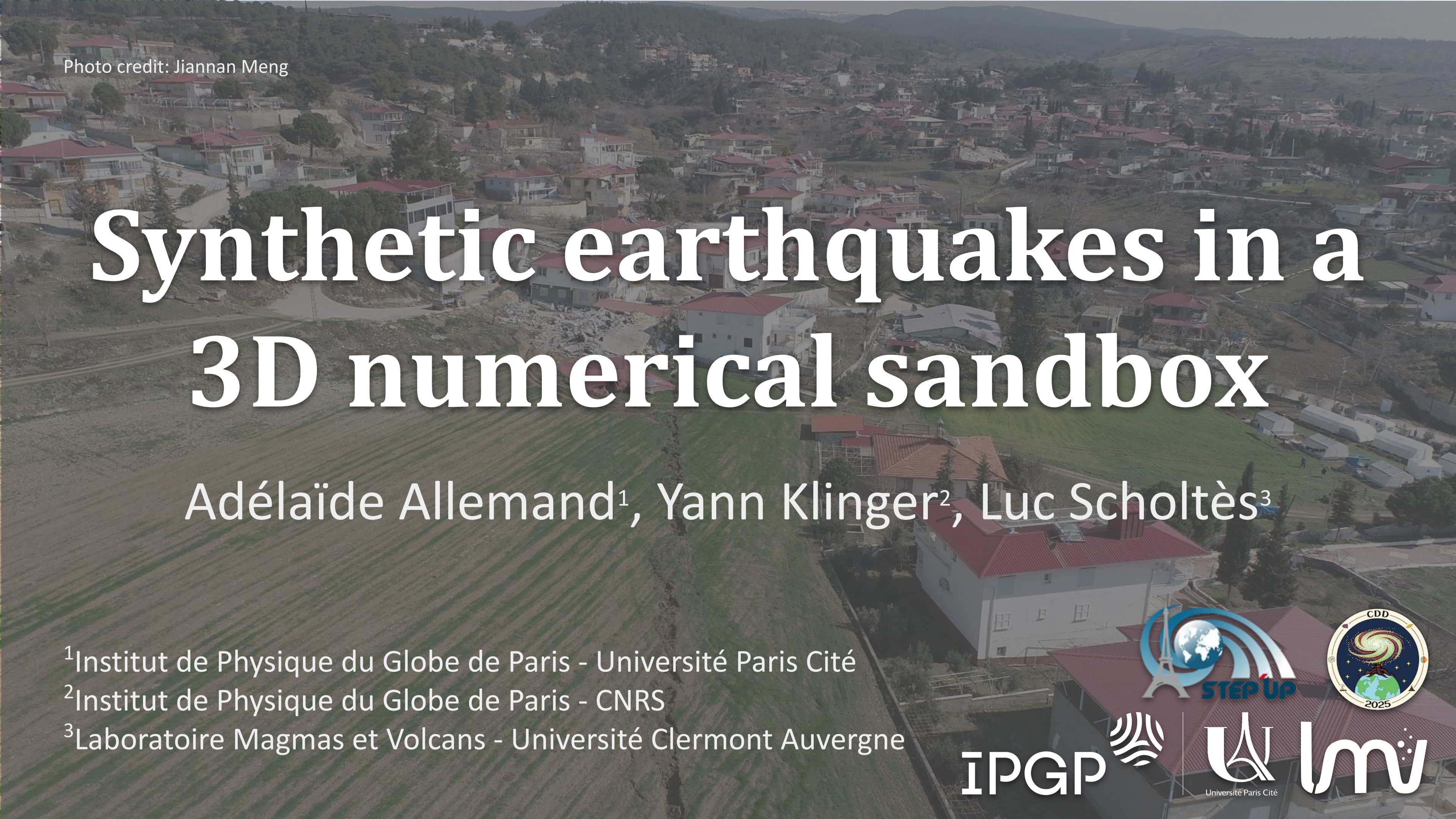


Photo credit: Jiannan Meng

Synthetic earthquakes in a 3D numerical sandbox

Adélaïde Allemand[1], Yann Klinger[2], Luc Scholtès[3]

[1]Institut de Physique du Globe de Paris - Université Paris Cité
[2]Institut de Physique du Globe de Paris - CNRS
[3]Laboratoire Magmas et Volcans - Université Clermont Auvergne


Surface rupture after the
2023 Kahramanmaraş
earthquakes (Turkey)
Photo credit: Jiannan Meng


Surface rupture after the 2023 Kahramanmaraş earthquakes (Turkey)
Photo credit: Jiannan Meng


Surface rupture after the
2023 Kahramanmaraş
earthquakes (Turkey)
Photo credit: Jiannan Meng
Context: continental strike-slip faults

Objective

Model a continental strike-slip fault and the mutual interaction between fault geometry and earthquake rupturing

This approach

Development of a mature fault zone

This approach

Development of a mature fault zone + Earthquake cycles →

This approach

Development of a mature fault zone

+

Earthquake cycles

→

Seismic cycles on an evolving strike-slip fault

This approach: Discrete Element Modelling (DEM)

Development of a mature fault zone + **Earthquake cycles** → **Seismic cycles on an evolving strike-slip fault**

