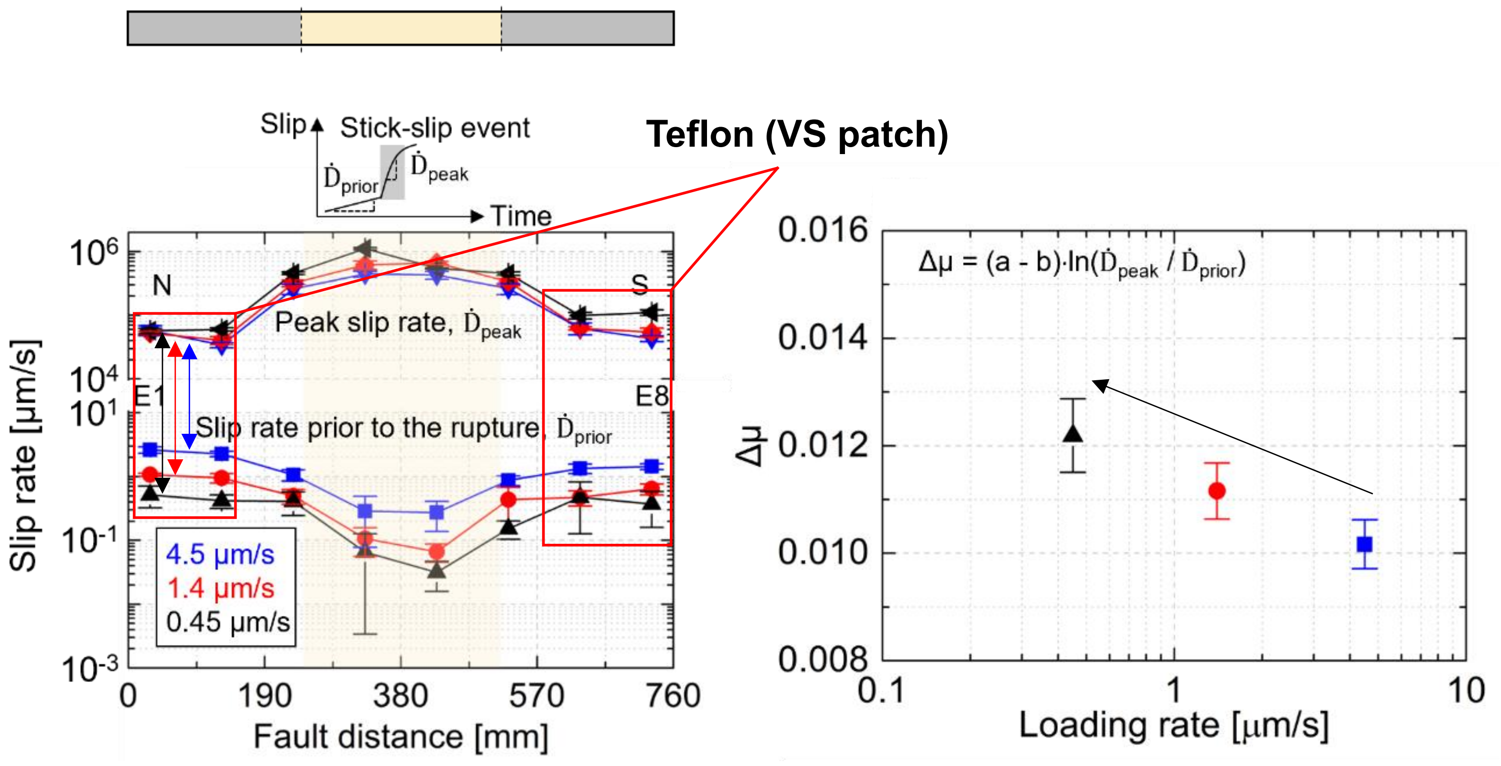
- Loading rate ↓, Magnitude (mainshock, foreshocks, and aftershocks) ↓

 • Fast loading rate: low effectiveness of VS barrier, leading to simultaneous rupture of VW patches

 • Slow loading rate: high effectiveness of VS barrier, leading to independent ruptures of VW patches

3. Results and Discussion

▣ Barrier effectiveness of VS patch



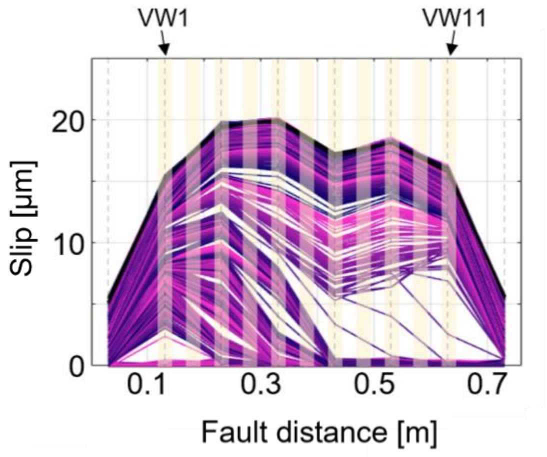
Slip velocity changes at slip event

- Frictional change in VS patch, $\boldsymbol{\Delta\mu_{Teflon}} = (a - b)\cdot\ln(\dot{\mathbf{D}}_{\mathbf{peak}} / \dot{\mathbf{D}}_{\mathbf{prior}})$