Principles of the DEM

Nature

Principles of the DEM

Nature

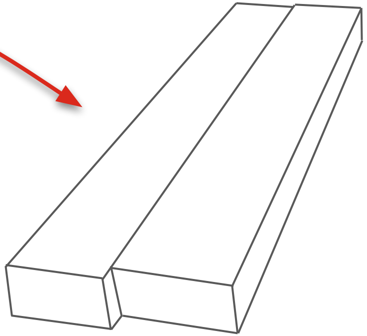
Strike-slip fault

Principles of the DEM

Nature

Strike-slip fault

Sub-volume

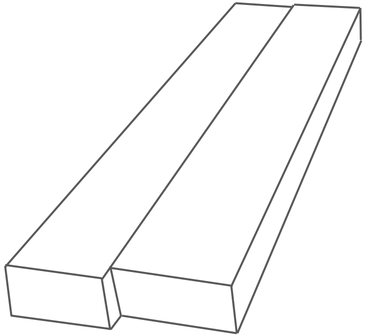


Principles of the DEM

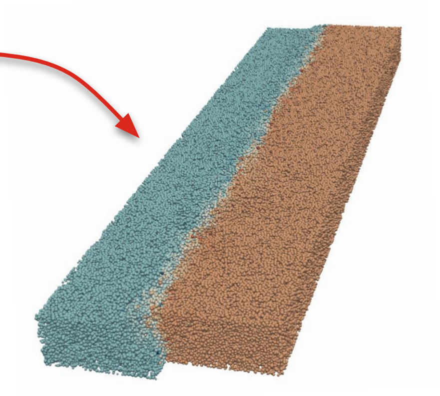
Nature

Strike-slip fault

Sub-volume

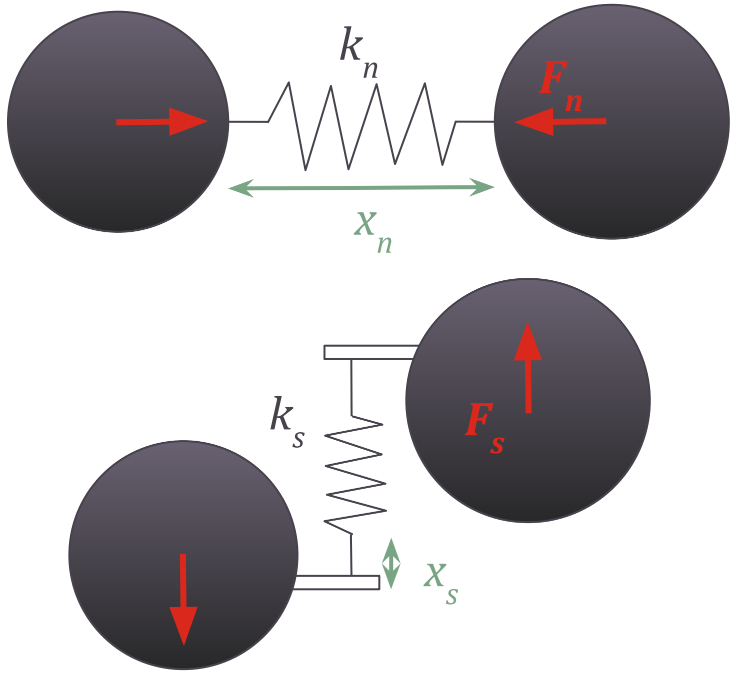


Packing of spherical particles



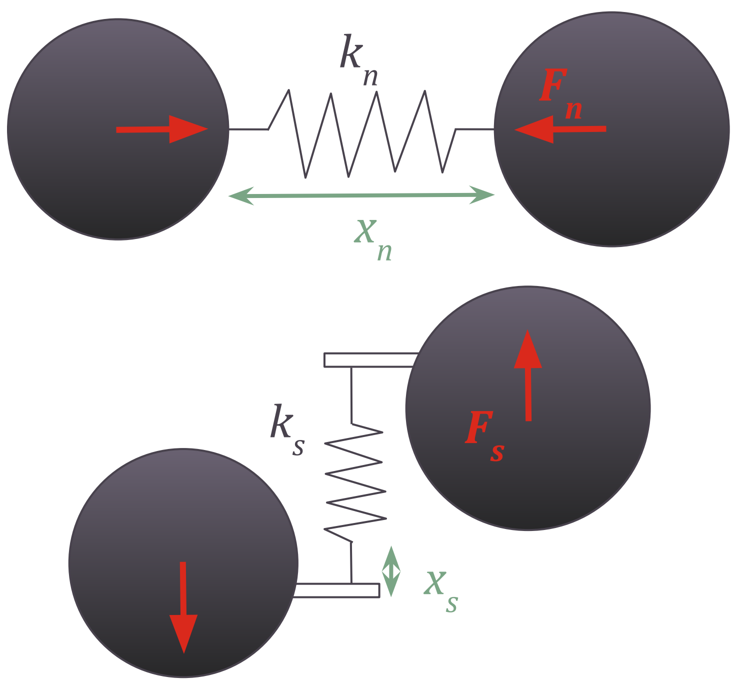
Principles of the DEM

Contact law between particles

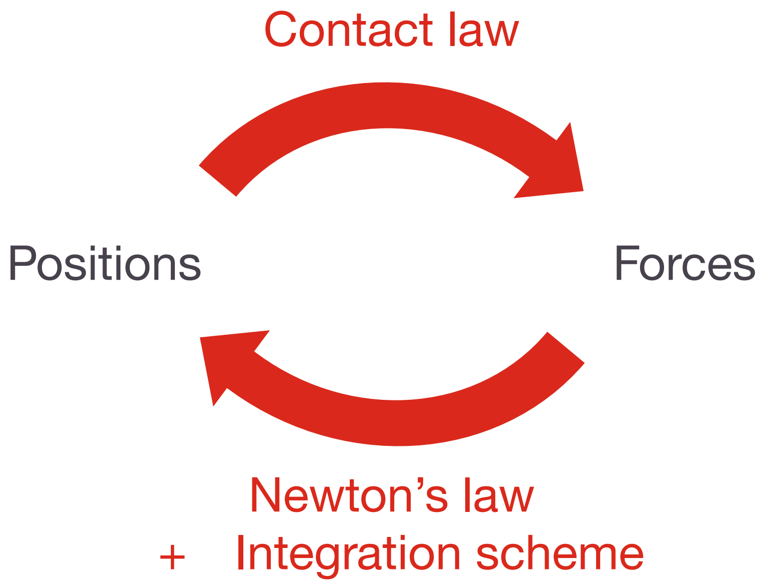


Principles of the DEM

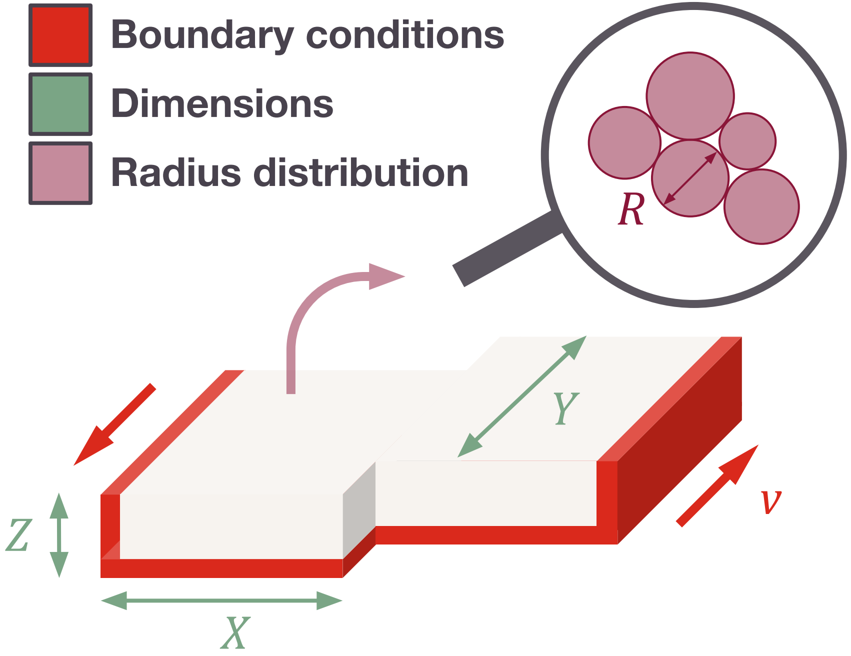
Contact law between particles



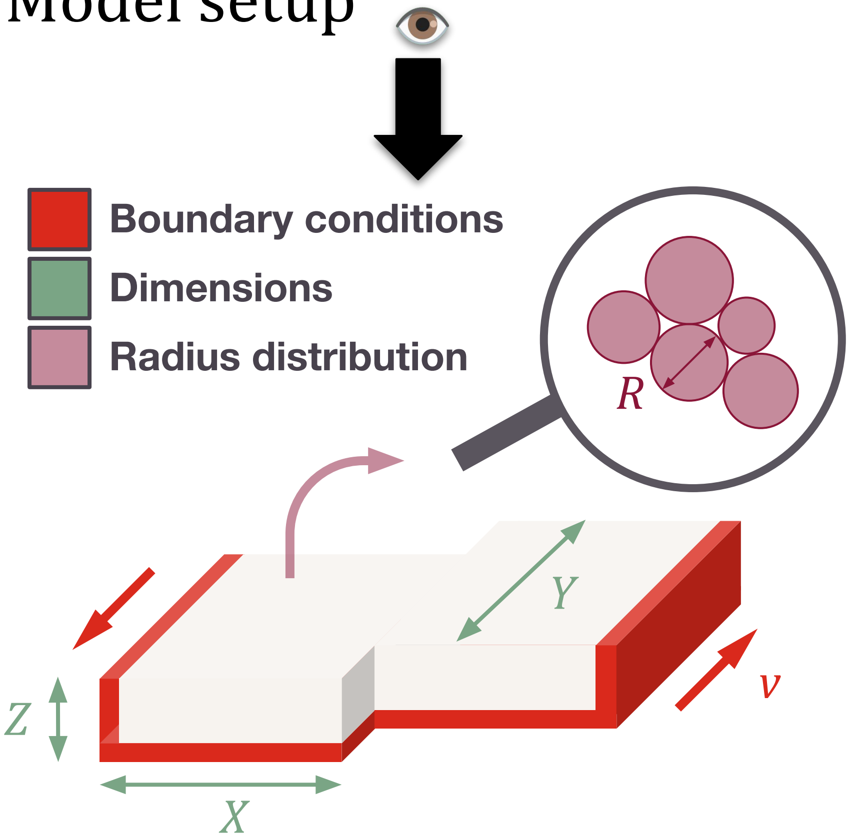
Iteration loop

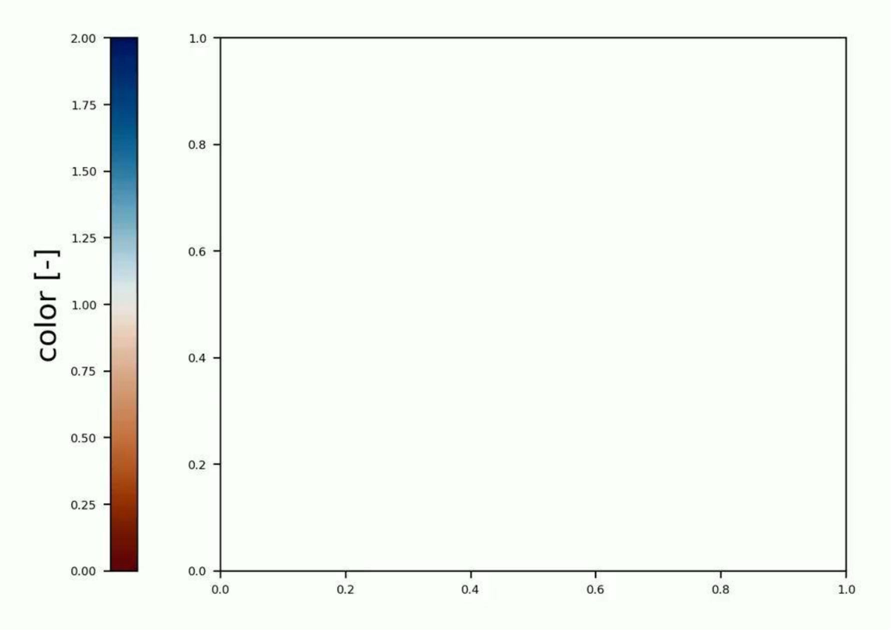


Model setup

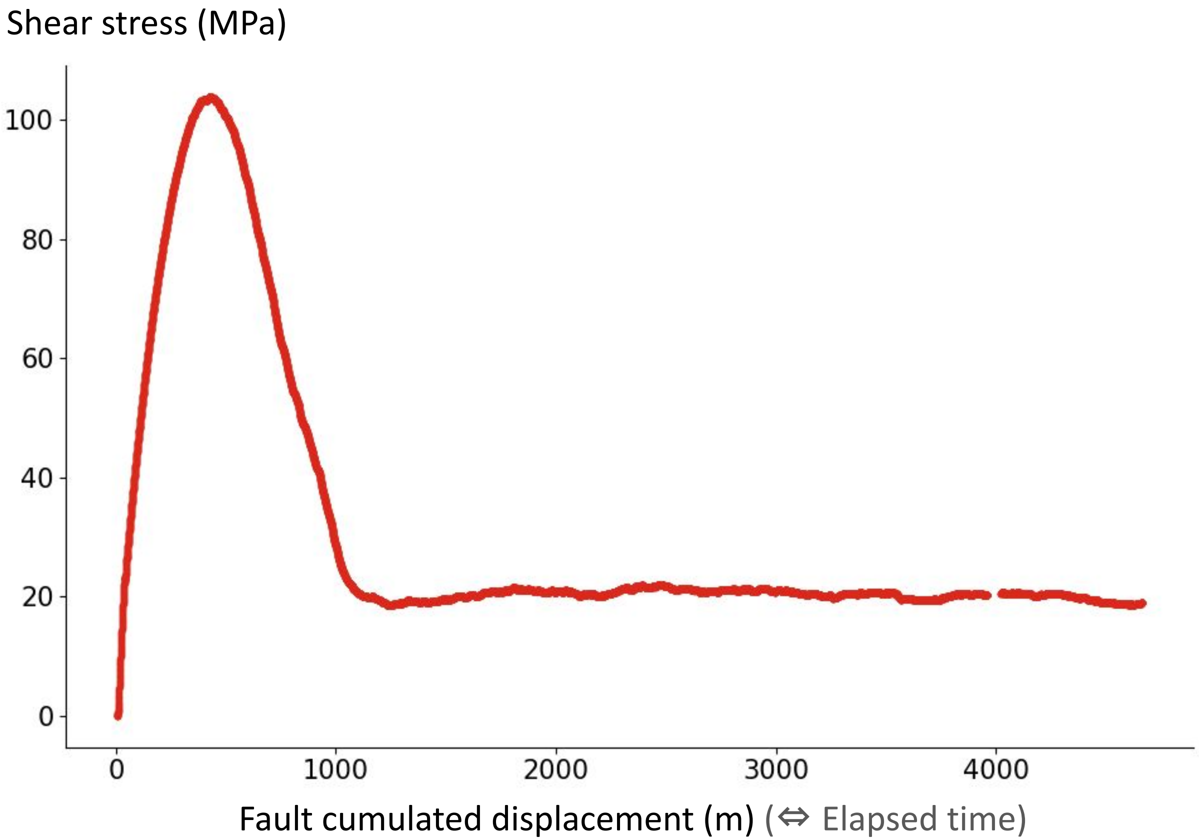

Boundary conditions
Dimensions
Radius distribution
R
Y
v
Z
X

Model setup

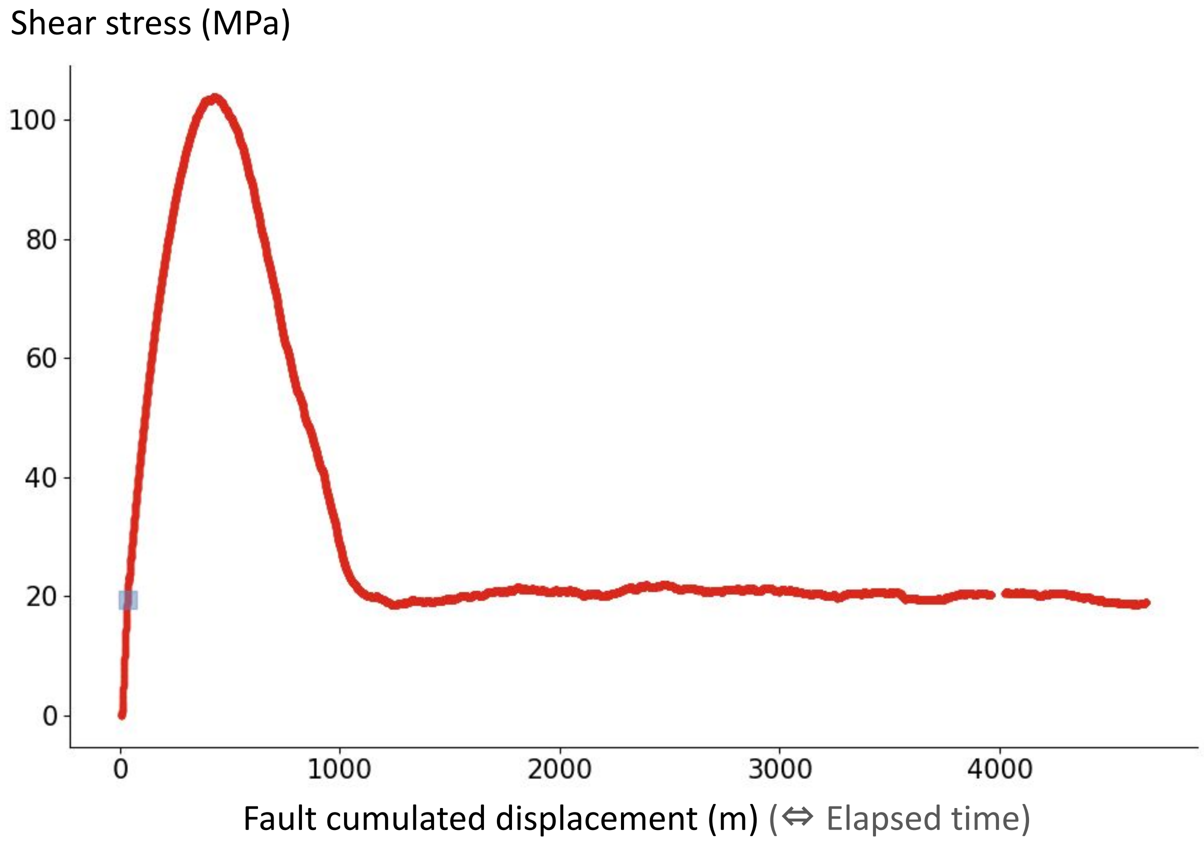

Boundary conditions
Dimensions
Radius distribution
R
Y
Z
X
v

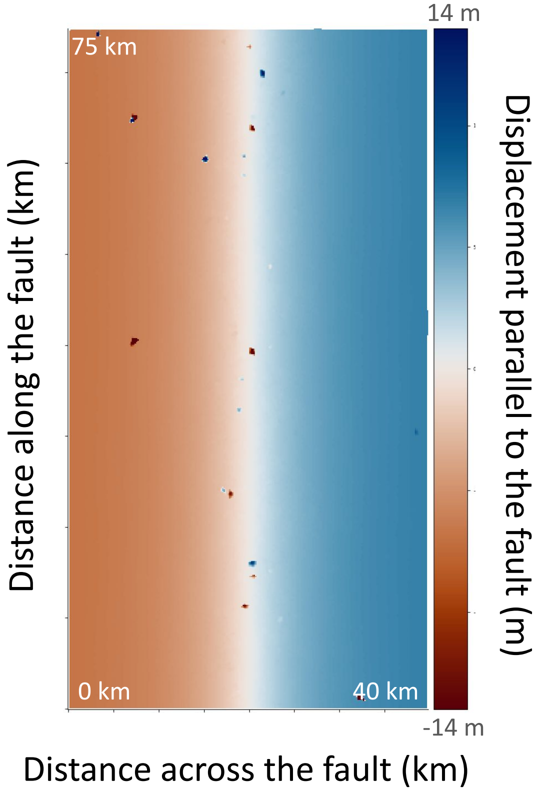

color [-]
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
1.0

Long term fault evolution

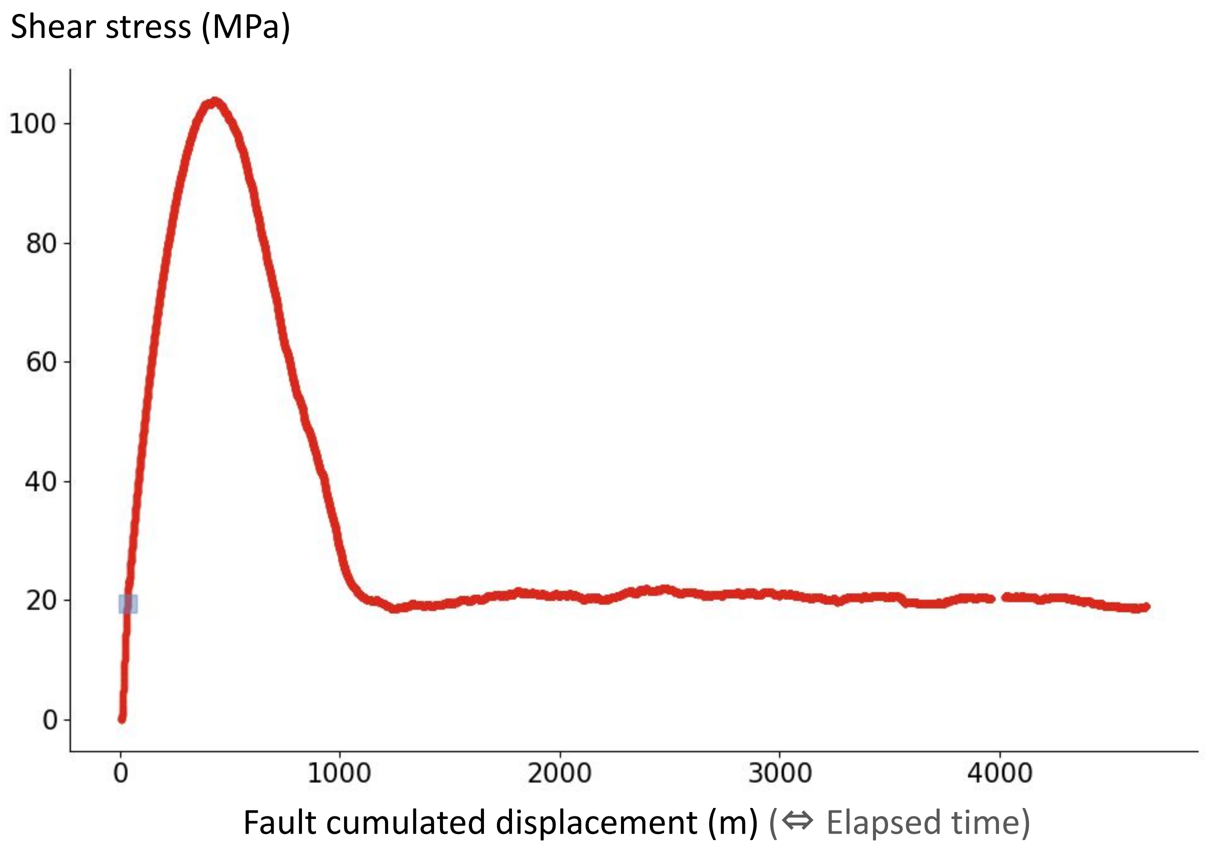


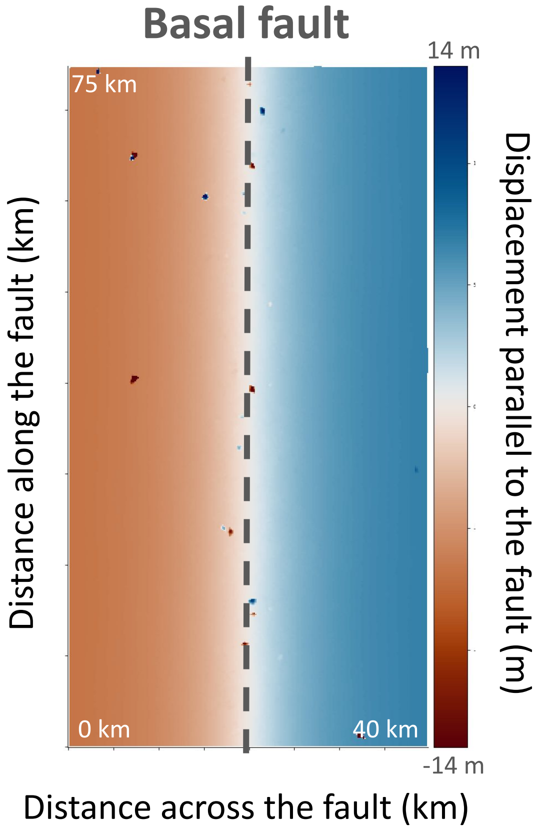
Long term fault evolution



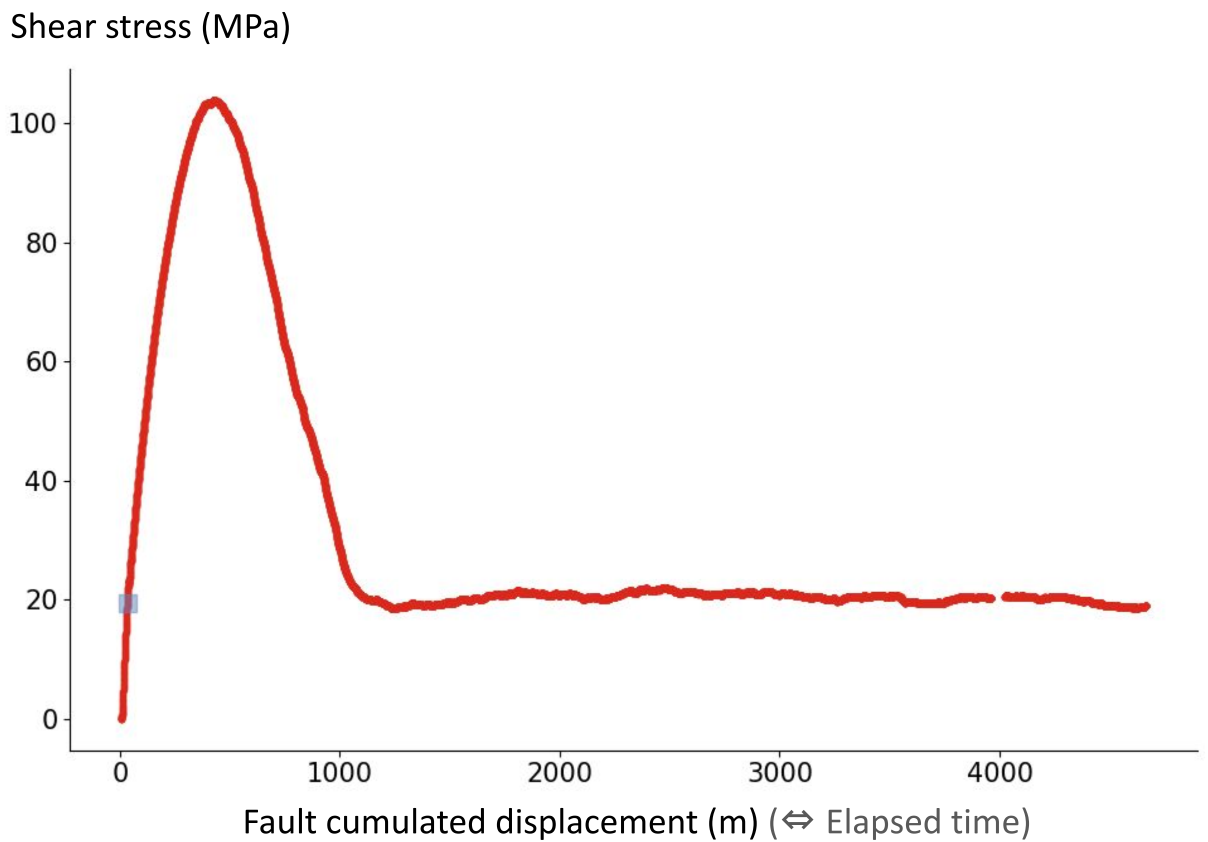


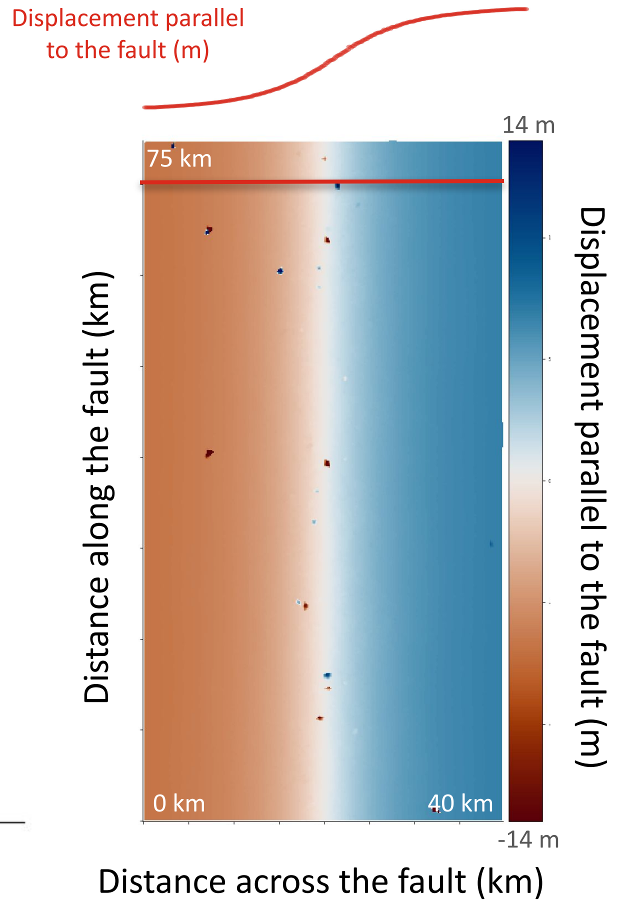
Long term fault evolution



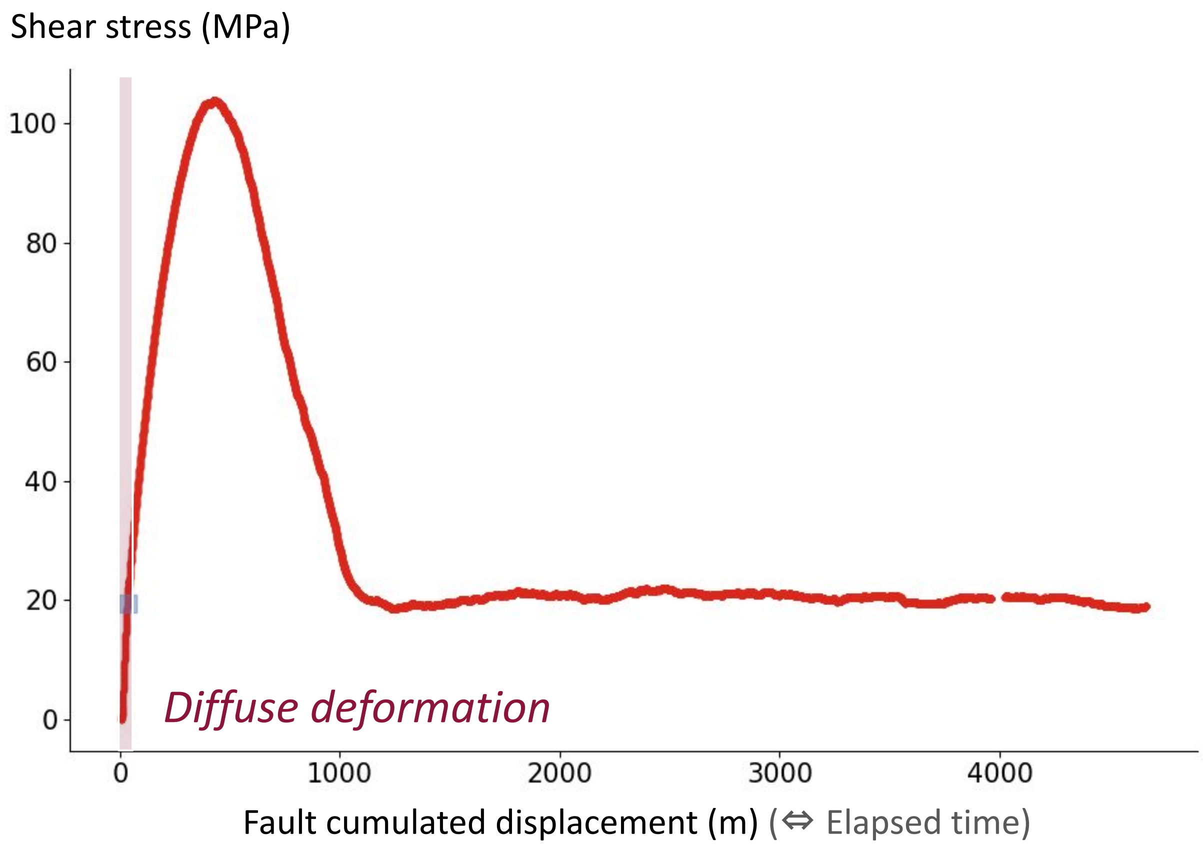


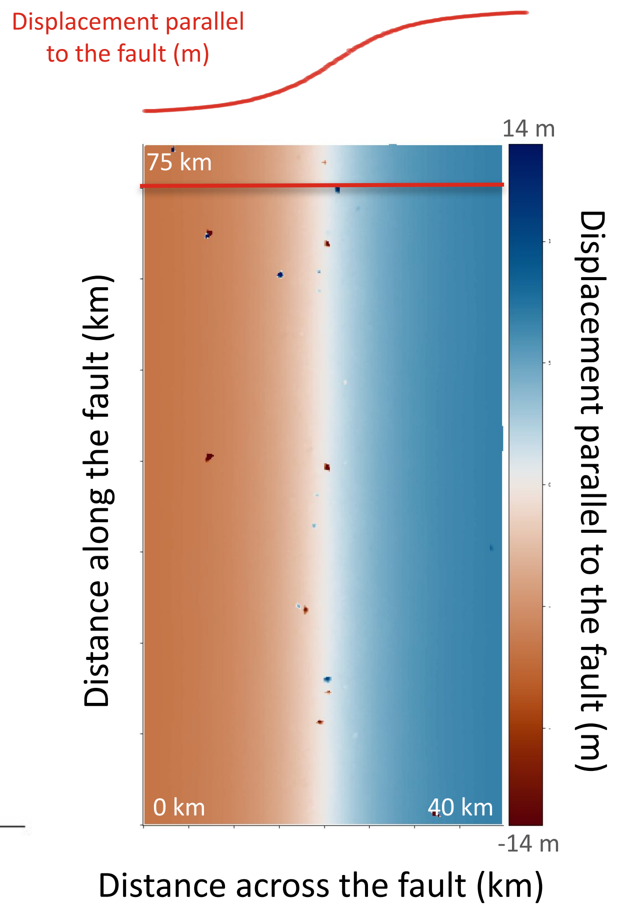
Long term fault evolution



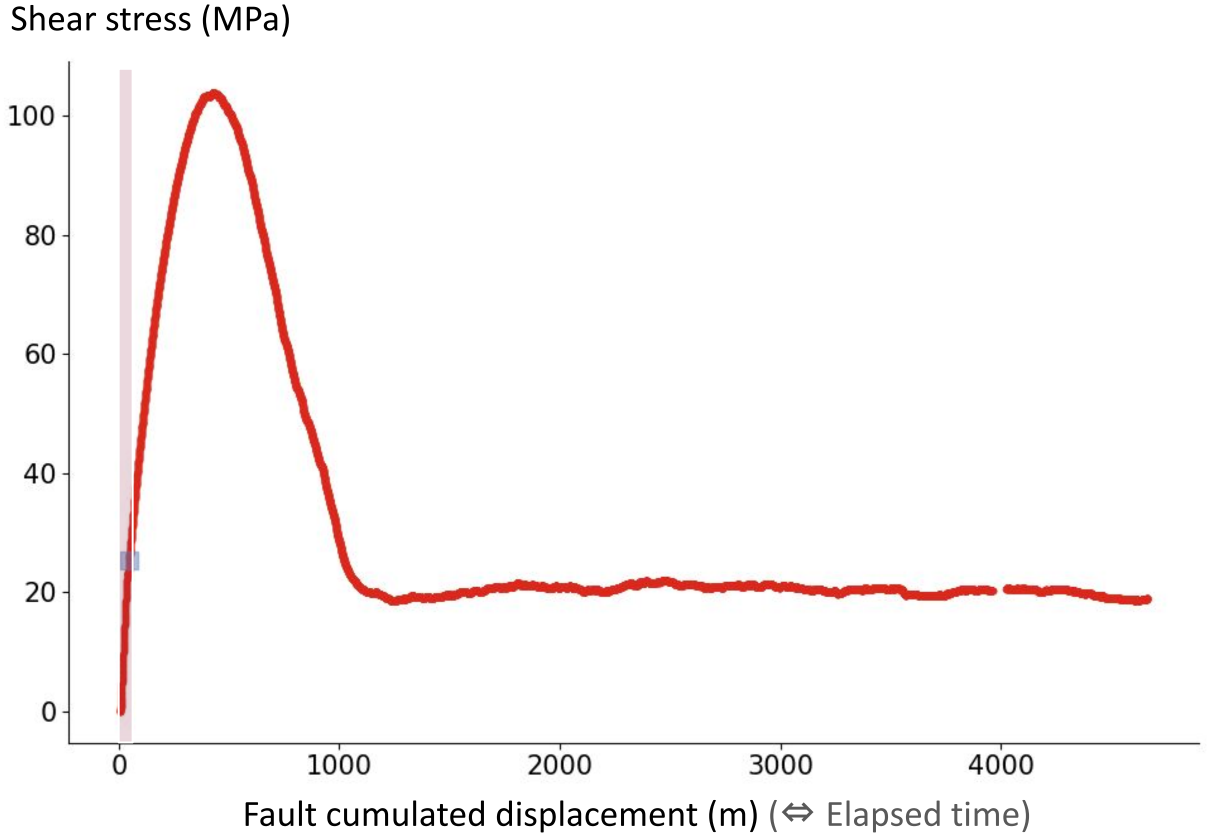


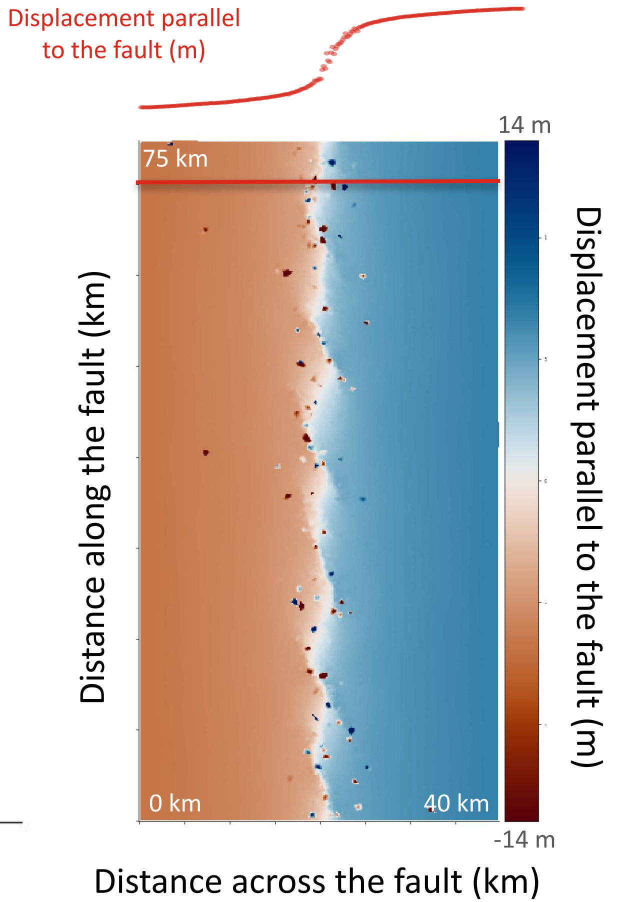
Long term fault evolution



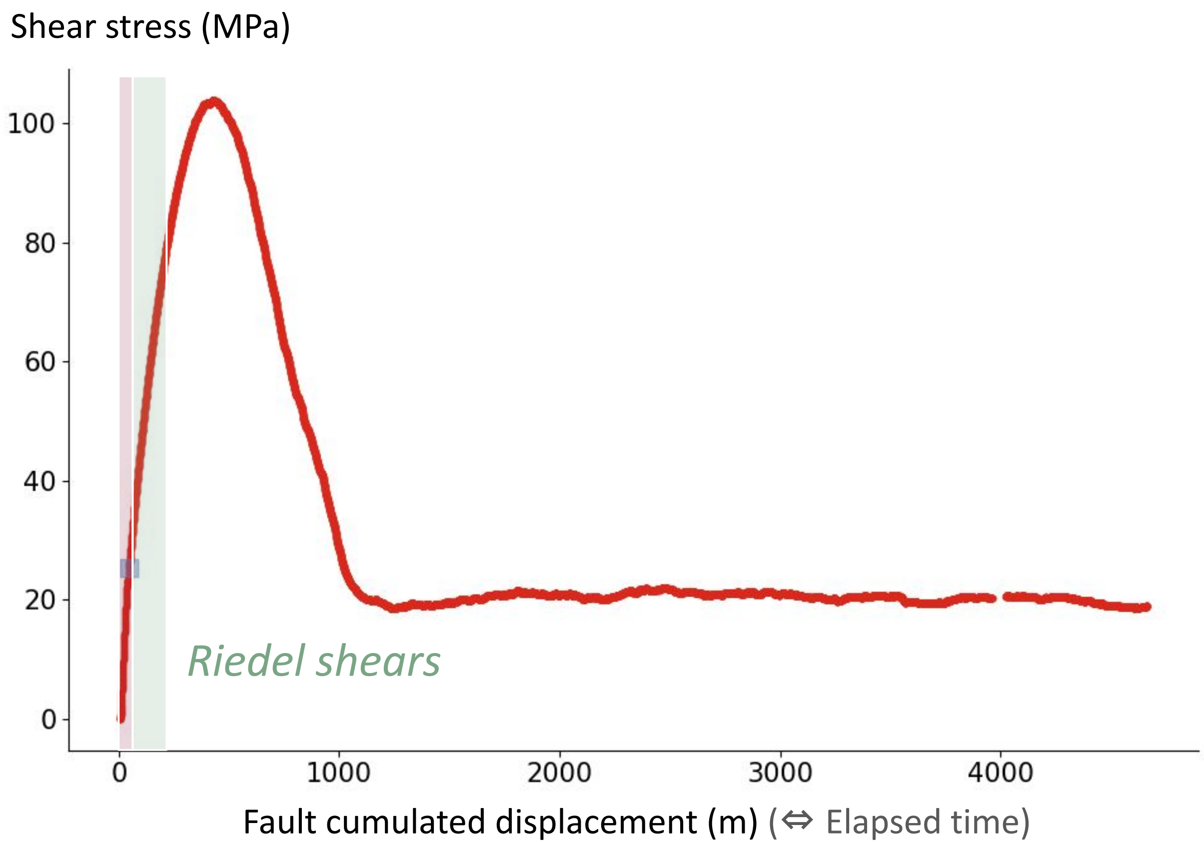


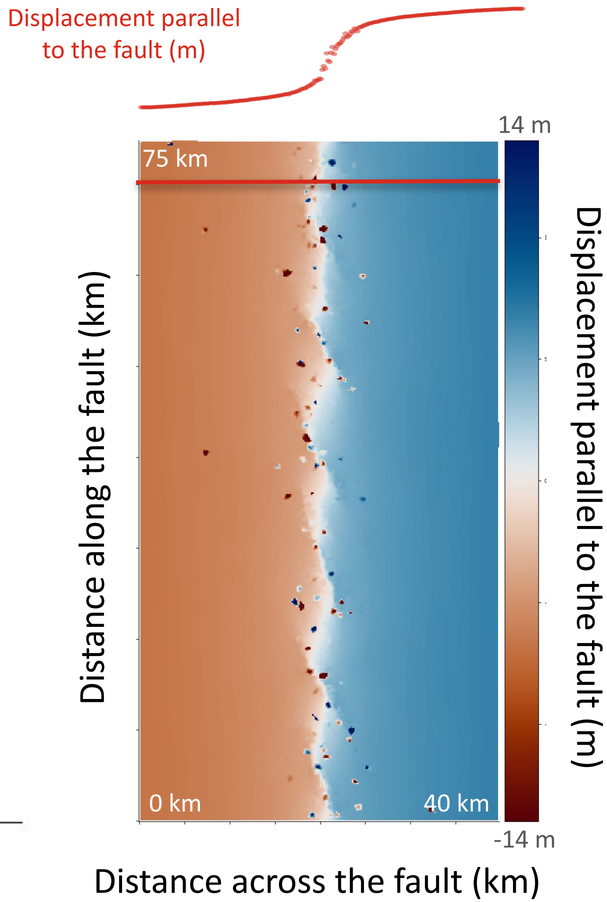
Long term fault evolution



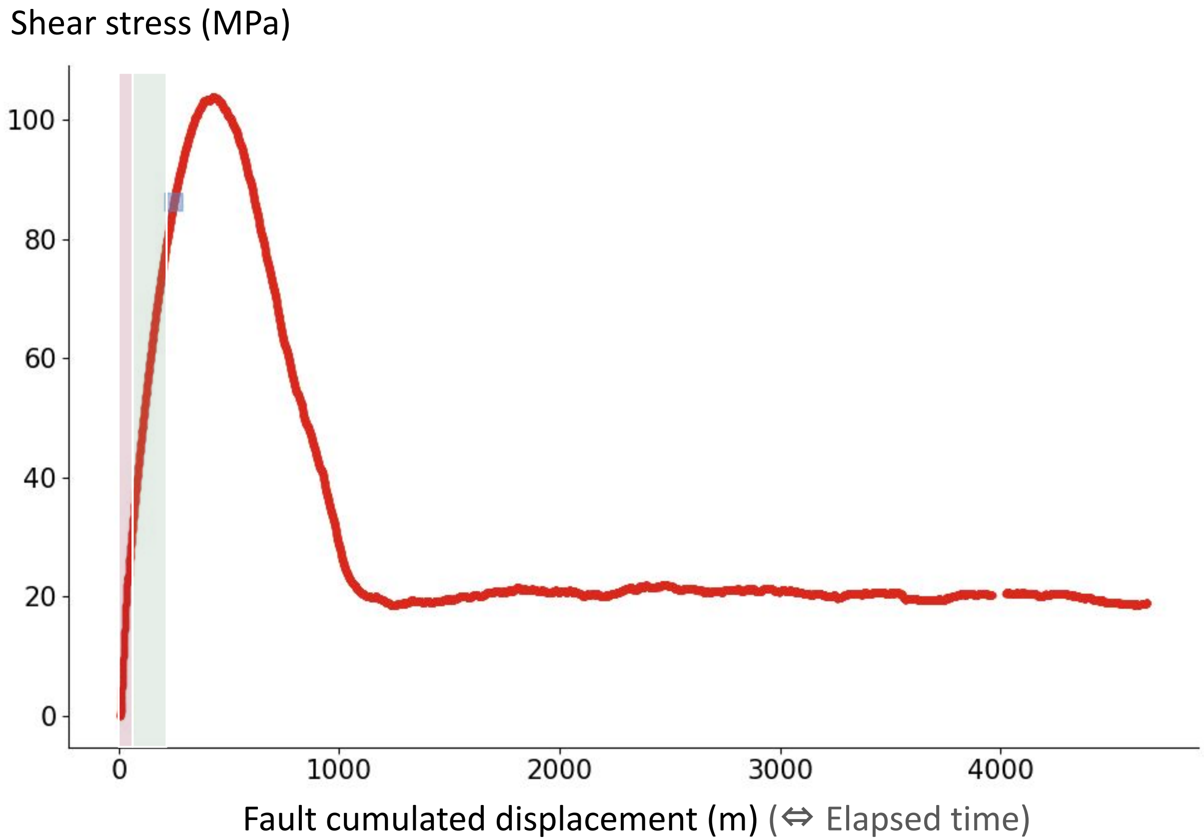


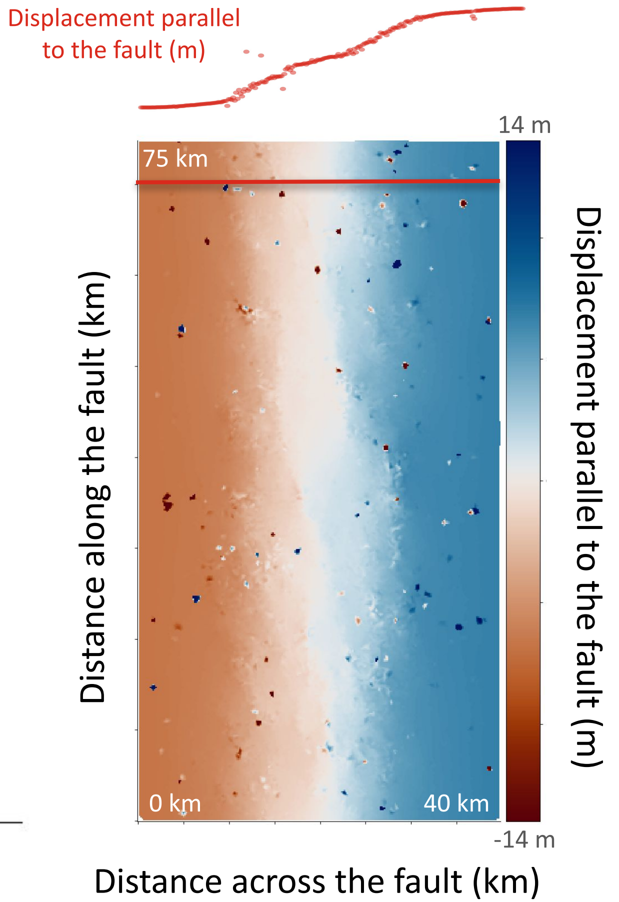
Long term fault evolution



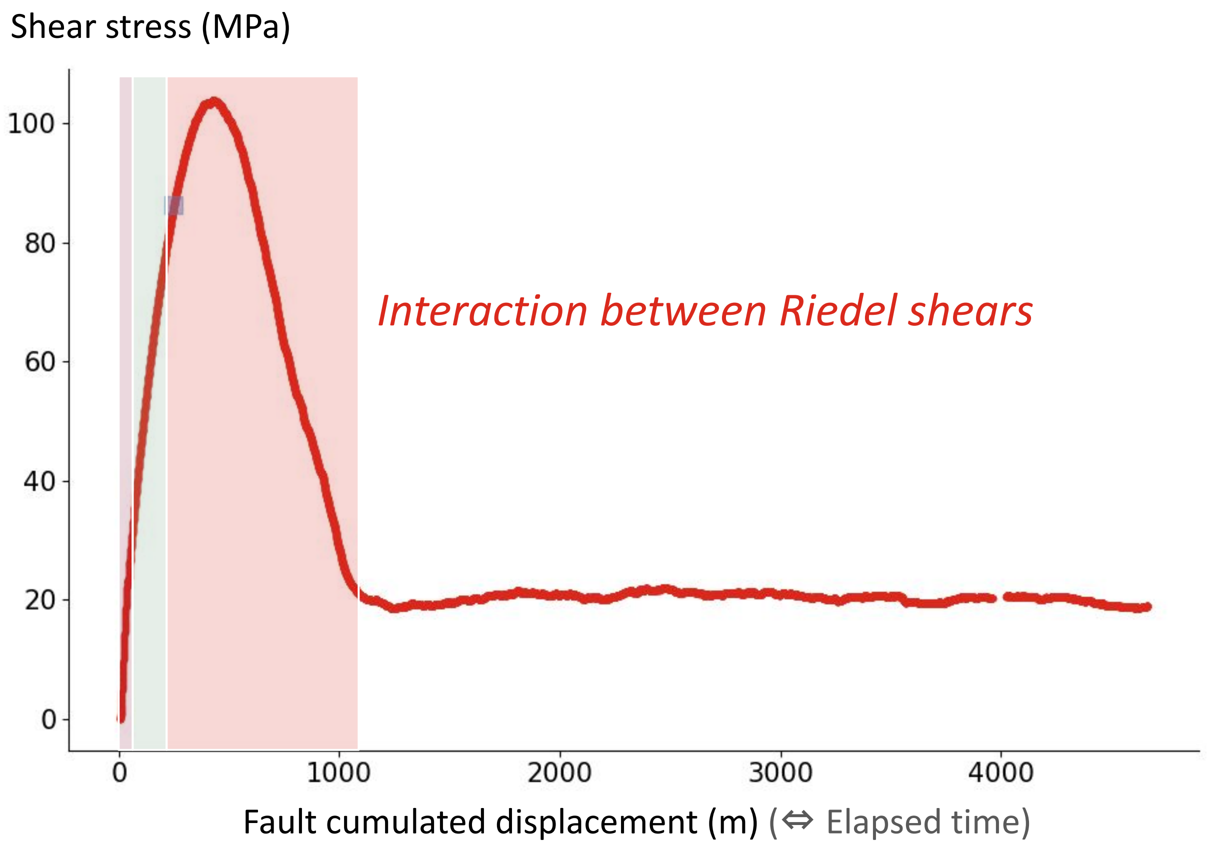


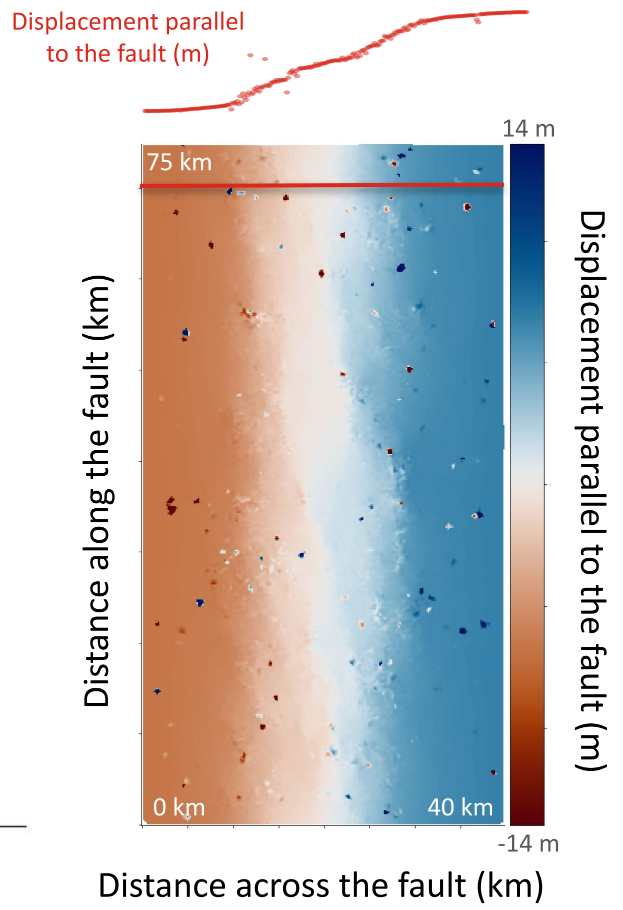
Long term fault evolution



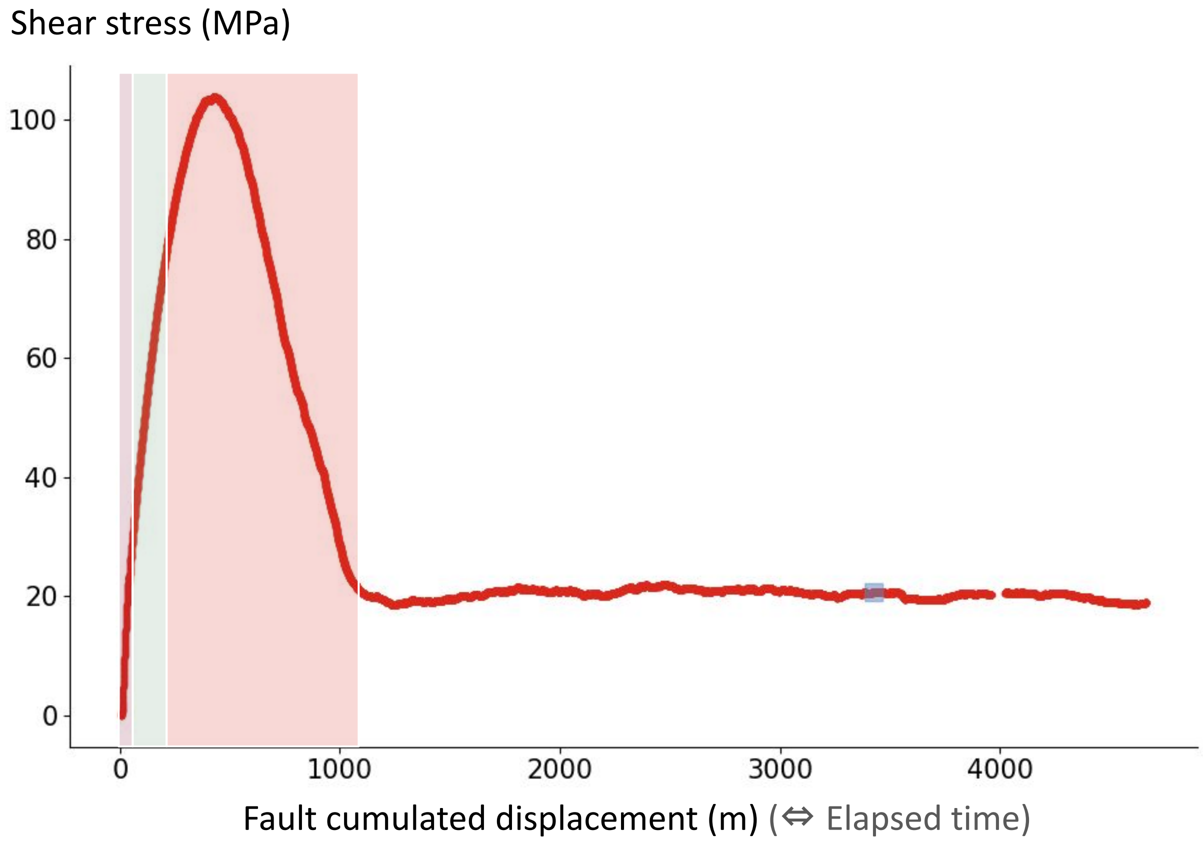


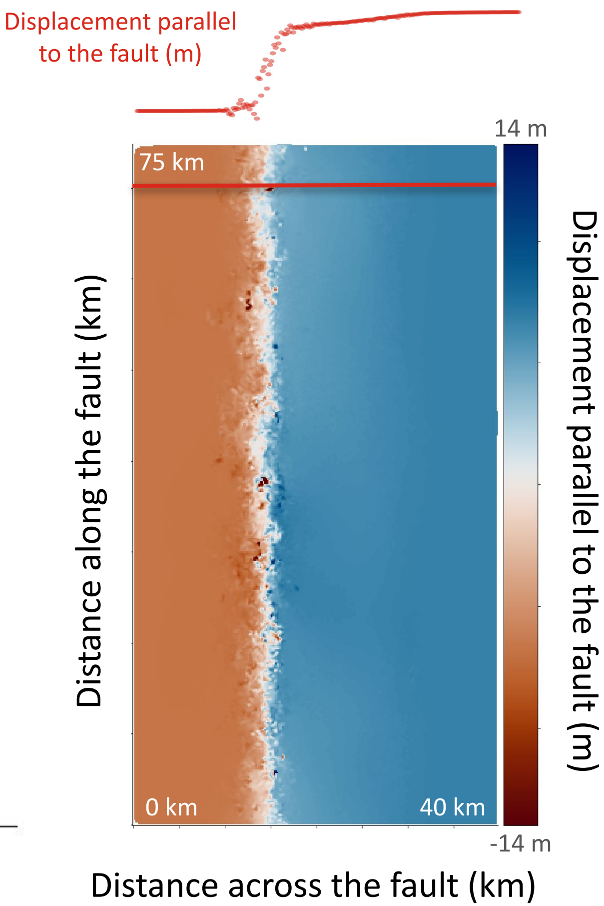
Long term fault evolution



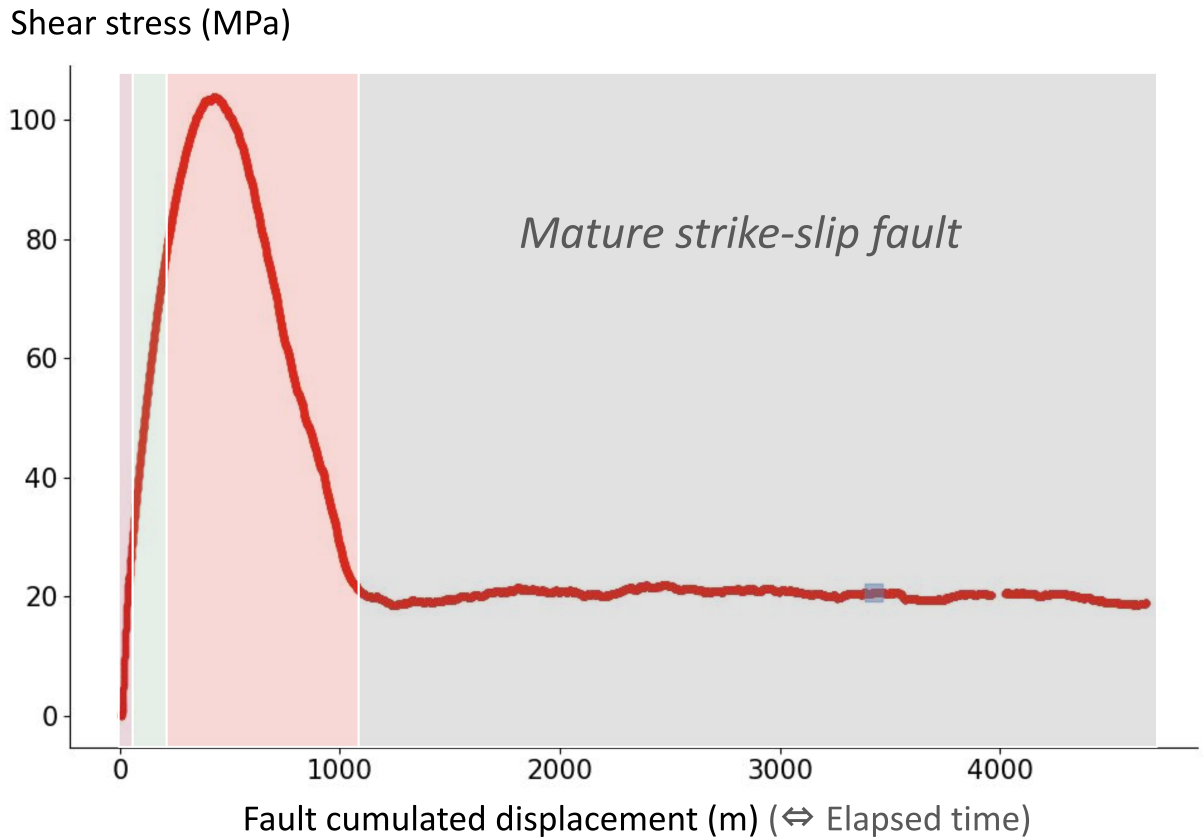


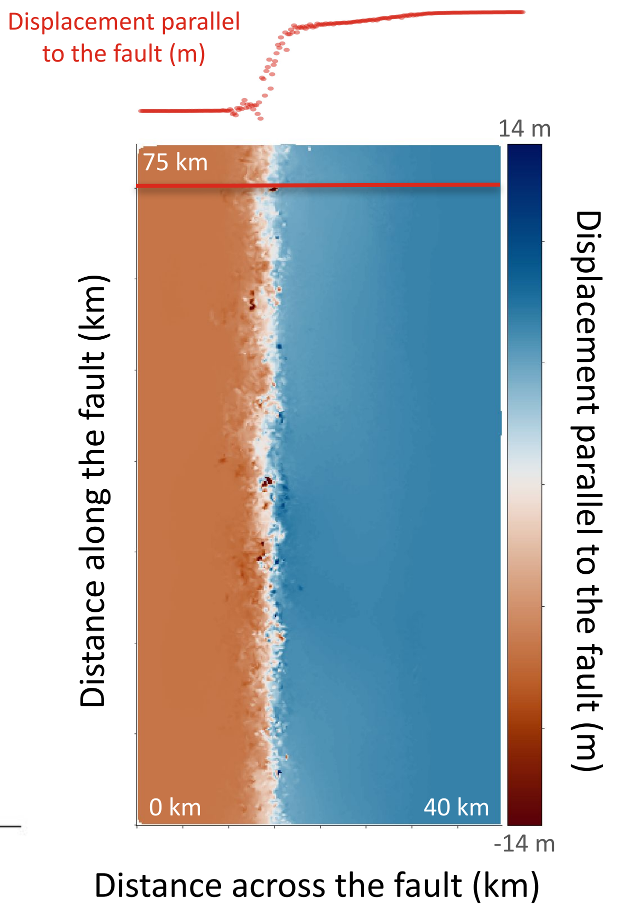
Long term fault evolution





Long term fault evolution

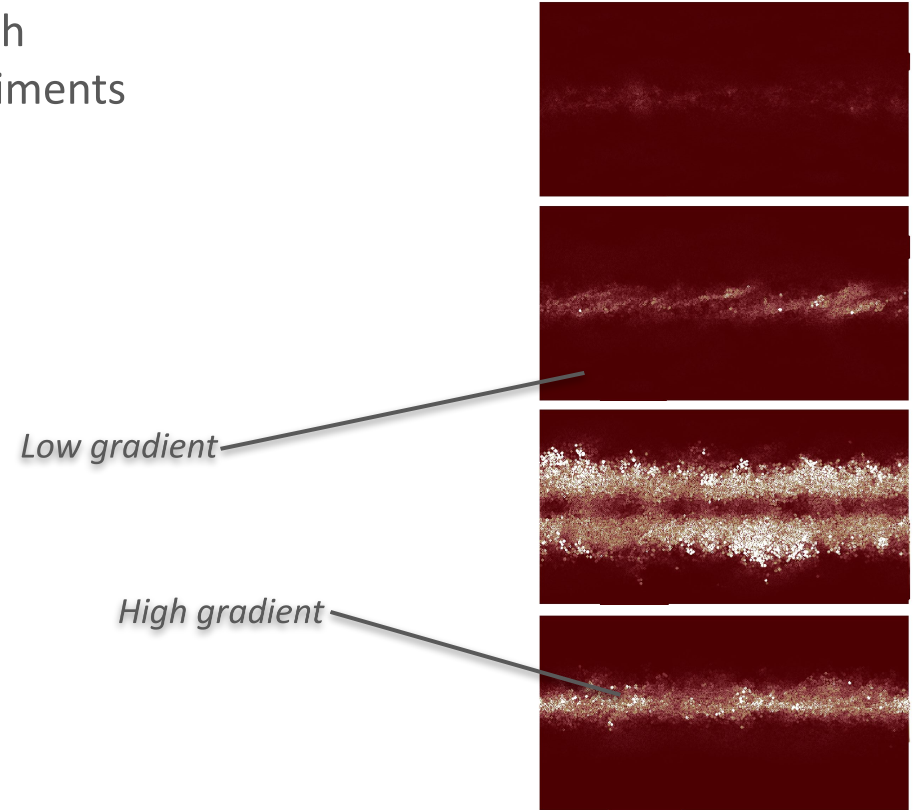




Long term fault evolution

Comparison with analogue experiments

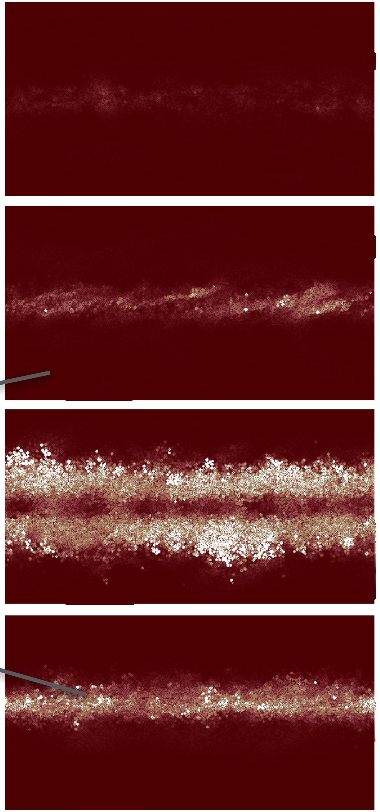
Gradient of displacement in the direction perpendicular to the fault