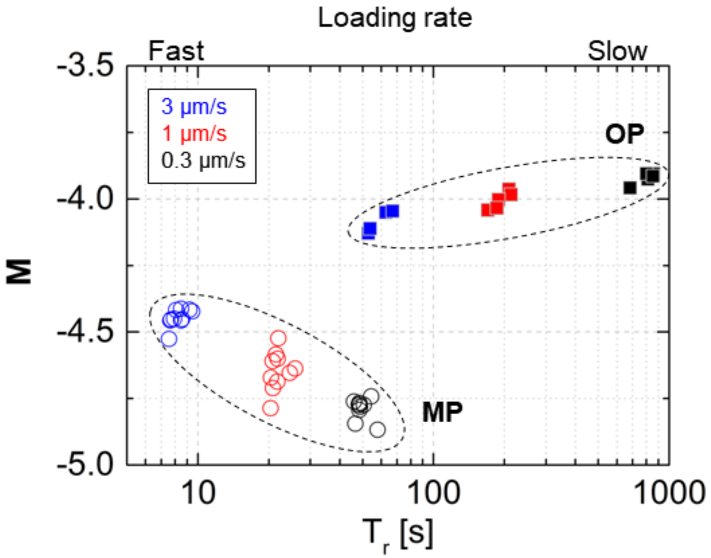
- Slow loading rate has higher $\dot{D}_{peak} / \dot{D}_{prior}$, indicating strong VS barrier

4. Conclusions

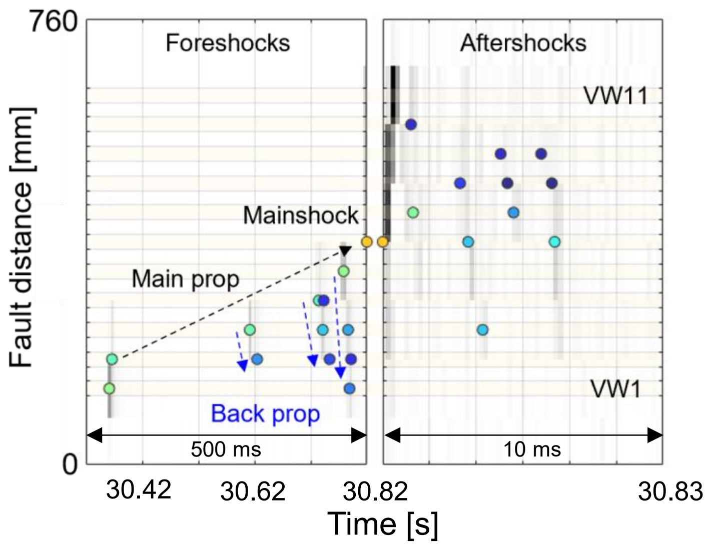
▣ Summary



Multiple slip events in the MP tests

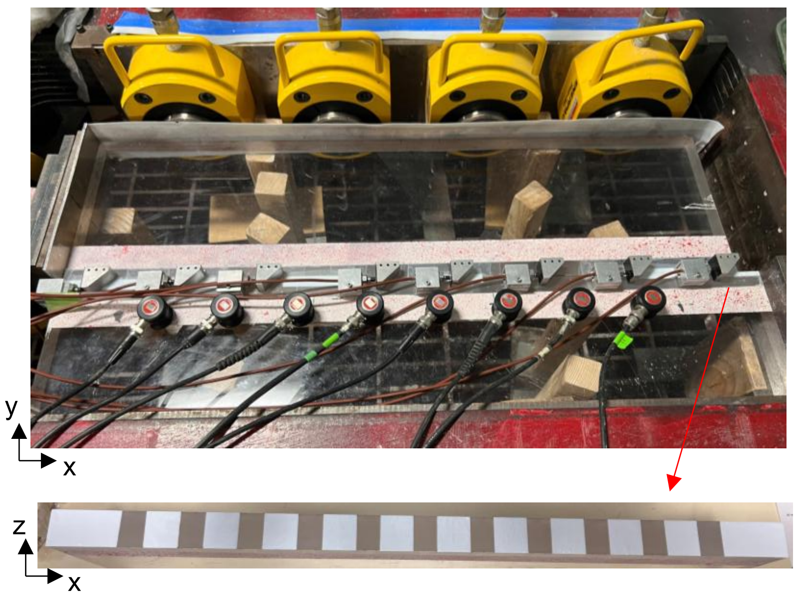


Magnitude of mainshocks with recurrence time



Back propagation in MP tests

- Teflon method is effective way to easily make frictionally heterogeneous fault in the lab
- Frictional heterogeneity is one of the factors that can explain the complex rupture behavior
  - Multiple ruptures (foreshocks, mainshock and aftershocks) in a slip cycle
  - Fast loading: simultaneous ruptures; slow: independent ruptures → inverse apparent fault healing
  - Backward propagation of VW patches, similar to Rapid Tremor Reversals in Subduction zone



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First published: 27 November 2025 | https://doi.org/10.1029/2025JB032055

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