Long term fault evolution

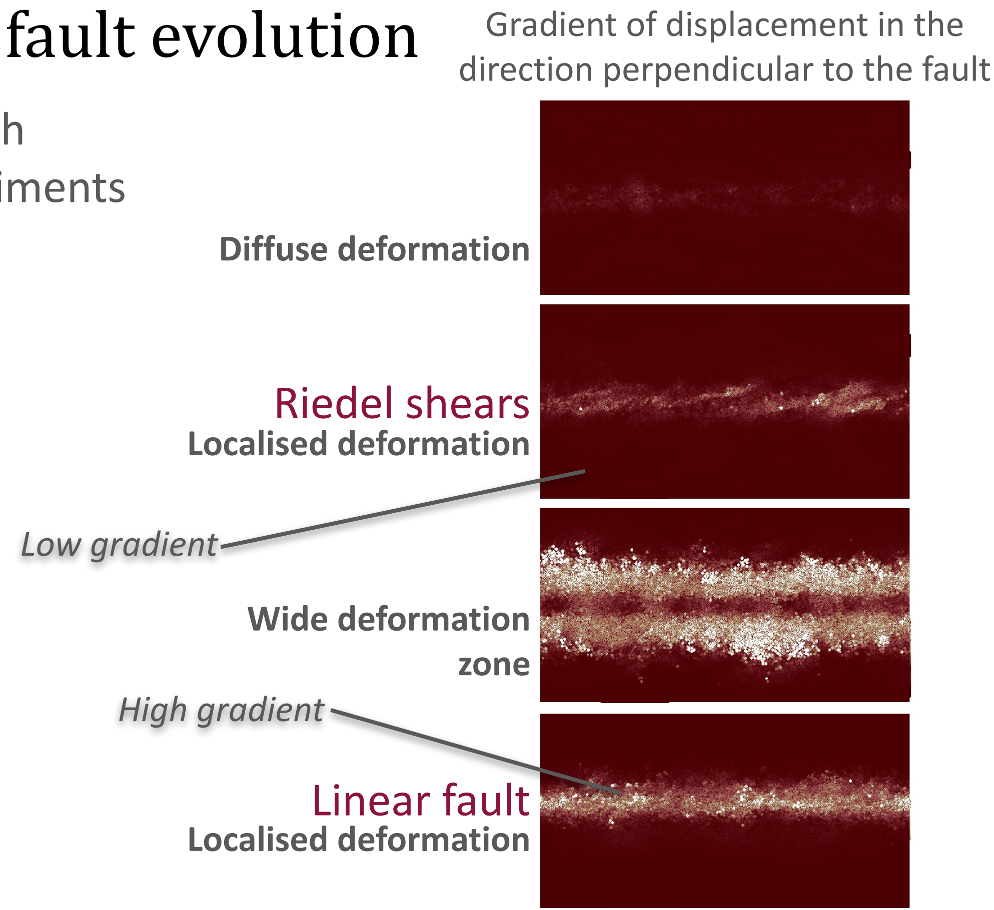
Comparison with analogue experiments

Gradient of displacement in the direction perpendicular to the fault



Long term fault evolution

Comparison with analogue experiments



Long term fault evolution

Comparison with analogue experiments

Gradient of displacement in the direction perpendicular to the fault

Visage et al. (2016)

Diffuse deformation

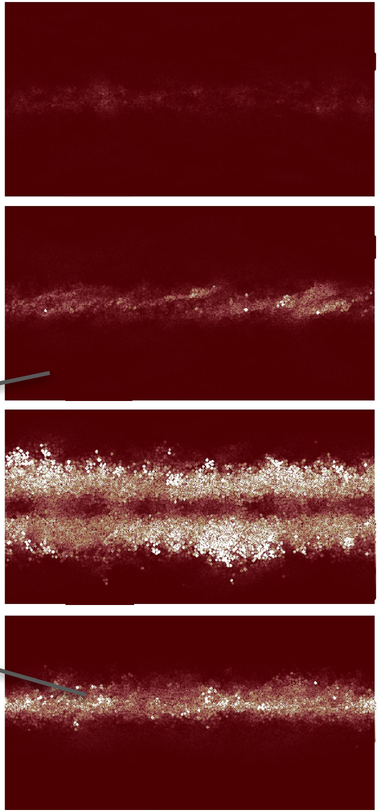
Riedel shears
Localised deformation

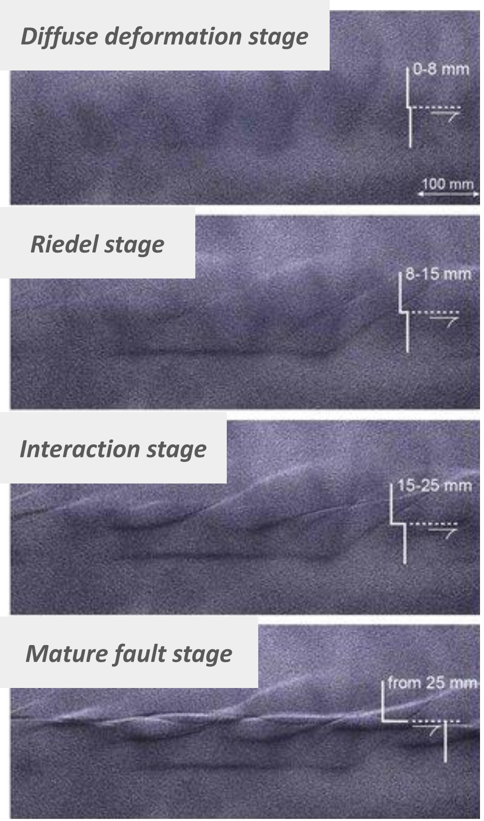
Low gradient

Wide deformation zone

High gradient

Linear fault
Localised deformation





Long term fault evolution

Comparison with analogue experiments

Gradient of displacement in the direction perpendicular to the fault

Diffuse deformation

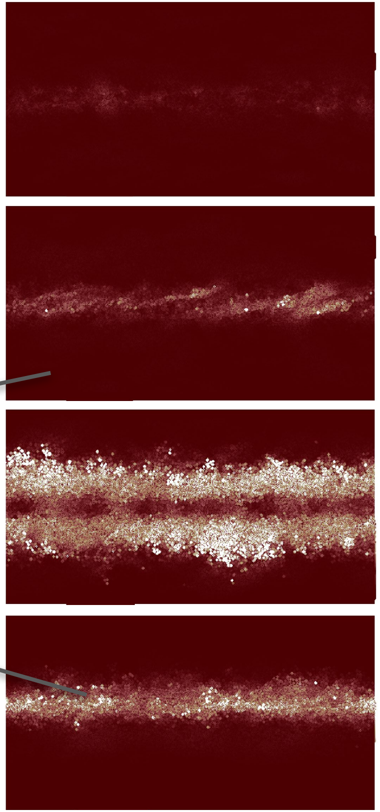
Riedel shears
Localised deformation

Low gradient

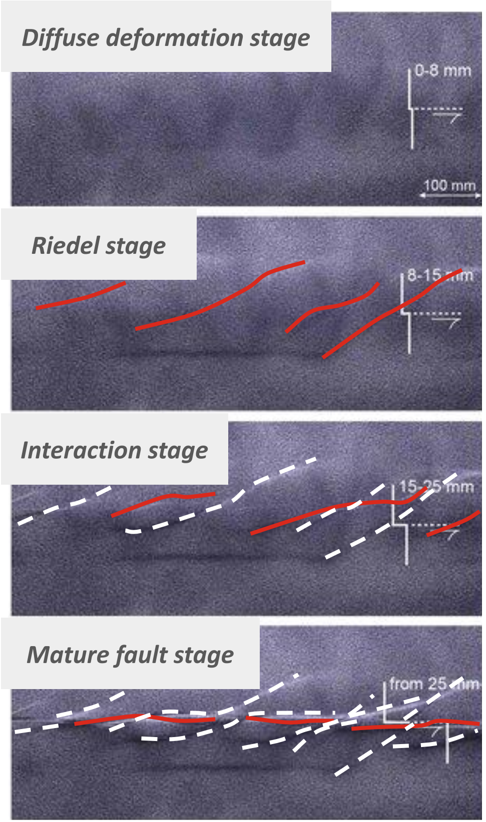
Wide deformation zone

High gradient

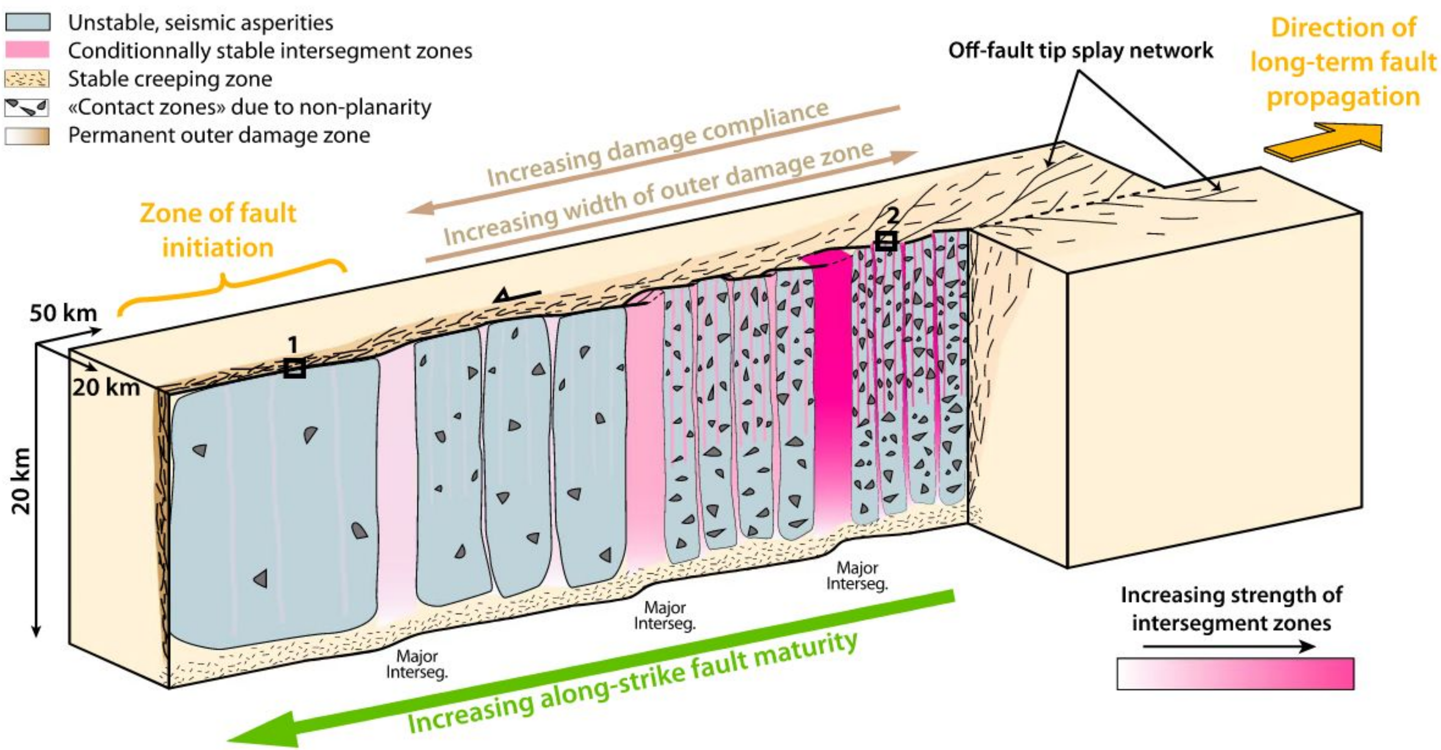
Linear fault
Localised deformation



Visage et al. (2016)

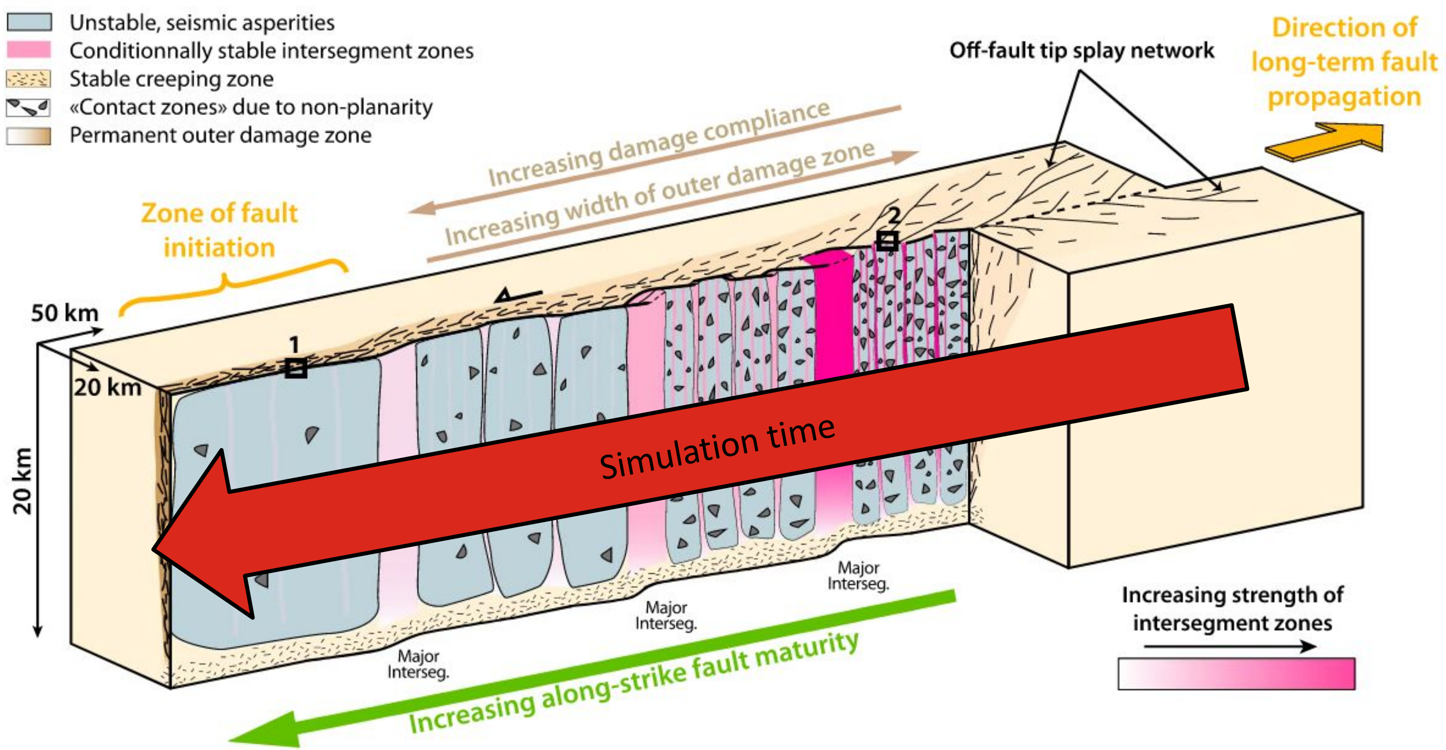


Long term fault evolution



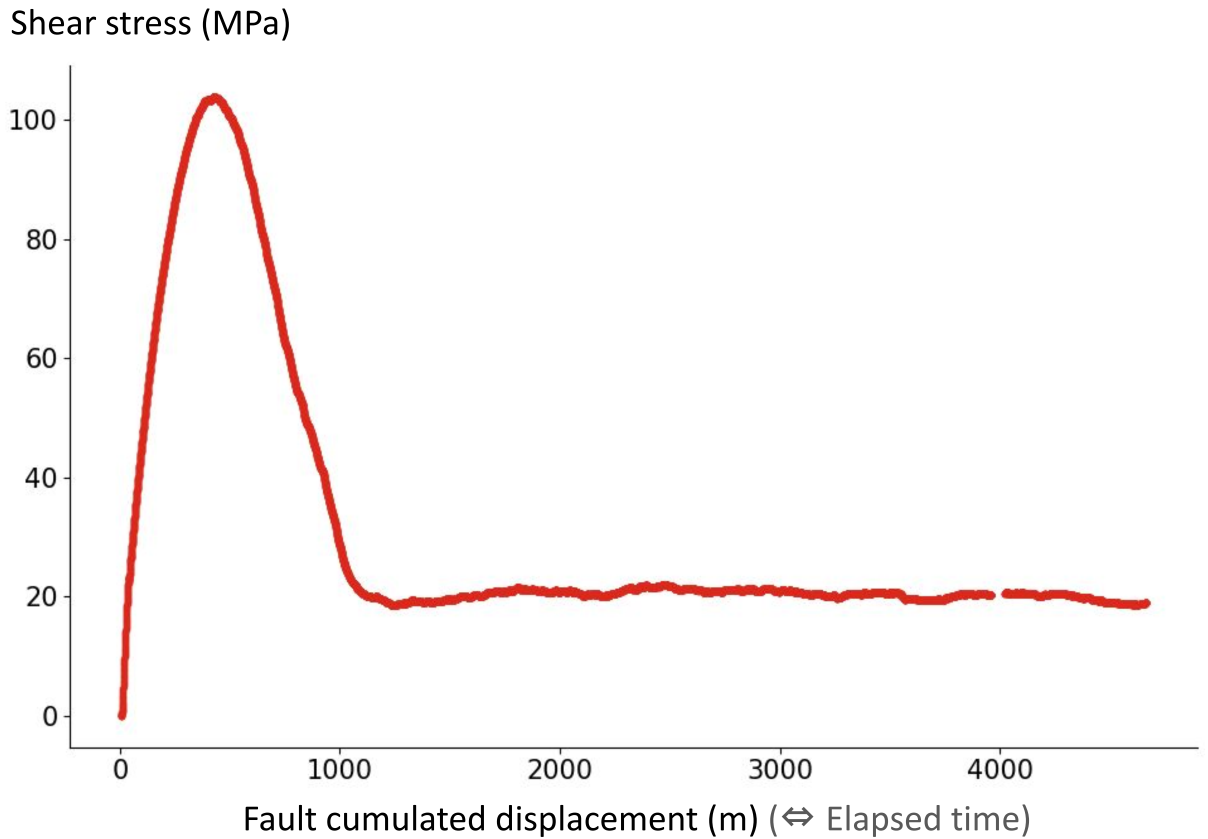
Perrin et al. (2016)

Long term fault evolution

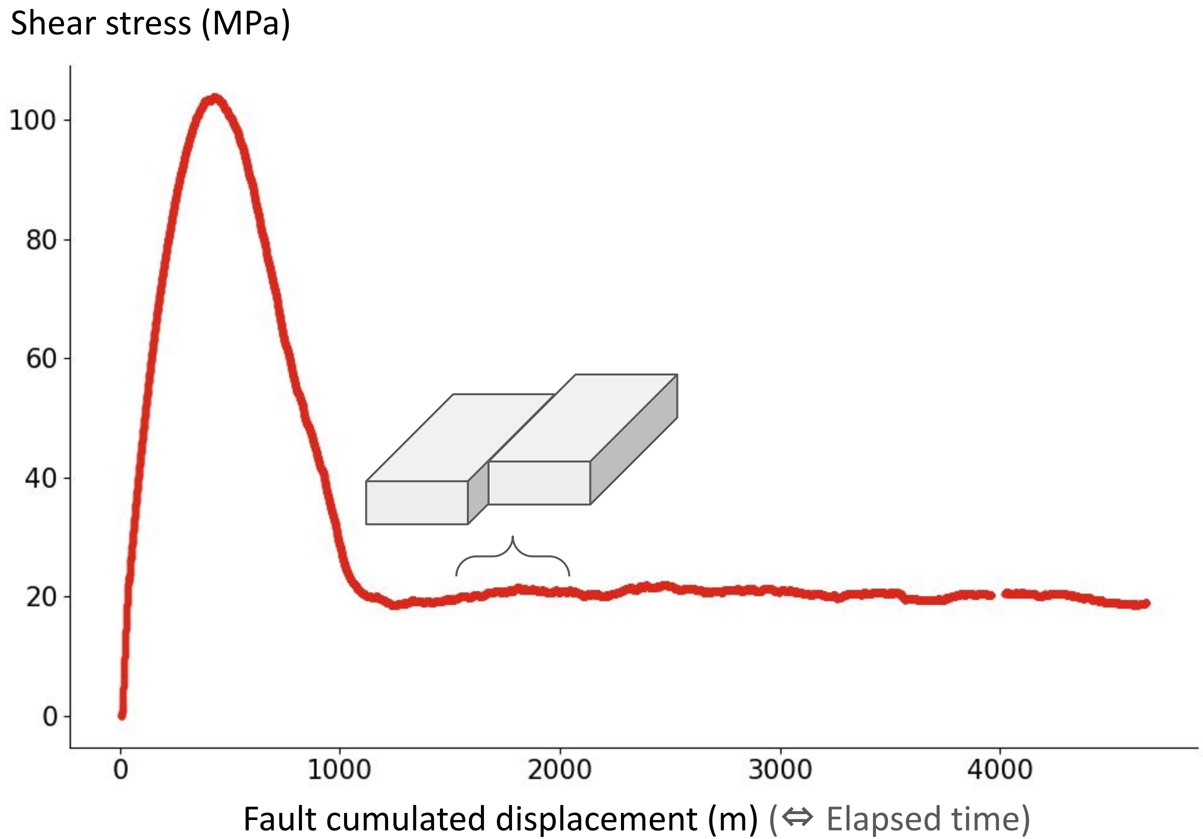


Perrin et al. (2016)

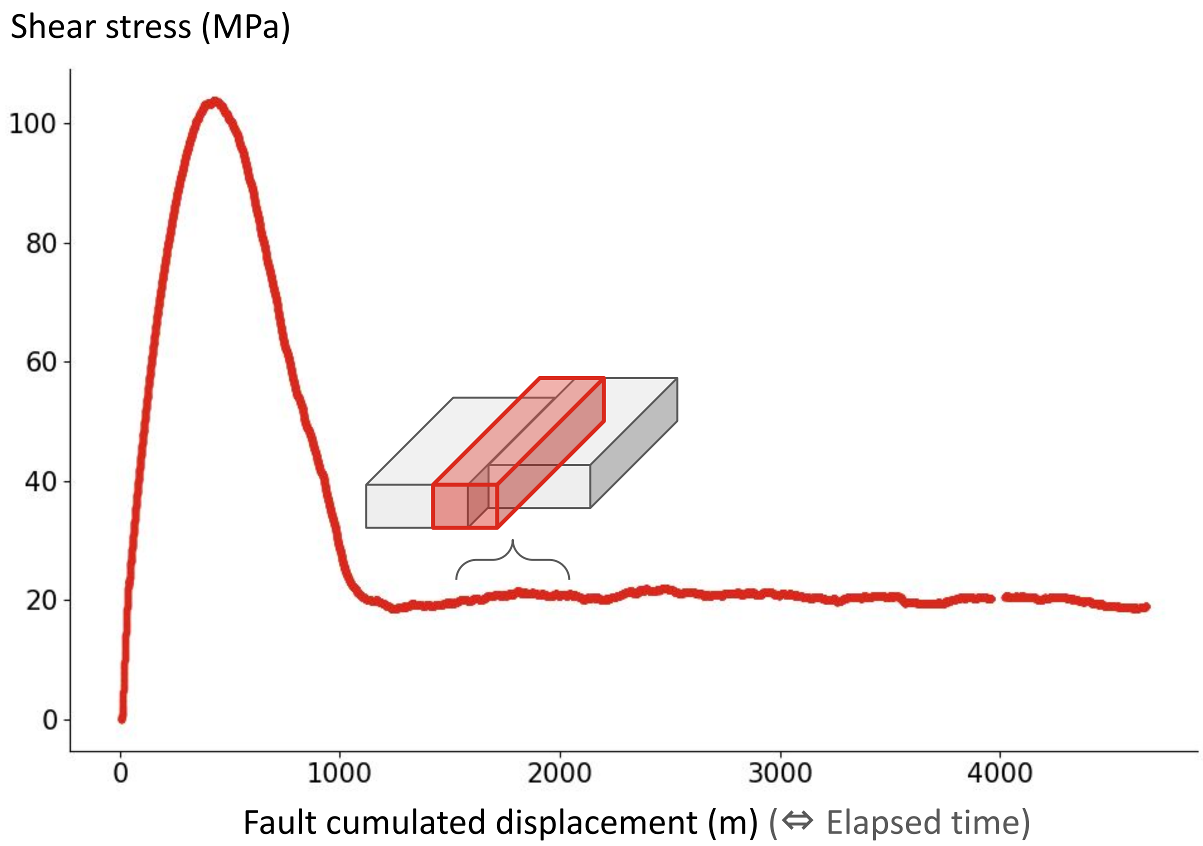
Seismic cycling



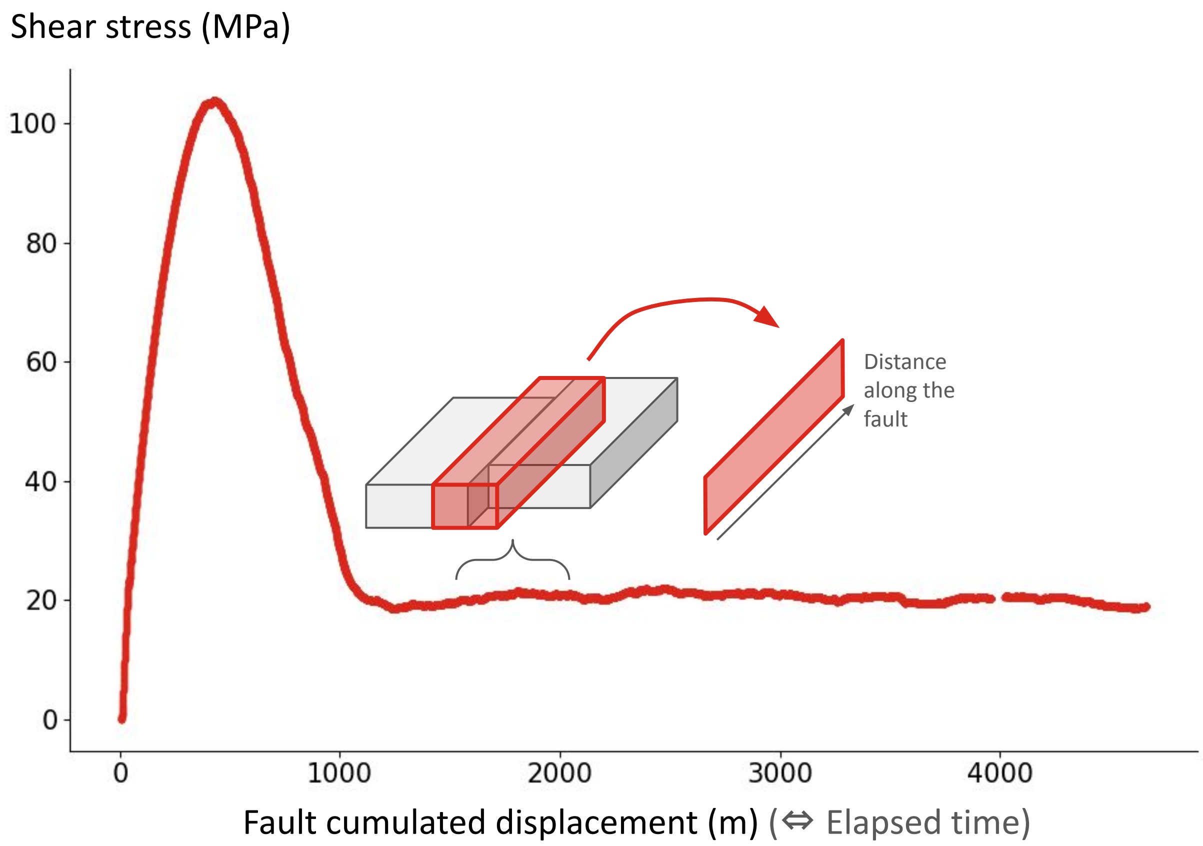
Seismic cycling



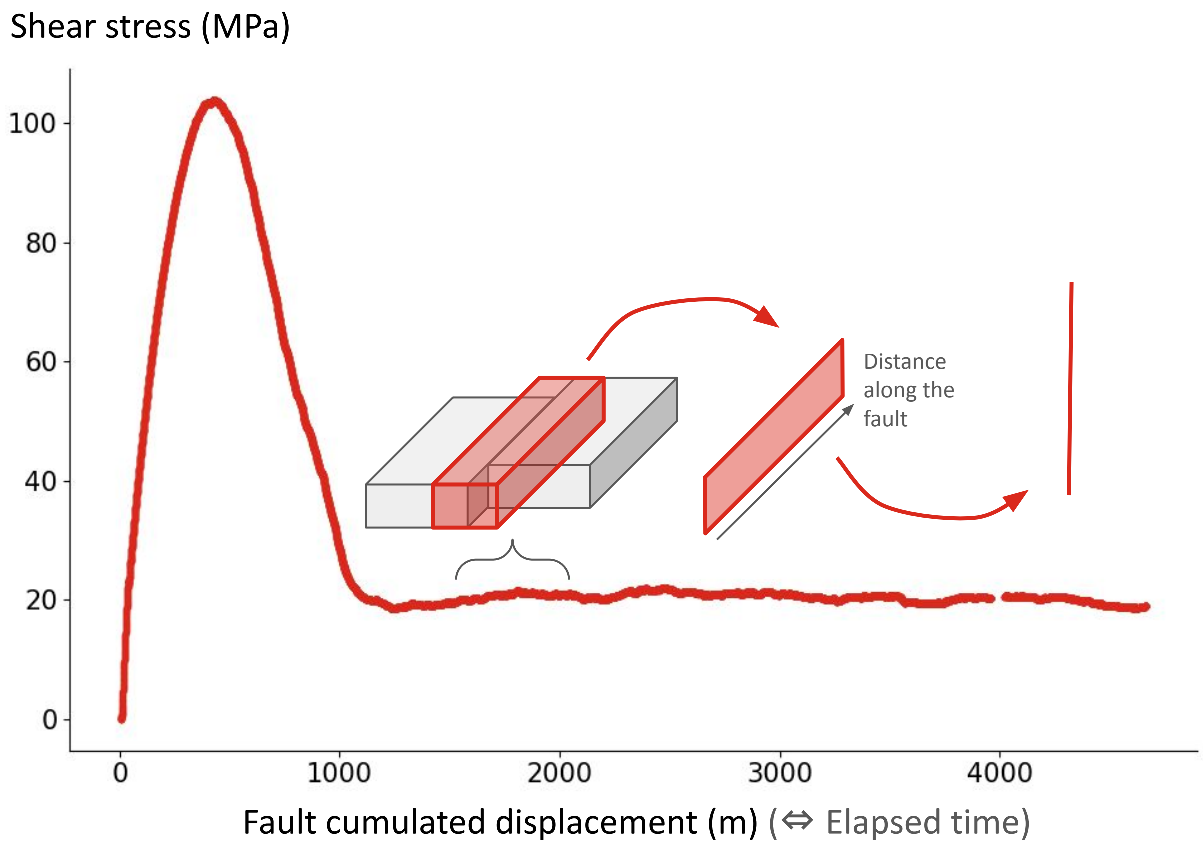
Seismic cycling



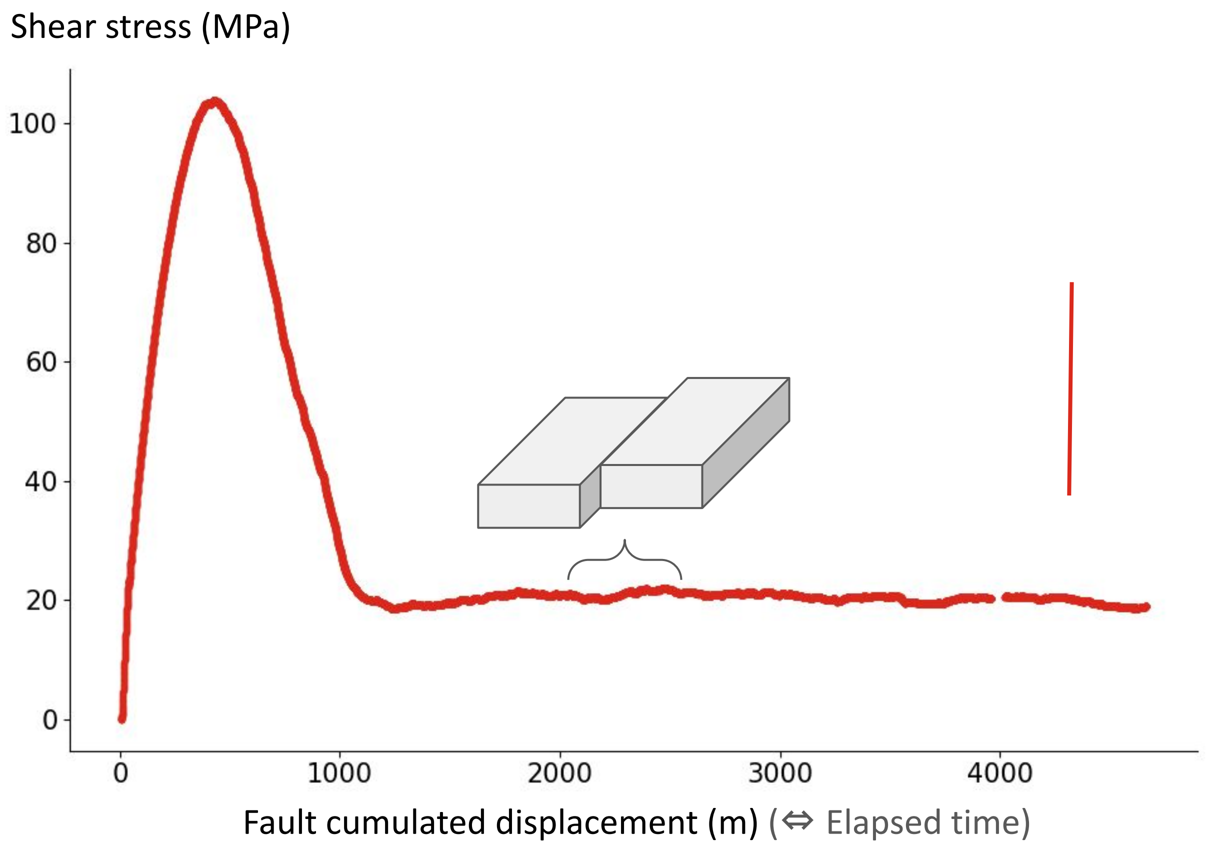
Seismic cycling



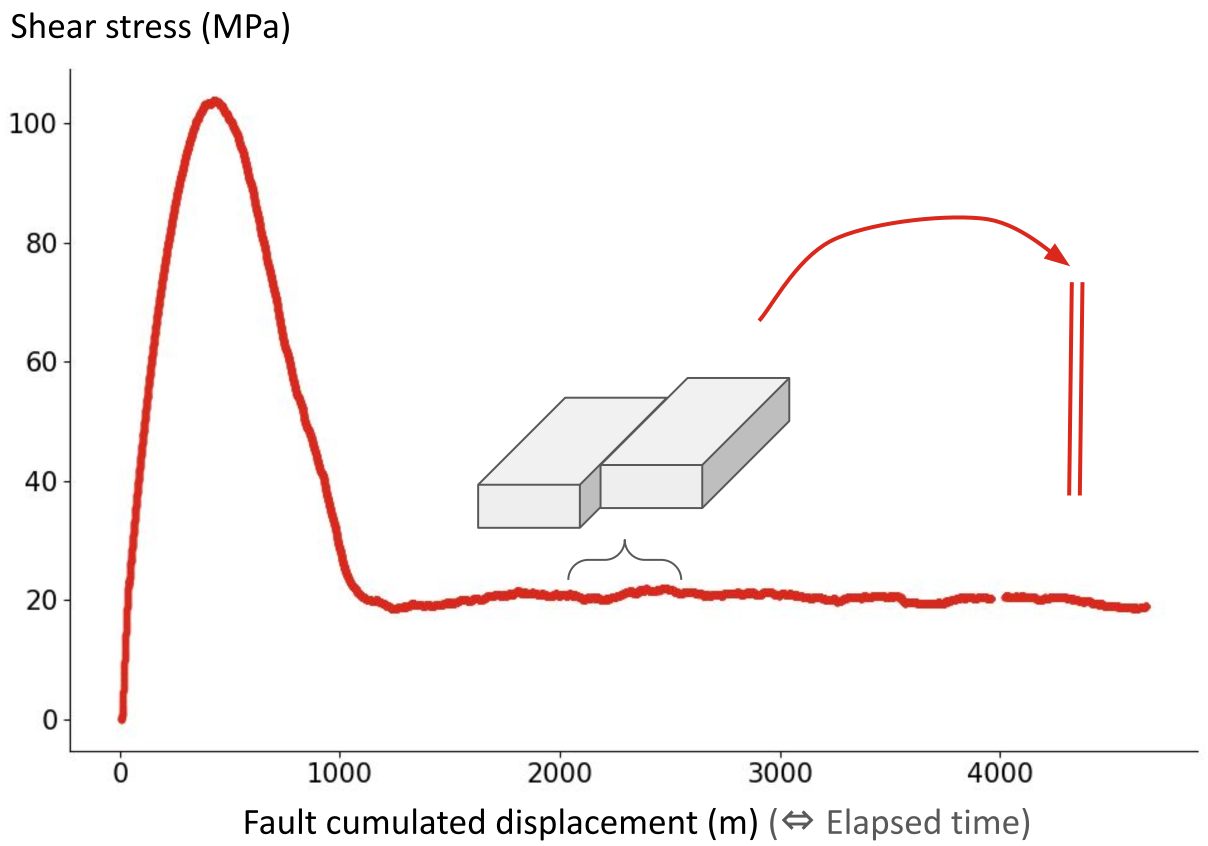
Seismic cycling



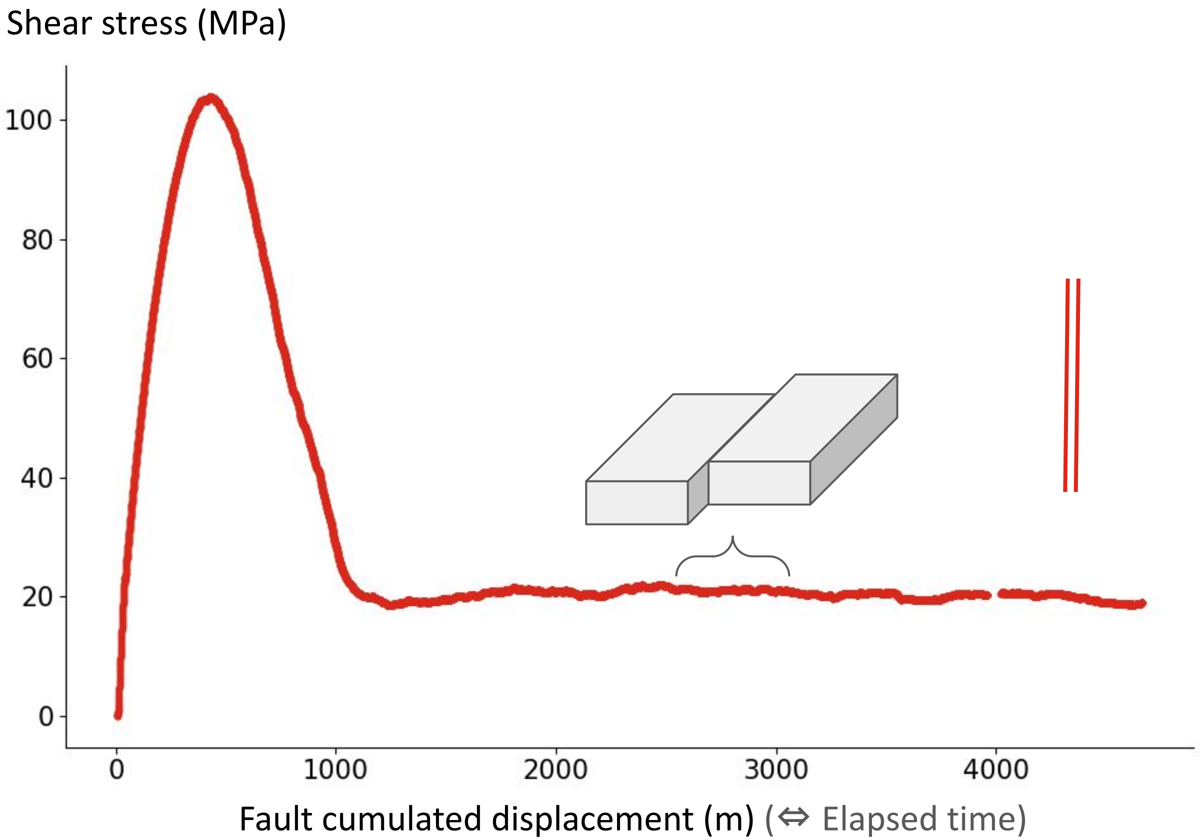
Seismic cycling



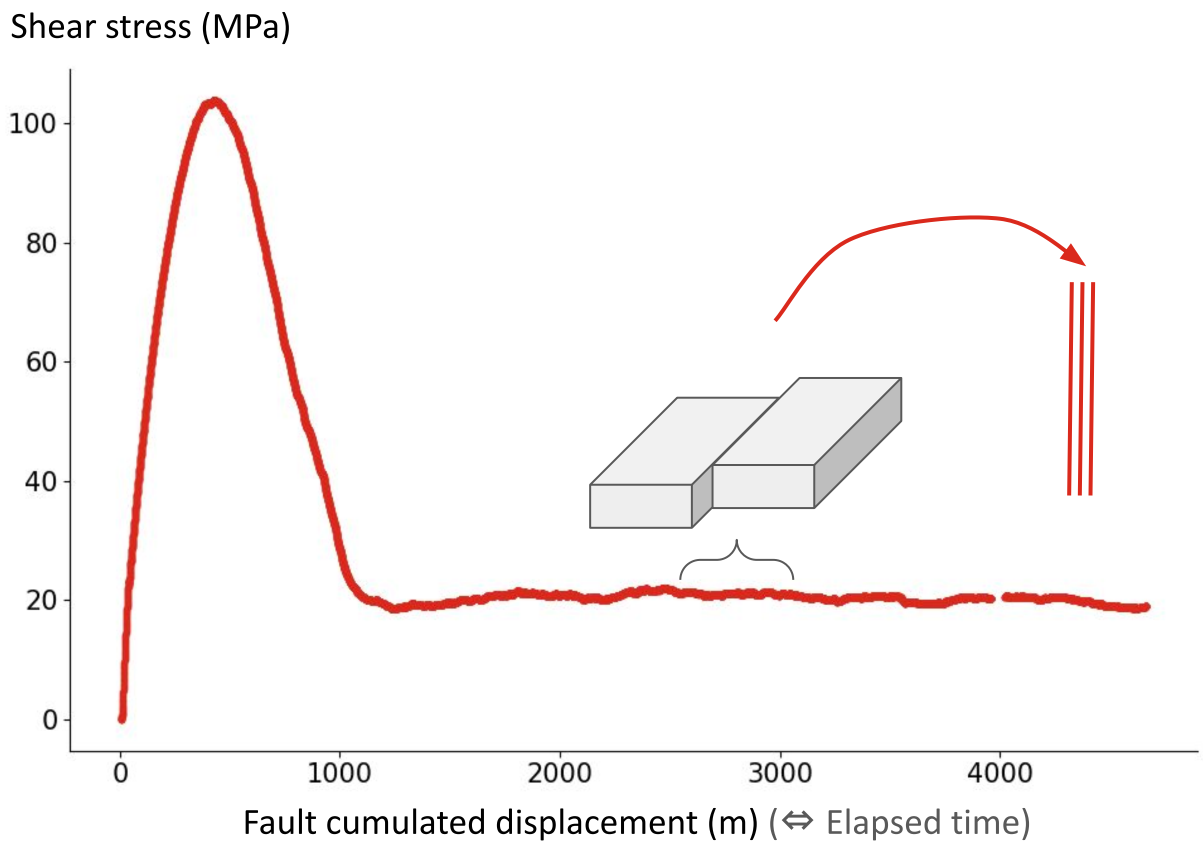
Seismic cycling



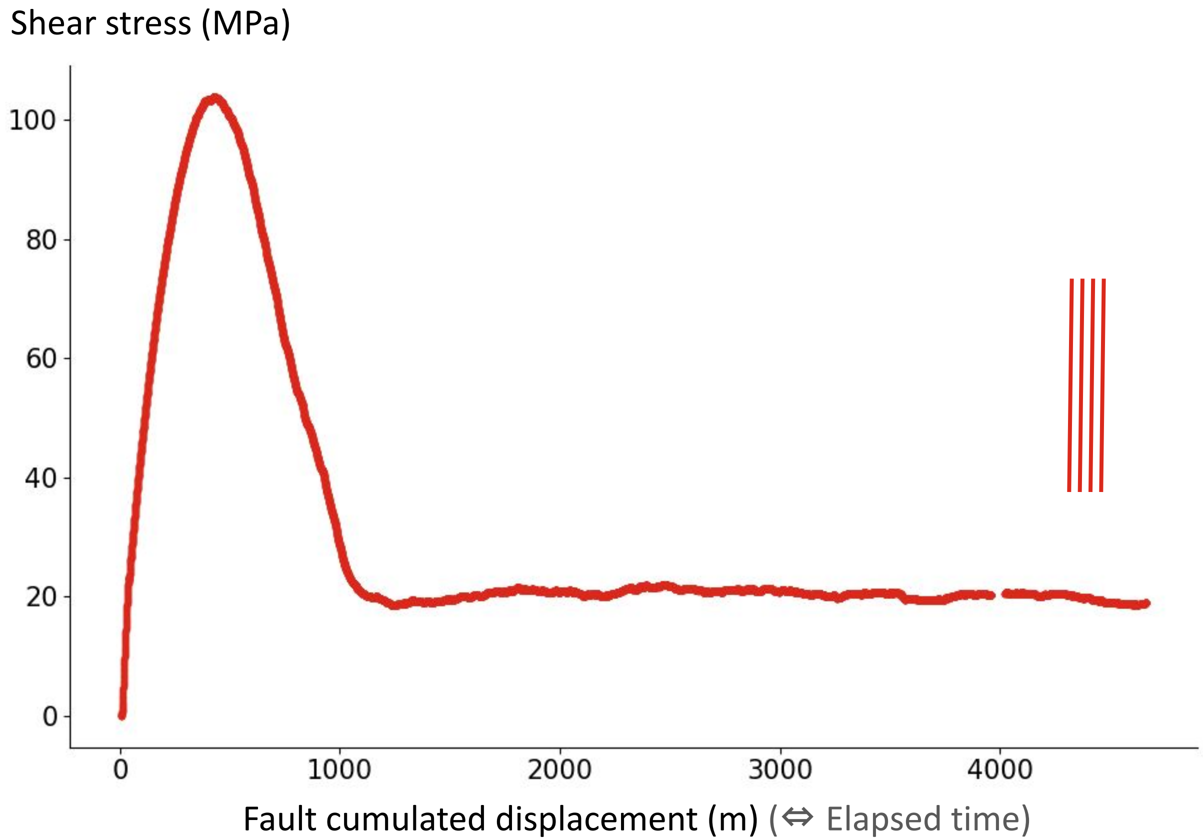
Seismic cycling



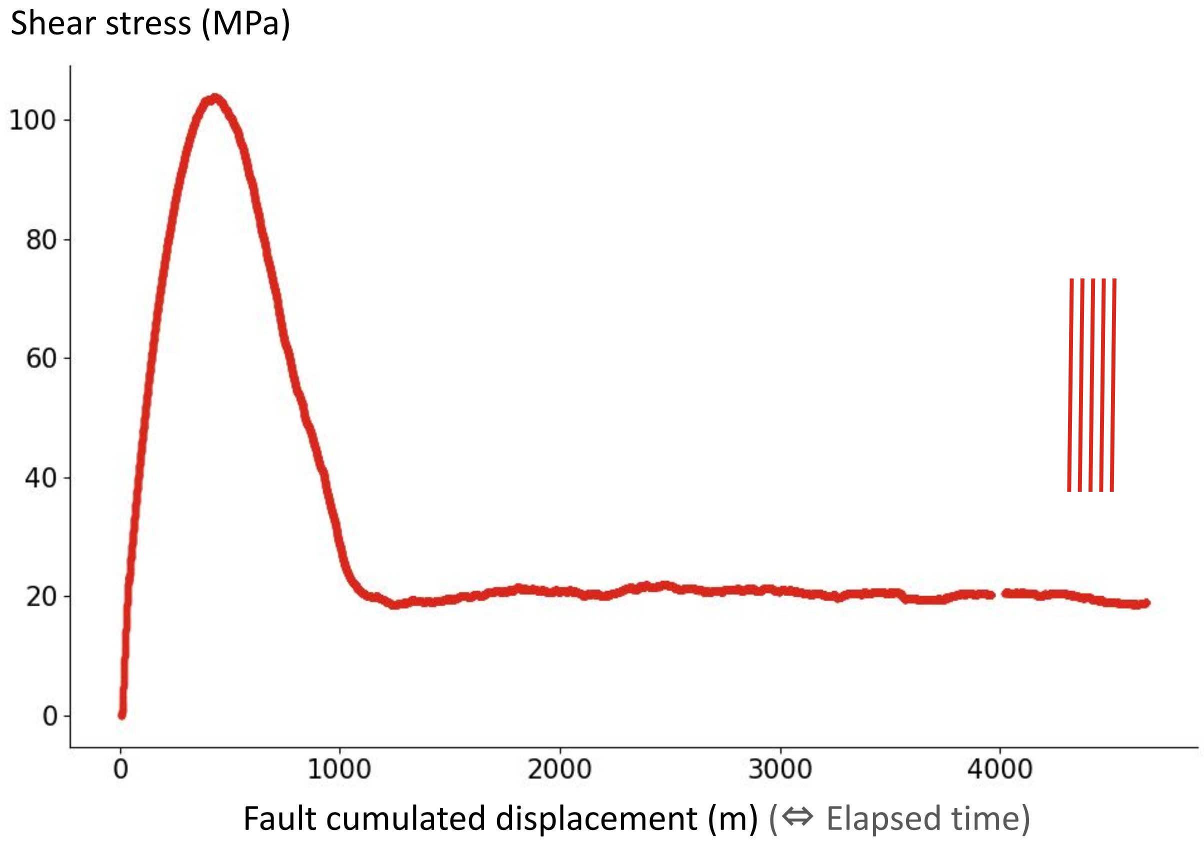
Seismic cycling



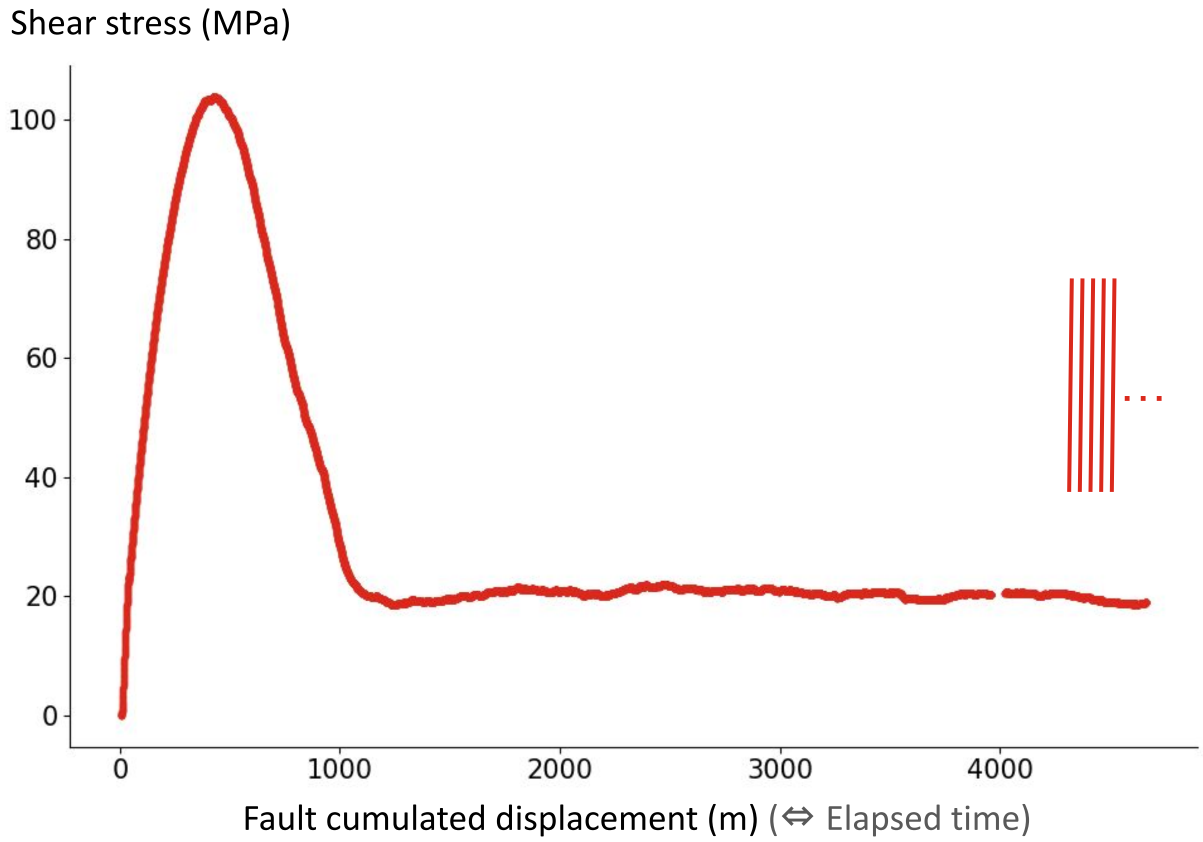
Seismic cycling



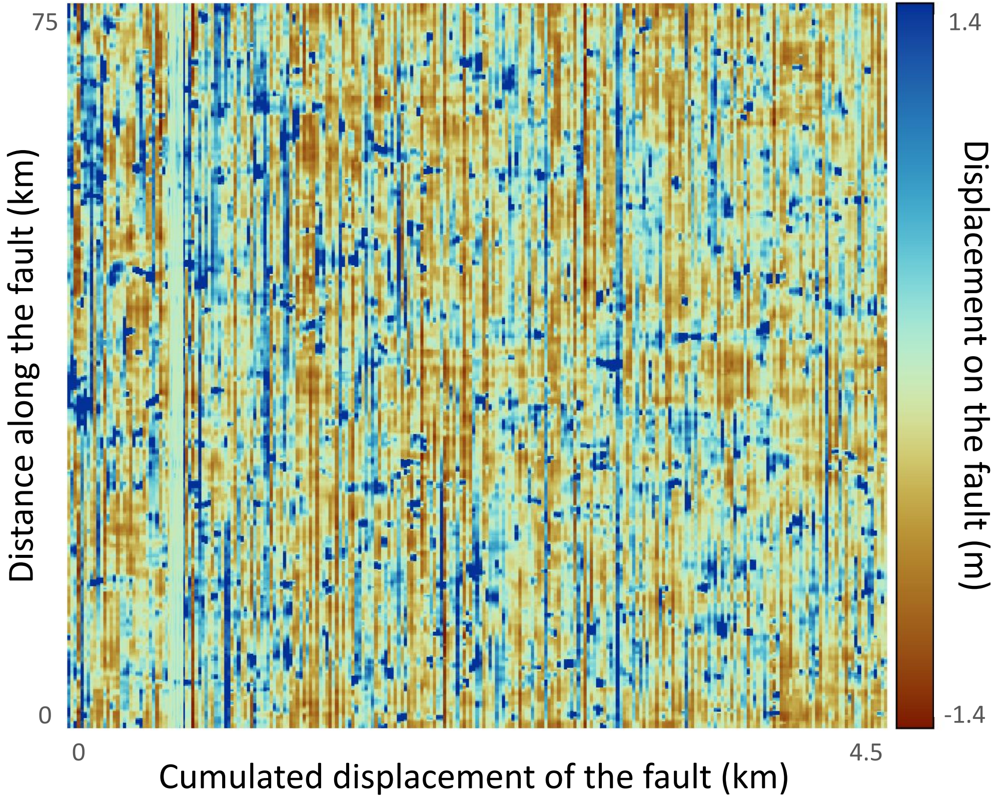
Seismic cycling



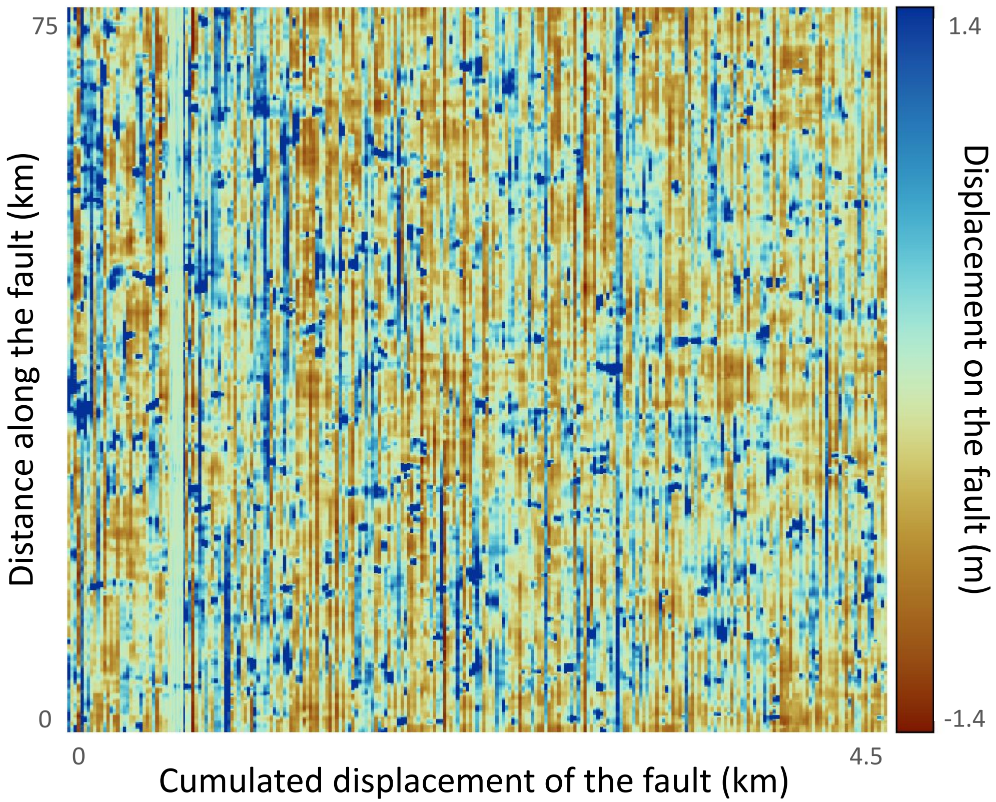
Seismic cycling



Seismic cycling

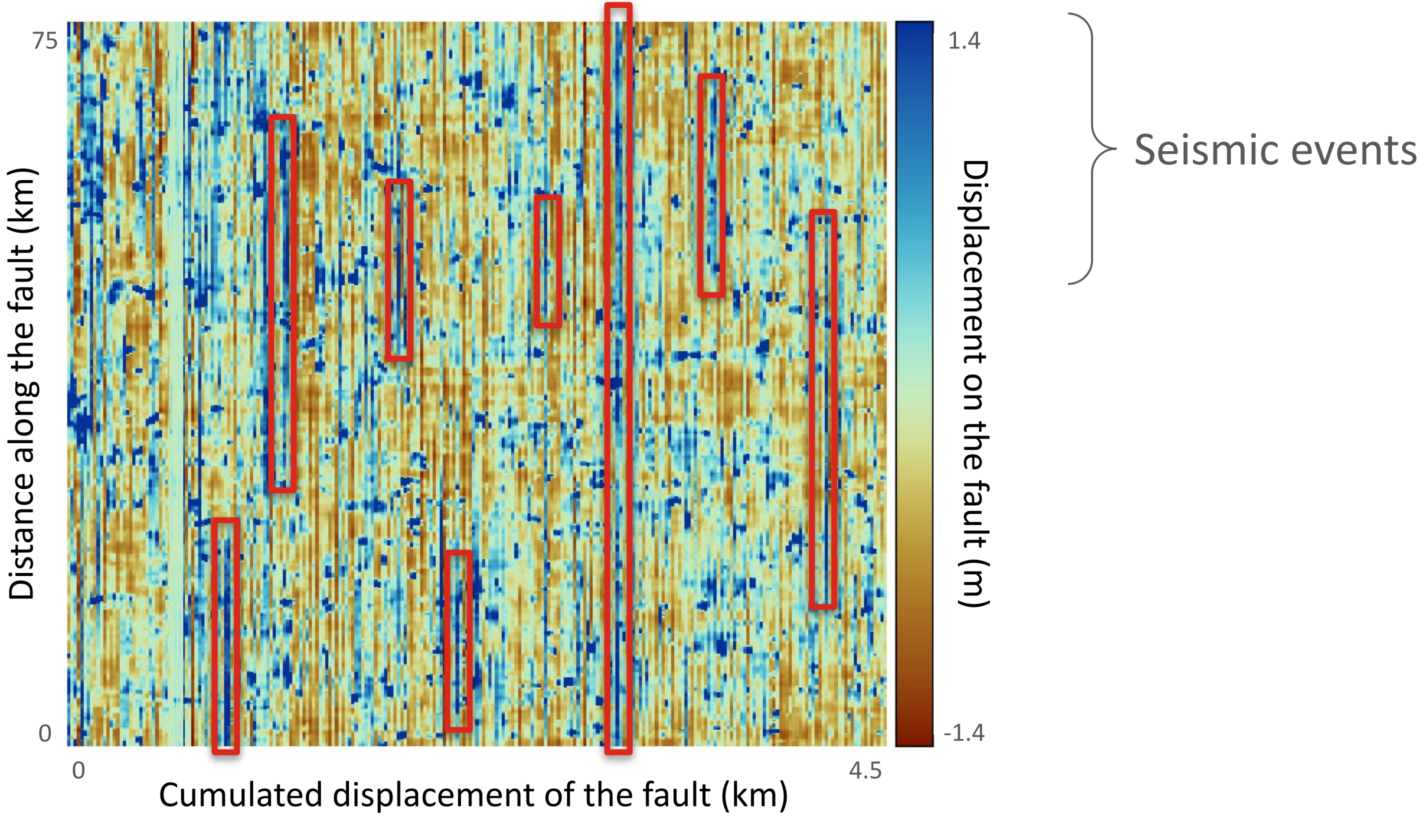


Seismic cycling

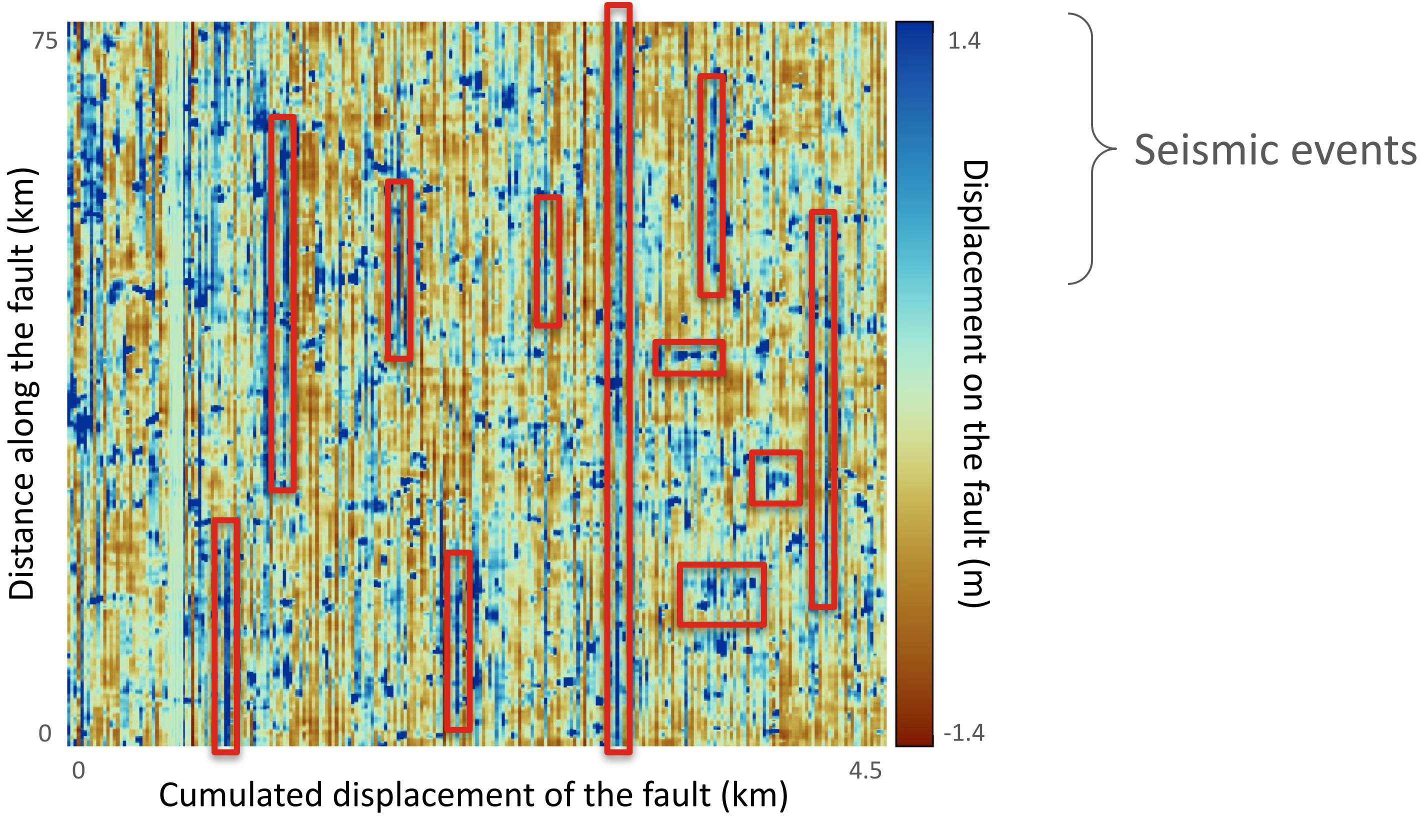


Seismic events

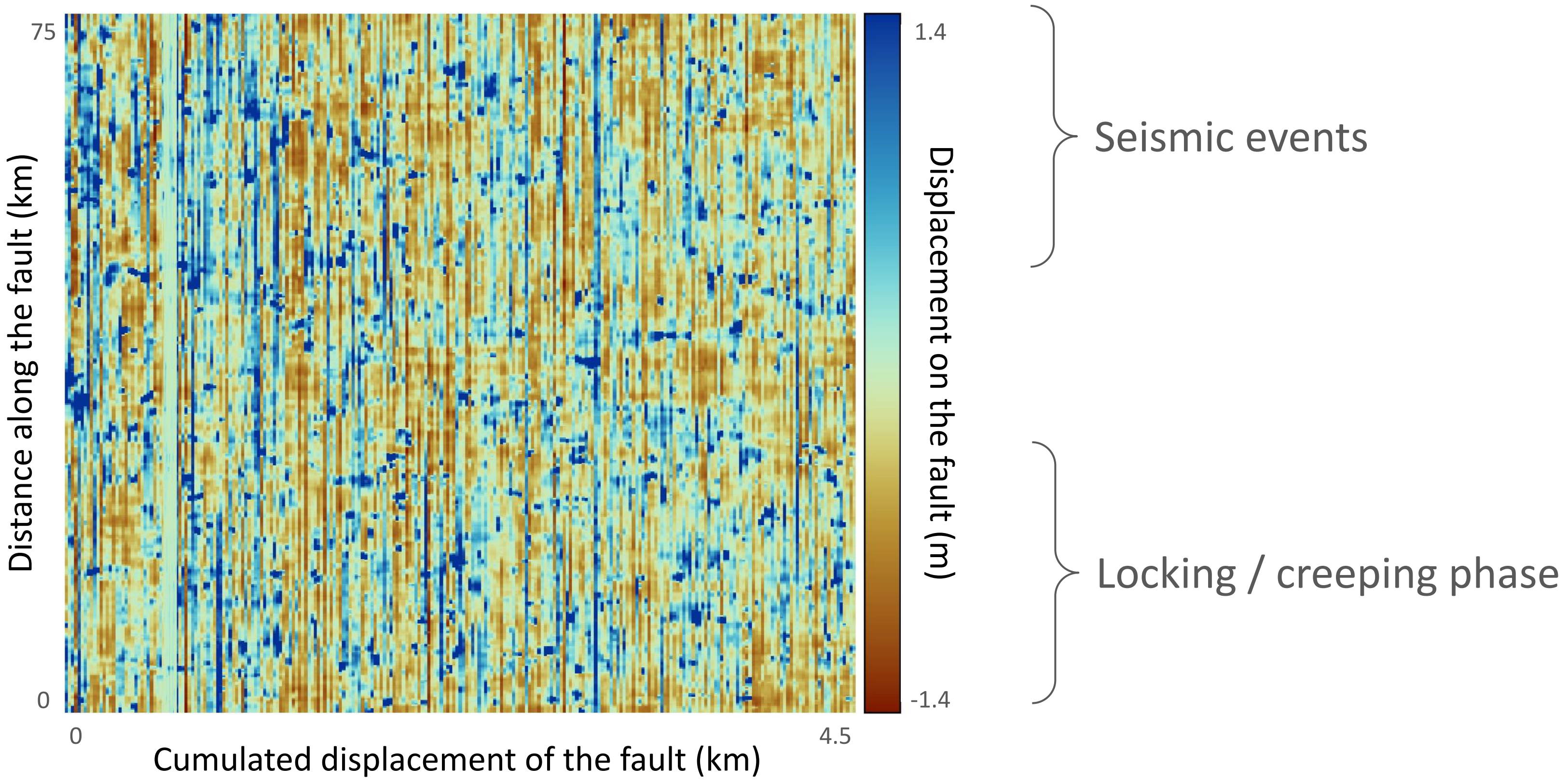
Seismic cycling



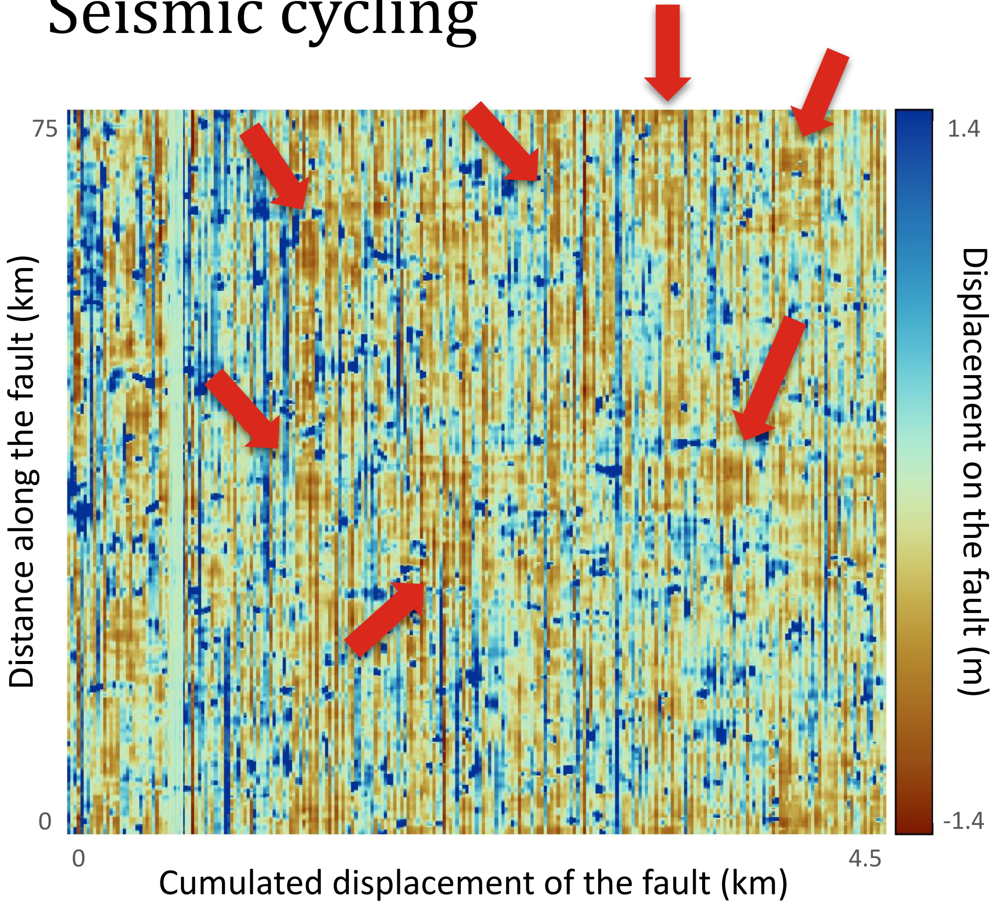
Seismic cycling



Seismic cycling



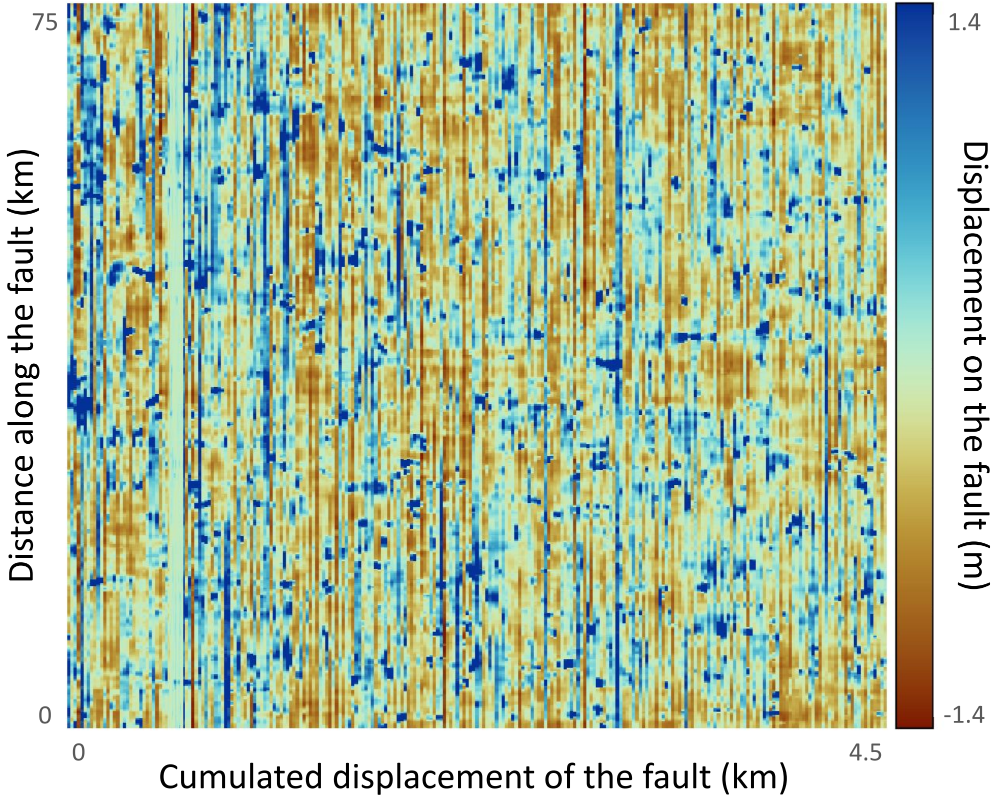
Seismic cycling

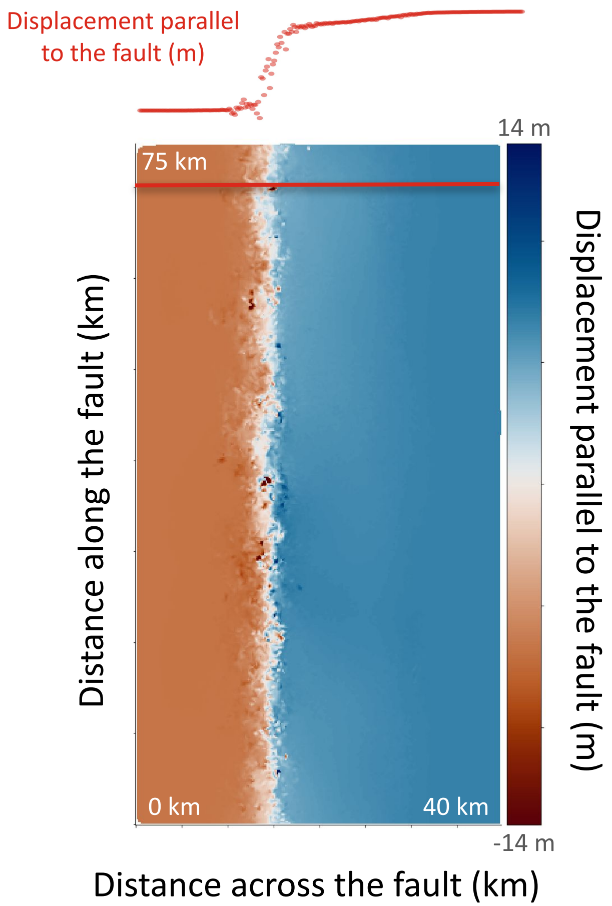


Seismic events

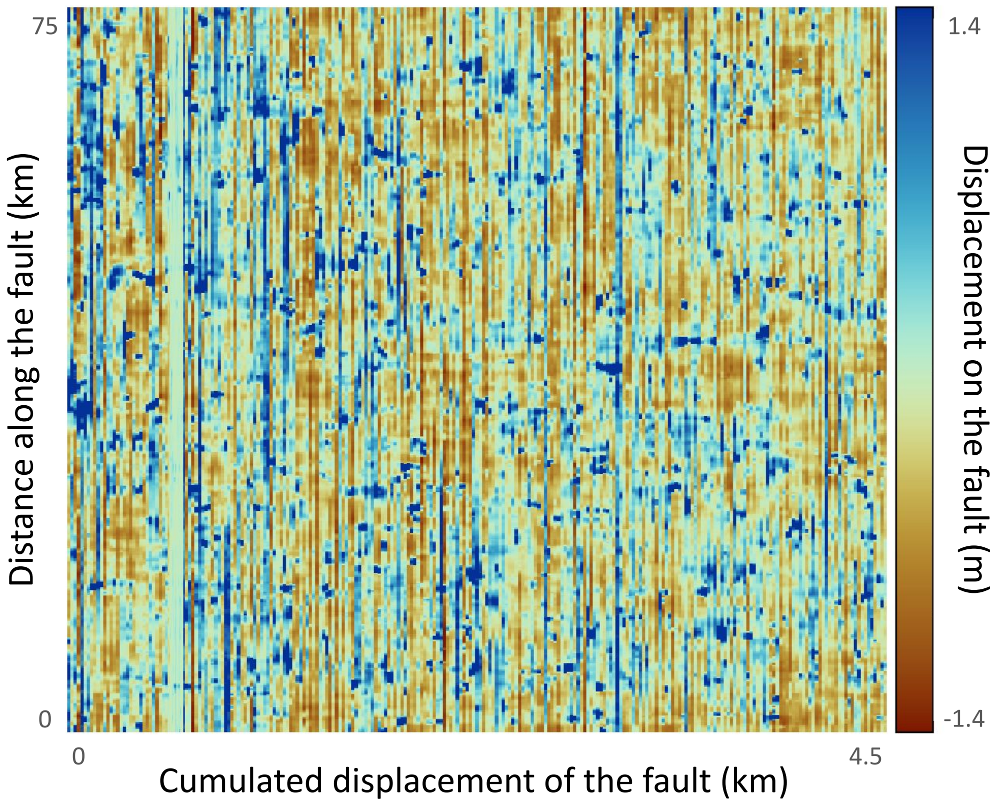
Locking / creeping phase

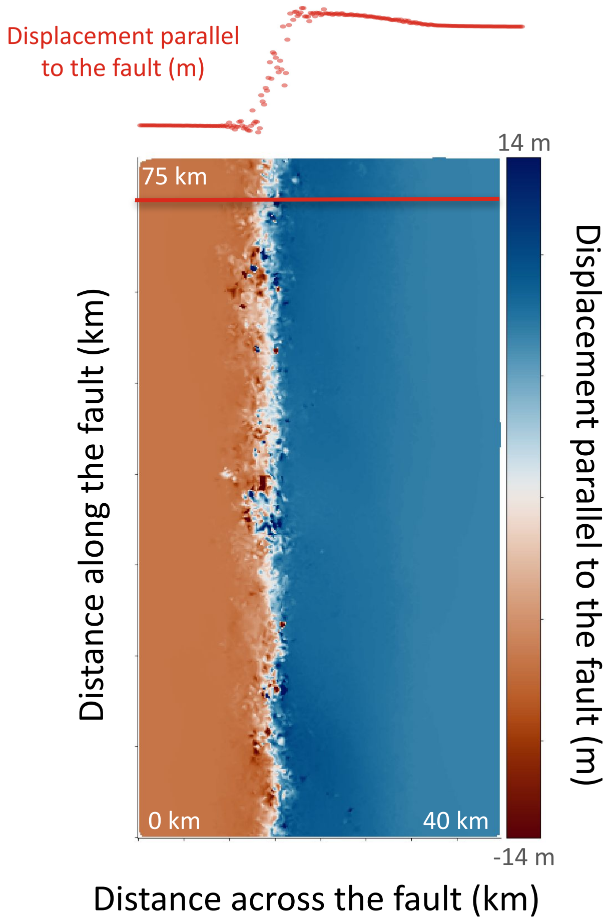
Seismic cycling



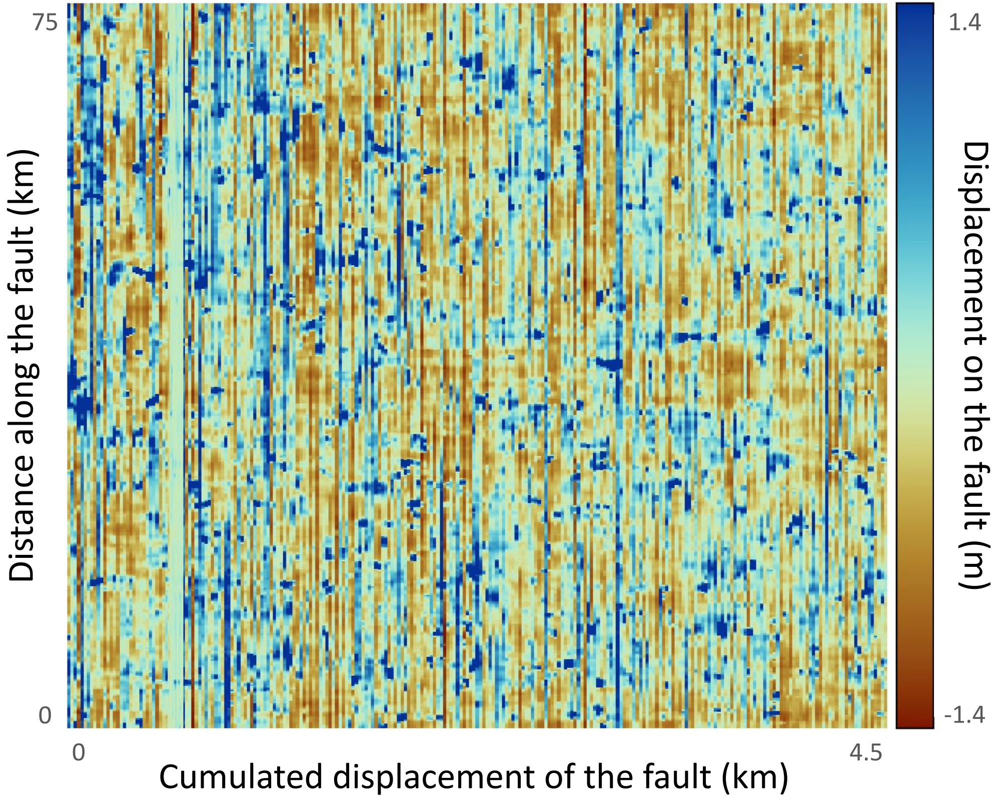


Seismic cycling



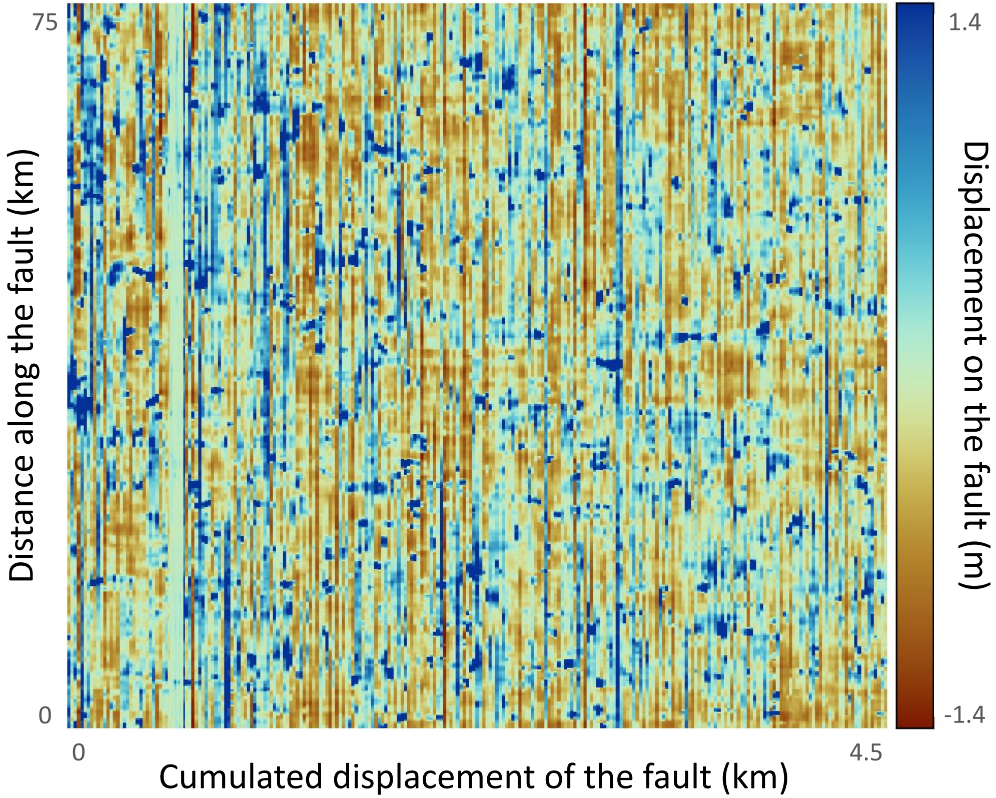


Seismic cycling



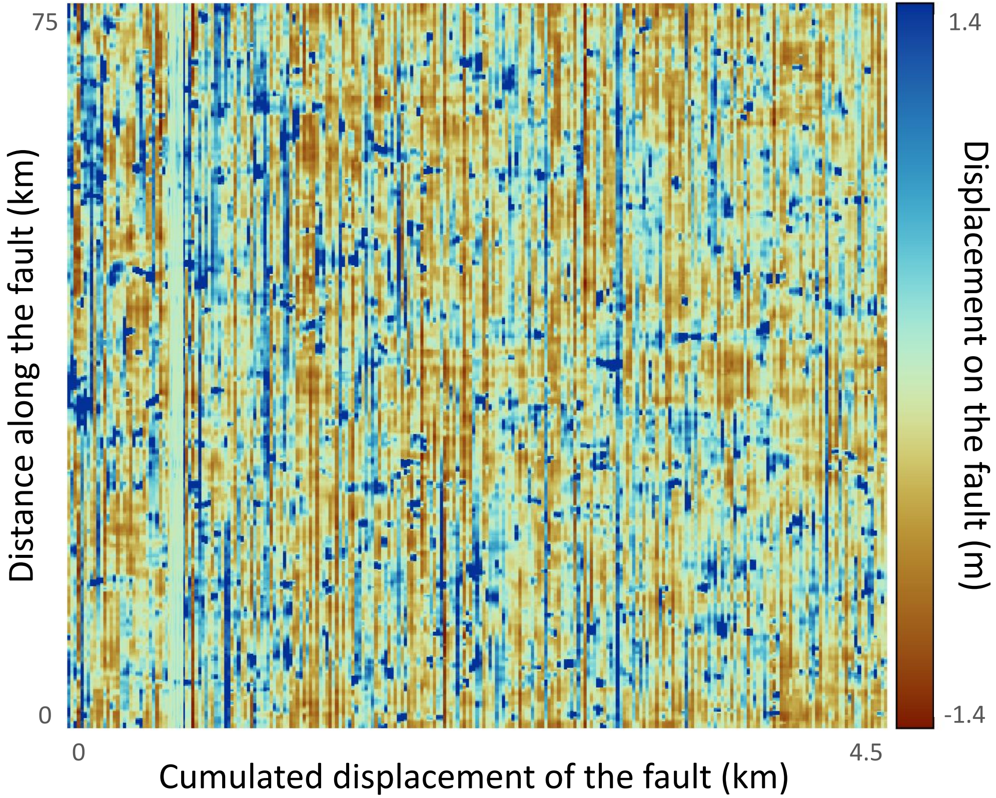
- Alternation between seismic and interseismic phases

Seismic cycling



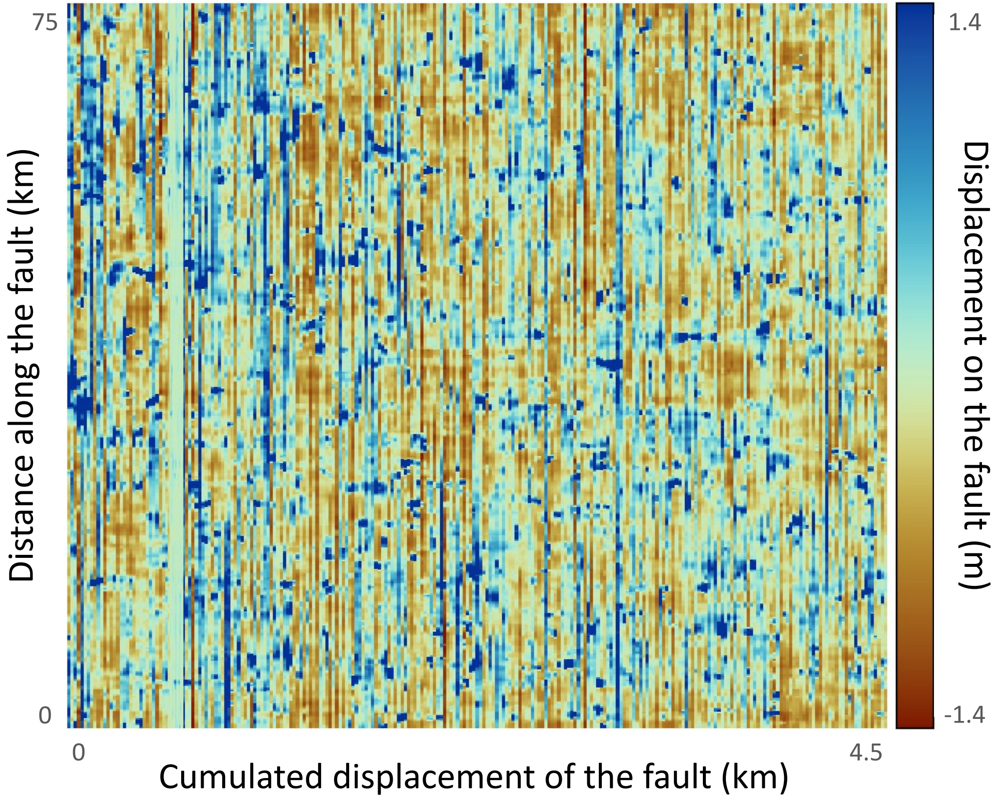
- Alternation between seismic and interseismic phases
- Variations among the rupture lengths

Seismic cycling



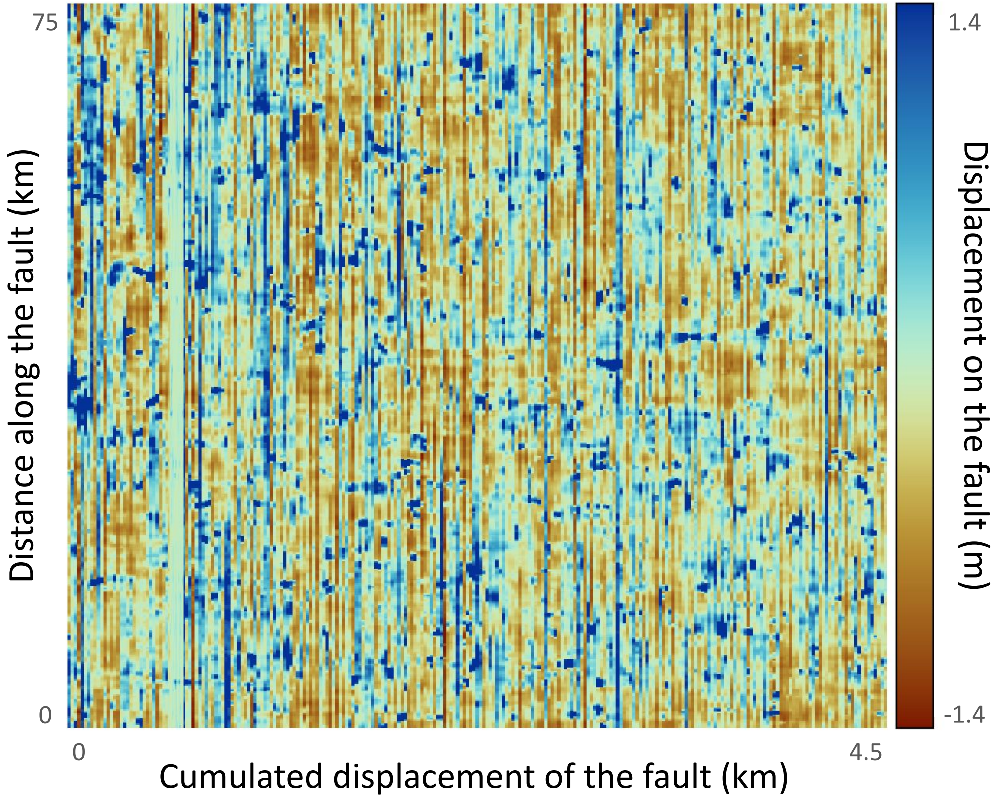
- Alternation between seismic and interseismic phases
- Variations among the rupture lengths
- Variations in the amount of slip released

Seismic cycling



- Alternation between seismic and interseismic phases
- Variations among the rupture lengths
- Variations in the amount of slip released
- Variations in the duration of interseismic periods

Seismic cycling

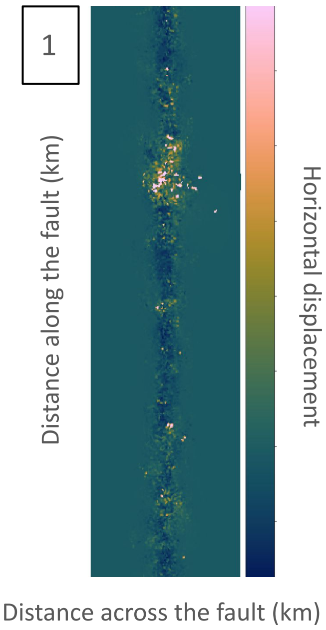


- Alternation between seismic and interseismic phases
- Variations among the rupture lengths
- Variations in the amount of slip released
- Variations in the duration of interseismic periods

⇒ Variations in the magnitude of events

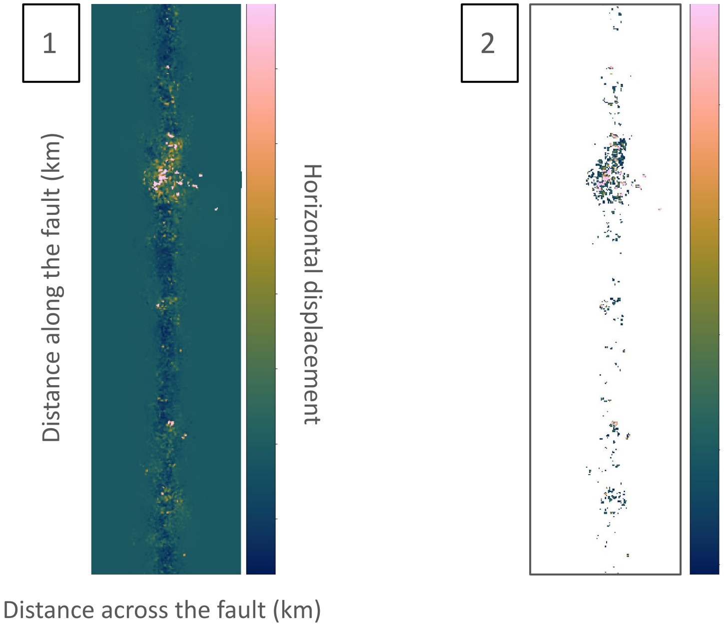
Magnitude distribution

1. Look at the displacement in one time interval



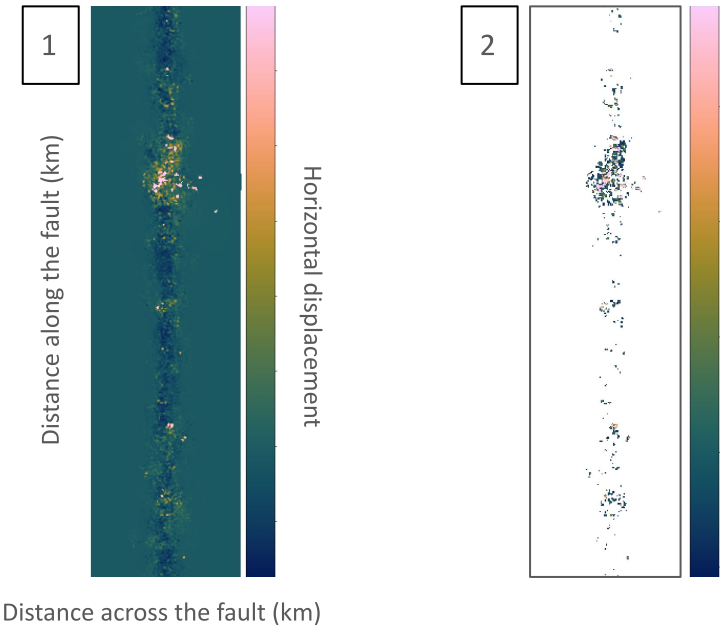
Magnitude distribution

1. Look at the displacement in one time interval
2. Filter out the particles below a given displacement threshold



Magnitude distribution

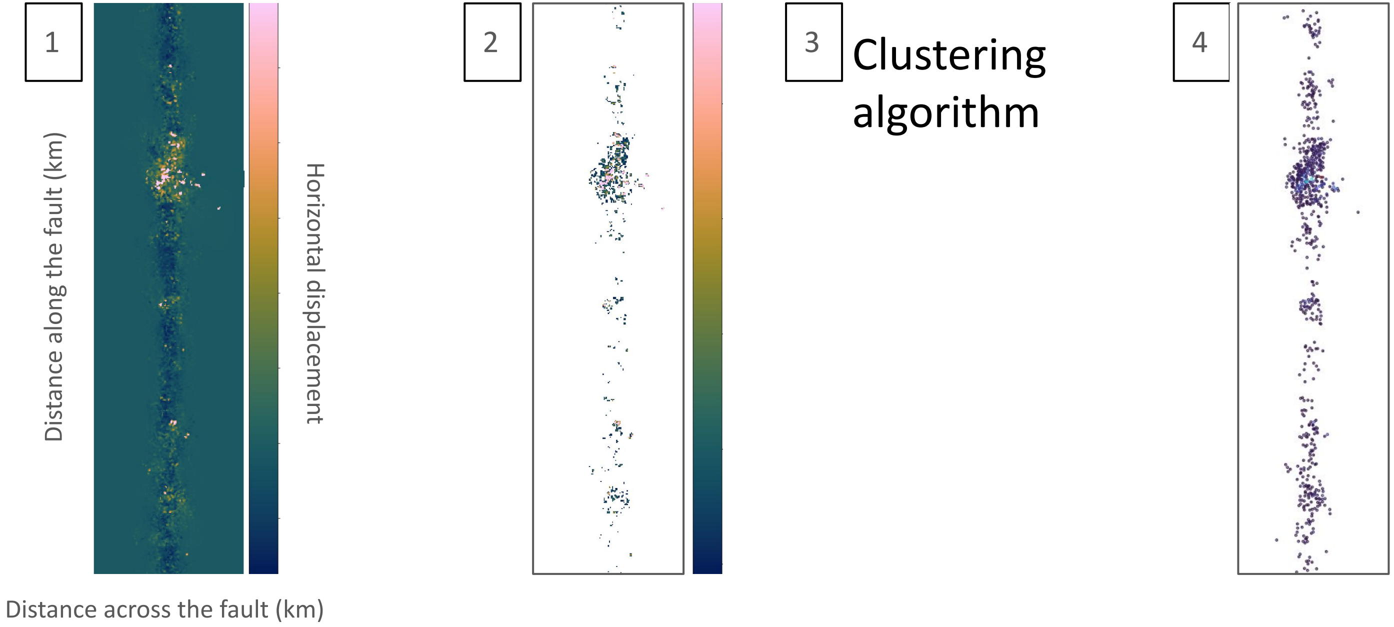
1. Look at the displacement in one time interval
2. Filter out the particles below a given displacement threshold
3. Spatially cluster the particles



3 Clustering algorithm

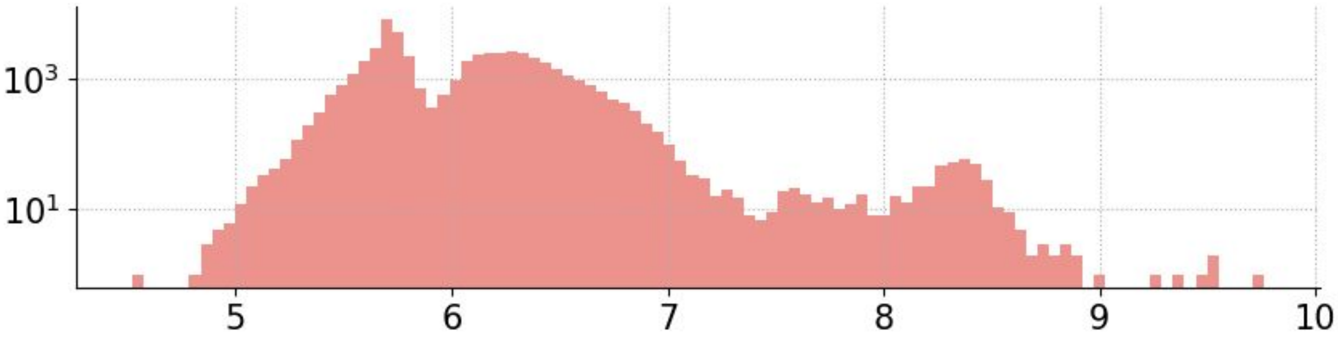
Magnitude distribution

1. Look at the displacement in one time interval
2. Filter out the particles below a given displacement threshold
3. Spatially cluster the particles
4. Compute the magnitude of each cluster



Magnitude distribution

Number N of occurrences

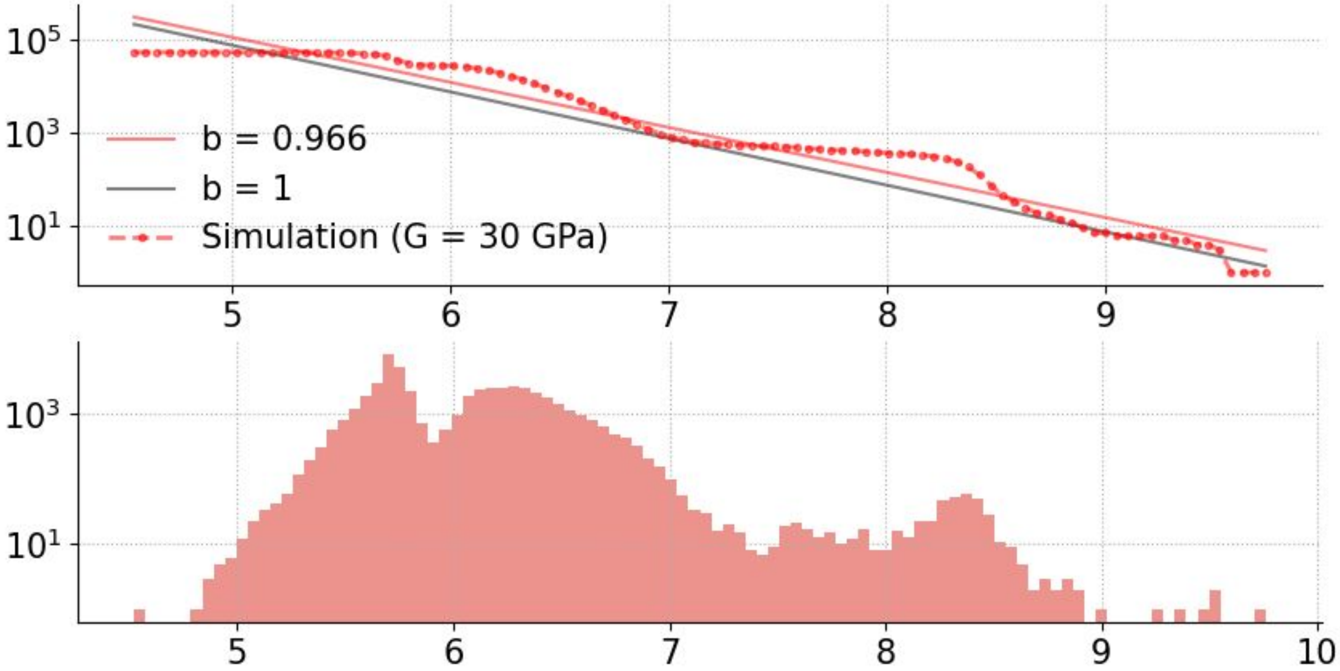


Magnitude M

Magnitude distribution

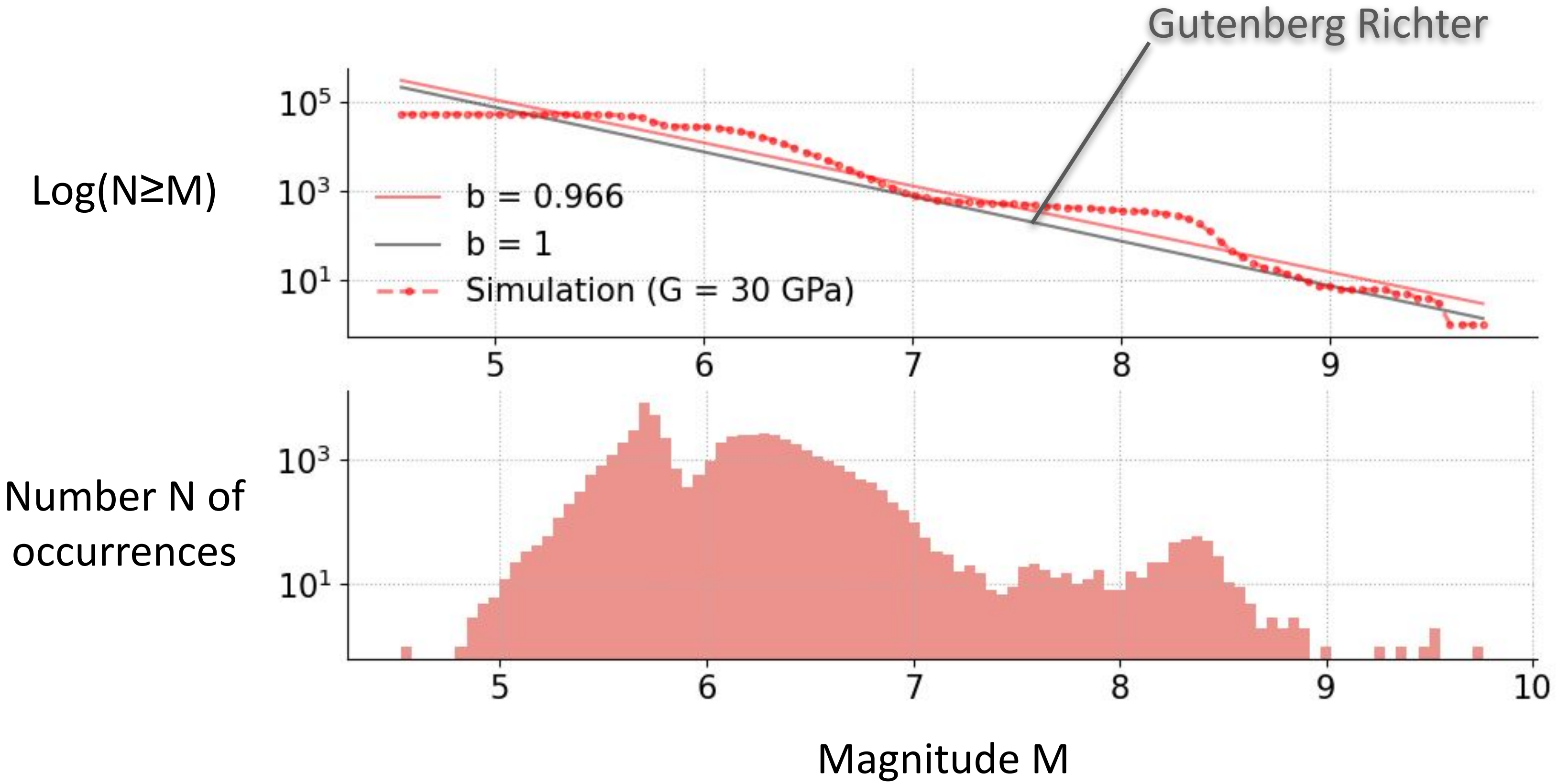
Log(N≥M)

Number N of occurrences



Magnitude M

Magnitude distribution



Conclusion

Development of a mature fault zone ✓

+

Earthquake cycles

→

Seismic cycles on an evolving strike-slip fault

Conclusion

Development of a mature fault zone + **Earthquake cycles** → **Seismic cycles on an evolving strike-slip fault**

Conclusion

Development of a mature fault zone ✓ + **Earthquake cycles** ✓ → **Seismic cycles on an evolving strike-slip fault**

❑ Study the 3D deformation pattern during interseismic and coseismic periods

Conclusion

Development of a mature fault zone + **Earthquake cycles** ✓ → **Seismic cycles on an evolving strike-slip fault**

- ❑ Study the 3D deformation pattern during interseismic and coseismic periods
- ❑ Increase the time resolution during coseismic phase

Conclusion

Development of a mature fault zone + **Earthquake cycles** → **Seismic cycles on an evolving strike-slip fault**

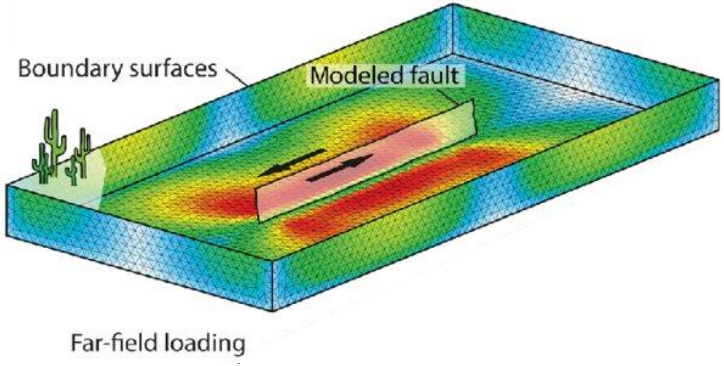
- ❑ Study the 3D deformation pattern during interseismic and coseismic periods
- ❑ Increase the time resolution during coseismic phase

Thank you!

Supplementary slides

Classical modelling approaches: numerical modelling

Main limitations:

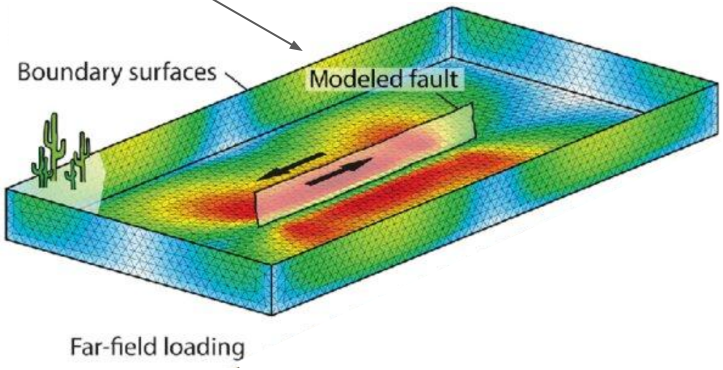


Zielke, Olaf & Mai, M.. (2023)

Classical modelling approaches: numerical modelling

Main limitations:

- Fixed fault geometry, size and strength

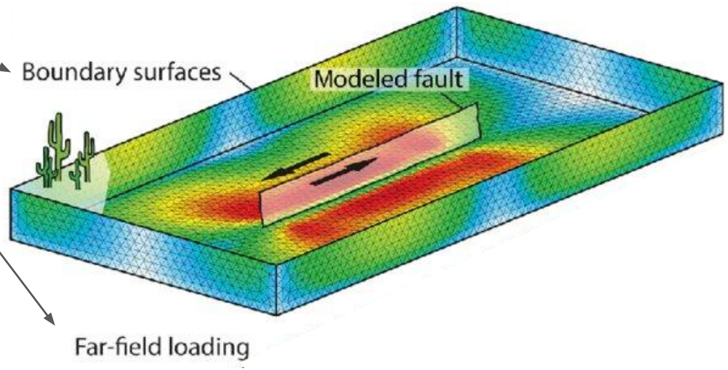


Zielke, Olaf & Mai, M.. (2023)

Classical modelling approaches: numerical modelling

Main limitations:

- Fixed fault geometry, size and strength
- Need of the stress history

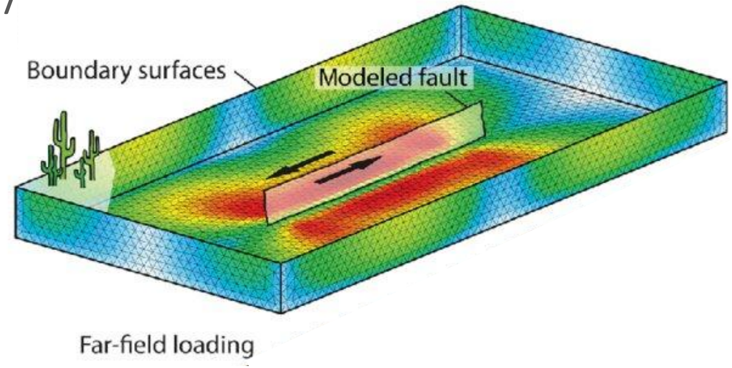


Zielke, Olaf & Mai, M.. (2023)

Classical modelling approaches: numerical modelling

Main limitations:

- Fixed fault geometry, size and strength
- Need of the stress history
- Constitutive law of the modeled rock / Artificial nucleation of earthquake

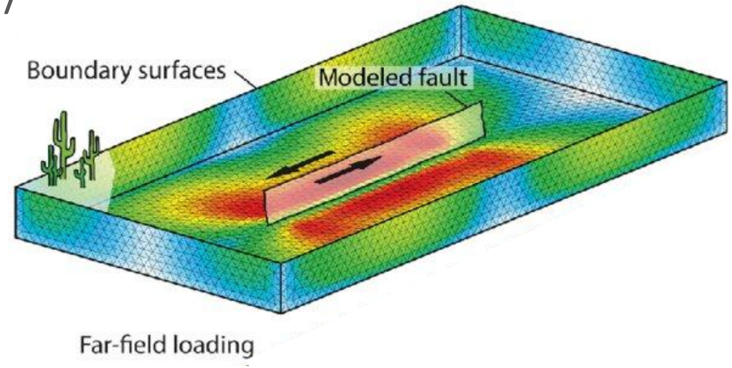


Zielke, Olaf & Mai, M.. (2023)

Classical modelling approaches: numerical modelling

Main limitations:

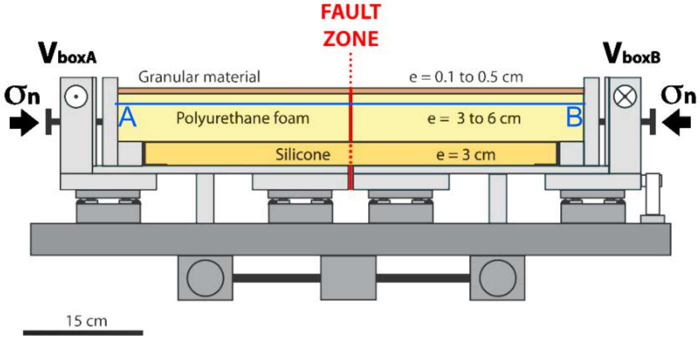
- Fixed fault geometry, size and strength
- Need of the stress history
- Constitutive law of the modeled rock / Artificial nucleation of earthquake

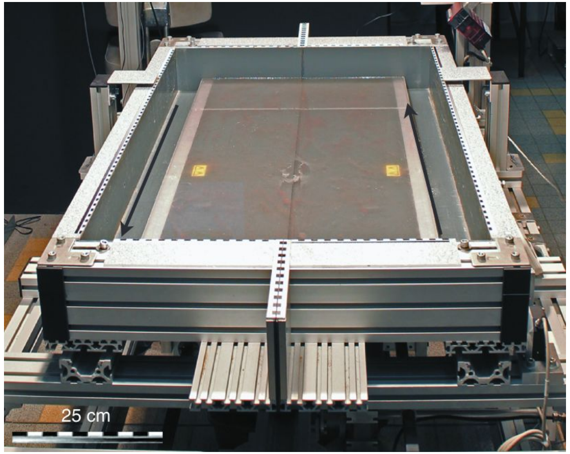


Zielke, Olaf & Mai, M.. (2023)

⇒ **Non-evolving fault**

Classical modelling approaches: analogue modelling

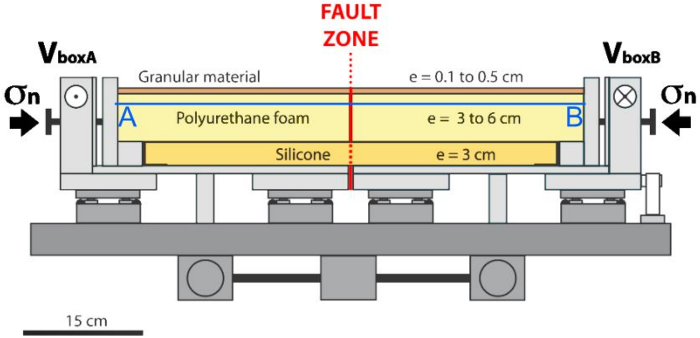


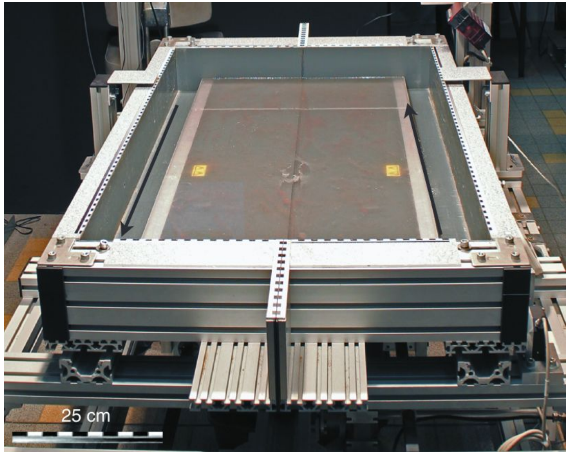


Preuss, S. (2020) and Caniven et al. (2015)

Classical modelling approaches: analogue modelling

- Need for scaling laws

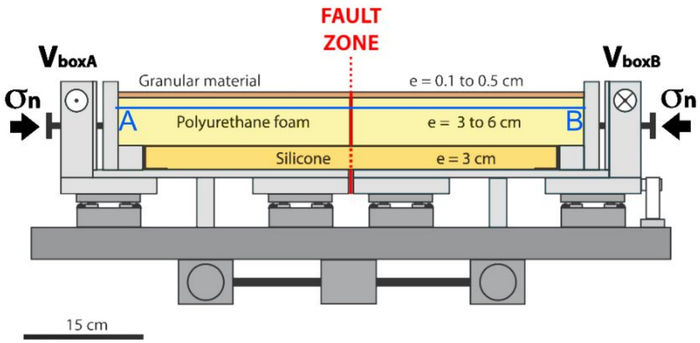


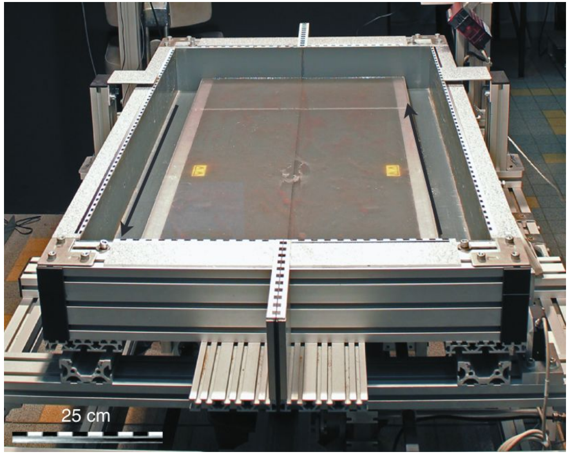


Preuss, S. (2020) and Caniven et al. (2015)

Classical modelling approaches: analogue modelling

- Need for scaling laws
- Physical limitations

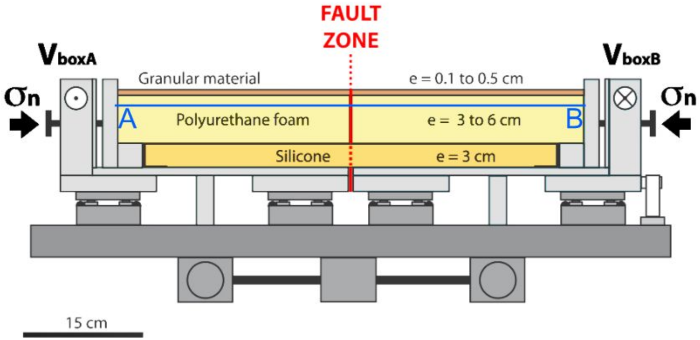


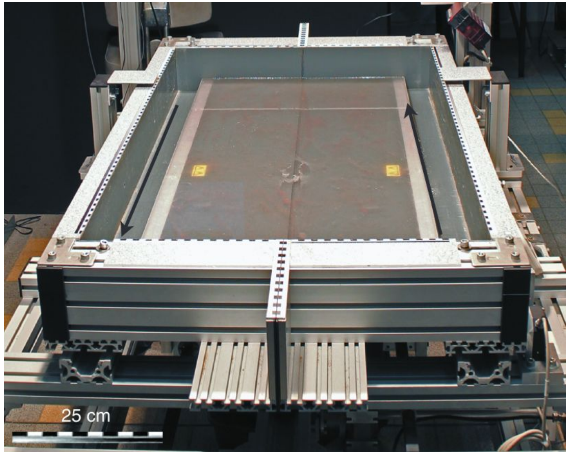


Preuss, S. (2020) and Caniven et al. (2015)

Classical modelling approaches: analogue modelling

- Need for scaling laws
- Physical limitations
- No 3D observations





Preuss, S. (2020) and Caniven et al. (2015)